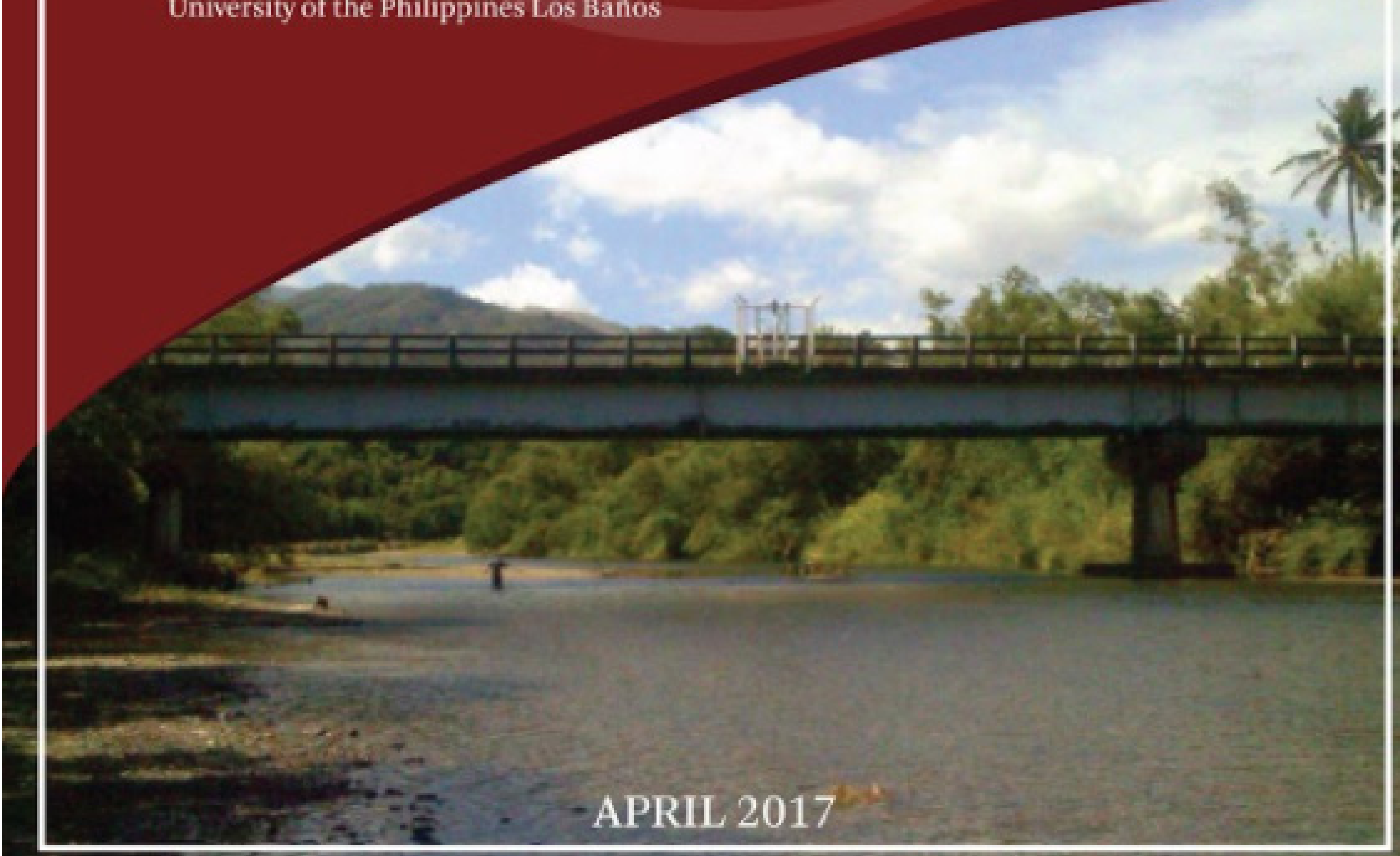
HAZARD MAPPING OF THE PHILIPPINES USING LIDAR (PHIL-LIDAR I)

LiDAR Surveys and Flood Mapping of Abra de ilog River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
University of the Philippines Los Baños



APRIL 2017

Published by the UP Training Center for Applied Geodesy and Photogrammetry (TCAGP)
College of Engineering
University of the Philippines – Diliman
Quezon City
1101 PHILIPPINES

This research project is supported by the Department of Science and Technology (DOST) as part of its Grants-in-Aid Program and is to be cited as:

E.C. Paringit and E.R. Abucay (Eds.) (2017), LiDAR Surveys and Flood Mapping of Abra de Ilog River. Quezon City: University of the Philippines Training Center for Applied Geodesy and Photogrammetry-146 pp.

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National Library of the Philippines
ISBN: 978-621-430-119-5

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LIST OF ACRONYMS AND ABBREVIATIONS

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

CHAPTER 1: OVERVIEW OF THE PROGRAM AND ABRA DE ILOG RIVER

Enrico C. Paringit, Dr. Eng., Asst. Prof. Edwin R. Abucay, and Mr. Dante Gideon K. Vergara

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 in 2014, supported by the Department of Science and Technology (DOST) Grants-in-Aid (GiA) Program. The program was primarily aimed at acquiring a national elevation and resource dataset at sufficient resolution to produce information necessary to support the different phases of disaster management. Particularly, it targeted to operationalize the development of flood hazard models that would produce updated and detailed flood hazard maps for the major river systems in the country.

Also, the program was aimed at producing an up-to-date and detailed national elevation dataset suitable for 1:5,000 scale mapping, with 50 cm and 20 cm horizontal and vertical accuracies, respectively. These accuracies were achieved through the use of the state-of-the-art Light Detection and Ranging (LiDAR) airborne technology procured by the project through DOST. The methods described in this report are thoroughly described in a separate publication entitled "Flood Mapping of Rivers in the Philippines Using Airborne LiDAR: Methods (Paringit, et. al., 2017) available separately.

The implementing partner university for the Phil-LiDAR 1 Program is the University of the Philippines Los Baños (UPLB) 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 45 river basins in the Southern Luzon Region. The university is located in Los Baños in the province of Laguna.

1.2 Overview of the Abra de Ilog River Basin

The Abra De Ilog River Basin is a 14,166-hectare watershed located in Occidental Mindoro. It covers the barangays of Armado, Balao, Cabacao, Poblacion, San Vicente and Tibag in the municipality of Abra De Ilog, as well as a small portion of the municipality of Paluan in Occidental Mindoro. The DENR River Basin Control Office (RBCO) states that the Abra de Ilog River Basin has a drainage are of 122 km^2 and an estimated 195 cubic meter (MCM) annual run-off (RBCO, 2015).

In terms of geology, the basin area has seven geological materials with Basement Complex as the most dominant type covering more than 60% of the total area. The rest of the area is classified as Oligocene-Miocene, Pliocene-Pleistocene, Oligocene, Paleocene and Cretaceous-Paleogene. The river basin generally has very steep slope of more than 50%. Most areas of the watershed lie on a very high ground elevation as high as 2,200 meters above mean sea level. The rest of the river basin has elevation of 10-200 meters above mean sea level. Abra de Ilog River Basin dominated by nine soil types: Alaminos loam and San Manuel clay loam, Quiangua silt loam, Sandy Manuel sand, Annam clay loam, Umingan silt loam, San Fabian clay loam and Faraon clay/ River Wash. Only two types of land cover that can be found in the watershed, namely: cultivated area mixed with brushland/grassland and arable land with cereals and sugar as main crops, with the former covering more than 90% of the total area.

The Abra de Ilog River Basin's main stem, Abra de Ilog River, is among the forty-five (45) river systems in MIMAROPA Region. The Abra De Ilog River passes through all the barangays covered by the Abra De Ilog River Basin, including Barangay Wawa. According to the 2015 national census of PSA, a total of 8,697 persons are residing within the immediate vicinity of the river, which is distributed among barangays Tibag, Wawa, and Lumangbayan in the Municipality of Abra de Ilog.

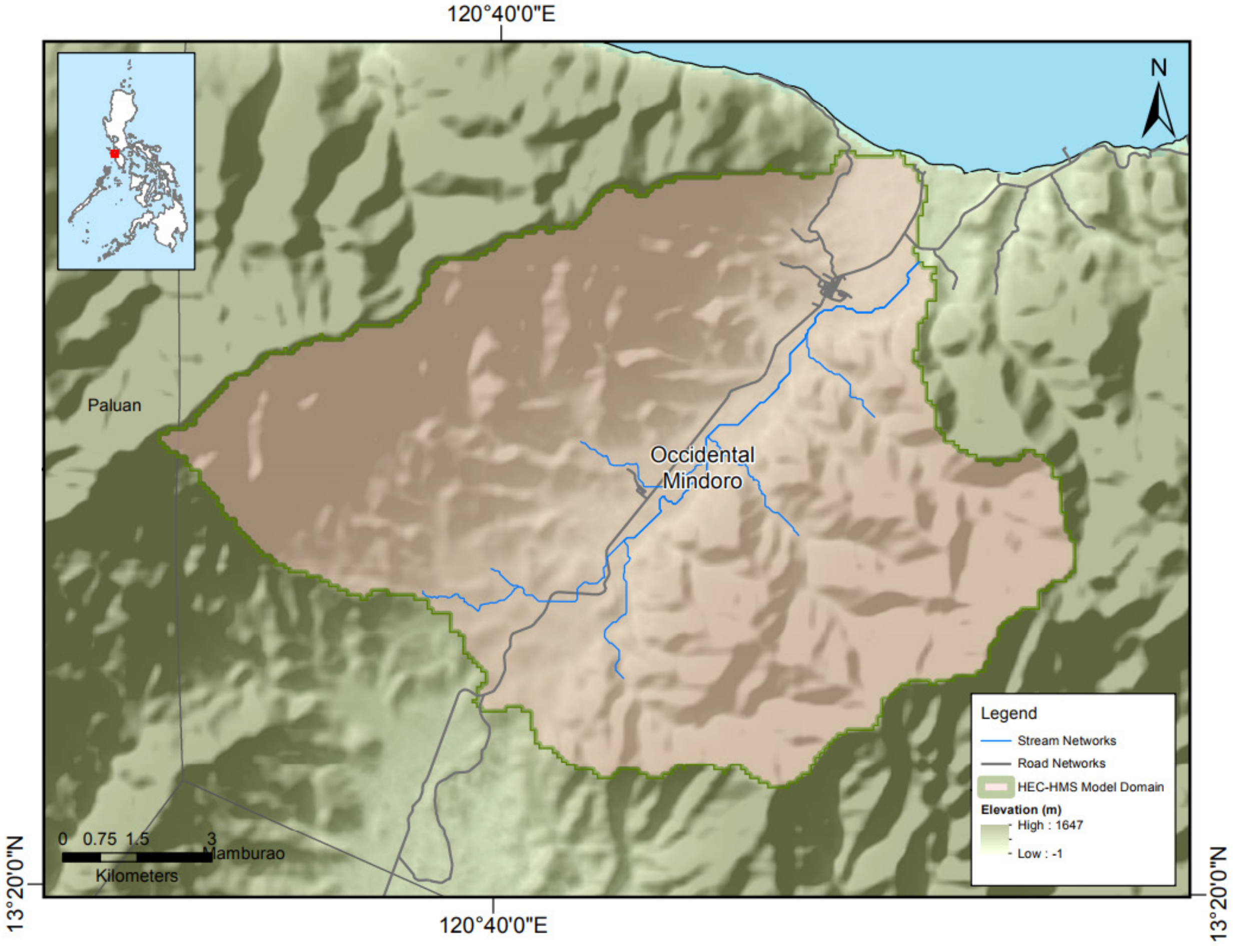

Figure 1. Map of Abra de Ilog River Basin (in brown)

The economy of the communities within the Abra de Ilog River Basin and the rest of Occidental Mindoro Province, rests on livestock and agriculture with rice, corn, and coconut as the main crops and products (Philippine Statistics Authority, 2017). This is due to the tropical environment of the Philippines. Specifically, Climate Type I and III prevails in MIMAROPA (Mindoro, Marinduque, Romblon, Palawan) Region and Laguna Province based on the Modified Corona Classification of climate. Type I has two pronounced seasons, dry from November to April, and wet the rest of the year with maximum rain period from June to September. On the other hand, Type III has no very pronounced maximum rain period and with short dry season lasting only from one to three months, during the period from December to February or from March to May.

The type of climate of the Philippines makes it also vulnerable to the typhoons during the wet season that cause flooding. According to the study of Mines and Geoscience Bureau, all the barangays are highly susceptible to flooding. On the other hand, in terms of landslide susceptibility, the barangays in the river basin have low to moderate risk. Based on the field surveys conducted by the PHIL-LiDAR 1 validation team, about seven notable weather disturbance caused flooding in 2006 (Reming and Caloy), 2013 (Yolanda and Odette), 2015 (Nina), and 2016 (Marce). Heavy rainfall in 2016 attributed to habagat also caused flooding in barangay Armado.

In addition, on September 23, 2013, floods due to southwest monsoon rains hit 3 municipalities in Occidental Mindoro, namely: Abra de Ilog, Sablayan and Mamburao. Heavy rains affected 516 families (2,014 persons) according to MIMAROPA DRRMC (Virola M., Cinco M., 2013).

CHAPTER 2: LIDAR DATA ACQUISITION OF THE ABRA DE ILOG FLOODPLAIN

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

2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Abra de Ilog floodplain in Occidental Mindoro. These missions were planned for 12 lines and ran for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameter used for the LiDAR system is found in Table 1 and Table 2. Figure 2 shows the flight plan for Abra de Ilog Floodplain.

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

Block Name	Flying Height (m AGL)	Overlap (%)	Field of view (ø)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK29A	1100	30	50	100	30	130	5
BLK29B	1100	30	50	100	30	130	5
BLK29C	1100	30	50	100	30	130	5
BLK29D	1100	30	50	100	32	130	5

Table 2. Flight planning parameters for the Aquarius LiDAR system.

Block Name	Flying Height (m AGL)	Overlap (%)	Field of view (ø)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK29M	600	30	36	50	40	130	5

[1] The explanation of the parameters used are in the volume "LiDAR Surveys and Flood Mapping in the Philippines: Methods."

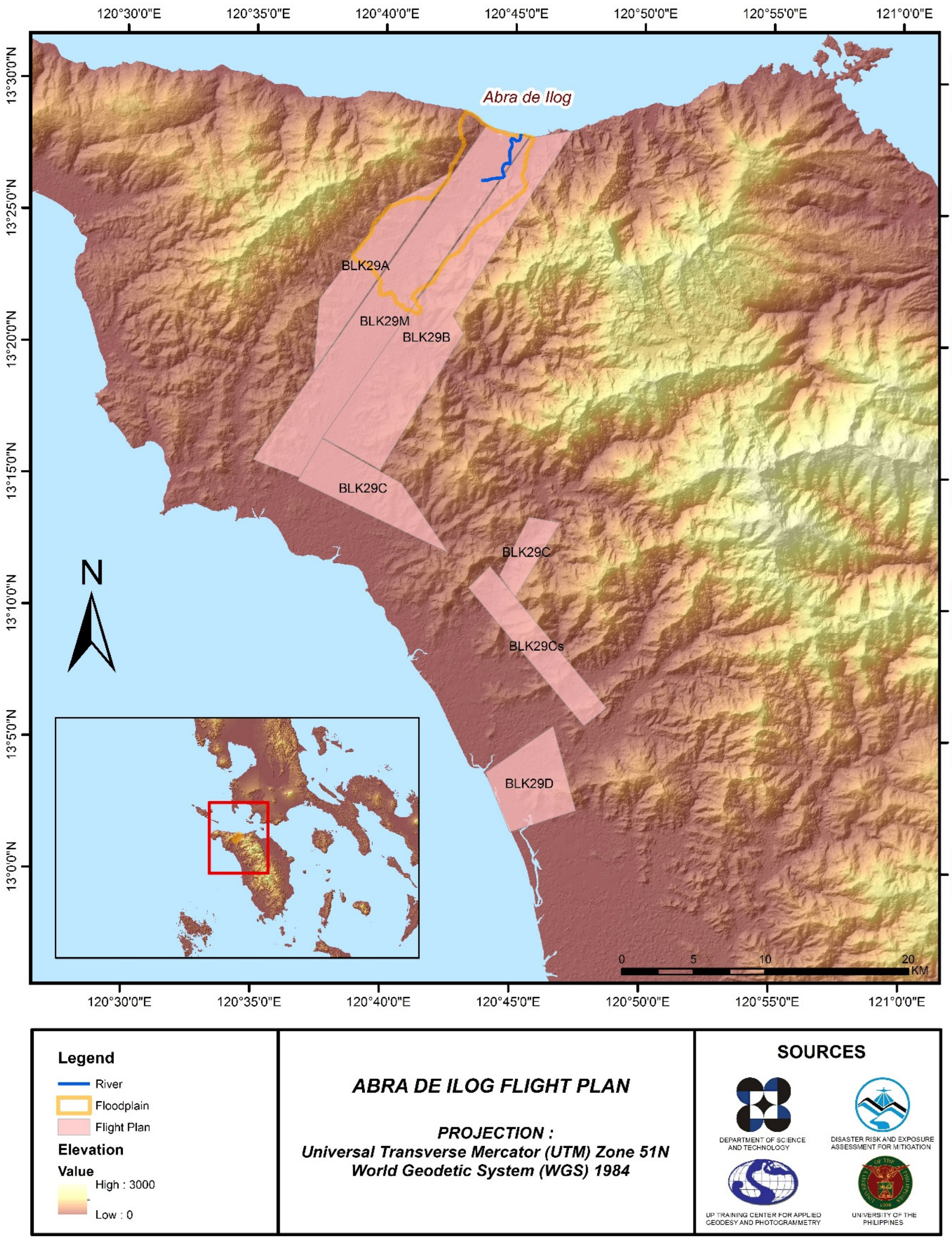


Figure 2. Flight plan used for the Abra de Ilog Floodplain survey.

2.2 Ground Base Stations

The project team was able to recover four (4) NAMRIA ground control points (GCPs): MRW-36, MRW-34, MRW-32, MRW-30, which are of second (2nd) order accuracy, and one (1) NAMRIA benchmark MC-52. The project team also established one GCP, MRW-DAC-00. The certifications for the NAMRIA reference points are found in Annex 2 while the baseline processing report for the established GCP is found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey (February 20-22, 2014 and December 7–8, 2015). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 882, SPS 985, and SPS 852. Flight plans and location of base stations used during the aerial LiDAR acquisition in Abra de Ilog floodplain are shown in Figure 3. The list of team members are shown in Annex 4.

Figure 4 to Figure 8 show the recovered NAMRIA reference point within the area. In addition, Table 3 to Table 7 show the details about the NAMRIA control stations and the established point while Table 8 shows the list of all ground control points (GCPs) occupied during the acquisition together with the corresponding dates of utilization.

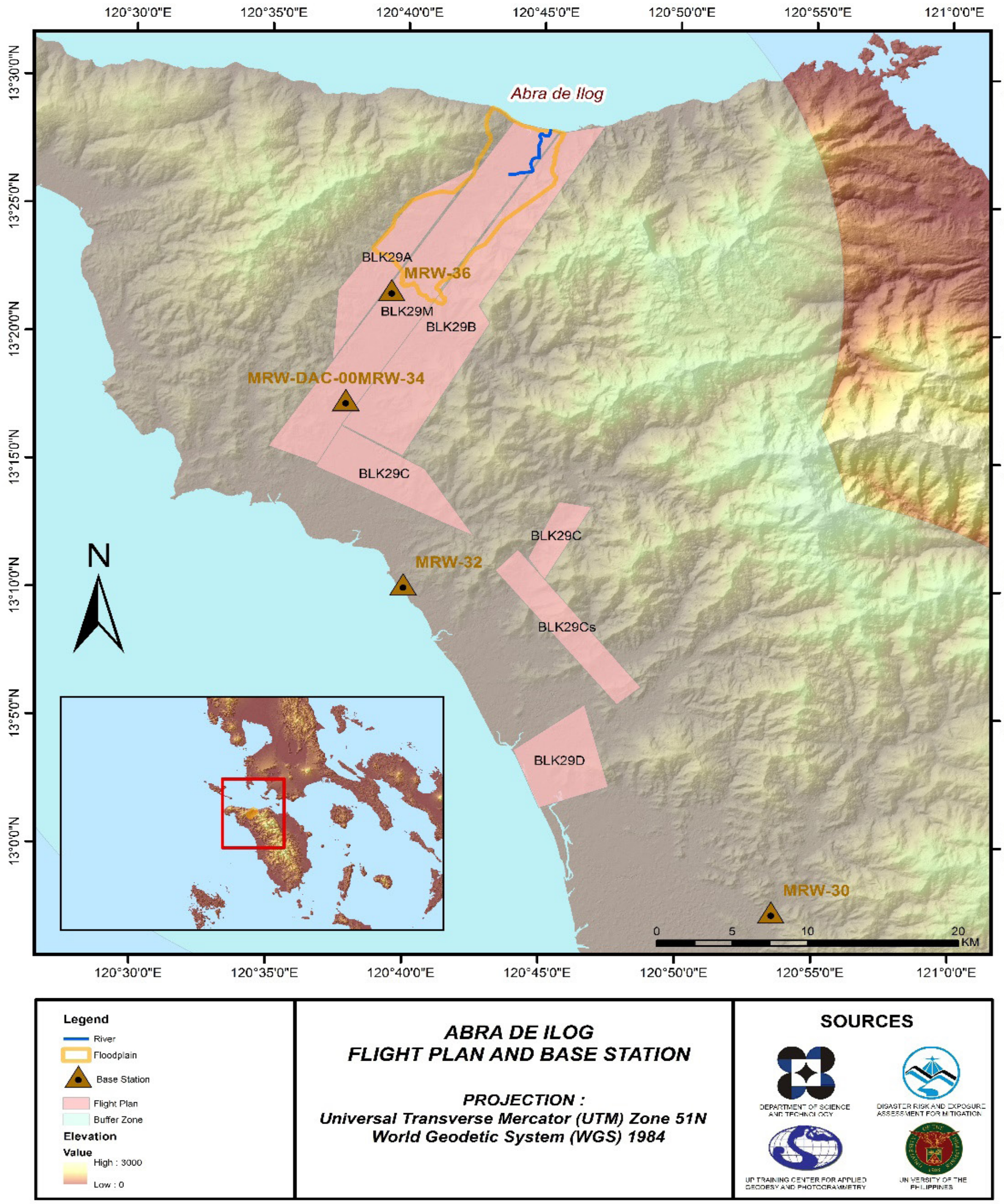


Figure 3. Flight plans and base stations used for the Abra de Ilog Floodplain survey.

(b)

(a)

Figure 4. GPS set-up over MRW-36 as recovered in Baclaran Bridge in Brgy. Cabacao, municipality of Abra de Ilog, Occidental Mindoro (a) and NAMRIA reference point MRW-36 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point MRW-36 used as base station for the LiDAR Acquisition with the processed coordinates.

Station Name	MRW-36	
Order of Accuracy	2nd Order	
Relative Error (Horizontal positioning)	1:50,000	
Geographic Coordinates, Philippine Reference 0f 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13°21’44.07349” North 120°39’20.54160” East 31.49300 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	462705.446 meters 1477646.985 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13°21’38.91908” North 120°39’25.54340” East 77.62100 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	246088.34 meters 1478304.87 meters

Figure 5. GPS set-up over MRW-34 as recovered in Balibago Bridge in Brgy. Armado, municipality of Abra de Ilog, Occidental Mindoro (a) and NAMRIA reference point MRW-34 (b) as recovered by the field team.

Table 4. Details of the recovered NAMRIA horizontal control point MRW-34 used as base station for the LiDAR Acquisition with the re-processed coordinates.

Station Name	MRW-34	
Order of Accuracy	2nd Order	
Relative Error (Horizontal positioning)	1:50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13°17’25.00981” North 120°37’41.53630” East 8.01600 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	459714.493 meters 1469690.588 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13°17’19.87026” North 120°37’ 46.54446” East 54.26900 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	243032.08 meters 1470369.33 meters

(a)

Figure 6. GPS set-up over MRW-32 as recovered in the corner of a day care center in Brgy. Fatima, municipality of Mamburao, Occidental Mindoro (a) and NAMRIA reference point MRW-32 (b) as recovered by the field team.

Table 5. Details of the recovered NAMRIA horizontal control point MRW-32 used as base station for the LiDAR Acquisition with the re-processed coordinates.

Station Name	**MRW-32**	
Order of Accuracy	**2nd Order**	
Relative Error (horizontal positioning)	**1:50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13°10’14.92094” North 120°39’52.29557” East 1.47400 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	463632.46 meters 1456469.064 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13°10’9.81293” North 120°39’57.31386” East 48.13600 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 52N PRS 1992)	Easting Northing	246845.90 meters 1457111.12 meters

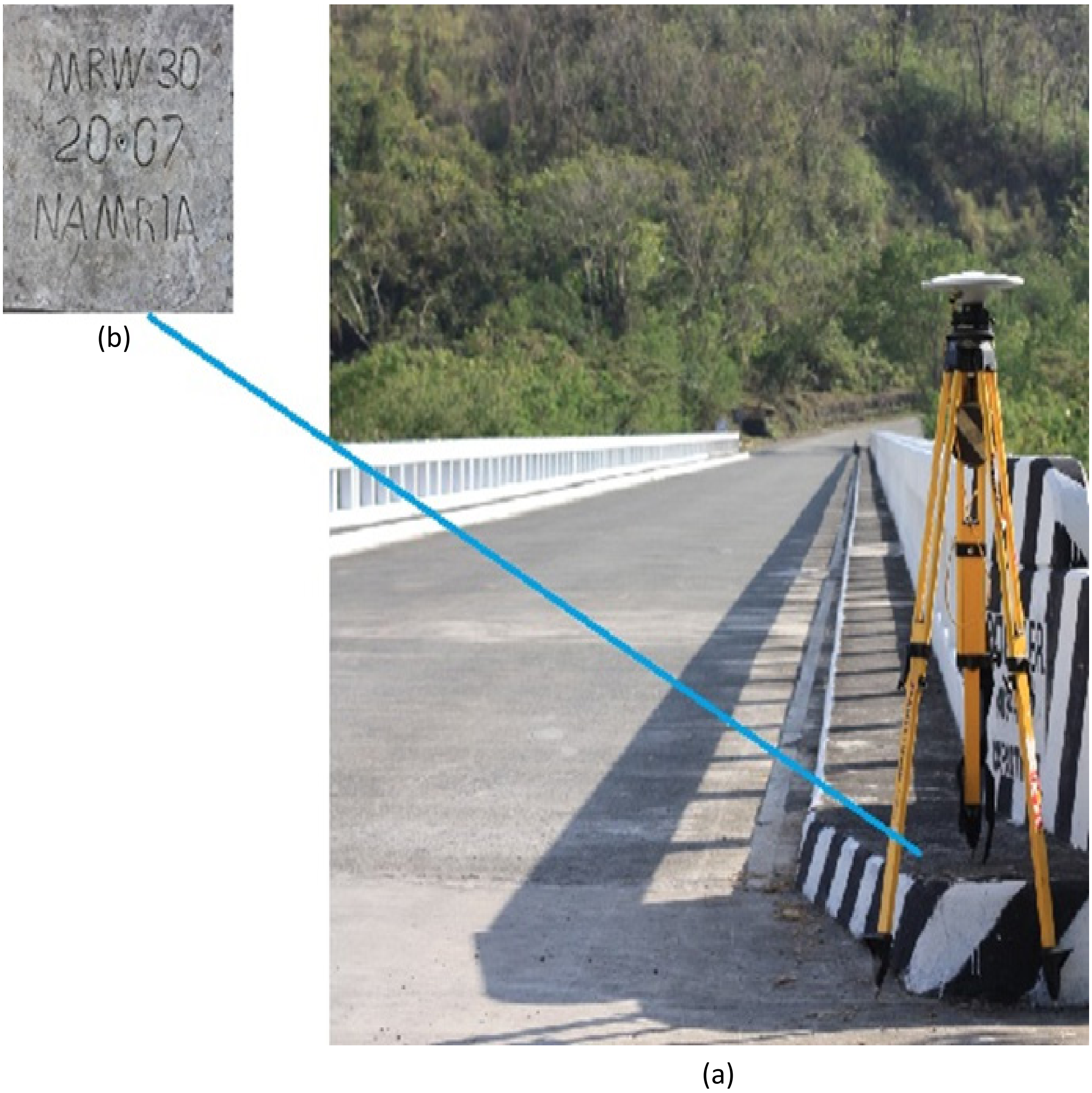
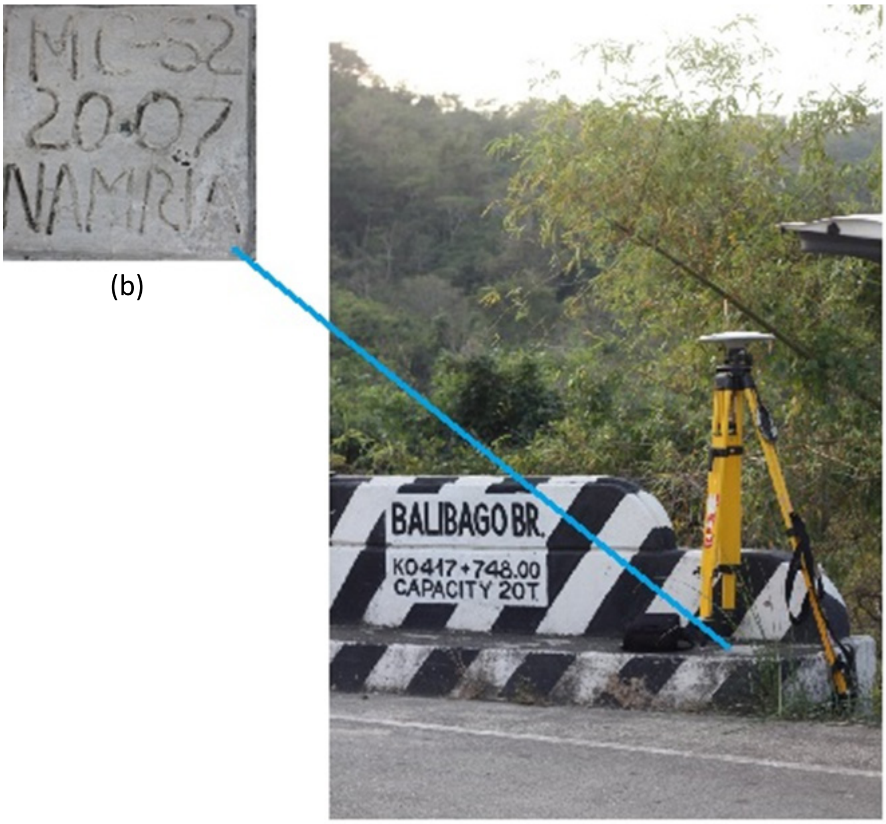


Figure 7. MRW-30 as recovered in Amnay Bridge in Brgy. Pinagturilan, municipality of Sta. Cruz, Occidental Mindoro.

Table 6. Details of the recovered NAMRIA horizontal control point MRW-30 used as base station for the LiDAR Acquisition with the re-processed coordinates.

Station Name	**MRW-30**	
Order of Accuracy	**2nd Order**	
Relative Error (horizontal positioning)	**1:50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	12°57'32.22950" North 120°53'28.50896" East 42.01300 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	488201.05 meters 1433011.7 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	12°57'27.19115" North 120°53'33.54442" East 89.79300 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 52N PRS 1992)	Easting Northing	271237.33 meters 1433451.97 meters



(b)

(a)

Figure 8. GPS set-up over MC-52 as recovered in Balibago Bridge in Brgy. Armado, municipality of Abra de Ilog, Occidental Mindoro (a) and NAMRIA reference point MC-52 (b) as recovered by the field team.

Table 7. Details of the recovered NAMRIA vertical control point MC-52 used as base station for the LiDAR Acquisition with the re-processed coordinates.

Station Name	**MC-52**	
Order of Accuracy	**2nd Order**	
Relative Error (horizontal positioning)	**1:50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude	13°17'25.66996" North 120°37'41.97783" East
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	242955.61 meters 1470904.34 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13°17'20.53041" North 120°37'46.98588" East 54.352 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 52N PRS 1992)	Easting Northing	243198.172 meters 1470321.018 meters

Table 8. Ground control points used during the LiDAR data acquisition.

Date Surveyed	Flight Number	Mission Name	Ground Control Points
February 20, 2014	1126A	3BLK29M51B	MRW-36, MC-52
February 22, 2014	1134A	3BLK29BA53B	MRW-34, MRW-32
December 7, 2014	3062P	1BLK29BCS341A	MRW-34, MC-52
December 8, 2014	3066P	1BLK29ACDF342A	MRW-DAC-00

2.3 Flight Missions

Four (4) missions were conducted to complete LiDAR data acquisition in Abra de Ilog floodplain, for a total of thirteen hours and seventeen minutes (13+17) of flying time for RP-C9122 and RP-C9022. All missions were acquired using the Pegasus and Aquarius LiDAR systems. Table 9 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 10 presents the actual parameters used during the LiDAR data acquisition.

Table 9. Flight missions for the LiDAR data acquisition in Abra de Ilog 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
February 20, 2014	1126A	100.69	107.77	44.13	63.64	1269	4	8
February 22, 2014	1134A	100.69	25.30	0.20	25.10	512	2	59
December 7, 2014	3062P	153.53	174.85	24.04	150.80	391	3	23
December 8, 2014	3066P	95.21	115.30	17.61	97.68	245	2	47
TOTAL		**450.12**	**423.21**	**85.98**	**337.22**	**2417**	**13**	**17**

Table 10. Actual parameters used during the LiDAR data acquisition of the Abra de Ilog Floodplain.

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (khz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
1126A	600	30	36	50	40	130	5
1134A	600	30	36	50	40	130	5
3062P	1100	30	50	100	30	130	5
3066P	1100	30	50	100	30	130	5

2.4 Survey Coverage

Abra de Ilog floodplain is located in the province of Occindetal Mindoro. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 11. The actual coverage of the LiDAR acquisition for Abra de Ilog floodplain is presented in Figure 9.

Table 11. List of municipalities and cities surveyed of the Abra de Ilog Floodplain LiDAR acquisition.

Province	Municipality/ City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Palawan	Mamburao	344.99	108.82	32%
	Abra de Ilog	523.87	137.59	26%
	Santa Cruz	709.53	82.91	12%
TOTAL		**1578.39**	**329.32**	**20.86%**

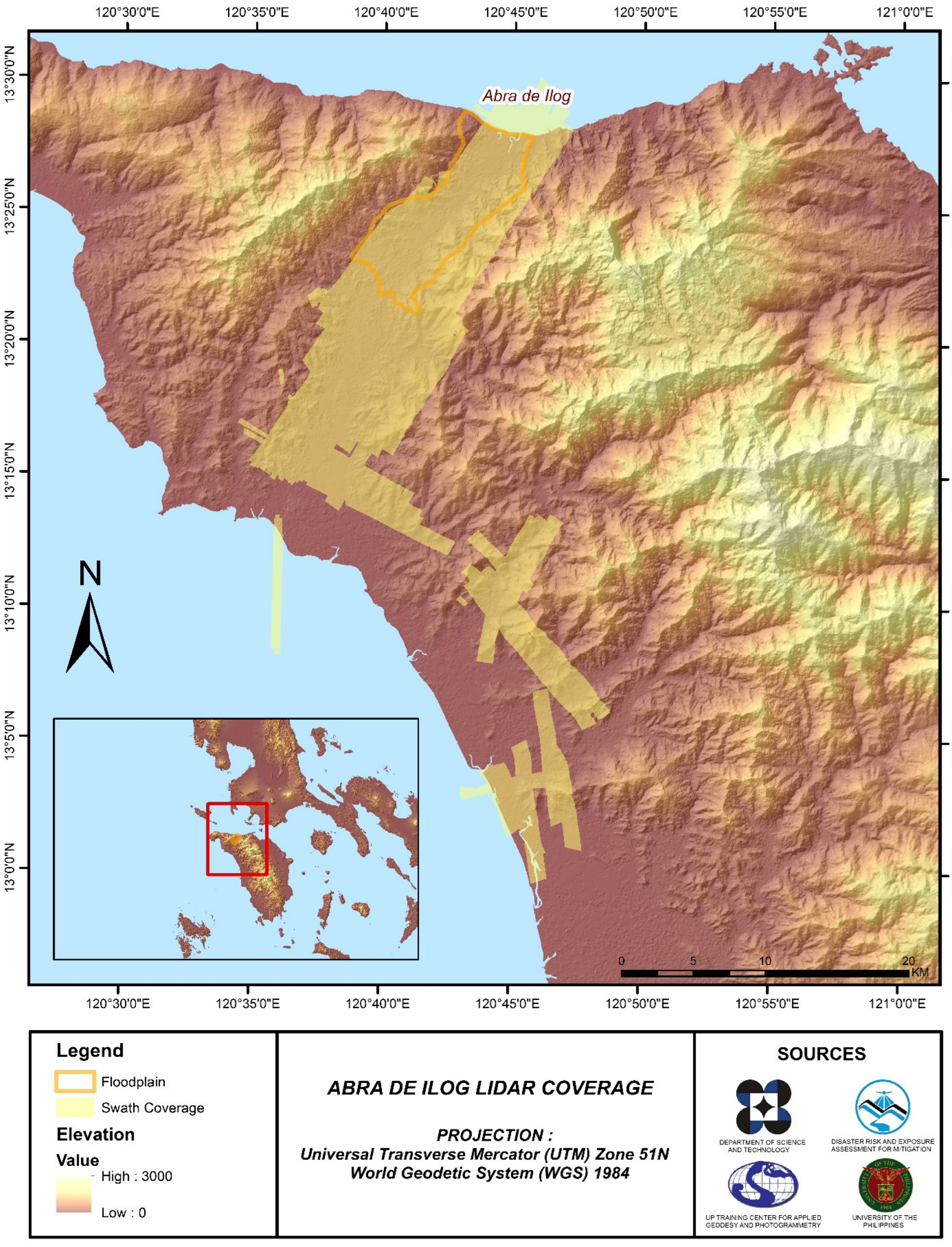


Figure 9. Actual LiDAR survey coverage of the Abra de Ilog Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE ABRA DE ILOG FLOODPLAIN

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

3.1 Overview of the LiDAR Data Pre-Processing

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

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

These processes are summarized in the flowchart shown in Figure 10.

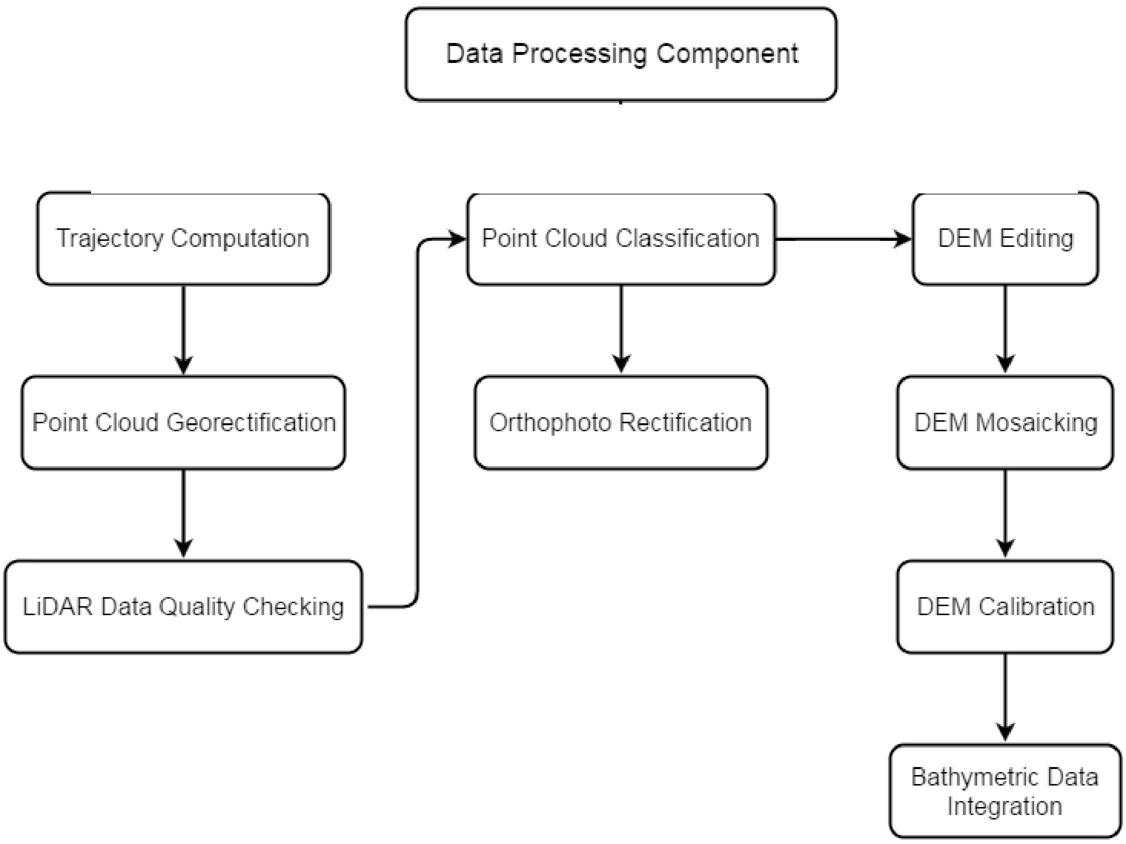

Figure 10. Schematic diagram for Data Pre-Processing Component.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Abra De Ilog floodplain can be found in Annex 5. Missions flown during the first survey conducted on February 2014 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Aquarius system while missions acquired during the second survey on December 2015 were flown using the Pegasus system over Abra de Ilog, Occidental Mindoro.

The Data Acquisition Component (DAC) transferred a total of 43.08 Gigabytes of Range data, 0.762 Gigabytes of POS data, 54.61 Megabytes of GPS base station data, and 43.08 Gigabytes of raw image data to the data server on March 7, 2014 for the first survey and January 13, 2016 for the second survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Abra De Ilog was fully transferred on January 15, 2016 as indicated on the Data Transfer Sheets for Abra De Ilog floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 1126A, one of the Abra De Ilog flights, which is the North, East, and Down position RMSE values are shown in Figure 11. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on February 20, 2014 00:00AM. The y-axis is the RMSE value for that particular position.

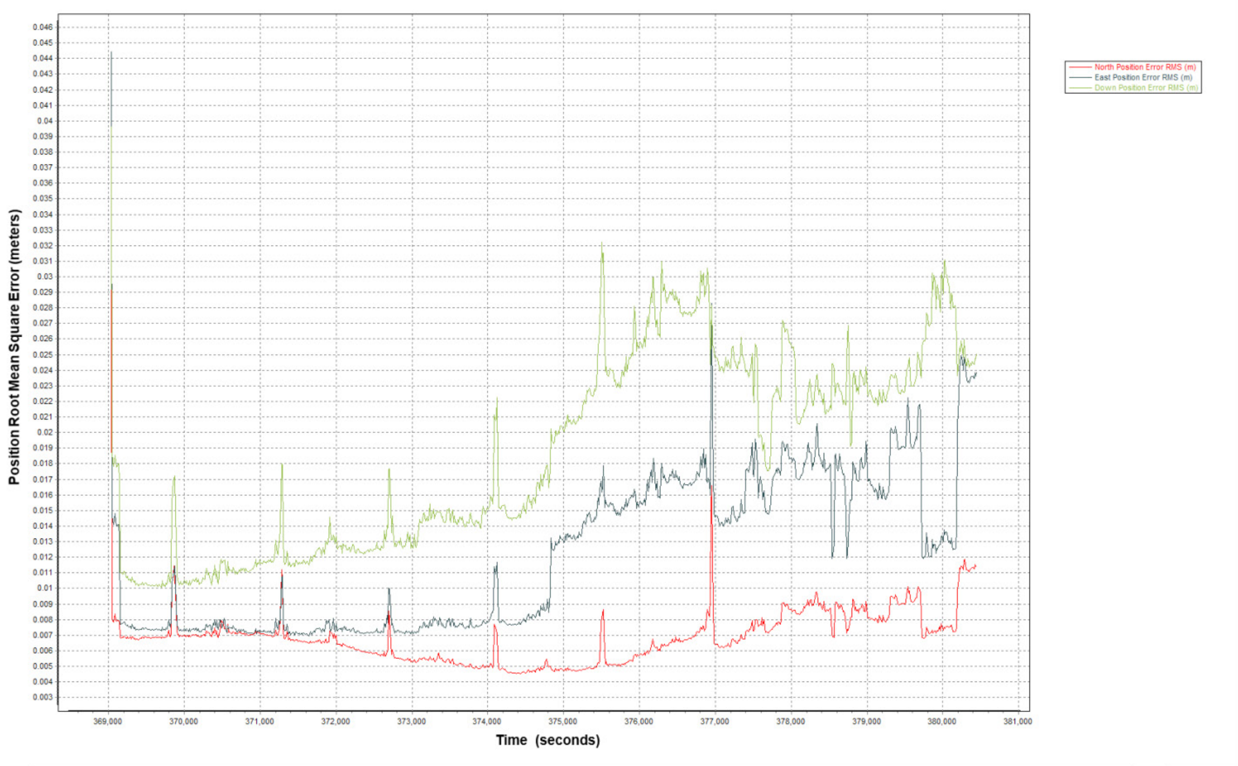

Figure 11. Smoothed Performance Metrics of Abra de Ilog Flight 1126A

The time of flight was from 369000 seconds to 380500 seconds, which corresponds to afternoon of February 20, 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 11 shows that the North position RMSE peaks at 1.70 centimeters, the East position RMSE peaks at 2.70 centimeters, and the Down position RMSE peaks at 3.20 centimeters, which are within the prescribed accuracies described in the methodology.

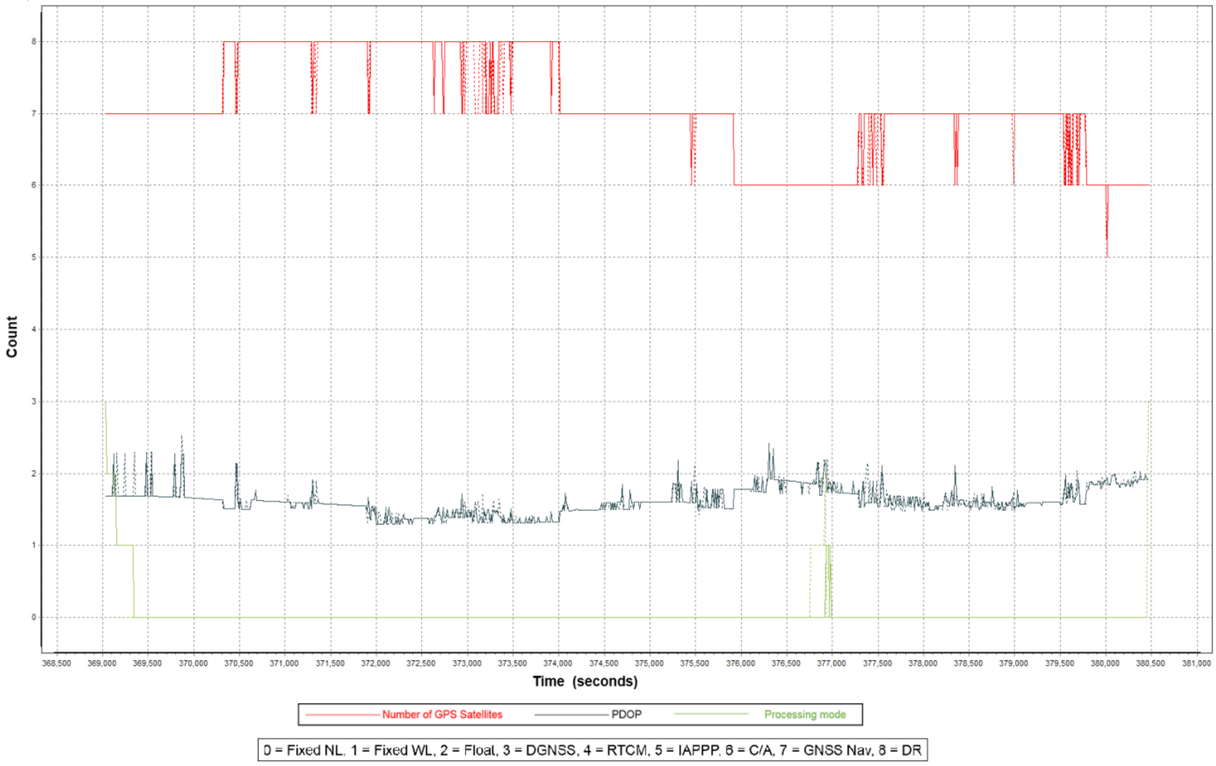

Figure 12. Solution Status Parameters of Abra de Ilog Flight 1126A.

The Solution Status parameters of flight 1126A, one of the Abra De Ilog flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 12. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Majority of the time, the number of satellites tracked was between 6 and 10. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode stayed at the value of 0 for majority of the survey with some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Abra De Ilog flights is shown in Figure 13.

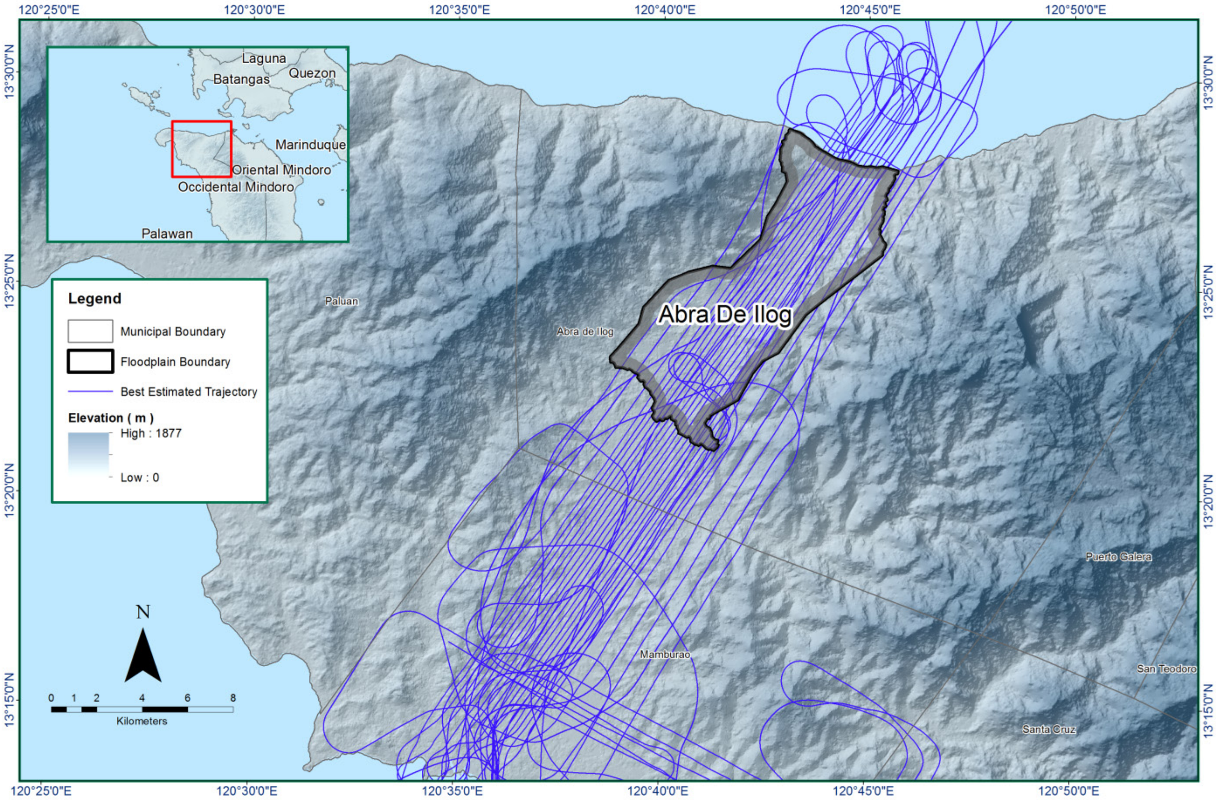

Figure 13. Best Estimated Trajectory of the LiDAR missions conducted over the Abra de Ilog Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 29 flight lines, with 11 flight lines containing two channels, since the Aquarius system contains one channel only, while 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 Abra De Ilog floodplain are given in Table 12.

