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

LiDAR Surveys and Flood Mapping of Bulod River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
Mindanao State University-Iligan Institute of Technology

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For questions/queries regarding this report, contact:

Prof. Alan E. Milano
Project Leader, Phil-LiDAR 1 Program
Mindanao State University - Iligan Institute of Technology
Iligan City, Lanao del Norte, Philippines 9200
E-mail: aemilano1960@yahoo.com

Enrico C. Paringit, Dr. Eng.
Program Leader, Phil-LiDAR 1 Program
University of the Philippines Diliman
Quezon City, Philippines 1101
E-mail: ecparingit@up.edu.ph

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AAC	Asian Aerospace Corporation
Ab	Abutment
ALTM	Airborne LiDAR Terrain Mapper
ARG	Automatic Rain Gauge
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
mAGL	Meters Above Ground Level
MMS	Mobile Mapping Suite
MSL	Mean sea level
MSU-IIT	Mindanao State University- Iligan Institute of Technology
NAMRIA	National Mapping and Resource Information Authority
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
UTM	Universal Transverse Mercator
WGS	World Geodetic System

CHAPTER 1: OVERVIEW OF THE PROGRAM AND BULOD RIVER

Enrico C. Paringit, Dr. Eng., Prof. Alan E. Milano, and Engr. Elizabeth Albiento

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 methods applied in this report are thoroughly described in a separate publiction entitled "FLOOD MAPING OF RIVERS IN THE PHILIPPINES USING AIRBORNE LiDAR: METHODS (Paringit, et al., 2017) available separately."

The implementing partner university for the Phil-LiDAR 1 Program is the Mindanao State University—Iligan Institute of Technology (MSU-IIT). MSU-IIT is in charge of processing LiDAR data and conducting data validation reconnaissance, cross section, bathymetric survey, validation, river flow measurements, flood height and extent data gathering, flood modeling, and flood map generation for the 16 river basins in Northern Mindanao. The university is located in Iligan City.

1.2 Overview of the Bulod River Basin

The river basin of the Municipality of Tubod is the Bulod River Basin (also known as the Tubod river basin), located in the southwestern part of Northern Mindanao in the Province of Lanao del Norte under Region 10, Philippines. The basin is bounded on the north by the Municipalities of Kolambugan and Magsaysay, on the east by the Municipality of Tangcal, on the south by the Municipality of Baroy, and on the west by the Bay of Panguil. All of the barangays of Tubod are found within the river basin because the largest portion of the river basin is within its boundary. The municipality consists of 24 barangays namely Barakanas, Baris (Lumangculob), Bualan, Bulod, Camp V, Candis, Caniogan, Dalama, Kakai Renabor, Kalilangan, Licapao, Malingao, Palao, Patudan, Pigcarangan, Pinpin (Tadura), Poblacion, Pualas, San Antonio, Santo Niño, Tadsen, Tangueguiron, Taguranao and Tubaran. Other barangays from other municipalities that are within the river basin are Lower Caningag (Perimbangan) and Baguiguicon of the Municipality of Magsaysay; Lumbac and Simbuco of the Municipality of Kolambugan; Princesa, Sagadan Lower and Sagadan Upper of the Municipality of Baroy. The basin is located in Lanao del Norte, particularly bounded within the Municipality of Tubod and some parts of Magsaysay with a total population of 62, 774 according to the 2010 census conducted by NSO. It has a catchment area of approximately 113.98 km2 based on the Flood Modelling Component database (UP-TCAGP, 2016).

The main river used in delineating the basin is Bulod River, which traverses through the Municipalities of Tubod, Magsaysay, and Tangcal. the Tubod River is among the 17 rivers in the Autonomous Region in Muslim Mindanao. The river stretches an approximate length of 21 km along the northwestern part of Lanao del Norte. Its headwaters start from the mountainous areas of the province and run through the Municipality of Magsaysay and traverse the Municipality of Tubod where it empties into the Panguil Bay.

According to the 2010 census conducted by the NSO, there is a total of 24,133 people living within the immediate vicinity of the river. The river is vital for irrigation and drainage of the municipality and serves as their washing and bathing area and their fishing ground that supports the livelihood of thousands of small-scale fishers in northwestern Mindanao (http://www.zamboanga.com/z/index.php?title=Tubod,_Lanao_del_Norte,_Philippines, 2011).

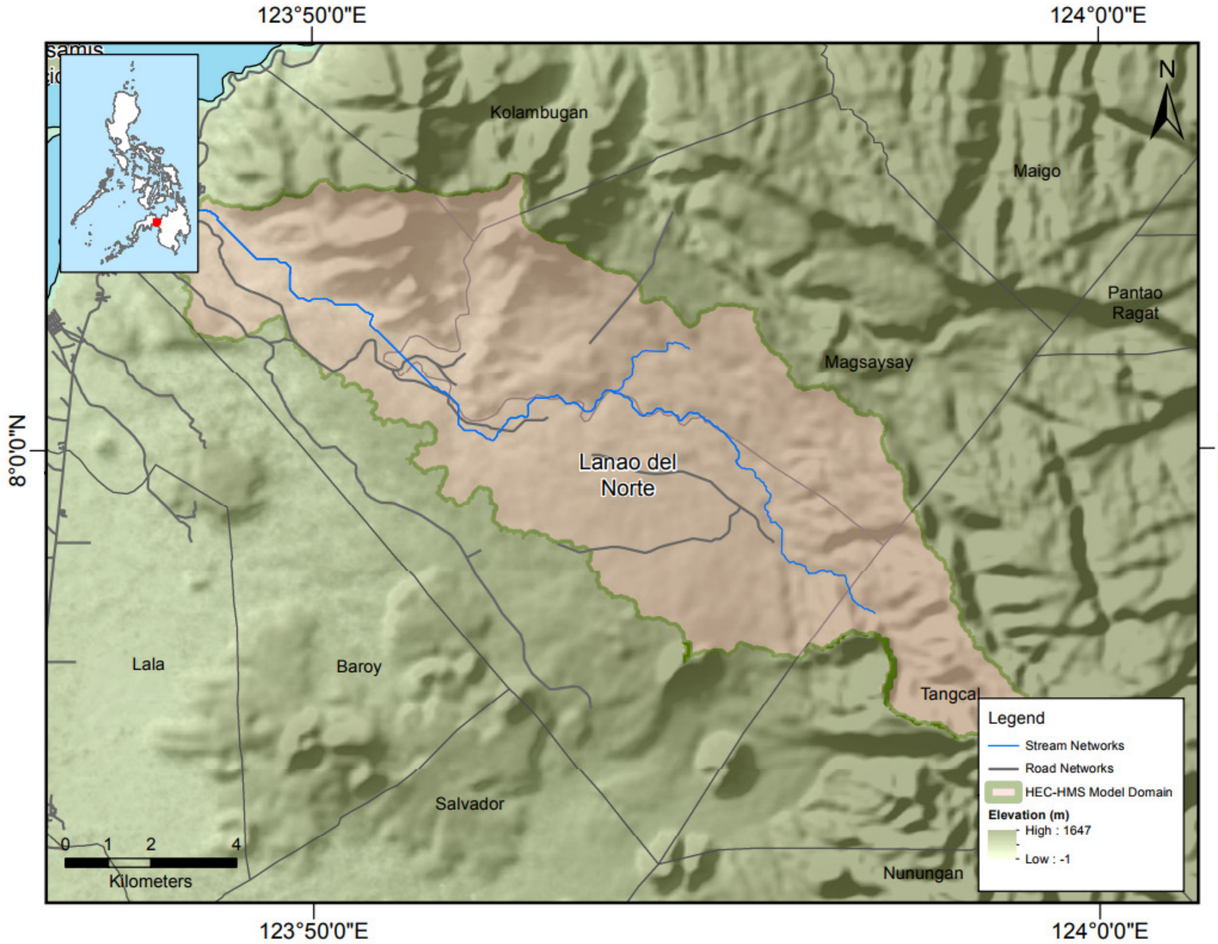


Figure 1. Map of Bulod River Basin (in brown)

The river basin has a total of 48 water bodies: 29 river streams and 14 fish pens. There are 8,593 building features that are extracted within the river basin. 8,209 of the features are residential, 96 are commercial establishments, 68 are part of schools, 54 are government offices, 47 are religious institutions, 34 are agricultural buildings, 18 are warehouses, 15 are medical institutions, 11 are barangay halls, 11 are markets, 10 are sports gymnasiums or covered courts, 6 are gas stations, 5 are telecommunication facilities, 3 are police stations, 2 are banks, a factory, a fire station, a non-government office, and a transport terminal.

Tubod's climate is classified as tropical wet. It is a city with a significant rainfall, although it is outside the typhoon belt. Even during the driest month, there is a lot of rain. Tubod has an annual mean temperature of 26.67°C and a mean monthly rainfall distribution of less than 74 millimeters. The topography of Tubod consists of regular terrains with low plains in the interior and undulating hills to rugged mountains along the northern portion down to the southern portion of the municipality.

Bulod River Basin has an estimated drainage area of 81.82 square kilometers and travels 18.42 kilometers from its source to its outlet and 26.1 kilometers from its source to the mouth of Panguil Bay. The outlet of the river basin, where the flow measurements were obtained, is located at Magsaysay Bridge.

A flooding incident in Tubod happened last March 09, 2017 due to heavy rains caused by the tail end of a cold front. The water reached until waist-deep. There were 4 barangays affected by the flooding, according to Vic Mar Paloma, the head of Tubod Disaster Risk Reduction and Management Office. The identified barangays were Tagueguiron, Bulod, Pigcarangan and Poblacion. The overflowing of the creeks and canals because of the on-going construction is said to be the main reason of the flooding. The tide (sea water level) was low even though the water level of the Bulod River reached critical level. The nonstop heavy rains also caused a landslide in Tangueguiron. Paloma said that a total of 250 individuals from Poblacion and 200 from Pigcarangan were evacuated to their multi-purpose gymnasiums and that Mayor Leoncio Bagul was forced to suspend classes in all levels as well as work in all local government offices. (SunStar Cagayan de Oro). The National Disaster Risk Reduction and Management Council (NDRRMC) reported that a flooding incident occurred on January 4, 2011 on the said municipalities due to the overflowing of Bulod River brought by continuous moderate to heavy rains caused by the tail-end of a cold front that prevailed since December 2010.

CHAPTER 2: LIDAR DATA ACQUISITION OF THE BULOD FLOODPLAIN

Engr. Louie P. Balicanta, Engr. Christopher Cruz, Lovely Gracia Acuña, Engr. Gerome Hipolito, Engr. Iro Niel D. Roxas, and Engr. Frank Nicolas H. Ilejay

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

2.1 Flight Plans

To initiate the LiDAR acquisition survey of the Bulod Floodplain, the Data Acquisition Component (DAC) created flight plans within the delineated priority area for Bulod Floodplain in Northern Mindanao. The missions were planned for 16 lines each, which ran for no more than (5) hours including take-off, landing and turning time. The flight planning parameter s for the LiDAR system is found in Table 1. Figure 2, on the other hand, shows the flight plan for Bulod Floodplain survey.

Table 1. Flight planning parameters for the Pegasus LiDAR System.

Block Name	Flying Height (m AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency	Average Speed (kts)	Average Turn Time (Minutes)
BLK71E	1000	30	50	200	30	130	5
BLK71F	1000	30	50	200	30	130	5
BLK 76I	1000	30	50	200	30	130	5
BLK 76J	1000	30	50	200	30	130	5
BLK 76N	1000	30	50	200	30	130	5

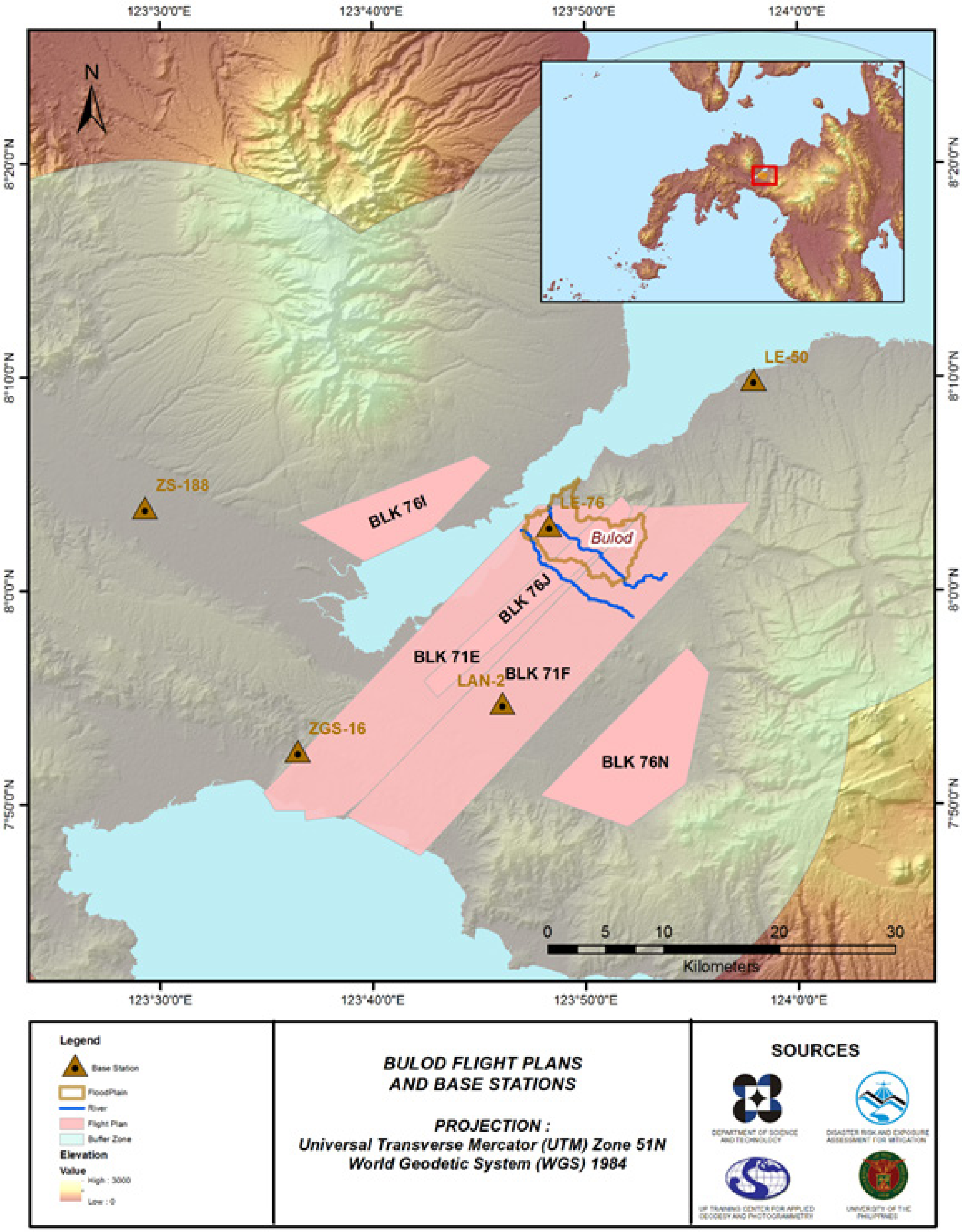


Figure 2. Flight plan and base stations used for Bulod Floodplain

2.2 Ground Base Station

The field team for this undertaking was able to recover two (2) NAMRIA horizontal ground control points: LAN-2, which is of first (1st) order accuracy, and ZGS-16 which is of second (2nd) order accuracy. Three (3) NAMRIA benchmarks were recovered: ZS-188, LE-50, and LE-76. These benchmarks were used as vertical reference points and were also established as ground control points. The certifications for the base stations and benchmarks are found in Annex 2, while the processing reports for the NAMRIA benchmarks are found in Annex 3. These were used as base stations during the flight operation for the entire duration of the survey (June 4 – July 9, 2014 and February 13, 2016). Base stations were observed using dual frequency GPS receivers: TRIMBLE SPS 882 and SPS 985. Flight plans and location of base stations used during the aerial LiDAR acquisition in Bulod Floodplain are shown in Figure 2.

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

Figure 3. GPS set-up over LAN-2 at Brgy. Pinoyak, Lala Lanao del Norte (a) and NAMRIA reference point LAN-2 (b) as recovered by the field team.

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

Station Name	**LAN-2**	
Order of Accuracy	**1st**	
Relative Error (horizontal positioning)	**1 in 50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7° 54’ 46.07859” North 123° 46’ 0.85333” East 17.35400 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	364,025.74 meters 875,110.149 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	7° 54’ 42.56546” North 123° 46’ 6.31720” East 83.92120 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	584,533.45 meters 874,680.35 meters

Figure 4. GPS set-up over LE-50 at Barogohan Bridge and at the NE of the Covenant Baptist Church, Maigo, Lanao del Norte (a) and NAMRIA reference point LE-50 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA vertical control point LE-50 used as base station for the LiDAR Acquisition.

Station Name	**LE-50**	
Order of Accuracy	**1st**	
Relative Error (horizontal positioning)	**1:100,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	8° 09’ 54.972” North 123° 57’ 50.357” East 6.91 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	8° 09’ 51.11024” North 123° 57’ 55.36634” East 73.452 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	606,345.902 meters 902,577.426 meters

Figure 5. GPS set-up over LE-76 at Bulod Bridge footwalk of Brgy. Bulod, Tubud, Lanao del Norte (a) and NAMRIA reference point LE-76 (b) as recovered by the field team.

Table 4. Details of the recovered NAMRIA vertical control point LE-76 used as base station for the LiDAR acquisition.

Station Name	LE-76	
Order of Accuracy	**1st**	
Relative Error (horizontal positioning)	**1:100,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	8° 03’ 05.36825” North 123° 48’ 12.37307” East 9.355 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	8° 03’ 01.82183” North 123° 48’ 17.82405” East 75.717 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	588,530.790 meters 890,021.013 meters

Figure 6. GPS set-up over ZGS-16 at Purok Nangka, Brgy. Baclay, Municipality of Tukuran, Zamboanga del Sur (a) and NAMRIA reference point ZGS-16 (b) as recovered by the field team.

Table 5. Details of the recovered NAMRIA horizontal control point ZGS-16 used as base station for the LiDAR qcquisition.

Station Name	ZGS-16	
Order of Accuracy	**2nd**	
Relative Error (horizontal positioning)	**1:50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7° 52' 35.53106" North 123° 36' 23.39905" East 18.17800 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	566,881.259 meters 870,8554.959 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	7° 52' 29.01321" North 123° 36' 28.86762" East 84.42000 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	566,857.85 meters 870,550.15 meters

Figure 7. GPS set-up over ZS-188 at Brgy. Licomo, Zamboanga City, Zamboanga del Sur (a) and NAMRIA reference point ZS-188 (b) as recovered by the field team.

Table 6. Details of the recovered NAMRIA vertical control point ZS-188 used as base station for the LiDAR qcquisition with established coordinates..

Station Name	ZS-188	
Order of Accuracy	**1st**	
Relative Error (horizontal positioning)	**1:100,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	8° 03’ 56.69408” North 123° 29’ 12.15500” East 19.832 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	8° 03’ 53.11537” North 123° 29’ 17.60722” East 85.400 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	553,627.634meters 891,542.089 meters

Table 7. Ground Control points used during LiDAR data acquisition

Date Surveyed	Flight Number	Mission Name	Ground Control Points
June 4, 2014	1549P	1BLK71D155A	LAN-2, LE-50
June 8, 2014	1565P	1BLK71B159A	LAN-2, LE-50
July 8, 2014	1685P	1BLK71S189A	LAN-2, LE-50
July 9, 2014	1689P	1BLK71S190A	LE-50, LE-76
February 13, 2016	23088P	1BLK76ILM044A	ZGS-16, ZS-188

2.3 Flight Missions

Five (5) missions were conducted to complete the LiDAR data acquisition in Bulod Floodplain, for a total of twenty hours and two minutes (20+2) of flying time for RP-C9122. The mission was acquired using the Pegasus LiDAR System. Table 8 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 9 presents the actual parameters used during the LiDAR data acquisition.

Table 8. Flight missions for LiDAR data acquisition in Bulod 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 Hour	
							Hr	Min
June 4, 2014	1549P	247.57	269.54	29.56	239.98	NA	4	24
June 8, 2014	1565P	258.45	88.01	0.74	87.27	324	2	53
July 8, 2014	1685P	258.45	158.49	12.58	145.91	569	4	5
July 9, 2014	1689P	247.57	240.77	14.14	226.62	NA	4	17
February 13, 2016	23088P	216.61	206.76	18.10	188.66	536	4	23
TOTAL		1228.64	963.56	75.11	888.44	1429	20	2

Table 9. Actual Parameters used during LiDAR data acquisition

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes
1549P	1000	30	50	200	30	110-130	5
1565P	1000	30	50	200	30	110-130	5
1685P	1000	30	50	200	30	110-130	5
1689P	1200	30	50	200	30	110-130	5
23088P	1200	30	50	200	30	110-130	5

2.4 Survey Coverage

Bulod Floodplain is located in the Province of Lanao del Norte covering parts of Bulod, Kolambugan, Magsaysay and Baroy. The list of municipalities/cities surveyed in these provinces during the LiDAR acquisition is shown in Table 10. The actual coverage of the LiDAR acquisition for Bulod Floodplain is shown in Figure 7.

Table 10. List of municipalities and cities surveyed during Bulod Floodplain LiDAR survey.

Province	Municipality/City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Zamboanga del Norte	Lala	125.181	116.8269	93.33%
	Kolambugan	70.6979	60.77445	85.96%
	Baroy	62.0834	47.19179	76.01%
	Kapatagan	184.763	124.414	67.34%
	Tubod	121.945	76.60344	62.82%
	Baloi	65.1791	36.86897	56.57%
	Salvador	46.4642	25.20979	54.26%
	Sapad	65.1321	35.08318	53.86%
	Magsaysay	83.0572	38.41287	46.25%
	Sultan Naga Dimaporo	143.651	37.57202	26.16%
	Nunungan	418.219	59.52066	14.23%
	Pantar	50.1939	6.85479	13.66%
	Linamon	22.2137	2.250863	10.13%
	Tagoloan	25.06	2.198019	8.77%

	Tangcal	118.942	6.457041	5.43%
	Maigo	126.357	5.938442	4.70%
	Iligan City	650.867	21.84929	3.36%
	Matungao	52.5005	1.453985	2.77%
Misamis Occidental	Tangub City	141.82	17.93114	12.64%
	Bonifacio	103.87	2.146343	2.07%
Zamboanga del Sur	Tukuran	119.01	36.53949	30.70%
	Aurora	162.224	44.24166	27.27%
	Tambulig	142.934	0.928011	0.65%
	Labangan	176.437	0.510711	0.29%
Total		3278.80	807.78	24.64%

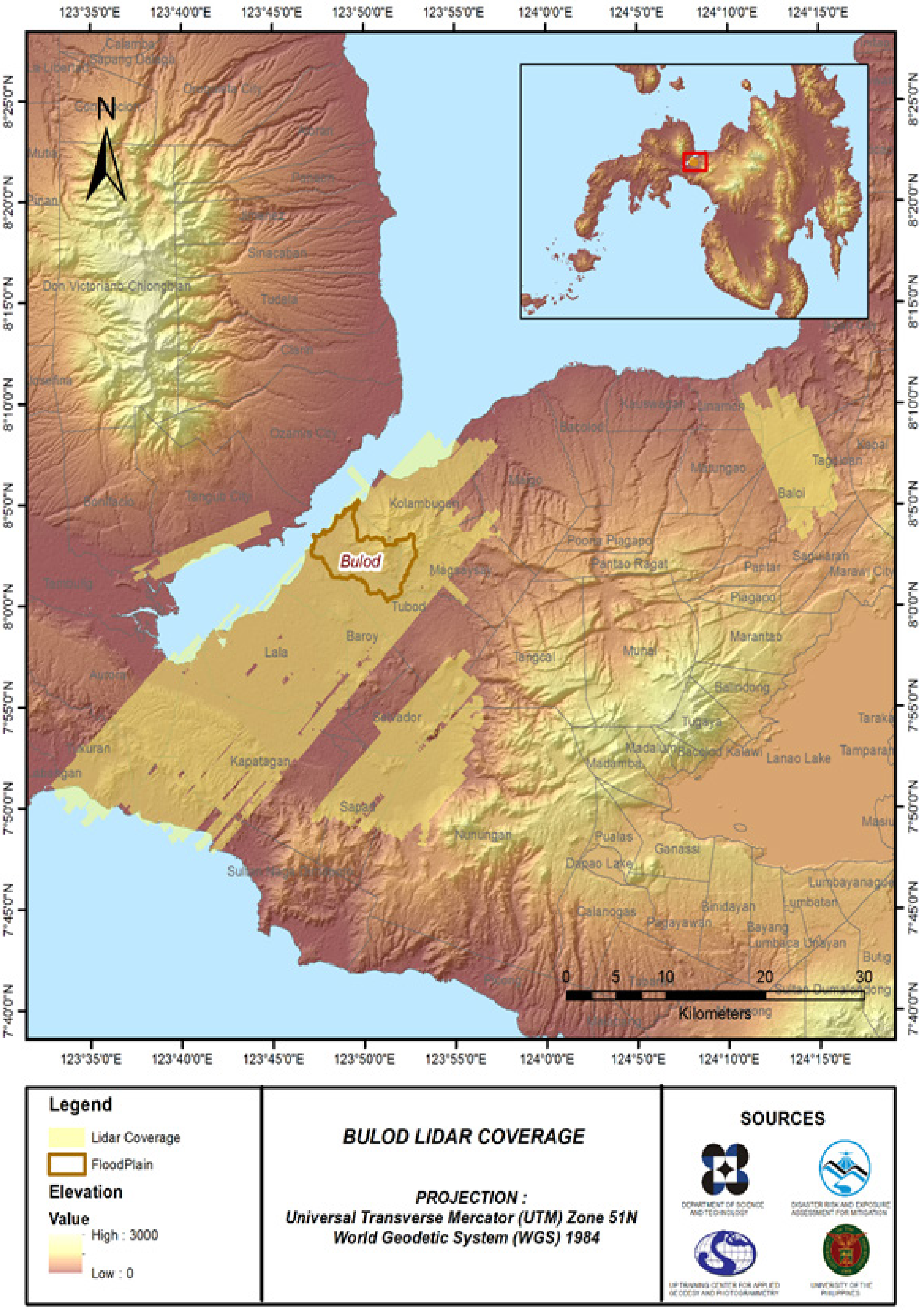


Figure 8. Actual LiDAR survey coverage for Bulod floodplain

CHAPTER 3: LIDAR DATA PROCESSING OF THE BULOD FLOODPLAIN

Engr. Ma. Rosario Concepcion O. Ang, Engr. John Louie D. Fabila, Engr. Sarah Jane D. Samalburo , Engr. Joida F. Prieto , Engr. Harmond F. Santos , Engr. Ma. Ailyn L. Olanda, Engr. Melanie C. Hingpit, Engr. James Kevin M. Dimaculangan , Engr. Jommer M. Medina, and John Arnold C. Jaramilla

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

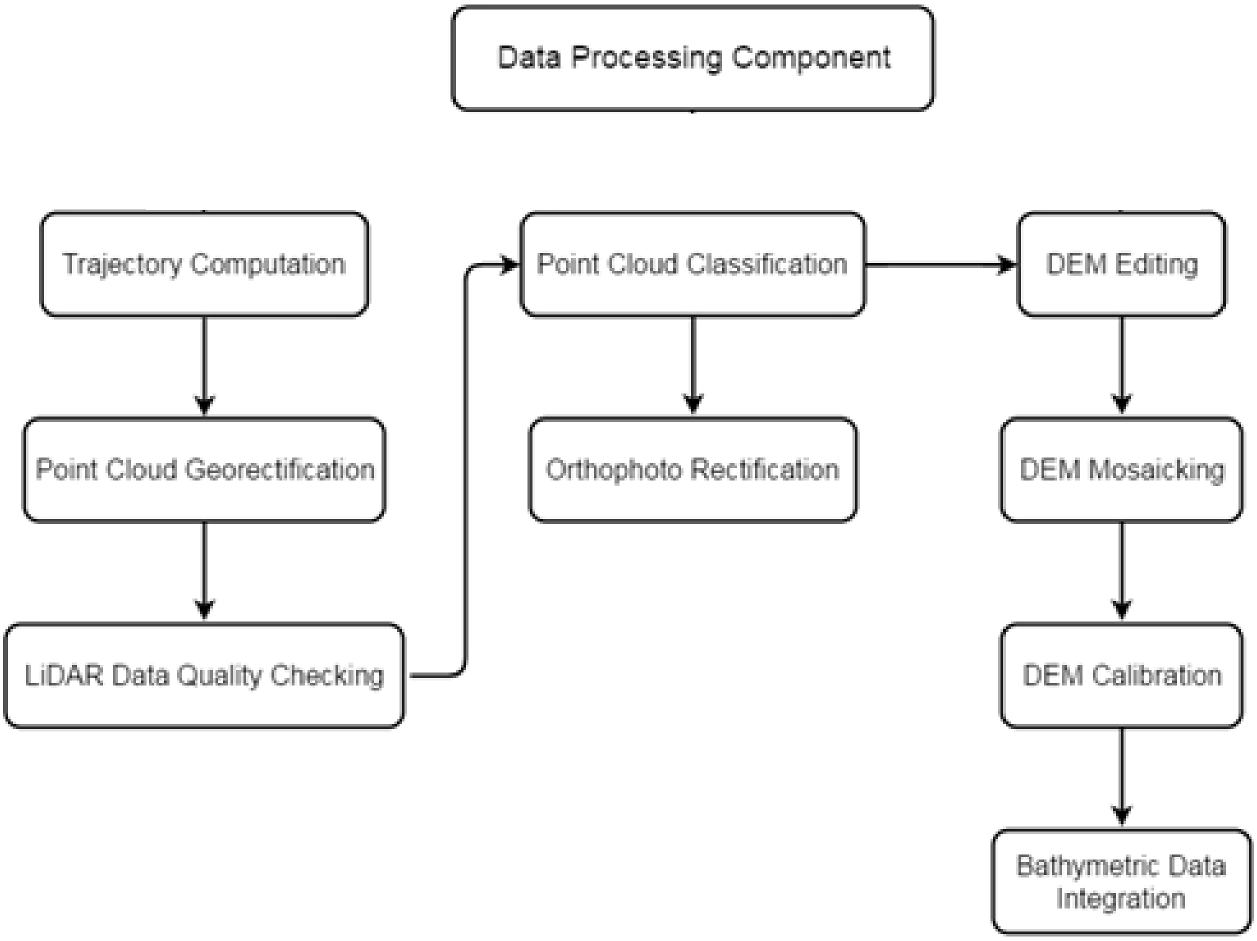


Figure 9. Schematic Diagram for Data Pre-Processing Component

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

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

These processes are summarized in the flowchart shown in Figure 9.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Bulod Floodplain can be found in Annex 5. Missions flown during the first survey conducted on June 2014 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus System, while missions acquired during the second survey on February 2016 were also flown using the Pegasus System over Impasug-Ong, Malaybalay City, Cabanglasan and San Fernando, Bukidnon. The Data Acquisition Component (DAC) transferred a total of 193.01 gigabytes of range data, 2.05 gigabytes of POS data, 419.22 megabytes of GPS base station data, and 475.98 gigabytes of raw image data to the data server on August 6, 2014 for the first survey and March 10, 2016 for the second survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Bulod was fully transferred on March 10, 2016, as indicated on the Data Transfer Sheets for Bulod Floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for Flight 23084P, one of the Bulod flights, which is the North, East, and Down position RMSE values are shown in Figure 10. 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 February 12, 2016 00:00AM. The y-axis is the RMSE value for that particular position.

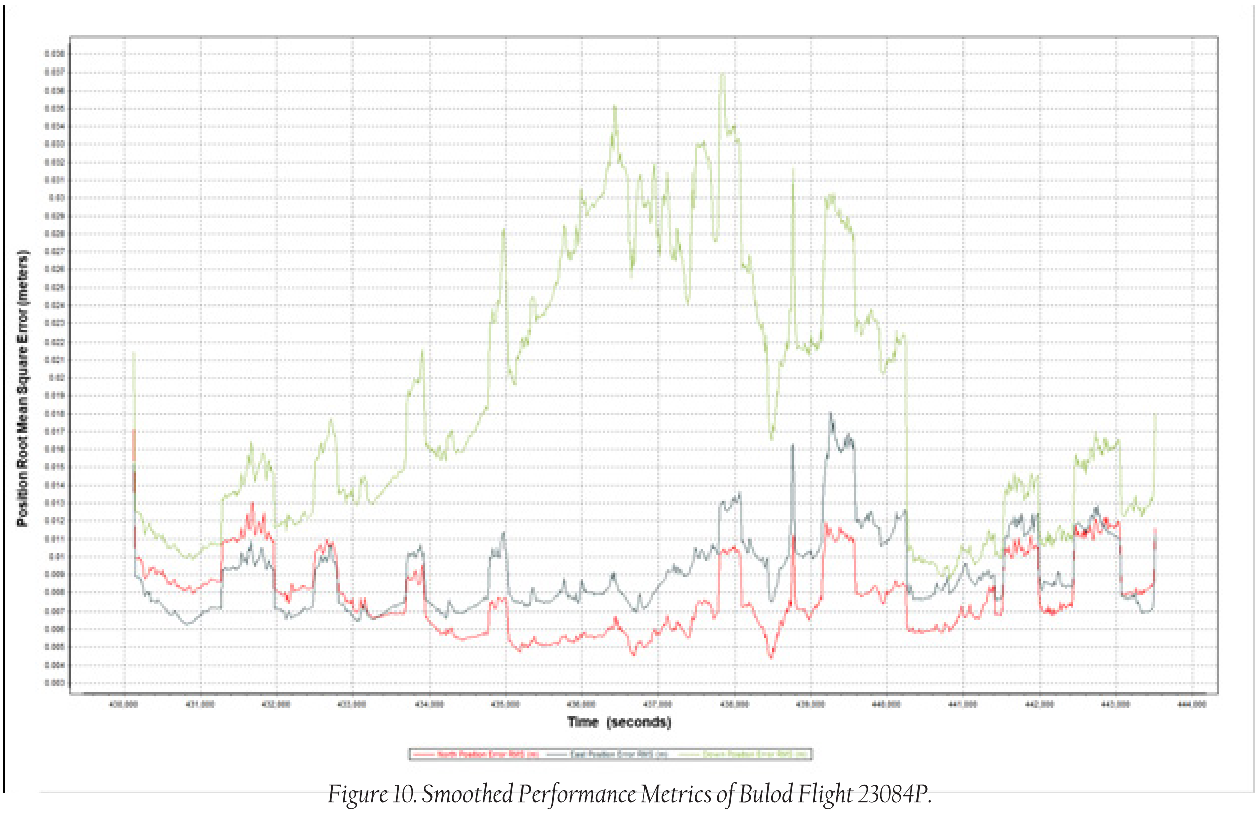


Figure 10. Smoothed Performance Metrics of Bulod Flight 23084P.

The time of flight was from 430,000 seconds to 443,500 seconds, which corresponds to the afternoon of February 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 minimize 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 10 shows that the North position RMSE peaks at 1.30 centimeters, the East position RMSE peaks at 1.80 centimeters, and the Down position RMSE peaks at 3.70 centimeters, which are within the prescribed accuracies described in the methodology.

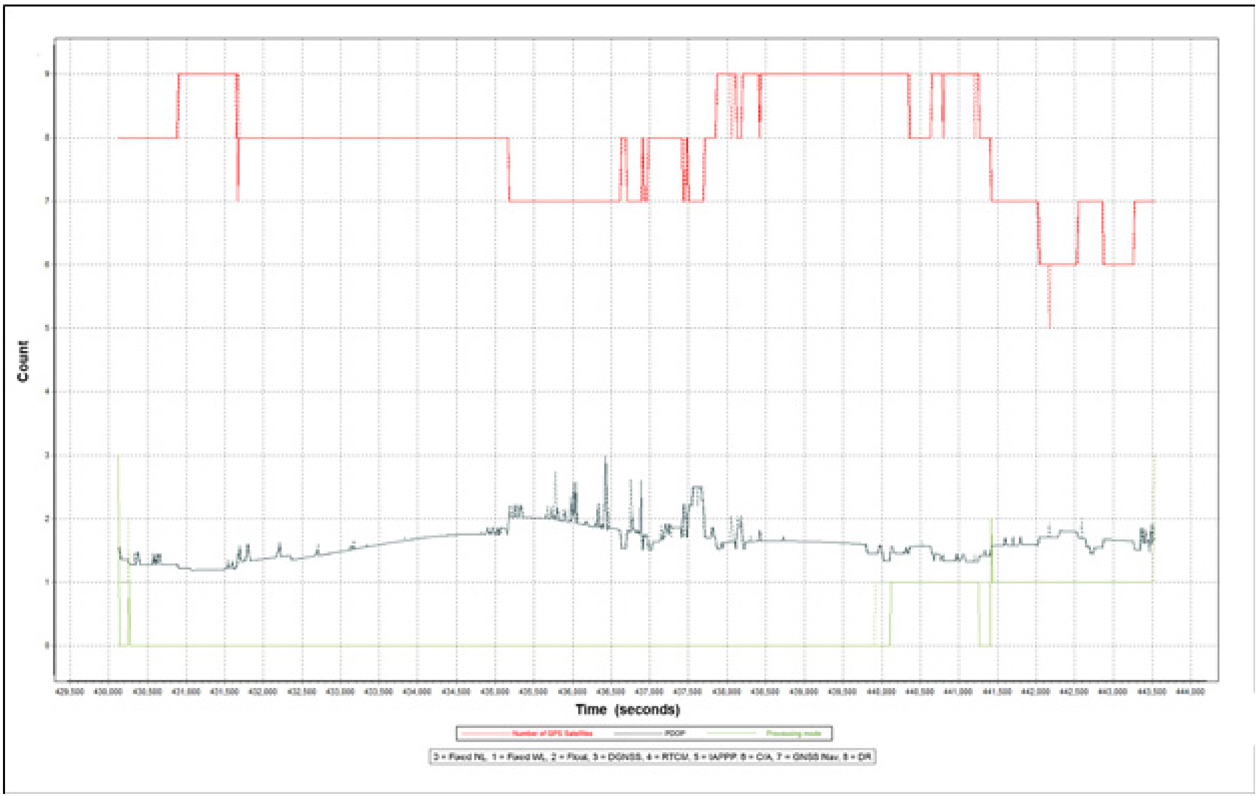


Figure 11. Solution Status Parameters of Bulod Flight 23084P.

The Solution Status parameters of Flight 23084P, one of the Bulod flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 11. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Majority of the time, the number of satellites tracked was between 6 and 9. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode stayed at the value of 0 for majority of the survey with some peaks up to 2 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Bulod flights is shown in Figure 12.

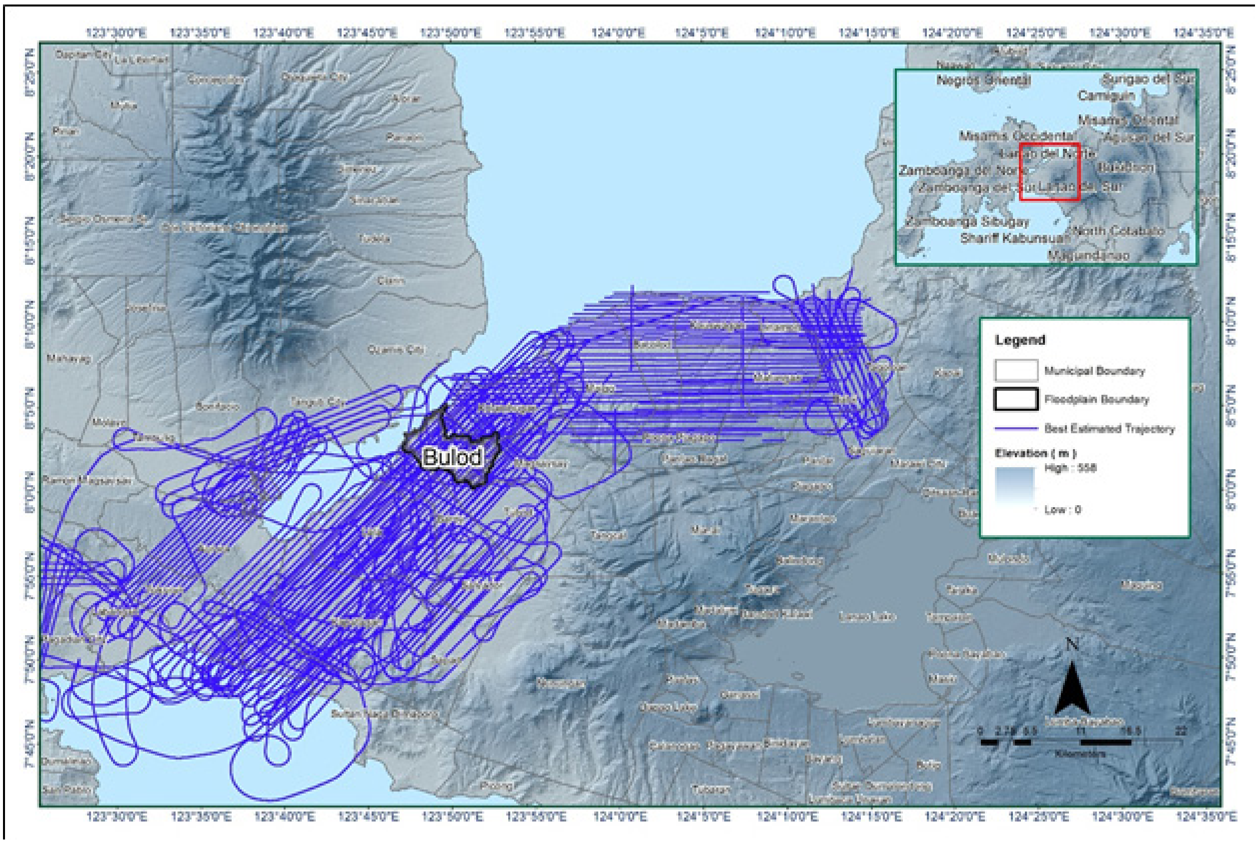


Figure 12. Best Estimated Trajectory of the LiDAR missions conducted over the Bulod Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 149 flight lines, with each flight line containing one channel, since the Pegasus System contains two channels. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Bulod Floodplain are given in Table 11.

Table 11. Self-Calibration Results values for Bulod flights.

Parameter	Acceptable Value	Computed Value
Boresight Correction stdev	(<0.001degrees)	0.000134
IMU Attitude Correction Roll and Pitch Corrections stdev	(<0.001degrees)	0.000524
GPS Position Z-correction stdev	(<0.01meters)	0.0064

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

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Bulod Floodplain is shown in Figure 13. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

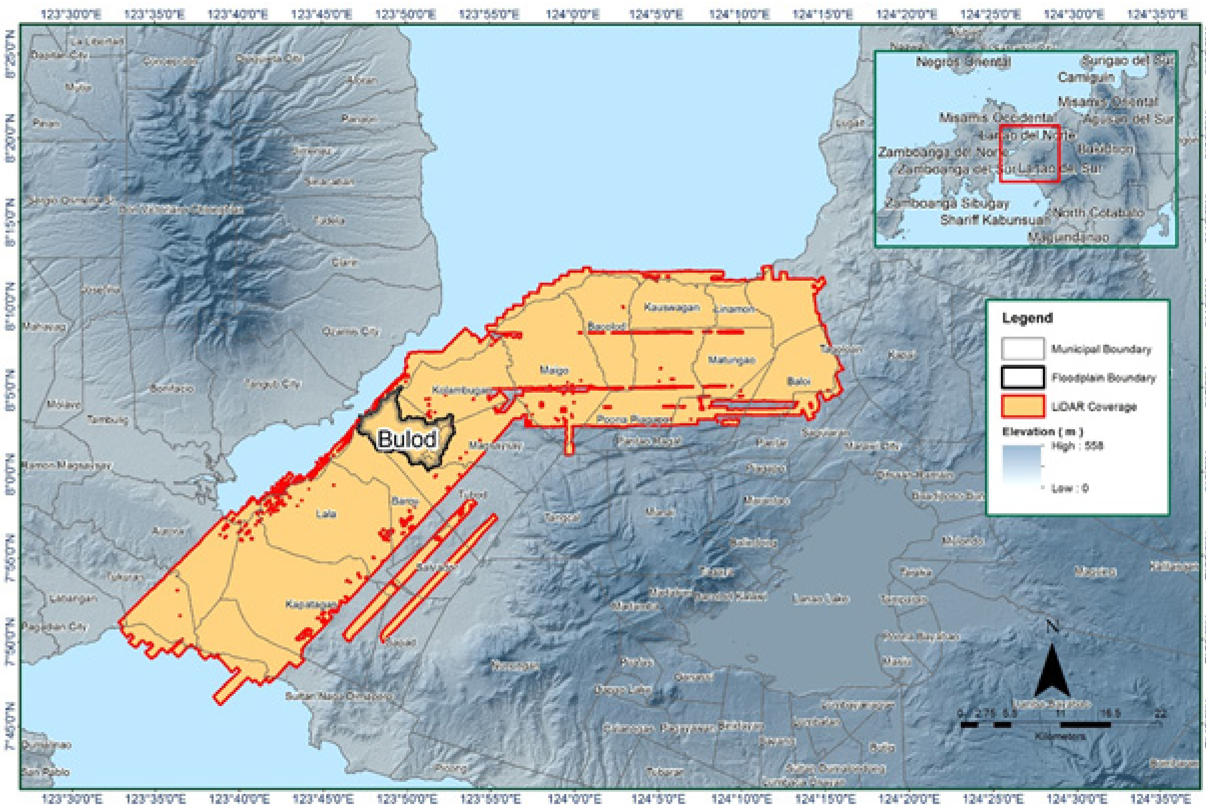


Figure 13. Boundary of the processed LiDAR data over Bulod Floodplain

The total area covered by the Bulod missions is 1,524.85 sq.km that is comprised of eight (8) flight acquisitions grouped and merged into seven (7) blocks as shown in Table 12.

Table 12. List of LiDAR blocks for Bulod Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Pagadian_Blk76J	23088P	40.53
Pagadian_Blk76K	23084P	180.29
Pagadian_Blk76K_additional	23104P	52.55
Pagadian_Blk76M	23128P	71.08
NorthernMindanao_Blk71E	1689P	178.76
NorthernMindanao_Blk71F	1565P	493.65
	1549P	
	1685P	
NorthernMindanao_Blk71ABC	1689P	507.99
	1685P	
TOTAL		1,524.85

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 14. Since the Pegasus System employs two channels, we would expect an average value of 2 (blue) for areas where there is limited overlap, and a value of 3 (yellow) or more (red) for areas with three or more overlapping flight lines.

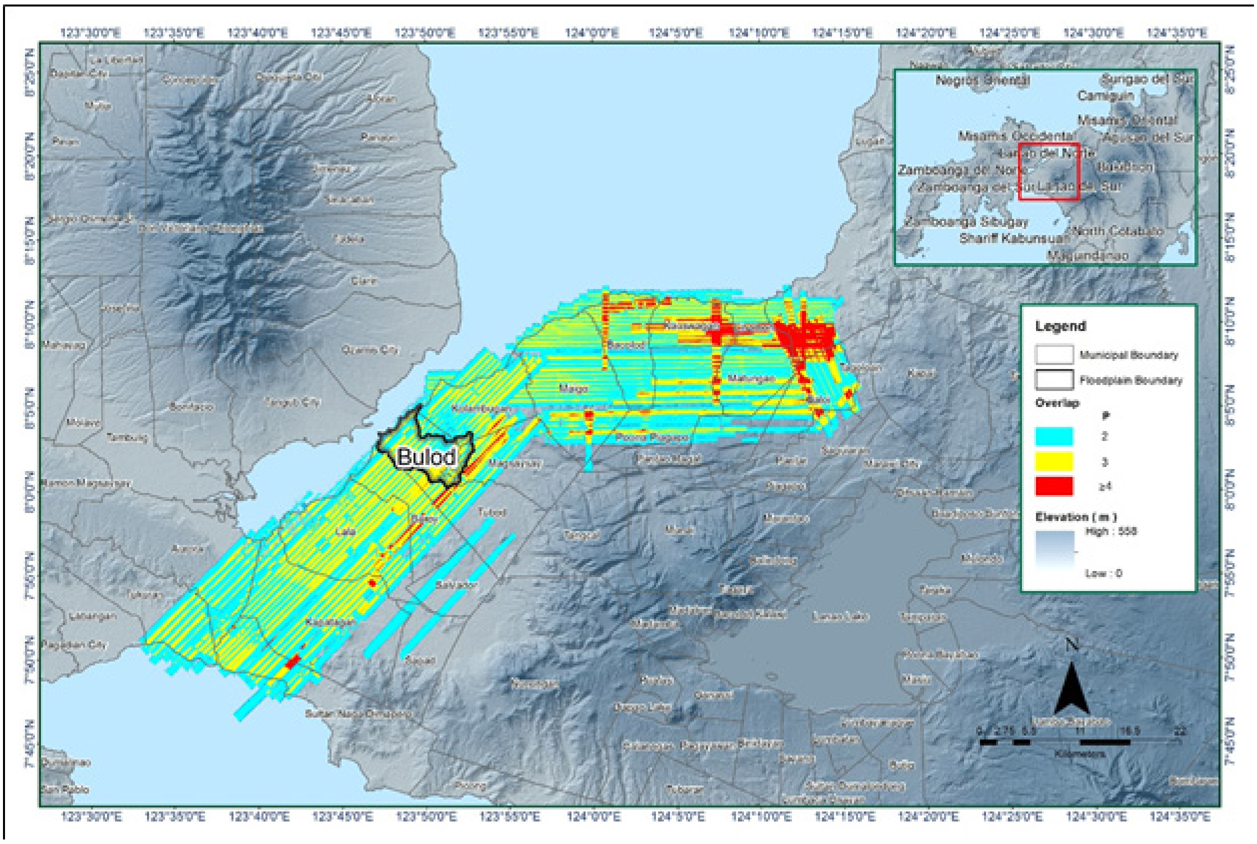


Figure 14. Image of data overlap for Bulod Floodplain.

The overlap statistics per block for the Bulod Floodplain can be found in Annex 8. One pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 27.90% and 51.56% respectively, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 15. It was determined that all LiDAR data for Bulod Floodplain satisfy the point density requirement, and the average density for the entire survey area is 3.38 points per square meter.

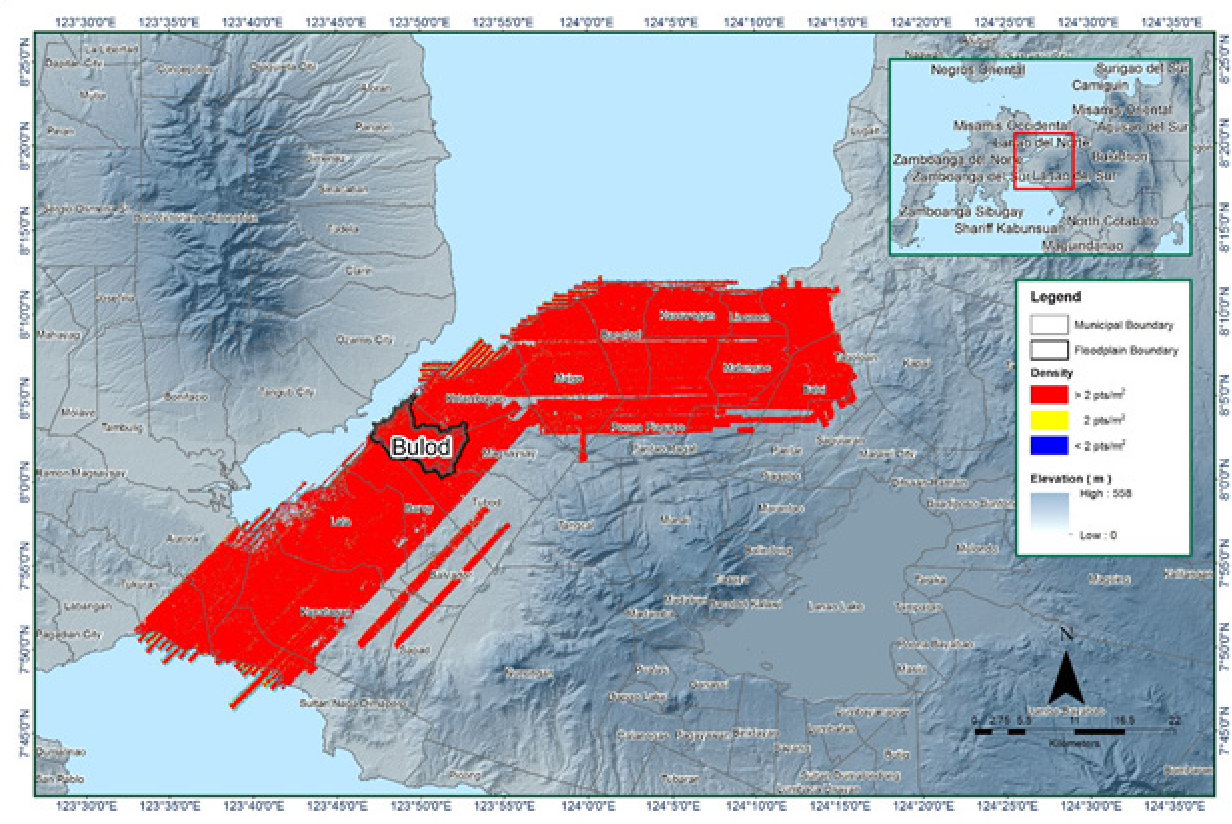


Figure 15. Pulse density map of merged LiDAR data for Bulod Floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 16. 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 0.20vm 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.

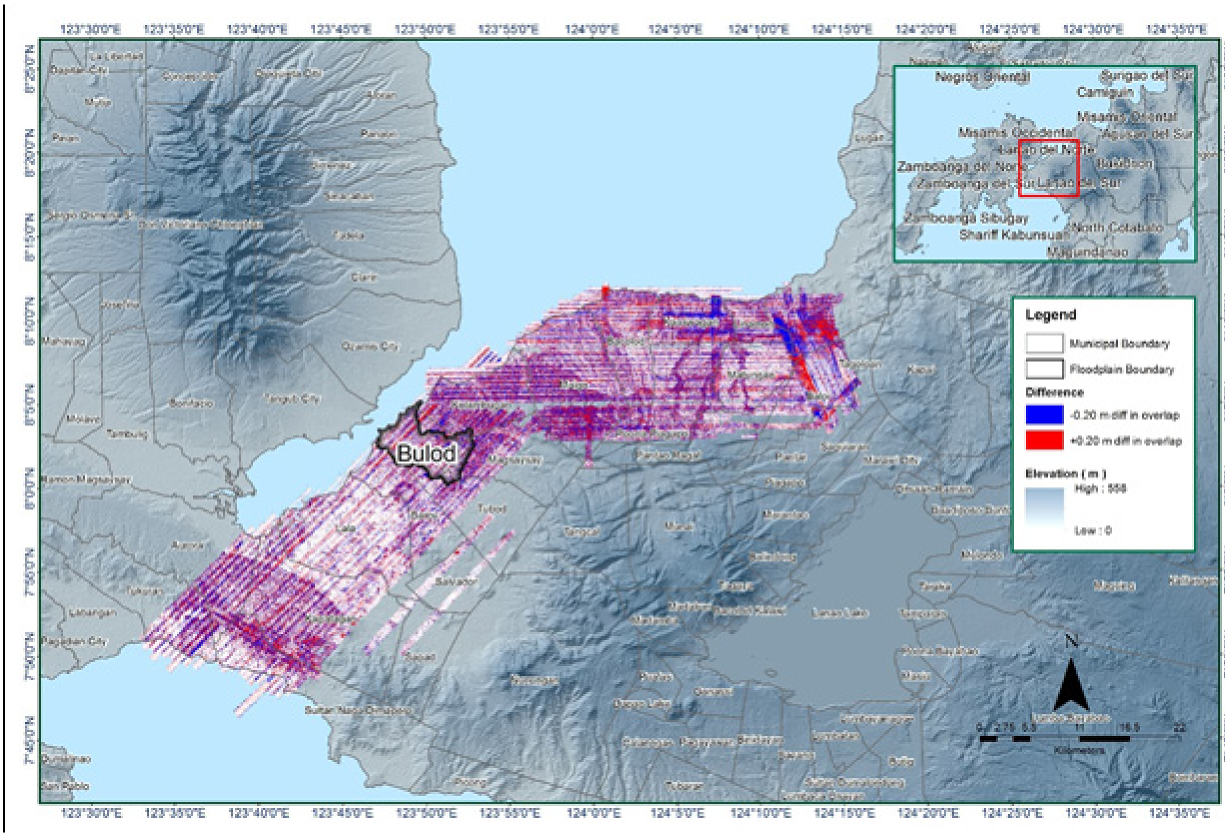


Figure 16. Elevation difference map between flight lines for Bulod Floodplain.

A screen capture of the processed LAS data from a Bulod Flight 23084P loaded in QT Modeler is shown in Figure 17. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed red line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

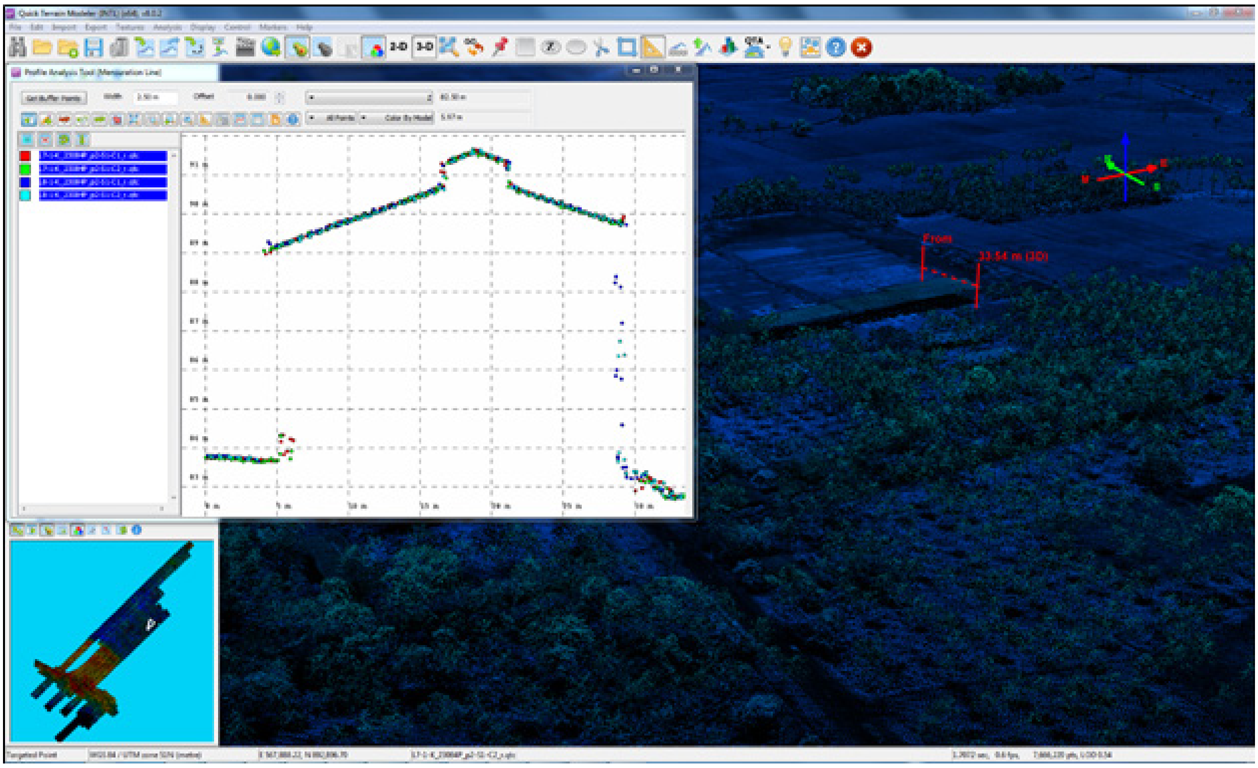


Figure 17. Quality checking for Bulod Flight 23084P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 13. Bulod classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	462,718,757
Low Vegetation	302,872,030
Medium Vegetation	316,503,851
High Vegetation	1,458,031,808
Building	8,305,211

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Bulod Floodplain is shown in Figure 18. A total of 630 1 km by 1 km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 13. The point cloud has a maximum and minimum height of 698.51 meters and 62.15 meters respectively.

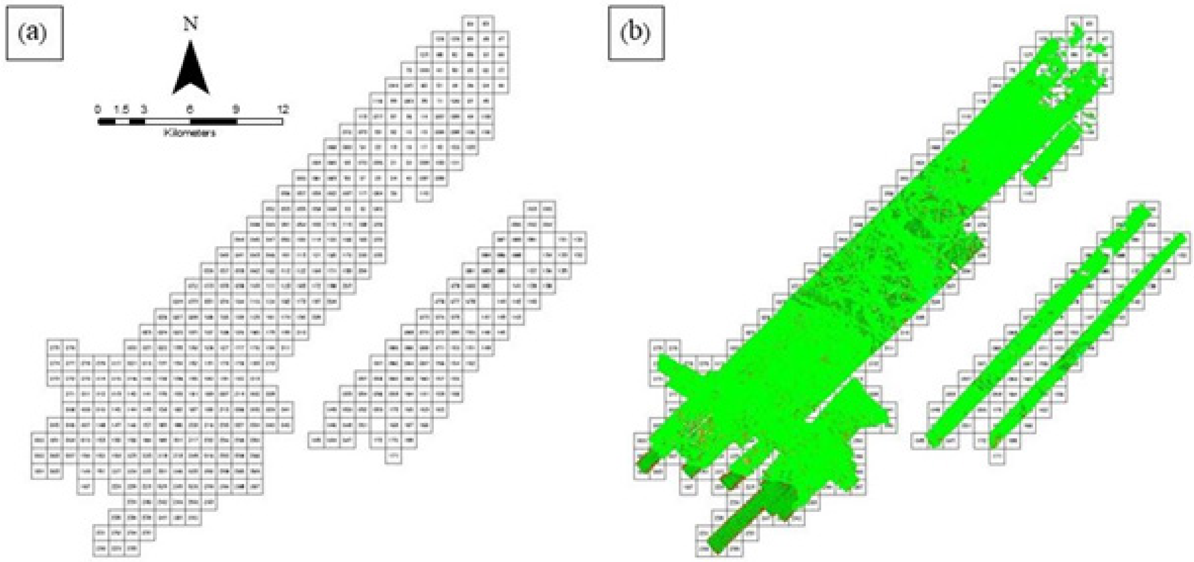


Figure 18. Tiles for Bulod Floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 19. 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.

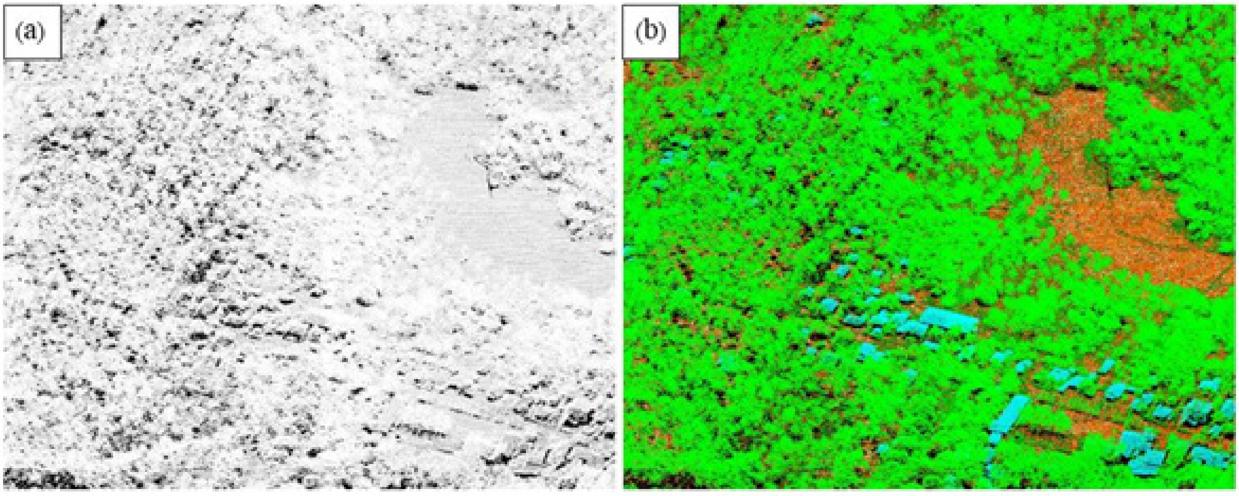


Figure 19. Point cloud before (a) and after (b) classification.

