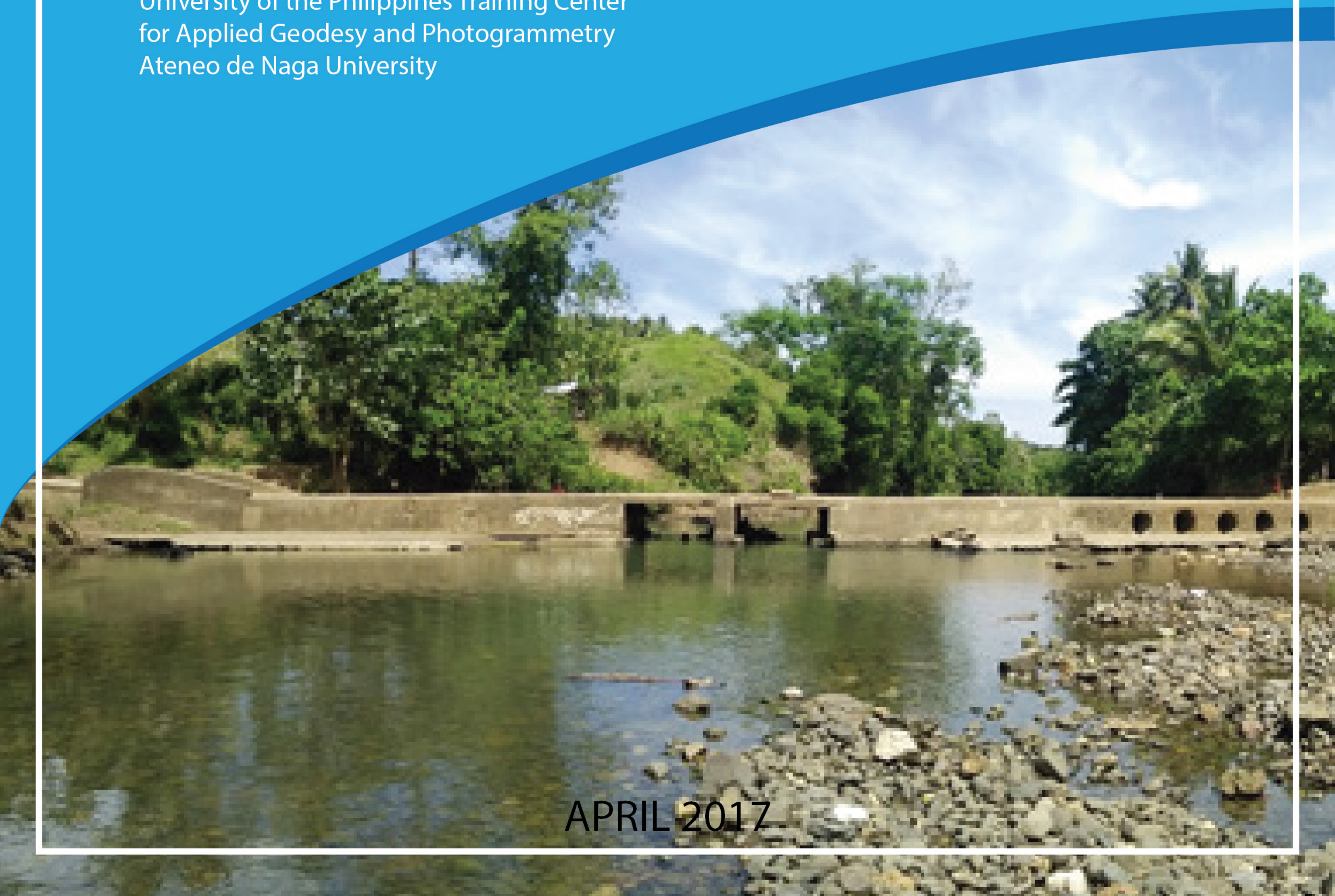
Hazard Mapping of the Philippines Using LIDAR (Phil-LIDAR 1)

LiDAR Surveys and Flood Mapping of Malbag River

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



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

CHAPTER 1: OVERVIEW OF THE PROGRAM AND THE MALBAG RIVER BASIN

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

1.1 Background of the Phil-LIDAR 1 Program

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

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

The implementing partner university for the Phil-LiDAR 1 Program is the Atene de Naga University (AdNU). AdNU 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 24 river basins in the Bicol Region . The university is located in Naga City in the province of Camarines Sur.

1.2 Overview of the Malbag River Basin

Malbag River Basin covers the Municipalities of Cawayan, Uson, and Milagros in the Province of Masbate. The DENR River Basin Control Office identified the basin to have a drainage area of 244 km2 and an estimated annual runoff of 330 million cubic meter (MCM) (RBCO, 2015).

Its main stem, Malbag River, is part of the twenty-four (24) river systems in Southern Luzon. According to the 2015 national census of NSO, a total of 6,970 persons are residing within the immediate vicinity of the river distributed among the barangays of the Municipality of Cawayan, namely: Lague-Lague, Taberna, Pulot, and Malbag. The province of Masbate is a province sitting on a "pot of gold" according to geologists. Masbate is rich in mineral and natural resources, and rich fishing grounds. The local livelihood of the town of Cawayan is primarily based on subsistence farming since the topography of the town is made up of grasslands which is suitable for cattle farming. Cawayan also has its local fishing industry from the outlying islands which are abundant in marine resources (Source: http://newsinfo.inquirer.net/62885/masbate-paradise-in-a-pool-of-blood and http://news.abs-cbn.com/nation/03/04/13/masbate-violence-paradise). Last December 2016, Masbate was among the hard-hit provinces by Typhoon Nina, internationally known as Nock-ten; where it was placed under Signal Number 2 by the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAG-ASA). Among the 91,281 affected people in Region V during the typhoon, Masbate was part of them (Source: http://www.rappler.com/move-ph/issues/disasters/156698-typhoon-nina-2016-hundred-thousand-affected).

Malbag River Basin is governed by four (4) municipalities. These are Milagros, Cawayan, Uson and Mobo which are first, second, third and fourth class respectively. Milagros is populated with 57,473 residents, Cawayan with 67,033, Uson with 56,168 and Mobo with 38,813.

Malbag River is about 84 km long. Its headwater is in the low mountain range to the northeast. It empties out to Asid Gulf. More than 50% of the area is brushland and with poor vegetation cover. Only around 15% of the area is cultivated for agricultural products. The area near the mouth of the river is used for fisheries while a good size of the total area of the basin is dedicated to tree plantation based on the land use map. A relatively large area is also categorized as grassland.

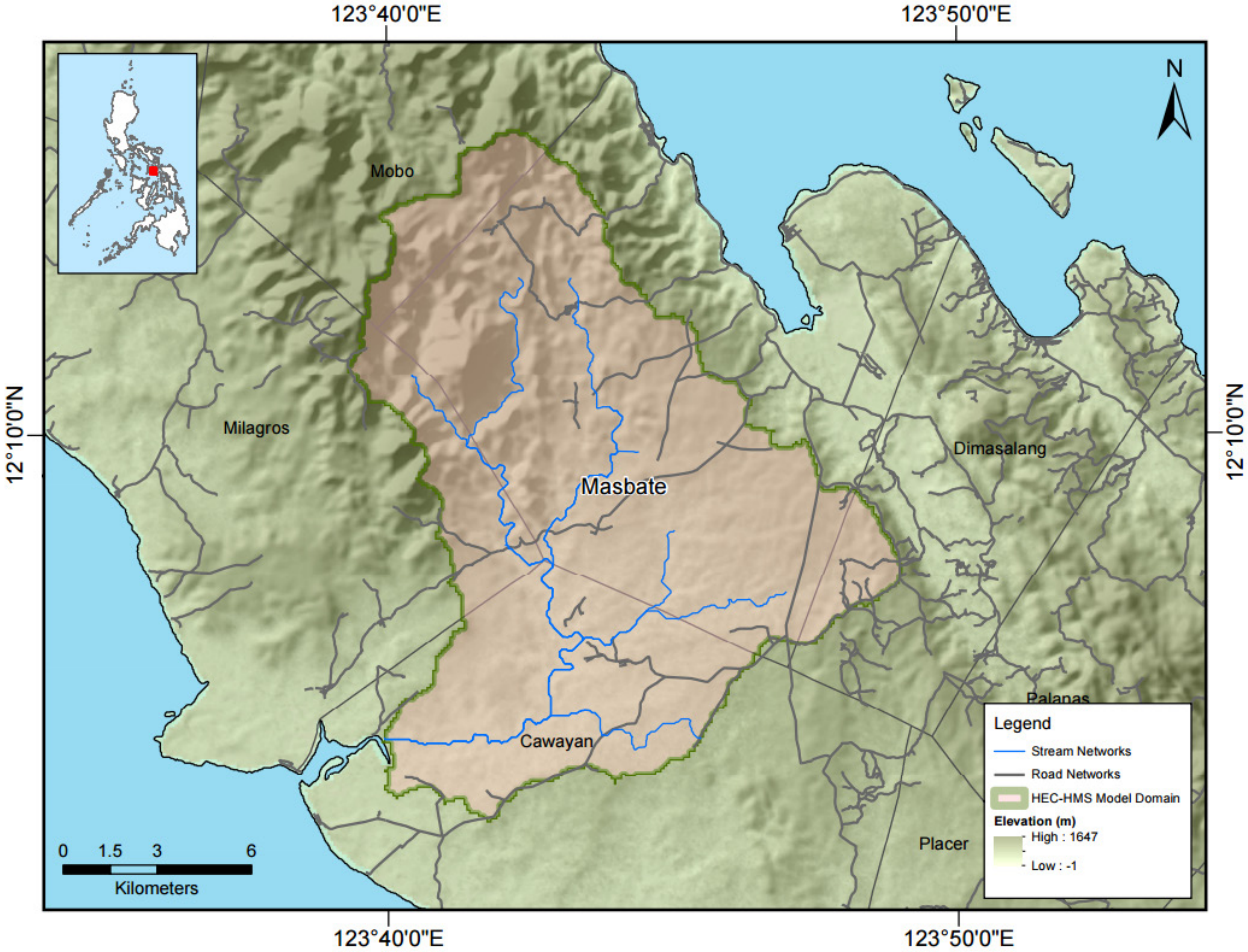


Figure 1. Map of the Malbag River Basin (in Brown)

The area receives an even distribution of rainfall all year through with a relatively dry season during November to April. This is Type III in the Corona classification of climate.

CHAPTER 2: LIDAR ACQUISITION IN MALBAG FLOODPLAIN

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

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

2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Malbag floodplain in Masbate. These missions were planned for 10 lines that run for at most three hours and twenty minutes (3.33 hours) including take-off, landing and turning time. The flight planning parameters for the LiDAR system are found in Table 1. Figure 2 shows the flight plan for Malbag floodplain survey.

Table 1. Flight planning parameters for Pegasus LiDAR system

Block Name	Flying Height (AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed	Average Turn Time (Minutes)
BLK32E	800/1000	25/30	50	200	30	130	5
BLK32H	600/800	25/30	40/50	200/250	30/36	130	5
BLK32I	1000/1200	25/40	50	200	30	130	5
BLK32J	800/1000/ 1200	25	50	200	30	130	5

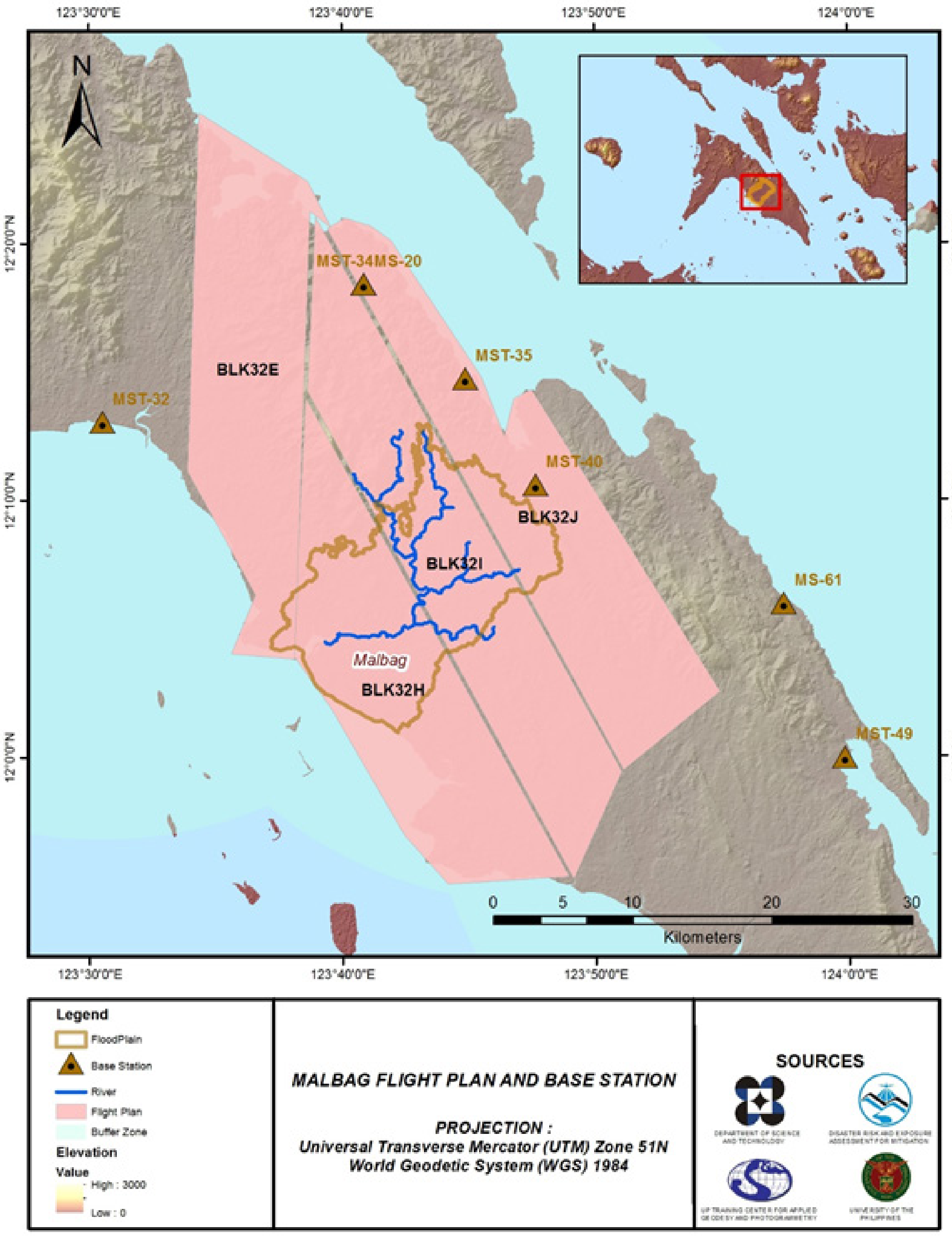


Figure 2. Flight plan and base stations used for Malbag floodplain.

2.2 Ground Base Station

The project team was able to recover five (5) NAMRIA ground control points: MST-32, MST-34, MST-35, MST-40 and MST-49 which are of second (2nd) order accuracy, also, MS-20 and MS-61, two (2) benchmarks which are of 1st order accuracy. The certifications for the NAMRIA reference points are found in Annex 2. These were used as base stations during flight operations for the entire duration of the survey (March 18- April 14, 2014). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 852 and SPS 882. Flight plans and location of base stations used during the aerial LiDAR acquisition in Malbag floodplain are shown in Figure 2.

Figure 3 to Figure 9 show the recovered NAMRIA reference points within the area. Table 2 to Table 8 show the details about the following NAMRIA control stations and established points, while shows the list of all ground control points occupied during the acquisition with the corresponding dates of utilization.

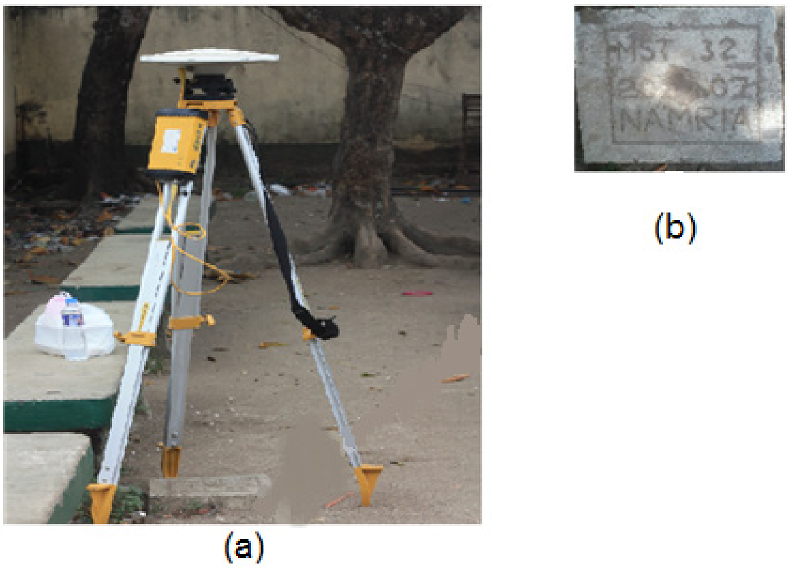


Figure 3. a) GPS set-up over MST-32 as recovered inside the compound of Milagros Municipal Hall, Masbate. b) NAMRIA reference point MST-32 as recovered by the field team.

Table 2. Details of the recovered NAMRIA horizontal control point MST-32 used as base station for the LiDAR Acquisition.

Station Name	MST-32	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	12° 13' 7.66936" North 123° 30' 26.72479" East 3.78300 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 4 PRS 92	Easting Northing	555213.396 meters 1351188.593 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	12° 13' 3.03064" North 123° 30' 31.80788" East 59.91100 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984	Easting Northing	555194.07 meters 1350715.65 meters

(a)

Figure 4. a) GPS set-up over MST-34 as recovered in Sagawsawan Bridge, Brgy. Umabay Exterior, municipality of Mobo, Masbate b) NAMRIA reference point MST-34 as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point MST-34 used as base station for the LiDAR Acquisition.

Station Name	**MST-34**	
Order of Accuracy	**2nd**	
Relative Error (horizontal positioning)	**1 in 50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	12° 18’ 29.18323” North 123° 40’ 46.86556” East 11.91000 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 4 PRS 92)	Easting Northing	573933.177 meters 1361109.053 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	12° 18’ 24.53692” North 123° 40’ 51.93952” East 68.23000 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	573907.30 meters 1360632.64 meters

(b)

(a)

Figure 5. a) GPS set-up over MST-35 as recovered in Marcella Bridge in Brgy. Cagay, City of Masbate, Province of Masbate b) NAMRIA reference point MST-35 as recovered by the field team.

Table 4. Details of the recovered NAMRIA horizontal control point MST-35 used as base station for the LiDAR Acquisition

Station Name	**MST-35**	
Order of Accuracy	**2nd**	
Relative Error (horizontal positioning)	**1:50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	12° 14' 48.14863" North 123° 44' 47.51779" East 5.31500 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 4 PRS 92)	Easting Northing	581223.775 meters 1354336.379 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	12° 14' 43.52314" North 123° 44' 52.59656" East 61.95700 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	581195.35 meters 1353862.34 meters

(a) (b)

Figure 6. a) GPS set-up over MST-40 as recovered in Buenavista Bridge in Brgy. Buenavista, municipality of Uson, Masbate. b) NAMRIA reference point MST-40 as recovered by the field team.

Table 5. Details of the recovered NAMRIA horizontal control point MST-40 used as base station for the LiDAR Acquisition.

Station Name	**MST-40**	
Order of Accuracy	**2nd**	
Relative Error (horizontal positioning)	**1 in 50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	12° 10’ 39.45274” North 123° 47’ 33.62147” East 4.72600 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 4 PRS 92)	Easting Northing	586266.511 meters 1346708.7 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	12° 10’ 34.84826” North 123° 47’ 38.70589” East 61.65900 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992	Easting Northing	586236.32 meters 1346237.33 meters

(b)

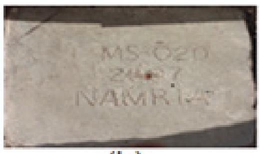
(a)

Figure 7. a) GPS set-up over MST-49 as recovered in front of the Cataingan Municipal Hall, municipality of Cataingan, Masbate b) NAMRIA reference point MST-49 as recovered by the field team.

Table 6. Details of the recovered NAMRIA horizontal control point MST-49 used as base station for the LiDAR Acquisition.

Station Name	MST-49	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	12° 00' 01.41677" 123° 59' 46.24265" 21.25500 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 4 PRS 92)	Easting Northing	608487.281 meters 1327175.1 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	11° 59' 56.87354" North 123° 59' 51.34085" East 79.14000 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	608449.31 meters 1326710.57 meters

(a)



(b)

Figure 8. a) GPS set-up over MS-20 as recovered in Manaswang Bridge in Brgy. Marcella, municipality of Uson, Masbate b) NAMRIA reference point MS-20 as recovered by the field team.

Table 7. Details of the recovered NAMRIA horizontal control point MS-20 used as base station for the LiDAR Acquisition.

Station Name	MS-20	
Order of Accuracy	2nd order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	12° 18' 29.18317" North 123° 40' 46.86570" East 11.92 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 4 PRS 92)	Easting Northing	12° 18' 24.53692" North 123° 40' 51.93952" East 68.230 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	574059.995 meters 1360574.929 meters

(b)

(a)

Figure 9. a) a) GPS set-up over MS-61 as recovered in Nabangig Bridge, Brgy. Nabangig, municipality of Palanas, Masbate b) NAMRIA reference point MS-61 as recovered by the field team.

Table 8. Details of the recovered NAMRIA horizontal control point MS-61 used as base station for the LiDAR Acquisition.

Station Name	MS-61	
Order of Accuracy (vertical)	2nd order	
Relative Error (horizontal positioning)	1:50000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	12° 06' 1.51238" 123° 57' 21.24483" 4.74 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	12° 05' 56.94091" North 123° 57' 26.33451" East 65.257 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	604178.664 meters 1337699.951 meters

Table 9. Ground control points used during LiDAR data acquisition.

Date Surveyed	Flight Number	Mission Name	Ground Control Points
March 19, 2014	1241P	1BLK32E078A	MST-34 and MST-35
March 20, 2014	1243P	1BLK32E079A	MS-20 and MST-34
March 20, 2014	1245P	1BLK32J079B	MS-20 and MST-34
March 21, 2014	1247P	1BLK32IJ080A	MST-34 and MST-40
March 27, 2014	1271P	1BLK32H086A	MST-49 and MS-61
March 28, 2014	1275P	1BLK32HI087A	MST-40 and MST-49
March 29, 2014	1281P	1BLK32I088B	MST-40 and MST-49
April 1, 2014	1293P	1BLK32H091B	MST-40 and MST-49
April 2, 2014	1295P	1BLK32E092A	MST-32

2.3 Flight Missions

Nine (9) missions were conducted to complete LiDAR data acquisition in Malbag Floodplain, for a total of twenty nine hours and forty six minutes (29+46) of flying time for RP-C9022. All missions were acquired using the Pegasus LiDAR systems. Table 10 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 11 presents the actual parameters used during the LiDAR data acquisition.

Table 10. Flight missions for LiDAR data acquisition in Malbag floodplain.

Date Surveyed	Flight Number	Flight Plan Area (km2)	Surveyed Area (km2)	Area Surveyed within the Floodplain (km2)	Area Surveyed Outside the Floodplain (km2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
March 19, 2014	1241P	256.41	146.522	3.445	208.107	587	4	29
March 20, 2014	1243P	256.41	157.137	5.796	205.756	643	2	59
March 20, 2014	1245P	276.40	143.44	13.919	197.633	721	3	5
March 21, 2014	1247P	559.60	326.96	61.229	150.323	846	4	0
March 27, 2014	1271P	267.86	169.487	71.870	139.682	1184	4	23
March 28, 2014	1275P	267.86	126.674	25.740	185.812	620	2	53
March 29, 2014	1281P	283.20	126.996	25.740	185.812	0	1	53
April 1, 2014	1293P	267.86	82.521	30.750	180.802	423	2	5
April 2, 2014	1295P	256.41	197.562	0.615	210.937	909	3	59
TOTAL		2692.01	1477.30	239.104	1664.864	5933	29	46

Table 12. 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)
1241P	800,1000	25	50	200	30	130	5
1243P	800	25	50	200	30	130	5
1245P	800	25	50	200	30	130	5
1247P	1000, 1200	25	50	200	30	130	5
1271P	800, 600	25, 30	50	200	30	130	5
1275P	800	25	40	250	36	130	5
1281P	1000	40	50	200	30	130	5
1293P	800	25	40	250	36	130	5
1295P	800,1000	30, 25	50	200	30	130	5

2.4 Survey Coverage

Malbag floodplain is located in the province of Masbate with majority of the floodplain situated within the municipality of Cawayan, Milagros and Uson. Municipalities of Cawayan and Mobo are mostly covered by the survey. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 12. The actual coverage of the LiDAR acquisition for Malbag Floodplain is presented in Figure 10.

Table 11. List of municipalities and/or cities surveyed during Malbag Floodplain LiDAR survey

Province	City/Municipality	Area of Munici-pality/ City (km2)	Total Area Surveyed (km2	Percentage of Area Surveyed
Masbate	Cawayan	261.38	245.331	94%
	Mobo	143.029	133.155	93%
	Uson	183.758	165.789	90%
	Dimasalang	100.442	52.1326	52%
	Masbate City	192.96	95.2225	49%
	Placer	253.547	107.27	42%
	Palanas	138.167	49.3392	36%
	Milagros	530.431	187.825	35%
	Cataingan	191.694	9.0429	5%
Total		1995.41	1045.11	52.38%

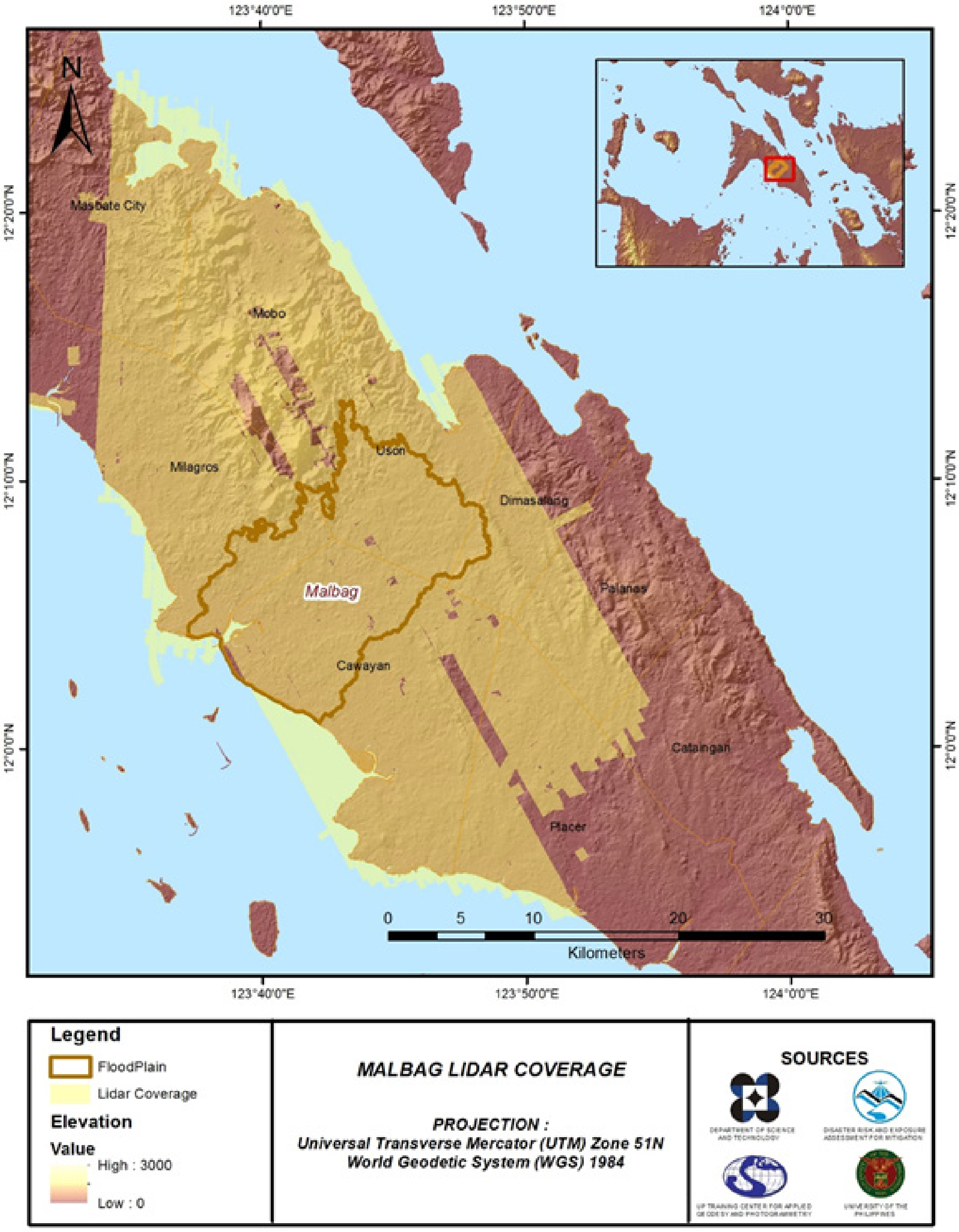


Figure 10. Actual LiDAR survey coverage for Malbag floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE MALBAG FLOODPLAIN

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

3.1 LiDAR Data Processing for Malbag Floodplain

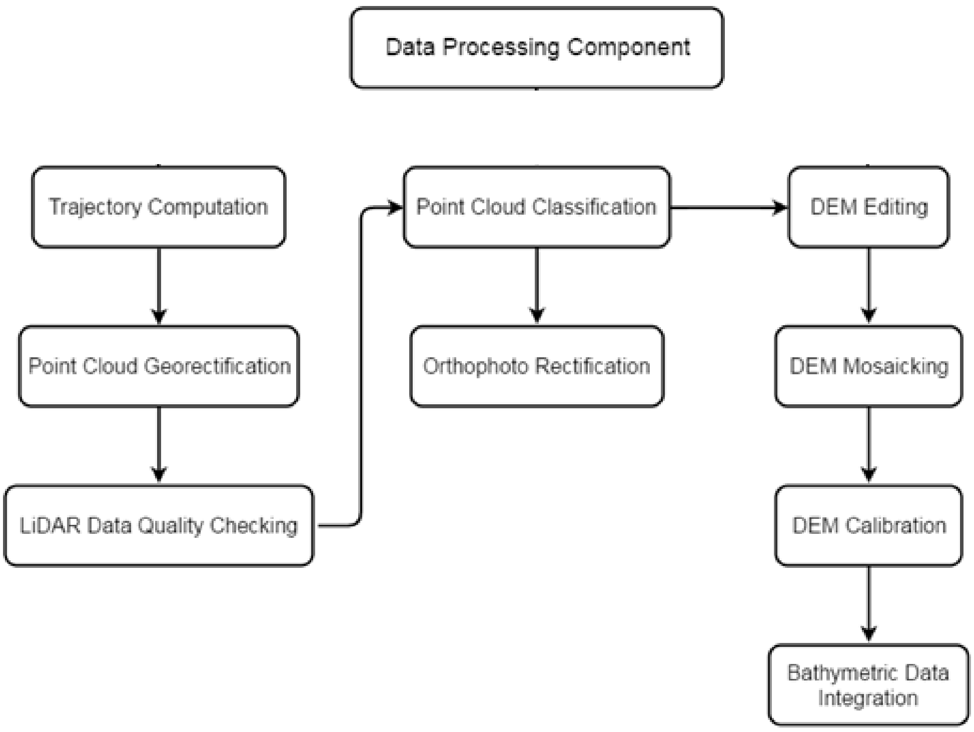


Figure 11. Schematic Diagram for Data Pre-Processing Component

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 11.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Malbag floodplain can be found in Annex 5. Missions flown during the first survey conducted on April 2014 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus system over Cawayan, Masbate. The Data Acquisition Component (DAC) transferred a total of 204.36 Gigabytes of Range data, 1.75 Gigabytes of POS data, 50.4 Megabytes of GPS base station data, and 370.80 Gigabytes of raw image data to the data server on April 22, 2014 for the first survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Malbag was fully transferred on April 23, 2014, as indicated on the Data Transfer Sheets for Malbag floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 1275P, one of the Malbag flights, which is the North, East, and Down position RMSE values are shown in Figure 12. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on April 3, 2014 00:00AM. The y-axis is the RMSE value for that particular position.

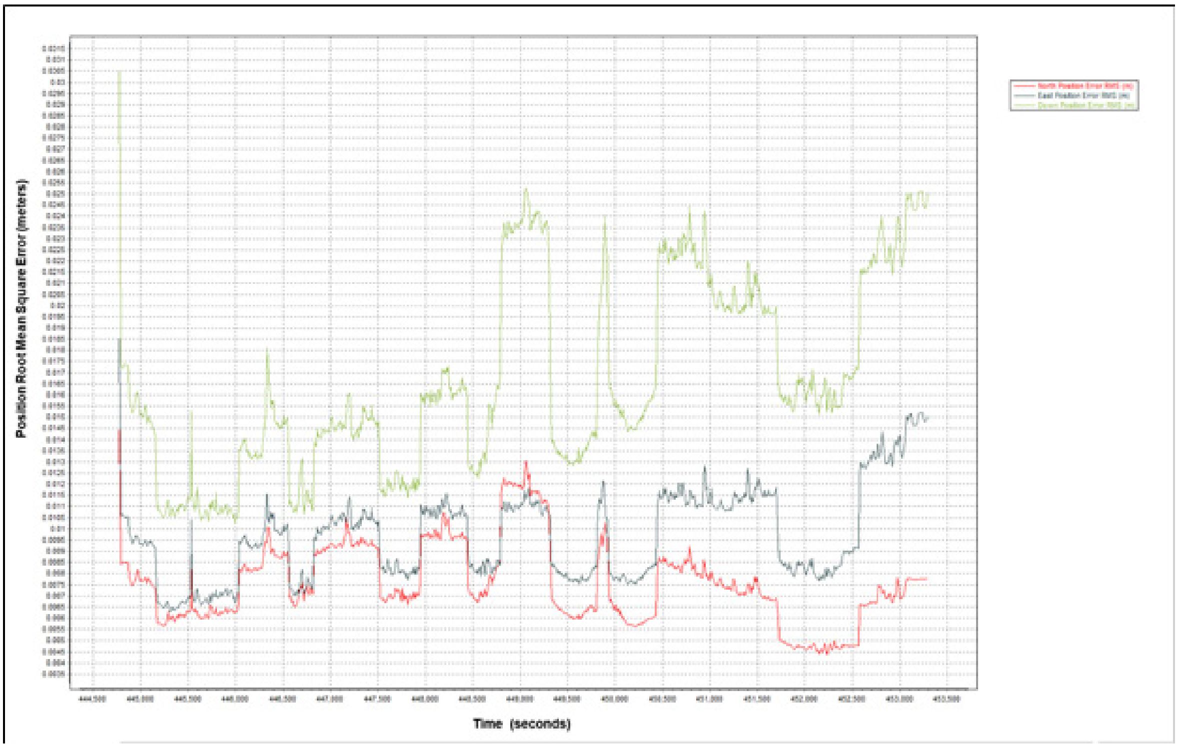


Figure 12. Smoothed Performance Metrics of a Malbag Flight 1275P.

The time of flight was from 444,800 seconds to 453,300 seconds, which corresponds to morning of April 3, 2014. The initial spike that is seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the POS system starts computing for the position and orientation of the aircraft. Redundant measurements from the POS system quickly minimized the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values correspond to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 12 shows that the North position RMSE peaks at 1.30 centimeters, the East position RMSE peaks at 1. 50 centimeters, and the Down position RMSE peaks at 2.50 centimeters, which are within the prescribed accuracies described in the methodology.

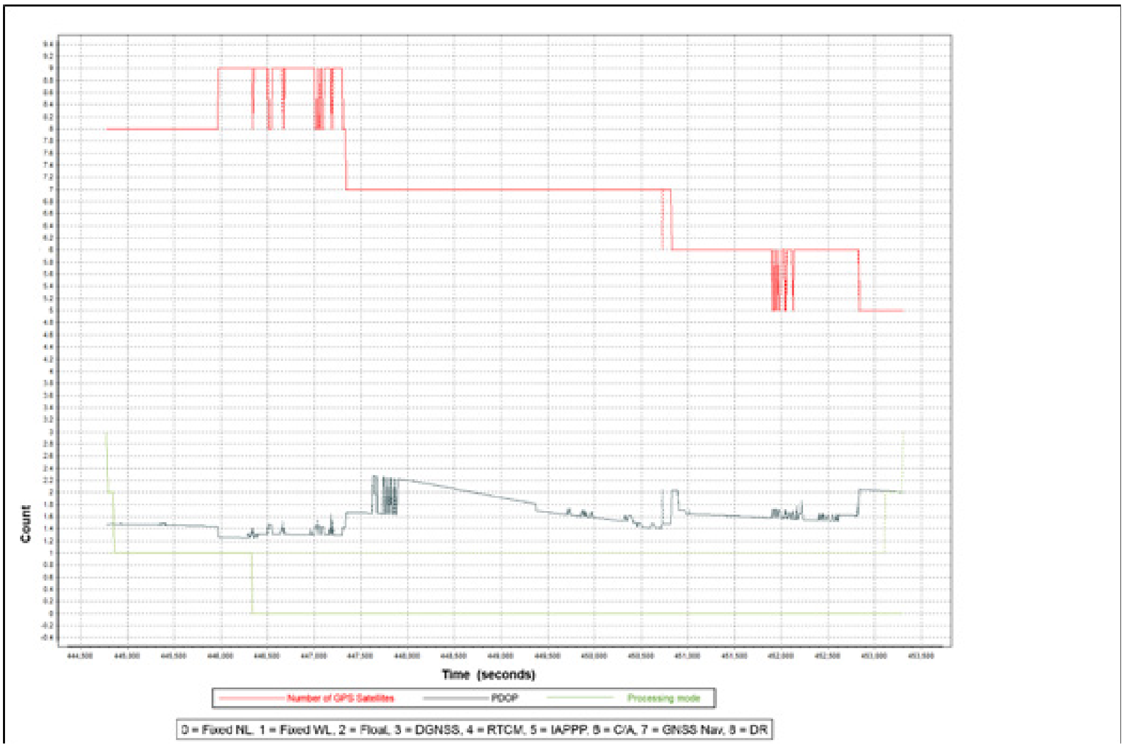


Figure 13. Solution Status Parameters of Malbag Flight 1275P.

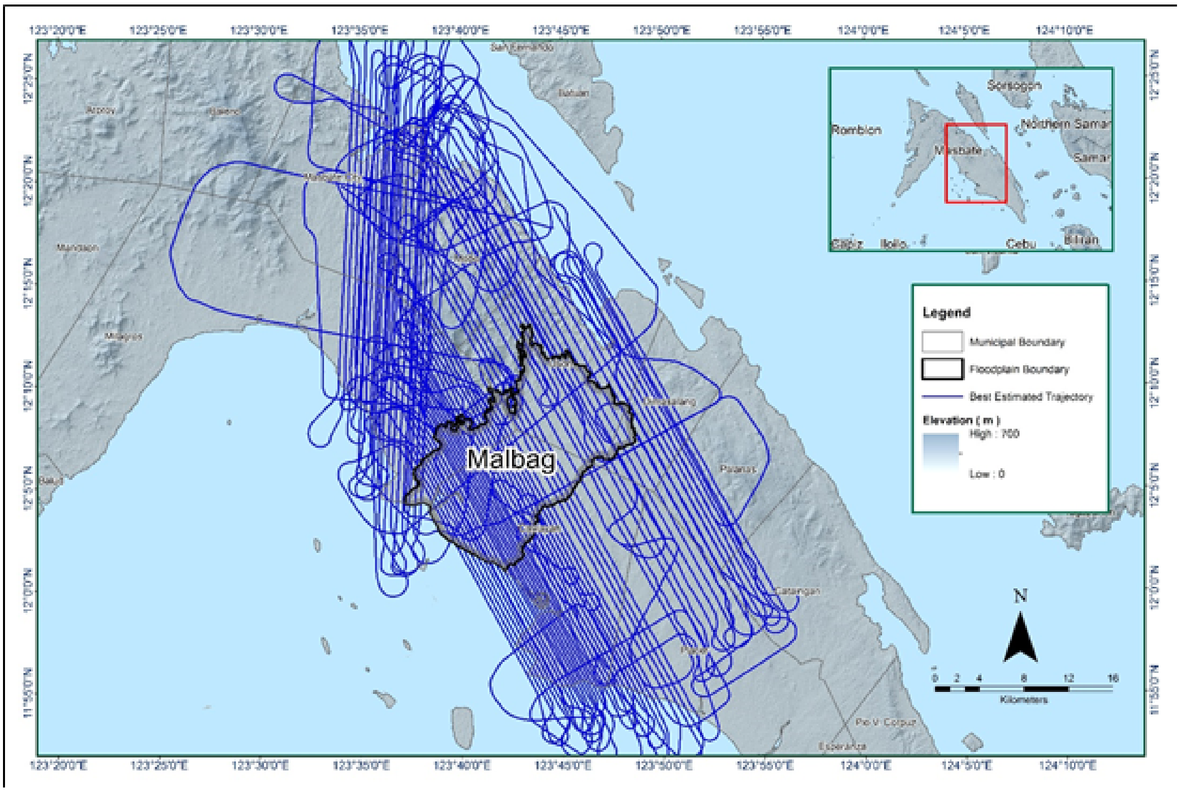


Figure 14. Best Estimated Trajectory for Malbag floodplain.

Table 13. Self-Calibration Results values for Malbag flights.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 78 flight lines, with each flight line containing two channels, 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 Malbag floodplain are given in Table 13.

Parameter	Value
Boresight Correction stdev (<0.001degrees)	0.000200
IMU Attitude Correction Roll and Pitch Corrections stdev (<0.001degrees)	0.000846
GPS Position Z-correction stdev (<0.01meters)	0.0022

The optimum accuracy is obtained for all Malbag flights based on the computed standard deviations of the corrections of the orientation parameters. Standard deviation values for individual blocks are available in the Annex B-1. Mission Summary Reports.

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Malbag Floodplain is shown in Figure 15. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

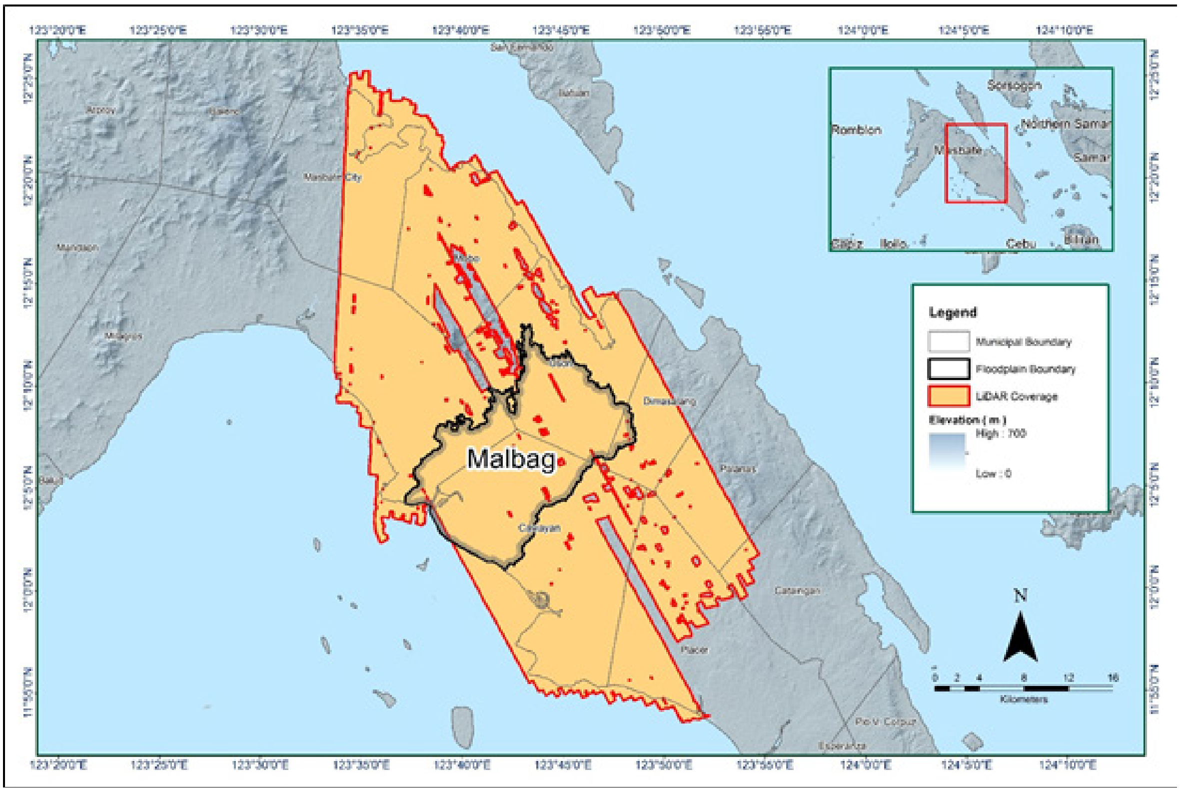


Figure 15. Boundary of the processed LiDAR data over Malbag Floodplain

Table 14. List of LiDAR blocks for Salug Diut Floodplain

LiDAR Blocks	Flight Numbers	Area (sq km)
Masbate_Blk32E	1241P	272.91
	1243P	
	1295P	
Masbate_Blk32IJ	1245P	540.53
	1247P	
	1281P	
Masbate_Blk32H	1293P	315.33
	1275P	
	1271P	
TOTAL		1,128.77 sq.km

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 16. 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.

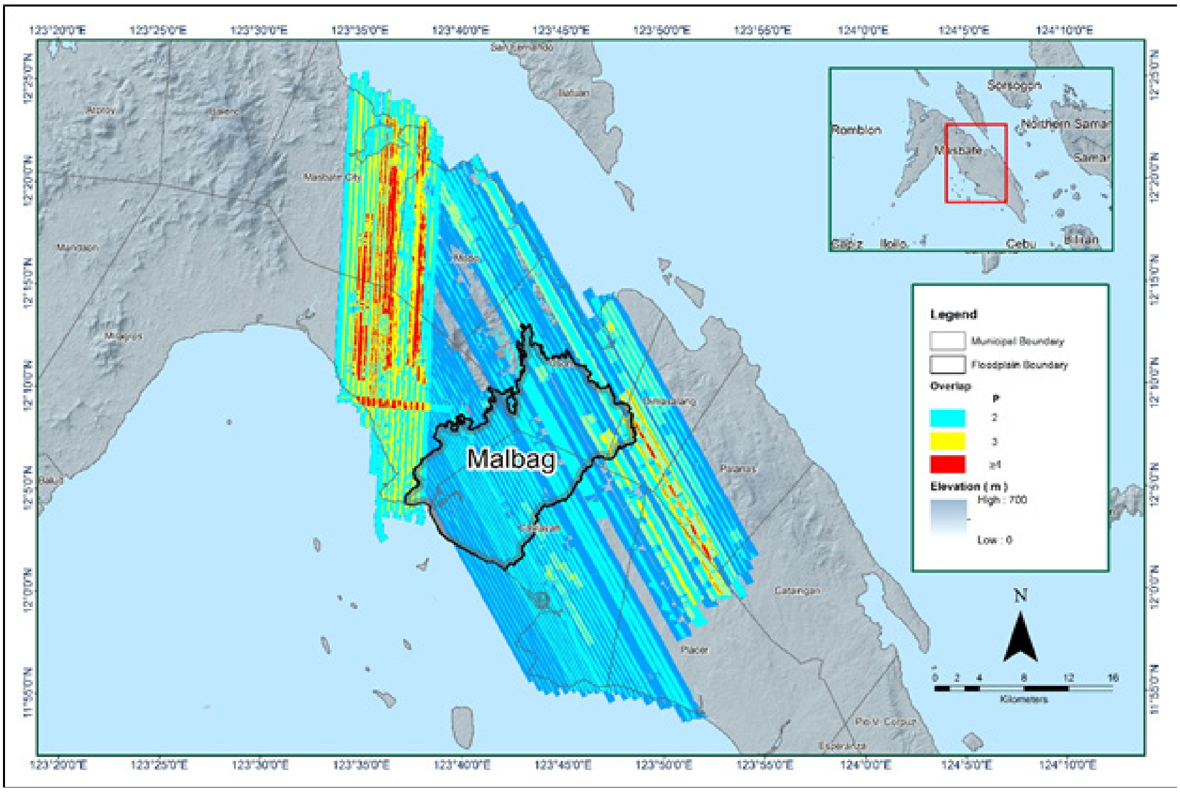


Figure 16. Image of data overlap for Malbag floodplain.

The overlap statistics per block for the Malbag floodplain can be found in Annex B-1. One pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps is 54.63% 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 17. It was determined that all LiDAR data for Malbag floodplain satisfy the point density requirement, and the average density for the entire survey area is 3.29 points per square meter.

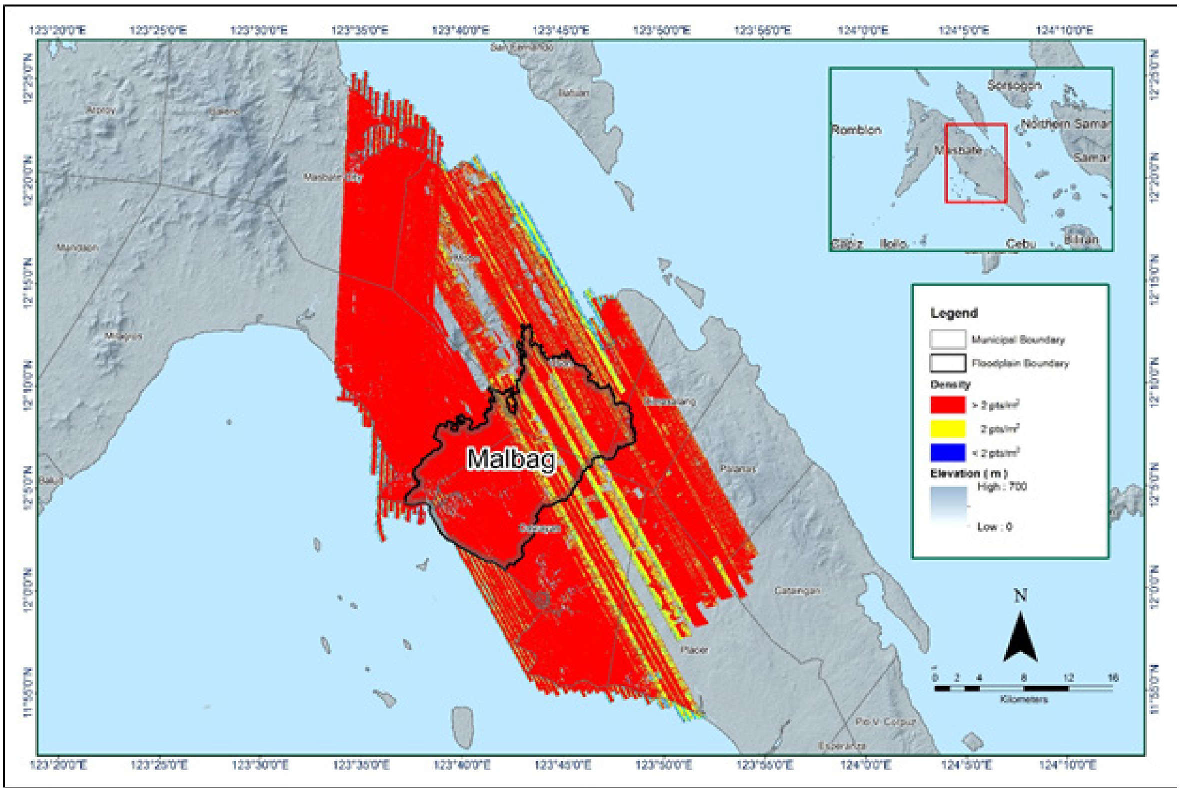


Figure 17. Pulse density map of merged LiDAR data for Malbag floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 18. The default color range is from blue to red, where bright blue areas correspond to portions where elevations of a previous flight line, identified by its acquisition time, are higher by more than 0.20m relative to elevations of its adjacent flight line. Bright red areas indicate portions where elevations of a previous flight line are lower by more than 0.20m relative to elevations of its adjacent flight line. Areas with bright red or bright blue need to be investigated further using Quick Terrain Modeler software.

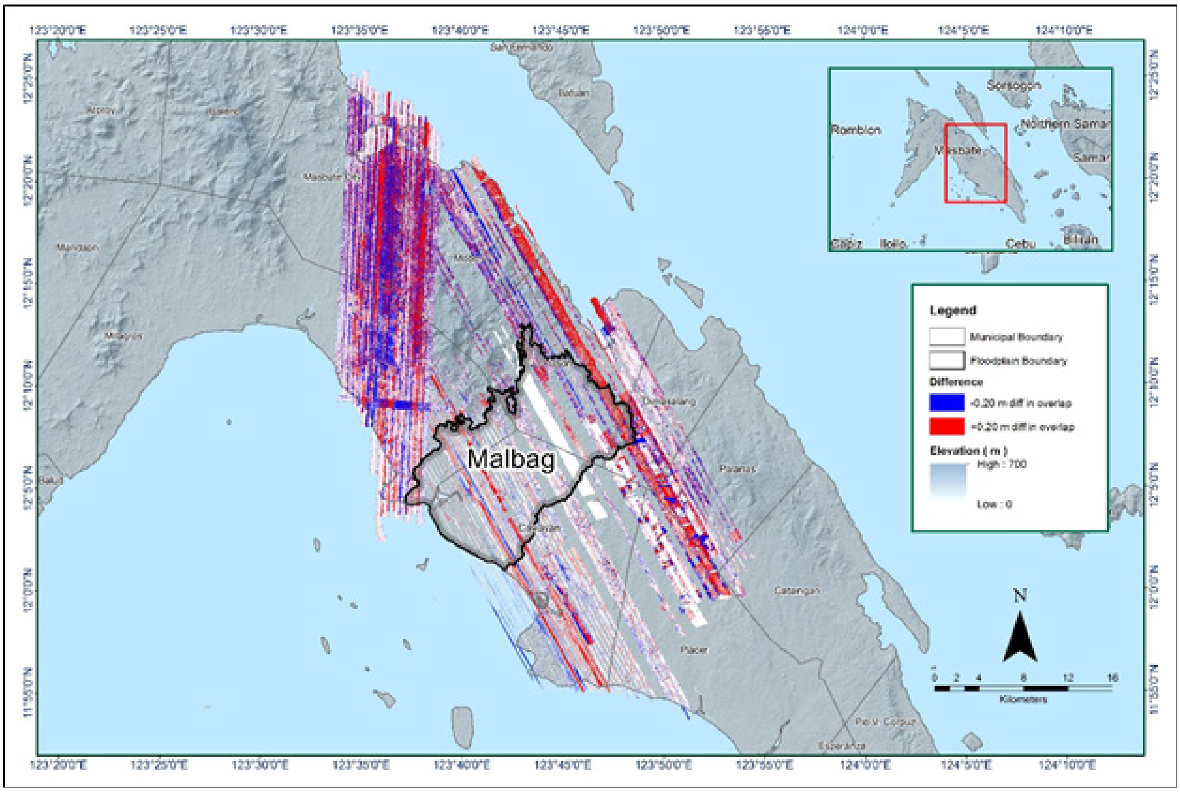


Figure 18. Elevation difference map between flight lines for Malbag floodplain.

A screen capture of the processed LAS data from a Malbag flight 1275P loaded in QT Modeler is shown in Figure 19. 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.

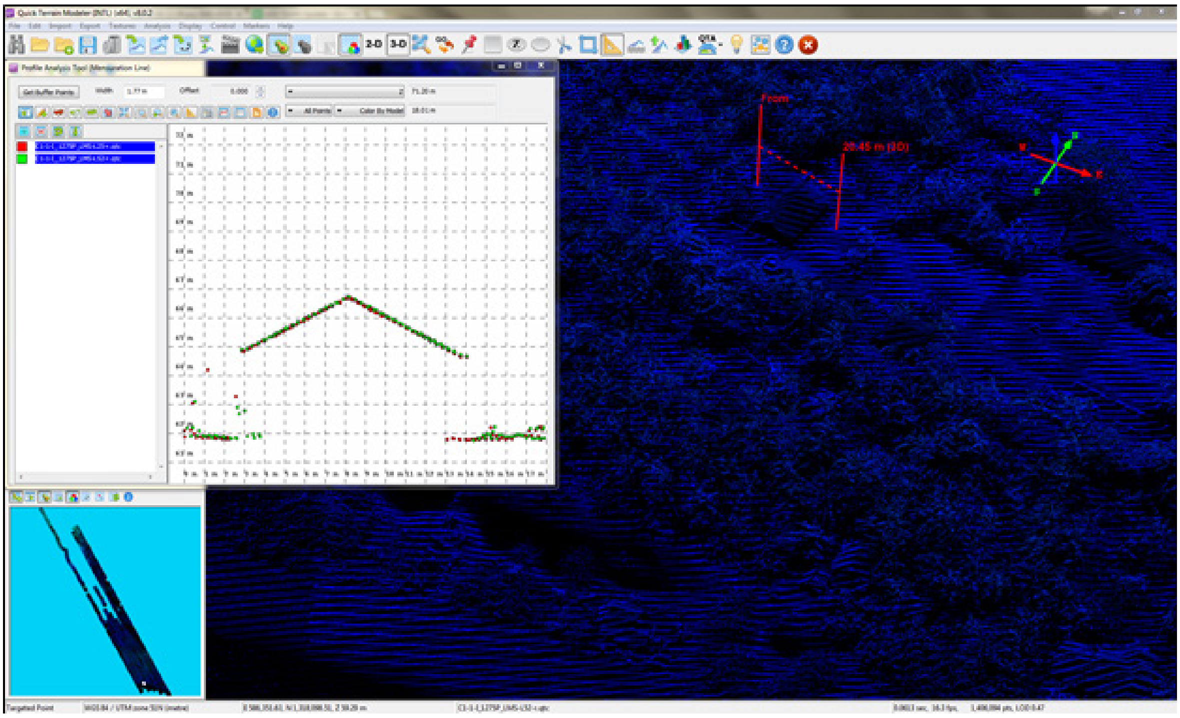


Figure 19. Quality checking for a Malbag flight 1275P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 15. Malbag classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	1,423,127,995
Low Vegetation	1,023,789,932
Medium Vegetation	1,302,325,177
High Vegetation	669,963,813
Building	15,192,245

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Malbag floodplain is shown in Figure 20. A total of 1,419 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 15. The point cloud has a maximum and minimum height of 603.95 meters and 42.31 meters respectively.