Table 12. Self-calibration Results values for Abra de Ilog flights.

Parameter	Acceptable Value	Computed Value
Boresight Correction stdev	<0.001degrees	0.000303
IMU Attitude Correction Roll and Pitch Correction stdev	<0.001degrees	0.000886
GPS Position Z-correction stdev	<0.01meters	0.0096

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

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Abra de Ilog Floodplain is shown in Figure 14. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

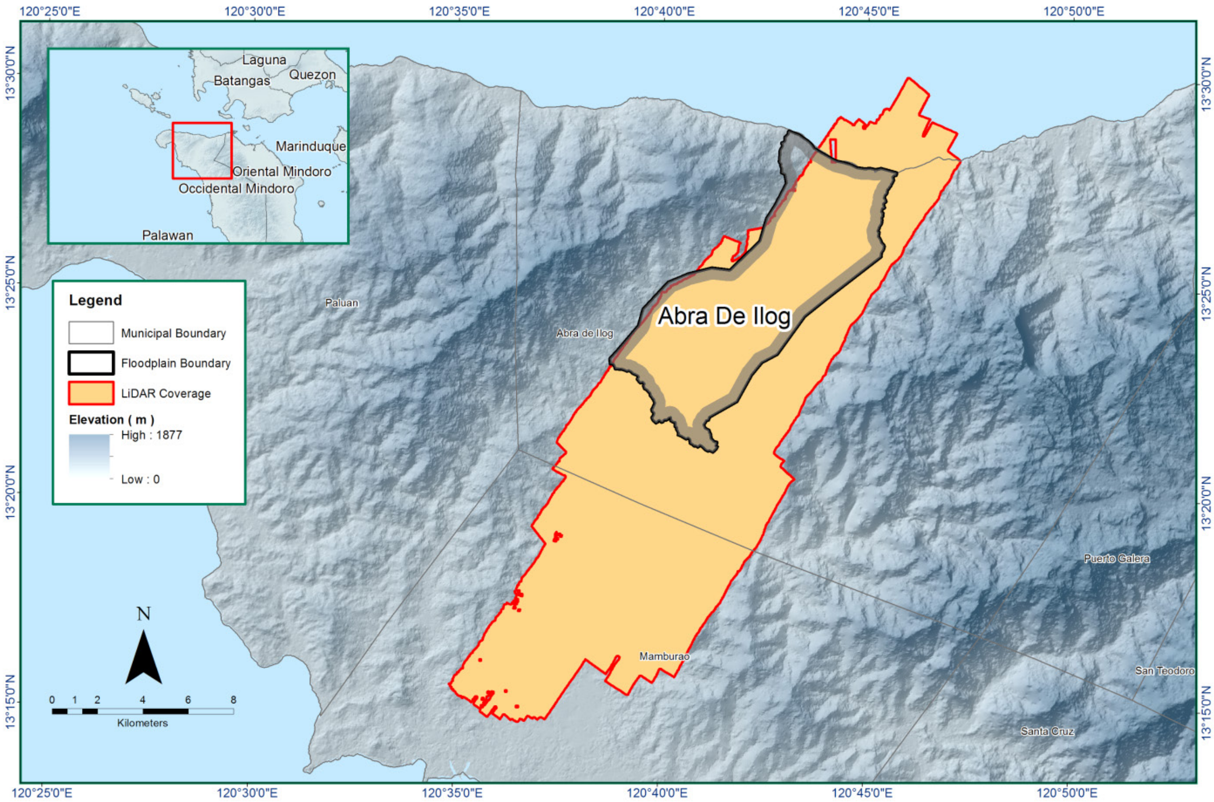

Figure 14. Boundary of the processed LiDAR data over Abra de Ilog Floodplain

The total area covered by the Abra de Ilog missions is 269.48 sq.km that is comprised of four (4) flight acquisitions grouped and merged into three (3) blocks as shown in Table 13.

Table 13. List of LiDAR blocks for Abra de Ilog Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
OccidentalMindoro_Blk29M	1126A	114.69
	1134A	
OccidentalMindoro_reflights_Blk29M	3066P	35.18
OccidentalMindoro_reflights_Blk29M_additional	3062P	119.61
TOTAL		**269.48 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 15. Since the Aquarius system employs one channel while 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.

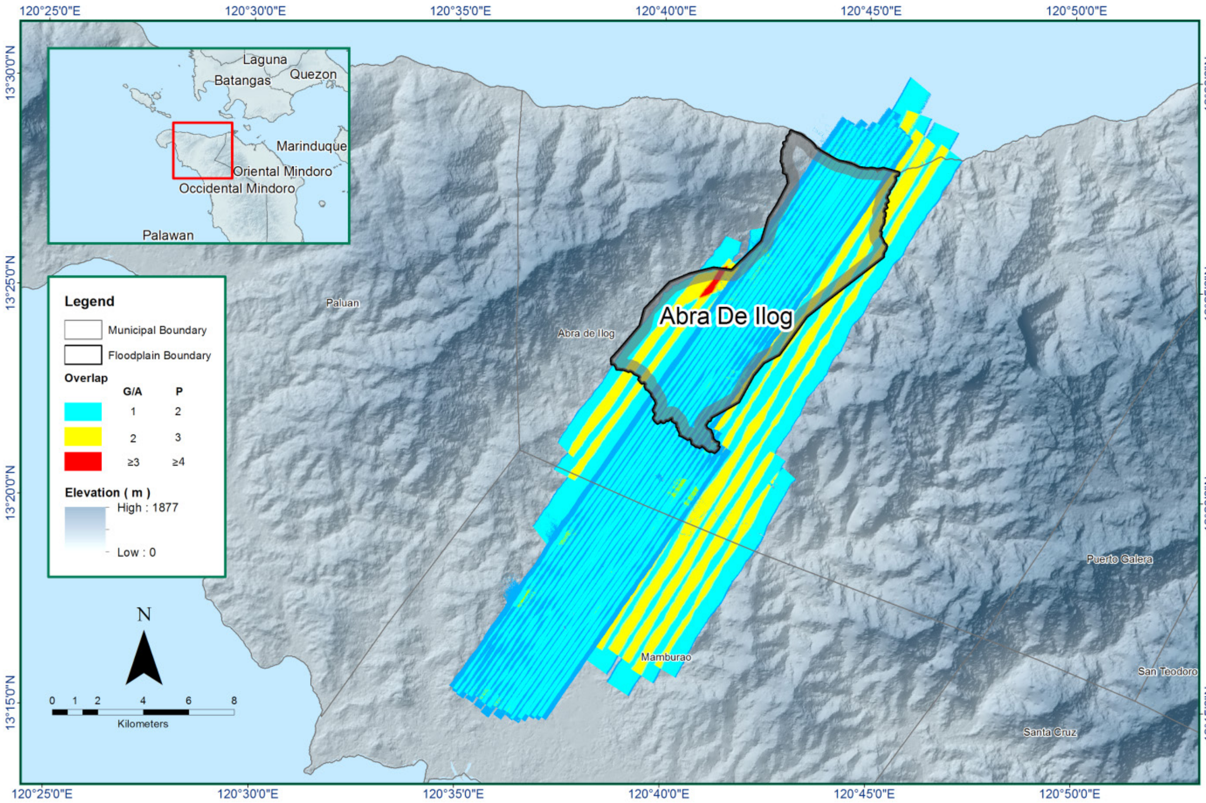

Figure 15. Image of data overlap for Abra de Ilog Floodplain.

The overlap statistics per block for the Abra De Ilog floodplain can be found in Annex 8. One pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 33.51% and 62.09% 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 16. It was determined that all LiDAR data for Abra De Ilog floodplain satisfy the point density requirement, and the average density for the entire survey area is 3.11 points per square meter.

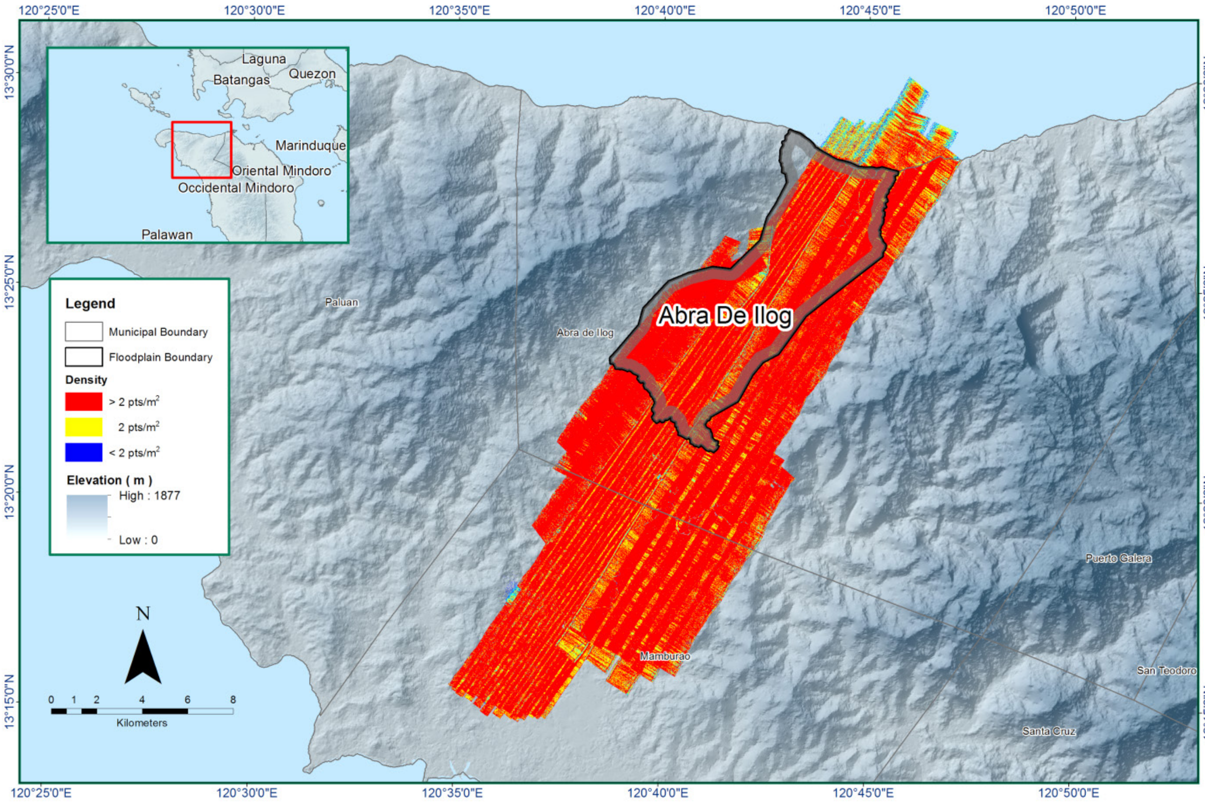

Figure 16. Pulse density map of merged LiDAR data for Abra de Ilog Floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 17. 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.

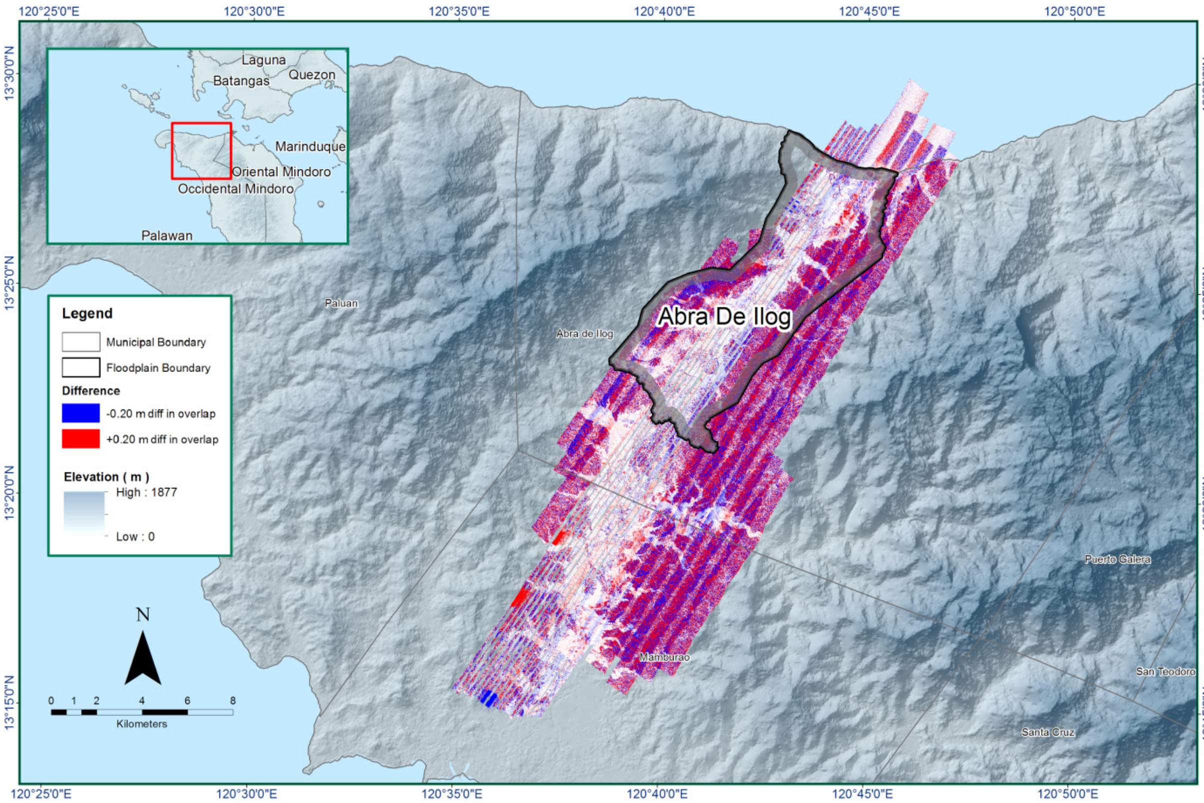

Figure 17. Elevation Difference Map between flight lines for Abra de Ilog Floodplain Survey.

A screen capture of the processed LAS data from an Abra de Ilog flight 1126A loaded in QT Modeler is shown in Figure 18. 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 became satisfactory. No reprocessing was done for this LiDAR dataset.

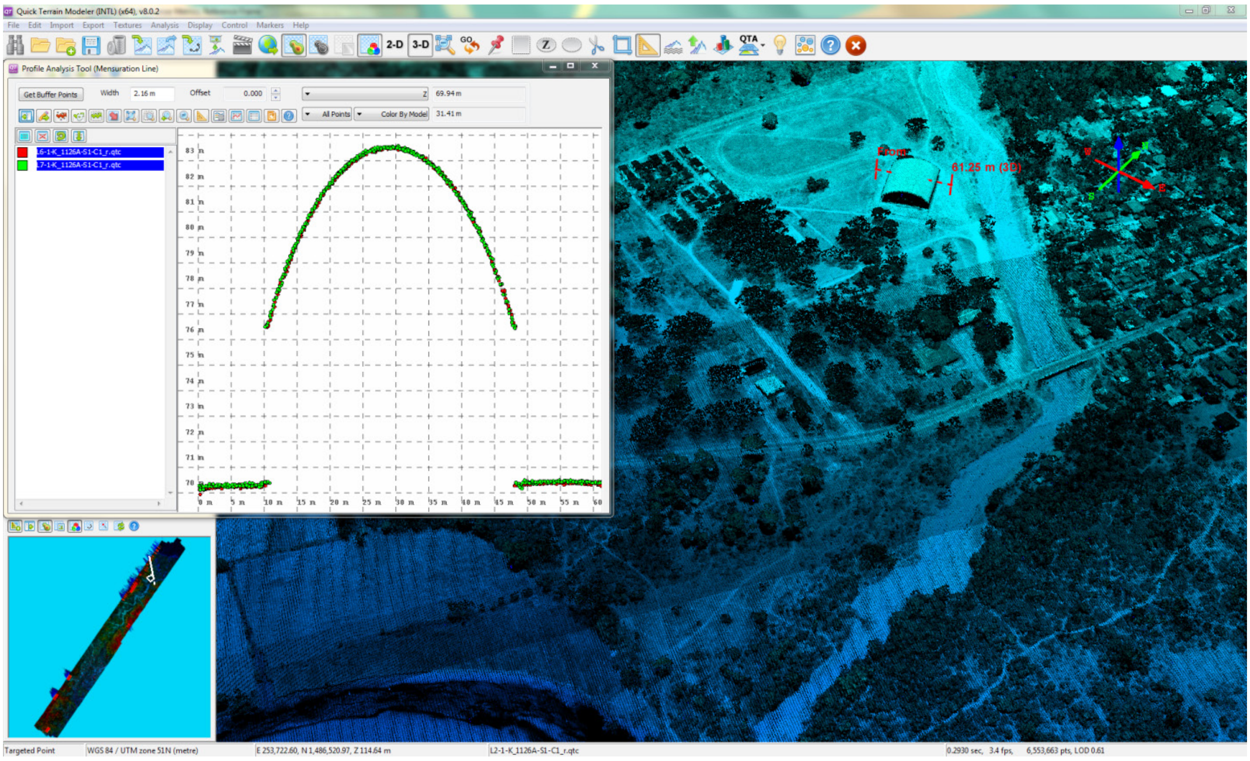

Figure 18. Quality checking for Abra de Ilog Flight 1126A using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 14. Abra de Ilog classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	190,656,233
Low Vegetation	93,886,875
Medium Vegetation	247,205,147
High Vegetation	560,602,891
Building	89,288,996

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Abra de Ilog floodplain is shown in Figure 19. A total of 416 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 14. The point cloud has a maximum and minimum height of 703.91 meters and 40.97 meters respectively.

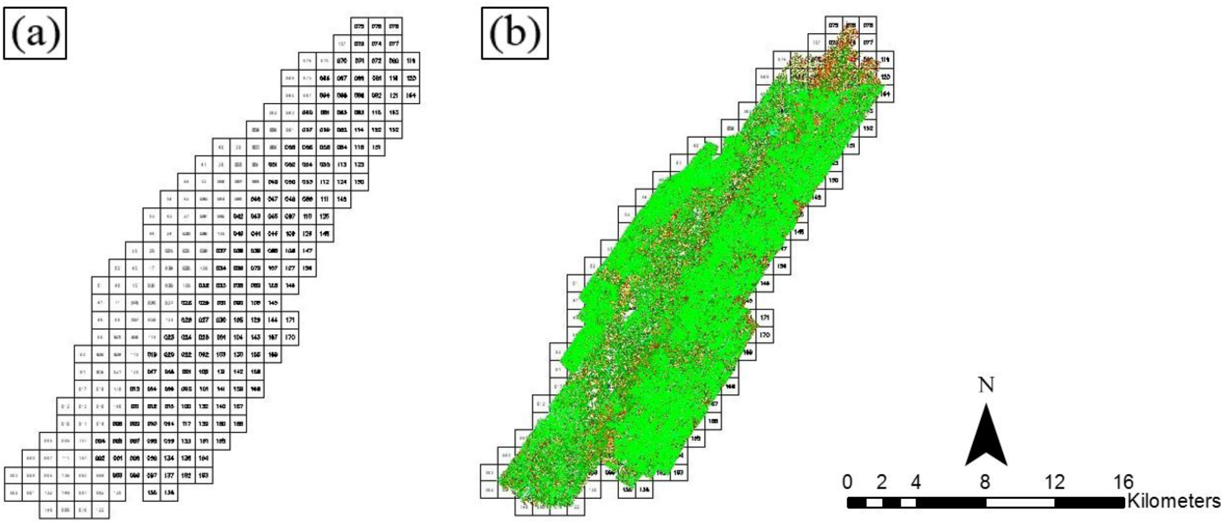

Figure 19. Tiles for Bacungan Floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 20. 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.

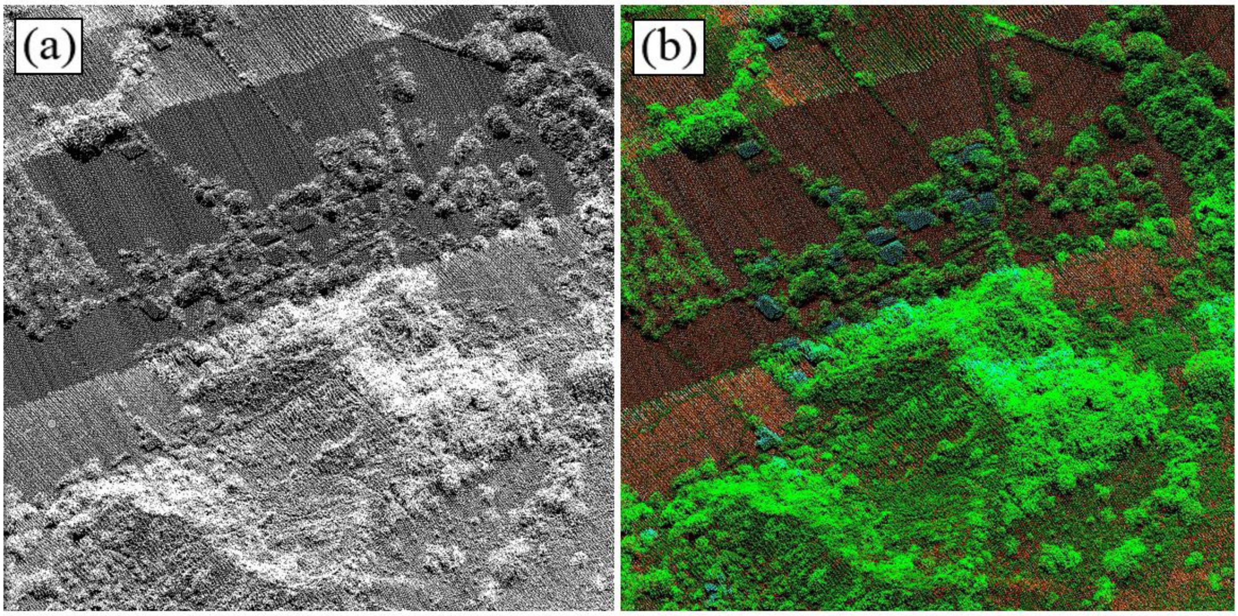

Figure 20. Point cloud before (a) and after (b) classification

The production of last return (V_ASCII) and the secondary (T_ ASCII) DTM, first (S_ ASCII) and last (D_ ASCII) return DSM of the area in top view display are shown in Figure 21. It shows that DTMs are the representation of the bare earth while on the DSMs, all features are present such as buildings and vegetation.

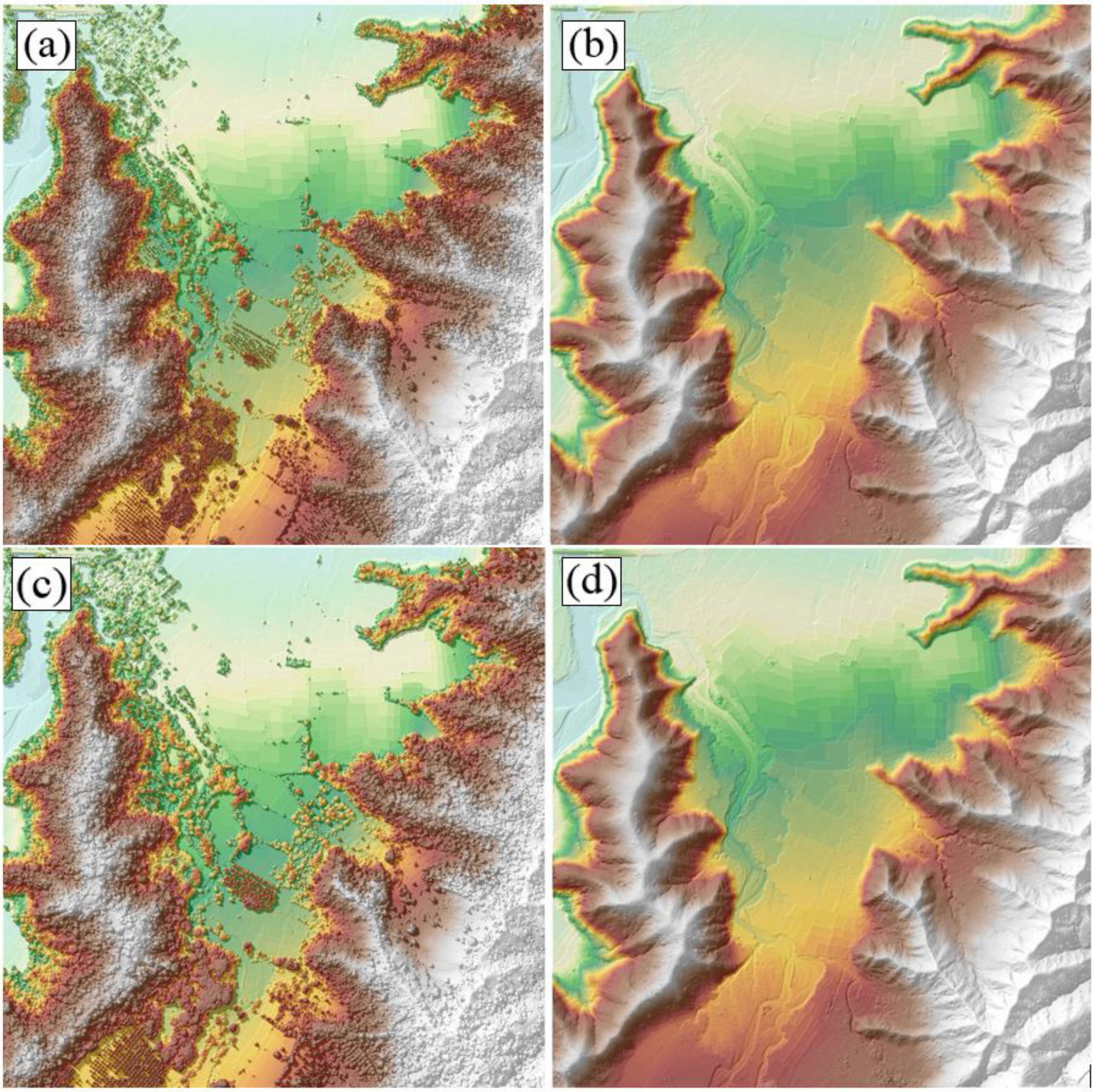

Figure 21. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Abra de Ilog Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 274 1km by 1km tiles area covered by Abra de Ilog floodplain is shown in Figure 22. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Abra de Ilog floodplain has a total of 160.57 sq.km orthophotogaph coverage comprised of 560 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 23.

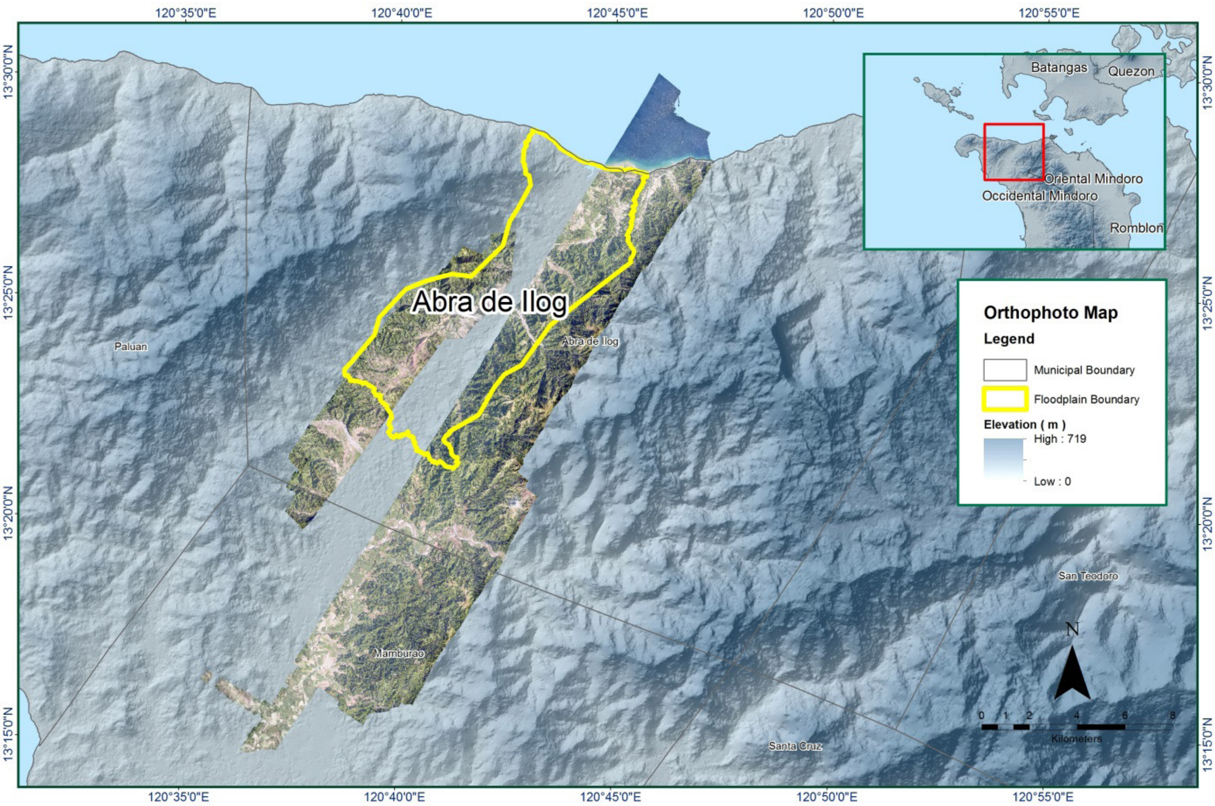

Figure 22. Abra de Ilog Floodplain with available orthophotographs

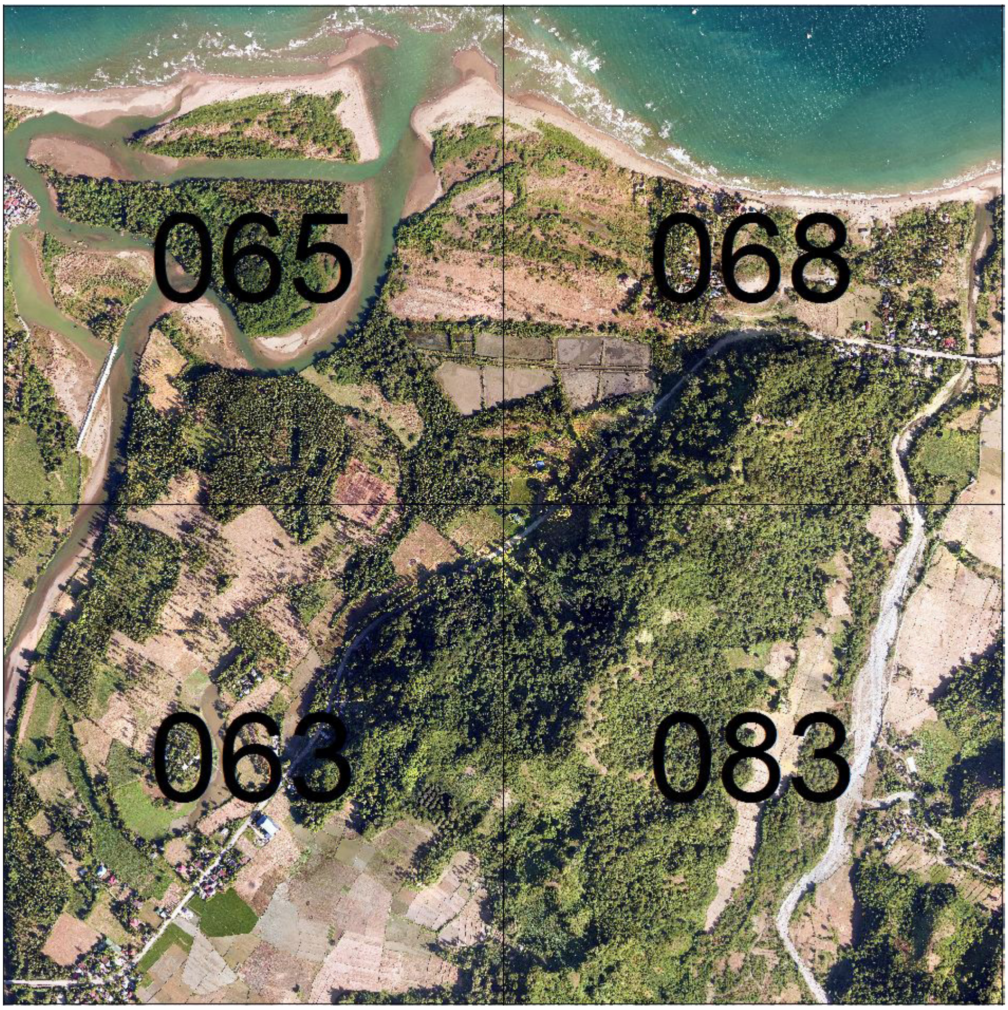

Figure 23. Sample orthophotograph tiles for Abra de Ilog Floodplain

3.8 DEM Editing and Hydro-Correction

Five (5) mission blocks were processed for Abra de Ilog floodplain. These blocks are composed of Occ. Mindoro and Occ. Mindoro Reflights blocks with a total area of 269.48 square kilometers. Table 15 shows the name and corresponding area of each block in square kilometers.

Table 15. LiDAR blocks with its corresponding areas.

LiDAR Blocks	Area (sq.km)
OccidentalMindoro_Blk29M	114.69
OccidentalMindoro_reflights_Blk29M	35.18
OccidentalMindoro_reflights_Blk29M_additional	119.61
TOTAL	**269.48 sq.km**

Portions of DTM before and after manual editing are shown in Figure 24. A part of the profile of the waterway (Figure 24a) was elevated and has to be interpolated (Figure 24b) to allow the correct flow of water. The data gap (Figure 24c) has been filled to complete the surface (Figure 24d).

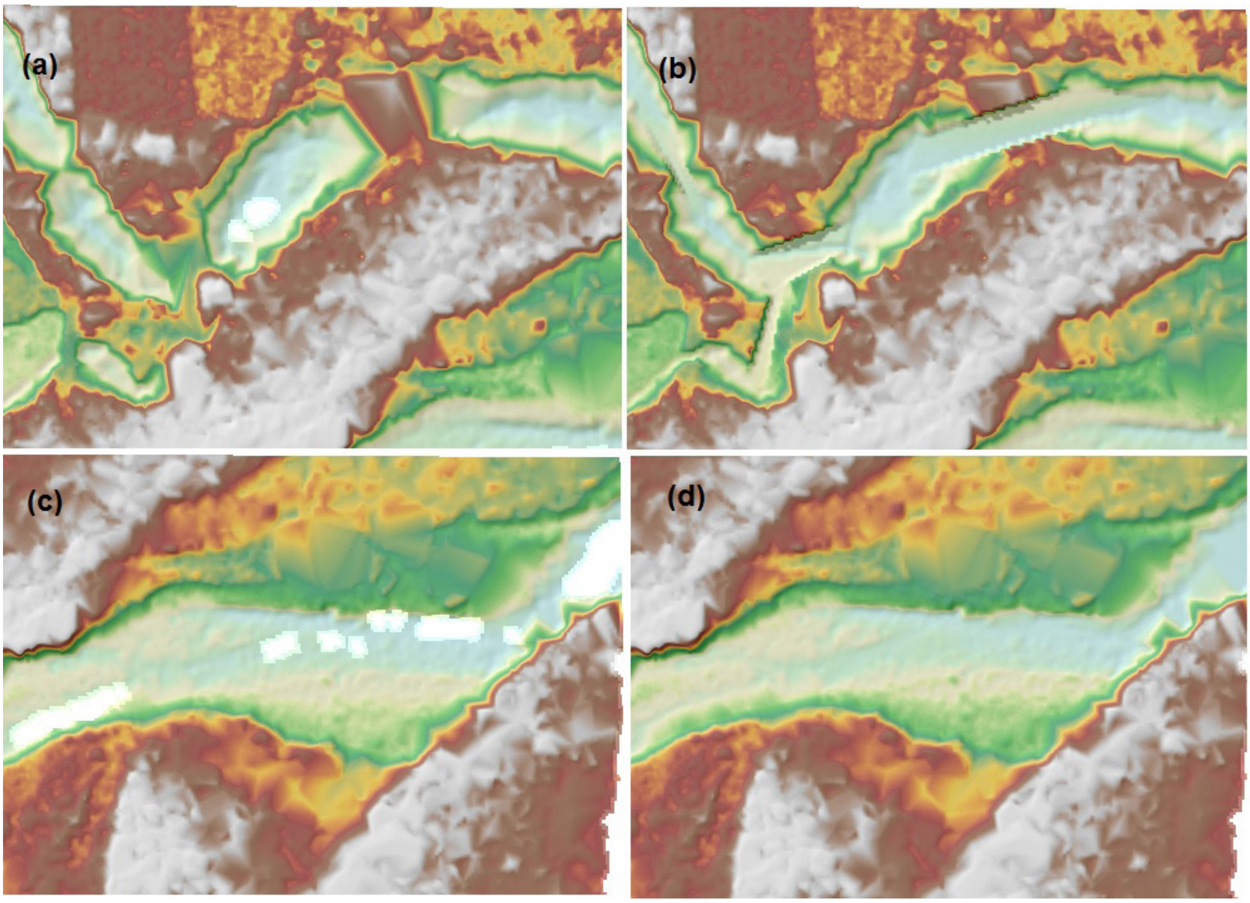

Figure 24. Portions in the DTM of Abra de Ilog Floodplain – an elevated part of the waterway before (a) and after (b) manual editing; and data gaps before (a) and after (b) filling.

3.9 Mosaicking of Blocks

Mindoro_Blk29M was used as the reference block at the start of mosaicking because it was the first block mosaicked to the larger DTM of Mindoro. Upon inspection of the blocks mosaicked for the Abra de Ilog floodplain, it was concluded that the elevation of Occidental_Mindoro_Reflight_Blk39M and Occidental_ Mindoro_Reflight_ Blk39M_additional needed adjustment before mosaicking. Table 16 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Abra de Ilog floodplain is shown in Figure 25. The entire Abra de Ilog floodplain is 93.80% covered by LiDAR data while portions with no LiDAR data were patched with the available IFSAR data.

Table 16. Shift values of each LiDAR block of Abra de Ilog Floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
OccidentalMindoro_Blk29M	0.00	0.00	0.00
OccidentalMindoro_reflights_Blk29M	0.00	0.00	-0.66
OccidentalMindoro_reflights_Blk29M_additional	0.00	0.00	-1.09

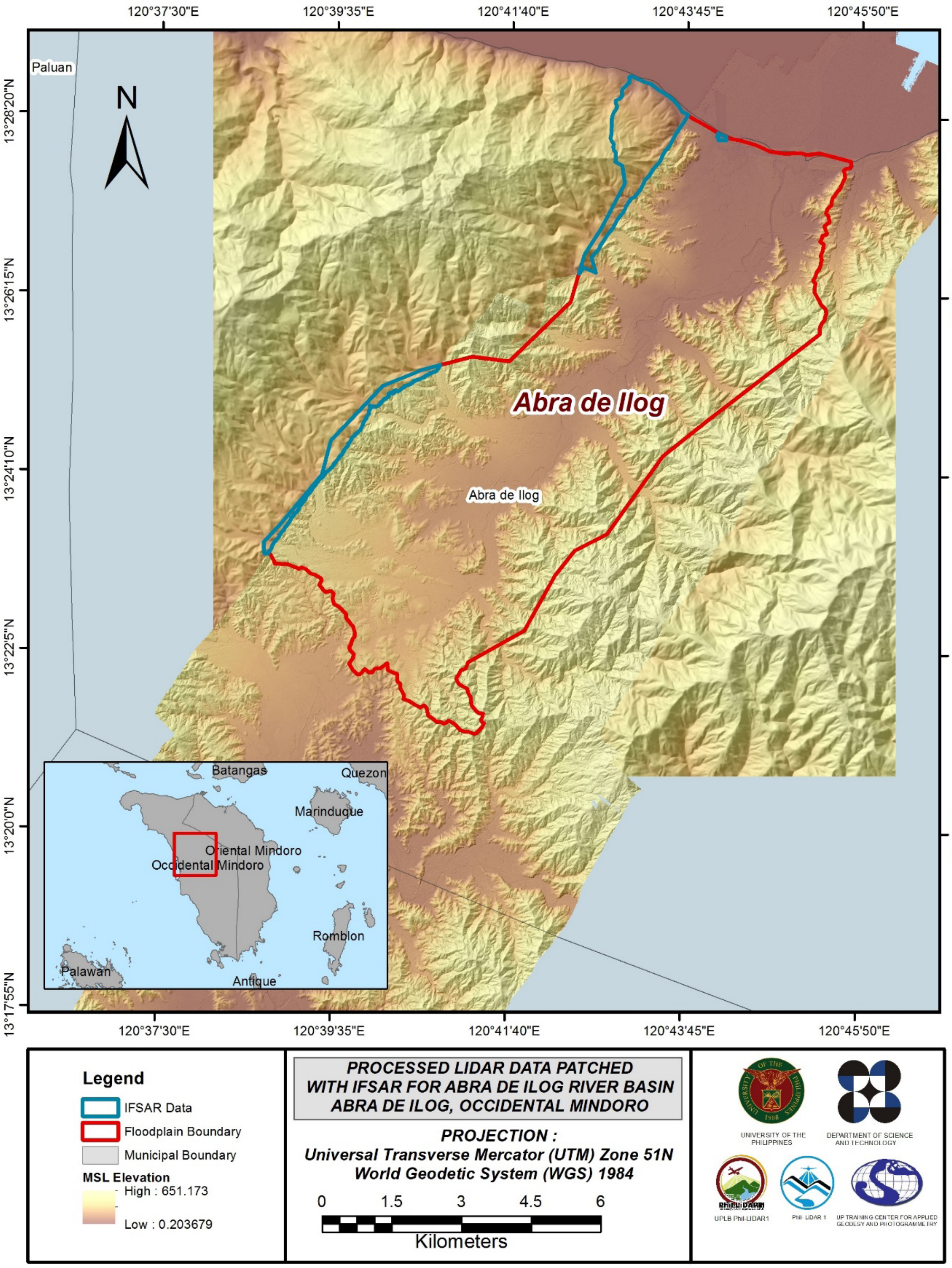

Figure 25. Map of Processed LiDAR Data for Abra de Ilog Floodplain

3.10 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model (DEM)

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Abra de Ilog to collect points with which the LiDAR dataset is validated is shown in Figure 26. A total of 28,494 survey points were gathered for all the flood plains within Occidental Mindoro wherein the Abra de Ilog floodplain is located. Random selection of 80% of the survey points, resulting to 22,795 points, were used for calibration.

A good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values is shown in Figure 27. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration elevation values is 0.23 meters with a standard deviation of 0.20 meters. Calibration of Abra de Ilog LiDAR data was done by adding the height difference value, 0.23 meters, to Abra de Ilog mosaicked LiDAR data. Table 17 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

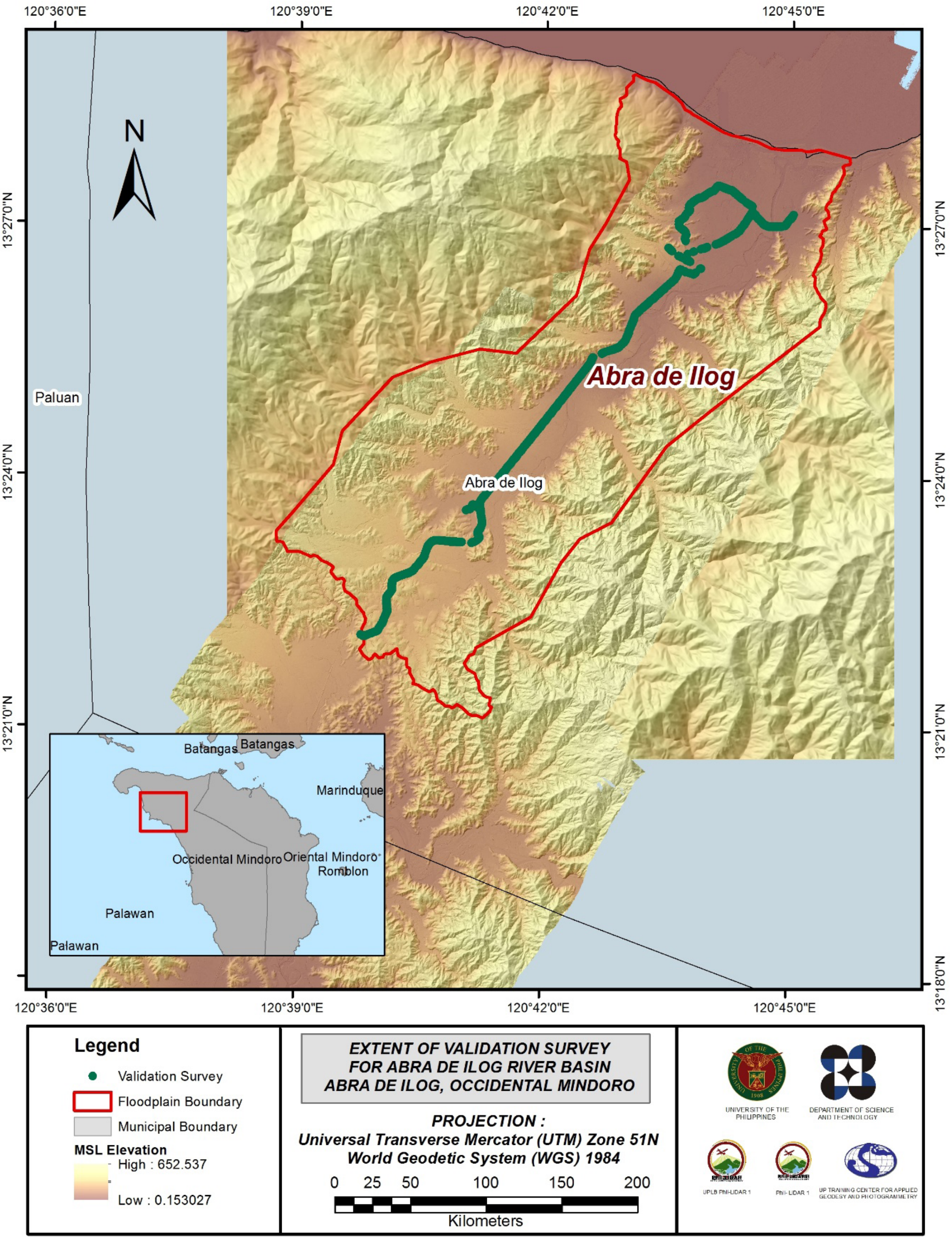

Figure 26. Map of Abra de Ilog Floodplain with validation survey points in green.

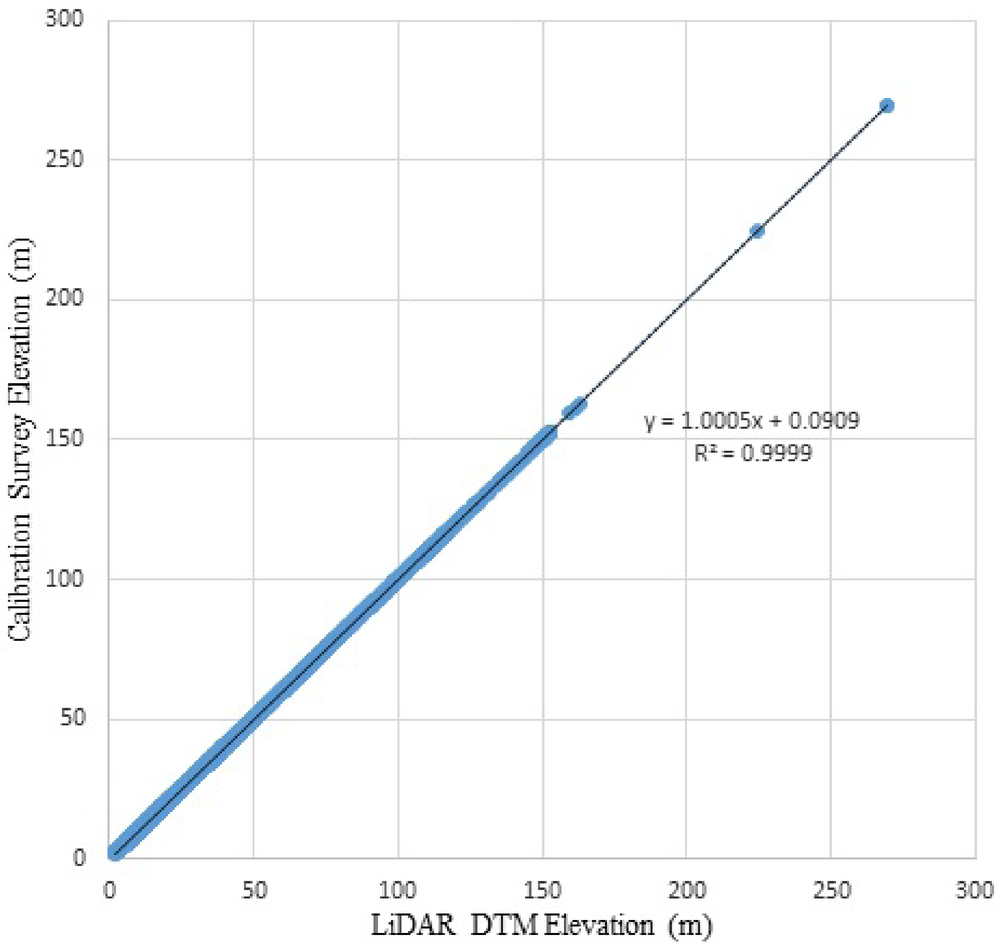

Figure 27. Correlation plot between calibration survey points and LiDAR data.

Table 17. Calibration Statistical Measures

Calibration Statistical Measures	Value (meters)
Height Difference	0.23
Standard Deviation	0.20
Average	0.10
Minimum	-0.33
Maximum	0.53

The remaining 20% of the total survey points were intersected to the flood plain, resulting to 467 points. These were used for the validation of calibrated Abra de Ilog 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 28. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.19 meters with a standard deviation of 0.09 meters, as shown in Table 18.

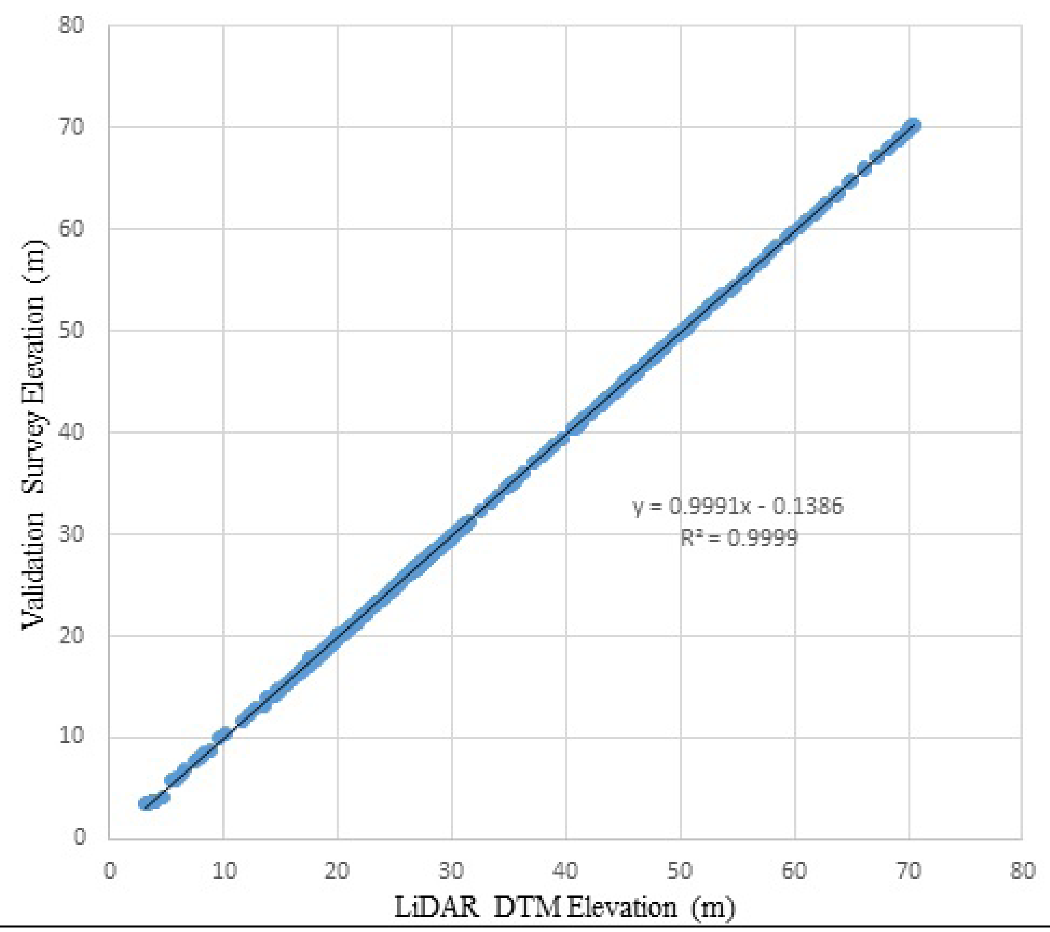

Figure 28. Correlation plot between validation survey points and LiDAR data.

