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

# LiDAR Surveys and Flood Mapping of Aborlan River


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


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 Grant-in-Aid Program and is to be cited as:

E.C. Paringit, E.R. Abucay, (Eds.). (2017), LiDAR Surveys and Flood Mapping Report of Aborlan River, in Enrico C. Paringit (Ed.), Flood Hazard Mapping of the Philippines using LIDAR. Quezon City: University of the Philippines Training Center for Applied Geodesy and Photogrammetry. 151pp



For questions/queries regarding this report, contact:

Asst. Prof. Edwin R. Abucay
Project Leader Phil-LiDAR 1 Program
University of the Philippines, Los Banos
Los Banos, Philippines 4031
erabucay@up.edu.ph

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

National Library of the Philippines
ISBN: 987-621-430-118-8

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF ACRONYMS AND ABBREVIATIONS

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

# CHAPTER 1: OVERVIEW OF THE PROGRAM AND ABORLAN RIVER

Enrico C. Paringit, Edwin R. Abucay, Efraim D. Roxas

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

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

The implementing partner university for the Phil-LiDAR 1 Program is the University of the Philippines Los Banos (UPLB). 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 MIMAROPA Region. The university is located in Los Banos, Laguna

## 1.2 Overview of the Aborlan River Basin

Aborlan River Basin is a 125,540-hectare watershed located in Palawan. It covers the barangays of Dumagueña in the municipality of Narra; and Apoc-apoc, Aporawan, Barake, Cabigaan, Culandanum, Gogognan, Iraan, Jose Rizal, Mabini, Magbabadil, Poblacion, Ramon Magsaysay, San Juan, and Tagpait in the municipality of Aborlan. Generally, the river basin is characterized of having 50% slope. This river basin has three soil types: Aborlan loam, Brooke's clay, and Babuyan silty clay loam. It is also covered by eight land cover types including dominant-type closed canopy (mature trees covering >50%), mossy forest, arable land with crops mainly cereals and sugar, cropland mixed with coconut plantation, cultivated area mixed with brushland/ grassland, built-up area, grassland (grass covering > 70%), coconut plantations.

Aborlan River passes through Apoc-apoc, Aporawan, Barake, Cabigaan, Culandanum, Gogognan, Iraan, Mabini, Magbabadil, Poblacion, Ramon Magsaysay and Tagpait in Aborlan. Based on the record of the 2010 NSO Census of Population and Housing, barangay San Juan is the most populated area.

Based on the studies conducted by the Mines and Geosciences Bureau (MGB), only Culandanum, Aporawan, and Iraan have no risk to flooding while the remaining barangays have low to high flood susceptibilities. For landslide, the barangays of Ramon Magsaysay, Magbabadil, Mabini, Gogognan, Poblacion, and Tagpait were classified as low-hazard. On the other hand, Apoc-Apoc, Cabigaan, Barake, and Iraan have low to high susceptibilities while Aporawan and Culandanum have moderate to high susceptibility to landslides. Based on the field surveys conducted by the Phil-LiDAR 1 validation team, there were five notable tropical storms that caused flooding: 2016 (Lawin), 2013 (Yolanda), 2011 (Sendong), 2009 (Ondoy) and 2000 (Seniang).

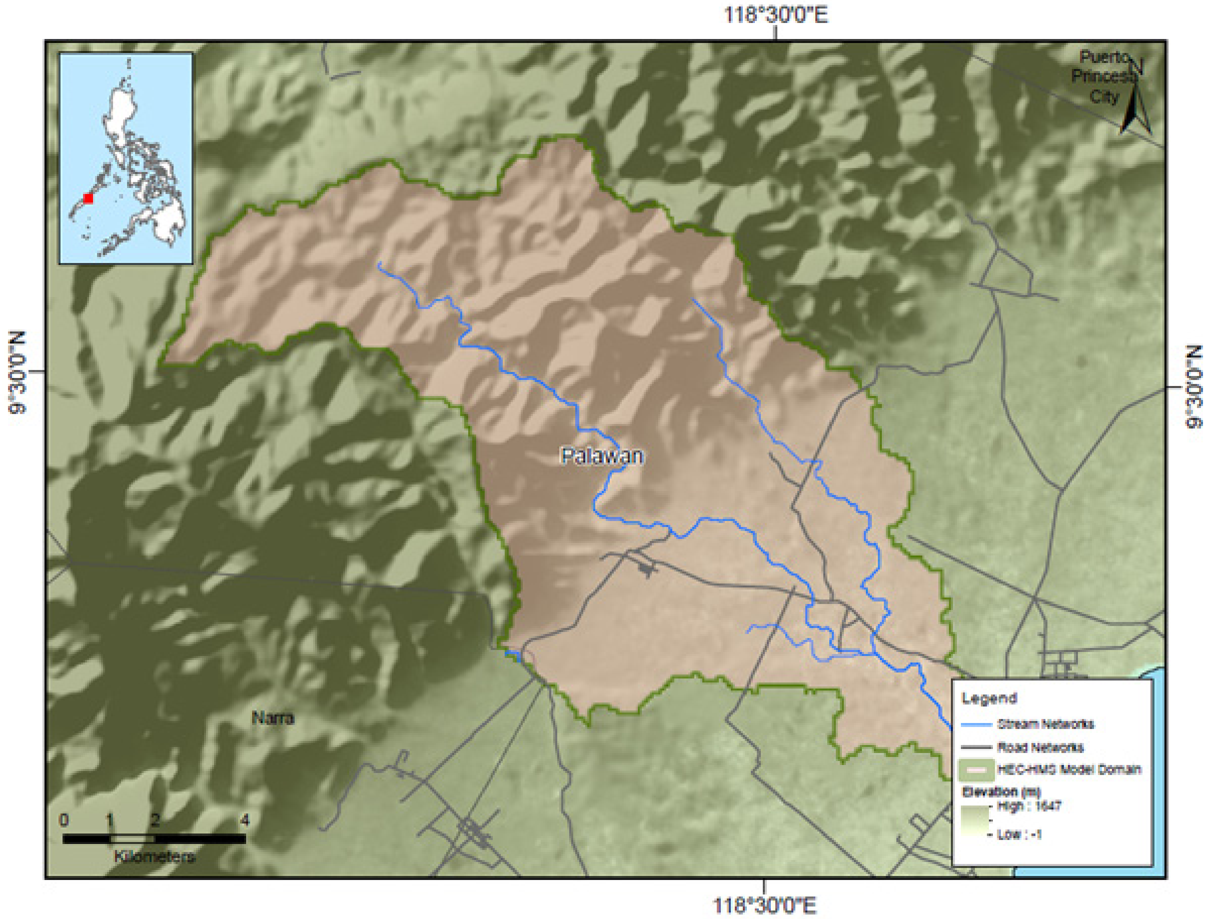



Figure 1. Map of the Aborlan River Basin (in brown).

# CHAPTER 2: LIDAR ACQUISITION IN ABORLAN FLOODPLAIN

Engr. Louie P. Balicanta, Engr. Christopher Cruz, Lovely Gracia Acuña, Engr. Gerome Hipolito, Ms. Julie Pearl S. Mars, For. Regina Aedrianne C. Felismino

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

## 2.1 Flight Plans

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

Table 1. Flight planning parameters for Pegasus LiDAR system.

| Block Name | Flying Height (m AGL) | Overlap (%) | Field of View (θ) | Pulse Repetition Frequency (PRF) (kHz) | Scan Frequency (Hz) | Average Speed (kts) | Average Turn Time (Minutes) |
|---|---|---|---|---|---|---|---|
| BLK 42I | 1200 | 40 | 50 | 200 | 30 | 140 | 5 |
| BLK 42J | 1200 | 40 | 50 | 200 | 30 | 140 | 5 |
| BLK 42AbS | 1100 | 40 | 50 | 200 | 30 | 120 | 5 |
| BLK 42Ac | 1100 | 40 | 50 | 200 | 30 | 120 | 5 |

Table 2. Flight planning parameters for Gemini LiDAR system.

| Block Name | Flying Height (m AGL) | Overlap (%) | Field of View (θ) | Pulse Repetition Frequency (PRF) (kHz) | Scan Frequency (Hz) | Average Speed (kts) | Average Turn Time (Minutes) |
|---|---|---|---|---|---|---|---|
| BLK 42eH | 1100 | 30 | 50 | 100 | 40 | 120 | 5 |
| BLK 42eJ | 1100 | 30 | 50 | 100 | 40 | 120 | 5 |
| BLK 42Ks | 1100 | 30 | 50 | 100 | 40 | 120 | 5 |

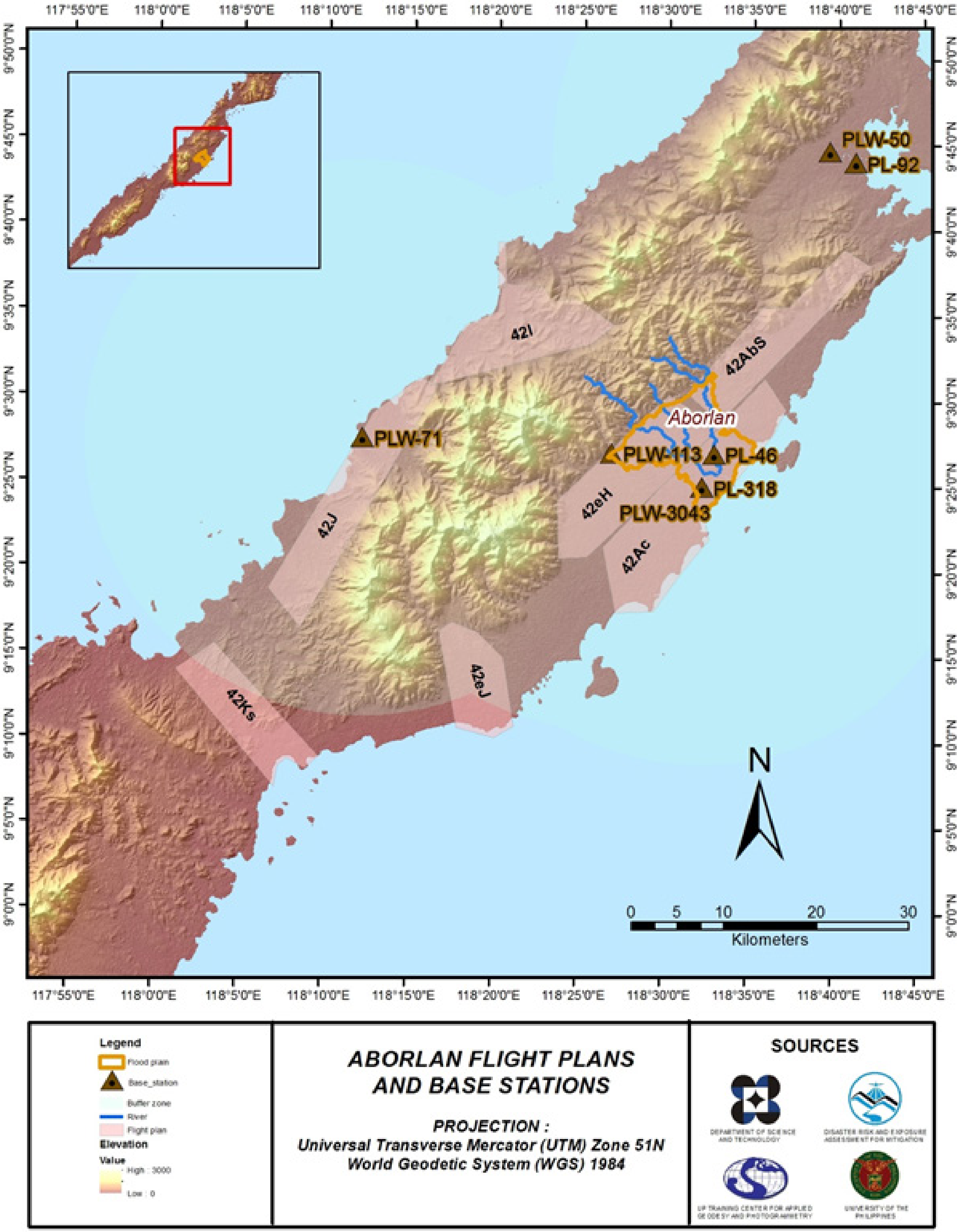



Figure 2. Flight plans and base stations used to cover Aborlan Floodplain.

## 2.2 Ground Base Stations

The project team was able to recover two (2) NAMRIA reference points, PLW-50 and PLW-71, which are of second (2nd)-order accuracy; two (2) benchmark points, PL-46 and PL-92, which are of first (2nd)-order accuracy; and three (3) reprocessed ground point, PLW-113, PLW-318, and PLW-3043, which are tied to second (2nd)-order accuracy. The certification for the base station is found in ANNEX 2. These points were used as base stations during flight operations for the entire duration of the survey (May to June 2015 and December 2015). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 852 and TRIMBLE SPS 985. Flight plans and location of base stations used during the aerial LiDAR Acquisition in Aborlan Floodplain are shown in Figure 2.

Figure 3 to Figure 7 show the recovered NAMRIA control station within the area, in addition Table 3 to Table 9 present the details about the NAMRIA control stations and established points, Table 10 shows the list of all ground control points occupied during the acquisition together with the dates they were utilized during the survey.