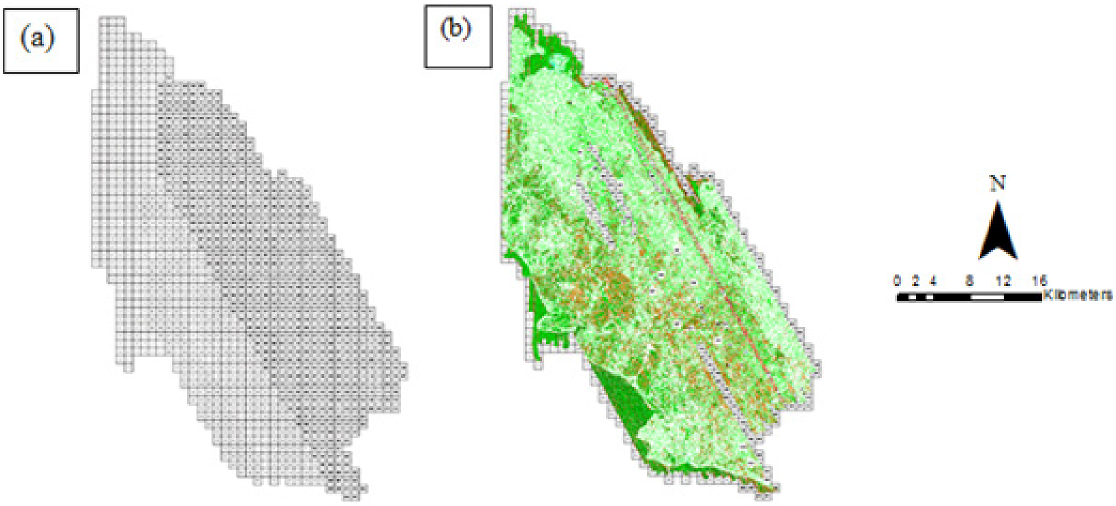


Figure 20. Tiles for Malbag floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 21. 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.

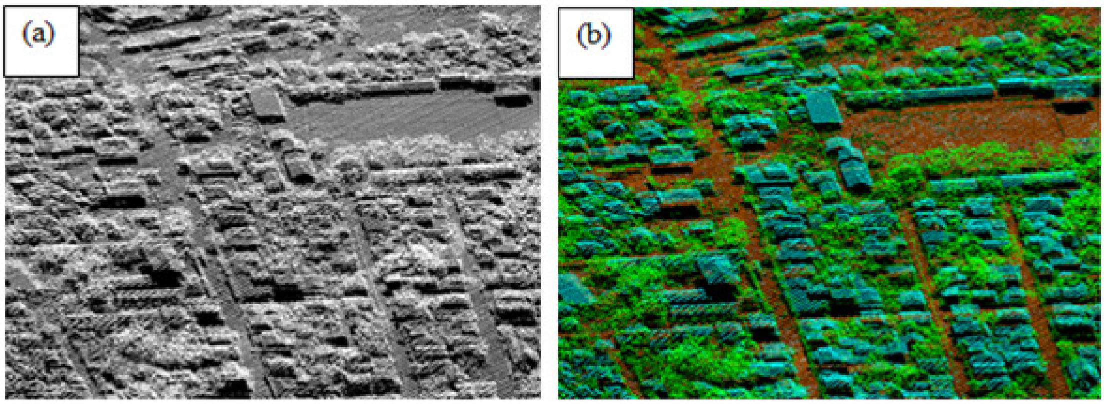


Figure 21. Point cloud before (a) and after (b) classification.

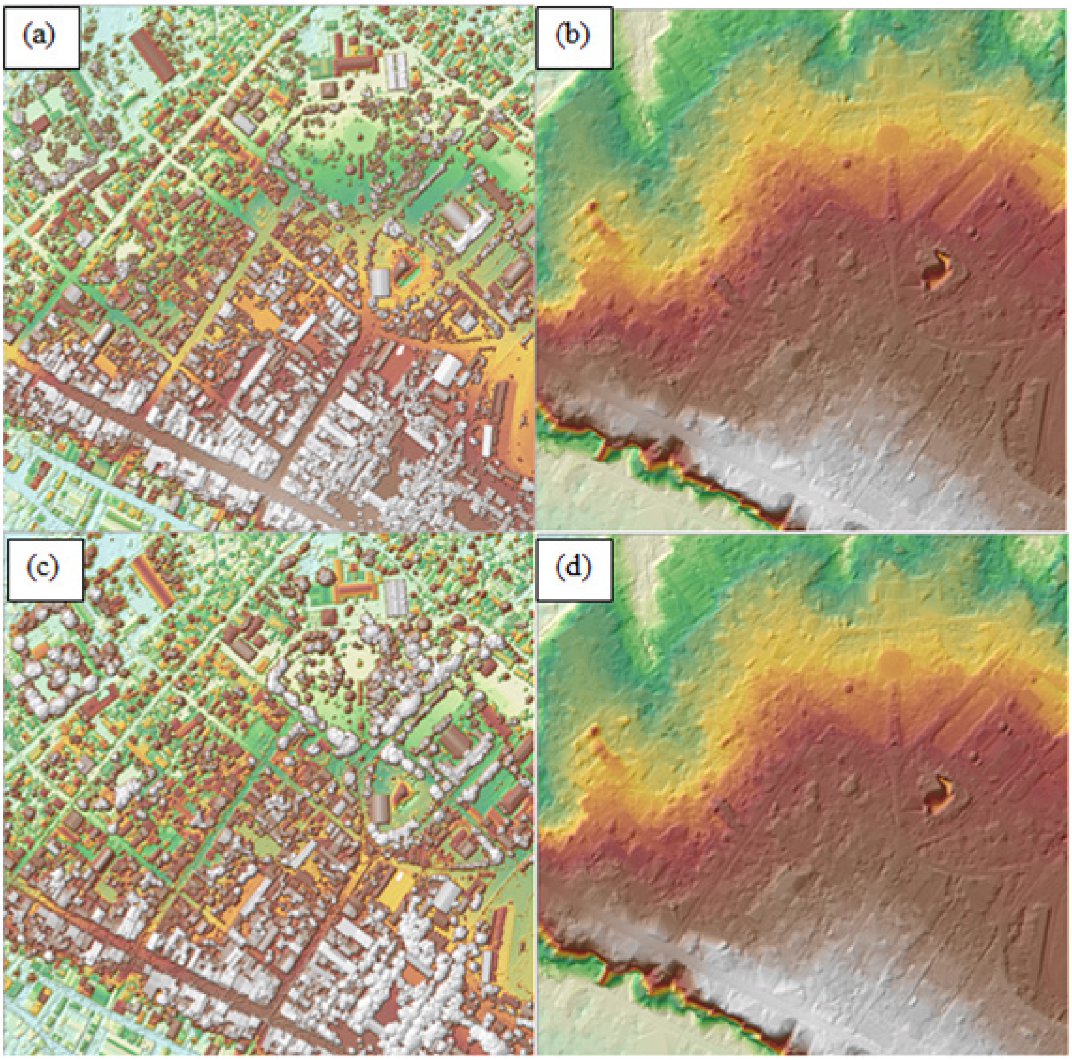


Figure 22. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Malbag floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 1,224 1km by 1km tiles area covered by Malbag floodplain is shown in Figure 23. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Malbag floodplain has a total of 1,038.98 sq.km orthophotogaph coverage comprised of 5,359 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 24.

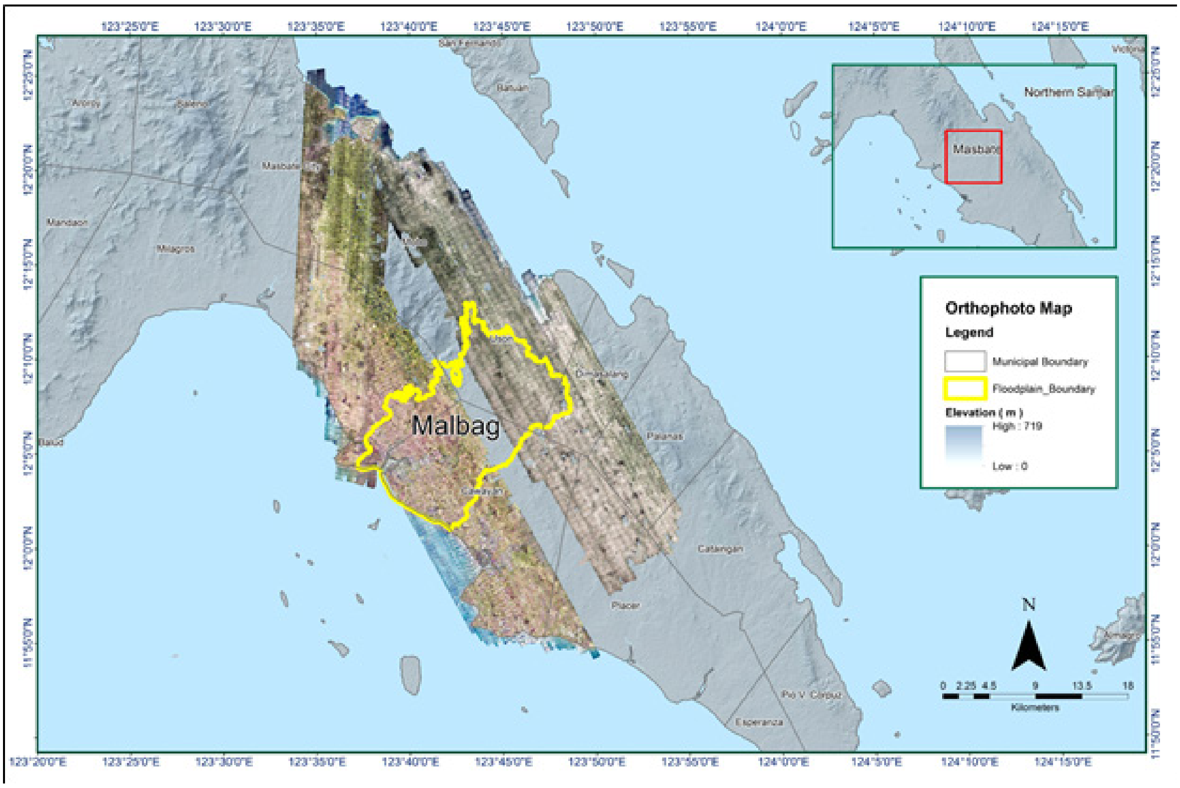


Figure 23. Malbag floodplain with available orthophotographs.

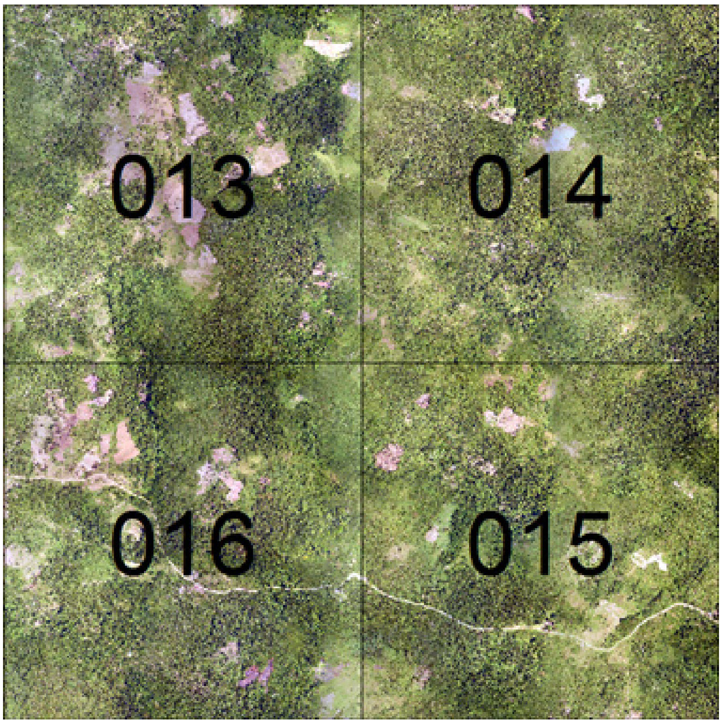


Figure 24. Sample orthophotograph tiles for Malbag floodplain.

3.8 DEM Editing and Hydro-Correction

Three (3) mission blocks were processed for Malbag flood plain. These blocks are composed of Masbate blocks with a total area of 1,128.77 square kilometers. Table 16 shows the name and corresponding area of each block in square kilometers.

Table 16. LiDAR blocks with its corresponding area.

LiDAR Blocks	Area (sq km)
Masbate_Blk32E	272.91
Masbate_Blk32IJ	540.53
Masbate_Blk32H	315.33
TOTAL	1,128.77 sq. km

Portions of DTM before and after manual editing are shown in Figure 25. The bridge (Figure 25a) is considered to be an impedance to the flow of water along the river and has to be removed (Figure 25b) in order to hydrologically correct the river. Also, the paddy field (Figure 25c) has been misclassified and removed during classification process and has to be retrieved to complete the surface (Figure 25d) to allow the correct flow of water.

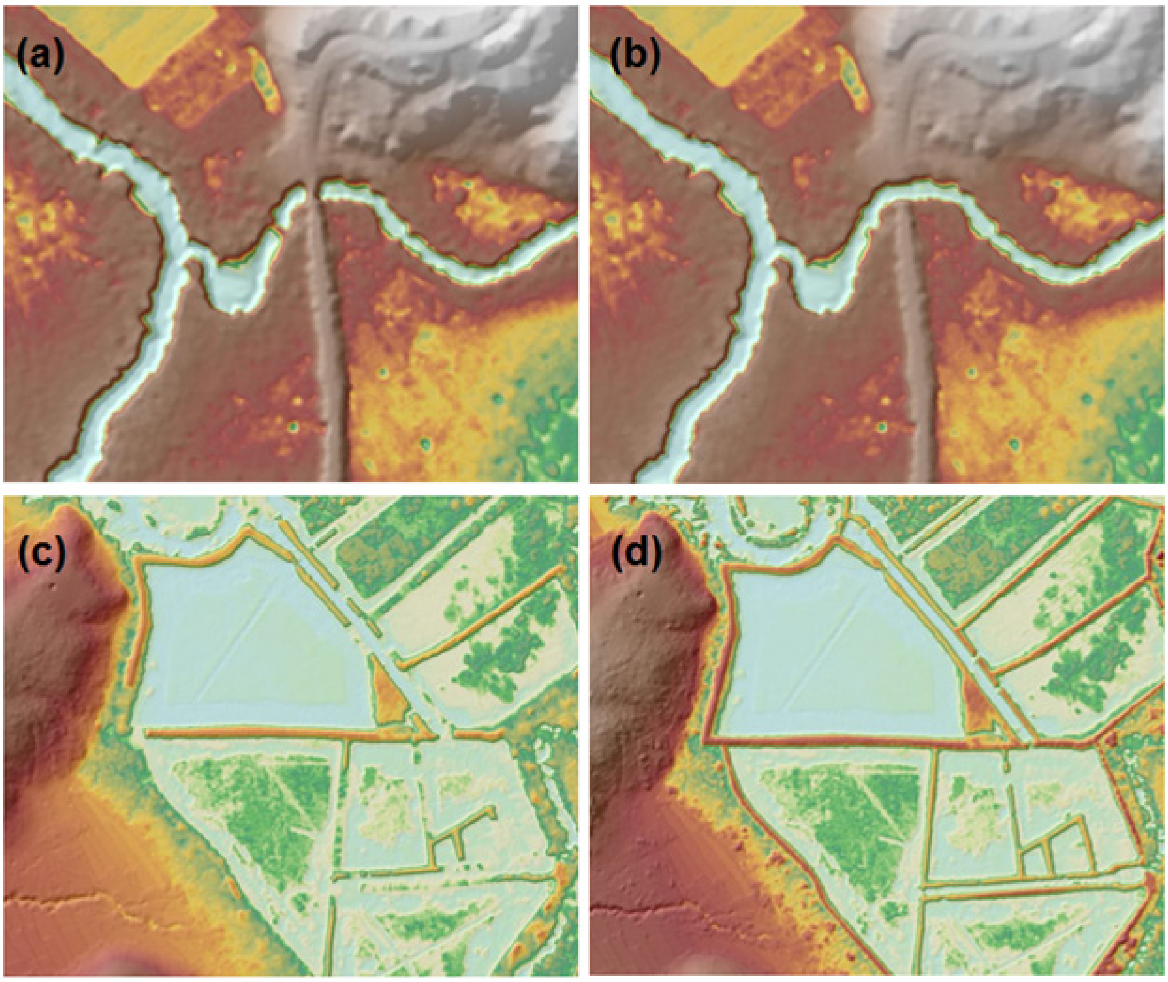


Figure 25. Portions in the DTM of Malbag floodplain – a bridge before (a) and after (b) manual editing; and paddy field before (c) and after (d) data retrieval

3.9 Mosaicking of Blocks

Masbate_Blk32D was used as the reference block at the start of mosaicking because it was referred to a base station with an acceptable order of accuracy. Table 17 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Malbag floodplain is shown in Figure 26. The entire Malbag flood plain is 98.50% covered by LiDAR data while portions with no LiDAR data were patched with the available IFSAR data.

Table 17. Shift Values of each LiDAR Block of Malbag floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
Masbate_Blk32E	0.00	0.00	1.61
Masbate_Blk32IJ	0.00	0.00	1.67
Masbate_Blk32H	0.00	0.00	1.64

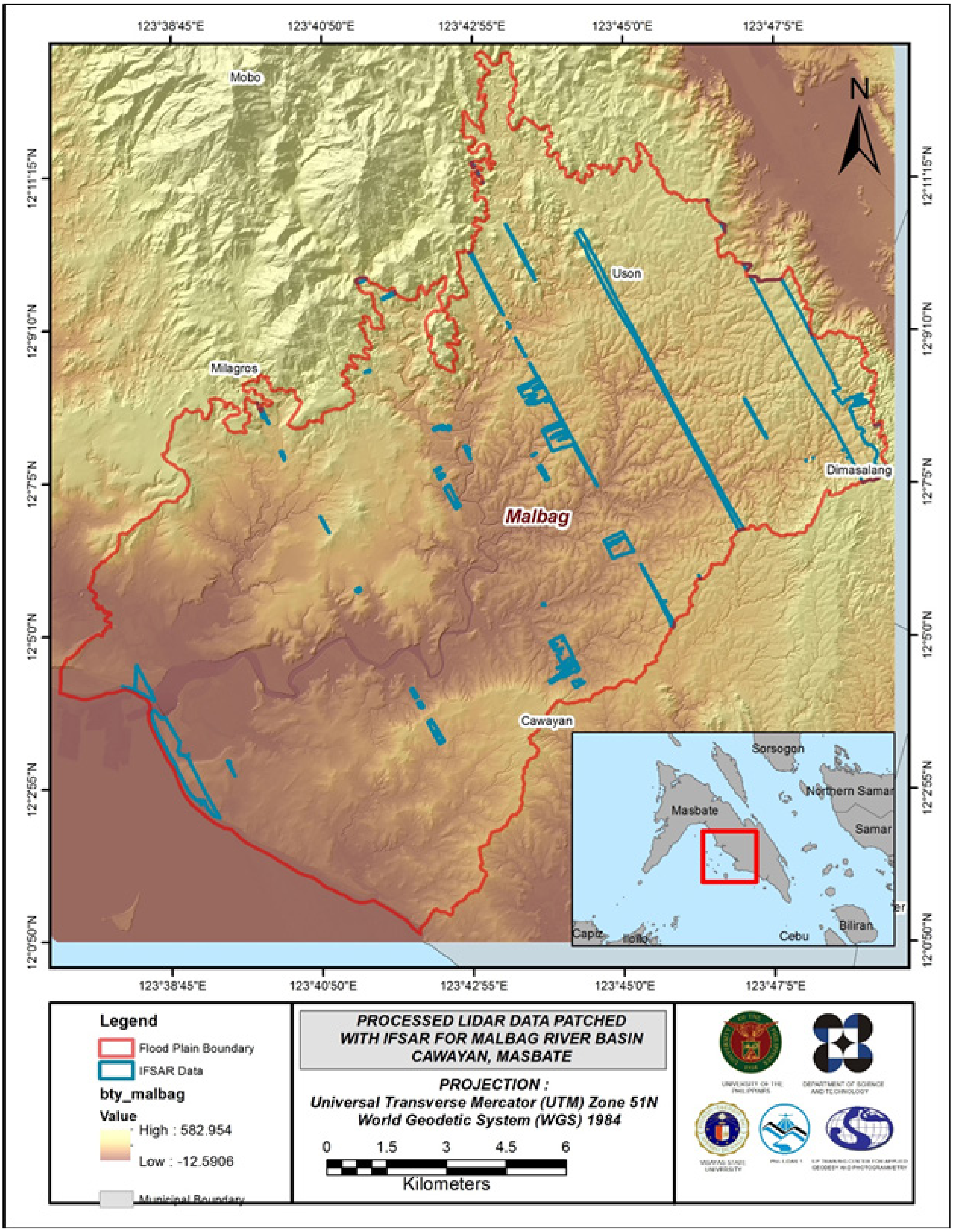


Figure 26. Map of Processed LiDAR Data for Malbag Flood Plain

3.10 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Malbag to collect points with which the LiDAR dataset is validated is shown in Figure 27. A total of 17,580 survey points were used for calibration and validation of Malbag LiDAR data. Random selection of 80% of the survey points, resulting to 14,064 points, were used for calibration.

A good correlation between the mosaicked LiDAR DTM and ground survey elevation values is shown in Figure 28. 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 3.22 meters with a standard deviation of 0.13 meters. Calibration of Malbag LiDAR data was done by subtracting the height difference value, 0.16 meters, to Malbag mosaicked LiDAR data. Table 18 shows the statistical values of the compared elevation values between Malbag LiDAR data and calibration data. These values were also applicable to the Malbag DEM.

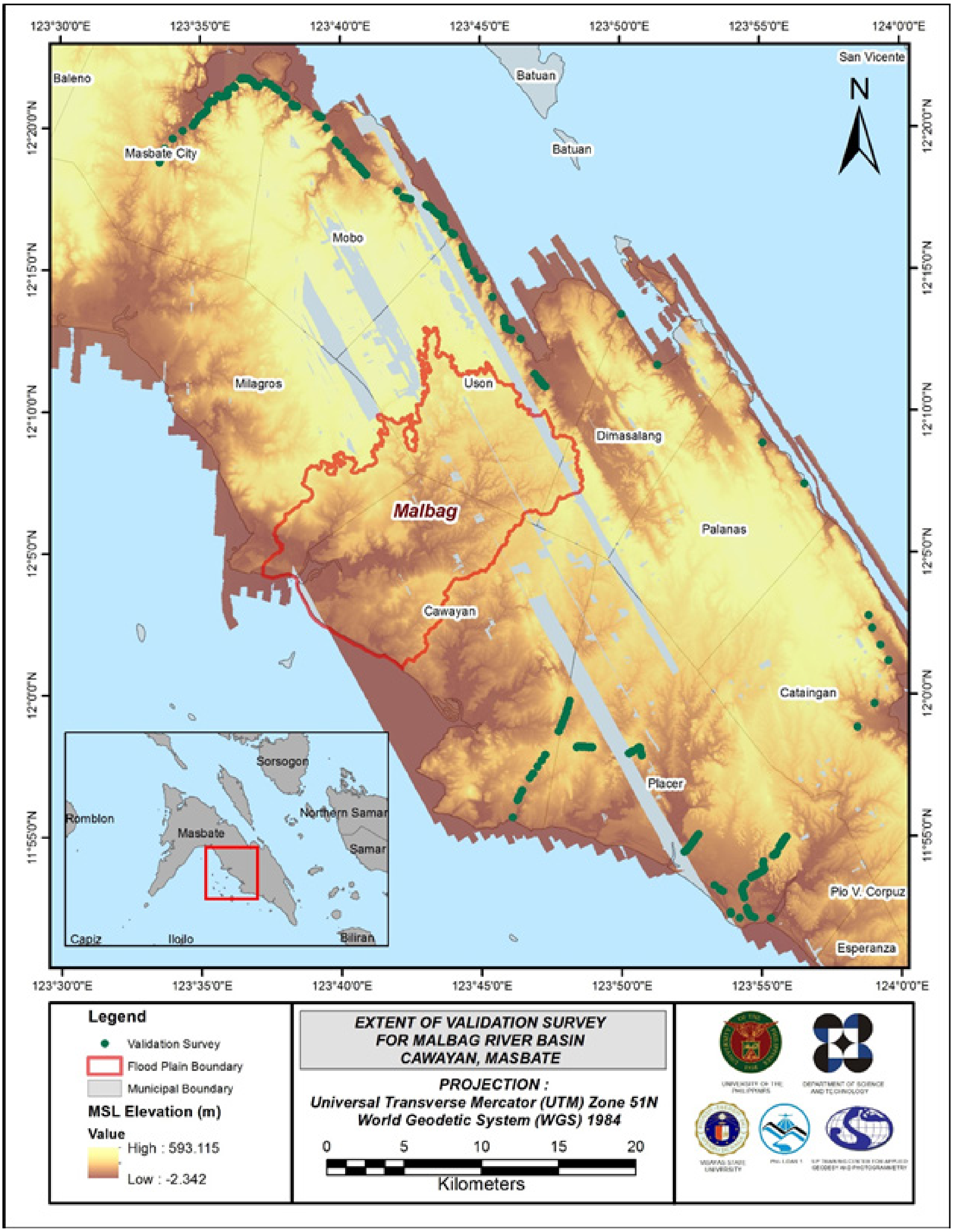


Figure 27. Map of Malbag Flood Plain with validation survey points in green.

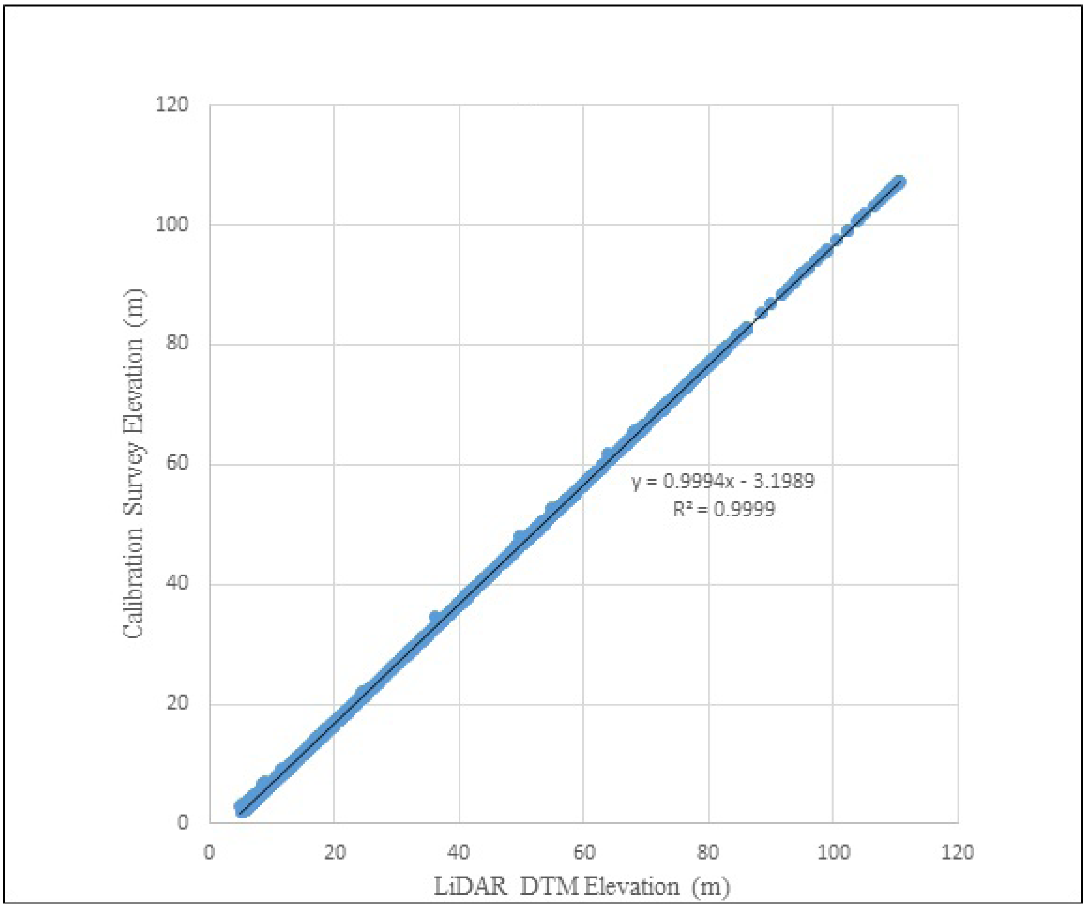


Figure 28. Correlation plot between calibration survey points and LiDAR data.

Table 18. Calibration Statistical Measures

Calibration Statistical Measures	Value (meters)
Height Difference	3.22
Standard Deviation	0.16
Average	-3.22
Minimum	-3.53
Maximum	-1.66

A total of 3,516 survey points lie within Malbag flood plain and were used for the validation of the calibrated Malbag 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 29. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.10 meters with a standard deviation of 0.07 meters, as shown in Table 19.

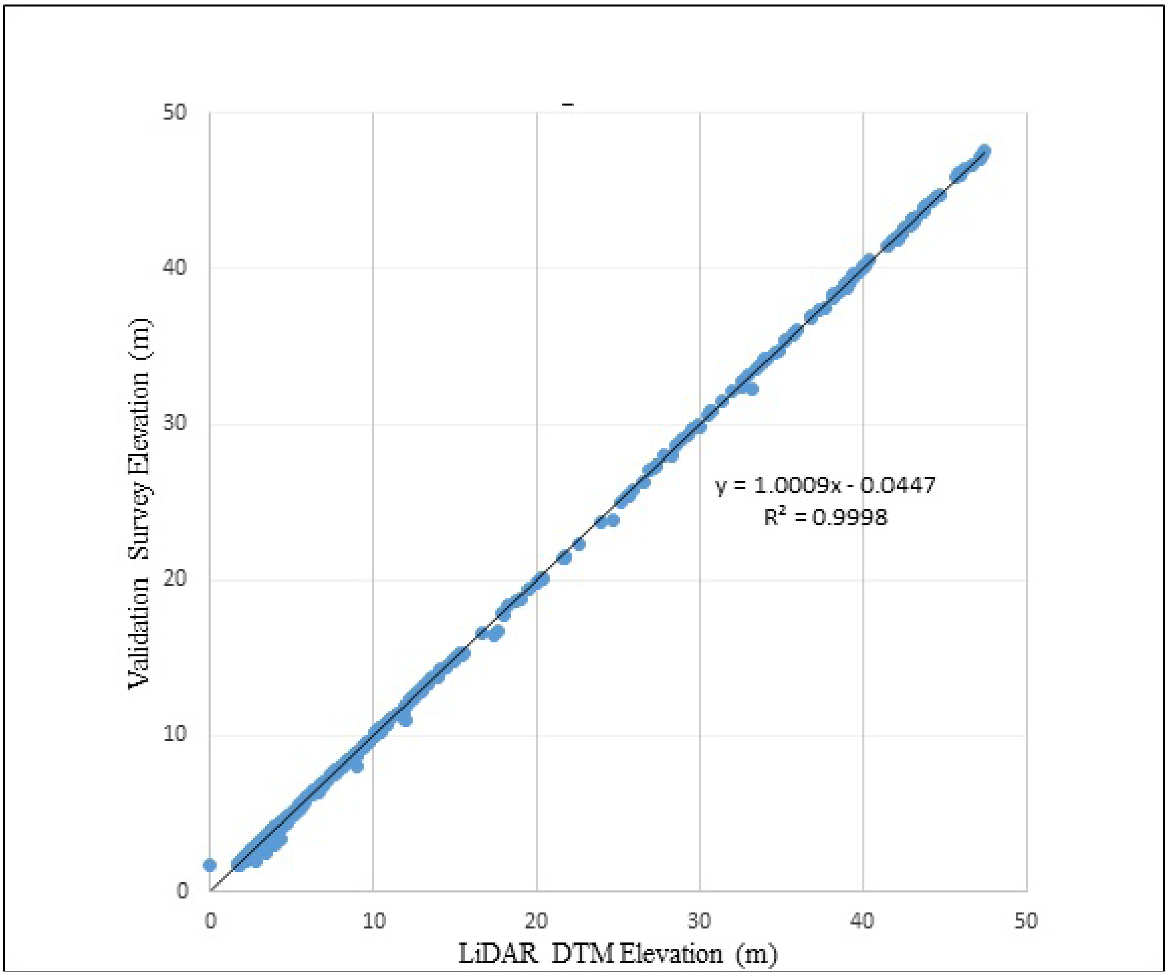


Figure 29. Correlation plot between validation survey points and LiDAR data

Table 19. Validation statistical measures

Validation Statistical Measures	Value (meters)
RMSE	0.104
Standard Deviation	0.069
Average	-0.078
Minimum	-0.216
Maximum	0.059

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and zigzag data was available for Malbag with 22,353 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 0.72 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Malbag integrated with the processed LiDAR DEM is shown in Figure 30.

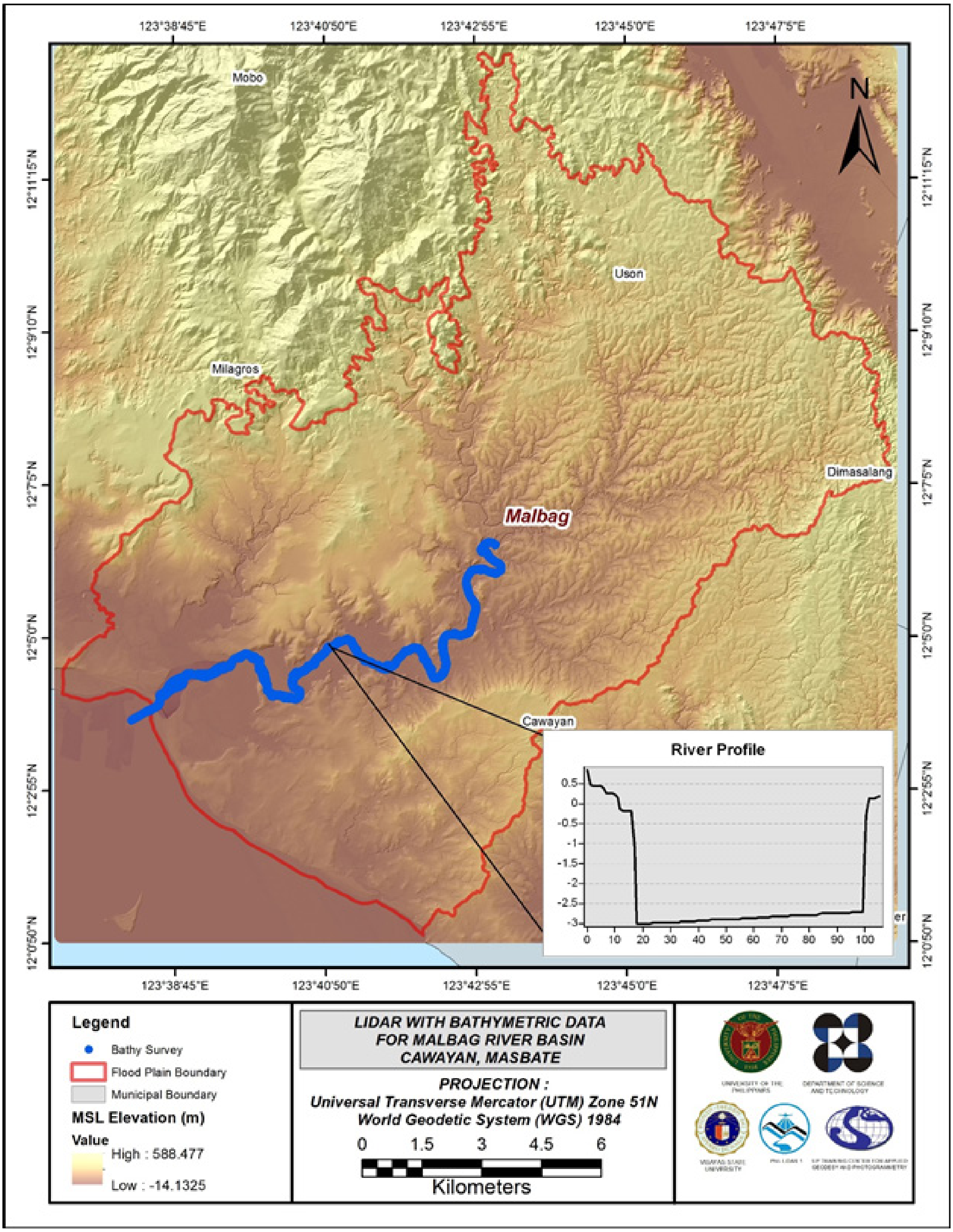


Figure 30. Map of Malbag Flood Plain with bathymetric survey points shown in blue.

3.12 Feature Extraction

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

3.12.1 Quality Checking of Digitized Features' Boundary

Malbag floodplain, including its 200 m buffer, has a total area of 231.49 sq km. For this area, a total of 7.0 sq km, corresponding to a total of 891 building features, are considered for QC. Figure 31 shows the QC blocks for Malbag floodplain.

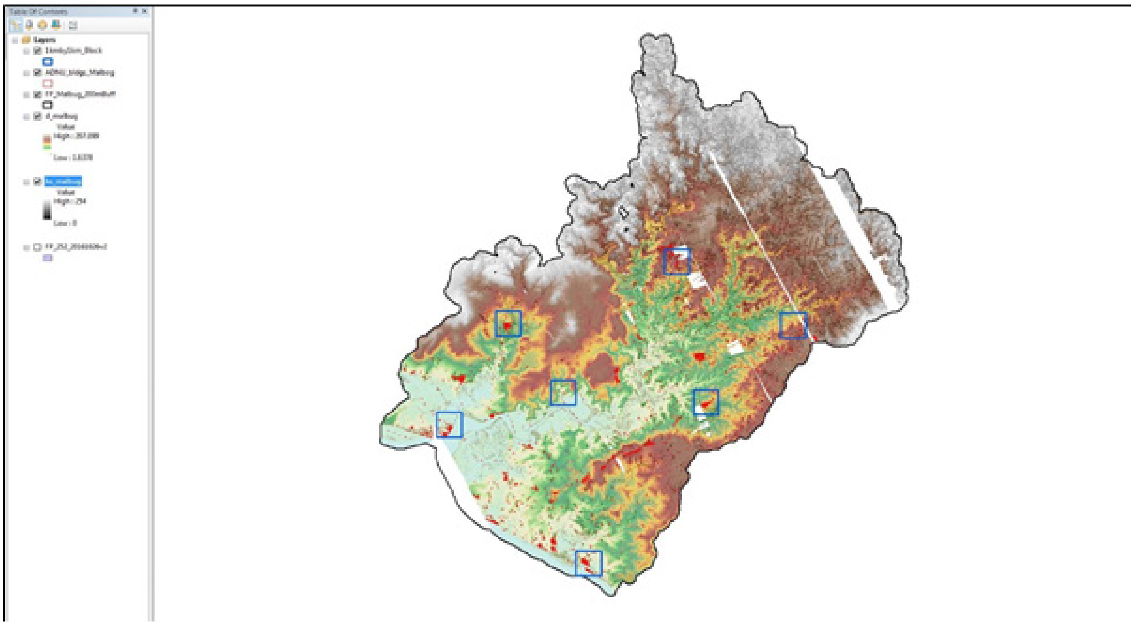


Figure 31. QC blocks for Malbag building features.

Quality checking of Malbag building features resulted in the ratings shown in Table 20.

Table 20. Table 20. Quality Checking Ratings for Malbag Building Features.

Floodplain	Completeness	Correctness	Quality	Remarks
Malbag	98.66	98.88	87.99	PASSED

3.12.2 Height Extraction

Height extraction was done for 5,487 building features in Malbag floodplain. Of these building features, 553 was filtered out after height extraction, resulting to 4,934 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 12.39 m.

3.12.3 Feature Attribution

Feature Attribution was done for 4,934 building features in Malbag Floodplain with the use of participatory mapping and innovations. The approach used in participatory mapping undergoes the creation of feature extracted maps in the area and presenting spatial knowledge to the community with the premise that the local community in the area are considered experts in determining the correct attributes of the building features in the area.

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

Table 21 summarizes the number of building features per type. On the other hand, Table 22 shows the total length of each road type, while Table 23 shows the number of water features extracted per type.

Table 21. Building features extracted for Malbag Floodplain

Facility Type	No. of Features
Residential	4810
School	89
Market	1
Agricultural/Agro-Industrial Facilities	1
Medical Institutions	5
Barangay Hall	7
Military Institution	0
Sports Center/Gymnasium/Covered Court	0
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	2
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	0
Water Supply/Sewerage	0
Religious Institutions	14
Bank	0
Factory	0
Gas Station	0
Fire Station	0
Other Government Offices	3
Other Commercial Establishments	2
Total	4,934

Table 22. Total Length of Extracted Roads for Malbag Floodplain.

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Malbag	87.66	0	0	0	0	87.66

Table 23. Number of extracted water bodies for Malbag Floodplain

Floodplain	Water Body Type					Total
	Rivers/ Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Malbag	1	209	0	0	0	210

A total of 7 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 32 shows the Digital Surface Model (DSM) of Malbag floodplain overlaid with its ground features

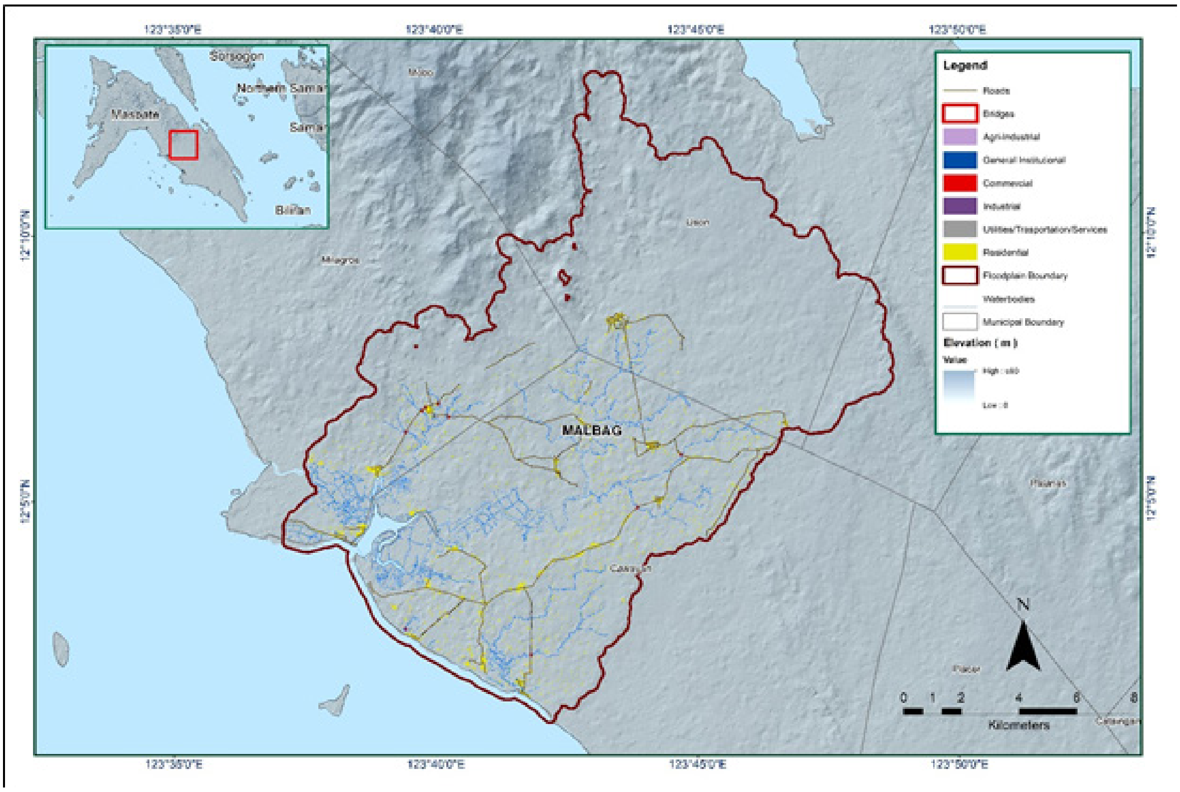


Figure 32. Extracted features for Malbag floodplain.

CHAPTER 4: LIDAR VALIDATION SURVEY AND MEASUREMENTS OF THE MALBAG 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

DVBC conducted a field survey in Malbag River on February 5 – 19, 2017 with the following scope of work: reconnaissance; control survey; cross-section and as-built survey of Malbag Culvert in Brgy. San Vicente, Municipality of Cawayan; validation points acquisition of about 122.19 km covering the Malbag River Basin area; and bathymetric survey from its upstream in Brgy. Lague-Lague, Municipality of Cawayan down to the mouth of the river located in Brgy. Malbag, in the same Municipality, with an approximate length of 16.463 km using Ohmex™ single beam echo sounder and Trimble® SPS 882 GNSS PPK survey technique (Figure 33).

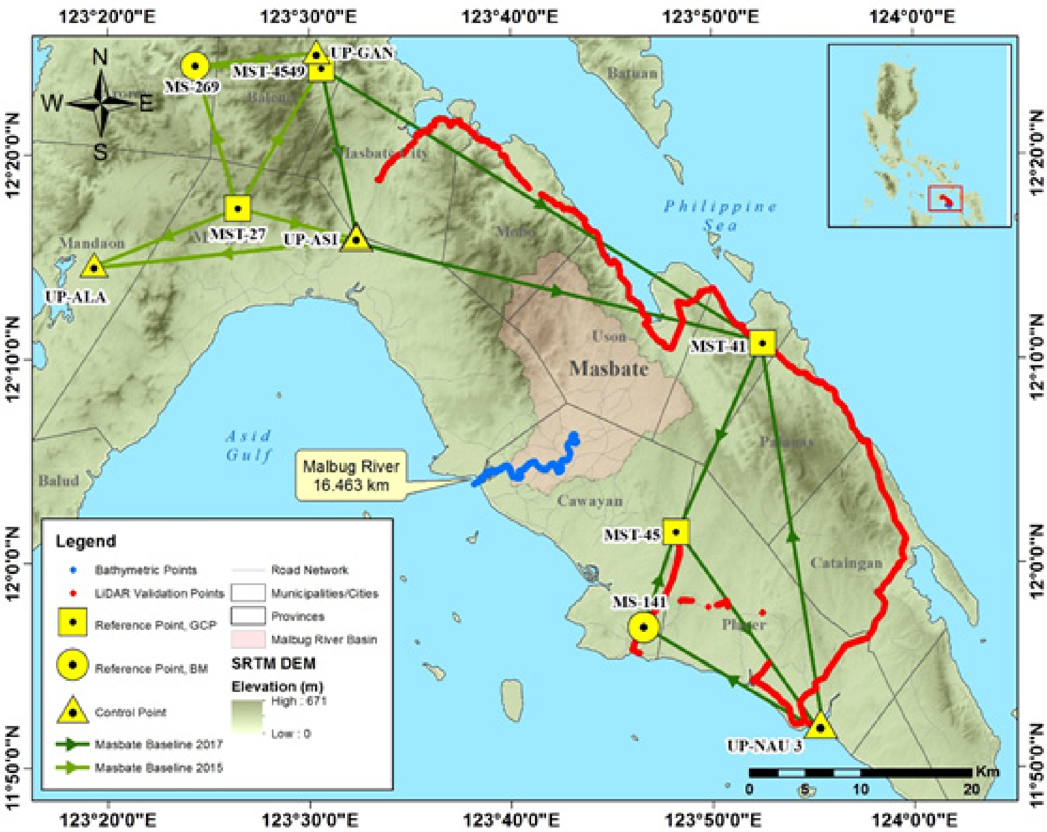


Figure 33. Malbag River Survey Extent

4.2 Control Survey

A GNSS network was established for a previous PHIL-LIDAR 1 DVBC fieldwork in Mandaon, Baleno, and Asid Rivers in Masbate on December 12, 2015 occupying the reference and control points MST-27, a 2nd order GCP in Brgy. Matiporon, Municipality of Milagros; MS-269, a 1st order Benchmark in Brgy. Luy-A, Municipality of Aroroy; MST-4549, a 4th order GCP in Brgy. Canjunday, Municipality of Baleno; UP-ALA, a UP established control point in Brgy. Tagpu, Municipality of Mandaon; UP-ASI, a UP established control point in Brgy. Cayabon, Municipality of Milagros; and, UP-GAN, a UP established control point in Brgy. Gangao, Municpality of Baleno, all in the province of Masbate.

The GNSS network used for Malbag River Basin is composed of three (3) loops established on February 14, 2017 occupying the following reference points: MST-4549, a 4th order GCP in Brgy. Canjunday, Municipality of Baleno; MS-141, a 1st order BM in Brgy. San Vicente, Municipality of Cawayan; and, UP-ASI, a UP established control point in Brgy. Cayabon, Municipality of Milagros, all in the province of Masbate.

A UP control point, namely UP-NAU3 was established in Brgy. Taboc, Municipality of Placer, Masbate. NAMRIA established control points namely: MST-41, located in Brgy. Gaid, Municipality of Dimasalang, Masbate; and, MST-45, located in Brgy. Villahermosa, Municipality of Cawayan, Masbate, were also occupied to use as marker during the survey.

The summary of reference and control points and its location is summarized in Table 24 while the GNSS network established is illustrated in Figure 34.

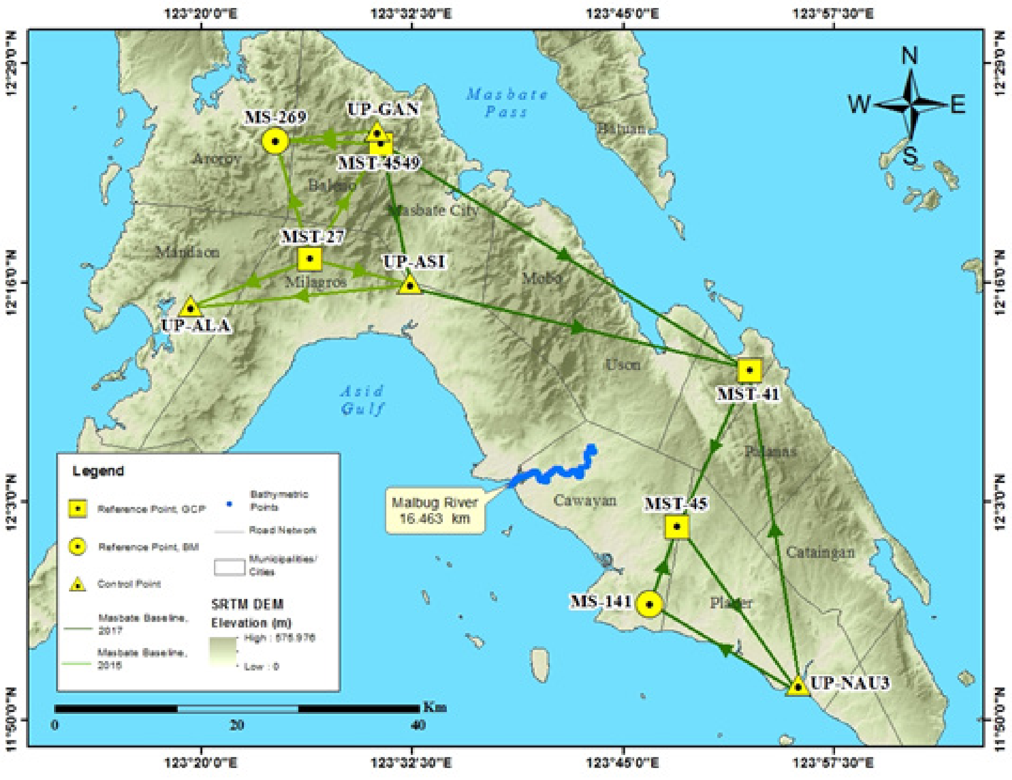


Figure 34. GNSS Network covering Malbag River

Table 24. List of Reference and Control Points occupied for Malbag River Survey

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoid Height (m)	BM Ortho (m)	Date Established
MST-4549	4th order, GCP	12°24'13.29041"	123°30'36.98735"	76.969	21.829	2013
MST-41	Used as Marker	-	-	64.943	-	2007
MST-45	Used as Marker	-	-	73.746	-	2007
MS-141	1st order, BM	-	-	71.378	13.221	2007
UP-ASI	UP established	12°15'59.72358"	123°32'20.76940"	66.451	10.476	2015
UP-NAU3	UP established	-	-	60.4	-	2017

The GNSS set-ups on recovered reference points and established control points in Malbag River are shown in Figure 35 to Figure 40.

Figure 35. GNSS base set up, Trimble® SPS 985, at MST-4549, located in Brgy. Canjunday, Municipality of Baleno, Masbate.

Figure 36. GNSS receiver setup, Trimble® SPS 985, at MST-41, located in Brgy. Gaid, Municipality of Dimasalang, Masbate

Figure 37. GNSS receiver setup, Trimble® SPS 985, at MST-45, located in Brgy. Villahermosa, Municipality of Cawayan, Masbate

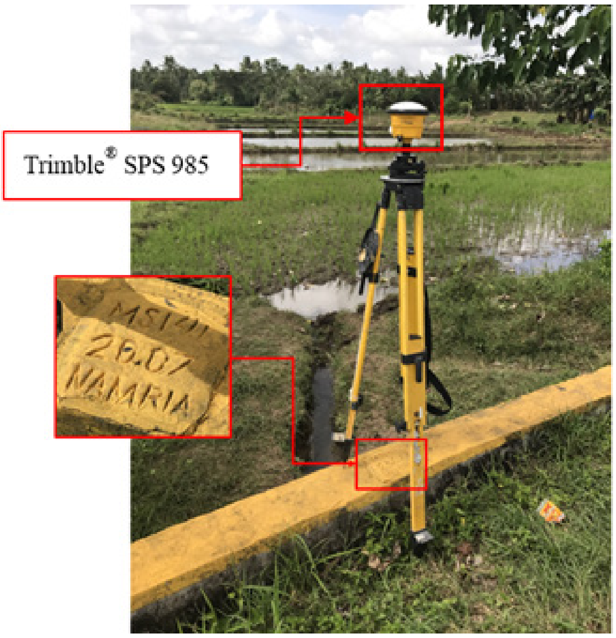


Figure 38. GNSS receiver setup, Trimble® SPS 985, at MS-141, located in Brgy. San Vicente, Municipality of Cawayan, Masbate

Figure 39. GNSS receiver setup, Trimble® SPS 985, at UP-ASI, located Brgy. Cayabon, Municipality of Milagros, Masbate

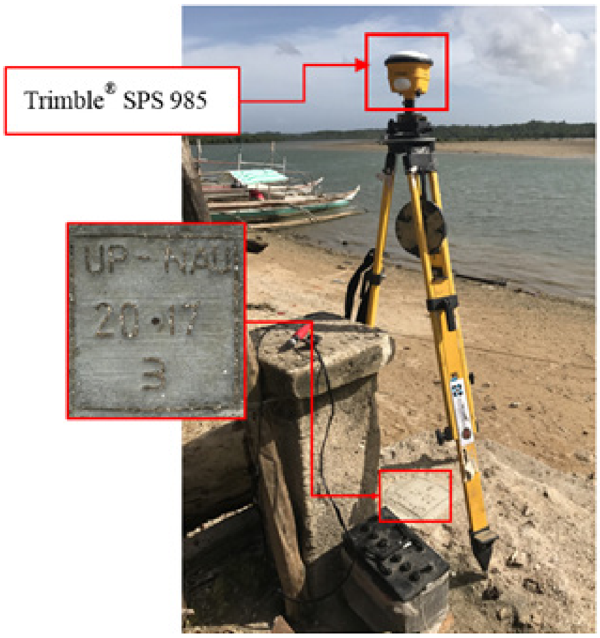


Figure 40. GNSS receiver setup, Trimble® SPS 985, at UP-NAU3, located in Brgy. Taboc, Municipality of Placer, Masbate

4.3 Baseline Processing

GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/- 20 cm and +/- 10 cm requirement, respectively. In case where one or more baselines did not meet all of these criteria, masking is performed. Masking is done by removing/masking portions of these baseline data using the same processing software. It is repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, resurvey is initiated. Baseline processing result of control points in Malbag River Basin is summarized in Table 25 generated by TBC software.

Table 25. Baseline Processing Summary Report for Malbag River Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
UP-NAU 3 --- MS-141 (B6)	08-28-16	Fixed	0.004	0.019	298°53'38"	18166.522	11.403
MS-141 --- MST-45 (B3)	08-28-16	Fixed	0.004	0.016	18°57'41"	9036.475	2.254
MST-4549 --- UPASI (B8)	08-28-16	Fixed	0.003	0.014	168°18'59"	15487.632	-10.554
UP-NAU 3 --- MST-41 (B10)	08-28-16	Fixed	0.003	0.015	351°30'42"	34736.682	4.574
MST-45 --- UP-NAU 3 (B4)	08-28-16	Fixed	0.003	0.014	143°09'49"	21636.574	-13.668
MST-41 --- MST-45 (B11)	08-28-16	Fixed	0.004	0.020	204°41'47"	18750.039	9.089
UP-ASI --- MST-41 (B9)	08-28-16	Fixed	0.003	0.016	104°48'50"	37813.501	-2.533
MST-4549 --- MST- 41 (B7)	08-28-16	Fixed	0.004	0.019	122°01'41"	46820.813	-13.099

As shown Table 25 a total of eight (8) baselines were processed with reference points MST-4549 and UP-ASI held fixed for coordinate values; and, MST-4549, MS-ASI, and UP-ASI fixed for elevation values. All of them passed the required accuracy.