Table 18. Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.19
Standard Deviation	0.09
Average	-0.17
Minimum	-0.45
Maximum	0.33

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathymetric data integration, only cross-section was available for Abra de Ilog with a total of 1747 survey points. The resulting raster surface produced was done by Kernel Interpolation with Barrier method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.49 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Abra de Ilog integrated with the processed LiDAR DEM is shown in Figure 29.

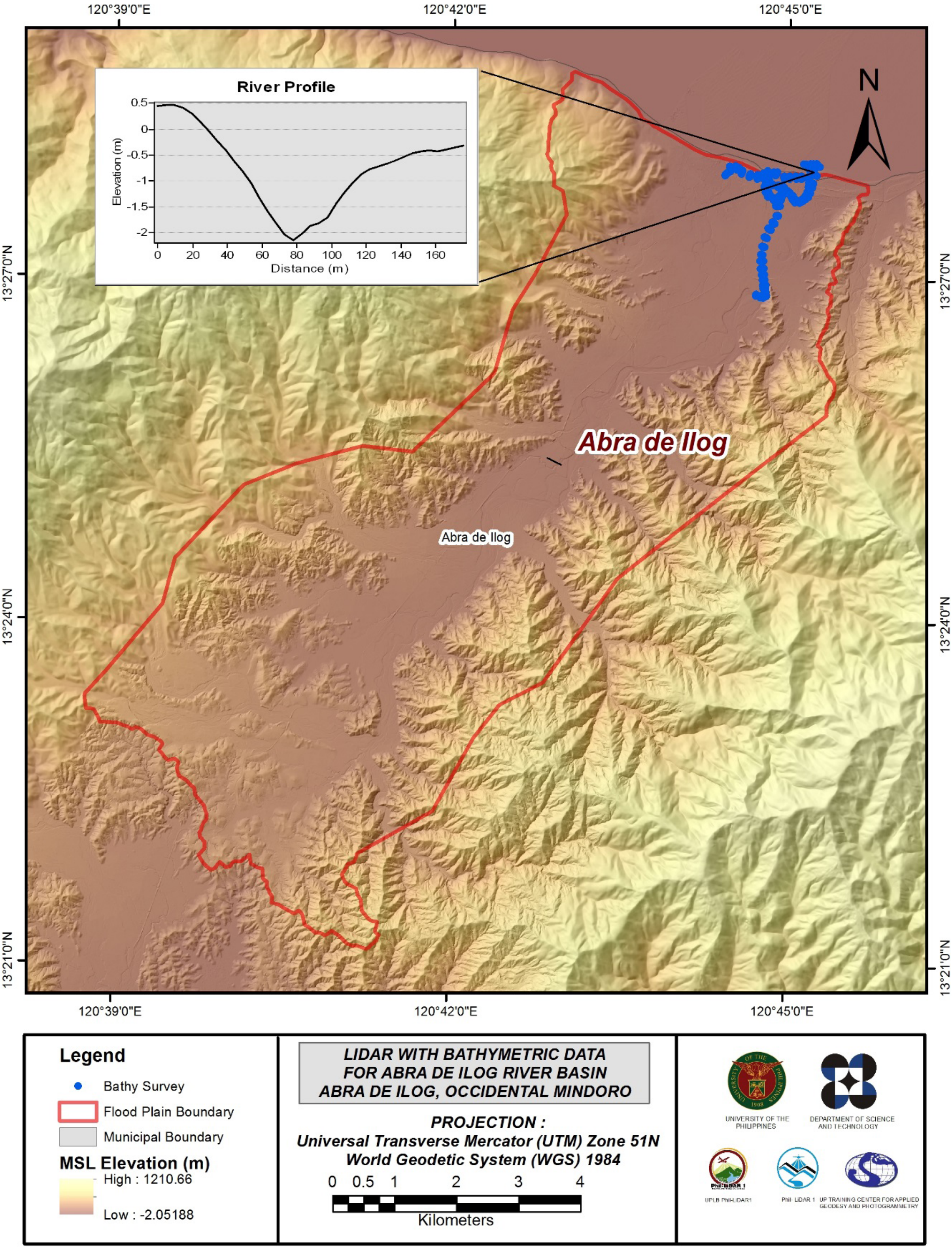

Figure 29. Map of Abra de Ilog Floodplain with bathymetric survey points shown in blue.

CHAPTER 4: LIDAR VALIDATION SURVEY AND MEASUREMENTS OF THE ABRA DE ILOG RIVER BASIN

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

4.1 Summary of Activities

AB Surveying and Development (ABSD) conducted a field survey in Bacungan River on November 26 and H.O. Noveloso Surveying (HONS) conducted a field survey in Abra de Ilog River on March 2, March 28, March 30 and April 1, 2017 with the following scope: reconnaissance; control survey; cross-section and as-built survey of Lumang Bayan Bridge in Brgy. Tibag, Abra de Ilog, Occidental Mindoro; and bathymetric survey of the river from the upstream in Brgy. Tibag, Abra de Ilog, Occidental Mindoro to the mouth of the river in Brgy. Lumangbayan, Abra de Ilog, Occidental Mindoro with an approximate length of 4.94 km. Random checking points for the contractor's cross-section and bathymetry data were gathered by DVBC on January 24 – 31, 2017 using a Trimble® SPS 882 GNSS PPK survey technique. In addition to this, validation points acquisition survey was conducted covering the Abra de Ilog River Basin area. The entire survey extent is illustrated in Figure 30.

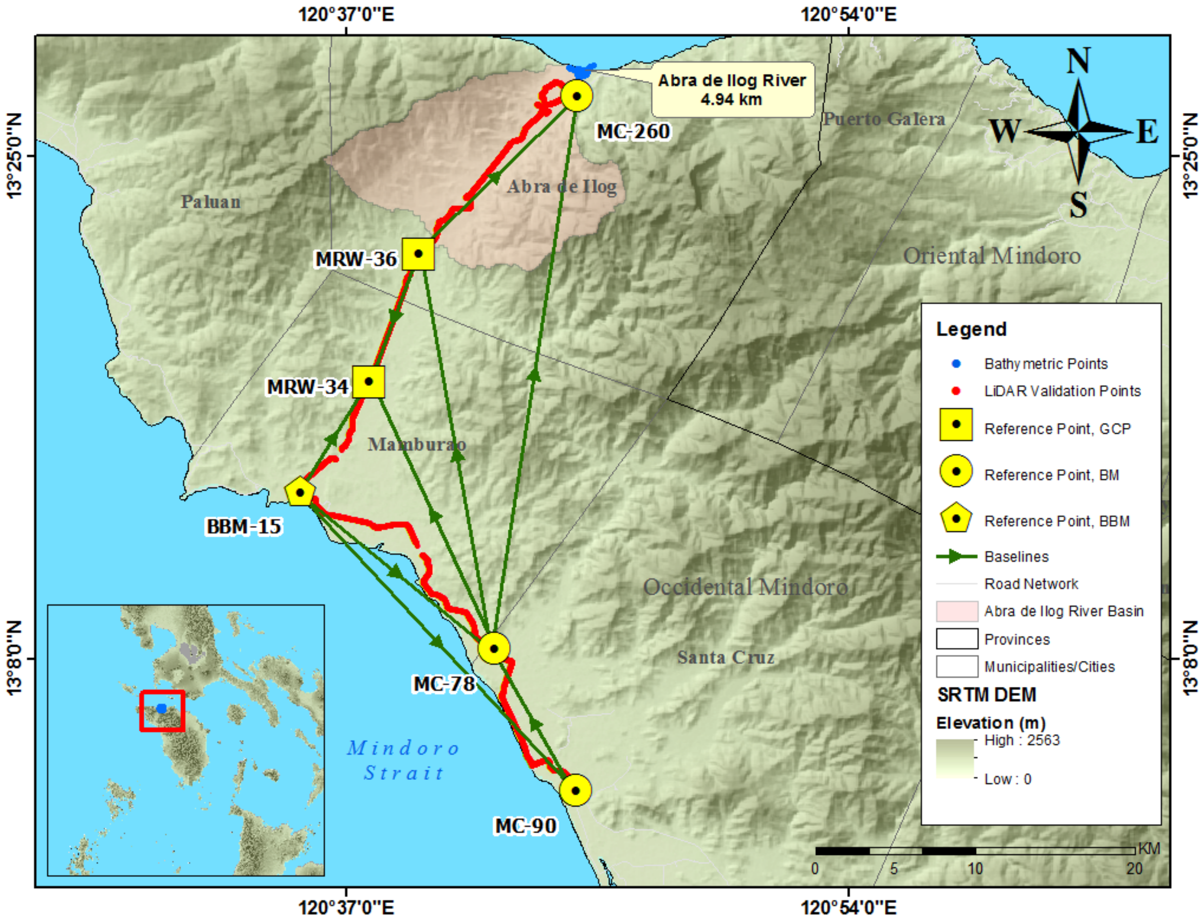


Figure 28. Extent of the bathymetric survey (in blue line) in Abra de Ilog River and the LiDAR data validation survey (in red).

4.2 Control Survey

The GNSS network used for Abra de Ilog River is composed of four (4) loops established on January 26-29, 2017 occupying the following reference point: MC-90, a first-order BM, in Brgy. Lumangbayan, Sta. Cruz, Occidental Mindoro.

Five (5) NAMRIA established points, MRW-34, in Brgy. Tangkalan, Mamburao, Occidental Mindoro; MRW-36, in Brgy. Armado, Abra de Ilog, Occidental Mindoro; MC-78, in Brgy. San Vicente, Sta. Cruz, Occidental Mindoro; MRW-260, in Brgy. Tibag, Abra de Ilog, Occidental Mindoro; and BBM-15, in Brgy. Poblacion 6, Mamburao, Occidental Mindoro, were used as markers.

The summary of reference and control points and its location is summarized in Table 19 while the GNSS network established is illustrated in Figure 31

.

Table 19. List of Reference and Control Points occupied for Abra de Ilog River Survey

(Source: NAMRIA; UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (Meter)	Elevation in MSL (Meter)	Date Established
MC-90	1st Order, BM	13°03'34.14427"N	120°44'46.70844"E	-	8.195	2007
MRW-34	Used as marker	-	-	-		2007
MRW-36	Used as marker	-	-	-	-	2007
MC-78	Used as marker	-	-	-	-	2007
MC-260	Used as marker	-	-	-	-	2008
BBM-15	Used as marker	-	-	-	-	-

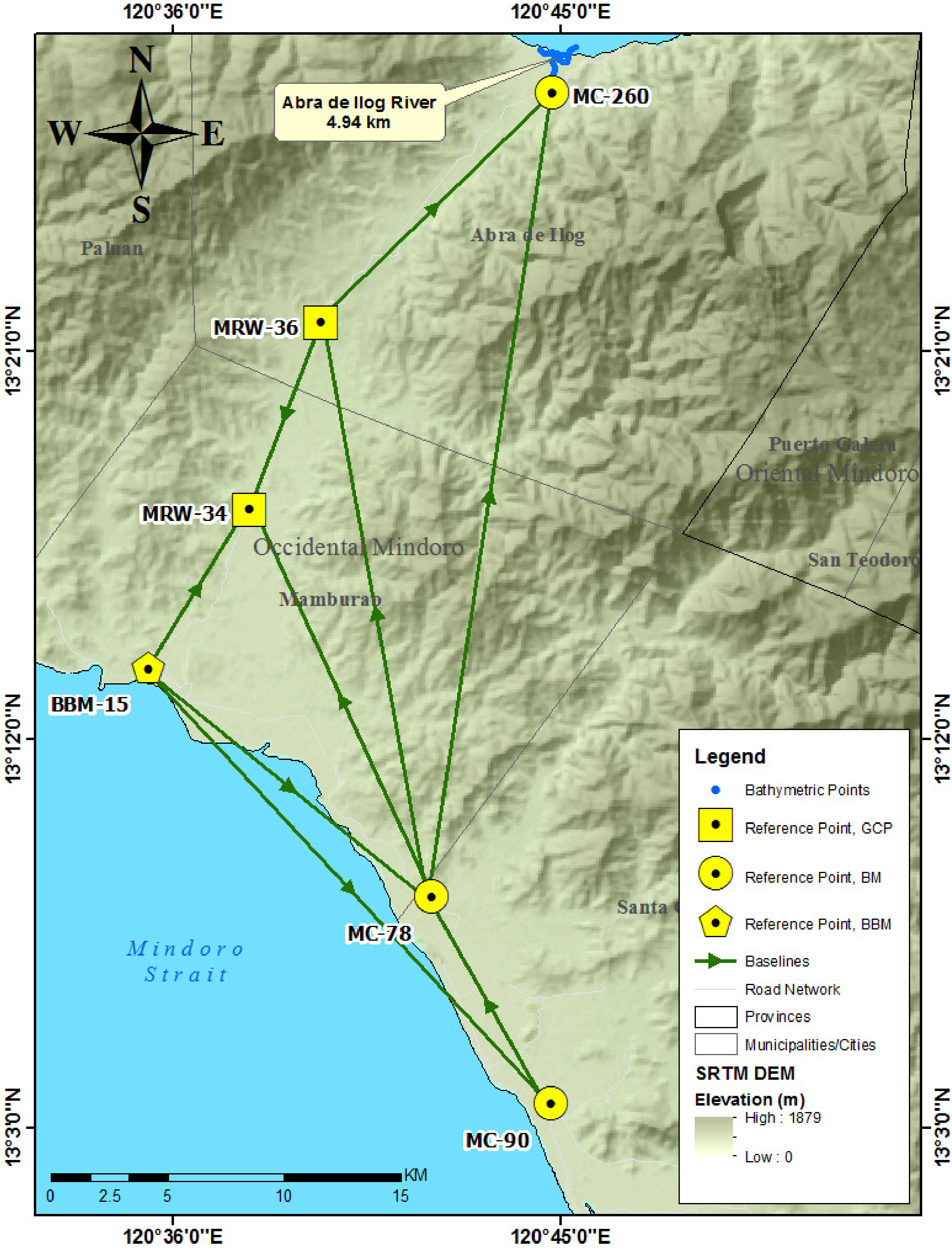


Figure 31. The GNSS Network established in the Abra de Ilog River Survey.

The GNSS set-ups on recovered reference points and established control points in Abra de Ilog River are shown from Figure 32 to Figure 37.

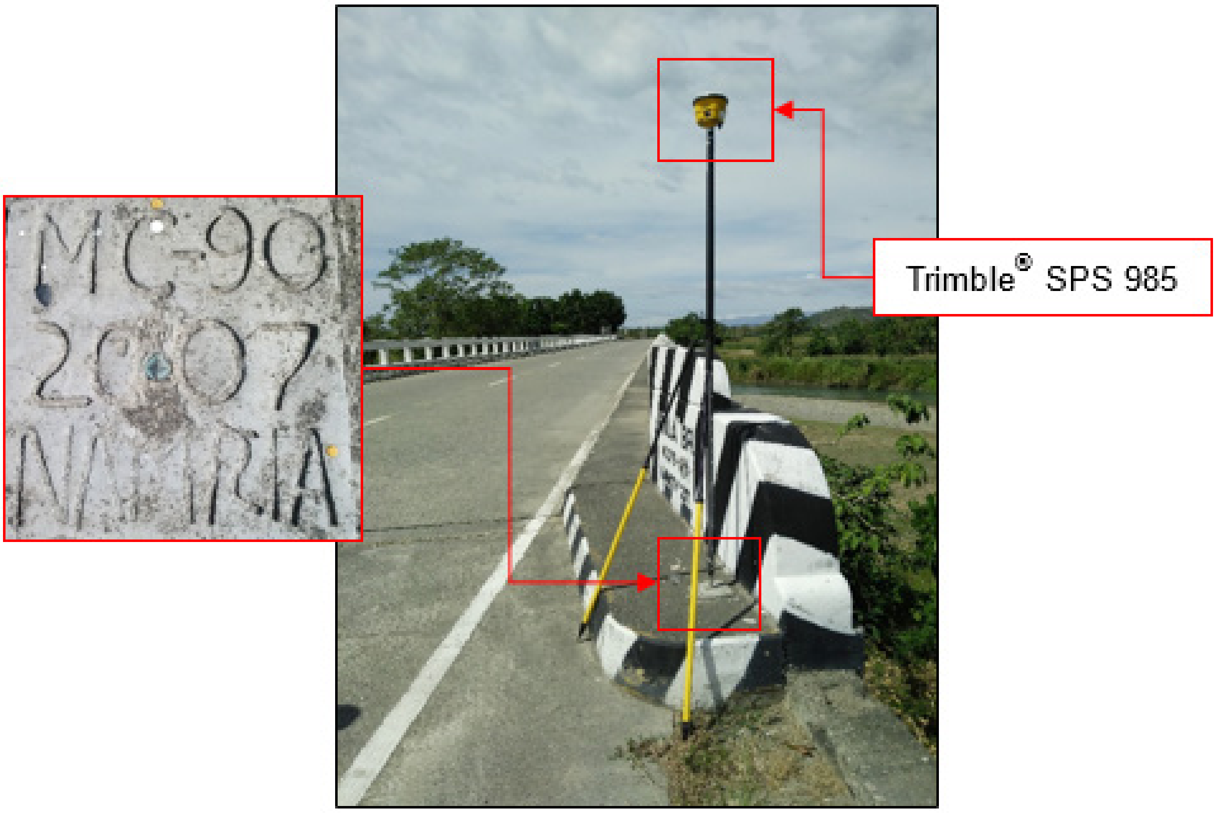


Figure 32. GNSS base set up, Trimble® SPS 985, at MC-90, located at the approach of Pola Bridge in Brgy. Lumangbayan, Sta. Cruz, Occidental Mindoro

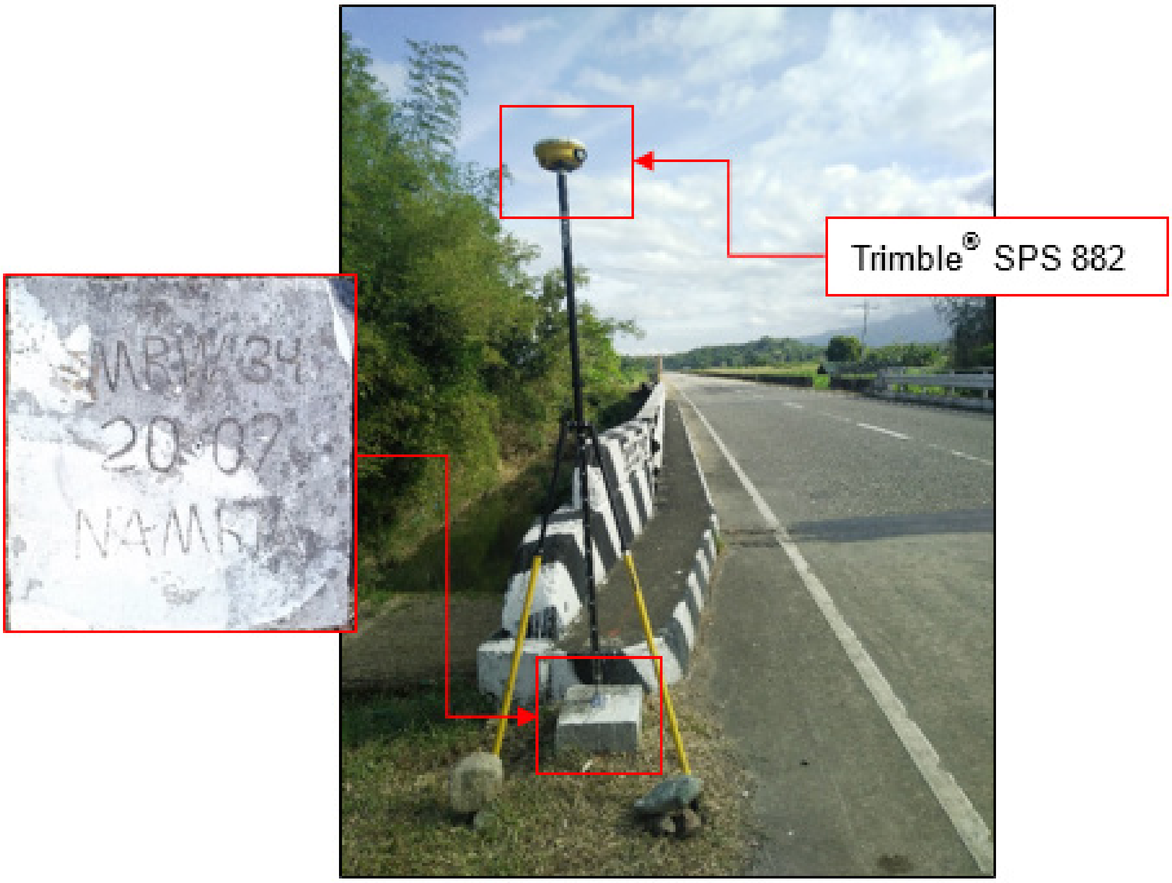


Figure 33. GNSS receiver set up, Trimble® SPS 882, at MRW-34, located beside the approach of Balibago Bridge in Brgy. Tangkalan, Mamburao, Occidental Mindoro

Figure 34. GNSS receiver set up, Trimble® SPS 882, at MRW-36, located beside the approach of Baclaran Bridge in Brgy. Armado, Abra de Ilog, Occidental Mindoro

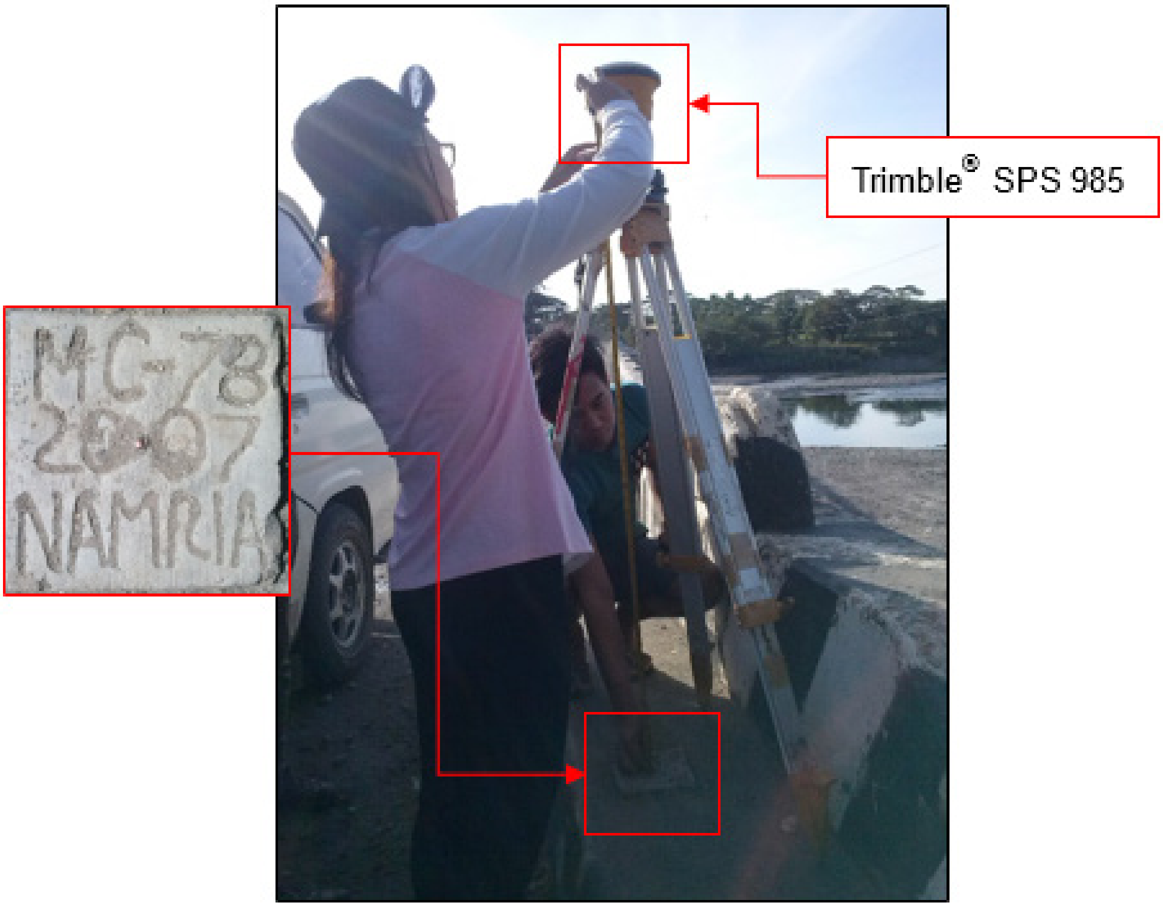


Figure 35. GNSS receiver set up, Trimble® SPS 985, at MC-78, located beside at the approach of Pagbahan Bridge in Brgy. San Vicente, Sta. Cruz, Occidental Mindoro

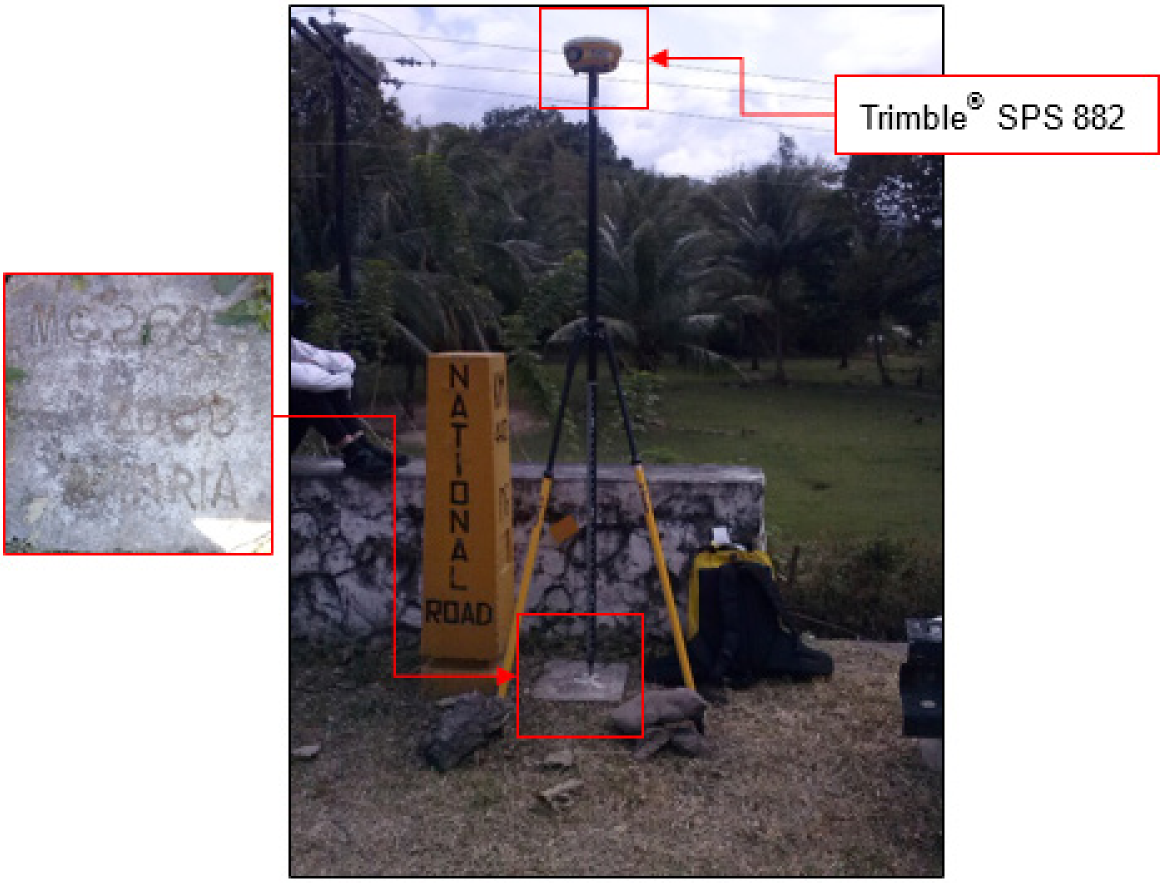


Figure 36. GNSS receiver set up, Trimble® SPS 882, at MC-260, located beside KM Post 442 near Lumang Bayan Bridge in Brgy. Tibag, Abra de Ilog, Occidental Mindoro

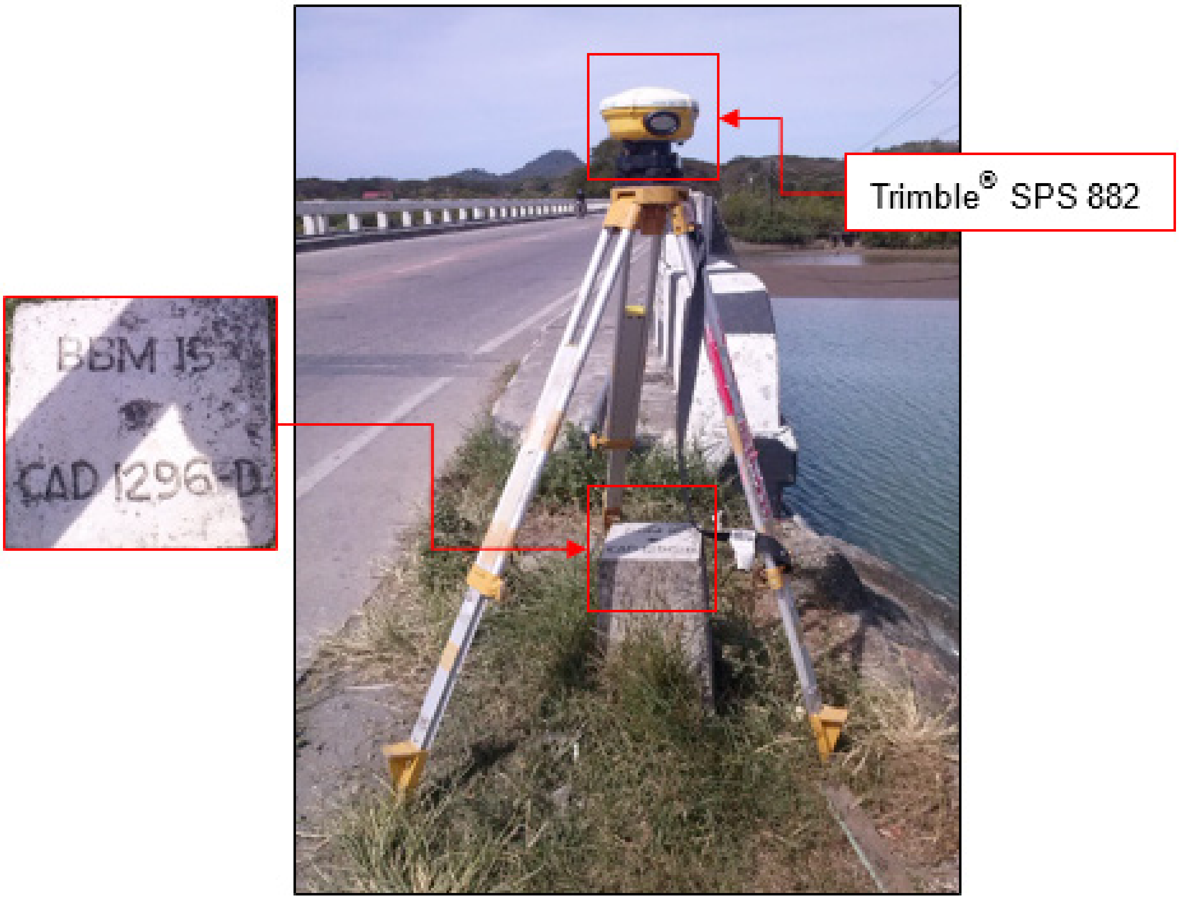


Figure 37. GNSS receiver set up, Trimble® SPS 882, at BBM-15, located beside the approach of Mamburao Bridge in Brgy. Poblacion 6, Mamburao, Occidental Mindoro

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 Bacungan River Basin is summarized in Table 20 generated by TBC software.

Table 20. Baseline Processing Summary Report for Bacungan River Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
BBM-15 --- MC-90	1-28-2017	Fixed	0.003	0.016	317°49'21"	25097.759	-4.522
MC-90--- MC-78	1-28-2017	Fixed	0.004	0.016	330°35'31"	10150.980	-0.061
MC-78--- MRW-36	1-26-2017 1-27-2017	Fixed	0.003	0.016	24938.405	24938.405	23.344
MC-78--- MC-260	1-26-2017	Fixed	0.003	0.017	8°21'06"	34751.555	-0.465
MC-78--- MRW-34	1-27-2017 1-28-2017 1-29-2017	Fixed	0.004	0.016	335°07'38"	18224.640	-0.041
MRW-34 --- BBM-15	1-27-2017 1-28-2017 1-29-2017	Fixed	0.004	0.021	31°46'19"	7977.493	4.428
BBM-15 --- MC-78	1-27-2017 1-28-2017 1-29-2017	Fixed	0.004	0.020	129°23'20"	15362.555	4.449
MRW-36 --- MC-260	1-26-2017	Fixed	0.003	0.017	44°31'56"	13874.000	-23.801
MRW-36 --- MRW-34	1-27-2017	Fixed	0.003	0.016	200°31'17"	8500.251	-23.362

As shown Table 20, a total of nine (9) baselines were processed with coordinate and elevation values of MC-90 held fixed. 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 squares of x and y must be less than 20 cm and z less than 10 cm in equation form:

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

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 21 to Table 23 for complete details.

The six (6) control points, MC-90, MRW-34, MRW-36, MC-78, MC-260, and BBM-15, were occupied and observed simultaneously to form a GNSS loop. The coordinate and elevation values of MC-90 were held fixed during the processing of the control points as presented in Table 21. Through this reference point, the coordinates and elevations of the unknown control points will be computed.

Table 21. Constraints applied to the adjustment of the control points.

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
MC-90	Grid				Fixed
MC-90	Local	Fixed	Fixed		
Fixed = 0.000001 (Meter)					

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 22.

Table 22. Adjusted grid coordinates for the control points used in the Abra de Ilog River Floodplain survey.

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
BBM-15	238917.143	0.009	1463556.933	0.007	6.091	0.055	
MC-78	250700.867	0.010	1453690.640	0.007	8.806	0.056	
MC-90	255607.924	?	1444800.407	?	8.195	?	LLe
MC-260	256067.623	0.013	1488037.689	0.010	8.241	0.079	
MRW-34	243184.693	0.012	1470301.042	0.009	9.791	0.068	
MRW-36	246240.673	0.012	1478236.660	0.009	32.721	0.072	

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

a. **BBM-15**
horizontal accuracy = √((0.9)² + (0.7)²
= √ (0.81 + 0.49)
= 1.14 < 20 cm
vertical accuracy = 5.5 < 10 cm

b. **MC-78**
horizontal accuracy = √((1.0)² + (0.7)²
= √ (1.00 + 0.49)
= 1.22 < 20 cm
vertical accuracy = 5.6 < 10 cm

c. **MC-90**
horizontal accuracy = Fixed
vertical accuracy = Fixed

d. **MC-260**
horizontal accuracy = √((1.3)² + (1.0)²
= √ (1.69 + 1.00)
= 1.64 < 20 cm
vertical accuracy = 7.9 < 10 cm

e. **MRW-34**
horizontal accuracy = √((1.2)² + (0.9)²
= √ (1.44 + 0.81)
= 1.50 < 20 cm
vertical accuracy = 6.8 < 10 cm

f. **MRW-36**
horizontal accuracy = √((1.2)² + (0.9)²
= √ (1.44 + 0.81)
= 1.50 < 20 cm
vertical accuracy = 7.2 < 10 cm

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

Table 23. Adjusted geodetic coordinates for control points used in the Abra de Ilog River Floodplain validation.

Point ID	Latitude	Longitude	Ellipsoid	Height	Constraint
BBM-15	N13°13'39.19826"	E120°35'26.99118"	48.714	0.055	
MC-78	N13°08'21.88467"	E120°42'01.21159"	53.170	0.056	
MC-90	N13°03'34.14427"	E120°44'46.70844"	53.232	?	LLe
MC-260	N13°27'00.69333"	E120°44'49.01983"	52.702	0.079	
MRW-34	N13°17'19.87652"	E120°37'46.54458"	53.137	0.068	
MRW-36	N13°21'38.92732"	E120°39'25.54335"	76.503	0.072	

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

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

Table 24. The reference and control points utilized in the Abra de Ilog River Static Survey, with their corresponding locations (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellips-oidal Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
MC-90	1st Order, BM	13°03'34.14427"N	120°44'46.70844"E	53.232	1444800.407	255607.924	8.195
MRW-34	Used as marker	13°17'19.87652"N	120°37'46.54458"E	53.137	1470301.042	243184.693	9.791
MRW-36	Used as marker	13°21'38.92732"N	120°39'25.54335"E	76.503	1478236.660	246240.673	32.721
MC-78	Used as marker	13°08'21.88467"N	120°42'01.21159"E	53.170	1453690.640	250700.867	8.806
MC-260	Used as marker	13°27'00.69333"N	120°44'49.01983"E	52.702	1488037.689	256067.623	8.241
BBM-15	Used as marker	13°13'39.19826"N	120°35'26.99118"E	48.714	1463556.933	238917.143	6.091

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

Cross-section and as-built surveys were conducted on March 28, 2017 at the downstream side of Lumang Bayan Bridge in Brgy. Tibag, Abra de Ilog, Occidental Mindoro as shown in Figure 38. A Sokkia™ Set CX Total Station was utilized for this survey as shown in Figure 39. The Automated Water Level System (AWLS) is located on the downstream side of the bridge and its elevation was measured 5.659 m above MSL.

Figure 38. Lumang Bayan facing downstream

Figure 39. Cross-section survey of Lumang Bayan Bridge

The cross-sectional line of Lumang Bayan Bridge is about 107 m with one hundred fifty-three (153) cross-sectional points using the control points UP-ABR-1, and MC-260 as the GNSS base stations. The location map, cross-section diagram, and the bridge data form are shown in Figure 41 to Figure 43, respectively.

Gathering of random points for the checking of HONS's bridge cross-section and bridge points data was performed by DVBC on January 26, 2017 using a survey grade GNSS Rover receiver attached to a 2-m pole as seen in Figure 40.

Figure 40. Gathering of random cross-section points along Lumang Bayan Bridge

Linear square correlation (R2) and RMSE analysis were performed on the two (2) datasets. The linear square coefficient range is determined to ensure that the submitted data of the contractor is within the accuracy standard of the project which is ±20 cm and ±10 cm for horizontal and vertical, respectively. The R2 value must be within 0.85 to 1. An R2 approaching 1 signifies a strong correlation between the vertical (elevation values) of the two datasets. A computed R2 value of 0.024 was obtained by comparing the data of the contractor and DVBC; signifying a weak correlation between the two (2) datasets.

In addition to the Linear Square correlation, Root Mean Square (RMSE) analysis is also performed in order to assess the difference in elevation between the DVBC checking points and the contractor's. The RMSE value should only have a maximum radial distance of 5 m and the difference in elevation within the radius of 5 meters should not be beyond 0.50 m. For the bridge points data, a computed value of 0.131 was acquired. The computed R2 and RMSE values are within the accuracy requirement of the program.

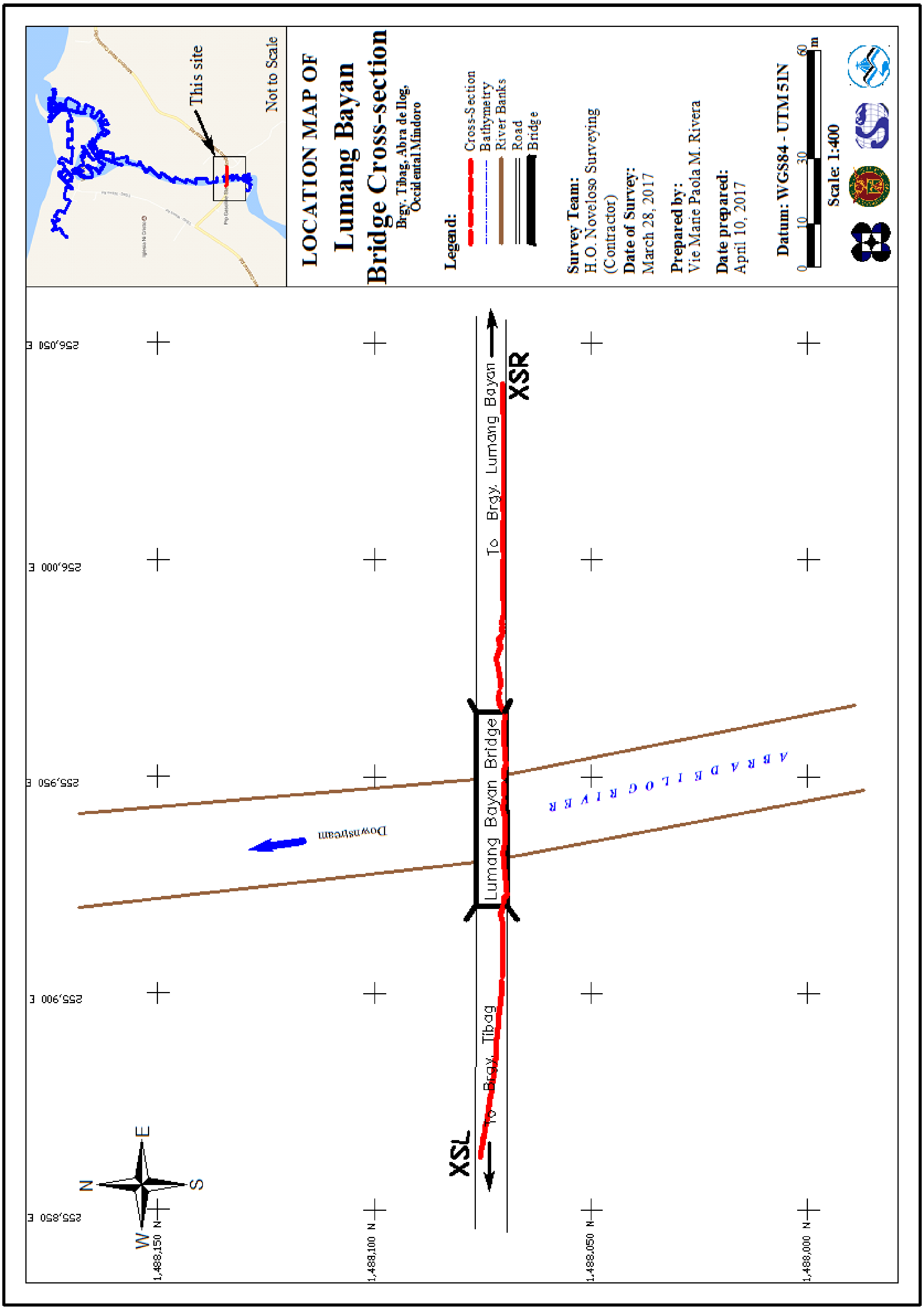


Figure 41. Location map of Lumang Bayan Bridge cross-section survey

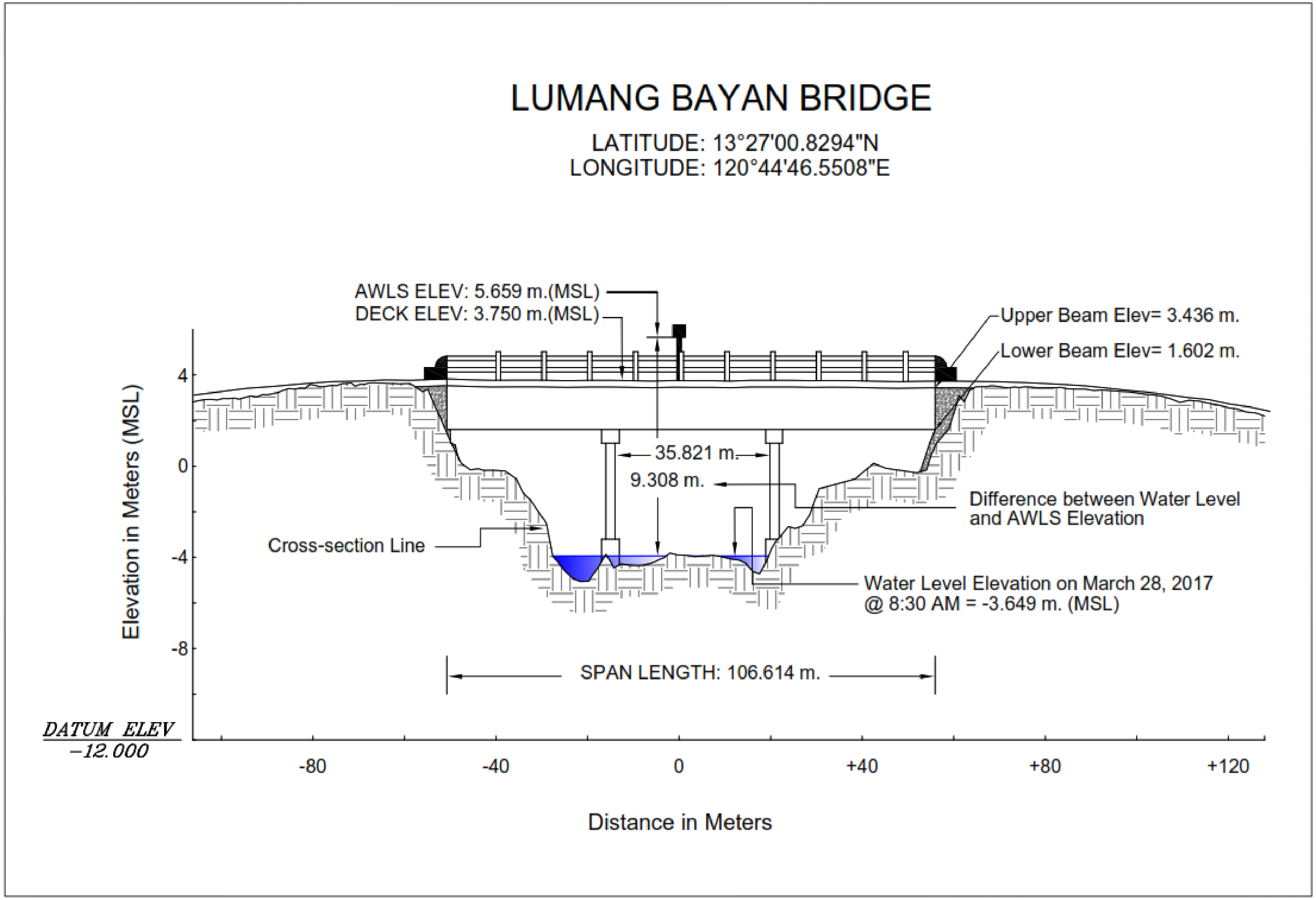


Figure 42. Lumang Bayan Bridge cross-section diagram

BRIDGE DATA FORM

Bridge Name: Lumang Bayan Bridge

River Name: Abra de Ilog River

Location (Brgy., City, Region): Brgy. Tibag , Abra de Ilog, Occidental Mindoro

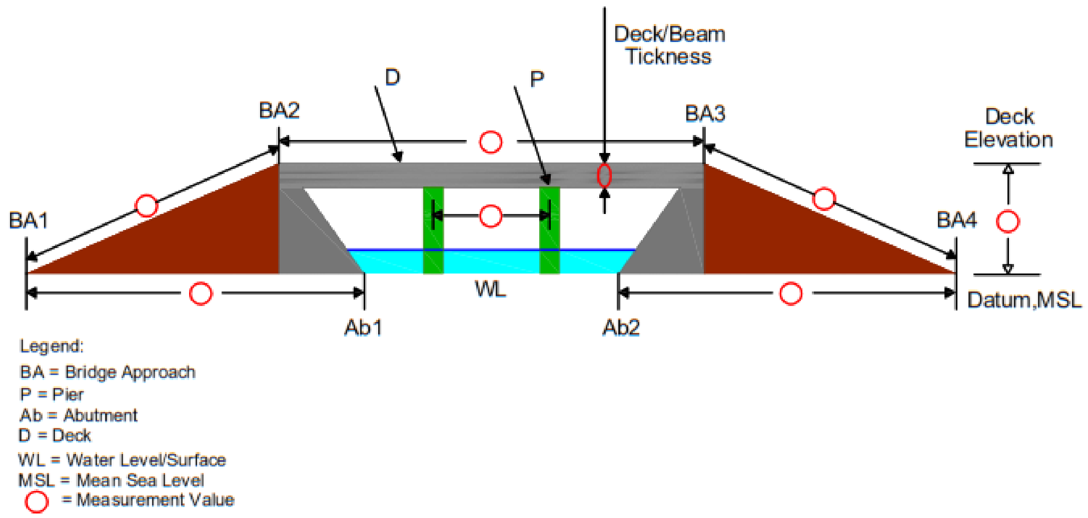
Survey Team: Julieto Cabilin, Romualdo Abelido, Jerry Domingo, Bong Belano and Ruffy Estrada,

Date and Time: March 28, 2017 @ 7:00 am - 5:00 pm

Flow Condition: Low Normal High

Weather Condition: Fair Rainy

Cross-sectional View (not to scale)



Line Segment	Measurement, m	Remarks
1. BA1-BA2	4.866 m.	Concrete
2. BA2-BA3	106.614 m.	Concrete
3. BA3-BA4	4.651 m.	Concrete
4. BA1-Ab1	4.826 m.	Concrete
5. Ab2-BA4	7.793 m.	Concrete
6. Deck/Beam thickness	1.834 m.	Steel
7. Deck Elevation	3.750 m. MSL	Concrete
8. P1-P2	35.821 m.	Concrete

Note: Observer should be facing downstream

Figure 43. As-built survey of Lumang Bayan Bridge

Water surface elevation of Abra de Ilog River was determined by a Sokkia™ Set CX Total Station on March 28, 2017 at the railings of Abra de Ilog Bridge in Brgy. San Vicente, Sta. Cruz, Occidental Mindoro with a value of 3.924 m in MSL. This was translated into marking on the bridge's sidewalk beside the AWLS as shown in Figure 44.

Figure 44. Water surface elevation marking on Lumang Bayan Bridge sidewalk

Water surface elevation of Abra de Ilog River was also determined by a Sokkia™ Set CX Total Station on March 28, 2017 at 8:30 AM at Lumang Bayan Bridge area with a value of -3.649 m in MSL as shown in Figure 42. This was translated into marking on the bridge's pier as shown in Figure 45. The markings will serve as reference for flow data gathering and depth gauge deployment of the partner HEI responsible for Abra de Ilog River, the University of the Philippines Los Baños.