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

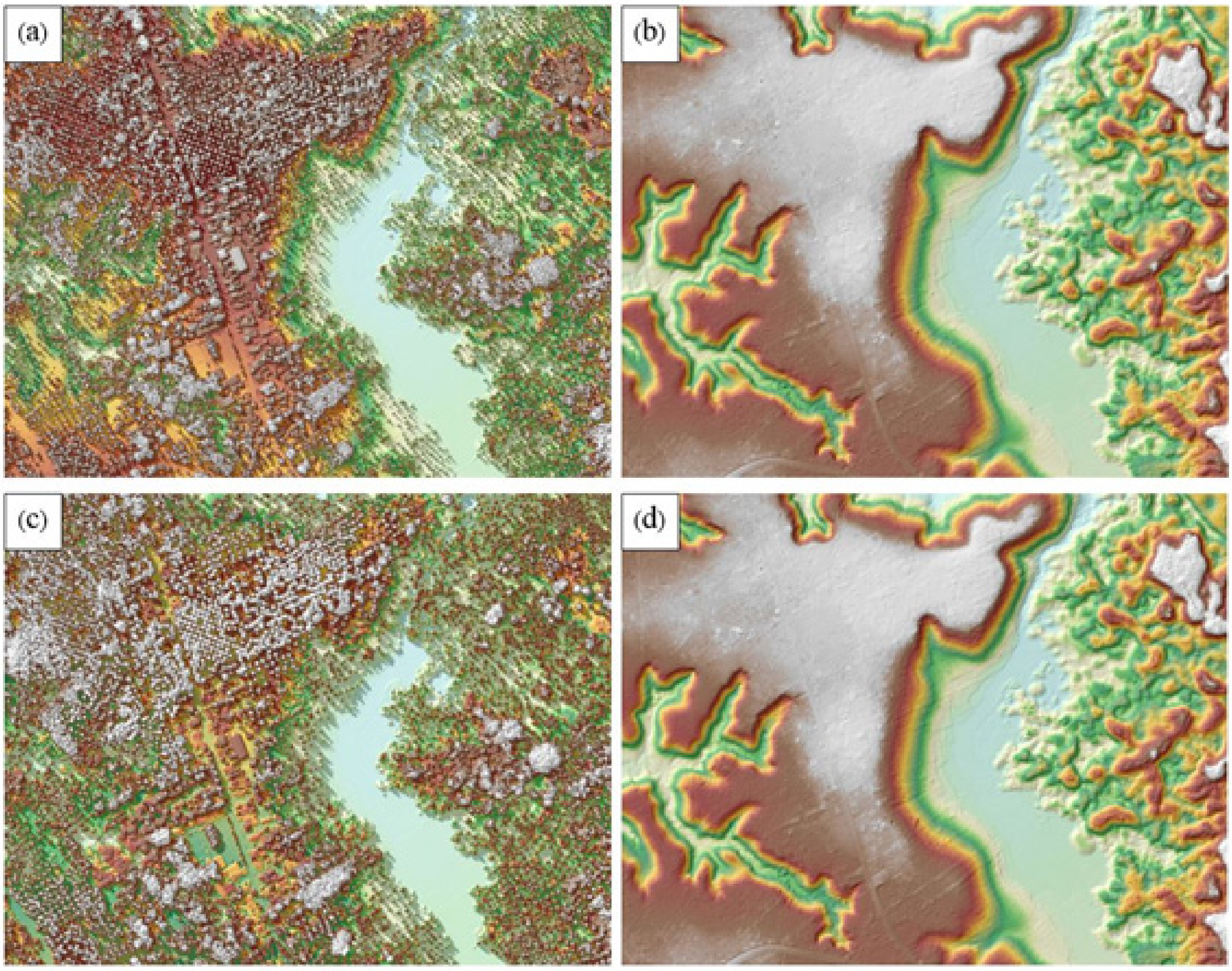


Figure 20. The Production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Bulod Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 445 1 km by 1 km tiles area covered by Bulod Floodplain is shown in Figure 21. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Bulod Floodplain has a total of 228.01 sq.km orthophotogaph coverage comprised of 512 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 22.

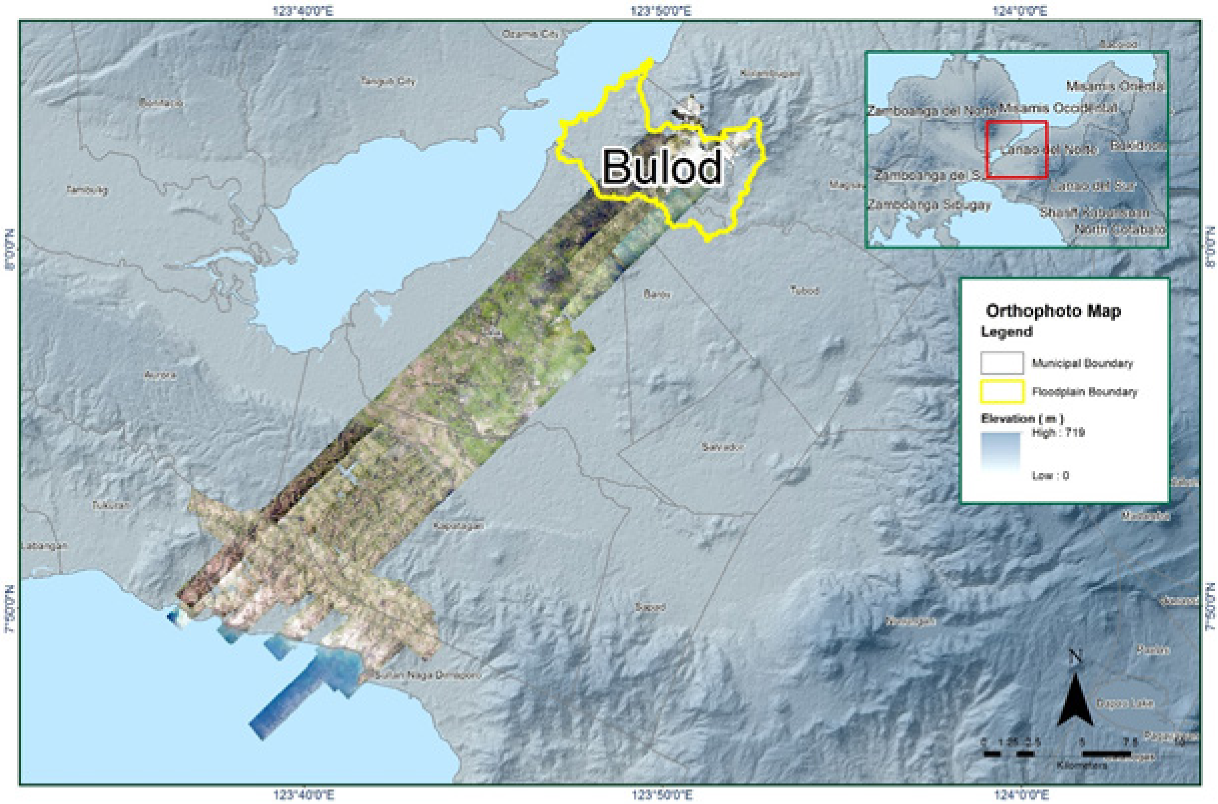


Figure 21. Bulod Floodplain with available orthophotographs

Figure 22. Sample orthophotograph tiles for Bulod Floodplain.

3.8 DEM Editing and Hydro-Correction

Seven (7) mission blocks were processed for Bulod Floodplain. These blocks are composed of Pagadian and NorthernMindanao blocks with a total area of 1,524.85 square kilometers. Table 14 shows the name and corresponding area of each block in square kilometers.

Table 1 4. LiDAR blocks with its corresponding area.

LiDAR Blocks	Area (sq.km)
Pagadian_Blk76J	40.53
Pagadian_Blk76K	180.29
Pagadian_Blk76K_additional	52.55
Pagadian_Blk76M	71.08
NorthernMindanao_Blk71E	178.76
NorthernMindanao_Blk71F	493.65
NorthernMindanao_Blk71ABC	507.99
TOTAL	1,524.85

Figure 23 shows portions of DTM before and after manual editing. The bridge (Figure 23-a) is considered to be an impedance to the flow of water along the river and has to be removed (Figure 23-b) in order to hydrologically correct the river. The river embankment (Figure 23-c) has been misclassified and removed during classification process and has to be retrieved to complete the surface (Figure 23-d) to allow the correct flow of water

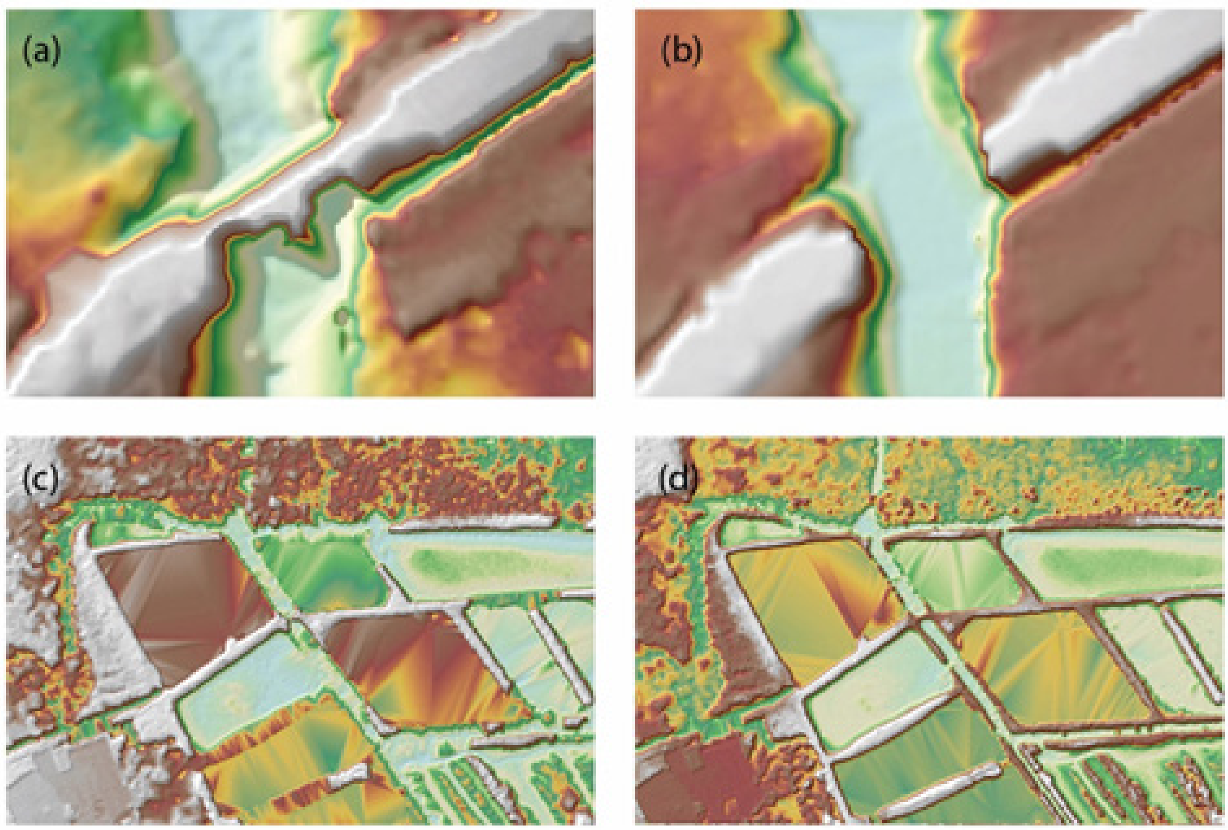


Figure 23. Portions in the DTM of Bulod Floodplain – a bridge before (Figure 23-a) and after (Figure 23-b) manual editing; a paddy field before (Figure 23-c) and after (Figure 23-d) data retrieval.

3.9 Mosaicking of Blocks

NorthernMindanao_Blk71F was used as the reference block at the start of mosaicking because it comprises the largest area among the missions blocks.

Mosaicked LiDAR DTM for Bulod Floodplain is shown in Figure 24. It can be seen that the entire Bulod Floodplain is 99.95% covered by LiDAR data.

Table 15. Shift Values of each LiDAR Block of Bulod Floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
Pagadian_Blk76J	-0.20	0.40	0.00
Pagadian_Blk76K	0.00	0.00	0.00
Pagadian_Blk76K_additional	0.00	0.00	0.00
Pagadian_Blk76M	0.00	0.00	0.00
NorthernMindanao_Blk71E	0.00	0.00	-0.30
NorthernMindanao_Blk71F	0.00	0.00	0.00
NorthernMindanao_Blk71G	0.00	0.00	0.00

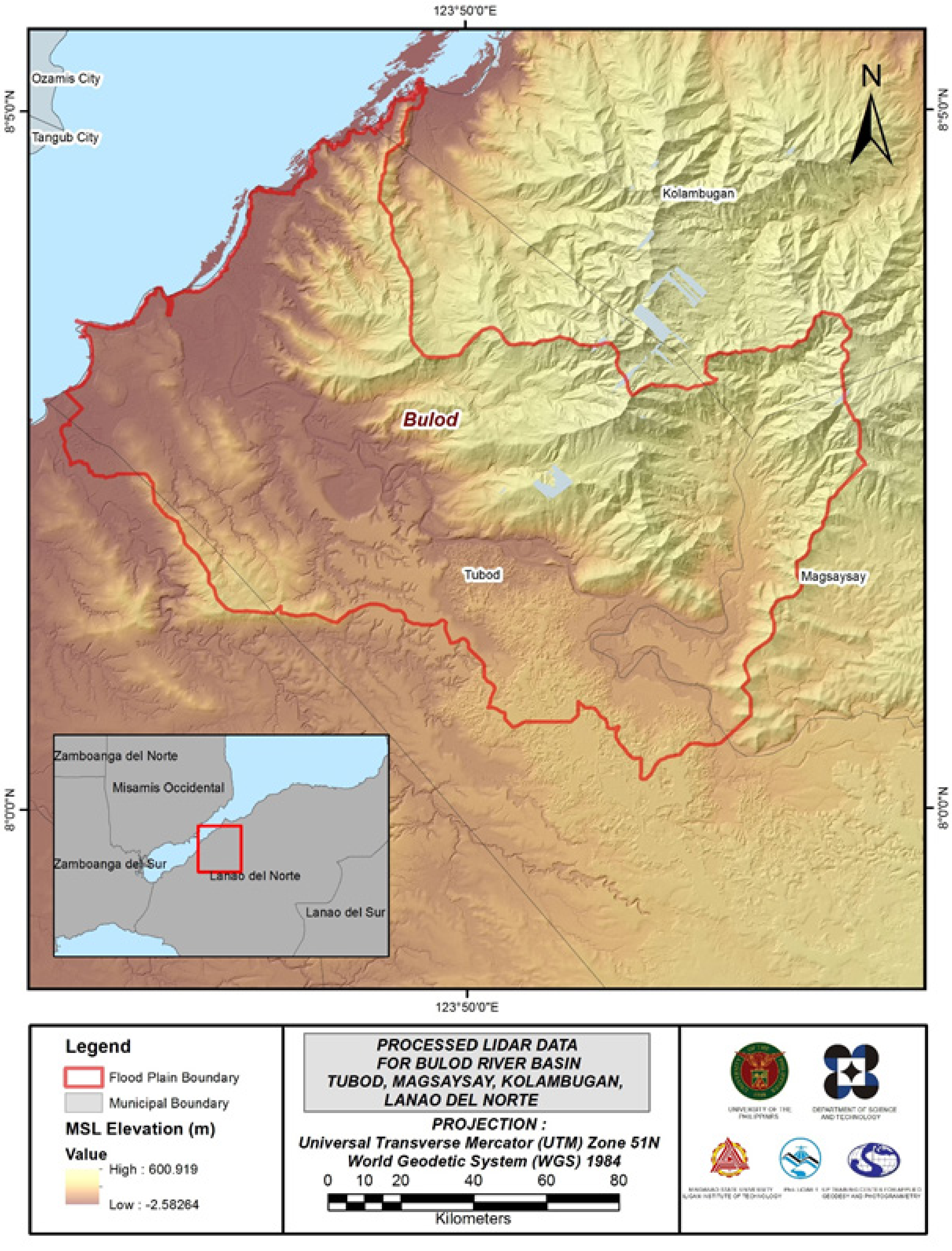


Figure 24. Map of Processed LiDAR Data for Bulod Floodplain.

3.10 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Bulod to collect points with which the LiDAR dataset is validated is shown in Figure 25. A total of 2003 survey points were used for calibration and validation of Bulod LiDAR data. Random selection of 80% of the survey points, resulting to 1602 points, were used for calibration.

A good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values is shown in Figure 26. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration elevation values is 2.27 meters with a standard deviation of 0.08 meters. Calibration of Bulod LiDAR data was done by adding the height difference value, 2.27 meters, to Bulod mosaicked LiDAR data. Table 16 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

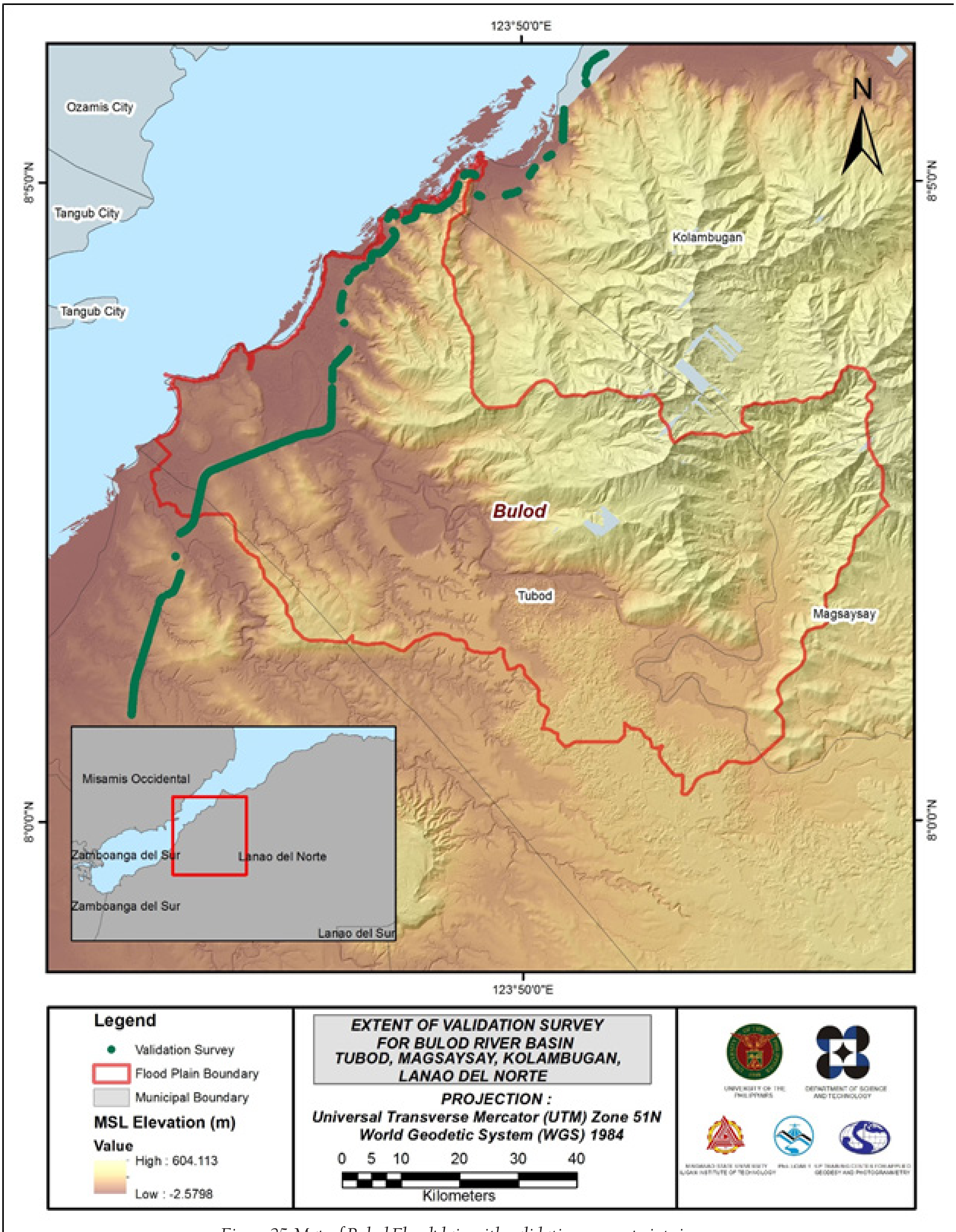


Figure 25. Map of Bulod Floodplain with validation survey points in green.

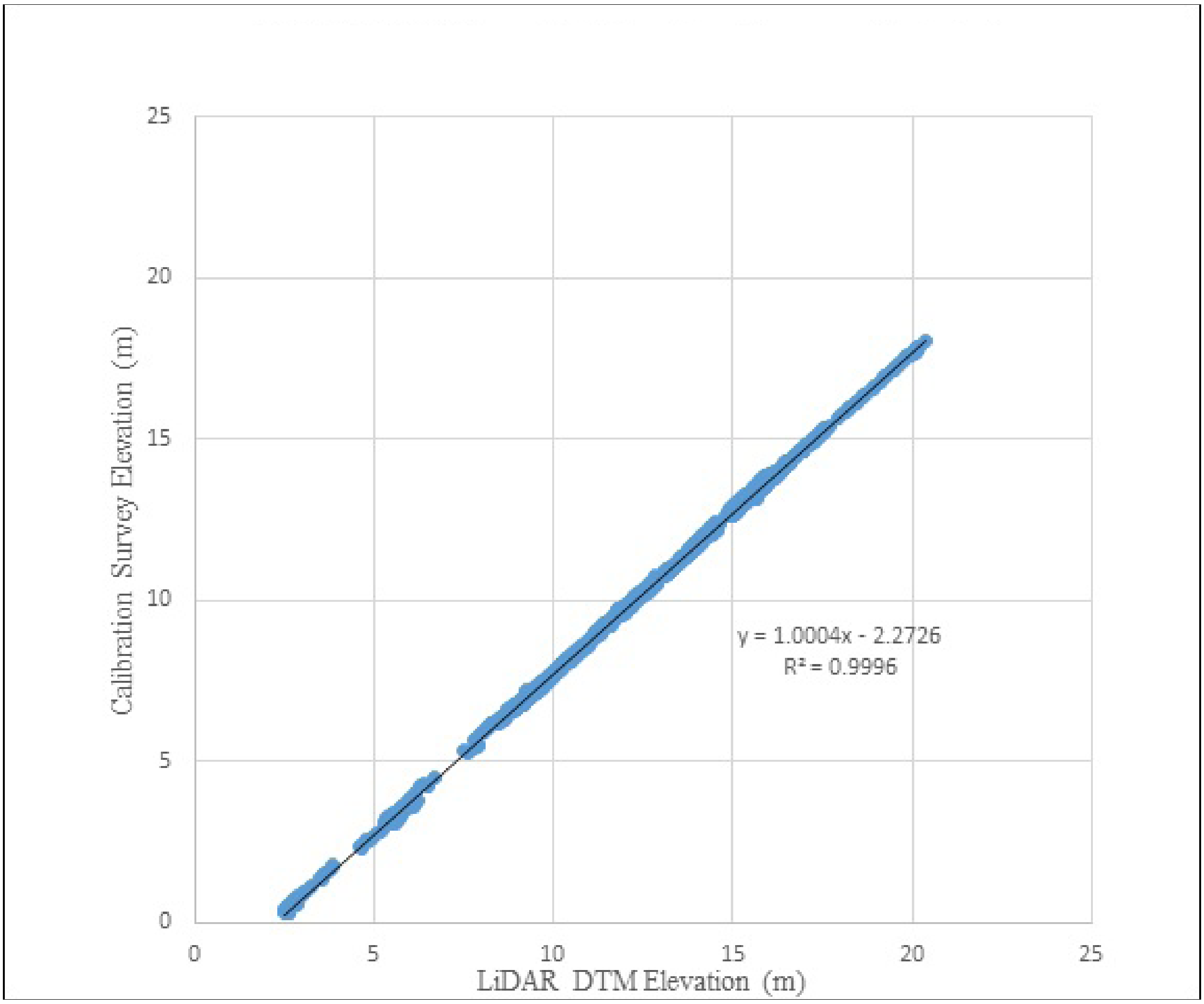


Figure 26. Correlation plot between calibration survey points and LiDAR data.

Table 16. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	2.27
Standard Deviation	0.08
Average	2.27
Minimum	2.06
Maximum	2.52

A total of 1308 survey points were collected by DVBC for the Bulod river basin. Random selection of 20% of the total survey points, resulting to 262 points, were used for the validation of calibrated Bulod 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 27. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.09 meters with a standard deviation of 0.08 meters, as shown in Table 17.

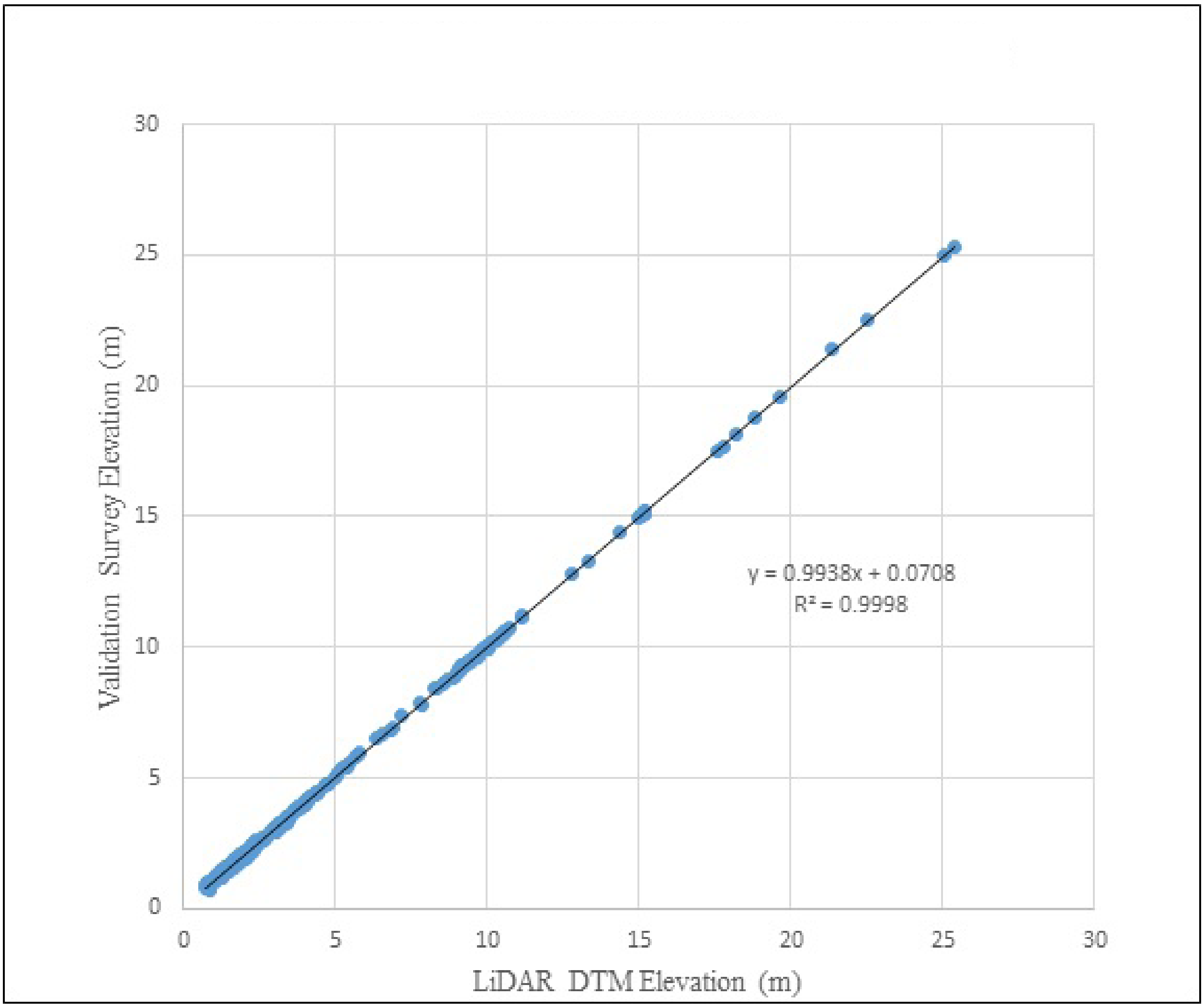


Figure 27. Correlation plot between validation survey points and LiDAR data.

Table 17. Validation Statistical Measures.

Validation Statistical Measures	Value (meters)
RMSE	0.09
Standard Deviation	0.08
Average	-0.04
Minimum	-0.23
Maximum	0.13

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, only centerline and cross-section data were available for Bulod with 15,239 bathymetric survey points. The resulting raster surface produced was done by Kernel interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.19 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Bulod integrated with the processed LiDAR DEM is shown in Figure 28.

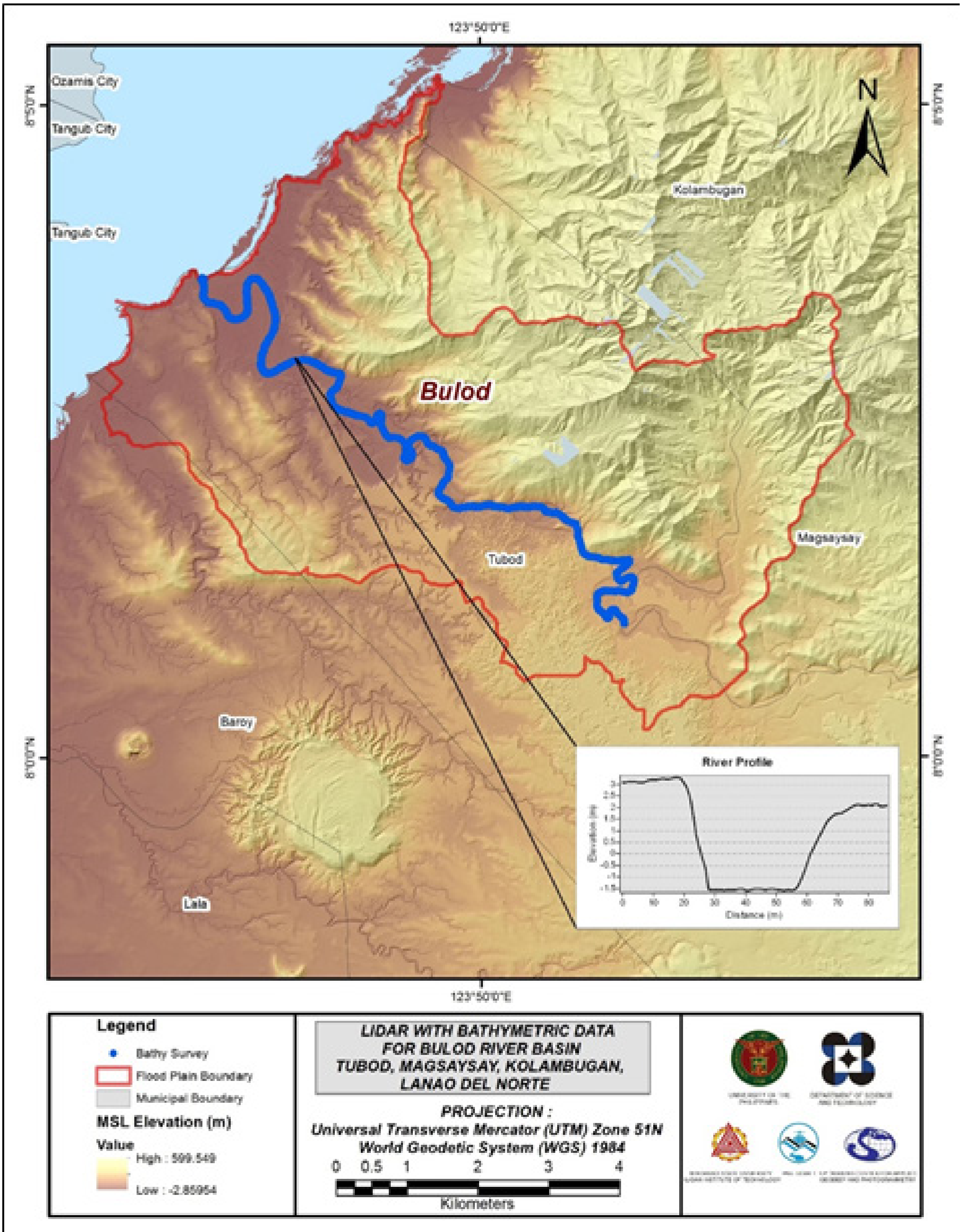


Figure 28. Map of Bulod Floodplain with bathymetric survey points shown in blue.

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 (QC) of Digitized Features' Boundary

Bulod Floodplain, including its 200 m buffer, has a total area of 52.38 sq km. For this area, a total of 5.00 sq km, corresponding to a total of 924 building features, are considered for QC. Figure 29 shows the QC blocks for Bulod Floodplain.

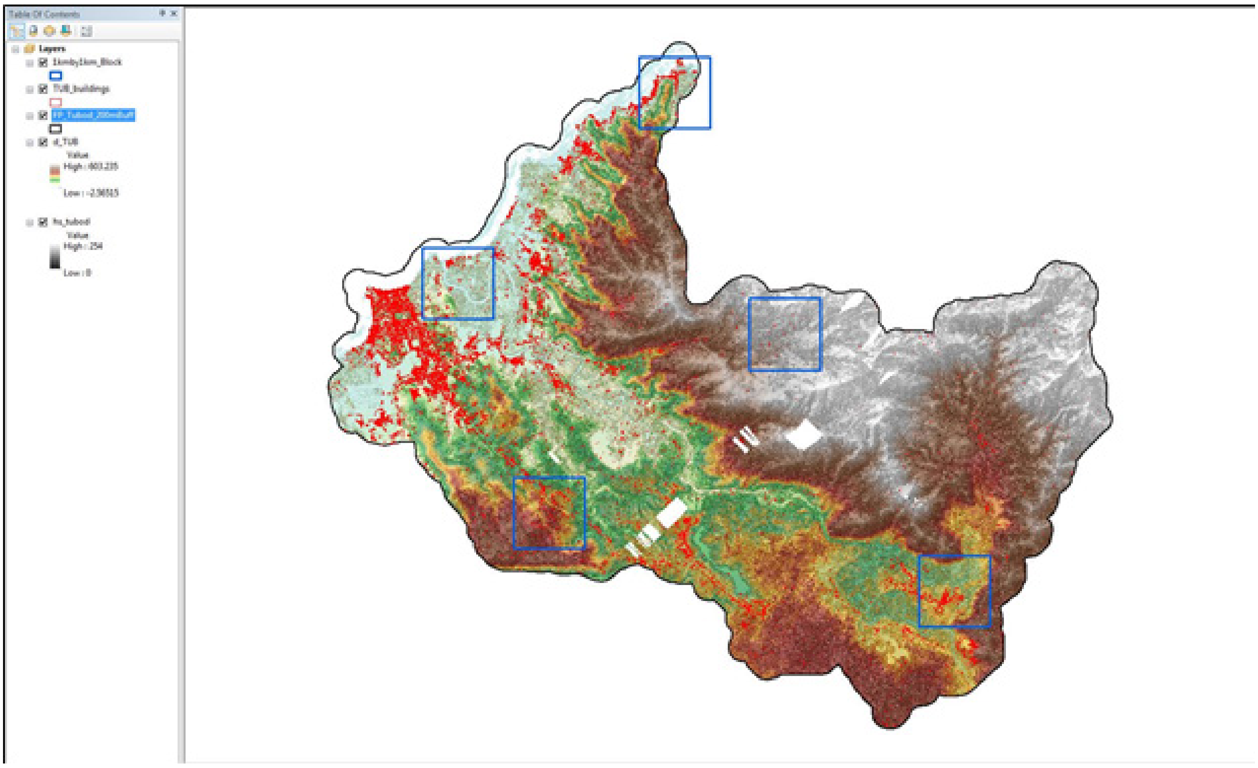


Figure 29. QC blocks for Bulod building features.

Quality checking of Bulod building features resulted in the ratings shown in Table 18.

Table 18. Quality Checking Ratings for Bulod Building Features.

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Bulod	98.92	88.85	83.87	PASSED

3.12.2 Height Extraction

Height extraction was done for 9,389 building features in Bulod Floodplain. Of these building features, 332 was filtered out after height extraction, resulting to 9,057 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 22.87 m.

3.12.3 Feature Attribution

Bulod Floodplain is shared by three (3) municipalities namely, Tubod, Magsaysay, and Kolambugan. The building attribution on the Municipalities of Tubod, Magsaysay and Kolambugan was done with the Google Earth approach. In Google Earth approach, aid from Purok representatives were sought for participatory mapping over the Google Earth software. The attributions of road, bridge and water body features were done using NAMRIA maps, municipal and city records, and participatory mapping of municipals and cities.

Table 19 summarizes the number of building features per type. On the other hand, Table 20 shows the total length of each road type, while Table 21 shows the number of water features extracted per type.

Table 19. Number of Building Features Extracted for Bulod Floodplain.

Facility Type	No. of Features
Residential	8,646
School	69
Market	11
Agricultural/Agro-Industrial Facilities	40
Medical Institutions	15
Barangay Hall	12
Military Institution	0
Sports Center/Gymnasium/Covered Court	15
Telecommunication Facilities	5
Transport Terminal	9
Warehouse	20
Power Plant/Substation	0
NGO/CSO Offices	1
Police Station	3
Water Supply/Sewerage	0
Religious Institutions	48
Bank	2
Factory	1
Gas Station	6
Fire Station	1
Other Government Offices	56
Other Commercial Establishments	97
Total	9,049

Table 20. Total Length of Extracted Roads for Bulod Floodplain.

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/ Municipal Road	Provincial Road	National Road	Others	
Bulod	52.1	24	0.00	8.59	0.00	84.69

Table 21. Number of Extracted Water Bodies for Bulod Floodplain.

Floodplain	Water Body Type					Total
	Rivers/ Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Bulod	29	0	0	0	14	43

A total of 8 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 30 shows the Digital Surface Model (DSM) of Bulod Floodplain overlaid with its ground features.

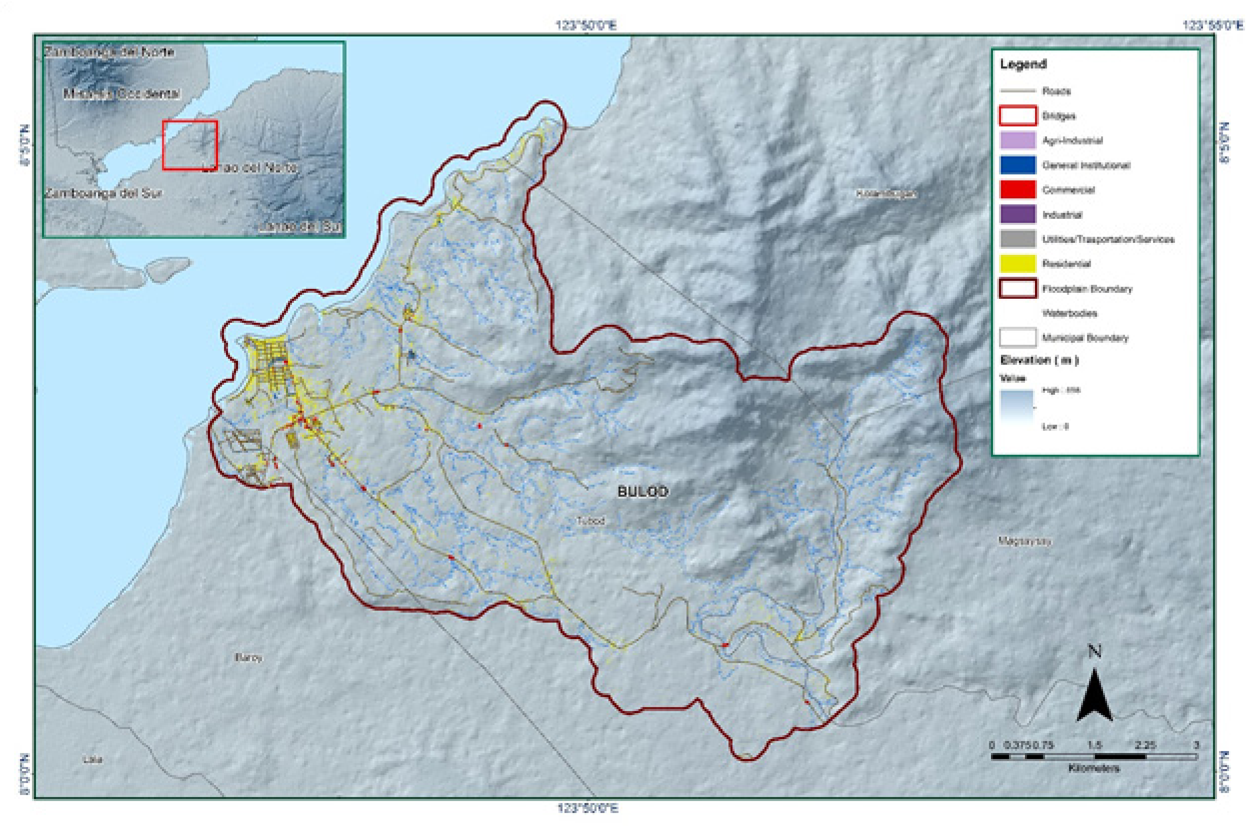


Figure 30. Extracted features for Bulod Floodplain

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

Engr. Louie P. Balicanta, Engr. Joemarie S. Caballero, Ms. Patrizcia Mae. P. dela Cruz, Engr. Dexter T. Lozano, Engr. Kristine Ailene B. Borromeo, For. Dona Rina Patricia C. Tajora, Elaine Bennet Salvador, and For. Rodel C. Alberto

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

4.1 Summary of Activities

The Data Validation and Bathymetry Component (DVBC) conducted a field survey in Bulod River on October 8 to 19, 2015 and October 23 – November 11, 2016 with the following scope of work: reconnaissance to determine the viability of traversing the planned routes for bathymetric survey; courtesy call with MSU-IIT, Tubod LGUs and MDRRMC; control survey for the establishment of control point as base station for GNSS surveys; cross-section survey, bridge-as-built features determination and water level marking at Magsaysay in Brgy. Baguiguicon, Municipality of Magsaysay, Lanao Del Norte; LiDAR validation survey of around 14 km distance; and bathymetric survey from Brgy. Baguiguicon in Municipality of Magsaysay down to its mouth in Brgy. Poblacion using Trimble® SPS 882 in GNSS PPK survey technique and an Ohmex™ single beam echo sounder.

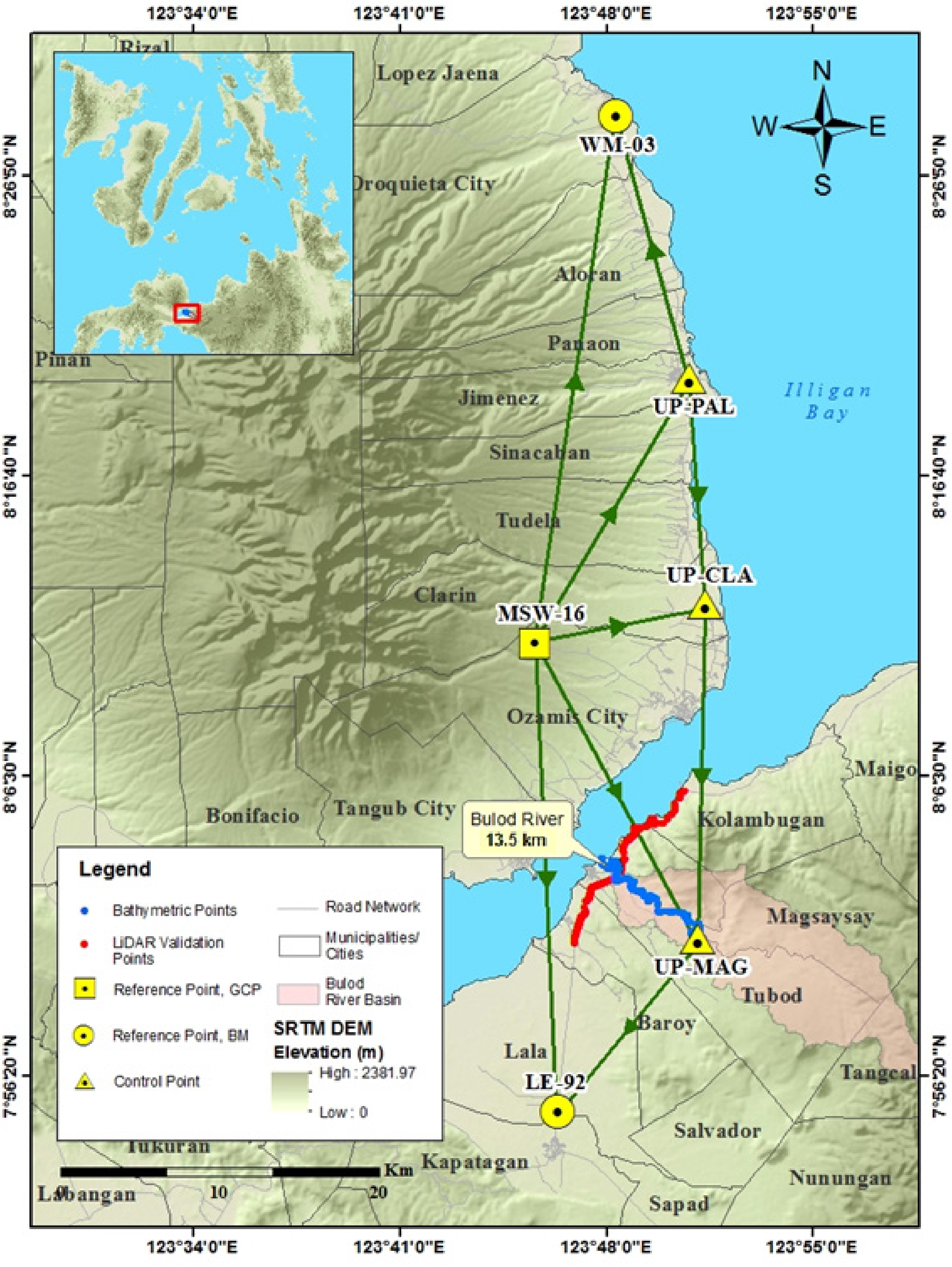


Figure 31. Extent of the bathymetric survey (in blue line) in Bulod River and the LiDAR data validation survey (red)

4.2 Control Survey

The GNSS network used for Bulod River is composed of four loops established on October 9 and 16, 2015 occupying the following reference points: MSW-16, a second order GCP located in Brgy. Stimson Abordo, Ozamis City, Misamis Occidental; and LE-92, a first order BM in Brgy. Maranding, Mun. of Lala, Lanao Del Norte.

Three (3) control points were established along approach of bridges namely: UP-CLA along Clarin Bridge in Brgy. Poblacion IV, Mun. of Clarin, Misamis Occidental, UP-MAG along Magsaysay Bridge in Brgy. Baguiguicon, Mun. of Magsaysay, Lanao Del Norte; and UP-PAL, along Palilan Bridge in Brgy. Rizal, Mun. of Jimenez, Misamis Occidental. A NAMRIA established control point namely WM-03 in Brgy. Langcangan Lower, Oroquieta City, Misamis Occidental, was also occupied to use as marker during the survey.

The list of control points used in the survey is summarized in Table 22 while the GNSS network established is illustrated in Figure 32.

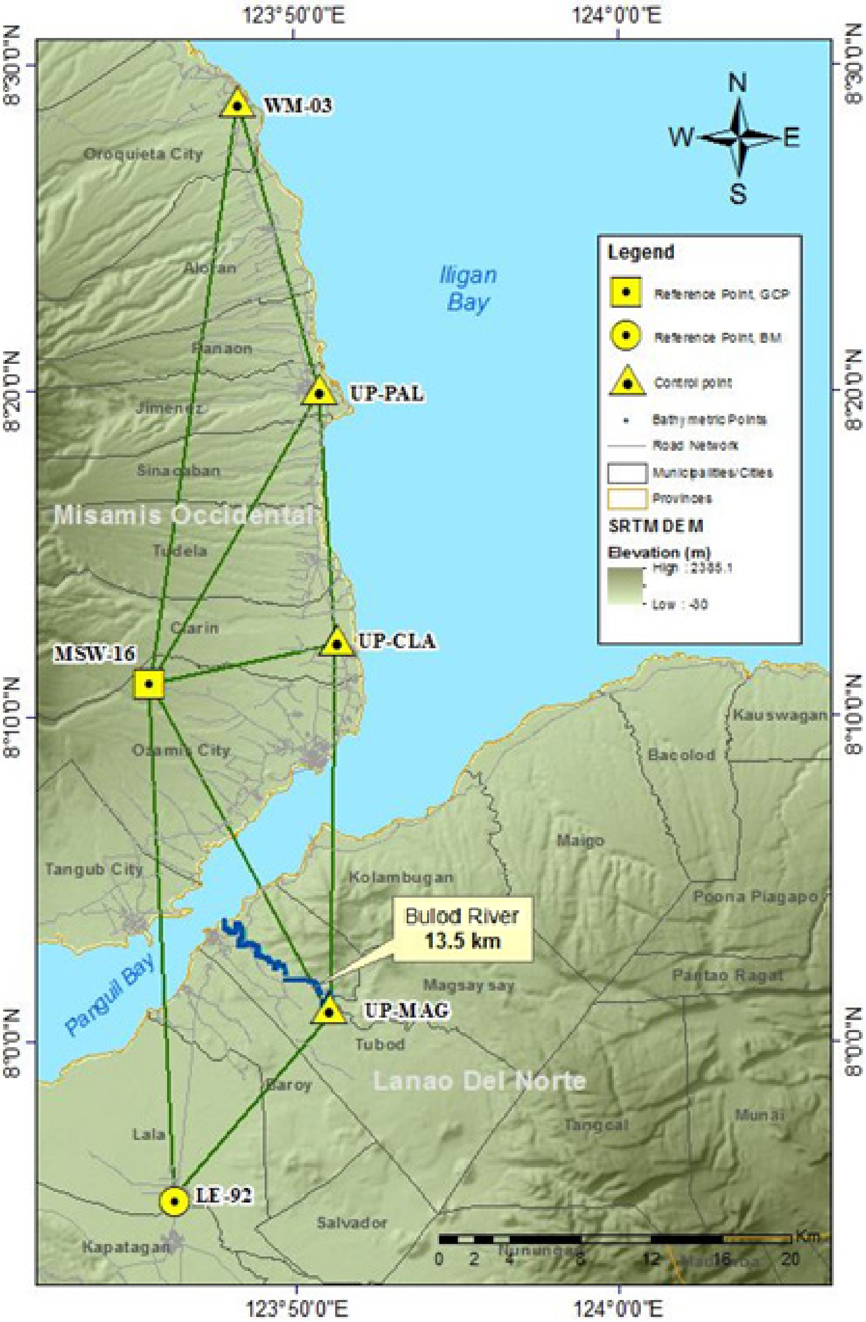


Figure 32. GNSS Network of Bulod River Basin Surveyr

Table 22. List of reference and control points occupied during control survey in the Bulod River Basin Survey (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (m)	Elevation in MSL (m)	Date Established
MSW-16	2nd Order, GCP	8°11'00.29164"N	123°45'35.16284"E	360.45	-	2007
LE-92	1st Order, BM	7°55'08.47442"N	123°46'19.89121"E	89.406	18.440	2007
WM-03	Used as Marker	-	-	71.984	-	10-09-2015
UP-CLA	UP Established	-	-	73.574	-	10-16-2015
UP-MAG	UP Established	-	-	75.086	-	10-16-2015
UP-PAL	UP Established	-	-	104.343	-	10-09-2015

The GNSS set up on the recovered reference and control points are shown in Figures 33 to 38

Figure 33. Trimble® SPS 852 setup at MSW-16 beside the fence of the basketball court in Brgy. Stimson Abordo, Ozamiz City, Misamis Occidental

Figure 34. Trimble® SPS 882 setup at LE-92 on the southwest end of Maranding Bridge foot walk in Brgy. Maranding, Mun. of Lala, Lanao del Norte

Figure 35. Trimble® SPS 882 setup at WM-03, G. Pelaez Bridge approach in Brgy. Langcangan Lower, Oroquieta City, Misamis Occidental

Figure 36. Trimble® SPS 985 setup at UP-CLA, Clarin Bridge approach in Brgy. Poblacion IV, Mun. of Clarin, Misamis Occidental

Figure 37. Trimble® SPS 852 setup at UP-MAG, Magsaysay Bridge approach in Brgy. Baguiguicon, Mun. of Magsaysay, Lanao del Norte

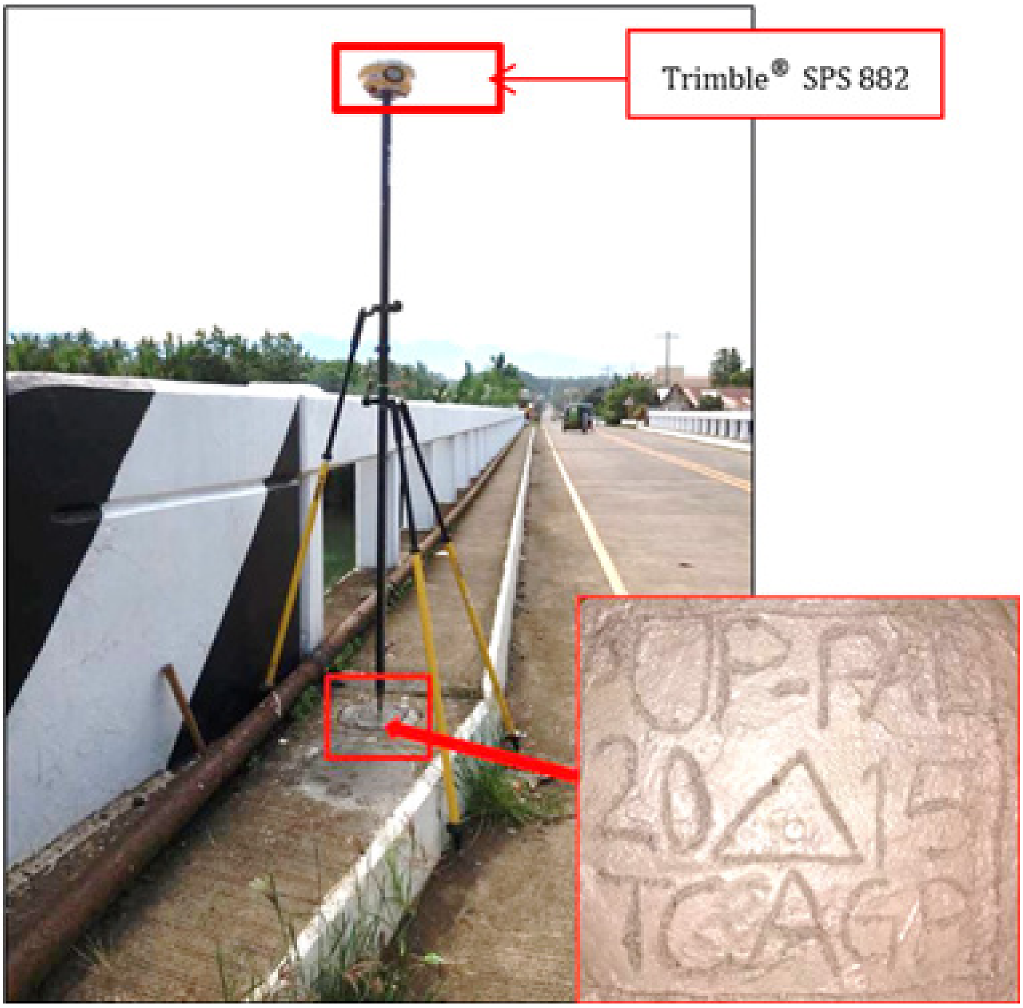


Figure 38. Trimble® SPS 882 setup at UP-PAL, Palilan Bridge approach in Brgy. Rizal, Jimenez, Misamis Occidental

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 when one or more baselines did not meet all of these criteria, masking is performed. Masking is the removal or covering portions of these baseline data using the same processing software. It is then repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, a resurvey is initiated. Table 23 presents baseline processing result of control points used in the Bulod River Basin survey as generated by TBC software.

Table 23. Baseline Processing Report for Bulod River Static Survey

Observation	Date of Observation	Solution Type	Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter	ΔHeight (Meter)
MSW-16 --- WM-03	10-09-2015	Fixed	0.004	0.020	8°43'51"	33276.508	-288.452
UP-MAG --- LE-92	10-16-2015	Fixed	0.005	0.022	218°55'21"	13902.765	-14.918
UP-CLA --- UP-MAG	10-16-2015	Fixed	0.007	0.029	181°19'19"	20888.063	29.273
UP-PAL --- UP-CLA	10-16-2015	Fixed	0.012	0.036	176°03'05"	14161.786	1.493
UP-PAL --- WM-03	10-09-2015	Fixed	0.004	0.020	344°25'08"	16925.934	-1.589

MSW-16 --- LE-92	10-16-2015	Fixed	0.005	0.028	177°19'03"	29272.955	-271.079
UP-MAG --- MSW-16	10-16-2015	Fixed	0.004	0.028	151°15'40"	21010.700	-256.104
MSW-16 --- UP-CLA	10-16-2015	Fixed	0.014	0.022	76°54'34"	10861.490	-285.310
UP-CLA --- MSW-16	10-16-2015	Fixed	0.004	0.026	76°54'34"	10861.481	-285.415
MSW-16 --- UP-PAL	10-09-2015	Fixed	0.005	0.019	30°03'43"	19166.124	-286.892

As shown in Table 23, a total of ten (10) baselines were processed with reference points MSW-16 fixed for coordinates values, and LE-91 fixed for elevation value. All of them passed the accuracy.

4.4 Network Adjustment

After the baseline processing procedure, network adjustment was 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 or in equation form:

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

Where:

x^e is the Easting Error,
y^e is the Northing Error, and
z^e is the Elevation Error

For complete details see the Network Adjustment Report shown in Tables 24 to 26:

The five (5) control points, MSW-16, LE-92, WM-03, UP-CLA, UP-MAG, and UP-PAL were occupied and observed simultaneously to form a GNSS loop. Coordinates of MSW-16 and elevation of LE-92 were held fixed during the processing of the control points as presented in Table 24. Through these reference points, the coordinates and elevation of the unknown control points will be computed.

Table 24. Control Point Constraints

Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
MSW-16	Global	Fixed	Fixed	
LE-92	Grid			Fixed
Fixed = 0.000001(Meter)				

Table 25. Adjusted Grid Coordinates

Point ID	Easting (meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
LE-92	585114.134	0.009	875424.503	0.007	20.730	0.066	
MSW-16	583690.278	?	904653.668	?	291.606	?	LLh
WM-03	588676.566	0.008	937544.108	0.006	4.964	0.051	
UP-PAL	593256.748	0.009	921254.886	0.006	5.558	0.046	

UP-CLA	594261.654	0.008	907132.926	0.007	6.428	0.043	
UP-MAG	593823.904	0.008	886255.511	0.007	35.363	0.058	

The network is fixed at a NAMRIA reference point MSW-16 and LE-92 for grid and elevation, respectively. With the mentioned equation, 〚〚√((x〛_e)〛^2+〚〚(y〛_e)〛^2)<20cm for horizontal and z_e<10 cm for the vertical; the computation for the accuracy for the horizontal and vertical accuracy are as follows:

a. MSW-16
Horizontal accuracy = Fixed
Vertical accuracy = 6.6 cm < 10 cm

b. LE-92
Horizontal accuracy $= \sqrt{((0.9)^2 + (0.8)^2)}$
$= \sqrt{(0.81 + 0.64)}$
$= 1.2$ cm < 20 cm
Vertical accuracy = Fixed

c. WM-03
Horizontal accuracy $= \sqrt{((0.8)^2 + (0.6)^2)}$
$= \sqrt{(0.64 + 0.36)}$
$= 1 < 20$ cm
Vertical accuracy = 8.2 c m < 10 cm

d. UP-CLA
Horizontal accuracy $= \sqrt{((0.8)^2 + (0.7)^2)}$
$= \sqrt{(0.64 + 0.49)}$
$= 1.06 < 20$ cm
Vertical accuracy = 7.3 cm < 10 cm

e. UP-MAG
Horizontal accuracy $= \sqrt{((0.8)^2 + (0.7)^2)}$
$= \sqrt{(0.64 + 0.49)}$
$= 1.06 < 20$ cm
Vertical accuracy = 6.0 cm < 10 cm

a. UP-PAL
Horizontal accuracy $= \sqrt{((0.9)^2 + (0.6)^2)}$
$= \sqrt{(0.81 + 0.36)}$
$= 1.17 < 20$ cm
Vertical accuracy = 7.9 cm < 10 cm

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

Table 26. Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
LE-92	N7°55'08.47407"	E123°46'19.89123"	87.116	?	e
MSW-16	N8°11'00.29164"	E123°45'35.16284"	358.160	0.066	LL
UP-CLA	N8°12'20.32560"	E123°51'20.80389"	72.796	0.073	
UP-MAG	N8°01'00.58291"	E123°51'05.06713"	102.053	0.060	
UP-PAL	N8°20'00.20593"	E123°50'48.94377"	71.284	0.079	
WM-03	N8°28'50.89651"	E123°48'20.30412"	69.694	0.082	

The Corresponding geodetic coordinates of LE-92, WM-03, UP-PAL, UP-CLA and UP-MAG which were derived from MSW-16 are within the required accuracy as shown in Table 26. Based on the result 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 used is indicated in Table 27.

Table 27. The reference and control points utilized in the Bulod River Survey, with its corresponding locations (Source: NAMRIA, UP-TCAGP)

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
MSW-16	2nd order, GCP	8°11'00.29164"	123°45'35.16284"	358.160	904653.668	583690.278	289.316
LE-92	1st order, BM	7°55'08.47407"	123°46'19.89123"	87.116	875424.492	585114.135	18.440
MW-03	Used as marker	8°28'50.89651"	123°48'20.30412"	69.694	937544.120	588676.568	2.673
UP-CLA	UP Established	8°12'20.32560"	123°51'20.80389"	72.796	907132.927	594261.657	4.138
UP-MAG	UP Established	8°01'00.58291"	123°51'05.06713"	102.053	886255.504	593823.908	33.073
UP-PAL	UP Established	8°20'00.20593"	123°50'48.94377"	71.284	921254.892	593256.751	3.268

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

The cross-section and as-built survey were done along the upstream side of Magsaysay Bridge in Brgy. Baguiguicon, Municipality of Magsaysay, Lanao Del Norte on October 16, 2015 using a Trimble® Total station through open traverse method and a GNSS receiver, Trimble® SPS 882, in PPK survey technique, respectively as shown in Figure 39. The former method was applied because the dense canopy cover along the bridge prohibited reception of satellite signals for GNSS PPK survey technique.

Figure 39. Cross-section for Bulod River along the upstream side of Magsaysay Bridge, Brgy. Sto. Nino, Tubod, Lanao del Norte.

The cross-sectional line for Magsaysay Bridge is about 70.55 meters with 24 cross-sectional points using UP-MAG as GNSS base station. The summary of gathered location map, cross-section in a diagram, and as-built data for Magsaysay Bridge is displayed in Figures 41 to 43, respectively.

Figure 40. Water level marking on the abutment of Magsaysay Bridge

Water surface elevation of 25.484in MSL of Bulod River was determined using Trimble® SPS 882 in PPK mode survey on October 18, 2015 at 3:34 PM. This was translated into marking the bridge's abutment using a total station. The marked abutment shown in Figure 40 shall serve as reference for flow data gathering and depth gauge deployment by the accompanying HEI, MSU-IIT, who is responsible for Bulod River.