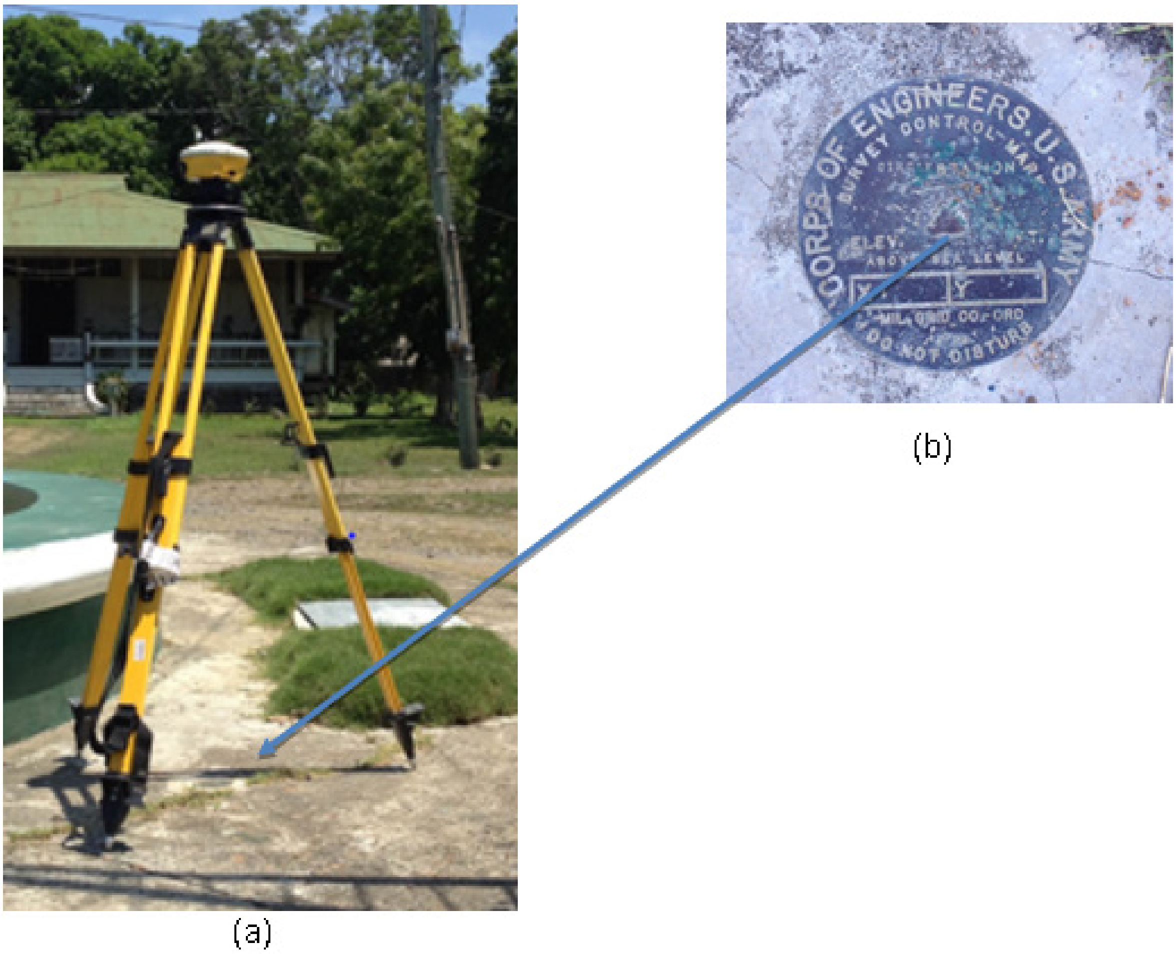



Figure 3. GPS set-up over PLW-50 as recovered at Brgy. Iwahig, Puerto Princesa City (a), NAMRIA reference point PLW-50 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point PLW-50 used as base station for the LiDAR acquisition.

| Station Name | PLW-50 | |
|---|---|---|
| Order of Accuracy | 2nd Order | |
| Relative Error (horizontal positioning) | 1:50,000 | |
| Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92) | Latitude<br>Longitude<br>Ellipsoidal Height | 9°44'42.16318"<br>118°29'28.02050"<br>16.81300 meters |
| Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92) | Easting<br>Northing | 517311.956 meters<br>1077537.527 meters |
| Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84) | Latitude<br>Longitude<br>Ellipsoidal Height | 9° 44'37.72390" North<br>118° 39' 33.34598" East<br>66.85300 meters |
| Grid Coordinates, Universal Transverse Mercator Zone 52 North (UTM 52N PRS 92) | Easting<br>Northing | 681851.72 meters<br>1077601.73 meters |

(a) (b)

Figure 4. GPS set-up over PLW-71 as recovered near the house of Ex Barangay Captain Victorino Danglong in Sitio Badlesan, Berong in Quezon, Palawan, (a) NAMRIA reference point PLW-71 (b) as recovered by the field team.

Table 4. Details of the recovered NAMRIA horizontal control point NGW-58 used as base station for the LiDAR acquisition.

| Station Name | PLW-71 | |
|---|---|---|
| Order of Accuracy | 2nd Order | |
| Relative Error (horizontal positioning) | 1 in 50,000 | |
| Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92) | Latitude<br>Longitude<br>Ellipsoidal Height | 9° 27' 39.91263"<br>118° 12' 4.53547"<br>3.87100 meters |
| Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92) | Easting<br>Northing | 467194.901 meters<br>1046143.749 meters |
| Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84) | Latitude<br>Longitude<br>Ellipsoidal Height | 9° 27' 35.50499" North<br>118° 12' 9.88716" East<br>53.394.00 meters |
| Grid Coordinates, Universal Transverse Mercator Zone 52 North (UTM 52N PRS 92) | Easting<br>Northing | 631874.59 meters<br>1045990.79 meters |

(a) (b)

Figure 5. GPS set-up over PLW-113 as recovered in Aborlan Water System in Brgy. Cabigaan, Aborlan, Palawan, (a) NAMRIA reference point PLW-113 (b) as recovered by the field team.

Table 5. Details of the recovered reprocessed ground control point PLW-113 used as base station for the LiDAR acquisition.

| | | |
|---|---|---|
| Station Name | PLW-113 | |
| Order of Accuracy | 2nd Order | |
| Relative Error (horizontal positioning) | 1:50,000 | |
| Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92) | Latitude<br>Longitude<br>Ellipsoidal Height | 9° 26’ 55.17200”<br>118° 26’ 46.88314”<br>95.70958 meters |
| Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92) | Easting<br>Northing | 494109.133 meters<br>1044718.65 meters |
| Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84) | Latitude<br>Longitude<br>Ellipsoidal Height | 9° 26’ 50.78858” North<br>118° 26’ 52.23545” East<br>145.86900 meters |
| Grid Coordinates, Universal Transverse Mercator Zone 52 North (UTM 52N PRS 92) | Easting<br>Northing | 658792.04 meters<br>1044718.65 meters |

(a) (b)

Figure 6. GPS set-up over PLW-3043 as recovered on the ground beside Tigman Barangay Hall, Aborlan, Palawan, (a) NAMRIA reference point PLW-3043 (b) as recovered by the field team.

Table 6. Details of the recovered reprocessed ground control point PLW-3043 used as base station for the LiDAR acquisition.

| | | |
|---|---|---|
| Station Name | PLW-3043 | |
| Order of Accuracy | 2nd Order | |
| Relative Error (horizontal positioning) | 1 in 10,000 | |
| Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92) | Latitude<br>Longitude<br>Ellipsoidal Height | 9° 21’ 42.33800”<br>118° 31’ 50.87908”<br>8.199 meters |
| Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92) | Easting<br>Northing | 8789.146 meters<br>1037903.794 meters |
| Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84) | Latitude<br>Longitude<br>Ellipsoidal Height | 9° 21’ 38.01536” North<br>118° 31’ 56.35775” East<br>57.404 meters |
| Grid Coordinates, Universal Transverse Mercator Zone 52 North (UTM 52N PRS 92) | Easting<br>Northing | 498793.48 meters<br>1128582.14 meters |

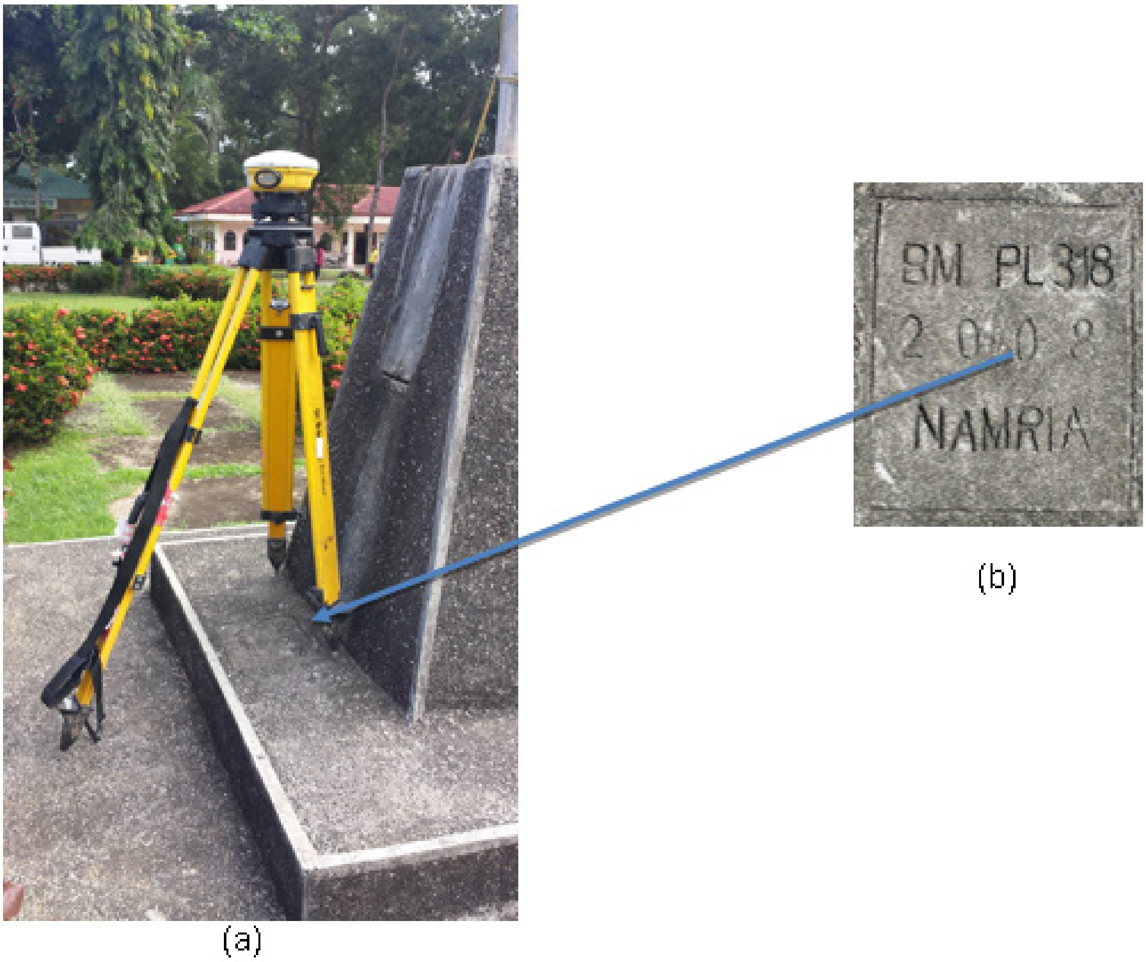



Figure 7. GPS set-up over PL-318 as recovered inside Aborlan Municipal Hall, Aborlan Palawan, (a) NAMRIA reference point PL-318 (b) as recovered by the field team.

Table 7. Details of the benchmark control point PL-318 used as base station for the LiDAR acquisition.

| Station Name | PL-318 | |
|---|---|---|
| Order of Accuracy | 2nd Order | |
| Relative Error (horizontal positioning) | 1:50,000 | |
| Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92) | Latitude<br>Longitude<br>Ellipsoidal Height | 9° 24’ 58.83705”<br>118° 32’ 06.27533”<br>17.702 meters |
| Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92) | Easting<br>Northing | 9337.208 meters<br>1043949.629 meters |
| Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84) | Latitude<br>Longitude<br>Ellipsoidal Height | 9° 24’ 54.46952” North<br>118° 32’ 11.63035” East<br>68.152 meters |

Table 8. Details of the recovered NAMRIA reference point PL-92 with processed coordinates used as base station for the LiDAR acquisition.

| Station Name | PL-92 | |
|---|---|---|
| Order of Accuracy | 2nd Order | |
| Relative Error (horizontal positioning) | 1:50,000 | |
| Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92) | Latitude<br>Longitude<br>Ellipsoidal Height | 9°44'04.01581" North<br>118°40'58.28065" East<br>8.218 m |
| Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84) | Latitude<br>Longitude<br>Ellipsoidal Height | 9°43'59.58138" North<br>118°41'03.60701" East<br>58.344 m |
| Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984) | Easting<br>Northing | 26049.752 m<br>1079008.192 m |

Table 9. the recovered NAMRIA benchmark point PL-46 with processed coordinates used as base station for the LiDAR acquisition

| Station Name | PL-46 | |
|---|---|---|
| Order of Accuracy | 2nd Order | |
| Relative Error (horizontal positioning) | 1:50,000 | |
| Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92) | Latitude<br>Longitude<br>Ellipsoidal Height | 9° 26' 56.28696"<br>118° 32' 48.62908"<br>15.833 meters |
| Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92) | Easting<br>Northing | 10678.747 meters<br>1047550.297 meters |
| Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84) | Latitude<br>Longitude<br>Ellipsoidal Height | 9° 26' 51.91226" North<br>118° 32'53.98117" East<br>66.241 meters |

Table 10. Ground control points used during LiDAR data acquisition.

| Date Surveyed | Flight Number | Mission Name | Ground Control Points |
|---|---|---|---|
| 11-Jun-15 | 3037P | 1BLK42IJ162A | PLW-71 |
| 17-Jun-15 | 3061P | 1BLK42Ab168A | PLW-50, PL-92 |
| 18-Jun-15 | 3065P | 1BLK42Ac169A | PLW-113, PL-46 |
| 26-Nov-15 | 3537G | 2BLK42HJ330A | PL-318, PLW-3043 |
| 30-Nov-15 | 3553G | 2BLK42HJ334A | PL-318, PLW-3043 |
| 1-Dec-15 | 3557G | 2BLK42HsL335A | PL-318, PLW-3043 |

## 2.3 Flight Missions

Six (6) missions were conducted to complete the LiDAR data acquisition in Aborlan Floodplain, for a total of twenty-one hours and seven minutes (21+7) of flying time for RP-C9022 and RP-C9122. All missions were acquired using the Pegasus and Gemini LiDAR systems. Table 11 shows the total area of actual coverage per mission and the flying length for each mission and Table 12 presents the actual parameters used during the LiDAR data acquisition.

Table 11. Flight missions for LiDAR data acquisition in Aborlan 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 |
| 11-Jun-15 | 3037P | 236.18 | 327.12 | 0 | 327.12 | 708 | 3 | 48 |
| 17-Jun-15 | 3061P | 99.27 | 178.79 | 17.21 | 161.58 | 600 | 3 | 4 |
| 18-Jun-15 | 3065P | 173.07 | 193.23 | 38.81 | 154.42 | 524 | 3 | 2 |
| 26-Nov-15 | 3537G | 129.82 | 81.61 | 21.36 | 60.25 | 0 | 3 | 30 |
| 30-Nov-15 | 3553G | 129.82 | 107.7 | 31.82 | 75.88 | 0 | 3 | 29 |
| 1-Dec-15 | 3557G | 215.73 | 130.79 | 8.43 | 122.36 | 0 | 3 | 53 |
| **TOTAL** | | 983.89 | 1019.24 | 117.63 | 901.61 | 1832 | 21 | 7 |

Table 12. Actual parameters used during LiDAR data acquisiton .

| Flight Number | Flying Height (m AGL) | Overlap (%) | FOV (θ) | PRF (KHz) | Scan Frequency (Hz) | Average Speed (kts) | Average Turn Time (Minutes) |
|---|---|---|---|---|---|---|---|
| 3037P | 1100 | 40 | 50 | 200 | 30 | 120 | 5 |
| 3061P | 1100 | 40 | 50 | 200 | 30 | 120 | 5 |
| 3065P | 1100 | 40 | 50 | 200 | 30 | 120 | 5 |
| 3537G | 1100 | 30 | 50 | 100 | 40 | 120 | 5 |
| 3553G | 1100 | 30 | 50 | 100 | 40 | 120 | 5 |
| 3557G | 1100 | 30 | 50 | 100 | 40 | 120 | 5 |

## 2.4 Survey Coverage

Aborlan Floodplain is located in the provinces of Palawan with majority of the floodplain situated within the municipality of Aborlan. The list of municipalities and cities surveyed with at least one (1) square kilometer coverage is shown in Table 13. The actual coverage of the LiDAR acquisition for Aborlan Floodplain is presented in Figure 8.