Figure 45. Water-level markings on the pier of Lumang Bayan Bridge

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted by DVBC on January 26-29, 2017 using a survey grade GNSS Rover receiver, Trimble® SPS 882, mounted on a range pole which was attached on the side of the vehicle as shown in Figure 46. It was secured with cable ties and ropes to ensure that it was horizontally and vertically balanced. The antenna height was 2.05 m and measured from the ground up to the bottom of the antenna mount of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with MC-78 and MC-90 occupied as the GNSS base stations in the conduct of the survey.

Figure 46. Validation points acquisition survey set-up for Abra de Ilog River

The survey started from Brgy. Tibag, Abra de Ilog, Occidental Mindoro going southeast along the national highway, covering five (5) barangays in Abra de Ilog, fourteen (14) barangays in Mamburao, five (5) barangays in Santa Cruz, and ended in Brgy. Barahan, Santa Cruz, Occidental Mindoro. The survey gathered a total of 10,368 points with approximate length of 67.65 km using MC-78 and MC-90 as GNSS base stations for the entire extent of validation points acquisition survey as illustrated in the map in Figure 47.

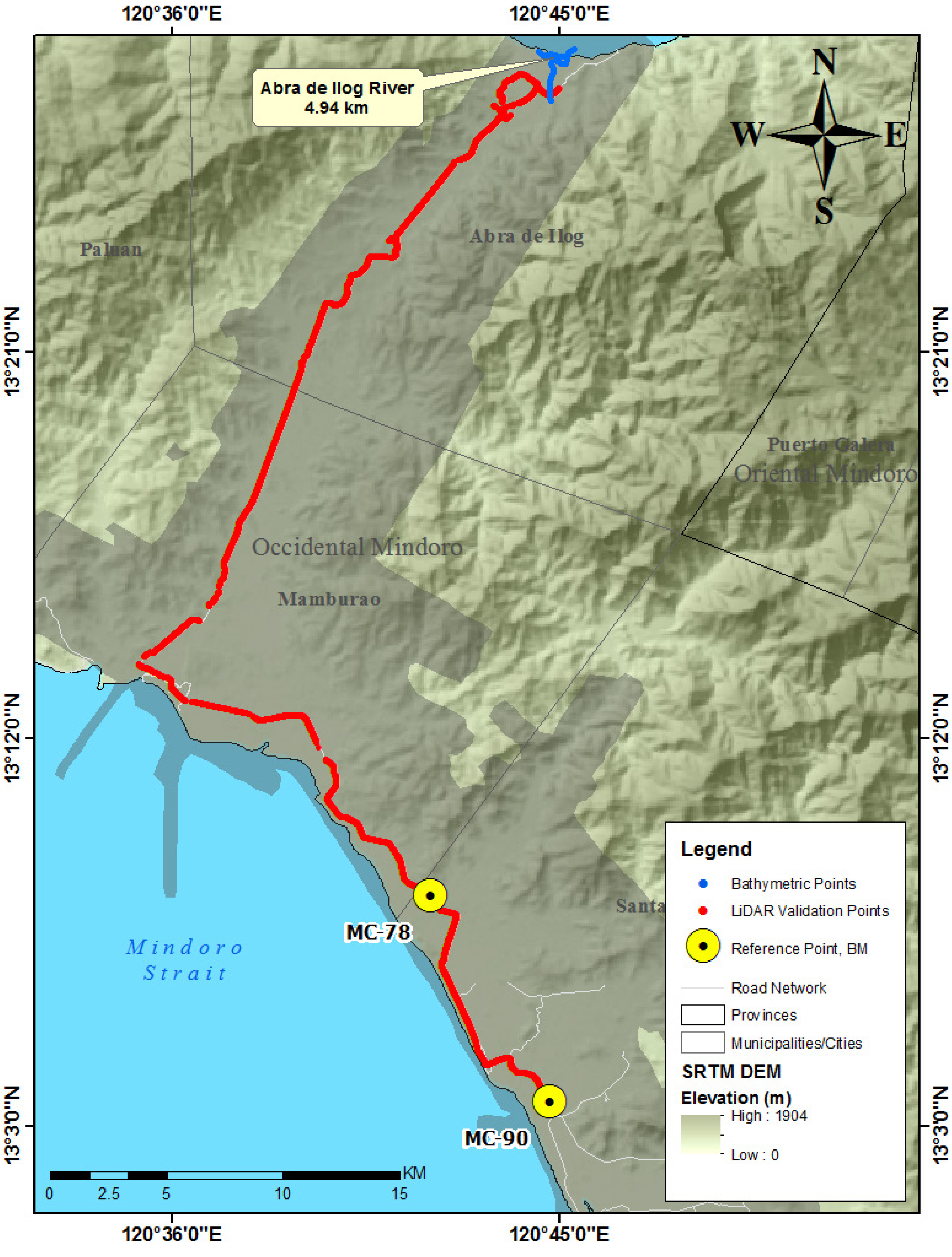


Figure 47. Validation point acquisition survey of Abra de Ilog River Basin

4.7 River Bathymetric Survey

Manual bathymetric survey was executed on March 28, March 30 and April 1, 2017 using a Sokkia™ Set CX Total Station and a Topcon™ GR 5 as illustrated in Figure 49. The control points UP-ABR-2 and UP-ABR-3 were used as GNSS base stations all throughout the entire survey.

For the main river, the survey started in Brgy. Tibag, Abra de Ilog, Occidental Mindoro, with coordinates 13°26’52.0674”N, 120°44’42.6325”E and ended at the mouth of the river in Brgy. Lumangbayan, also in Abra de Ilog, with coordinates 13°28’01.0864”N, 120°45’14.8472”E.

For the tributary, the survey started in Brgy. Wawa, Abra de Ilog, Occidental Mindoro, with coordinates 13°27’56.6344”N, 120°44’27.7954”E and also ended in Brgy. Wawa, with coordinates 13°27’53.5914”N, 120°45’10.5036”E.

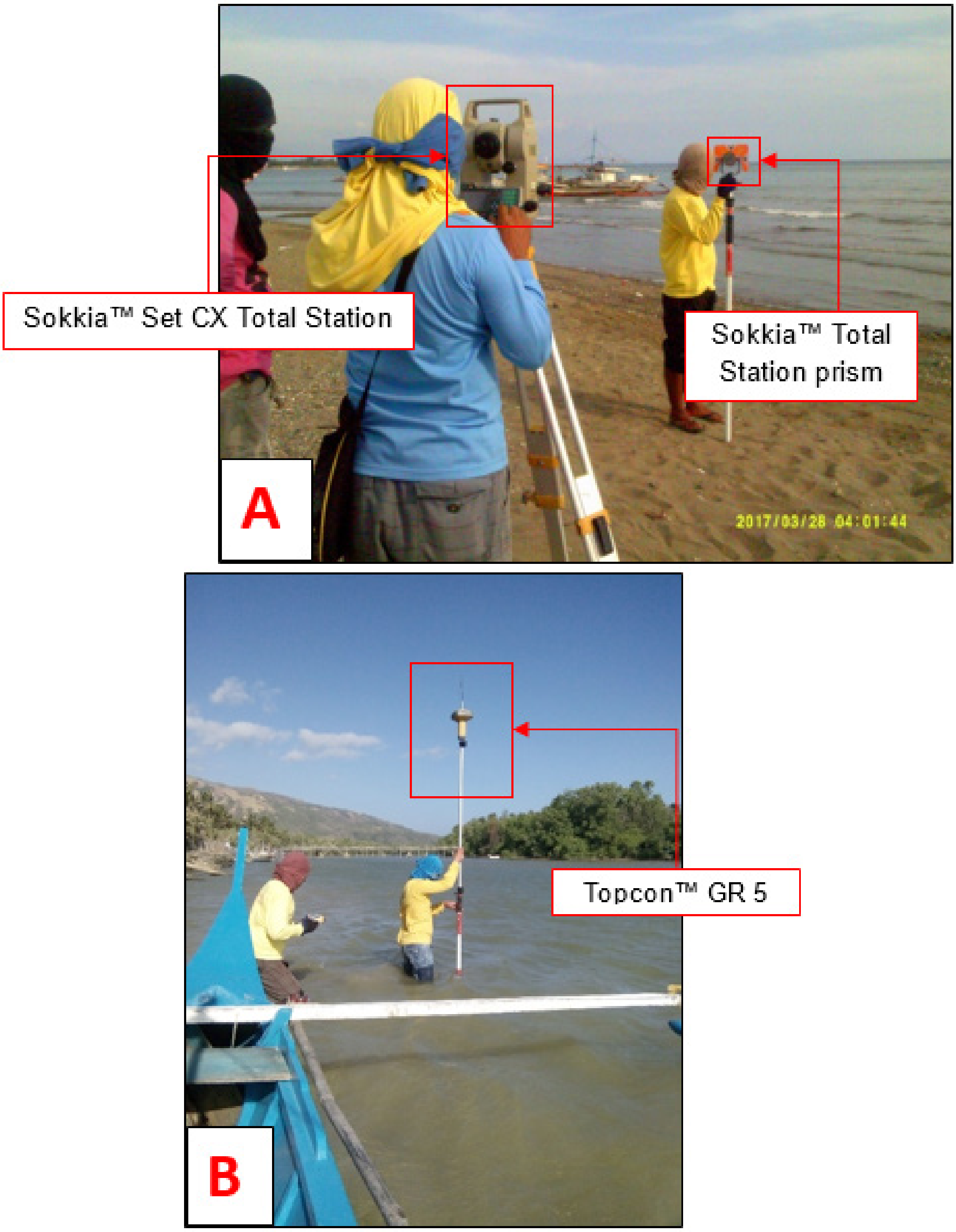


Figure 48. Manual bathymetric survey using a using (A) Sokkia™ Set CX Total Station and (B) Topcon™ GR 5 in Abra de Ilog River

Gathering of random points for the checking of HONS's bathymetric data was performed by DVBC on January 31, 2017 using a survey grade GNSS Rover receiver attached to a boat as seen in Figure 49. A map showing the DVBC bathymetric checking points is shown in Figure 51.

Figure 49. Gathering of random bathymetric points along Abra de Ilog River

Linear square correlation (R2) and RMSE analysis were also performed on the two (2) datasets and a computed R2 value of 0.801 for the bathymetric data is not within the required range for R2, which is 0.85 to 1. Additionally, an RMSE value of 0.110 for the bathymetric data was obtained. Both the computed R2 and RMSE values are within the accuracy required by the program.

The bathymetric survey for Abra de Ilog River gathered a total of 2,427 points covering 4.94 km of the river traversing barangays Tibag, Wawa, and Lumangbayan in the Municipality of Abra de Ilog, shown in Figure 50.

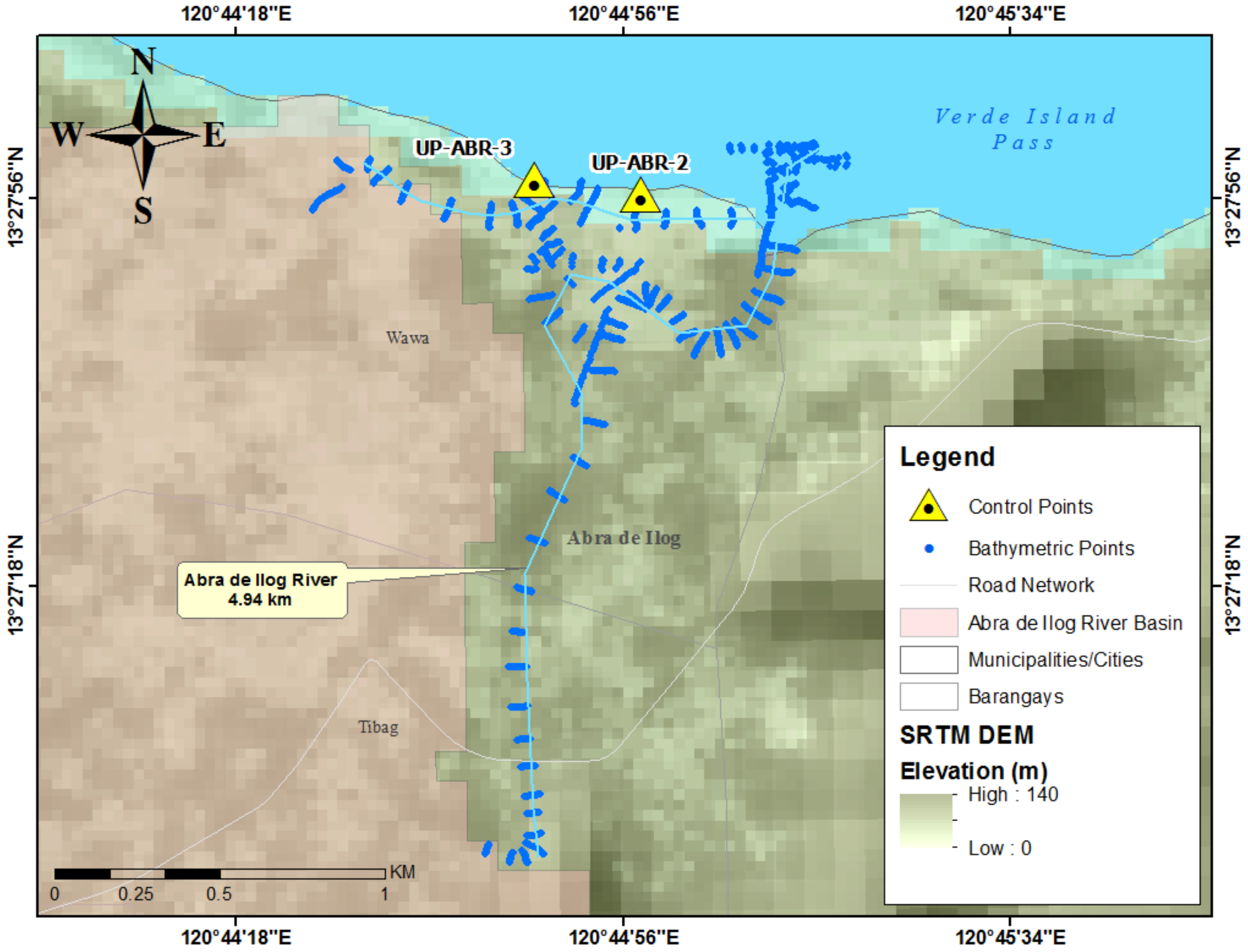


Figure 50. Extent of the Abra de Ilog River Bathymetry Survey

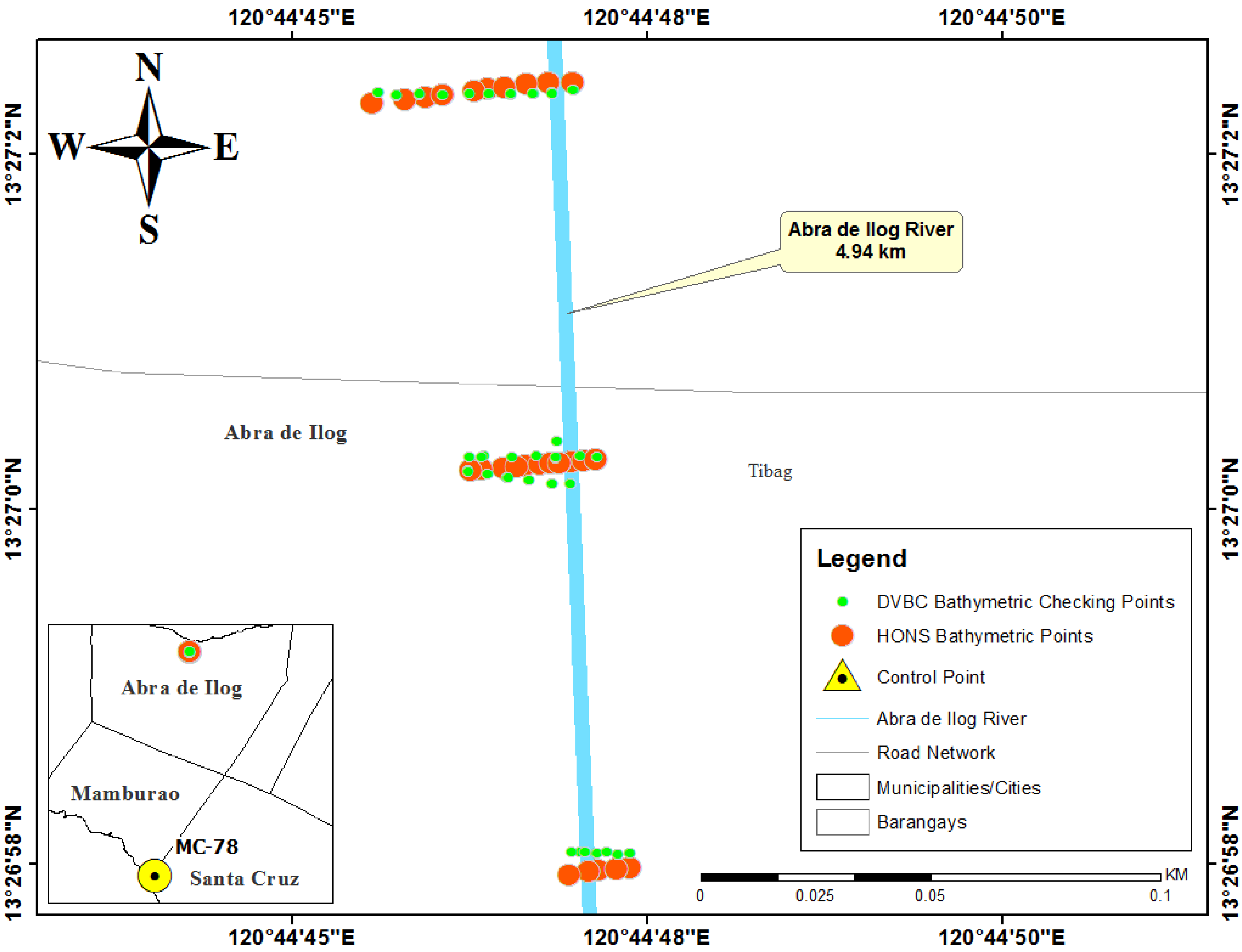


Figure 51. Quality checking points gathered along Abra de Ilog River by DVBC

A CAD drawing was also produced to illustrate the riverbed profile of Abra de Ilog River. As shown in Figure 52, the highest and lowest elevation has a 2.04-m difference. The highest elevation observed was -3.479 m below MSL located in Brgy. Wawa, Abra de Ilog, Occidental Mindoro while the lowest was -5.515 m below MSL located in Brgy. Wawa, Abra de Ilog, Occidental Mindoro..

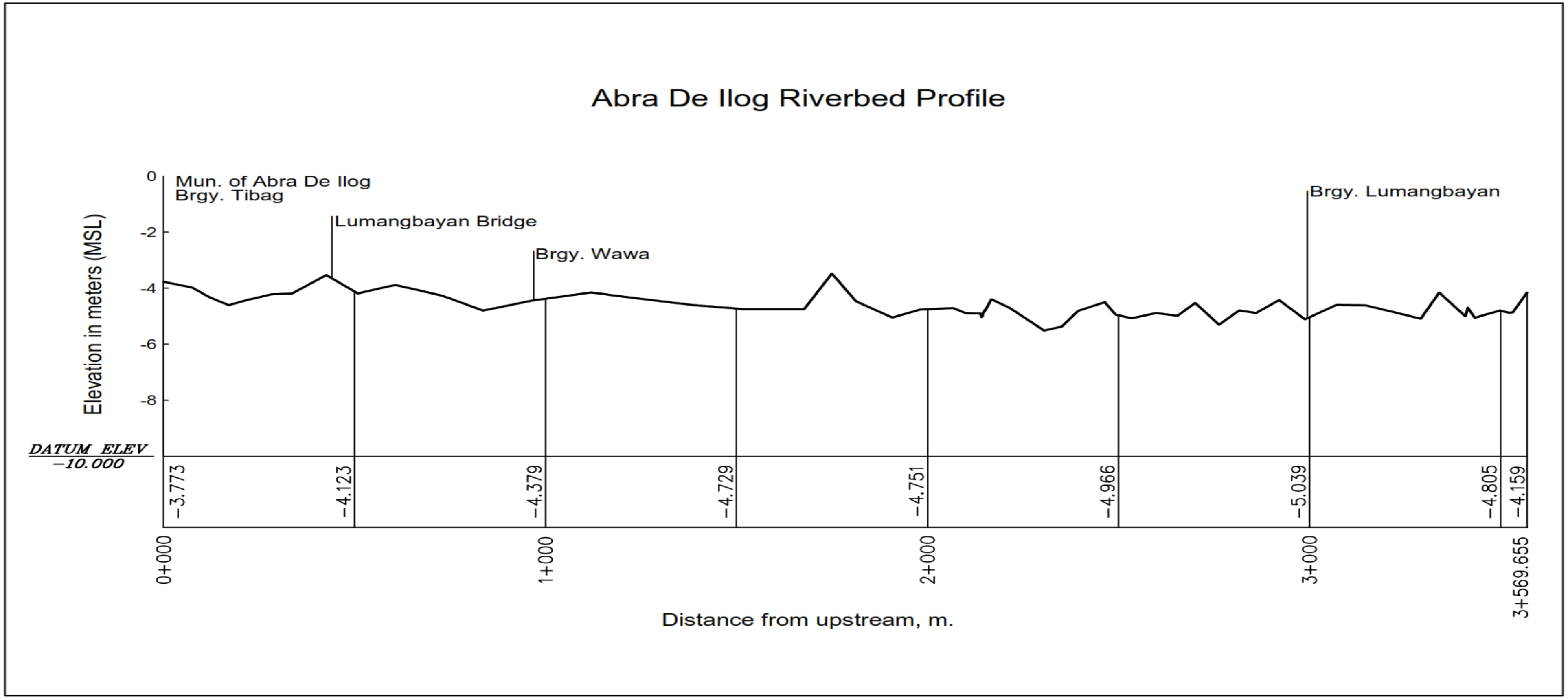


Figure 52. Abra de Ilog riverbed profile.

CHAPTER 5: FLOOD MODELING AND MAPPING

Dr. Alfredo Mahar Francisco A. Lagmay, Enrico C. Paringit, Dr. Eng., Christopher Noel L. Uichanco, Sylvia Sueno, Marc Moises, Hale Ines, Miguel del Rosario, Kenneth Punay, Neil R. Tingin, Khristoffer Quinton, John Alvin B. Reyes, Alfi Lorenz B. Cura, Angelica T. Magpantay, Maria Michaela A. Gonzales Paulo Joshua U. Quilao, Jayson L. Arizapa, Raphael P. Gonzales, and Kevin M. Manalo

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 Abra de Ilog 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 Abra de Ilog River Basin were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from an Automatic Rain Gauge (ARG) Station installed in Balao Elementary School (13.441920°N, 120.729854°E). The location of the rain gauge is seen in Figure 53.

The total precipitation for this event is 77.0 mm. It has a peak rainfall of 14.40 mm. on August 21, 2015 at 11:45 am. The lag time between the peak rainfall and corresponding discharge is 3 hour and 30 minutes, as seen in Figure 56.

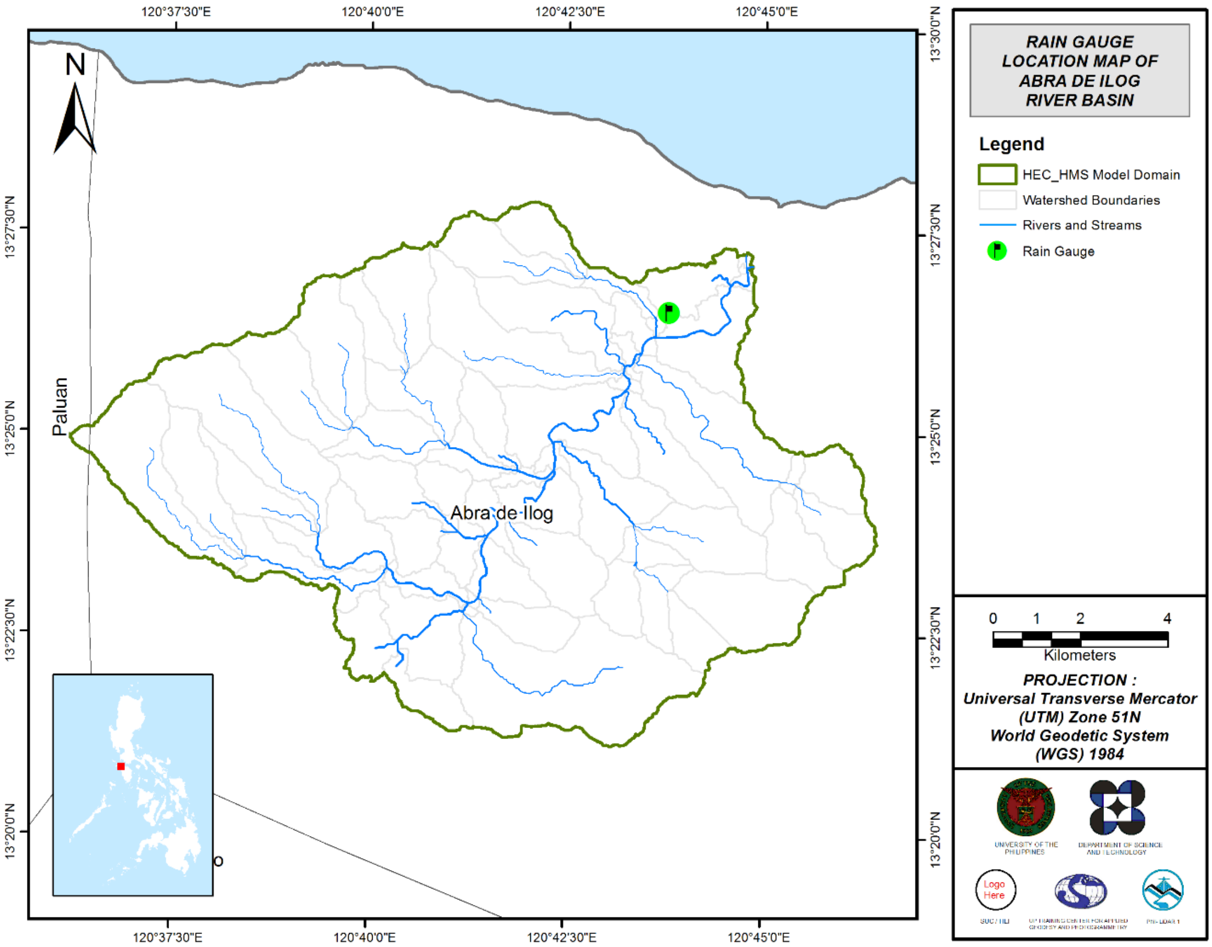


Figure 53. Location map of the Abra de Ilog HEC-HMS model used for calibration.

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Lumangbayan Bridge, Abra De Ilog, Occidental Mindoro 13.450283°N, 120.745743°E). It gives the relationship between the observed water levels from the Lumangbayan Bridge and outflow of the watershed at this location using Bankfull Method in Manning's Equation.

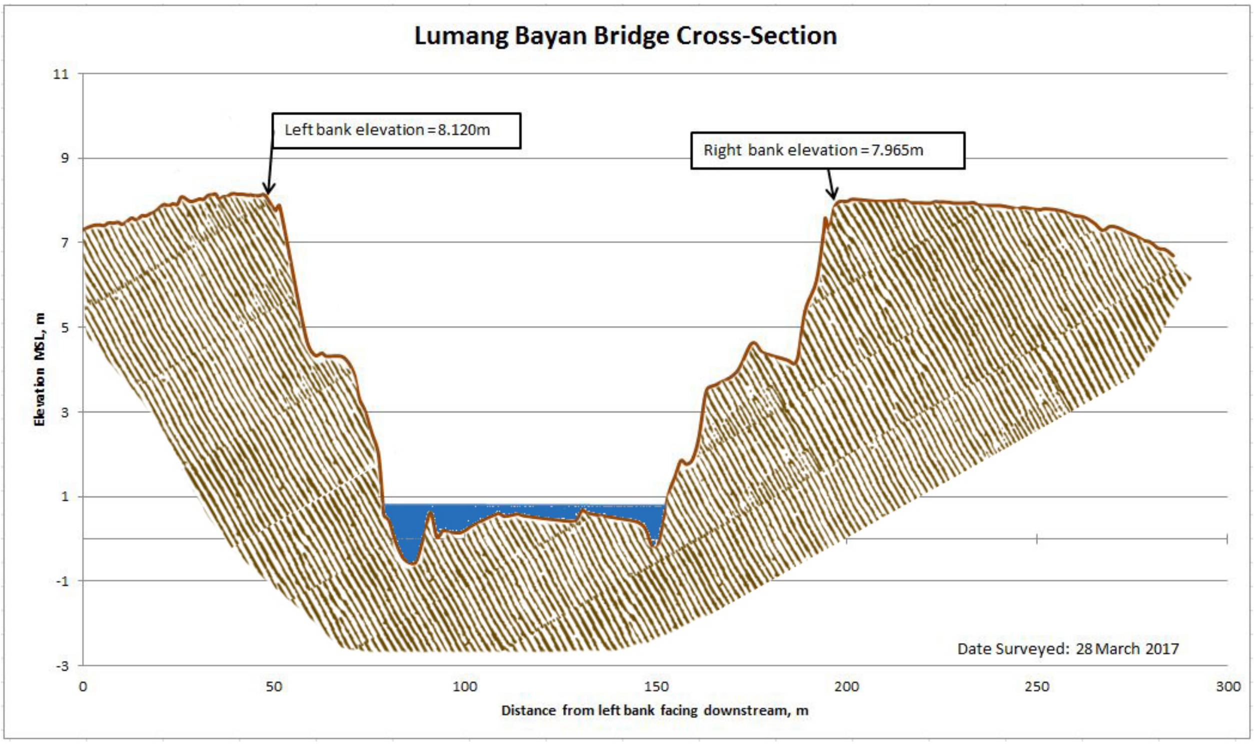


Figure 54. Cross-section plot of Lumangbayan Bridge (over Abra de Ilog River)

For Lumangbayan Bridge, the rating curve is expressed as Q = 11.622exp(0.8644X) as shown in Figure 55.

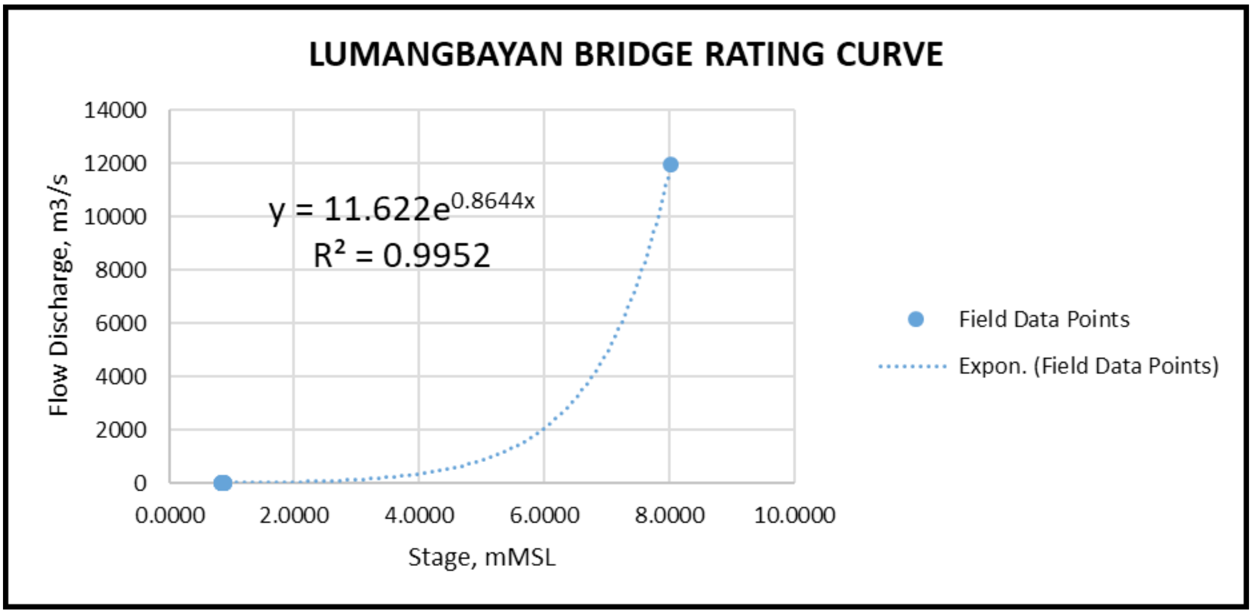


Figure 55. Rating curve at Abra de Ilog Bridge, Occidental Mindoro

For the calibration of the HEC-HMS model, shown in Figure 56, actual flow discharge during a rainfall event was collected in the Lumangbayan bridge. Peak discharge is 90.60 cu.m/s on August 21, 2015 at 3:15 pm.

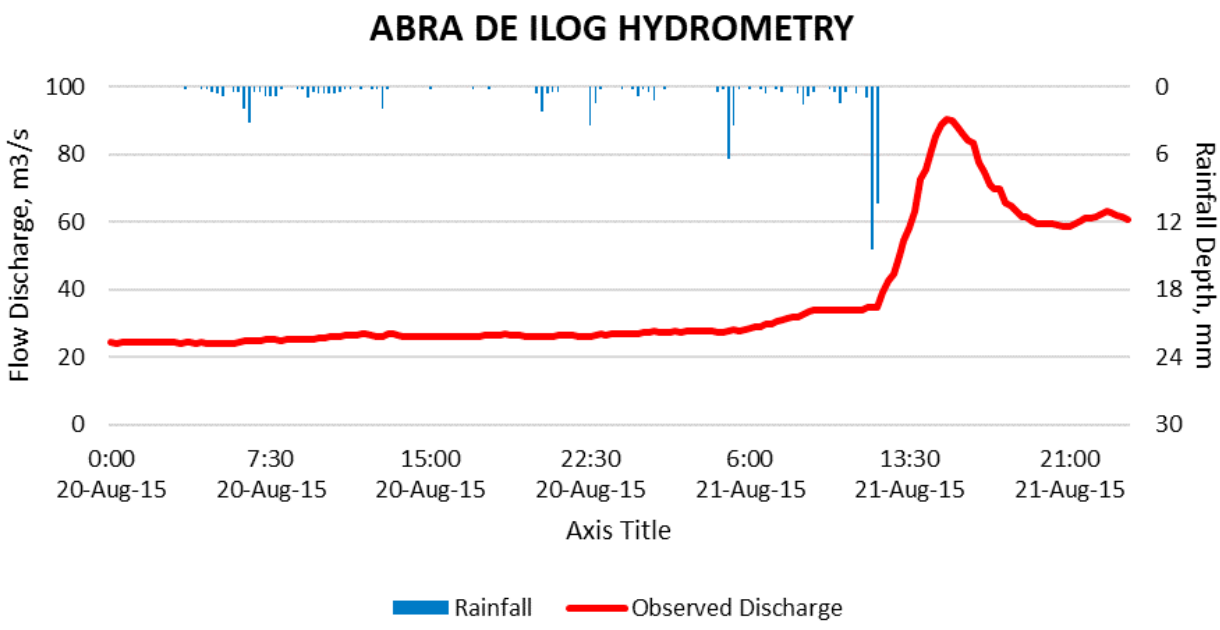


Figure 56. Rainfall and outflow data at Abra de Ilog Bridge used for modeling

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Ambulong Rain Gauge. The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the values in such a way a certain peak value will be attained at a certain time. This station chosen based on its proximity to the Abra De Ilog watershed. The extreme values for this watershed were computed based on a 54-year record, with the computed extreme values shown in Table 25.

Table 25. RIDF values for Ambulong Rain Gauge computed by PAGASA

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	**10 mins**	**20 mins**	**30 mins**	**1 hr**	**2 hrs**	**3 hrs**	**6 hrs**	**12 hrs**	**24 hrs**
2	22.7	35.5	36.3	50.2	68.2	80.1	104.1	125.7	150.8
5	27.9	45.5	53.8	74.2	103.4	122.5	159.7	192.9	226.7
10	34.2	52.1	65.4	90.1	126.7	150.6	196.5	237.3	276.9
15	37.8	57.4	71.9	99	139.8	166.4	217.3	262.4	305.3
20	40.3	61	76.5	105.3	149	177.5	231.9	280	325.1
25	42.2	63.9	80	110.1	156.1	186	243.1	293.5	340.4
50	48.1	72.6	90.9	125	178	212.3	277.6	335.2	387.5
100	54	81.2	101.6	139.8	199.7	238.4	311.8	376.6	434.3

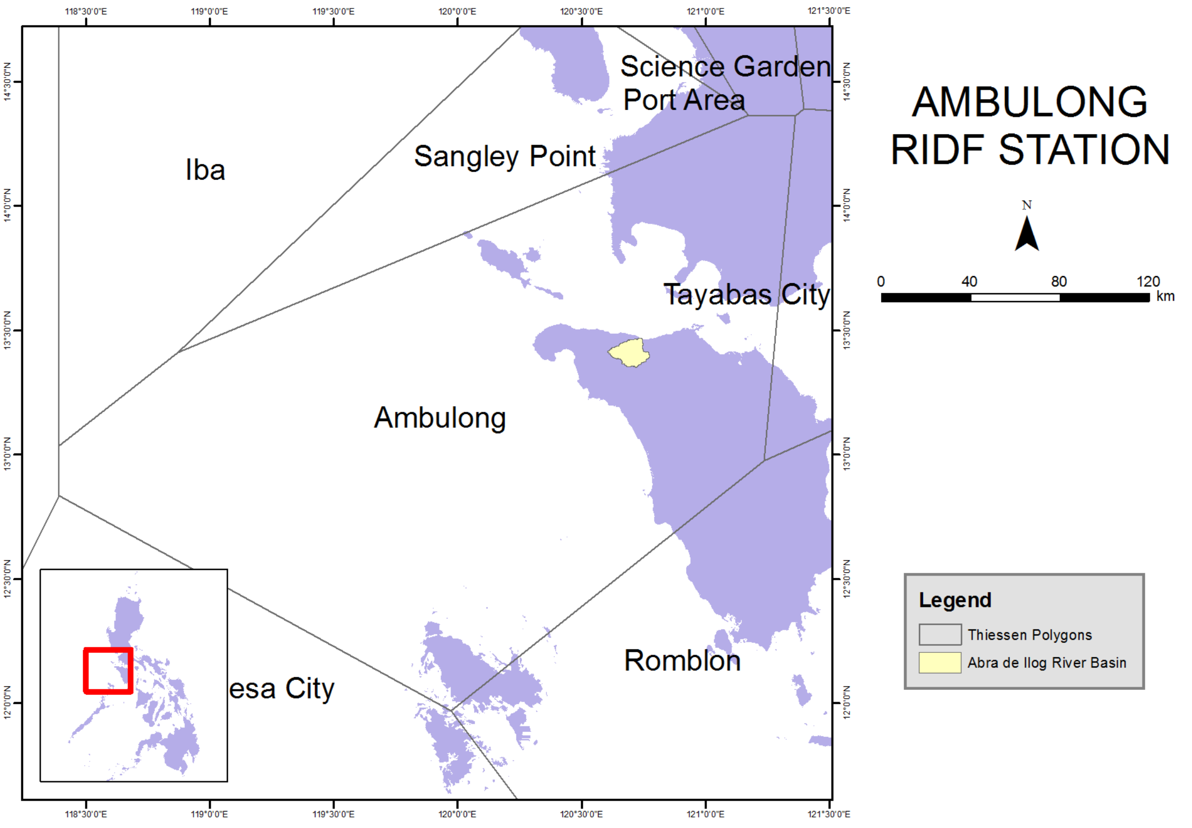


Figure 57. Location of Ambulong RIDF Station relative to Abra de Ilog River Basin

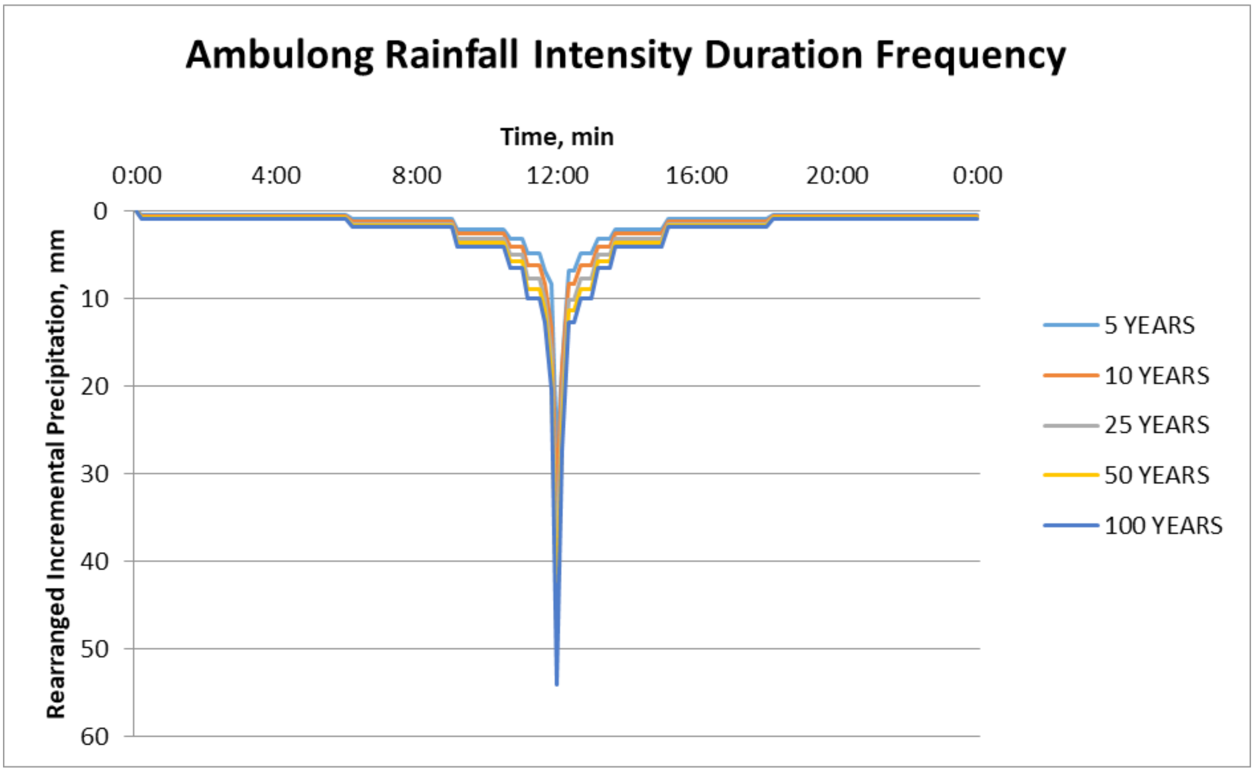


Figure 58. Synthetic storm generated for a 24-hr period rainfall for various return periods.

5.3 HMS Model

The soil dataset was generated before 2004 by the Bureau of Soils and Water Management under the Department of Agriculture (DA-BSWM). The land cover dataset is from the National Mapping and Resource Information Authority (NAMRIA). The soil and land cover of the Abra de Ilog River Basin are shown in Figure 59 and Figure 60, respectively.

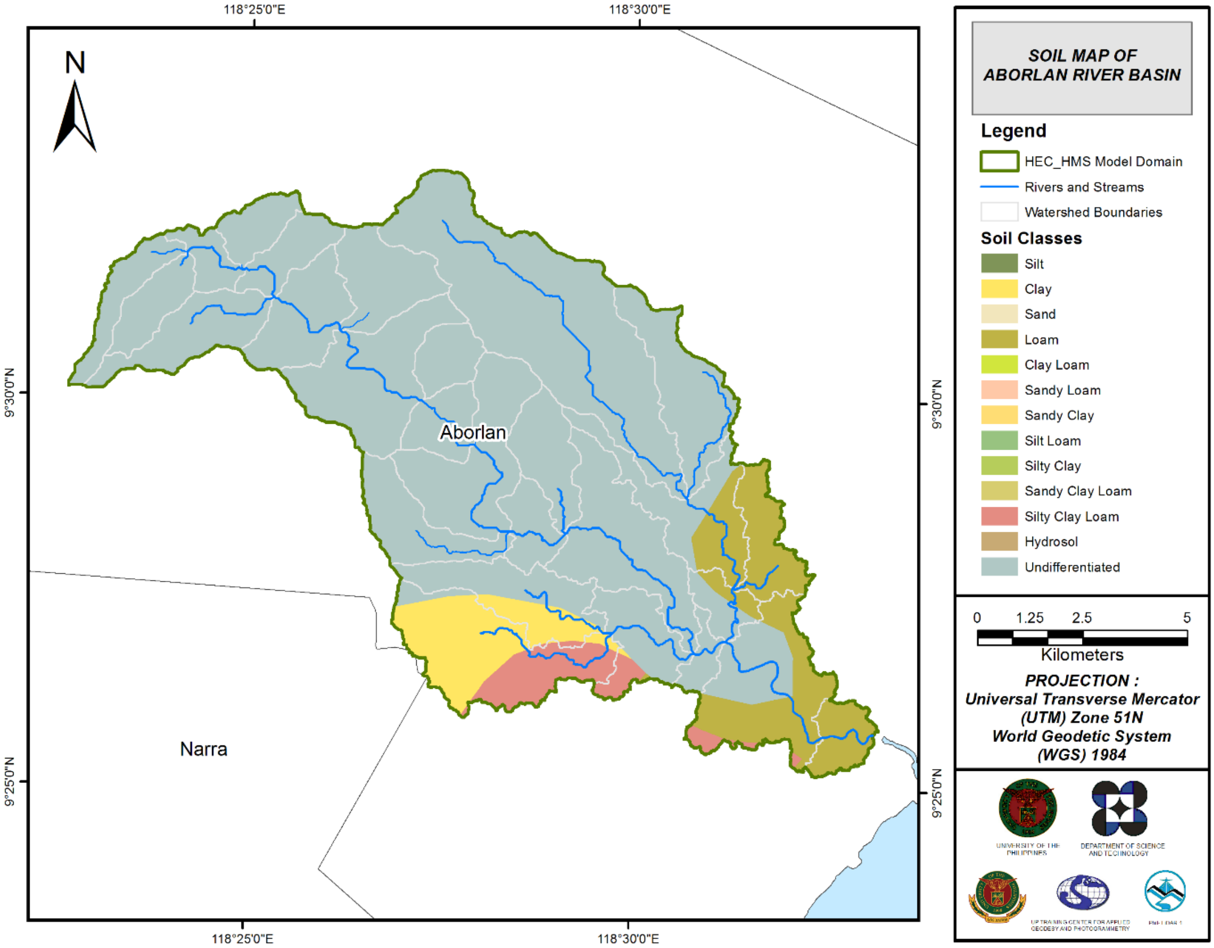


Figure 59. Soil Map of Abra de Ilog River Basin used for the estimation of the CN parameter. (Source: DA)

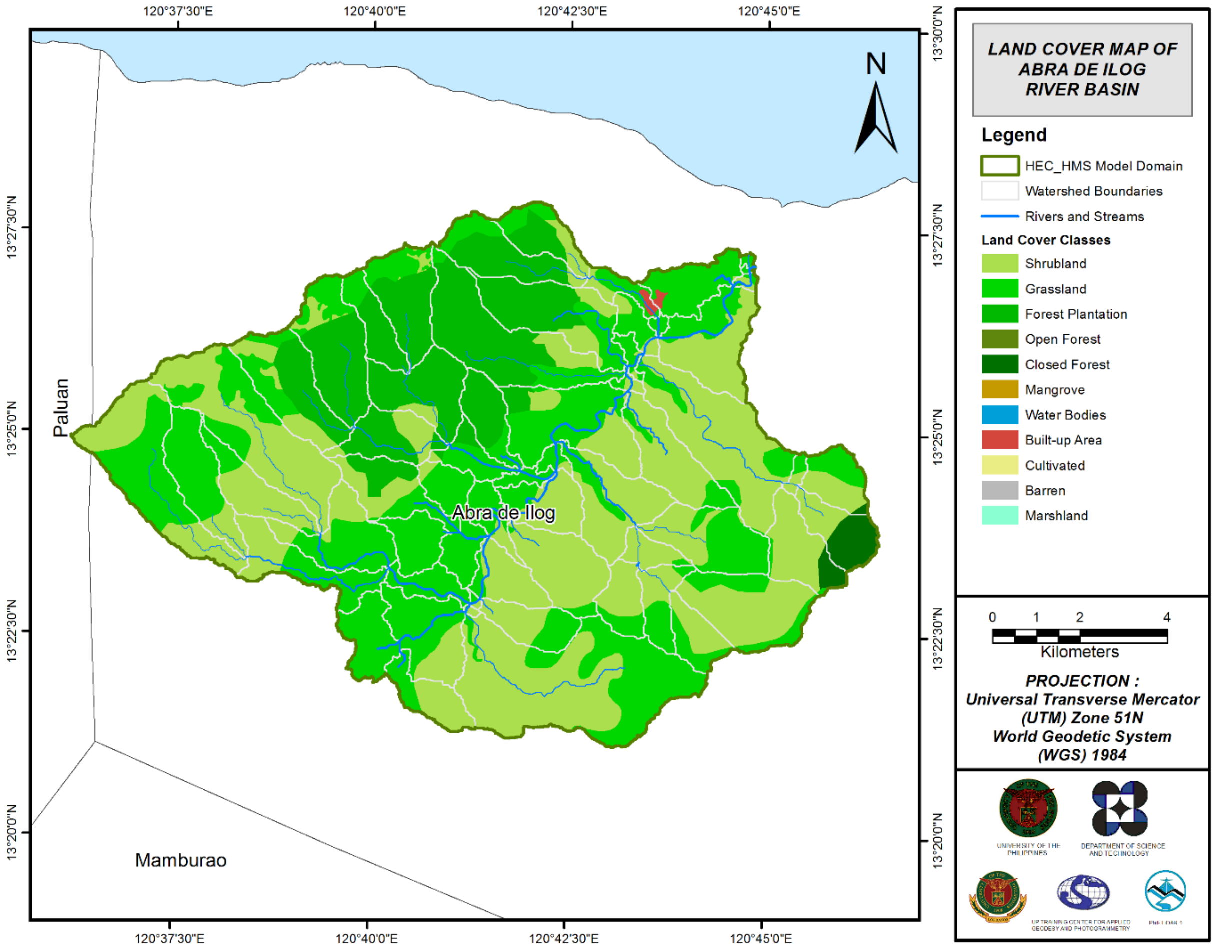


Figure 60. Land Cover Map of Abra de Ilog River Basin used for the estimation of the Curve Number (CN) and the watershed lag parameters of the rainfall-runoff model.

For Abra de Ilog river basin, the four (4) soil classes identified were clay, loam, silty clay loam, while the rest is undifferentiated soil. The five (5) land cover types identified were largely shrubland, followed by grassland and forest plantation, with small portions of closed forest and built-up area.