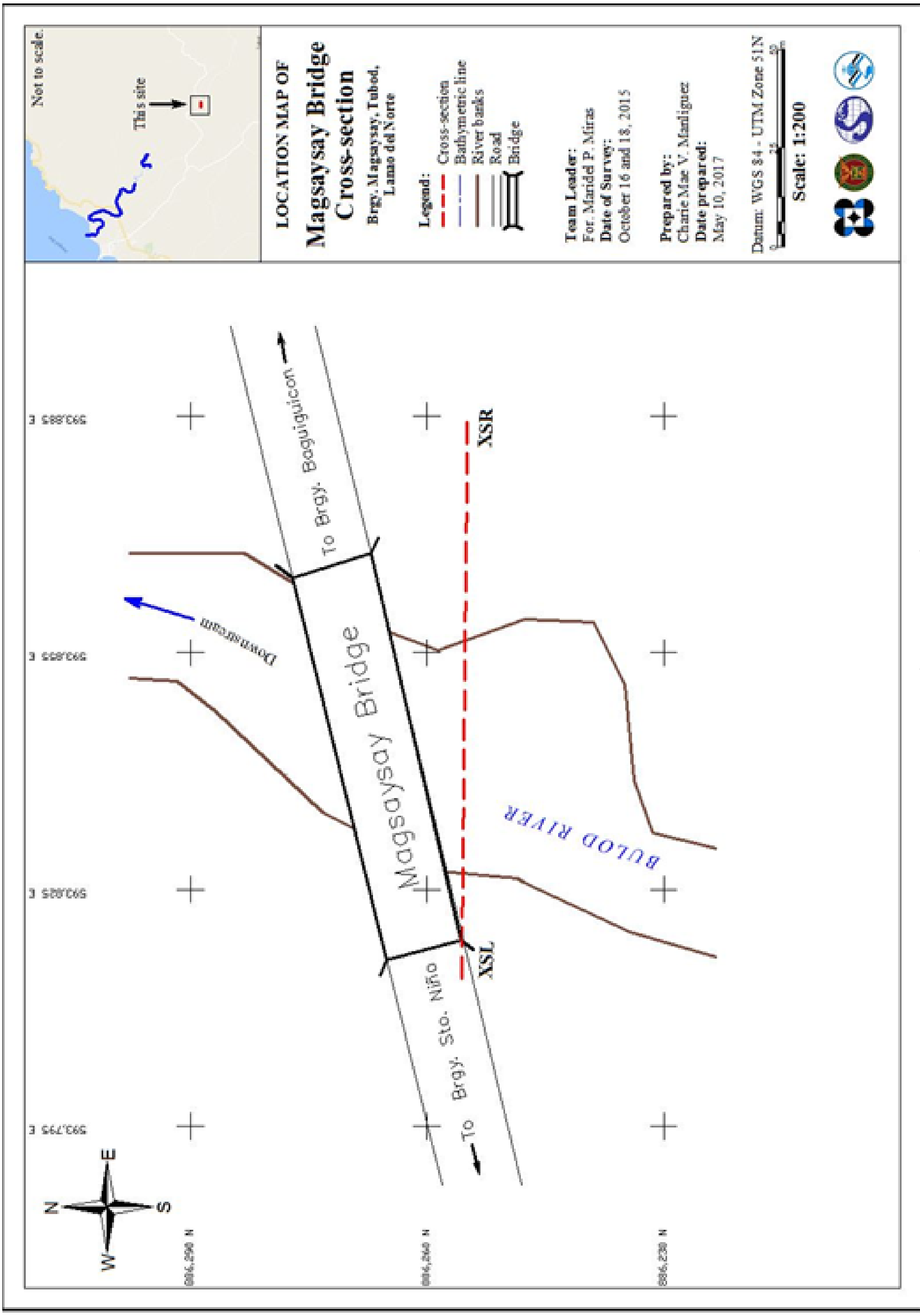


Figure 41. Magsaysay Bridge cross-section location map

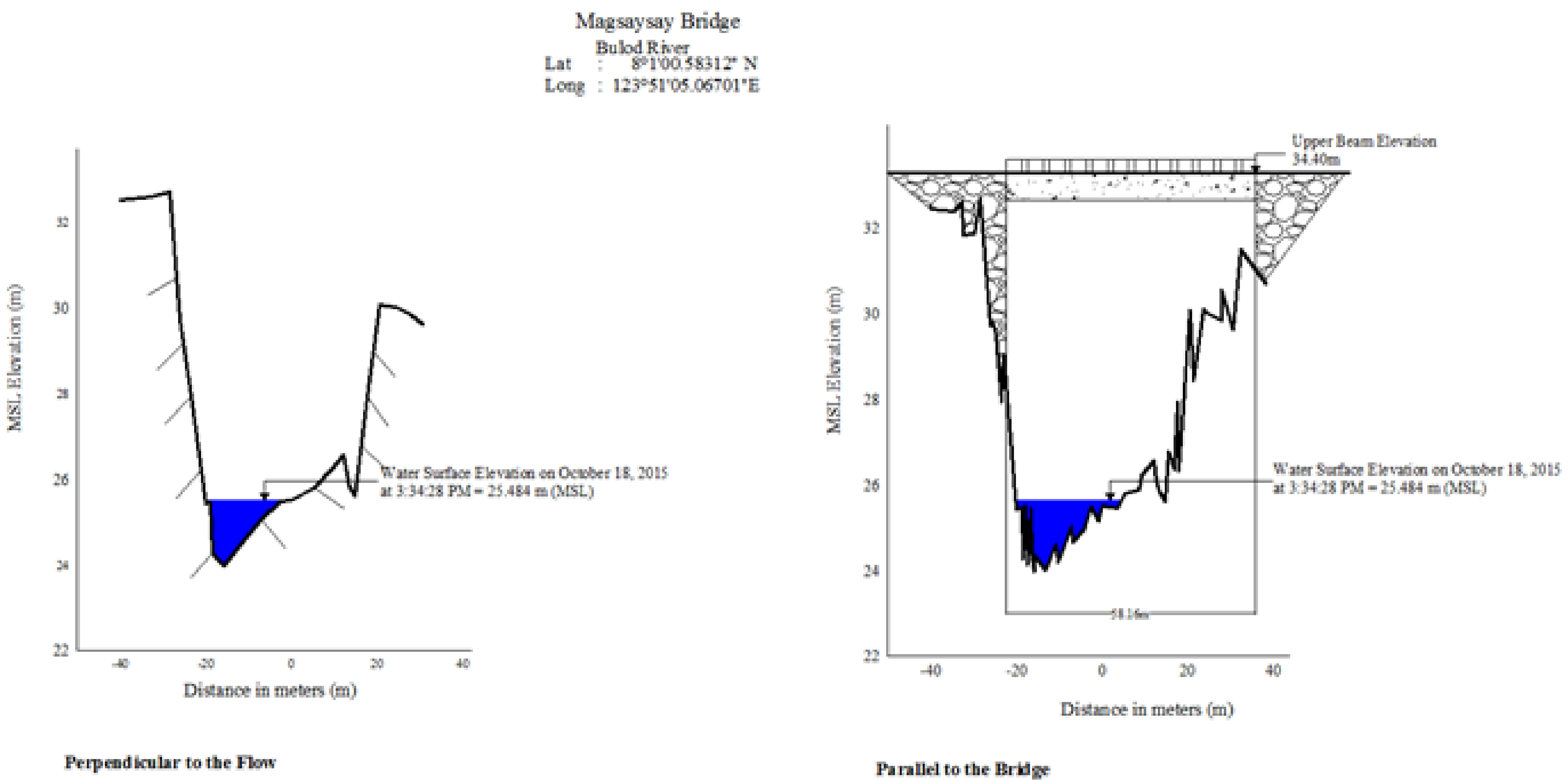


Figure 42. Cross section diagram at Magsaysay Bridge

Bridge Data Form

Bridge Name: Magsaysay Bridge **Date:** October 18, 2015

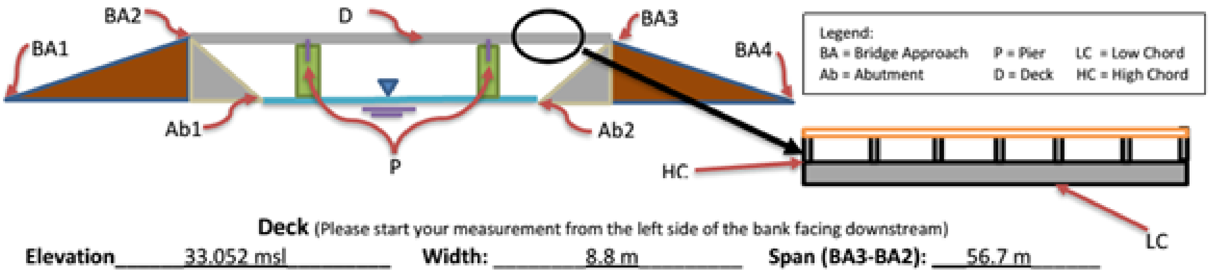
River Name: Bulod River **Time:** 3:34 PM

Location (Brgy, City, Region): Brgy. Sto.Nino, Mun. of Tubod, Lanao del Norte

Survey Team: Team Mady

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

Latitude: 8d01'00.58300" N **Longitude:** 123d51'05.06777" E



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

Elevation 33.052 msl **Width:** 8.8 m **Span (BA3-BA2):** 56.7 m

	Station	High Chord Elevation	Low Chord Elevation
1			
2			
3			
4			
5			

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

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	0		BA3		
BA2			BA4		

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

	Station (Distance from BA1)	Elevation
Ab1		
Ab2		

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

Shape: N/A **Number of Piers:** 0 **Height of column footing:**

	Station (Distance from BA1)	Elevation	Pier Width
Pier 1			
Pier 2			
Pier 3			
Pier 4			
Pier 5			
Pier 6			

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

Figure 43. Bridge Data Form of Magsaysay Bridge

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on November 3, 2016 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted at the side of a vehicle as shown Figure 44. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The antenna height was 1.85 m and measured from the ground up to the bottom of notch of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with UP-MAG occupied as the GNSS base station in the conduct of the survey.

Figure 44. Validation points acquisition survey set up along Bulod River Basin

The survey started in Brgy. Tabigue, Municipality of Kolambugan going south along national highway covering three (3) Municipalities in Lanao del Norte: Kolambugan, Baroy and Tubod; and ended in Brgy. Baroy Daku, Municipality of Baroy. A total of 5,310 points with approximate length of 15 km using UP-MAG as GNSS base station for the entire extent validation points acquisition survey as illustrated in the map in Figure 45.

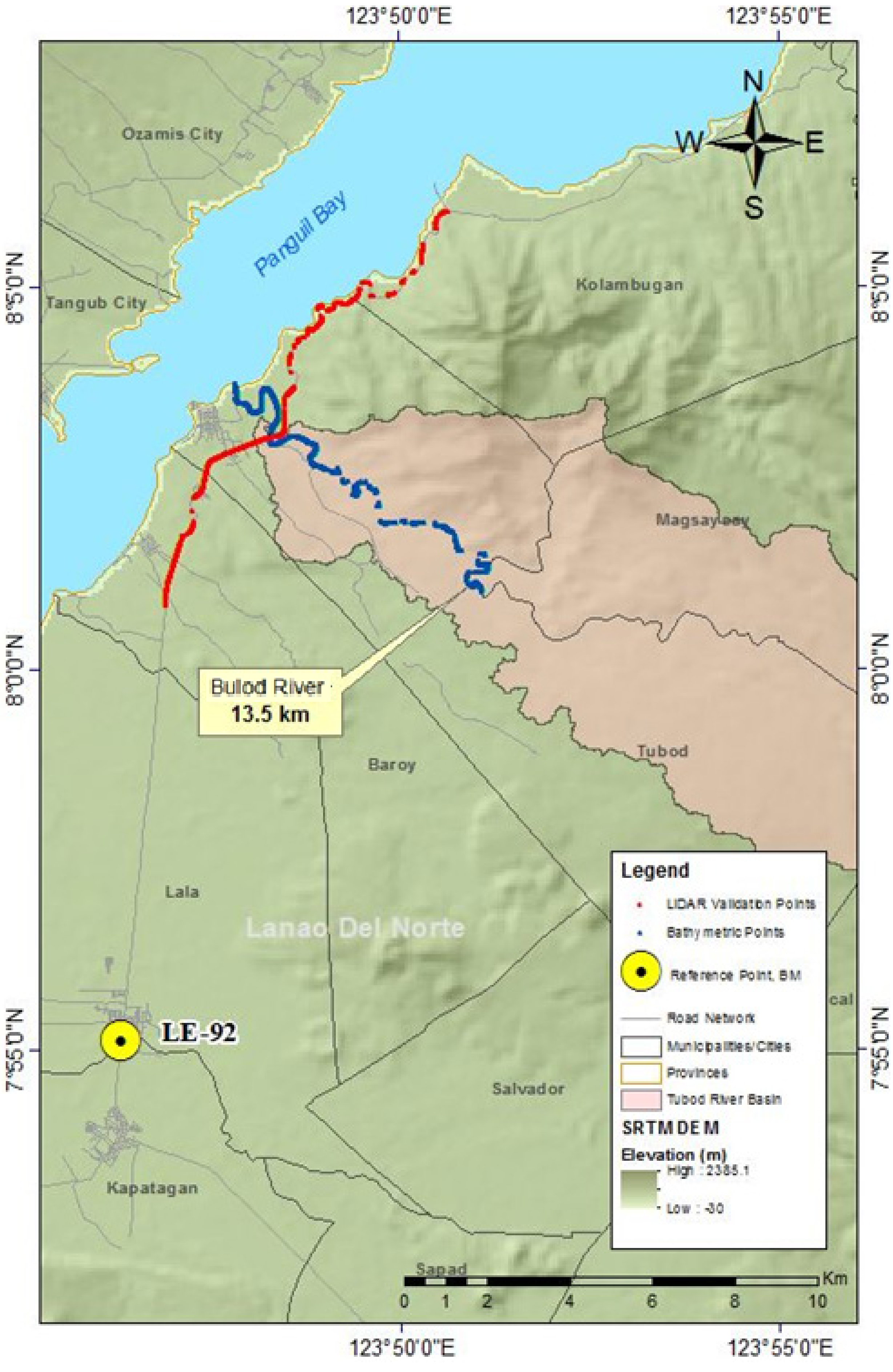


Figure 45. Validation point acquisition survey of Bulod River Basin

4.7 Bathymetric Survey

A bathymetric survey was conducted on October 17, 2015 using an Ohmex™ single beam echo sounder and Trimble® SPS 882 in PPK technique as shown in Figure 46. The survey started from the middle part of the river in Brgy. Bulod, Municipality of Tubod with coordinates 8°02’37.16162”N, 123°49’02.57516”E, down to the mouth of the river in Brgy. Poblacion, also in Tubod with coordinates 8°03’44.83835”N, 123°47’51.96945”E.

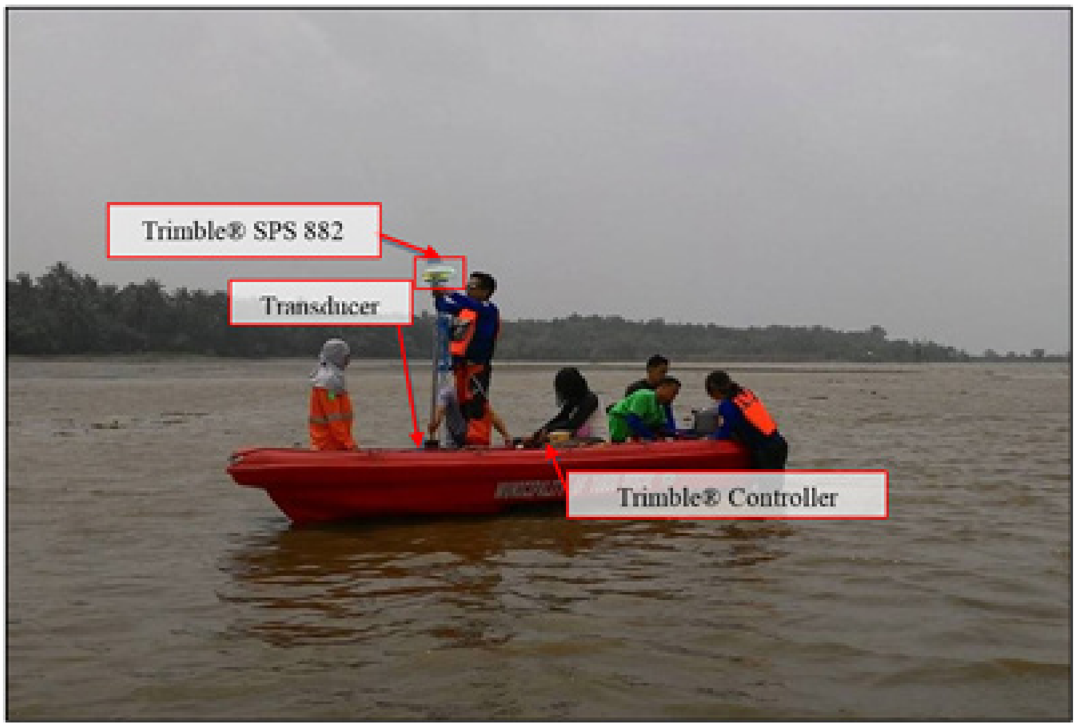


Figure 46. Bathymetric survey using an Ohmex™ single beam echo sounder along Bulod River

A manual bathymetric survey on the other hand was performed on October 17, 2015 and on November 4 to 6, 2016 using Trimble® SPS 882 in GNSS PPK technique and a Trimble® Total Station through open traverse method as shown in Figure 47. The survey started from the upstream part of the river in Magsaysay Bridge, Brgy. Baguiguicon, Municipality of Magsaysay, traversed down by foot and ended at the starting point of the bathymetric survey using boat. The control point UP-MAG was used as base station all throughout the survey.

Figure 47. Manual bathymetric survey along Bulod River

The entire bathymetric data coverage for Bulod River gathered a total of 15,365 bathymetric points covering a total of 13.5 km of the river traversing nine (9) barangays namely: Bulod, Kakai Renabor, Patudan, Pigcarangan, Poblacion, Pualas, Santo Niño and Tubaran in Municipality of Tubod; and Brgy. Baguiguicon in Municipality of Magsaysay, Lanao Del Norte as shown in Figure 48. A CAD drawing was also produced to illustrate the riverbed profile of Bulod River. As shown in Figure 49, the highest and lowest elevation value has a 31-m difference. The highest elevation gathered was 25.565 m in MSL located near Magsaysay Bridge in Brgy. Baguiguicon, Mun. of Magsaysay, while the lowest elevation value gathered was -6.376 m below MSL located at the downstream portion of the river in Brgy. Poblacion, Municipality of Tubod. The gaps in the bathymetric surveyed with an estimated distance of 700 m has no data due to difficulties in acquiring satellite caused by the presence of obstructions such as dense canopy cover of trees, abrupt change in elevation, rapids and time constraints.

Figure 48. Bathymetric Survey of Bulod River

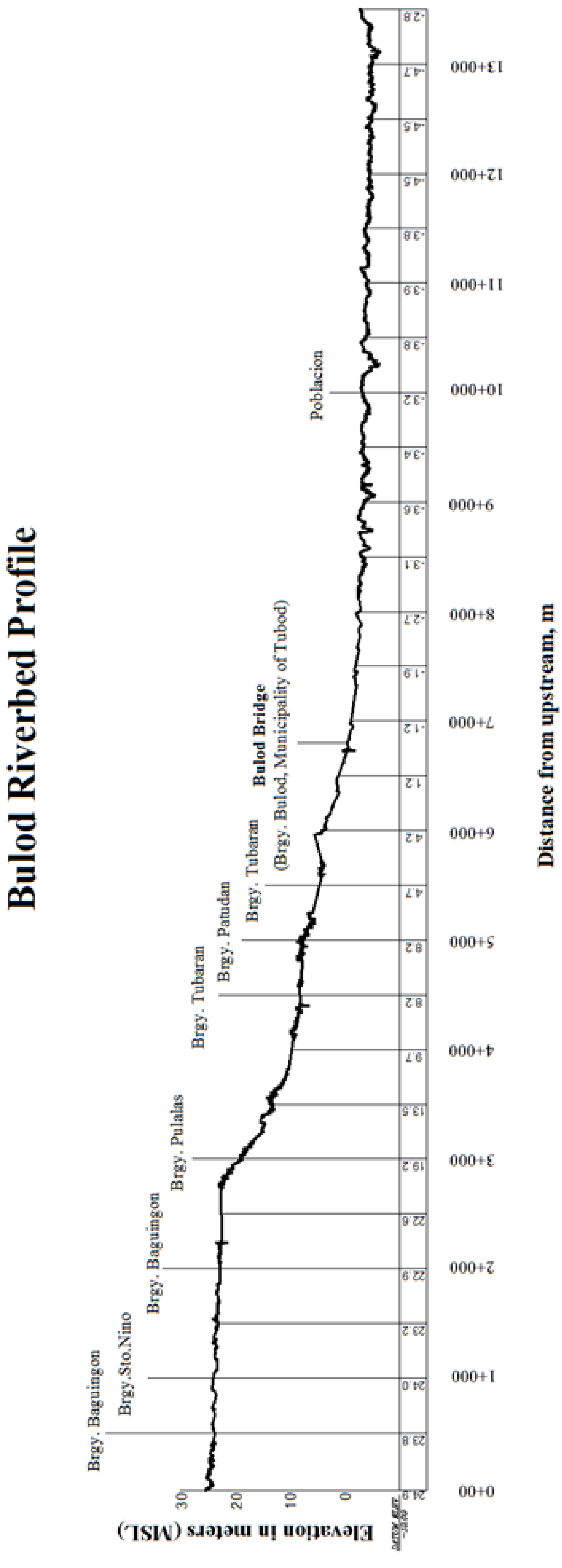


Figure 49. Riverbed Profile of Bulod River

CHAPTER 5: FLOOD MODELING AND MAPPING

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

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

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

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

5.1.2 Precipitation

Precipitation data was taken from the Automatic Rain Gauge (ARG) installed upstream by the Department of Science and Technology (DOST). The ARG was specifically installed in the Municipality of Tubod with coordinates 7°59’13.58”N Latitude and 123°51’20.32”E Longitude. The location of the rain gauge is shown in Figure 50.

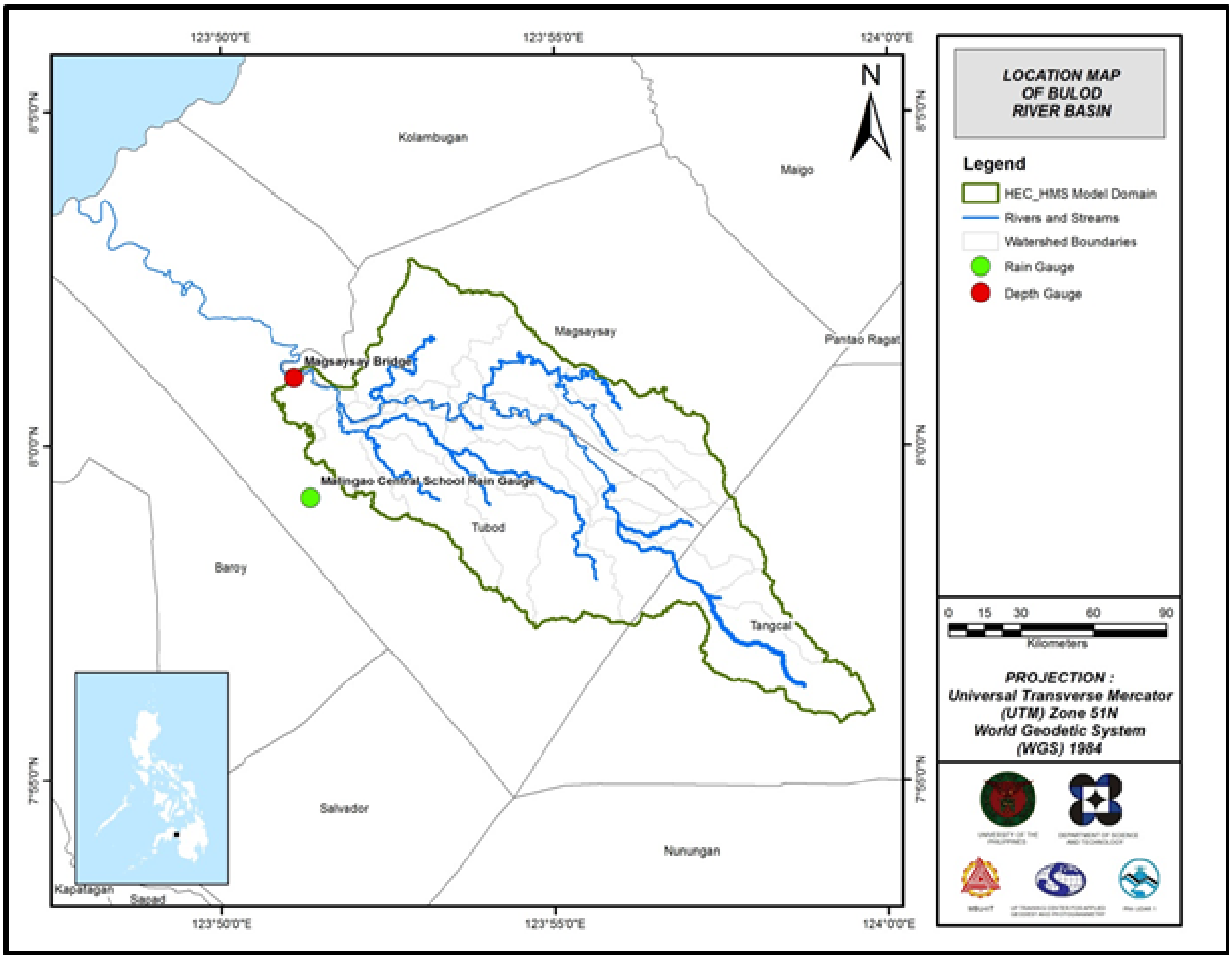


Figure 50. The location map of Bulod HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

HQ curve analysis is important in determining the equation to be used in establishing Q values with R-Squared values closer to 1. A trendline is more accurate if the R-Squared value is closer or at 1.

Figure 52 shows the highest R-Squared value of 0.9538 compared to the graphs using the original Q. In this case, Q boxed values with Q at bank-full were plotted versus the stage.

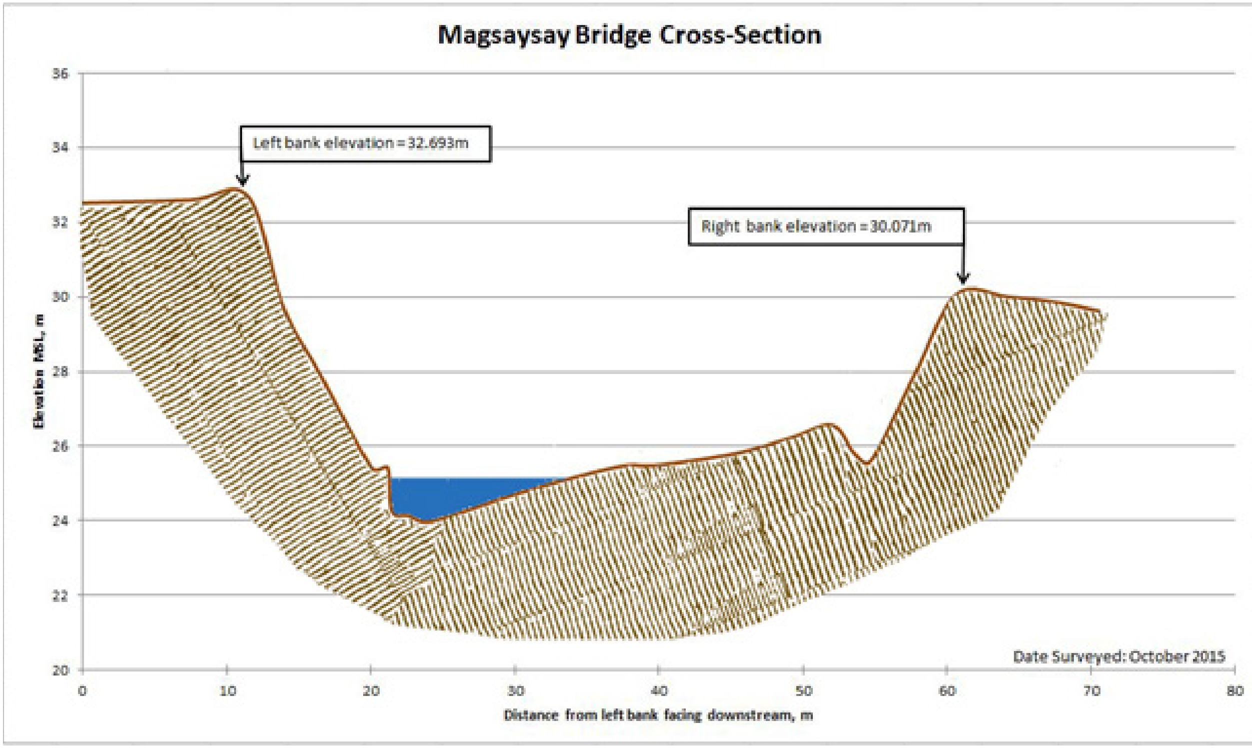


Figure 51. Cross-Section Plot of Magsaysay Bridge

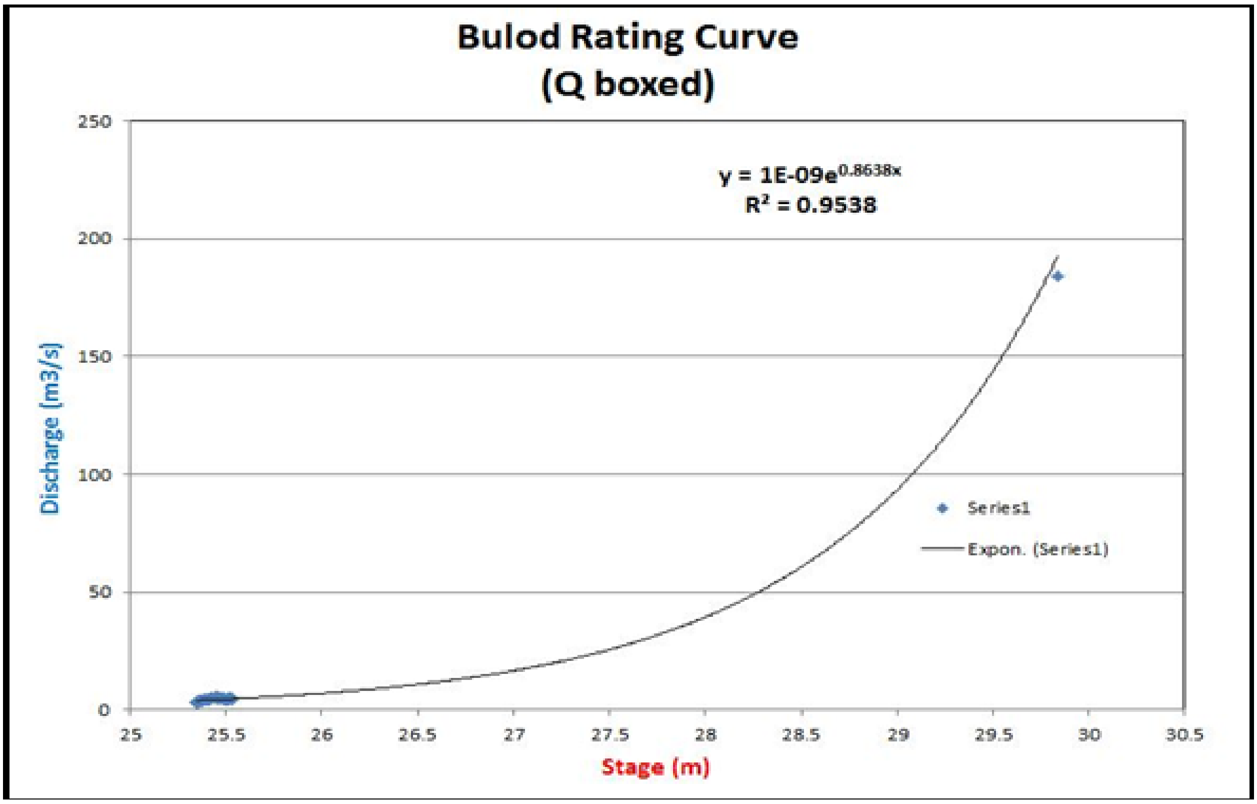


Figure 52. The rating curve at Magsaysay Bridge

This rating curve equation was used to compute the river outflow at Magsaysay Bridge for the calibration of the HEC-HMS model shown in Figure 53.

Total rainfall taken from the ARG at Malingao, Tubod was 12 mm. It peaked to 3.6 mm on 31 May 2016, 20:00. The lag time between the peak rainfall and discharge is 3 hour and 20 minutes.

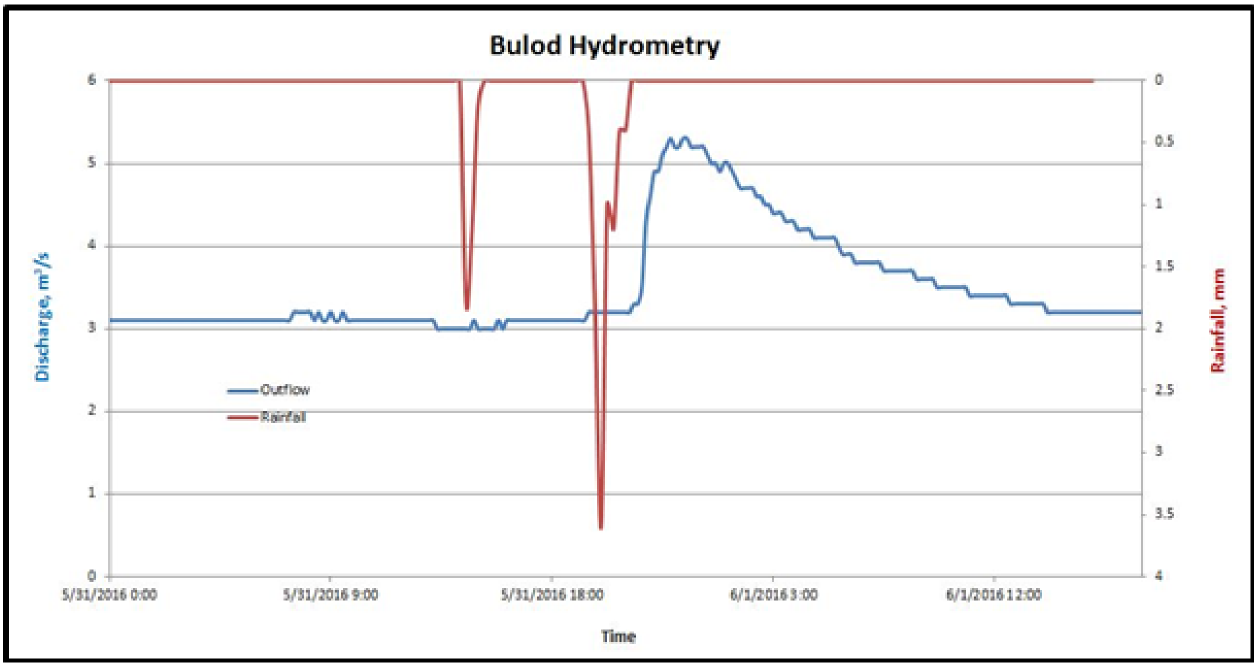


Figure 53. Rainfall and outflow data at Magsaysay Bridge used for modeling

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Dipolog Rain Gauge (Figure 54). The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the value in such a way certain peak value will be attained at a certain time (Figure 55). This station was selected based on its proximity to the Bulod watershed. The extreme values for this watershed were computed based on a 51-year record.

Table 28. RIDF values for Dipolog Rain Gauge computed by PAGASA

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	10 mins	20 mins	30 mins	1 hr	2 hrs	3 hrs	6 hrs	12 hrs	24 hrs
2	19.7	30.9	38.7	53.8	73.6	85.5	105.7	120.3	136.2
5	25.9	39.6	50.1	72.6	99.7	117.3	140.9	158.3	178.5
10	30	45.4	57.6	85.1	117	138.3	164.3	183.4	206.5
15	32.3	48.6	61.8	92.1	126.8	150.2	177.4	197.6	222.4
20	34	50.9	64.8	97.1	133.6	158.5	186.6	207.6	233.4
25	35.2	52.7	67.1	100.9	138.9	164.9	193.7	215.2	242
50	39	58.1	74.1	112.5	155.1	184.6	215.6	238.8	268.3
100	42.9	63.4	81.1	124.1	171.2	204.2	237.3	262.1	294.4

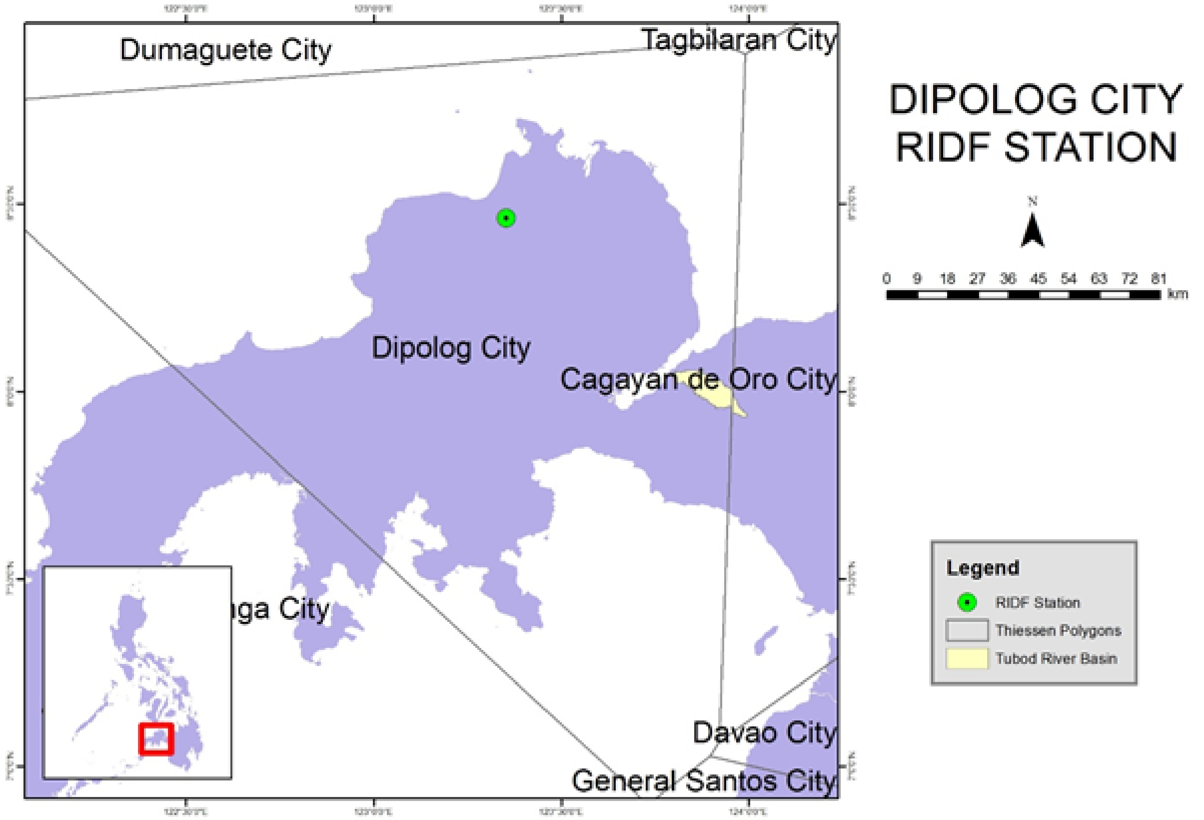


Figure 54. Location of Dipolog RIDF station relative to the Bulod River Basin

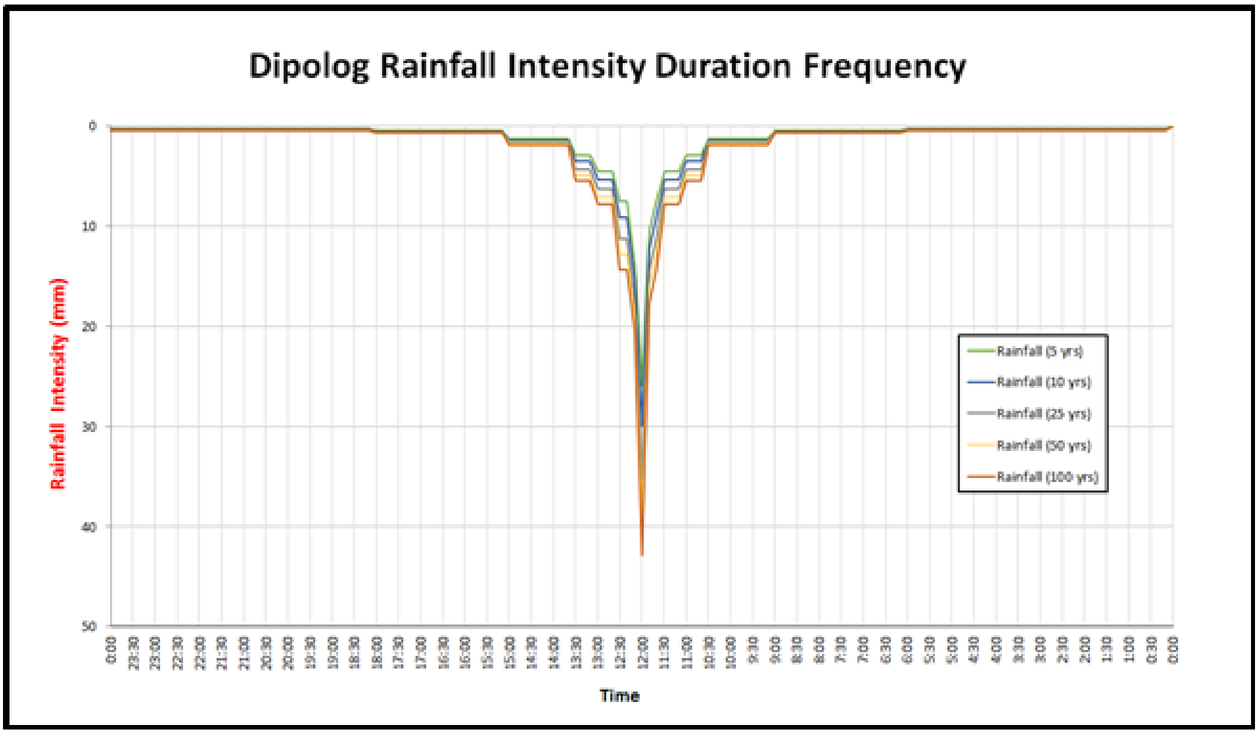


Figure 55. Synthetic storm generated for a 24-hr period rainfall for various return periods

5.3 HMS Model

The soil dataset was generated before 2004 by the Bureau of Soils and Water Management (BSWM) under the Department of Agricultue (DA). The soil texture map (Figure 56) of the Bulod River Basin was used as one of the factors for the estimation of the CN parameter.

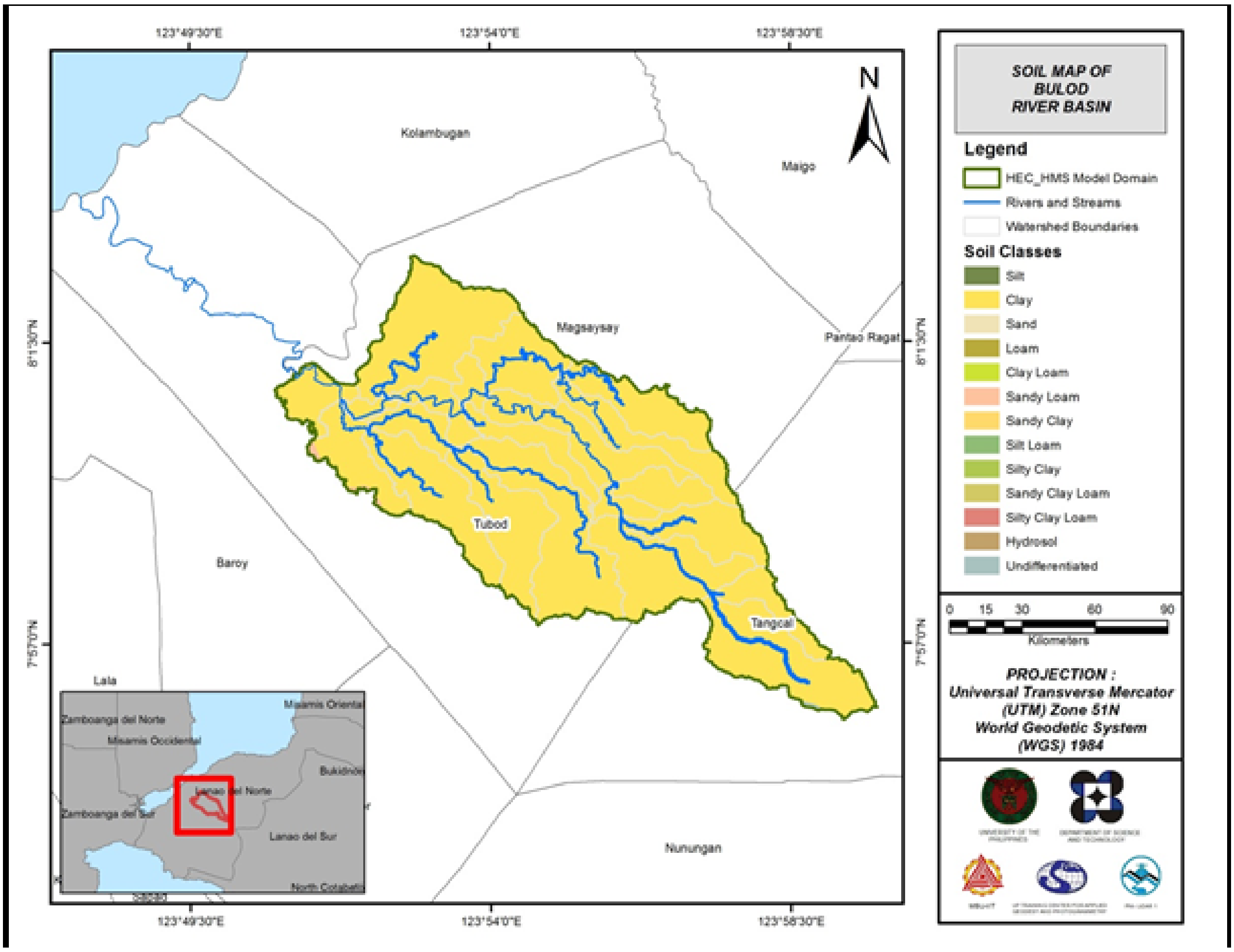


Figure 56. Soil Map of Bulod River Basin

The land cover data was generated in 2003 from the National Mapping and Resource Information Authority (NAMRIA), DENR. Figure 57 shows the Land Cover inside Bulod River Basin. The land cover map of Bulod River Basin was used as another factor for the estimation of the CN and watershed lag parameters of the rainfall-runoff model.

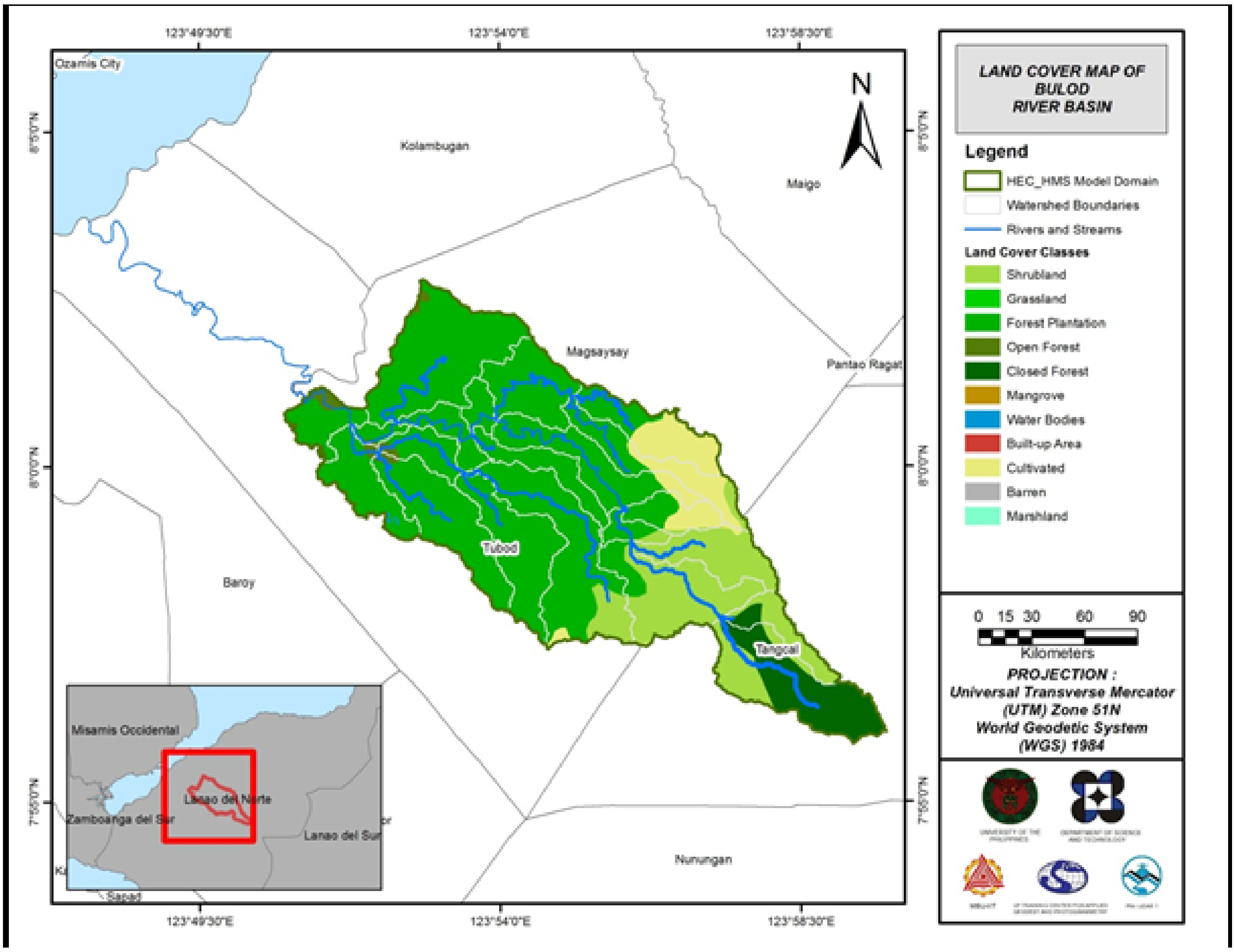


Figure 57. Land Cover Map of Bulod River Basin (SOURCE: NAMRIA)

For Bulod, the soil class identified was clay. The land cover types identified were shrubland, grassland, forest plantation, open forest, and closed forest.

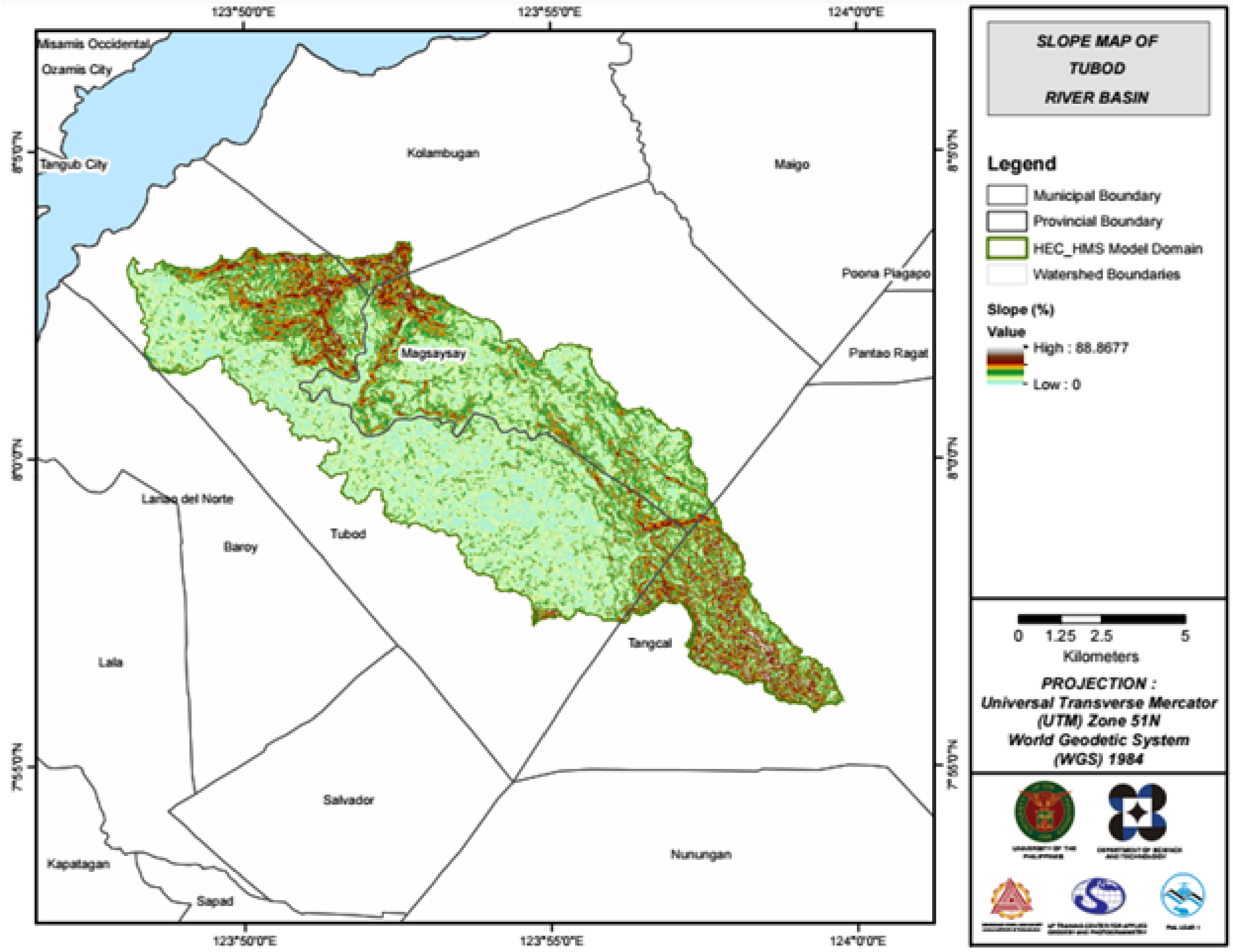


Figure 58. Slope Map of the Bulod River Basin

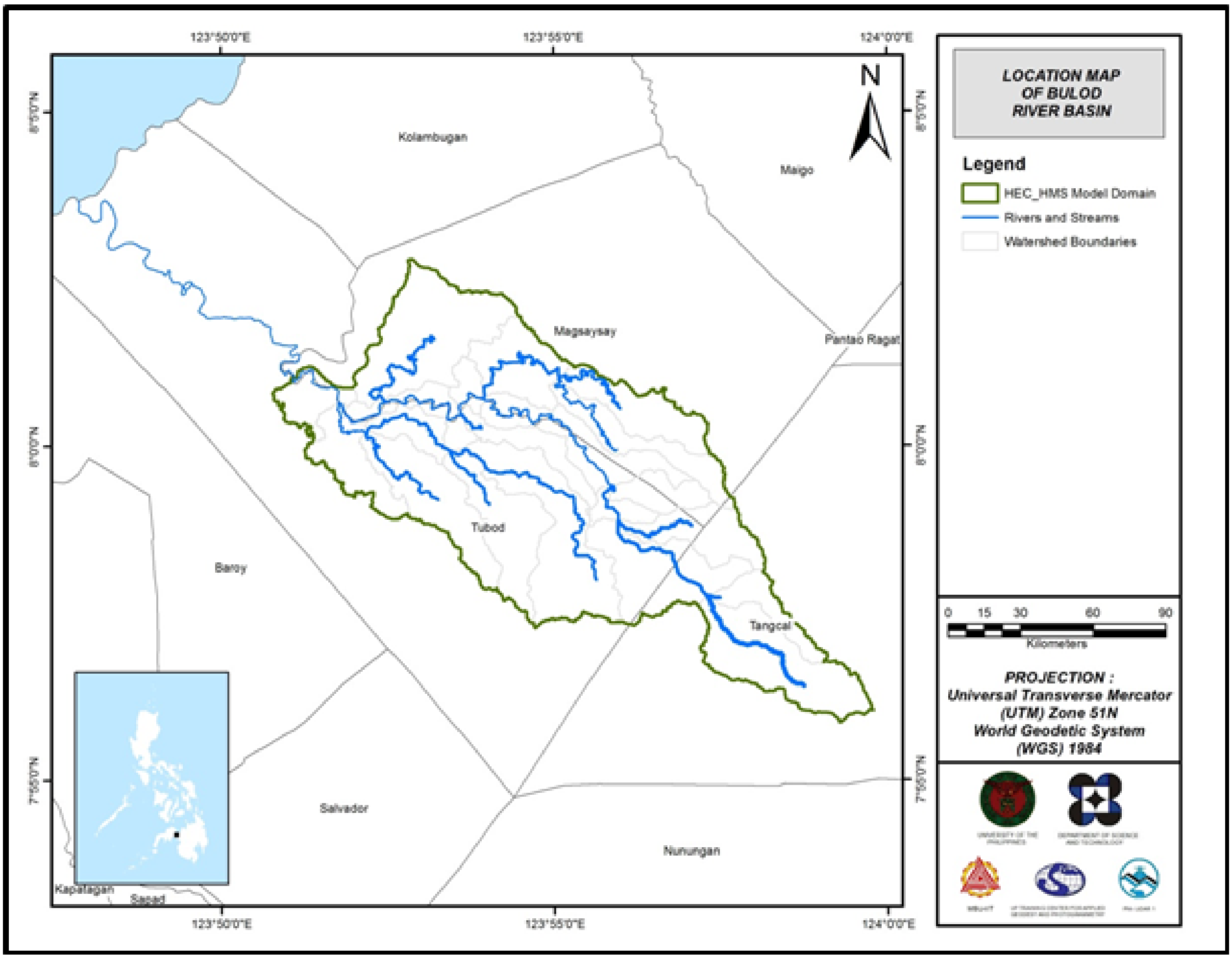


Figure 59. Stream delineation map of the Bulod River Basin

Using the SAR-based DEM, the Bulod basin was delineated and further subdivided into subbasins. The model consists of 21 sub basins, 10 reaches, and 10 junctions. The main outlet is located at Magsaysay Bridge, Bulod. This basin model is illustrated in Figure 60. Finally, it was calibrated using hydrological data derived from the depth gauge and flow meter deployed at Magsaysay Bridge.

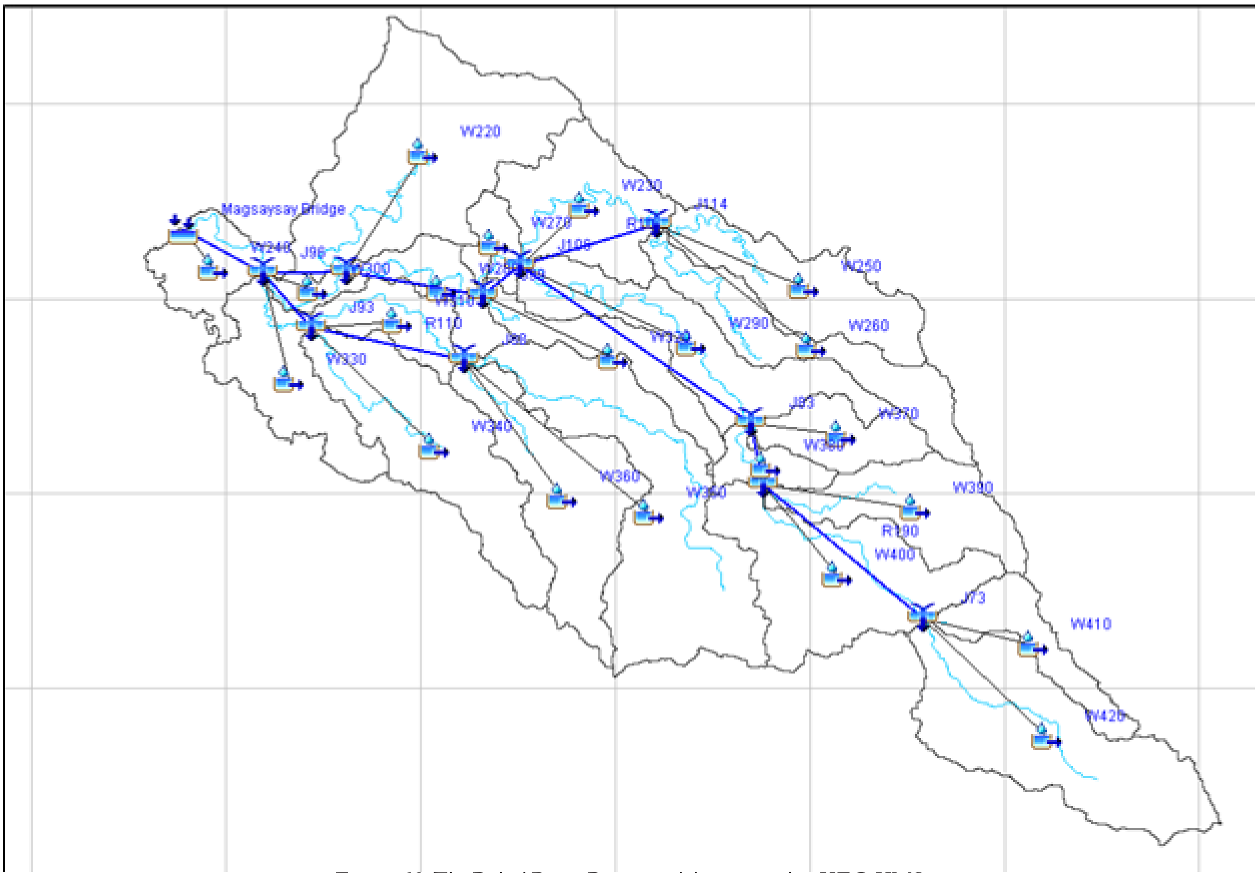


Figure 60. The Bulod River Basin model generated in HEC-HMS

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. It was defined using the HEC GeoRAS tool and was post-processed in ArcGIS (Figure 61).

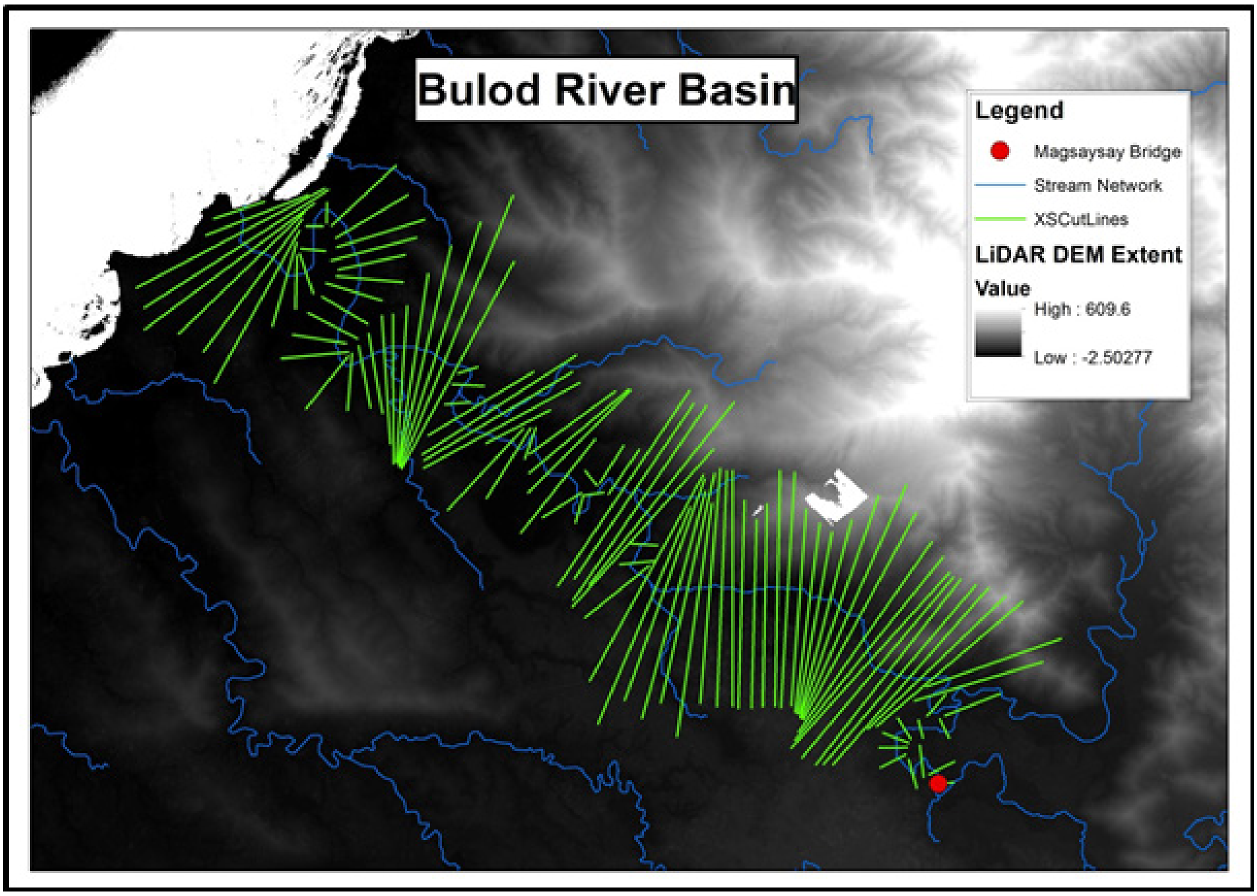


Figure 61. River cross-section of Bulod River generated through Arcmap HEC GeoRAS tool

5.5 Flo 2D Model

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

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

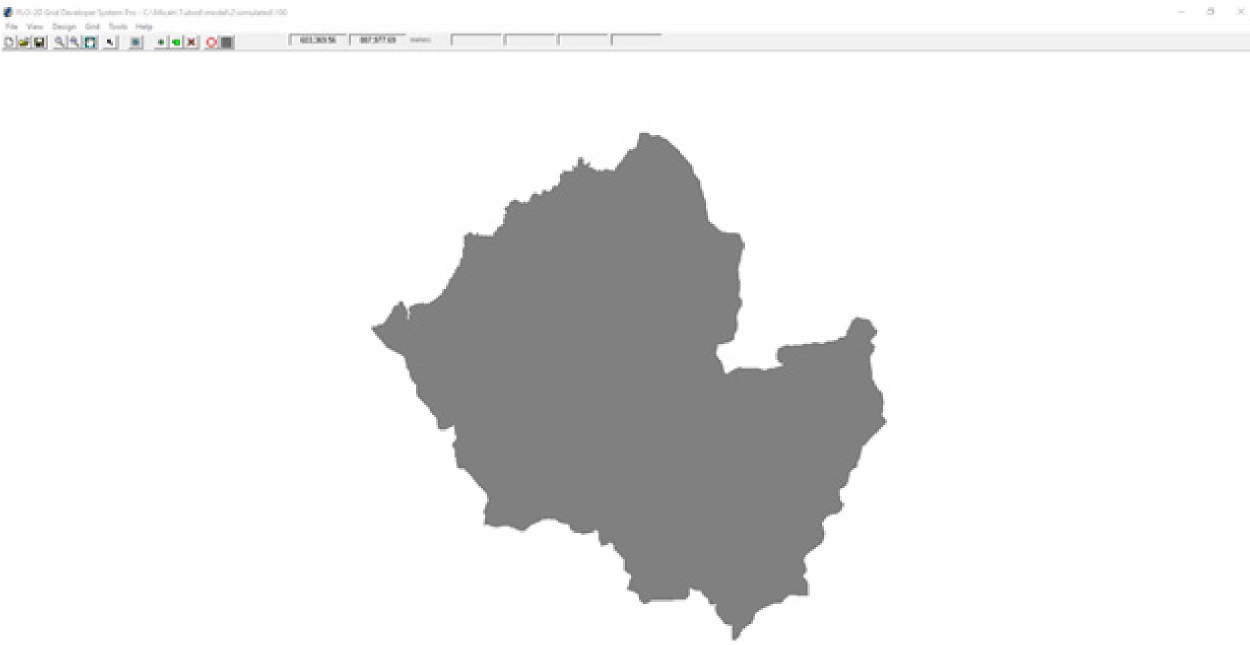


Figure 62. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 41.59076 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 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 50 881 400.00 m2.