Table 13. List of municipalities/cities surveyed in Palawan.

| Province | Municipality/City | Area of Municipality/City (km2) | Total Area Surveyed (km2) | Percentage of Area Surveyed |
|---|---|---|---|---|
| Palawan | Aborlan | 645.11 | 394.09 | 61% |
| | Quezon | 917.90 | 191.79 | 21% |
| | Narra | 831.19 | 171.31 | 21% |
| | Puerto Princesa City | 2186.36 | 113.69 | 5% |
| | Sofronio Espanola | 477.50 | 15.29 | 3% |
| **Total** | | **5058.06** | **886.17** | **17.52%** |

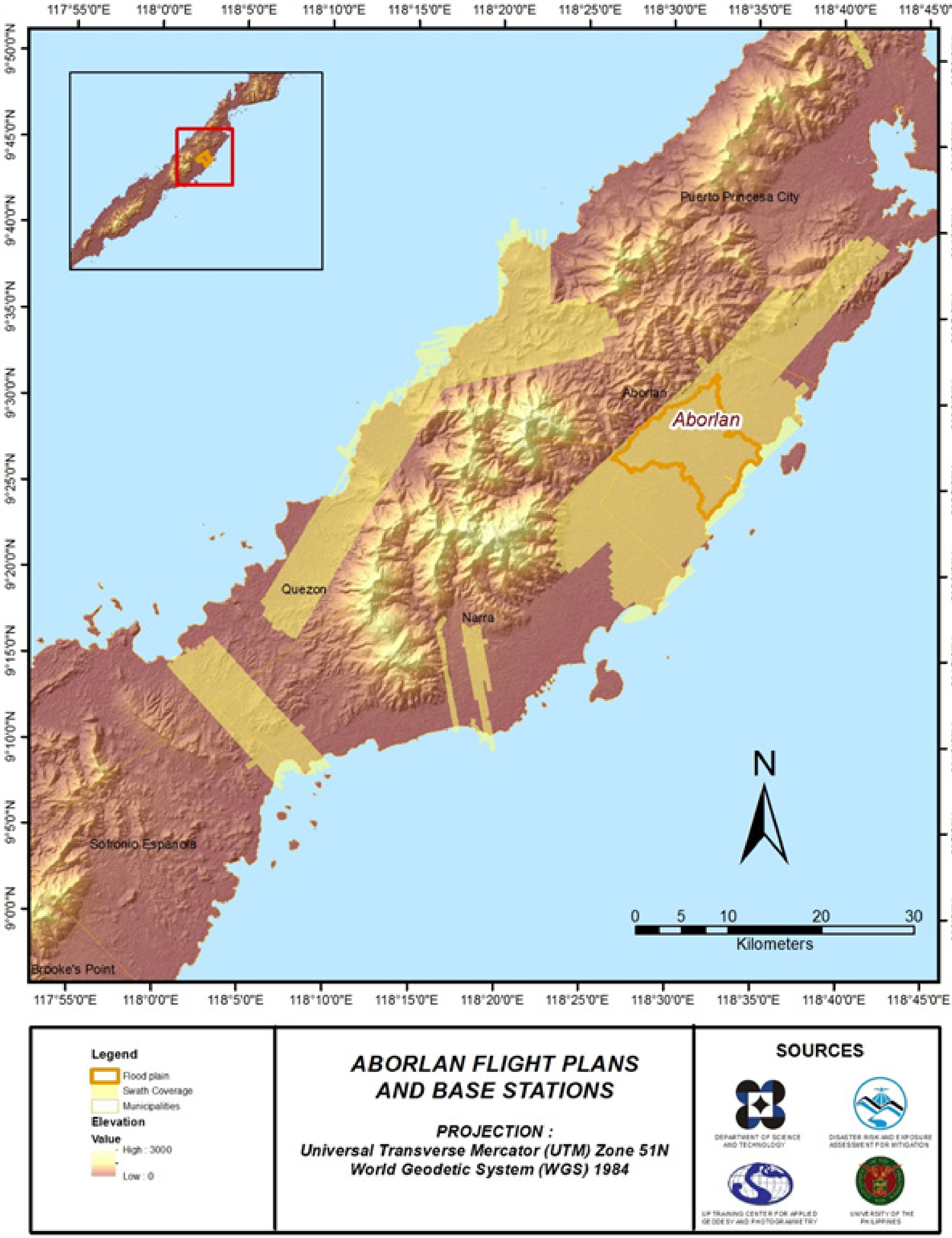



Figure 8. Actual LiDAR data acquisition for Aborlan Floodplain.

# CHAPTER 3: LIDAR DATA PROCESSING FOR ABORLAN FLOODPLAIN

Engr. Ma. Rosario Concepcion O. Ang, Engr. John Louie D. Fabila, Engr. Sarah Jane D. Samalburo, Engr. Harmond F. Santos, Engr. Angelo Carlo B. Bongat, Engr. Ma. Ailyn L. Olanda, Engr. Velina Angela S. Bemida, Marie Denise V. Bueno, Engr. Regis R. Guhiting, Engr. Merven Matthew D. Natino Gillian Katherine L. Inciong, Gemmalyn E. Magnaye, Leendel Jane D. Punzalan, Sarah Joy A. Acepcion, Ivan Marc H. Escamos, Allen Roy C. Roberto, Jan Martin C. Magcale

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

## 3.1 Overview of the LIDAR Data Pre-Processing

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

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

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

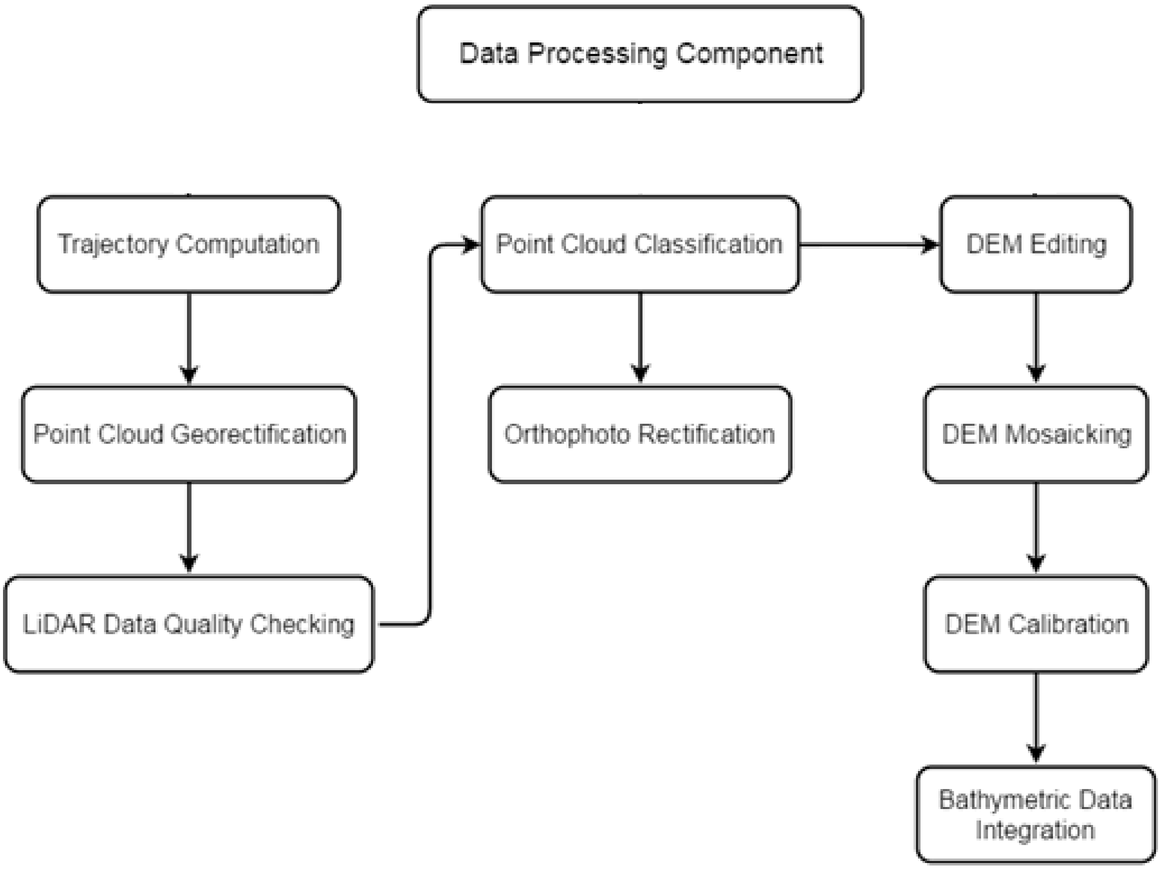



Figure 9. Schematic diagram for Data Pre-Processing Component.

## 3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Aborlan Floodplain can be found in ANNEX 5. Data Transfer Sheets. Missions flown during the first survey conducted on June 2015 and during the second survey conducted on November 2015 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus system and Gemini system, respectively, over Municipality of Aborlan, Palawan. The Data Acquisition Component (DAC) transferred a total of 123.70 Gigabytes of Range data, 1.19 Gigabytes of POS data, 30.67 Megabytes of GPS base station data, and 122.90 Gigabytes of raw image data to the data server on December 08, 2015. The Data Pre-Processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Aborlan was fully transferred on January 04, 2016 as indicated on the data transfer sheets for Aborlan Floodplain.

## 3.3 Trajectory Computation

The Smoothed Performance Metric parameters of the computed trajectory for flight 3037P, one of the Aborlan flights, which is the North, East, and Down position RMSE values are shown in Figure 10. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on June 07, 2015 00:00AM. The y-axis is the RMSE value for that particular position.

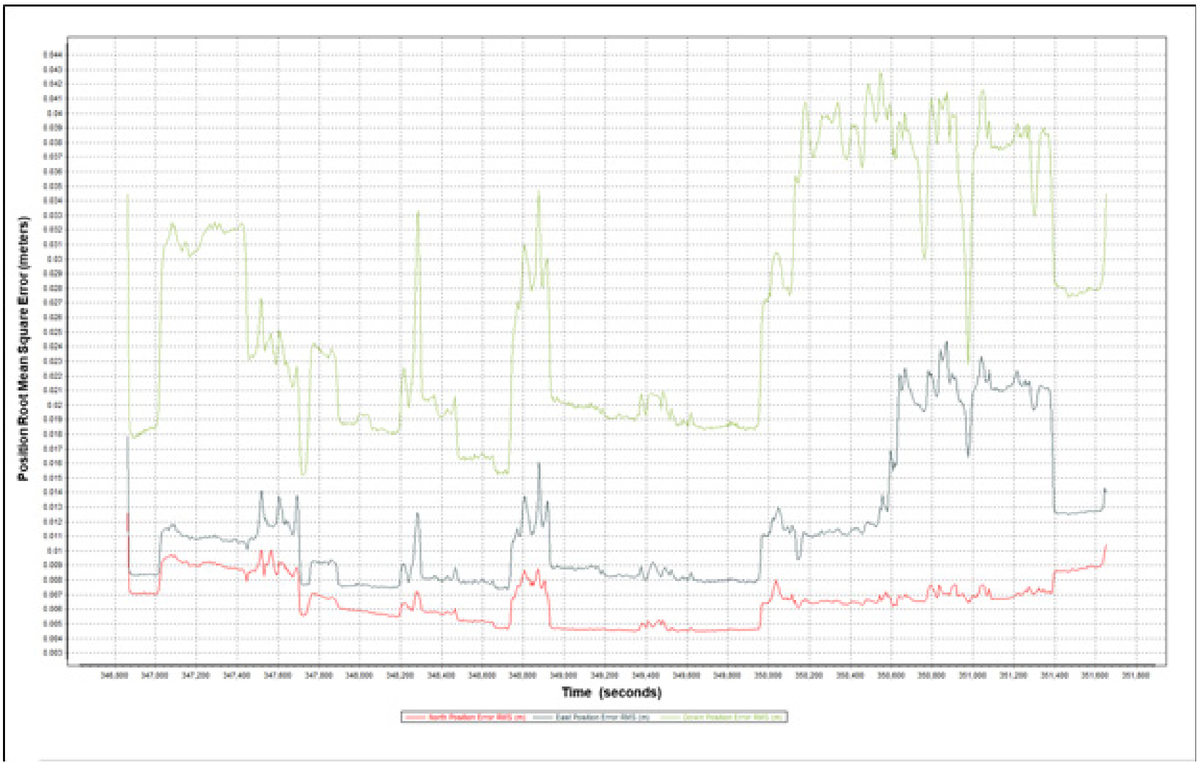



Figure 10. Smoothed Performance Metric parameters of an Aborlan Flight 3037P.

The time of flight was from 346,800 seconds to 351,800 seconds, which corresponds to morning of June 11, 2015. The initial spike that is seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the time the POS system started computing for the position and orientation of the aircraft. Redundant measurements from the POS system quickly minimize the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values correspond to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 10 shows that the North position RMSE peaks at 1.00 centimeters, the East position RMSE peaks at 2.44 centimeters, and the Down position RMSE peaks at 4.29 centimeters, which are within the prescribed accuracies described in the methodology.