4.4 Network Adjustment

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

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

Where:

x_e is the Easting Error,

y_e is the Northing Error, and

z_e is the Elevation Error

for each control point. See the Network Adjustment Report shown in Table 26 to Table 29 for complete details.

The six (6) control points, MST-4549, MST-41, MST-45, MS-141, UP-ASI, and, UP-NAU3 were occupied and observed simultaneously to form a GNSS loop. Coordinates of MST-4549 and UP-ASI; and elevation values of MST-4549, MS-141, and UP-ASI were held fixed during the processing of the control points as presented in Table 26. Through these reference points, the coordinates and elevation of the unknown control points will be computed.

Table 26. Control Point Constraints

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
MS-141	Grid				Fixed
MST-4549	Grid	Fixed	Fixed		Fixed
UP-ASI	Grid	Fixed	Fixed		Fixed
Fixed = 0.000001 (Meter)					

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 27. The fixed controls MST-4549 and UP-ASI have no values for grid errors while MST-4549, MS-141, and UP-ASI have no value for elevation error.

Table 27. Adjusted Grid Coordinates

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
MST-4549	555464.635	?	1371246.784	?	21.829	?	ENe
MST-41	595192.614	0.004	1346499.397	0.004	7.564	0.045	
MST-45	587415.558	0.005	1329444.427	0.004	15.819	0.017	
MS-141	584504.292	0.005	1320892.702	0.005	13.221	?	e
UP-ASI	558628.712	?	1356091.508	?	10.476	?	ENe
UP-NAU 3	600433.760	0.007	1312170.323	0.006	1.747	0.024	

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

MST-4549
horizontal accuracy = Fixed
vertical accuracy = Fixed

MST-41
horizontal accuracy = $\sqrt{(0.4)^2 + (0.4)^2}$
= $\sqrt{0.16 + 0.16}$
= 0.57 < 20 cm
vertical accuracy = 4.5 cm < 10 cm

MST-45
horizontal accuracy = $\sqrt{(0.5)^2 + (0.4)^2}$
= $\sqrt{0.25 + 0.16}$
= 0.64 < 20 cm
vertical accuracy = 1.7 cm < 10 cm

MS-141
horizontal accuracy = $\sqrt{(0.5)^2 + (0.5)^2}$
= $\sqrt{0.25 + 0.25}$
= 0.71 < 20 cm
vertical accuracy = Fixed

UP-ASI
horizontal accuracy = Fixed
vertical accuracy = Fixed

UP-NAU 3
horizontal accuracy = $\sqrt{(0.7)^2 + (0.6)^2}$
= $\sqrt{0.49 + 0.36}$
= 0.92 < 20 cm
vertical accuracy = 2.4 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 28. Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
MST-4549	N12°24'13.29041"	E123°30'36.98735"	76.969	?	ENe
MST-41	N12°10'44.36122"	E123°52'30.02722"	64.943	0.045	
MST-45	N12°01'29.95768"	E123°48'11.03606"	73.746	0.017	
MS-141	N11°56'51.84368"	E123°46'33.96438"	71.378	?	e
UP-ASI	N12°15'59.72358"	E123°32'20.76940"	66.451	?	ENe
UP-NAU 3	N11°52'06.32015"	E123°55'19.63857"	60.400	0.024	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 28. Based on the result of the computation, the accuracy condition is satisfied; hence, the required accuracy for the program was met.

The summary of reference and control points used is indicated in Table 29.

Table 29. Reference and control points used and its location (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
MST-4549	4th order, GCP	12°24'13.29041"	123°30'36.98735"	76.969	1371246.784	555464.635	21.829
MST-41	Used as Marker	12°10'44.36122"	123°52'30.02722"	64.943	1346499.397	595192.614	7.564
MST-45	Used as Marker	12°01'29.95768"	123°48'11.03606"	73.746	1329444.427	587415.558	15.819
MS-141	1st order, BM	11°56'51.84368"	123°46'33.96438"	71.378	1320892.702	584504.292	13.221
UP-ASI	UP established	12°15'59.72358"	123°32'20.76940"	66.451	1356091.508	558628.712	10.476
UP-NAU3	UP established	11°52'06.32015"	123°55'19.63857"	60.4	1312170.323	600433.760	1.747

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

Cross-section and as-built survey were conducted on February 10, 2017 at the downstream side of Malbag Culvert in Brgy. San Vicente, Municipality of Cawayan, Masbate as shown in Figure 41. A Trimble® SPS 882 GNSS in PPK survey technique was used as shown in Figure 42.

Figure 41. Malbag Culvert facing upstream

Figure 42. Bridge As-Built Survey using PPK Technique

The cross-sectional line of Malbag Culvert is about 44.3173 m with 38 cross-sectional points using the control point MST-45 as the GNSS base station. The cross-section diagram, location map, and the bridge data form are shown in Figure 43 to Figure 45, respectively.

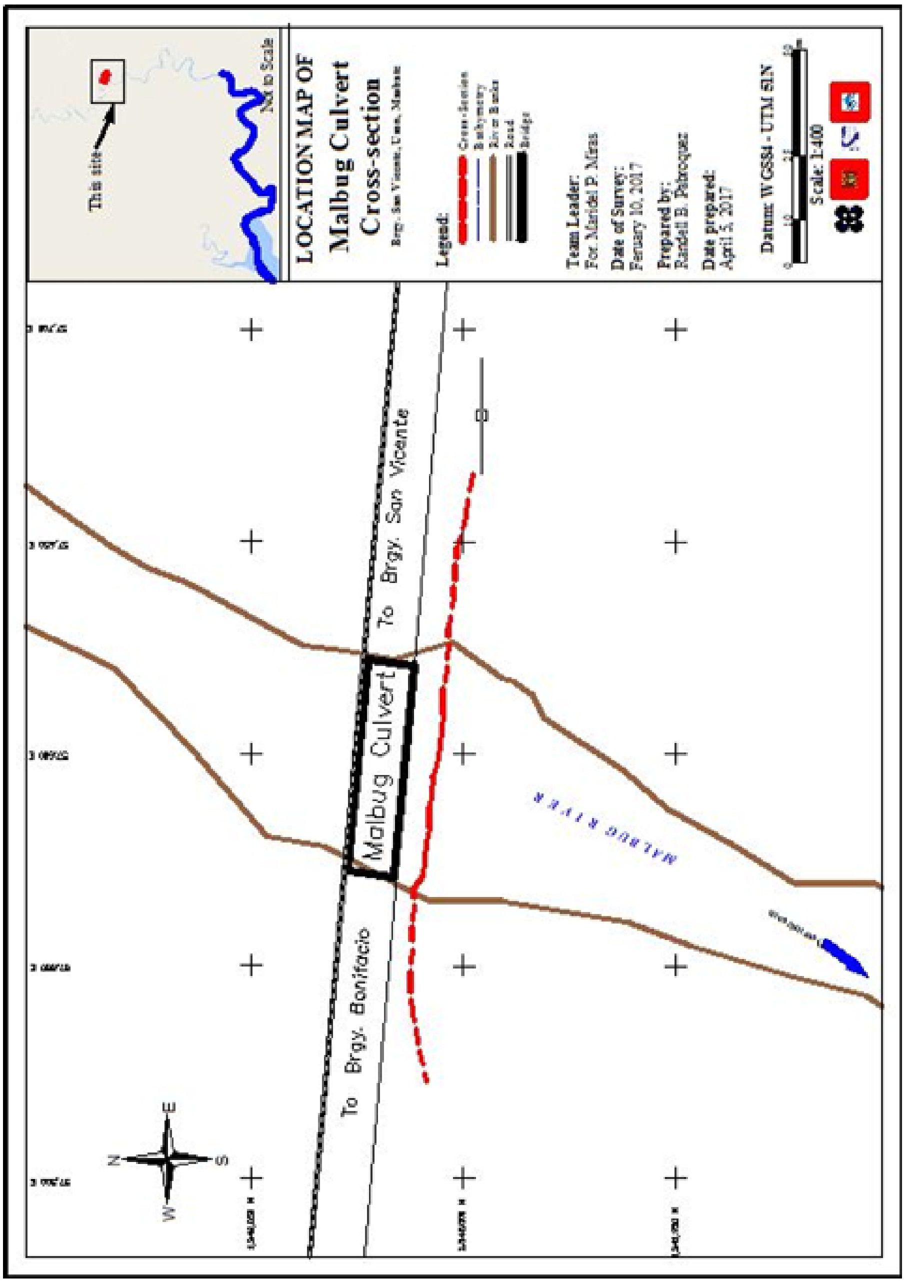


Figure 43. Malbag culvert cross-section location map

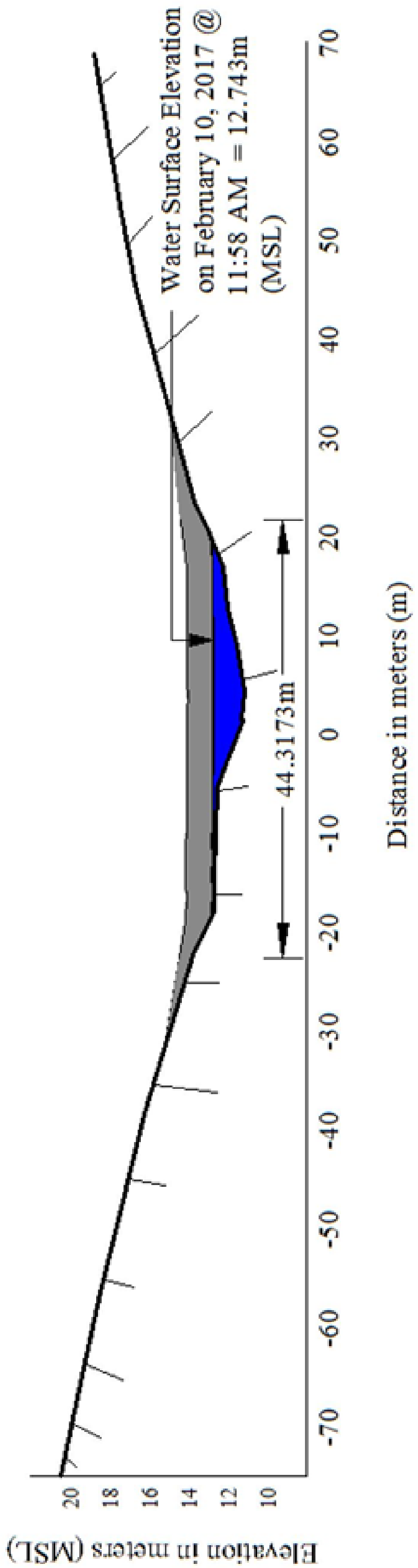


Figure 44. Malbag Culvert cross-section diagram

Bridge Data Form

Bridge Name: Malbug Culvert | Date: February 10, 2017

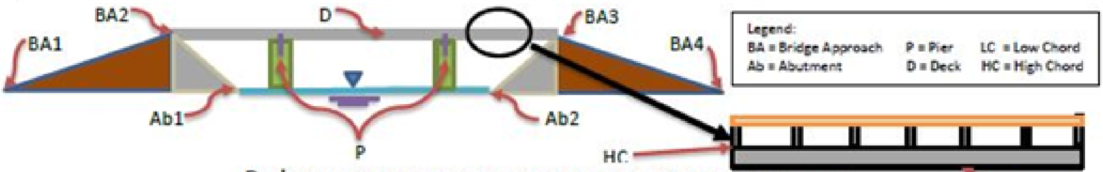
River Name: Malbug River | Time: 11:58 AM

Location (Brgy, City,Region): Brgy. San Vicente, Uson, Masbate

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

Flow condition: average | Weather Condition: fair

Latitude: 12°08'19.75938"N | Longitude: 123°42'48.00157"E



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

Elevation: 14.474 m | Width: 3.630 m | Span (BA3-BA2): Not available

	Station	High Chord Elevation	Low Chord Elevation
1	Not available	Not available	Not available

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

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	Not available	Not available	BA3	Not available	Not available
BA2	Not available	Not available	BA4	Not available	Not available

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

	Station (Distance from BA1)	Elevation
Ab1	Not available	Not available
Ab2	Not available	Not available

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

Shape: Not available | Number of Piers: Not available | Height of column footing: Not available

	Station (Distance from BA1)	Elevation	Pier Diameter
Pier 1	Not available	Not available	Not available

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

DREAM
Disaster Risk and Exposure Assessment for Mitigation

Figure 45. Bridge as-built form of Malbag Culvert

Water surface elevation of Malbag River was determined using a survey grade GNSS receiver Trimble® SPS 882 in PPK survey technique on February 10, 2017 at 11:58 AM with a value of 12.743 m in MSL as shown in Figure 43. This was translated into marking on the Malbag Culvert's deck using the same technique as shown in Figure 46. This will serve as reference for flow data gathering and depth gauge deployment of partner HEI responsible for Malbag river, the Ateneo de Naga University.

Figure 46. Water-level markings on Malbag Culvert

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on January 28, February 7 and 13, 2017 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted on top of a vehicle as shown in Figure 47. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The antenna height was 1.884 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-NAU3, MST-41, and UP-ASI occupied as the GNSS base stations.

Figure 47. Validation points acquisition survey set up along Malbug River Basin

The conducted survey on January 28, 2017 started from Brgy. Libas, Municipality of Placer going east, traversing the Municipality of Cataingan. On February 7, 2017 the survey continued from the Municipality of Cataingan going west to the Municipality of Mobo; and on February 13, 2017, the survey started in Masbate City going east to the Municipality of Mobo until it ended in Brgy. Marintoc, Municipality of Mobo. A total of 16,824 points were gathered with approximate length of 122.19 km, as illustrated in the map in Figure 48.

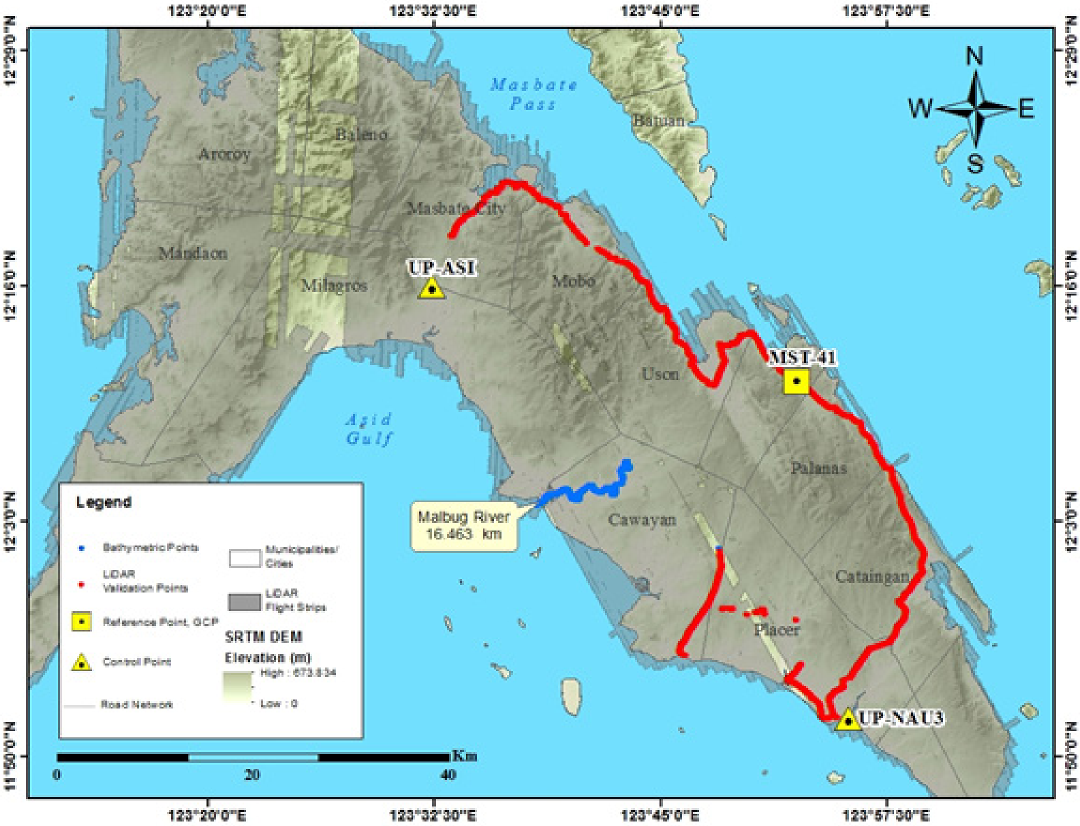


Figure 48. Validation point acquisition survey of Malbag River Basin

4.7 River Bathymetric Survey

Bathymetric survey was executed on February 9, 10, and 11, 2017 using an Ohmex™ single beam echo sounder and Trimble® SPS 882 in GNSS PPK survey technique in continuous topo mode as illustrated in Figure 49. The survey started in the upstream part of the river in Brgy. Lague-Lague, Municipality of Cawayan with coordinates 12°04'30.66113"N, 123°42'59.60994"E, and ended at the mouth of the river in Brgy. Malbag, in the same Municipality with coordinates 12°04'30.66113"N, 123°38'10.22429"E. The control MST-45 was used as GNSS base station all throughout the entire survey.

Figure 49. Bathymetric survey using Ohmex™ single beam echo sounder in Malbag River

Manual bathymetric survey was executed on February 11, 2017 using Trimble® SPS 882 in GNSS PPK survey technique in continuous topo mode. The survey covered 400 meters in the upstream with coordinates 12°06'15.43430"N, 123°43'11.34474"E up to where the bathymetric survey started, both in Brgy. Lague-Lague, Municipality of Cawayan. The control point MST-45 was used as the GNSS base station throughout the entire survey.

The bathymetric survey for Malbag River gathered a total of 47,313 points covering 16.463 km of the river traversing Brgy. Lague-Lague, Municipality of Cawayan, Masbate downstream to Brgy. Malbag, in the same Municipality. A CAD drawing was also produced to illustrate the riverbed profile of Malbag River. As shown in Figure 51, the highest and lowest elevation has a 8.929-m difference for Malbag River. The highest elevation observed was 0.986 m above MSL located at the upstream part of Malbag river; while the lowest was –9.915 m below MSL located in the downstream portion of the river.

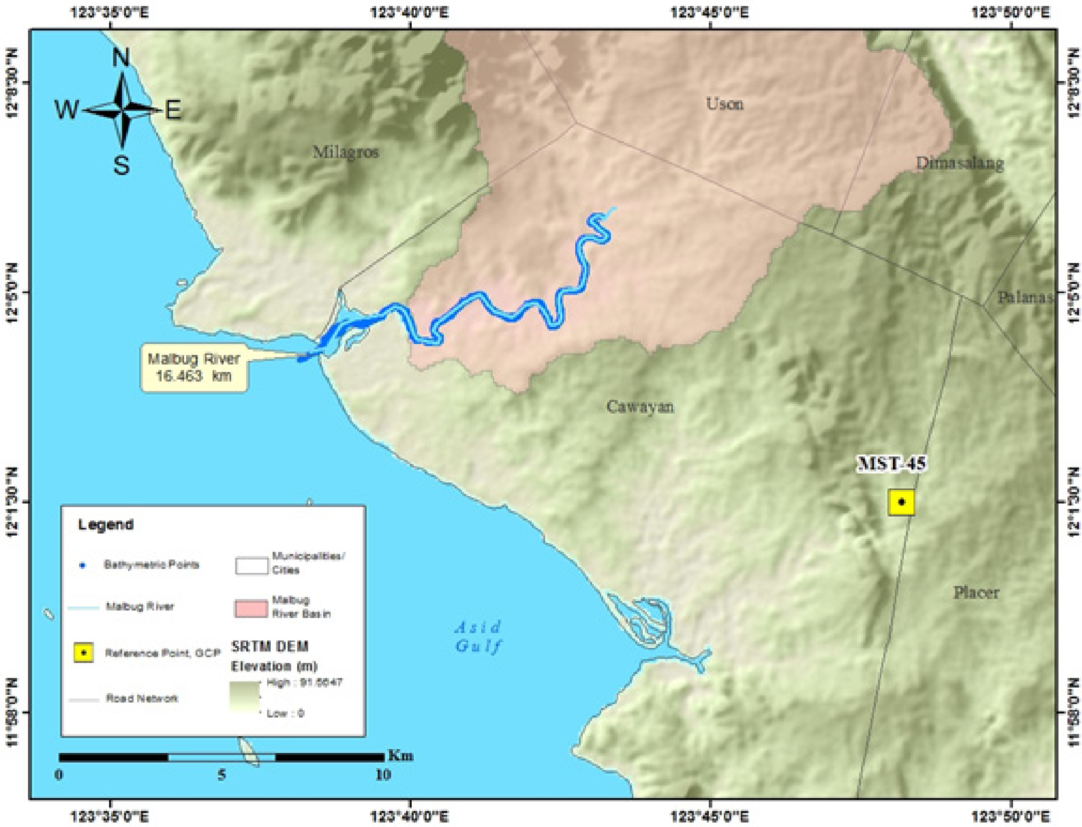


Figure 50. Bathymetric survey of Malbag River

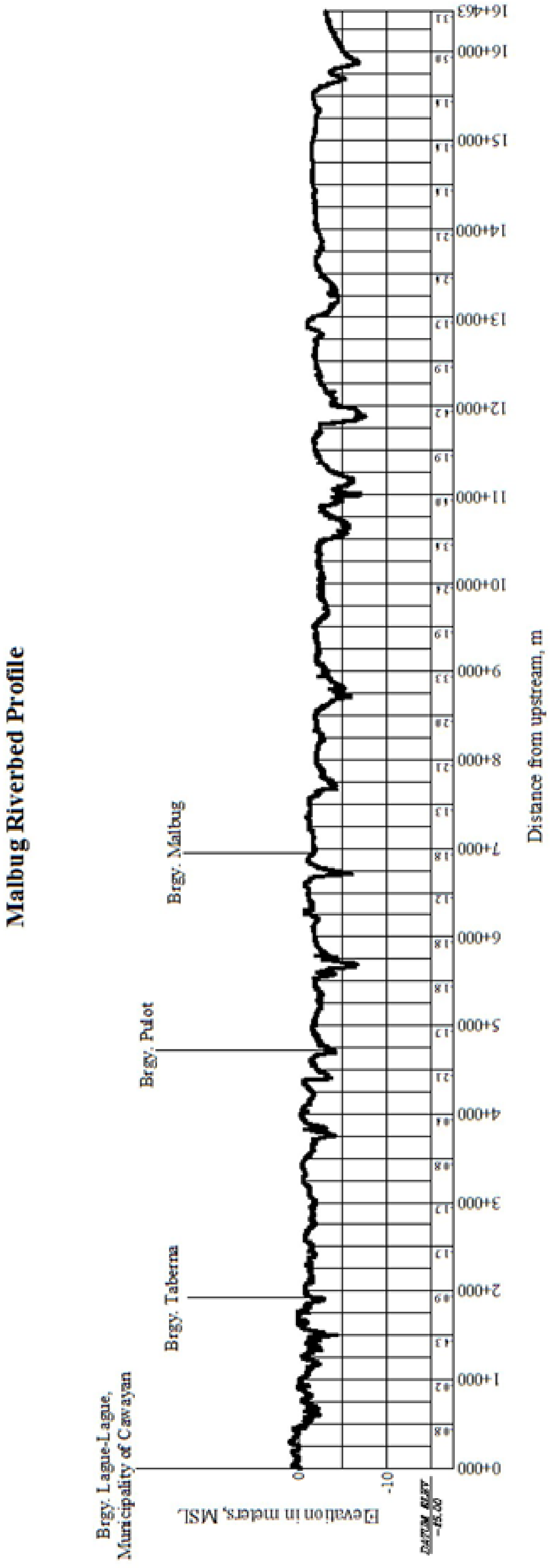


Figure 51. Malbag Riverbed Profile

CHAPTER 5: FLOOD MODELLING AND MAPPING

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

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

5.1 Data Used for Hydrologic Modeling

5.1.1. Hydrometry and Rating Curves

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

5.1.2. Precipitation

Precipitation data was taken from one rain gauge (RGs) installed by the ADNU-FMC team. The rain gauge was installed at Brgy. Uson (Figure 52). The precipitation data collection started from February 16, 2017 at 10:30 PM to February 17, 2017 at 10:30 PM with a 10-minute recording interval.

The total precipitation for this event in the deployed rain gauge is 276.8mm. It has a peak rainfall of 5mm on February 17, 2017 at 2:50 AM. The lag time between the peak rainfall and discharge is 3 hours and 30 minutes.

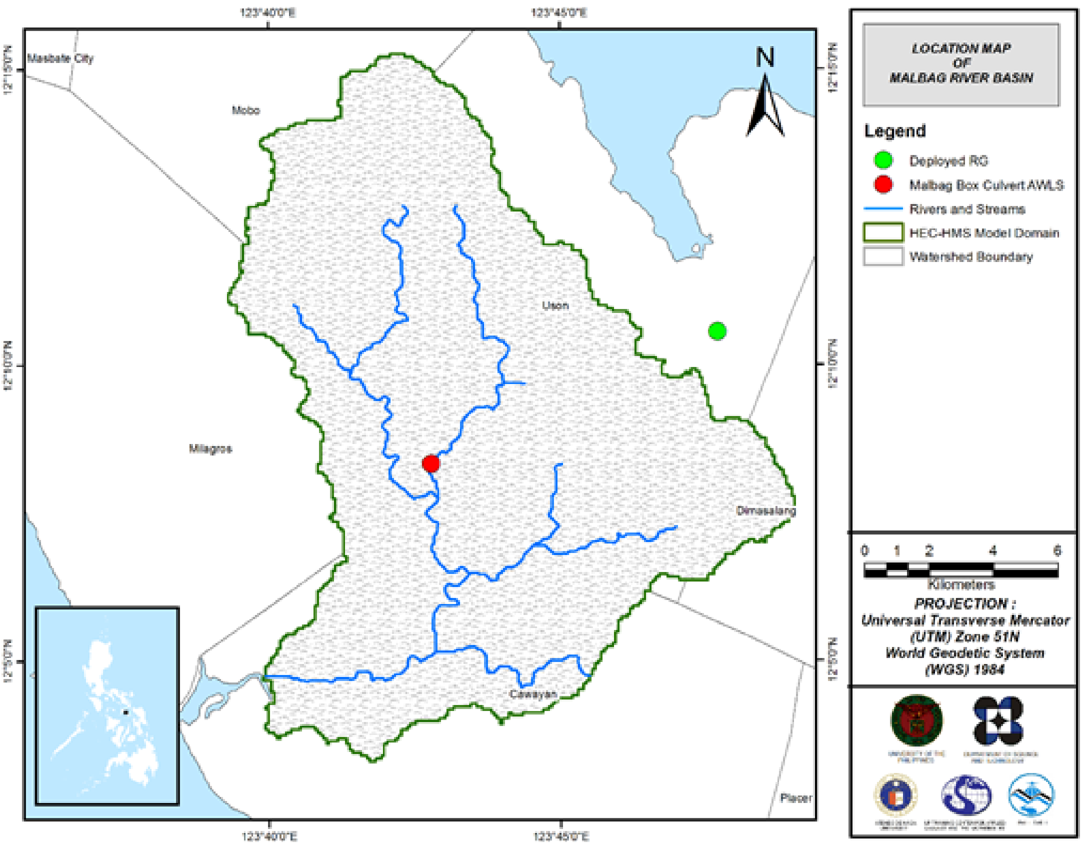


Figure 52. The location map of Malbag HEC-HMS model used for calibration

5.1.3. Rating Curves and River Outflow

A rating curve was developed at Malbag Box Culvert, Malbag, Masbate (12°8'19.95"N, 123°42'46.95"E). It gives the relationship between the observed water levels at Malbag Box Culvert and outflow of the watershed at this location.

For Malbag Box Culvert, the rating curve is expressed as Q = 2E-14e49.118h as shown in Figure 53.

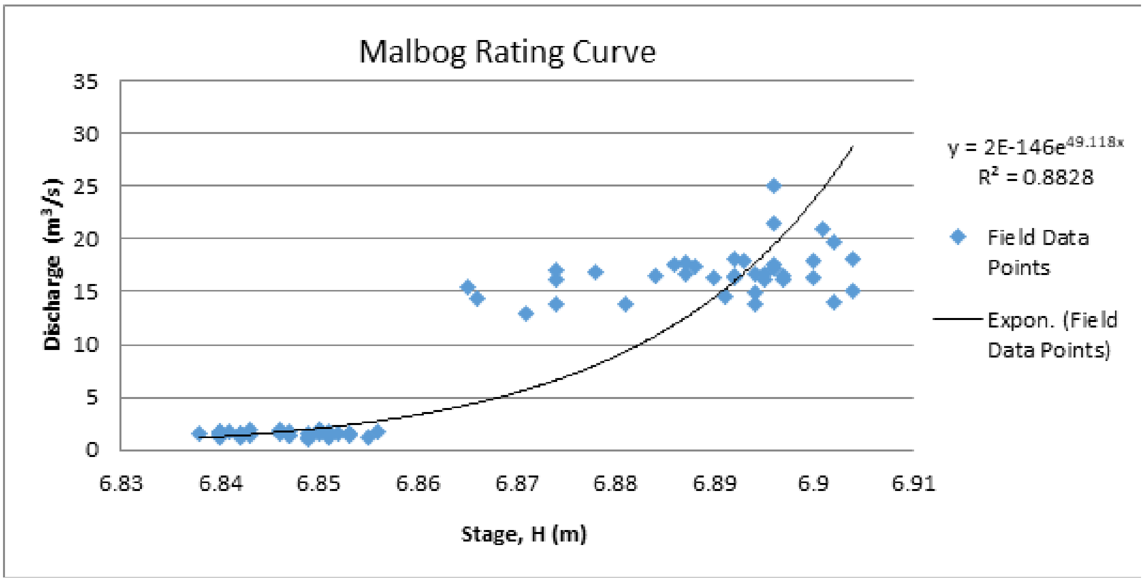


Figure 53. The rating curve of Malbag Box Culvert in Malbag, Masbate

This rating curve equation was used to compute the river outflow at Malbag Box Culvert for the calibration of the HEC-HMS model shown in Figure 54. The total rainfall for this event is 276.8mm and the peak discharge is 71.8m3/s at 6:20 AM, February 17, 2017.

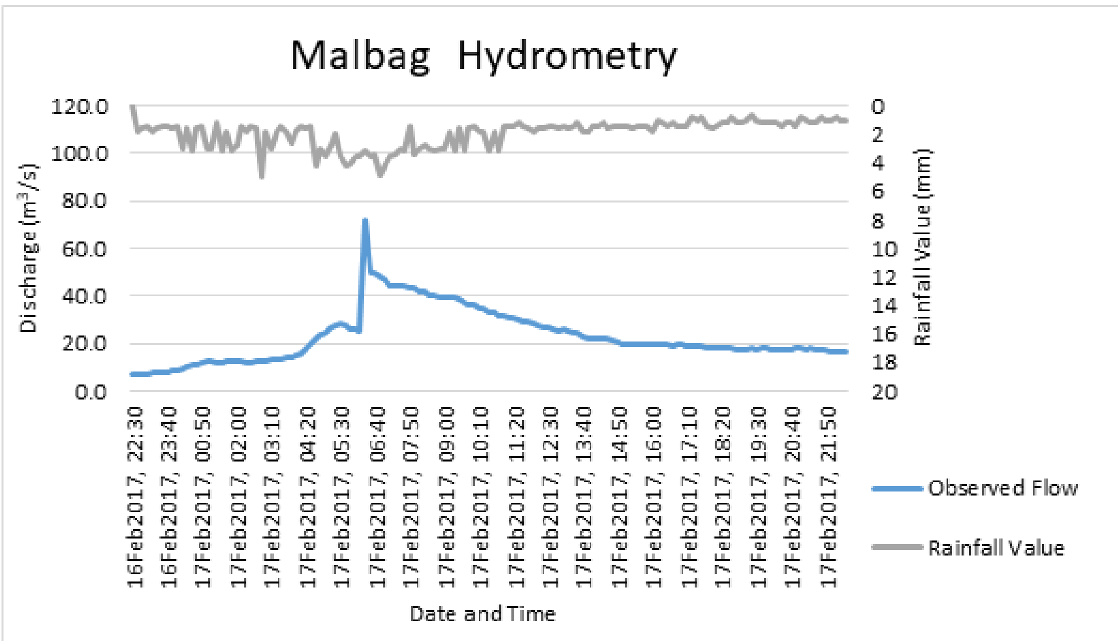


Figure 54. Rainfall and outflow data of the Malbag River Basin, which was used for modeling

5.2. RIDF Station

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

Table 30. RIDF values for Malbag Rain Gauge computed by PAG-ASA

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	10 mins	20 mins	30 mins	1 hr	2 hrs	3 hrs	6 hrs	12 hrs	24 hrs
2	21	31.9	39.6	53.4	74.5	89.3	119.2	145.5	176.4
5	29.1	43.8	54.5	76.7	113.4	138.5	189.8	228.7	260.5
10	34.5	51.6	64.3	92.2	139.1	171.1	236.6	283.8	316.1
15	37.5	56	69.8	100.9	153.6	189.4	263	314.8	347.5
20	39.6	59.1	73.7	107	163.7	202.3	281.5	336.6	369.5
25	41.3	61.5	76.7	111.7	171.6	212.2	295.7	353.4	386.4
50	46.3	68.9	85.9	126.2	195.7	242.7	339.6	405	438.6
100	51.3	76.2	95.1	140.5	219.6	273.1	383.1	456.2	490.3

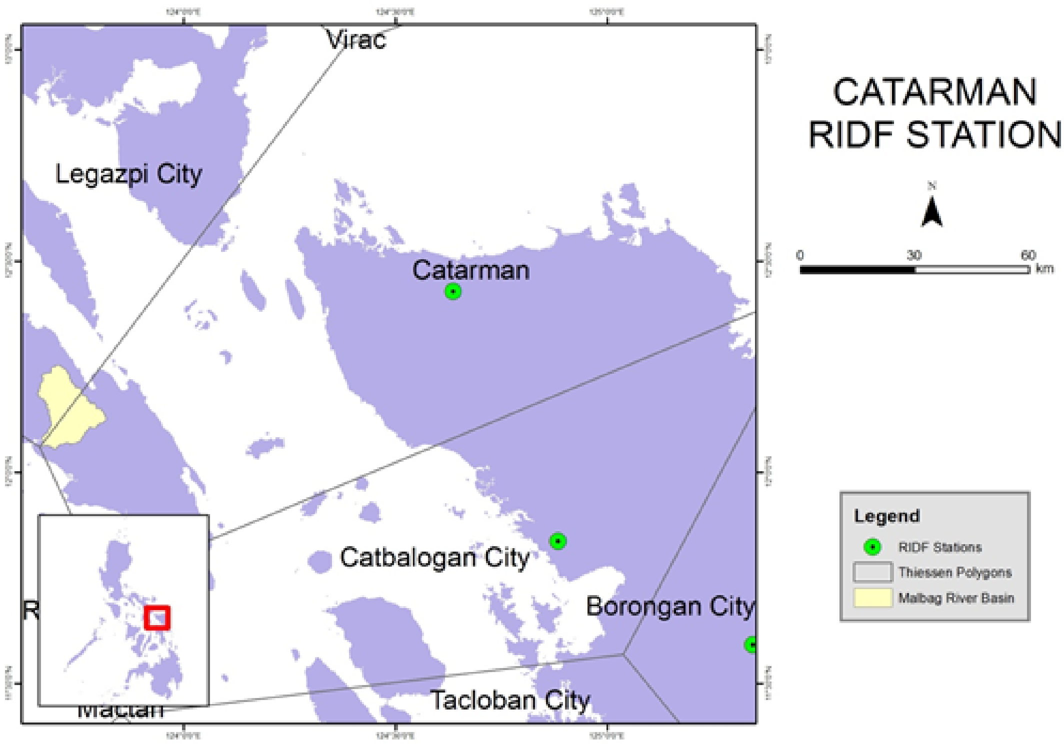


Figure 55. The location of the Legazpi City RIDF station relative to the Malbag River Basin

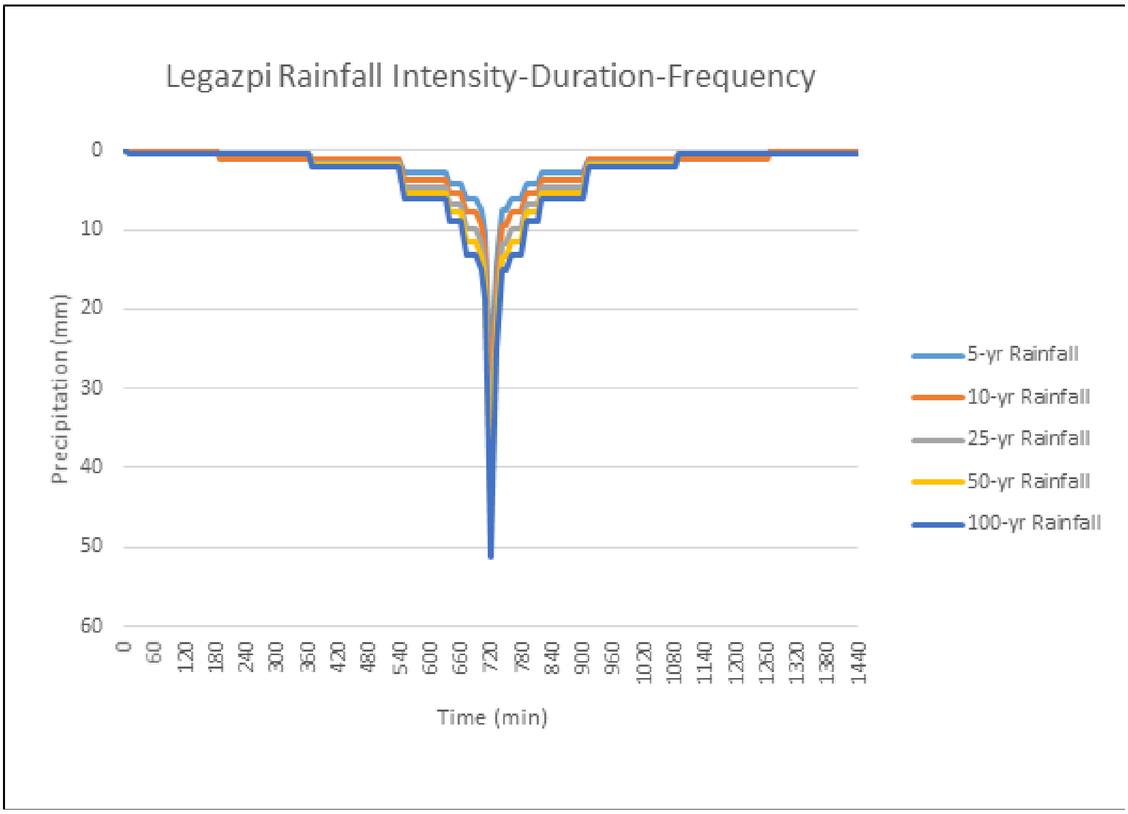


Figure 56. The synthetic storm generated for a 24-hour period rainfall for various return periods.

5.3 HMS Model

The soil shapefile was taken on 2004 from the Bureau of Soils; this is under the Department of Environment and Natural Resources Management (DENR). The land cover shape file is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Malbag River Basin are shown in Figure 57 and Figure 58, respectively.

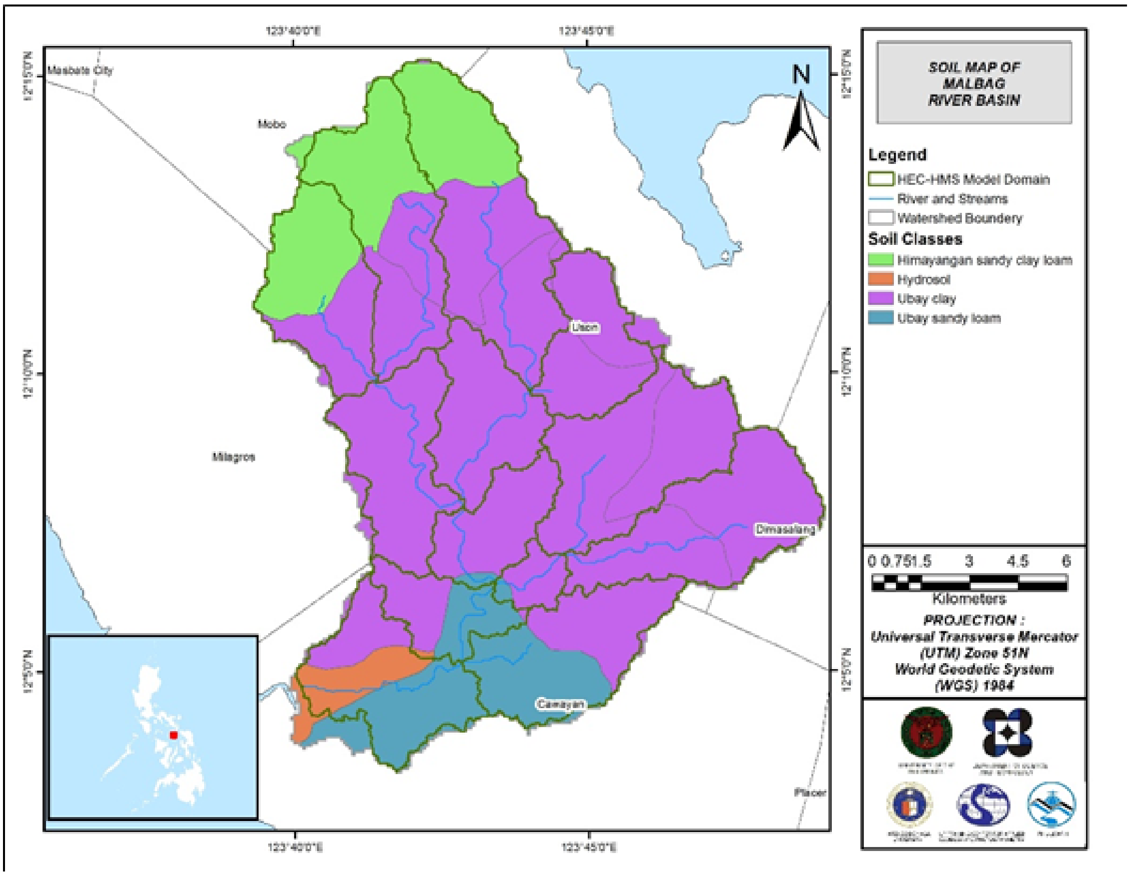


Figure 57. Soil map of Malbag River Basin

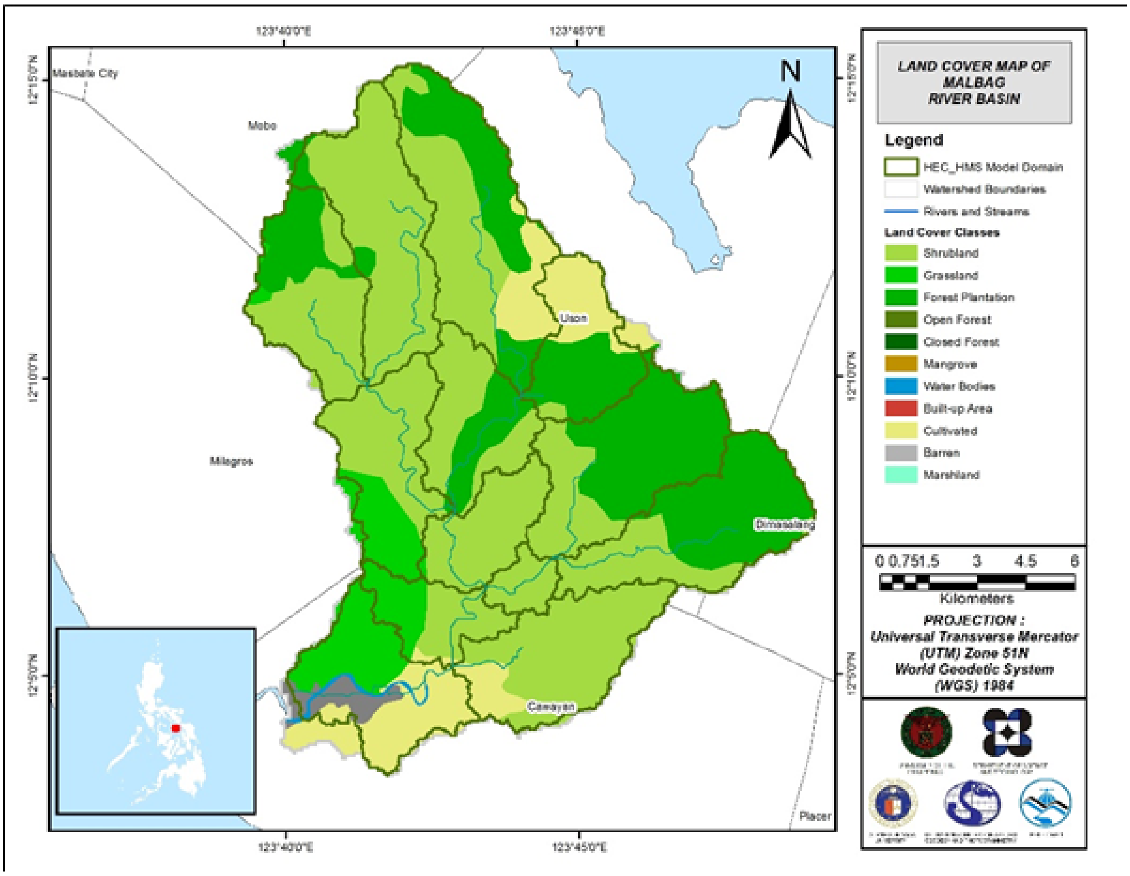


Figure 58. Land cover map of Malbag River Basin

For Malbag, four soil classes were identified. These are Himayangan sandy clay loam, Ubay clay and sandy loam, and hydrosol. Moreover, five land cover classes were identified. These are grassland, shrubland, forest plantation, cultivated, and barren areas.

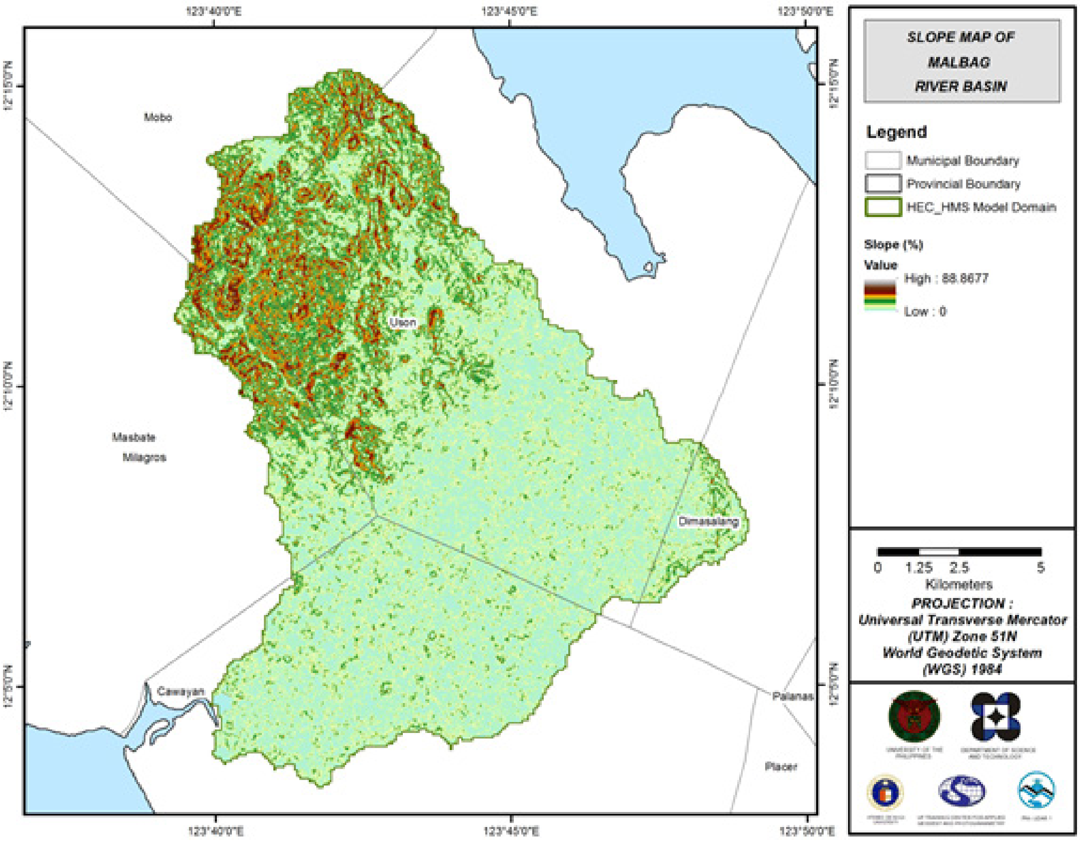


Figure 59. Slope map of Malbag River Basin

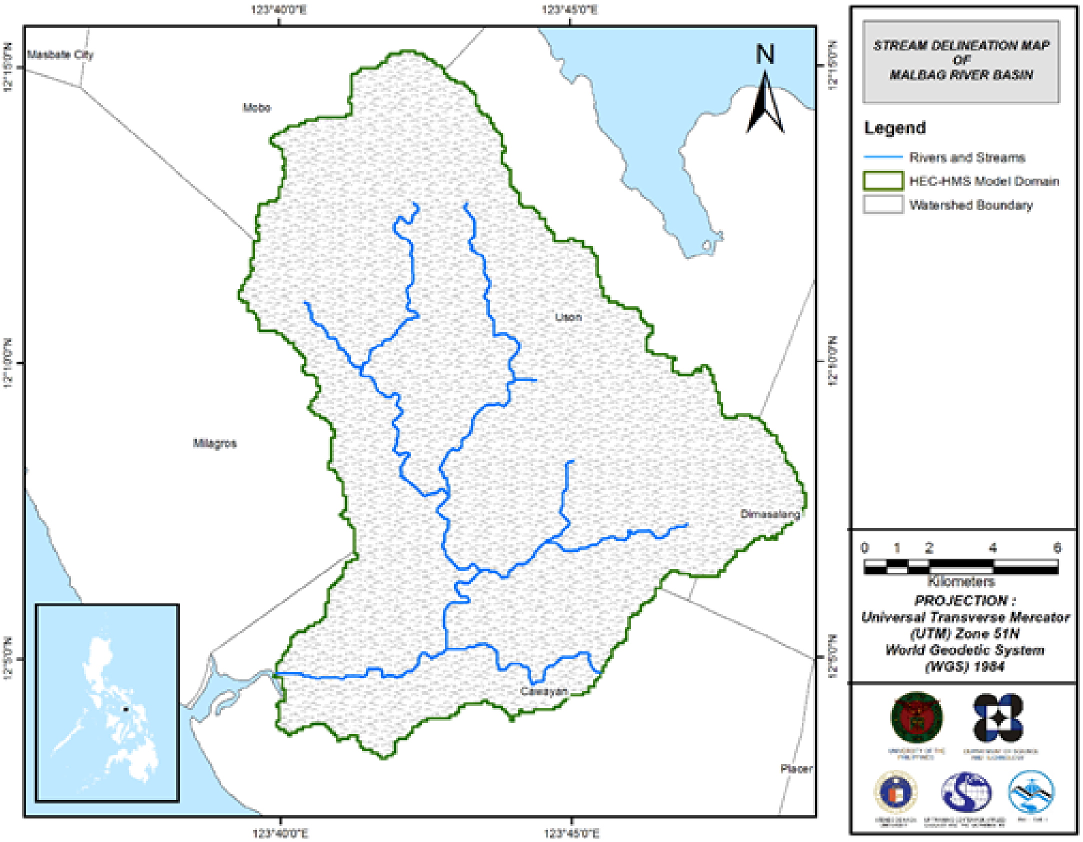


Figure 60. Stream delineation map of Malbag River Basin

Using the SAR-based DEM, the Malbag basin was delineated and further divided into subbasins. The model consists of 21 sub basins, 10 reaches, and 10 junctions, as shown in Figure 61. The main outlet is Malbag Box Culvert.

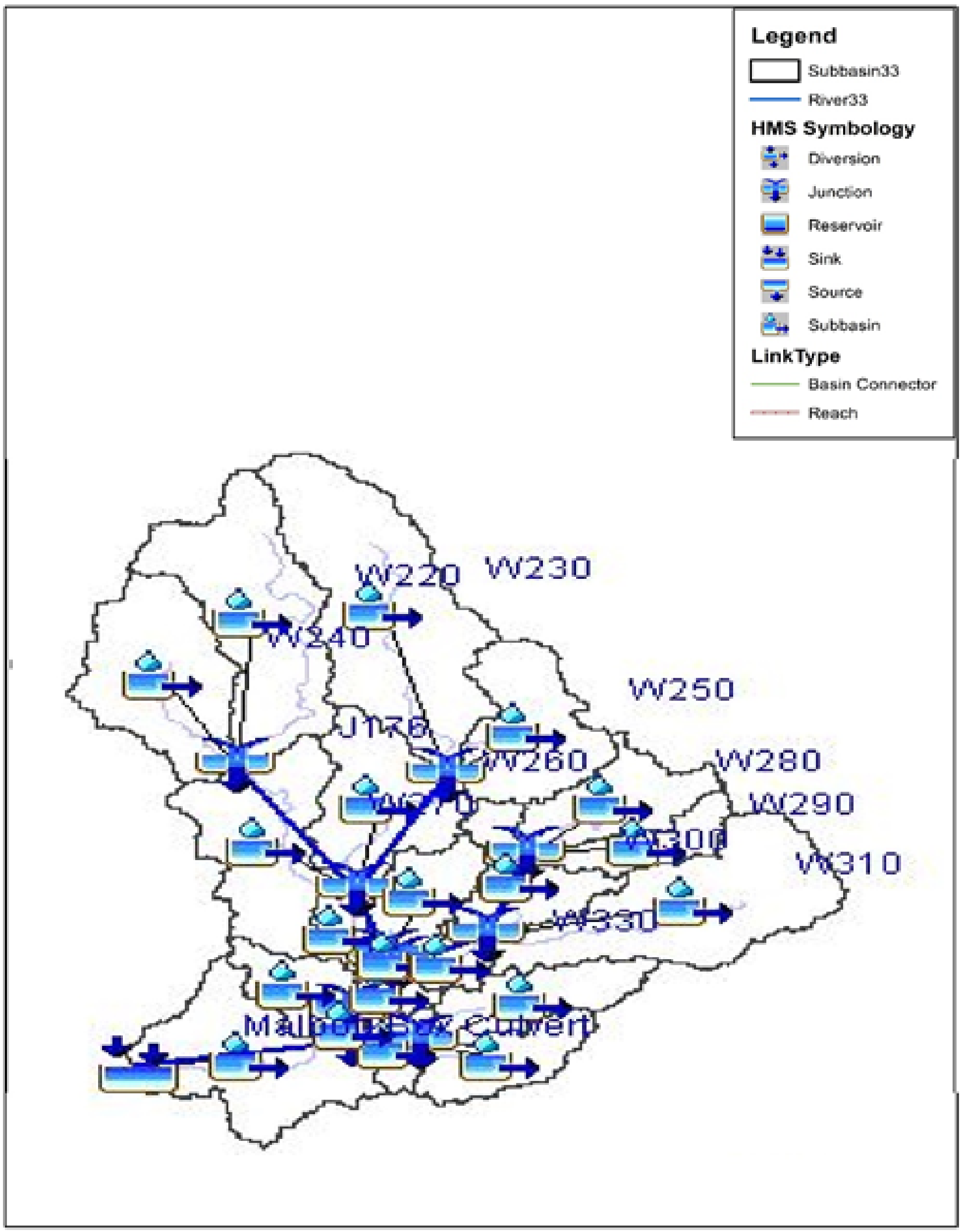


Figure 61. The Malbag River Basin model generated in HEC-HMS

5.4 Cross-section Data

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

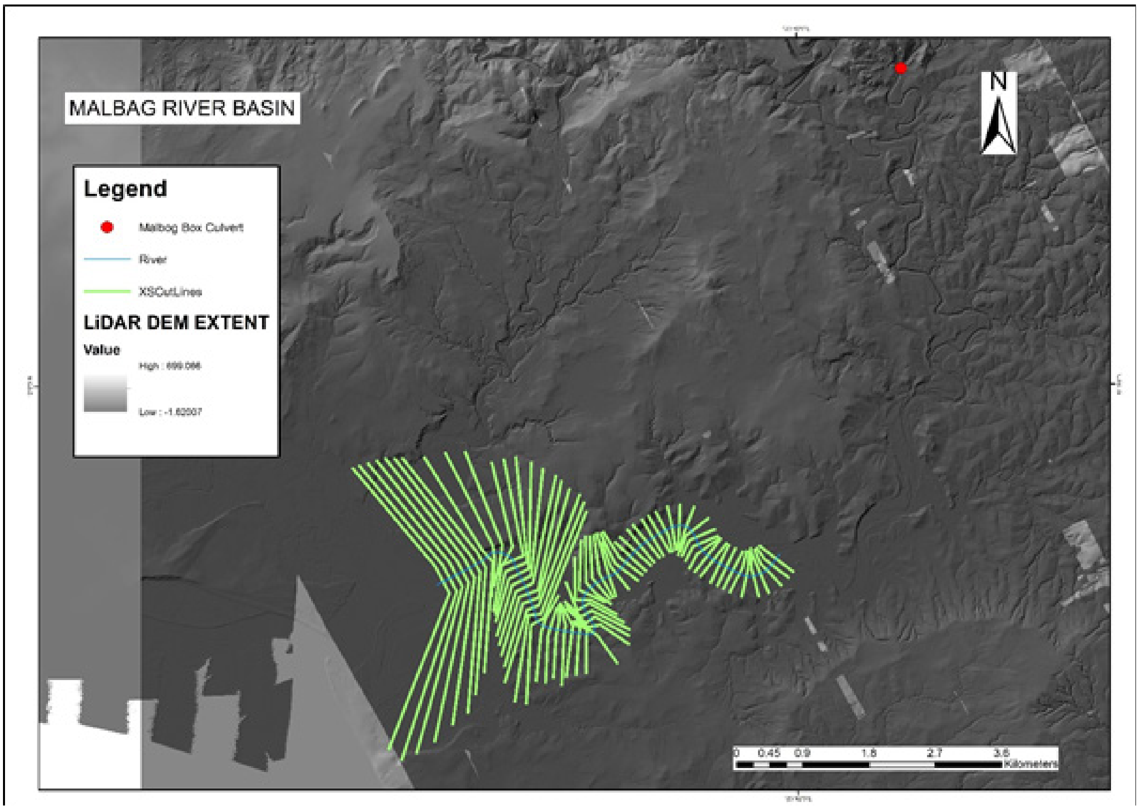


Figure 62. River cross-section of Malbag River generated through Arcmap HEC GeoRAS tool

5.5 Flo 2D Model

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

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

Figure 63. Screenshot of subcatchment with the computational area to be modeled in FLO-2D Grid Developer System Pro (FLO-2D GDS Pro)

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 47.41861 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m2/s. the generated hazard maps for Malbag are in Figure78, Figure 80, and Figure 82.