There is a total of 26 932 492.15 m3 of water entering the model. Of this amount, 12 819 348.04 m3 is due to rainfall while 14 113 144.11 m3 is inflow from other areas outside the model. 4 108 426.25 m3 of this water is lost to infiltration and interception, while 8 315 775.80 m3 is stored by the flood plain. The rest, amounting up to 14 508 289.55 m3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Bulod HEC-HMS river basin model (See Annex 9), its accuracy was measured against the observed values. Figure 63 shows the comparison between the two discharge data.

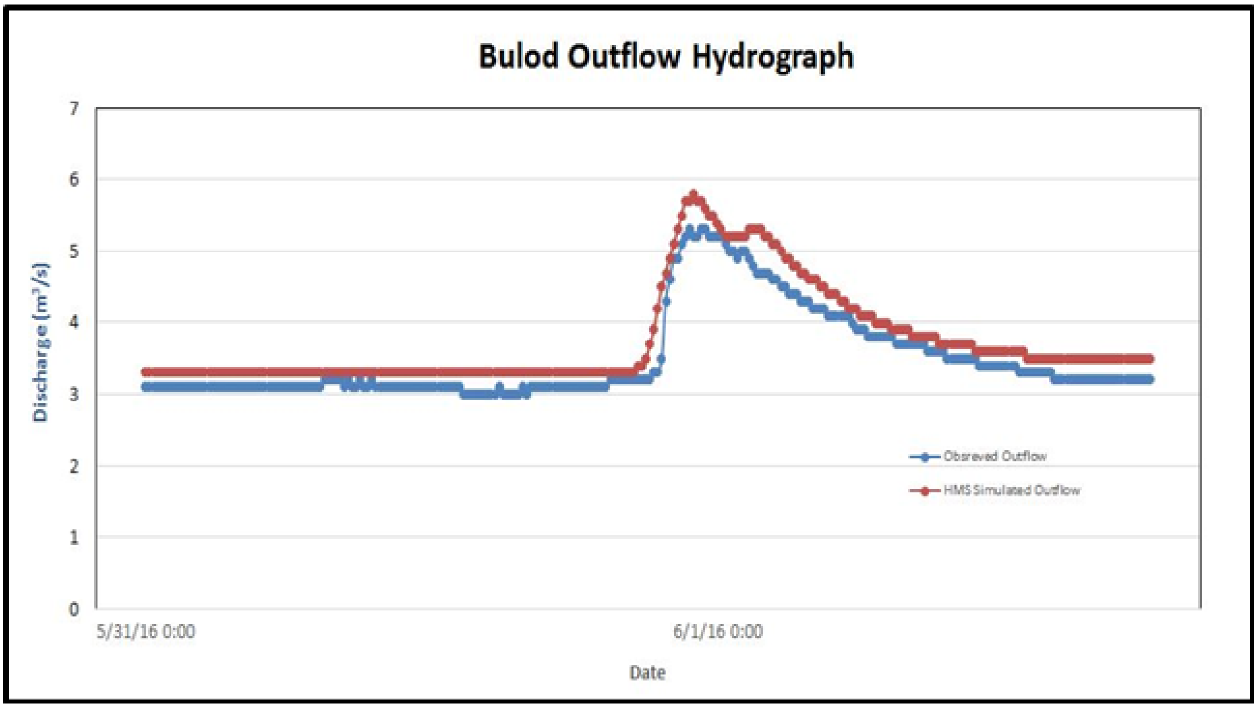


Figure 63. Outflow Hydrograph of Magsaysay Bridge generated in HEC-HMS model compared with observed outflow

Table 29 shows the adjusted ranges of values of the parameters used in calibrating the model.

Table 29. Range of Calibrated Values for Bulod

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	3 - 7
			Curve Number	73 - 86
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.3 - 9
			Storage Coefficient (hr)	1 - 14
	Baseflow	Recession	Recession Constant	1
			Ratio to Peak	0.35
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.035

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 3 mm to 7 mm means that there is a minimal amount of infiltration or rainfall interception by vegetation.

The curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 73 to 86 for curve number is advisable for Philippine watersheds depending on the soil and land cover of the area (M. Horritt, personal communication, 2012).

The time of concentration and storage coefficient are the travel time and index of temporary storage of runoff in a watershed. The range of calibrated values from 0.3 to 14 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events, while ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant of 1 indicates that the basin is unlikely to quickly go back to its original discharge and instead, will be higher. Ratio to peak of 0.35 indicates a steeper receding limb of the outflow hydrograph.

Manning's roughness coefficient of 0.035 corresponds to the common roughness of Bulod watershed, which is determined to be cultivated with mature field crops (Brunner, 2010).

Table 30. Summary of the Efficiency Test of Bulod HMS Model

Accuracy Measure	Value
RMSE	0.27
r2	0.95
NSE	0.809
PBIAS	-6.58
RSR	0.44

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 0.27 (m3/s).

The Pearson correlation coefficient (r2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.95.

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 0.809.

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 -6.58.

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 0.44.

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 64) shows the Bulod outflow using the Dipolog 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 PAG-ASA data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

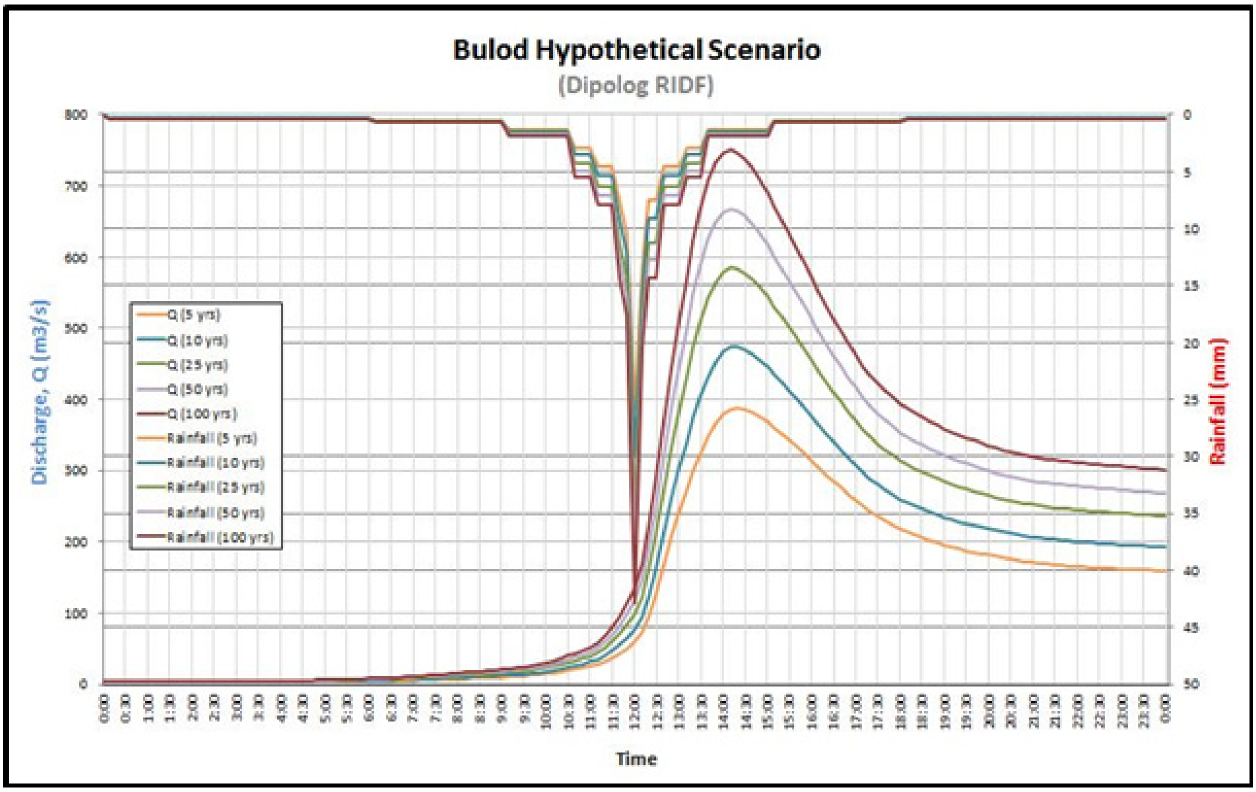


Figure 64. The Outflow hydrograph at Bulod Station generated using Dipolog RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of the Bulod discharge using the Dipolog RIDF in five different return periods is shown in Table 31.

Table 31. Peak values of the Bulod HEC-HMS Model outflow using Dipolog RIDF 24-hour values

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m3s)	Time to Peak
5-Year	178.32	25.9	388.1	14 hours 20 mins
10-Year	206.37	30	474.3	14 hours 20 mins
25-Year	241.91	35.2	584.4	14 hours 10 mins
50-Year	268.14	39	667.7	14 hours 10 mins
100-Year	294.55	42.9	891.1	14 hours 10 mins

5.8 River Analysis Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. or this publication, only a sample output map river was to be shown. Figure 65 shows a generated sample map of the Bulod River using the calibrated HMS base flow.

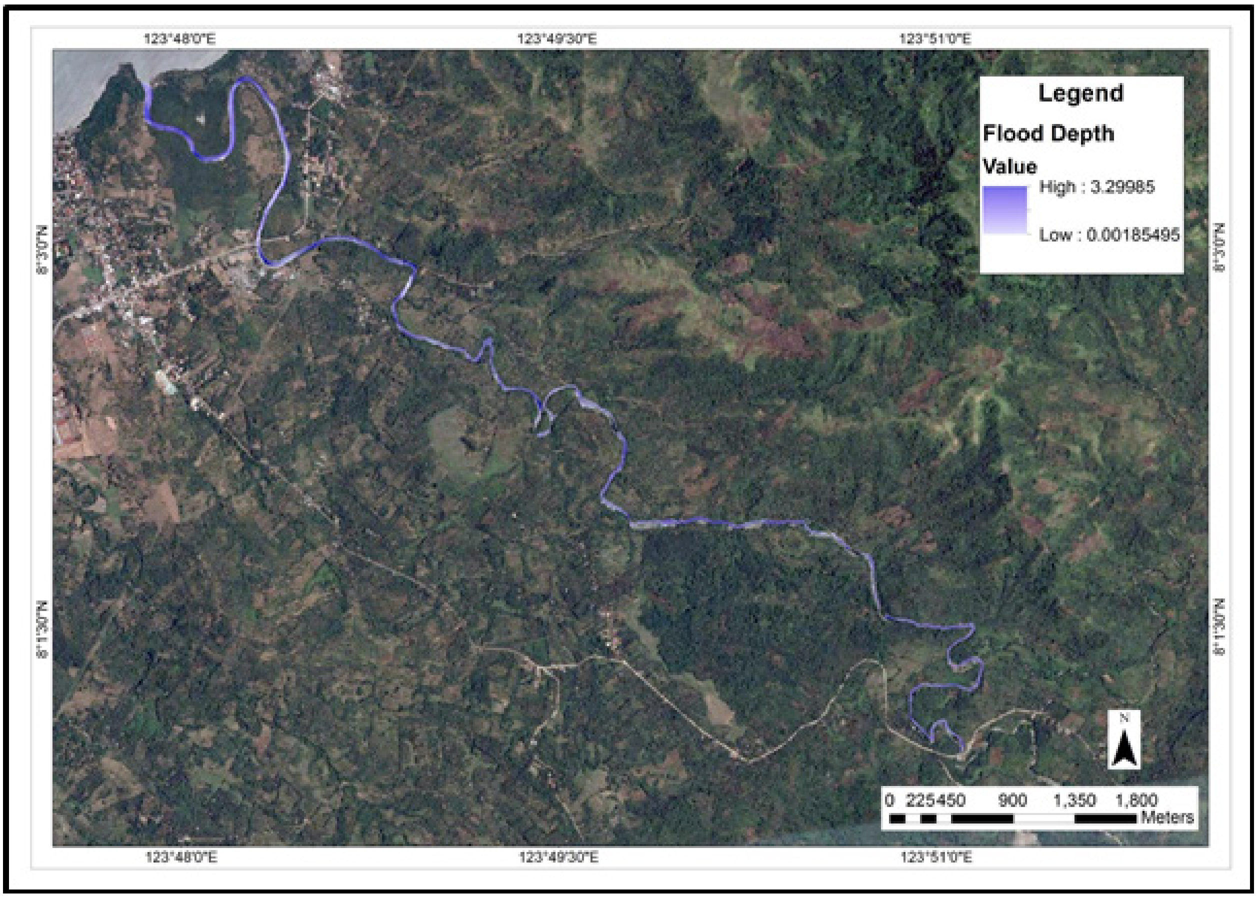


Figure 65. Sample output map of the of Bulod RAS Model

5.9 Flood Hazard and Flow Depth Map

The resulting hazard and flow depth maps have a 10 m resolution. Figures 66 to 71 show the 5-, 25-, and 100-year rain return scenarios of the Bulod Floodplain. The floodplain, with an area of 57.07 sq. km., covers three (3) municipalities, namely Kolambugan, Magsaysay, and Tubod. Table 32 shows the percentage of area affected by flooding per municipality.

Table 32. Municipalities affected in Bulod Floodplain

Municipality	Total Area	Area Flooded	% Flooded
Kolambugan	70.70	7.91	11%
Magsaysay	83.06	4.91	6%
Tubod	121.95	41.19	34%

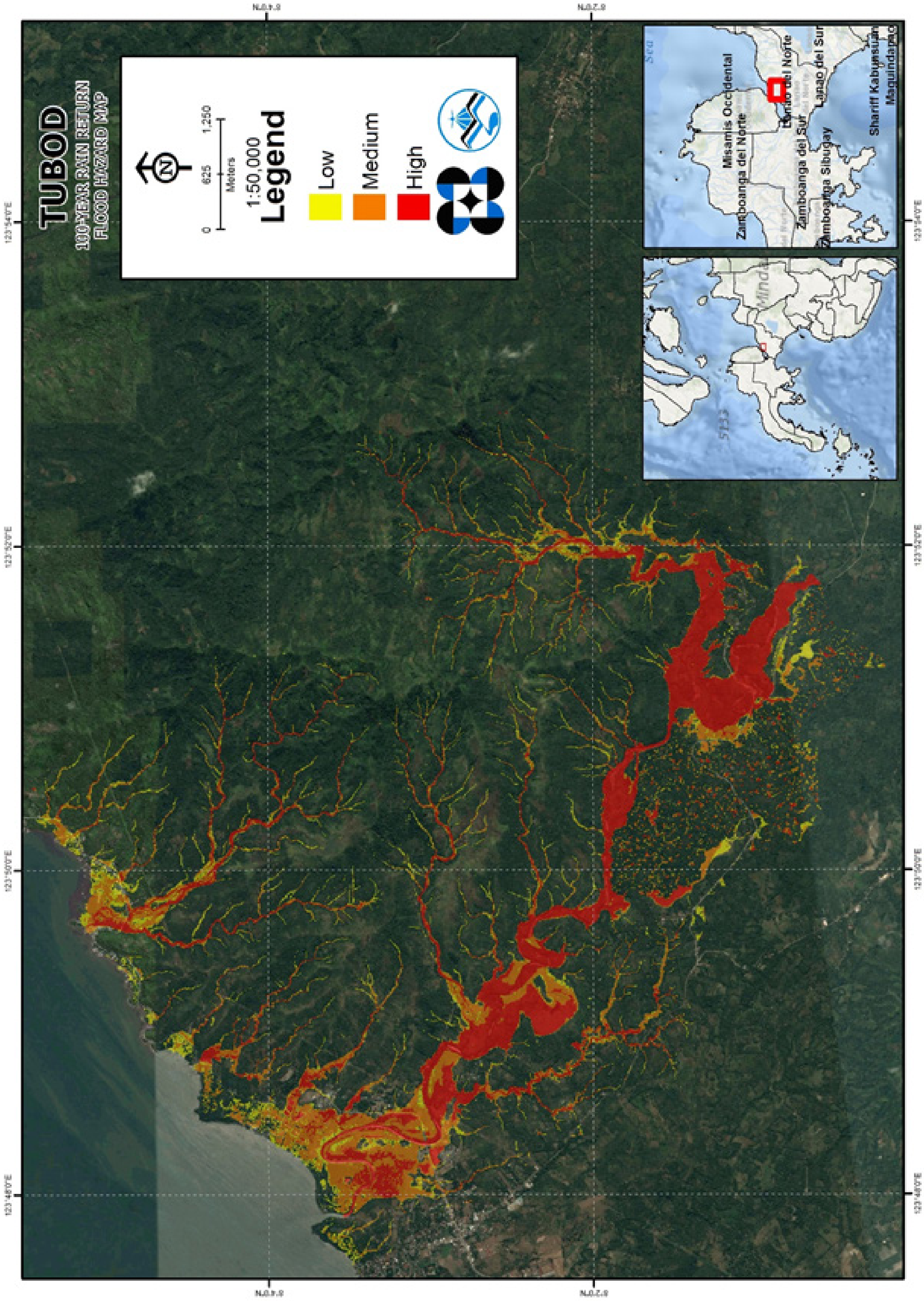


Figure 66. A 100-year flood hazard map for the Bulod (Tubod) Floodplain

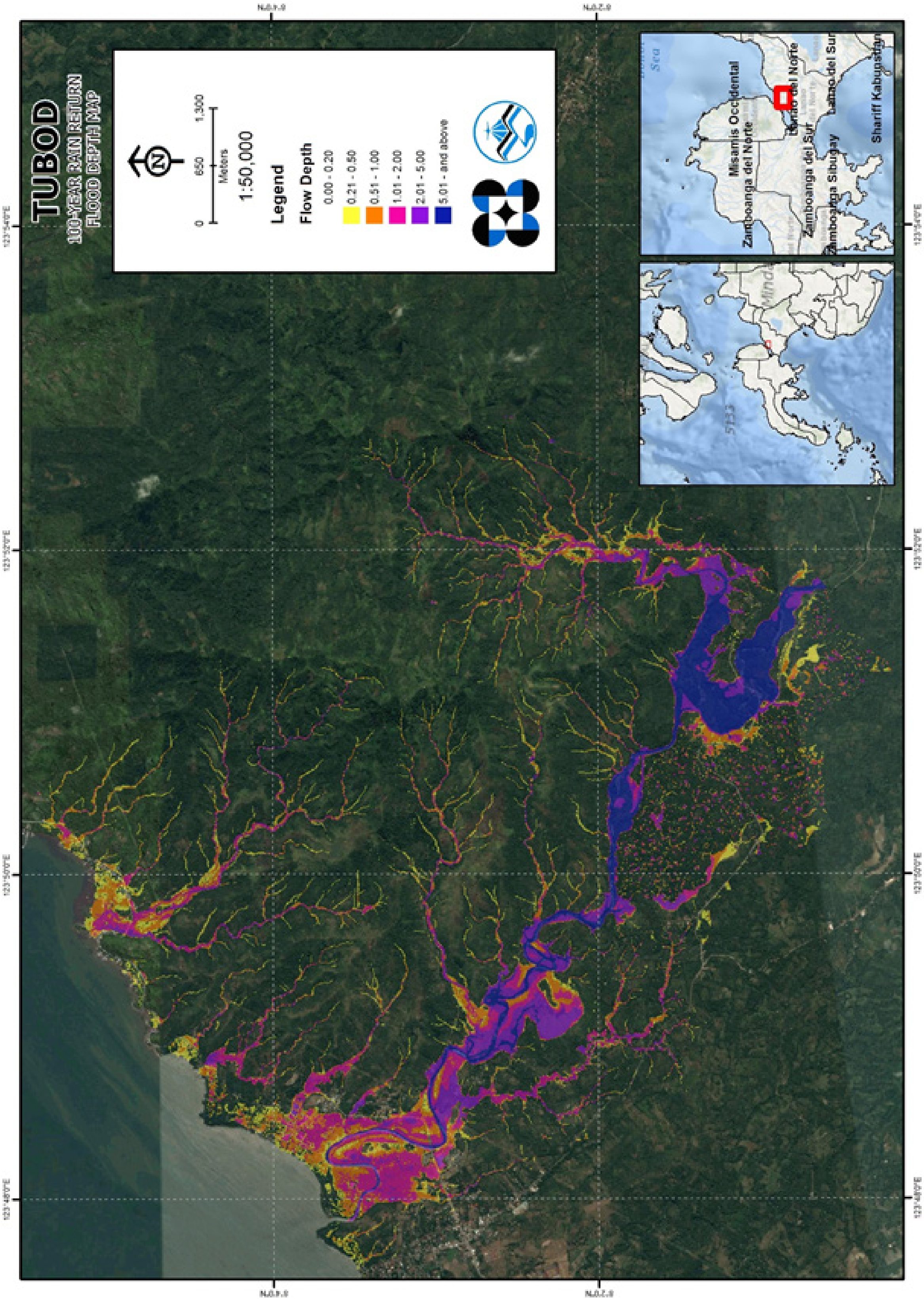


Figure 67. A 100-year flow depth map for Bulod (Tubod) Floodplain

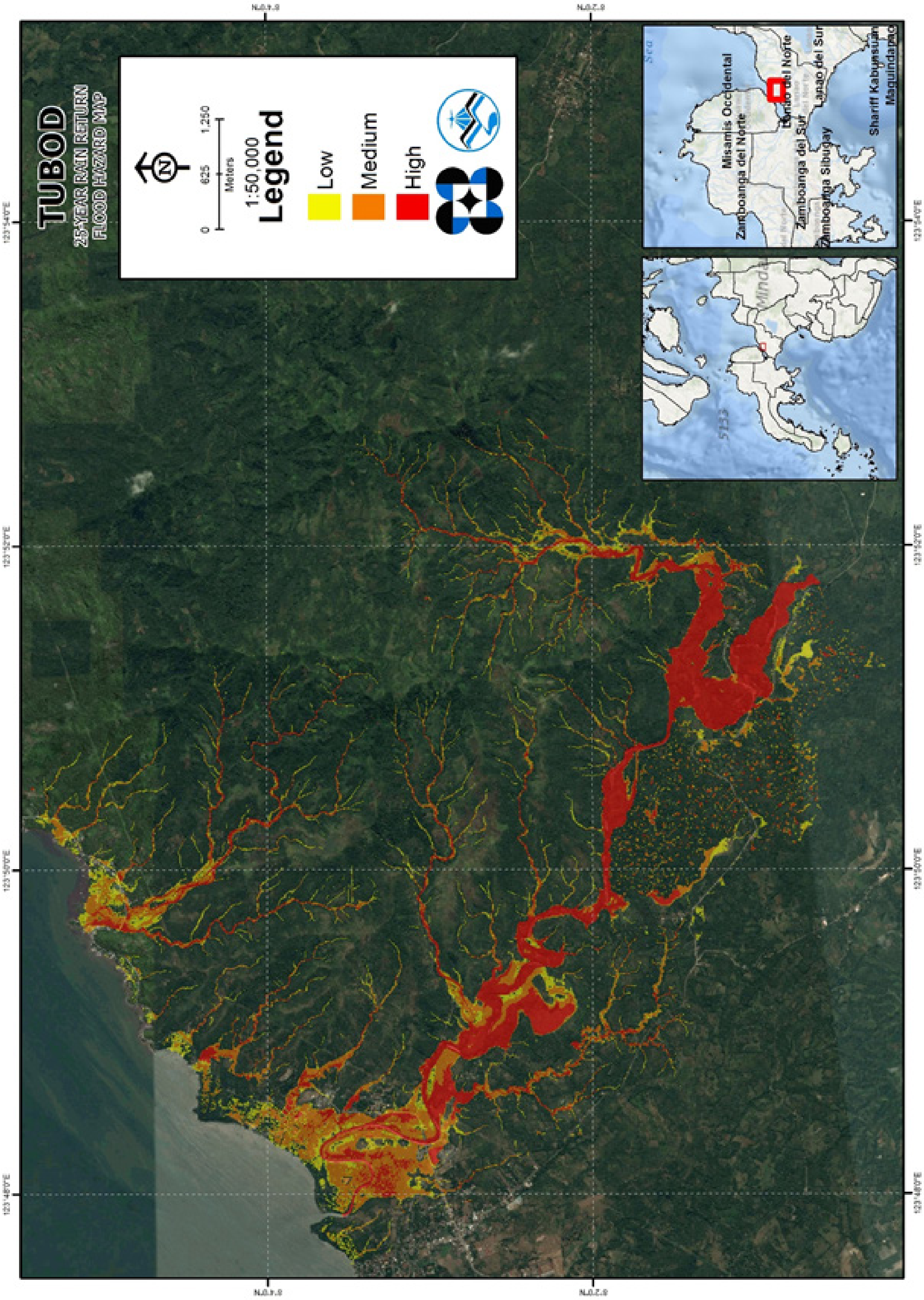


Figure 68. A 25-year flood hazard map for Bulod (Tubod) Floodplain

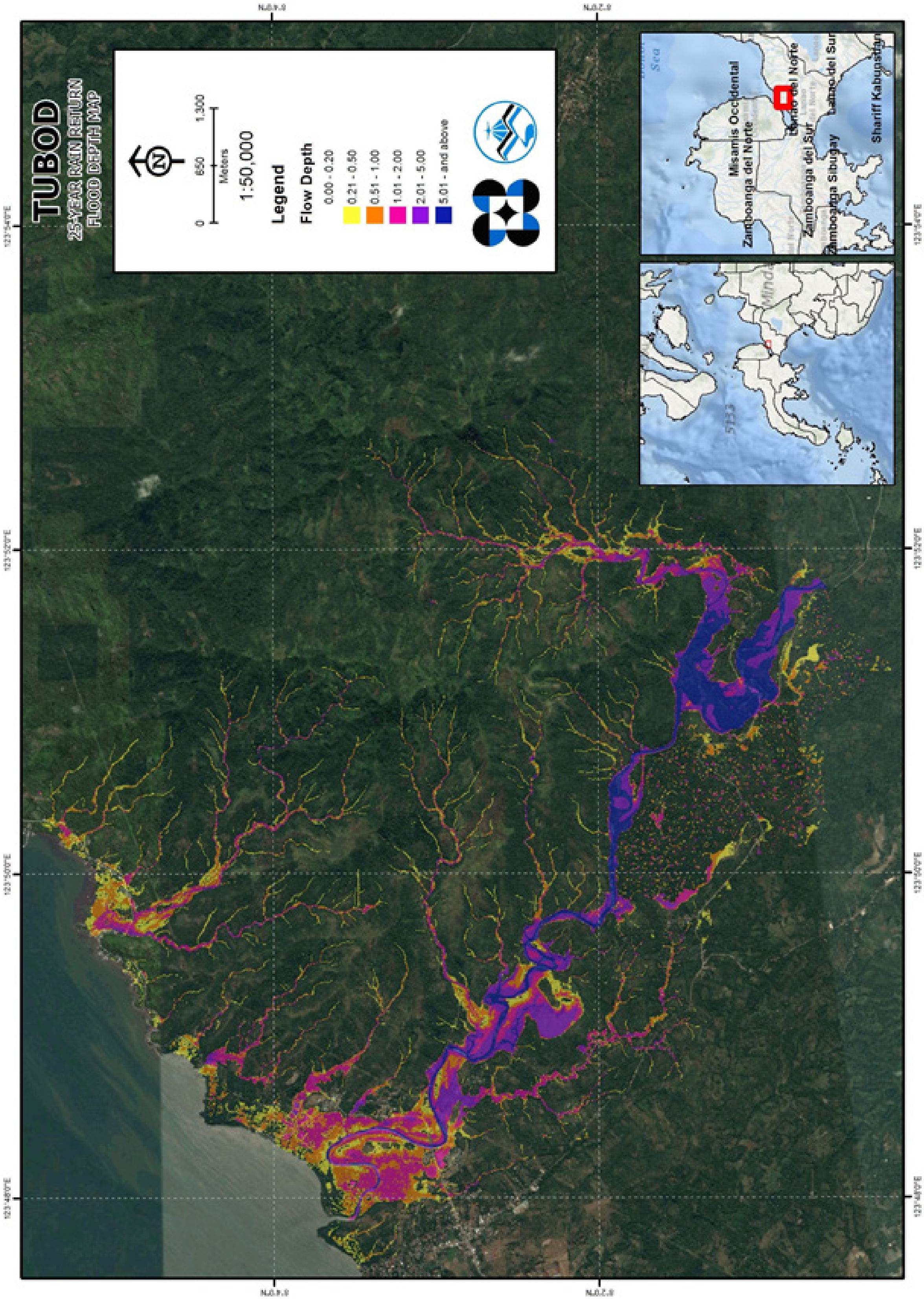


Figure 69. A 25-year flow depth map for Bulod (Tubod) Floodplain

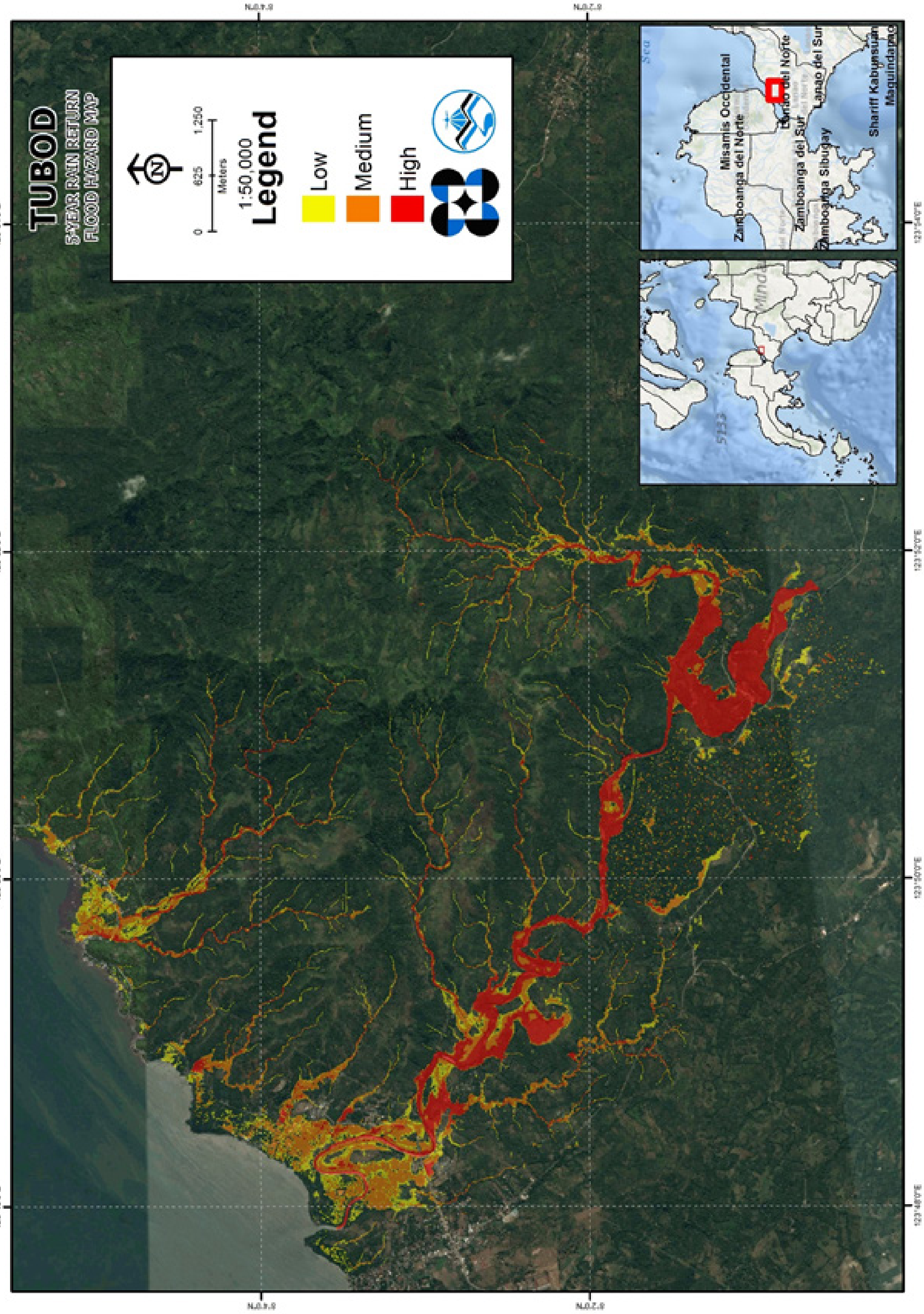


Figure 70. A 5-year flood hazard map for Bulod (Tubod) Floodplain

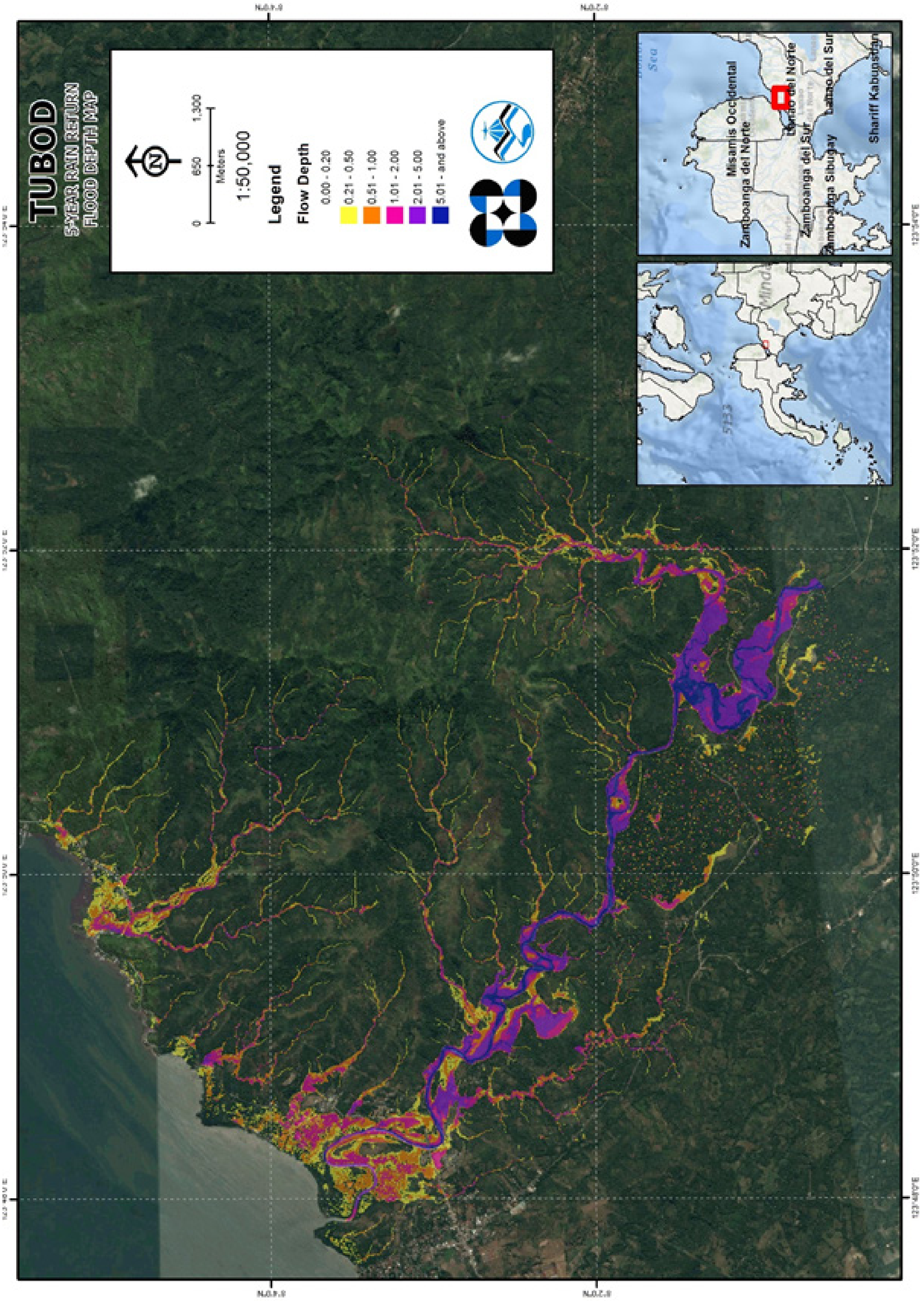


Figure 71. A 5-year flow depth map for Bulod (Tubod) Floodplain

5.10 Inventory of Areas Exposed to Flooding

Listed below are the barangays affected in Bulod River Basin, grouped by municipality. For the said basin, three (3) municipalities consisting of 19 barangays are expected to experience flooding when subjected to 5-, 25-, and 100-yr rainfall return period.

For the 5-year return period, 10.12% of the Municipality of Kolambugan with an area of 70.70 sq. km. will experience flood levels of less 0.20 meters. 0.51% of the area will experience flood levels of 0.21 to 0.50 meters while 0.32%, 0.20%, 0.04%, and 0.0006% 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. Table 33 depicts the affected areas in square kilometres by flood depth per barangay.

Table 33. Affected Areas in Kolambugan, Lanao del Norte during 5-Year Rainfall Return Period

Affected Area (in sq. km.) by flood depth (in m.)	Affected Barangays in Kolambugan			
	Lumbac	Manga	Simbuco	Tabigue
0.03-0.20	1.54	2.46	2.6	0.56
0.21-0.50	0.034	0.25	0.055	0.022
0.51-1.00	0.023	0.17	0.027	0.0098
1.01-2.00	0.017	0.092	0.027	0.0032
2.01-5.00	0.0037	0.017	0.01	0
> 5.00	0	0	0.0004	0

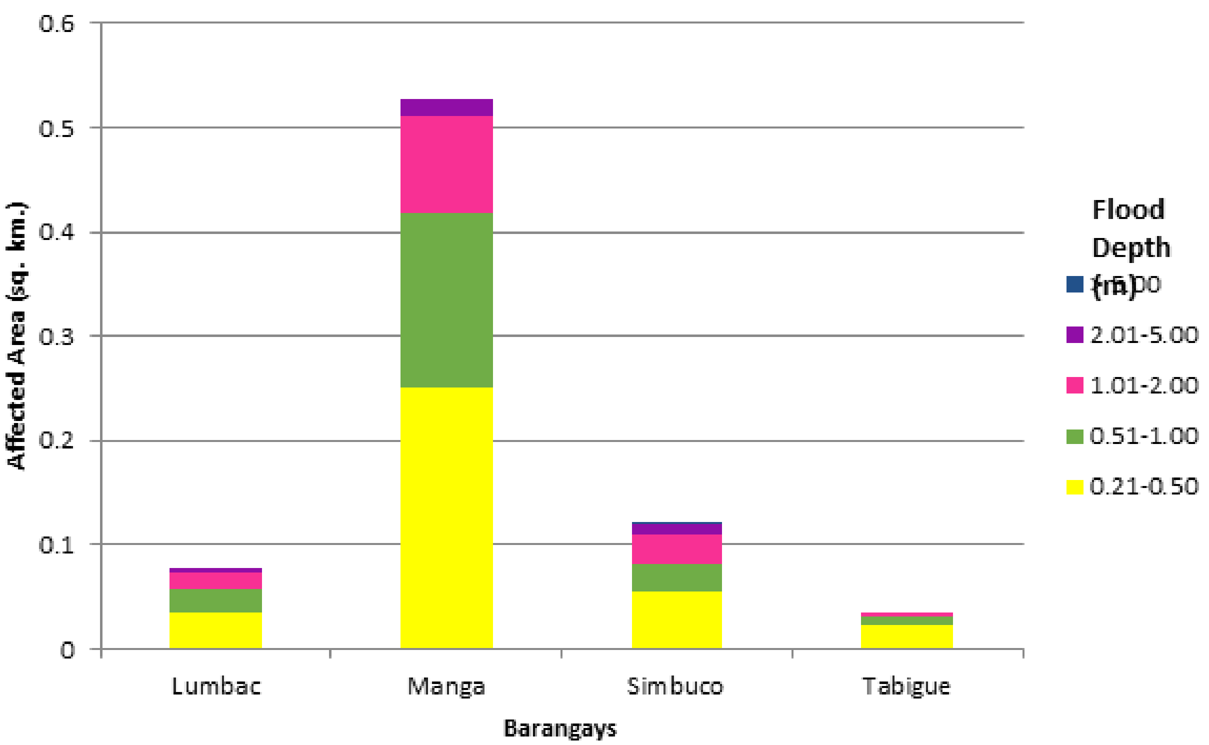


Figure 72. Affected Areas in Kolambugan, Lanao del Norte during 5-Year Rainfall Return Period

For the Municipality of Magsaysay, with an area of 83.06 sq. km., 4.80% will experience flood levels of less than 0.20 meters. 0.27% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.26%, 0.33%, 0.21%, and 0.05% 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 kilometres by flood depth per barangay.

Table 34. Affected Areas in Magsaysay, Lanao del Norte during 5-Year Rainfall Return Period

Affected Area (in sq. km.) by flood depth (in m.)	Affected Barangays in Magsaysay		
	Baguiguicon	Lower Caningag	Tambacon
0.03-0.20	2.6	1.19	0.19
0.21-0.50	0.2	0.025	0.0033
0.51-1.00	0.2	0.011	0.0018
1.01-2.00	0.27	0.0027	0.0017
2.01-5.00	0.17	0.0013	0.00047
> 5.00	0.038	0	0

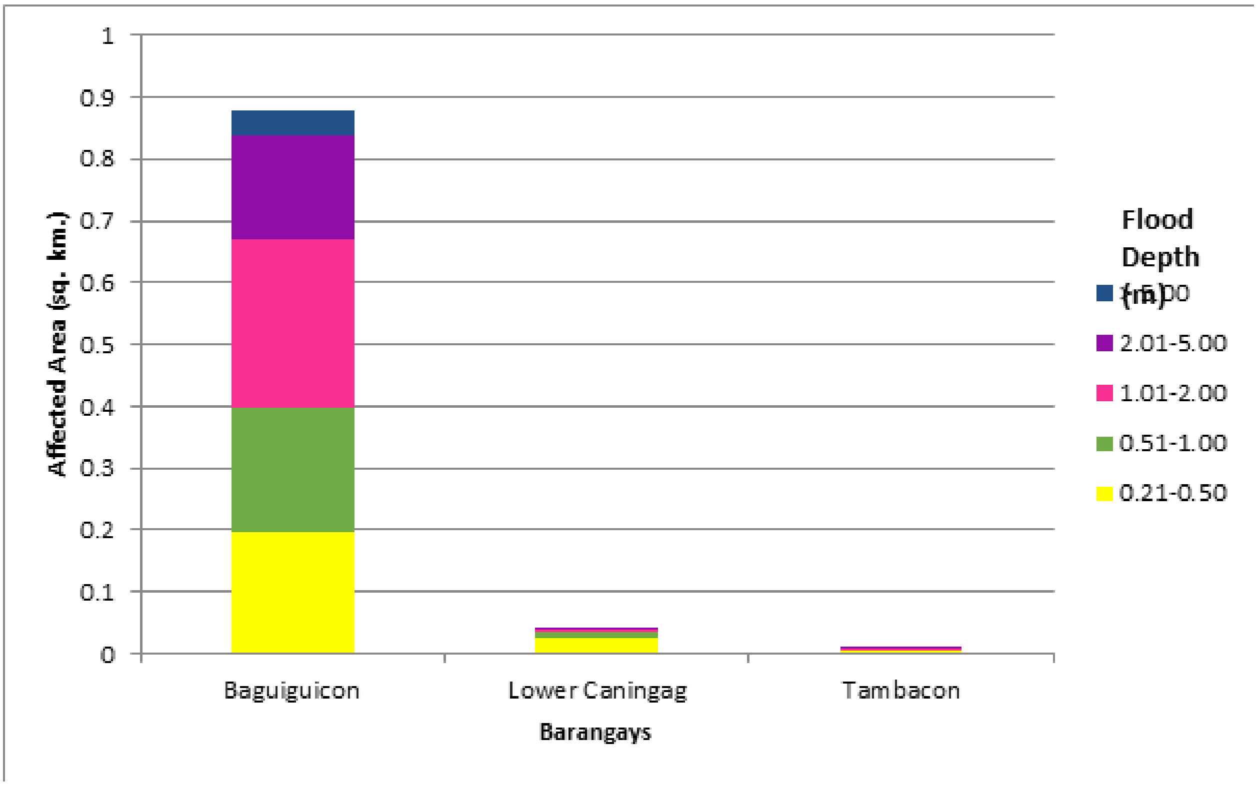


Figure 73. Affected Areas in Magsaysay, Lanao del Norte during 5-Year Rainfall Return Period

For the municipality of Tubod, with an area of 121.95 sq. km., 10.97% will experience flood levels of less 0.20 meters. 0.49% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.37%, 0.29%, 0.26%, and 0.07% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 35 are the affected areas in square kilometres by flood depth per barangay.

Table 35. Affected Areas in Tubod, Lanao del Norte during 5-Year Rainfall Return Period

Affected Area (in sq. km.) by flood depth (in m.)	Affected Barangays in Tubod											
	Bulod	Camp V	Kakai Renabor	Malingao	Patudan	Pigcarangan	Poblacion	Pualas	San Antonio	Santo Niño	Tangueguiron	Tubaran
0.03-0.20	2.02	0.035	6.28	0.0061	2.59	1.31	0.93	5.14	0.9	4.28	4.72	4.39
0.21-0.50	0.12	0.00061	0.22	0.0013	0.093	0.22	0.2	0.2	0.021	0.27	0.2	0.12
0.51-1.00	0.14	0.00076	0.14	0.00019	0.093	0.22	0.16	0.14	0.033	0.22	0.17	0.061
1.01-2.00	0.2	0.00096	0.14	0.0001	0.096	0.16	0.044	0.082	0.034	0.22	0.11	0.033
2.01-5.00	0.13	0.0011	0.13	0	0.058	0.038	0.018	0.075	0.0063	0.27	0.021	0.033
> 5.00	0.044	0.00019	0.058	0	0.031	0.016	0.00014	0.0098	0	0.06	0	0.024

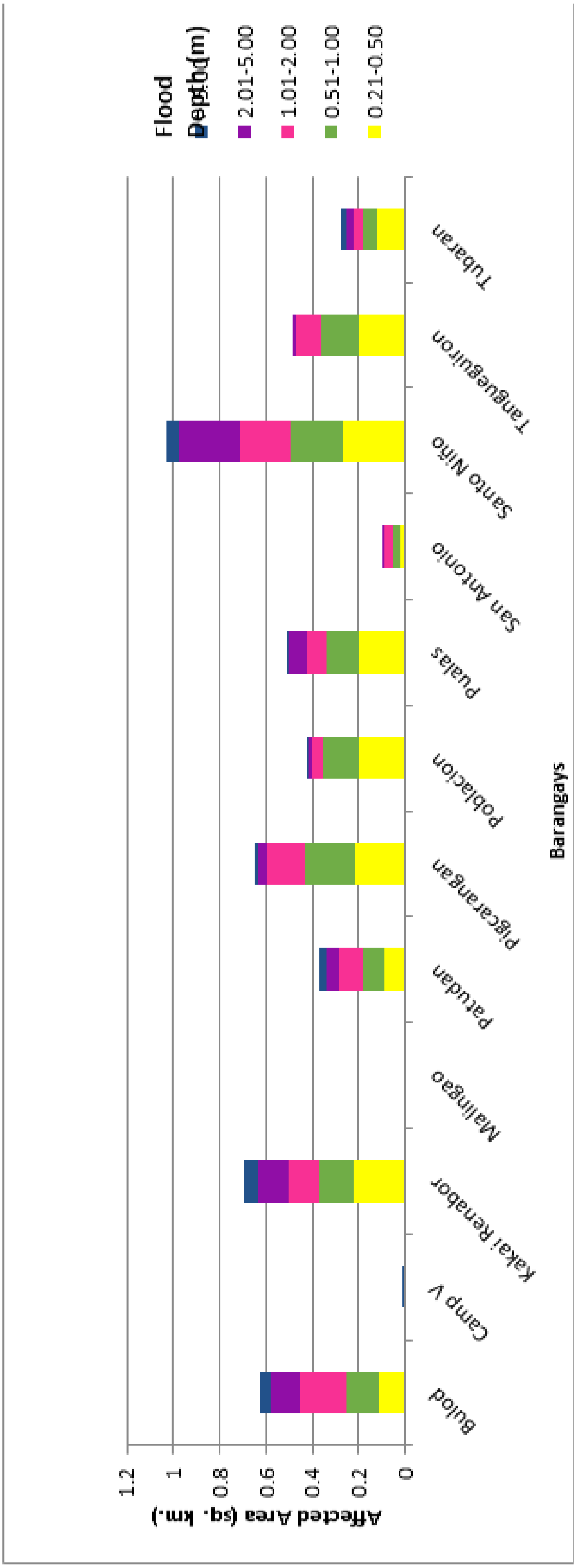


Figure 74. Affected Areas in Tubod, Lanao del Norte during 5-Year Rainfall Return Period

For the 25-year return period, 9.93% of the Municipality of Kolambugan with an area of 70.70 sq. km. will experience flood levels of less 0.20 meters. 0.53% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.39%, 0.27%, 0.07%, and 0.001% 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. Table 36 depicts the areas in square kilometres by flood depth per barangay.

Table 36. Affected Areas in Kolambugan, Lanao del Norte during 25-Year Rainfall Return Period

Affected Area (in sq. km.) by flood depth (in m.)	Affected Barangays in Kolambugan			
	Lumbac	Manga	Simbuco	Tabigue
0.03-0.20	1.52	2.37	2.58	0.55
0.21-0.50	0.036	0.25	0.062	0.025
0.51-1.00	0.025	0.21	0.032	0.013
1.01-2.00	0.022	0.13	0.031	0.0051
2.01-5.00	0.0058	0.028	0.017	0.00018
> 5.00	0.0002	0	0.0007	0

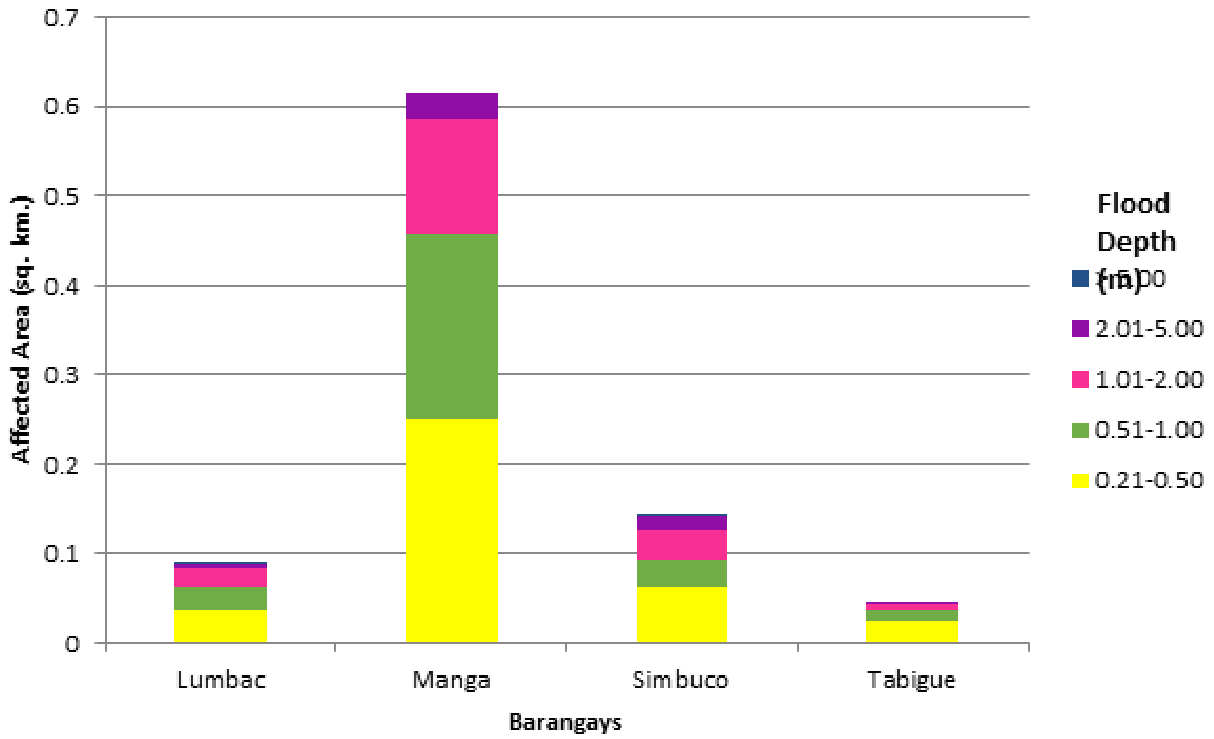


Figure 75. Affected Areas in Kolambugan, Lanao del Norte during 25-Year Rainfall Return Period

For the Municipality of Magsaysay, with an area of 83.06 sq. km., 4.59% will experience flood levels of less 0.20 meters. 0.27% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.23%, 0.22%, 0.49%, and 0.11% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Table 37 depicts the affected areas in square kilometres by flood depth per barangay.

Table 37. Affected Areas in Magsaysay, Lanao del Norte during 25-Year Rainfall Return Period

Affected Area (in sq. km.) by flood depth (in m.)	Affected Barangays in Magsaysay		
	Baguiguicon	Lower Caningag	Tambacon
0.03-0.20	2.44	1.19	0.19
0.21-0.50	0.19	0.027	0.0036
0.51-1.00	0.17	0.015	0.0018
1.01-2.00	0.18	0.0042	0.0021
2.01-5.00	0.4	0.0016	0.00097
> 5.00	0.091	0	0.00012

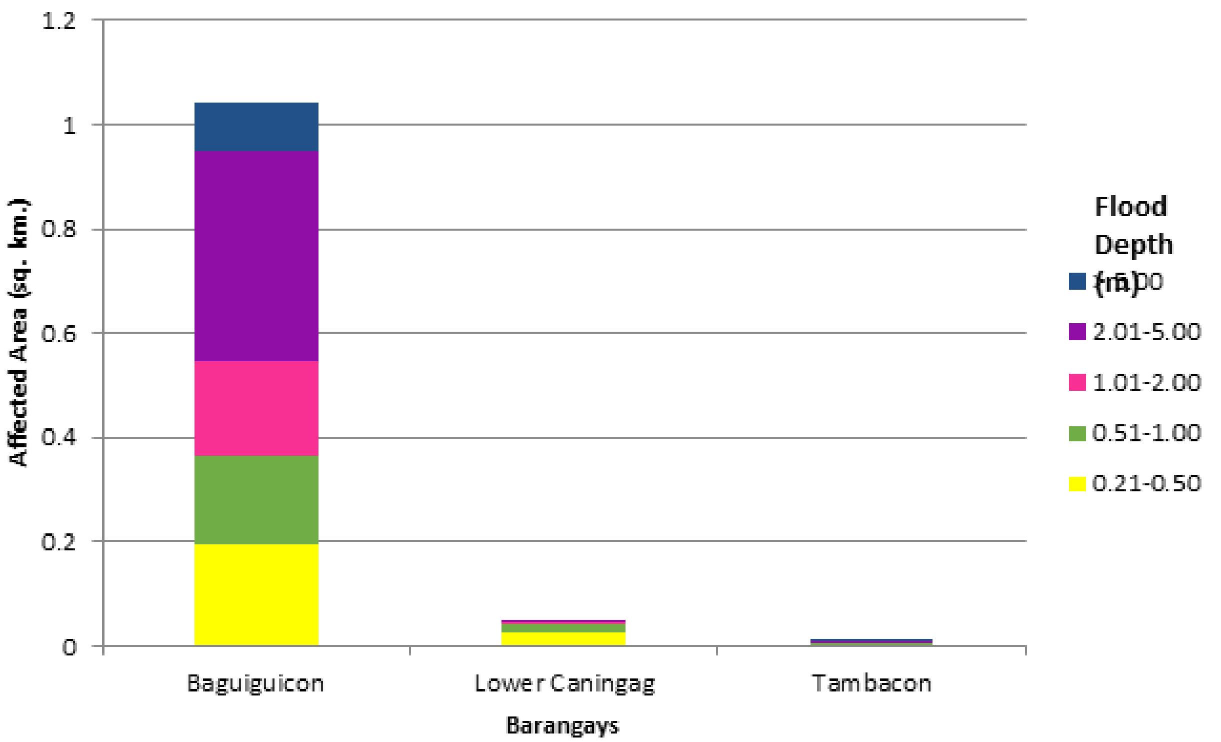


Figure 76. Affected Areas in Magsaysay, Lanao del Norte during 25-Year Rainfall Return Period

For the Municipality of Tubod, with an area of 121.95 sq. km., 10.66% will experience flood levels of less 0.20 meters. 0.49% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.35%, 0.35%, 0.37%, and 0.19% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Table 38 depicts the affected areas in square kilometres by flood depth per barangay.

Table 38. Affected Areas in Tubod, Lanao del Norte during 25-Year Rainfall Return Period

Affected Area (in sq. km.) by flood depth (in m.)	Affected Barangays in Tubod											
	Bulod	Camp V	Kakai Renabor	Malingao	Patudan	Pigcarangan	Poblacion	Pualas	San Antonio	Santo Niño	Tangueguiron	Tubaran
0.03-0.20	1.77	0.034	6.11	0.0056	2.49	1.06	0.77	4.97	0.88	4.04	4.63	4.33
0.21-0.50	0.13	0.00079	0.25	0.001	0.087	0.26	0.19	0.22	0.027	0.26	0.21	0.13
0.51-1.00	0.16	0.00099	0.19	0.00094	0.094	0.3	0.22	0.15	0.026	0.22	0.17	0.086
1.01-2.00	0.23	0.00095	0.16	0.0001	0.12	0.28	0.15	0.15	0.051	0.23	0.16	0.044
2.01-5.00	0.3	0.0012	0.19	0	0.12	0.049	0.018	0.11	0.014	0.38	0.036	0.035
> 5.00	0.056	0.00086	0.081	0	0.047	0.022	0.0033	0.05	0	0.19	0	0.042

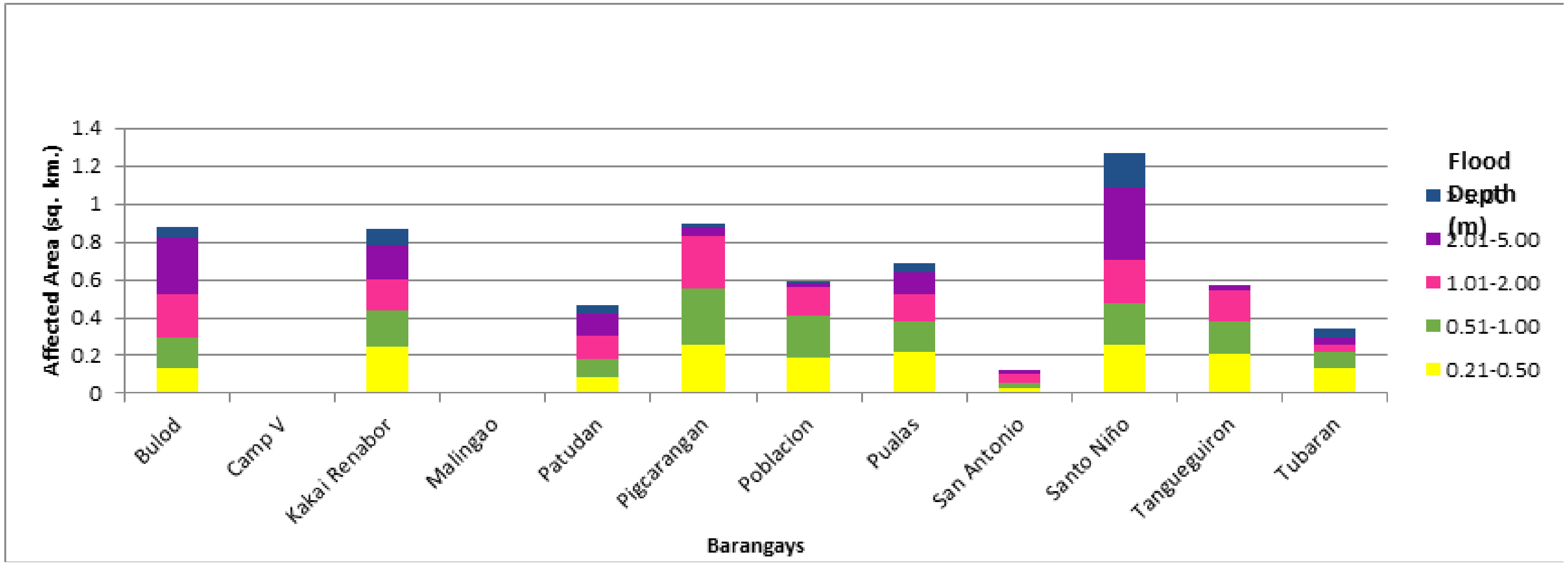


Figure 77. Affected Areas in Tubod, Lanao del Norte during 25-Year Rainfall Return Period

For the 100-year return period, 9.81% of the Municipality of Kolambugan with an area of 70.70 sq. km. will experience flood levels of less 0.20 meters. 0.54% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.43%, 0.31%, 0.10%, and 0.002% 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 kilometres by flood depth per barangay.

Table 39. Affected Areas in Kolambugan, Lanao del Norte during 100-Year Rainfall Return Period

Affected Area (in sq. km.) by flood depth (in m.)	Affected Barangays in Kolambugan			
	Lumbac	Manga	Simbuco	Tabigue
0.03-0.20	1.52	2.32	2.56	0.54
0.21-0.50	0.041	0.25	0.068	0.026
0.51-1.00	0.025	0.23	0.038	0.015
1.01-2.00	0.025	0.15	0.032	0.0062
2.01-5.00	0.0089	0.04	0.022	0.00057
> 5.00	0.0003	0	0.0009	0

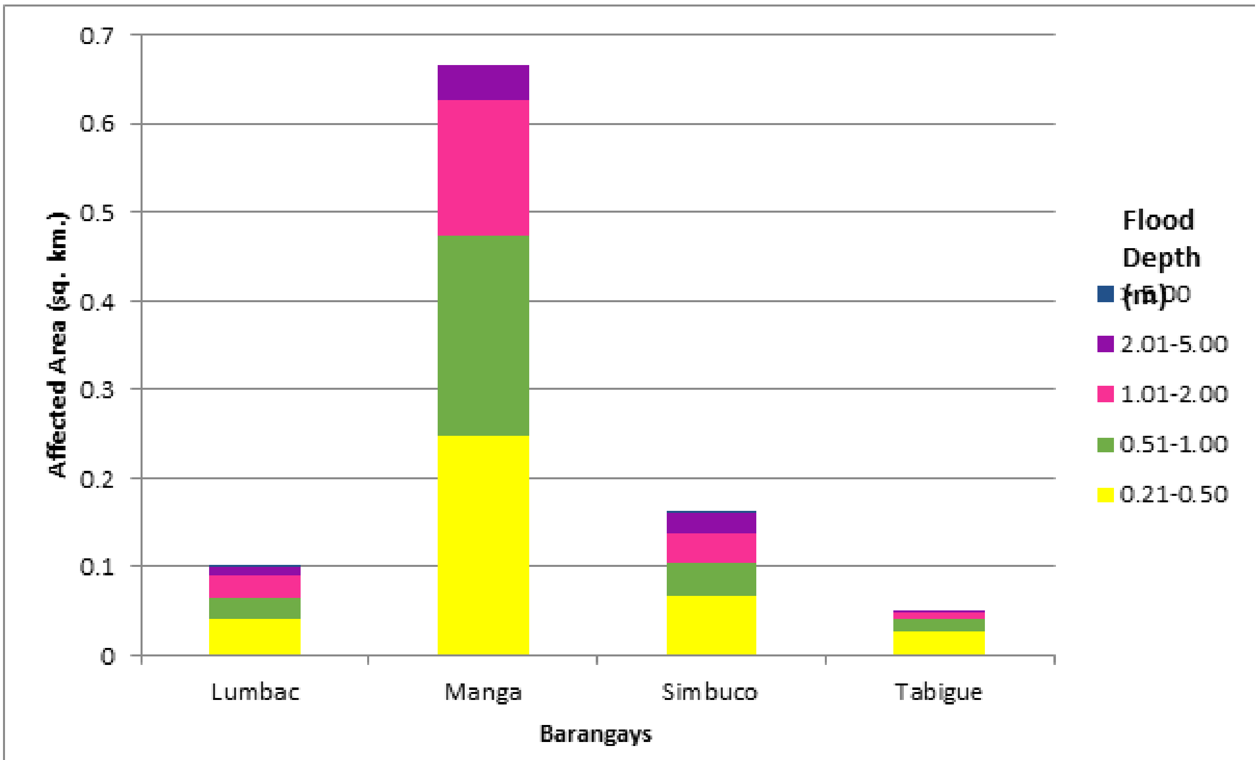


Figure 78. Affected Areas in Kolambugan, Lanao del Norte during 100-Year Rainfall Return Period

For the Municipality of Magsaysay, with an area of 83.06 sq. km., 4.46% will experience flood levels of less 0.20 meters. 0.26% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.26%, 0.22%, 0.40%, 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. Table 40 depicts affected areas in square kilometres by flood depth per barangay.