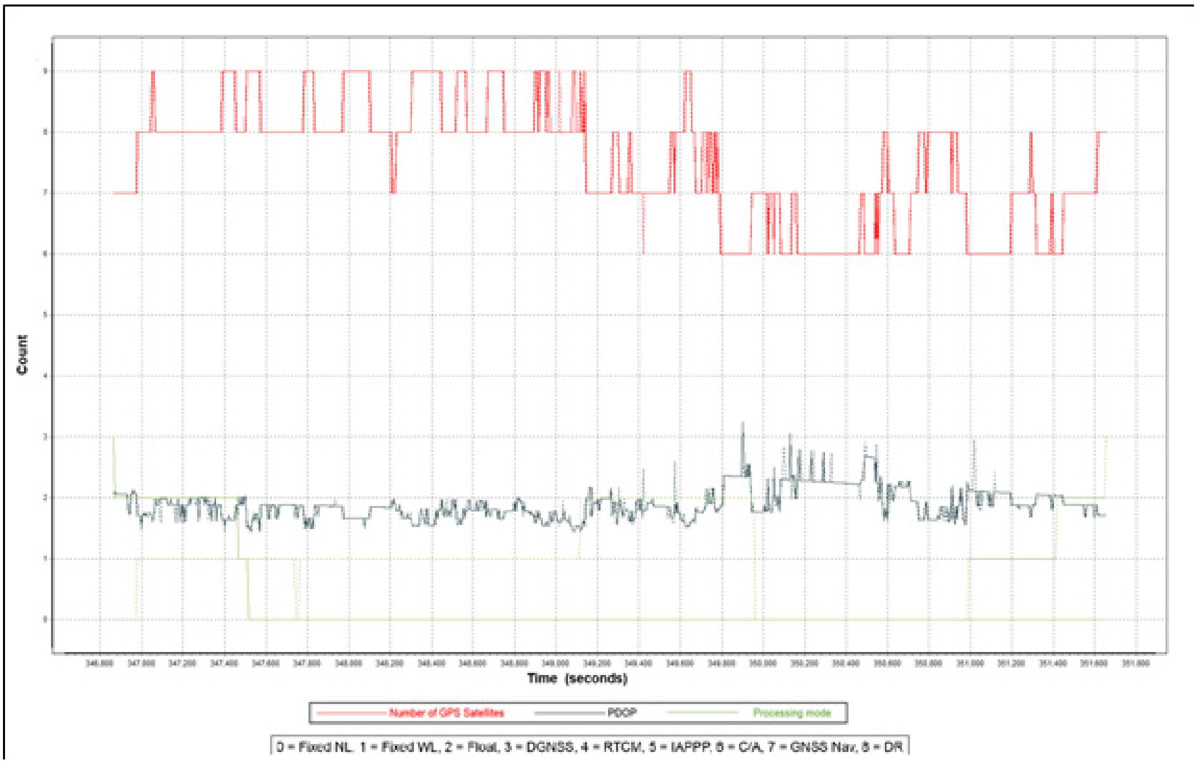



Figure 11. Solution Status parameters of Aborlan Flight 3037P.

Figure 9. Solution Status parameters of Aborlan Flight 3037P
The Solution Status parameters of flight 3037P, one of the Aborlan flights, which are the number of GPS satellites, Positional Dilution of Precision, and the GPS processing mode used, are shown in Figure 11. The graphs indicate that the number of satellites during the acquisition did not go down below 6. Majority of the time, the number of satellites tracked was between 6 and 9. The PDOP value most of the time did not go above the value of 3, which still indicates optimal GPS geometry. The processing mode stayed at the value of 0 for almost the entire survey time with some parts go to 1 attributed to the turn 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 Aborlan flights is shown in Figure 12.

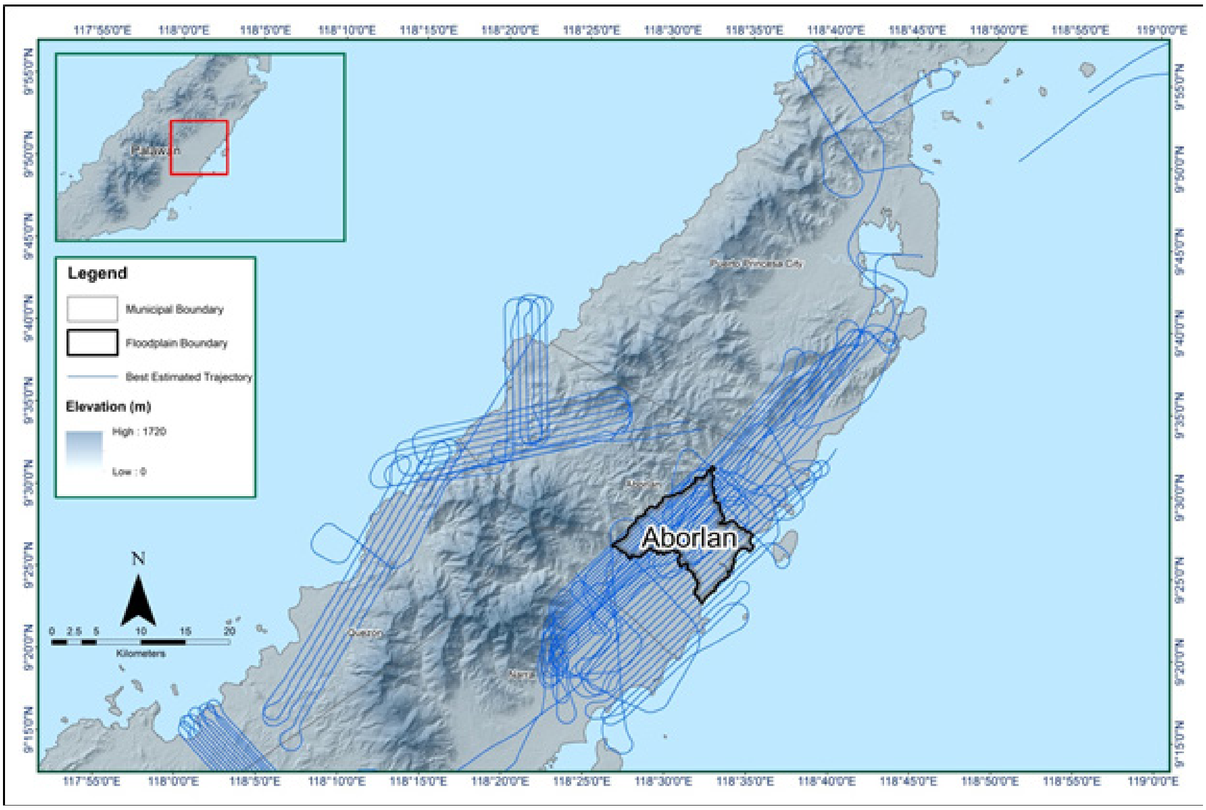



Figure 12. Best estimated trajectory of LiDAR missions conducted over Aborlan Floodplain.

## 3.4 LiDAR Point Cloud Computation

The produced LAS data contains 65 flight lines. Fifty (50) of those flight lines contains two (2) channels for the Pegasus system, and the remaining 15 flight lines contains only one channel since the Gemini system contains only one channel. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Aborlan Floodplain are given in Table 14.

Table 14. Self-calibration results values for Aborlan flights.

| Parameter | Acceptable Value | Computed Value |
|---|---|---|
| Boresight Correction stdev) | <0.001degrees | 0.000212 |
| IMU Attitude Correction Roll and Pitch Corrections stdev) | <0.001degrees | 0.000774 |
| GPS Position Z-correction stdev) | <0.01meters | 0.0020 |

The optimum accuracy is obtained for all Aborlan 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.

## 3.5 LiDAR Quality Checking

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

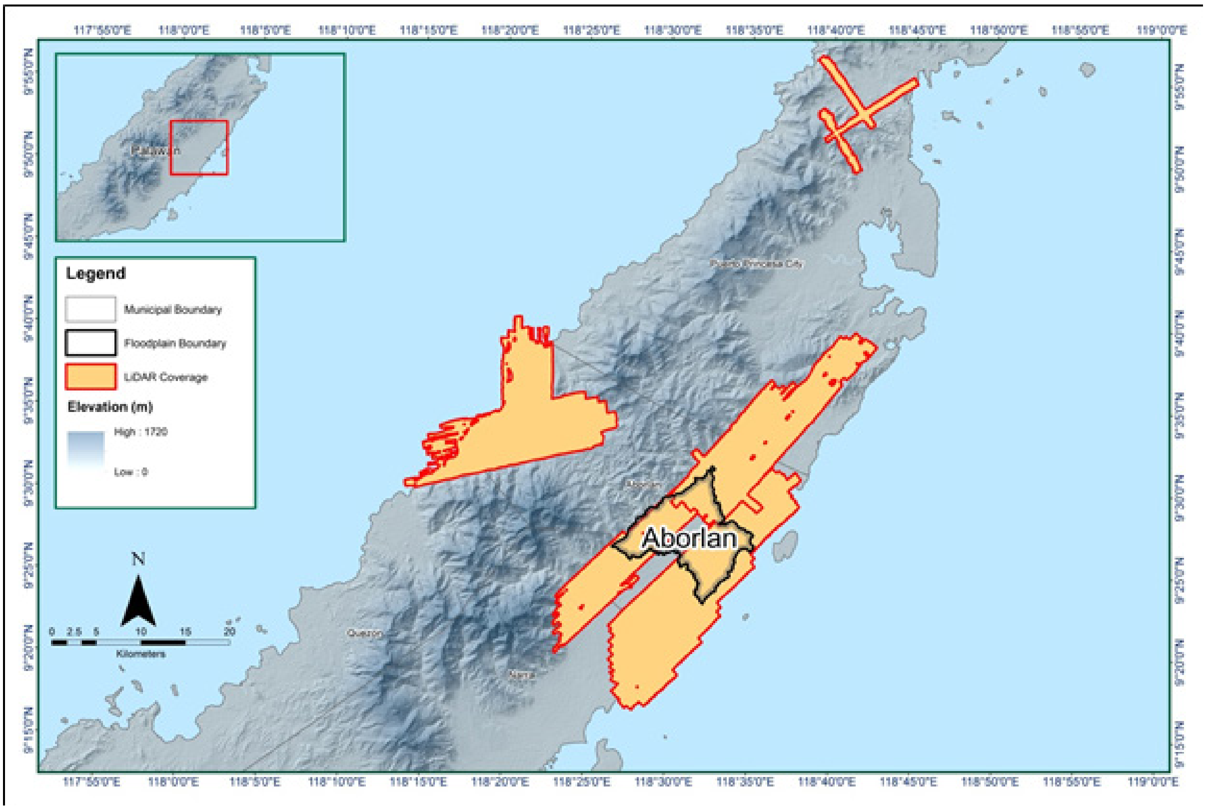



Figure 13. Boundary of the processed LiDAR data over Aborlan Floodplain.

The total area covered by the Aborlan missions is 629.25 sq km comprised of six (6) flight acquisitions grouped and merged into five (5) blocks as shown in Table 15.

Table 15. List of LiDAR blocks for Aborlan Floodplain.

| LiDAR Blocks | Flight Numbers | Area (sq.km) |
|---|---|---|
| Palawan_Blk42Ab | 3061P | 149.98 |
| Palawan_Blk42Ac | 3065P | 202.59 |
| Palawan_Blk42E_additional | 3061P | 24.32 |
| Palawan_Blk42I | 3037P | 162.79 |
| Palawan_Reflights_Blk42eH | 3537G | 89.57 |
| | 3553G | |
| | 3557G | |
| **TOTAL** | | **629.25 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 14. Since the Gemini system employs one channel, we an average value of 1 (blue) would be expected for areas where there is limited overlap, and a value of 2 (yellow) or more (red) for areas with three or more overlapping flight lines. Meanwhile, for the Pegasus system which employs two channels, an average value of 2 (blue) would be expected for areas where there is limited overlap and a value of 3 (yellow) or more (red) for areas with three or more overlapping flight lines.

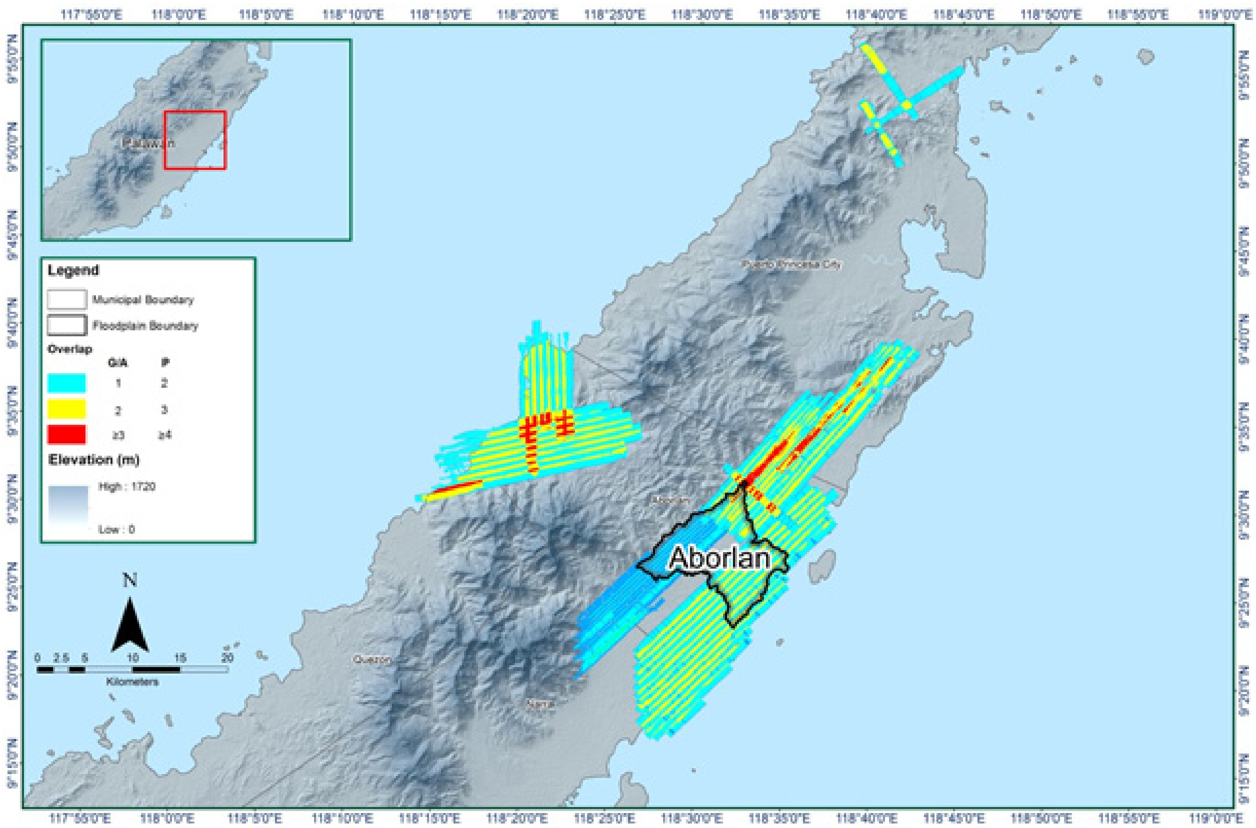



Figure 14. Image of data overlap for Aborlan Floodplain.