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 86 571 100.00 m2. The generated flood depth maps for Malbag are in Figure79, Figure 81, and Figure 83.

There is a total of 43 641 865.97 m3 of water entering the model. Of this amount, 21 072 192.18 m3 is due to rainfall while 22 569 673.80 m3 is inflow from other areas outside the model. 8 714 793.00 m3 of this water is lost to infiltration and interception, while 29 518 152.70 m3 is stored by the flood plain. The rest, amounting up to 5 408 873.99 m3, is outflow.

5.6. Results of HMS Calibration

After calibrating the Malbag HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 64 shows the comparison between the two discharge data.

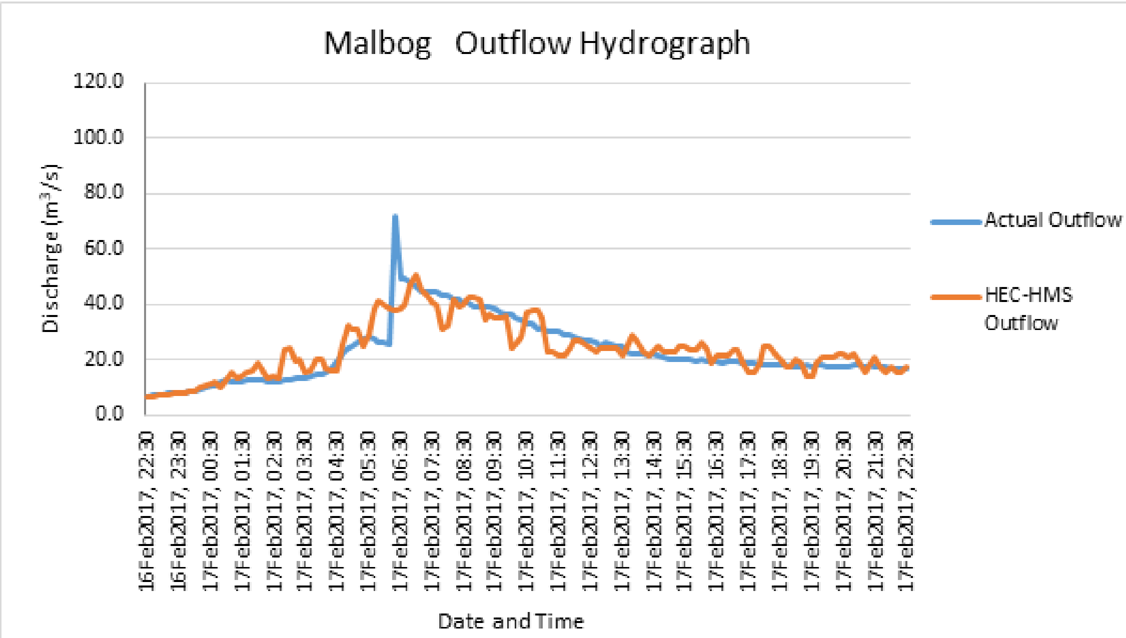


Figure 64. Outflow hydrograph of Malbag River Basin produced by the HEC-HMS model compared with observed outflow

Enumerated in Table 31 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 31. Range of calibrated values for the Malbag River Basin

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	0.002 - 500
			Curve Number	35 - 99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.02 - 0.2
			Storage Coefficient (hr)	0.02 - 10
	Baseflow	Recession	Recession Constant	0.00001
			Ratio to Peak	0.0001 - 0.2
Reach	Routing	Muskingum-Cunge	Slope	0.0001 - 0.008
			Manning's n	0.0001 - 0.9

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 35 to 99 for curve number is wider than the advisable for Philippine watersheds (70-80), depending on the soil and land cover of the area (M. Horritt, personal communication, 2012). For Malbag, the basin mostly consists of shrubland and the soil consists of Ubay clay and sandy loam, and Himayangan sandy clay loam.

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 0.02 hours to 0.2 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. For Malbag, it will take at least 15 hours from the peak discharge to go back to the initial discharge.

Manning's roughness coefficient of 0.0001 corresponds to the common roughness in Malbag watershed, which is determined to have a smooth surface (Brunner, 2010).

Table 32. Summary of the Efficiency Test of the Malbag HMS Model

RMSE	0.49
r2	0.93
NSE	0.93
PBIAS	0.44
RSR	0.27

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 5.489 (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 0.763.

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 0.759.

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 -3.051.

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 0.491.

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 65) shows the Malbag outflow using the synthetic storm events using the Legazpi Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAG-ASA) data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods from 241.7m3/s in a 5-year return period to 603.7m3/s in a 100-year return period.

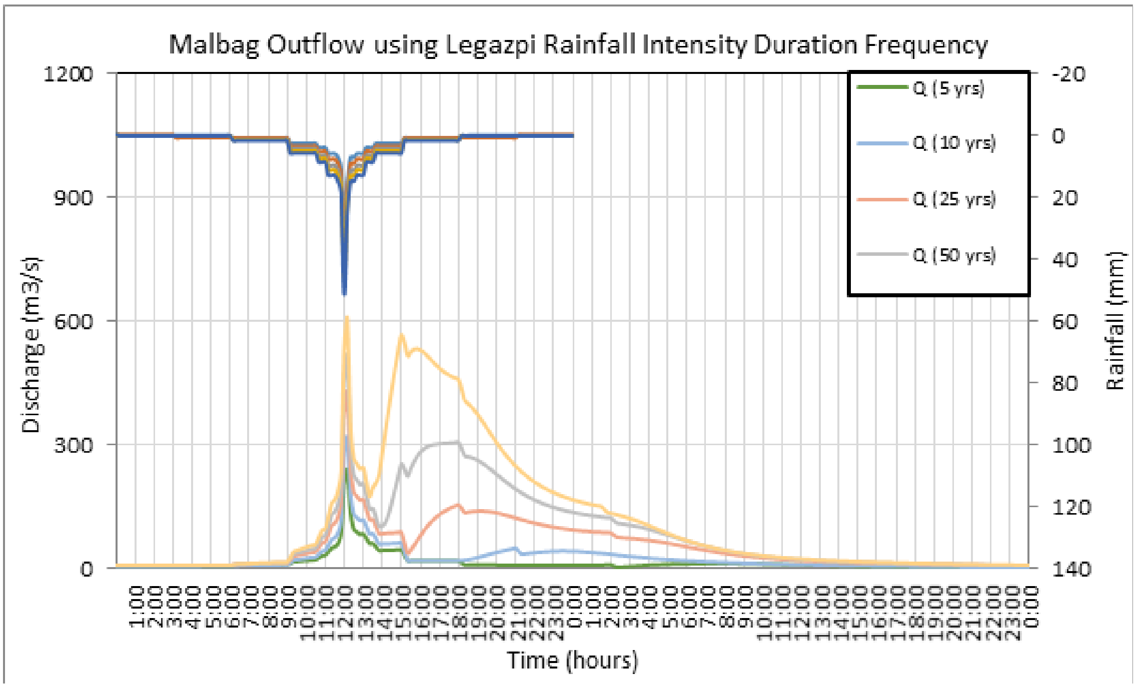


Figure 65. The outflow hydrograph at the Malbag Basin, generated using the simulated rain events for 24-hour period for Legazpi station

A summary of the total precipitation, peak rainfall, peak outflow, and time to peak of the Malbag discharge using the Legazpi Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 33.

Table 33. Outlines the peak values of the Malbag HEC-HMS Model outflow using the Legazpi RIDF 24-hour values.

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	260.5	29.1	241.7	10 minutes
10-Year	316.1	34.5	321.2	10 minutes
25-Year	386.4	41.3	430.1	10 minutes
50-Year	438.4	46.3	516	10 minutes
100-Year	490.3	51.3	603.7	10 minutes

5.8 River Analysis Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. For this publication, only a sample output map river was to be shown, since only the ADNU-DVC base flow was calibrated. Figure 66 shows a generated sample map of the Malbag River using the calibrated HMS base flow.

Figure 66. The sample output map of the Malbag RAS Model

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. Figure 67 to Figure 72 show the 5-, 25-, and 100-year rain return scenarios of the Malbag flood plain. The flood plain, with an area of 265.63km2, covers five (5) municipalities, namely Cawayan, Dimasalang, Milagros, Mobo, and Uson. Table 34 shows the percentage of area affected by flooding per municipality.

Table 34. Municipalities affected in Malbag flood plain

City / Municipality	Total Area	Area Flooded	% Flooded
Cawayan	261.38	94.7	36.23
Dimasalang	100.44	6.52	6.49
Milagros	530.43	57.61	10.86
Mobo	143.03	2.82	1.97
Uson	183.76	103.68	56.42

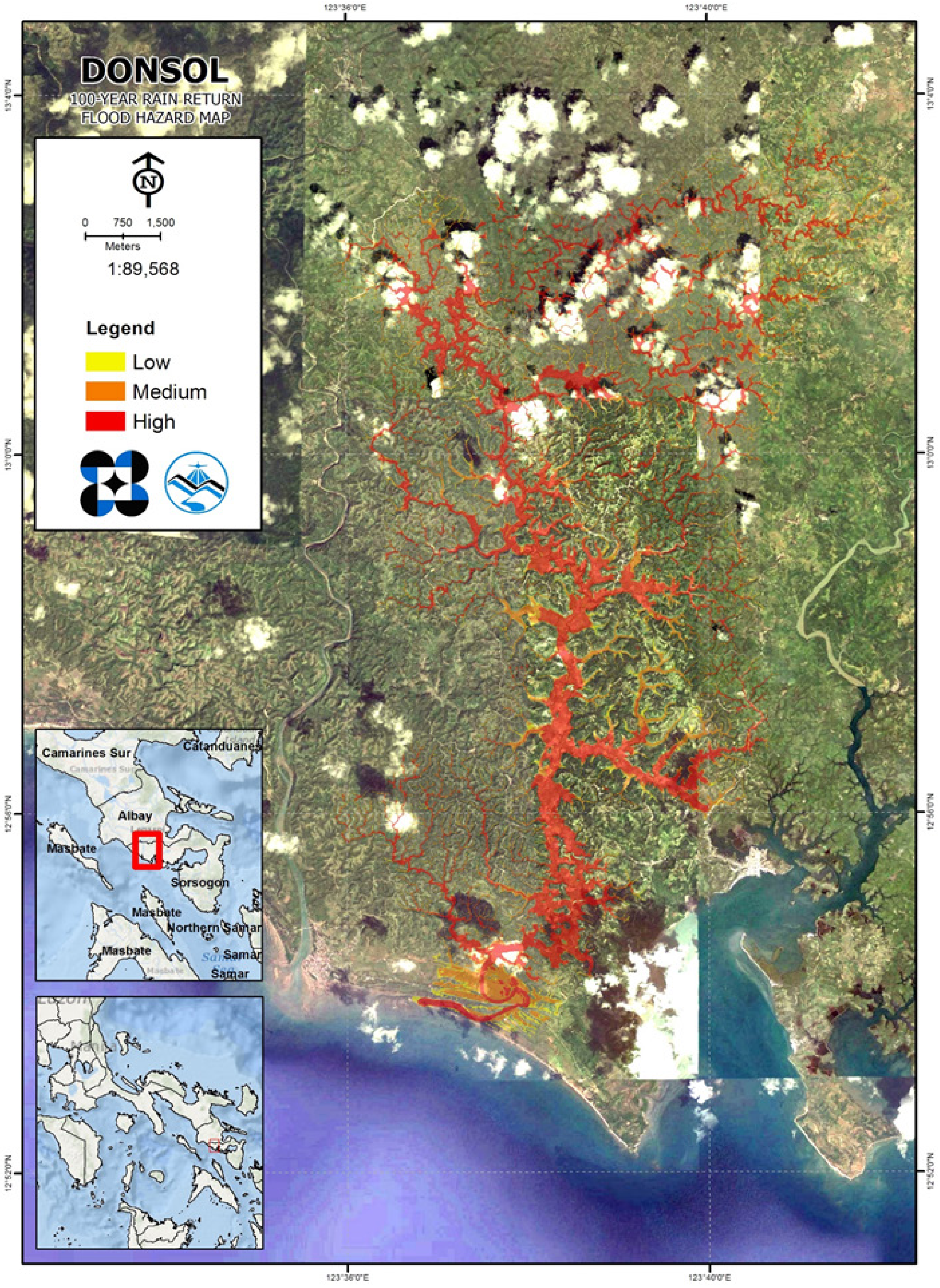


Figure 67. 100-year flood hazard map for the Malbag flood plain overlaid on Google Earth imagery

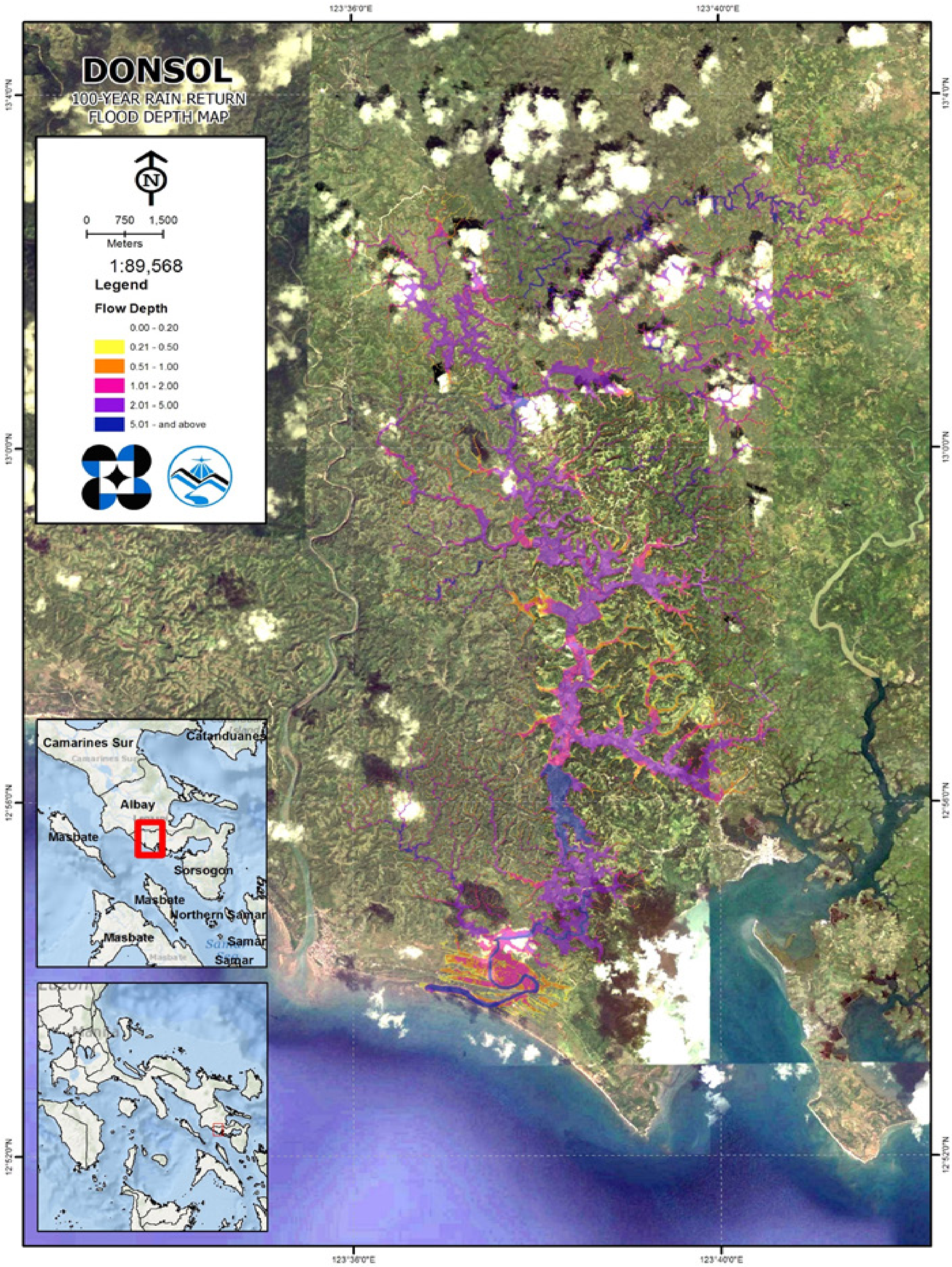


Figure 68. 100-year flow depth map for the Malbag flood plain overlaid on Google Earth imagery

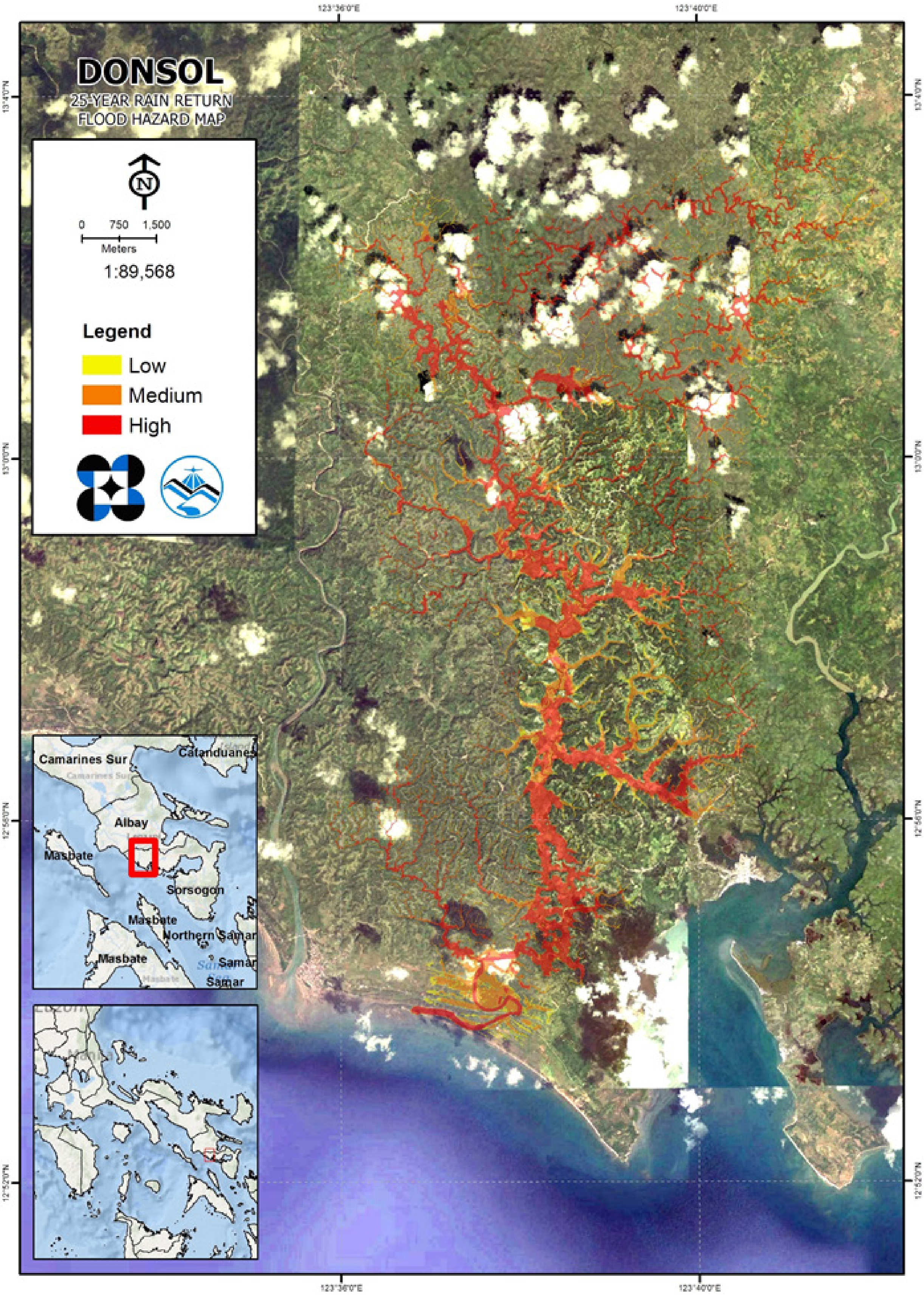


Figure 69. 25-year flood hazard map for the Malbag flood plain overlaid on Google Earth imagery

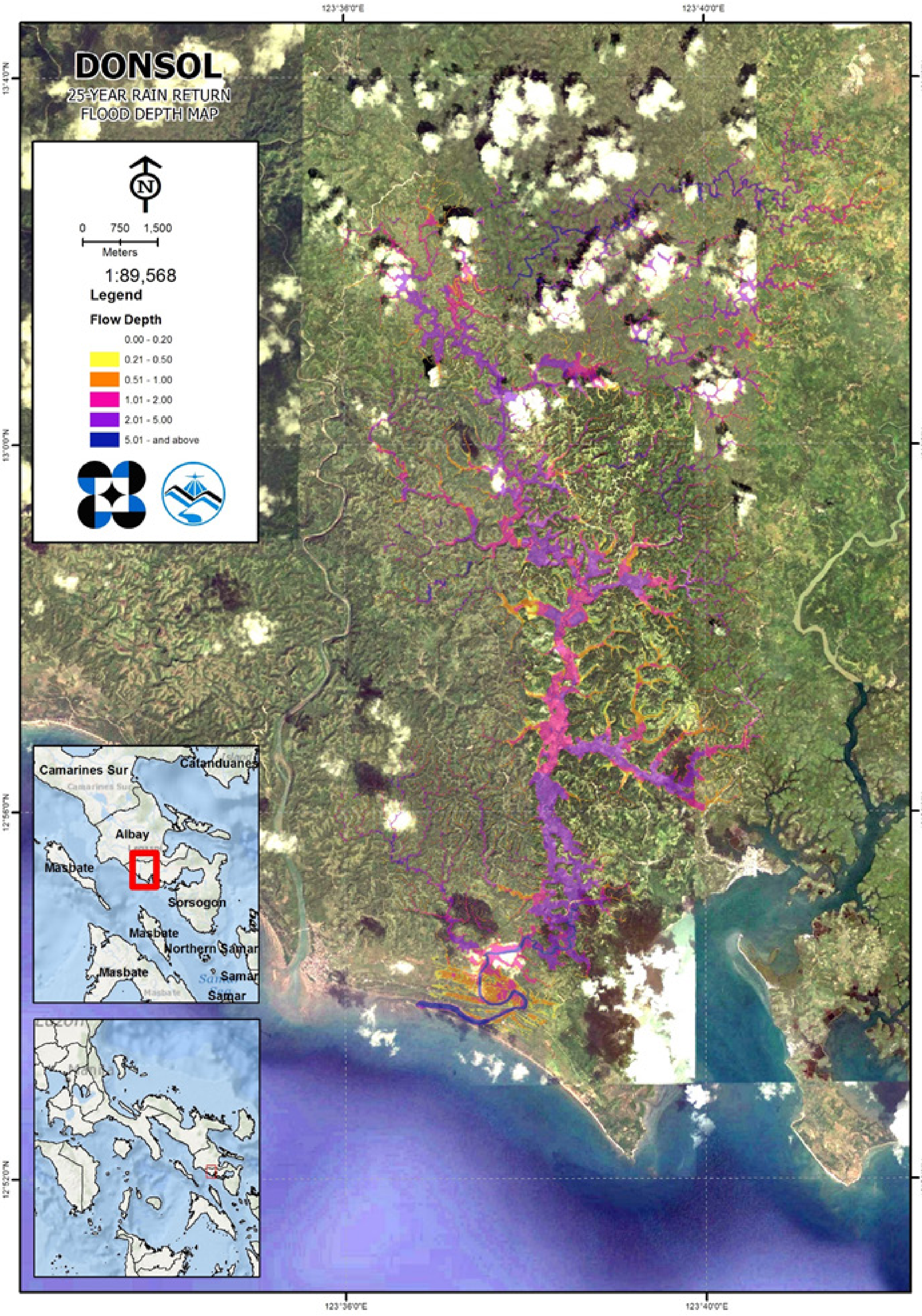


Figure 70. 25-year flow depth map for the Malbag flood plain overlaid on Google Earth imagery

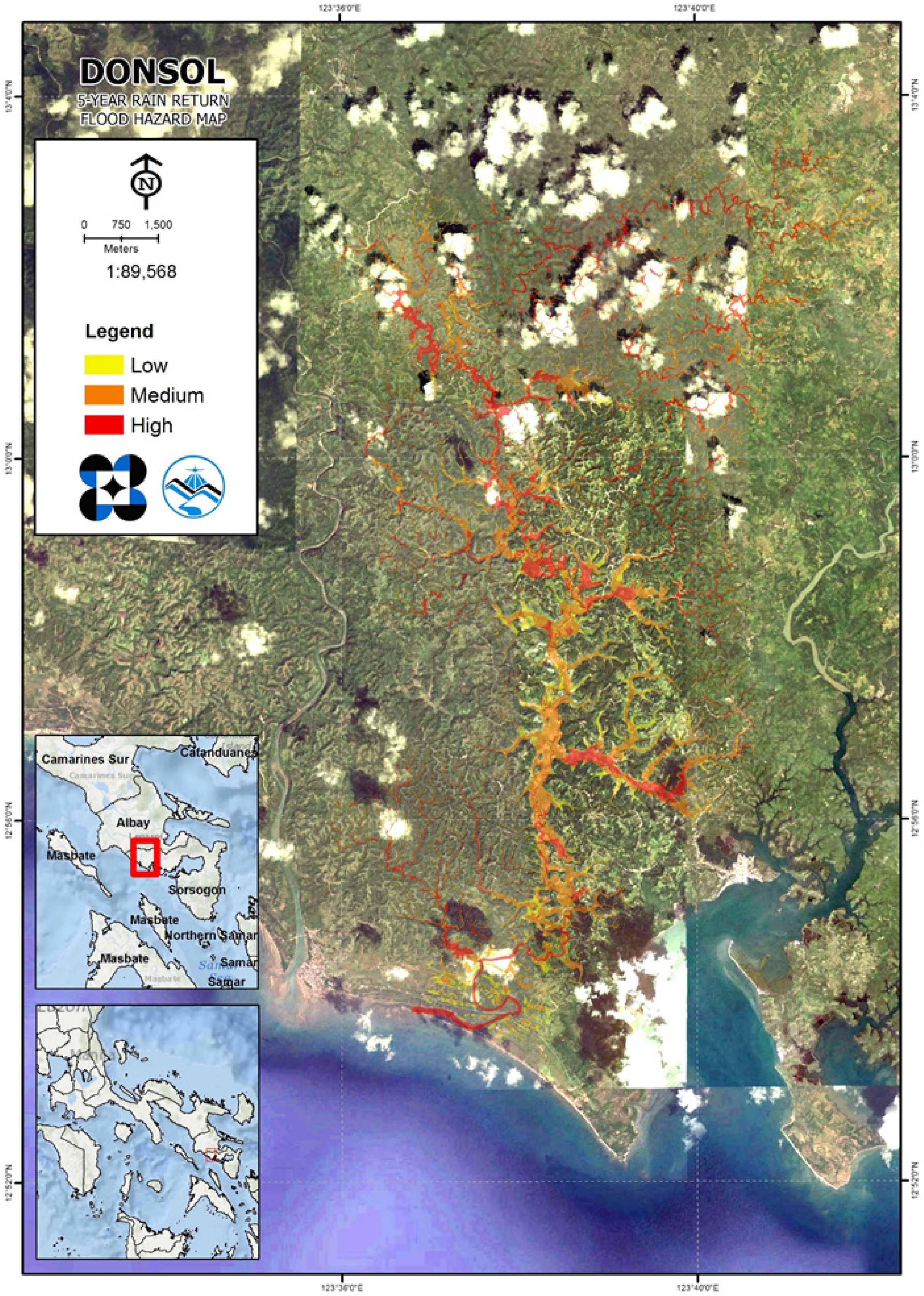


Figure 71. 5-year flood hazard map for the Malbag flood plain overlaid on Google Earth imagery

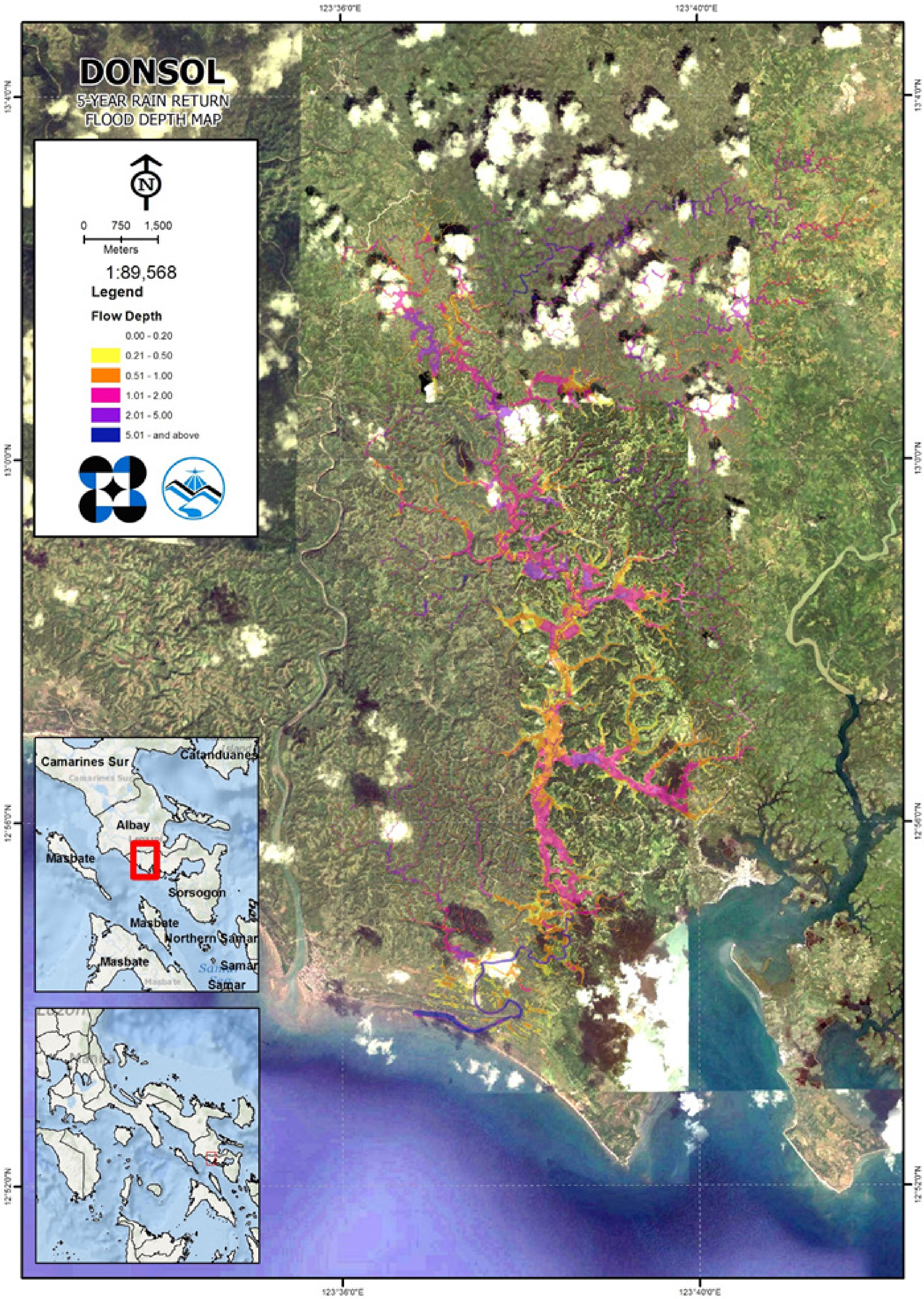


Figure 72. 5-year flow depth map for the Malbag flood plain overlaid on Google Earth imagery

5.10 Inventory of Areas Exposed to Flooding

Listed below are the barangays affected by the Malbag River Basin, grouped accordingly by municipality. For the said basin, five (5) municipalities consisting of 38 barangays are expected to experience flooding when subjected to the three rainfall return period scenarios.

For the 5-year rainfall return period, 30.68% of the municipality of Cawayan with an area of 261.38 sq. km. will experience flood levels of less than 0.20 meters. 2.92% of the area will experience flood levels of 0.21 to 0.50 meters, while 1.75%, 0.65%, 0.23%, and 0.008% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 35 depicts the areas affected in Cawayan in square kilometers by flood depth per barangay.

Table 35. Affected areas in Cawayan, Masbate during a 5-year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of barangays affected in Cawayan								
	Cabayugan	Lague-Lague	Mactan	Malbug	Palobandera	Pulot	R.M. Magbalon	San Jose	Taberna
0.03-0.20	20.75	10.08	7.41	18.89	1.35	8.52	0.28	3.32	9.59
0.21-0.50	1.72	0.5	0.47	2.99	0.059	0.91	0.0093	0.15	0.82
0.51-1.00	1.15	0.33	0.42	1.5	0.032	0.45	0.0014	0.075	0.61
1.01-2.00	0.47	0.19	0.13	0.52	0.0079	0.14	0	0.052	0.2
2.01-5.00	0.047	0.36	0.041	0.031	0.0005	0.055	0	0.029	0.045
>5.00	0	0.016	0.0044	0	0	0	0	0	0

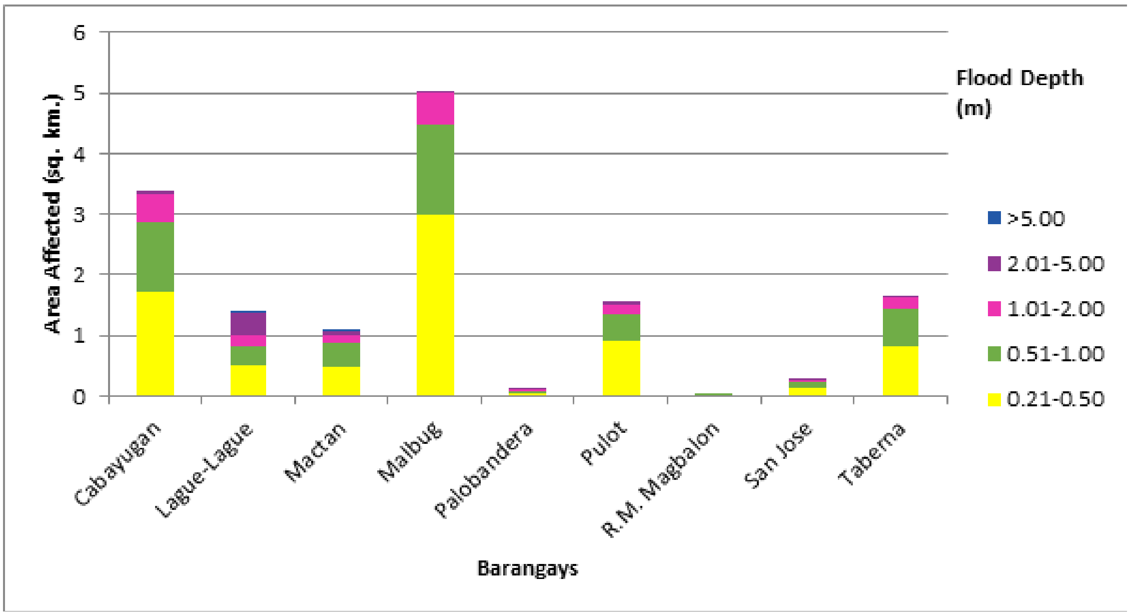


Figure 73. Affected Areas in Cawayan, Masbate during the 5-Year Rainfall Return Period

For the municipality of Dimasalang with an area of 100.44 sq. km., 6.04% will experience flood levels of less than 0.20 meters. 0.17% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.12%, 0.09%, 0.07%, and 0.01% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 36 depicts the areas affected in Dimasalang in square kilometers by flood depth per barangay.

Table 36. Affected Areas in Dimasalang, Masbate during the 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of barangays affected in Dimasalang	
	Buenaflor	Mambog
0.03-0.20	2.79	3.27
0.21-0.50	0.083	0.085
0.51-1.00	0.06	0.064
1.01-2.00	0.04	0.048
2.01-5.00	0.029	0.036
>5.00	0	0.01

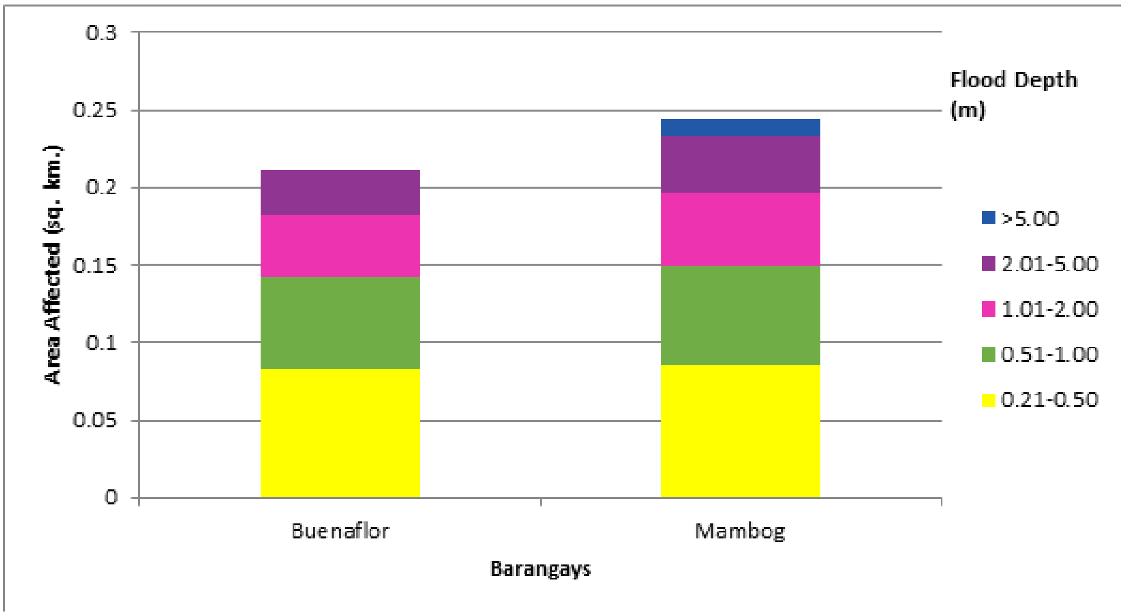


Figure 74. Affected Areas in Dimasalang, Masbate during the 5-Year Rainfall Return Period

For the municipality of Milagros with an area of 530.43 sq. km., 9.72% will experience flood levels of less than 0.20 meters. 0.55% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.3%, 0.18%, 0.11%, and 0.006% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 37 depicts the areas affected in Milagros in square kilometers by flood depth per barangay.

Table 37. Affected Areas in Dimasalang, Masbate during the 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of barangays affected in Milagros				
	Bara	Matagbac	San Antonio	San Carlos	Sawmill
0.03-0.20	7.01	13.42	15.7	10.61	4.79
0.21-0.50	1.36	0.69	0.43	0.25	0.17
0.51-1.00	0.69	0.41	0.29	0.17	0.056
1.01-2.00	0.26	0.31	0.19	0.15	0.032
2.01-5.00	0.043	0.25	0.13	0.13	0.016
>5.00	0.00061	0.011	0.015	0.0037	0

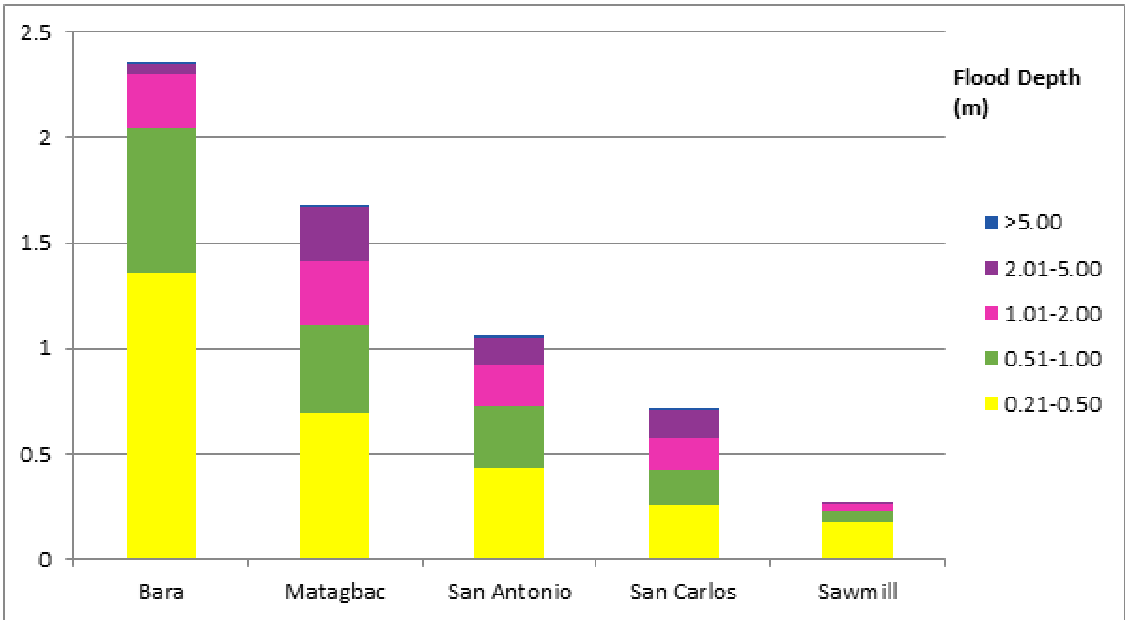


Figure 75. Affected Areas in Milagros, Masbate during the 5-Year Rainfall Return Period

For the municipality of Mobo with an area of 143.03 sq. km., 1.91% will experience flood levels of less than 0.20 meters. 0.04% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.01%, 0.008%, and 0.001% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, and 2.01 to 5 meters, respectively. Table 38 depicts the areas affected in Mobo in square kilometers by flood depth per barangay.

Table 38. Affected Areas in Mobo, Masbate during the 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of barangays affected in Mobo
	Barag
0.03-0.20	2.73
0.21-0.50	0.06
0.51-1.00	0.018
1.01-2.00	0.012
2.01-5.00	0.0016
>5.00	0

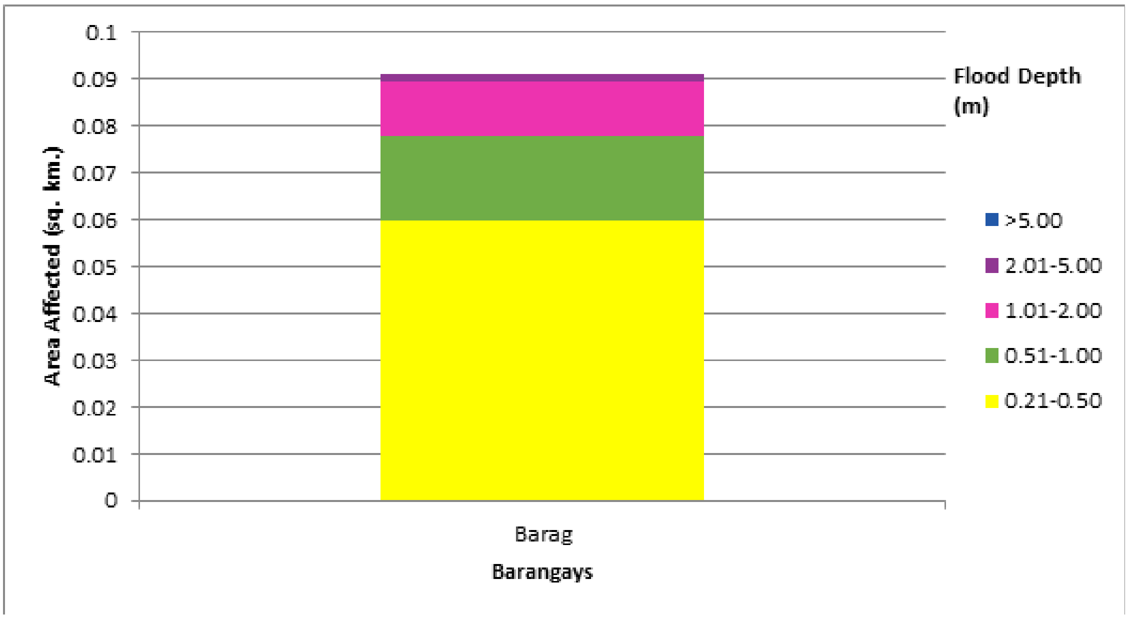


Figure 76. Affected Areas in Mobo, Masbate during the 5-Year Rainfall Return Period

For the municipality of Uson with an area of 183.76 sq. km., 51.88% will experience flood levels of less than 0.20 meters. 1.51% of the area will experience flood levels of 0.21 to 0.50 meters, while 1.09%, 1%, 0.82%, and 0.12% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 39 depicts the areas affected in Uson in square kilometers by flood depth per barangay.

Table 39. Affected Areas in Uson, Masbate during the 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of barangays affected in Uson									
	Arado	Aurora	Bonifacio	Buenasuerte	Campana	Candelaria	Centro	Dapdap	Del Carmen	Del Rosario
0.03-0.20	1.88	4.31	18.61	1.04	7.52	5.51	2.69	0.035	1.05	0.87
0.21-0.50	0.061	0.14	0.46	0.039	0.35	0.18	0.037	0	0.024	0.024
0.51-1.00	0.069	0.095	0.32	0.027	0.23	0.15	0.043	0	0.023	0.014
1.01-2.00	0.065	0.075	0.3	0.024	0.22	0.14	0.055	0	0.025	0.012
2.01-5.00	0.032	0.034	0.3	0.0028	0.19	0.13	0.073	0	0.036	0.003
>5.00	0	0	0.067	0	0.0068	0.019	0.0002	0	0.0036	0

Libertad	Mabuhay	Madao	Mongahay	Paguihaman	Panicijan	San Isidro	San Jose	San Ramon	San Vicente	Simawa
4.58	1.89	12.65	0.011	4.26	2.86	4.61	0.4	4.61	8.06	7.87
0.13	0.05	0.27	0	0.11	0.12	0.13	0.011	0.15	0.29	0.21
0.11	0.038	0.13	0	0.091	0.084	0.11	0.014	0.12	0.18	0.18
0.11	0.018	0.1	0	0.088	0.054	0.12	0.0093	0.11	0.16	0.14
0.094	0.0049	0.069	0	0.043	0.006	0.088	0.0049	0.12	0.11	0.17
0.041	0	0.001	0	0.0027	0	0.0002	0	0.034	0.0004	0.052

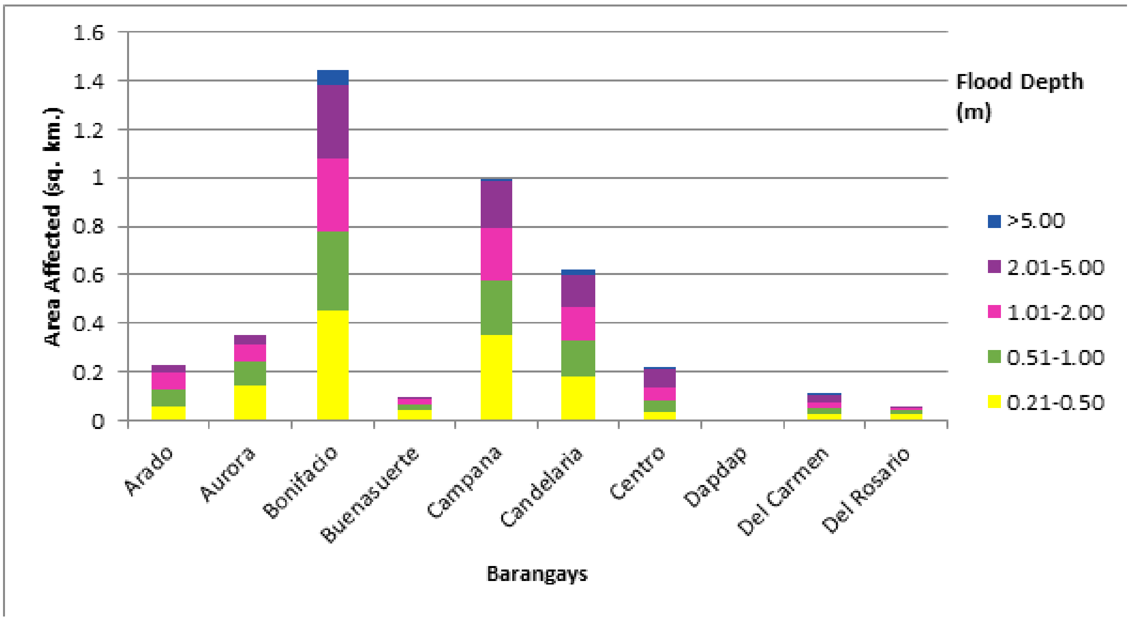


Figure 77. Affected Areas in Uson, Masbate during the 5-Year Rainfall Return

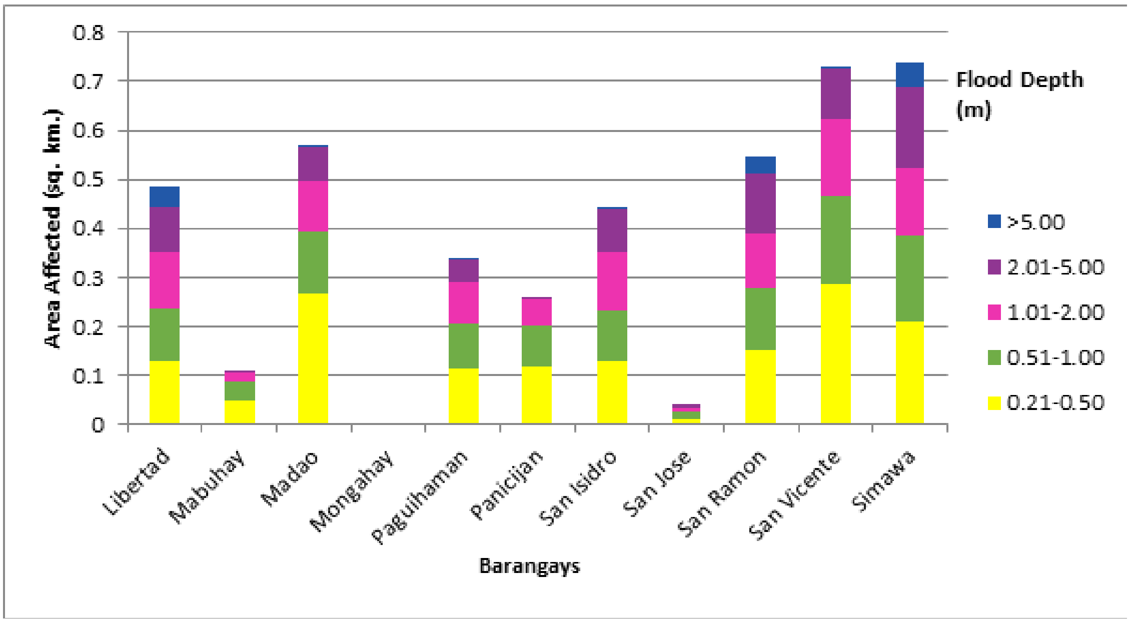


Figure 78. Affected Areas in Uson, Masbate during the 5-Year Rainfall

For the 25-year rainfall return period, 27.56% of the municipality of Cawayan with an area of 261.38 sq. km. will experience flood levels of less than 0.20 meters. 2.7% of the area will experience flood levels of 0.21 to 0.50 meters, while 1.9%, 2.47%, 1.38%, and 0.22% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 40 depicts the areas affected in Cawayan in square kilometers by flood depth per barangay.

Table 40. Affected Areas in Cawayan, Masbate during the 25-Year Rainfall Return

Affected area (sq. km.) by flood depth (in m.)	Area of barangays affected in Cawayan								
	Cabayugan	Lague-Lague	Mactan	Malbug	Palobandera	Pulot	R.M. Magbalon	San Jose	Taberna
0.03-0.20	19.87	7.96	7.15	15.74	1.33	7.76	0.28	3.26	8.67
0.21-0.50	1.83	0.48	0.41	2.87	0.061	0.62	0.012	0.16	0.62
0.51-1.00	1.24	0.48	0.43	1.96	0.041	0.4	0.0024	0.091	0.33
1.01-2.00	1.04	0.71	0.35	3	0.013	0.68	0	0.072	0.59
2.01-5.00	0.15	1.32	0.1	0.36	0.0011	0.61	0	0.045	1.03
>5.00	0	0.53	0.028	0	0	0.0002	0	0	0.021

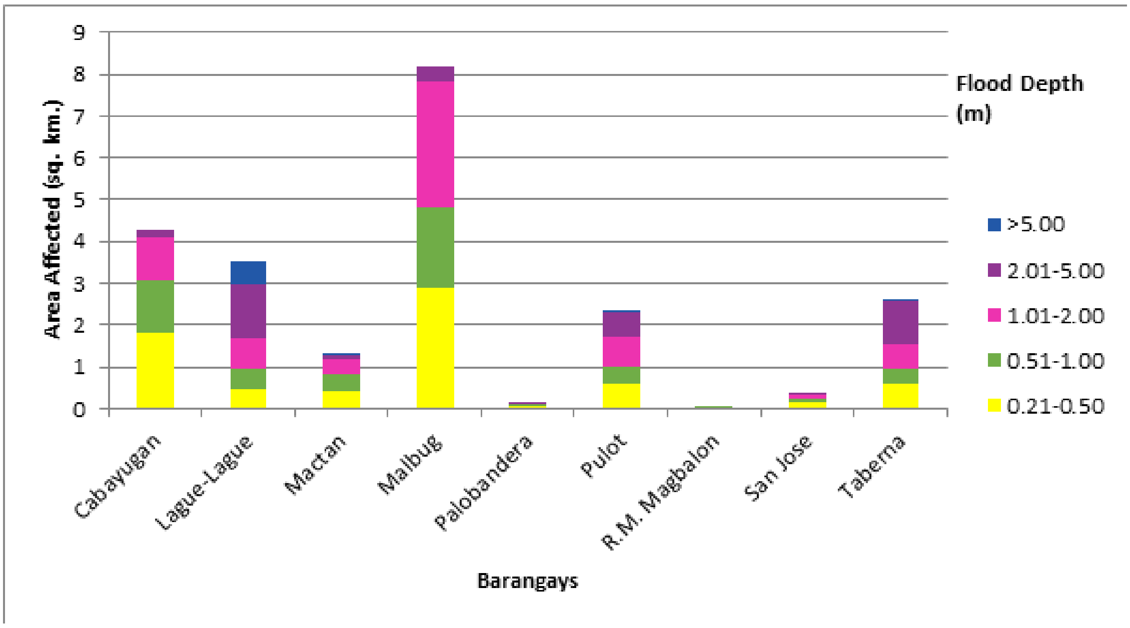


Figure 79. Affected Areas in Cawayan, Masbate during the 25-Year Rainfall Return Period

For the municipality of Dimasalang with an area of 100.44 sq. km., 5.94% will experience flood levels of less than 0.20 meters. 0.18% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.14%, 0.12%, 0.09%, and 0.01% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 41 depicts the areas affected in Dimasalang in square kilometers by flood depth per barangay.