Table 40. Affected Areas in Magsaysay, Lanao del Norte during 100-Year Rainfall Return Period

Affected Area (in sq. km.) by flood depth (in m.)	Affected Barangays in Magsaysay		
	Baguiguicon	Lower Caningag	Tambacon
0.03-0.20	2.34	1.18	0.19
0.21-0.50	0.18	0.029	0.0031
0.51-1.00	0.19	0.018	0.0026
1.01-2.00	0.17	0.0062	0.002
2.01-5.00	0.33	0.0017	0.0013
> 5.00	0.26	0	0.00022

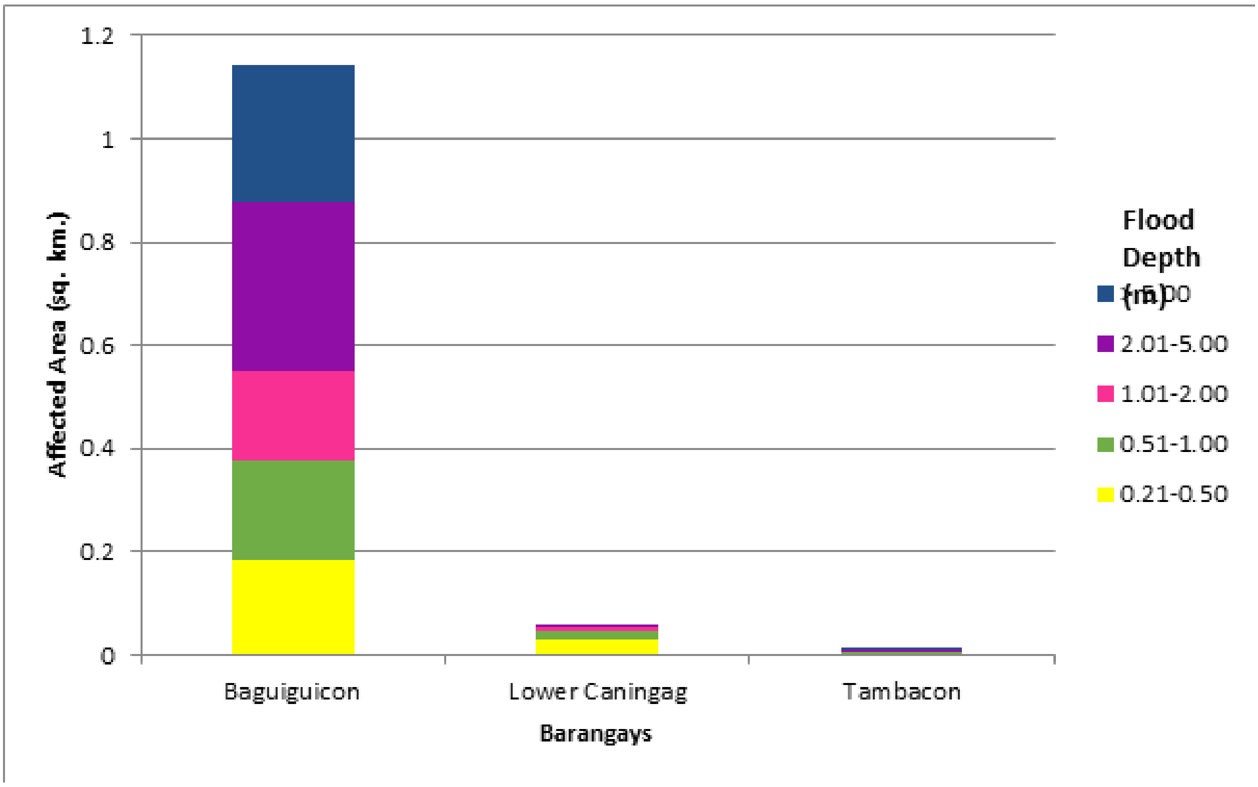


Figure 79. Affected Areas in Magsaysay, Lanao del Norte during 100-Year Rainfall Return Period

MFor the municipality of Tubod, with an area of 121.95 sq. km., 10.48% will experience flood levels of less 0.20 meters. 0.53% of the area will experience flood levels of 0.21 to 0.50 meters while 0.39%, 0.37%, 0.37%, 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. Table 41 depicts the affected areas in square kilometres by flood depth per barangay.

Table 41. Affected Areas in Tubod, Lanao del Norte during 100-Year Rainfall Return Period

Affected Area (in sq. km.) by flood depth (in m.)	Affected Barangays in Tubod											
	Bulod	Camp V	Kakai Renabor	Malingao	Patudan	Pigcarangan	Poblacion	Pualas	San Antonio	Santo Niño	Tangueguiron	Tubaran
0.03-0.20	1.65	0.033	6.01	0.0053	2.42	0.96	0.68	4.86	0.86	3.92	4.58	4.28
0.21-0.50	0.13	0.0012	0.25	0.00065	0.091	0.22	0.14	0.23	0.033	0.27	0.23	0.14
0.51-1.00	0.16	0.0012	0.22	0.0015	0.089	0.33	0.25	0.16	0.029	0.22	0.17	0.092
1.01-2.00	0.25	0.00084	0.18	0.0002	0.13	0.37	0.26	0.15	0.052	0.22	0.18	0.05
2.01-5.00	0.39	0.0013	0.21	0	0.16	0.064	0.018	0.13	0.023	0.35	0.052	0.041
> 5.00	0.071	0.0011	0.097	0	0.071	0.024	0.01	0.11	0	0.34	0	0.056

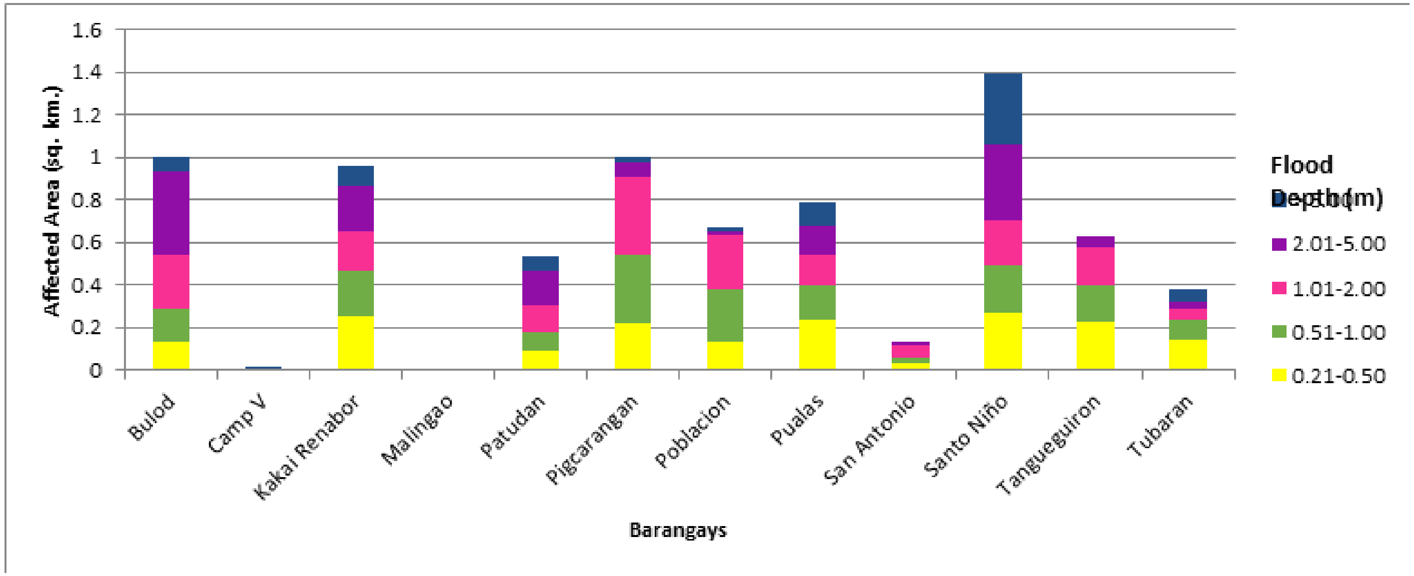


Figure 80. Affected Areas in Tubod, Lanao del Norte during 100-Year Rainfall Return Period

Among the barangays in the Municipality of Kolambugan, Manga is projected to have the highest percentage of area that will experience flood levels at 4.22%. Meanwhile, Simbuco posted the second highest percentage of area that may be affected by flood depths at 3.85%.

Among the barangays in the Municipality of Magsaysay, Baguiguicon is projected to have the highest percentage of area that will experience flood levels at 4.19%. Meanwhile, Lower Caningag posted the second highest percentage of area that may be affected by flood depths at 1.49%.
Among the barangays in the Municipality of Tubod, Kakai Renabor is projected to have the highest percentage of area that will experience flood levels at 5.72%. Meanwhile, Pualas posted the second highest percentage of area that may be affected by flood depths at 4.64%.

Moreover, the generated flood hazard maps for the Bulod 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 42. Area covered by each warning level with respect to the rainfall scenario

Warning Level	Area Covered in sq. km.		
	5 year	25 year	100 year
Low	2.16	2.26	2.22
Medium	2.68	3.13	3.37
High	2.02	3.29	4.12

Of the 54 identified education institutions in Bulod Floodplain, 4 schools were assessed to be exposed to the Low level flooding during a 5-year scenario, while 1 school was assessed to be exposed to Medium level flooding, and 7 schools were assessed to be exposed to High level flooding in the same scenario. In the 25-year scenario, 4 schools were assessed to be exposed to the Low level flooding, while 2 schools were assessed to be exposed to Medium level flooding, and 7 schools were assessed to be exposed to High level flooding in the same scenario. For the 100-year scenario, 4 schools were assessed for Low level flooding and 2 schools for Medium level flooding. In the same scenario, 7 schools were assessed to be exposed to High level flooding. See Annex 12 for a detailed enumeration of schools inside Bulod Floodplain.

Of the 16 identified medical institutions in Bulod Floodplain, only one was assessed to be exposed to the Low level flooding during a 5, 25, and 100-year scenario. See Appendix 13 for a detailed enumeration of medical institutions inside Bulod 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 gathered secondary data regarding flood occurrences in the area within the major river system in the Philippines.

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

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

The flood validation data were obtained on February 2017. 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 what is needed. The points in the flood map versus its corresponding validation depths are shown in Figure 81.

The flood validation consists of 156 points randomly selected all over the Bulod Floodplain. It has an RMSE value of 0.68.

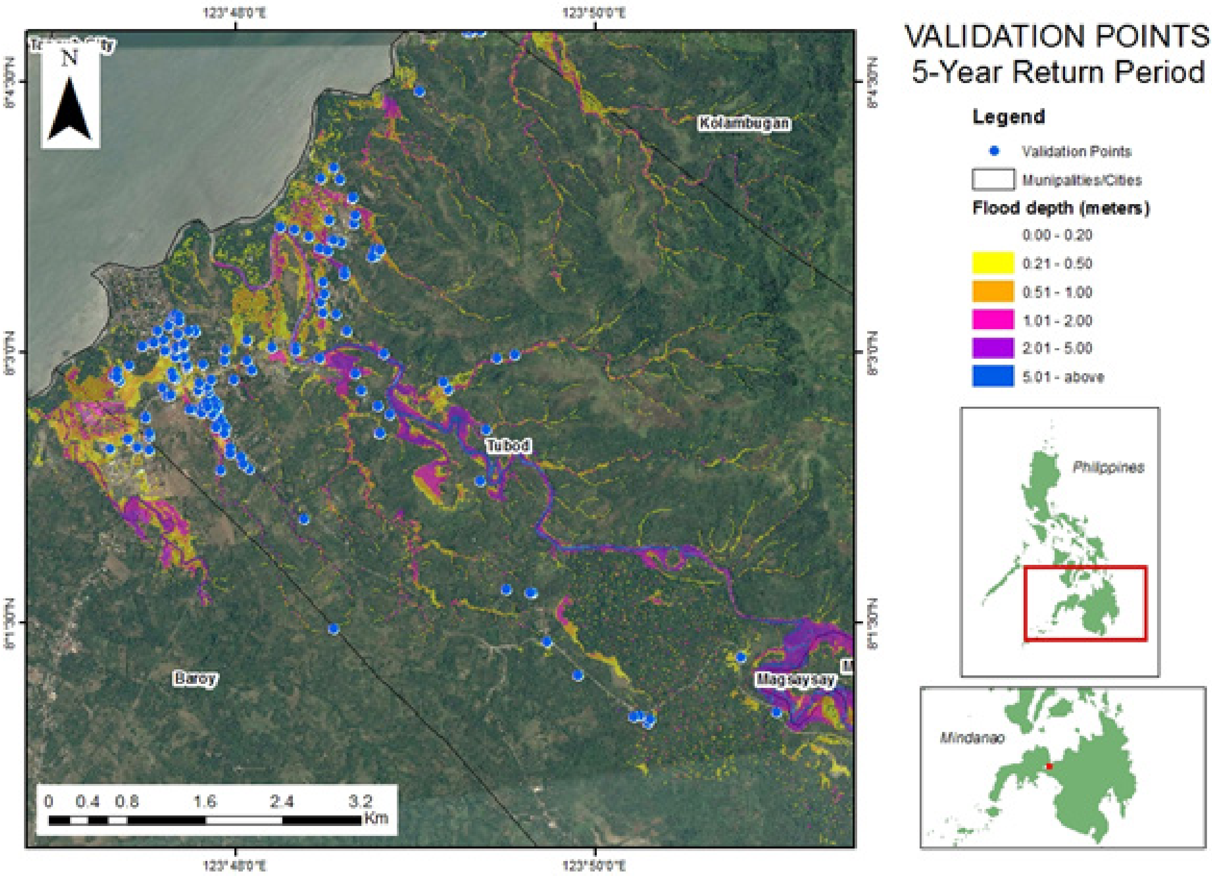


Figure 81. Validation points for the 5-year flood depth map of Bulod Floodplain

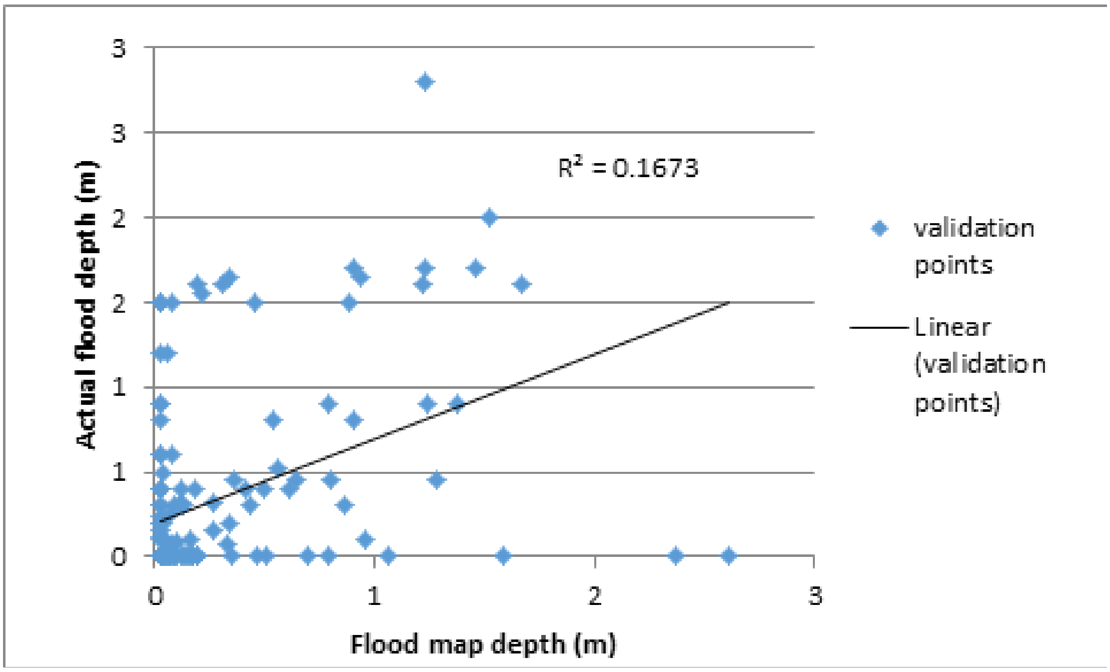


Figure 82. Flood map depth vs Actual flood depth

Table 43. Actual flood depth vs simulated flood depth in the Bulod River Basin

Actual Flood Depth (in m.)	Modeled Flood Depth (m)						
	0-0.20	0.21-0.50	0.51-1.00	1.01-2.00	2.01-5.00	> 5.00	Total
0.03-0.20	87	5	4	2	2	0	100
0.21-0.50	14	5	4	1	0	0	24
0.51-1.00	6	0	4	2	0	0	12
1.01-2.00	7	4	3	5	0	0	19
2.01-5.00	0	0	0	1	0	0	1
> 5.00	0	0	0	0	0	0	0
Total	114	14	15	11	2	0	156

On the whole, the overall accuracy generated by the flood model is estimated at 64.74%, with 101 points correctly matching the actual flood depths. In addition, there were 29 points estimated one level above and below the correct flood depths, while there were 15 points and 11 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 20 points were overestimated, while a total of 35 points were underestimated in the modelled flood depths of Bulod.Table 44 depicts the summary of the Accuracy Assessment in the Bulod River Basin Flood Depth Map

Table 44. Summary of Accuracy Assessment in Bulod River Basin Survey

	No. of Points	%
Correct	101	64.74
Overestimated	20	12.82
Underestimated	35	22.44
Total	156	100

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.

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

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

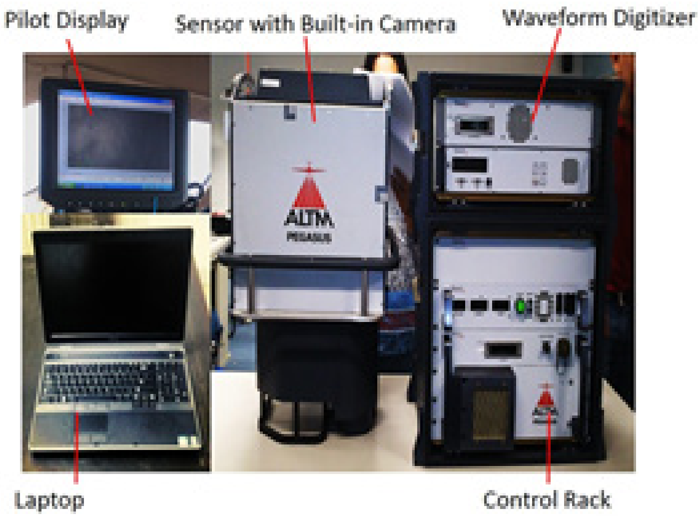
Paringit E.C, Balicanta L.P., Ang, M.O., Sarmiento, C. 2017. Flood Mapping of Rivers in the Philippines Using Airborne LiDAR: Methods. Quezon City, Philippines: UP Training Center for Applied Geodesy and Photogrammetry.

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

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

ANNEXES

Annex 1. Technical Specifications



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

Annex 2. NAMRIA Certificates of Reference Points Used

1. LAN-2

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

June 24, 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: **LANAO DEL NORTE**	
	Station Name: **LAN-2**	
Island: **MINDANAO**	Order: **1st**	Barangay: **PINOYAK**
Municipality: **LALA**		
	PRS92 Coordinates	
Latitude: **7° 54' 46.07859"**	Longitude: **123° 46' 0.85333"**	Ellipsoidal Hgt: **17.35400 m.**
	WGS84 Coordinates	
Latitude: **7° 54' 42.56546"**	Longitude: **123° 46' 6.31720"**	Ellipsoidal Hgt: **83.92120 m.**
	PTM Coordinates	
Northing: **875110.149 m.**	Easting: **364025.74 m.**	Zone: **5**
	UTM Coordinates	
Northing: **874,680.35**	Easting: **584,533.45**	Zone: **51**

Location Description

LAN-2
From Iligan City, travel southwest along the National highway for 74.5 kilometers to the municipality of Lala. Travel farther along the national highway for 1.4 kilometers up to Maranding junction. Thence from the junction travel southeast along the national highway for another 1.3 kilometers to a dirt road going to Pinoyak barangay proper. Turn right on the dirt road and national highway intersection and continue travelling westward for 400 meters up to the irrigation canal. Station is located on top of the concrete irrigation canal water gate. Station mark is 0.15 m x 0.01 m in diameter brass rod, with cross cut on top, set in a drill hole on top of the concrete irrigation canal water gate; centered in cement patty and inscribed on top with the station name. All reference marks are 0.15 m x 0.01 m in diameter brass rod, with cross cut on top, set in drill holes on top of the concrete irrigation canal water gate; centered in cement patty and inscribed with the reference mark numbers and arrow pointing to the station.

Requesting Party:	**Engr. Cruz**
Pupose:	**Reference**
OR Number:	**8796376 A**
T.N.:	**2014-1441**

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

2. ZGS-16

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

February 10, 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: **ZAMBOANGA DEL SUR**			
		Station Name: **ZGS-16**			
		Order: **2nd**			
Island:	**MINDANAO**	Barangay:	**BACLAY**		
Municipality:	**TUKURAN**	MSL Elevation:			
		PRS92 Coordinates			
Latitude:	**7° 52' 32.53106"**	Longitude:	**123° 36' 23.39905"**	Ellipsoidal Hgt:	**18.17800 m.**
		WGS84 Coordinates			
Latitude:	**7° 52' 29.01321"**	Longitude:	**123° 36' 28.86762"**	Ellipsoidal Hgt:	**84.42000 m.**
		PTM / PRS92 Coordinates			
Northing:	**870854.959 m.**	Easting:	**566881.259 m.**	Zone:	**4**
		UTM / PRS92 Coordinates			
Northing:	**870,550.15**	Easting:	**566,857.85**	Zone:	**51**

Location Description

ZGS-16
Is located at Purok Nangka, Brgy. Baclay. It is situated 1 m. NE of Km. Post # 1644 and about 50 m. SW of the chapel, approx. 3 km. from the road junction leading to Aurora town. Mark is the head of a 3 in. concrete nail embedded and centered on a 30 cm. x 30 cm. x 58 cm. concrete monument, with inscriptions "ZGS-16 2005 NAMRIA/LEP-IX".

Requesting Party:	**UP DREAM**
Purpose:	**Reference**
OR Number:	**8089774 I**
T.N.:	**2016-0334**

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

9902102016122213

CP/4701/12/09/814

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3. LE-50

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

June 24, 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: **LANAO DEL NORTE**
Station Name: **LE-50**

Island: **Mindanao**	Municipality: **MAIGO**	Barangay: **CLARO M. RECTO**
Elevation: **5.3895 m.**	Order: **1st Order**	Datum: **Mean Sea Level**

Location Description

BM LE-50 is in the Province of Lanao Del Norte, Town of Maigo, Brgy. C.M. Recto, along the Butuan - Zamboanga National Road, and about 50 meters North East of the Covenant Baptist Church. The station is located at the South West end of the Barogohan Bridge footwalk and about 70 meters South West of KM post 1561.

A brass rod is set on a drilled hole and cemented flushed on top of a 15cm x 15cm cement putty with inscription "LE-50, 2007, NAMRIA".

Requesting Party:	**Engr. Cruz**
Pupose:	**Reference**
OR Number:	**8796376 A**
T.N.:	**2014-1440**

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

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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
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4. LE-76

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

August 08, 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: **LANAO DEL NORTE**
Station Name: **BM LE-76**

Island: **Mindanao**	Municipality: **TUBOD (CAPITAL)**	Barangay: **BULOD**
Elevation: **5.0250 m.**	Order: **2nd Order**	Datum: **Mean Sea Level**

Location Description

BM LE-76 is in the Province of Lanao del Norte, Municipality of Tubug, Bgry. Bulod, along the Butuan-Zamboanga National Road. The station is located at the south west end of Bulod Bridge footwalk, about 2 meters north west of KM Post 1587, and about 4 meters north west of the centerline of the road

Requesting Party:	**ENGR. CHRISTOPHER CRUZ**
Pupose:	**Reference**
OR Number:	**8799670 A**
T.N.:	**2014-1787**

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

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Branch : 421 Barraca St. San Nicolas, 1010 Manila, Philippines, Tel. No. (632) 241-3494 to 98
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5. ZS-188

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

February 10, 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: **ZAMBOANGA DEL SUR**		
Station Name: **ZS-188**		
Island: **Mindanao**	Municipality: **ZAMBOANGA CITY**	Barangay: **LICOMO**
Elevation: **22.1396 +/- 0.16 m.**	Accuracy Class at 95% C.L: **2 CM**	Datum: **Mean Sea Level**
Latitude:	Longitude:	

Location Description

ZS-188 is located in Sitio Simoropan Purok 1 Brgy. Licomo Vital District Zamboanga City The BM established in hedawall of Pipe Culvert, about 4 m from the cneterline of the road leftside going to Maria Clara lobgegat Hi-way.

Mark is the head of a 4" copper nail on a drilled hole and cemented flushed on top of a 15x15cm cement putty with inscription "ZS-188, 2008, NAMRIA".

Requesting Party:	**UP DREAM**
Purpose:	**Reference**
OR Number:	**8089774 I**
T.N.:	**2016-0337**

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

9902102016122745

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ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

6. ZGS-1 (reference for ZS-188)

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

February 10, 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: **ZAMBOANGA DEL SUR**	
	Station Name: **ZGS-1**	
	Order: **1st**	
Island: **MINDANAO**	Barangay: **DIPOLO**	
Municipality: **MOLAVE**	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **8° 4' 26.98334"**	Longitude: **123° 29' 14.53868"**	Ellipsoidal Hgt: **22.61100 m.**
	WGS84 Coordinates	
Latitude: **8° 4' 23.40249"**	Longitude: **123° 29' 19.99013"**	Ellipsoidal Hgt: **88.18300 m.**
	PTM / PRS92 Coordinates	
Northing: **892784.79 m.**	Easting: **553718.284 m.**	Zone: **4**
	UTM / PRS92 Coordinates	
Northing: **892,472.30**	Easting: **553,699.48**	Zone: **51**

Location Description

ZGS-1
From Iligan City, travel SW along the national highway for 138 km., about 2 hrs. and 5 min., passing through the towns of Kolambugan, Tubod, and Salvador, Lanao del Norte. Then turn right, travel NW direction passing by Aurora town, 138 km. about 2 hrs. and 52 min. drive. About 5.4 km. going W direction before the junction to Molave proper proceed to the junction going E direction to Pagadian City, 3.2 km. to National Irrigation Administration (NIA) compound. Station is located at the top S corner of the concrete water tank 6 m. high beside the NIA building. Station mark is a cross cut on top of a 0.15 m. x 0.01 m. in dia. brass rod, set in a drill hole, centered in a 0.30 m. x 0.30 m. cement putty with inscription of the station name.

*Note: Reported EXISTING by FNSP-DENR Region IX (By: Engr. Fermin Encro 06 August 2003)

Requesting Party: **UP DREAM**
Purpose: **Reference**
OR Number: **8089774 I**
T.N.: **2016-0332**

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

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Annex 3. Baseline Processing Report

1. LE-50

LE50 - LAN2 (10:05:34 AM-2:59:59 PM) (S1)

Baseline observation:	LE50 --- LAN2 (B1)
Processed:	7/27/2014 10:28:26 PM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.012 m
Vertical precision:	0.024 m
RMS:	0.005 m
Maximum PDOP:	3.688
Ephemeris used:	Broadcast
Antenna model:	NGS Absolute
Processing start time:	6/20/2014 10:05:34 AM (Local: UTC+8hr)
Processing stop time:	6/20/2014 2:59:59 PM (Local: UTC+8hr)
Processing duration:	04:54:25
Processing interval:	5 seconds

Vector Components (Mark to Mark)

From:	LAN2				
Grid		Local		Global	
Easting	584699.973 m	Latitude	N7°54'42.56546"	Latitude	N7°54'42.56546"
Northing	874628.035 m	Longitude	E123°46'06.31720"	Longitude	E123°46'06.31720"
Elevation	15.242 m	Height	83.921 m	Height	83.921 m

To:	LE50				
Grid		Local		Global	
Easting	606345.902 m	Latitude	N8°09'51.11024"	Latitude	N8°09'51.11024"
Northing	902577.426 m	Longitude	E123°57'55.36634"	Longitude	E123°57'55.36634"
Elevation	4.394 m	Height	73.452 m	Height	73.452 m

Vector					
ΔEasting	21645.929 m	NS Fwd Azimuth	37°51'51"	ΔX	-15847.070 m
ΔNorthing	27949.392 m	Ellipsoid Dist.	35361.439 m	ΔY	-15348.392 m
ΔElevation	-10.847 m	ΔHeight	-10.469 m	ΔZ	27636.144 m

2

2. LE-76

Vector Components (Mark to Mark)

From:	LE-50				
Grid		Local		Global	
Easting	606180.417 m	Latitude	N8°09'54.67217"	Latitude	N8°09'51.11024"
Northing	902629.434 m	Longitude	E123°57'49.92699"	Longitude	E123°57'55.36634"
Elevation	4.394 m	Height	6.900 m	Height	73.452 m

To:	LE-76				
Grid		Local		Global	
Easting	588530.790 m	Latitude	N8°03'05.36825"	Latitude	N8°03'01.82183"
Northing	890021.013 m	Longitude	E123°48'12.37307"	Longitude	E123°48'17.82405"
Elevation	7.017 m	Height	9.335 m	Height	75.717 m

Vector					
ΔEasting	-17649.627 m	NS Fwd Azimuth	234°35'42"	ΔX	13688.663 m
ΔNorthing	-12608.421 m	Ellipsoid Dist.	21696.715 m	ΔY	11332.042 m
ΔElevation	2.623 m	ΔHeight	2.435 m	ΔZ	-12447.993 m

Standard Errors

Vector errors:					
σ ΔEasting	0.021 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.024 m
σ ΔNorthing	0.006 m	σ Ellipsoid Dist.	0.015 m	σ ΔY	0.034 m
σ ΔElevation	0.036 m	σ ΔHeight	0.036 m	σ ΔZ	0.009 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0005606089		
Y	-0.0003223999	0.0011623638	
Z	-0.0000556148	0.0002703935	0.0000791896

2

3. ZS-188

Vector Components (Mark to Mark)

From:	ZGS-1				
Grid		Local		Global	
Easting	553699.482 m	Latitude	N8°04'26.98335"	Latitude	N8°04'23.40249"
Northing	892472.300 m	Longitude	E123°29'14.53868"	Longitude	E123°29'19.99013"
Elevation	20.051 m	Height	22.611 m	Height	88.163 m

To:	ZS-188A				
Grid		Local		Global	
Easting	553627.634 m	Latitude	N8°03'56.69408"	Latitude	N8°03'53.11537"
Northing	891542.089 m	Longitude	E123°29'12.15500"	Longitude	E123°29'17.60722"
Elevation	17.277 m	Height	19.832 m	Height	85.400 m

Vector					
ΔEasting	-71.848 m	NS Fwd Azimuth	184°29'06"	ΔX	-9.705 m
ΔNorthing	-930.211 m	Ellipsoid Dist.	933.322 m	ΔY	146.900 m
ΔElevation	-2.773 m	ΔHeight	-2.778 m	ΔZ	-921.644 m

Standard Errors

Vector errors:					
σ ΔEasting	0.004 m	σ NS fwd Azimuth	0°00'01"	σ ΔX	0.001 m
σ ΔNorthing	0.001 m	σ Ellipsoid Dist.	0.001 m	σ ΔY	0.005 m
σ ΔElevation	0.004 m	σ ΔHeight	0.004 m	σ ΔZ	0.001 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000013603		
Y	0.0000026352	0.0000296273	
Z	0.0000004069	0.0000057486	0.0000013978

2

Annex 4. The Survey Team

Data Acquisition Component Sub-Team	Designation	Name	Agency/ Affiliation
PHIL-LiDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	ENGR. LOUIE BALICANTA	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUÑA	UP-TCAGP
FIELD TEAM			
LiDAR Operation, Ground Survey, Data Download and Transfer	Supervising Science Research Specialist (Supervising SRS)	GEROME HIPOLITO	UP-TCAGP
	Senior Science Research Specialist (Senior SRS)	JASMINE ALVIAR	UP-TCAGP
	Research Associate (RA)	GEF SORIANO	UP-TCAGP
	RA	JONATHAN ALMALVEZ	UP-TCAGP
	RA	IRO ROXAS	UP-TCAGP
	RA	GRACE SINADJAN	UP-TCAGP
	RA	LANCE CINCO	UP-TCAGP
LiDAR OPERATION	AIRBORNE SECURITY	SSG. JAYCO S. MANZANO	PHILIPPINE AIR FORCE (PAF)
	AIRBORNE SECURITY	SSG. LEE JAY PUNZALAN	PAF
	PILOT	CAPT. SHERWIN ALFONSO III	ASIAN AEROSPACE CORPORATION (AAC)
	PILOT	CAPT. JERICHO JECIEL	AAC
	PILOT	CAPT. C. ALFONSO	AAC
	PILOT	CAPT. J. LIM	AAC

Annex 5. Data Transfer Sheets for Bulod Floodplain

DATA TRANSFER SHEET
06/20/2014(Northern Mindanao)

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	
29-May-14	1525P	1KXB149A	PEGASUS	1.6	457	9.27	265	na	na	26.5	NA	9.83	1KB	1KB	40	NA	Z:\Airborne_Raw\1525P
31-May-14	1533P	1BLKK67151A	PEGASUS	3.32	270	14.4	224	43.2	428	33.3	NA	8.87	1KB	1KB	47/38	NA	Z:\Airborne_Raw\1533P
2-Jun-14	1541P	1BLK71B153A	PEGASUS	4	242	0	265	19.7	139	39	674MB	12.6	1KB	1KB	47/45/40/34	NA	Z:\Airborne_Raw\1541P
3-Jun-14	1545P	1BLK71C154A	PEGASUS	4.13	2259	13	253	69.7	533	40.1	272MB	9.95	1KB	1KB	141	NA	Z:\Airborne_Raw\1545P
4-Jun-14	1549P	1BLK71D155A	PEGASUS	3.48	150	14.3	264	NA	NA	34.6	NA	11.2	1KB	1KB	54/50/45	NA	Z:\Airborne_Raw\1549P
7-Jun-14	1561P	1KXE158A	PEGASUS	NA	44	NA	187	NA	NA	22	NA	8.1	1KB	1KB	71	NA	Z:\Airborne_Raw\1561P
8-Jun-14	1565P	1BLK71B158A	PEGASUS	NA	16	5.35	168	22.1	163	13.3	NA	7.75	1KB	1KB	36	NA	Z:\Airborne_Raw\1565P

Received from

Name
Position
Signature

Received by

Name
Position
Signature

6/23/2014

DATA TRANSFER SHEET
08/06/2014(Northern Mindanao - ready)

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	SHP	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	
7/3/2014	1665P	1BLK71ES184A	Pegasus	606	93	4.69	94.5	169	NA	NA	6.77	NA	6.94	1KB	1KB	35	NA	Z:\Airborne_Raw
7/5/2014	1673P	1BLK71ES186A	Pegasus	1.05	379	7.58	335	190	22.4	167	12.6	27.8	5.09	1KB	1KB	92/84	NA	Z:\Airborne_Raw
7/6/2014	1677P	1BLK71S187A	Pegasus	695	68	5.33	188	141	11.2	86	7.79	NA	4.94	1KB	1KB	130	NA	Z:\Airborne_Raw
7/8/2014	1685P	1BLK71S189A	Pegasus	2.31	515	11	578	242	37	288	22.4	47.4	4.39	1KB	1KB	184	NA	Z:\Airborne_Raw
7/8/2014	1687P	1BLK71S189B	Pegasus	749	79	4.81	176	136	NA	NA	7.47	NA	4.39	1KB	1KB	NA	NA	Z:\Airborne_Raw
7/9/2014	1689P	1BLK71S190A	Pegasus	2.56	156	12.6	740	257	NA	NA	27.1	NA	3.68	1KB	1KB	196/207	NA	Z:\Airborne_Raw
7/10/2014	1693P	1RXES191A	Pegasus	1.78	551	8.11	448	175	NA	NA	16.9	NA	4.08	1KB	1KB	53	NA	Z:\Airborne_Raw

Received from

Name TIN ANDAYA
Position RA
Signature

Received by

Name JOIDA F. PRIETO
Position SSRS
Signature
8/6/14

DATA TRANSFER SHEET
PAGADIAN 2/29/16

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	
2016-02-17	23104P	1BLK76DLM48A	Pegasus	1.81 GB	NA	10.09 MB	287.01 MB	25.87 GB	193.97 KB	18.3 GB	0 B	116.78 MB	133 B	1.08 KB	0 B	NA	Z:\DAC\RAW DATA\23104P
2016-02-16	23100P	1BLK76G047A	Pegasus	2.83 GB	NA	12.33 MB	285.96 MB	38 GB	297.52 KB	27.31 GB	0 B	103.23 MB	132 B	341B	0 B	NA	Z:\DAC\RAW DATA\23100P
2016-02-15	23096P	1BLK76NO46A	Pegasus	665.91 MB	NA	4.64 MB	164.2 MB	9.7 GB	82.64 KB	7.07 GB	0 B	90.32 MB	133 B	603 B	0 B	NA	Z:\DAC\RAW DATA\23096P
2016-02-14	23092P	1BLK76IG045A	Pegasus	2.19 GB	NA	10.66 MB	203.46 MB	28.87 GB	230.75 KB	22.33 GB	0 B	110.72 MB	132 B	279 B	0 B	NA	Z:\DAC\RAW DATA\23092P
2016-02-13	23088P	1BLK76ILM044A	Pegasus	2.48 GB	NA	11.64 MB	283.62 MB	35.45 GB	263.38 KB	24.65 GB	0 B	101.29 MB	133 B	889 B	0 B	NA	Z:\DAC\RAW DATA\23088P
2016-02-12	23084P	1BLK76KJLM043A	Pegasus	3.01 GB	NA	13.36 MB	276.9 MB	44.56 GB	332.83 KB	29.36 GB	0 B	129.73 MB	133 B	362 B	0 B	NA	Z:\DAC\RAW DATA\23084P

Received from

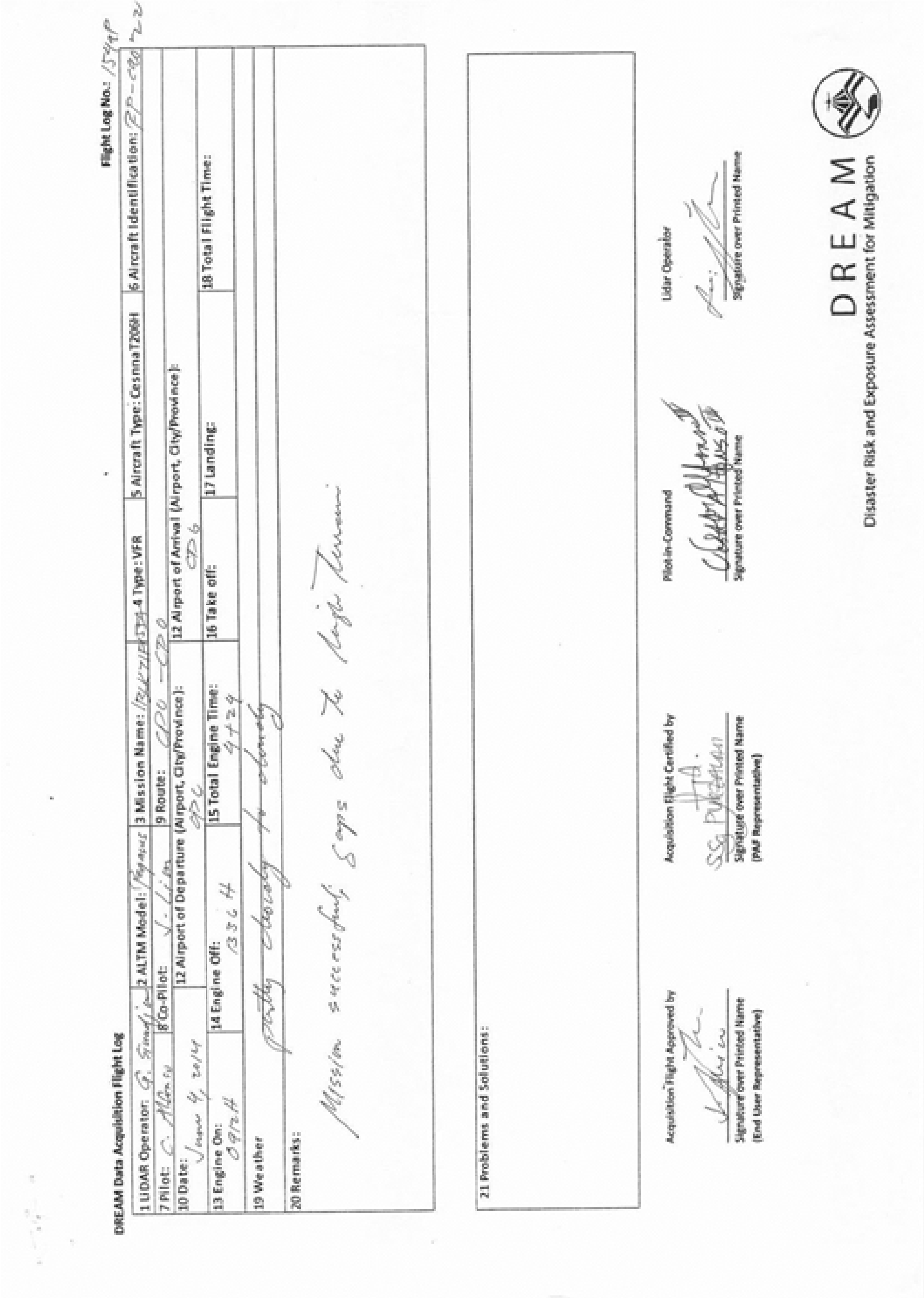
Name R. Punto
Position RA
Signature [signature]

Received by

Name AC Bongat
Position SSRS
Signature [signature] 3/1/16

Annex 6. Flight Logs fo the Flight Missions

1.   Flight Log for 1549P Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 1549P

1 LiDAR Operator: G. Sinadjan	2 ALTM Model: Pegasus	3 Mission Name: 1BLK71ER155A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso	8 Co-Pilot: J. Lim	9 Route: CDO - CDO			
10 Date: June 4, 2014	12 Airport of Departure (Airport, City/Province): CDO		12 Airport of Arrival (Airport, City/Province): CDO		
13 Engine On: 0912H	14 Engine Off: 1336H	15 Total Engine Time: 4+24	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather	partly cloudy to cloudy				
20 Remarks:	Mission successful; gaps due to high terrain				

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
Signature over Printed Name (End User Representative)	SSG Pukasan Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

DREAM
Disaster Risk and Exposure Assessment for Mitigation

2. Flight Log for 1565P Mission

DREAM Data Acquisition Flight Log

Flight Log No.: 1565P

1 LiDAR Operator: G. Sinadjan	2 ALTM Model: Pegasus	3 Mission Name: 1BLK71B159A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso	8 Co-Pilot: J. Lim	9 Route: CDO - CDO			
10 Date: June 8, 2014	12 Airport of Departure (Airport, City/Province): CDO		12 Airport of Arrival (Airport, City/Province): CDO		
13 Engine On: 0806H	14 Engine Off: 1059H	15 Total Engine Time: 2+53	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: very cloudy					
20 Remarks: Data acquired but shortened mission due to heavy build up					
21 Problems and Solutions:					

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

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

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

Lidar Operator — Signature over Printed Name

DREAM
Disaster Risk and Exposure Assessment for Mitigation

3. Flight Log for 1685P Mission

DREAM Data Acquisition Flight Log

Flight Log No.: 1685P

1 LiDAR Operator: I. Roxas	2 ALTM Model: Peg	3 Mission Name: 1BLK71S187A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP C9022
7 Pilot: C. Alfonso	8 Co-Pilot: J. Lim	9 Route: CDO			
10 Date: July 8, 2014	12 Airport of Departure (Airport, City/Province): CDO		12 Airport of Arrival (Airport, City/Province): CDO		
13 Engine On: 0958H	14 Engine Off: 1403H	15 Total Engine Time: 4+5	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: cloudy					

20 Remarks:

Surveyed BLK 71F at 1200m.

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
J. Alviar	W. Punzalan	Cesar Alfonso III	I. Roxas
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

4. Flight Log for 1689P Mission

Flight Log No.: 1689P

ition Flight Log

or: I.Roxas	2 ALTM Model: Peg	3 Mission Name:	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RP-C9022
Alfonso	8 Co-Pilot: J. Lim	9 Route: CDO			
9, 2014	12 Airport of Departure (Airport, City/Province): CDO		12 Airport of Arrival (Airport, City/Province): CDO		
t	14 Engine Off: 1552H	15 Total Engine Time: 4+17	16 Take off:	17 Landing:	18 Total Flight Time:

Cloudy

Mission successful at 1200m flying height

and Solutions:

uisition Flight Approved by
J. Alviar
nature over Printed Name
d User Representative)

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

Pilot-in-Command
Cesar Alfonso III
Signature over Printed Name

Lidar Operator
I. Roxas
Signature over Printed Name

5. Flight Log for 23088P Mission

PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 23088P

1 LiDAR Operator: J. Almalvez	2 ALTM Model: Peg	3 Mission Name: [illegible]	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP-C9122
7 Pilot: C. Alfonso III	8 Co-Pilot: J. Jecrel	9 Route:			
10 Date: 13 Feb 16	12 Airport of Departure (Airport, City/Province): Pagadian		12 Airport of Arrival (Airport, City/Province): Pagadian		
13 Engine On: 0720H	14 Engine Off: 1143H	15 Total Engine Time: 4+23	16 Take off: 0725H	17 Landing: 1138H	18 Total Flight Time: 4H13
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

Surveyed BLK76 I, L and M with voids due to clouds.

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

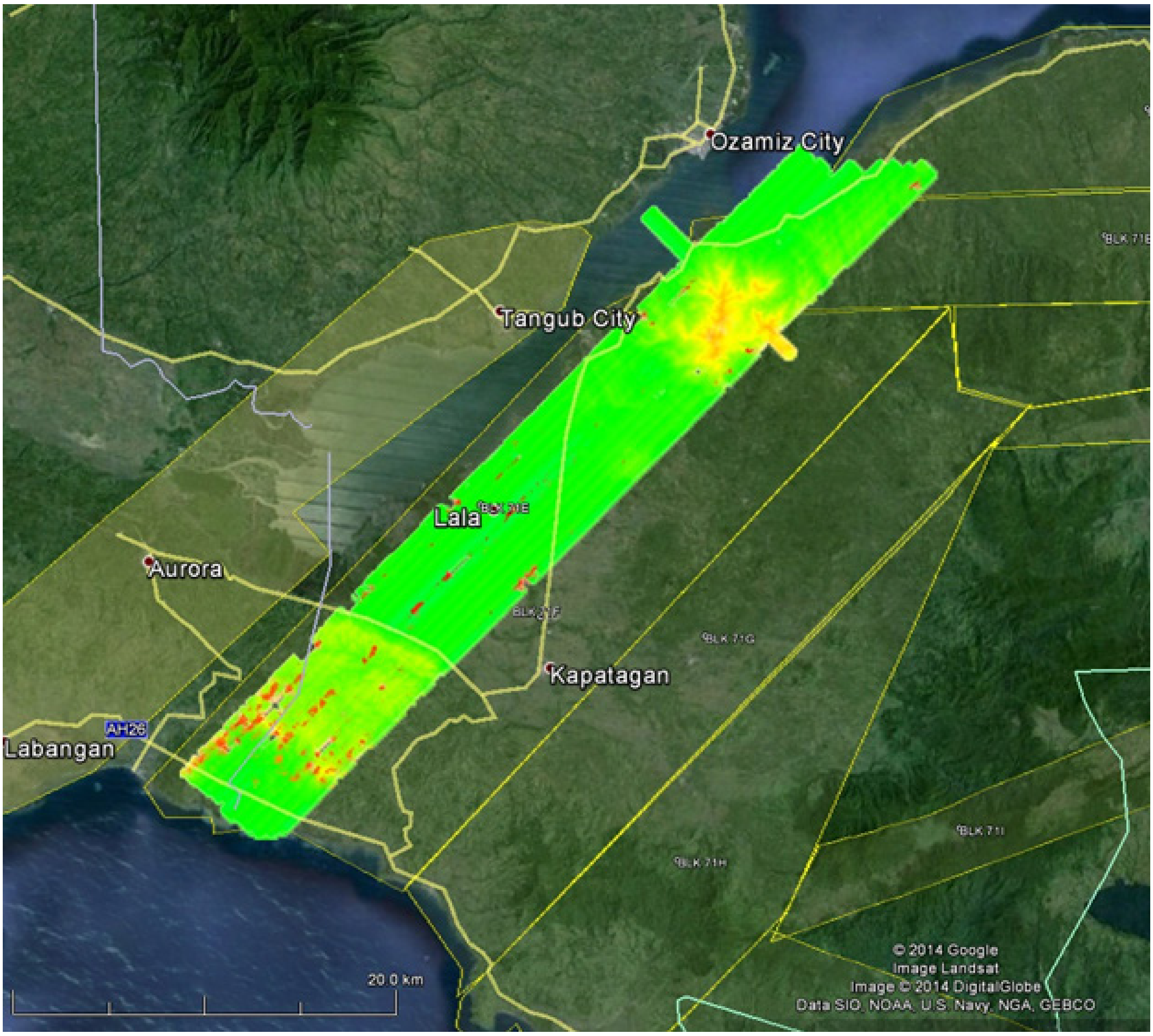
Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	LiDAR Operator	Aircraft Mechanic/ LiDAR Technician
[signature]	[signature]	C. Alfonso III	J. Almalvez	N/A
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

Annex 7. Flight Status Reports

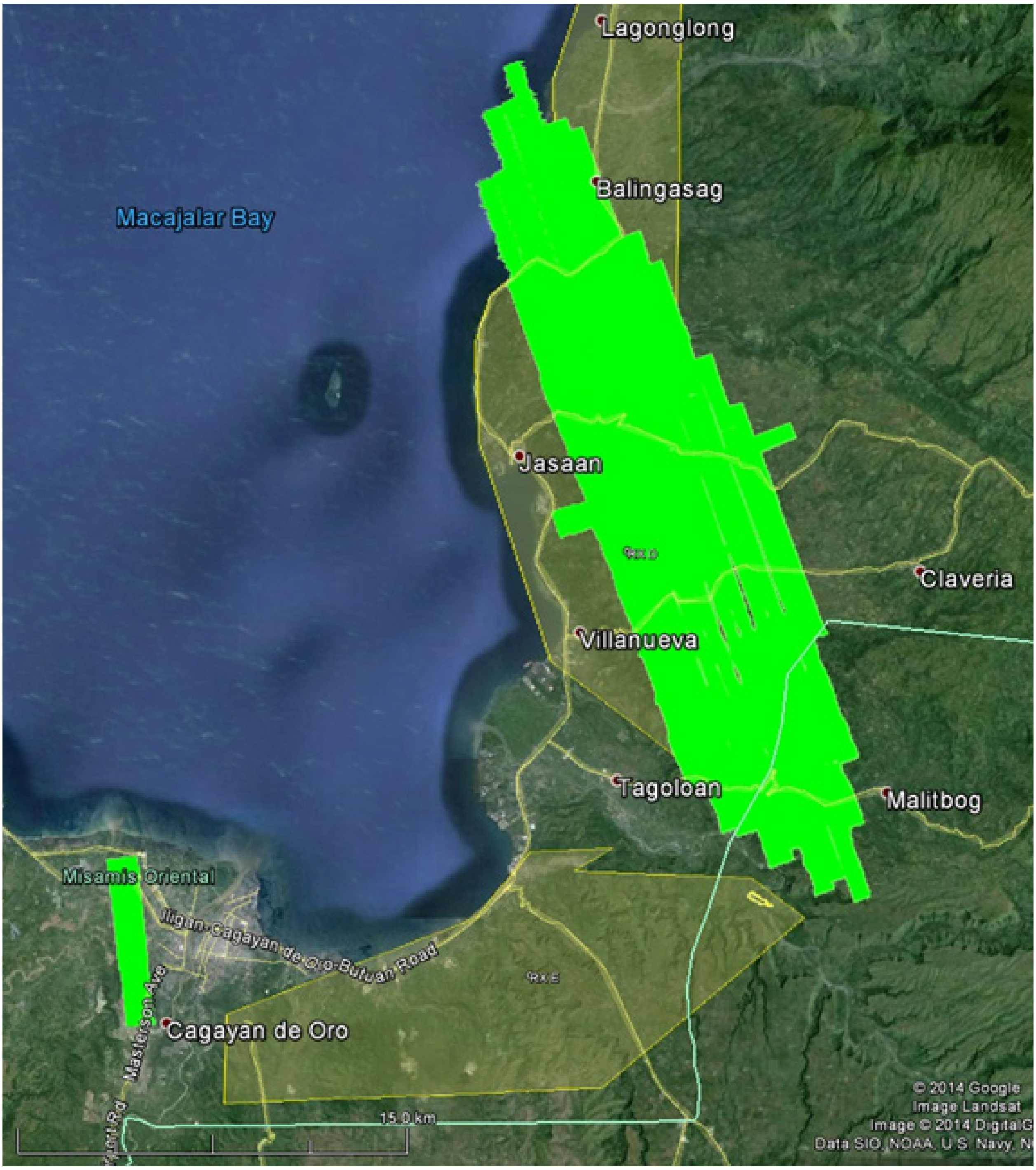
DIPOLOG-ZAMBOANGA DEL NORTE
(October 8 to November 11, 2014 and November 20 to 26, 2016)

FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
1549P	BLK 71E	1BLK 71D155A	G. Sinadjan	June 4	Surveyed BLK 71E with gaps due to clouds; to be renamed to 1BLK71E155A; 231.82 sq.km
1565P	BLK 71F	1BLK71B159A	G. Sinadjan	June 8	Surveyed half of BLK 71F with gaps due to clouds; to be renamed 1BLK71F159A; 105.5 sq.km
1685P	BLK 71F	1BLK71S189A	I.Roxas	July 8	Surveyed BLK 71F at 1200m; 233.71 sq.km
1689P	BLK 71E and BLK 71ABCs	1BLK71S190A	I.Roxas	July 9	Surveyed BLK 71E and the gaps in BLK 71ABC; 278.697 sq.km
23088P	BLK I,L,M	1BLK76ILM044A	JM ALMALVEZ	FEB 13, 2016	Cloudy over L & M. Pegasus problem encountered so no tie lines over I; please use 23078's and 23092's tie line

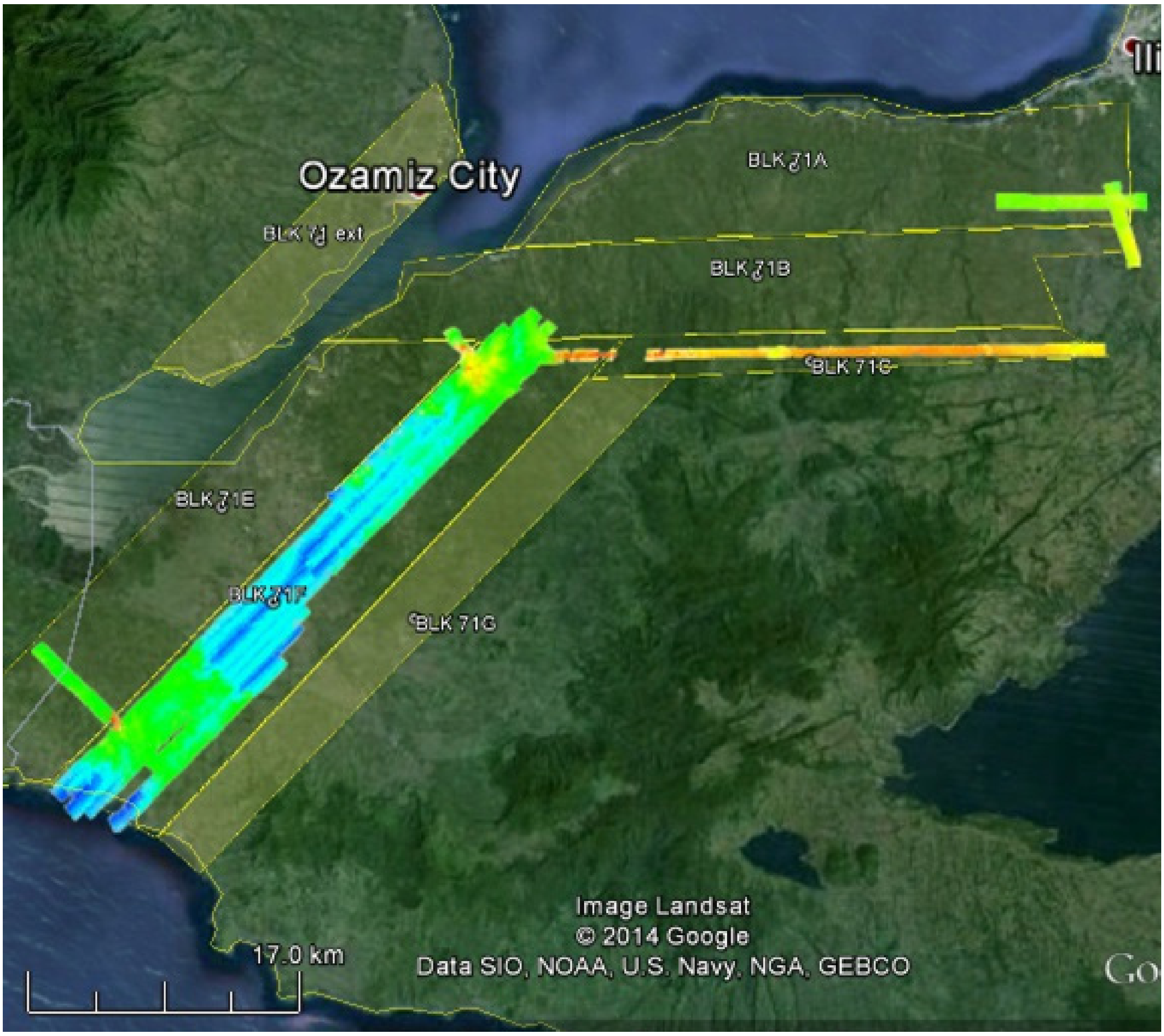
Flight No. : 1549P
Area: BLK 71E
Mission Name: 1BLK71D155A
Parameters: Altitude: 1000m;
Scan Frequency: 30Hz;
Scan Angle: 25deg; Overlap: 30%



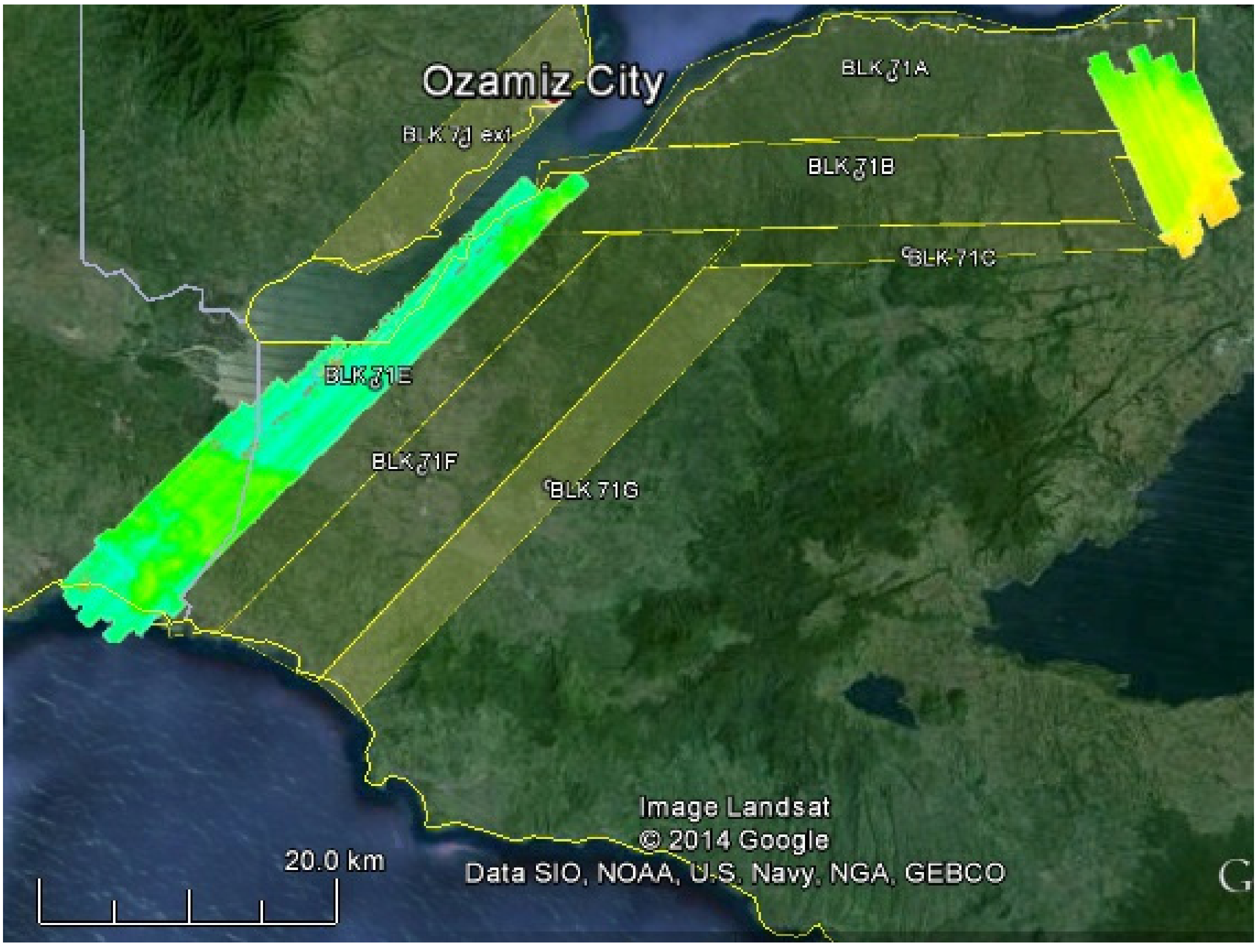
Mission Name: 1BLK71B159A
Parameters: Altitude: 1000m;
Scan Frequency: 30Hz;
Scan Angle: 25deg; Overlap: 30%