The overlap statistics per block for the Aborlan Floodplain can be found in ANNEX 8. It should be noted that one pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 29.02% and 47.37%, respectively, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion, is shown in Figure 15. It was determined that all LiDAR data for Aborlan Floodplain satisfy the point density requirement, and the average density for the entire survey area is 2.85 points per square meter.

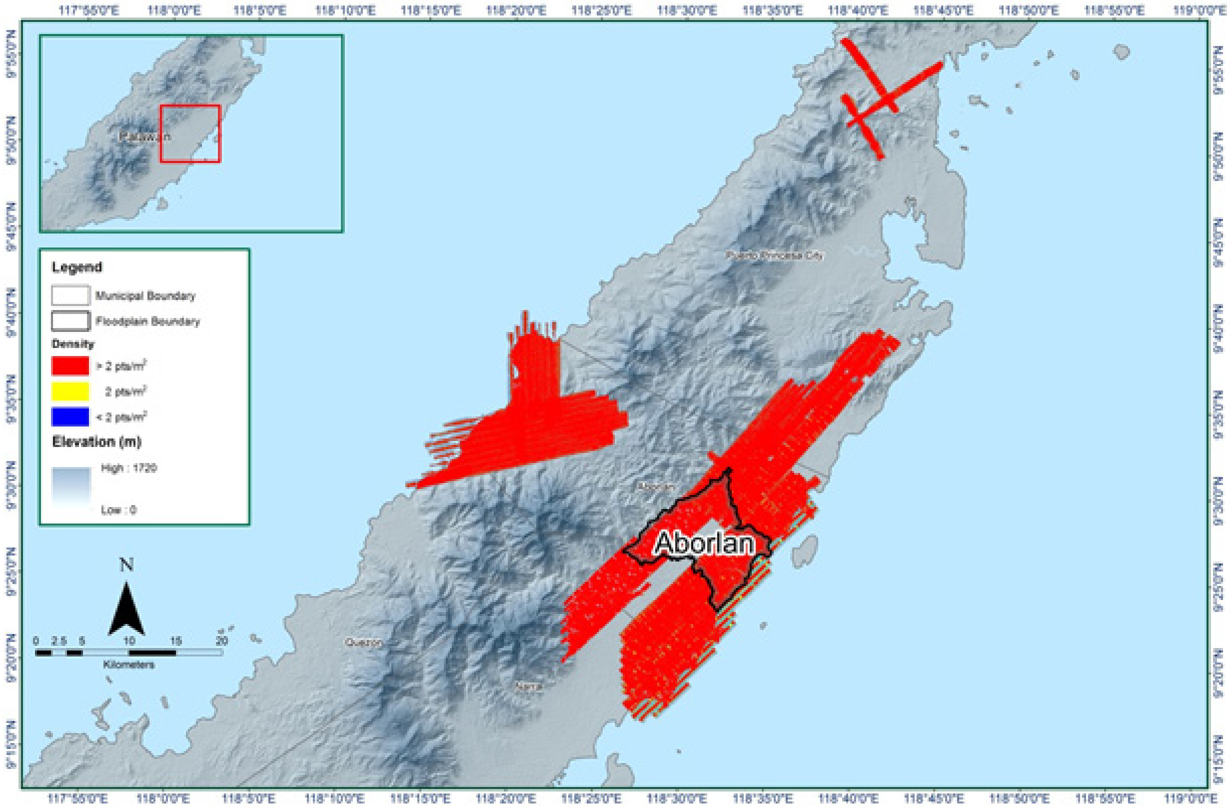



Figure 15. Pulse density map of merged LiDAR data for Aborlan Floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 16. The default color range is from blue to red, where bright blue areas correspond to portions where elevations of a previous flight line, identified by its acquisition time, are higher by more than 0.20 m relative to elevations of its adjacent flight line. Bright red areas indicate portions where elevations of a previous flight line are lower by more than 0.20 m relative to elevations of its adjacent flight line. Areas with bright red or bright blue need to be investigated further using Quick Terrain Modeler software.

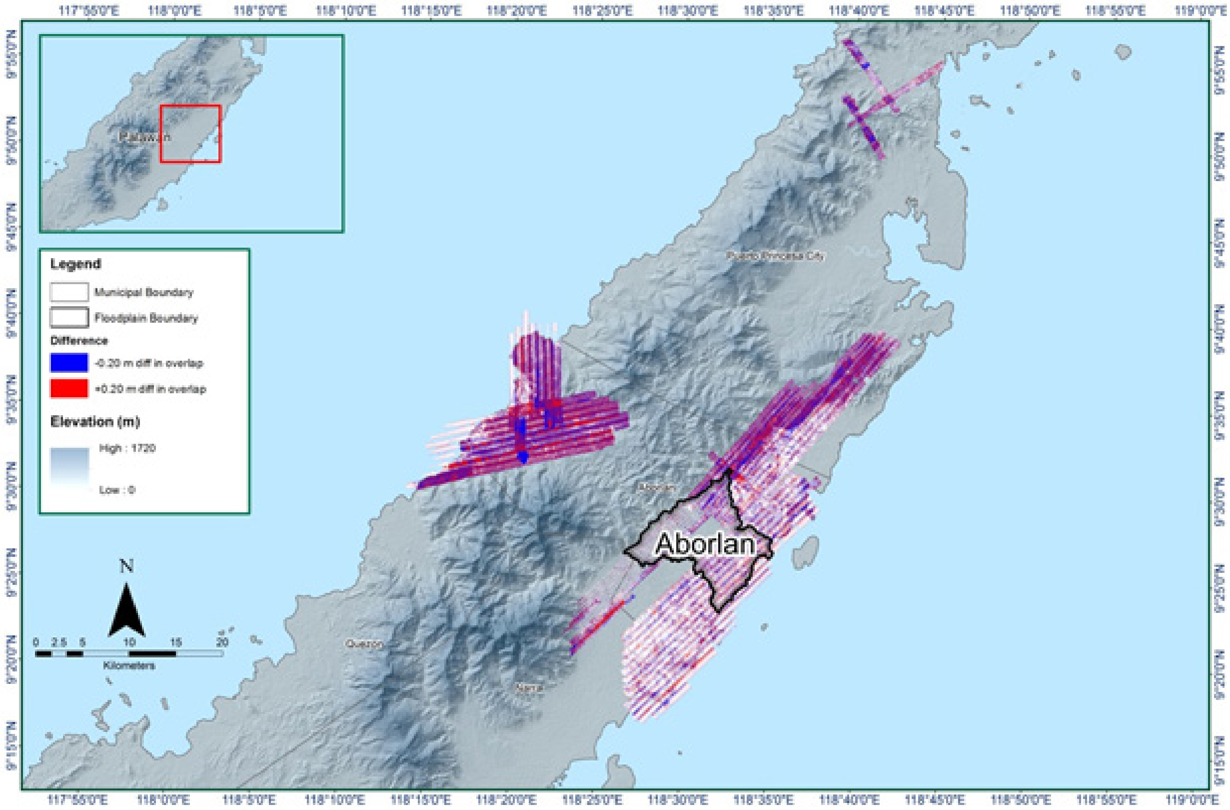



Figure 16. Elevation difference map between flight lines for Aborlan Floodplain.

A screen capture of the processed LAS data from an Aborlan flight 3037P loaded in QT Modeler is shown in Figure 17. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed yellow line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LIDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

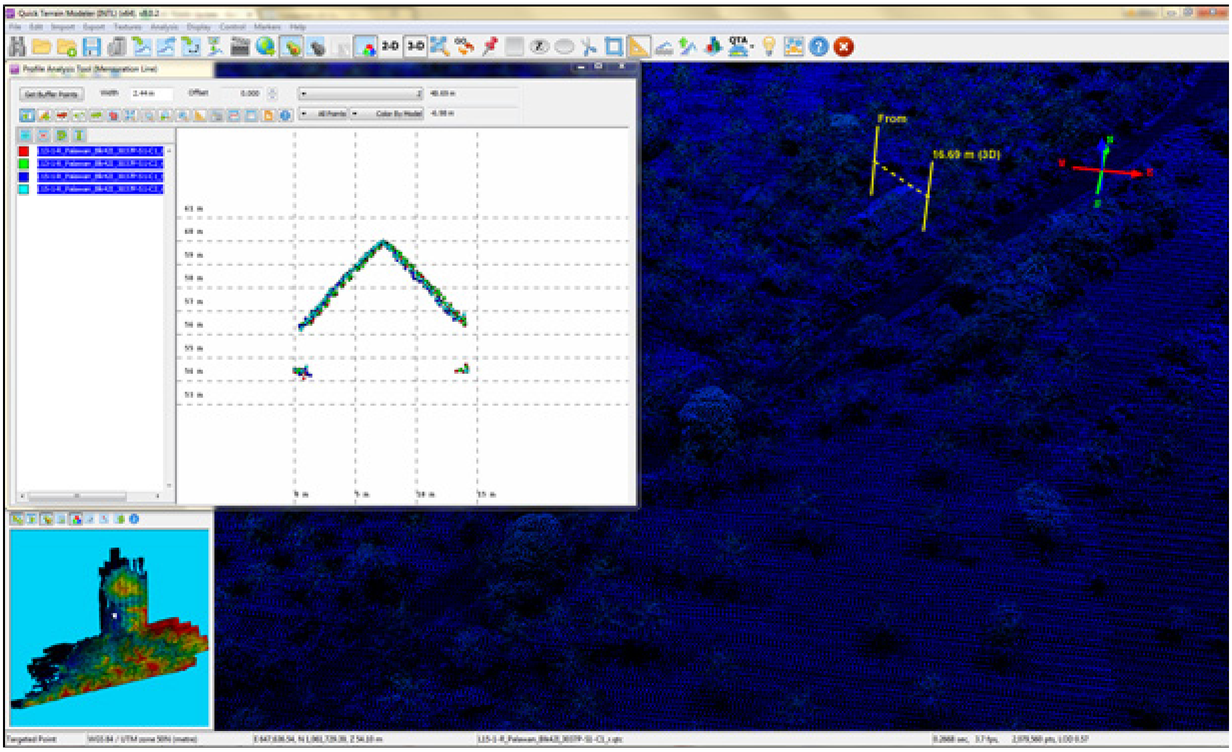


Figure 17. Quality checking for an Aborlan flight 3037P using the Profile Tool of QT Modeler.

## 3.6 LiDAR Point Cloud Classification and Rasterization

Table 16. Aborlan classification results in TerraScan.

| Pertinent Class | Total Number of Points |
|---|---|
| Ground | 493,557,482 |
| Low Vegetation | 380,416,013 |
| Medium Vegetation | 715,187,818 |
| High Vegetation | 2,294,156,857 |
| Building | 16,474,016 |

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Aborlan Floodplain is shown in Figure 18. A total of 780 1 km by 1 km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 16. The point cloud has a maximum and minimum height of 816.42 meters and 49.39 meters, respectively.

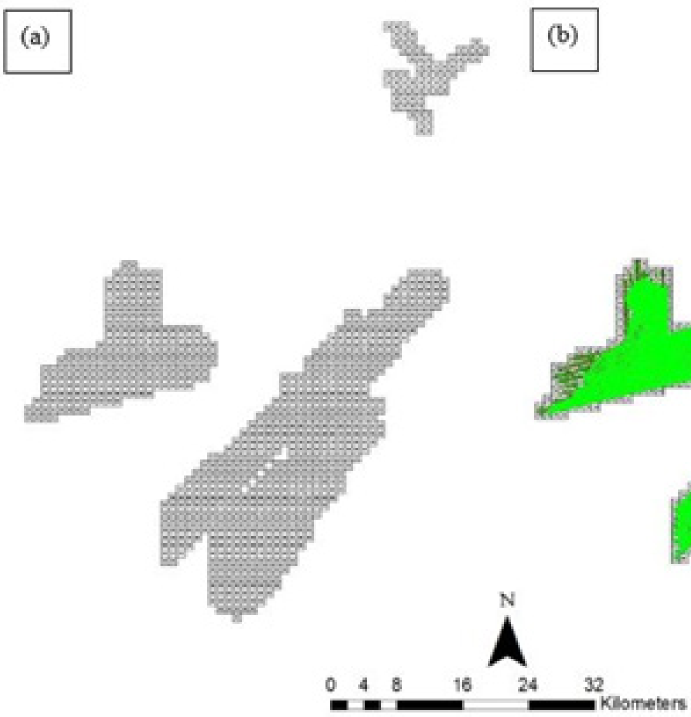



Figure 18. Tiles for Aborlan Floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 19. The ground points are in orange, the vegetation is in different shades of green, and the buildings are in cyan. It can be seen that residential structures adjacent or even below canopy are classified correctly due to the density of the LiDAR data.

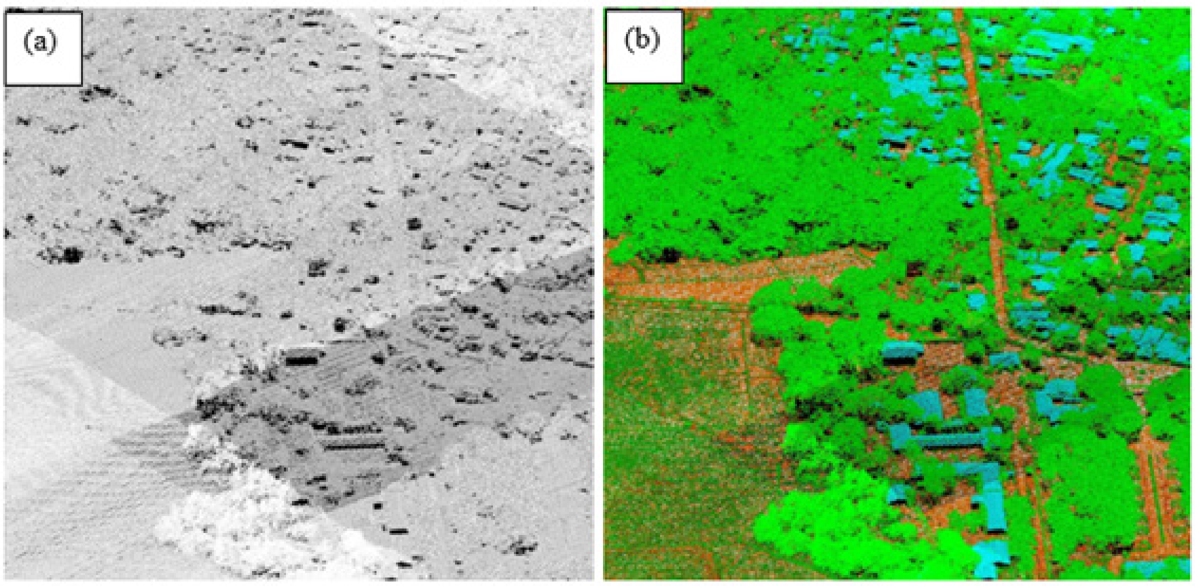



Figure 19. Point cloud before (a) and after (b) classification.