Table 41. Affected Areas in Mobo, Masbate during the 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of barangays affected in Dimasalang	
	Buenaflor	Mambog
0.03-0.20	2.75	3.21
0.21-0.50	0.085	0.095
0.51-1.00	0.068	0.077
1.01-2.00	0.055	0.067
2.01-5.00	0.044	0.05
>5.00	0	0.014

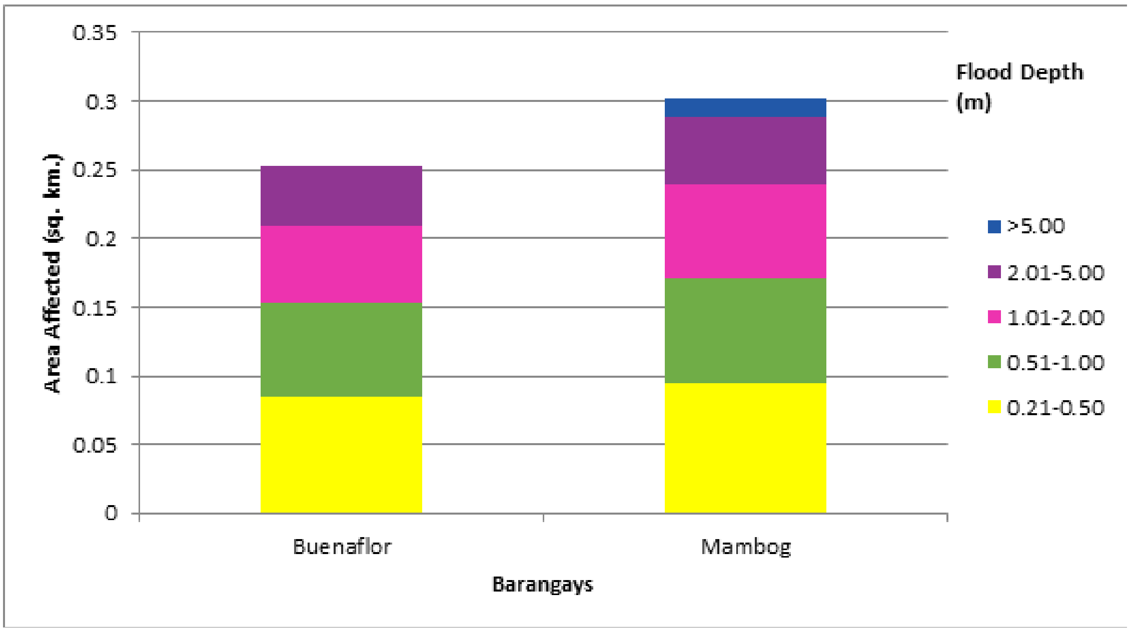


Figure 80. Affected Areas in Dimasalang, Masbate during the 25-Year Rainfall Return Period

For the municipality of Milagros with an area of 530.43 sq. km., 9.29% will experience flood levels of less than 0.20 meters. 0.68% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.34%, 0.29%, 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 greater than 5 meters, respectively. Table 42 depicts the areas affected in Milagros in square kilometers by flood depth per barangay.

Table 42. Affected Areas in Milagros, Masbate during the 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of barangays affected in Milagros				
	Bara	Matagbac	San Antonio	San Carlos	Sawmill
0.03-0.20	6.15	13	14.91	10.49	4.73
0.21-0.50	1.91	0.76	0.46	0.28	0.2
0.51-1.00	0.65	0.52	0.37	0.18	0.073
1.01-2.00	0.52	0.4	0.39	0.18	0.037
2.01-5.00	0.12	0.38	0.4	0.17	0.029
>5.00	0.0042	0.031	0.23	0.018	0.00028

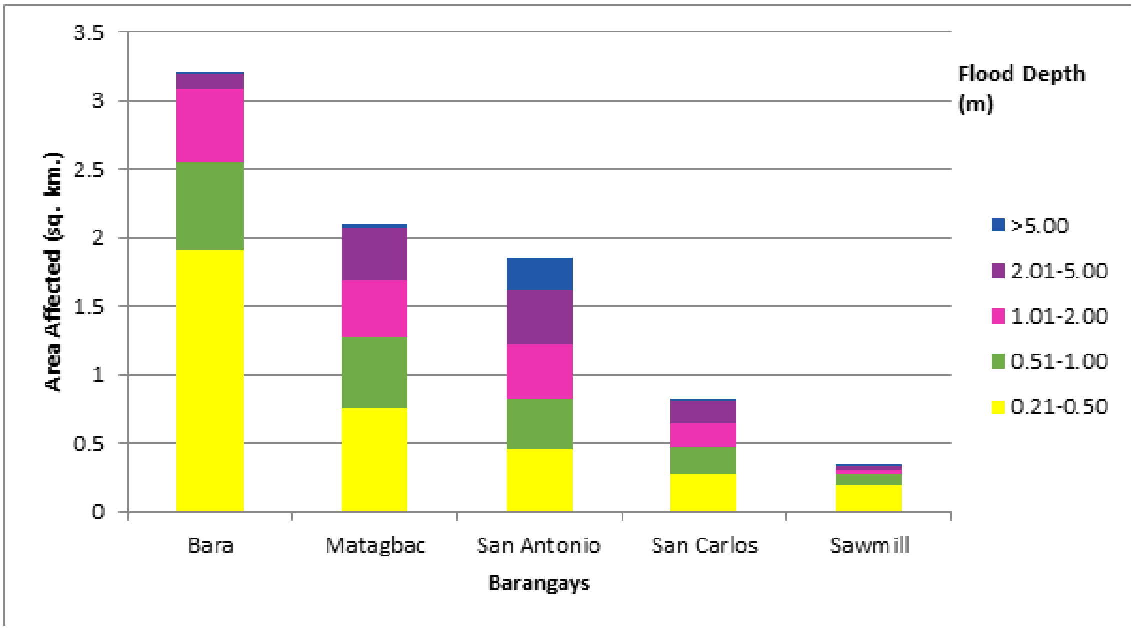


Figure 81. Affected Areas in Milagros, Masbate during the 25-Year Rainfall Return Period

For the municipality of Mobo with an area of 143.03 sq. km., 1.89% will experience flood levels of less than 0.20 meters. 0.05% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.02%, 0.01%, and 0.002% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, and 2.01 to 5 meters, respectively. Table 43 depicts the areas affected in Mobo in square kilometers by flood depth per barangay.

Table 43. Affected Areas in Mobo, Masbate during the 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of barangays affected in Mobo
	Barag
0.03-0.20	2.71
0.21-0.50	0.071
0.51-1.00	0.024
1.01-2.00	0.015
2.01-5.00	0.0028
>5.00	0

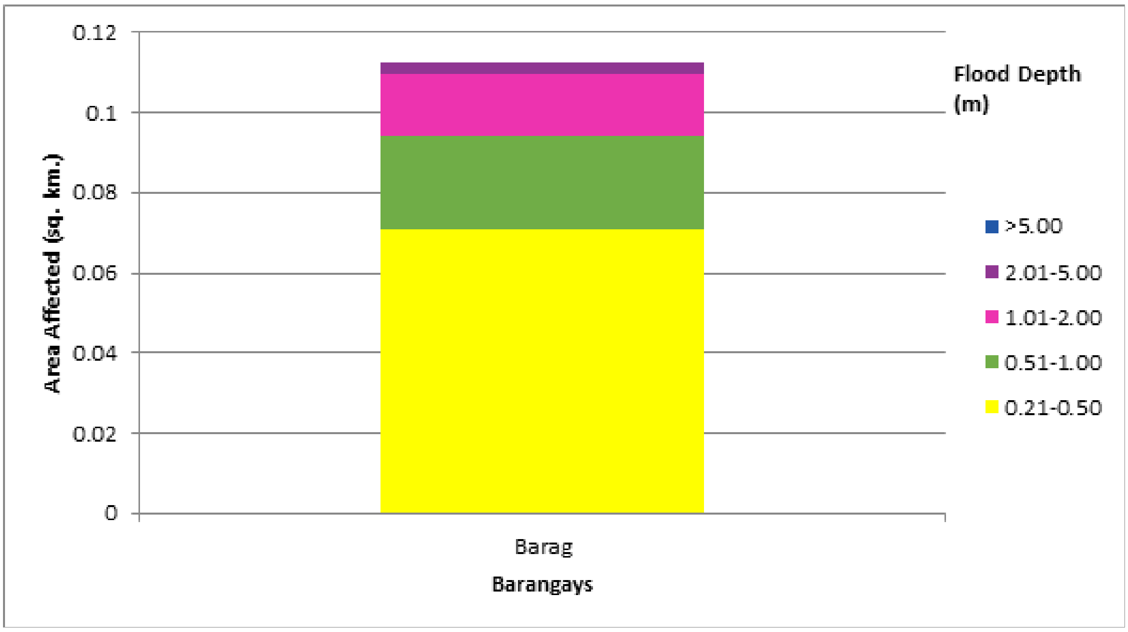


Figure 82. Affected Areas in Mobo, Masbate during the 25-Year Rainfall Return Period

For the municipality of Uson with an area of 183.76 sq. km., 50.37% will experience flood levels of less than 0.20 meters. 1.55% of the area will experience flood levels of 0.21 to 0.50 meters, while 1.29%, 1.37%, 1.42%, and 0.42% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 44 depicts the areas affected in Uson in square kilometers by flood depth per barangay.

Table 44. Affected Areas in Cawayan, Masbate during the 25-Year Rainfall Return

Affected area (sq. km.) by flood depth (in m.)	Area of barangays affected in Uson									
	Arado	Aurora	Bonifacio	Buenasuerte	Campana	Candelaria	Centro	Dapdap	Del Carmen	Del Rosario
0.03-0.20	1.83	4.24	18.18	1.03	7.22	5.27	2.64	0.035	1.03	0.86
0.21-0.50	0.06	0.15	0.49	0.038	0.32	0.16	0.038	0	0.025	0.029
0.51-1.00	0.072	0.11	0.37	0.035	0.33	0.16	0.044	0	0.021	0.018
1.01-2.00	0.085	0.092	0.37	0.03	0.34	0.24	0.059	0	0.03	0.012
2.01-5.00	0.052	0.061	0.48	0.0065	0.25	0.24	0.11	0	0.043	0.0079
>5.00	0	0.0003	0.16	0	0.062	0.065	0.0033	0	0.012	0

Area of barangays affected in Uson										
Libertad	Mabuhay	Madao	Mongahay	Paguihaman	Panicijan	San Isidro	San Jose	San Ramon	San Vicente	Simawa
4.47	1.87	12.53	0.011	4.19	2.82	4.51	0.39	4.42	7.37	7.64
0.14	0.052	0.32	0	0.12	0.12	0.13	0.013	0.16	0.29	0.2
0.12	0.046	0.15	0	0.1	0.11	0.11	0.013	0.15	0.24	0.19
0.13	0.024	0.12	0	0.11	0.066	0.14	0.013	0.16	0.31	0.19
0.15	0.0086	0.11	0	0.068	0.015	0.15	0.012	0.19	0.4	0.26
0.057	0.0001	0.0016	0	0.0042	0	0.014	0	0.091	0.18	0.12

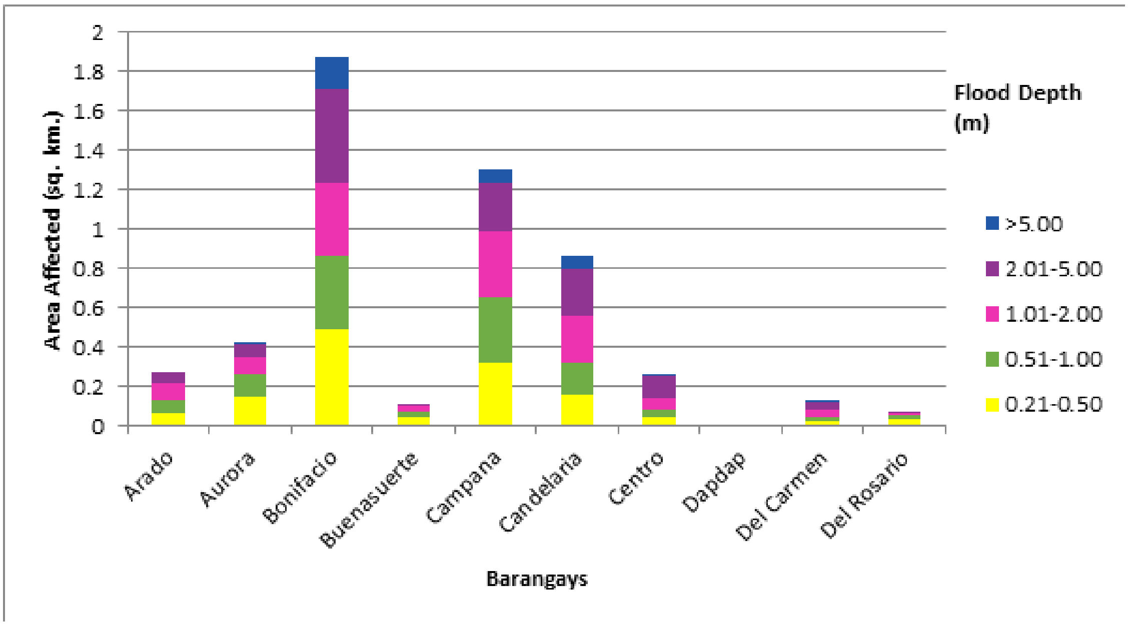


Figure 83. Affected Areas in Uson, Masbate during the 25-Year Rainfall Return Period

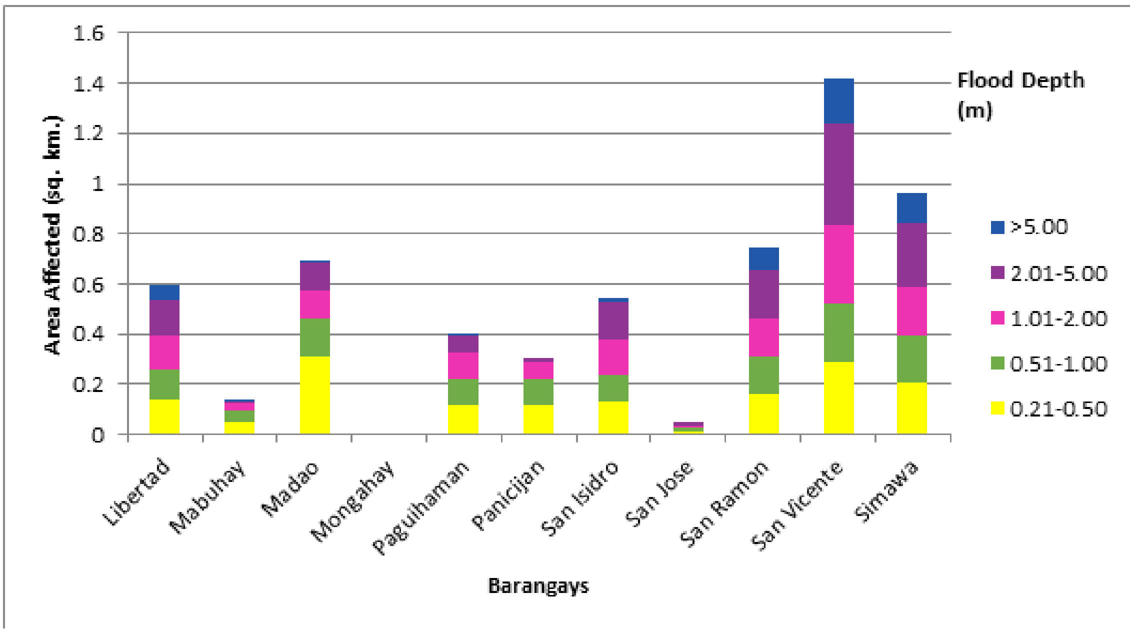


Figure 84. Affected Areas in Uson, Masbate during the 25-Year Rainfall Return Period

For the 100-year rainfall return period, 26.37% of the municipality of Cawayan with an area of 261.38 sq. km. will experience flood levels of less than 0.20 meters. 2.81% of the area will experience flood levels of 0.21 to 0.50 meters, while 1.91%, 2.32%, 2.47%, and 0.35% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 45 depicts the areas affected in Cawayan in square kilometers by flood depth per barangay.

Table 45. Affected Areas in Cawayan, Masbate during the 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of barangays affected in Cawayan								
	Cabayugan	Lague-Lague	Mactan	Malbug	Palobandera	Pulot	R.M. Magbalon	San Jose	Taberna
0.03-0.20	19.23	7.42	7.02	14.65	1.32	7.44	0.27	3.22	8.36
0.21-0.50	1.94	0.42	0.4	3.01	0.06	0.62	0.015	0.16	0.7
0.51-1.00	1.43	0.5	0.37	1.81	0.046	0.39	0.003	0.1	0.34
1.01-2.00	1.16	0.72	0.46	2.73	0.019	0.58	0.0001	0.078	0.32
2.01-5.00	0.38	1.63	0.19	1.72	0.0015	1.04	0	0.061	1.43
>5.00	0	0.78	0.037	0	0	0.0008	0	0.0014	0.1

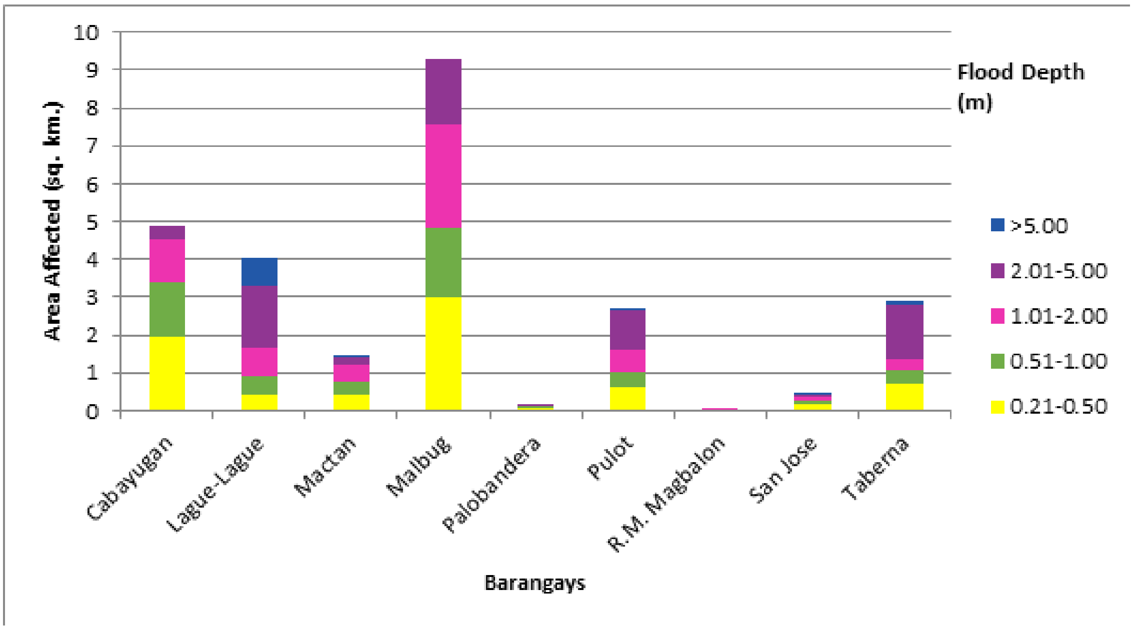


Figure 85. Affected Areas in Cawayan, Masbate during the 100-Year Rainfall Return Period

For the municipality of Dimasalang with an area of 100.44 sq. km., 5.87% will experience flood levels of less than 0.20 meters. 0.18% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.15%, 0.15%, 0.12%, and 0.02% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 46 depicts the areas affected in Dimasalang in square kilometers by flood depth per barangay.

Table 46. Affected Areas in Dimasalang, Masbate during the 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of barangays affected in Dimasalang	
	Buenaflor	Mambog
0.03-0.20	2.72	3.17
0.21-0.50	0.089	0.096
0.51-1.00	0.068	0.082
1.01-2.00	0.065	0.085
2.01-5.00	0.057	0.063
>5.00	0.0073	0.016

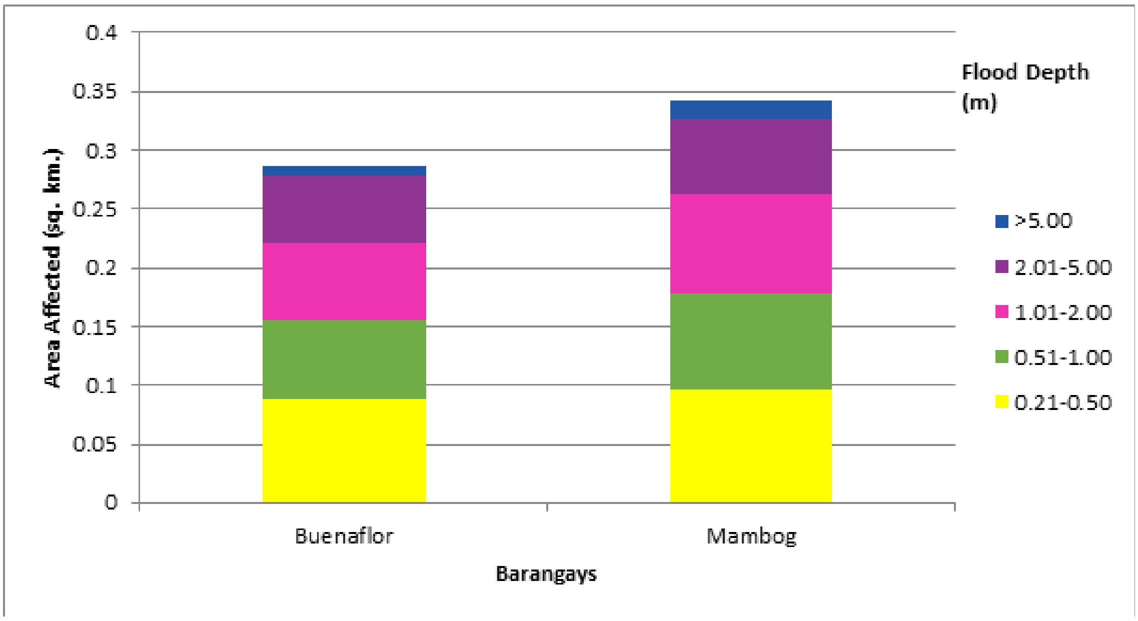


Figure 86. Affected Areas in Dimasalang, Masbate during the 100-Year Rainfall Return Period

For the municipality of Milagros with an area of 530.43 sq. km., 9.07% will experience flood levels of less than 0.20 meters. 0.73% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.39%, 0.32%, 0.27%, 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 greater than 5 meters, respectively. Table 47 depicts the areas affected in Milagros in square kilometers by flood depth per barangay.

Table 47. Affected Areas in Milagros, Masbate during the 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of barangays affected in Milagros				
	Bara	Matagbac	San Antonio	San Carlos	Sawmill
0.03-0.20	5.57	12.72	14.75	10.4	4.69
0.21-0.50	2.12	0.8	0.47	0.3	0.22
0.51-1.00	0.84	0.59	0.37	0.19	0.089
1.01-2.00	0.59	0.44	0.45	0.2	0.042
2.01-5.00	0.23	0.5	0.47	0.2	0.035
>5.00	0.008	0.06	0.26	0.035	0.002

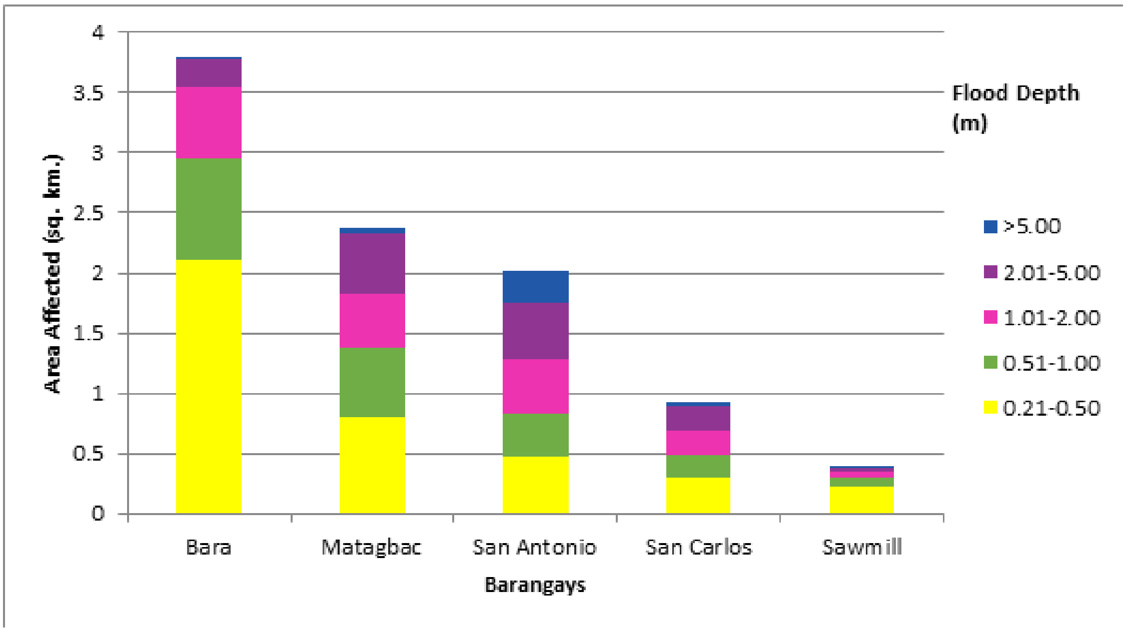


Figure 87. Affected Areas in Milagros, Masbate during the 100-Year Rainfall Return Period

For the municipality of Mobo with an area of 143.03 sq. km., 1.88% will experience flood levels of less than 0.20 meters. 0.06% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.02%, 0.01%, and 0.003% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, and 2.01 to 5 meters, respectively. Table 48 depicts the areas affected in Mobo in square kilometers by flood depth per barangay.

Table 48. Affected Areas in Mobo, Masbate during the 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of barangays affected in Mobo
	Barag
0.03-0.20	2.69
0.21-0.50	0.081
0.51-1.00	0.027
1.01-2.00	0.017
2.01-5.00	0.0042
>5.00	0

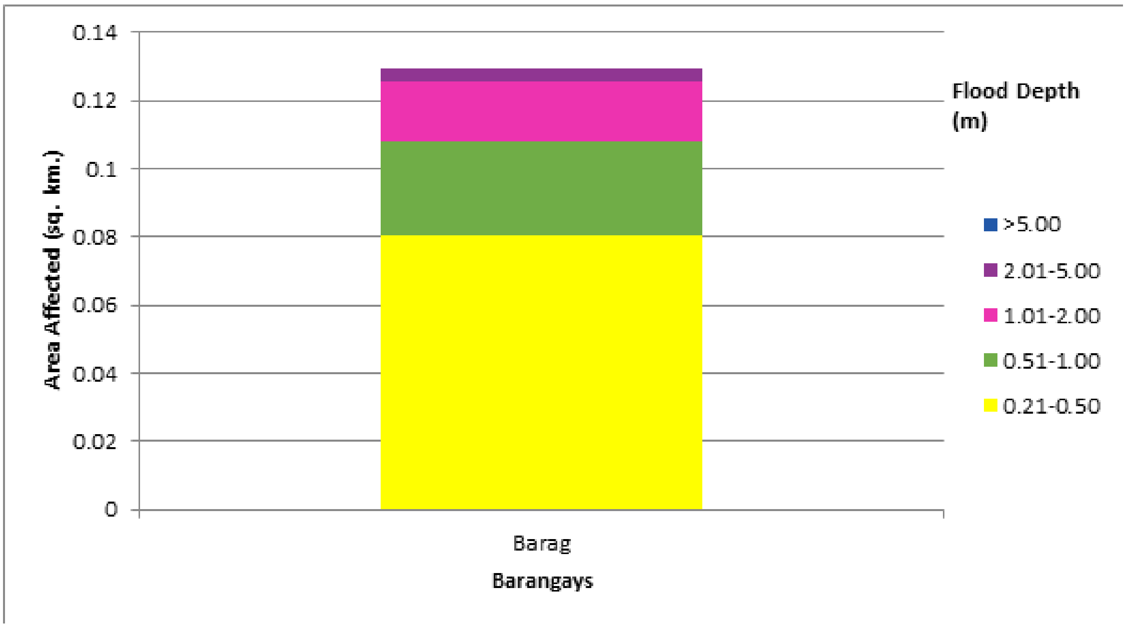


Figure 88. Affected Areas in Mobo, Masbate during the 100-Year Rainfall Return Period

For the municipality of Uson with an area of 183.76 sq. km., 49.63% will experience flood levels of less than 0.20 meters. 1.56% of the area will experience flood levels of 0.21 to 0.50 meters, while 1.28%, 1.51%, 1.82%, and 0.63% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 49 depicts the areas affected in Uson in square kilometers by flood depth per barangay

Table 49. Affected Areas in Uson, Masbate during the 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of barangays affected in Uson									
	Arado	Aurora	Bonifacio	Buenasuerte	Campana	Candelaria	Centro	Dapdap	Del Carmen	Del Rosario
0.03-0.20	1.81	4.19	17.92	1.02	7.07	5.15	2.61	0.035	1.02	0.85
0.21-0.50	0.055	0.15	0.51	0.037	0.28	0.16	0.041	0	0.026	0.03
0.51-1.00	0.071	0.13	0.37	0.041	0.27	0.15	0.039	0	0.021	0.021
1.01-2.00	0.096	0.11	0.4	0.033	0.46	0.23	0.064	0	0.031	0.015
2.01-5.00	0.069	0.077	0.58	0.01	0.34	0.35	0.13	0	0.052	0.009
>5.00	0	0.0015	0.27	0	0.093	0.097	0.013	0	0.017	0.0003

Area of barangays affected in Uson										
Libertad	Mabuhay	Madao	Mongahay	Paguihaman	Panicijan	San Isidro	San Jose	San Ramon	San Vicente	Simawa
4.39	1.86	12.44	0.011	4.15	2.79	4.44	0.39	4.3	7.23	7.53
0.14	0.055	0.35	0	0.12	0.12	0.13	0.011	0.16	0.28	0.2
0.12	0.048	0.16	0	0.1	0.11	0.11	0.012	0.15	0.24	0.19
0.15	0.03	0.13	0	0.12	0.08	0.15	0.017	0.18	0.28	0.21
0.18	0.011	0.13	0	0.089	0.021	0.19	0.015	0.25	0.53	0.31
0.076	0.0001	0.013	0	0.0059	0	0.033	0	0.13	0.23	0.18

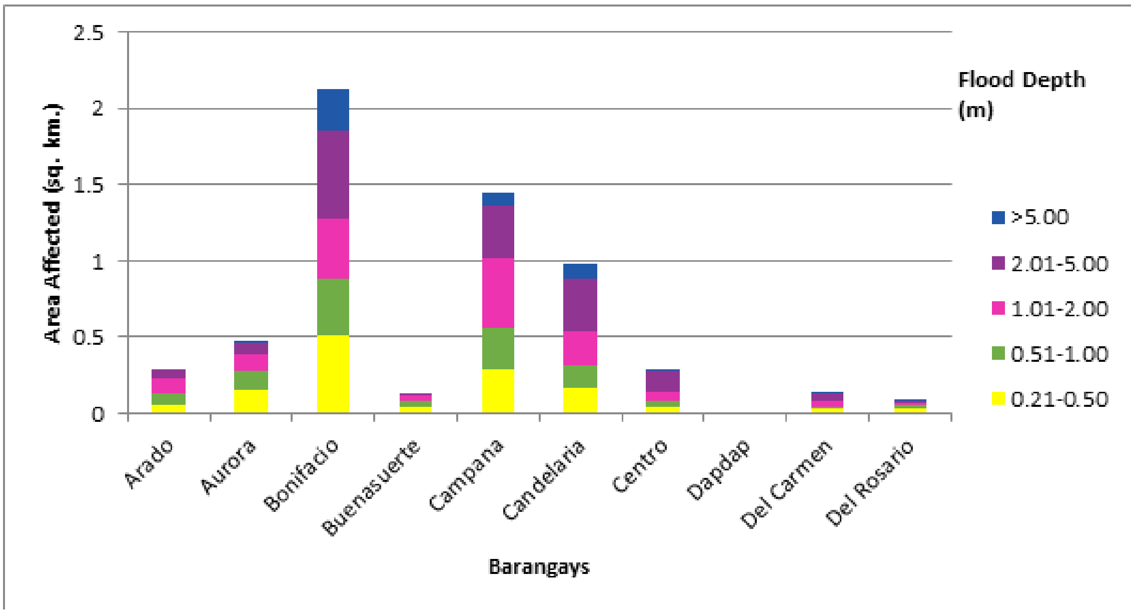


Figure 89. Affected Areas in Uson, Masbate during the 100-Year Rainfall Return Period

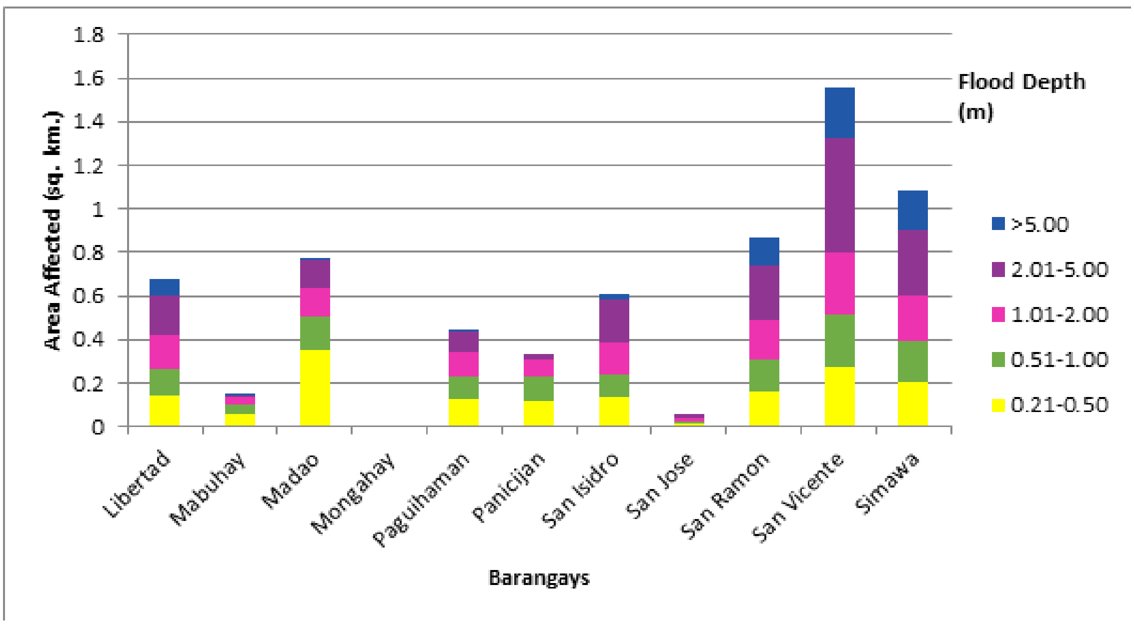


Figure 90. Affected Areas in Uson, Masbate during the 100-Year Rainfall Return Period

Among the barangays in the municipality of Cawayan, Cabayugan is projected to have the highest percentage of area that will experience flood levels at 9.23%. Meanwhile, Malbug posted the second highest percentage of area that may be affected by flood depths at 9.15%.

Among the barangays in the municipality of Dimasalang, Mambog is projected to have the highest percentage of area that will experience flood levels at 3.5%. Meanwhile, Buenaflor posted the second highest percentage of area that may be affected by flood depths at 2.99%.

Among the barangays in the municipality of Milagros, San Antonio is projected to have the highest percentage of area that will experience flood levels of at 3.16%. Meanwhile, Matagbac posted the second highest percentage of area that may be affected by flood depths at 2.85%.

Among the barangays in the municipality of Mobo, only Barag is projected to experience flood levels of at 2.82%.

Among the barangays in the municipality of Uson, Bonifacio is projected to have the highest percentage of area that will experience flood levels of at 10.91%. Meanwhile, Madao posted the second highest percentage of area that may be affected by flood depths at 7.19%.

5.11 Flood Validation

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

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

The validation personnel went to the specified points identified in a river basin and gathered data regarding the actual flood level in each location. Data gathering was done through a local DRRM office 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.

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

The flood validation consisted of 227 points randomly selected all over the Malbag flood plain. It has an RMSE value of 0.301598.

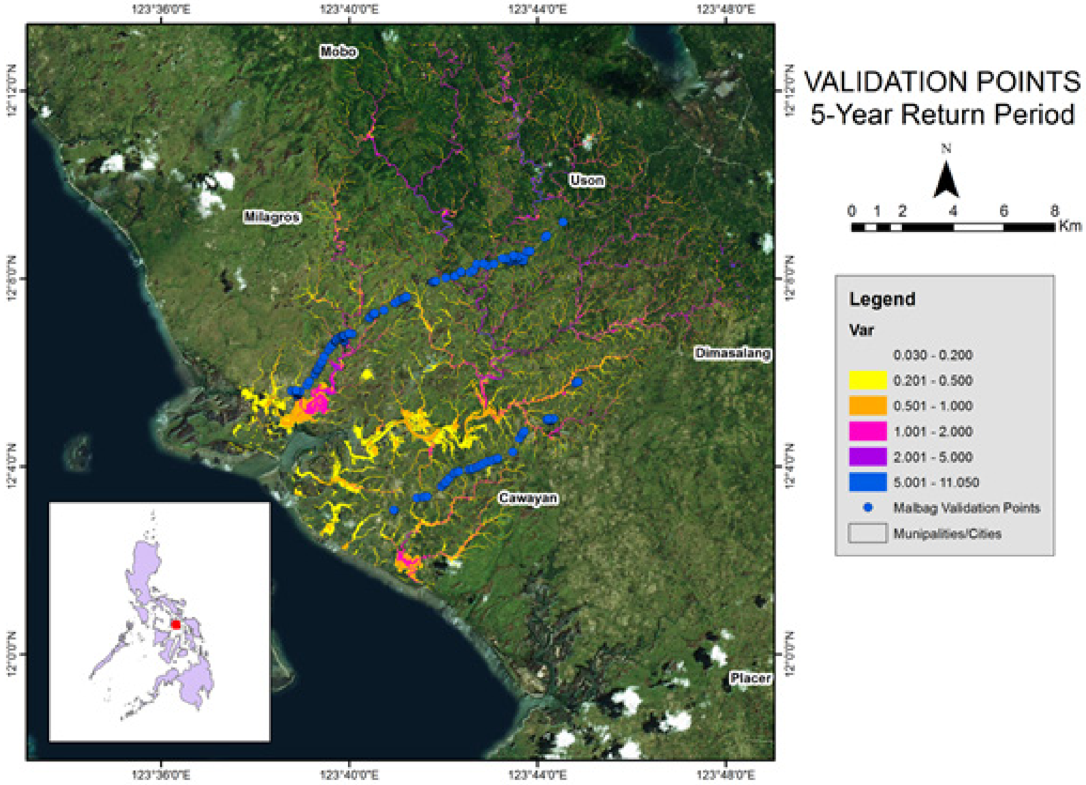


Figure 91. The validation points for the 5-Year flood depth map of the Malbag flood plain

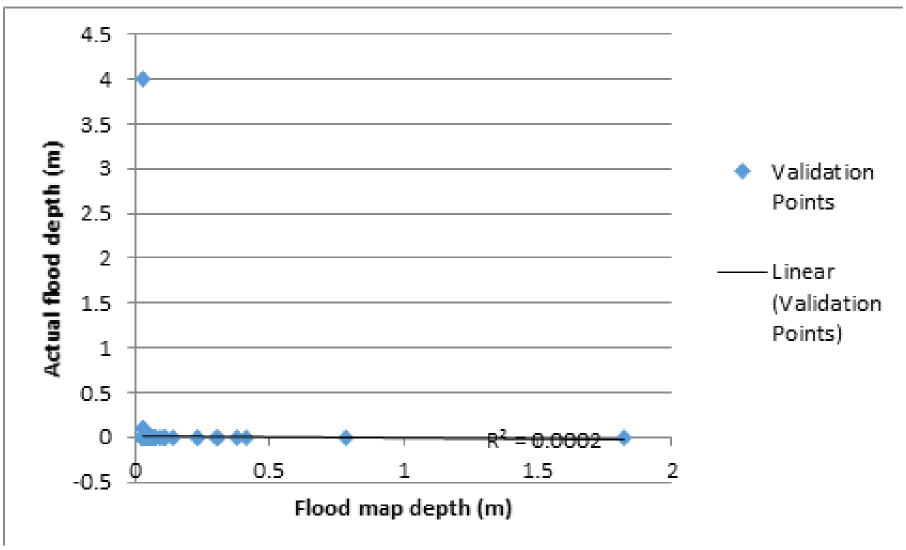


Figure 92. Flood map depth vs. Actual flood depth

Table 50. Actual flood vs. Simulated flood depth at different levels in the Malbag River Basin

MALBAG		Modeled Flood Depth (m)						
		0-0.20	0.21-0.50	0.51-1.00	1.01-2.00	2.01-5.00	> 5.00	Total
Actual Flood Depth (m)	0-0.20	218	6	1	1	0	0	226
	0.21-0.50	0	0	0	0	0	0	0
	0.51-1.00	0	0	0	0	0	0	0
	1.01-2.00	0	0	0	0	0	0	0
	2.01-5.00	1	0	0	0	0	0	1
	> 5.00	0	0	0	0	0	0	0
	Total	219	6	1	1	0	0	227

On the whole, the overall accuracy generated by the flood model is estimated at 96.04%, with 218 points correctly matching the actual flood depths. In addition, there were 6 points estimated one level above and below the correct flood depths, 1 point estimated two levels above and below, and 2 points estimated three or more levels above and below the correct flood depths. A total of 8 points were overestimated while only 1 point was underestimated in the modelled flood depths of Malbag. Table _ depicts the summary of the accuracy assessment in the Malbag River Basin survey.

Table 51. The Summary of Accuracy Assessment in the Malbag River Basin Survey

MALBAG	No. of Points	%
Correct	218	96.04
Overestimated	8	3.52
Underestimated	1	0.44
Total	227	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. 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 of the LIDAR Sensor

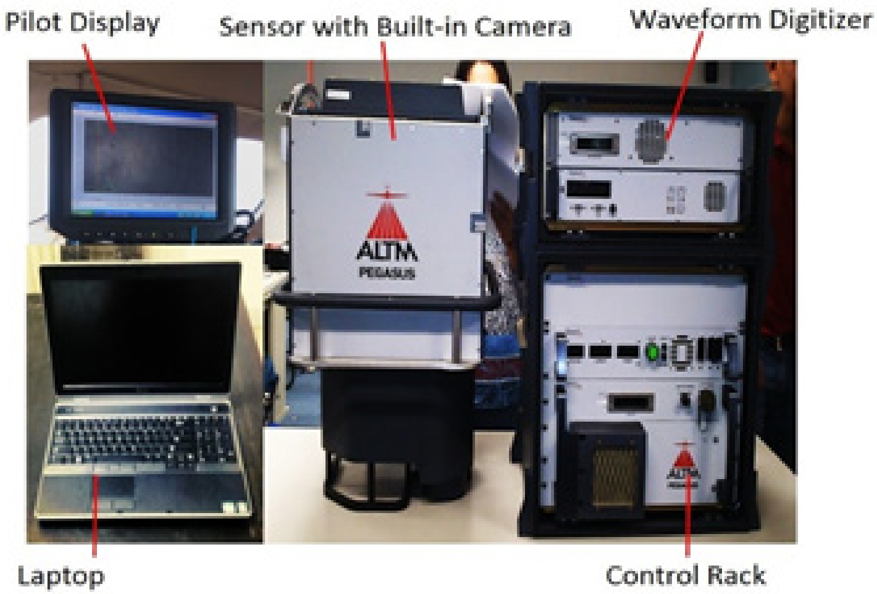


Figure A.1.1. Pegasus Sensor

Table A.1.1. Parameters and Specifications of the Pegasus Sensor

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

Annex 2. NAMRIA Certificates of Reference Points Used

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

April 10, 2014

CERTIFICATION

To whom it may concern:

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

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

Island: **LUZON**
Municipality: **MILAGROS**
Barangay:

PRS92 Coordinates

Latitude:	12° 13' 7.66936"	Longitude:	123° 30' 26.72479"	Ellipsoidal Hgt:	3.78300 m.

WGS84 Coordinates

Latitude:	12° 13' 3.03064"	Longitude:	123° 30' 31.80788"	Ellipsoidal Hgt:	59.91100 m.

PTM Coordinates

Northing:	1351188.593 m.	Easting:	555213.396 m.	Zone:	4

UTM Coordinates

Northing:	1,350,715.65	Easting:	555,194.07	Zone:	51

Location Description

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

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

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

9904102014140542

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A.2.1. MST-32

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

April 10, 2014

CERTIFICATION

To whom it may concern:

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

Province: **MASBATE**
Station Name: **MST-34**
Order: **2nd**

Island: **LUZON**
Municipality: **MOBO**
Barangay: **UMABAY EXTERIOR**

PRS92 Coordinates

Latitude:	**12° 18' 29.18323"**	Longitude:	**123° 40' 46.86556"**	Ellipsoidal Hgt:	**11.91000 m.**

WGS84 Coordinates

Latitude:	**12° 18' 24.53692"**	Longitude:	**123° 40' 51.93952"**	Ellipsoidal Hgt:	**68.23000 m.**

PTM Coordinates

Northing:	**1361109.053 m.**	Easting:	**573933.177 m.**	Zone:	**4**

UTM Coordinates

Northing:	**1,360,632.64**	Easting:	**573,907.30**	Zone:	**51**

Location Description

MST-34
From Masbate City Proper, travel for about 9.5 km. along the Nat'l. Highway going to Uson Town Proper until reaching Brgy. Umabay Ext., Mobo Town. Station is located at the left wing of Sagawsawan Bridge, 12 m. NE of a signboard and 20 m. SE of a store. Mark is the head of a 4 in. copper nail centered on a triangle on a 0.3 m. x 0.3 m. concrete block protruding 0.05 m. above the ground surface, with inscriptions "MST-34 2007 NAMRIA".

Requesting Party: **UP-DREAM**
Pupose: **Reference**
OR Number: **8795949 A**
T.N.: **2014-823**

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

9904102014140036

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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Figure A.2.2. MST-34

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

April 10, 2014

CERTIFICATION

To whom it may concern:

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

	Province: **MASBATE**	
	Station Name: **MST-35**	
	Order: **2nd**	
Island: **LUZON**		Barangay: **CAGAY**
Municipality: **CITY OF MASBATE (CAPITAL)**		
	PRS92 Coordinates	
Latitude: **12° 14' 48.14863"**	Longitude: **123° 44' 47.51779"**	Ellipsoidal Hgt: **5.31500 m.**
	WGS84 Coordinates	
Latitude: **12° 14' 43.52314"**	Longitude: **123° 44' 52.59656"**	Ellipsoidal Hgt: **61.95700 m.**
	PTM Coordinates	
Northing: **1354336.379 m.**	Easting: **581223.775 m.**	Zone: **4**
	UTM Coordinates	
Northing: **1,353,862.34**	Easting: **581,195.35**	Zone: **51**

Location Description

MST-35
From Masbate City Proper, travel for about 20.2 km. along the Nat'l. Highway going to Brgy. Marcella, Uson Town. Station is located at the right side wing of Marcella Bridge, 7 m. NW of Cristela Bravo Store, 20 m. N of Abaja Store and 5 m. NW of Marcella Brgy. Welcome Arch. Mark is the head of a 4 in. copper nail centered on a triangle on a 0.3 m. x 0.3 m. concrete block, with inscriptions "MST-35 2007 NAMRIA".

Requesting Party: **UP-DREAM**
Pupose: **Reference**
OR Number: **8795949 A**
T.N.: **2014-824**

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

9904102014140101

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

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Figure A.2.3. MST-35

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

April 10, 2014

CERTIFICATION

To whom it may concern:

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

Province: **MASBATE**
Station Name: **MST-35**
Order: **2nd**

Island: **LUZON**		Barangay: **CAGAY**
Municipality: **CITY OF MASBATE (CAPITAL)**		
	PRS92 Coordinates	
Latitude: **12° 14' 48.14863"**	Longitude: **123° 44' 47.51779"**	Ellipsoidal Hgt: **5.31500 m.**
	WGS84 Coordinates	
Latitude: **12° 14' 43.52314"**	Longitude: **123° 44' 52.59656"**	Ellipsoidal Hgt: **61.95700 m.**
	PTM Coordinates	
Northing: **1354336.379 m.**	Easting: **581223.775 m.**	Zone: **4**
	UTM Coordinates	
Northing: **1,353,862.34**	Easting: **581,195.35**	Zone: **51**

Location Description

MST-35
From Masbate City Proper, travel for about 20.2 km. along the Nat'l. Highway going to Brgy. Marcella, Uson Town. Station is located at the right side wing of Marcella Bridge, 7 m. NW of Cristela Bravo Store, 20 m. N of Abaja Store and 5 m. NW of Marcella Brgy. Welcome Arch. Mark is the head of a 4 in. copper nail centered on a triangle on a 0.3 m. x 0.3 m. concrete block, with inscriptions "MST-35 2007 NAMRIA".

Requesting Party: **UP-DREAM**
Pupose: **Reference**
OR Number: **8795949 A**
T.N.: **2014-824**

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

9904102014140101

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A.2.4. MST-40

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

April 10, 2014

CERTIFICATION

To whom it may concern:

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

Province: **MASBATE**
Station Name: **MST-49**
Order: **2nd**

Island: **LUZON** Municipality: **CATAINGAN**		Barangay: **QUEZON**
	PRS92 Coordinates	
Latitude: **12° 0' 1.41677"**	Longitude: **123° 59' 46.24265"**	Ellipsoidal Hgt: **21.25500 m.**
	WGS84 Coordinates	
Latitude: **11° 59' 56.87354"**	Longitude: **123° 59' 51.34085"**	Ellipsoidal Hgt: **79.14000 m.**
	PTM Coordinates	
Northing: **1327175.1 m.**	Easting: **608487.281 m.**	Zone: **4**
	UTM Coordinates	
Northing: **1,326,710.57**	Easting: **608,449.31**	Zone: **51**

Location Description

MST-49
From Masbate City Proper, travel for about 74.8 km. along the Nat'l. Highway going to Placer Town Proper to reach Brgy. Quezon, Cataingan Town. Station is located in front (17 m. SE) of Cataingan Mun. Hall, 10 N of the Mun. Trial Court and 15 m. E of the COMELEC Bldg. Mark is the head of a 4 in. copper nail centered on a triangle on a 0.3 m. x 0.3 m. concrete block, with inscriptions "MST-49 2007 NAMRIA".

Requesting Party: **UP-DREAM**
Pupose: **Reference**
OR Number: **8795949 A**
T.N.: **2014-826**

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A.2.5. MST-49

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

April 10, 2014

CERTIFICATION

To whom it may concern:

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

Province: **MASBATE**
Station Name: **MS-20**

Island: **Luzon**	Municipality: **USON**	Barangay: **MARCELLA**
Elevation: **4.4091 m.**	Order: **1st Order**	Datum: **Mean Sea Level**

Location Description

Station is in the Municipality of Uson, along the national Highway going to the town of Dimasalang at Barangay Marcella at Manaswang Bridge, just before crossing Brgy. Welcome arc.

Mark i sthe head of a 3"copper nail embedded in the bridge walkway with cement putty and the standard NAMRIA name designation on it.

Requesting Party: **UP-DREAM**
Pupose: **Reference**
OR Number: **8795949 A**
T.N.: **2014-839**

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

9 9 0 4 1 0 2 0 1 4 1 4 0 6 0 3

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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Figure A.2.6. MS-20

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

April 10, 2014

CERTIFICATION

To whom it may concern:

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

	Province: **MASBATE** Station Name: **MS-61**	
Island: **LUZON**	Municipality: **PALANAS**	Barangay: **NABANGIG**
Elevation: **7.0705 m.**	Order: **1st Order**	Datum: **Mean Sea Level**

Location Description

MS-061

Station is in the Municipality of Palanas, along National Highway leading to town of Cataingan, at Brgy. Nabangig, atop Nabangig Bridge (km 061+156). It is 55m from the Municipality's Boundary Arc. Mark is the head of a 3" copper nail set flush in cement putty with inscription "MS-061 2007 NAMRIA."