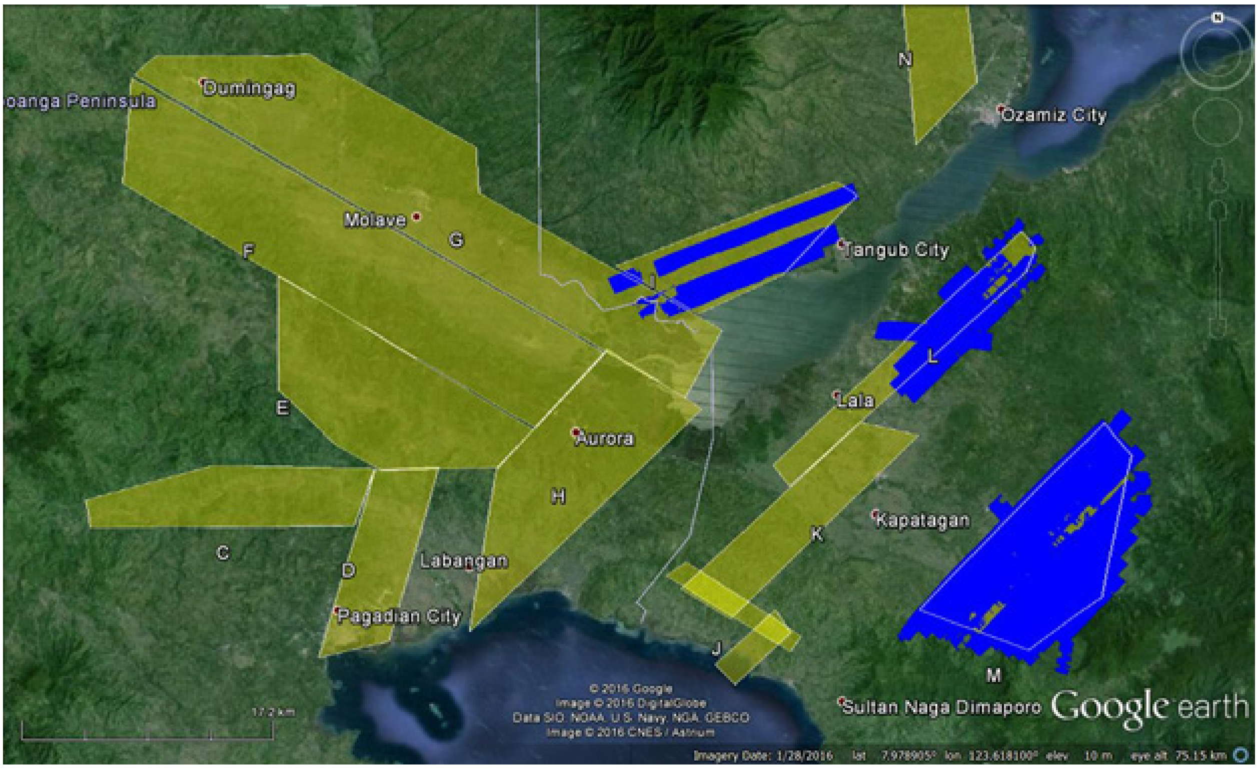
Flight No. : 1685P
Area: BLK 71F
Mission Name: 1BLK71S189A
Parameters: Altitude: 1000m;
Scan Frequency: 30Hz;
Scan Angle: 25deg; Overlap: 30%



Flight No. : 1689P
Area: BLK 71E and BLK 71ABCs
Mission Name: 1BLK71S190A
Parameters: Altitude: 1200m;
Scan Frequency: 30Hz;
Scan Angle: 25deg; Overlap: 30%



Flight No. : 23088P
Area: BLK I, L, M
Mission Name: 1BLK76ILM044A
Parameters: Altitude: 1200m;
Scan Frequency: 30Hz;
Scan Angle: 25deg; Overlap: 30%



Annex 8. Mission Summary Reports

Flight Area	Pagadian
Mission Name	76J
Inclusive Flights	23088P
Range data size	24.65
POS data size	283.62
Base data size	101.29
Image	n/a
Transfer date	March 01, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.3
RMSE for East Position (<4.0 cm)	1.4
RMSE for Down Position (<8.0 cm)	2.5
Boresight correction stdev (<0.001deg)	0.000281
IMU attitude correction stdev (<0.001deg)	0.000180
GPS position stdev (<0.01m)	0.0014
Minimum % overlap (>25)	27.90
Ave point cloud density per sq.m. (>2.0)	3.23
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	72
Maximum Height	698.51 m
Minimum Height	68.61 m
Classification (# of points)	
Ground	34,165,050
Low vegetation	19,594,241
Medium vegetation	28,178,750
High vegetation	95,242,866
Building	801,190
Orthophoto	Yes
Processed by	Engr. Regis Guhiting, Engr. Jovelle Anjeanette Canlas, Engr. Krisha Marie Bautista

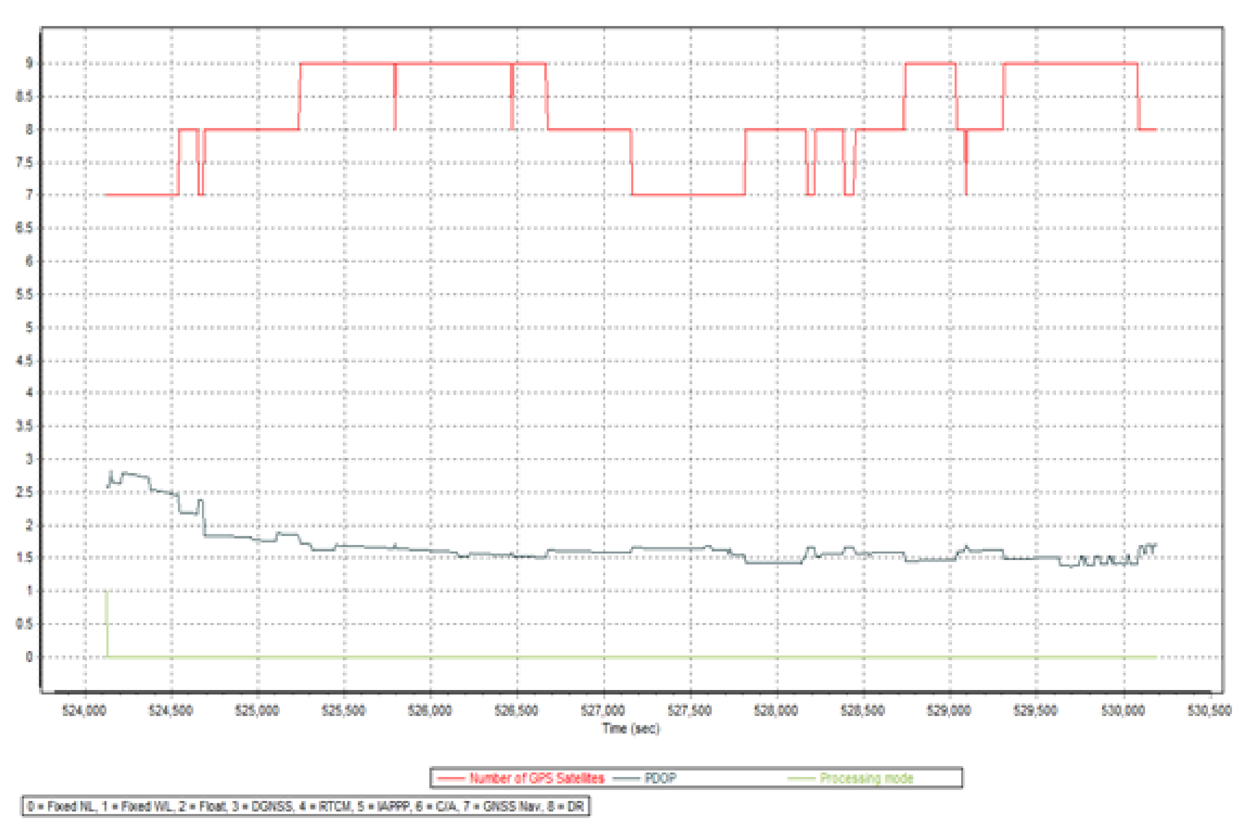


Figure A-8.1. Solution Status

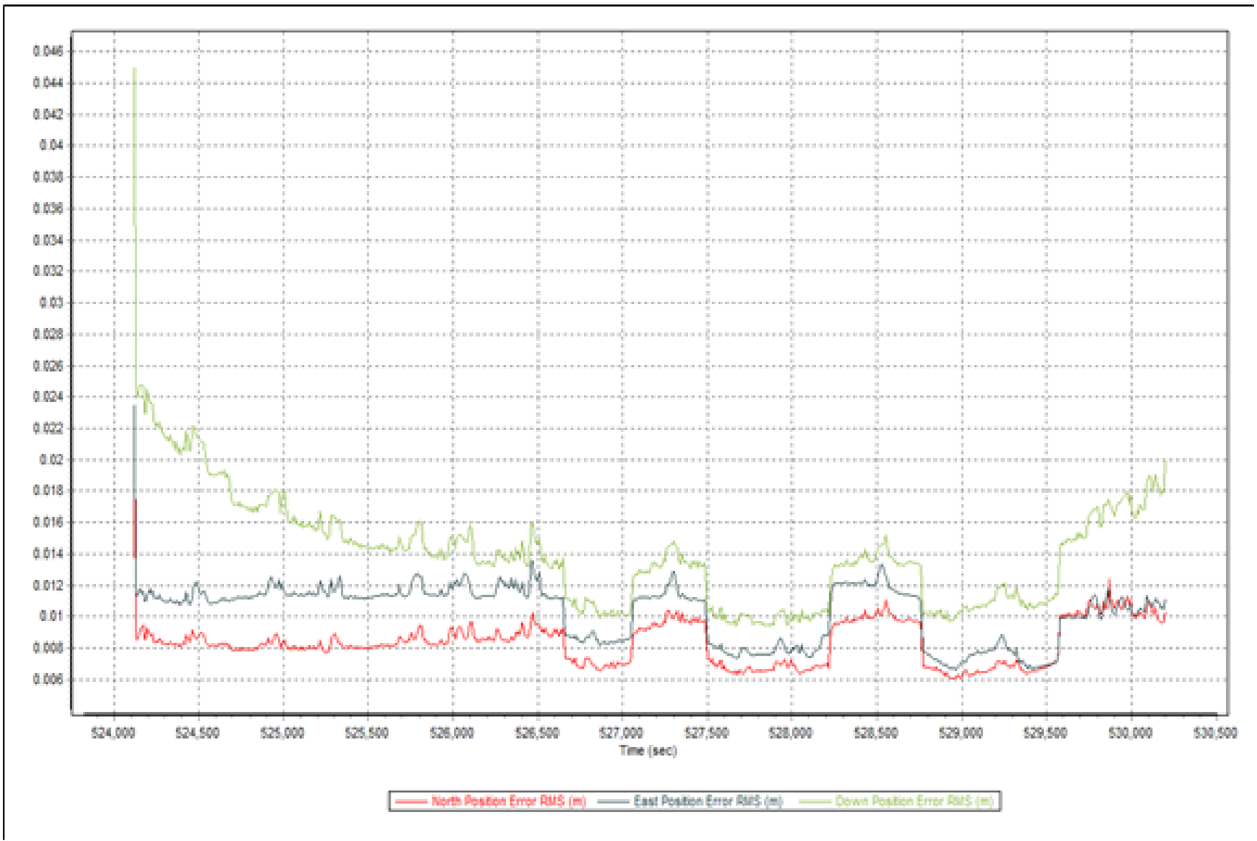


Figure A-8.2. Smoothed Performance Metric Parameters

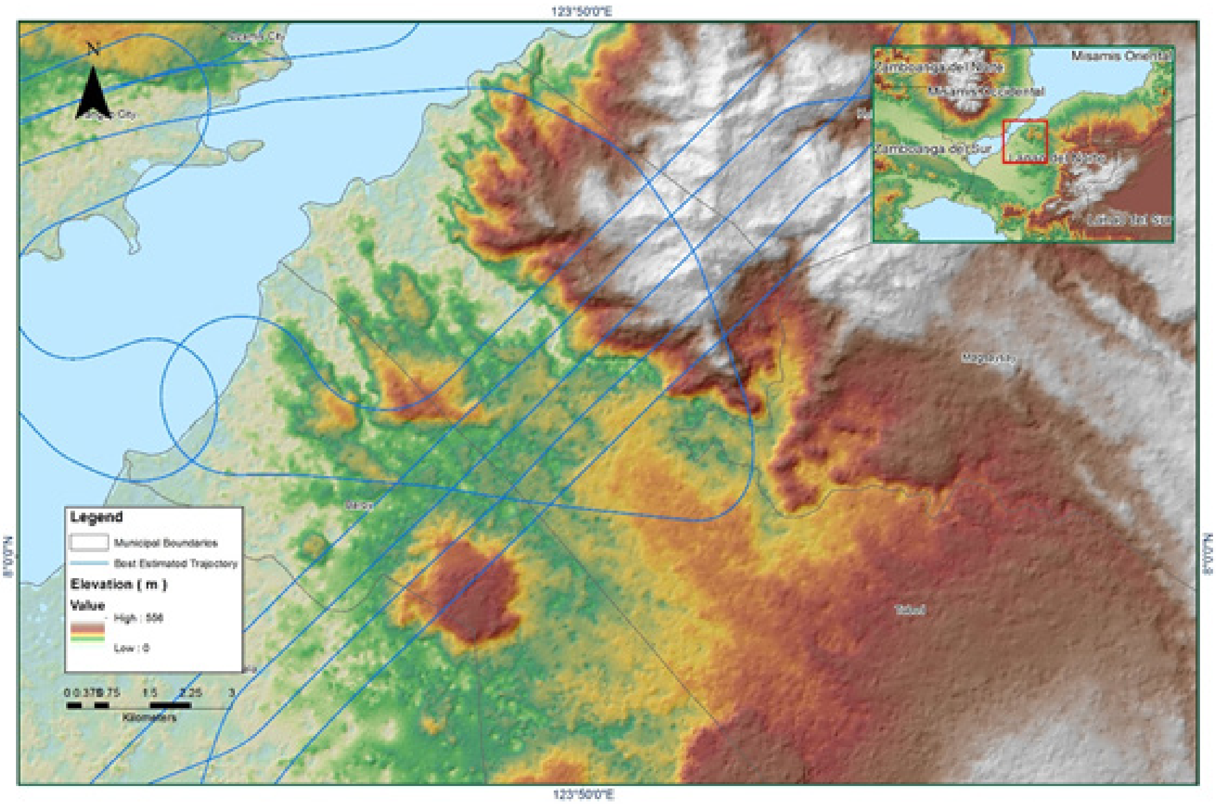


Figure A-8.3. Best Estimated Trajectory

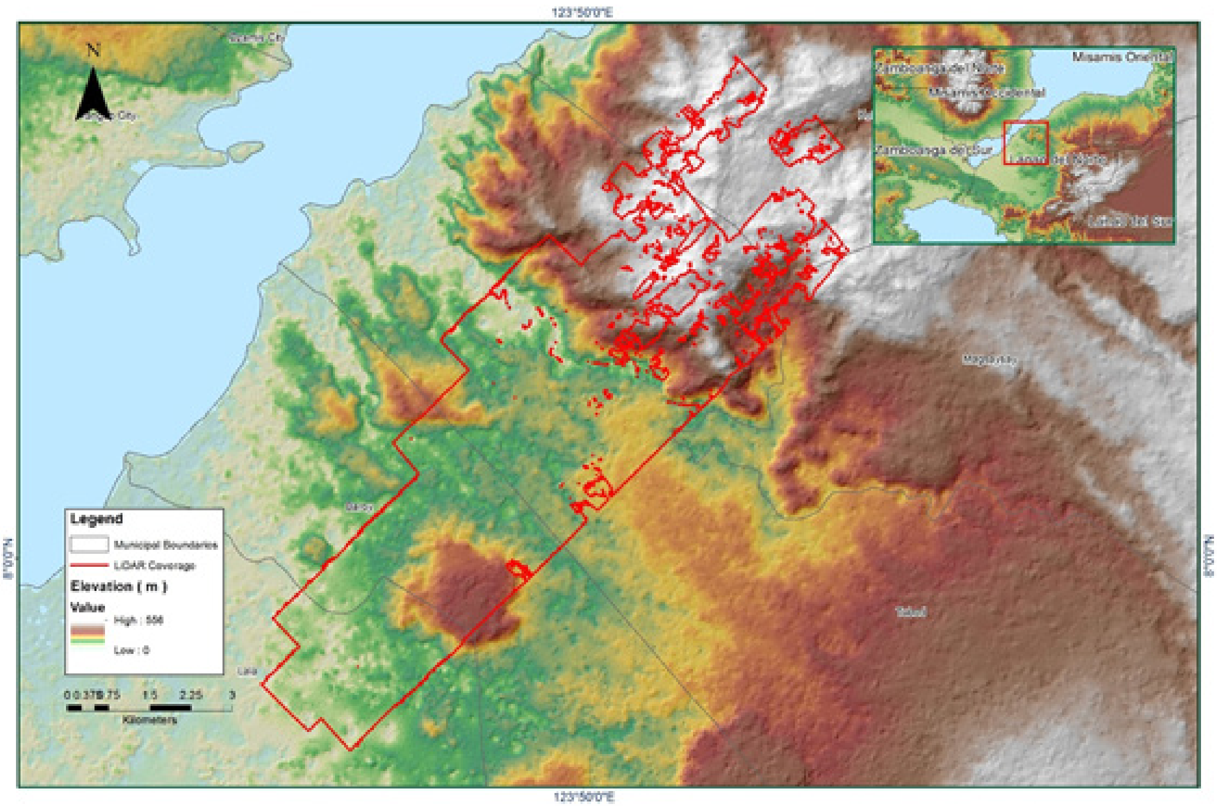


Figure A-8.4. Coverage of LiDAR Data

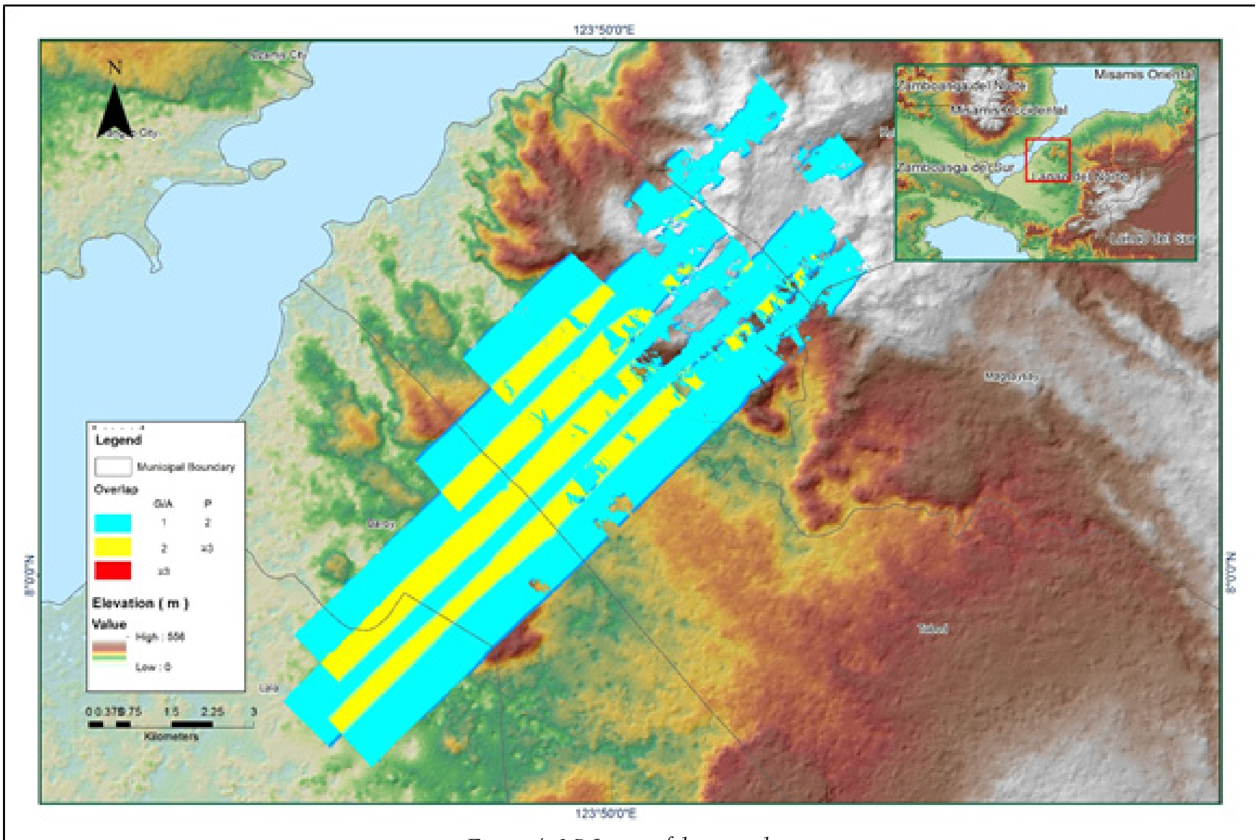


Figure A-8.5. Image of data overlap

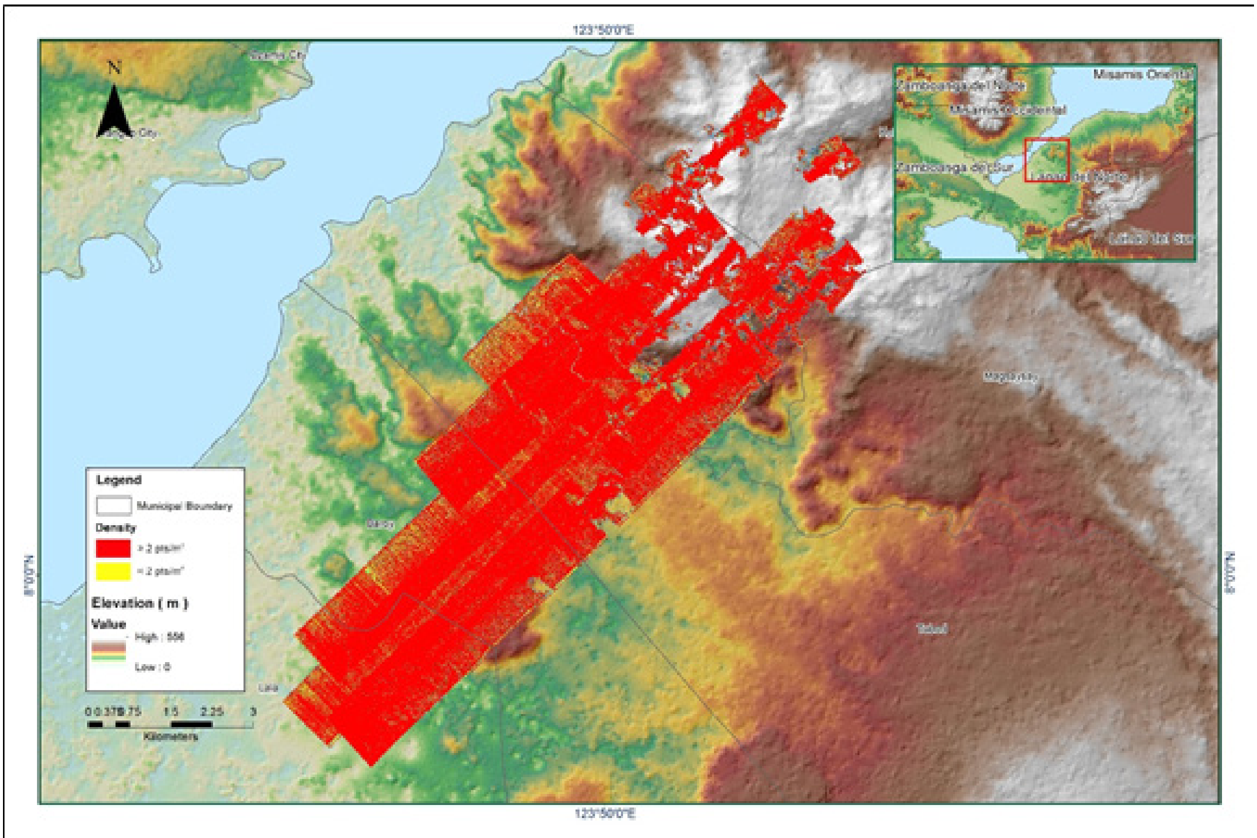


Figure A-8.6. Density map of merged LiDAR data

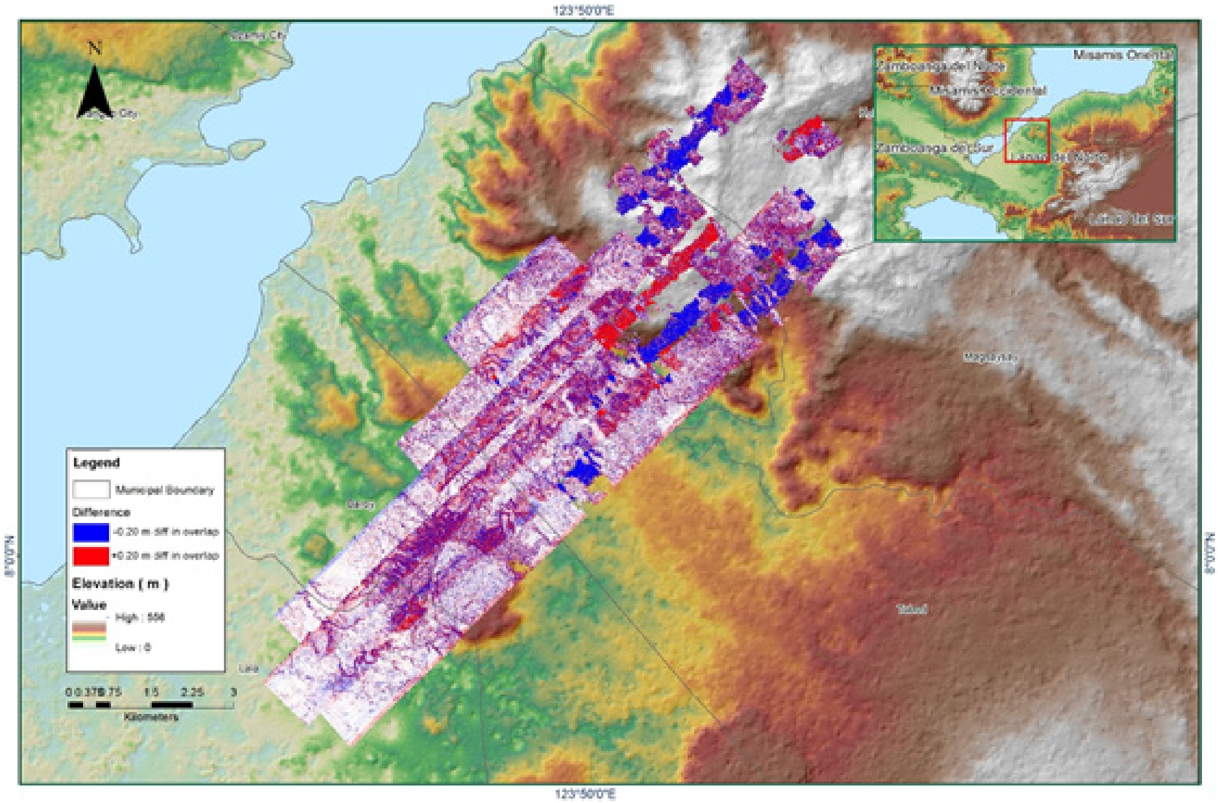


Figure A-8.7. Elevation difference between flight lines

Flight Area	Pagadian
Mission Name	76K
Inclusive Flights	23084P
Range data size	29.36
POS data size	276.9
Base data size	129.73
Image	n/a
Transfer date	March 01, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.3
RMSE for East Position (<4.0 cm)	1.8
RMSE for Down Position (<8.0 cm)	3.7
Boresight correction stdev (<0.001deg)	0.000134
IMU attitude correction stdev (<0.001deg)	0.000524
GPS position stdev (<0.01m)	0.0064
Minimum % overlap (>25)	39.61
Ave point cloud density per sq.m. (>2.0)	3.19
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	280
Maximum Height	475.01 m
Minimum Height	62.15 m
Classification (# of points)	
Ground	263,061,671
Low vegetation	186,080,376
Medium vegetation	173,663,045
High vegetation	1,062,882,246
Building	4,176,141
Orthophoto	Yes
Processed by	Engr. Kenneth Solidum, Engr. Justine Francisco, Maria Tamsyn Malabanan

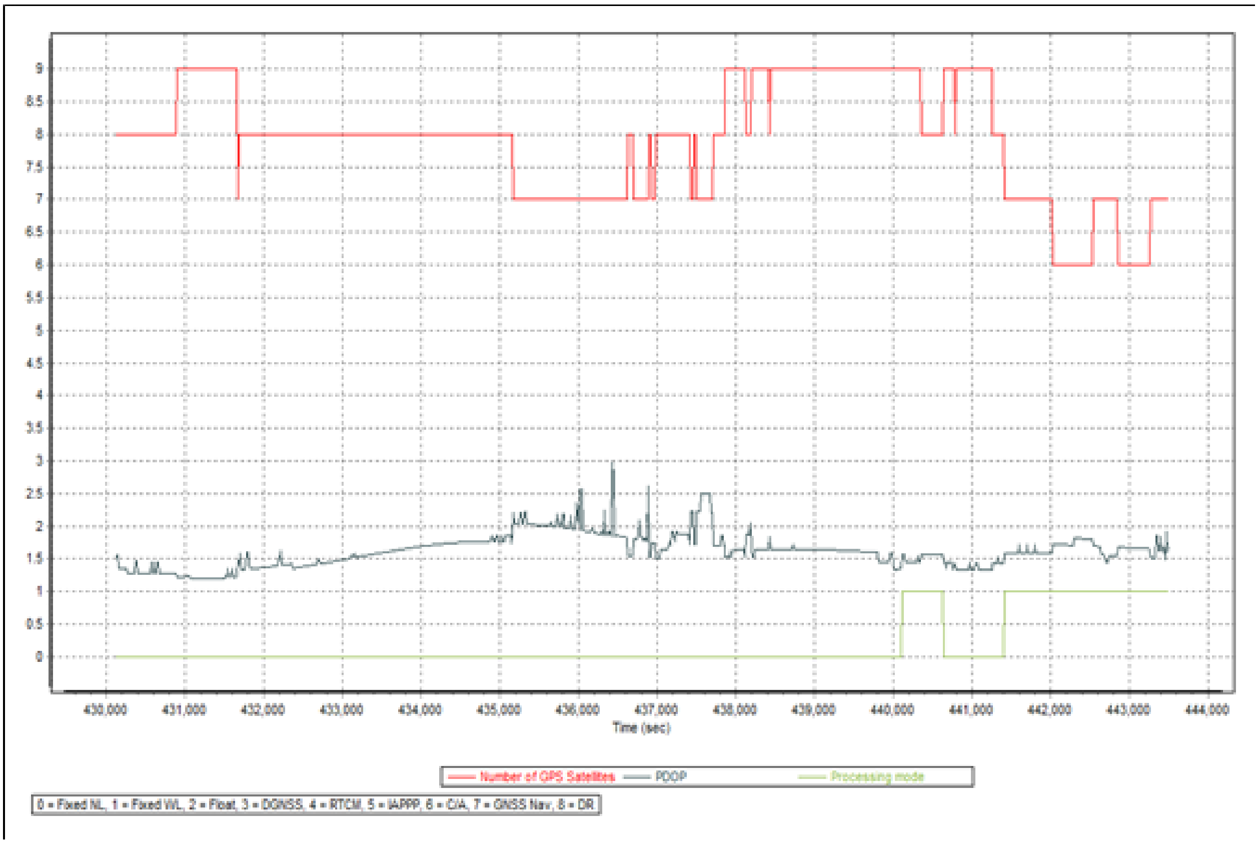


Figure A-8.8. Solution Status

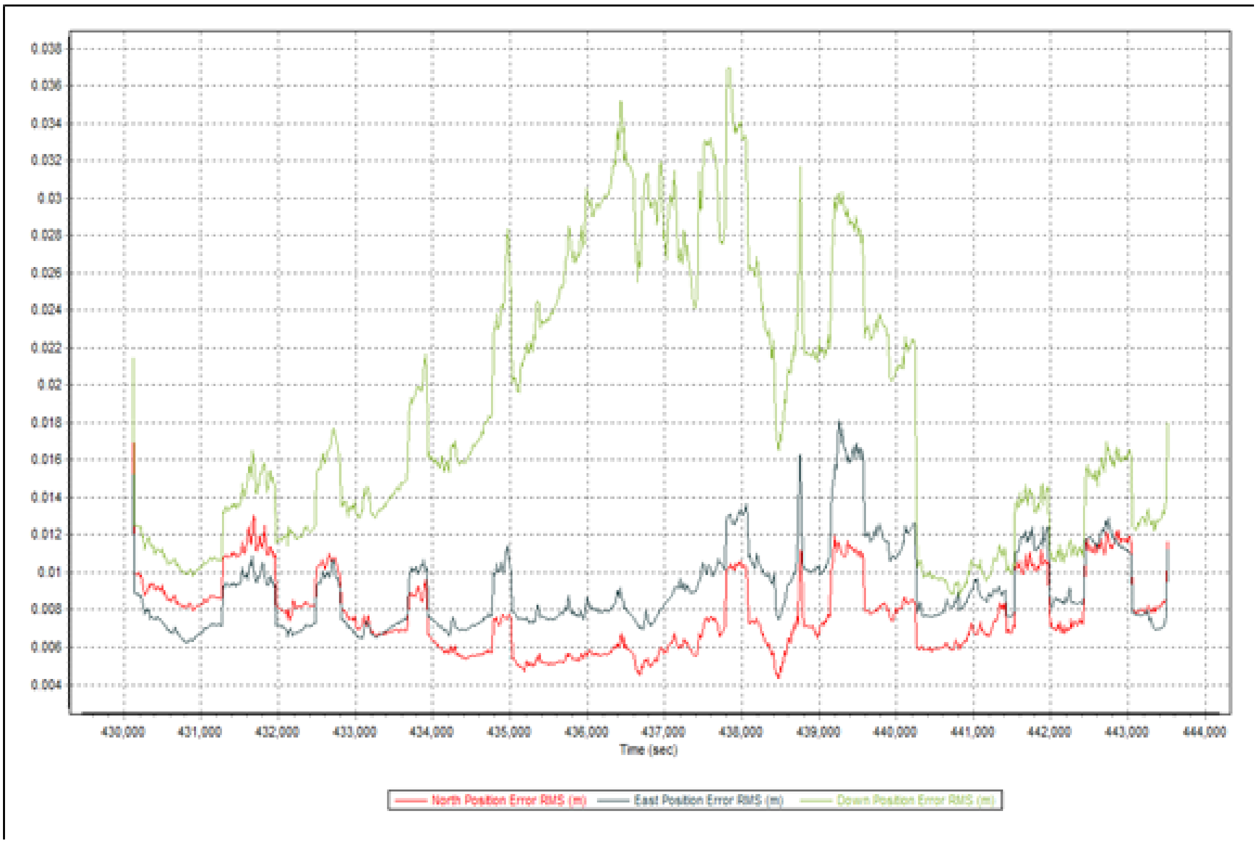


Figure A-8.9. Smoothed Performance Metric Parameters

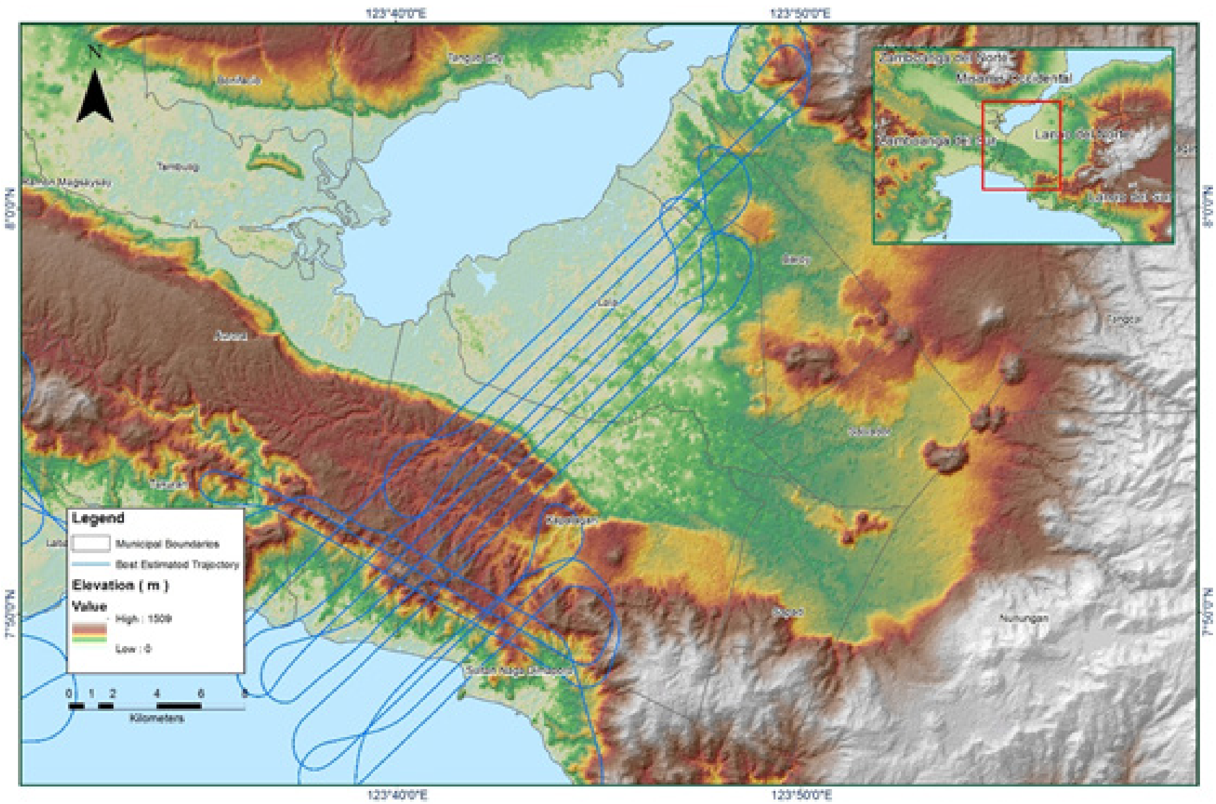


Figure A-8.10. Best Estimated Trajectory

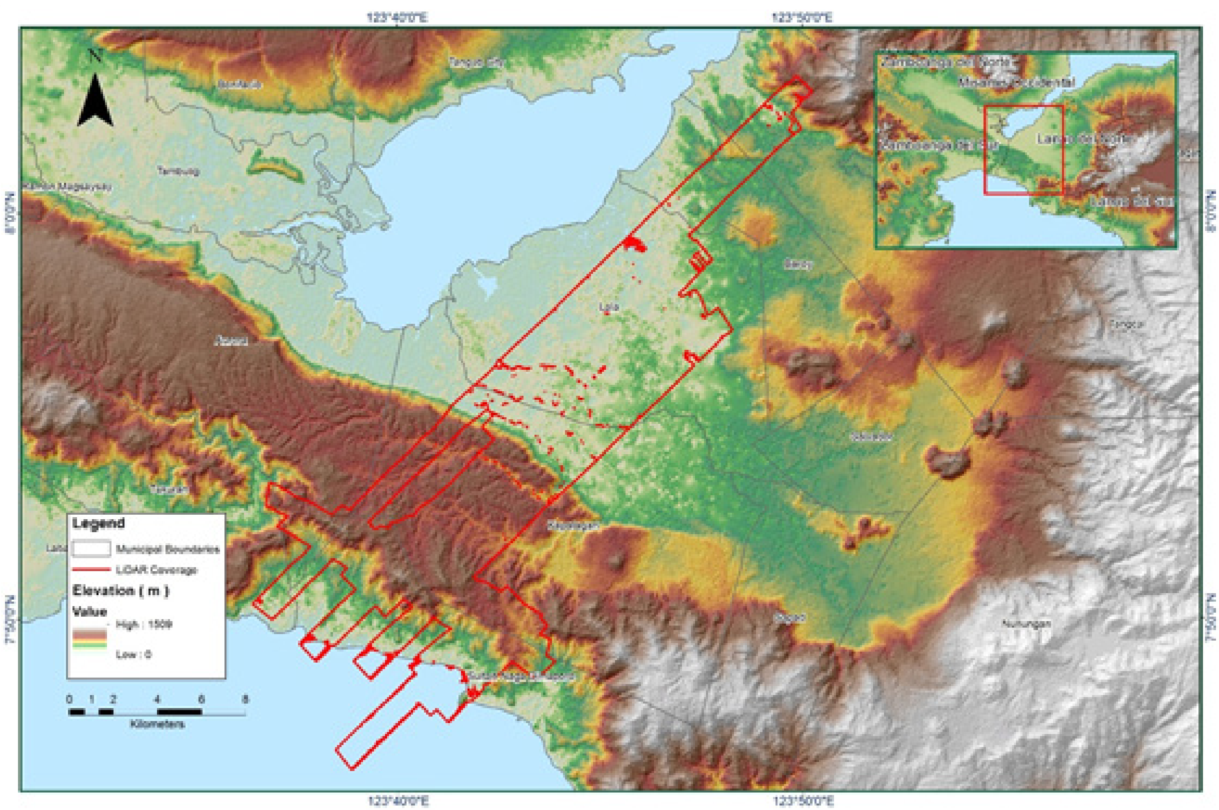


Figure A-8.11. Coverage of LiDAR Data

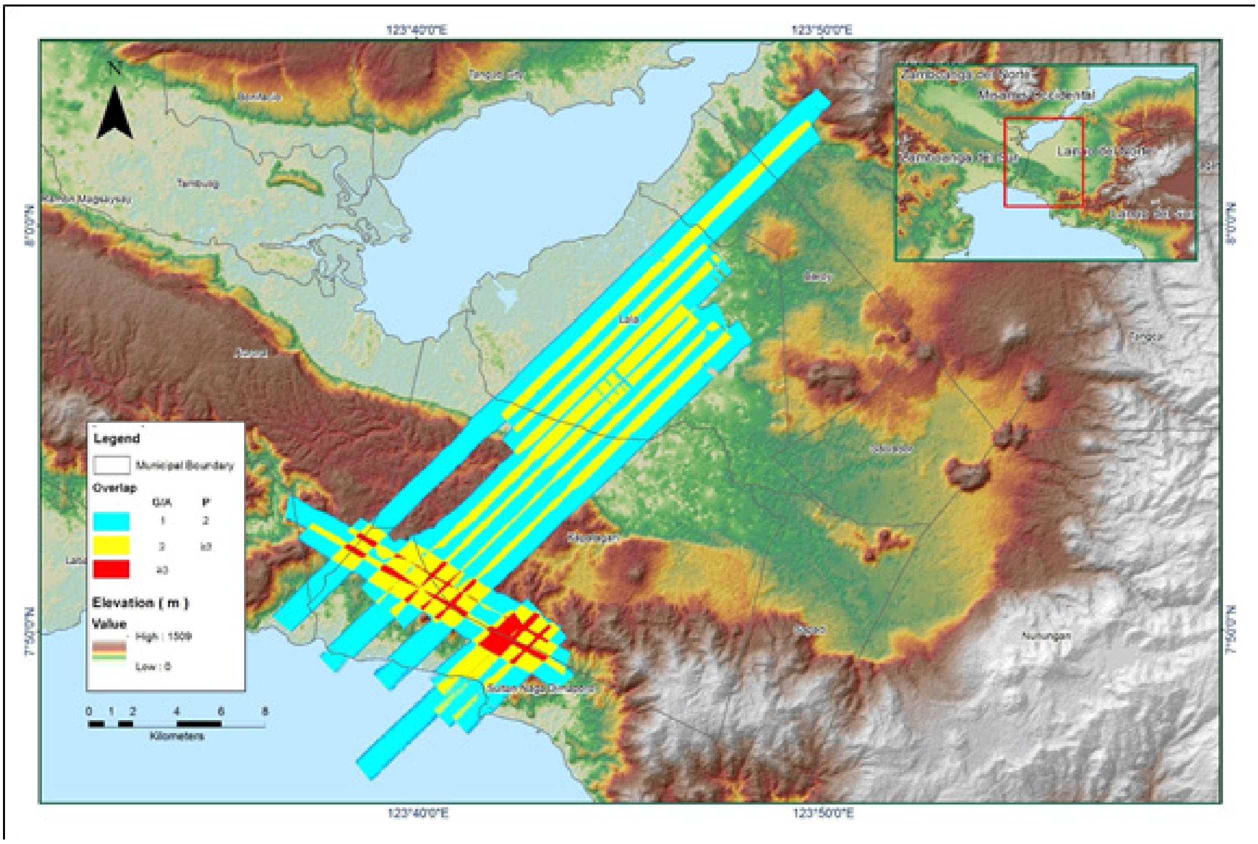


Figure A-8.12. Image of data overlap

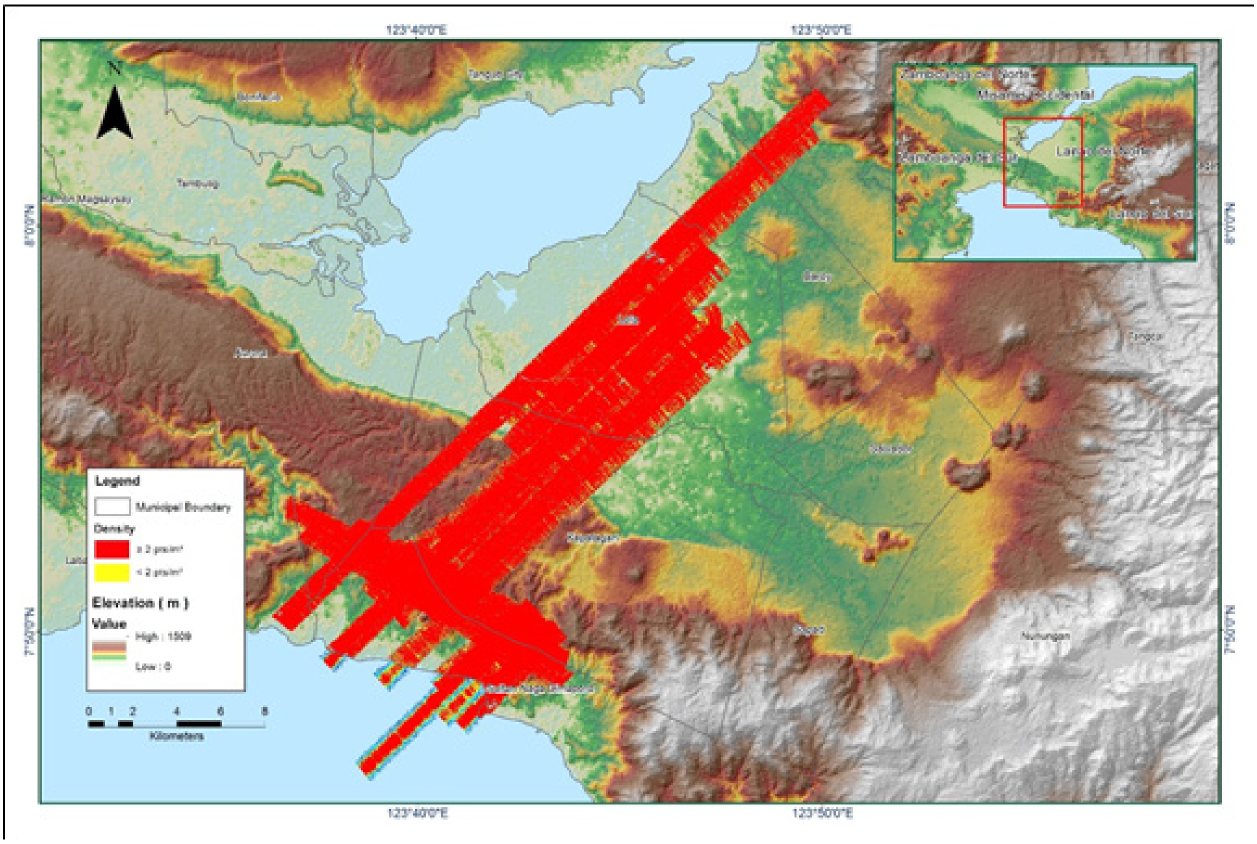


Figure A-8.13. Density map of merged LiDAR data

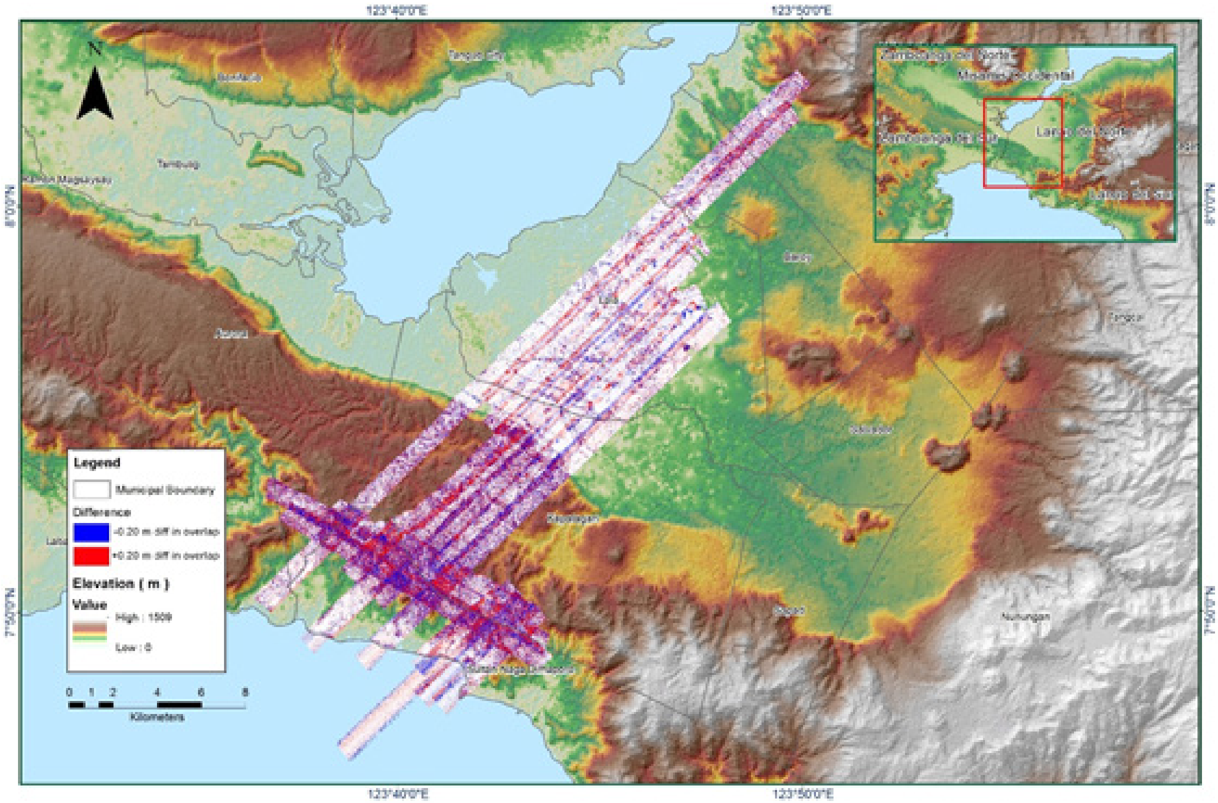


Figure A-8.14. Elevation difference between flight lines

Flight Area	Pagadian
Mission Name	76K_Additional
Inclusive Flights	23104P
Range data size	14.6
POS data size	202
Base data size	60.7
Image	n/a
Transfer date	March 16, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	No
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.8
RMSE for East Position (<4.0 cm)	2.2
RMSE for Down Position (<8.0 cm)	4.4
Boresight correction stdev (<0.001deg)	0.000102
IMU attitude correction stdev (<0.001deg)	N/A
GPS position stdev (<0.01m)	0.0014
Minimum % overlap (>25)	9.58
Ave point cloud density per sq.m. (>2.0)	2.85
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	105
Maximum Height	1224.52 m
Minimum Height	68.45 m
Classification (# of points)	
Ground	64,960,783
Low vegetation	36,363,387
Medium vegetation	41,311,737
High vegetation	33,464,475
Building	699,287
Orthophoto	Yes
Processed by	Engr. Don Matthew Banatin, Engr. Melanie Hingpit, Karl Adrian Vergara

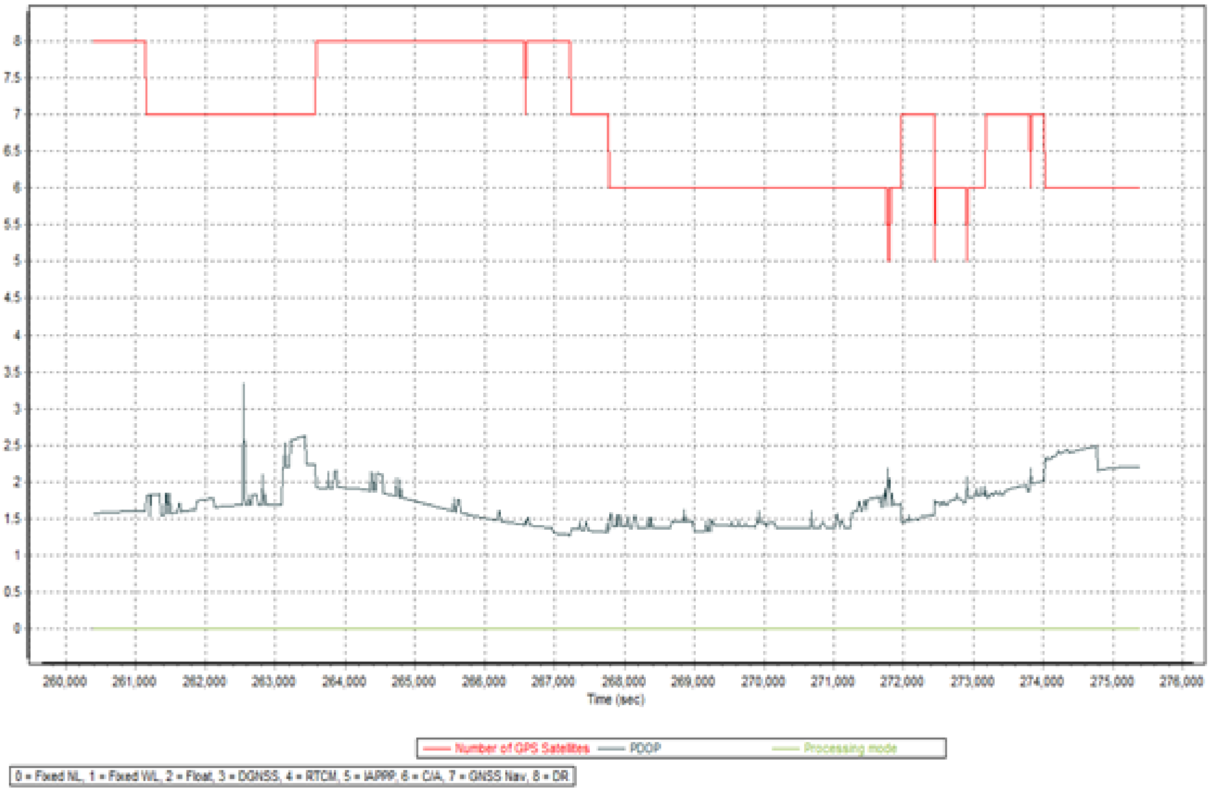


Figure A-8.15. Solution Status

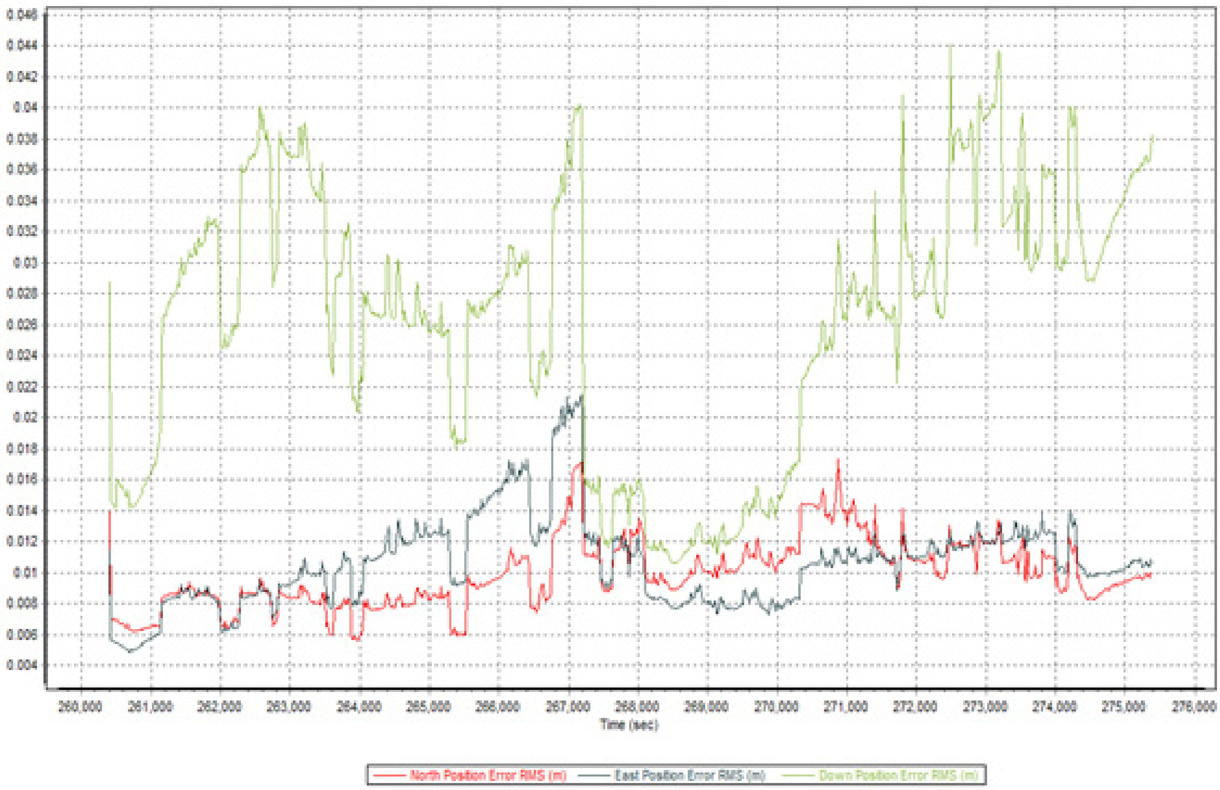


Figure A-8.16. Smoothed Performance Metric Parameters

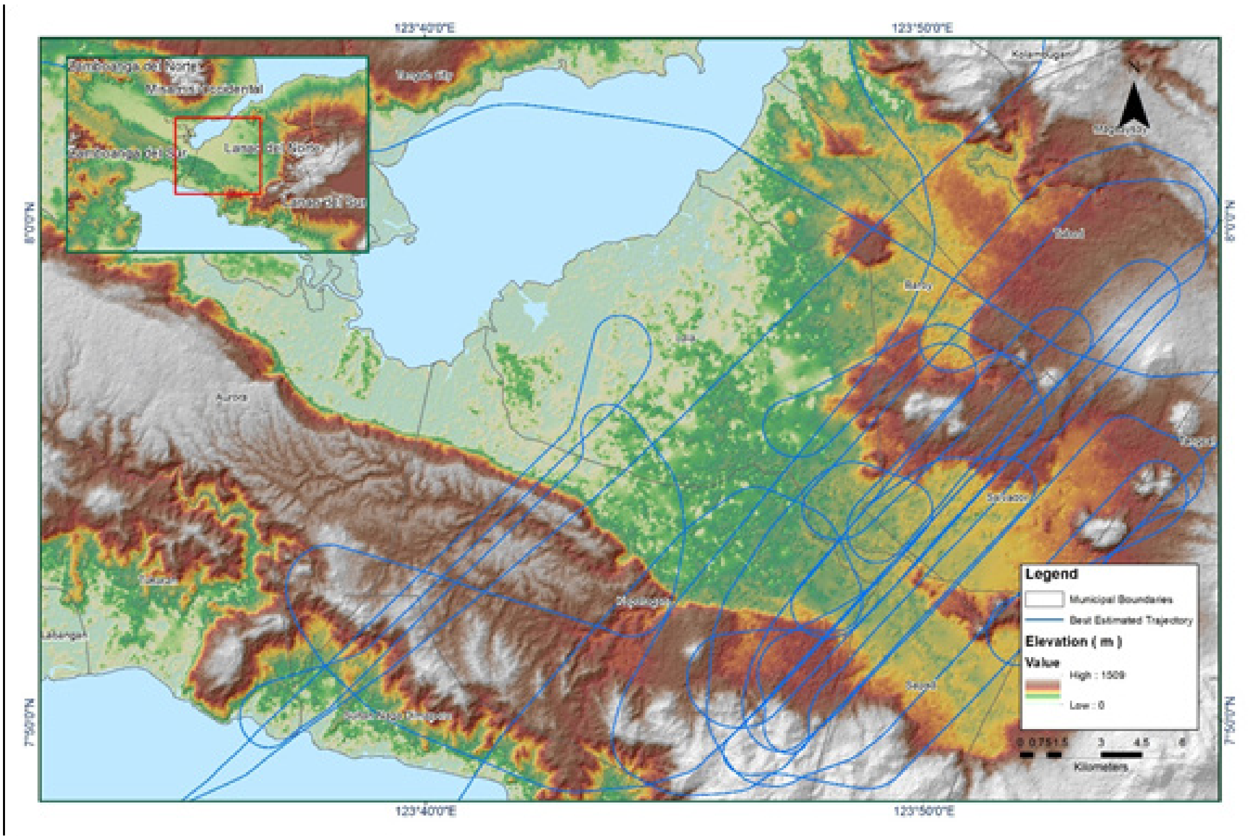


Figure A-8.17. Best Estimated Trajectory

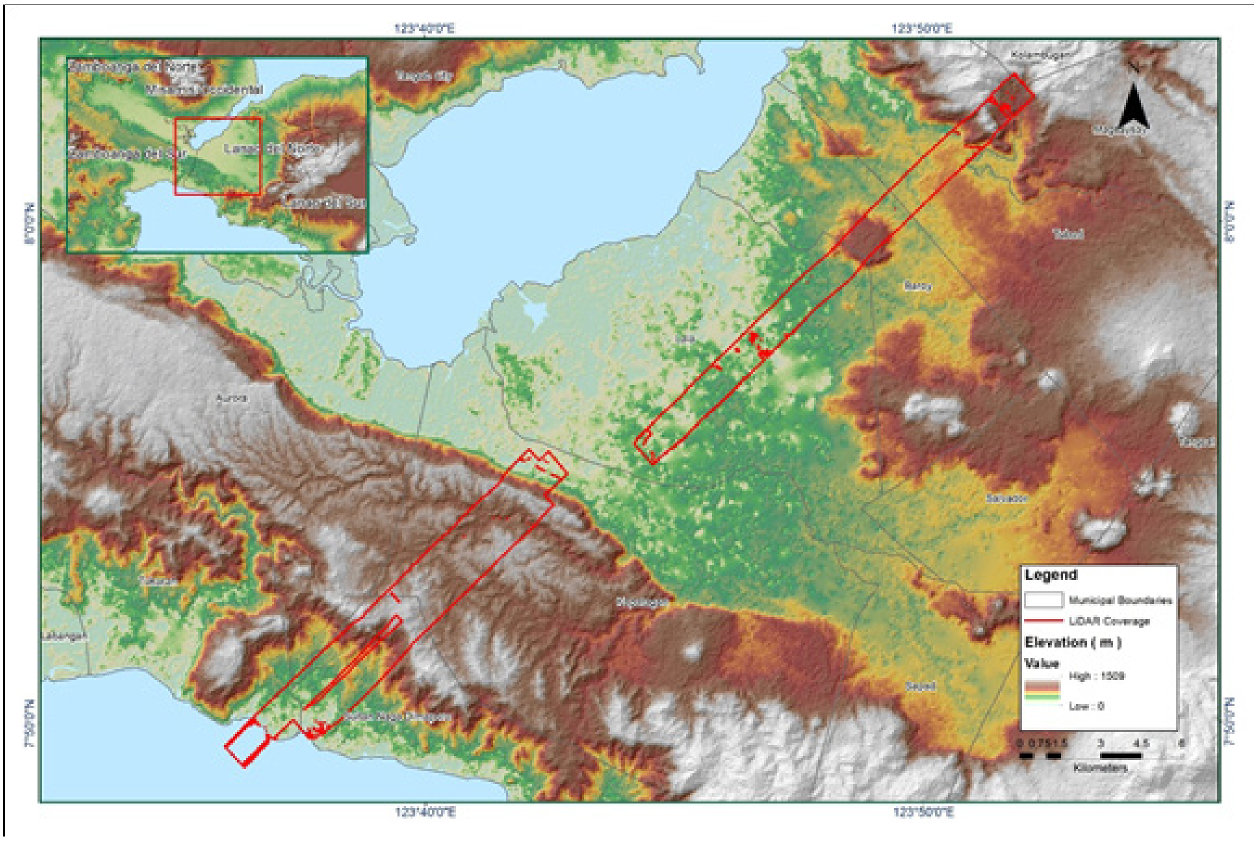


Figure A-8.18. Coverage of LiDAR Data

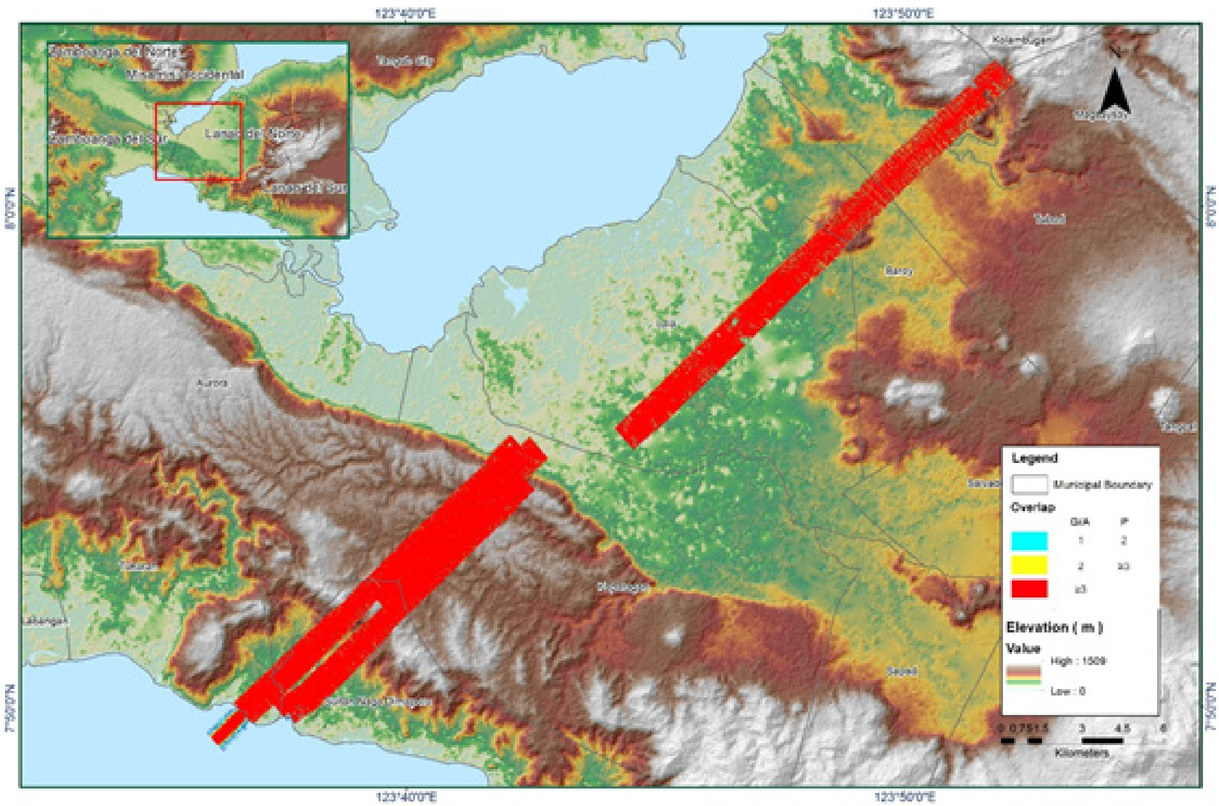


Figure A-8.19. Image of data overlap

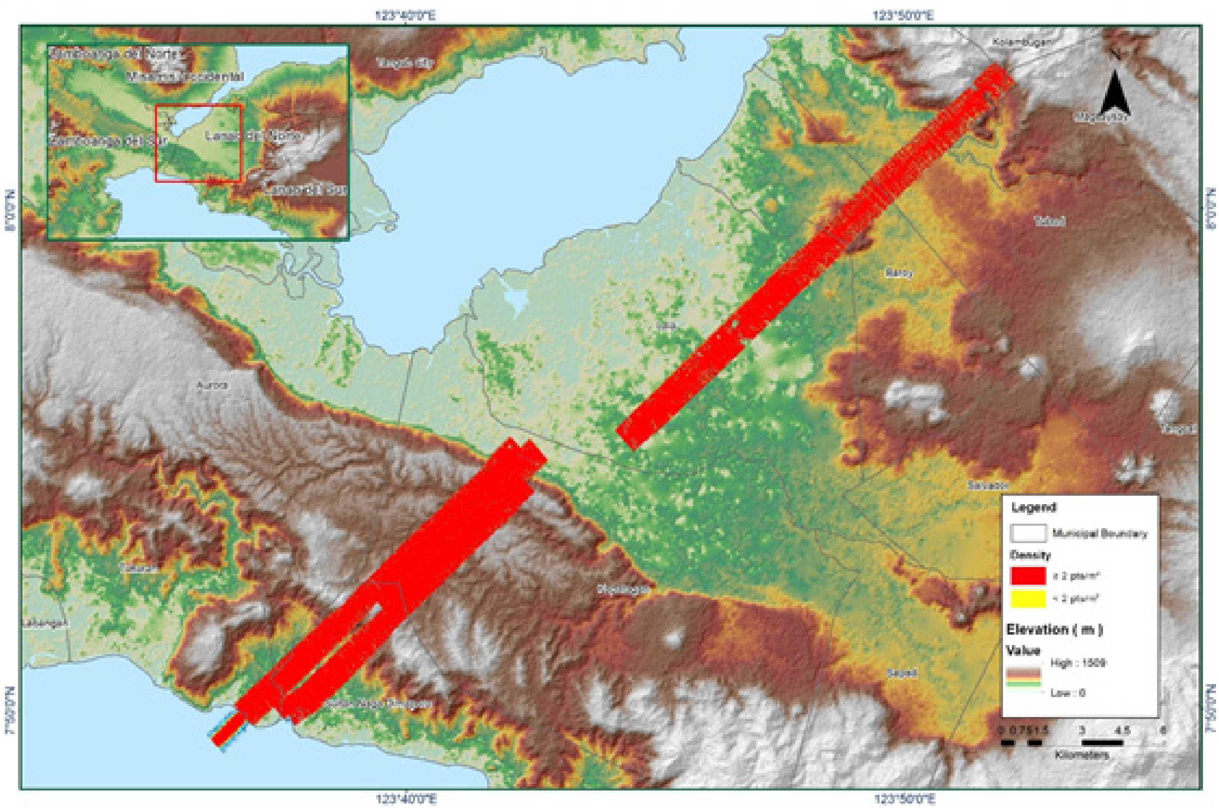


Figure A-8.20. Density map of merged LiDAR data

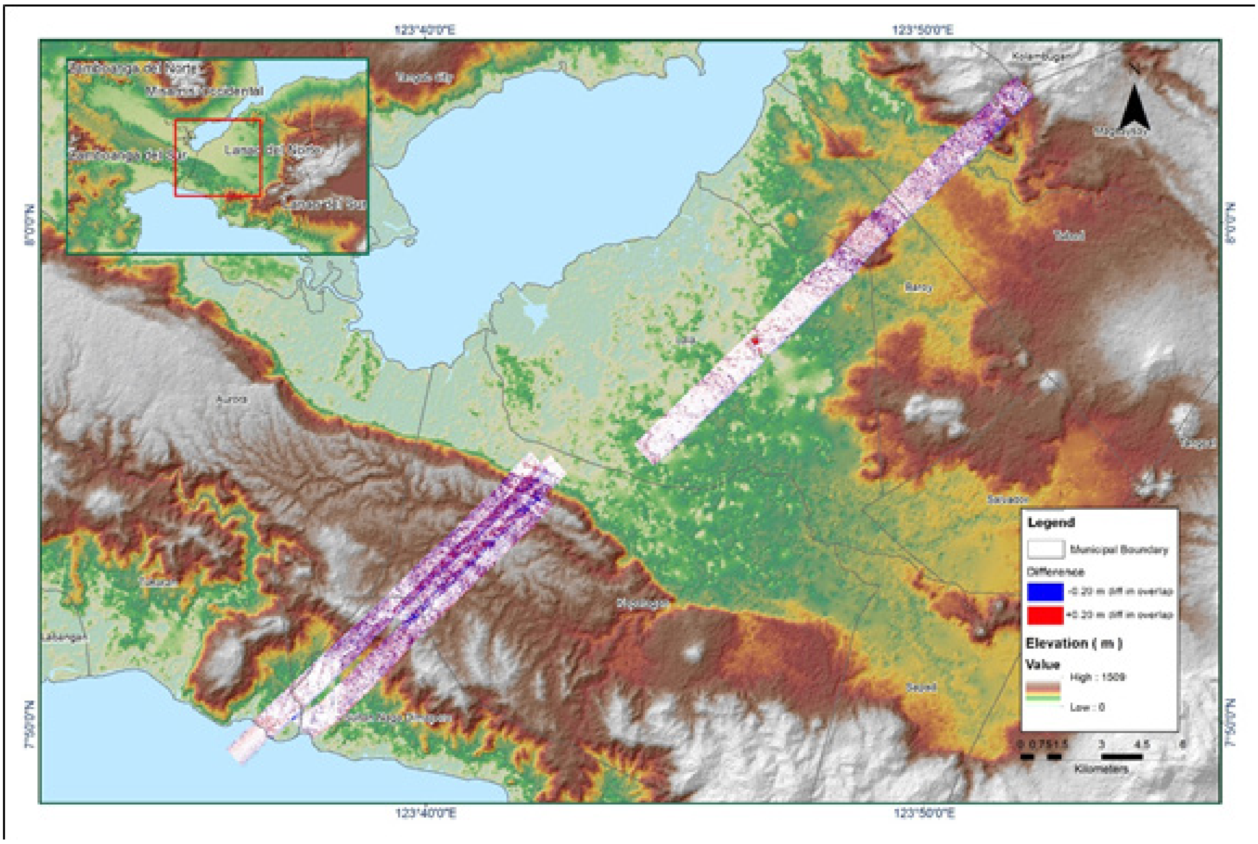


Figure A-8.21. Elevation difference between flight lines

Flight Area	Pagadian
Mission Name	76M
Inclusive Flights	23128P
Range data size	23.3
POS data size	273
Base data size	44.4
Image	n/a
Transfer date	
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	No
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.4
RMSE for East Position (<4.0 cm)	1.9
RMSE for Down Position (<8.0 cm)	4.1
Boresight correction stdev (<0.001deg)	0.000128
IMU attitude correction stdev (<0.001deg)	0.000139
GPS position stdev (<0.01m)	0.0122
Minimum % overlap (>25)	14.01
Ave point cloud density per sq.m. (>2.0)	3.32
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	173
Maximum Height	503.88 m
Minimum Height	67.66 m
Classification (# of points)	
Ground	100,531,253
Low vegetation	60,833,381
Medium vegetation	70,336,602
High vegetation	177,937,163
Building	1,895,317
Orthophoto	No
Processed by	Engr. Jennifer Saguran, Aljon Rie Araneta, Maria Tamsyn Malabanan