The production of last return (V_ASCII) and the secondary (T_ ASCII) DTM, first (S_ ASCII) and last (D_ ASCII) return DSM of the area in top view display are shown in Figure 20. It shows that DTMs are the representation of the bare earth while on the DSMs, all features are present such as buildings and vegetation.

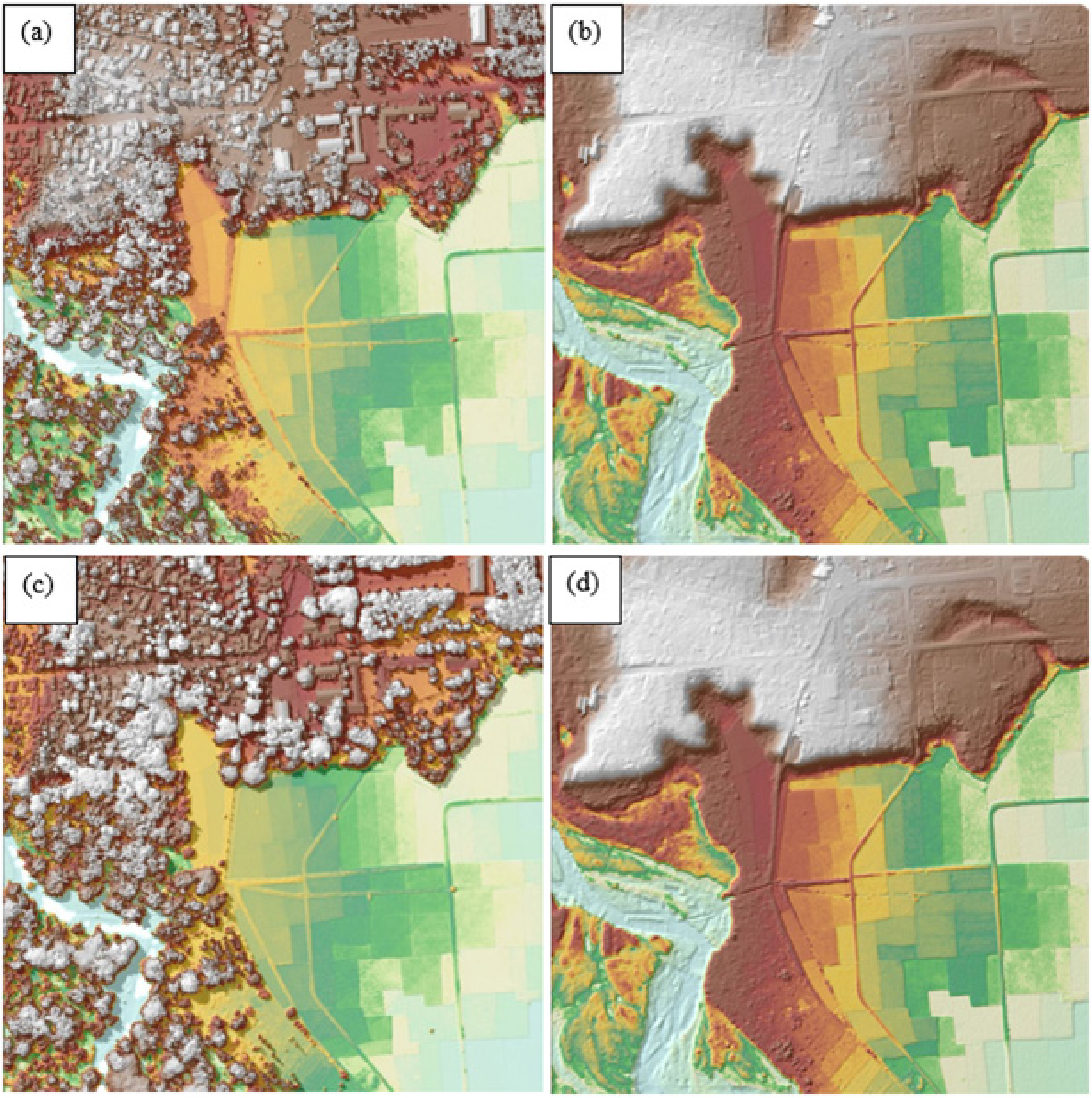



Figure 20. The Production of last return DSM (a) and DTM (b); first return DSM (c) and secondary DTM (d) in some portion of Aborlan Floodplain.

## 3.7 LiDAR Image Processing and Orthophotograph Rectification

The 764 1 km by 1 km tiles area covered by Aborlan Floodplain is shown in Figure 21. After tie-point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Aborlan Floodplain attained a total of 531.17 sq km in orthophotogaph coverage comprised of 974 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 22.

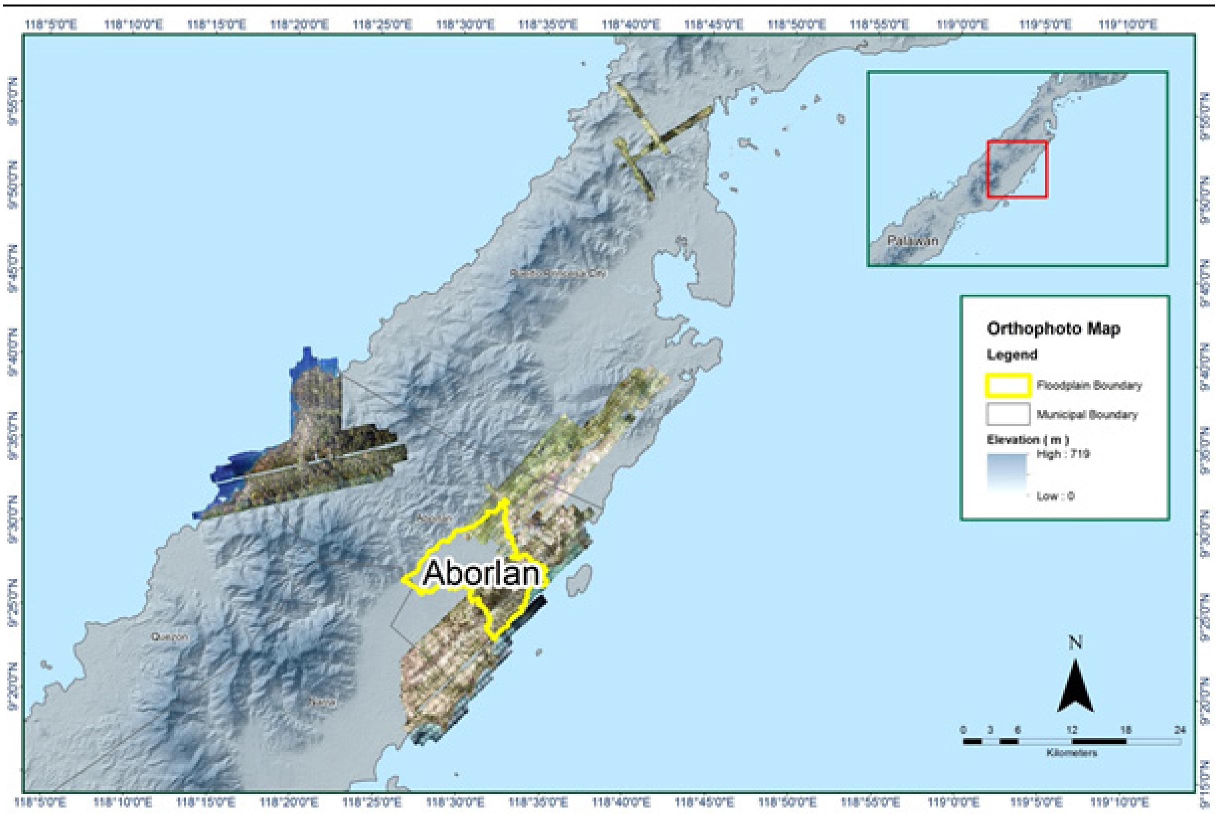



Figure 21. Aborlan Floodplain with available orthophotographs.


Figure 22. Sample orthophotograph tiles for Aborlan Floodplain.

## 3.8 DEM Editing and Hydro-Correction

Five (5) mission blocks were processed for Aborlan Floodplain. These blocks are composed of Palawan and Palawan Reflights blocks with a total area of 629.25 square kilometers. Table 17 shows the name and corresponding area of each block in square kilometers.

Table 17. LiDAR blocks with their corresponding area.

| LiDAR Blocks | Area (sq. km.) |
|---|---|
| Palawan_Blk42Ab | 149.98 |
| Palawan_Blk42Ac | 202.59 |
| Palawan_Blk42E_additional | 24.32 |
| Palawan_Blk42I | 162.79 |
| Palawan_Reflights_Blk42eH | 89.57 |
| **TOTAL** | **629.25 sq km** |

Portions of DTM before and after manual editing are shown in Figure 23. The bridge (Figure 23a) was considered to be an impedance to the flow of water along the river and had to be removed (Figure 23b) in order to hydrologically correct the river. The data gap (Figure 23c) had been filled to complete the surface (Figure 23d) to allow the correct flow of water.

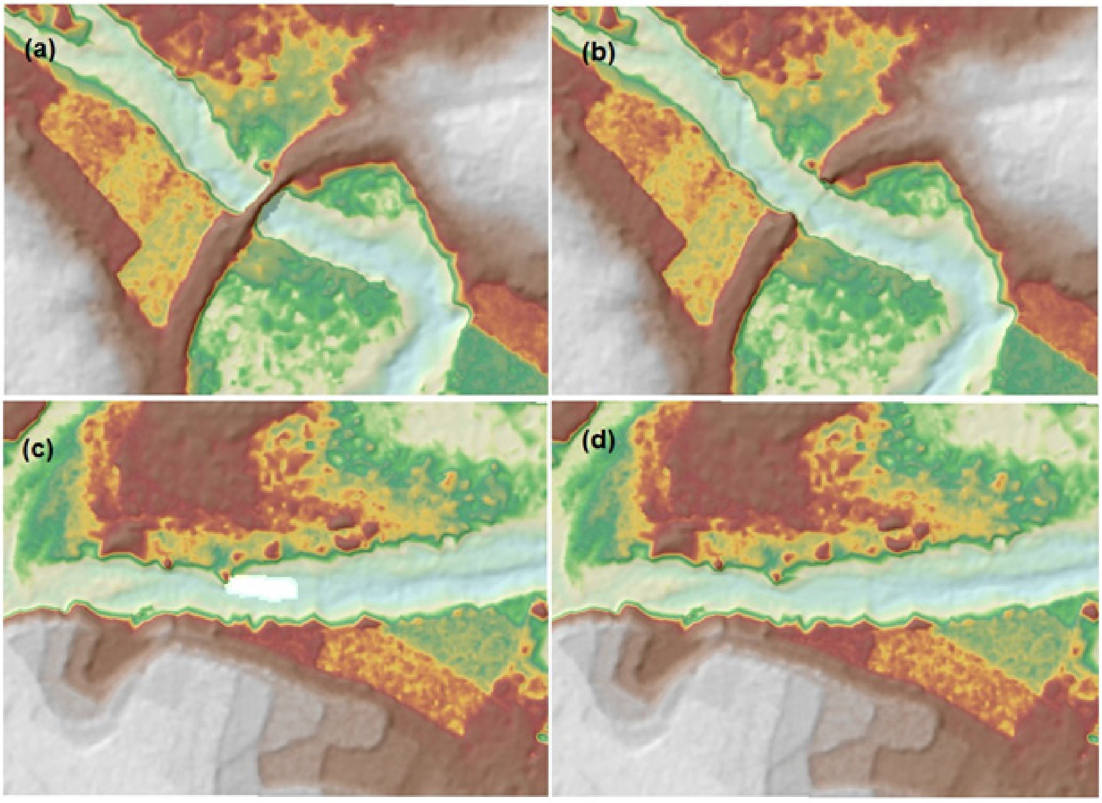



Figure 23. Portions in the DTM of Aborlan Floodplain—a bridge before (a) and after (b) manual editing; and a data gap before (a) and after (b) filling.

## 3.9 Mosaicking of Blocks

Palawan Block 42Aa was used as the reference block at the start of mosaicking because it was the first block mosaicked to the larger DTM of West Coast Palawan. Upon inspection of the blocks mosaicked for the Aborlan Floodplain, it was concluded that only the elevation of Palawan Blk42I and Palawan Reflights Blk42eH needed adjustment of the DTM before merging.

Mosaicked LiDAR DTM for Aborlan Floodplain is shown in Figure 24. The entire Aborlan Floodplain is 86.31% covered by LiDAR data while portions with no LiDAR data were patched with the available IFSAR data.