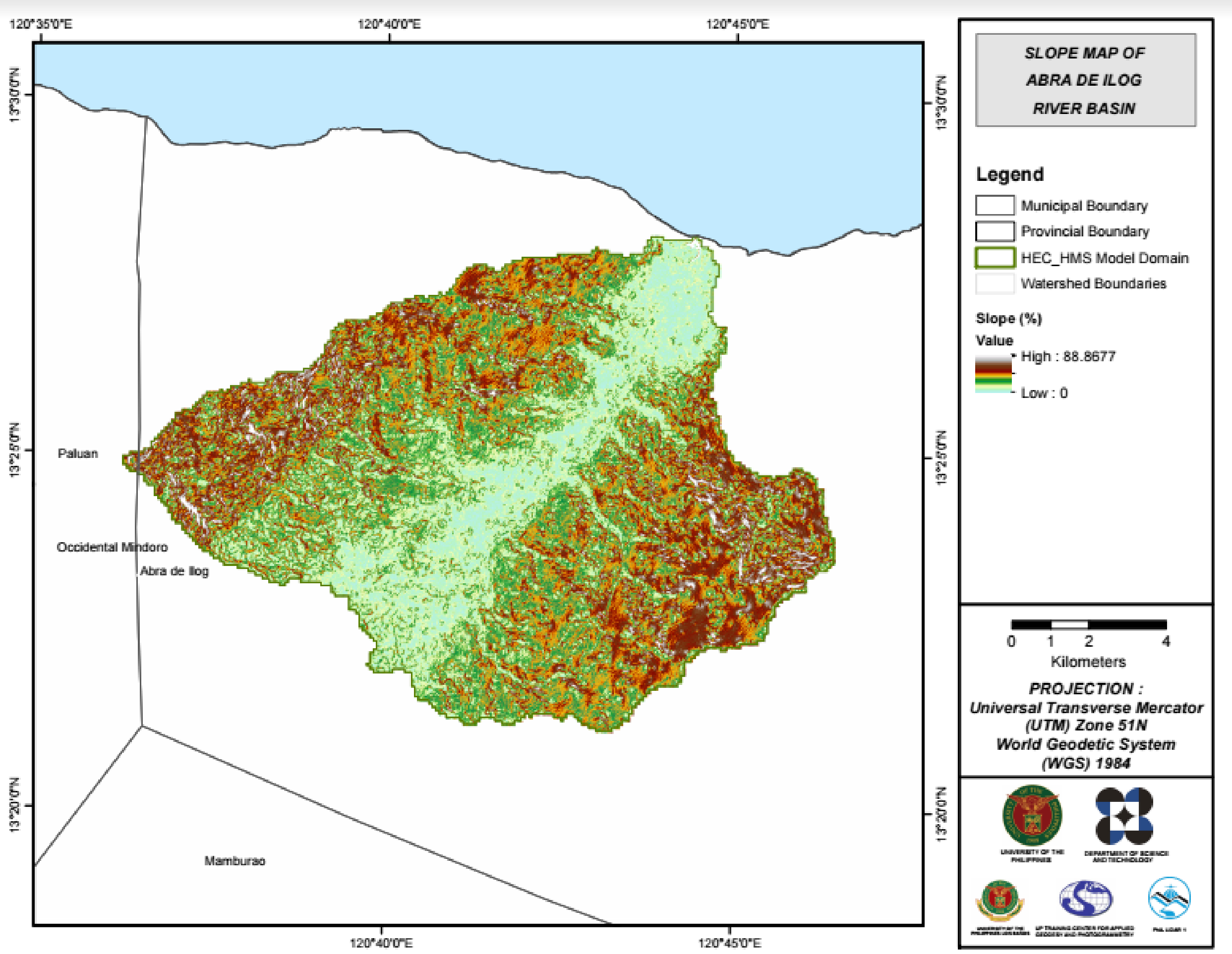


Figure 61. Slope Map of Abra de Ilog River Basin

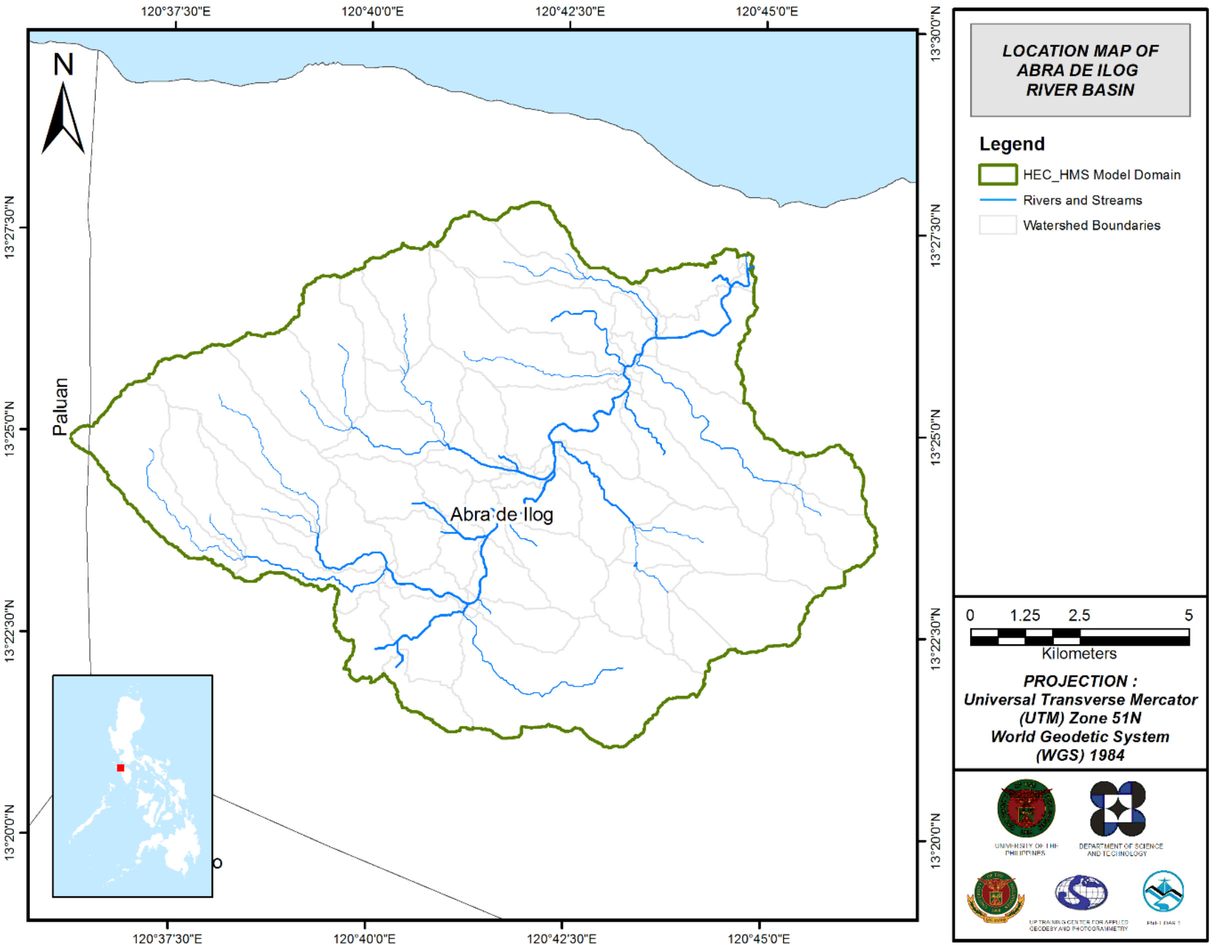


Figure 62. Stream Delineation Map of Abra de Ilog River Basin

Using SAR-based DEM, the Abra De Ilog basin was delineated and further subdivided into subbasins. The model consists of 93 sub basins, 26 reaches, and 31 junctions. The main outlet is labelled as 196. This basin model is illustrated in Figure 63. The basins were identified based on soil and land cover characteristics of the area. Precipitation was taken from the Automatic Rain Gauge Station (ARG) located in Balao Elementary School (13.441920°N, 120.729854°E). Finally, it was calibrated using data collected from the Automatic Water Level Station (AWLS) installed on the bridge itself (13.450283°N, 120.745743°E).

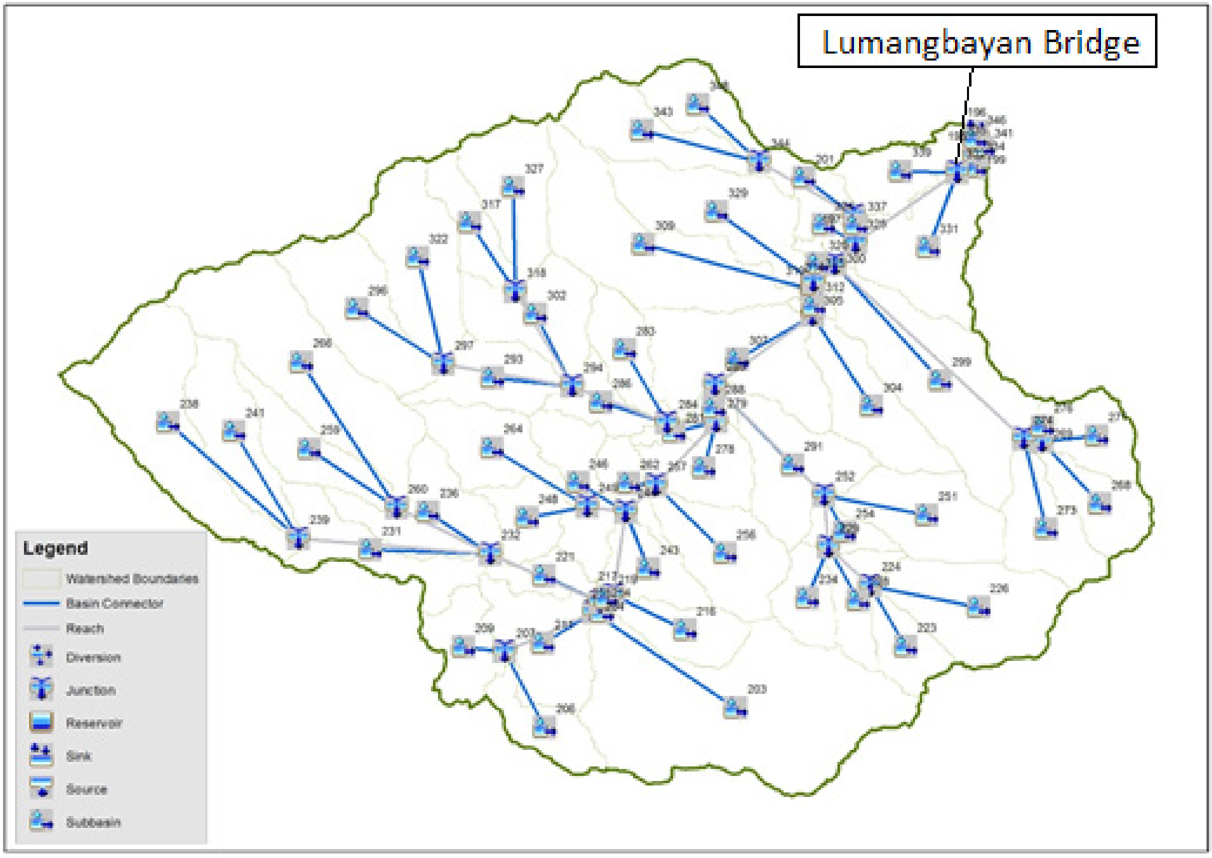


Figure 63. Abra de Ilog River Basin model generated in HEC-HMS

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 64. River cross-section of Abra de Ilog 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 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 west south of the model to the northeast, following the main channel. As such, boundary elements in those particular regions of the model are assigned as inflow and outflow elements respectively.

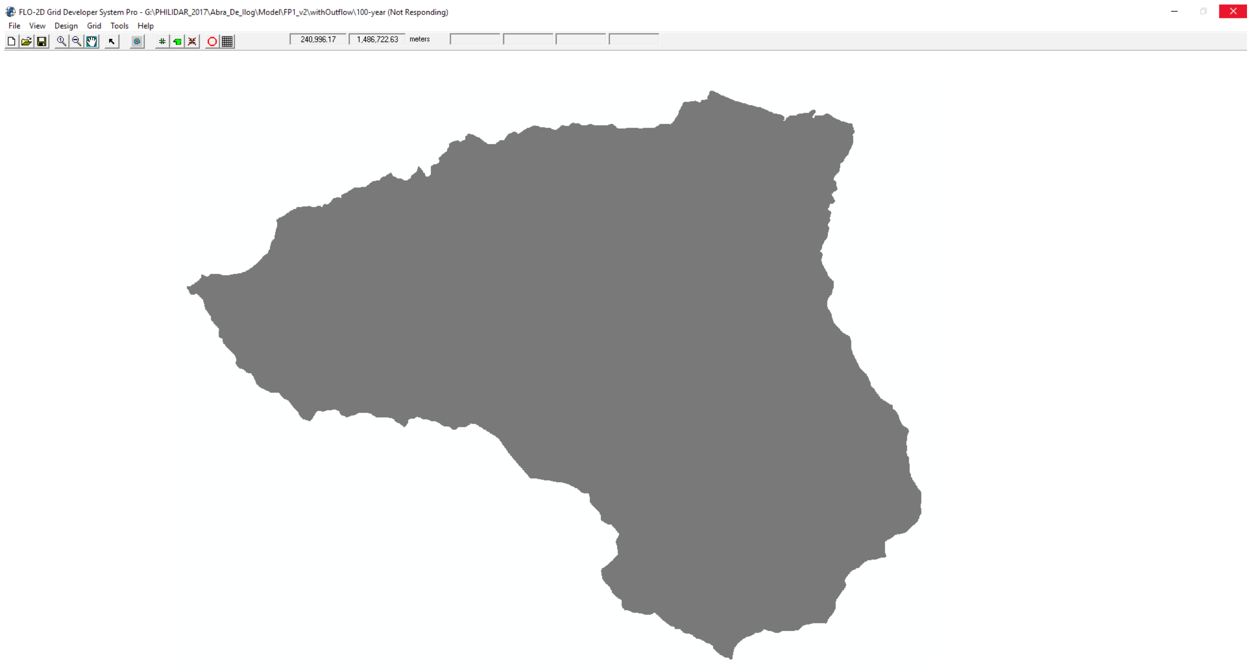


Figure 65. Screenshot of the river sub-catchment with the computational area to be modeled in FLO-2D Grid Developer System Pro (FLO-2D GDS Pro)

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 118.29346 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m2/s.

The creation of a flood hazard map from the model also automatically creates a flow depth map depicting the maximum amount of inundation for every grid element. The legend used by default in Flo-2D Mapper is not a good representation of the range of flood inundation values, so a different legend is used for the layout. In this particular model, the inundated parts cover a maximum land area of 93327936.00 m2.

There is a total of 52611627.19 m3 of water entering the model. Of this amount, 36292470.77 m3 is due to rainfall while 16319156.42 m3 is inflow from other areas outside the model. 3 960 626.75 m3 of this water is lost to infiltration and interception, while 7918116.00 m3 is stored by the flood plain. The rest, amounting up to 4906651.42 m3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Abra de Ilog HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 66 shows the comparison between the two discharge data.

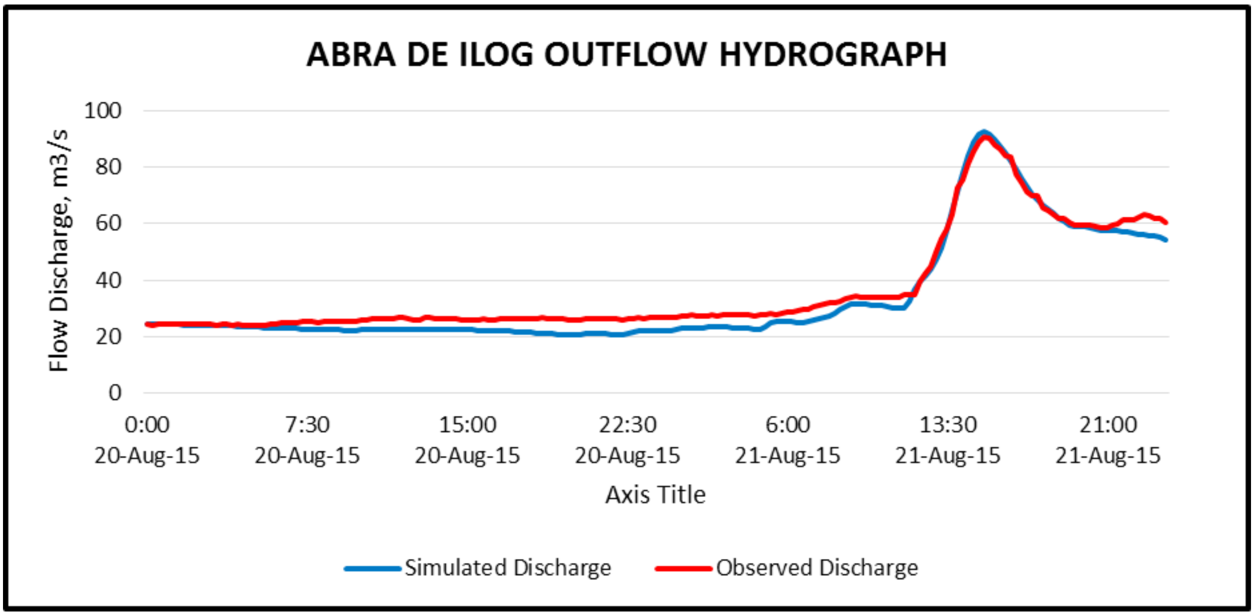


Figure 66. Outflow hydrograph of Abra de Ilog produced by the HEC-HMS model compared with observed outflow

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

Table 26. Range of calibrated values for the Abra de Ilog River Basin.

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	4 - 400
			Curve Number	82 - 99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.03 - 5
			Storage Coefficient (hr)	0.3 - 40
	Baseflow	Recession	Recession Constant	0.01 - 1
			Ratio to Peak	0.008 – 0.5
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.07

Initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as initial abstraction decreases. The range of values from 4 to 400mm means that there is a high amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 82 to 99 for curve number is advisable for Philippine watersheds depending on the soil and land cover of the area (M. Horritt, personal communication, 2012).

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 0.03 hours to 40 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 this watershed, the characteristics differ per reach.

Manning's roughness coefficient of 0.07 is relatively high compared to the common roughness of watersheds (Brunner, 2010).

Table 27. Summary of the Efficiency Test of the Abra de Ilog HMS Model

Accuracy measure	Value
RMSE	3.610
r2	0.995
NSE	0.960
PBIAS	7.661
RSR	0.200

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 3.610.

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 0.995.

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 0.960.

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 7.661.

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 0.200.

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

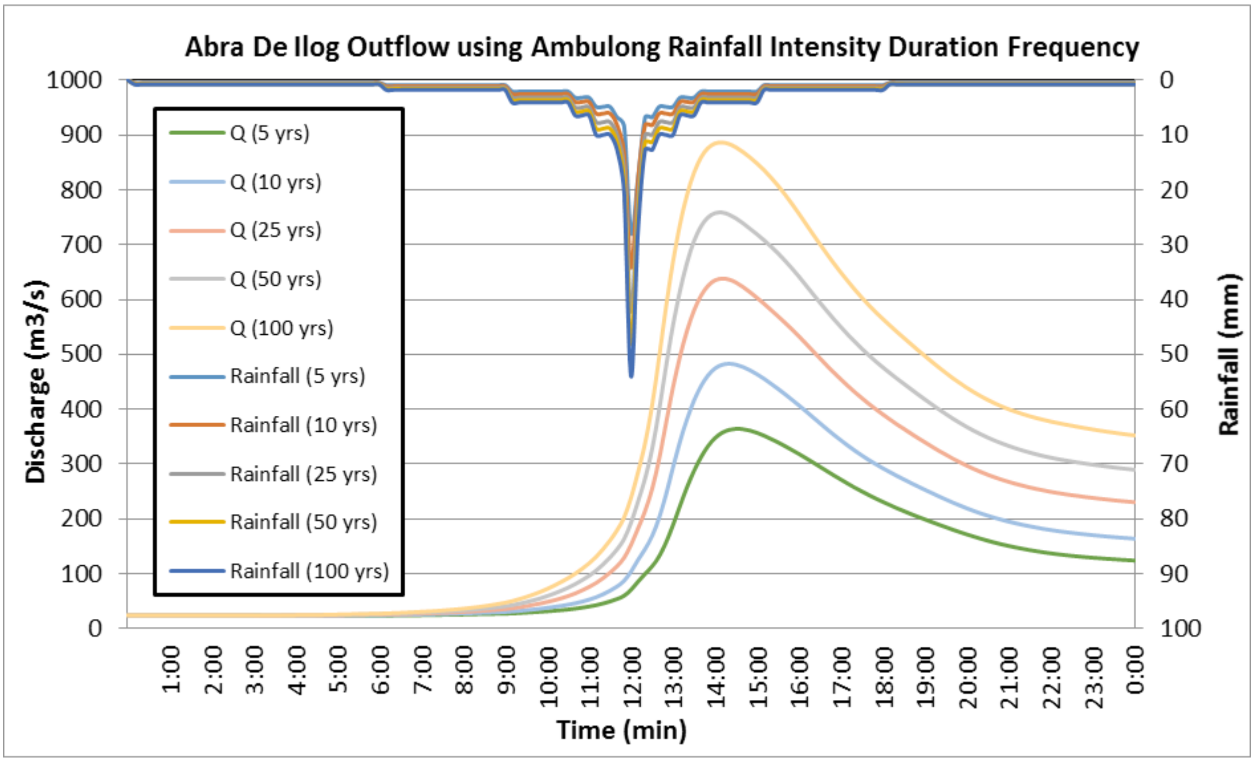


Figure 67. Outflow hydrograph at Abra de Ilog Station generated using the Ambulong RIDF simulated in HEC-HMS.

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

Table 28. Peak values of the Abra de Ilog HEC-HMS Model outflow using the Ambulong RIDF 24-hour values.

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (cu.m./s)	Time to Peak	Lag Time
5-Year	226.70	27.90	364.40	2 hours 30 minutes	226.70
10-Year	276.90	34.20	483.0	2 hours 20 minutes	276.90
25-Year	340.40	42.20	638.20	2 hours 10 minutes	340.40
50-Year	387.50	48.10	758.60	2 hours 10 minutes	387.50
100-Year	434.30	54.0	886.40	2 hours 10 minutes	434.30

5.8 River Analysis (RAS) Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. The sample map of Abra de Ilog River using the HMS base flow is shown on Figure 68.

Figure 68. Sample output of Abra de Ilog RAS Model

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps for 5-, 25-, and 100-year rain return scenarios of the Abra de Ilog floodplain are shown in Figure 69 to Figure 74. The floodplain, with an area of 150.96 sq. km., covers two municipalities namely Abra de Ilog, and Paluan. Table 29 shows the percentage of area affected by flooding per municipality.

Table 29. Municipalities affected in Abra de Ilog Floodplain

Province	Municipality	Total Area	Area Flooded	% Flooded
Occidental Mindoro	Abra de Ilog	523.87	150.57	28.74
	Paluan	557.78	0.18	0.03

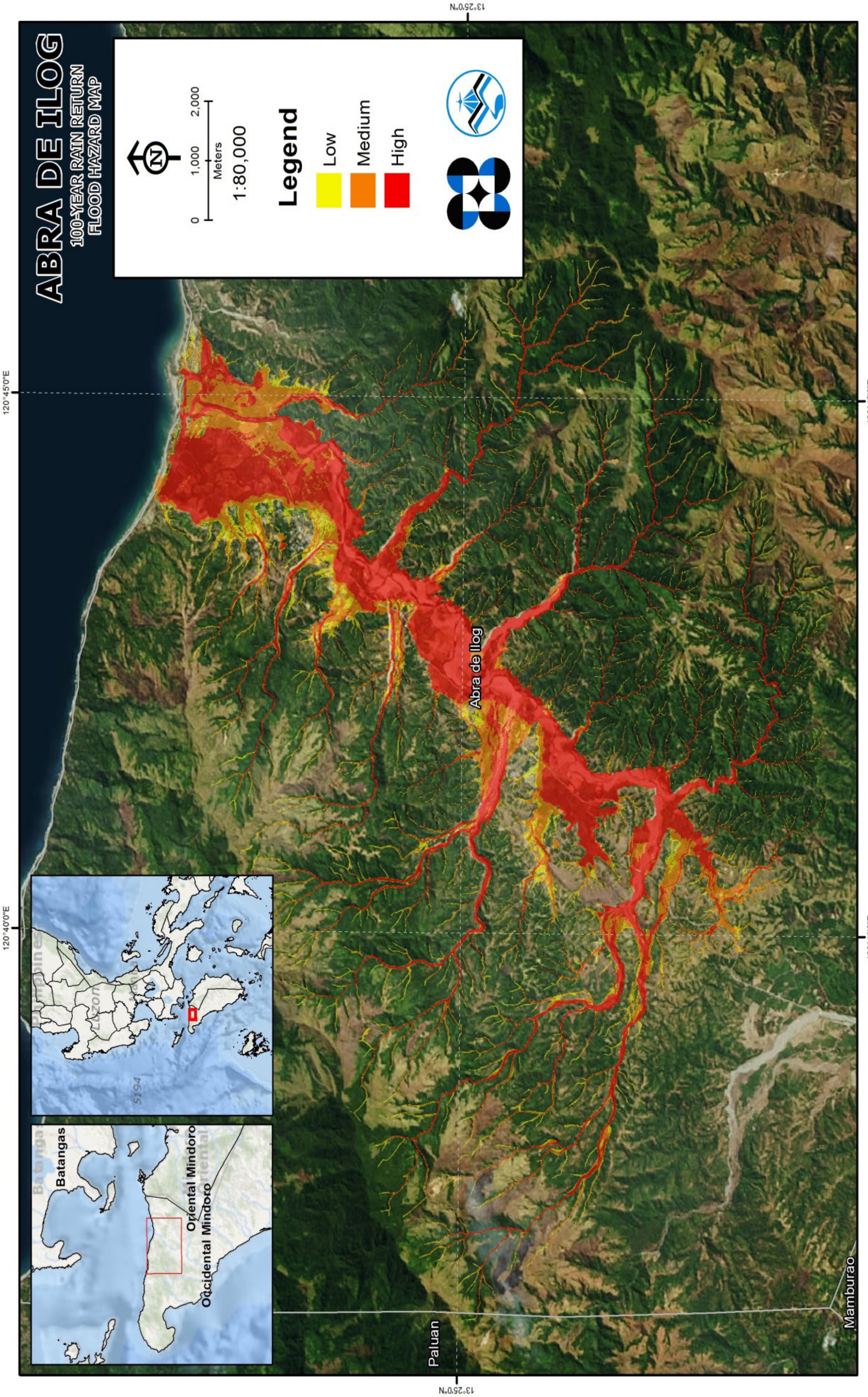


Figure 69. 100-year Flood Hazard Map for Abra de Ilog Floodplain overlaid on Google Earth imagery

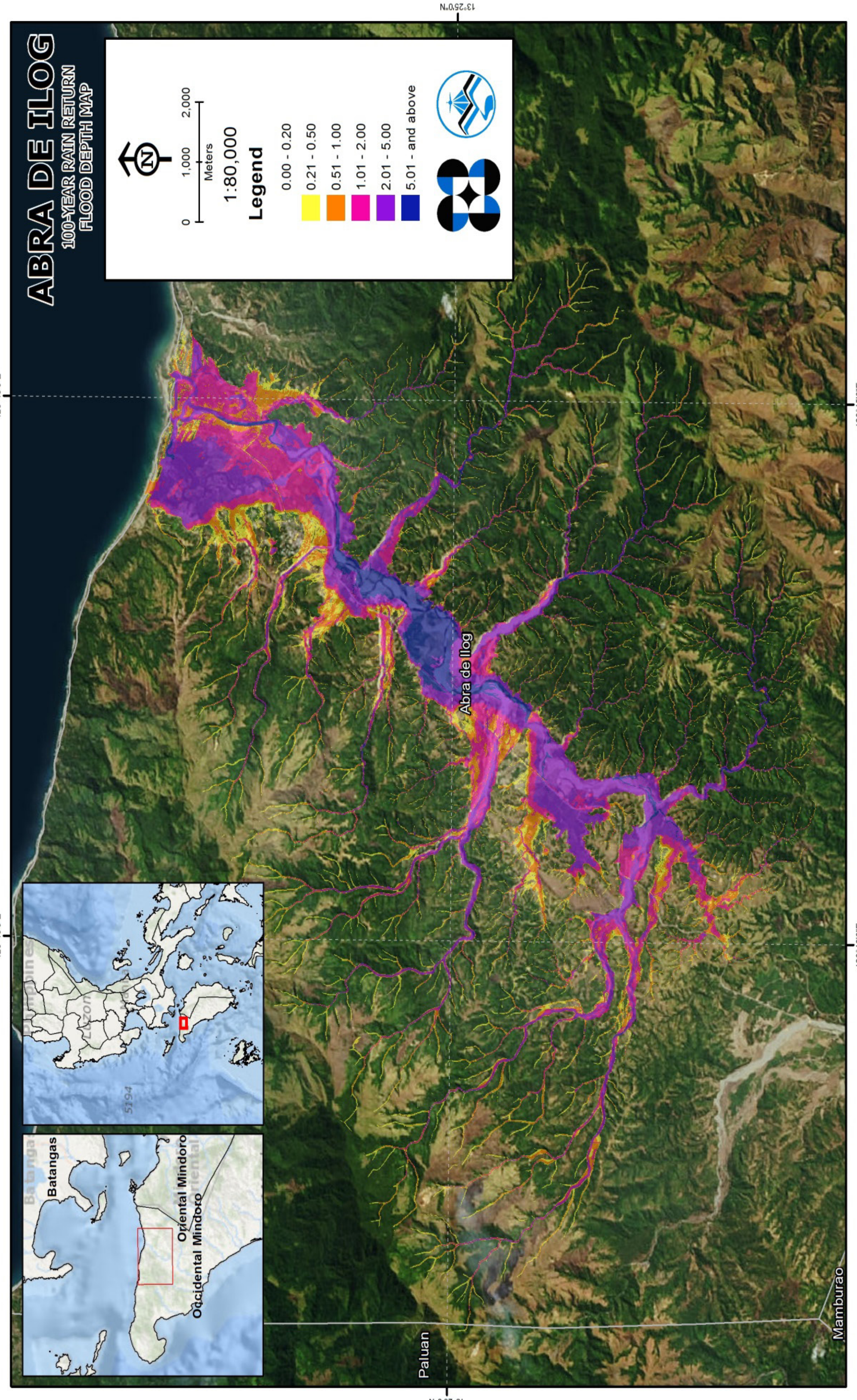


Figure 70. 100-year Flow Depth Map for Abra de Ilog Floodplain overlaid on Google Earth imagery

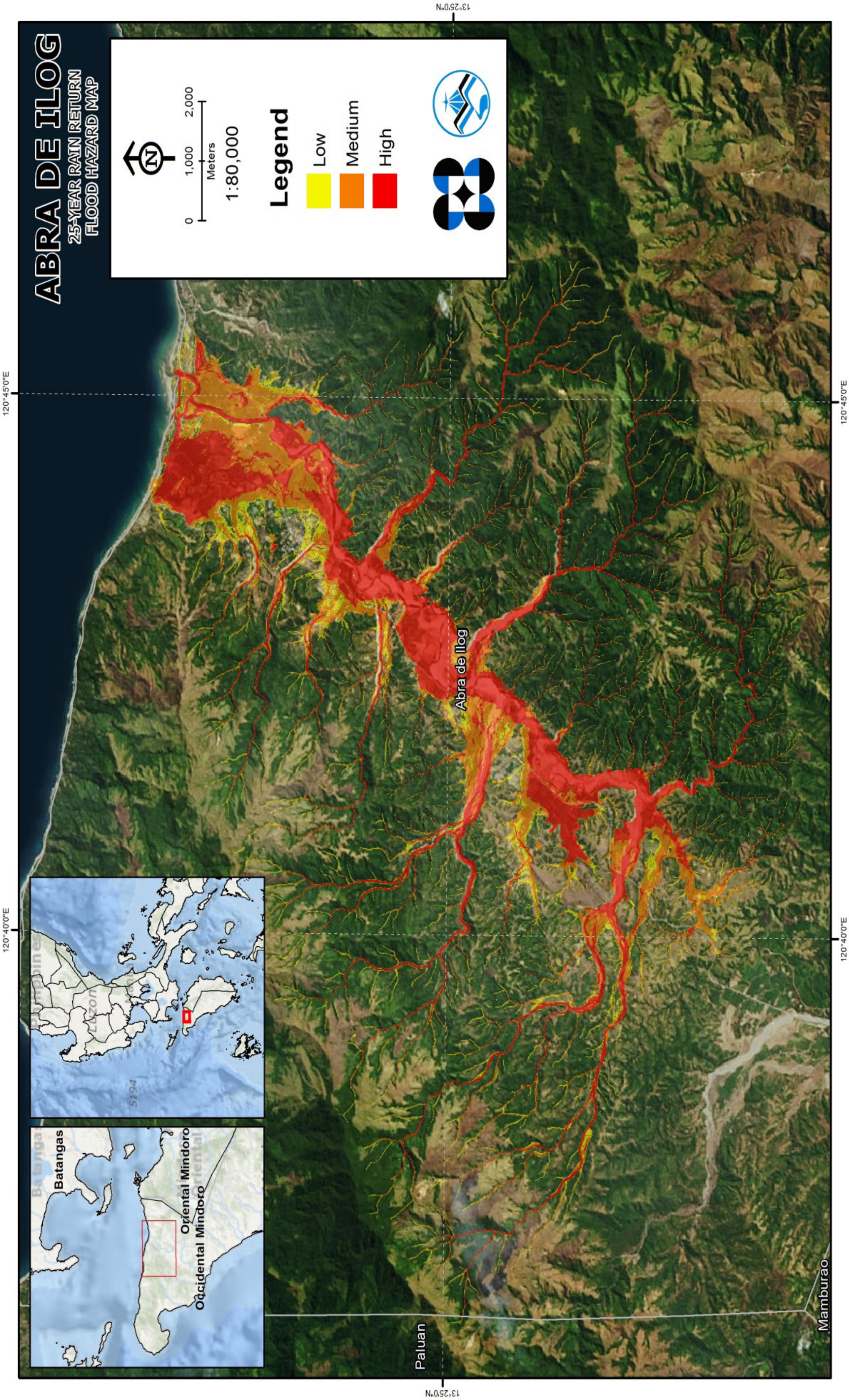


Figure 71. 25-year Flood Hazard Map for Abra de Ilog Floodplain overlaid on Google Earth imagery

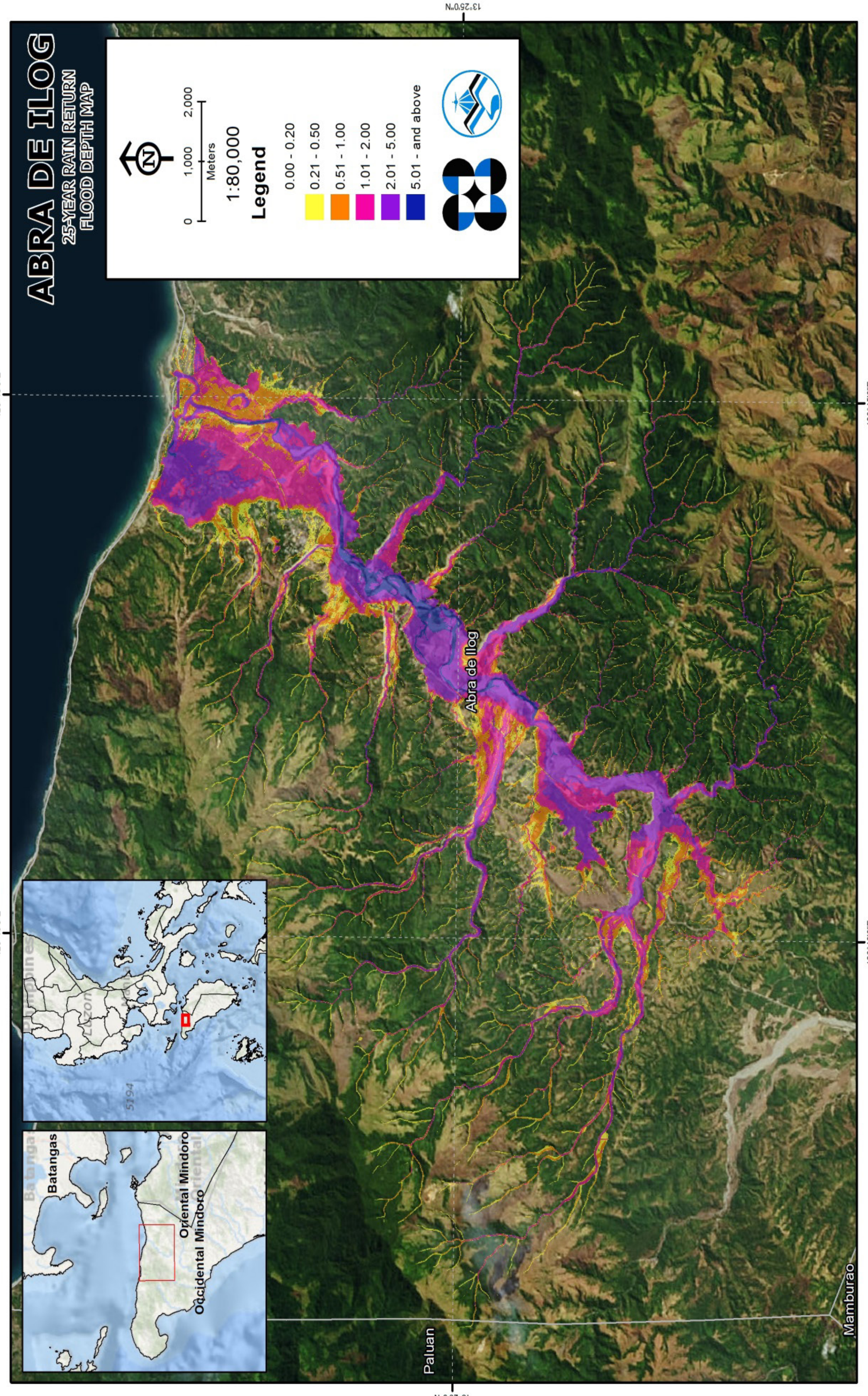


Figure 72. 25-year Flow Depth Map for Abra de Ilog Floodplain overlaid on Google Earth imagery

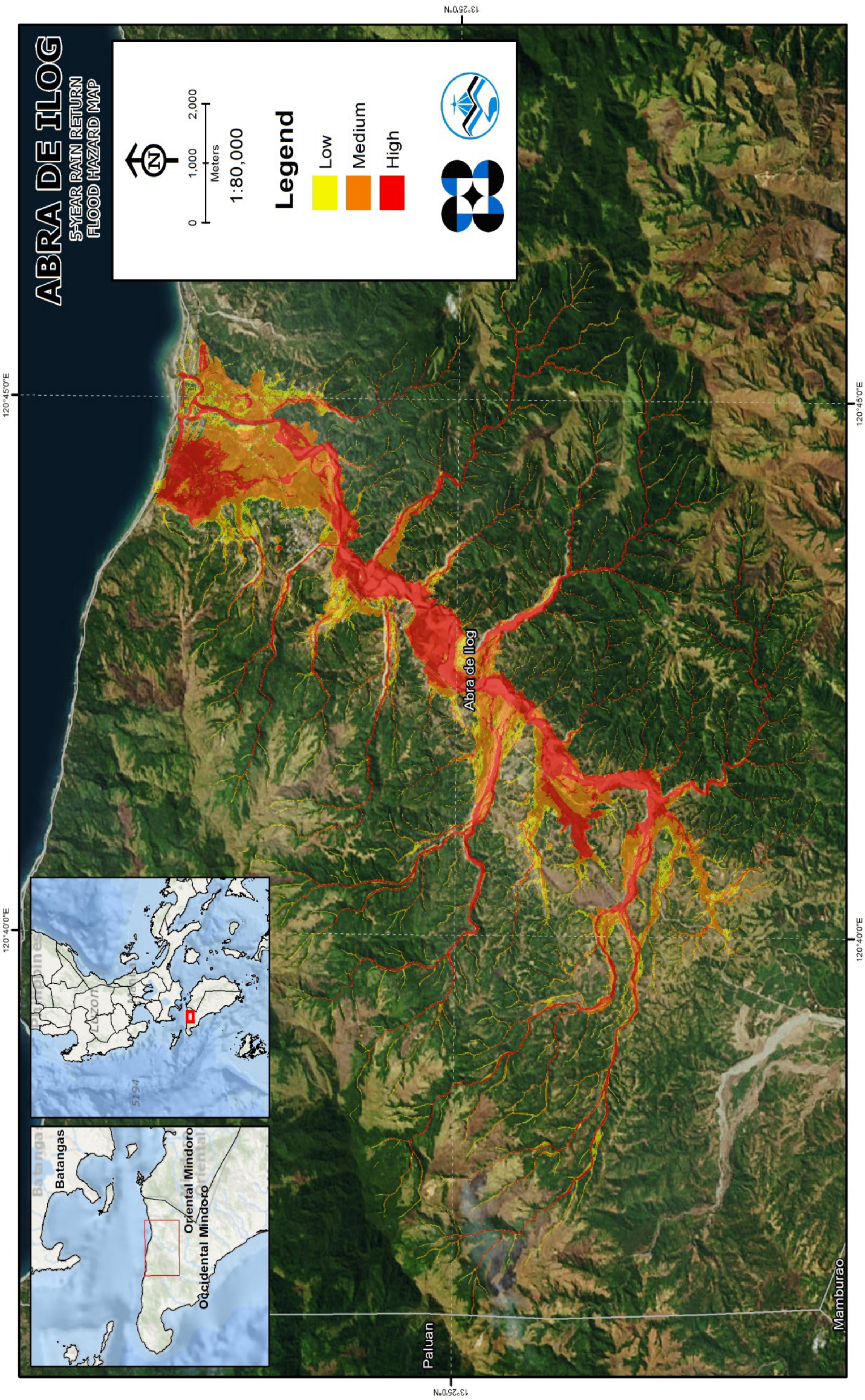


Figure 73. 5-year Flood Hazard Map for Abra de Ilog Floodplain overlaid on Google Earth imagery

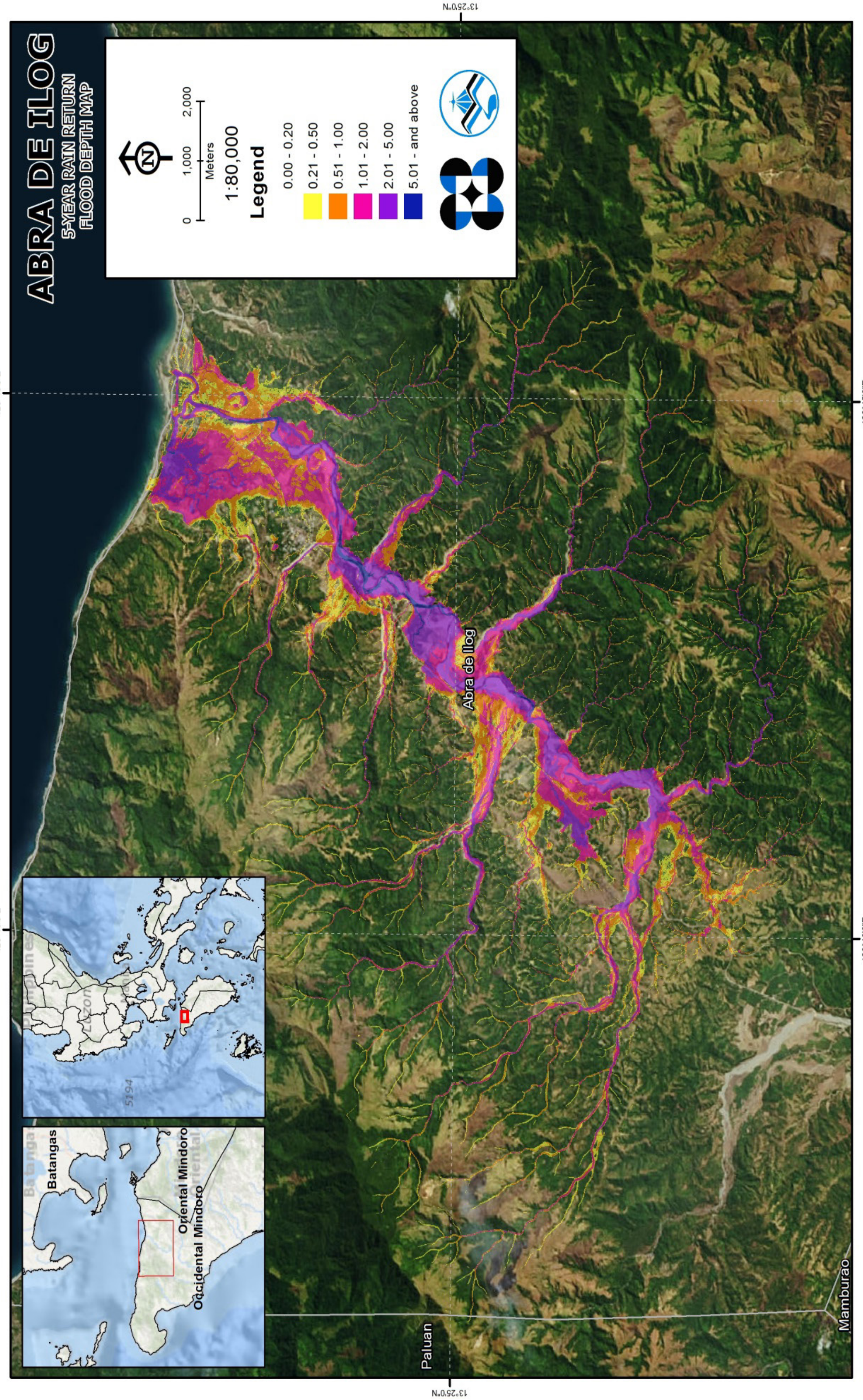


Figure 74. 5-year Flood Depth Map for Abra de Ilog Floodplain overlaid on Google Earth imagery

5.10 Inventory of Areas Exposed to Flooding

Listed below are the barangays affected by the Abra de Ilog River Basin, grouped accordingly by municipality. For the said basin, two (2) municipalities consisting of nine (9) barangays are expected to experience flooding when subjected to a 5-year rainfall return period.

For the 5-year return period, 23.74% of the municipality of Abra de Ilog with an area of 523.87 sq. km. will experience flood levels of less 0.20 meters, while 1.19% of the area will experience flood levels of 0.21 to 0.50 meters; 1.25%, 1.49%, 1.03%, and 0.06% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 t0 5 meters, and more than 5 meters respectively. Table 30 and Figure 75 depict the areas affected in Abra de Ilog in square kilometers by flood depth per barangay.

Table 30. Affected areas in Abra de Ilog, Occidental Mindoro during a 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Abra de Ilog (in sq. km.)							
	Armado	Balao	Cabacao	Lumangbayan	Poblacion	San Vicente	Tibag	Wawa
0.03-0.20	8.93	35.01	5.1	1.26	25.02	34.92	10.42	3.69
0.21-0.50	0.54	1.88	0.12	0.098	1.08	1.22	0.73	0.54
0.51-1.00	0.54	1.95	0.055	0.13	0.94	1.05	1.28	0.59
1.01-2.00	0.34	2.58	0.032	0.17	0.94	1.18	1.5	1.03
2.01-5.00	0.13	2.27	0.02	0.0055	0.93	0.81	0.48	0.75
> 5.00	0.0044	0.077	0.0003	0	0.19	0.0067	0.043	0.009

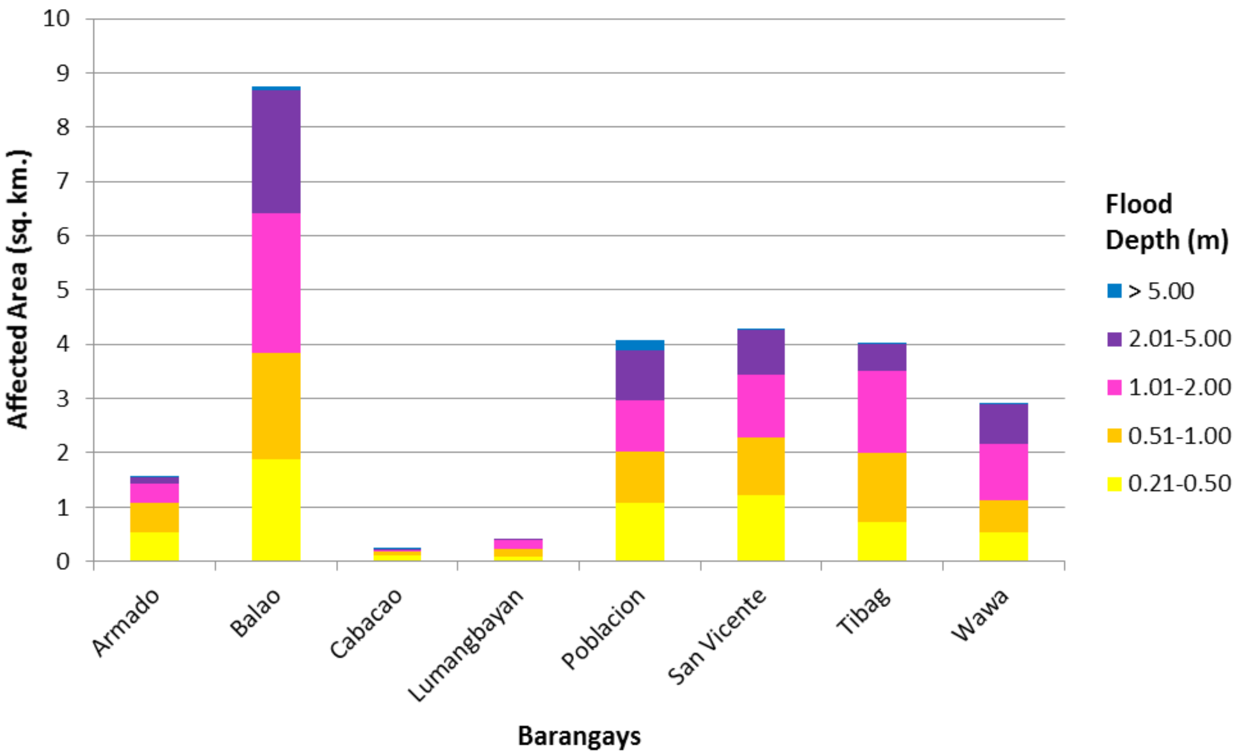


Figure 75. Affected Areas in Abra de Ilog, Occidental Mindoro during 5-Year Rainfall Return Period

For the municipality of Paluan, with an area of 557.78 sq. km., 0.03% will experience flood levels of less 0.20 meters. 0.0004% of the area will experience flood levels of 0.21 to 0.50 meters while 0.00001%, of the area will experience flood depths of 0.51 to 1 meter, respectively. Table 31 and Figure 76 depict the affected areas in square kilometers by flood depth per barangay.

Table 31. Affected areas in Paluan, Occidental Mindoro during a 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Paluan (in sq. km.)
	Marikit
0.03-0.20	0.18
0.21-0.50	0.002
0.51-1.00	0.000072
1.01-2.00	0
2.01-5.00	0
> 5.00	0

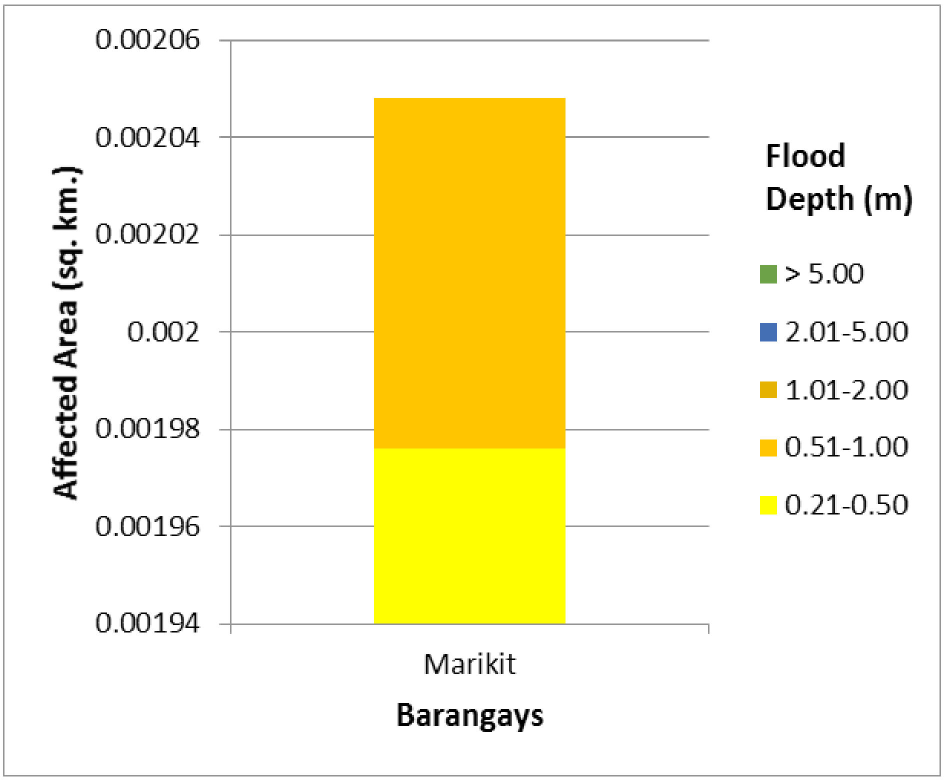


Figure 76. Affected Areas in Paluan, Occidental Mindoro during a 5-Year Rainfall Return Period

For the 25-year return period, 23.19% of the municipality of Abra de Ilog with an area of 523.87 sq. km. will experience flood levels of less 0.20 meters, while 1.12% of the area will experience flood levels of 0.21 to 0.50 meters; 1.11%, 1.56%, 1.57%, and 0.19% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 t0 5 meters, and more than 5 meters respectively. Table 32 and Figure 77 depict the areas affected in Abra de Ilog in square kilometers by flood depth per barangay.