Requesting Party: **UP-DREAM**
Pupose: **Reference**
OR Number: **8795949 A**
T.N.: **2014-840**

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

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A.2.7. MS-61

Annex 3. Baseline Processing Reports of References Points Used

MS-20 - MST-34 (8:11:07 AM-8:58:19 AM) (S1)

Baseline observation:	MS-20 --- MST-34 (B1)
Processed:	5/13/2014 11:34:56 AM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.006 m
Vertical precision:	0.017 m
RMS:	0.003 m
Maximum PDOP:	2.504
Ephemeris used:	Broadcast
Antenna model:	NGS Absolute
Processing start time:	3/20/2014 8:11:09 AM (Local: UTC+8hr)
Processing stop time:	3/20/2014 8:58:19 AM (Local: UTC+8hr)
Processing duration:	00:47:10
Processing interval:	5 seconds

Vector Components (Mark to Mark)

From:	MST-34				
Grid		Local		Global	
Easting	574059.995 m	Latitude	N12°18'24.53692"	Latitude	N12°18'24.53692"
Northing	1360574.929 m	Longitude	E123°40'51.93952"	Longitude	E123°40'51.93952"
Elevation	11.764 m	Height	68.230 m	Height	68.230 m

To:	MS-20				
Grid		Local		Global	
Easting	581315.239 m	Latitude	N12°14'43.77974"	Latitude	N12°14'43.77974"
Northing	1353812.693 m	Longitude	E123°44'51.50748"	Longitude	E123°44'51.50748"
Elevation	4.956 m	Height	61.971 m	Height	61.971 m

Vector					
ΔEasting	7255.244 m	NS Fwd Azimuth	133°07'50"	ΔX	-6819.309 m
ΔNorthing	-6762.236 m	Ellipsoid Dist.	9921.211 m	ΔY	-2823.722 m
ΔElevation	-6.808 m	ΔHeight	-6.259 m	ΔZ	-6629.938 m

Figure A.3.1. MS-20

MS-61 - MST-49 (6:30:34 AM-11:24:24 AM) (S1)

Baseline observation:	MS-61 --- MST-49 (B1)
Processed:	5/13/2014 11:54:33 AM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.006 m
Vertical precision:	0.025 m
RMS:	0.009 m
Maximum PDOP:	3.505
Ephemeris used:	Broadcast
Antenna model:	NGS Absolute
Processing start time:	3/26/2014 6:30:54 AM (Local: UTC+8hr)
Processing stop time:	3/26/2014 11:24:24 AM (Local: UTC+8hr)
Processing duration:	04:53:30
Processing interval:	5 seconds

Vector Components (Mark to Mark)

From:	MST-49				
Grid		Local		Global	
Easting	608602.644 m	Latitude	N11°59'56.87354"	Latitude	N11°59'56.87354"
Northing	1326654.175 m	Longitude	E123°59'51.34085"	Longitude	E123°59'51.34085"
Elevation	21.031 m	Height	79.140 m	Height	79.140 m

To:	MS-61				
Grid		Local		Global	
Easting	604178.664 m	Latitude	N12°05'56.94091"	Latitude	N12°05'56.94091"
Northing	1337699.951 m	Longitude	E123°57'26.33451"	Longitude	E123°57'26.33451"
Elevation	7.554 m	Height	65.257 m	Height	65.257 m

Vector					
ΔEasting	-4423.979 m	NS Fwd Azimuth	338°22'53"	ΔX	4935.367 m
ΔNorthing	11045.776 m	Ellipsoid Dist.	11901.865 m	ΔY	524.472 m
ΔElevation	-13.477 m	ΔHeight	-13.883 m	ΔZ	10817.803 m

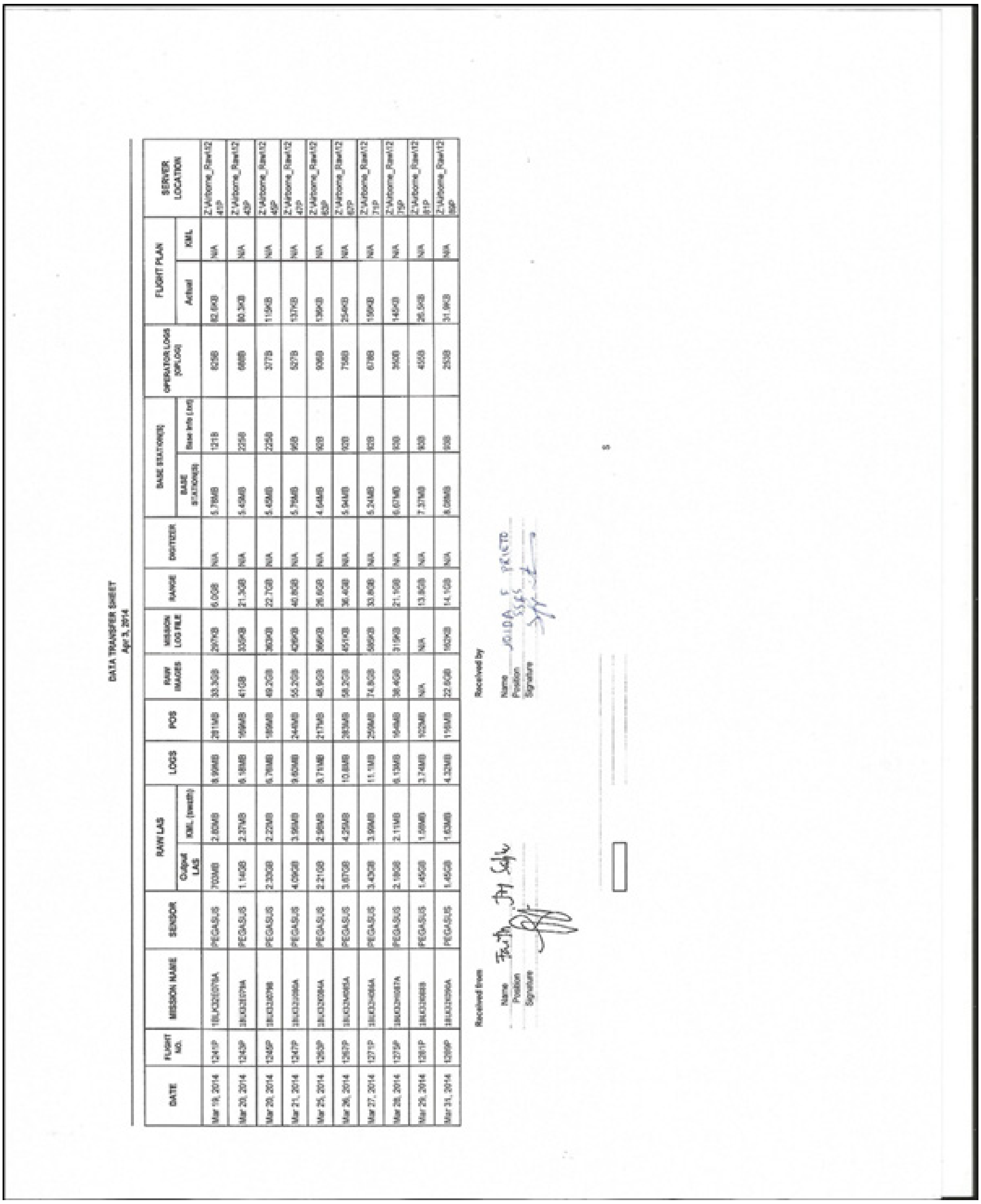
Figure A.3.2. MS-61

Annex 4. The LiDAR Survey Team Composition

Table A.4.1. The LiDAR Survey Team Composition

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

Annex 5. Data Transfer Sheet for Malbag Floodplain



DATA TRANSFER SHEET
Apr 3, 2014

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS	POS	RAW IMAGES	MISSION LOG FILE	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
Mar 19, 2014	1241P	1BLK32E078A	PEGASUS	703MB	2.80MB	8.99MB	281MB	33.3GB	297KB	6.0GB	N/A	5.78MB	121B	825B	82.6KB	N/A	Z:\Airborne_Raw\1241P
Mar 20, 2014	1243P	1BLK32E079A	PEGASUS	1.14GB	2.37MB	6.18MB	169MB	41GB	335KB	21.3GB	N/A	5.45MB	225B	688B	80.3KB	N/A	Z:\Airborne_Raw\1243P
Mar 20, 2014	1245P	1BLK32J079B	PEGASUS	2.33GB	2.22MB	6.76MB	189MB	49.2GB	363KB	22.7GB	N/A	5.45MB	225B	377B	115KB	N/A	Z:\Airborne_Raw\1245P
Mar 21, 2014	1247P	1BLK32J080A	PEGASUS	4.09GB	3.96MB	9.60MB	244MB	55.2GB	426KB	40.8GB	N/A	5.78MB	95B	527B	137KB	N/A	Z:\Airborne_Raw\1247P
Mar 25, 2014	1263P	1BLK32K084A	PEGASUS	2.21GB	2.98MB	8.71MB	217MB	48.9GB	366KB	26.6GB	N/A	4.64MB	92B	936B	136KB	N/A	Z:\Airborne_Raw\1263P
Mar 26, 2014	1267P	1BLK32M085A	PEGASUS	3.67GB	4.25MB	10.8MB	283MB	58.2GB	451KB	36.4GB	N/A	5.94MB	92B	758B	254KB	N/A	Z:\Airborne_Raw\1267P
Mar 27, 2014	1271P	1BLK32H086A	PEGASUS	3.43GB	3.99MB	11.1MB	259MB	74.8GB	585KB	33.8GB	N/A	5.24MB	92B	678B	156KB	N/A	Z:\Airborne_Raw\1271P
Mar 28, 2014	1275P	1BLK32H087A	PEGASUS	2.18GB	2.11MB	6.13MB	164MB	38.4GB	315KB	21.1GB	N/A	6.67MB	93B	350B	145KB	N/A	Z:\Airborne_Raw\1275P
Mar 29, 2014	1281P	1BLK32K088B	PEGASUS	1.45GB	1.58MB	3.74MB	102MB	N/A	N/A	13.8GB	N/A	7.37MB	93B	455B	26.5KB	N/A	Z:\Airborne_Raw\1281P
Mar 31, 2014	1289P	1BLK32K090A	PEGASUS	1.45GB	1.63MB	4.32MB	116MB	22.8GB	162KB	14.1GB	N/A	8.08MB	93B	253B	31.9KB	N/A	Z:\Airborne_Raw\1289P

Received from

Name Faith Joy Sabile
Position
Signature

Received by

Name JOIDA F. PRIETO
Position SSRS
Signature

Figure A.5.1. Data Transfer Sheet - A

DATA TRANSFER SHEET
4/22/2014(MASBATE)

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS (MB)	POS (MB)	RAW IMAGES	MISSION LOG FILE	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
4/1/2014	1291P	1BLK32KL091A	PEGASUS	2.91	3.36	9.99	256	43.6	332	29.8	NA	7.81	1KB	602	376	NA	Z:\Airborne_Raw\1291P
4/1/2014	1293P	1BLK32H091B	PEGASUS	1.75	1.46	3.85	115	24.7	213	15.6	NA	7.81	1KB	221	68.5	NA	Z:\Airborne_Raw\1293P
4/2/2014	1295P	1BLK32I092A	PEGASUS	2.93	3.42	8.9	225	54.2	404	29.2	NA	887KB	1KB	512	137	NA	Z:\Airborne_Raw\1295P
4/3/2014	1299P	1BLK32FG093A	PEGASUS	2.68	3.23	8.65	232	33.4	267	26.8	NA	7.59	1KB	358	113	NA	Z:\Airborne_Raw\1299P
4/3/2014	1301P	1BLK32F093B	PEGASUS	1.95	2.42	5.95	149	44.6	352	19.6	NA	7.59	1KB	538	201	NA	Z:\Airborne_Raw\1301P
4/4/2014	1303P	1BLK32A094A	PEGASUS	2.77	3.48	2.99	218	52.5	404	29.4	NA	6.67	1KB	694	186	NA	Z:\Airborne_Raw\1303P
4/4/2014	1305P	1BLK32A094B	PEGASUS	2.41	2.85	6.88	161	44.3	324	23.3	NA	6.67	1KB	400	2.41	NA	Z:\Airborne_Raw\1305P
4/5/2014	1307P	1BLK32DG095A	PEGASUS	3.84	4.48	4.12	271	67.2	514	37.7	NA	6.49	1KB	823	270	NA	Z:\Airborne_Raw\1307P
4/8/2014	1319P	1BLK32B098A	PEGASUS	3.66	4.32	9.93	254	17.7	526	36.2	NA	4.95	1KB	731	382	NA	Z:\Airborne_Raw\1319P
4/10/2014	1327P	1BLK32D100A	PEGASUS	2.16	2.47	6.99	175	37	277	21.7	NA	5.27	1KB	747	243	NA	Z:\Airborne_Raw\1327P
4/11/2014	1331P	1BLK32B101A	PEGASUS	1.76	1.9	5.09	134	29.8	232	17.8	NA	4.09	1KB	574	316	NA	Z:\Airborne_Raw\1331P

Received from

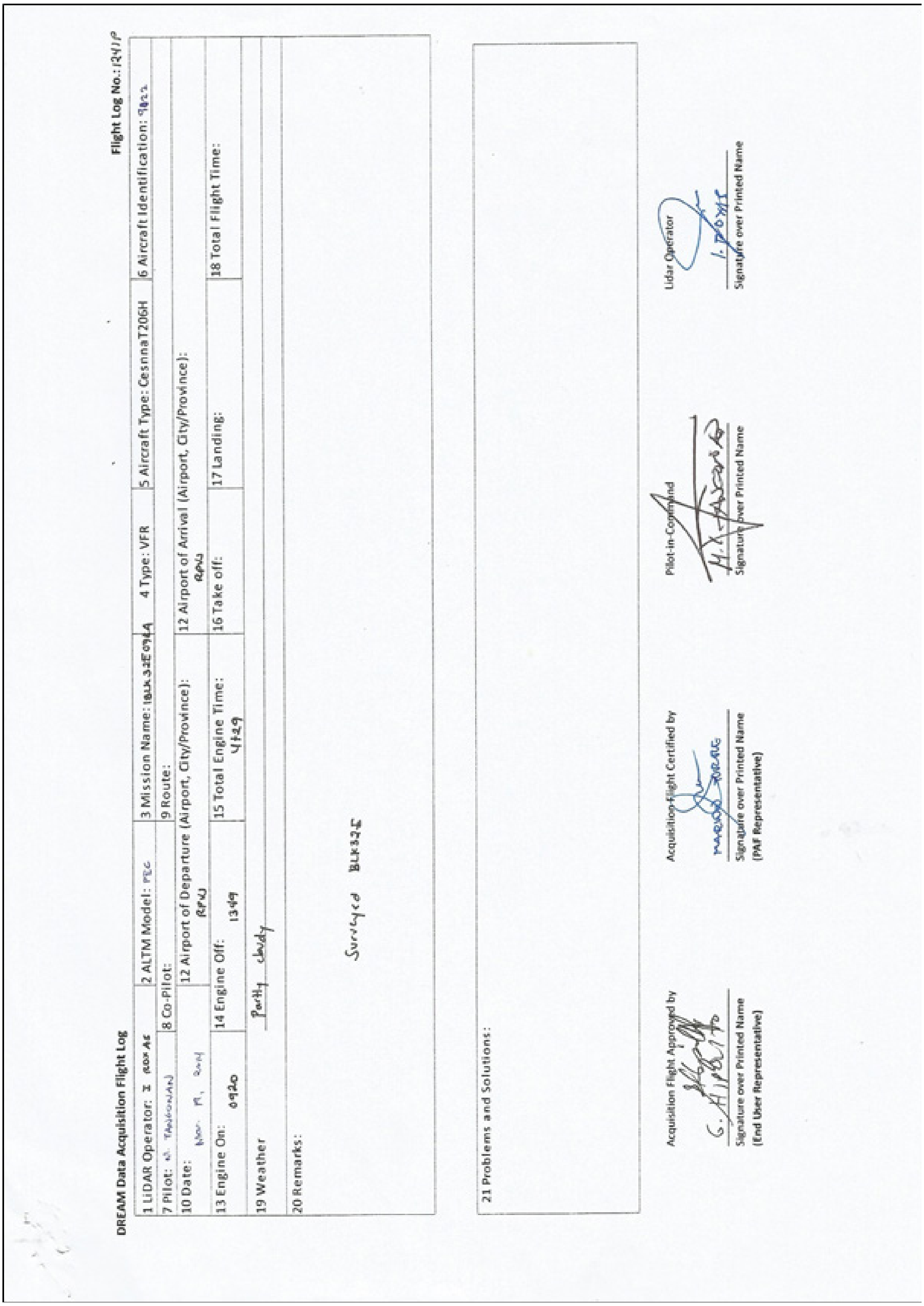
Name CARLOS JOAQUIN
Position RA
Signature [signature] 4/23/14

Received by

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

Figure A.5.2. Data Transfer Sheet - B

Annex 6. Flight Logs for the Flight Missions



Flight Log No.: 1241P

DREAM Data Acquisition Flight Log

1 LiDAR Operator: I. ROXAS	2 ALTM Model: PEG	3 Mission Name: 1BLK32E094A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9122
7 Pilot: M. TANGONAN	8 Co-Pilot:	9 Route:			
10 Date: Nov. 19, 2014	12 Airport of Departure (Airport, City/Province): RPVJ		12 Airport of Arrival (Airport, City/Province): RPVJ		
13 Engine On: 0920	14 Engine Off: 1349	15 Total Engine Time: 4+29	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather	Partly cloudy				

20 Remarks:

Surveyed BLK32E

21 Problems and Solutions:

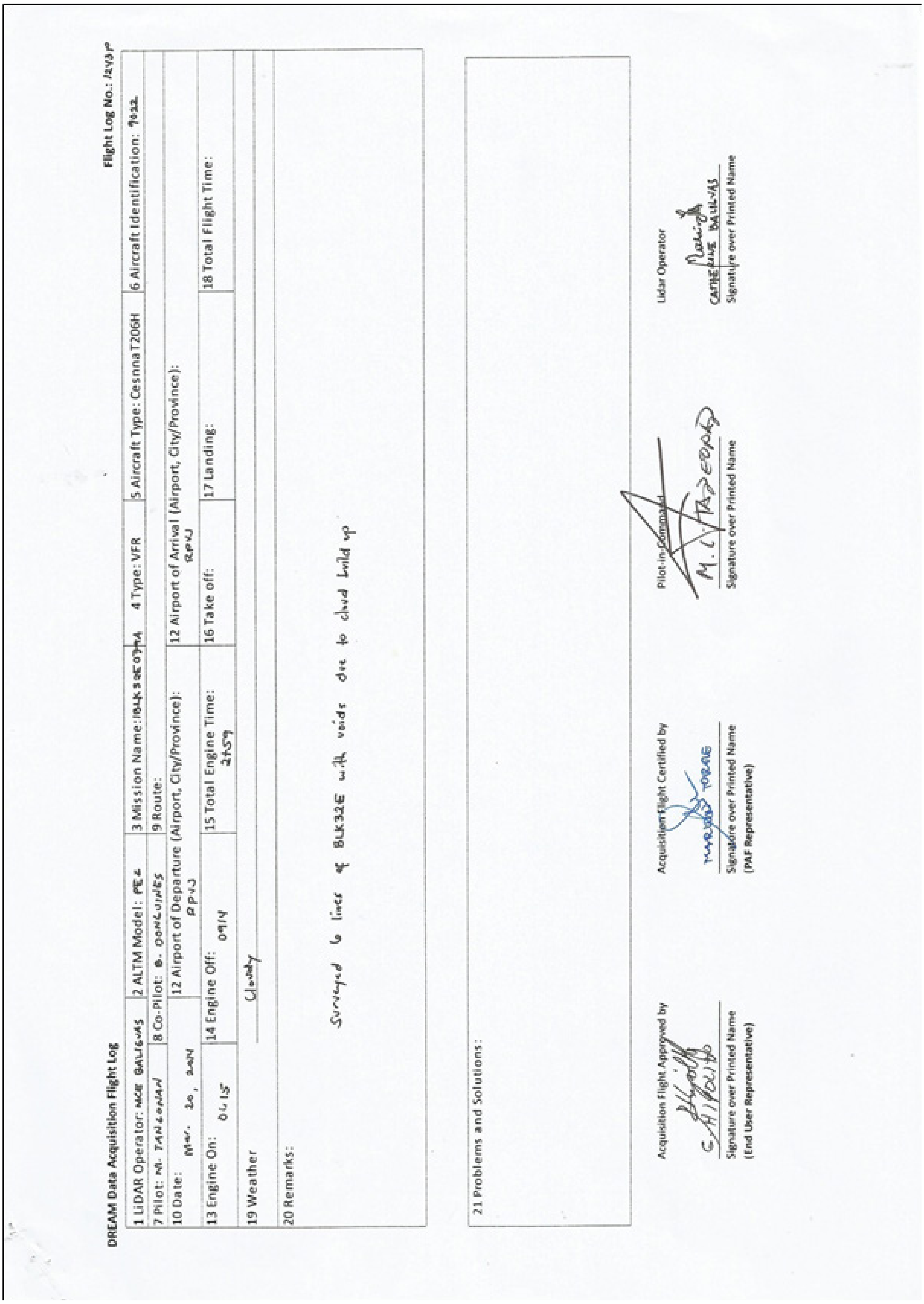
Acquisition Flight Approved by: G. [illegible] — Signature over Printed Name (End User Representative)

Acquisition Flight Certified by: [illegible] — Signature over Printed Name (PAF Representative)

Pilot-in-Command: M. [illegible] — Signature over Printed Name

Lidar Operator: I. ROXAS — Signature over Printed Name

Figure A.6.1.1. Flight Log for 1241P Mission



DREAM Data Acquisition Flight Log — Flight Log No.: 1243P

1 LiDAR Operator: MCE BALIGVAS	2 ALTM Model: PEG	3 Mission Name: 1BLK32E079A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9022
7 Pilot: M. TANGONAN	8 Co-Pilot: B. DONGUINES	9 Route:			
10 Date: Mar. 20, 2014	12 Airport of Departure (Airport, City/Province): RPVJ		12 Airport of Arrival (Airport, City/Province): RPVJ		
13 Engine On: 0415	14 Engine Off: 0914	15 Total Engine Time: 2+59	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: Cloudy					
20 Remarks: Surveyed 6 lines of BLK32E with voids due to cloud build up					
21 Problems and Solutions:					

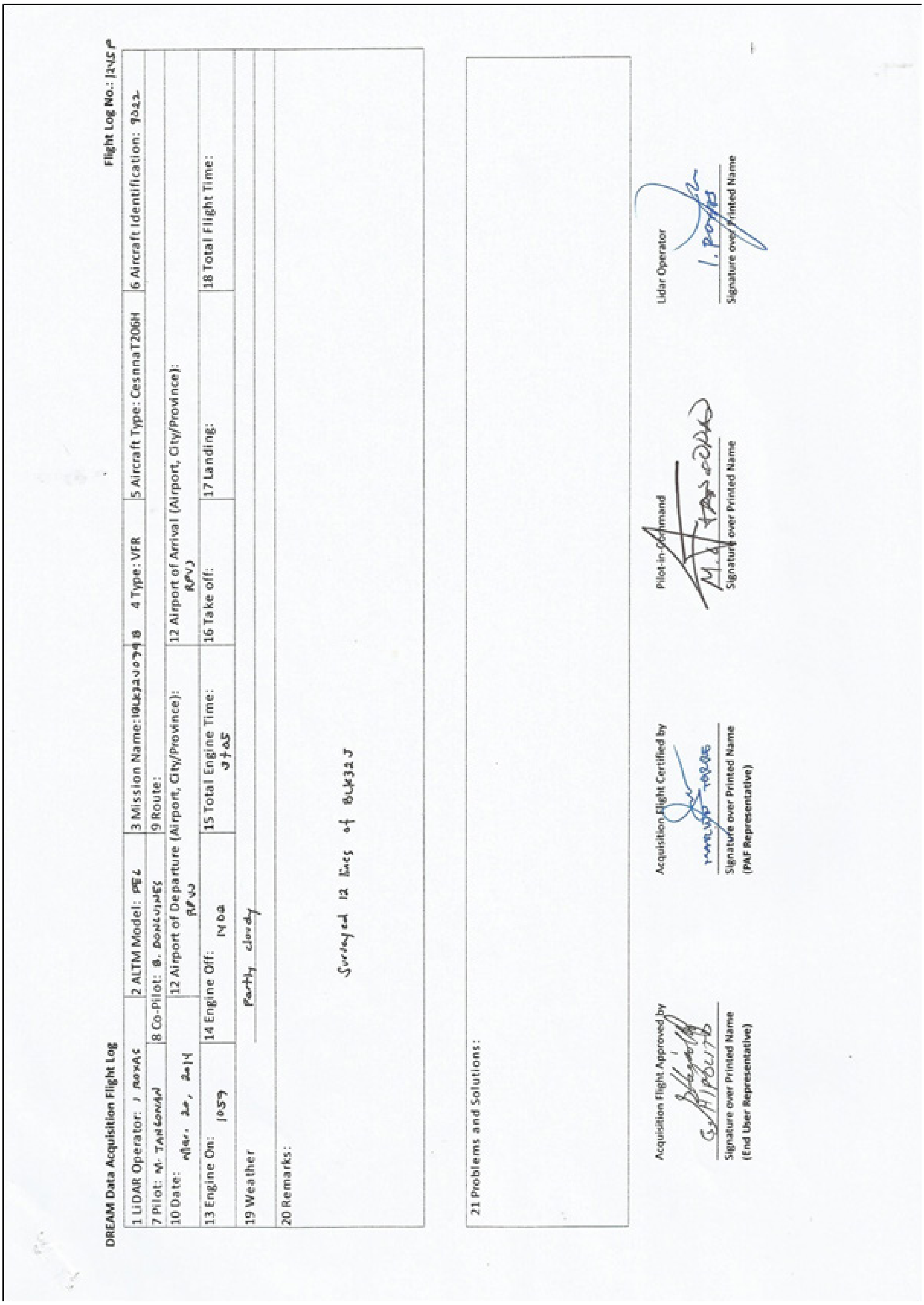
Acquisition Flight Approved by: C. HIPOLITO — Signature over Printed Name (End User Representative)

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

Pilot-in-Command: M. C. TADEORA — Signature over Printed Name

Lidar Operator: CATHERINE BALIGVAS — Signature over Printed Name

Figure A.6.2.2.Flight Log for 1243P Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 1245P

1 LiDAR Operator: I. ROXAS	2 ALTM Model: PEG	3 Mission Name: 1BLK32J079B	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9022
7 Pilot: M. TANGONAN	8 Co-Pilot: B. DONGUINES	9 Route:			
10 Date: Mar. 20, 2014	12 Airport of Departure (Airport, City/Province): RPVJ		12 Airport of Arrival (Airport, City/Province): RPVJ		
13 Engine On: 1059	14 Engine Off: 1402	15 Total Engine Time: 3+05	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: Partly cloudy					
20 Remarks: Surveyed 12 lines of BLK32J					
21 Problems and Solutions:					

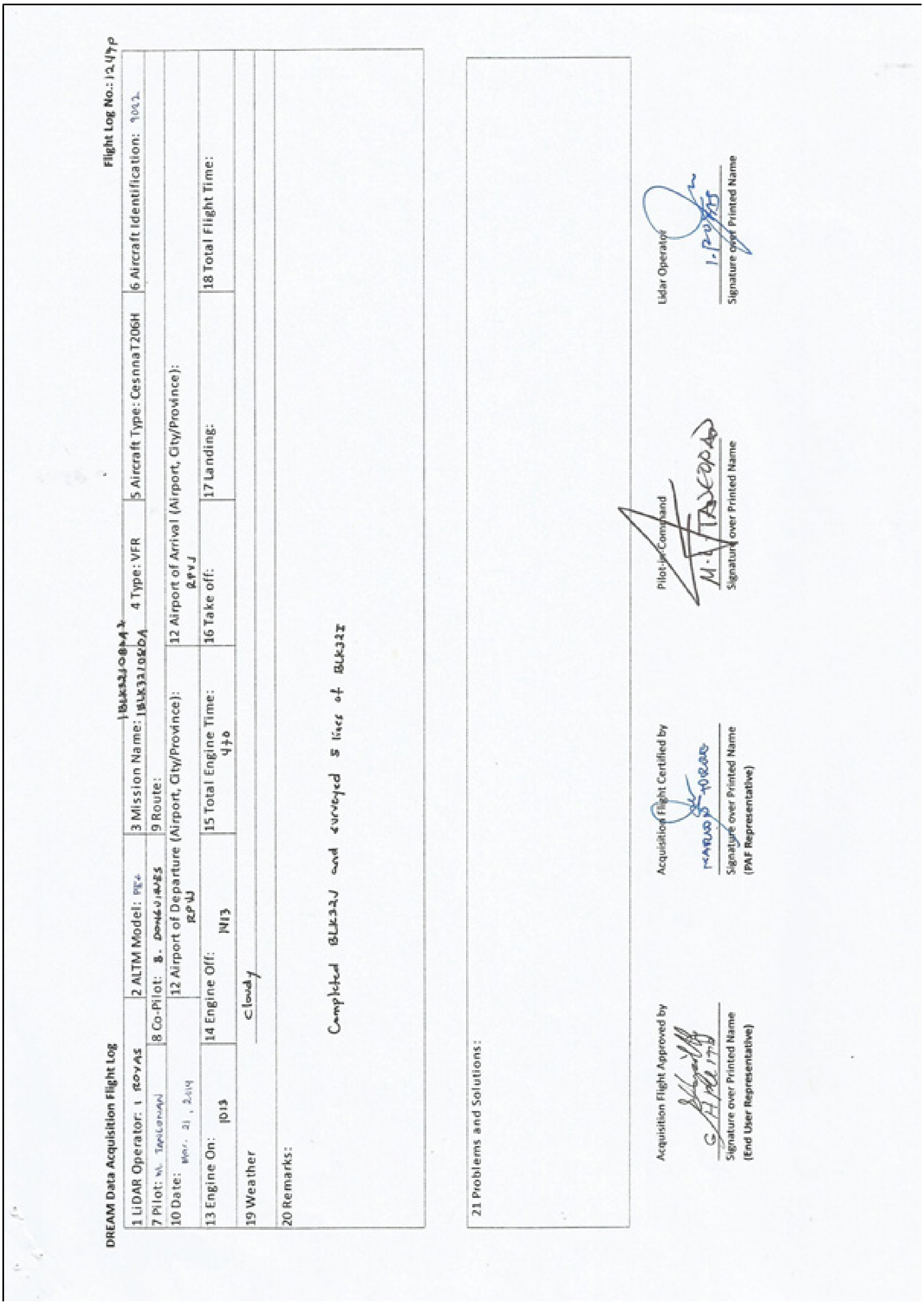
Acquisition Flight Approved by: G. HIPOLITO — Signature over Printed Name (End User Representative)

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

Pilot-in-Command: M. TANGONAN — Signature over Printed Name

Lidar Operator: I. ROXAS — Signature over Printed Name

Figure A.6.3.3. Flight Log for 1245P Mission


DREAM Data Acquisition Flight Log

Flight Log No.: 1247P

1 LiDAR Operator: I. ROXAS	2 ALTM Model: PEG	3 Mission Name: 1BLK32IO80A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9022
7 Pilot: M. TANGONAN	8 Co-Pilot: B. DONGUINES	9 Route:			
10 Date: Mar. 21, 2014	12 Airport of Departure (Airport, City/Province): RPVJ		12 Airport of Arrival (Airport, City/Province): RPVJ		
13 Engine On: 1013	14 Engine Off: 1413	15 Total Engine Time: 4+0	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: cloudy					
20 Remarks: Completed BLK32J and surveyed 5 lines of BLK32I					
21 Problems and Solutions:					

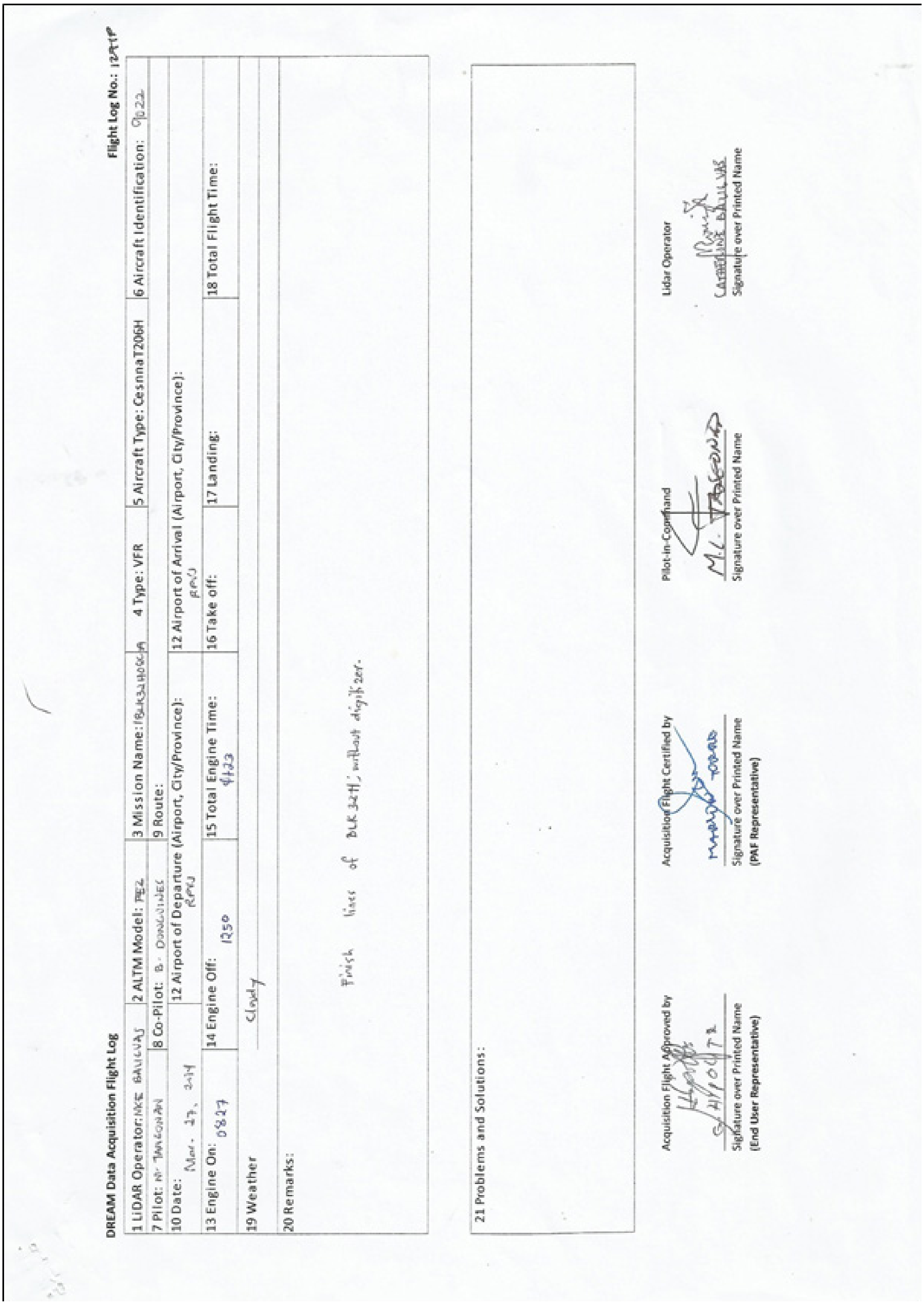
Acquisition Flight Approved by: Signature over Printed Name (End User Representative)

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

Pilot-in-Command: Signature over Printed Name

Lidar Operator: Signature over Printed Name

Figure A.6.4. Flight Log for 1247P Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 1271P

1 LiDAR Operator: MCE BALICVAS	2 ALTM Model: PEZ	3 Mission Name: 1BLK32H086A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9022
7 Pilot: M. TANGONAN	8 Co-Pilot: B. DONGUINES	9 Route:			
10 Date: Mar. 27, 2014	12 Airport of Departure (Airport, City/Province): RPVJ		12 Airport of Arrival (Airport, City/Province): RPVJ		
13 Engine On: 0827	14 Engine Off: 1250	15 Total Engine Time: 4+23	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather	Cloudy				
20 Remarks: Finish lines of BLK 32H; without digitizer.					

21 Problems and Solutions:

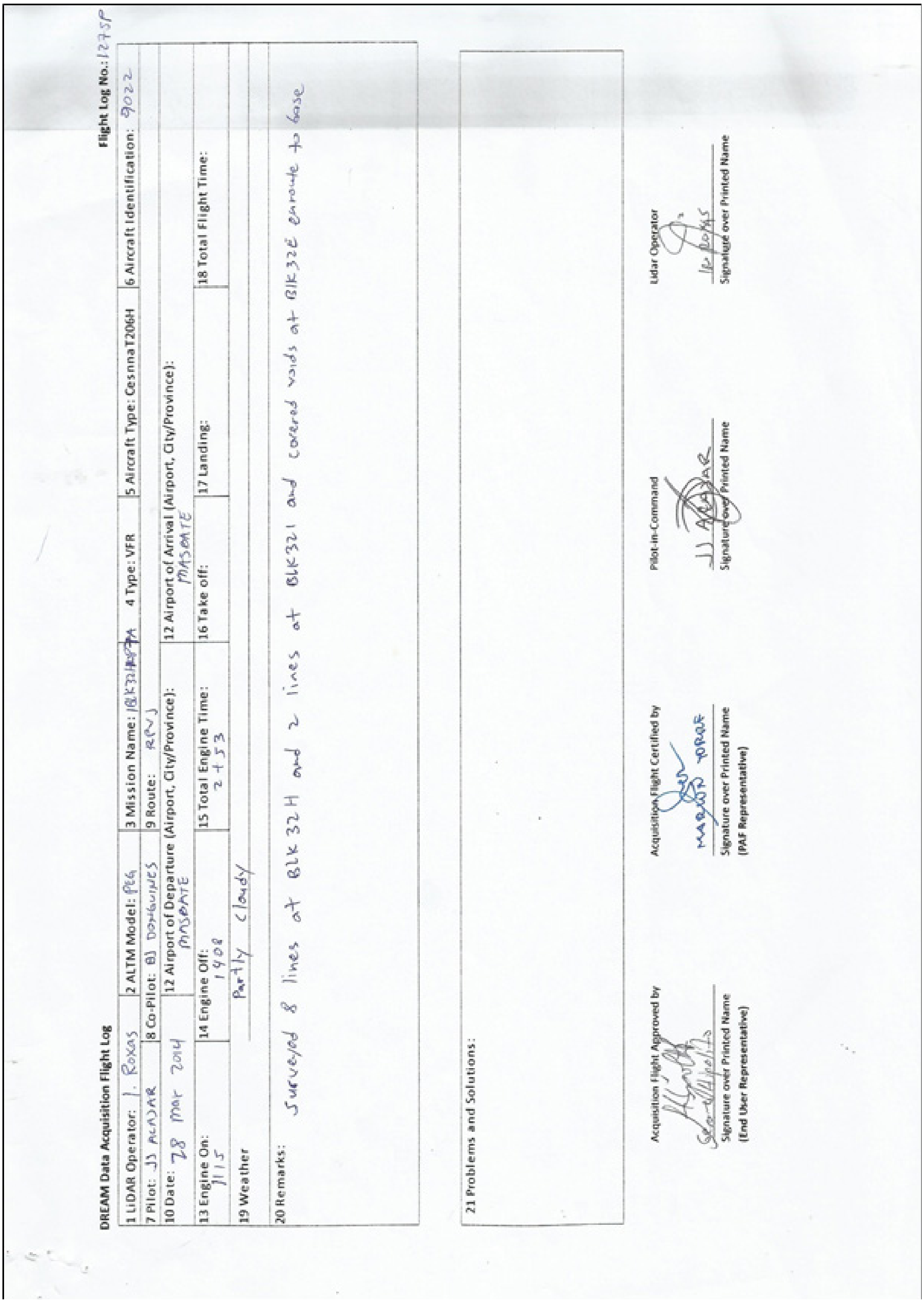
Acquisition Flight Approved by
G. H/ROLTR
Signature over Printed Name
(End User Representative)

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

Pilot-in-Command
M.L. TANGONAN
Signature over Printed Name

Lidar Operator
CATHERINE BALICVAS
Signature over Printed Name

Figure A.6.5. Flight Log for 1271P Mission



DREAM Data Acquisition Flight Log — **Flight Log No.:** 1275P

1 LiDAR Operator: J. Roxas	2 ALTM Model: PEG	3 Mission Name: 1BLK32H[illegible]A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9022
7 Pilot: JJ Alajar	8 Co-Pilot: BJ Donguines	9 Route: RPVJ			
10 Date: 28 Mar 2014	12 Airport of Departure (Airport, City/Province): Masbate		12 Airport of Arrival (Airport, City/Province): Masbate		
13 Engine On: 1115	14 Engine Off: 1408	15 Total Engine Time: 2+53	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather	Partly cloudy				

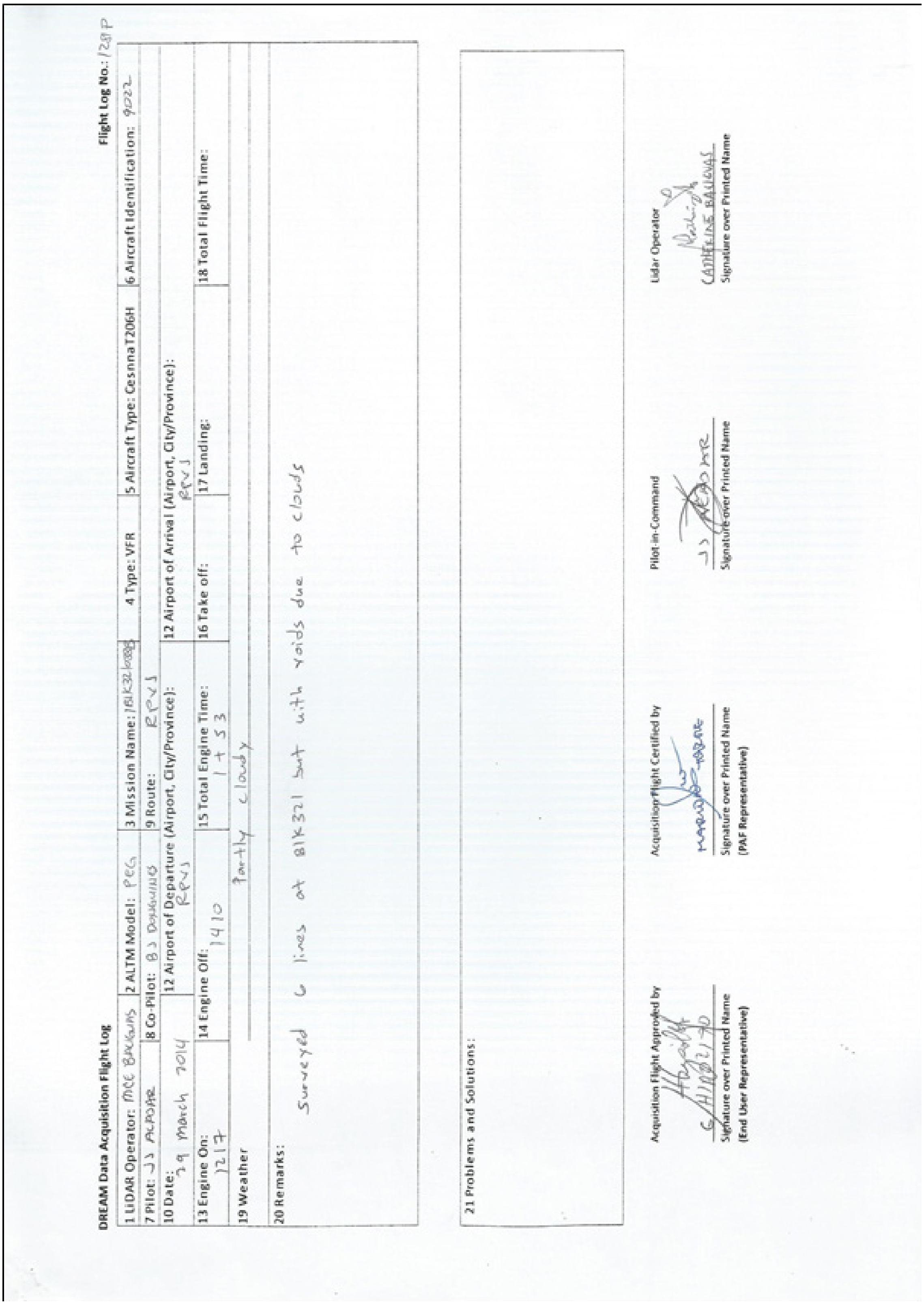
20 Remarks: Surveyed 8 lines at BLK 32H and 2 lines at BLK32I and covered voids at BLK32E enroute to base

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
Sec. Hipolito	Marvin Jorge	JJ Alajar	JR Roxas
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

Figure A.6.6. Flight Log for 1275P Mission

Figure A.6.7. Flight Log for 1281P Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 1281P

1 LiDAR Operator: MCE Balguias	2 ALTM Model: PEG	3 Mission Name: 1BLK32I088A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9022
7 Pilot: JJ Alajar	8 Co-Pilot: BJ Dongiuines	9 Route: RPVJ			
10 Date: 29 March 2014	12 Airport of Departure (Airport, City/Province): RPVJ		12 Airport of Arrival (Airport, City/Province): RPVJ		
13 Engine On: 1217	14 Engine Off: 1410	15 Total Engine Time: 1+53	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: Partly cloudy					
20 Remarks: Surveyed 6 lines at BLK32I but with voids due to clouds					

21 Problems and Solutions:

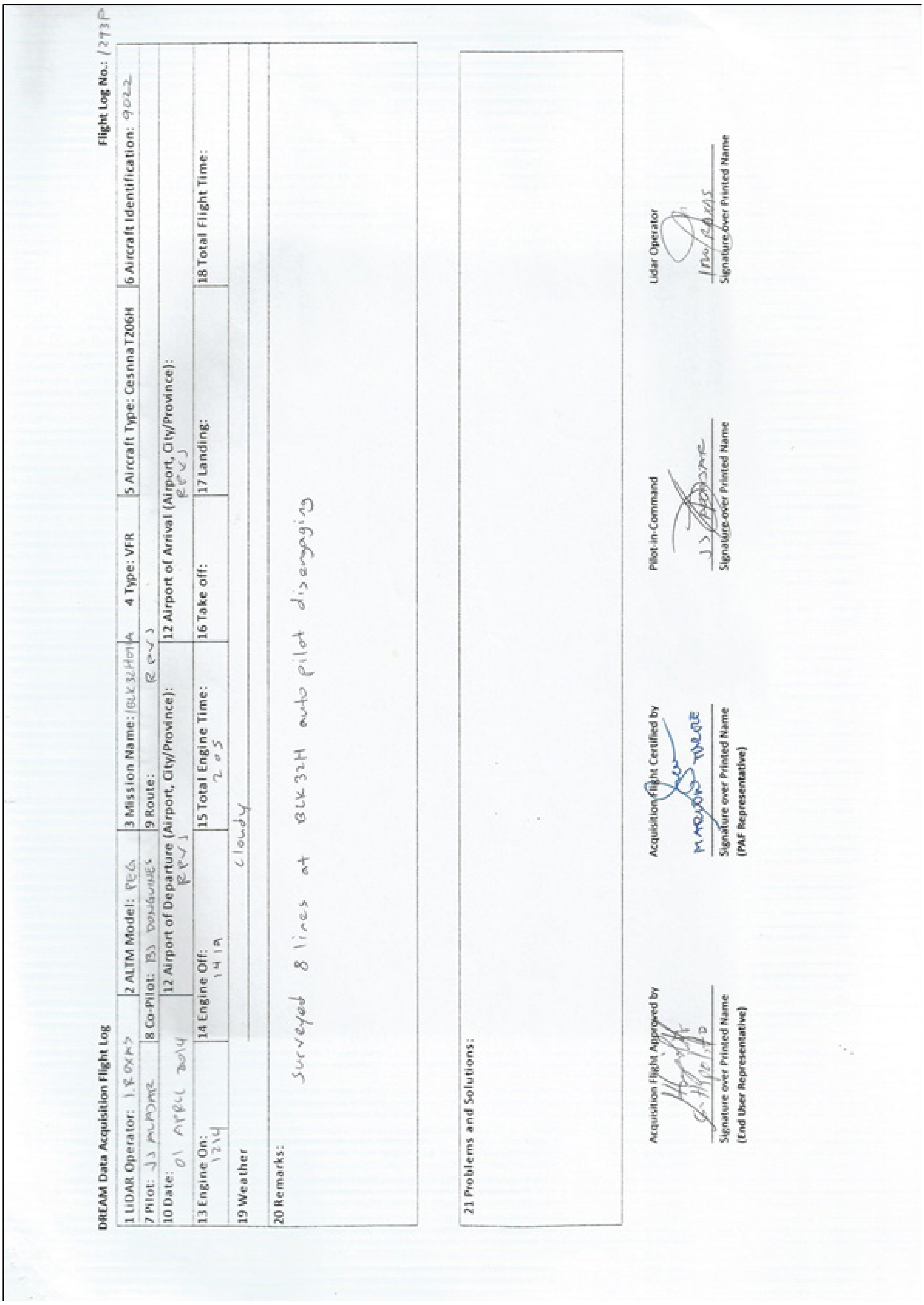
Acquisition Flight Approved by — Signature over Printed Name (End User Representative)

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

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

Lidar Operator — Catherine Balguias — Signature over Printed Name

Figure A.6.7. Flight Log for 1281P Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 1293P

1 LiDAR Operator: I. ROXAS	2 ALTM Model: PEG	3 Mission Name: 1BLK32H091A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9022
7 Pilot: JJ ALADJAR	8 Co-Pilot: BJ DONGUINES	9 Route: RPVJ			
10 Date: 01 APRIL 2014	12 Airport of Departure (Airport, City/Province): RPVJ		12 Airport of Arrival (Airport, City/Province): RPVJ		
13 Engine On: 1214	14 Engine Off: 1419	15 Total Engine Time: 205	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: cloudy					

20 Remarks:

surveyed 8 lines at BLK32H auto pilot disengaging

21 Problems and Solutions:

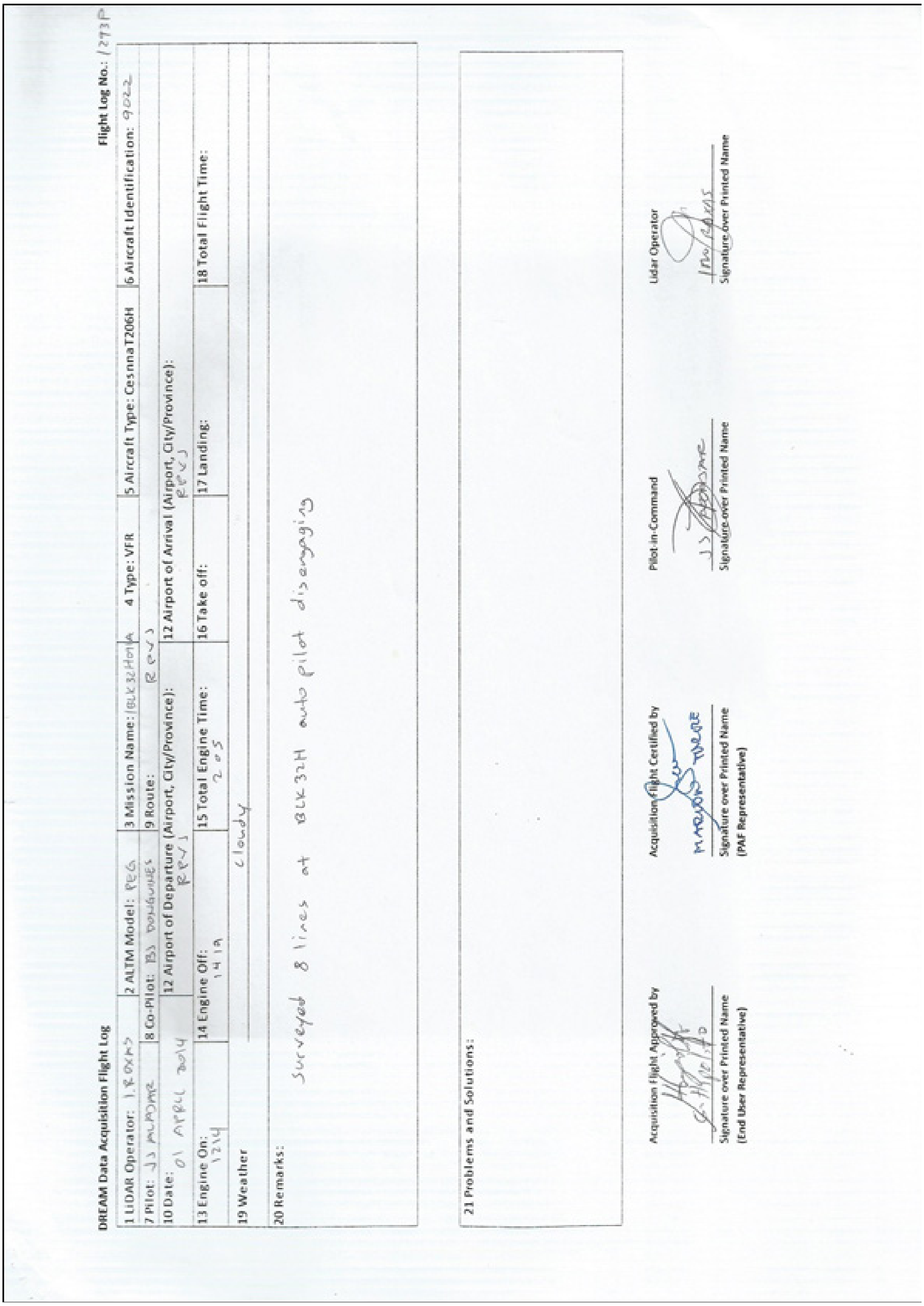
Acquisition Flight Approved by — Signature over Printed Name (End User Representative)

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

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

Lidar Operator — I. ROXAS — Signature over Printed Name

Figure A.6.8. Flight Log for 1293P Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 1273P

1 LiDAR Operator: J. ROXAS	2 ALTM Model: PEG	3 Mission Name: 1BLK32H091A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9022
7 Pilot: JJ ALADJAR	8 Co-Pilot: BJ DONGUINES	9 Route: RPVJ			
10 Date: 01 APRIL 2014	12 Airport of Departure (Airport, City/Province): RPVJ		12 Airport of Arrival (Airport, City/Province): RPVJ		
13 Engine On: 1214	14 Engine Off: 1419	15 Total Engine Time: 2+05	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather	cloudy				

20 Remarks:

Surveyed 8 lines at BLK 32H auto pilot disengaging

21 Problems and Solutions:

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

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

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

Lidar Operator — J. ROXAS — Signature over Printed Name

Figure A.6.9. Flight Log for 1295P Mission

Annex 7. Flight Status Reports

FLIGHT STATUS REPORT
Northern Mindanao / Pagadian
July 5 to 9, 2014 & February 7 to 26, 2016

Table A.7.1. Flight Status Report

FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
1241P	BLK32E	1BLK32E078A	I. Roxas	19 MAR 14	Surveyed BLK32E but needs reflight due to problematic swath
1243P	BLK32E	1BLK32E079A	MCE. Baliguas	20 MAR 14	Surveyed 6 lines of BLK32E with voids due to heavy cloud build up
1245P	BLK32J	1BLK32J079B	I. Roxas	20 MAR 14	Surveyed 12 lines of BLK32J
1247P	BLK32J	1BLK32IJ080A	I. Roxas	21 MAR 14	Completed BLK32J and surveyed 5 lines of BLK32I
1271P	BLK32H	1BLK32H086A	MCE. Baliguas	27 MAR 14	Surveyed 18 lines at BLK32H; without digitizer
1275P	BLK32H	1BLK32HI087A	I. Roxas	28 MAR 14	Surveyed 8 lines at BLK32H and 2 lines at BLK32I and covered voids at BLK32E en route to base
1281P	BLK32I	1BLK32I088B	MCE. Baliguas	29 MAR 14	Surveyed 6 lines at BLK32I but with voids due to clouds
1293P	BLK32H	1BLK32H091B	I. Roxas	01APR 14	Surveyed 8 lines at BLK32H; auto pilot disengaging
1295P	BLK32E	1BLK32E092A	MCE. Baliguas	02 APR 14	Finished the rest of BLK32 E and BLK32K and covered voids at BLK32I

SWATH PER FLIGHT MISSION

Flight: 1241P
Area: BLK32E
Mission Name: 1BLK32E078A
Area Surveyed: 148.94 sq.km.

Altitude: 800m
PRF: 200 kHz SCF: 30 Hz
Lidar FOV: 50 deg Sidelap: 25%

Altitude: 1000m
PRF: 200 kHz SCF: 30 Hz
Lidar FOV: 50 deg Sidelap: 25%

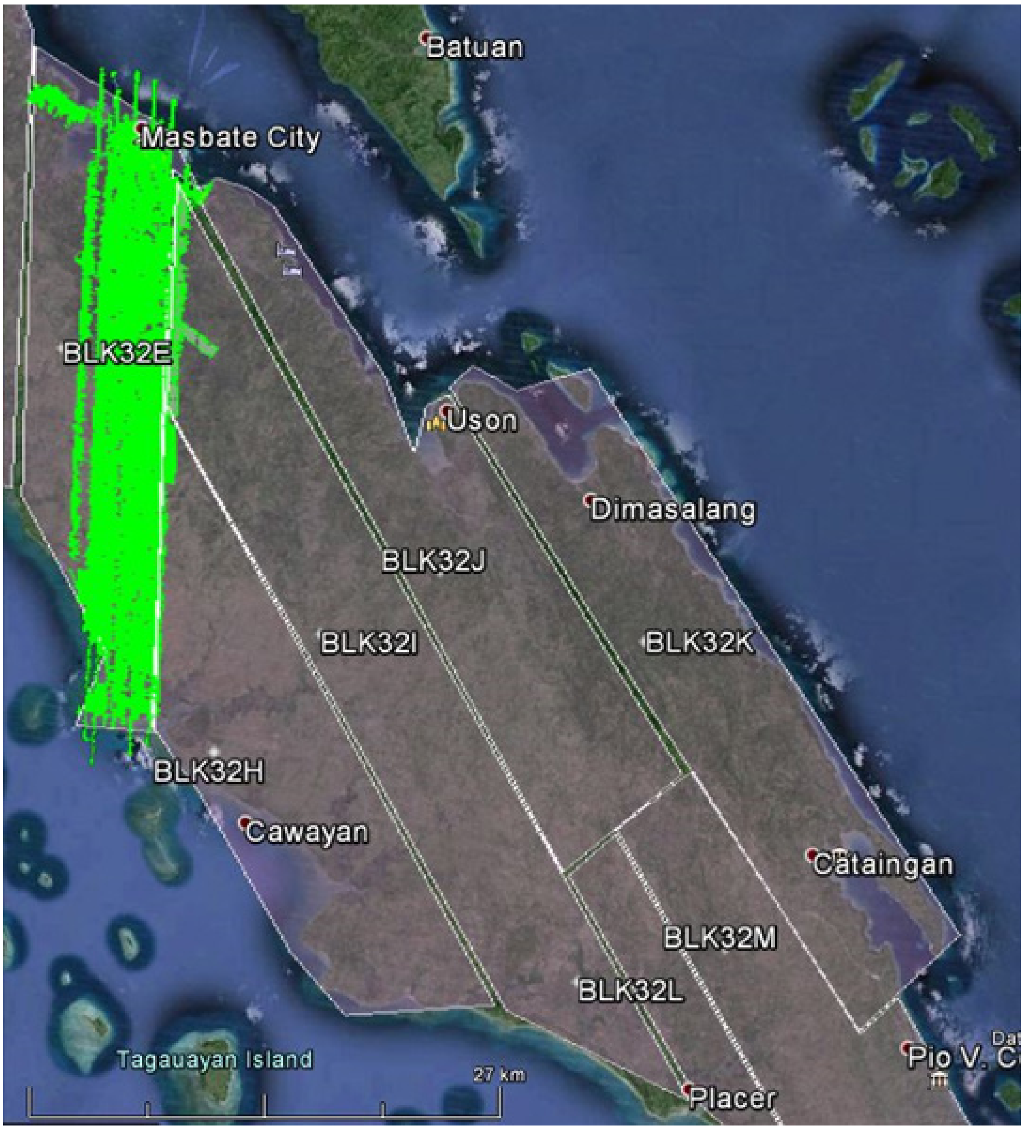


Figure A.7.1. Swath for Flight No. 1241P

Flight No. : 1243P
Area: BLK32E
Mission Name: 1BLK32E079A
Area Surveyed: 156.087 sq.km.

Altitude: 800m
PRF: 200 kHz SCF: 30 Hz
Lidar FOV: 50 deg Sidelap: 25%

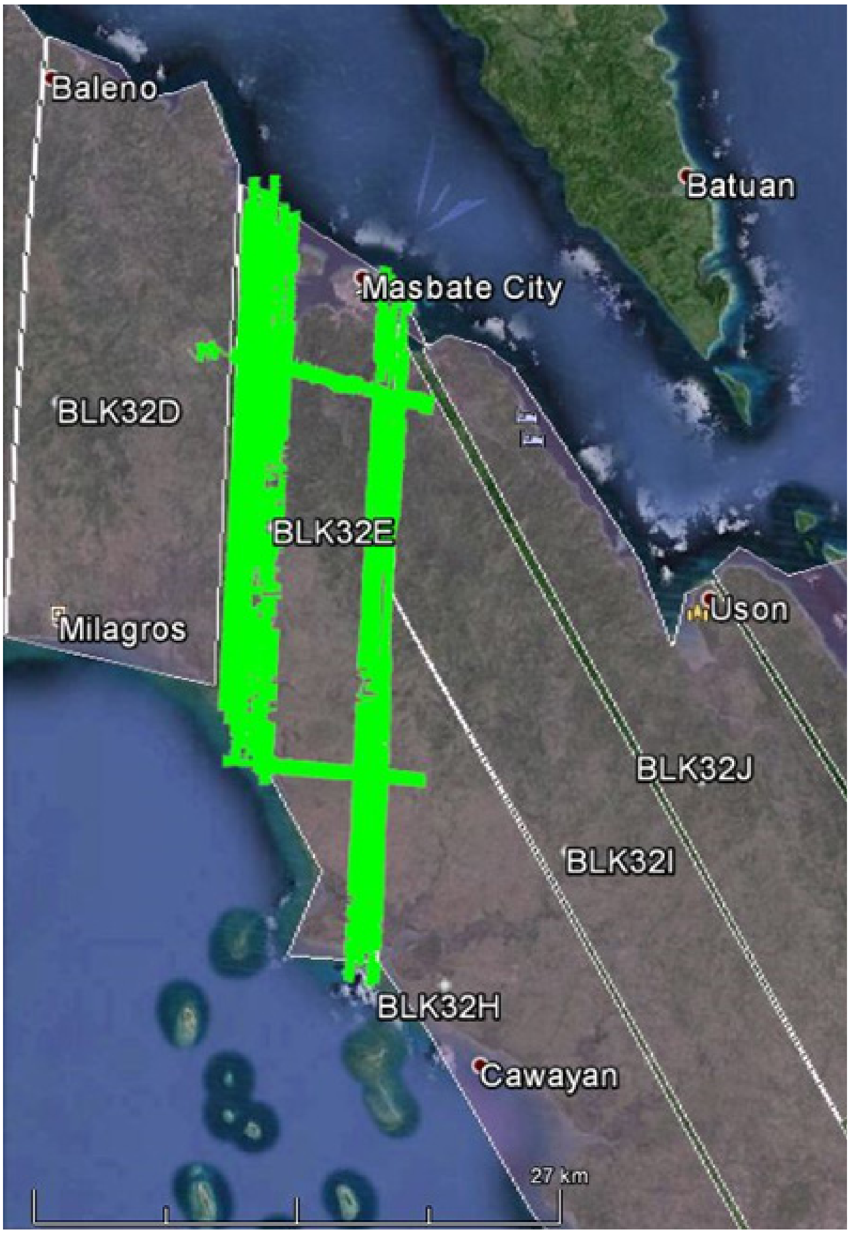


Figure A.7.2. Swath for Flight No. 1243P

Flight No. : 1245P
Area: BLK32J
Mission Name: 1BLK32J079B
Area Surveyed: 145.344 sq.km.

Altitude: 800m
PRF: 200 kHz SCF: 30 Hz
Lidar FOV: 50 deg Sidelap: 25%

Figure A.7.3. Swath for Flight No. 1245P

Flight No. : 1247P
Area: BLK32J
Mission Name: 1BLK32IJ080A
Area Surveyed: 333.843 sq.km.