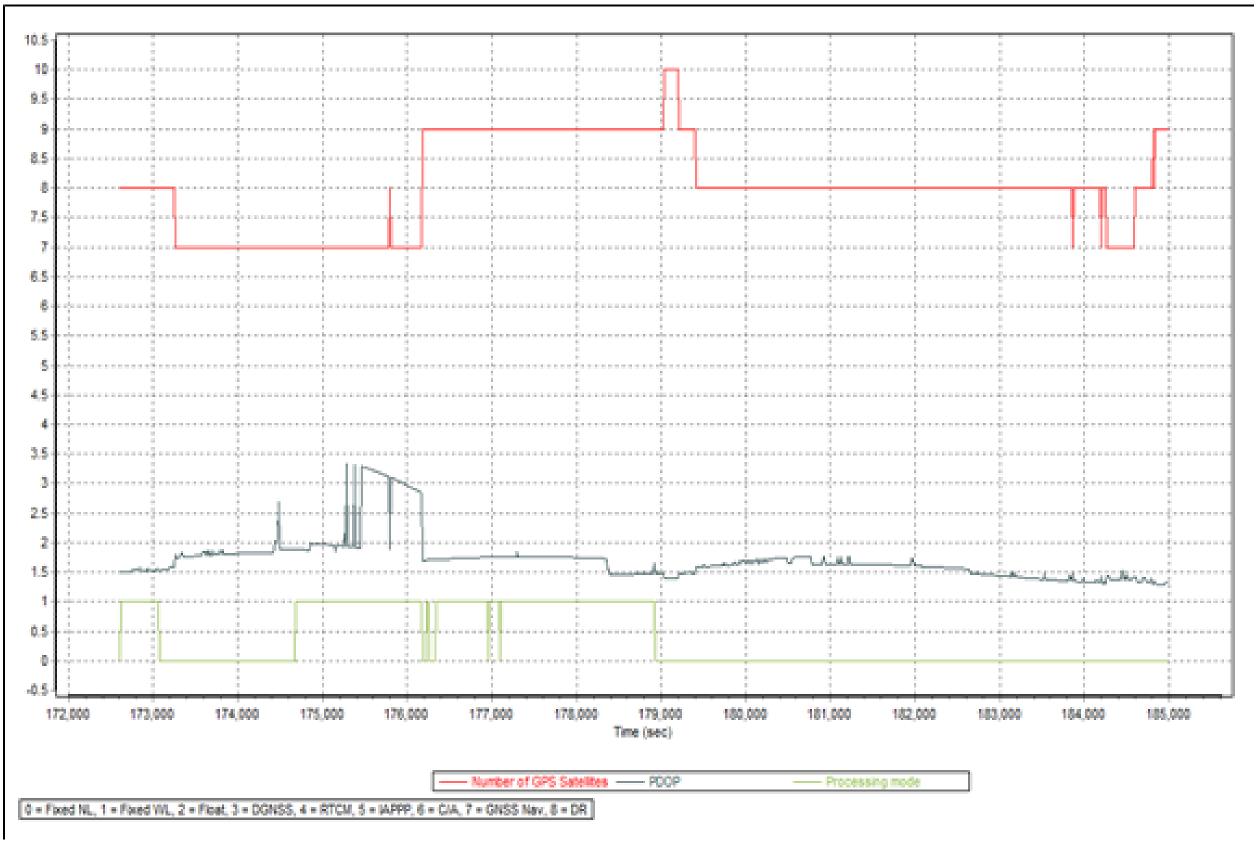


Figure A-8.22. Solution Status

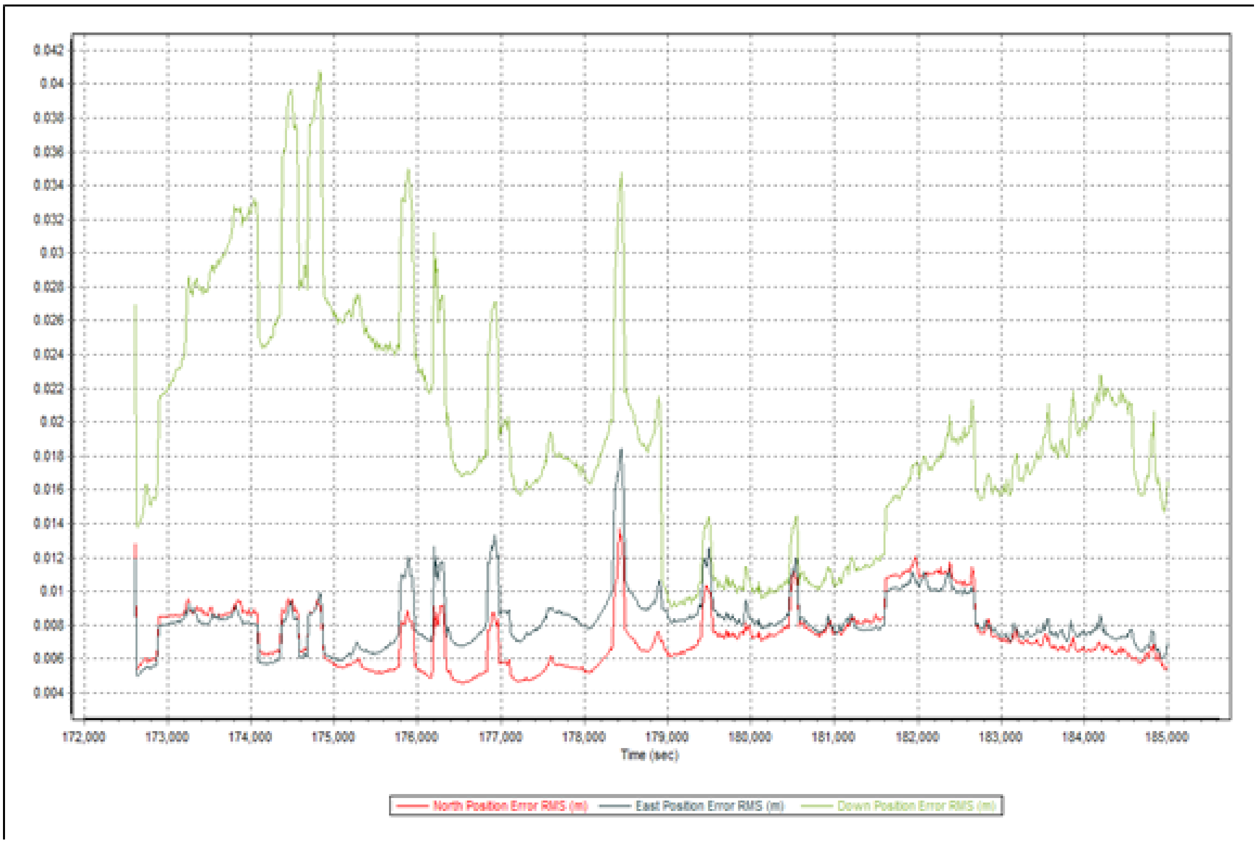


Figure A-8.23. Smoothed Performance Metric Parameters

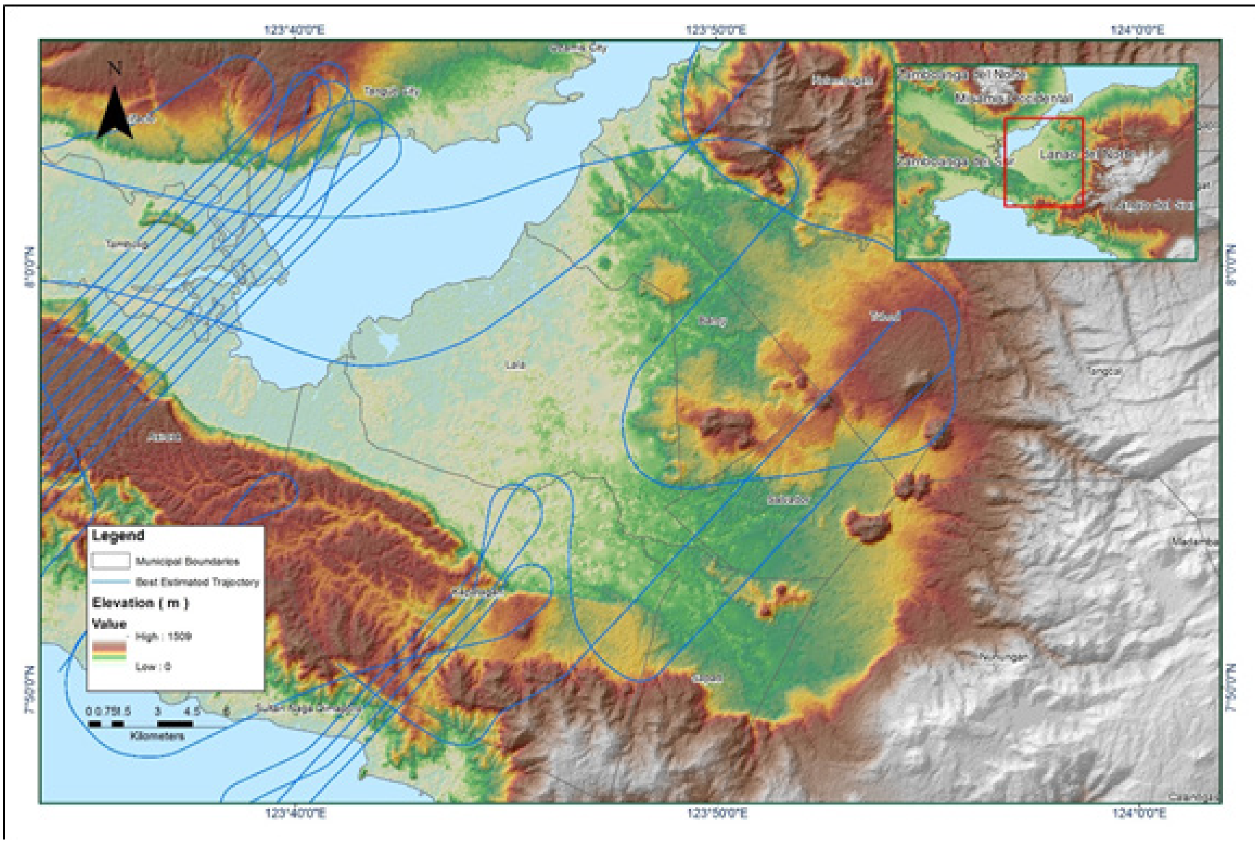


Figure A-8.24. Best Estimated Trajectory

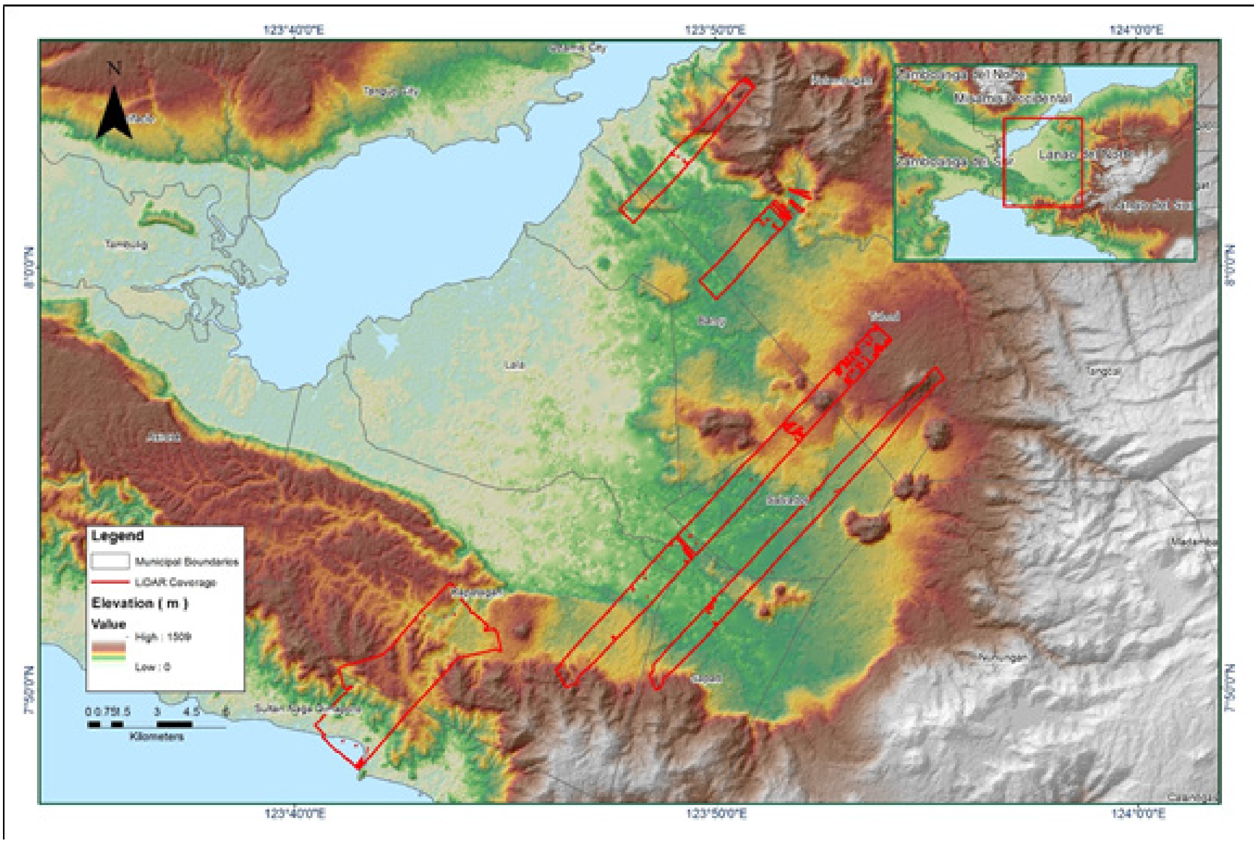


Figure A-8.25. Coverage of LiDAR Data

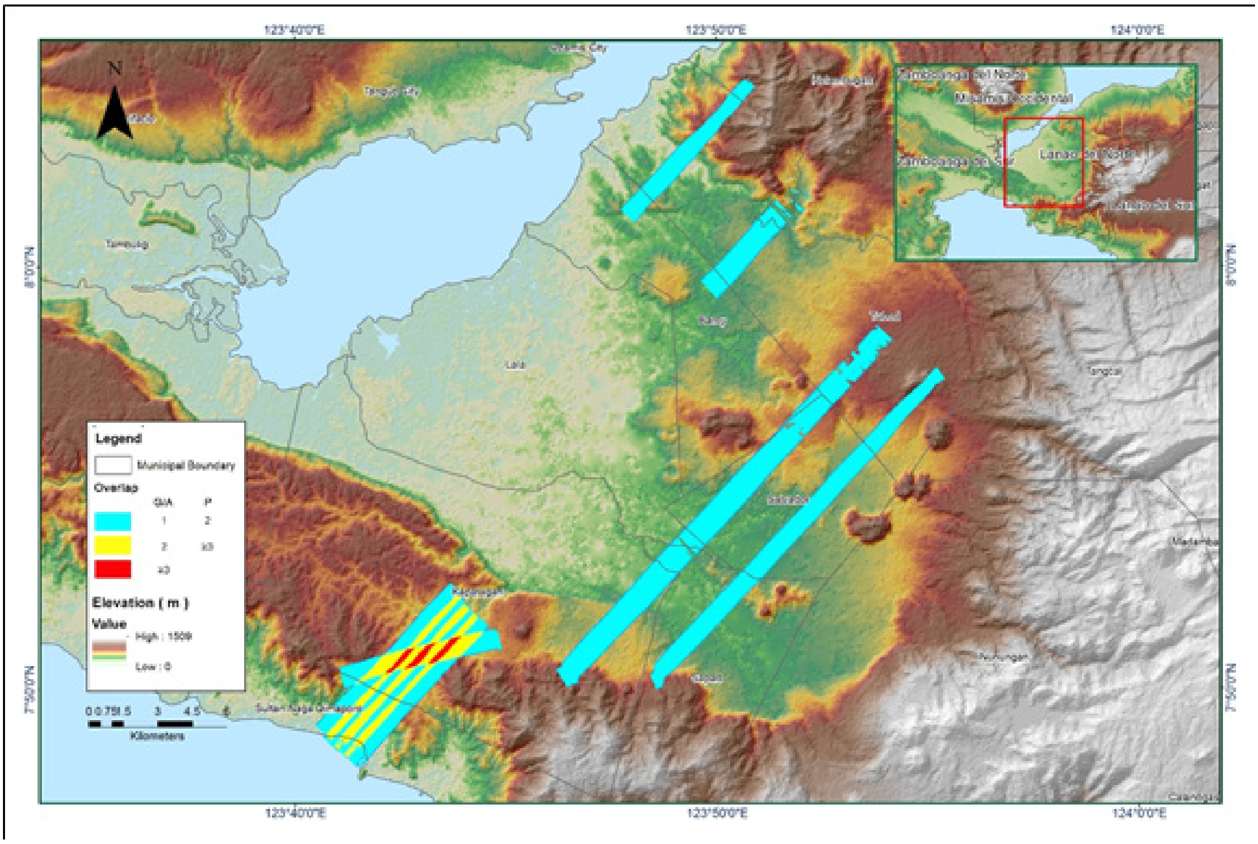


Figure A-8.26. Image of data overlap

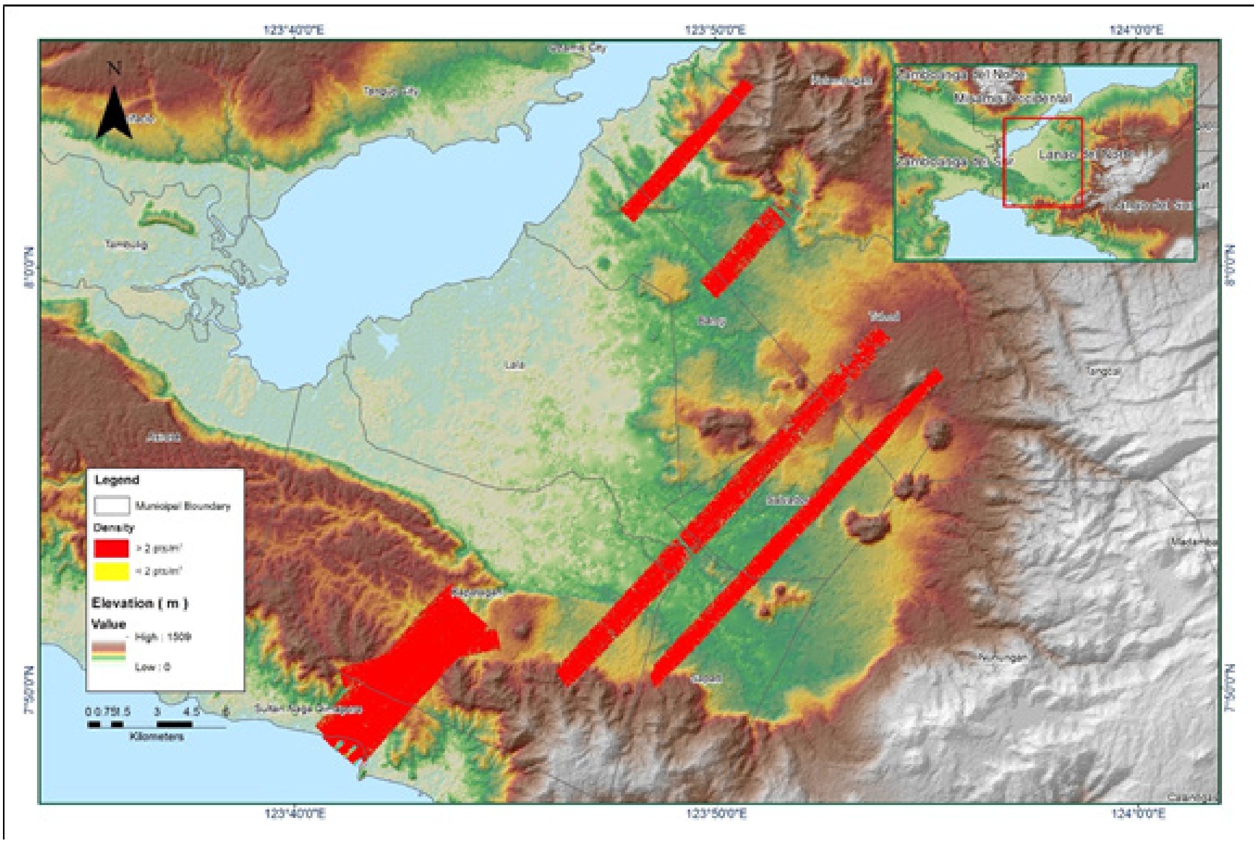


Figure A-8.27. Density map of merged LiDAR data

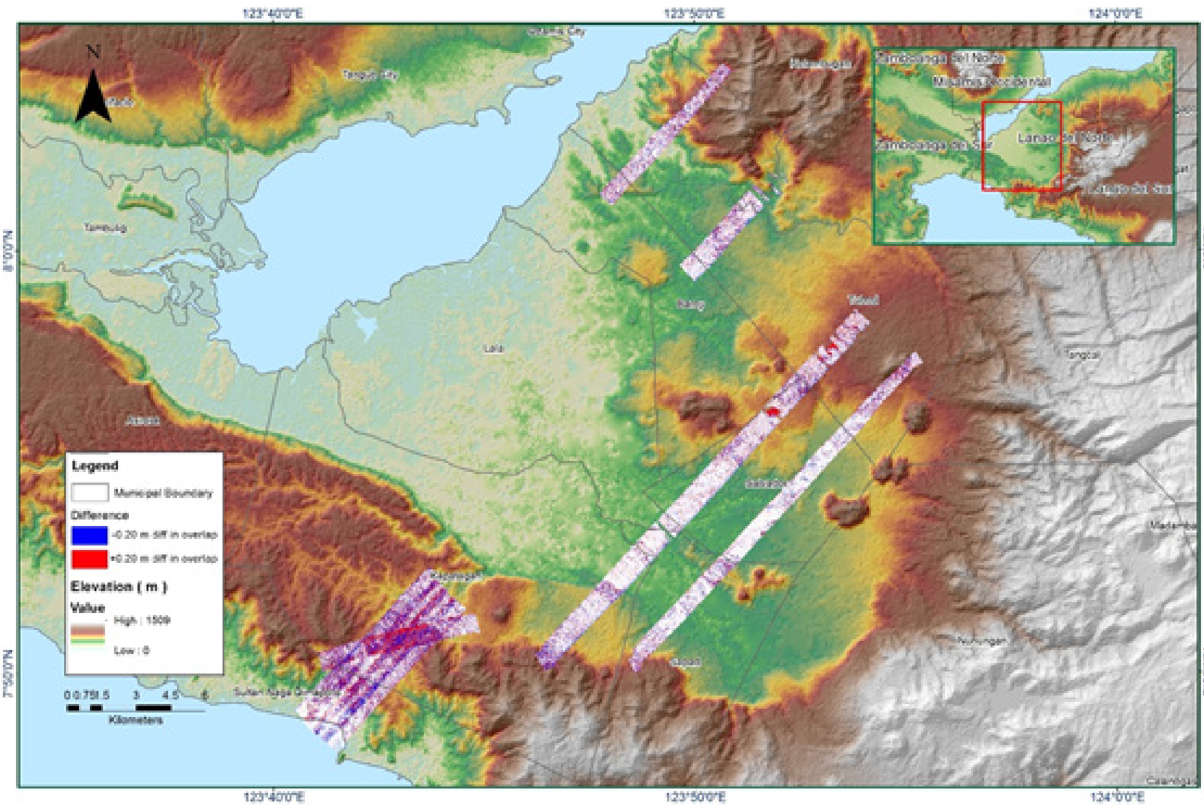


Figure A-8.28 Elevation difference between flight lines

Flight Area	Northern Mindanao
Mission Name	Blk71ABC
Inclusive Flights	1533P, 1541P, 1643P, 1645P, 1685P, 1689P
Range data size	154.85 GB
POS	1369 MB
Image	151.7 GB
Transfer date	August 01, 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)	1.2
RMSE for East Position (<4.0 cm)	1.4
RMSE for Down Position (<8.0 cm)	4.0
Boresight correction stdev (<0.001deg)	0.001254
IMU attitude correction stdev (<0.001deg)	0.001356
GPS position stdev (<0.01m)	0.0252
Minimum % overlap (>25)	50.18%
Ave point cloud density per sq.m. (>2.0)	4.23
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	711
Maximum Height	951.89 m
Minimum Height	65.97 m
Classification (# of points)	
Ground	448,326,038
Low vegetation	554,302,928
Medium vegetation	898,361,476
High vegetation	739,706,375
Building	21,364,020
Orthophoto	YES

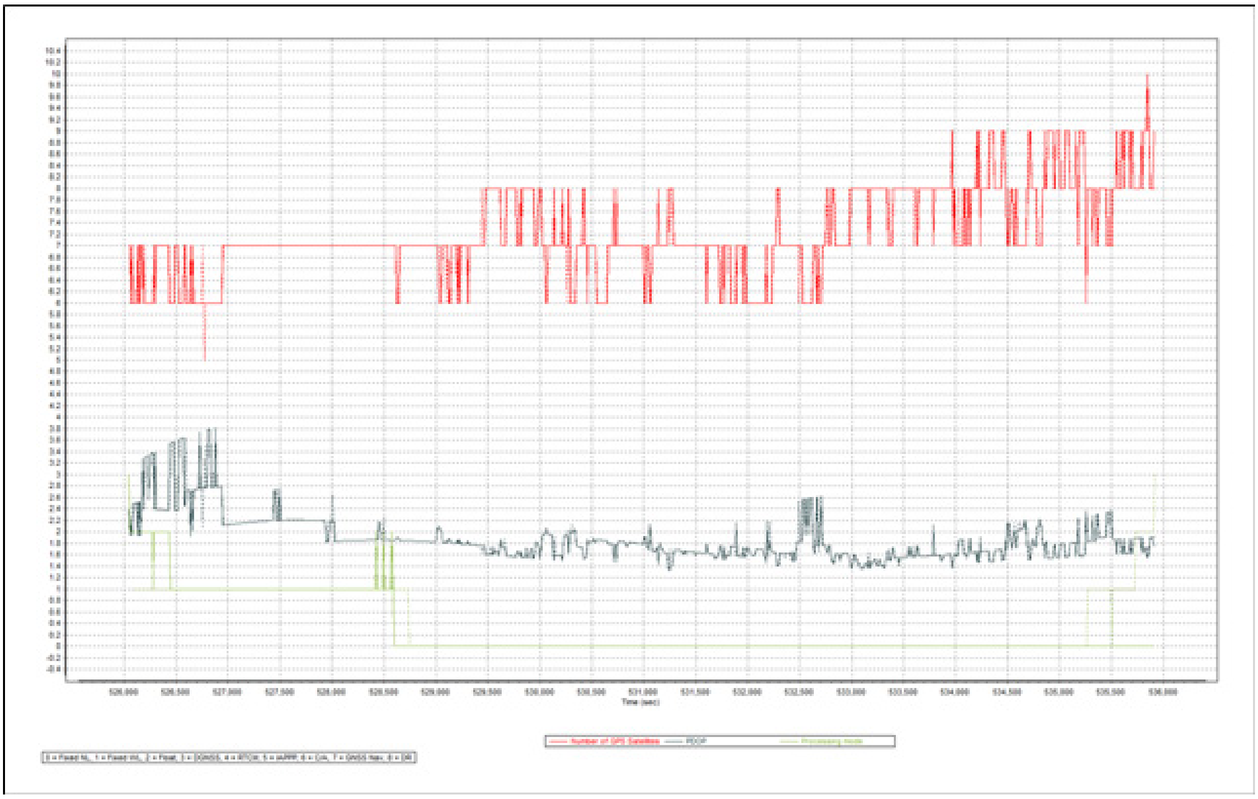


Figure A-8.29 Solution Status

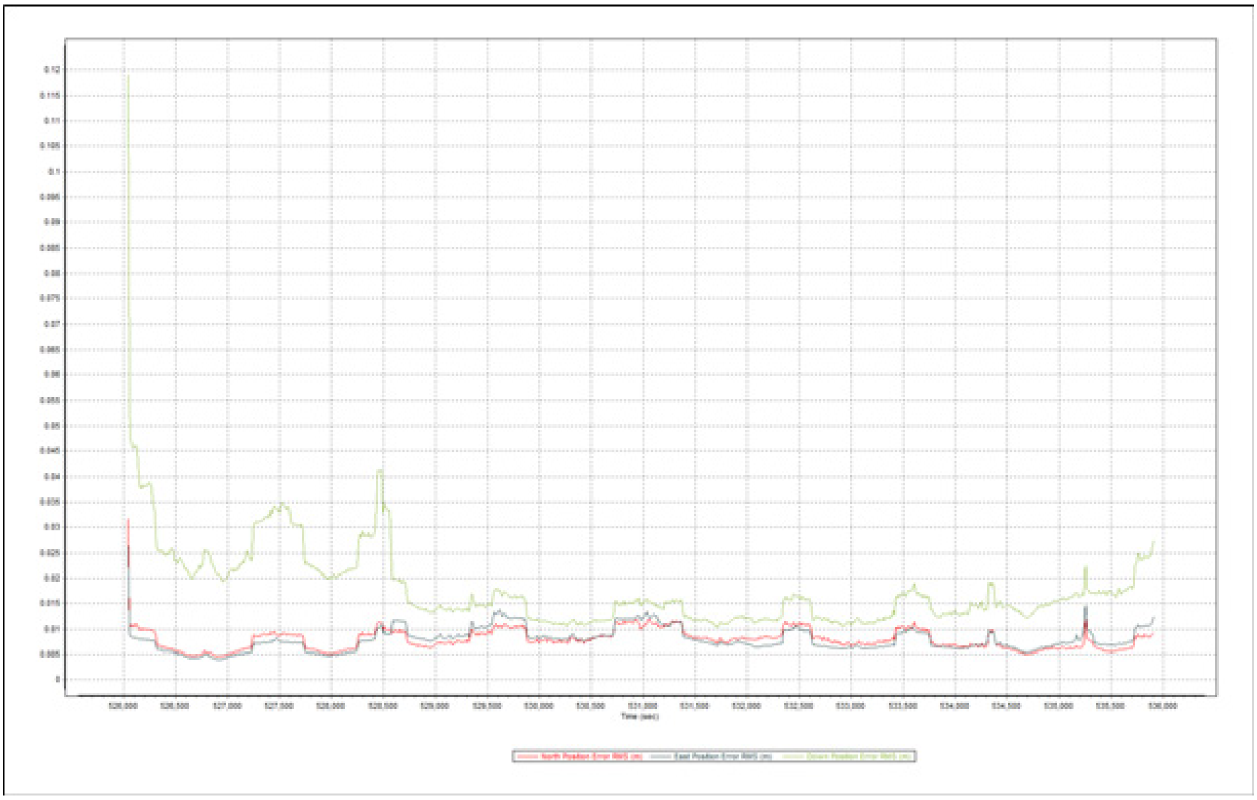


Figure A-8.30 Smoothed Performance Metric Parameters

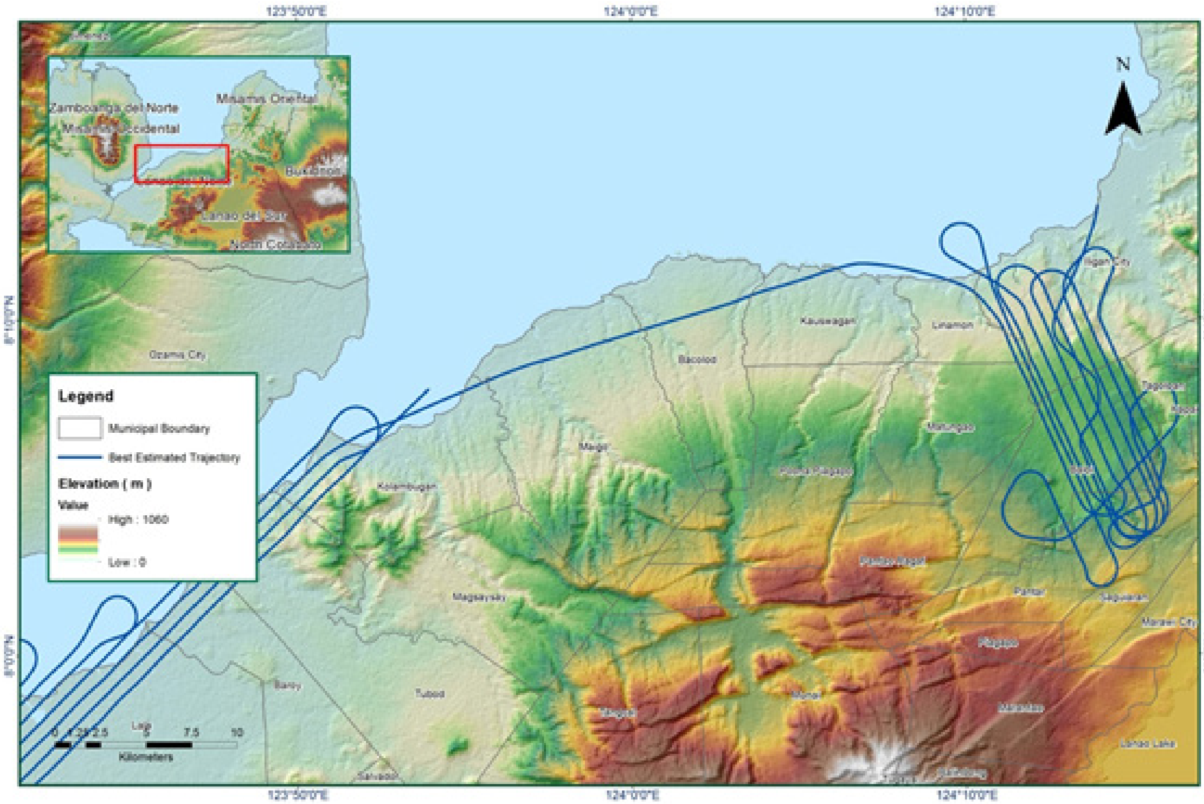


Figure A-8.31 Best Estimated Trajectory

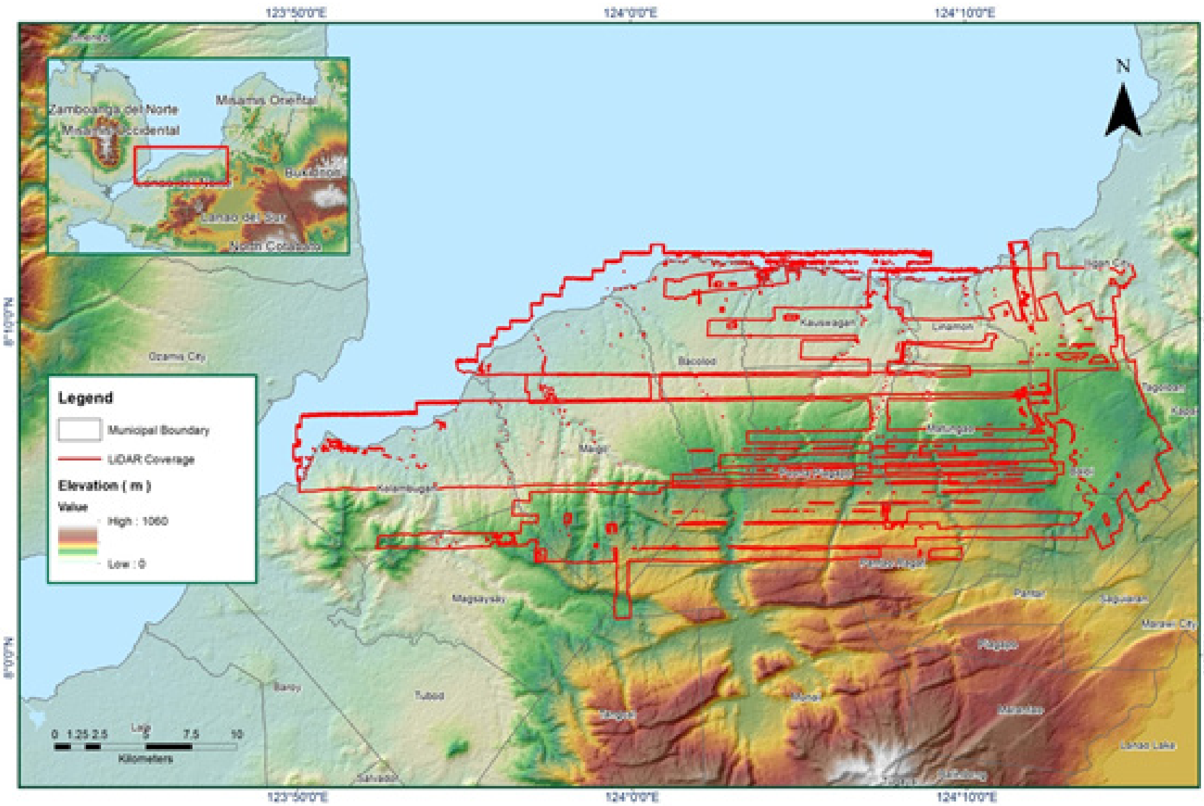


Figure A-8.32 Coverage of LiDAR data

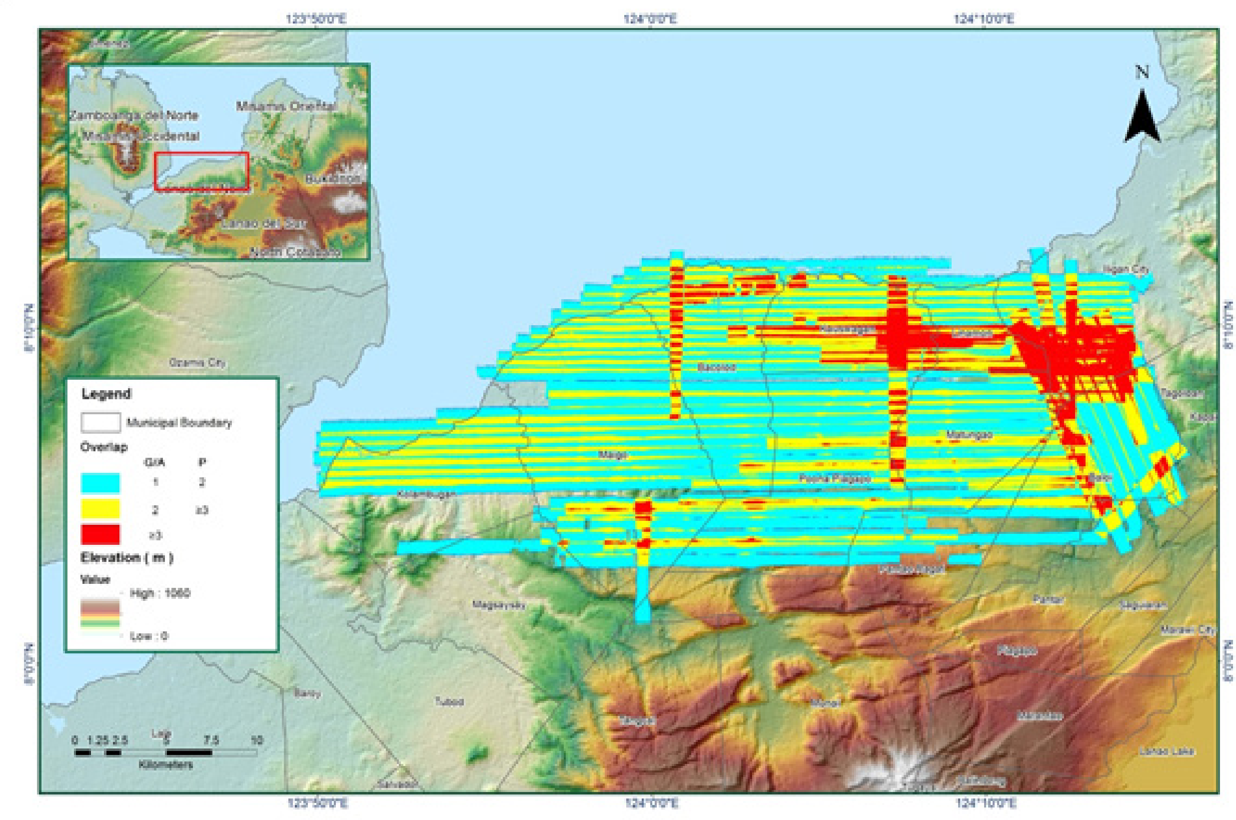


Figure 8.33 Image of data overlap

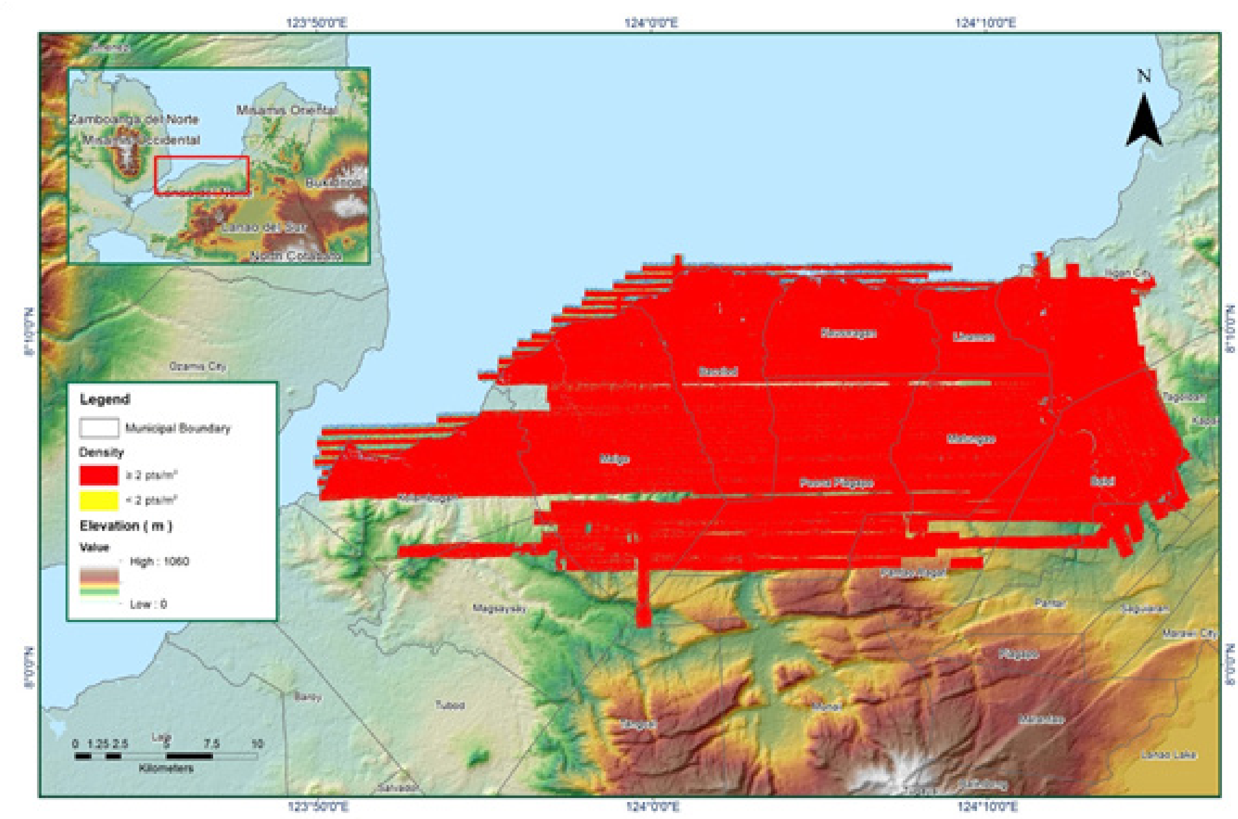


Figure 8.34 Density map of merged LiDAR data

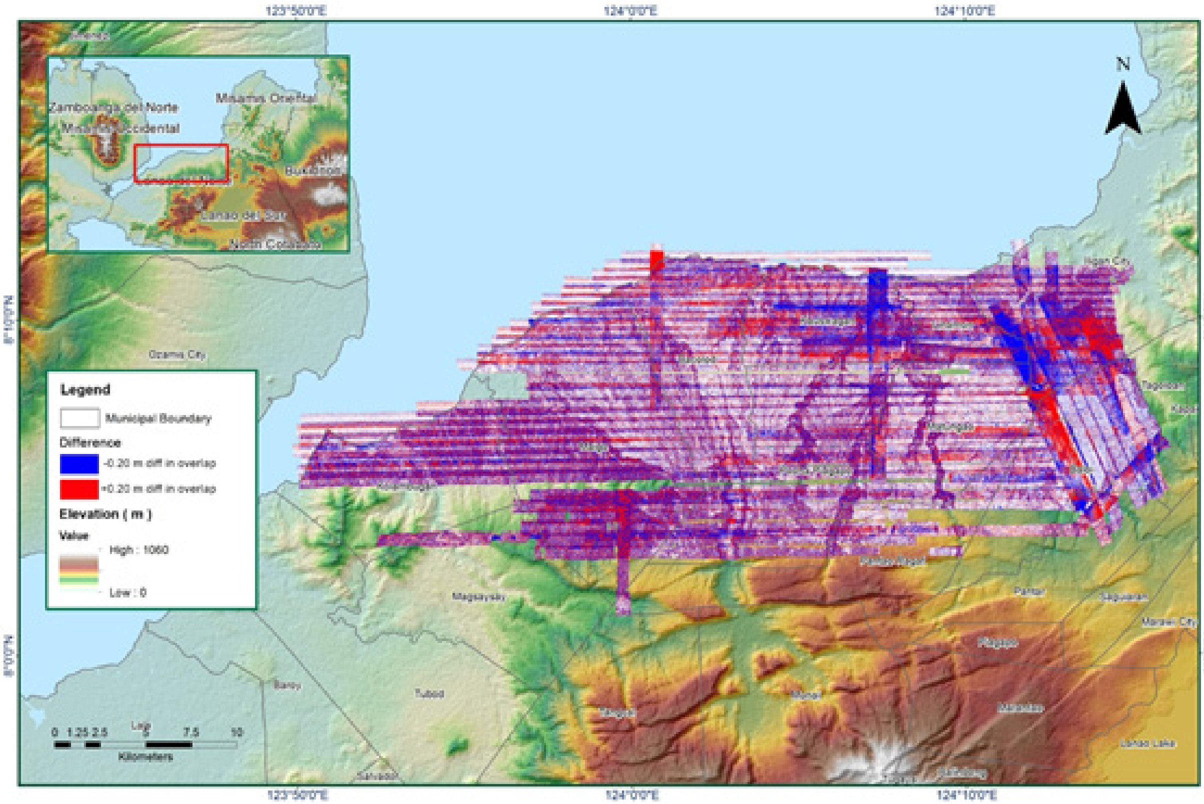


Figure A-8.35 Elevation difference between flight lines

Flight Area	Northern Mindanao
Mission Name	Blk71E
Inclusive Flights	1689P
Range data size	27.1 GB
POS	257 MB
Image	n/a
Transfer date	August 6, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	2.5
RMSE for East Position (<4.0 cm)	5.5
RMSE for Down Position (<8.0 cm)	10
Boresight correction stdev (<0.001deg)	0.000536
IMU attitude correction stdev (<0.001deg)	0.001171
GPS position stdev (<0.01m)	0.0079
Minimum % overlap (>25)	35.35%
Ave point cloud density per sq.m. (>2.0)	2.79
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	253
Maximum Height	476.79
Minimum Height	66.37
Classification (# of points)	
Ground	157,189,225
Low vegetation	118,155,426
Medium vegetation	187,516,392
High vegetation	168,342,412
Building	7,092,549
Orthophoto	NO