Table 32. Affected areas in Abra de Ilog, Occidental Mindoro during a 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Abra de Ilog (in sq. km.)							
	Armado	Balao	Cabacao	Lumangbayan	Poblacion	San Vicente	Tibag	Wawa
0.03-0.20	8.75	34.14	5.05	1.2	24.39	34.39	10.1	3.45
0.21-0.50	0.42	1.75	0.14	0.12	1.22	1.2	0.67	0.36
0.51-1.00	0.57	1.77	0.062	0.071	0.87	0.96	0.86	0.68
1.01-2.00	0.51	2.36	0.039	0.22	1.03	1.27	1.97	0.78
2.01-5.00	0.21	3.34	0.03	0.045	1.14	1.32	0.8	1.31
> 5.00	0.018	0.41	0.0011	0	0.45	0.035	0.049	0.022

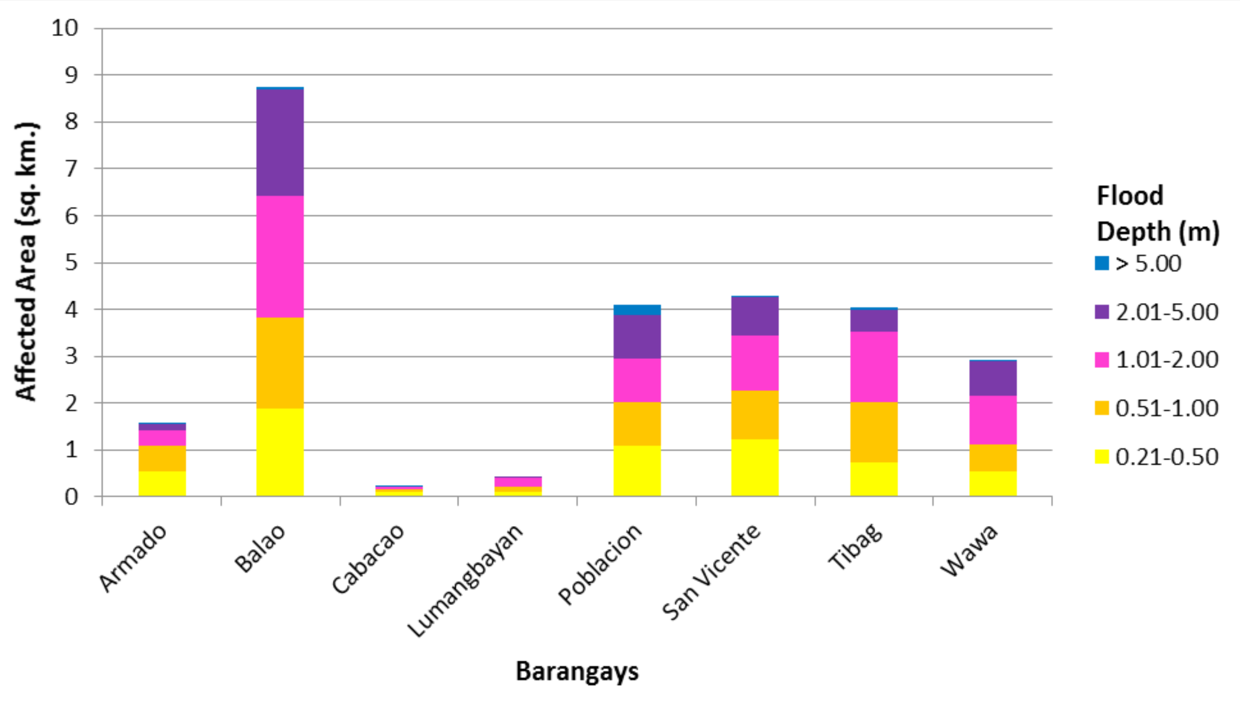


Figure 77. Affected Areas in Abra de Ilog, Occidental Mindoro during 25-Year Rainfall Return Period

For the municipality of Paluan, with an area of 557.78 sq. km., 0.03% will experience flood levels of less 0.20 meters. 0.0007% of the area will experience flood levels of 0.21 to 0.50 meters while 0.00007%, of the area will experience flood depths of 0.51 to 1 meter, respectively. Table 33 and Figure 78 depict the affected areas in square kilometers by flood depth per barangay.

Table 33. Affected areas in Paluan, Occidental Mindoro during a 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Paluan (in sq. km.)
	Marikit
0.03-0.20	0.18
0.21-0.50	0.0037
0.51-1.00	0.00037
1.01-2.00	0
2.01-5.00	0
> 5.00	0

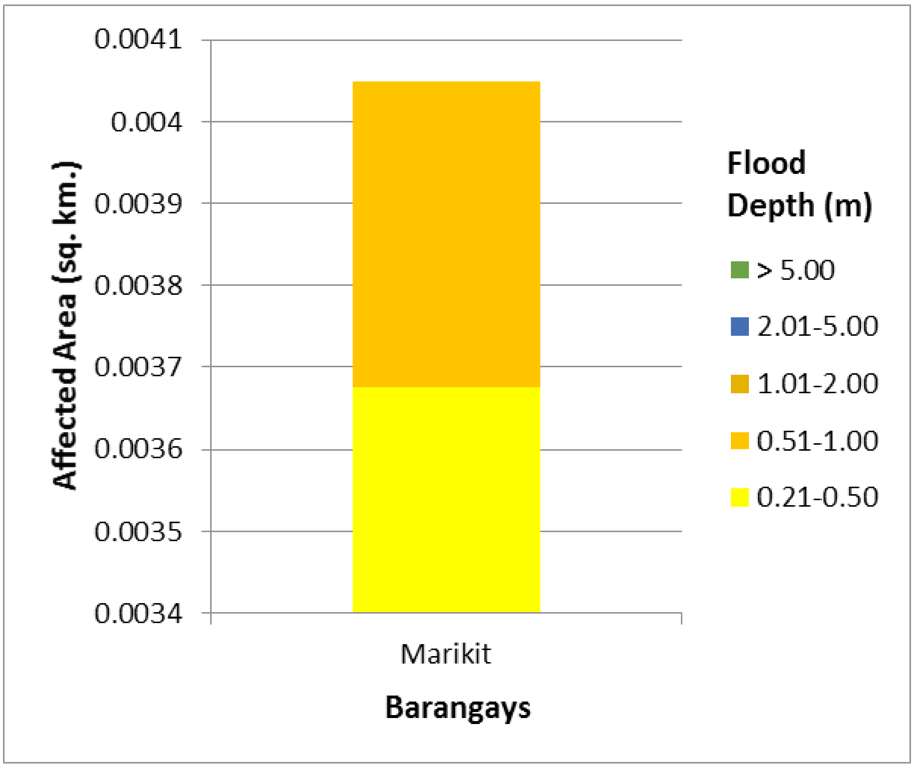


Figure 78. Affected Areas in Paluan, Occidental Mindoro during a 25-Year Rainfall Return Period

For the 100-year return period, 22.19% of the municipality of Abra de Ilog with an area of 523.87 sq. km. will experience flood levels of less 0.20 meters, while 1.11% of the area will experience flood levels of 0.21 to 0.50 meters; 1%, 1.55%, 1.88%, and 0.43% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 t0 5 meters, and more than 5 meters respectively. Table 34 and Figure 79 depict the areas affected in Abra de Ilog in square kilometers by flood depth per barangay.

Table 34. Affected areas in Abra de Ilog, Occidental Mindoro during a 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Abra de Ilog (in sq. km.)							
	Armado	Balao	Cabacao	Lumangbayan	Poblacion	San Vicente	Tibag	Wawa
0.03-0.20	8.61	33.51	5.01	1.15	23.91	33.98	9.9	3.33
0.21-0.50	0.38	1.68	0.16	0.13	1.25	1.24	0.64	0.32
0.51-1.00	0.49	1.63	0.068	0.075	0.94	0.92	0.7	0.41
1.01-2.00	0.58	2.18	0.042	0.22	1.01	1.21	1.9	0.96
2.01-5.00	0.37	3.51	0.038	0.093	1.3	1.72	1.26	1.55
> 5.00	0.047	1.27	0.0038	0	0.7	0.12	0.063	0.031

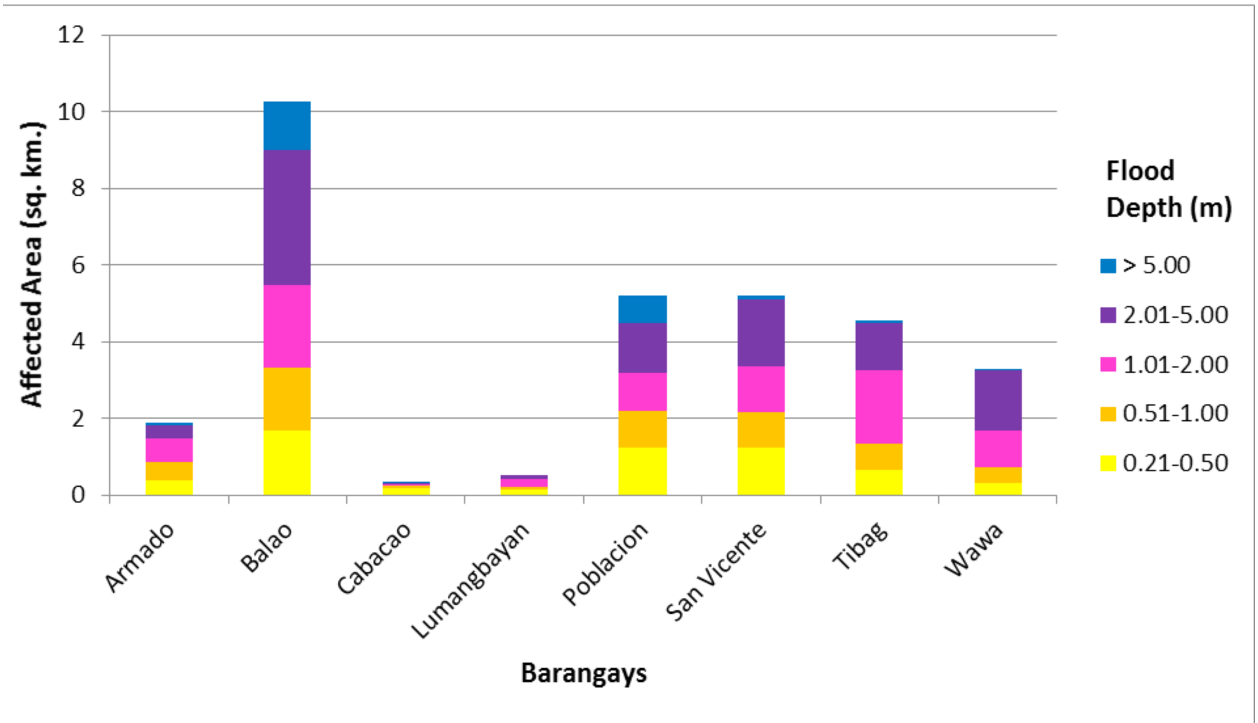


Figure 79. Affected Areas in Abra de Ilog, Occidental Mindoro during 100-Year Rainfall Return Period

For the municipality of Paluan, with an area of 557.78 sq. km., 0.03% will experience flood levels of less 0.20 meters. 0.0008% of the area will experience flood levels of 0.21 to 0.50 meters while 0.0001%, of the area will experience flood depths of 0.51 to 1 meter, respectively. Table 35 and Figure 80 depict the affected areas in square kilometers by flood depth per barangay.

Table 35. Affected areas in Paluan, Occidental Mindoro during a 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Paluan (in sq. km.)
	Marikit
0.03-0.20	0.18
0.21-0.50	0.0043
0.51-1.00	0.00057
1.01-2.00	0
2.01-5.00	0
> 5.00	0

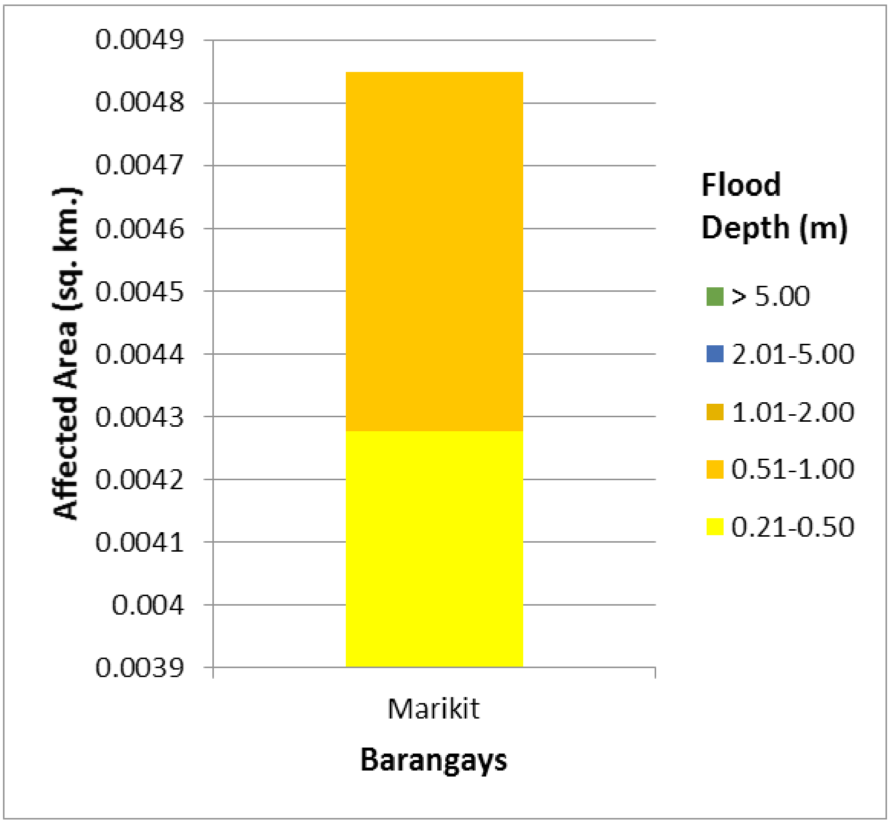


Figure 80. Affected Areas in Paluan, Occidental Mindoro during a 100-Year Rainfall Return Period

Among the barangays in the municipality of Abra de Ilog, Balao is projected to have the highest percentage of area that will experience flood levels of at 8.36%. On the other hand, San Vicente posted the percentage of area that may be affected by flood depths of at 7.48%.

Among the barangays in the municipality of Paluan, Marikit is projected to have the highest percentage of area that will experience flood levels of at 0.03%.

5.11 Flood Validation

In order to check and validate the extent of flooding in different river systems, there was 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 interviews with some residents who have knowledge of or have had experienced flooding in a particular area.

After which, the actual data from the field was compared to the simulated data to assess the accuracy of the Flood Depth Maps produced and to improve on what is needed. The points in the flood map versus its corresponding validation depths are shown in Figure 82.

The flood validation consisted of 49 points randomly selected all over the Abra de Ilog floodplain (Figure 81). Comparing it with the flood depth map of the nearest storm event, the map has an RMSE value of 1.01m. Table 36 shows a contingency matrix of the comparison.

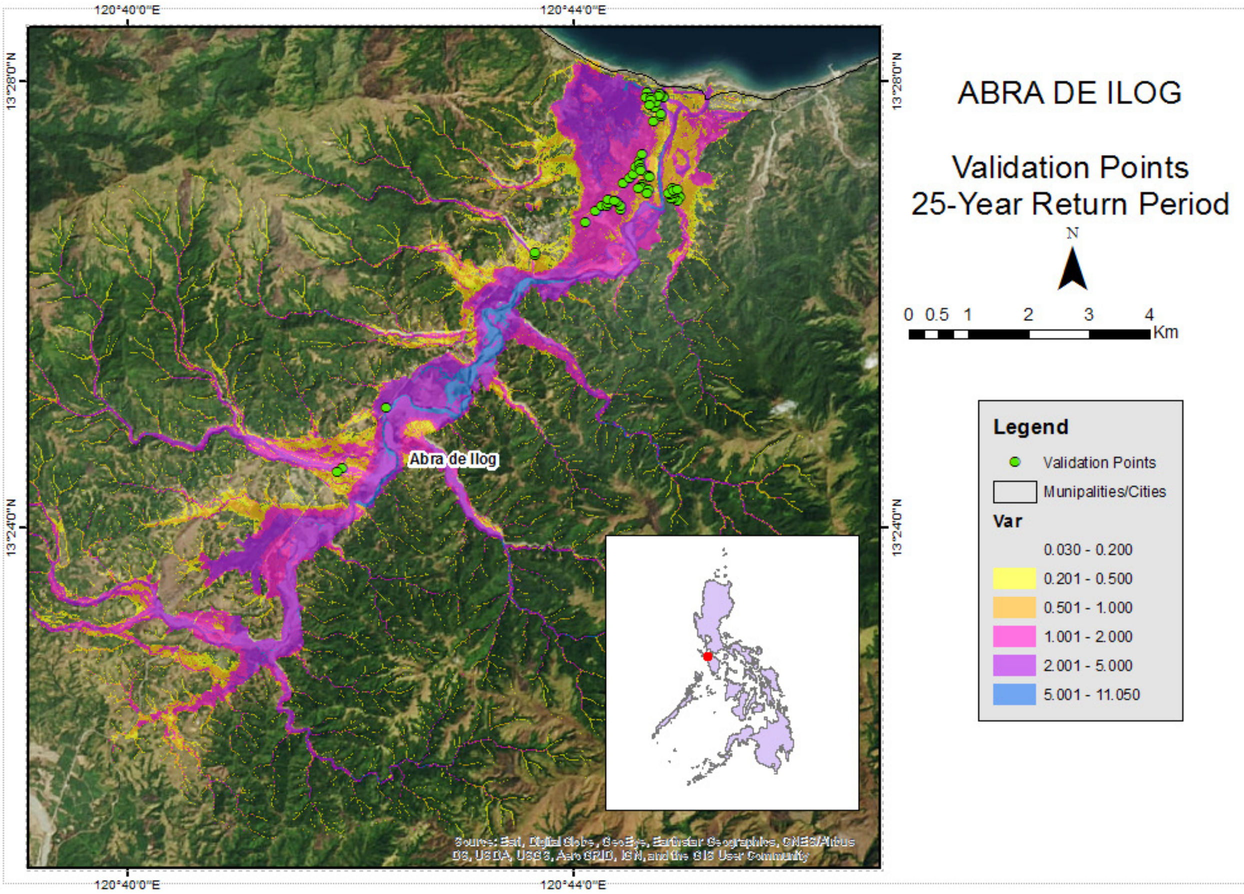


Figure 81. Validation points for 25-year Flood Depth Map of Abra de Ilog Floodplain

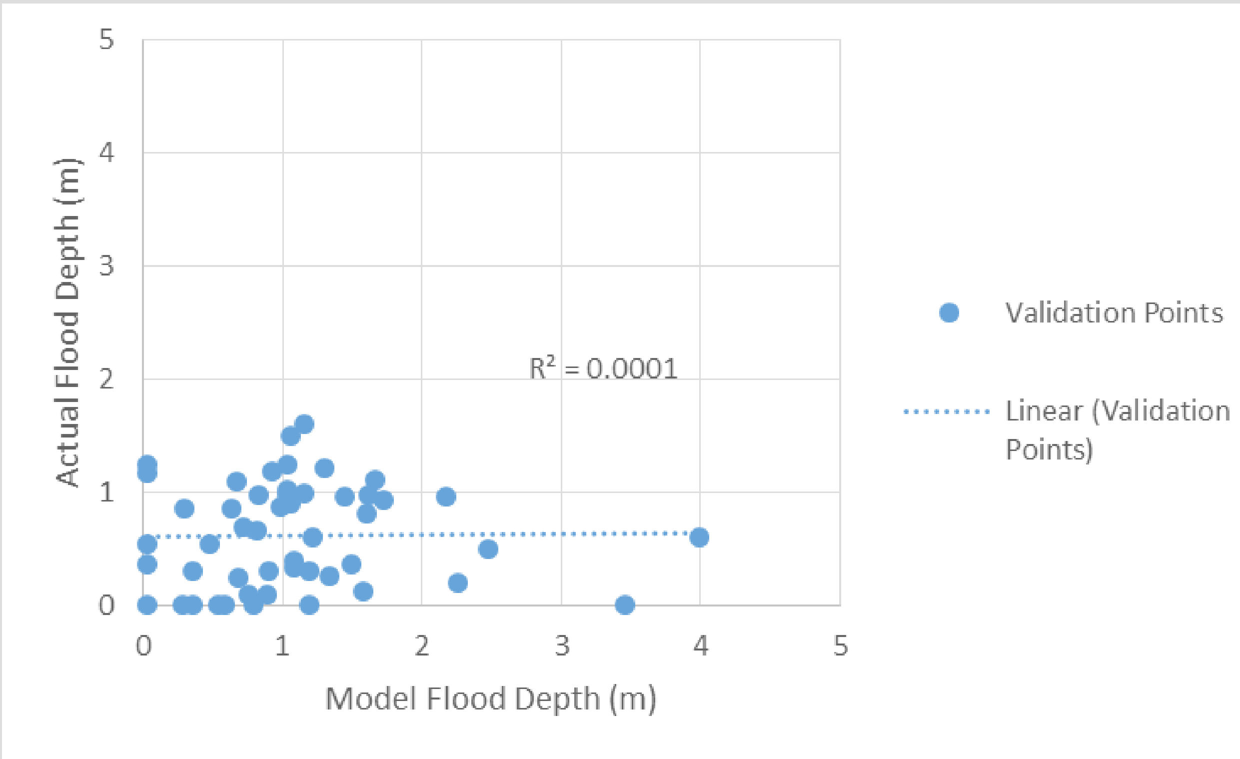


Figure 82. Flood map depth vs. actual flood depth

Table 36. Actual flood vs simulated flood depth at different levels in the Abra de Ilog River Basin.

Actual Flood Depth (m)	Modeled Flood Depth (m)						
	0-0.20	0.21-0.50	0.51-1.00	1.01-2.00	2.01-5.00	> 5.00	Total
0-0.20	1	2	5	2	2	0	12
0.21-0.50	1	1	2	5	1	0	10
0.51-1.00	1	2	5	8	2	0	18
1.01-2.00	2	0	2	6	0	0	10
2.01-5.00	0	0	0	0	0	0	0
> 5.00	0	0	0	0	0	0	0
Total	5	5	14	21	5	0	50

The overall accuracy generated by the flood model is estimated at 26.00% with 13 points correctly matching the actual flood depths. In addition, there were 15 points estimated one level above and below the correct flood depths while there were 13 points and 7 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 4 points were overestimated while a total of 8 points were underestimated in the modelled flood depths of Abra de Ilog. Table 37 depicts the summary of the Accuracy Assessment in the Abra de Ilog River Basin Survey.

Table 37. Summary of the Accuracy Assessment in the Abra de Ilog River Basin Survey

	No. of Points	%
Correct	13	26.00
Overestimated	29	58.00
Underestimated	8	16.00
Total	50	100.00

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ANNEXES

Annex 1. Optech Technical Specification of the Pegasus and Aquarius Sensors

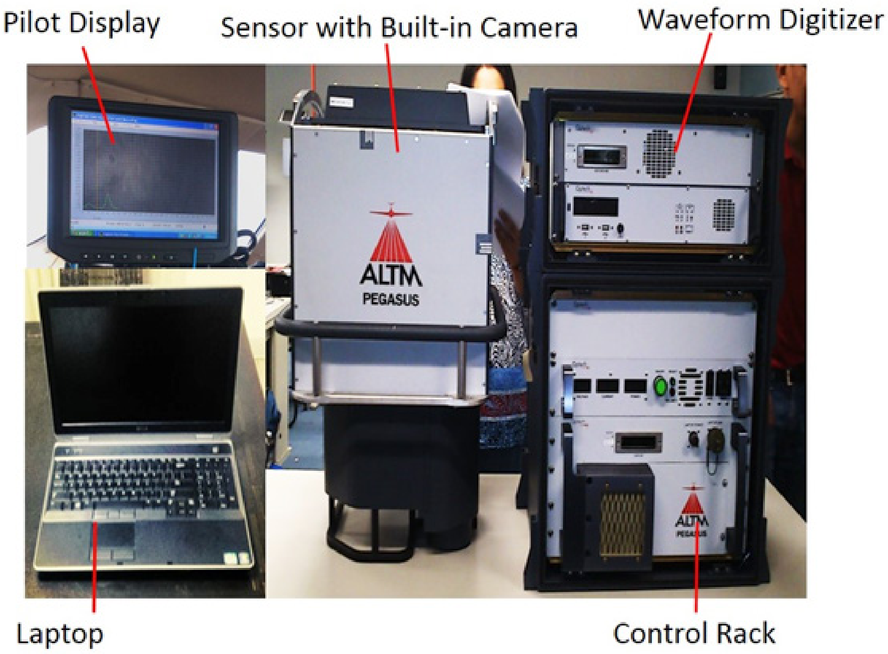

Figure A-1.2. Pegasus Sensor

Table A-1.2. Parameters and Specification 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

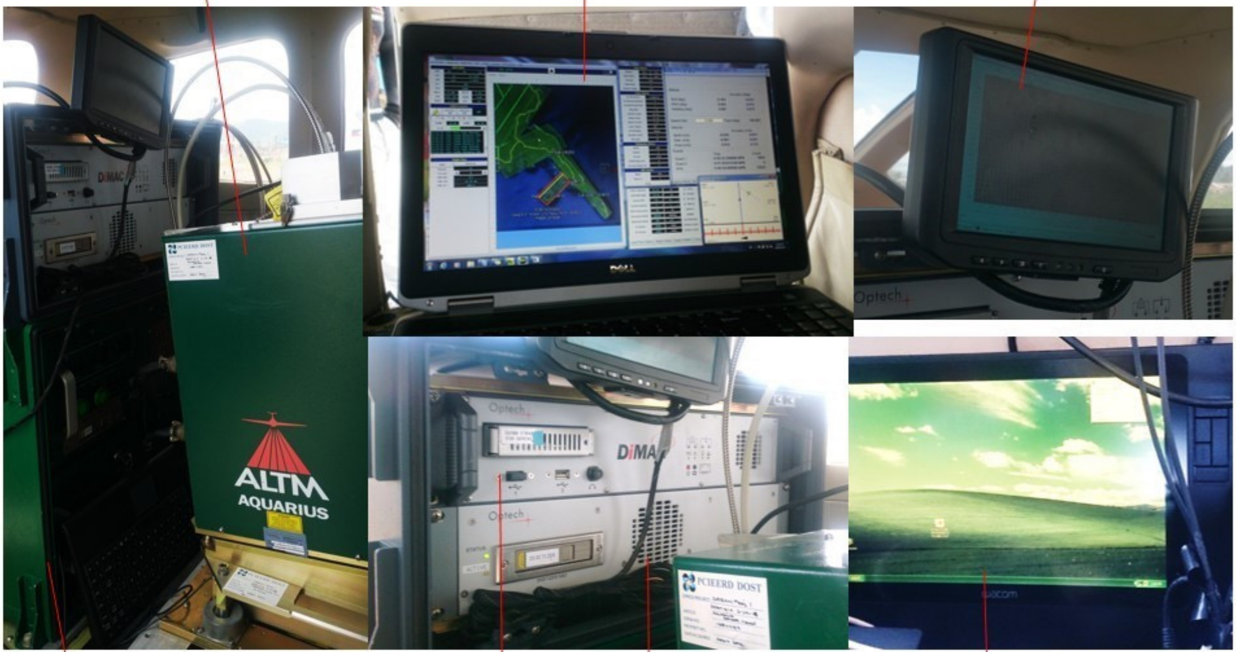

Figure A-1.2. Aquarius Sensor

Table A-1.2. Parameters and Specification of the Aquarius Sensor

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

Annex 2. NAMRIA Certification of Reference Points Used in the LIDAR Survey

1. MRW-36

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

February 26, 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: **OCCIDENTAL MINDORO**
Station Name: **MRW-36**
Order: **2nd**

Island: **LUZON**		Barangay: **CABACAO**
Municipality: **ABRA DE ILOG**		
	PRS92 Coordinates	
Latitude: **13° 21' 44.07349"**	Longitude: **120° 39' 20.54160"**	Ellipsoidal Hgt: **31.49300 m.**
	WGS84 Coordinates	
Latitude: **13° 21' 38.91908"**	Longitude: **120° 39' 25.54340"**	Ellipsoidal Hgt: **77.62100 m.**
	PTM Coordinates	
Northing: **1477646.985 m.**	Easting: **462705.446 m.**	Zone: **3**
	UTM Coordinates	
Northing: **1,478,304.87**	Easting: **246,088.34**	Zone: **51**

Location Description

MRW-36

From Abra de Ilog to Mamburao, along Nat'l Road, approx. 12.6 Km. from Abra de Ilog Town Proper, 600 m from Km. post 427, 400 m before Km. post 426, located Baclaran Bridge at Brgy. Cabacao, Abra de Ilog, Occ., Mindoro. Station is located near footpath of Baclaran Bridge. Mark is the head of a 4 in. copper nail flushed in a cement block embedded in the ground with inscriptions, MRW-36, 2007, NAMRIA".

Requesting Party: **UP DREAM**
Pupose: **Reference**
OR Number: **8795440 A**
T.N.: **2014-395**

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

9902262014143513

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

Figure A-2.1. MRE-36

2. MRE-34

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

February 26, 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: **OCCIDENTAL MINDORO**
Station Name: **MRW-34**
Order: **2nd**

Island: **LUZON**		Barangay: **ARMADO**
Municipality: **ABRA DE ILOG**		
	PRS92 Coordinates	
Latitude: **13° 17' 25.00981"**	Longitude: **120° 37' 41.53630"**	Ellipsoidal Hgt: **8.01600 m.**
	WGS84 Coordinates	
Latitude: **13° 17' 19.87026"**	Longitude: **120° 37' 46.54446"**	Ellipsoidal Hgt: **54.26900 m.**
	PTM Coordinates	
Northing: **1469690.588 m.**	Easting: **459714.493 m.**	Zone: **3**
	UTM Coordinates	
Northing: **1,470,369.33**	Easting: **243,032.08**	Zone: **51**

Location Description

MRW-34

From Abra de Ilog to San Jose, along Nat'l Road approx. 20.3 Km. from Abra de Ilog Town Proper, 300 m from Km. post 418, 9.7 Km. before Mamburao Proper, located Balibago Bridge at Brgy. Armado, Sitio Balibago, Abra de Ilog, Occ. Mindoro. Station is located near footpath of Balibago Bridge. Mark is the head of a 4 in. copper nail flushed in a cement block embedded in the ground with inscriptions, "MRW-34, 2007, NAMRIA".

Requesting Party: **UP DREAM**
Pupose: **Reference**
OR Number: **8795440 A**
T.N.: **2014-396**

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

9902262014143532

CERTIFICATION INTERNATIONAL ISO 9001:2008
CIP/4701/12/09/814

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

Figure A-2.2. MRE-34

3. MRE-32

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

February 26, 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: **OCCIDENTAL MINDORO**
Station Name: **MRW-32**
Order: **2nd**

Island: **LUZON**		Barangay: **FATIMA (TII)**
Municipality: **MAMBURAO (CAPITAL)**		
	PRS92 Coordinates	
Latitude: **13° 10' 14.92094"**	Longitude: **120° 39' 52.29557"**	Ellipsoidal Hgt: **1.47400 m.**
	WGS84 Coordinates	
Latitude: **13° 10' 9.81293"**	Longitude: **120° 39' 57.31386"**	Ellipsoidal Hgt: **48.13600 m.**
	PTM Coordinates	
Northing: **1456469.064 m.**	Easting: **463632.46 m.**	Zone: **3**
	UTM Coordinates	
Northing: **1,457,111.12**	Easting: **246,845.90**	Zone: **51**

Location Description

MRW-32
From Abra de Ilog to San Jose, along Nat'l Road, approx. 11.4 Km. from Mamburao Town Proper, 400 m from Km. post 396, 12.6 Km. before Sta. Cruz Town Proper, right side of road located brgy. hall of Fatima, Mamburao, Occ. Mindoro, beside Fatima Elem. School. Station is located in corner fence of Day Care Center. Mark is the head of a 4 in. copper nail flushed in a cement block embedded in the ground with inscriptions, "MRW-32, 2007, NAMRIA".

Requesting Party: **UP DREAM**
Pupose: **Reference**
OR Number: **8795440 A**
T.N.: **2014-397**

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

9 9 0 2 2 6 2 0 1 4 1 4 3 5 5 2

CERTIFICATION INTERNATIONAL ISO 9001:2008 CIP/4701/12/09/814

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

Figure A-2.3. MRE-32

4. MRE-30

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

February 19, 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: **OCCIDENTAL MINDORO**	
	Station Name: **MRW-30**	
	Order: **2nd**	
Island: **LUZON**		Barangay: **PINAGTURILAN (SAN PEDRO)**
Municipality: **SANTA CRUZ**		
	PRS92 Coordinates	
Latitude: **12° 57' 32.22950"**	Longitude: **120° 53' 28.50896"**	Ellipsoidal Hgt: **42.01300 m.**
	WGS84 Coordinates	
Latitude: **12° 57' 27.19115"**	Longitude: **120° 53' 33.54442"**	Ellipsoidal Hgt: **89.79300 m.**
	PTM Coordinates	
Northing: **1433011.7 m.**	Easting: **488201.05 m.**	Zone: **3**
	UTM Coordinates	
Northing: **1,433,451.97**	Easting: **271,237.33**	Zone: **51**

Location Description

MRW-30

From the Sablayan Astrodome, travel N along the Nat'l Road approx. 35 Km. up to Amny bridge, the Station is permanently marked and located at the SE end of the catwalk of Amnay bridge, and about 2 m SE of Km. post 356. Station is located in Brgy. Pinagturilan, Sitio Kabangkalan, Occ. Mindoro. Mark is the head of 4 in. copper nail flushed in a cement block embedded in the ground with inscriptions, "MRW-30, 2007, NAMRIA".

Requesting Party: **UP DREAM**
Pupose: **Reference**
OR Number: **8795394 A**
T.N.: **2014-356**

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

9902192014140947

CERTIFICATION INTERNATIONAL ISO 9001:2008
CIP/4701/12/09/814

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

Figure A-2.4. MRE-30

5. MC-52

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

February 26, 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: **OCCIDENTAL MINDORO**
Station Name: **MC-52**

Island: **LUZON**	Municipality: **ABRA DE ILOG**	Barangay: **ARMADO**
Elevation: **9.0283 m.**	Order: **1st Order**	Datum: **Mean Sea Level**

Location Description

BM MC-52
The station is in Sitio Balibago, Brgy. Armado, municipality of Abra de Ilog, Occidental Mindoro. From Abra de Ilog, station is located along the national road in the NE end of the catwalk of Balibago bridge. Approximately 150 m from KM post 418 and about 21.15 KM from the municipality of Abra de Ilog and 9.85 KM to the municipality of Mamburao. Mark is the head of a 4" copper nail flushed in a cement block embedded in the ground with inscription MC-52 2007 NAMRIA.

Requesting Party:	**UP DREAM**
Pupose:	**Reference**
OR Number:	**8795440 A**
T.N.:	**2014-390**

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

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

CERTIFICATION INTERNATIONAL ISO 9001:2008
CIP/4701/12/09/814

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

Figure A-2.5. MC-52

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

1. MC-52

Baseline Processing Report

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
MRW-34 --- MC-52 (B1)	MRW-34	MC-52	Fixed	0.002	0.003	33°08'19"	24.291	0.070
MRW-34 --- MC-52 (B3)	MRW-34	MC-52	Fixed	0.002	0.003	33°07'47"	24.284	0.064
MRW-34 --- MC-52 (B2)	MRW-34	MC-52	Fixed	0.001	0.003	33°07'15"	24.282	0.072

Acceptance Summary

Processed	Passed	Flag	Fail
3	3	0	0

Vector Components (Mark to Mark)

From:	MRW-34				
Grid		Local		Global	
Easting	243032.088 m	Latitude	N13°17'25.00981"	Latitude	N13°17'19.87026"
Northing	1470369.329 m	Longitude	E120°37'41.53631"	Longitude	E120°37'46.54446"
Elevation	10.923 m	Height	8.016 m	Height	54.269 m

To:	MC-52				
Grid		Local		Global	
Easting	243045.566 m	Latitude	N13°17'25.67172"	Latitude	N13°17'20.53214"
Northing	1470389.550 m	Longitude	E120°37'41.97748"	Longitude	E120°37'46.98562"
Elevation	10.990 m	Height	8.086 m	Height	54.339 m

Vector					
ΔEasting	13.478 m	NS Fwd Azimuth	33°08'19"	ΔX	-9.078 m
ΔNorthing	20.221 m	Ellipsoid Dist.	24.291 m	ΔY	-10.730 m
ΔElevation	0.068 m	ΔHeight	0.070 m	ΔZ	19.812 m

Standard Errors

Vector errors:					
σ ΔEasting	0.001 m	σ NS fwd Azimuth	0°00'06"	σ ΔX	0.001 m
σ ΔNorthing	0.001 m	σ Ellipsoid Dist.	0.001 m	σ ΔY	0.001 m
σ ΔElevation	0.002 m	σ ΔHeight	0.002 m	σ ΔZ	0.001 m

Figure A-3.1. Baseline Processing Report - A

2. MRW-DAC-00

Baseline Processing Report

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
MRWDAC-00 --- MRW-30 (B1)	MRW-30	MRWDAC-00	Fixed	0.003	0.011	312°40'19"	43136.391	-30.412
MRWDAC-00 --- MRW-30 (B2)	MRW-30	MRWDAC-00	Fixed	0.006	0.016	312°40'19"	43136.383	-30.384

Acceptance Summary

Processed	Passed	Flag	Fail
2	2	0	0

Vector Components (Mark to Mark)

From:	MRW-30				
Grid		Local		Global	
Easting	271237.336 m	Latitude	N12°57'32.22951"	Latitude	N12°57'27.19115"
Northing	1433451.975 m	Longitude	E120°53'28.50896"	Longitude	E120°53'33.54442"
Elevation	42.722 m	Height	42.013 m	Height	89.793 m

To:	MRWDAC-00				
Grid		Local		Global	
Easting	239755.834 m	Latitude	N13°13'23.10541"	Latitude	N13°13'17.97945"
Northing	1462963.518 m	Longitude	E120°35'55.10583"	Longitude	E120°36'00.11991"
Elevation	15.198 m	Height	11.601 m	Height	57.961 m

Vector					
ΔEasting	-31481.502 m	NS Fwd Azimuth	312°40'19"	ΔX	30671.804 m
ΔNorthing	29511.543 m	Ellipsoid Dist.	43136.391 m	ΔY	10509.502 m
ΔElevation	-27.524 m	ΔHeight	-30.412 m	ΔZ	28452.496 m

Standard Errors

Vector errors:					
σ ΔEasting	0.001 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.003 m
σ ΔNorthing	0.001 m	σ Ellipsoid Dist.	0.001 m	σ ΔY	0.005 m
σ ΔElevation	0.006 m	σ ΔHeight	0.006 m	σ ΔZ	0.002 m

Figure A-3.2. Baseline Processing Report - B

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, DR.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader - I	ENGR. CZAR JAKIRI SARMIENTO	UP-TCAGP
		ENGR. LOUIE P. BALICANTA	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUÑA	UP-TCAGP
		ENGR. LOVELYN ASUNCION	UP-TCAGP

FIELD TEAM

LiDAR Operation	Senior Science Research Specialist (SSRS)	PAULINE JOANNE ARCEO	UP-TCAGP
	Research Associate (RA)	ENGR. LARAH PARAGAS	UP-TCAGP
	RA	PATRICIA YSABEL ALCANTARA	UP-TCAGP
	RA	MILLIE SHANE REYES	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	GRACE SINADJAN	UP-TCAGP
	RA	FRANK NICOLAS ILEJAY	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. ERIC CACANINDIN	PHILIPPINE AIR FORCE (PAF)
		BENJIE CARBOLLEDO	PAF
	Pilot	CAPT. JEFFREY JEREMY ALAJAR	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. CESAR SHERWIN ALFONSO	AAC
		CAPT. JACKSON JAVIER	AAC
		CAPT. JUSTIN REI JOYA	AAC

Annex 5. Data Transfer Sheet for Abra de Ilog Floodplain

DATA TRANSFER SHEET
Mar 7, 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	
16-2-14	1108A	3BLK29J47A	AQUARIUS	NA	368KB	622KB	134MB	699MB	2/1/6/1KB	5.37GB	NA	14MB	1KB	1KB	194KB	N/A	X:\Airborne_Raw\1108A
16-2-14	1110A	3BLK29K47B	AQUARIUS	NA	562/138KB	1.01MB	240MB	39.7GB	1KB	13.3GB	43.6GB	14MB	1KB	1KB	46KB	N/A	X:\Airborne_Raw\1110A
18-2-14	1116A	3BLK29KS49A	AQUARIUS	NA	659KB	4.08MB	245MB	71.7GB	32/165/2535KB	12GB	61.6GB	15.3MB	1KB	1KB	46KB	N/A	X:\Airborne_Raw\1116A
18-2-14	1118A	3BLK29JS49B	AQUARIUS	NA	540KB	1.04MB	204MB	48GB	1/372KB	11.3GB	59.2GB	15.3MB	1KB	1KB	211KB	N/A	X:\Airborne_Raw\1118A
19-2-14	1120A	3BLK29L50A	AQUARIUS	NA	691KB	1.13MB	251MB	75.8GB	526KB	14.2GB	19.8GB	13.2MB	1KB	1KB	252KB	N/A	X:\Airborne_Raw\1120A
19-2-14	1122A	3BLK29O50B	AQUARIUS	NA	168KB	1.48MB	98.3MB	17.1GB	3/150KB	3.74GB	17.3GB	13.2MB	1KB	1KB	57KB	N/A	X:\Airborne_Raw\1122A
20-2-14	1124A	3BLK29OS51A	AQUARIUS	NA	308KB	1.34MB	246MB	75.4GB	1/103/418/24KB	12.6GB	16.7GB	17.7MB	1KB	1KB	18KB	N/A	X:\Airborne_Raw\1124A
20-2-14	1126A	3BLK29M51B	AQUARIUS	NA	803KB	1.71MB	235MB	78GB	NA	13.9GB	74.8GB	17.7MB	1KB	1KB	NA	N/A	X:\Airborne_Raw\1126A

Received from

Name CHRIS JOAQUIN
Position RA
Signature

Received by

Name JOIDA F. PRIETO
Position SSRS
Signature

Figure A-5.1. Data Transfer Sheet for Abra de Ilog Floodplain - A

DATA TRANSFER SHEET
Occ. Mindoro 1/13/16

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
6-Dec-15	3058P	1BLK29C340A	pegasus	752	189	5.69	120	9.79	74	7.56	na	15.4	1KB	1KB	40	na	Z:\DAC\RAW DATA
6-Dec-15	3060P	1BLK29DE340B	pegasus	460	108	3.43	115	6.09	48	4.79	na	15.4	1KB	1KB	394/344/58	na	Z:\DAC\RAW DATA
7-Dec-15	3062P	1BLK29BCS341A	pegasus	1.45	430	9.18	206	26.6	192	14.4	na	7.51	1KB	1KB	100/89/95	na	Z:\DAC\RAW DATA
8-Dec-15	3066P	1BLK29ACDI342A	pegasus	982	276	7.18	177	17	121	9.79	na	16	1KB	1KB	146/156	na	Z:\DAC\RAW DATA
8-Dec-15	3068P	1BLK29GJ342B	pegasus	0	67	2.7	114	4.63	37	2.77	na	16	1KB	1KB	146/156	na	Z:\DAC\RAW DATA
9-Dec-15	3070P	1BLK29GHI343A	pegasus	953	217	5.7	143	14.3	na	9.37	na	5.96	1KB	1KB	146/156	na	Z:\DAC\RAW DATA
10-Dec-15	3074P	1BLK29KLMO344A	pegasus	2.09	212	9.12	225	30.9	224	20.7	na	14.1	1KB	1KB	313	na	Z:\DAC\RAW DATA
10-Dec-15	3076P	1BLK29P344B	pegasus	259	73	3.5	102	4.32	34	3.2	na	14.1	1KB	1KB	366/318/295/ 313/146/156	na	Z:\DAC\RAW DATA
11-Dec-15	3078P	1BLK29NQRS345A	pegasus	551	171	5.23	167	12.9	105	6.2	na	7.02	1KB	1KB	47/394/344/3 13/140	na	Z:\DAC\RAW DATA
12-Dec-15	3082P	1BLK29R346A	pegasus	932	206	6.85	174	13.1	95	9.22	na	7.61	1KB	1KB	47/140	na	Z:\DAC\RAW DATA

Received from

Name C. Joaquin
Position
Signature [signature]

Received by

Name AC Bongat AcBongat
Position SSRS
Signature AcBongat 1/15/16

Figure A-5.2. Data Transfer Sheet ffor Abra de Ilog Floodplain - B

DATA TRANSFER SHEET
Mar 19, 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	
Jan 15, 2014	989P	1PAMS015A	PEGASUS	1.02MB	NA	5.85MB	168MB	NA	NA	9.2GB	N/A	11MB	1KB	1KB	NA	N/A	X:\Airborne_Raw\989P
Jan 21, 2014	1004A	3PNG1AB021A	AQUARIUS	NA	NA	620KB	209MB	23.4GB	194KB	10.6GB	47.7GB	8.24MB	1KB	2KB	7/114/114KB	389/16KN	X:\Airborne_Raw\1004A
Jan 21, 2014	1006A	3PNG1ABS021B	AQUARIS	NA	NA	214KB	128MB	6.78GB	65KB	4.08GB	15.5GB	8.24MB	1KB	1KB	16/46/7KB	124KB	X:\Airborne_Raw\1006A
Jan 22, 2014	1008A	3PNG1AS022A	AQUARIUS	NA	NA	482KB	204MB	26.3GB	209KB	8.14GB	33.1GB	10.6MB	1KB	1KB	1/7/101KB	281KB	X:\Airborne_Raw\1008A
Feb 21, 2014	1128A	3BLK29I52A	AQUARIUS	NA	NA	1.34MB	269MB	6.32GB	1/872KB	16.1GB	NA	12.3MB	1KB	1KB	6/303KB	854KB	X:\Airborne_Raw\1128A
Feb 22, 2014	1132A	3BLK29IS53A/3BLK29H53A	AQUARIUS	NA	NA	1.62MB	276MB	34.3GB	251/1/326KB	16.1GB	83.7GB	13.4MB	1KB	1KB	432KB	383/506/320/384KB	(DREAMPC30) C:\DAC Back up\OCC MINDORO FLIGHTS\1132A
Feb 22, 2014	1134A	3BLK29MS53B/3BLK29MR53B	AQUARIUS	NA	NA	1.08MB	144MB	27.8GB	105/28/1/30/55/44KB	4.99GB	12.6GB	13.4MB	1KB	1KB	102KB	131KB	(DREAMPC30) C:\DAC Back up\OCC MINDORO FLIGHTS\1134A
Feb 23, 2014	1136A	3BLK29HS54A/3BLK29HB54A	AQUARIUS	NA	NA	1.37MB	256MB	88.5GB	227/337/61KB	15GB	NA	15.8MB	1KB	1KB	268KB	265/265/520/36KB	(DREAMPC30) C:\DAC Back up\OCC MINDORO FLIGHTS\1136A
Feb 23, 2014	1138A	3BLK29E54B	AQUARIUS	NA	NA	833KB	196MB	50.4GB	408KB	8.89GB	42.6GB	15.8MB	1KB	1KB	172KB	500KB	(DREAMPC30) C:\DAC Back up\OCC MINDORO FLIGHTS\1138A
Feb 24, 2014	1140A	3BLK29ES55A/3BLK29G55A	AQUARIUS	NA	NA	961KB	241MB	53.3GB	401KB	9.99GB	40.8GB	12.1MB	1KB	1KB	367KB	244/264KB	(DREAMPC30) C:\DAC Back up\OCC MINDORO FLIGHTS\1140A
Feb 24, 2014	1142A	3BLK29P55B	AQUARIUS	NA	NA	2.04MB	228MB	61.7GB	56/490KB	12.4GB	64.2GB	12.1MB	1KB	1KB	709KB	247KB	(DREAMPC30) C:\DAC Back up\OCC MINDORO FLIGHTS\1142A

TRANSFERRED IN FREENAS.