Altitude: 1000m
PRF: 200 kHz SCF: 30 Hz
Lidar FOV: 50 deg Sidelap: 25%

Altitude: 1200m
PRF: 300 kHz SCF: 30 Hz
Lidar FOV: 50 deg Sidelap: 25%

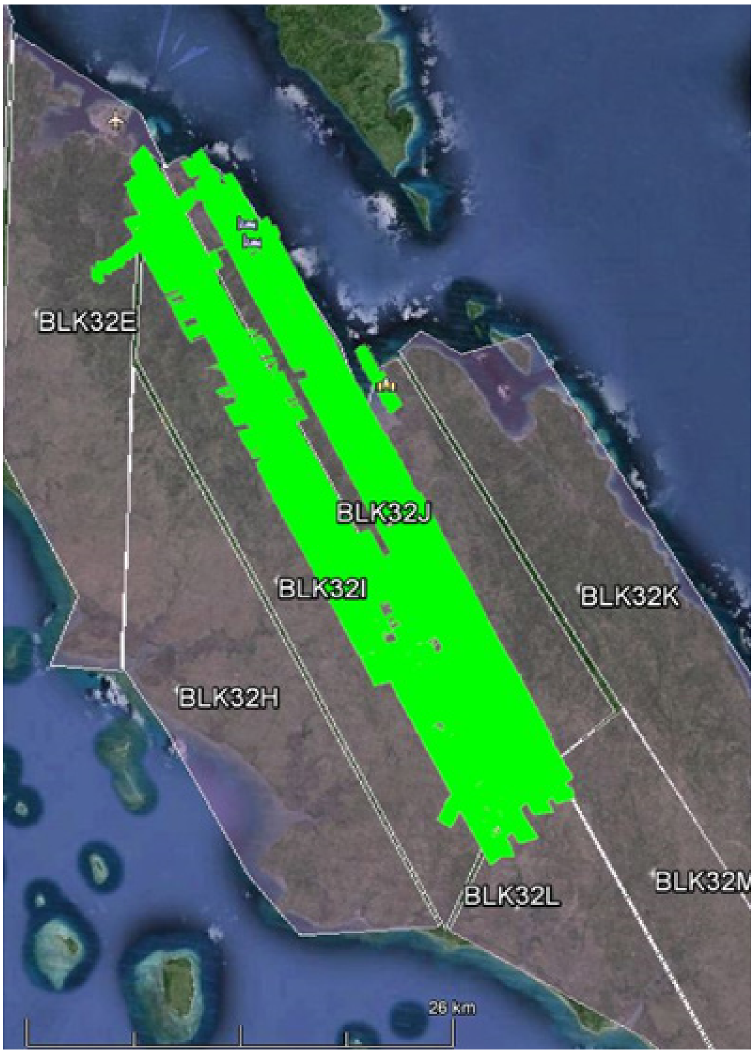


Figure A.7.4. Swath for Flight No. 1247P

Flight No. : 1271P
Area: BLK32H
Mission Name: 1BLK32H086A
Area Surveyed: 173.31 sq.km.

Altitude: 800m
PRF: 200 kHz SCF: 30 Hz
Lidar FOV: 50 deg Sidelap: 25%

Altitude: 600m
PRF: 200 kHz SCF: 30 Hz
Lidar FOV: 50 deg Sidelap: 30%

Figure A.7.5. Swath for Flight No. 1271P

Flight No. : 1275P
Area: BLK32H
Mission Name: 1BLK32HI087A
Area Surveyed: 127.76 sq.km.

Altitude: 800m
PRF: 250 kHz SCF: 36 Hz
Lidar FOV: 40 deg Sidelap: 25%

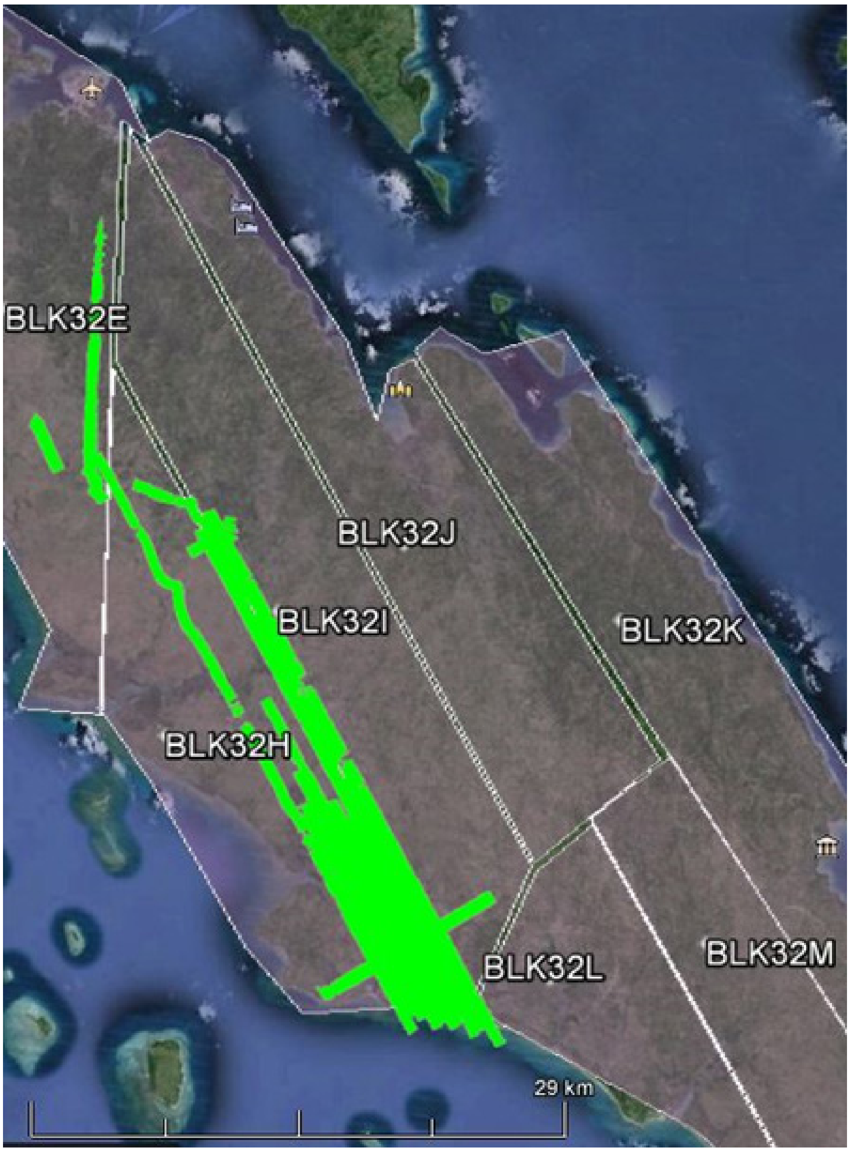


Figure A.7.6. Swath for Flight No. 1275P

Flight No. : 1281P
Area: BLK32I
Mission Name: 1BLK32I088B
Area Surveyed: 129.109 sq.km.

Altitude: 1000m
PRF: 200kHz SCF: 30Hz
Lidar FOV: 50deg Sidelap: 40%

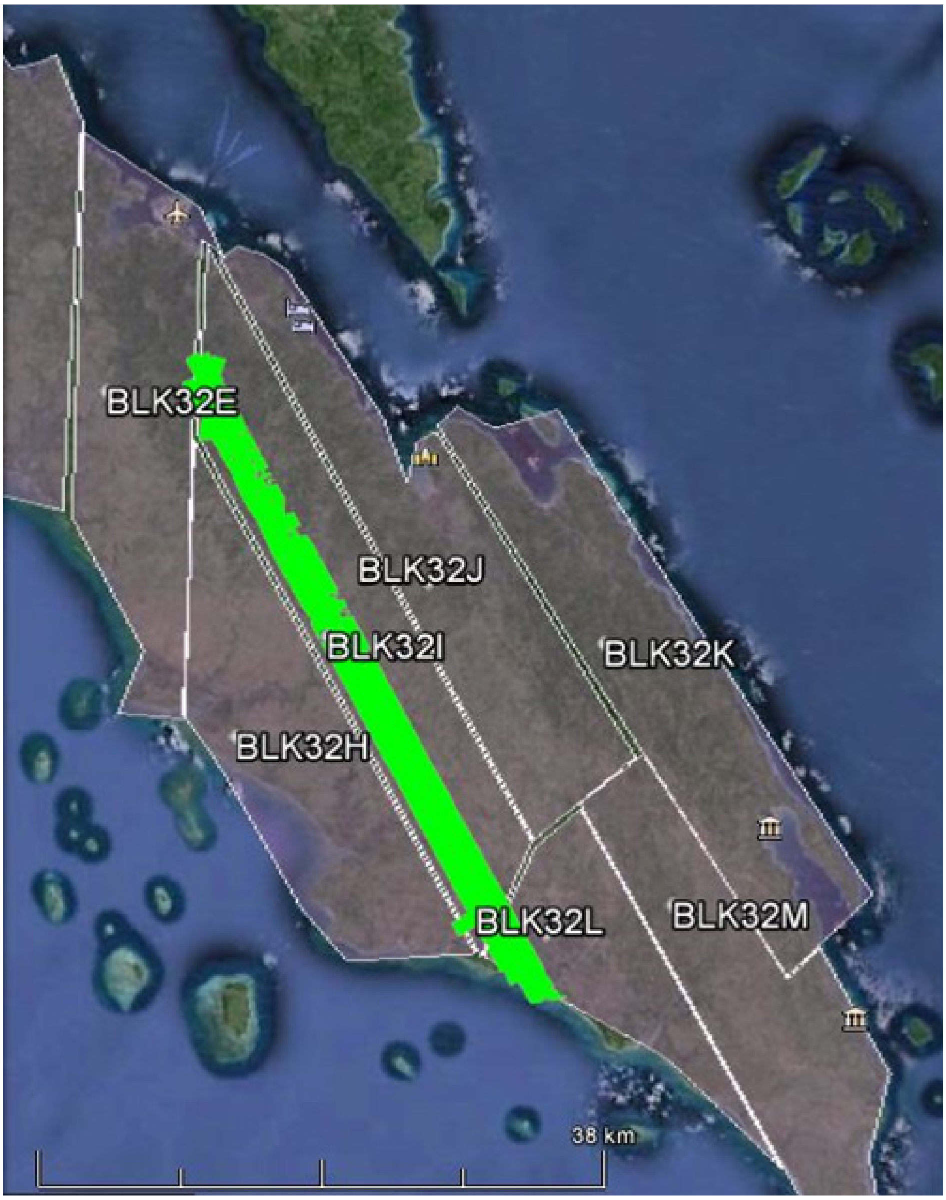


Figure A.7.7. Swath for Flight No. 1281P

Flight No. : 1293P
Area: BLK32H
Mission Name: 1BLK32H091B
Area Surveyed: 83.369 sq.km.

Altitude: 800m
PRF: 250 kHz SCF: 36 Hz
Lidar FOV: 40 deg Sidelap: 25%

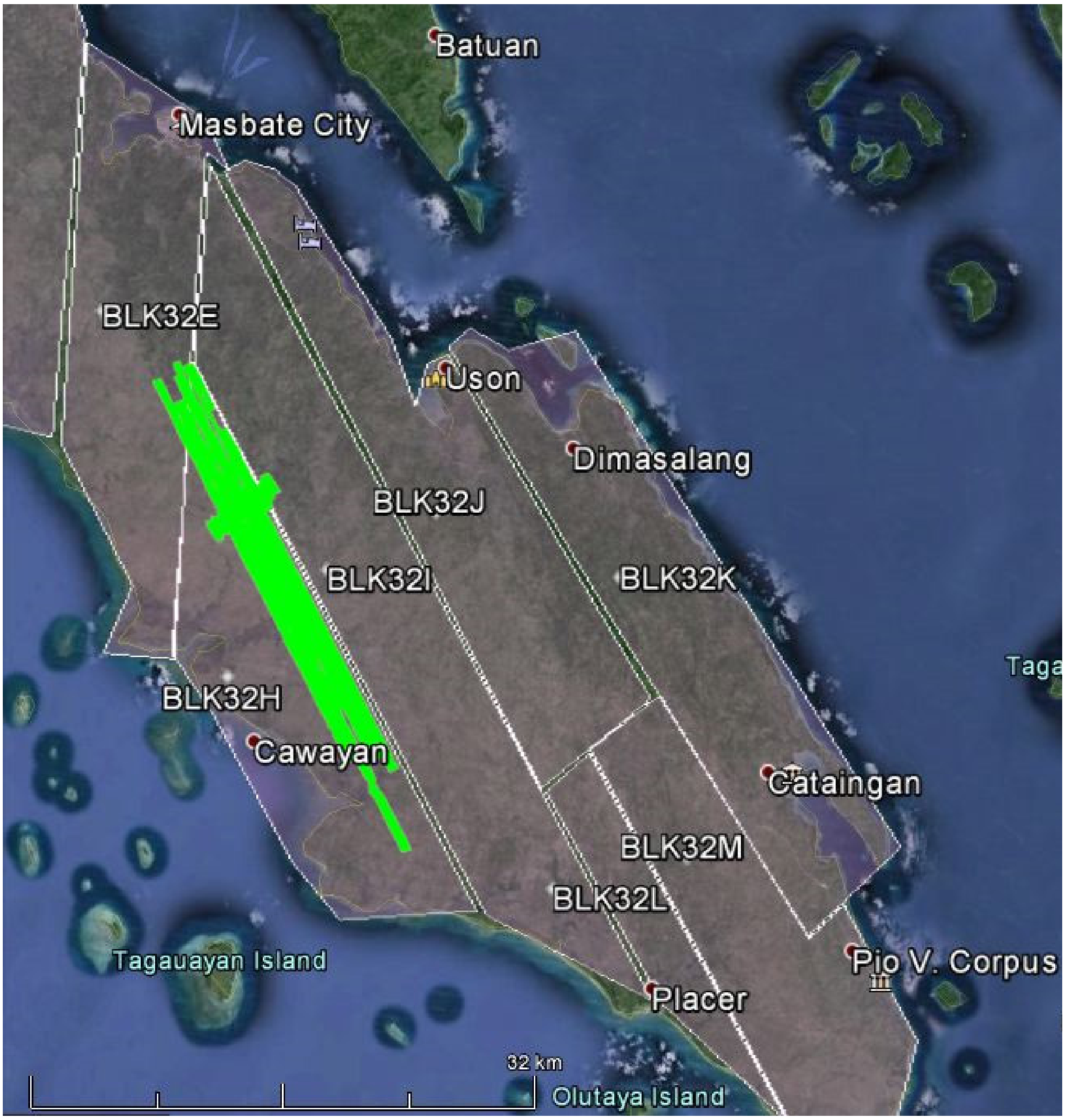


Figure A.7.8. Swath for Flight No. 1293P

Flight No. : 1295P
Area: BLK32E
Mission Name: 1BLK32E092A
Area Surveyed: 194.51 sq.km.

Altitude: 800m
PRF: 200 kHzSCF: 30 Hz
Lidar FOV: 50 deg Overlap: 30%

Altitude: 1000m
PRF: 200 kHzSCF: 30 Hz
Lidar FOV: 50 deg Overlap: 25%

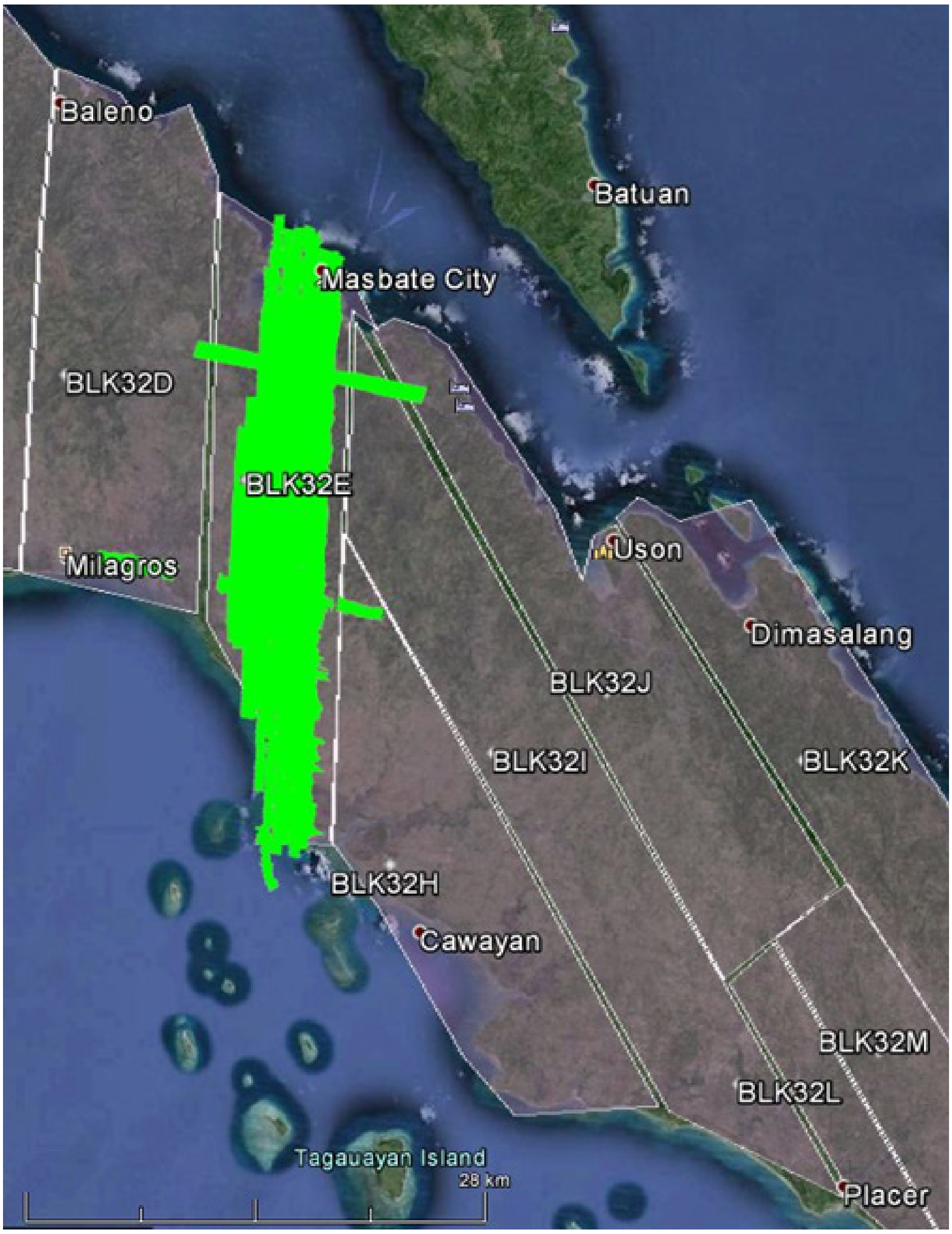


Figure A.7.9. Swath for Flight No. 1295P

Annex 8. Mission Summary Reports

Table A-8.1 Mission Summary Report for Mission Blk32U

Flight Area	**Masbate**
Mission Name	Blk32IJ
Inclusive Flights	1245P, 1247P, 1281P
Mission Name	1BLK32J079B, 1BLK32IJ080A, 1BLK32I088B
Range data size	77.3 GB
POS	535 MB
Image	104.4 GB
Transfer date	April 23 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.63
RMSE for East Position (<4.0 cm)	1.70
RMSE for Down Position (<8.0 cm)	3.20
Boresight correction stdev (<0.001deg)	0.000398
IMU attitude correction stdev (<0.001deg)	0.001191
GPS position stdev (<0.01m)	0.00270
Minimum % overlap (>25)	17.09%
Ave point cloud density per sq.m. (>2.0)	2.30
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	683
Maximum Height	603.95 m
Minimum Height	42.31 m
Classification (# of points)	
Ground	476,127,438
Low vegetation	250,199,416
Medium vegetation	363,150,463
High vegetation	265,574,430
Building	4,664,222
Orthophoto	Yes
Processed by	Engr. Kenneth Solidum, Engr. Harmond Santos,Engr. John Dill Macapagal, Engr. Roa Shalemar Redo

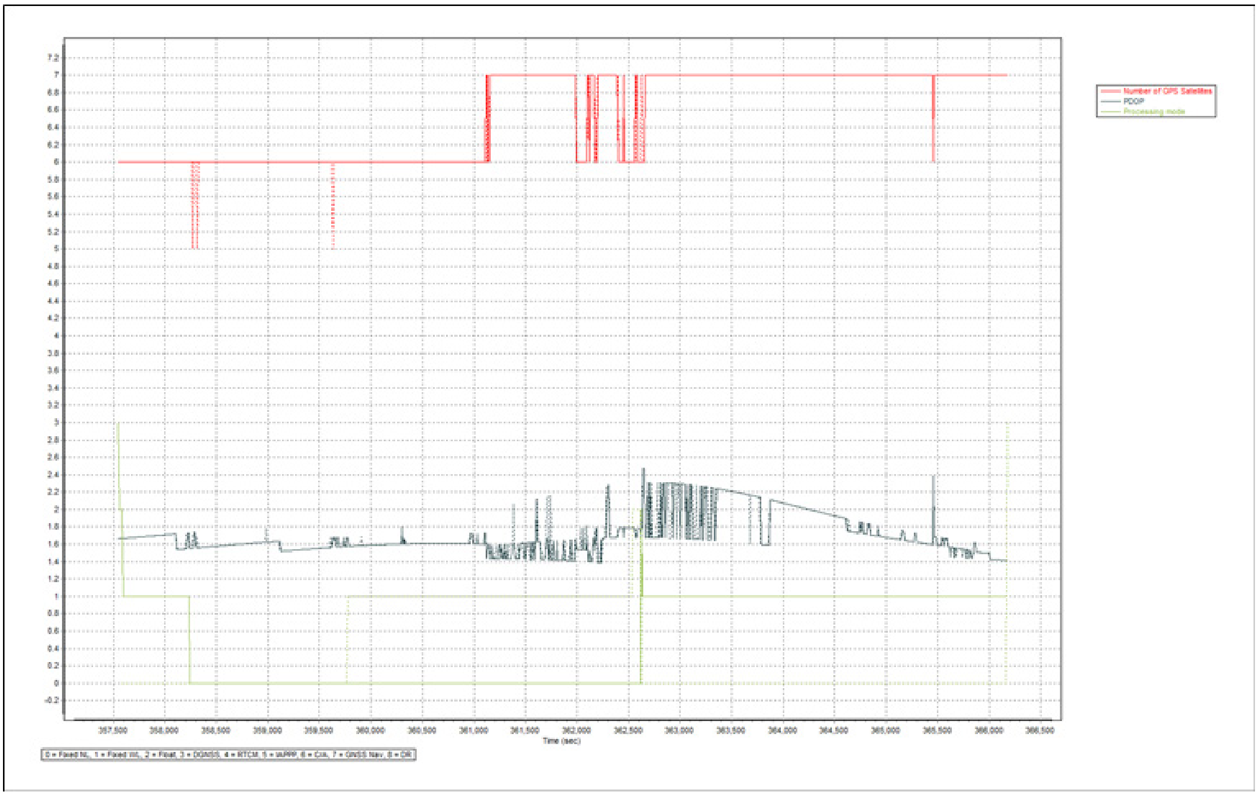


Figure A-8.1 Solution Status

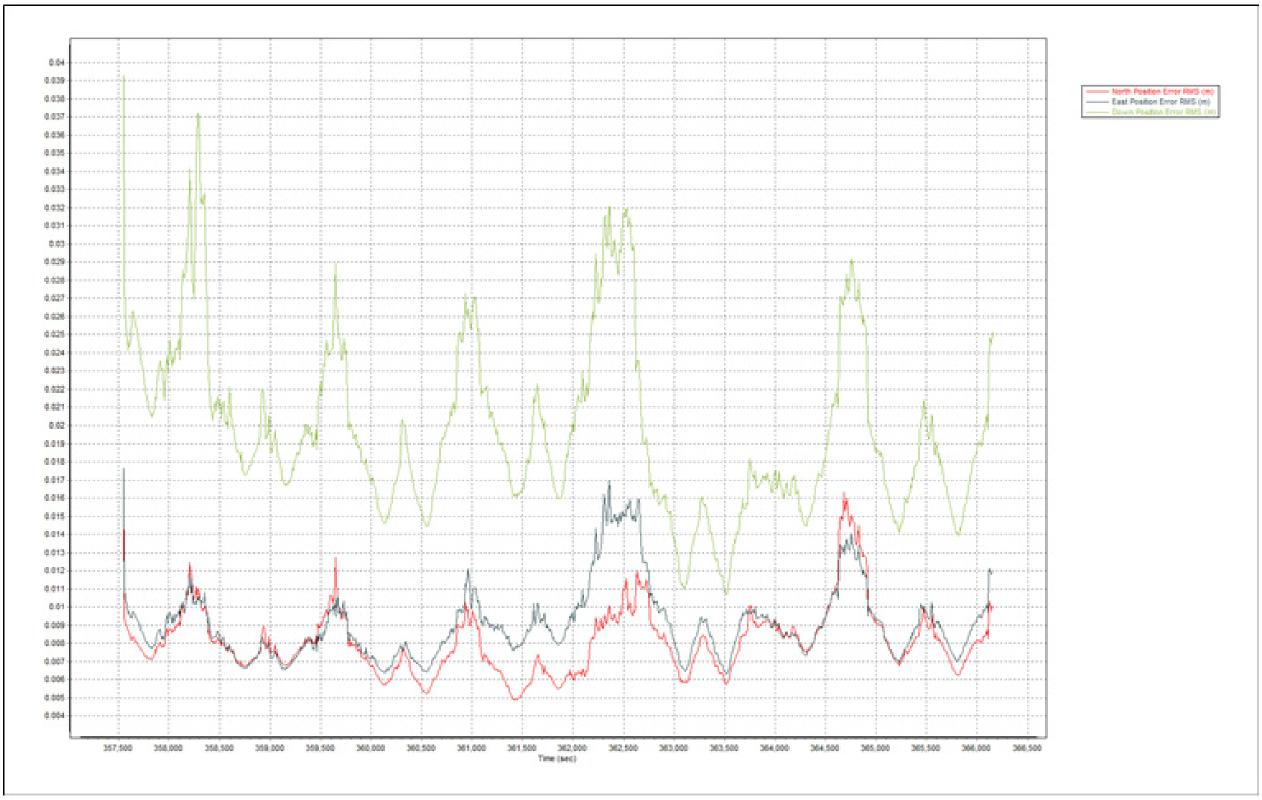


Figure A-8.2 Smoothed Performance Metric Parameters

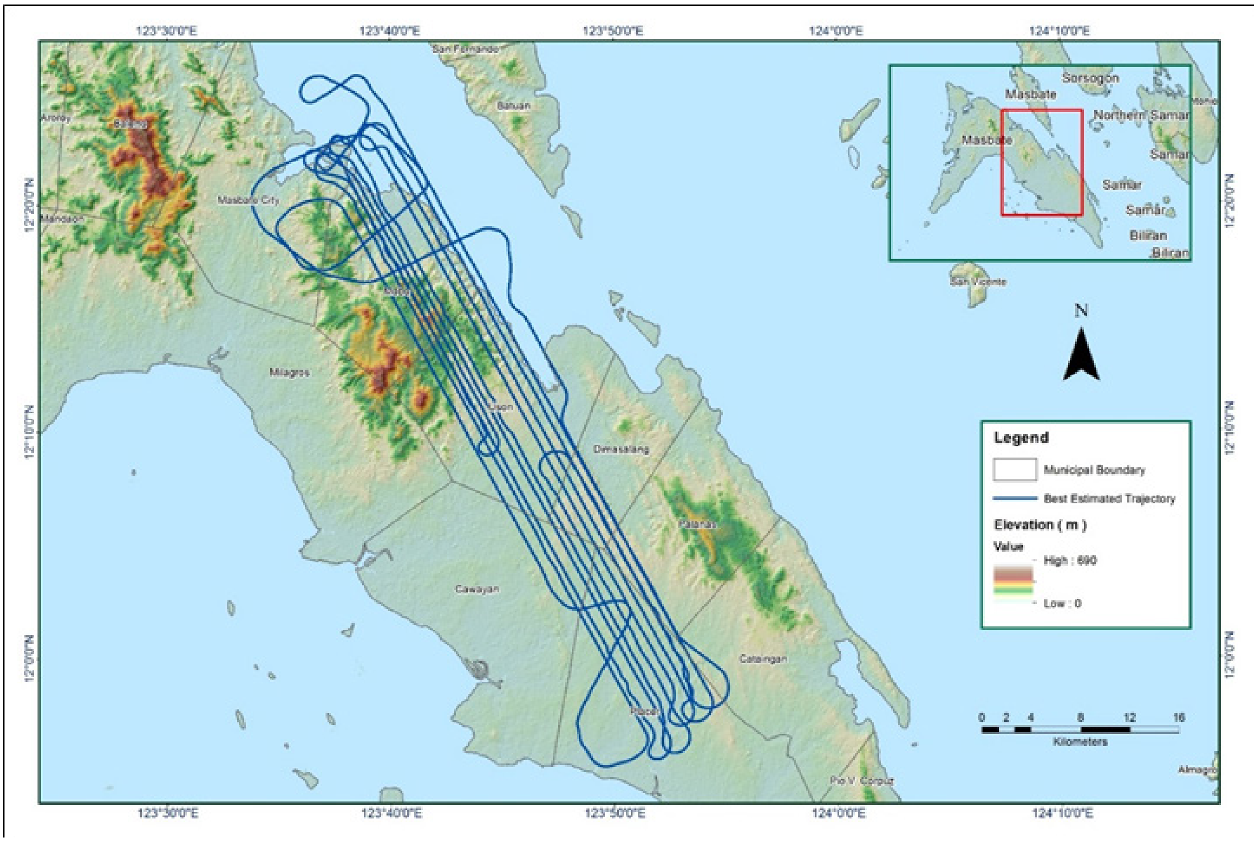


Figure A-8.3 Best Estimated Trajectory

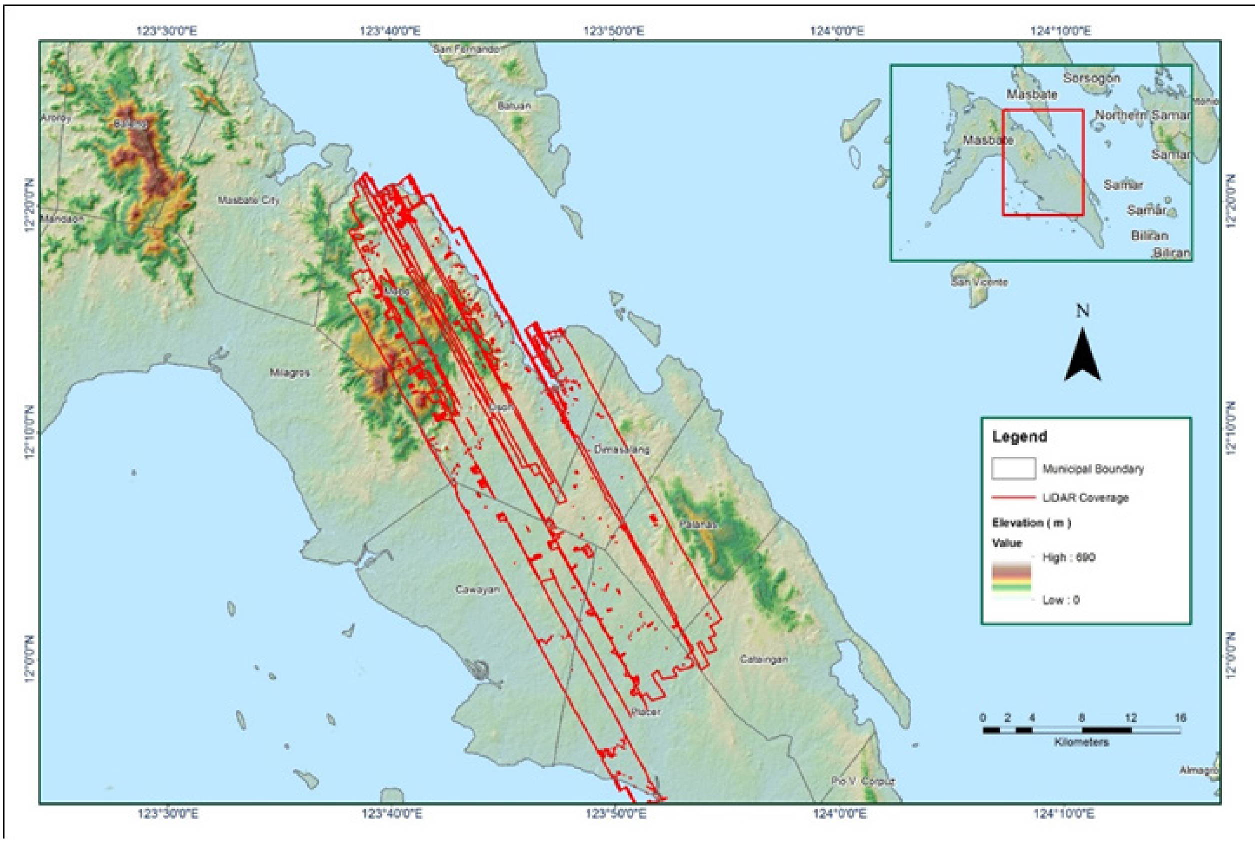


Figure A-8.4 Coverage of LiDAR Data

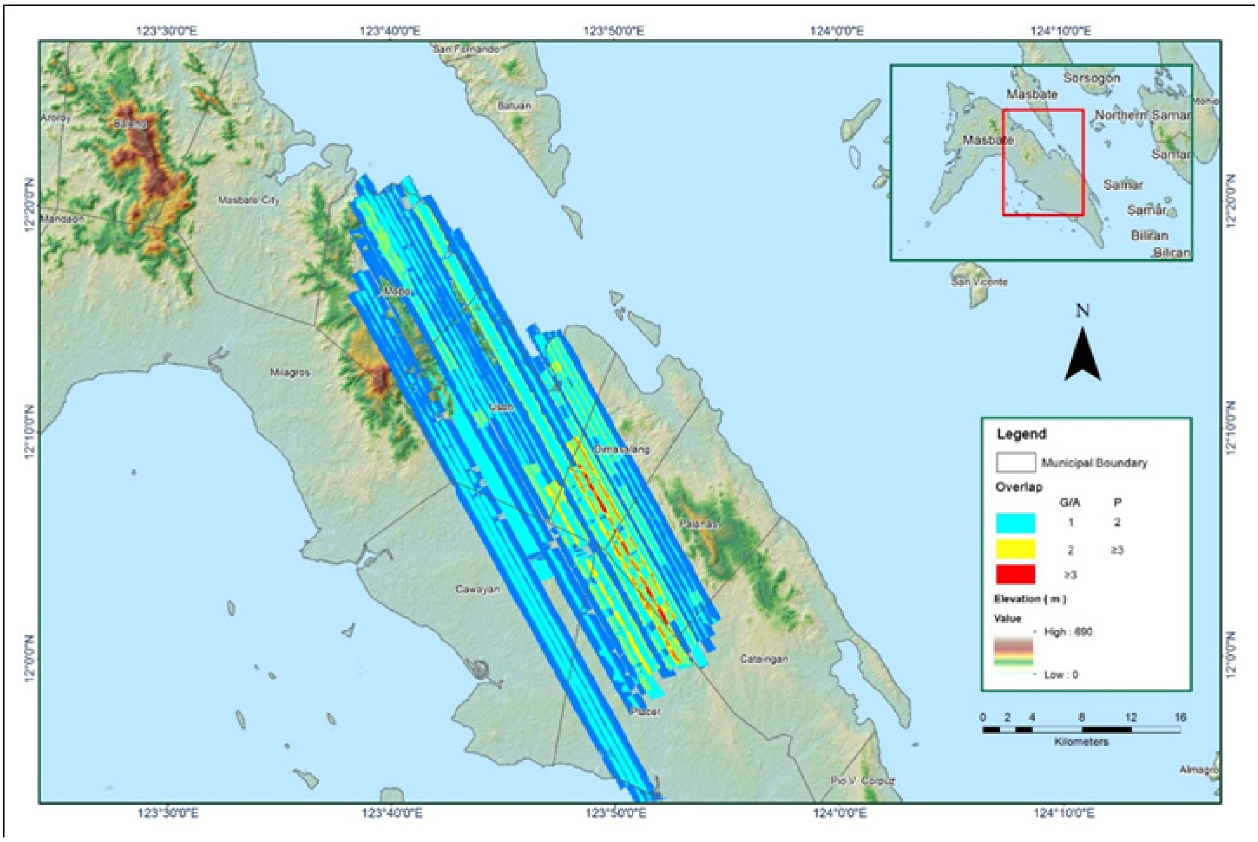


Figure A-8.5 Image of Data Overlap

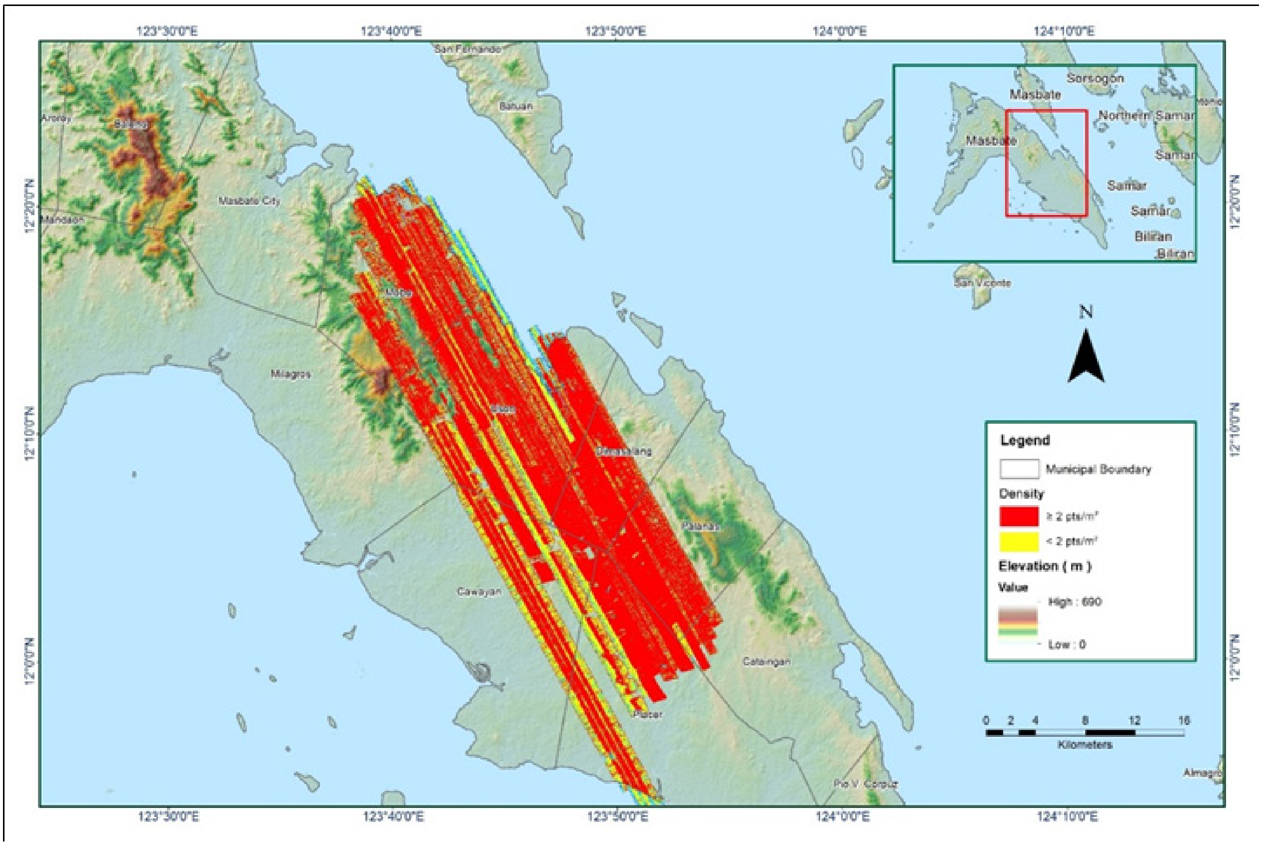


Figure A-8.6 Density map of merged LiDAR data

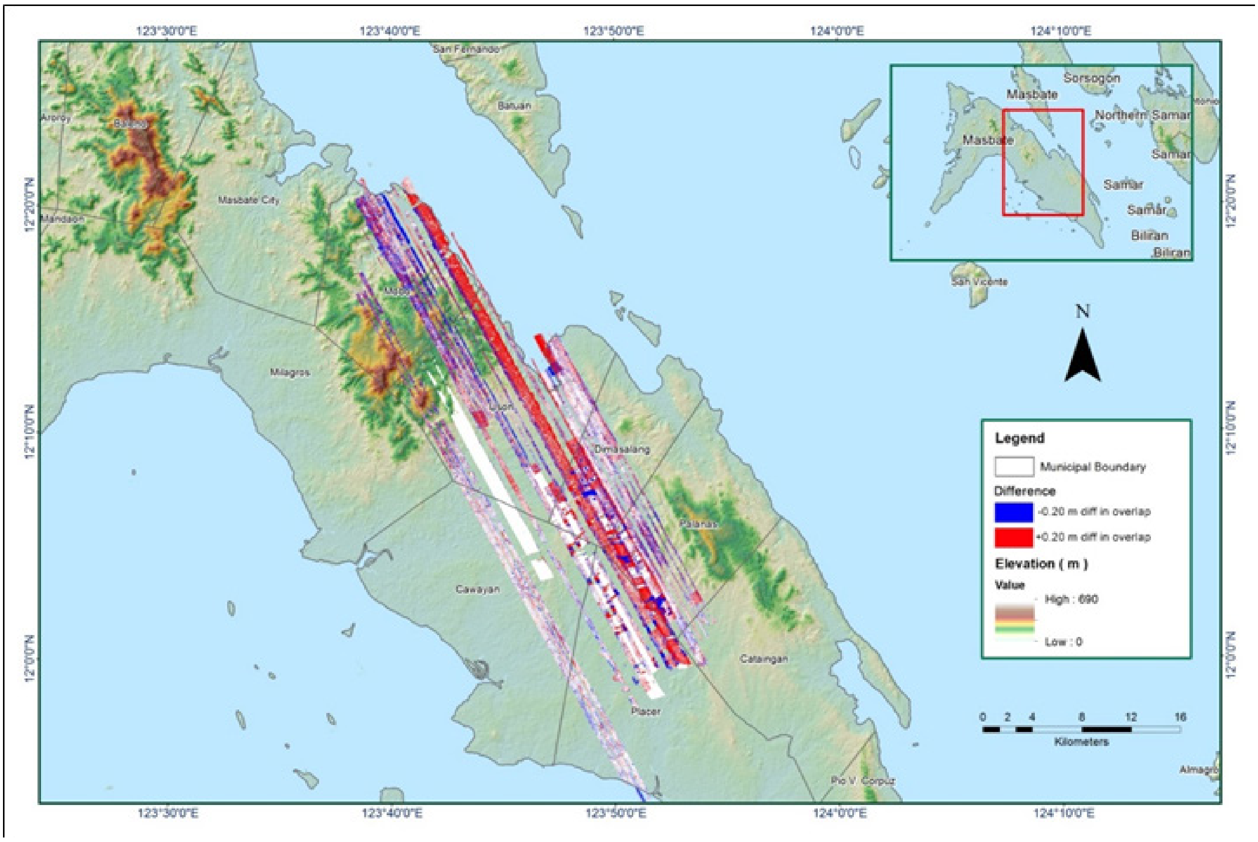


Figure A-8.7 Elevation difference between flight lines

Table A-8.2 Mission Summary Report for Mission Blk 32E

Flight Area	**MASBATE**
Mission Name	Blk 32E
Inclusive Flights	1241P, 1243P , 1275P, 1295P
Mission Name	1BLK32E078A, 1BLK32E079A, 1BLK32HI087A, 1BLK32E092A
Range data size	77.6 GB
POS	839 MB
Image	166.9 GB
Transfer date	April 22, 2014
Solution Status	
Number of Satellites (>6)	No
PDOP (<3)	No
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	3.0
RMSE for East Position (<4.0 cm)	1.5
RMSE for Down Position (<8.0 cm)	5.5
Boresight correction stdev (<0.001deg)	N/A
IMU attitude correction stdev (<0.001deg)	N/A
GPS position stdev (<0.01m)	N/A
Minimum % overlap (>25)	54.63%
Ave point cloud density per sq.m. (>2.0)	4.83
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	349
Maximum Height	468.75m
Minimum Height	53.61m
Classification (# of points)	
Ground	445,560,056
Low vegetation	437,936,875
Medium vegetation	623,304,708
High vegetation	325,965,918
Building	8,257,766
Orthophoto	Yes
Processed by	ENgr. Carlyn Ann Ibañez, Engr. Irish Cortez, Engr. Merven Matthew Natino, Engr. Jeffrey Delica