Table 18. Shift values of each LiDAR Block of Aborlan Floodplain.

| Mission Blocks | Shift Values (meters) | | |
|---|---|---|---|
| | x | y | z |
| Palawan_Blk42Ab | 0.00 | 0.00 | 0.00 |
| Palawan_Blk42Ac | 0.00 | 0.00 | 0.00 |
| Palawan_Blk42E_additional | 0.00 | 0.00 | 0.00 |
| Palawan_Blk42I | 0.00 | 0.00 | -1.17 |
| Palawan_Reflights_Blk42eH | 0.00 | 0.00 | -1.59 |

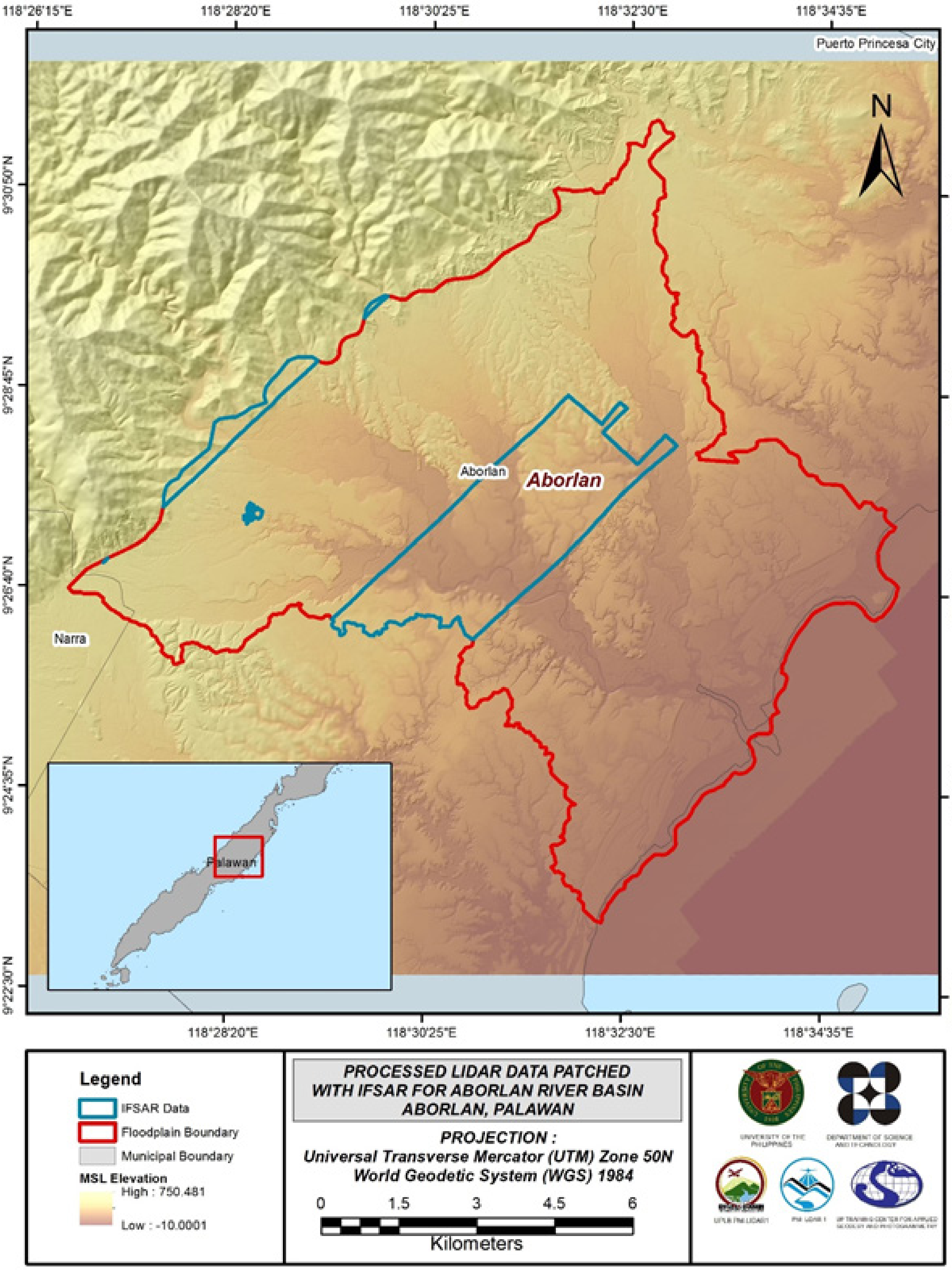



Figure 24. Map of processed LiDAR data for Aborlan Floodplain.

## 3.10 Calibration and Validation of Mosaicked LiDAR DEM

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Aborlan to collect points with which the LiDAR dataset is validated is shown in Figure 25. A total of 2,816 survey points were used for calibration and validation of Aborlan LiDAR data. Eighty percent of the survey points, which were randomly selected and resulting in 2,253 points, were used for calibration. A good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values is shown in Figure 26. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration elevation values is 9.63 meters with a standard deviation of 0.20 meters. Calibration of Aborlan LiDAR data was done by adding the height difference value, 9.63 meters, to Aborlan mosaicked LiDAR data. Table 19 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

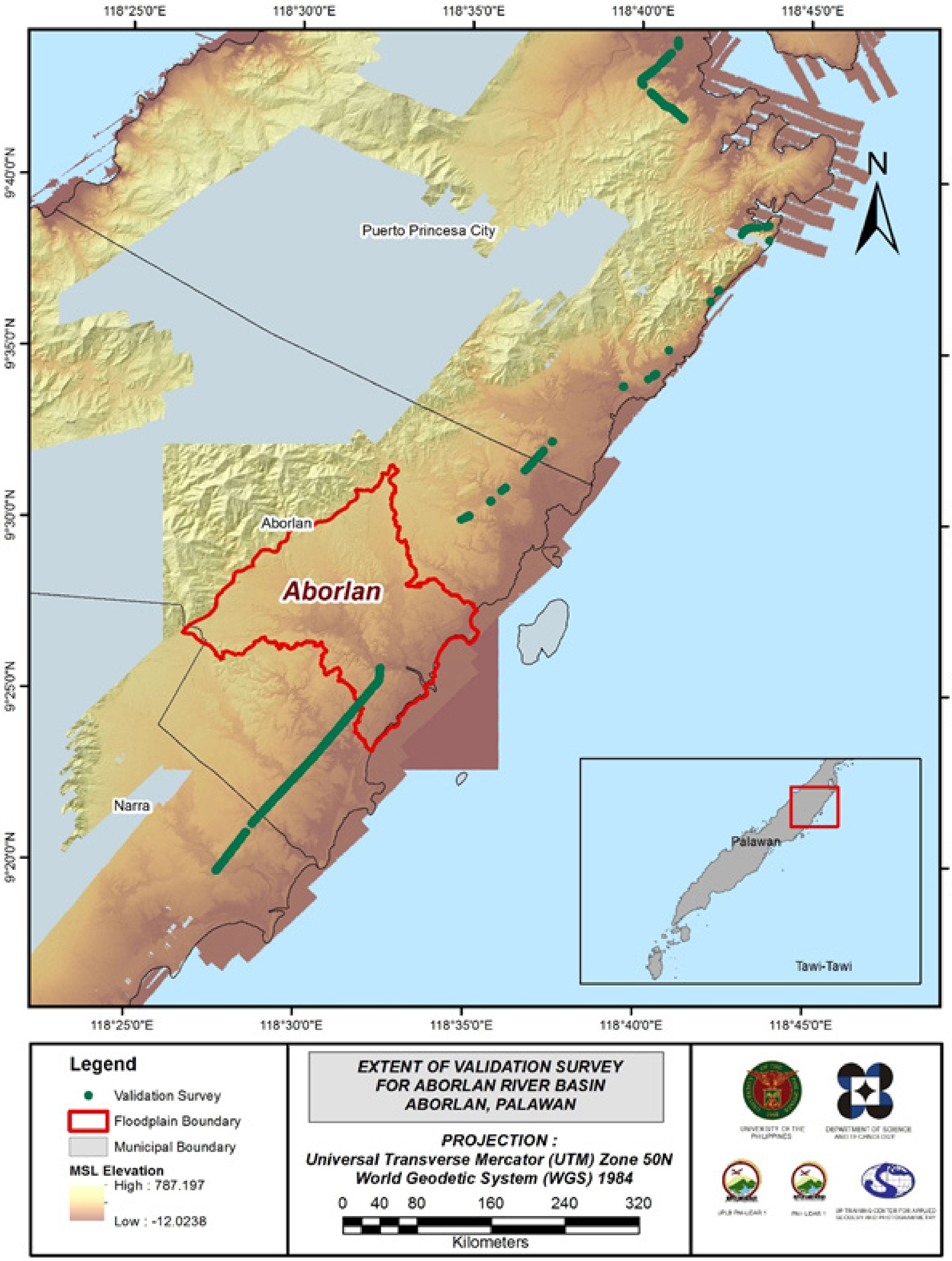



Figure 25. Map of Aborlan Floodplain with validation survey points in green.

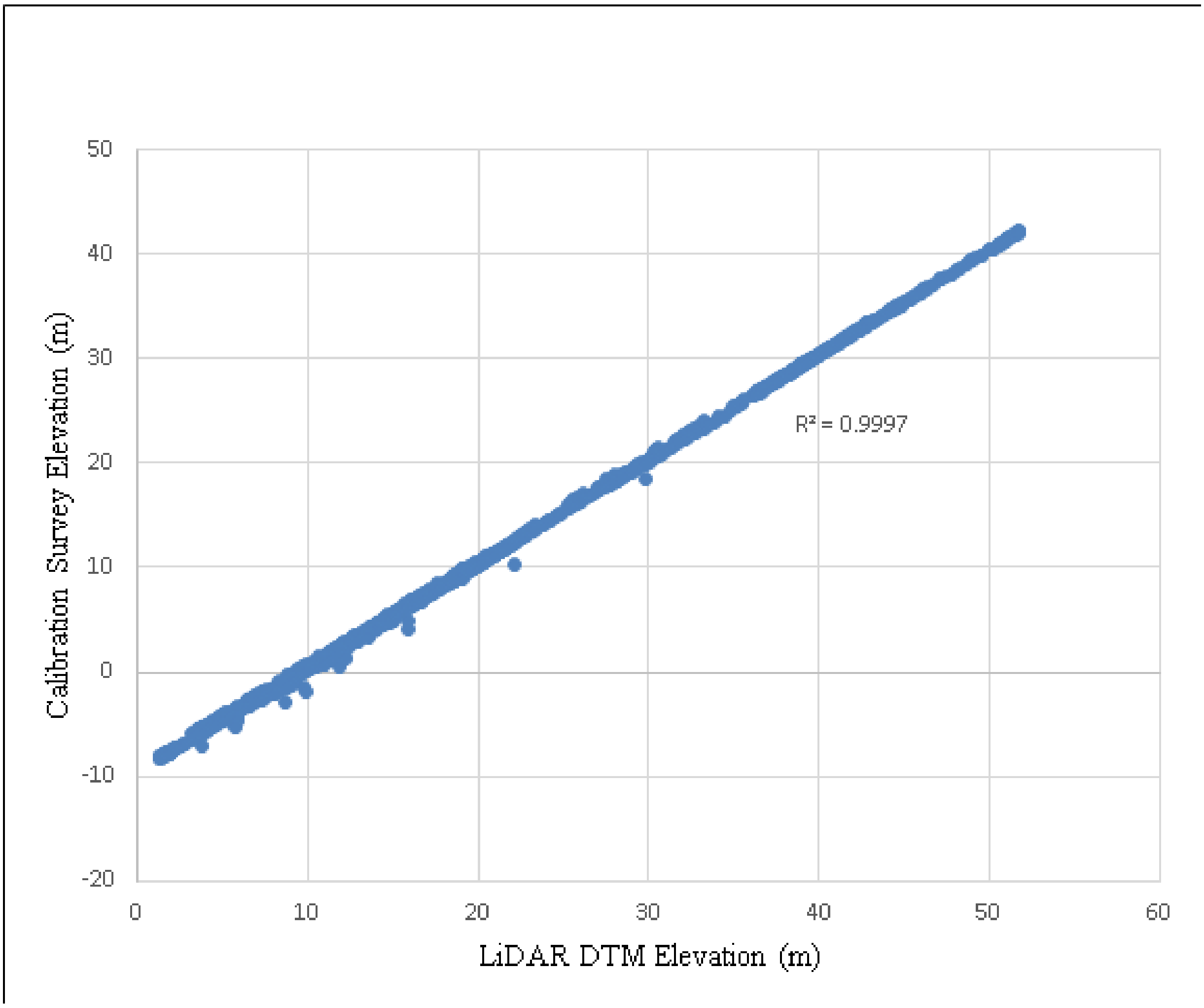



Figure 26. Correlation plot between calibration survey points and LiDAR data.

Table 19. Calibration statistical measures.

| Calibration Statistical Measures | Value (meters) |
|---|---|
| Height Difference | 9.63 |
| Standard Deviation | 0.20 |
| Average | 9.62 |
| Minimum | 9.23 |
| Maximum | 10.02 |

The remaining 20% of the total survey points, resulting in 563, were used for the validation of calibrated Aborlan DTM. A good correlation between the calibrated mosaicked LiDAR elevation values and the ground survey elevation, which reflects the quality of the LiDAR DTM, is shown in Figure 27. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.20 meters with a standard deviation of 0.20 meters, as shown in Table 20.

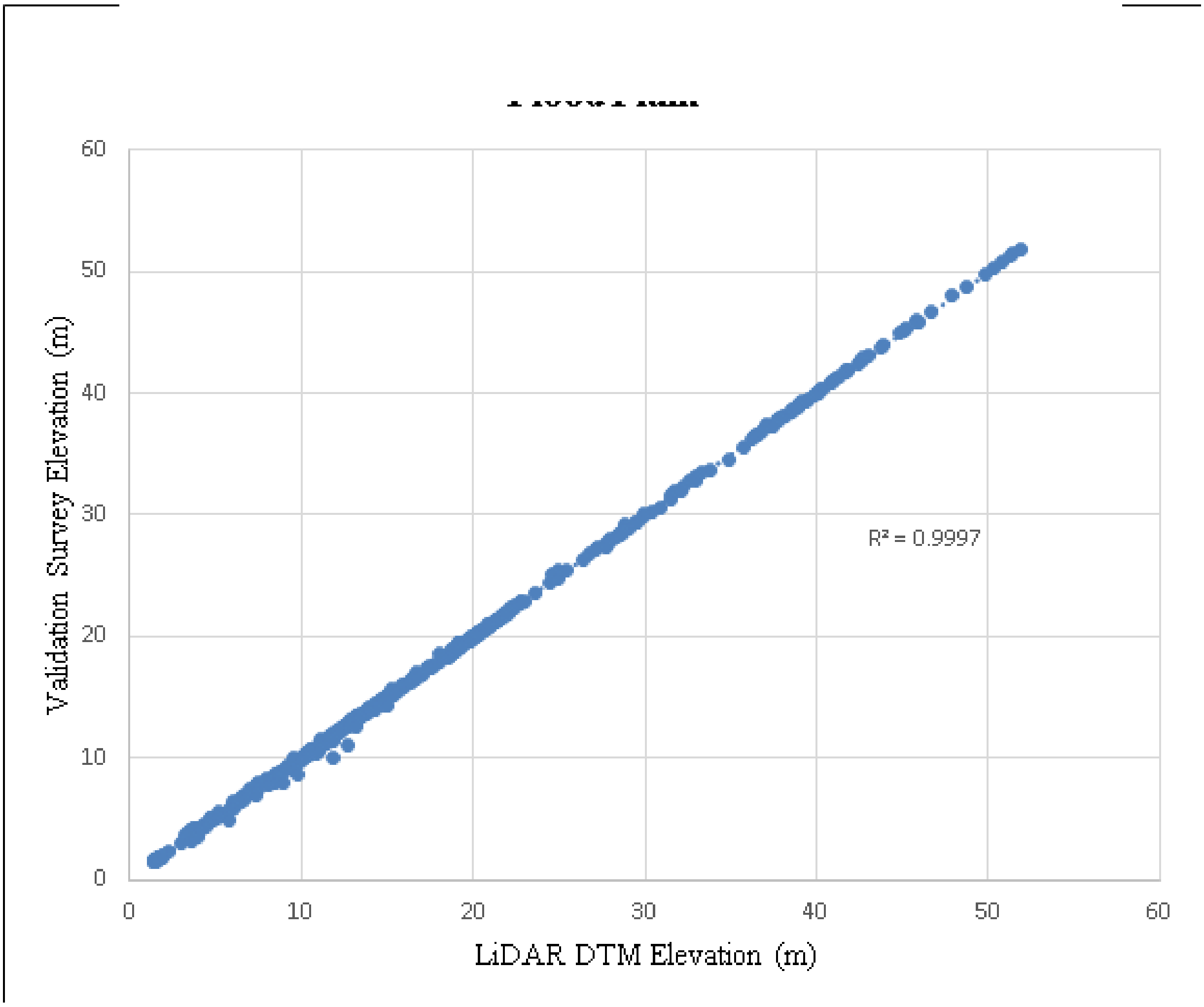



Figure 27. Correlation plot between validation survey points and LiDAR data.