Received from

Name CHRIS JOAQUIN

Position RA

Signature

Received by

Name JOIDA PRIETO

Position SSRS

Signature

Figure A-5.3. Data Transfer Sheet for Abra de Ilog Floodplain - C

Annex 6. Flight Logs for the Flight Missions

1. Flight Log for Mission 3BLK29M51B

DREAM Data Acquisition Flight Log — Flight Log No.: 1126

1 LiDAR Operator: LK Paragas	2 ALTM Model: Aqua	3 Mission Name: 3BLK29M51B	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification:
7 Pilot: J Javier	8 Co-Pilot: J Alajar	9 Route:			
10 Date: 2/20/14	12 Airport of Departure (Airport, City/Province): Mamburao		12 Airport of Arrival (Airport, City/Province):		
13 Engine On: 1404	14 Engine Off: 1809	15 Total Engine Time: 4+05	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather					
20 Remarks: Completed lines in area M					

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
Lorelyn Asuncion	JE C Lacaninan	JRS Javier	LK Paragas
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

Figure A-6.1. Flight Log for Mission 3BLK29M51B

2. Flight Log for 3BLK29MS53B/3BLK29MR53B Mission

DREAM Data Acquisition Flight Log

Flight Log No.: 1134

1 LiDAR Operator: PY Alcantara	2 ALTM Model: AQUA	3 Mission Name: 3BLK29MSMR53B	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification:
7 Pilot: J Alajar	8 Co-Pilot: J Javier	9 Route:			
10 Date: 2/22/14	12 Airport of Departure (Airport, City/Province): Mamburao		12 Airport of Arrival (Airport, City/Province): Mamburao		
13 Engine On: 1433	14 Engine Off: 1732	15 Total Engine Time: 2 759	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather					
20 Remarks: Mission Completed					

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
	JEC CACANINDIN	JEFFREY JEREMY ALAJAR	
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

Figure A-6.2. Flight Log for Mission 3BLK29MS53B/3BLK29MR53B

3. Flight Log for 1BLK29BC341A Mission

DREAM Program's Data Acquisition Flight Log — Flight Log No.: 2942

1 LiDAR Operator: MSREYES	2 ALTM Model: PEGASUS	3 Mission Name: 1BLK29BCS341A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9122
7 Pilot: CS ALFONSO	8 Co-Pilot: J JOTA	9 Route: Mamburao			
10 Date: DEC 7, 2015	12 Airport of Departure (Airport, City/Province): MAMBURAO		12 Airport of Arrival (Airport, City/Province): MAMBURAO		
13 Engine On: 0725	14 Engine Off: 1048	15 Total Engine Time: 3+23	16 Take off: 0730	17 Landing: 1043	18 Total Flight Time: 3+13
19 Weather: Windy with passing clouds					

20 Flight Classification

20.a Billable
- ✓ Acquisition Flight
- o Ferry Flight
- o System Test Flight
- o Calibration Flight

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

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

21 Remarks

Surveyed BLK 29B &C

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator	Aircraft Mechanic/ Technician
PAULINE ARCEO	[illegible] Carballedo	C. ALFONSO III	MS REYES	N.R. CALEON
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

Figure A-6.3. Flight Log for Mission 1BLK29BC341A

4. Flight Log for 1BLK29ACDF342A Mission

DREAM Program's Data Acquisition Flight Log — Flight Log No.: 2946

1 LiDAR Operator: G SINADJAN	2 ALTM Model: PEGASUS	3 Mission Name: 1BLK29ACDF342A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9122
7 Pilot: CS ALFONSO	8 Co-Pilot: J JOYA	9 Route: Mamburao - Mamburao			
10 Date: DEC 8, 2015	12 Airport of Departure (Airport, City/Province): MAMBURAO		12 Airport of Arrival (Airport, City/Province): MAMBURAO		
13 Engine On: 0708	14 Engine Off: 0955	15 Total Engine Time: 02+47	16 Take off: 0713	17 Landing: 0950	18 Total Flight Time: 2+37
19 Weather: Partly cloudy					

20 Flight Classification

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

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

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

21 Remarks

Successful flight. Surveyed BLK 29A,C,D,I

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator	Aircraft Mechanic/ Technician
PAULINE ARCEO	[signature] Carballedo	C. ALFONSO III	GRACE SINADJAN	N.R. CALEON
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

Figure A-6.4. Flight Log for Mission 1BLK29ACDF342A

Annex 7. Flight Status Reports

OCCIDENTAL MINDORO
February 20-22, 2014 and December 7–8, 2015

Table A-7.1. Flight Status Report

FLIGHT NO.	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
1126A	BLK29M	3BLK29M51B	LK PARAGAS	20-FEB-14	Completed 14 lines of Area M. Restarted the camera twice due to error in line 10 and 11.
1134A	BLK29MS & BLK29MR	3BLK29MS53B/ 3BLK29MR53B	PY ALCANTARA/ L ASUNCION	22-FEB-14	Completed the rest of area M. and Bathymetric test over Mamburao Reef (2 lines for the Bathy Area-BLK29MR). Digitizer hanged in line 1, no disk detected. Repeated line 1, still digitizer hanged and range missing. Restarted the system then moved to Area M then Mamburao Reef Area for the Bathy Test @300,400 and 550m flying altitudes.
3062P	SANTA CRUZ & ABRA DE ILOG	1BLK29BCS341A	MS REYES	7-DEC-15	SURVEYED BLK29B & C (PREVIOUS FLIGHT NO: 2942)
3066P	SANTA CRUZ, MAMBURAO & ABRA DE ILOG	1BLK29ACDI342A	G SINADJAN	8-DEC-15	SURVEYED BLK29A, C, D & I (PREVOUS FLIGHT NO: 2946)

LAS/SWATH BOUNDARIES PER MISSION FLIGHT

FLIGHT LOG NO. 1126A
AREA: BLK29M
MISSION NAME: 3BLK29M51B

SURVEY COVERAGE:

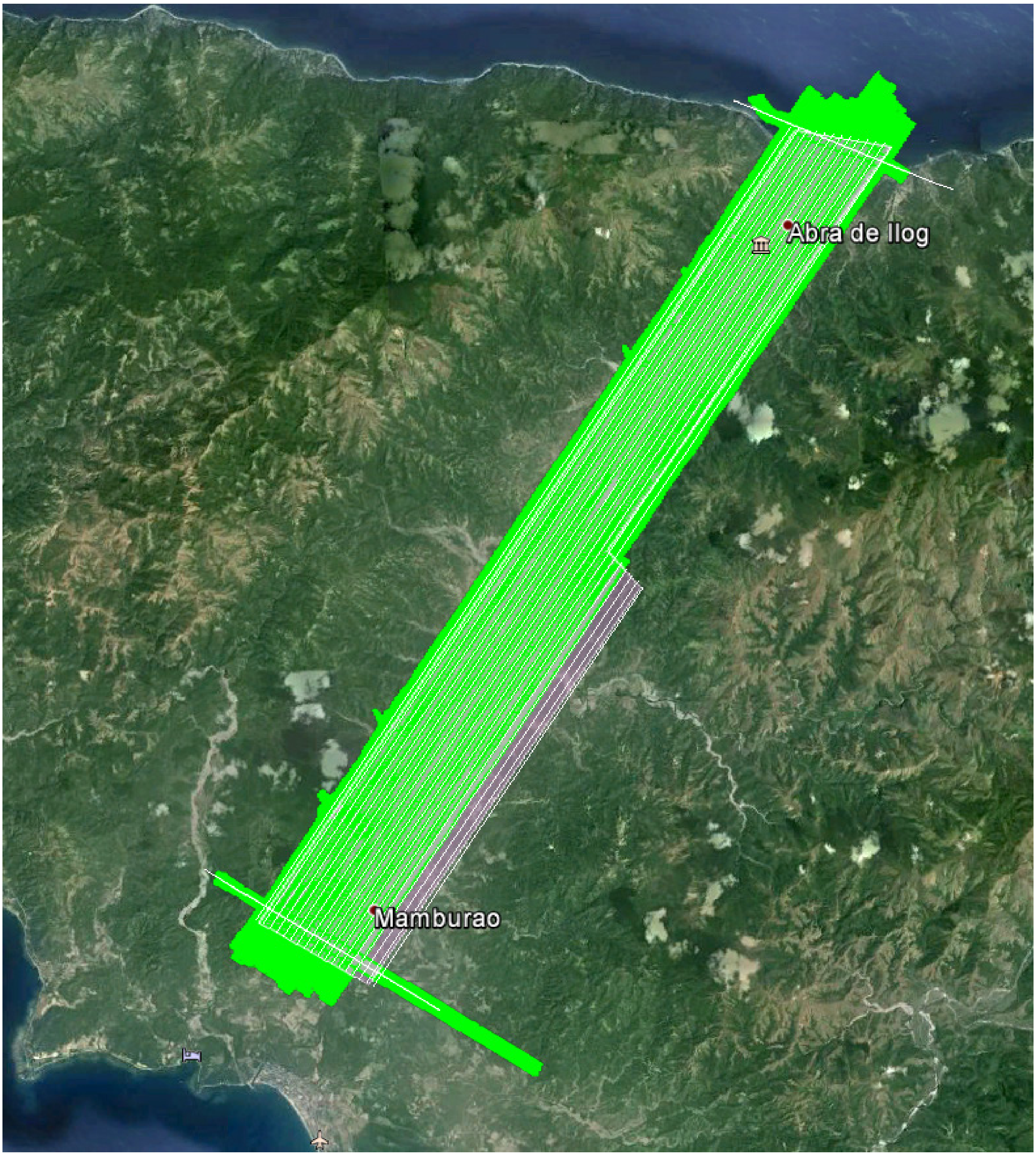

Figure A-7.1. Swath for Flight No. 1126A

FLIGHT LOG NO. 1134A
AREA: BLK29M
MISSION NAME: 3BLK29MS53B

SURVEY COVERAGE:

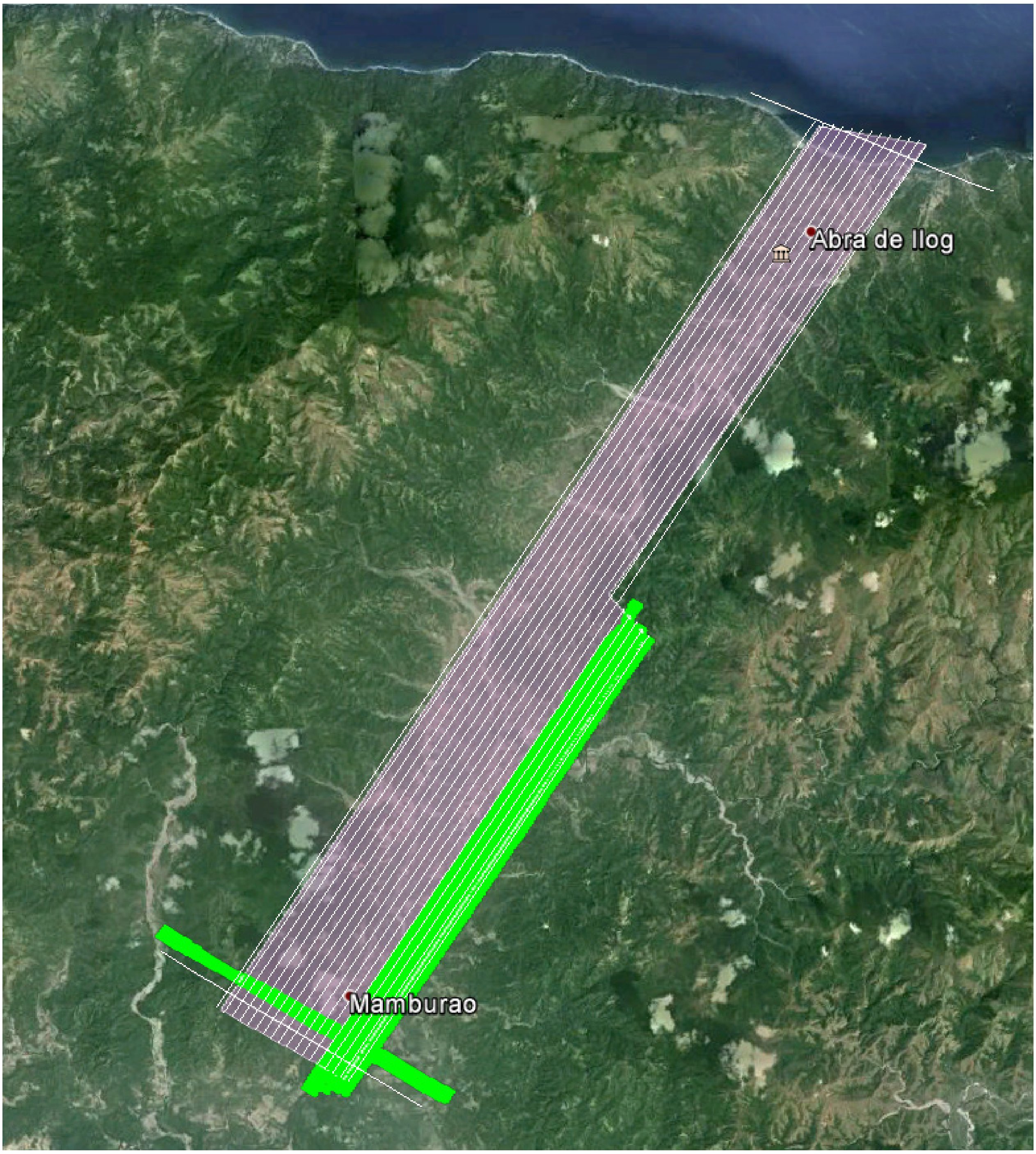

Figure A-7.2. Swath for Flight No. 1134A

FLIGHT NO.: 3062P
AREA: SANTA CRUZ & ABRA DE ILOG
MISSION NAME: 1BLK29BCS341A
PARAMETERS: ALT: 1100 m SCAN FREQ: 30 SCAN ANGLE: 25

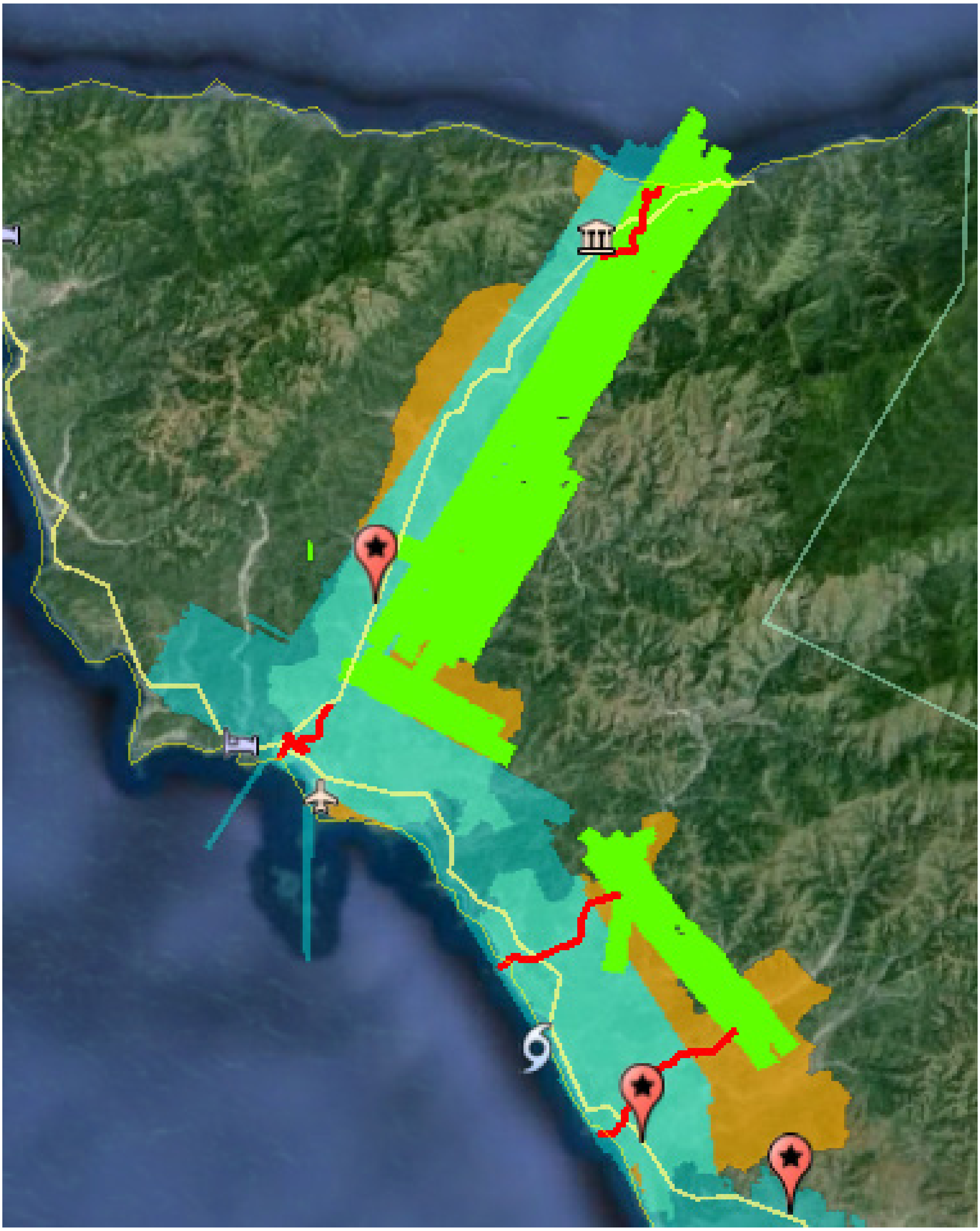

Figure A-7.3. Swath for Flight No. 3062P

FLIGHT NO.: 3066P
AREA: SANTA CRUZ, MAMBURAO & ABRA DE ILOG
MISSION NAME: 1BLK29ACDI342A
PARAMETERS: ALT: 1100 m SCAN FREQ: 30 SCAN ANGLE: 25

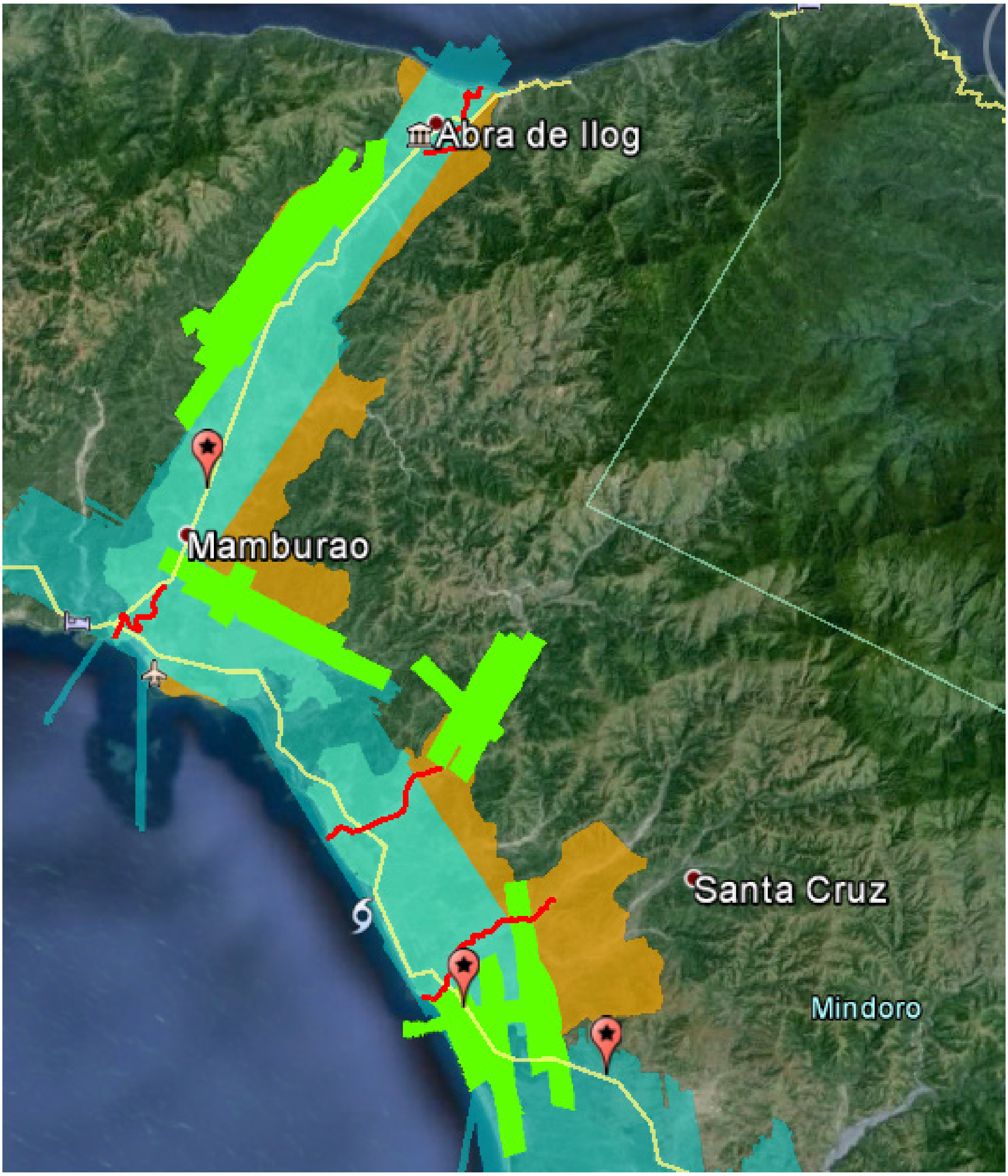

Figure A-7.4. Swath for Flight No. 3066P

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Blk29M

Flight Area	Occidental Mindoro
Mission Name	Blk29M
Inclusive Flights	1126A, 1134A
Range data size	18.89 GB
POS	379 MB
Image	105.8 GB
Transfer date	03/19/2014
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)	1.7
RMSE for East Position (<4.0 cm)	2.8
RMSE for Down Position (<8.0 cm)	3.2
Boresight correction stdev (<0.001deg)	0.000303
IMU attitude correction stdev (<0.001deg)	0.000886
GPS position stdev (<0.01m)	0.0339
Minimum % overlap (>25)	62.09%
Ave point cloud density per sq.m. (>2.0)	3.68
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	183
Maximum Height	380.3 m
Minimum Height	40.97 m
Classification (# of points)	
Ground	78,453,172
Low vegetation	45,704,761
Medium vegetation	86,385,387
High vegetation	106,569,732
Building	76,880,046
Orthophoto	Yes
Processed by	Engr. Kenneth Solidum, Engr. Melanie Hingpit, Jovy Narisma

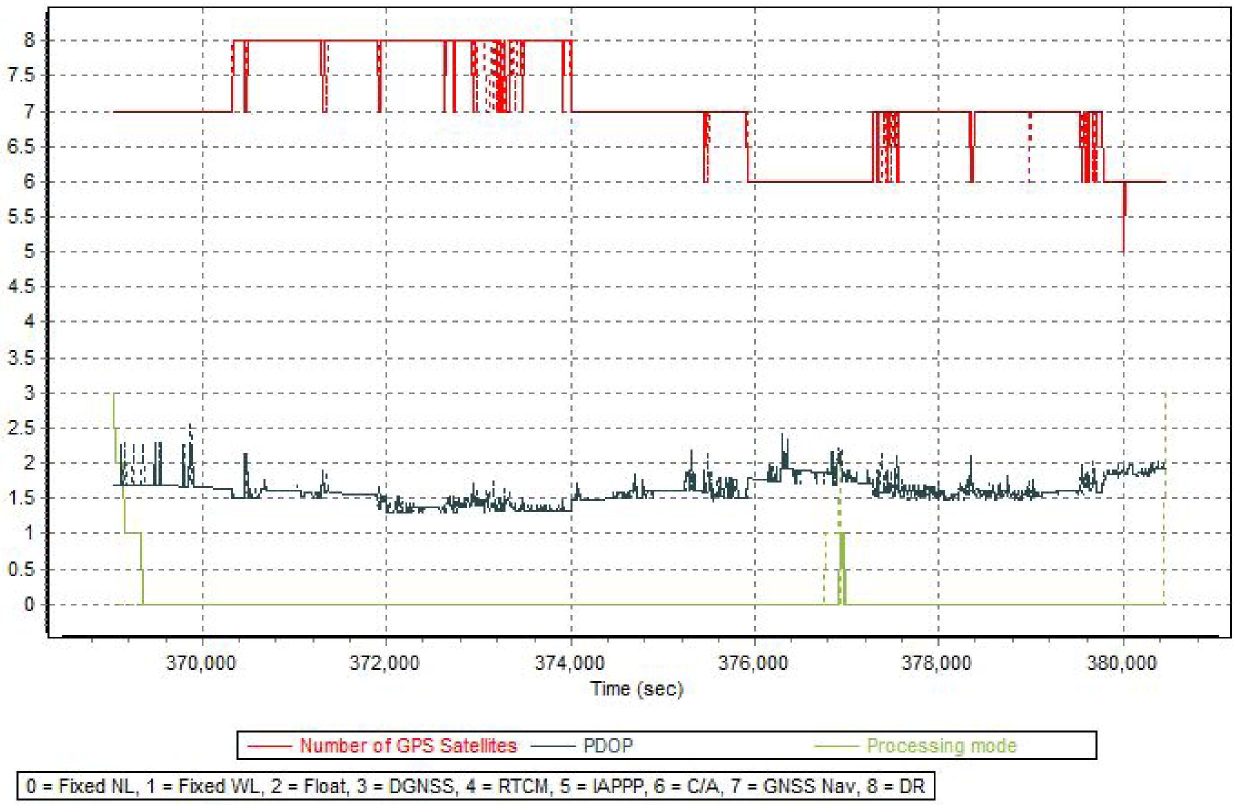

Figure A-8.1. Solution Status

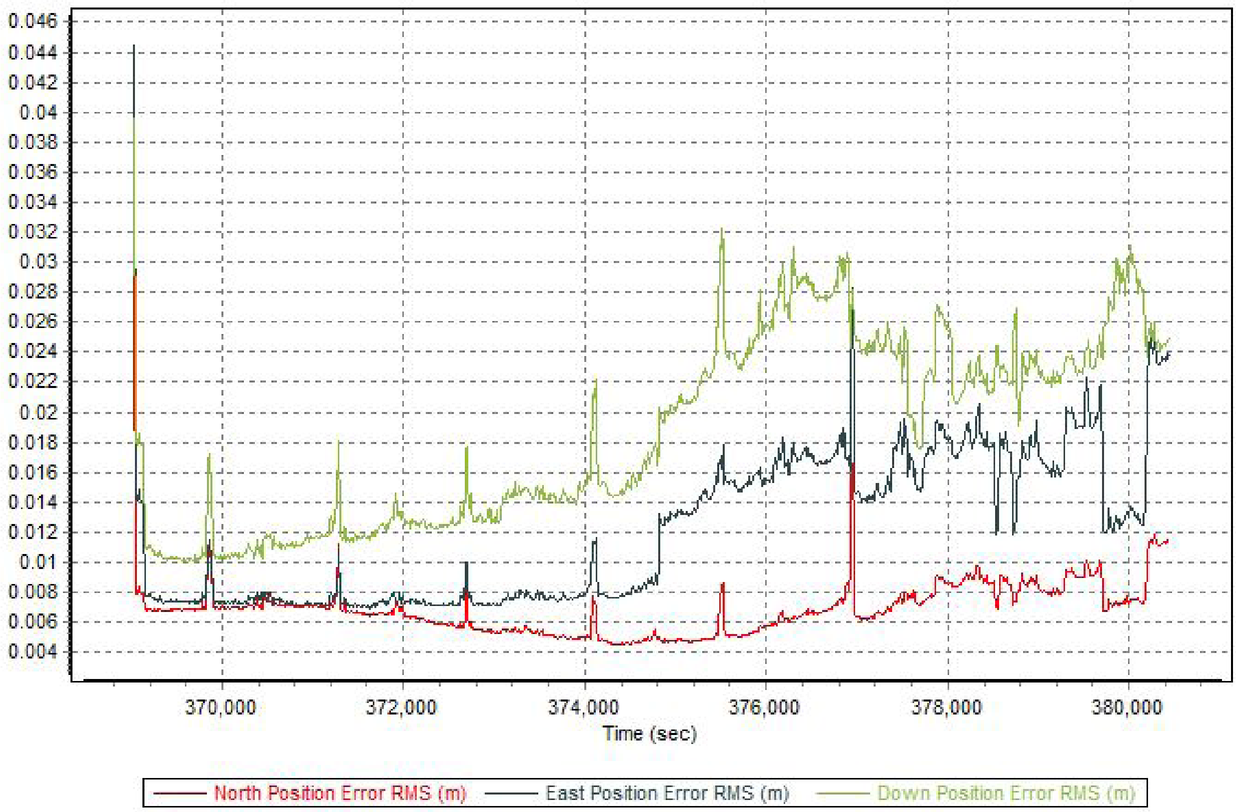

Figure A-8.2. Smoothed Performance Metrics Parameters

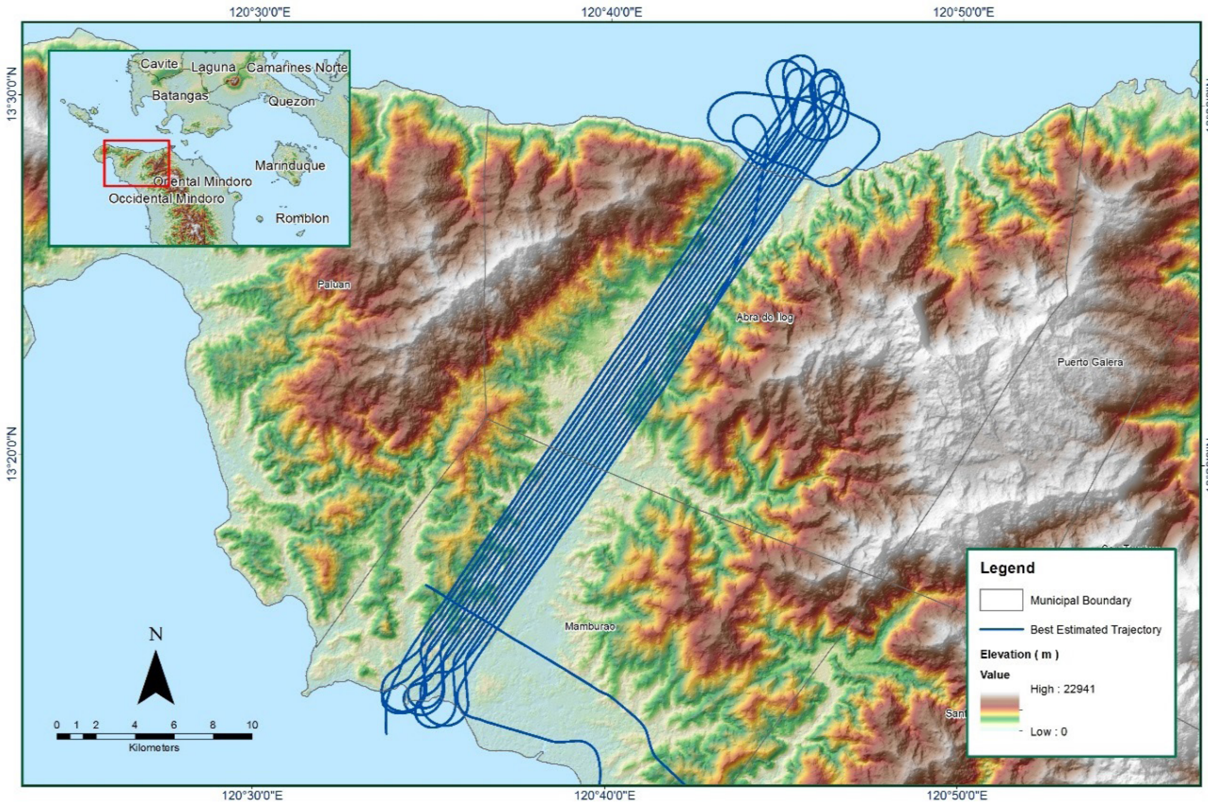

Figure A-8.3. Best Estimated Trajectory

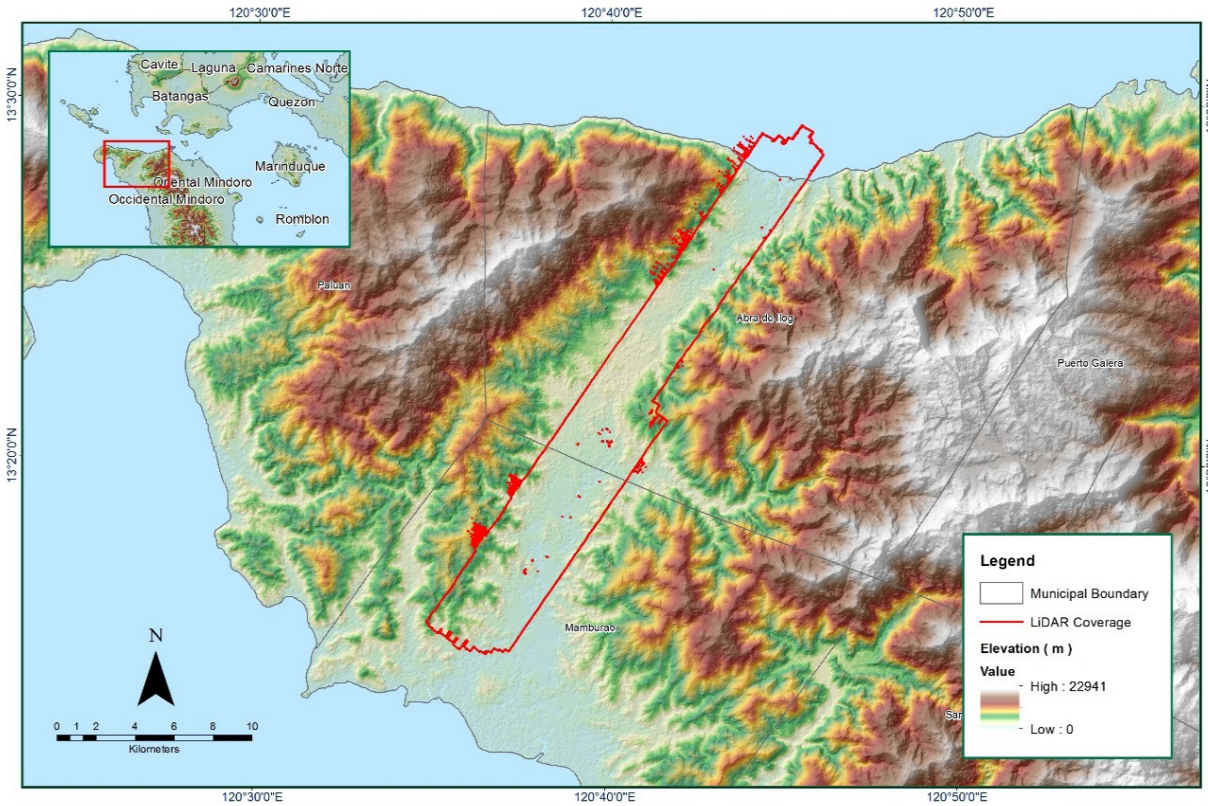

Figure A-8.4. Coverage of LiDAR data

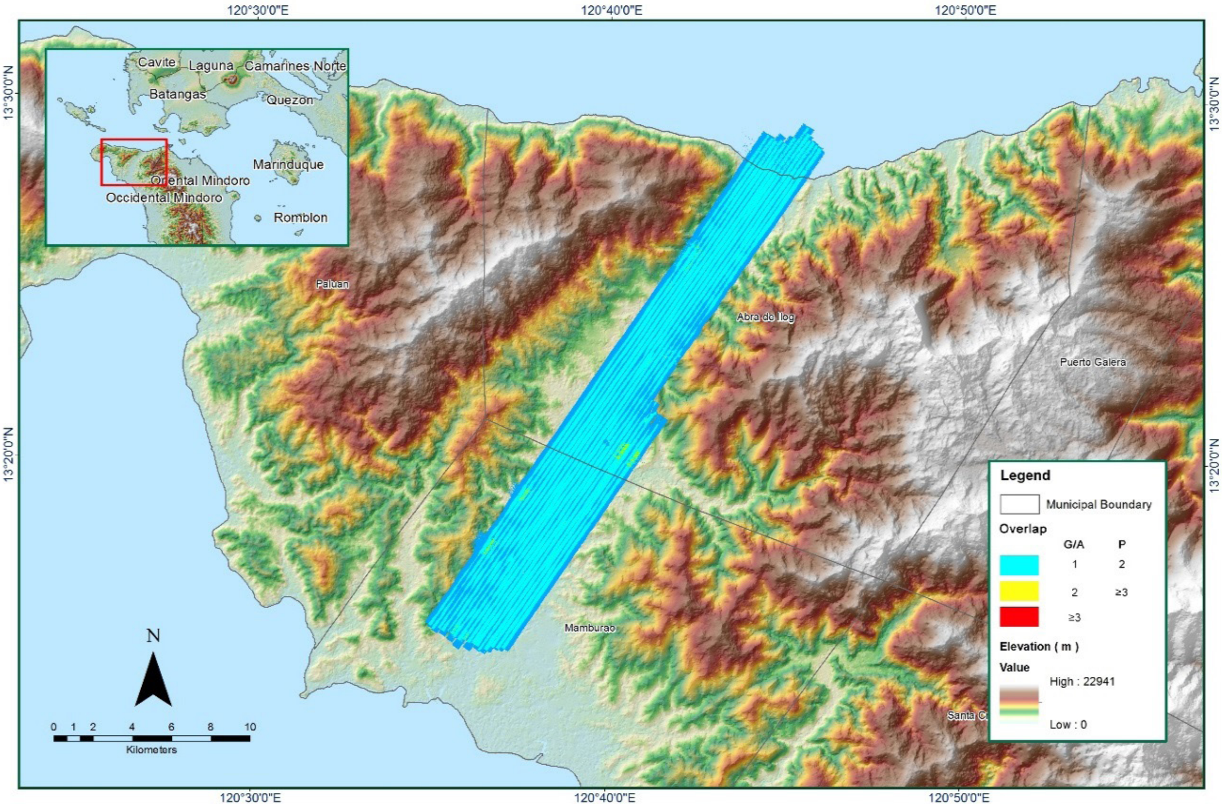

Figure A-8.5. Image of Data Overlap

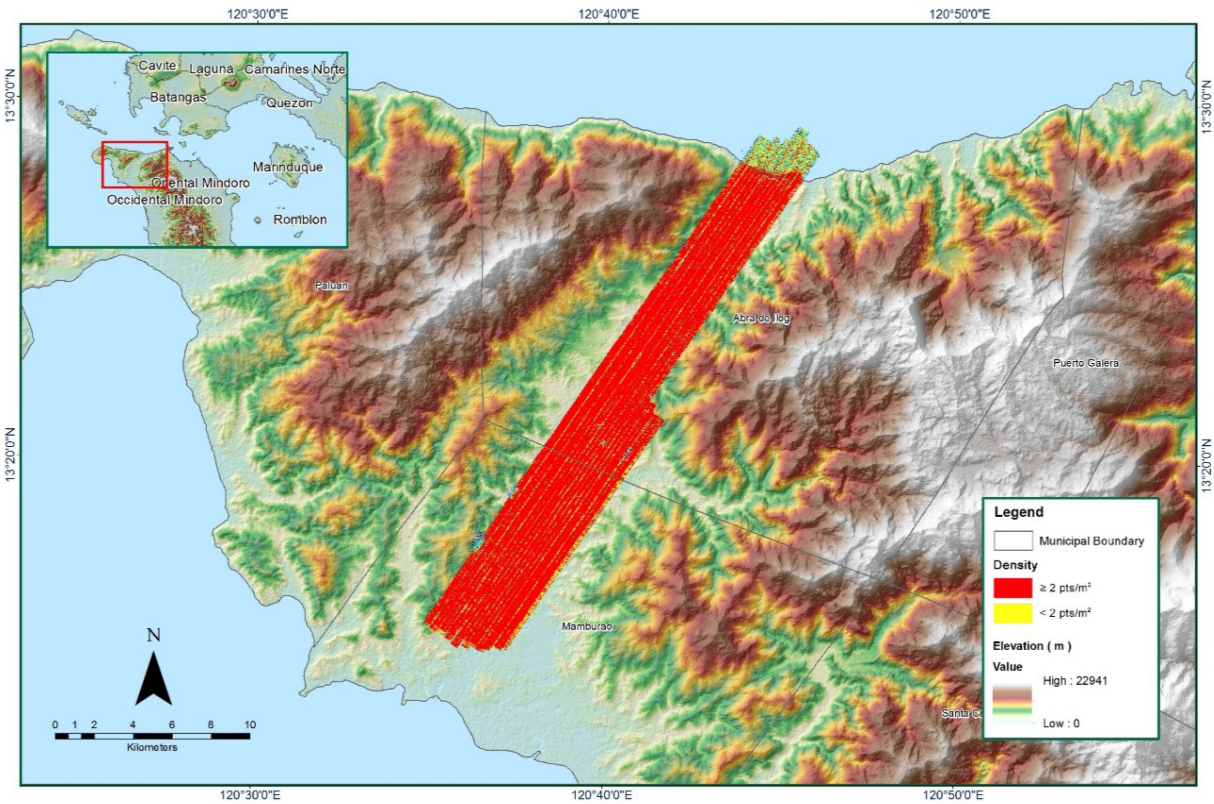

Figure A-8.6. Density map of merged LiDAR data

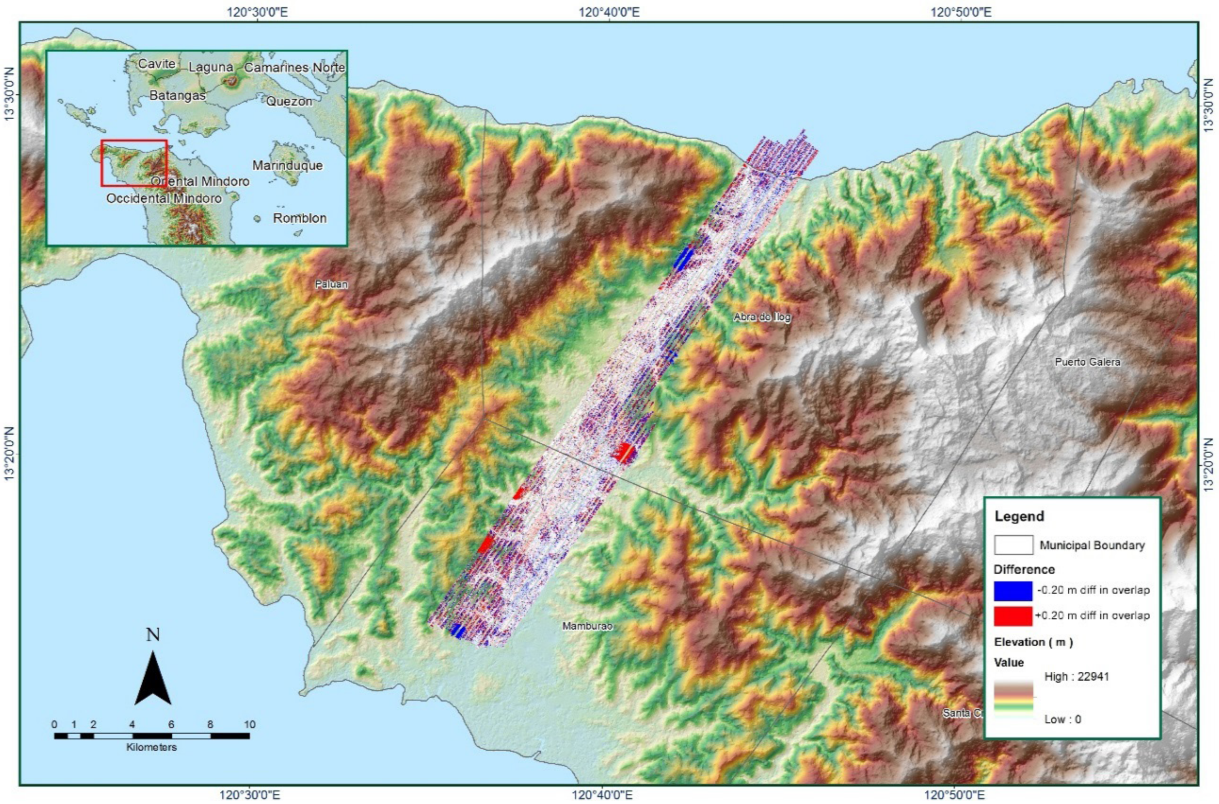

Figure A-8.7. Elevation difference between flight lines

Table A-8.2. Mission Summary Report for Mission Blk29M

Flight Area	Occidental Mindoro Reflights
Mission Name	Blk29M
Inclusive Flights	3066P
Range data size	9.79GB
POS	177MB
Image	17MB
Transfer date	January 15, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.45
RMSE for East Position (<4.0 cm)	1.89
RMSE for Down Position (<8.0 cm)	4.05
Boresight correction stdev (<0.001deg)	0.000356
IMU attitude correction stdev (<0.001deg)	0.000819
GPS position stdev (<0.01m)	0.0023
Minimum % overlap (>25)	33.51
Ave point cloud density per sq.m. (>2.0)	2.16
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	63
Maximum Height	477.95 m
Minimum Height	59.48 m
Classification (# of points)	
Ground	25,347,291
Low vegetation	15,633,995
Medium vegetation	54,037,309
High vegetation	122,201,386
Building	4,036,108
Orthophoto	Yes
Processed by	Engr. Irish Cortez, Engr. Jovelle Anjeanette Canlas, Jovy Narisma