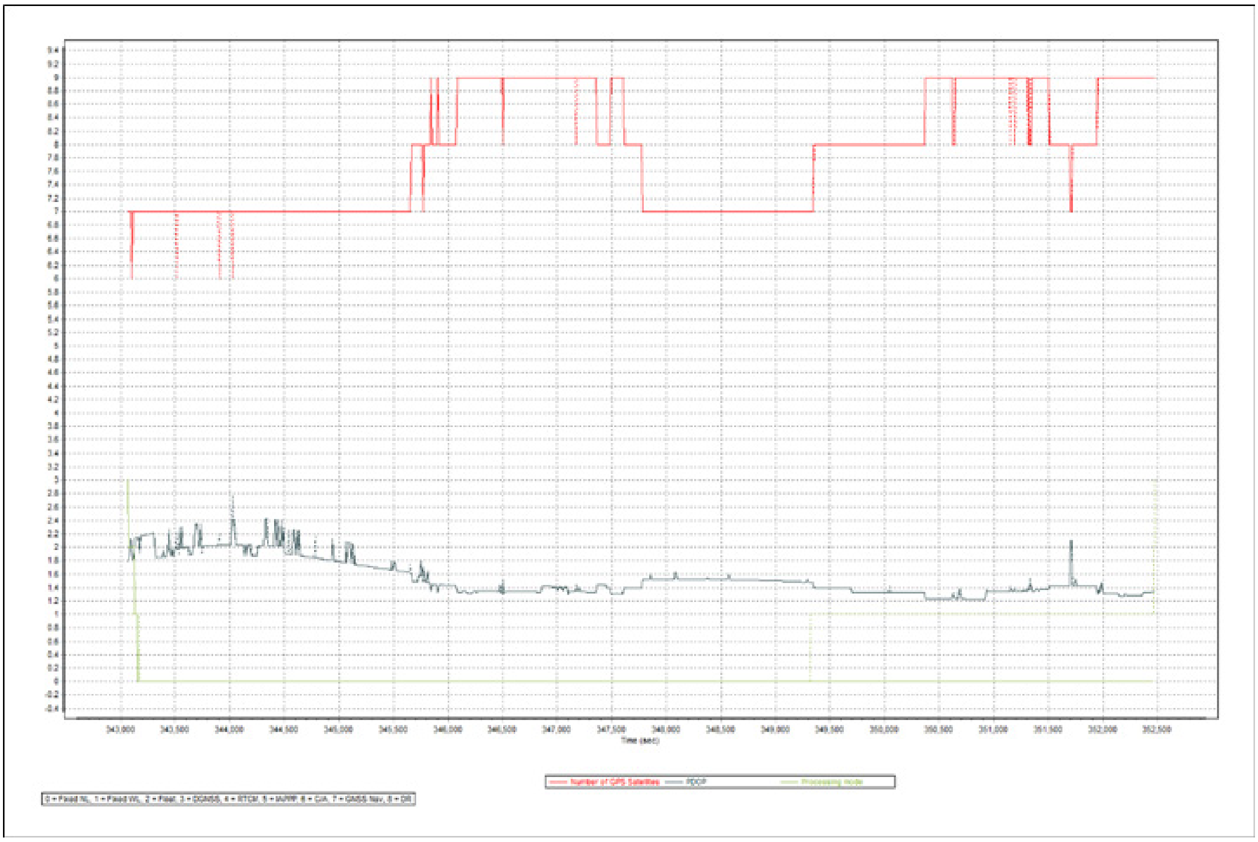


Figure A-8.8 Solution Status Parameters

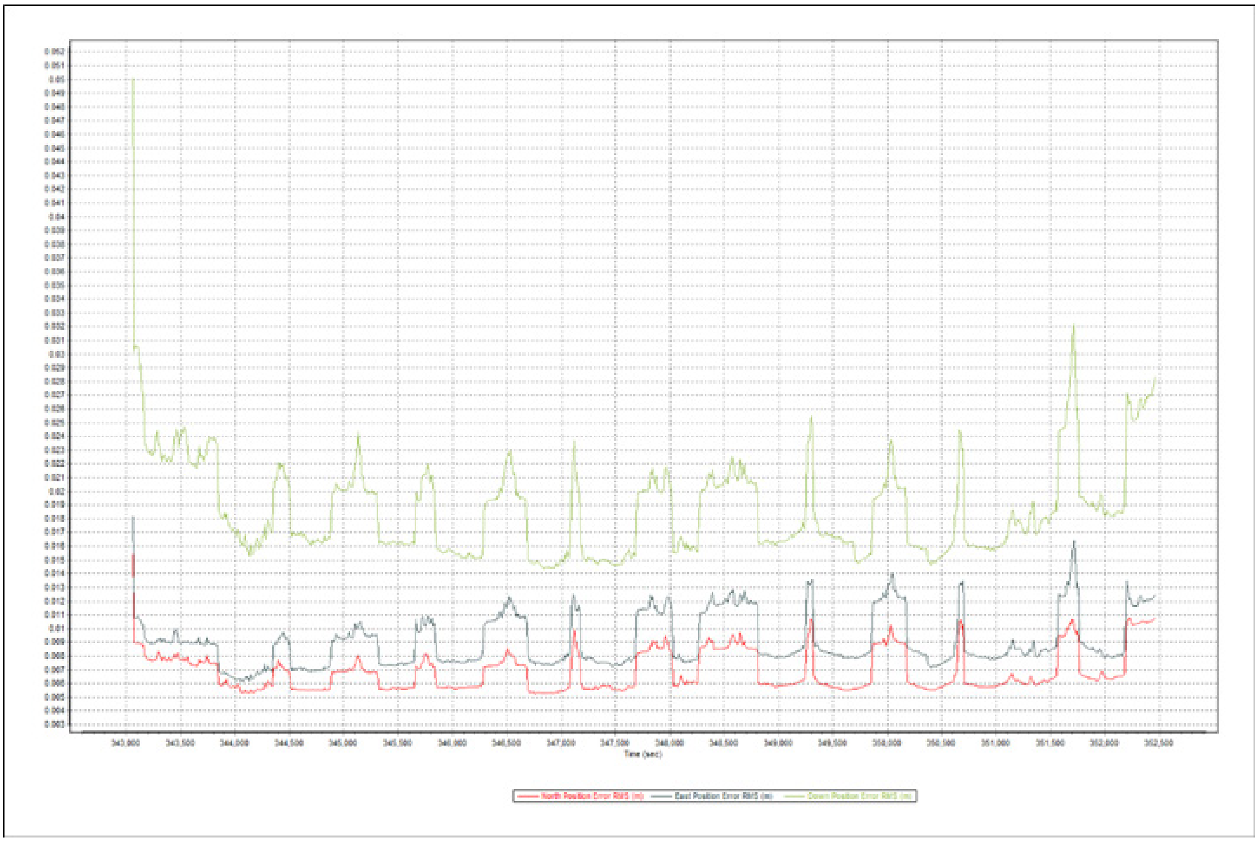


Figure A-8.9 Smoothed Performance Metrics Parameters

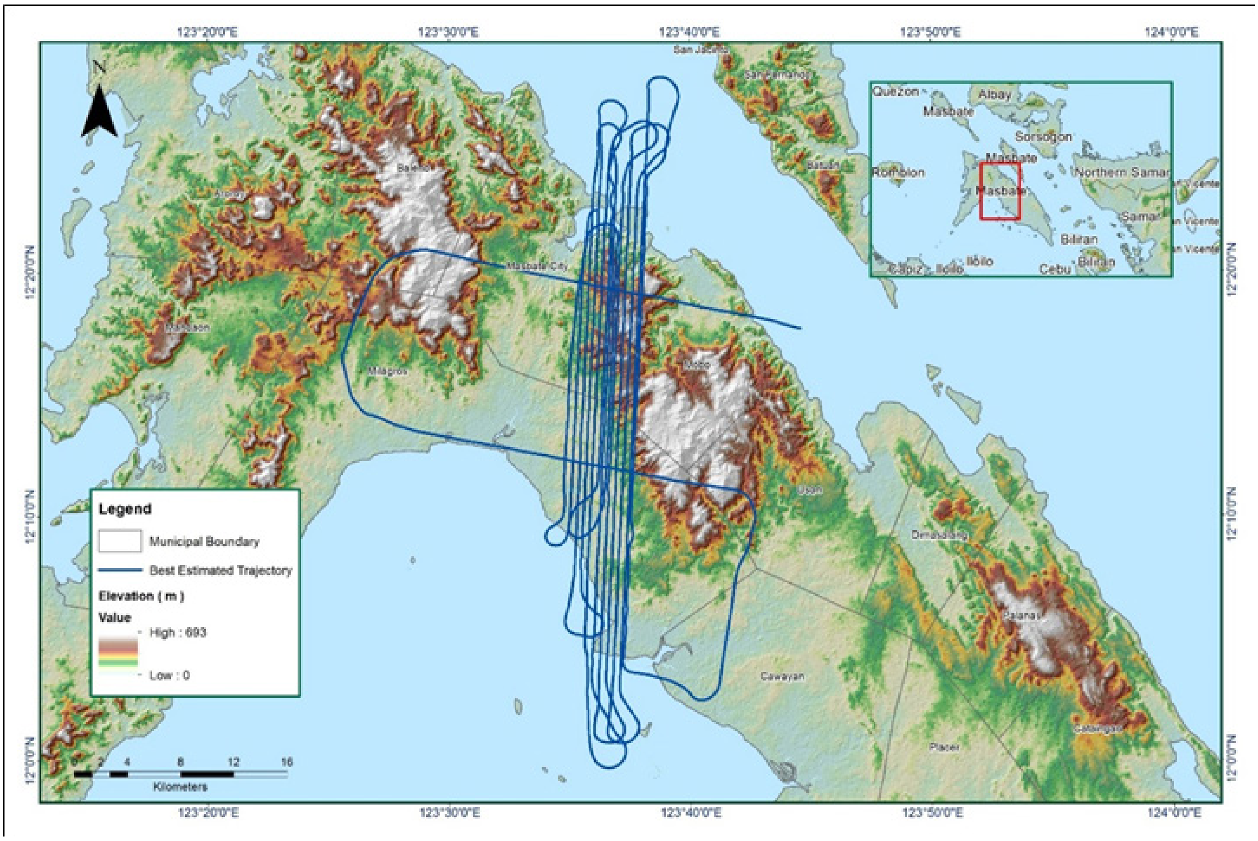


Figure A-8.10 Best Estimated Trajectory

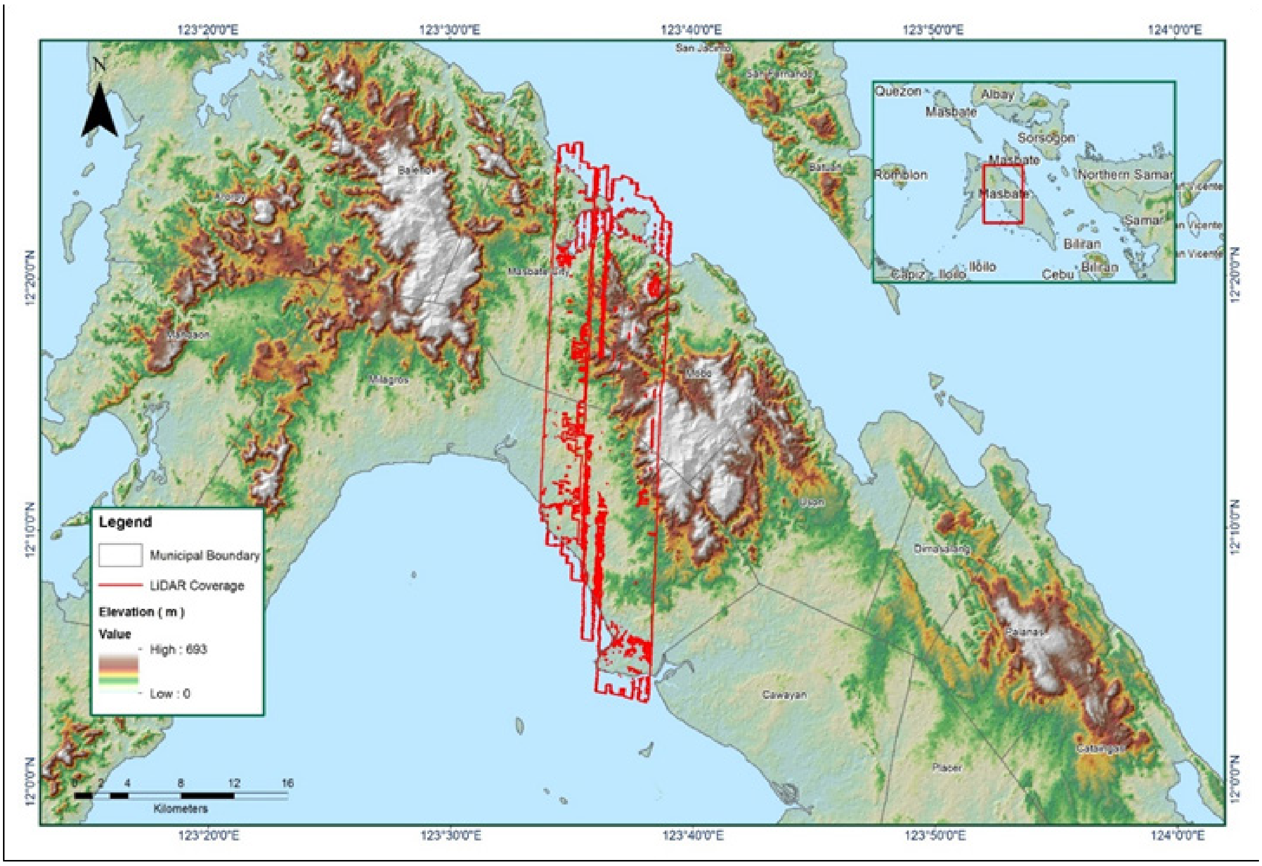


Figure A-8.11 Coverage of LiDAR data

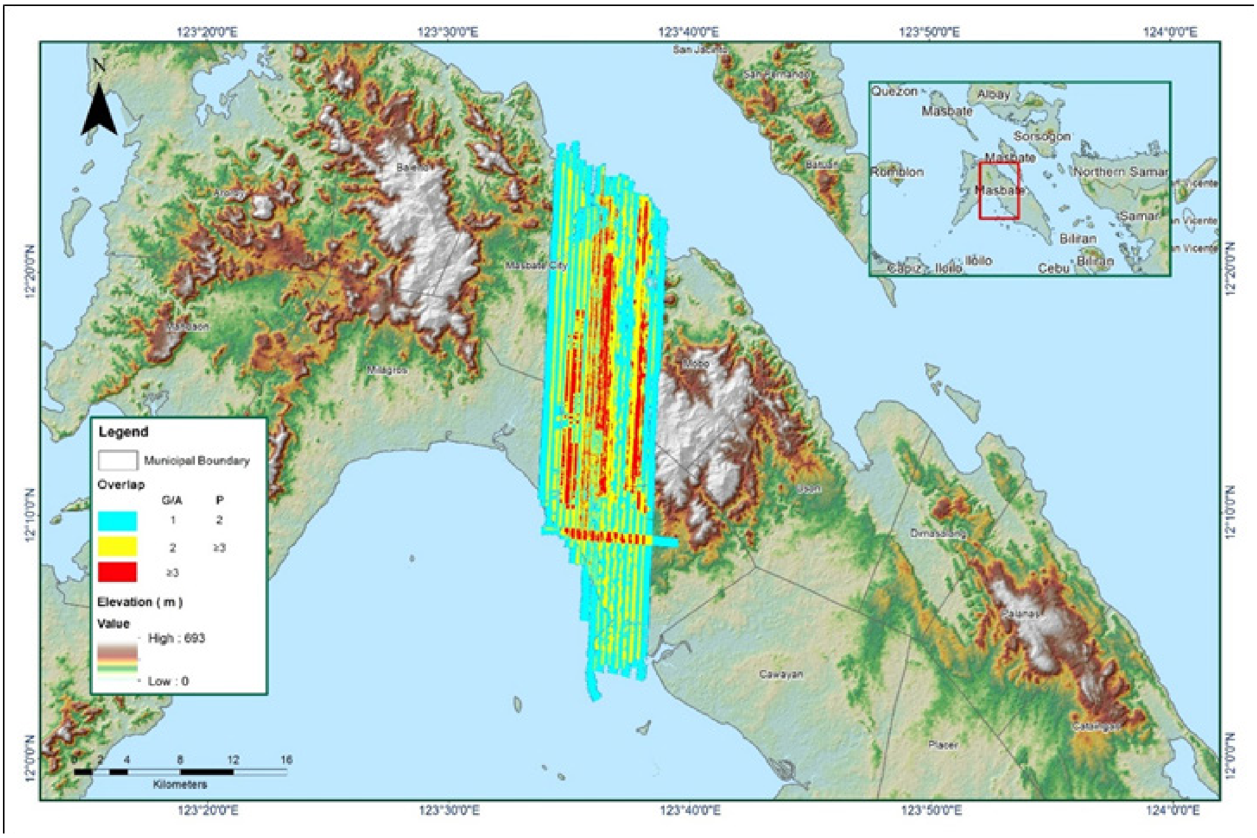


Figure A-8.12 Image of Data Overlap

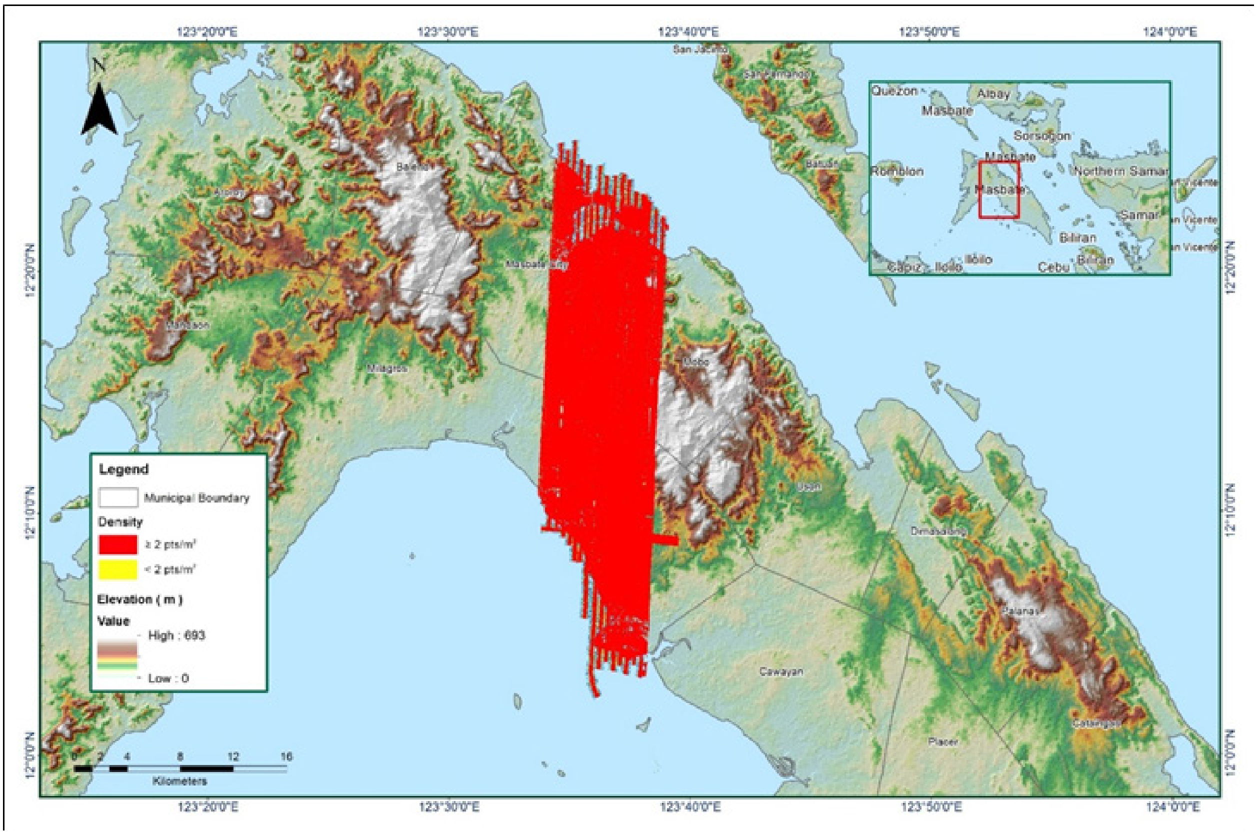


Figure A-8.13 Density map of merged LiDAR data

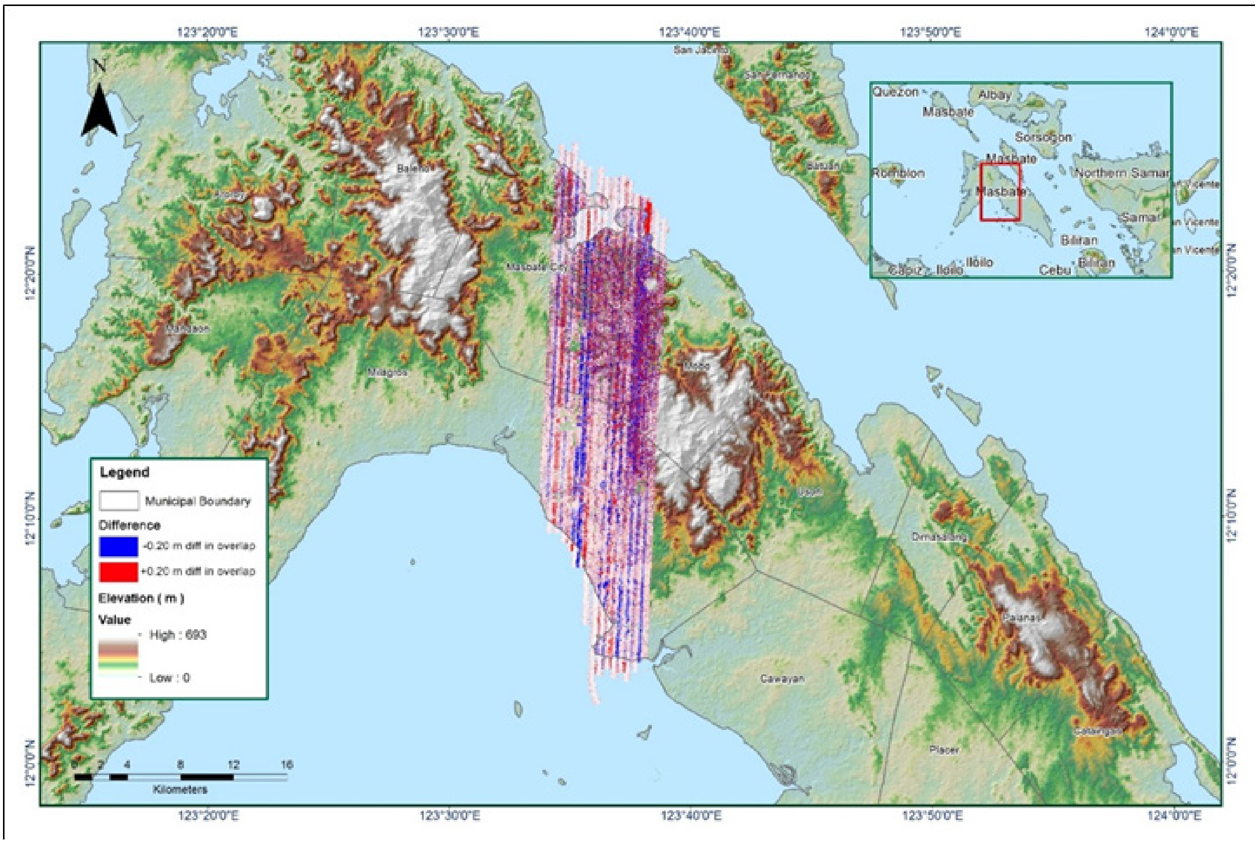


Figure A-8.14 Elevation difference between flight lines

Table A-8.3 Mission Summary Report for Mission Blk32H

Flight Area	**Masbate**
Mission Name	Blk32H
Inclusive Flights	1271P, 1275P, 1293P
Mission Name	1BLK32H086A, 1BLK32DG095A, 1BLK32H091B
Range data size	70.5 GB
POS	538 MB
Image	138.0 GB
Transfer date	April 23 2014
Solution Status	
Number of Satellites (>6)	No
PDOP (<3)	No
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	5.04
RMSE for East Position (<4.0 cm)	3.40
RMSE for Down Position (<8.0 cm)	7.90
Boresight correction stdev (<0.001deg)	0.00058
IMU attitude correction stdev (<0.001deg)	0.00828
GPS position stdev (<0.01m)	0.00270
Minimum % overlap (>25)	2.25%
Ave point cloud density per sq.m. (>2.0)	2.74
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	387
Maximum Height	555.56m
Minimum Height	47.88m
Classification (# of points)	
Ground	501,440,501
Low vegetation	335,653,641
Medium vegetation	315,870,006
High vegetation	78,423,465
Building	2,270,257
Orthophoto	Yes
Processed by	Engr. Irish Cortez, Engr. Harmond Santos, Jovy Narisma, Engr. Melissa Fernandez

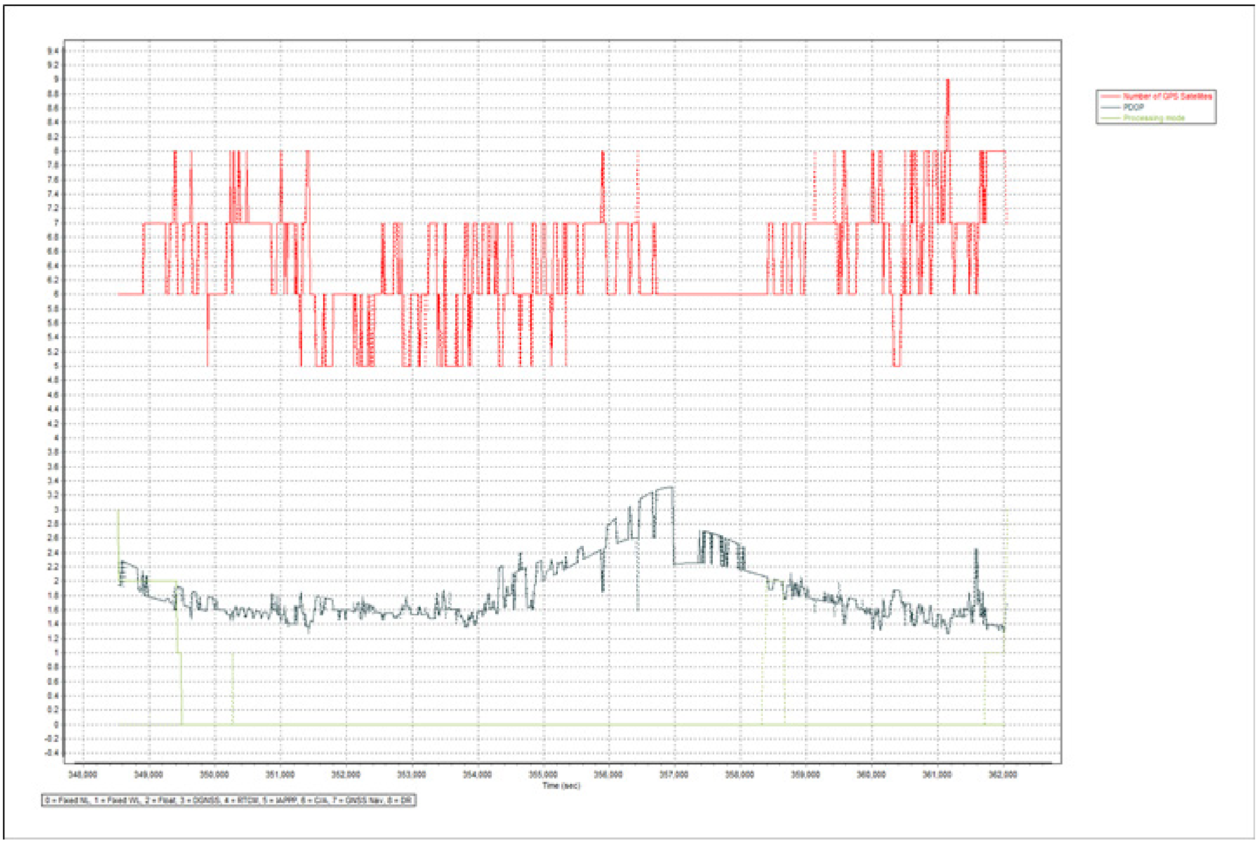


Figure A-8.15 Solution Status

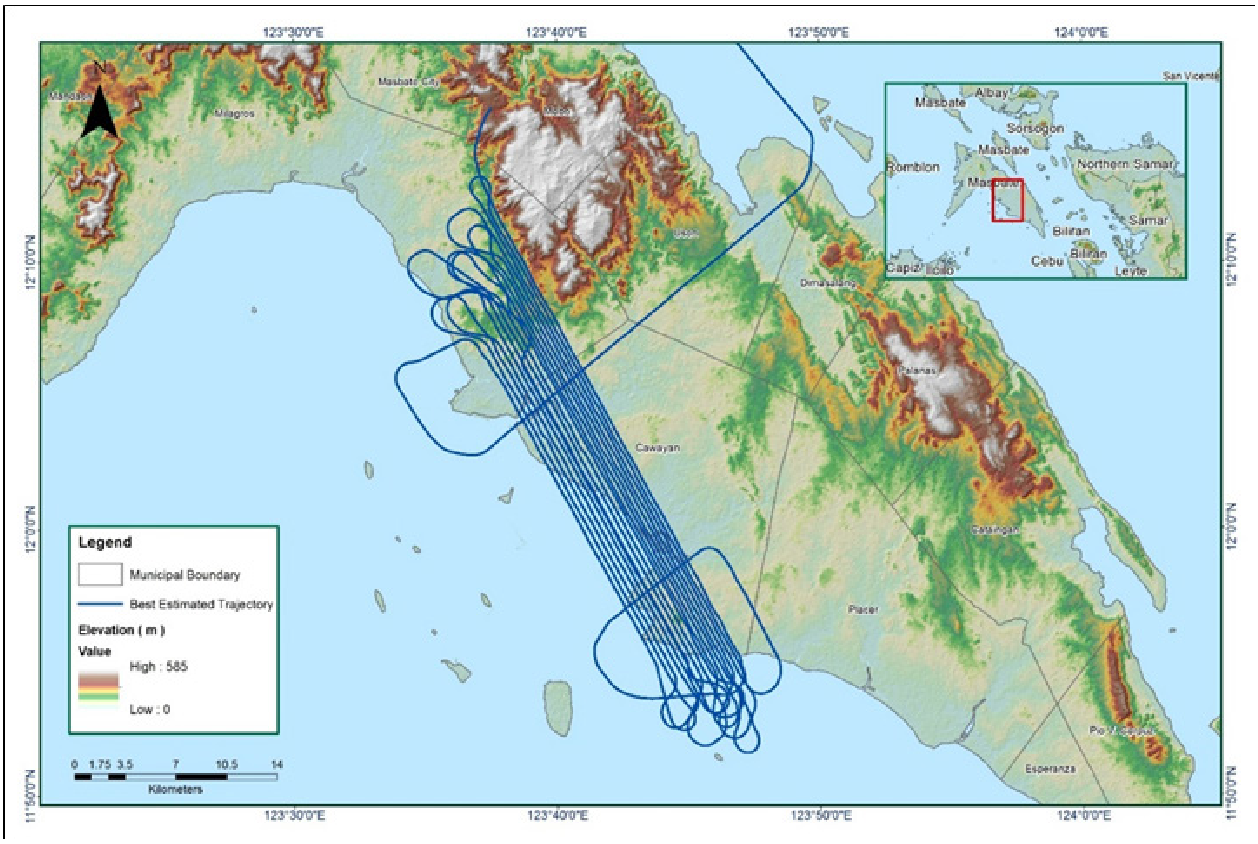


Figure A-8.16 Smoothed Performance Metric Parameters

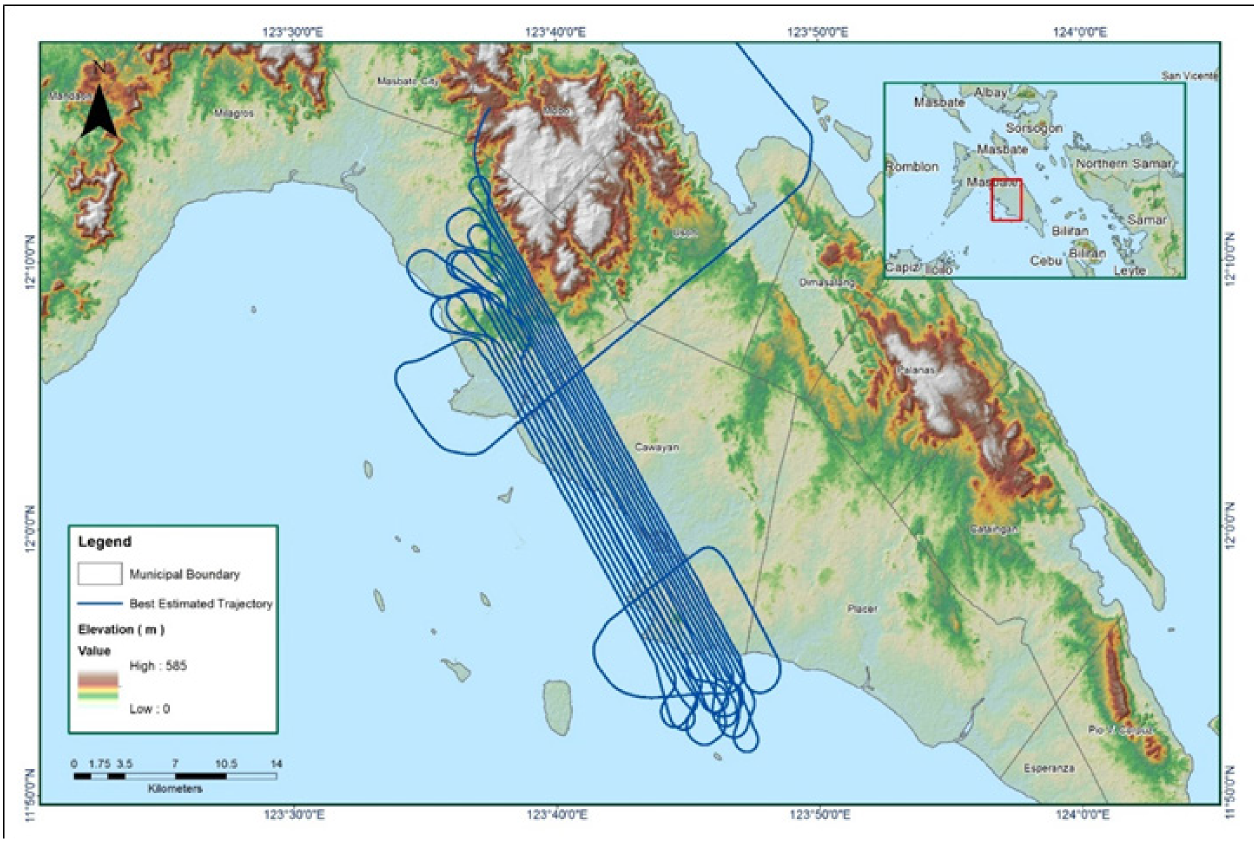


Figure A-8.17 Best Estimated Trajectory

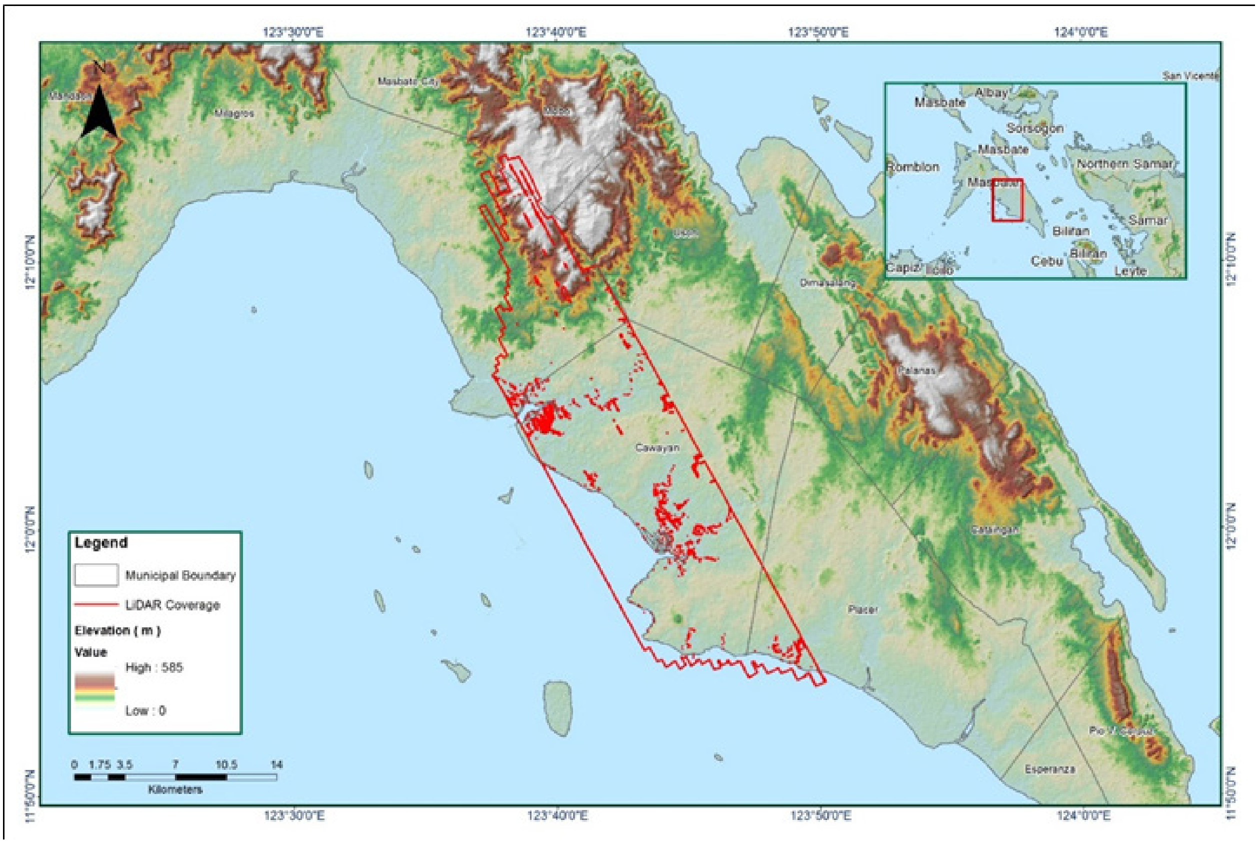


Figure A-8.18 Coverage of LiDAR data

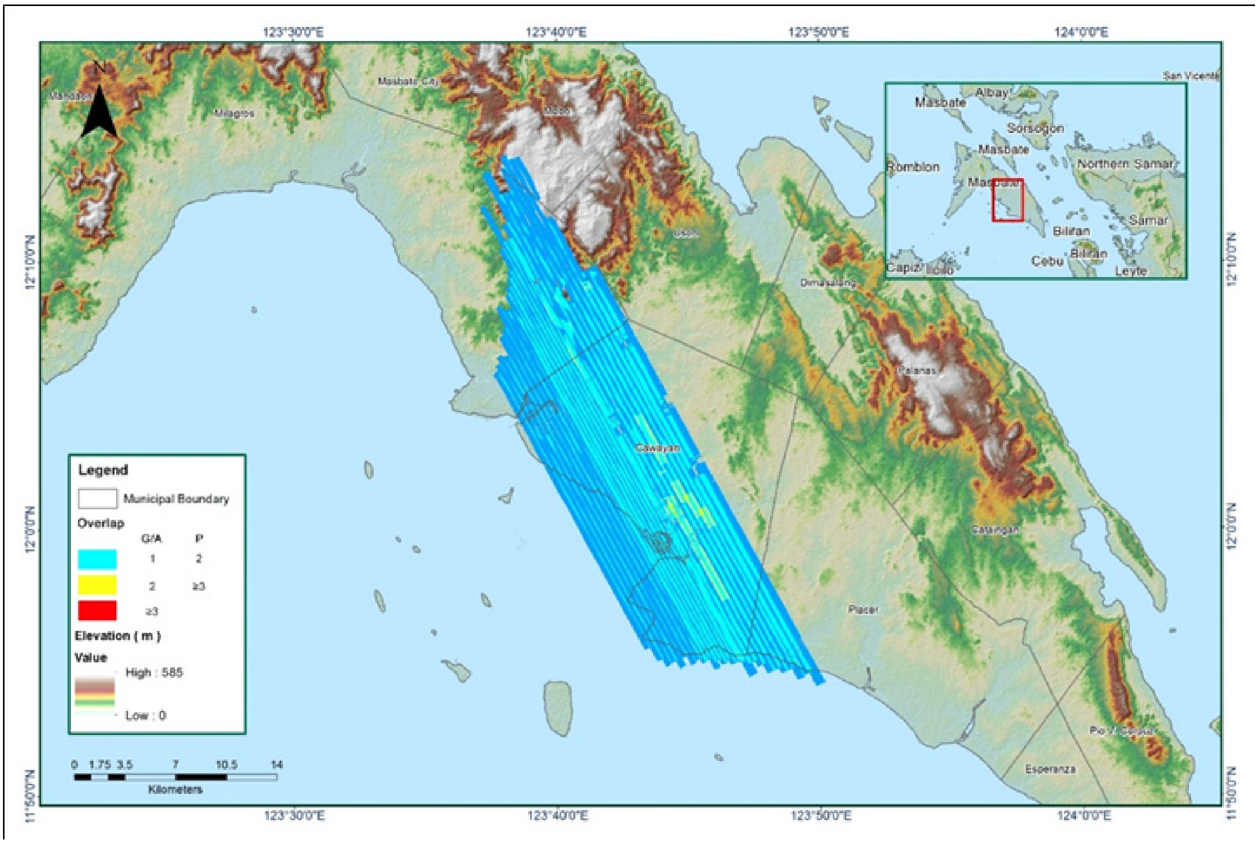


Figure A-8.19 Image of Data Overlap

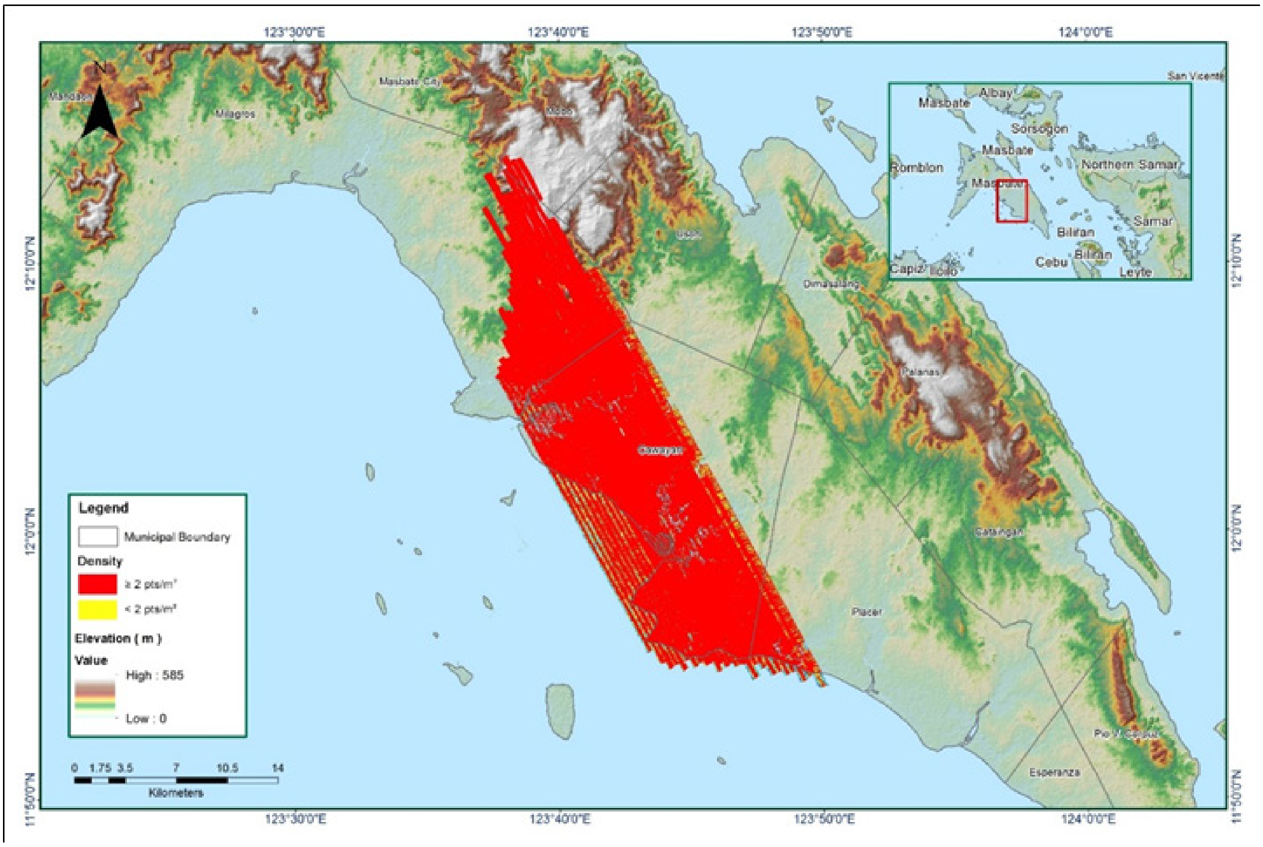


Figure A-8.20 Density map of merged LiDAR data

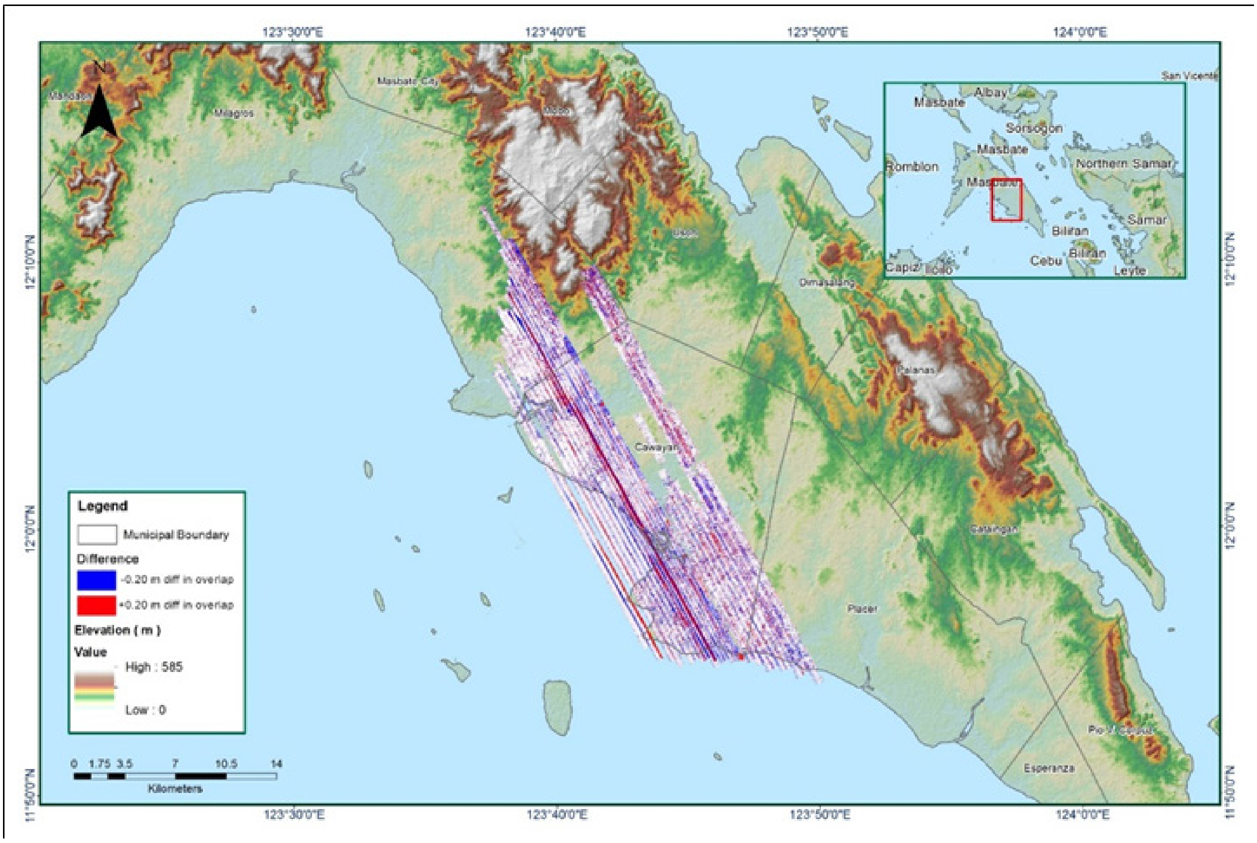


Figure A-8.21 Elevation difference between flight lines

Annex 9. Malbag Model Basin Parameters

Table A.8.1.

Basin Number	Curve Number Loss			Clark Unit Hydrograph Transform		Recession Base flow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (m3/s)	Recession Constant	Threshold Type	Ratio to Peak
W220	329.22	52.965	0	0.016667	0.069247	Discharge	0.69832	1.00E-05	Ratio to Peak	0.20117
W230	220.12	50.575	0	0.016667	0.05956	Discharge	0.92202	1.00E-05	Ratio to Peak	0.00023
W240	346.02	42.077	0	0.16523	0.016667	Discharge	0.545048	1.00E-05	Ratio to Peak	0.00033
W250	228.7	99	0	0.016667	9.5638	Discharge	0.40891	1.00E-05	Ratio to Peak	0.057844
W260	363.22	53.008	0	0.14903	0.016667	Discharge	0.43883	1.00E-05	Ratio to Peak	0.049129
W270	384.54	66	0	0.15475	0.083214	Discharge	0.52557	1.00E-05	Ratio to Peak	0.00149
W280	315.66	77.18	0	0.016667	0.082144	Discharge	0.28059	1.00E-05	Ratio to Peak	0.04084
W290	184.28	45.616	0	0.016667	0.016667	Discharge	0.16988	1.00E-05	Ratio to Peak	0.00539
W300	500	52.773	0	0.14686	0.016667	Discharge	0.26659	1.00E-05	Ratio to Peak	0.0082
W310	349.12	52.602	0	0.14605	0.016667	Discharge	0.69678	1.00E-05	Ratio to Peak	0.00016
W320	325.26	99	0	0.14582	0.016667	Discharge	0.21177	1.00E-05	Ratio to Peak	0.003872
W330	380.88	60.876	0	0.16529	0.079833	Discharge	0.10847	1.00E-05	Ratio to Peak	0.016679
W340	339.2	99	0	0.12604	0.98319	Discharge	0.004031	1.00E-05	Ratio to Peak	0.00014
W350	276.98	52.791	0	0.016667	0.081022	Discharge	0.10214	1.00E-05	Ratio to Peak	0.011814
W360	308.24	85.773	0	0.14269	0.080547	Discharge	0.074669	1.00E-05	Ratio to Peak	0.001852
W370	211.83	36.772	0	0.16662	0.074884	Discharge	0.26142	1.00E-05	Ratio to Peak	0.00243
W380	284.94	52.916	0	0.016667	0.083227	Discharge	0.18461	1.00E-05	Ratio to Peak	0.00023
W390	355.03	64.68	0	0.016667	0.069247	Discharge	0.01447	1.00E-05	Ratio to Peak	0.009072
W400	343.68	77.453	0	0.016667	0.05956	Discharge	0.099828	1.00E-05	Ratio to Peak	0.042789
W410	0.001538	35.283	0	0.16523	0.016667	Discharge	0.55533	1.00E-05	Ratio to Peak	0.005146
W420	290.82	52.976	0	0.016667	520.17	Discharge	0.2307	1.00E-05	Ratio to Peak	0.00049

Annex 10. Malbag Model Reach Parameters

Table A-10.1 Malbag Model Reach Parameters

Reach Number	Muskingum-Cunge Channel Routing						
	Time Step Method	Length (m)	Slope (m/m)	Manning's n	Shape (m)	Width (m)	Side slope
R70	Automatic Fixed Interval	7473.9	0.00821	0.0001	Trapezoid	41.569	1
R80	Automatic Fixed Interval	5592.5	0.0039	0.0001	Trapezoid	41.569	1
R90	Automatic Fixed Interval	3389.1	0.00301	0.0001	Trapezoid	41.569	1
R120	Automatic Fixed Interval	3319.8	0.00159	0.11745	Trapezoid	41.569	1
R130	Automatic Fixed Interval	397.69	0.00212	0.17527	Trapezoid	41.569	1
R140	Automatic Fixed Interval	2765.2	0.00244	0.20878	Trapezoid	41.569	1
R150	Automatic Fixed Interval	2978.4	0.00202	0.15307	Trapezoid	41.569	1
R170	Automatic Fixed Interval	927.41	0.00194	0.92834	Trapezoid	41.569	1
R180	Automatic Fixed Interval	1746.7	0.00283	0.47748	Trapezoid	41.569	1
R210	Automatic Fixed Interval	6265.6	0.000122	0.014501	Trapezoid	41.569	1

Annex 11. Malbag Floodplain Field Validation Points

Table A-11.1 Malbag Floodplain Field Validation Points

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/ Date	Rain Return / Scenario
	Lat	Long					
197	12.05118667	123.68269	0.03	0	0.03		5-Year
196	12.051205	123.6824183	0.031	0	0.031		5-Year
195	12.05130167	123.682425	0.03	0	0.03		5-Year
171	12.05546816	123.6906914	0.031	0	0.031		5-Year
172	12.0556631	123.6928073	0.031	0	0.031		5-Year
173	12.05590469	123.6930868	0.031	0	0.031		5-Year
174	12.05600538	123.6941435	0.031	0	0.031		5-Year
198	12.059585	123.6993283	0.033	0	0.033		5-Year
199	12.06021167	123.699905	0.031	0	0.031		5-Year
200	12.06059	123.7004533	0.031	0	0.031		5-Year
201	12.06100833	123.7004067	0.03	0	0.03		5-Year
202	12.061315	123.7009383	0.03	0	0.03		5-Year
203	12.06248	123.7019733	0.031	0	0.031		5-Year
175	12.06428167	123.7036877	0.031	0	0.031		5-Year
176	12.06450157	123.7040071	0.03	0	0.03		5-Year
177	12.06455862	123.7038517	0.03	0	0.03		5-Year
204	12.06475167	123.704815	0.031	0	0.031		5-Year
205	12.06491833	123.70546	0.069	0	0.069		5-Year
206	12.06562667	123.709075	0.031	0	0.031		5-Year
207	12.06570333	123.709855	0.031	0	0.031		5-Year
209	12.06579833	123.7102267	0.031	0	0.031		5-Year
208	12.06597	123.7103883	0.031	0	0.031		5-Year
178	12.06646677	123.7117452	0.031	0	0.031		5-Year
179	12.06674105	123.7122988	0.041	0	0.041		5-Year
180	12.06712588	123.7130113	0.051	0	0.051		5-Year
181	12.06775535	123.7141004	0.063	0	0.063		5-Year
211	12.06843	123.7160733	0.031	0	0.031		5-Year
210	12.06844833	123.7155267	0.03	0	0.03		5-Year
212	12.068595	123.7169267	0.042	0	0.042		5-Year
214	12.06910667	123.718235	0.031	0	0.031		5-Year
213	12.06919667	123.717935	0.031	0	0.031		5-Year
183	12.06945371	123.7191533	0.06	0	0.06		5-Year
182	12.06958807	123.7192103	0.063	0	0.063		5-Year
215	12.07190667	123.72456	0.032	0	0.032		5-Year
216	12.076645	123.7268617	0.033	0	0.033		5-Year
217	12.078075	123.7278183	0.03	0	0.03		5-Year
218	12.07853333	123.7280517	0.031	0	0.031		5-Year

219	12.07909	123.728605	0.03	0	0.03		5-Year
222	12.08268167	123.7376817	0.032	0	0.032		5-Year
221	12.08273	123.7377617	0.032	0	0.032		5-Year
220	12.082935	123.737235	0.23	0	0.23		5-Year
223	12.082995	123.7377717	0.031	0	0.031		5-Year
224	12.08307667	123.737715	0.032	0	0.032		5-Year
184	12.0833112	123.7366485	0.03	0	0.03		5-Year
190	12.08332198	123.7381186	0.03	0	0.03		5-Year
187	12.08334702	123.7375468	0.03	0	0.03		5-Year
191	12.08335801	123.7384565	0.032	0	0.032		5-Year
188	12.08337599	123.7379727	0.03	0	0.03		5-Year
185	12.08341526	123.7371443	0.231	0	0.231		5-Year
192	12.08342036	123.7385136	0.072	0	0.072		5-Year
189	12.08356648	123.7381199	0.11	0	0.11		5-Year
193	12.08364064	123.7389723	0.038	0	0.038		5-Year
186	12.08364973	123.7371697	0.03	0	0.03		5-Year
59	12.09175	123.6480933	0.03	0	0.03		5-Year
60	12.09192167	123.6482117	0.031	0	0.031		5-Year
63	12.09229333	123.6482983	0.031	0	0.031		5-Year
61	12.092325	123.6484467	0.03	0	0.03		5-Year
62	12.09238333	123.6483017	0.031	0	0.031		5-Year
64	12.09260833	123.6485117	0.03	0	0.03		5-Year
65	12.09272667	123.6486783	0.057	0	0.057		5-Year
89	12.092845	123.6484467	0.038	0	0.038		5-Year
66	12.09293167	123.6487067	0.03	0	0.03		5-Year
69	12.09301167	123.6482467	0.03	0	0.03		5-Year
88	12.09303333	123.6477467	0.034	0	0.034		5-Year
67	12.09304333	123.6489267	0.067	0	0.067		5-Year
71	12.09304833	123.6479983	0.049	0	0.049		5-Year
87	12.09312333	123.6476133	0.03	0	0.03		5-Year
70	12.09314	123.64798	0.03	0	0.03		5-Year
82	12.09315167	123.64702	0.031	0	0.031		5-Year
85	12.09316	123.6472617	0.031	0	0.031		5-Year
86	12.09316167	123.6474383	0.033	0	0.033		5-Year
90	12.09317333	123.6484483	0.115	0	0.115		5-Year
68	12.09318167	123.6489567	0.03	0	0.03		5-Year
78	12.09320833	123.6466317	0.302	0	0.302		5-Year
81	12.09323333	123.646745	0.031	0	0.031		5-Year
83	12.09324	123.6471183	0.031	0	0.031		5-Year
84	12.09324833	123.6472	0.04	0	0.04		5-Year
79	12.09326833	123.6464783	0.383	0	0.383		5-Year
77	12.09329167	123.6468883	0.031	0	0.031		5-Year
91	12.09338667	123.6492967	0.031	0	0.031		5-Year
80	12.09345833	123.6463917	0.311	0	0.311		5-Year
74	12.09350167	123.6480417	0.033	0	0.033		5-Year

73	12.09351333	123.64803	0.033	0	0.033		5-Year
76	12.09352333	123.6476733	0.031	0	0.031		5-Year
72	12.09356167	123.6477067	0.031	0	0.031		5-Year
75	12.09377	123.6478067	0.106	0	0.106		5-Year
92	12.09553833	123.6517517	0.031	0	0.031		5-Year
225	12.09615167	123.74684	0.032	0	0.032		5-Year
226	12.09628	123.7467883	0.04	0	0.04		5-Year
194	12.09645777	123.7472154	0.03	0	0.03		5-Year
93	12.09686333	123.65257	0.031	0	0.031		5-Year
227	12.09682	123.74774	0.031	0	0.031		5-Year
94	12.09938333	123.6544367	0.073	0	0.073		5-Year
95	12.09982	123.6546333	0.09	0	0.09		5-Year
96	12.100655	123.655125	0.032	0	0.032		5-Year
97	12.10089	123.655275	0.032	0	0.032		5-Year
98	12.101065	123.6553883	0.03	0	0.03		5-Year
99	12.101395	123.6555883	0.03	0	0.03		5-Year
100	12.10196833	123.6558533	0.031	0	0.031		5-Year
101	12.102645	123.65622	0.034	0	0.034		5-Year
102	12.10314333	123.6565017	0.038	0	0.038		5-Year
103	12.10345333	123.65666	0.041	0	0.041		5-Year
104	12.10425667	123.6570933	0.06	0	0.06		5-Year
105	12.10567333	123.6577833	0.038	0	0.038		5-Year
106	12.10800333	123.6592167	0.031	0	0.031		5-Year
107	12.10835833	123.65948	0.03	0	0.03		5-Year
108	12.10932333	123.6602083	0.03	0	0.03		5-Year
109	12.10990667	123.6607	0.031	0	0.031		5-Year
55	12.11107167	123.6648817	0.032	0	0.032		5-Year
110	12.11115667	123.6615917	0.03	0	0.03		5-Year
54	12.11127333	123.6648417	0.03	0	0.03		5-Year
111	12.11130833	123.661665	0.03	0	0.03		5-Year
112	12.11136333	123.6617483	0.03	0	0.03		5-Year
113	12.11145	123.66182	0.03	0	0.03		5-Year
114	12.11158	123.6619733	0.031	0	0.031		5-Year
53	12.111575	123.66467	0.041	0	0.041		5-Year
115	12.111675	123.6620983	0.031	0	0.031		5-Year
52	12.11198667	123.6645333	0.06	0	0.06		5-Year
58	12.11207	123.6629017	0.03	0	0.03		5-Year
57	12.112245	123.6629567	0.03	0	0.03		5-Year
51	12.11229	123.66439	0.03	0	0.03		5-Year
56	12.11239667	123.66305	0.144	0	0.144		5-Year
46	12.11256	123.66477	0.04	0	0.04		5-Year
50	12.11261333	123.664205	0.065	0	0.065		5-Year
45	12.11267167	123.6651917	0.03	0	0.03		5-Year
116	12.11274167	123.6635883	0.418	0	0.418		5-Year
49	12.11279833	123.6641483	0.03	0	0.03		5-Year

117	12.112825	123.6639383	0.071	0	0.071		5-Year
47	12.11283833	123.6645267	0.03	0	0.03		5-Year
118	12.11296667	123.6642017	0.031	0	0.031		5-Year
48	12.11300833	123.664265	0.031	0	0.031		5-Year
44	12.113045	123.6650483	0.03	0	0.03		5-Year
119	12.11308167	123.66442	0.031	0	0.031		5-Year
120	12.11313333	123.6647067	0.03	0	0.03		5-Year
121	12.113195	123.66489	0.035	0	0.035		5-Year
122	12.11324667	123.665145	0.03	0	0.03		5-Year
123	12.113655	123.6660667	0.036	0	0.036		5-Year
124	12.11378333	123.6664767	0.072	0	0.072		5-Year
126	12.11381833	123.66724	0.03	0	0.03		5-Year
127	12.11385167	123.66765	1.822	0	1.822		5-Year
125	12.11391667	123.66662	0.03	0	0.03		5-Year
128	12.11937	123.67375	0.032	0	0.032		5-Year
129	12.11957	123.6740317	0.03	0	0.03		5-Year
130	12.12039833	123.6749467	0.03	0	0.03		5-Year
131	12.12061	123.6751367	0.031	0	0.031		5-Year
132	12.120925	123.675485	0.03	0	0.03		5-Year
133	12.121065	123.6755967	0.031	0	0.031		5-Year
134	12.12218833	123.6789233	0.031	0	0.031		5-Year
135	12.12472167	123.6826783	0.031	0	0.031		5-Year
136	12.12480167	123.6828467	0.067	0	0.067		5-Year
137	12.12564667	123.68435	0.03	0	0.03		5-Year
138	12.12620667	123.6855983	0.031	0	0.031		5-Year
140	12.126365	123.6860317	0.031	0	0.031		5-Year
139	12.12638167	123.6859433	0.032	0	0.032		5-Year
141	12.12654167	123.686215	0.031	0	0.031		5-Year
142	12.126935	123.6869333	0.031	0	0.031		5-Year
143	12.132125	123.6960933	0.031	0	0.031		5-Year
144	12.13218667	123.696245	0.031	0	0.031		5-Year
146	12.13222333	123.696455	0.031	0	0.031		5-Year
145	12.13222667	123.69629	0.031	0	0.031		5-Year
148	12.13226833	123.6965833	0.031	0	0.031		5-Year
147	12.13237167	123.6966083	0.031	0	0.031		5-Year
149	12.132435	123.696985	0.031	0	0.031		5-Year
150	12.132545	123.6973167	0.032	0	0.032		5-Year
151	12.13364833	123.7007517	0.031	0	0.031		5-Year
152	12.13406833	123.7039117	0.03	0	0.03		5-Year
153	12.13433	123.7042167	0.783	0	0.783		5-Year
155	12.13561833	123.706305	0.03	0	0.03		5-Year
156	12.13564667	123.70952	0.033	0	0.033		5-Year
154	12.135775	123.7062133	0.031	0	0.031		5-Year
157	12.13631667	123.7105917	0.034	0	0.034		5-Year
160	12.13805333	123.715625	0.03	0	0.03		5-Year

161	12.13855167	123.7178917	0.03	0	0.03		5-Year
158	12.13858333	123.7117783	0.03	0	0.03		5-Year
159	12.13871833	123.71416	0.031	0	0.031		5-Year
16	12.1392	123.7237833	0.031	0	0.031		5-Year
41	12.13939833	123.7280133	0.03	0	0.03		5-Year
40	12.13943833	123.7277883	0.03	0	0.03		5-Year
15	12.13946667	123.723835	0.031	0	0.031		5-Year
34	12.13956833	123.7255883	0.032	0	0.032		5-Year
39	12.13960167	123.7275967	0.03	0	0.03		5-Year
13	12.13961833	123.7239433	0.046	0	0.046		5-Year
42	12.13963833	123.7282083	0.031	0	0.031		5-Year
14	12.13967667	123.7239517	0.046	0	0.046		5-Year
38	12.13967167	123.7274433	0.031	0	0.031		5-Year
12	12.13969	123.7239567	0.032	0	0.032		5-Year
33	12.13970167	123.72506	0.031	0	0.031		5-Year
11	12.13976667	123.72385	0.031	4	-3.969		5-Year
37	12.13982	123.72721	0.03	0	0.03		5-Year
32	12.13986	123.7250483	0.031	0	0.031		5-Year
35	12.139865	123.7259367	0.03	0	0.03		5-Year
43	12.1399	123.7282183	0.03	0	0.03		5-Year
36	12.13996	123.7269833	0.03	0	0.03		5-Year
2	12.14036333	123.721815	0.031	0.1	-0.069		5-Year
162	12.14038167	123.7213017	0.031	0	0.031		5-Year
17	12.14038333	123.7240333	0.03	0	0.03		5-Year
8	12.1404	123.7231967	0.031	0	0.031		5-Year
5	12.14040667	123.7226383	0.031	0	0.031		5-Year
6	12.14041	123.722905	0.033	0	0.033		5-Year
10	12.14041333	123.7240333	0.031	0	0.031		5-Year
9	12.14044333	123.723315	0.047	0	0.047		5-Year
20	12.14046	123.7262017	0.03	0	0.03		5-Year
4	12.14047	123.722505	0.032	0.1	-0.068		5-Year
21	12.14046833	123.726235	0.03	0	0.03		5-Year
19	12.14050167	123.724865	0.03	0	0.03		5-Year
18	12.14051	123.7246533	0.03	0	0.03		5-Year
7	12.14053167	123.722755	0.031	0	0.031		5-Year
3	12.14053833	123.7222017	0.03	0.1	-0.07		5-Year
22	12.14056333	123.7259967	0.03	0	0.03		5-Year
163	12.140585	123.724945	0.031	0	0.031		5-Year
27	12.140625	123.7253433	0.032	0	0.032		5-Year
28	12.14063833	123.725055	0.031	0	0.031		5-Year
1	12.14065333	123.7209117	0.032	0	0.032		5-Year
23	12.14070667	123.7256867	0.03	0	0.03		5-Year
24	12.14082833	123.7256967	0.03	0	0.03		5-Year
25	12.14094833	123.7262083	0.031	0	0.031		5-Year
29	12.1411	123.7249517	0.037	0	0.037		5-Year

26	12.14114	123.7264367	0.031	0	0.031		5-Year
31	12.14118167	123.7247833	0.031	0	0.031		5-Year
164	12.14155	123.72882	0.078	0	0.078		5-Year
30	12.14156667	123.7248233	0.032	0	0.032		5-Year
165	12.14292667	123.7295467	0.032	0	0.032		5-Year
166	12.14299	123.72952	0.031	0	0.031		5-Year
167	12.143175	123.7305417	0.032	0	0.032		5-Year
168	12.14787167	123.7359517	0.033	0	0.033		5-Year
169	12.14857	123.736615	0.03	0	0.03		5-Year
170	12.15341667	123.7423233	0.03	0	0.03		5-Year

Annex 12. Educational Institutions affected by flooding in Malbag Floodplain

Table A-12.1. Educational Institutions in Cawayan, Masbate affected by flooding in Malbag Floodplain

Masbate				
Cawayan				
Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Cabayugan Daycare Cawayan	Cabayugan			
Cabayugan Elementary School Cawayan	Cabayugan			
Elementary School Malbug Cawayan	Cabayugan			
Malbug Elementary School Cawayan	Cabayugan			
Malbug School Cawayan	Cabayugan			
Villaganas Elementary School Malbug Cawayan	Cabayugan			
Uson South District Cawayan	Mactan			
Daycare Center Lague-Lague Cawayan	Pulot	Low	Low	Low
Daycare Center Taberna Cawayan	Pulot			
Elementary School Lague Lague Cawayan	Pulot			
Taberna Elementary School	Pulot			
Taberna School	Taberna			

Table A-12.2. Educational Institutions in Milagros, Masbate affected by flooding in Malbag Floodplain

Masbate				
Milagros				
Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Bara High School Milagros	Bara			
Daycare Center Sawmill Milagros	Bara			
New Daycare Center Sawmill Milagros	Bara			
Matagbac Elementary School Milagros	Matagbac			

Table A-12.3. Educational Institutions in Uson, Masbate affected by flooding in Malbag Floodplain

Masbate				
Uson				
Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Daycare San Isidro Uson	San Vicente			
San Ramon Elementary San Isidro Uson	San Vicente			
San Ramon High School Uson	San Vicente			

Annex 13. Health Institutions affected by flooding in Malbag Floodplain

Table A-13.1. Health Institutions in Cawayan, Masbate affected by flooding in Malbag Floodplain

Masbate				
Cawayan				
Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Cabayugan Health Center Cawayan	Cabayugan			
Brgy. Nutrition Center Candelaria Cawayan	Lague-Lague			
Health Center Lague Lague Cawayan	Pulot			
Health Center Taberna Cawayan	Pulot			

Table A-13.2. Health Institutions in Milagros, Masbate affected by flooding in Malbag Floodplain

Masbate				
Milagros				
Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Health Center Matagbac Milagros	Matagbac			