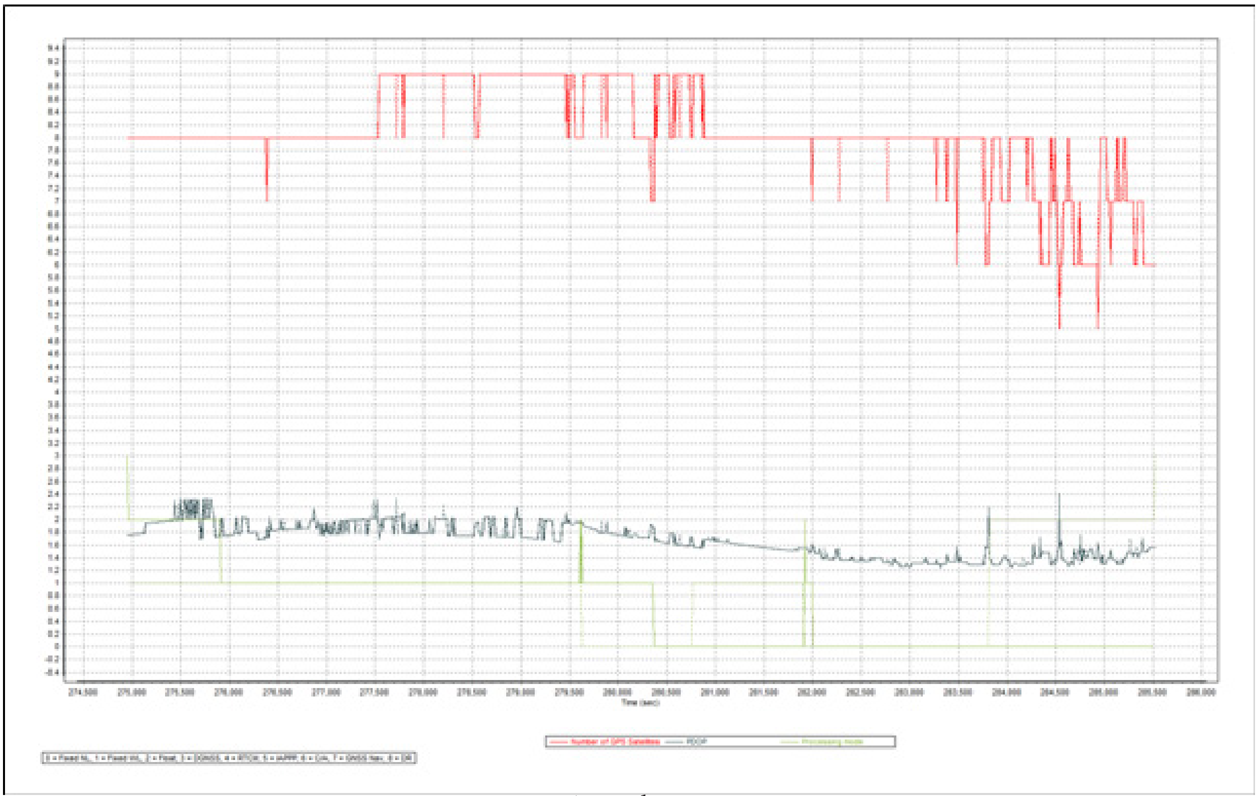


Figure A-36 Solution Status

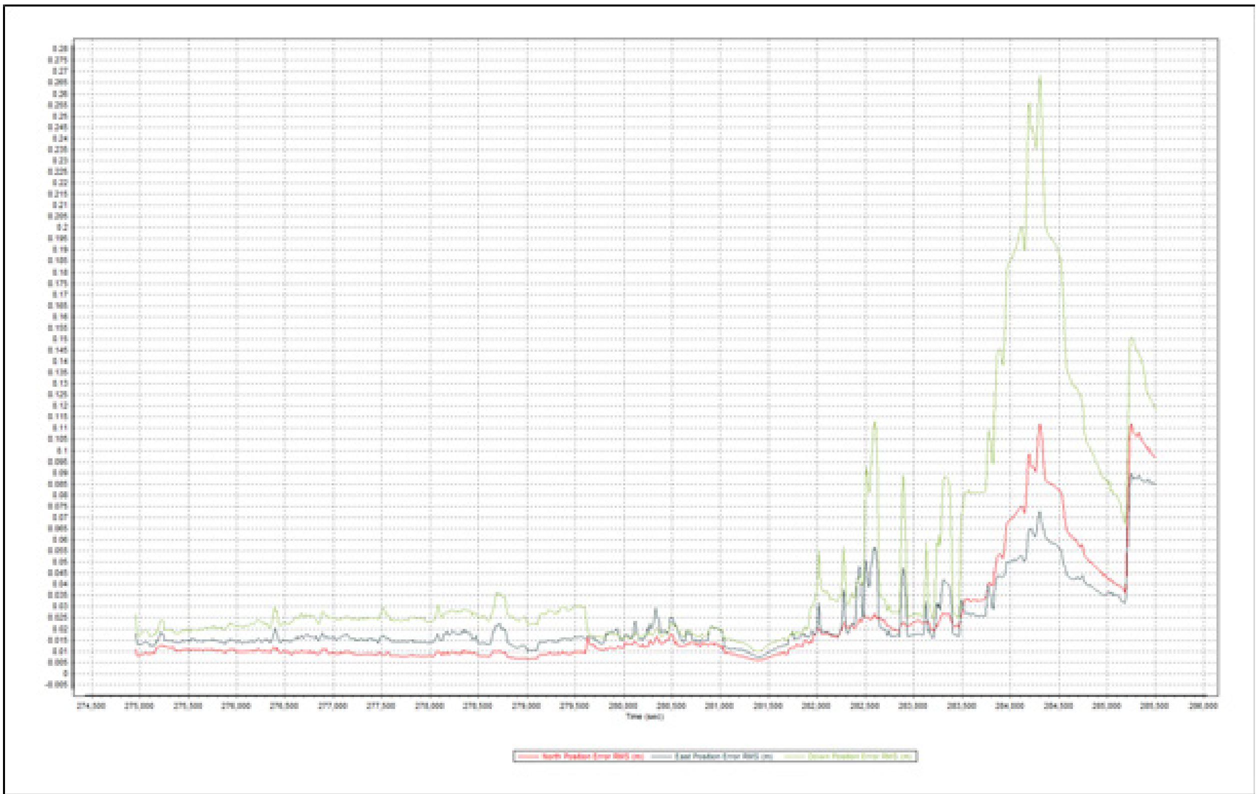


Figure A-37 Smoothed Performance Metric Parameters

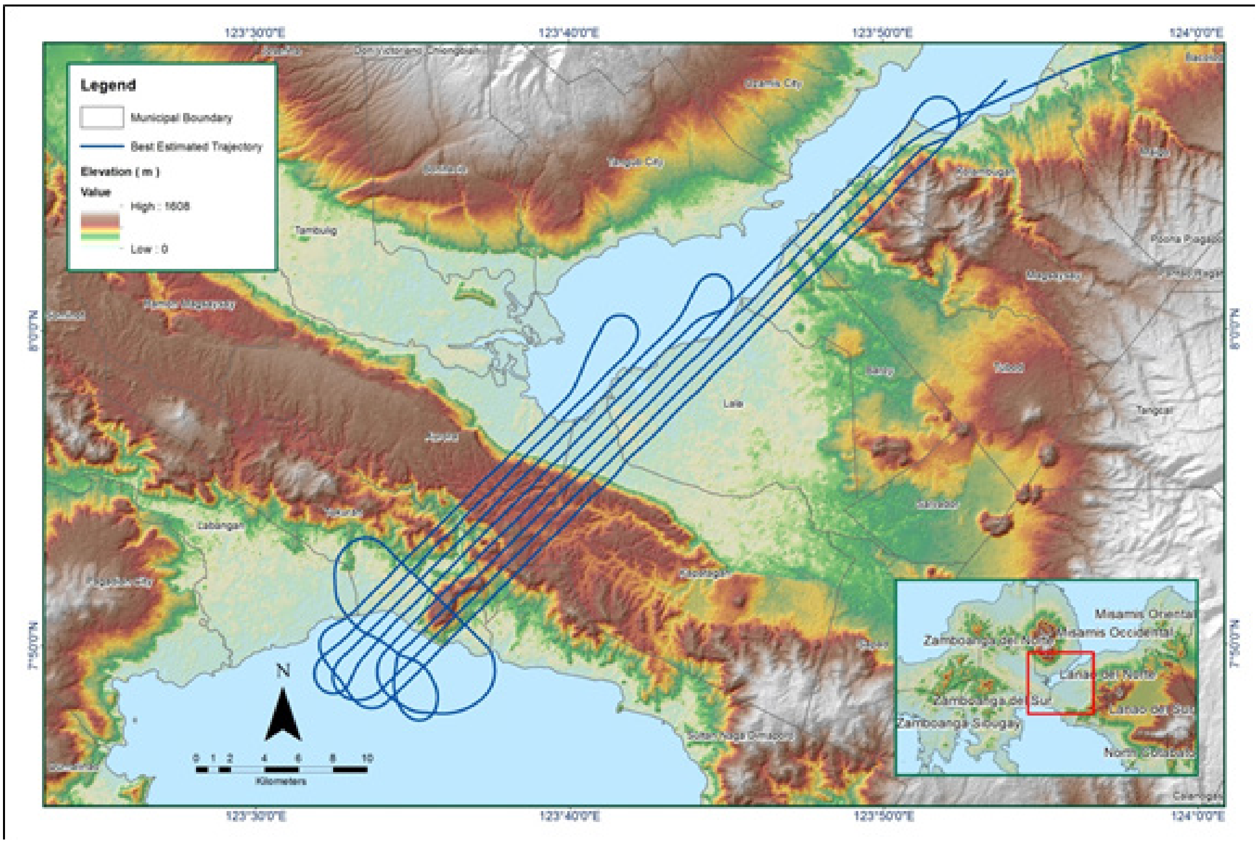


Figure A-38 Best Estimated Trajectory

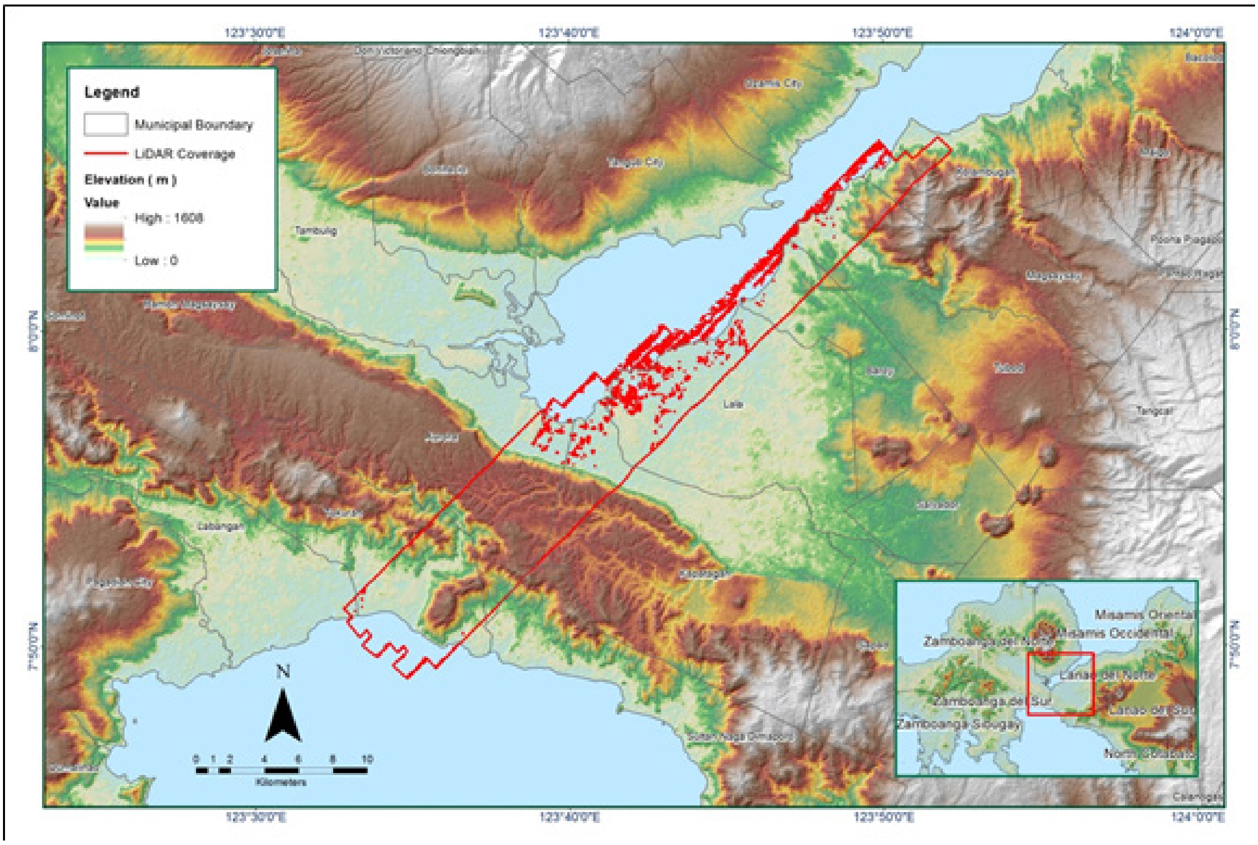


Figure A-39 Coverage of LiDAR data

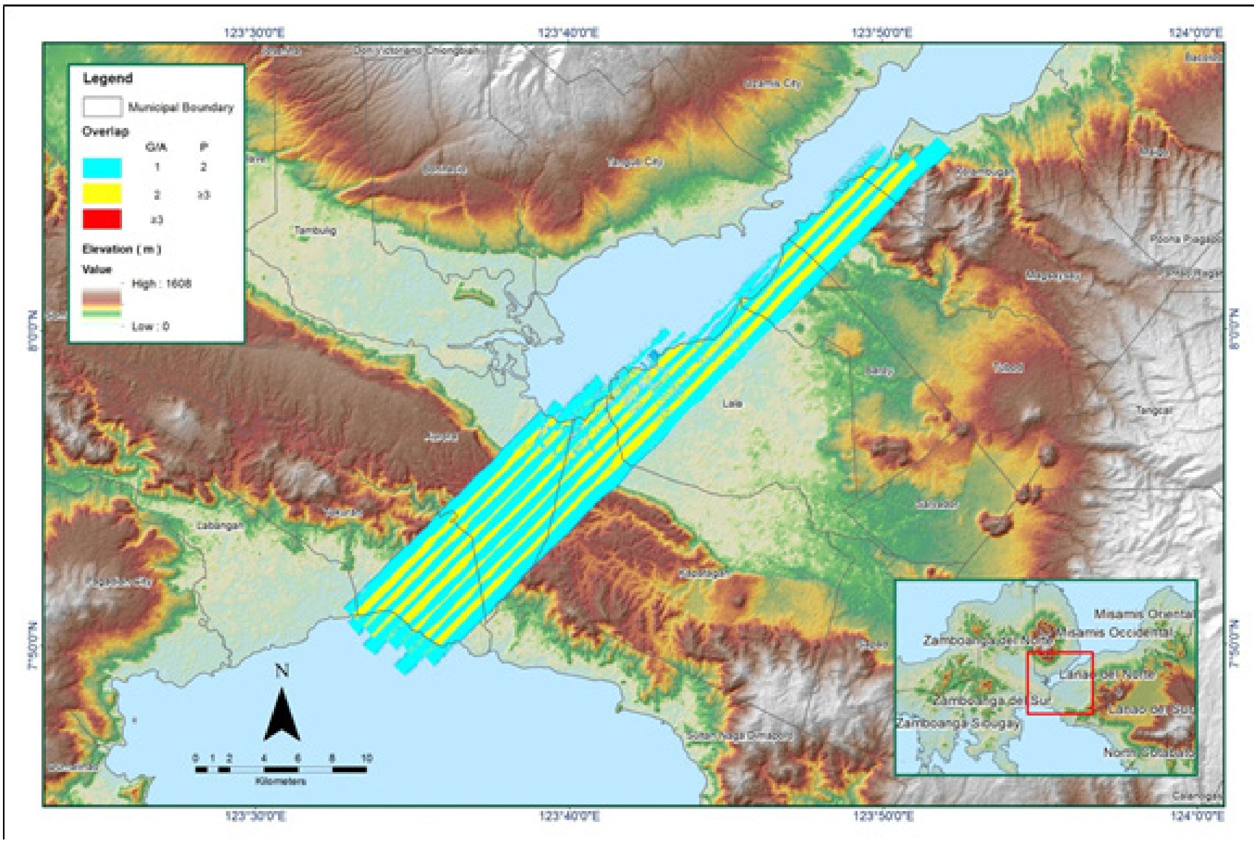


Figure A-40 Image of data overlap

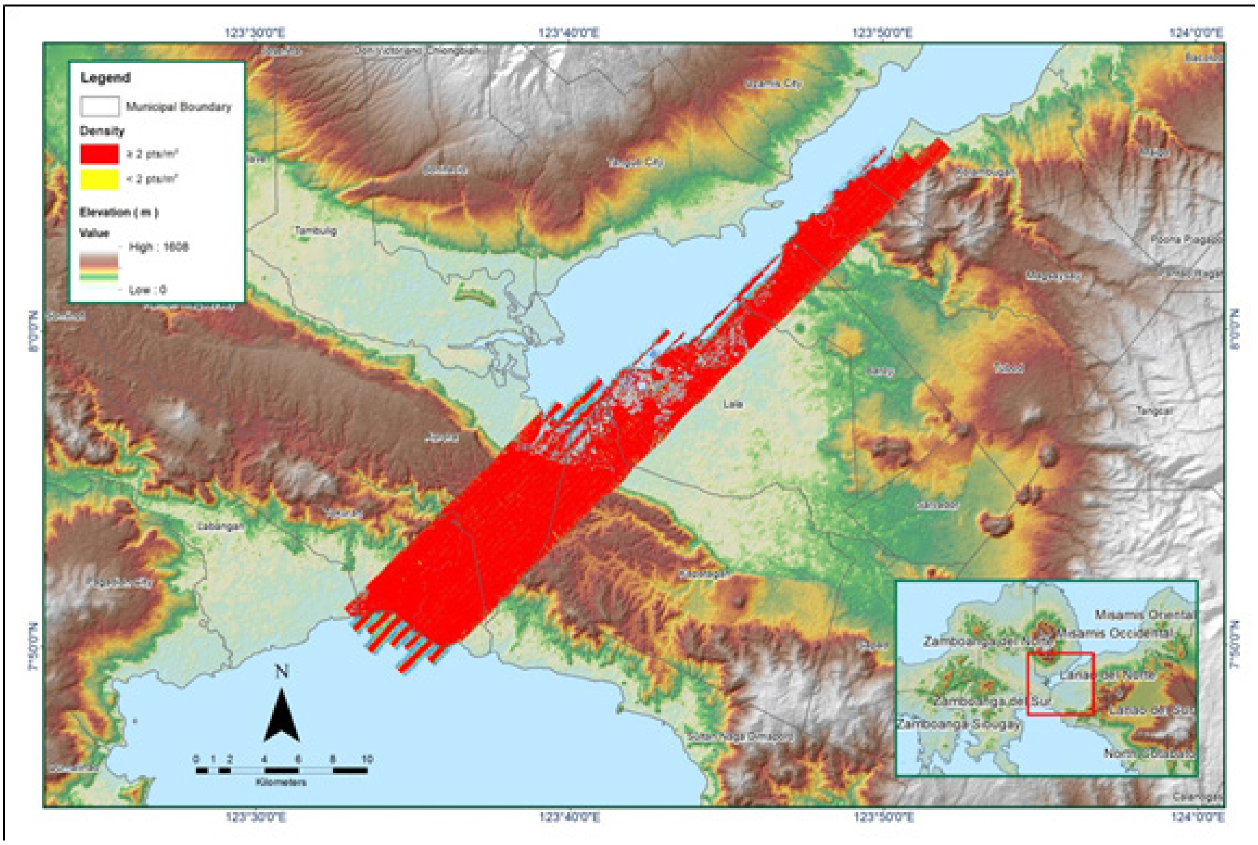


Figure A-41 Density map of merged LiDAR data

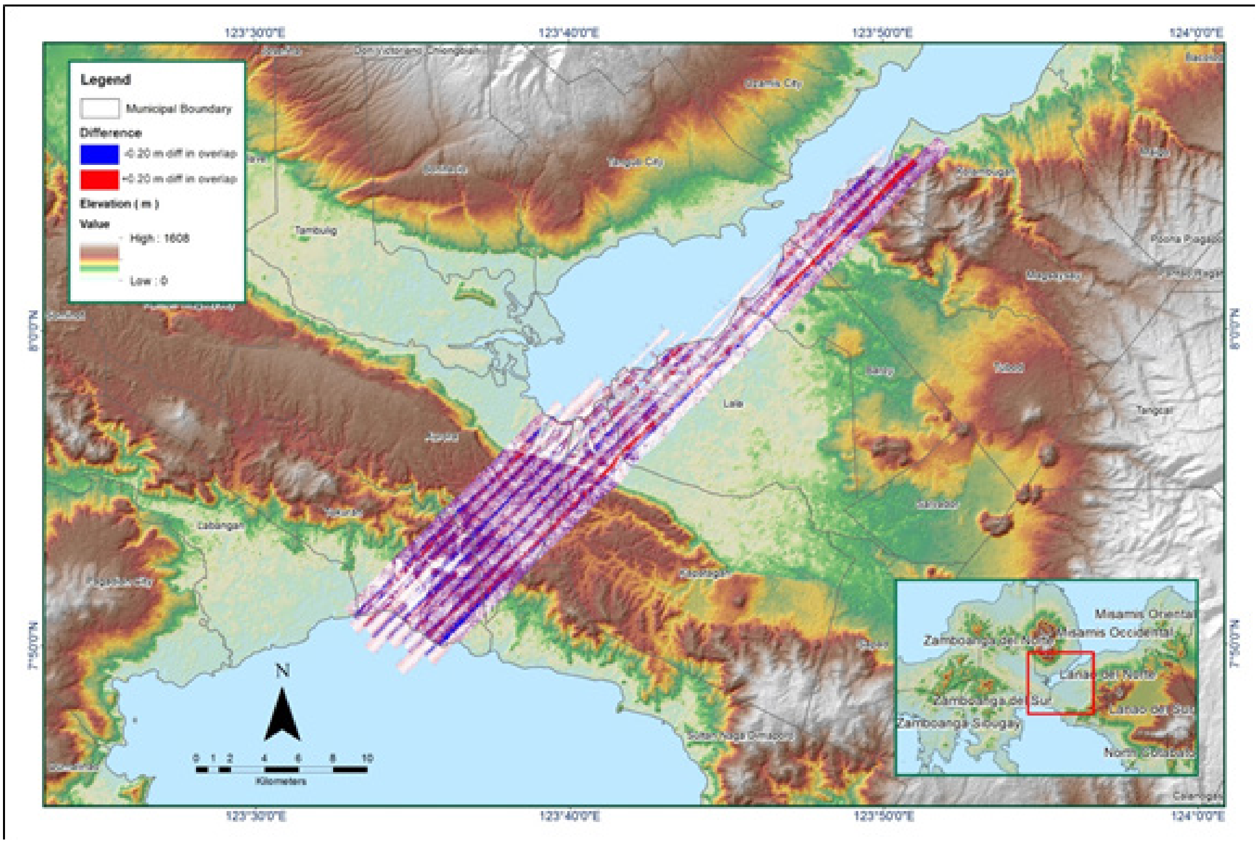


Figure A-42 Elevation difference between flight lines

Flight Area	Northern Mindanao
Mission Name	Blk71F
Inclusive Flights	1565P, 1549P, 1685P
Range data size	70.3 GB
POS	674 MB
Image	59.1 GB
Transfer date	June 23, 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)	1.1
RMSE for East Position (<4.0 cm)	1.1
RMSE for Down Position (<8.0 cm)	3.8
Boresight correction stdev (<0.001deg)	0.000471
IMU attitude correction stdev (<0.001deg)	0.004323
GPS position stdev (<0.01m)	0.0198
Minimum % overlap (>25)	51.56%
Ave point cloud density per sq.m. (>2.0)	4.06
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	614
Maximum Height	685.55
Minimum Height	64.65
Classification (# of points)	
Ground	591,908,481
Low vegetation	609,869,904
Medium vegetation	757,441,192
High vegetation	606,070,790
Building	21,867,436
Orthophoto	Yes

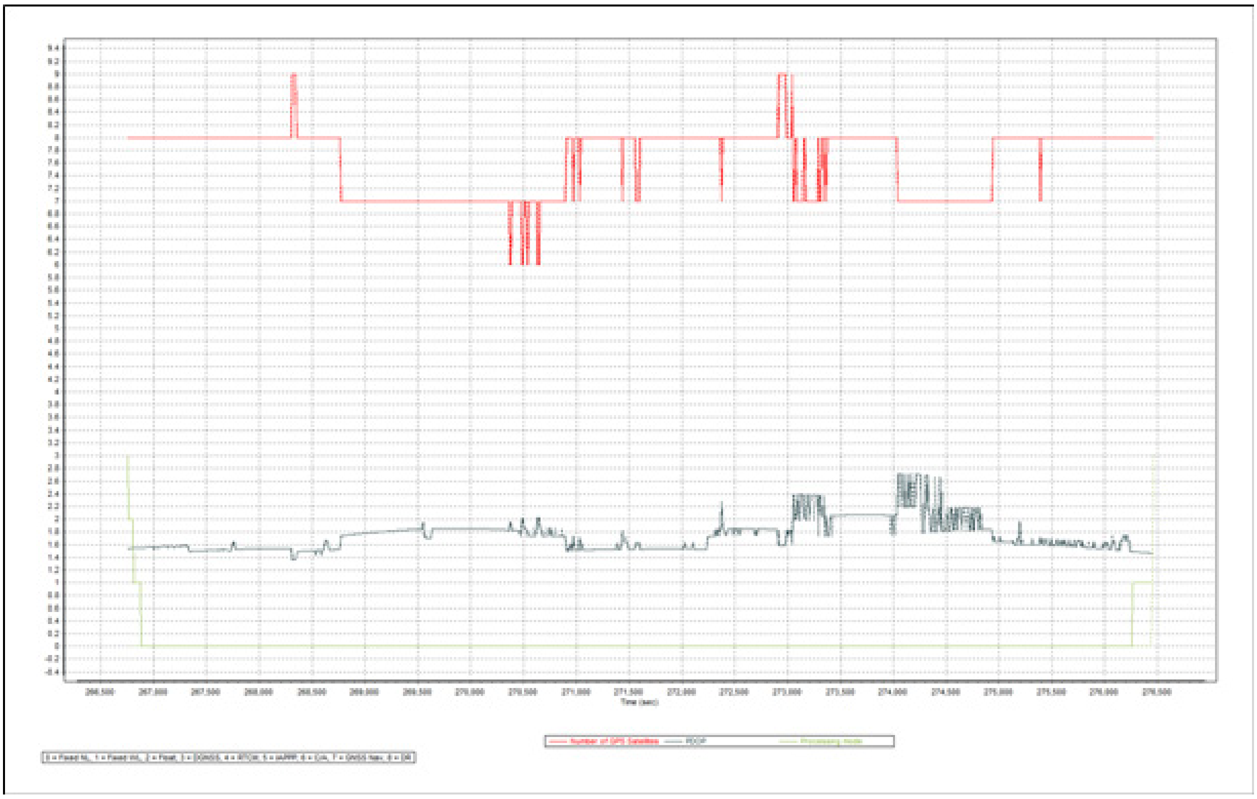


Figure A-43 Solution Status

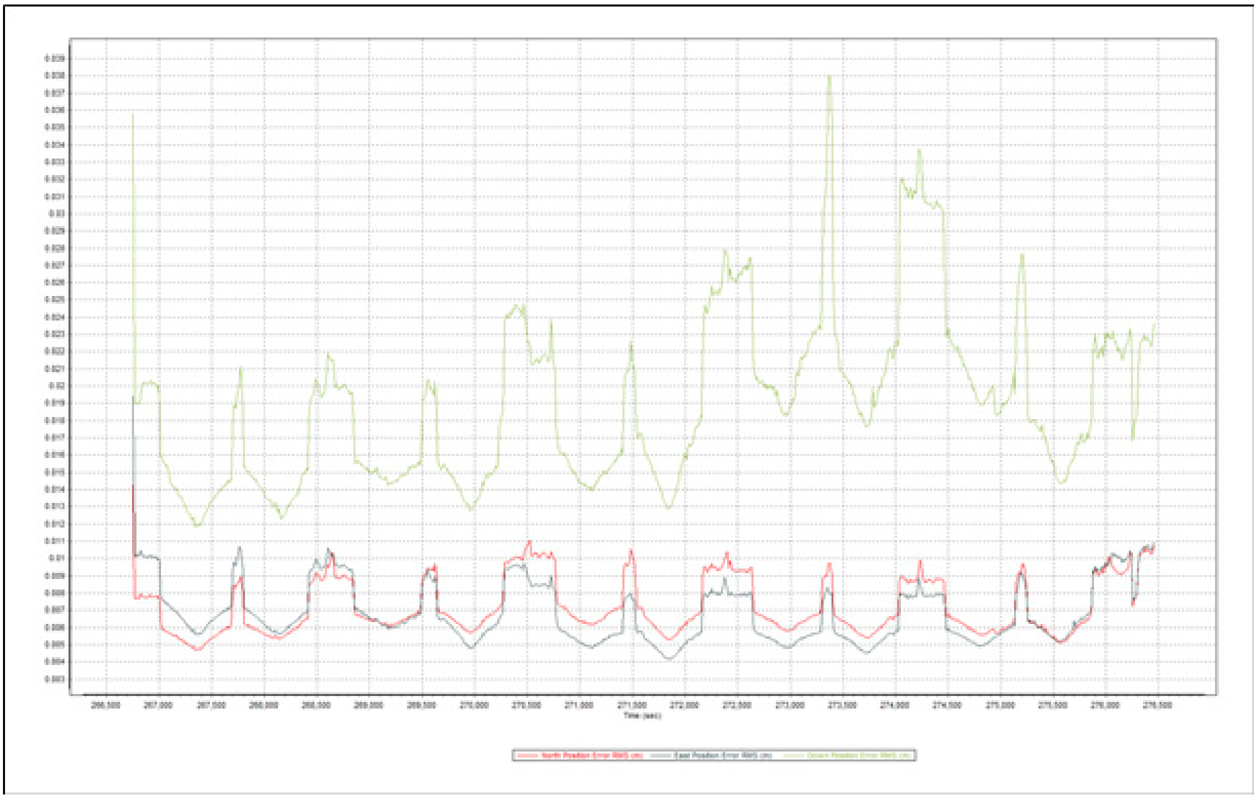


Figure A-44 Smoothed Performance Metric Parameters

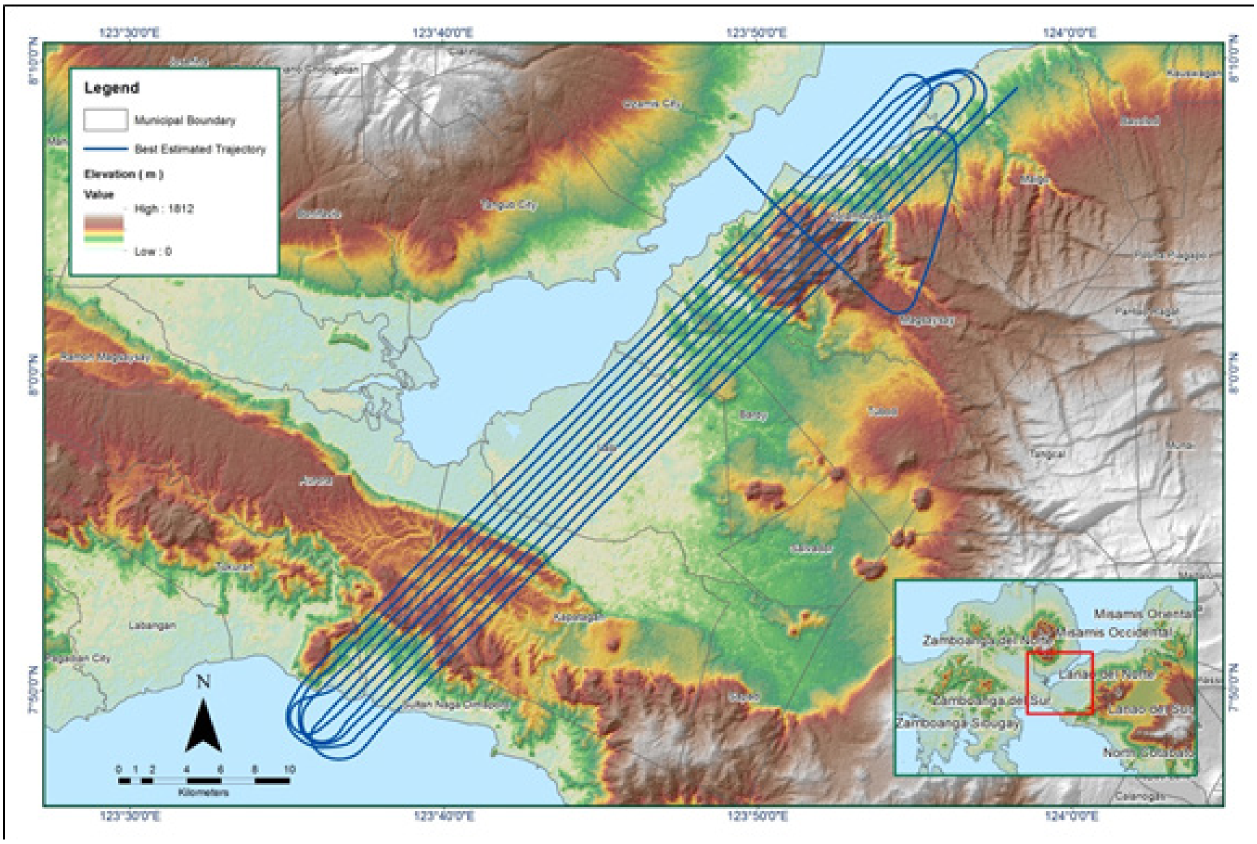


Figure A-45 Best Estimated Trajectory

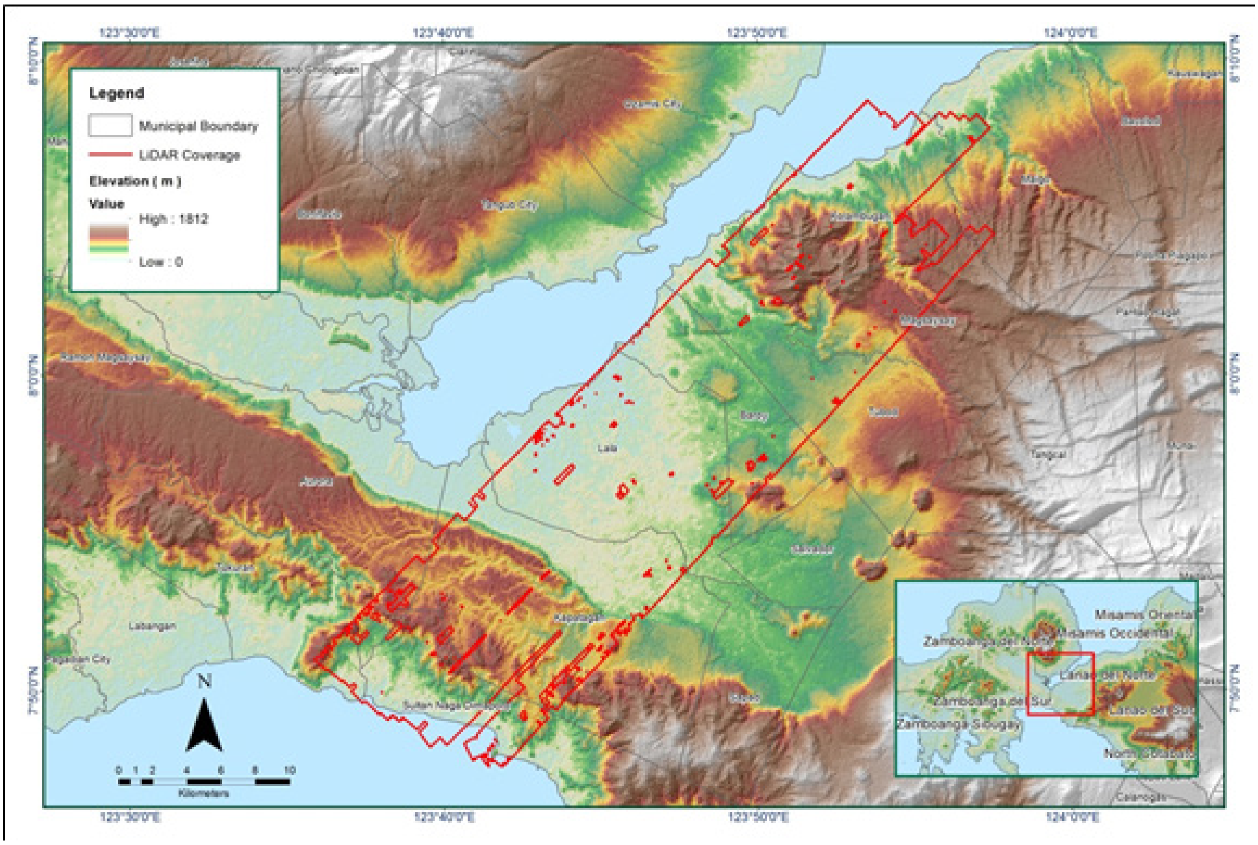


Figure A-46 Coverage of LiDAR data

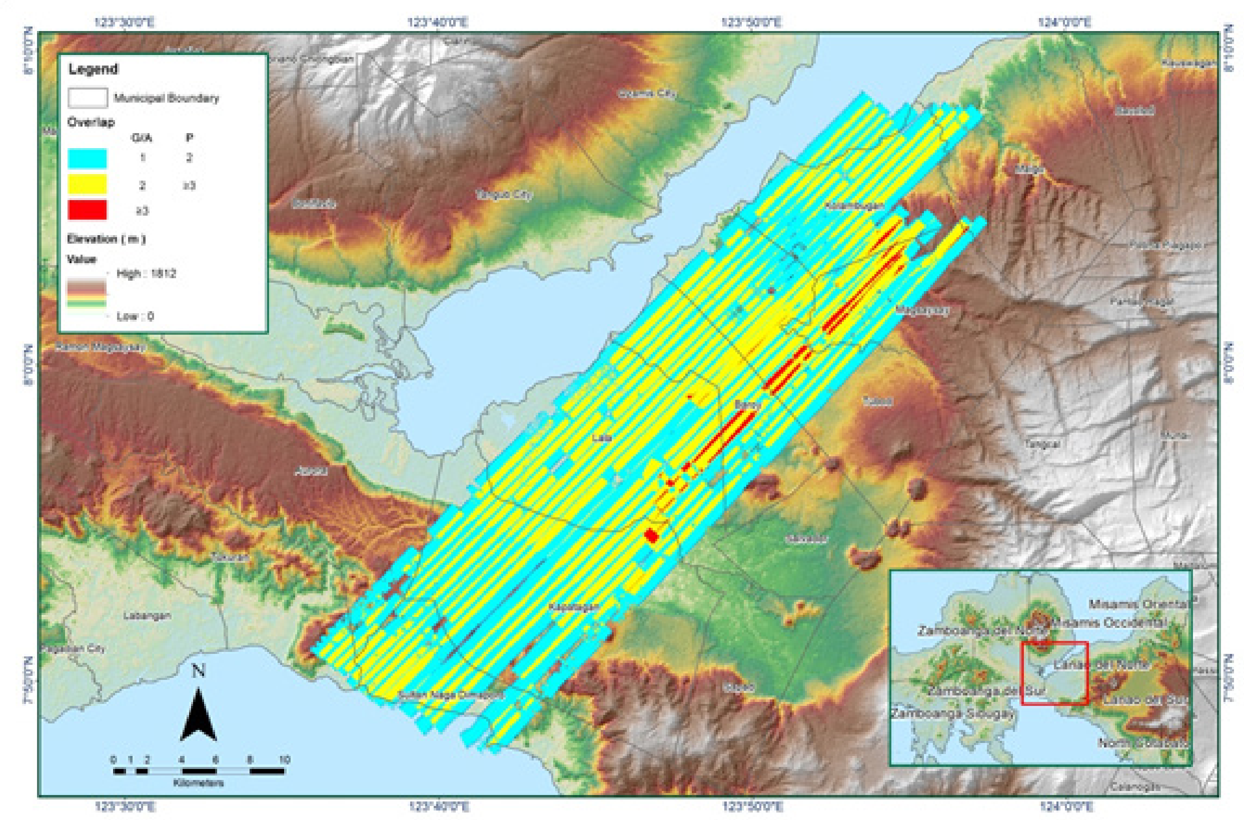


Figure A-47 Image of data overlap

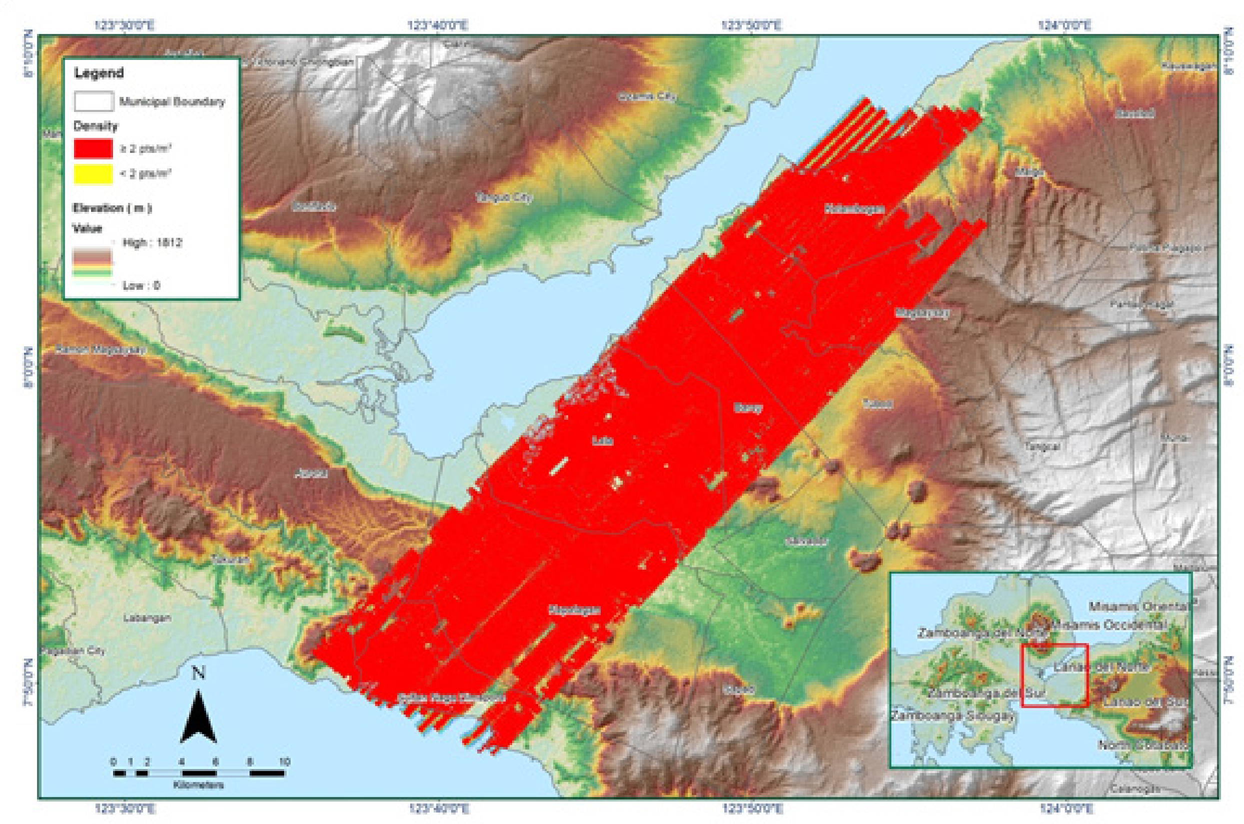


Figure A-48 Density map of merged LiDAR data

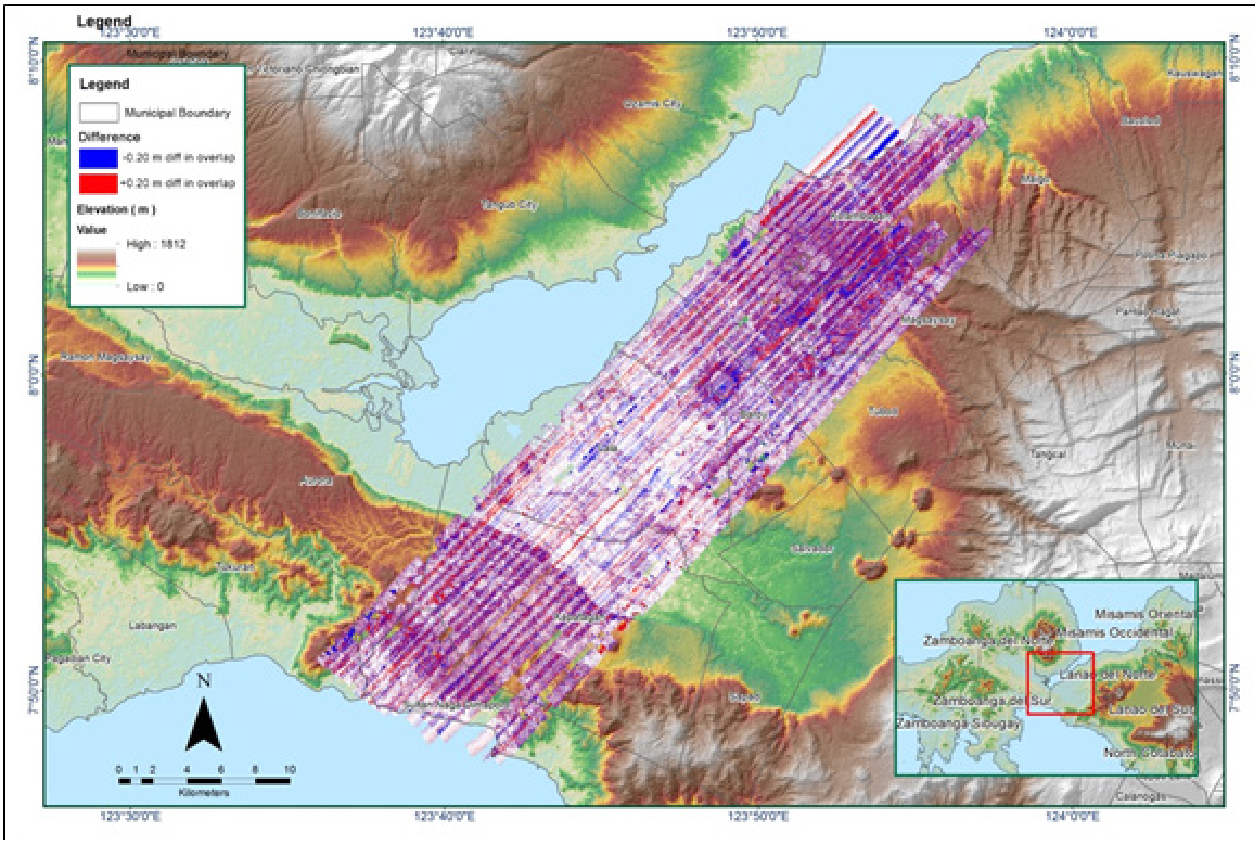


Figure A-49 Elevation difference between flight lines

Annex 9. Bulod Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
W220	4.5623	82.555	0	0.66789	3.5331	Discharge	0.37053	1	Ratio to Peak	0.35
W230	4.4220	83	0	0.53106	4.3075	Discharge	0.16761	1	Ratio to Peak	0.35
W240	4.8839	81.552	0	2.8891	2.402	Discharge	0.0907980	1	Ratio to Peak	0.35
W250	3.5369	85.924	0	5.6278	4.1183	Discharge	0.16241	1	Ratio to Peak	0.35
W260	3.5538	85.866	0	8.922	14.697	Discharge	0.14746	1	Ratio to Peak	0.35
W270	4.4220	83	0	0.25287	2.1091	Discharge	0.0412688	1	Ratio to Peak	0.35
W280	4.4220	83	0	1.2218	2.9931	Discharge	0.0706966	1	Ratio to Peak	0.35
W290	4.2329	83.608	0	1.2537	4.5257	Discharge	0.19436	1	Ratio to Peak	0.35
W300	4.4220	83	0	1.4463	2.5815	Discharge	0.0256598	1	Ratio to Peak	0.35
W310	4.4865	82.795	0	0.80824	2.0359	Discharge	0.0771014	1	Ratio to Peak	0.35
W320	4.4220	83	0	1.4067	3.9601	Discharge	0.0941021	1	Ratio to Peak	0.35
W330	5.1072	80.870	0	1.4649	2.2228	Discharge	0.14084	1	Ratio to Peak	0.35
W340	4.4984	82.757	0	0.5376	2.9058	Discharge	0.24457	1	Ratio to Peak	0.35
W350	4.7133	82.081	0	0.41324	5.0189	Discharge	0.36189	1	Ratio to Peak	0.35
W360	4.4220	83	0	0.56474	4.1153	Discharge	0.21407	1	Ratio to Peak	0.35
W370	3.7584	85.173	0	1.8927	2.0876	Discharge	0.0829771	1	Ratio to Peak	0.35
W380	4.4475	82.919	0	1.5505	1.6952	Discharge	0.0427744	1	Ratio to Peak	0.35
W390	6.8831	75.826	0	1.0465	1.7245	Discharge	0.15072	1	Ratio to Peak	0.35
W400	7.0717	75.327	0	1.5219	1.706	Discharge	0.25688	1	Ratio to Peak	0.35
W410	7.8639	73.301	0	0.92503	2.3217	Discharge	0.0868631	1	Ratio to Peak	0.35
W420	7.0553	75.370	0	2.5538	6.2776	Discharge	0.30558	1	Ratio to Peak	0.35

Annex 10. Bulod Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R10	Automatic Fixed Interval	4947.6	0.0175725	0.035	Trapezoid	13.75	1
R110	Automatic Fixed Interval	3761.6	0.0148507	0.035	Trapezoid	26.88	1
R120	Automatic Fixed Interval	7285.7	0.0084906	0.035	Trapezoid	20.5375	1
R160	Automatic Fixed Interval	1367.1	0.0285466	0.035	Trapezoid	23.4375	1
R190	Automatic Fixed Interval	3998.2	0.0390923	0.035	Trapezoid	19.61	1
R30	Automatic Fixed Interval	2551.9	0.0031215	0.035	Trapezoid	10.73	1
R50	Automatic Fixed Interval	1313.0	0.0082618	0.035	Trapezoid	8.02	1
R60	Automatic Fixed Interval	3691.9	0.0071300	0.035	Trapezoid	17.2325	1
R70	Automatic Fixed Interval	2117.2	0.0068946	0.035	Trapezoid	20.12	1
R90	Automatic Fixed Interval	1988.9	0.0058421	0.035	Trapezoid	11.21	1

Annex 11. Bulod Field Validation

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Lat	Long					
1	8.050438	123.803342	0.03	0.60	-0.570	Typhoon Nina / Dec. 23, 2016	5 - Year
2	8.051090	123.801080	0.11	0.30	-0.190	Typhoon Nina / Dec. 23, 2016	5 - Year
3	8.048035	123.811059	2.61	0.00	2.607	Typhoon Nina / Dec. 23, 2016	5 - Year
4	8.049432	123.807720	2.37	0.00	2.369	Typhoon Nina / Dec. 23, 2016	5 - Year
5	8.053619	123.808143	0.91	1.70	-0.791	Typhoon Nina / Dec. 23, 2016	5 - Year
6	8.054704	123.807846	1.53	2.00	-0.474	Typhoon Nina / Dec. 23, 2016	5 - Year
7	8.056508	123.808043	0.03	0.00	0.031	Typhoon Nina / Dec. 23, 2016	5 - Year
8	8.059649	123.807762	0.80	0.45	0.346	Typhoon Nina / Dec. 23, 2016	5 - Year
9	8.060743	123.806793	0.03	1.50	-1.470	Typhoon Nina / Dec. 23, 2016	5 - Year
10	8.061345	123.805419	0.03	1.50	-1.470	Typhoon Nina / Dec. 23, 2016	5 - Year
11	8.061602	123.804094	0.03	1.20	-1.170	Typhoon Nina / Dec. 23, 2016	5 - Year
12	8.060359	123.808900	0.03	0.90	-0.868	Typhoon Nina / Dec. 23, 2016	5 - Year
13	8.066019	123.809633	0.03	0.00	0.031	Typhoon Nina / Dec. 23, 2016	5 - Year
14	8.058915	123.812891	0.03	0.20	-0.168	Typhoon Nina / Dec. 23, 2016	5 - Year
15	8.057522	123.810084	1.46	1.70	-0.241	Typhoon Nina / Dec. 23, 2016	5 - Year
16	8.057240	123.810046	0.03	0.00	0.030	Typhoon Nina / Dec. 23, 2016	5 - Year
17	8.051978	123.810300	0.03	0.00	0.030	Typhoon Nina / Dec. 23, 2016	5 - Year
18	8.047382	123.789264	0.30	1.60	-1.296	Typhoon Nina / Dec. 23, 2016	5 - Year
19	8.047848	123.788703	0.34	1.65	-1.307	Typhoon Nina / Dec. 23, 2016	5 - Year
20	8.048320	123.789025	0.19	1.60	-1.411	Typhoon Nina / Dec. 23, 2016	5 - Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Lat	Long					
21	8.042834	123.823193	1.23	2.80	-1.567	Typhoon Nina / Dec. 23, 2016	5 - Year
22	8.064222	123.810687	0.03	0.50	-0.466	Typhoon Nina / Dec. 23, 2016	5 - Year
23	8.066091	123.807842	0.17	0.00	0.174	Typhoon Nina / Dec. 23, 2016	5 - Year
24	8.067053	123.809106	0.19	0.40	-0.215	Typhoon Nina / Dec. 23, 2016	5 - Year
25	8.062274	123.808625	0.08	1.50	-1.416	Typhoon Nina / Dec. 23, 2016	5 - Year
26	8.050421	123.805578	1.22	1.60	-0.378	Typhoon Nina / Dec. 23, 2016	5 - Year
27	8.061956	123.810975	0.86	0.30	0.558	Typhoon Nina / Dec. 23, 2016	5 - Year
28	8.062725	123.811109	1.38	0.90	0.480	Typhoon Nina / Dec. 23, 2016	5 - Year
29	8.059388	123.808490	0.03	0.00	0.031	Typhoon Nina / Dec. 23, 2016	5 - Year
30	8.052150	123.796218	0.03	0.30	-0.268	Typhoon Nina / Dec. 23, 2016	5 - Year
31	8.049245	123.801093	0.20	0.00	0.196	Typhoon Nina / Dec. 23, 2016	5 - Year
32	8.039276	123.801304	0.79	0.00	0.786	Typhoon Nina / Dec. 23, 2016	5 - Year
33	8.041167	123.790961	0.34	0.20	0.137	Typhoon Nina / Dec. 23, 2016	5 - Year
34	8.084494	123.827124	0.03	0.00	0.030	Typhoon Nina / Dec. 23, 2016	5 - Year
35	8.079614	123.821455	0.03	0.00	0.034	Typhoon Nina / Dec. 23, 2016	5 - Year
36	8.074128	123.817010	0.03	0.00	0.030	Typhoon Nina / Dec. 23, 2016	5 - Year
37	8.059509	123.812818	0.03	0.00	0.031	Typhoon Nina / Dec. 23, 2016	5 - Year
38	8.059524	123.813426	1.28	0.45	0.833	Typhoon Nina / Dec. 23, 2016	5 - Year
39	8.053577	123.809309	0.03	0.40	-0.370	Typhoon Nina / Dec. 23, 2016	5 - Year
40	8.049908	123.813705	1.59	0.00	1.588	Typhoon Nina / Dec. 23, 2016	5 - Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Lat	Long					
41	8.049786	123.825779	0.03	0.00	0.031	Typhoon Nina / Dec. 23, 2016	5 - Year
42	8.047737	123.789073	0.22	1.55	-1.333	Typhoon Nina / Dec. 23, 2016	5 - Year
43	8.046627	123.819714	0.61	0.40	0.214	Typhoon Nina / Dec. 23, 2016	5 - Year
44	8.047603	123.794427	0.36	0.00	0.355	Typhoon Nina / Dec. 23, 2016	5 - Year
45	8.046717	123.793254	0.06	1.20	-1.140	Typhoon Nina / Dec. 23, 2016	5 - Year
46	8.041982	123.790010	0.03	0.00	0.030	Typhoon Nina / Dec. 23, 2016	5 - Year
47	8.041089	123.788431	0.12	0.40	-0.277	Typhoon Nina / Dec. 23, 2016	5 - Year
48	8.048108	123.794053	0.50	0.40	0.097	Typhoon Nina / Dec. 23, 2016	5 - Year
49	8.052000	123.796320	0.03	0.20	-0.167	Typhoon Nina / Dec. 23, 2016	5 - Year
50	8.048564	123.795513	0.03	0.00	0.033	Typhoon Nina / Dec. 23, 2016	5 - Year
51	8.046478	123.796530	0.45	1.50	-1.046	Typhoon Nina / Dec. 23, 2016	5 - Year
52	8.045414	123.798231	0.36	0.45	-0.092	Typhoon Nina / Dec. 23, 2016	5 - Year
53	8.044780	123.796106	0.65	0.45	0.197	Typhoon Nina / Dec. 23, 2016	5 - Year
54	8.044970	123.796920	0.94	1.65	-0.713	Typhoon Nina / Dec. 23, 2016	5 - Year
55	8.044768	123.798213	1.06	0.00	1.058	Typhoon Nina / Dec. 23, 2016	5 - Year
56	8.043500	123.798449	1.24	0.90	0.339	Typhoon Nina / Dec. 23, 2016	5 - Year
57	8.042986	123.798853	0.03	0.90	-0.869	Typhoon Nina / Dec. 23, 2016	5 - Year
58	8.040994	123.791995	0.08	0.00	0.082	Typhoon Nina / Dec. 23, 2016	5 - Year
59	8.040314	123.800467	0.04	0.00	0.043	Typhoon Nina / Dec. 23, 2016	5 - Year
60	8.039085	123.798599	0.03	0.10	-0.066	Typhoon Nina / Dec. 23, 2016	5 - Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Lat	Long					
61	8.027760	123.827463	0.07	0.00	0.065	Typhoon Nina / Dec. 23, 2016	5 - Year
62	8.083209	123.824978	0.04	0.00	0.039	Typhoon Nina / Dec. 23, 2016	5 - Year
63	8.082842	123.824846	0.10	0.00	0.104	Typhoon Nina / Dec. 23, 2016	5 - Year
64	8.081979	123.824256	0.03	0.00	0.033	Typhoon Nina / Dec. 23, 2016	5 - Year
65	8.079884	123.821772	0.07	0.00	0.069	Typhoon Nina / Dec. 23, 2016	5 - Year
66	8.064386	123.810902	0.05	0.00	0.047	Typhoon Nina / Dec. 23, 2016	5 - Year
67	8.048813	123.790089	0.03	0.00	0.032	Typhoon Nina / Dec. 23, 2016	5 - Year
68	8.047307	123.819249	0.03	0.00	0.034	Typhoon Nina / Dec. 23, 2016	5 - Year
69	8.051979	123.795792	0.41	0.40	0.010	Typhoon Nina / Dec. 23, 2016	5 - Year
70	8.051863	123.796205	0.03	0.00	0.031	Typhoon Nina / Dec. 23, 2016	5 - Year
71	8.045576	123.798010	0.03	0.30	-0.269	Typhoon Nina / Dec. 23, 2016	5 - Year
72	8.045061	123.796930	0.51	0.00	0.512	Typhoon Nina / Dec. 23, 2016	5 - Year
73	8.045081	123.798354	0.03	0.80	-0.769	Typhoon Nina / Dec. 23, 2016	5 - Year
74	8.044867	123.798260	1.23	1.70	-0.473	Typhoon Nina / Dec. 23, 2016	5 - Year
75	8.044035	123.798258	0.90	0.80	0.104	Typhoon Nina / Dec. 23, 2016	5 - Year
76	8.043731	123.798710	0.19	0.00	0.192	Typhoon Nina / Dec. 23, 2016	5 - Year
77	8.043549	123.798424	0.79	0.90	-0.108	Typhoon Nina / Dec. 23, 2016	5 - Year
78	8.041244	123.799534	0.03	0.10	-0.070	Typhoon Nina / Dec. 23, 2016	5 - Year
79	8.040639	123.799492	0.96	0.10	0.858	Typhoon Nina / Dec. 23, 2016	5 - Year
80	8.028123	123.825081	0.03	0.00	0.031	Typhoon Nina / Dec. 23, 2016	5 - Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Lat	Long					
81	8.016773	123.850105	0.16	0.00	0.158	Typhoon Nina / Dec. 23, 2016	5 - Year
82	8.016471	123.837392	0.13	0.00	0.134	Typhoon Nina / Dec. 23, 2016	5 - Year
83	8.079765	123.822732	0.89	1.50	-0.613	Typhoon Nina / Dec. 23, 2016	5 - Year
84	8.079660	123.821728	0.03	0.00	0.033	Typhoon Nina / Dec. 23, 2016	5 - Year
85	8.016300	123.836902	0.03	0.00	0.031	Typhoon Nina / Dec. 23, 2016	5 - Year
86	8.052000	123.795674	0.03	0.00	0.031	Typhoon Nina / Dec. 23, 2016	5 - Year
87	8.045971	123.793653	0.03	0.00	0.032	Typhoon Nina / Dec. 23, 2016	5 - Year
88	8.044909	123.798138	0.69	0.00	0.693	Typhoon Nina / Dec. 23, 2016	5 - Year
89	8.044396	123.797939	0.43	0.30	0.132	Typhoon Nina / Dec. 23, 2016	5 - Year
90	8.043697	123.798619	0.54	0.80	-0.257	Typhoon Nina / Dec. 23, 2016	5 - Year
91	8.043041	123.799050	0.08	0.07	0.012	Typhoon Nina / Dec. 23, 2016	5 - Year
92	8.042567	123.813253	0.06	0.25	-0.186	Typhoon Nina / Dec. 23, 2016	5 - Year
93	8.042542	123.798980	0.03	0.00	0.031	Typhoon Nina / Dec. 23, 2016	5 - Year
94	8.027760	123.827270	0.17	0.00	0.173	Typhoon Nina / Dec. 23, 2016	5 - Year
95	8.024522	123.809129	0.09	0.00	0.093	Typhoon Nina / Dec. 23, 2016	5 - Year
96	8.015794	123.838138	0.20	0.00	0.198	Typhoon Nina / Dec. 23, 2016	5 - Year
97	8.044067	123.791637	0.07	0.00	0.070	Typhoon Nina / Dec. 23, 2016	5 - Year
98	8.042178	123.792021	0.03	0.00	0.031	Typhoon Nina / Dec. 23, 2016	5 - Year
99	8.046408	123.797467	0.03	0.00	0.030	Typhoon Nina / Dec. 23, 2016	5 - Year
100	8.046878	123.797410	0.03	0.00	0.033	Typhoon Nina / Dec. 23, 2016	5 - Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Lat	Long					
101	8.045448	123.797292	0.03	0.00	0.032	Typhoon Nina / Dec. 23, 2016	5 - Year
102	8.045126	123.813209	0.05	0.00	0.045	Typhoon Nina / Dec. 23, 2016	5 - Year
103	8.044256	123.797803	0.03	0.00	0.031	Typhoon Nina / Dec. 23, 2016	5 - Year
104	8.044012	123.791635	0.07	0.00	0.070	Typhoon Nina / Dec. 23, 2016	5 - Year
105	8.039696	123.800711	0.03	0.00	0.031	Typhoon Nina / Dec. 23, 2016	5 - Year
106	8.060194	123.809787	0.06	0.00	0.063	Typhoon Nina / Dec. 23, 2016	5 - Year
107	8.042548	123.791961	0.04	0.00	0.038	Typhoon Nina / Dec. 23, 2016	5 - Year
108	8.046118	123.793981	0.03	0.00	0.032	Typhoon Nina / Dec. 23, 2016	5 - Year
109	8.044384	123.796832	0.03	1.50	-1.470	Typhoon Nina / Dec. 23, 2016	5 - Year
110	8.043121	123.798189	0.03	0.12	-0.090	Typhoon Nina / Dec. 23, 2016	5 - Year
111	8.049239	123.798968	0.03	0.00	0.033	Typhoon Nina / Dec. 23, 2016	5 - Year
112	8.050263	123.799081	0.03	0.00	0.032	Typhoon Nina / Dec. 23, 2016	5 - Year
113	8.045006	123.797428	0.05	0.00	0.050	Typhoon Nina / Dec. 23, 2016	5 - Year
114	8.046557	123.811672	0.03	0.00	0.031	Typhoon Nina / Dec. 23, 2016	5 - Year
115	8.044321	123.814245	0.03	0.00	0.033	Typhoon Nina / Dec. 23, 2016	5 - Year
116	8.060348	123.809121	0.03	0.00	0.031	Typhoon Nina / Dec. 23, 2016	5 - Year
117	8.055388	123.808258	0.03	0.00	0.031	Typhoon Nina / Dec. 23, 2016	5 - Year
118	8.048414	123.801445	0.04	0.00	0.041	Typhoon Nina / Dec. 23, 2016	5 - Year
119	8.047131	123.796604	0.03	0.00	0.031	Typhoon Nina / Dec. 23, 2016	5 - Year
120	8.044704	123.795782	0.04	0.00	0.040	Typhoon Nina / Dec. 23, 2016	5 - Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Lat	Long					
121	8.042511	123.813360	0.12	0.00	0.118	Typhoon Nina / Dec. 23, 2016	5 - Year
122	8.034648	123.806306	0.47	0.00	0.471	Typhoon Nina / Dec. 23, 2016	5 - Year
123	8.023231	123.828848	0.16	0.10	0.061	Typhoon Nina / Dec. 23, 2016	5 - Year
124	8.021813	123.846795	0.07	0.60	-0.526	Typhoon Nina / Dec. 23, 2016	5 - Year
125	8.020189	123.831692	0.14	0.00	0.137	Typhoon Nina / Dec. 23, 2016	5 - Year
126	8.016104	123.838415	0.16	0.00	0.157	Typhoon Nina / Dec. 23, 2016	5 - Year
127	8.058895	123.812601	0.03	0.00	0.032	Typhoon Nina / Dec. 23, 2016	5 - Year
128	8.079880	123.821939	0.09	0.00	0.089	Typhoon Nina / Dec. 23, 2016	5 - Year
129	8.038083	123.822611	0.03	0.00	0.032	Typhoon Nina / Dec. 23, 2016	5 - Year
130	8.049528	123.824222	0.13	0.30	-0.171	Typhoon Nina / Dec. 23, 2016	5 - Year
131	8.079806	123.822583	0.09	0.30	-0.206	Typhoon Nina / Dec. 23, 2016	5 - Year
132	8.050194	123.805611	1.67	1.60	0.068	Typhoon Nina / Dec. 23, 2016	5 - Year
133	8.047722	123.794194	0.33	0.07	0.258	Typhoon Nina / Dec. 23, 2016	5 - Year
134	8.048814	123.795557	0.03	0.60	-0.570	Typhoon Nina / Dec. 23, 2016	5 - Year
135	8.049575	123.795231	0.03	0.15	-0.119	Typhoon Nina / Dec. 23, 2016	5 - Year
136	8.049622	123.794463	0.27	0.15	0.117	Typhoon Nina / Dec. 23, 2016	5 - Year
137	8.050229	123.794424	0.07	0.02	0.054	Typhoon Nina / Dec. 23, 2016	5 - Year
138	8.050526	123.794568	0.03	0.40	-0.369	Typhoon Nina / Dec. 23, 2016	5 - Year
139	8.050611	123.795200	0.03	0.24	-0.209	Typhoon Nina / Dec. 23, 2016	5 - Year
140	8.050799	123.795202	0.03	0.20	-0.170	Typhoon Nina / Dec. 23, 2016	5 - Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Lat	Long					
141	8.051660	123.794680	0.05	0.10	-0.048	Typhoon Nina / Dec. 23, 2016	5 - Year
142	8.052850	123.793977	0.03	0.00	0.031	Typhoon Nina / Dec. 23, 2016	5 - Year
143	8.052434	123.793752	0.04	0.00	0.043	Typhoon Nina / Dec. 23, 2016	5 - Year
144	8.051969	123.792780	0.26	0.32	-0.056	Typhoon Nina / Dec. 23, 2016	5 - Year
145	8.050872	123.792183	0.05	0.00	0.045	Typhoon Nina / Dec. 23, 2016	5 - Year
146	8.050941	123.792402	0.03	0.00	0.031	Typhoon Nina / Dec. 23, 2016	5 - Year
147	8.050637	123.791385	0.03	0.00	0.031	Typhoon Nina / Dec. 23, 2016	5 - Year
148	8.051116	123.793317	0.10	0.09	0.010	Typhoon Nina / Dec. 23, 2016	5 - Year
149	8.050160	123.793474	0.03	0.00	0.031	Typhoon Nina / Dec. 23, 2016	5 - Year
150	8.053370	123.794209	0.56	0.52	0.044	Typhoon Nina / Dec. 23, 2016	5 - Year
151	8.053534	123.794459	0.12	0.32	-0.204	Typhoon Nina / Dec. 23, 2016	5 - Year
152	8.053312	123.794728	0.03	0.40	-0.369	Typhoon Nina / Dec. 23, 2016	5 - Year
153	8.052901	123.794719	0.03	0.00	0.032	Typhoon Nina / Dec. 23, 2016	5 - Year
154	8.048918	123.797009	0.06	0.00	0.060	Typhoon Nina / Dec. 23, 2016	5 - Year
155	8.047487	123.797765	0.03	0.00	0.032	Typhoon Nina / Dec. 23, 2016	5 - Year
156	8.047449	123.799858	0.04	0.00	0.038	Typhoon Nina / Dec. 23, 2016	5 - Year

Annex 12. Educational Institutions Affected in Bulod Floodplain

LANAO DEL NORTE				
KOLAMBUGAN				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Day Care Center	Manga			Low

LANAO DEL NORTE				
MAGSAYSAY				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Datu Bebet Dalug Elem. School	Baguiguicon	Low	Low	Low
Day Care Center	Baguiguicon	Low	Low	Low
Magsaysay High School Annex	Baguiguicon			
School Bldg.	Baguiguicon			
School Room2	Baguiguicon			
School Room3	Baguiguicon			
School Rooms	Baguiguicon			

LANAO DEL NORTE				
TUBOD				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Bulod Elem. School	Bulod	High	High	High
Day Care Center	Bulod			
HE Bldg.	Bulod	High	High	High
Madraza Bldg. (Islam School)	Bulod	High	High	High
Pricipal's Office 2nd Floor	Bulod	High	High	High
San Antonio Elementary School Multi-Purpose Hall	Bulod			
School Stage	Bulod	High	High	High
Daycare	Kakai Renabor			
Kakai Elementary	Kakai Renabor	Low	Medium	Medium
Canteen	Patudan			
Day Care Center	Patudan			
Grade 1	Patudan			
Grade 2	Patudan			
Grade 4	Patudan			
Grade 6	Patudan			

LANAO DEL NORTE				
TUBOD				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
H.E. (Home Economics)	Patudan			
Kindergarten	Patudan			
Principl's Office/Audio/ Computer Room/ Grade 6	Patudan			
School Stage	Patudan			
Sergio Mata Elementary School Grade 1	Patudan			
Baptist Elem. School	Pigcarangan			
Baptist Guard House	Pigcarangan			
Baptist Guest House	Pigcarangan			
Baptist Staff House	Pigcarangan			
Day Care Center	Pigcarangan			
School Bldg. 1	Pigcarangan			
School Bldg.1	Pigcarangan	Low	Low	Low
School Bldg.2	Pigcarangan	Low	Low	Low
Pigcarangan Elem. School	Pigcarangan			
MG8 TESDA School	Poblacion	Medium	Medium	Medium
Campus Convent	Poblacion			
Daycare	Poblacion			
Daycare Center	Poblacion			
Lighthouse Daycare	Poblacion			
Mercy Junior College	Poblacion			
Principal's Office	Poblacion			
School Office	Poblacion			
TESDA	Poblacion			
Tubod Central Elementary School	Poblacion			
Purok 5 Day Care Cener	Pualas			
Daycare Center	San Antonio			
Grade 1 - 6	San Antonio			
Non-functional building (burnt)	San Antonio			
San Antonio Elementary School Waiting Shed	San Antonio			
F V bond Elem. School	Tangueguiron	High	High	High
School Office	Tangueguiron	High	High	High

Annex 13. Medical Institutions Affected in Bulod Floodplain

LANAO DEL NORTE				
MAGSAYSAY				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Baguigicon Health Center	Baguiguicon			

LANAO DEL NORTE				
TUBOD				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Brgy. Health Center	Bulod			
Barangay Health Center	Patudan			
Clinic	Patudan			
Health Center	Pigcarangan			
Dial Me Pharmacy	Poblacion			
Health center	Poblacion			
RJQ Pharmacy	Poblacion			
Rural Health Unit	Poblacion			
Tubod natures Pharmacy	Poblacion			
Health Center	San Antonio			
Magdales Pharmacy General Merchandise	San Antonio			
Tubod Community Hospital	San Antonio			
Tubod Community Hosptal/ Philhealth	San Antonio			
Tubod natures Pharmacy	San Antonio			
Health Center	Tangueguiron	Low	Low	Low