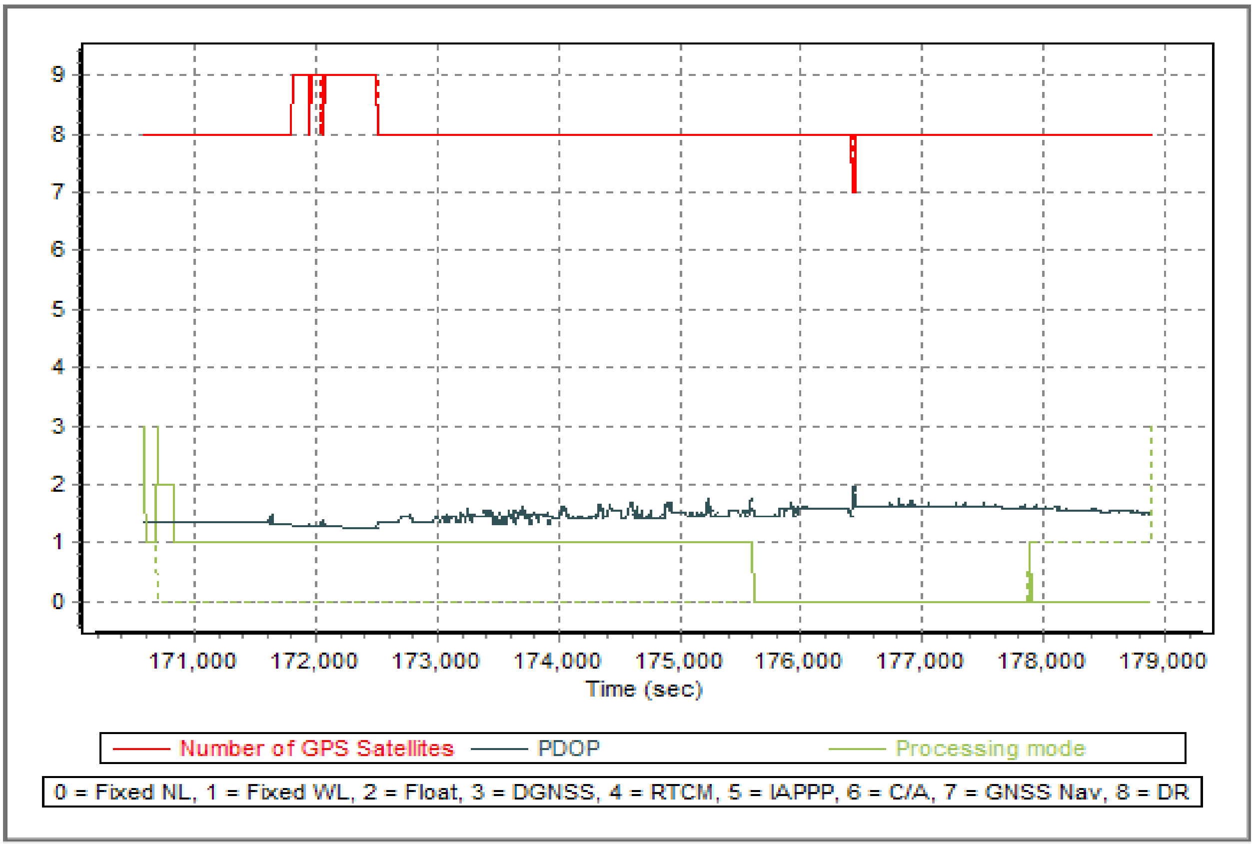

Figure A-8.8. Solution Status

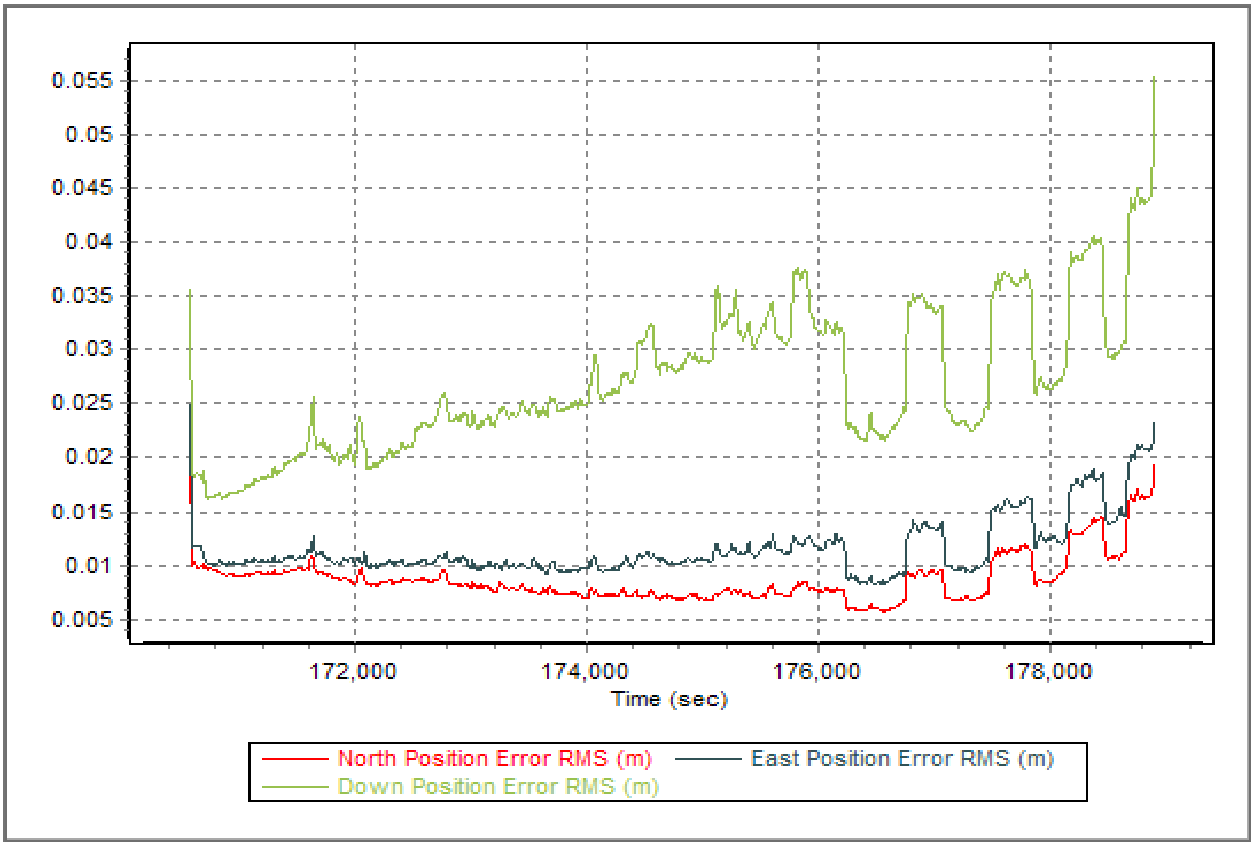

Figure A-8.9. Smoothed Performance Metrics Parameters

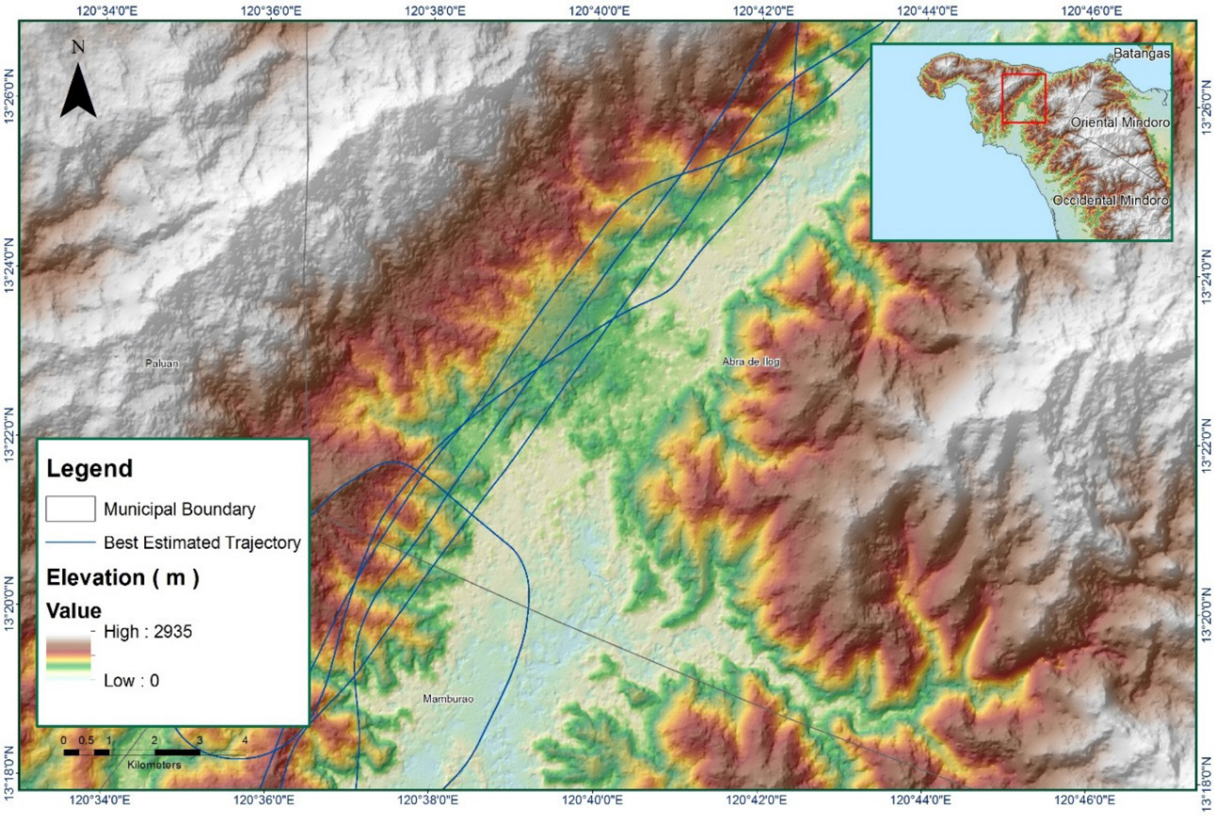

Figure A-8.10. Best Estimated Trajectory

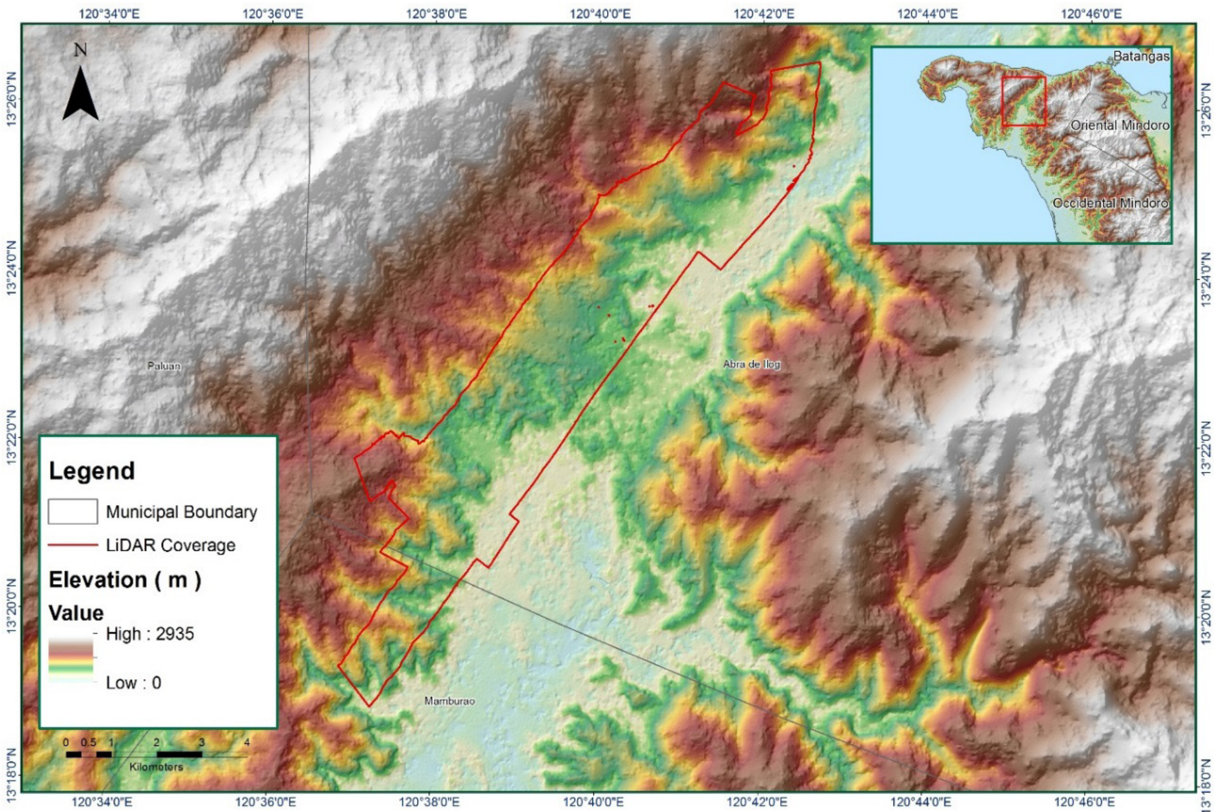

Figure A-8.11. Coverage of LiDAR data

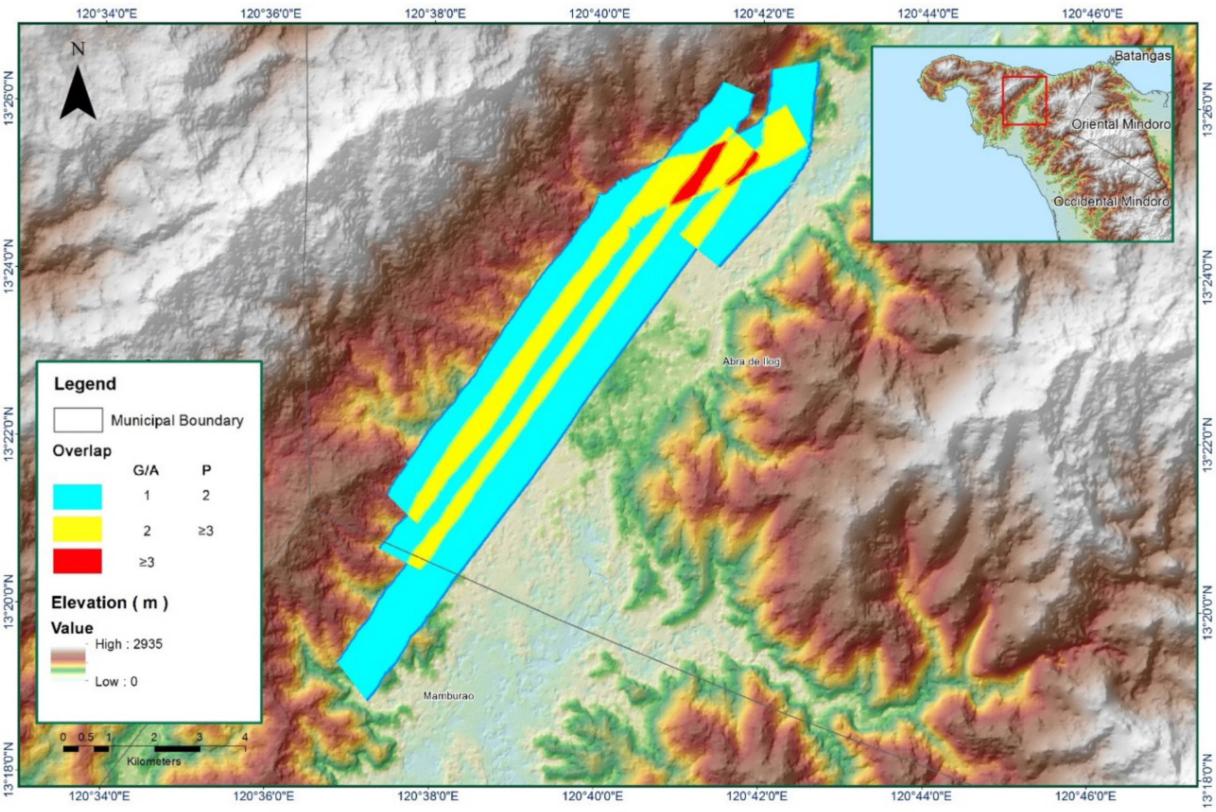

Figure A-8.12. Image of Data Overlap

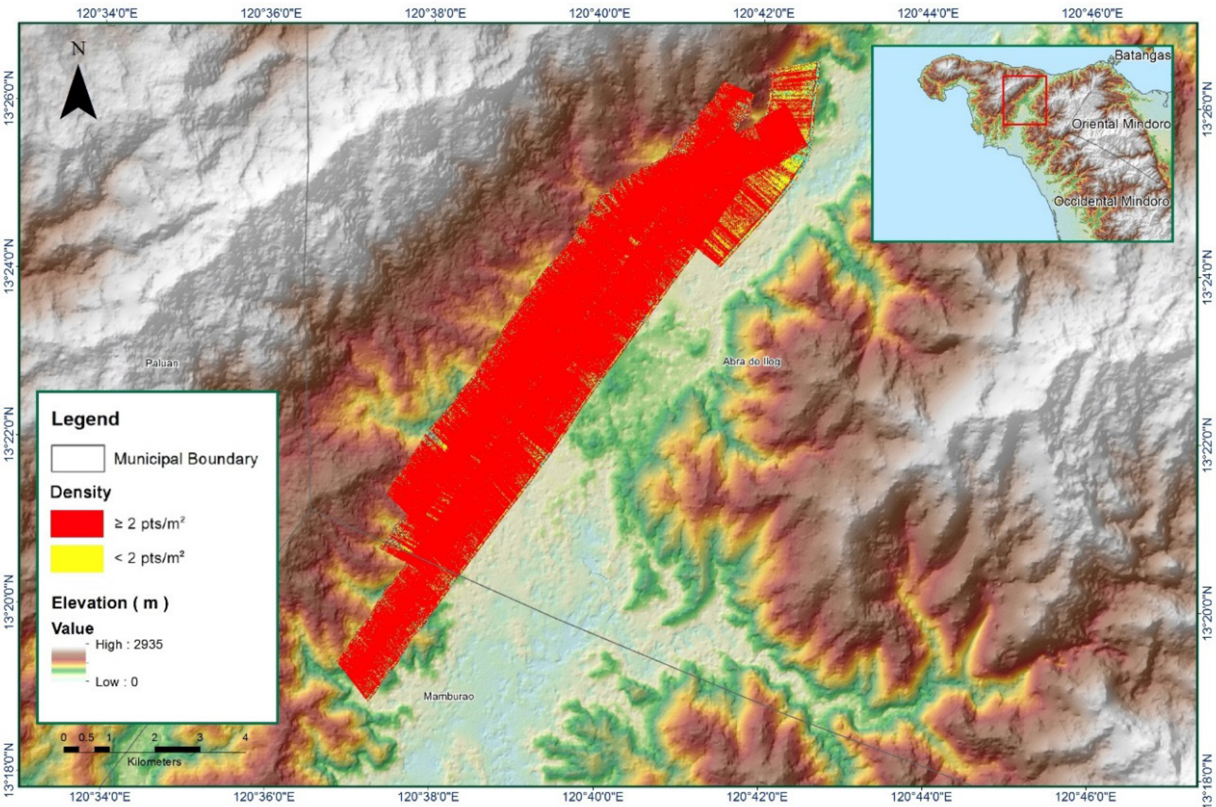

Figure A-8.13. Density map of merged LiDAR data

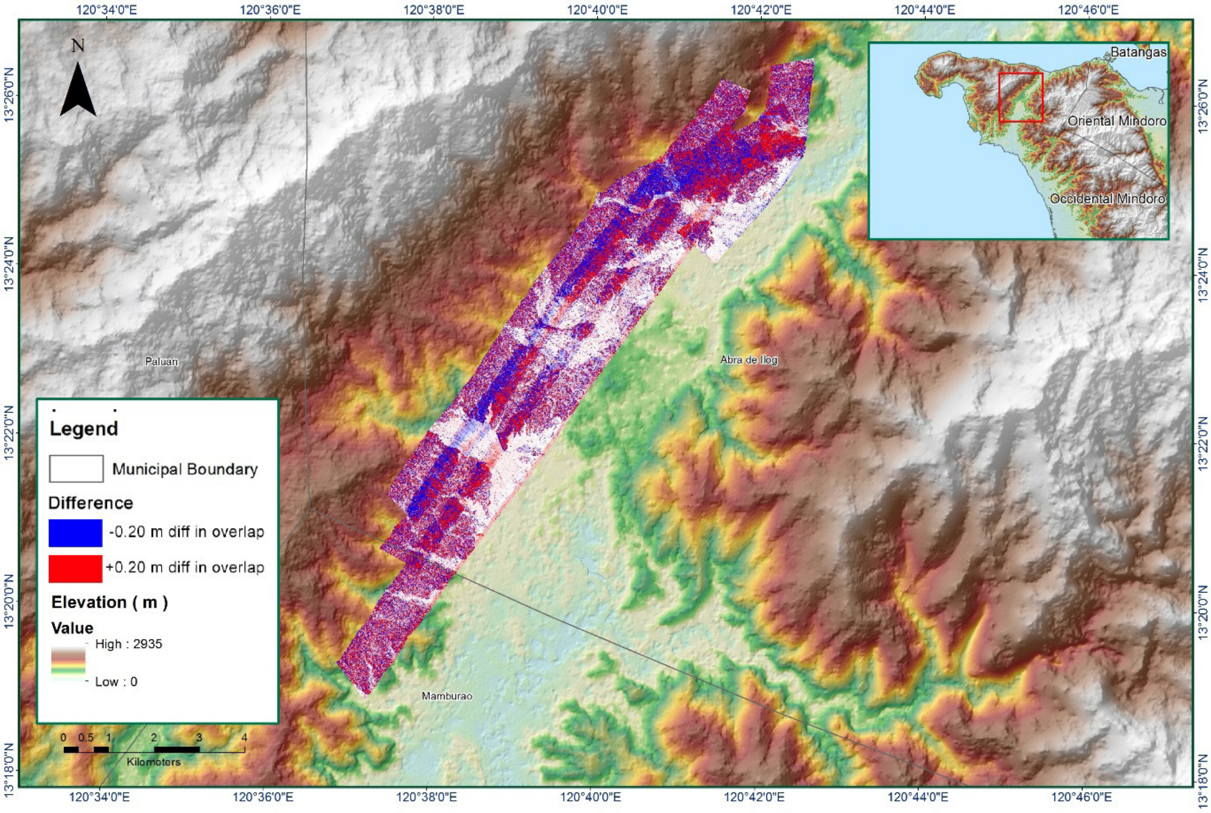

Figure A-8.14. Elevation difference between flight lines

Table A-8.3. Mission Summary Report for Mission Blk29M_additional

Flight Area	Occidental Mindoro Reflights
Mission Name	Blk29M_additional
Inclusive Flights	3062P
Range data size	14.4GB
POS	206MB
Image	26.6MB
Transfer date	January 15, 2016
Solution Status	
Number of Satellites (>6)	No
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.23
RMSE for East Position (<4.0 cm)	1.79
RMSE for Down Position (<8.0 cm)	3.92
Boresight correction stdev (<0.001deg)	0.000313
IMU attitude correction stdev (<0.001deg)	0.001914
GPS position stdev (<0.01m)	0.0029
Minimum % overlap (>25)	47.27
Ave point cloud density per sq.m. (>2.0)	1.64
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	171
Maximum Height	703.91 m
Minimum Height	45.39 m
Classification (# of points)	
Ground	86,855,770
Low vegetation	32,548,119
Medium vegetation	106,782,451
High vegetation	331,831,773
Building	8,372,842
Orthophoto	Yes
Processed by	Engr. Irish Cortez, Engr. Edgardo Gubatanga Jr., Jovy Narisma

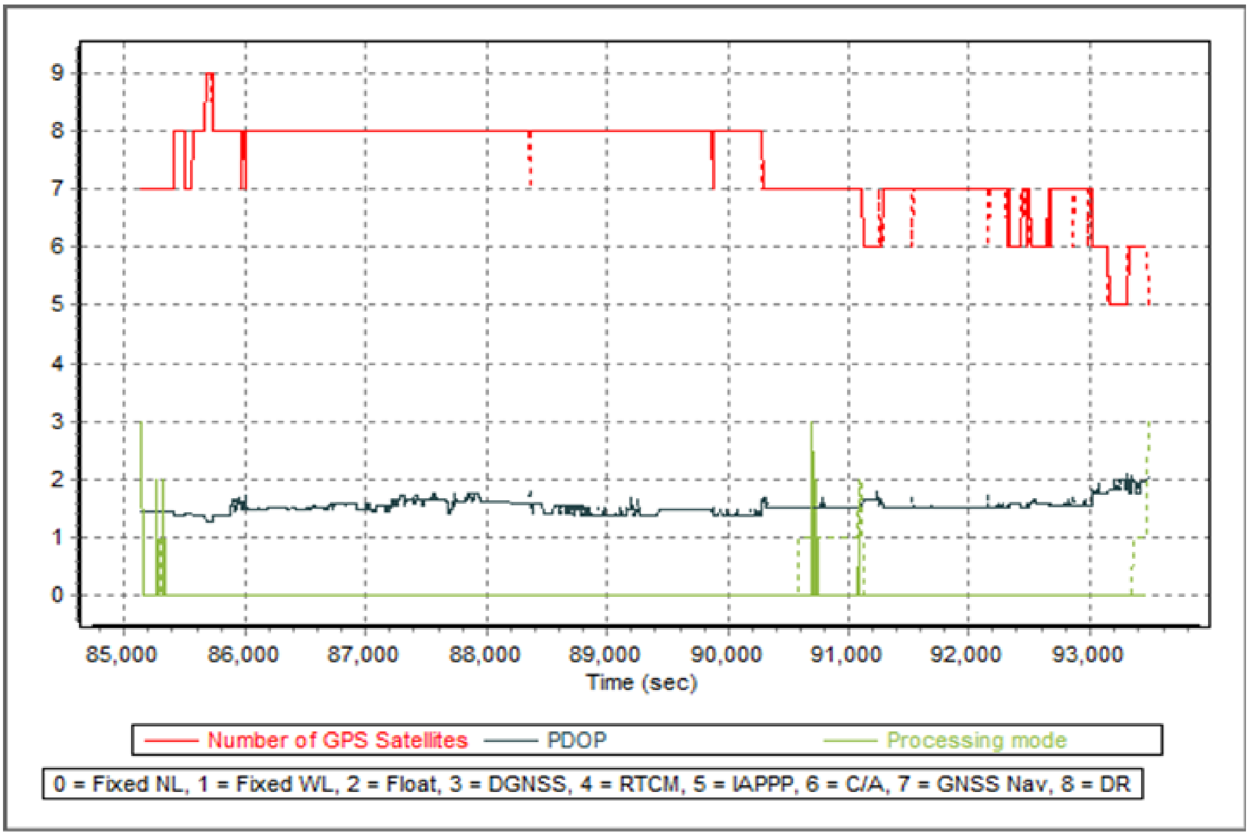

Figure A-8.15. Solution Status

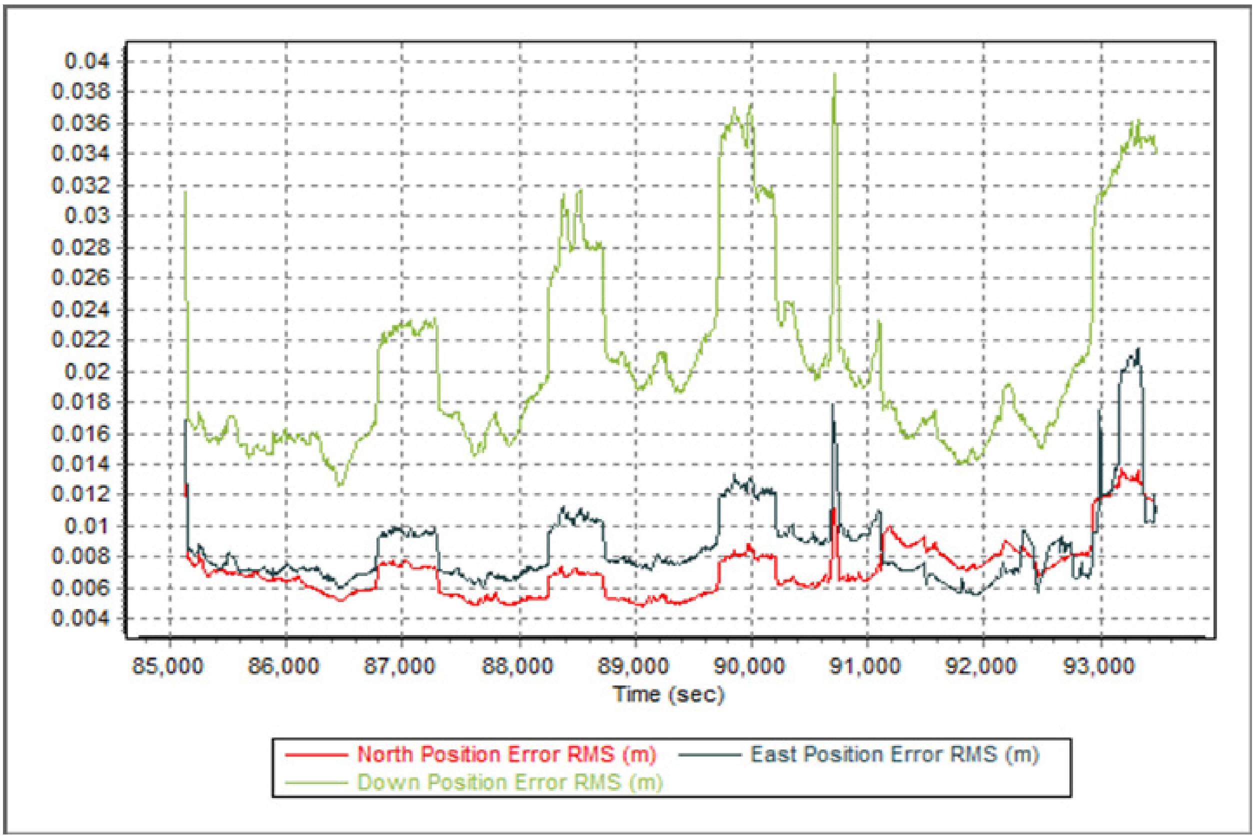

Figure A-8.16. Smoothed Performance Metrics Parameters

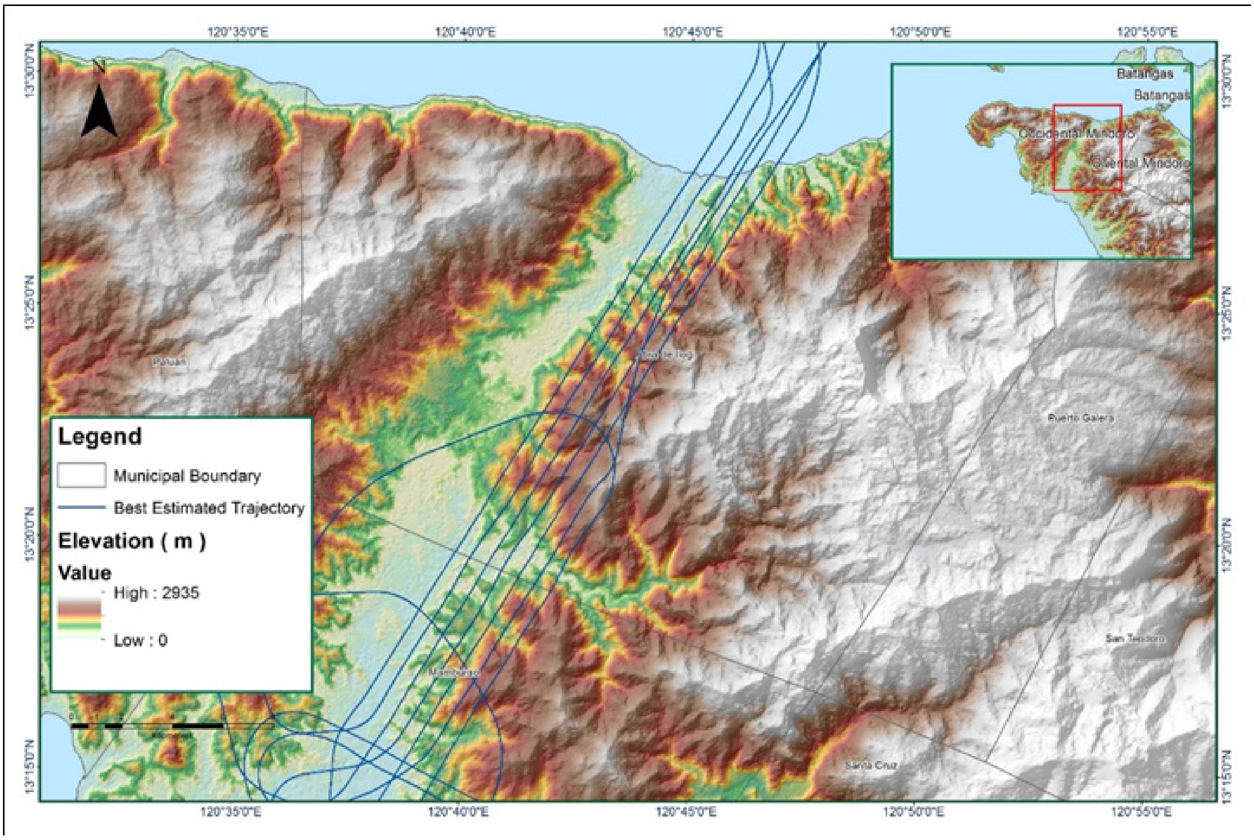

Figure A-8.17. Best Estimated Trajectory

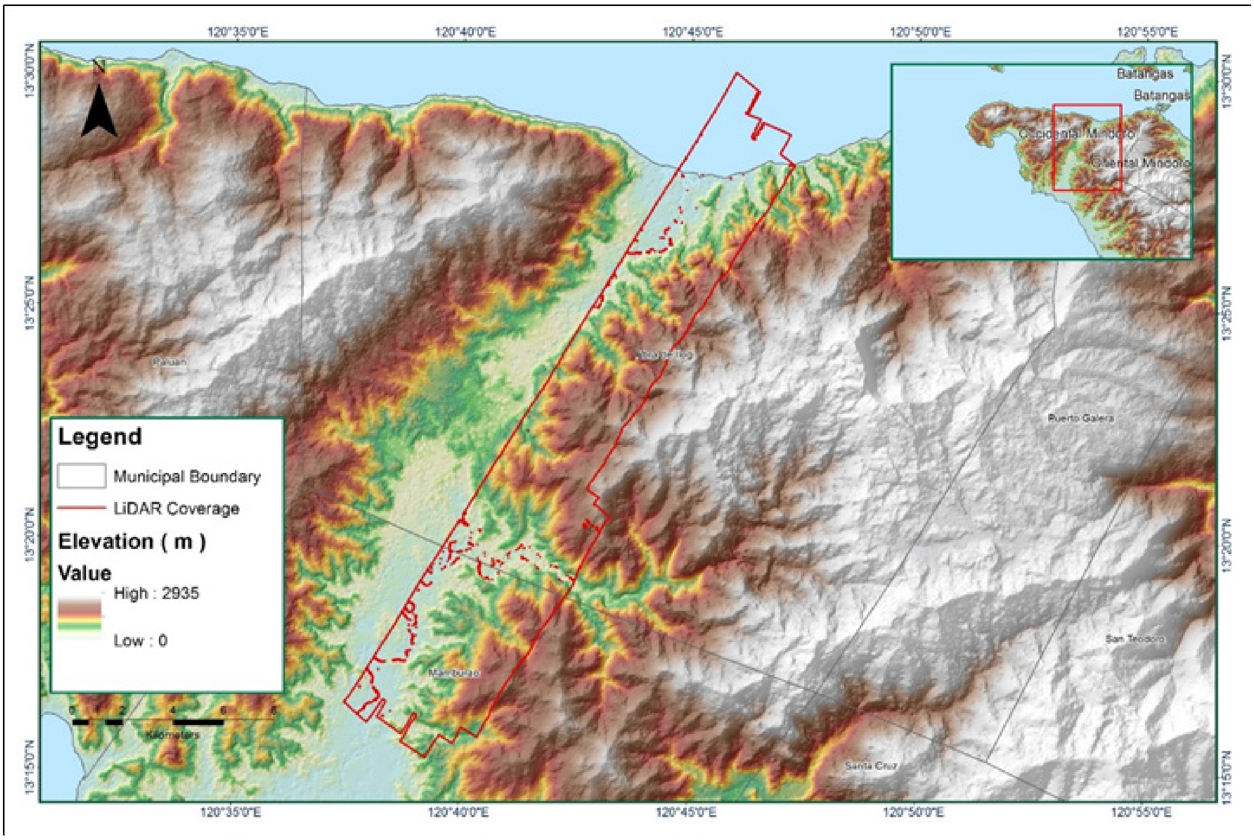

Figure A-8.18. Coverage of LiDAR data

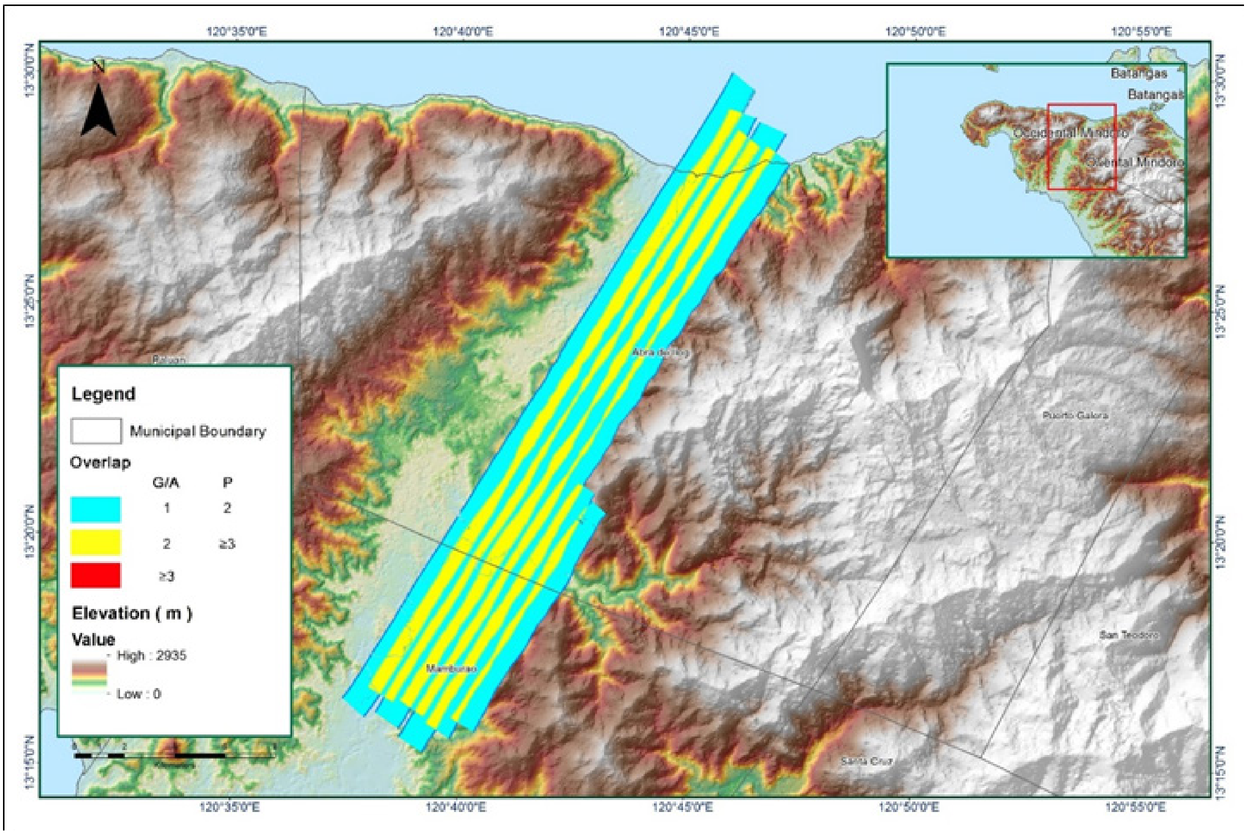

Figure A-8.19. Image of Data Overlap

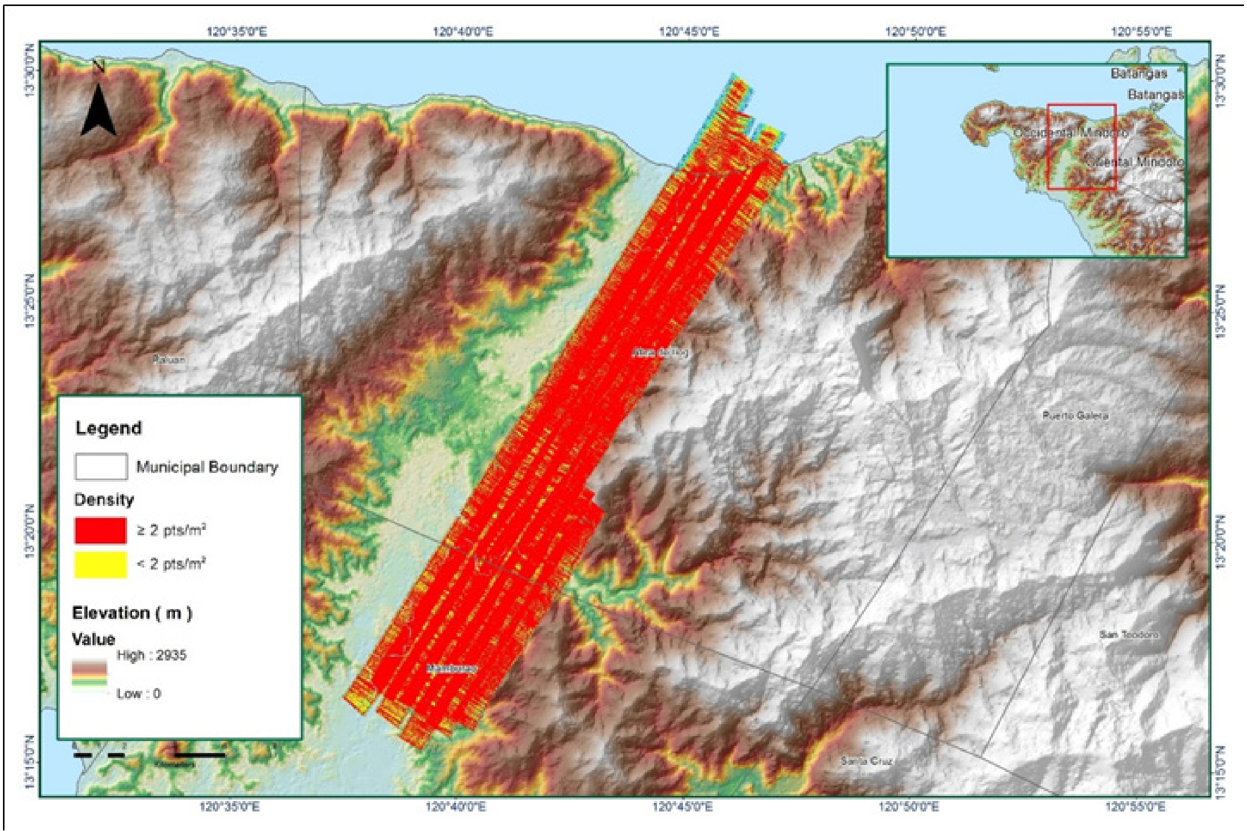

Figure A-8.20. Density map of merged LiDAR data

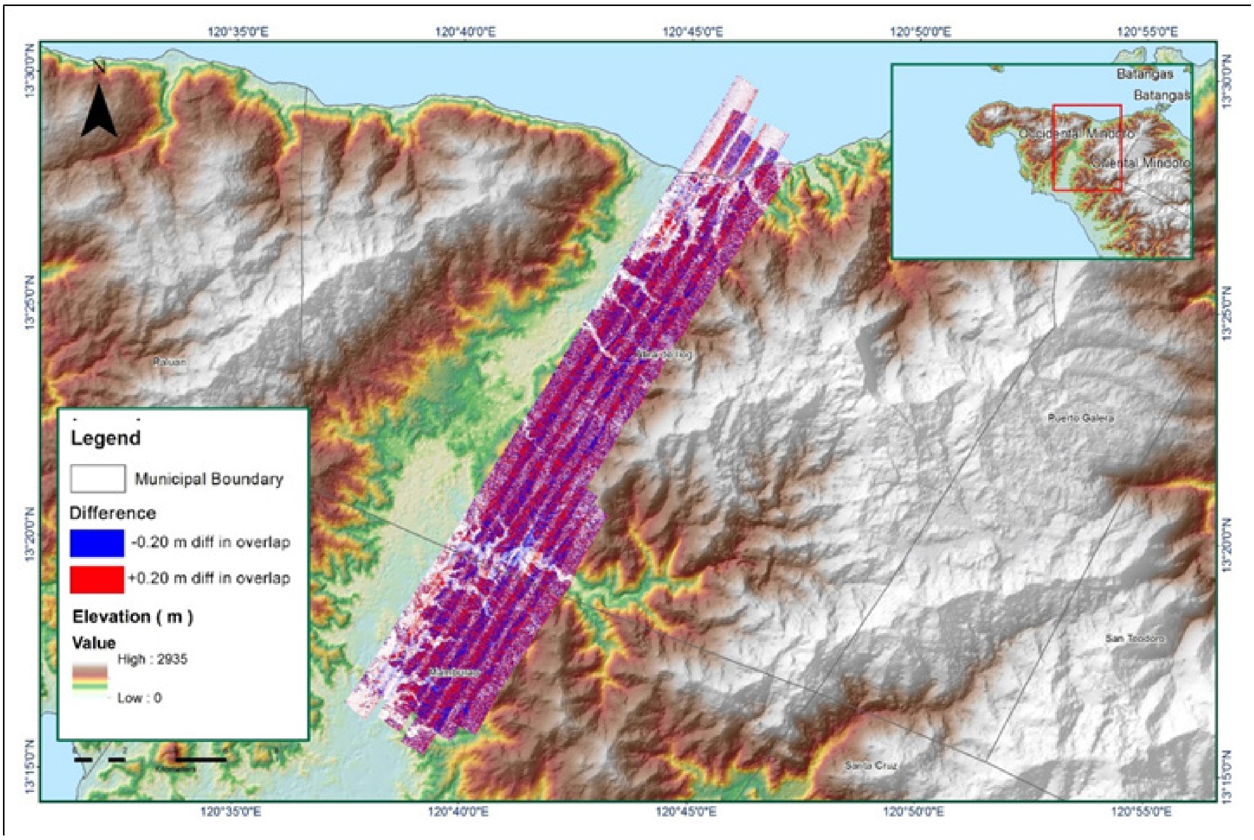

Figure A-8.21. Elevation difference between flight lines

Annex 9. Abra de Ilog Model Basin Parameters

Table A-9.1. Abra de Ilog Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
W1000	214.908	83.33194	0.0	0.036714	2.10882	1.0313	1	0.45196	Ratio to Peak	0.02868
W1010	268.476	83.28456	0.0	3.4662	16.954	0.52689	1	0.4706	Ratio to Peak	0.027261
W1020	400.704	99	0.0	0.088202	3.34334	0.25564	1	0.44292	Ratio to Peak	0.043019
W1030	28.68	83.32957	0.0	0.105846	13.9097	0.45773	1	0.4802	Ratio to Peak	0.043896
W1040	382.068	99	0.0	0.065838	13.6185	0.25189	0.76805	0	Ratio to Peak	0.019119
W1050	186.948	83.33194	0.0	5.29	11.6095	0.19027	1	0.46118	Ratio to Peak	0.005441
W1060	85.4856	83.33194	0.0	0.053728	3.87268	0.72405	1	0.29528	Ratio to Peak	0.003327
W1070	80.4	95.66732	0.0	0.053038	6.22202	0.25507	1	0.26157	Ratio to Peak	0.31
W1080	6.61668	99	0.0	0.0333333	0.92421	0.0142884	1	0.17089	Ratio to Peak	0.0125
W1090	390.3	99	0.0	0.036478	10.5	0.30777	1	0.44292	Ratio to Peak	0.001645
W1100	281.4	83.33194	0.0	0.0333333	9.8329	0.0118951	1	0.45196	Ratio to Peak	0.011756
W1110	101.0892	85.75543	0.0	0.22712	3.81094	0.53619	0.76113	0	Ratio to Peak	0.042158
W1120	364.32	83.33194	0.0	0.043134	28.3955	0.32410	0.92314	0.46118	Ratio to Peak	0.008498
W1130	354.84	86.32162	0.0	0.169226	33.8303	0.28655	1	0.4802	Ratio to Peak	0.094858
W1140	255.492	82.94579	0.0	3.368	11.0383	1.9746	0.65008	0.5	Ratio to Peak	0.13943
W580	48.8148	93.27463	0.0	0.054024	2.26303	0.31840	0.13234	0.25121	Ratio to Peak	0.018362
W590	29.8968	83.33194	0.0	0.0333333	2.765	0.47697	0.0868932	0.25121	Ratio to Peak	0.02868
W600	11.28	99	0.0	0.0333333	3.90831	0.35337	0.99117	0.26255	Ratio to Peak	0.001548
W610	78.2724	97.80179	0.0	0.0333333	5.08634	0.17866	0.97101	0.25122	Ratio to Peak	0.00158
W620	12.4188	99	0.0	0.25566	0.79149	0.0288626	0.0396061	0.012343	Ratio to Peak	0.0618
W630	22.7772	83.65649	0.0	0.053338	2.73392	0.64728	0.13432	0.19653	Ratio to Peak	0.013
W640	241.464	83.33194	0.0	0.161206	6.13669	0.70808	0.84737	0.4706	Ratio to Peak	0.011
W650	48.8784	83.33194	0.0	0.060264	14.8176	0.51717	0.878	0.31373	Ratio to Peak	0.000305

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	THreschold Type	Ratio to Peak
W660	38.058	83.34378	0.0	0.054052	2.58958	0.14672	1	0.26157	Ratio to Peak	0.064529
W670	21.444	83.33194	0.0	0.051202	2.90297	0.68483	0.9579	0.28359	Ratio to Peak	0.000144
W680	87.2064	99	0.0	0.0333333	3.14664	0.0636549	0.94658	0	Ratio to Peak	0.003777
W690	8.41788	99	0.0	0.0333333	0.77791	0.27052	1	0.056537	Ratio to Peak	0.000459
W700	4.16724	84.07107	0.0	0.0333333	0.516712	0.0022504	1.0	0.011521	Ratio to Peak	0.000217
W710	12.48	99	0.0	0.117844	0.512351	0.0396861	1	0.007837	Ratio to Peak	0.21778
W720	236.16	83.33194	0.0	0.45608	25.3498	1.0177	1	0.4802	Ratio to Peak	0.000212
W730	32.328	83.47645	0.0	0.04253	3.76292	0.82814	1	0.39235	Ratio to Peak	0.000459
W740	312.144	99	0.0	0.0333333	12.9598	0.51840	1	0.45196	Ratio to Peak	0.000212
W750	292.452	83.33194	0.0	0.15373	20.125	0.51996	0.62837	0.45196	Ratio to Peak	0.000458
W760	322.236	97.41564	0.0	0.099122	13.2755	1.1026	1	0.46118	Ratio to Peak	0.000318
W770	14.2836	83.33194	0.0	0.26316	2.14648	0.65923	0.88655	0.1709	Ratio to Peak	0.000145
W780	32.5908	83.36747	0.0	0.198066	2.36257	0.38661	0.13431	0.079085	Ratio to Peak	0.000459
W790	46.5204	83.43618	0.0	0.05483	4.55329	0.59459	0.44169	0.45599	Ratio to Peak	0.000674
W800	13.3956	99	0.0	0.0333333	0.533274	0.0744069	0.0176008	0.036598	Ratio to Peak	0.000312
W810	27.5928	95.96819	0.0	0.05308	2.41864	0.22377	0.39956	0.25122	Ratio to Peak	0.000133
W820	18.4272	95.78340	0.0	0.052262	2.02559	0.29481	0.45296	0.11626	Ratio to Peak	0.005018
W830	12.4824	83.68018	0.0	0.0333333	1.05525	0.0723708	0.4488	0.11917	Ratio to Peak	0.001494
W840	324.864	99	0.0	0.082542	16.0328	0.33851	1	0.5	Ratio to Peak	0.000144
W850	15.42	99	0.0	0.0333333	0.299971	0.0501702	0.0116751	0.016936	Ratio to Peak	0.000991
W860	47.9016	91.45524	0.0	0.0333333	1.29843	0.42792	0.13228	0.025923	Ratio to Peak	0.000674
W870	73.5156	83.51198	0.0	0.70928	1.21786	0.29286	1	0.20053	Ratio to Peak	0.000495
W880	92.8848	83.63754	0.0	0.197618	2.42053	0.33826	1	0.37682		
W890	243.588	83.33194	0.0	3.7628	27.8026	1.1831	0.86299	0.4802		

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	THreschold Type	Ratio to Peak
W900	9.2742	83.33194	0.0	0.22362	2.48332	0.44467	1	0.25122	Ratio to Peak	0.064529
W910	27.6864	99	0.0	0.0333333	3.67423	0.19180	0.20047	0.25122	Ratio to Peak	0.000144
W920	310.764	83.33194	0.0	2.4748	40.3032	0.38679	1	0.4706	Ratio to Peak	0.003777
W930	281.244	83.33194	0.0	0.06643	9.1539	0.53842	0.71747	0	Ratio to Peak	0.000459
W940	281.436	83.33194	0.0	0.054598	10.4993	0.14964	0.98524	0.45196	Ratio to Peak	0.000217
W950	28.632	83.44328	0.0	0.056238	1.86053	0.57316	0.20144	0.17919	Ratio to Peak	0.21778
W960	24.4488	83.33194	0.0	0.2047	2.05821	0.25717	1	0.30081	Ratio to Peak	0.000212
W970	30.9276	83.59964	0.0	0.0333333	18.0425	0.38541	1	0.4802	Ratio to Peak	0.000459
W980	49.9536	84.92154	0.0	0.2924	11.4947	0.30316	0.91363	0.46118	Ratio to Peak	0.000212
W990	25.572	88.57217	0.0	0.035086	16.5648	0.51381	1	0.4706	Ratio to Peak	0.000458

Annex 10. Abra de Ilog Model Reach Parameters

Table A-10.1. Abra de Ilog Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R100	Automatic Fixed Interval	146.57	0.0266341	0.0666667	Trapezoid	55	1
R140	Automatic Fixed Interval	539.41	.000397769	0.0666667	Trapezoid	55	1
R170	Automatic Fixed Interval	2374.5	0.0683421	0.0666667	Trapezoid	55	1
R180	Automatic Fixed Interval	3117.8	0.0010378	0.0666667	Trapezoid	55	1
R190	Automatic Fixed Interval	2711.1	0.0437397	0.0666667	Trapezoid	55	1
R210	Automatic Fixed Interval	679.71	0.0047858	0.0666667	Trapezoid	55	1
R220	Automatic Fixed Interval	1986.8	0.0217754	0.0666667	Trapezoid	55	1
R240	Automatic Fixed Interval	989.12	0.0127066	0.0666667	Trapezoid	55	1
R250	Automatic Fixed Interval	5782.6	0.057435	0.0666667	Trapezoid	55	1
R260	Automatic Fixed Interval	326.57	0.0729526	0.0666667	Trapezoid	55	1
R300	Automatic Fixed Interval	1932.4	0.0040649	0.0666667	Trapezoid	55	1
R310	Automatic Fixed Interval	3176.8	0.0212756	0.0666667	Trapezoid	55	1
R360	Automatic Fixed Interval	1439.2	0.0015961	0.0666667	Trapezoid	55	1
R370	Automatic Fixed Interval	759.41	0.0102098	0.0666667	Trapezoid	55	1
R40	Automatic Fixed Interval	764.06	0.0400966	0.0666667	Trapezoid	55	1
R420	Automatic Fixed Interval	950.42	0.0680056	0.0666667	Trapezoid	55	1
R440	Automatic Fixed Interval	2806.9	0.0185793	0.0666667	Trapezoid	55	1
R450	Automatic Fixed Interval	4130.2	0.0299682	0.0666667	Trapezoid	55	1
R460	Automatic Fixed Interval	1146.4	0.0861342	0.0666667	Trapezoid	55	1
R490	Automatic Fixed Interval	1622.3	0.0051925	0.0666667	Trapezoid	55	1
R50	Automatic Fixed Interval	2706.6	0.0400966	0.0666667	Trapezoid	55	1
R500	Automatic Fixed Interval	2372.8	0.0094303	0.0666667	Trapezoid	55	1

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R510	Automatic Fixed Interval	255.56	0.0121405	0.0666667	Trapezoid	55	1
R520	Automatic Fixed Interval	221.42	0.0042962	0.0666667	Trapezoid	55	1
R540	Automatic Fixed Interval	1961.4	0.0053958	0.0666667	Trapezoid	55	1
R60	Automatic Fixed Interval	2980.1	0.0040448	0.0666667	Trapezoid	55	1
R70	Automatic Fixed Interval	592.84	0.0032557	0.0666667	Trapezoid	55	1
R90	Automatic Fixed Interval	564.56	0.0144853	0.0666667	Trapezoid	55	1

Annex 11. Abra de Ilog Field Validation Points

Table A-11.1. Abra de Ilog Field Validation Points

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
1	13.440737	120.7274	0.79	0			25-Year
2	13.449505	120.74874	0.68	0.24	Caloy	September 2006	25-Year
3	13.449273	120.7491	0.89	0.1	Yolanda	November 2013	25-Year
4	13.448831	120.7487	0.9	0.3	Yolanda	November 2013	25-Year
5	13.449251	120.74814	1.08	0.4	Habagat		25-Year
6	13.449144	120.74777	2.26	0.2	Yolanda	November 2013	25-Year
7	13.449987	120.748	0.03	1.18	Yolanda	November 2013	25-Year
8	13.449689	120.74757	0.81	0.67	Yolanda	November 2013	25-Year
9	13.449972	120.7474	0.03	0.55	Yolanda	November 2013	25-Year
10	13.450598	120.74797	0.76	0.1			25-Year
11	13.450367	120.74805	0.36	0.3			25-Year
12	13.450424	120.74869	0.58	0			25-Year
13	13.445601	120.73491	1.5	0.37		2013	25-Year
14	13.447218	120.73648	0.72	0.7		2013	25-Year
15	13.448104	120.73741	2.17	0.96	Yolanda	November 2013	25-Year
16	13.448072	120.73817	1.72	0.93		2013	25-Year
17	13.44889	120.7383	1.58	0.12			25-Year
18	13.447484	120.74012	1.34	0.26		2014	25-Year
19	13.44863	120.73953	1.61	0.98		2013	25-Year
20	13.448831	120.73921	1.6	0.81		2013	25-Year
21	13.451373	120.74063	1.45	0.97		2016	25-Year
22	13.452112	120.74158	0.03	1.25		2013	25-Year
23	13.452774	120.74204	1.06	1.5		2013	25-Year
24	13.453906	120.74242	1.08	0.34		2013	25-Year
25	13.454765	120.74308	1.04	1.25		2013	25-Year
26	13.45566	120.74332	1.66	1.12		2013	25-Year
27	13.454215	120.74293	1.15	1		2013	25-Year
28	13.453529	120.74293	0.67	1.1		2002	25-Year
29	13.453641	120.74314	1.03	1.03		2013/2014	25-Year
30	13.452492	120.7443	1.06	0.91		2012	25-Year
31	13.451188	120.74346	0.98	0.88		2012	25-Year
32	13.450581	120.74288	1.3	1.22		2012	25-Year
33	13.450494	120.74439	0.92	1.19		2012	25-Year
34	13.449828	120.74422	0.83	0.98		2012	25-Year
35	13.460564	120.74507	1.19	0			25-Year
36	13.461448	120.74628	0.03	0.36		2013	25-Year
37	13.462746	120.74533	0.54	0	Odette	September 2013	25-Year

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
38	13.463507	120.74547	1.03	0.98	Odette	September 2013	25-Year
39	13.464434	120.74661	0.48	0.55	Odette	September 2013	25-Year
40	13.464134	120.74659	1.16	1.6	Odette	September 2013	25-Year
41	13.464372	120.74595	0.28	0			25-Year
42	13.464727	120.74592	3.99	0.6	Marce	November 2016	25-Year
43	13.464973	120.74417	2.48	0.5	Marce	November 2016	25-Year
44	13.464298	120.74397	1.22	0.6	Marce	November 14, 2016	25-Year
45	13.464276	120.74465	0.03	0			25-Year
46	13.463817	120.74476	1.19	0.3		2015	25-Year
47	13.463107	120.74459	0.35	0			25-Year
48	13.408978	120.6986	0.64	0.86		2013	25-Year
49	13.408385	120.69789	0.29	0.86		2013	25-Year
50	13.424896	120.71689	3.45	0			25-Year

Annex 12. Phil-LiDAR 1 UPLB Team Composition

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