Table 20. Validation statistical measures.

| Validation Statistical Measures | Value (meters) |
|---|---|
| RMSE | 0.20 |
| Standard Deviation | 0.20 |
| Average | 0.003 |
| Minimum | -0.39 |
| Maximum | 0.39 |

## 3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathymetric data integration, only centerline was available for Aborlan with a total of 905 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 0.41 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Aborlan integrated with the processed LiDAR DEM is shown in Figure 28.

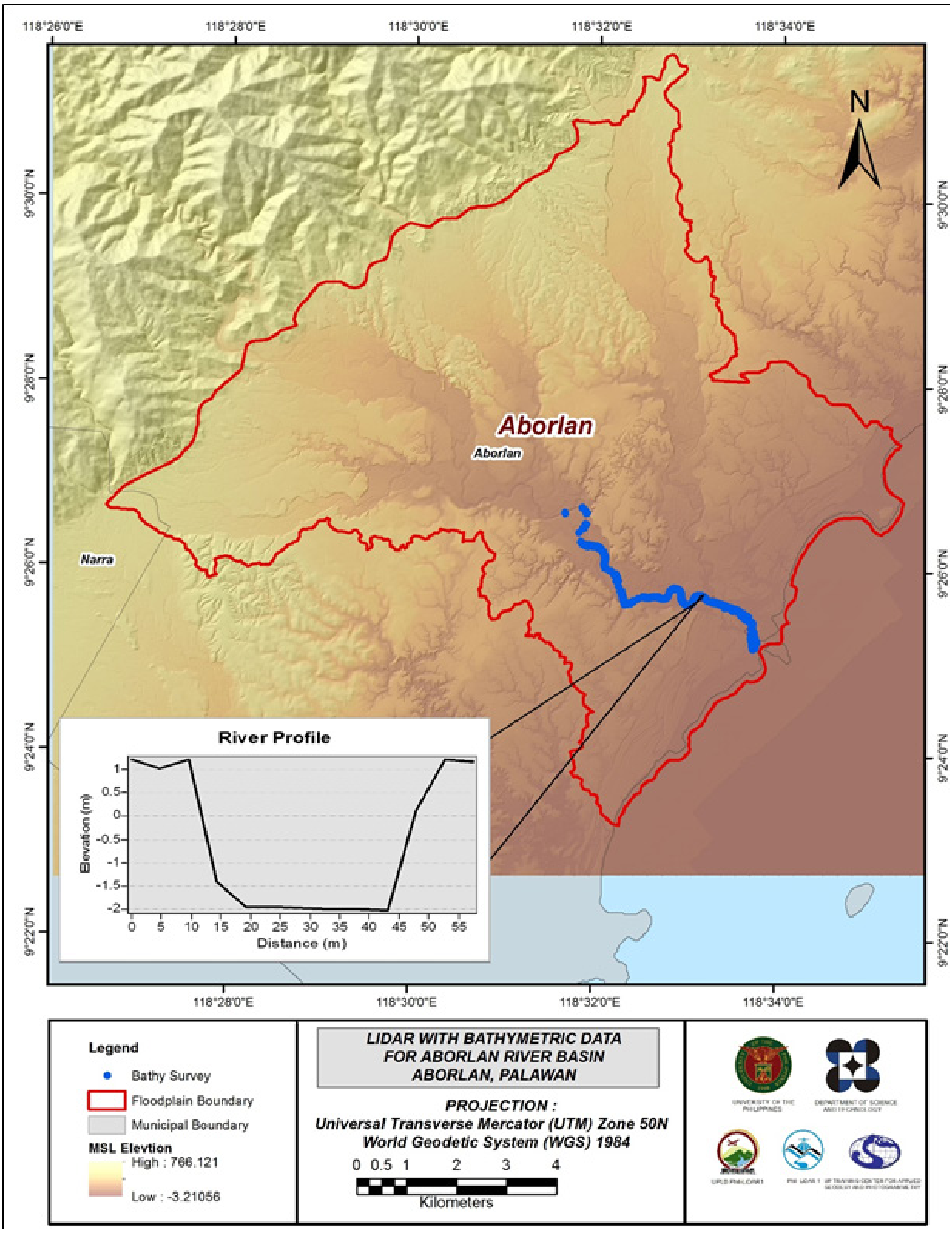



Figure 28. Map of Aborlan Floodplain with bathymetric survey points shown in blue.

## 3.12 Feature Extraction

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

### 3.12.1 Quality Checking (QC) of Digitized Features' Boundary

Aborlan Floodplain, including its 200 m buffer, has a total area of 303.43 sq km. For this area, a total of 10.00 sq km, corresponding to a total of 2,326 building features, are considered for QC. Figure 29 shows the QC blocks for Aborlan Floodplain.

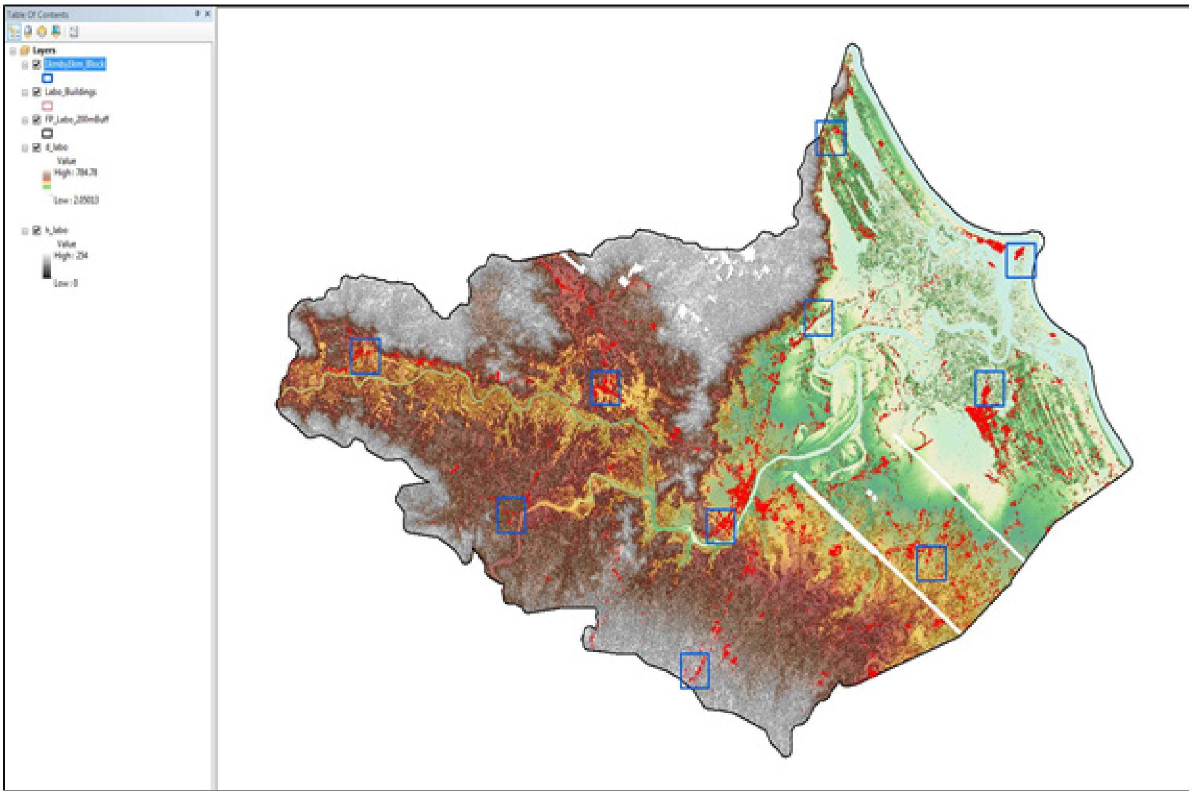


Figure 29. Blocks of Aborlan building features subjected to QC.

Quality checking of Aborlan building features resulted in the ratings shown in Table 21.

Table 21. Quality Checking Ratings for Aborlan Building Features.

| FLOODPLAIN | COMPLETENESS | CORRECTNESS | QUALITY | REMARKS |
|---|---|---|---|---|
| Aborlan | 99.19 | 100.00 | 89.42 | PASSED |

### 3.12.2 Height Extraction

Height extraction was done for 19,484 building features in Aborlan Floodplain. Of these building features, 914 were filtered out after height extraction, resulting in 18,570 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 10.13 m.

### 3.12.3 Feature Attribution

Table 22 summarizes the number of building features per type. On the other hand, Table 23 shows the total length of each road type, while Table 24 shows the number of water features extracted per type.

Table 22. Number of building features extracted for Aborlan Floodplain.

| Facility Type | No. of Features |
|---|---|
| Residential | |
| School | |
| Market | |
| Agricultural/Agro-Industrial Facilities | |
| Medical Institutions | |
| Barangay Hall | |
| Military Institution | |
| Sports Center/Gymnasium/Covered Court | |
| Telecommunication Facilities | |
| Transport Terminal | |
| Warehouse | |
| Power Plant/Substation | |
| NGO/CSO Offices | |
| Police Station | |
| Water Supply/Sewerage | |
| Religious Institutions | |
| Bank | |
| Factory | |
| Gas Station | |
| Fire Station | |
| Other Government Offices | |
| Other Commercial Establishments | |
| **Total** | |

Table 23. Total length of extracted roads for Aborlan Floodplain.

| Floodplain | Road Network Length (km) | | | | | Total |
|---|---|---|---|---|---|---|
| | Barangay Road | City/ Municipal Road | Provincial Road | National Road | Others | |
| Aborlan | | | | | | |

Table 24. Number of extracted water bodies for Aborlan Floodplain.

| Floodplain | Water Body Type | | | | | Total |
|---|---|---|---|---|---|---|
| | Rivers/ Streams | Lakes/Ponds | Sea | Dam | Fish Pen | |
| Aborlan | | | | | | |

A total of 62 bridges and culverts over small channels that are part of the river network were also extracted for the floodplain.

## 3.12.4 Final Quality Checking of Extracted Features

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

Figure 30 shows the Digital Surface Model (DSM) of Aborlan Floodplain overlaid with its ground features.

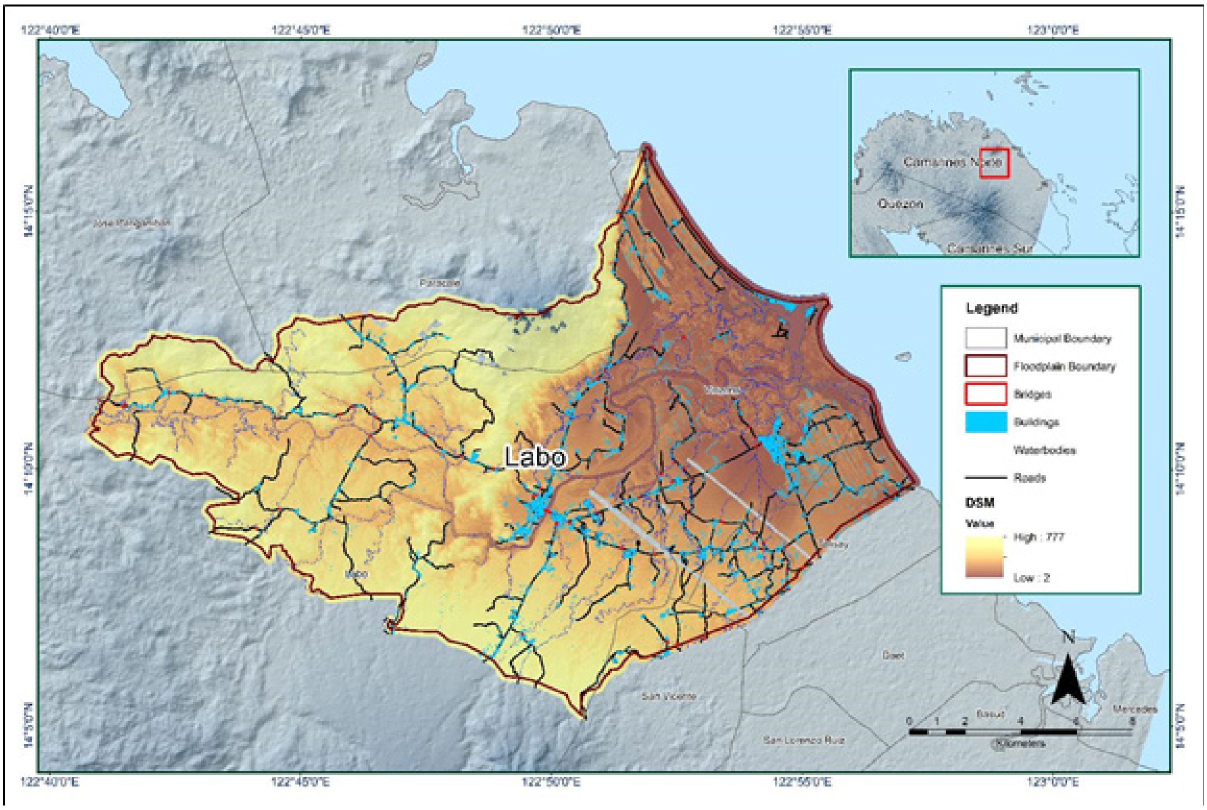



Figure 30. Extracted features for Aborlan Floodplain.

# CHAPTER 4: LIDAR VALIDATION SURVEY AND MEASUREMENTS IN THE ABORLAN RIVER BASIN

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

The methods applied in this chapter were based on the DREAM methods manual (Ang, 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 Aborlan River on November 26 to 27, 2015; December 9, 2015; February 6, 2016; April 26, 2016; and May 28, 2016 with the following scope: reconnaissance; control survey; cross-section and as-built survey at Aborlan Bridge in Brgy. Gogognan, Aborlan, Palawan; and bathymetric survey from its upstream in Brgy. Gogognan to the mouth of the river located in Brgy. Tagpait, Aborlan, with an approximate length of 6.46 km using Horizon® Total Station. Random checking points for the contractor's cross-section and bathymetry data were gathered by DVBC on August 16–28, 2016 using an Ohmex™ Single-Beam Echo Sounder and Trimble® SPS 882 GNSS PPK survey technique. In addition to this, validation points acquisition survey was conducted covering the Aborlan River Basin area. The entire survey extent is illustrated in Figure 31.

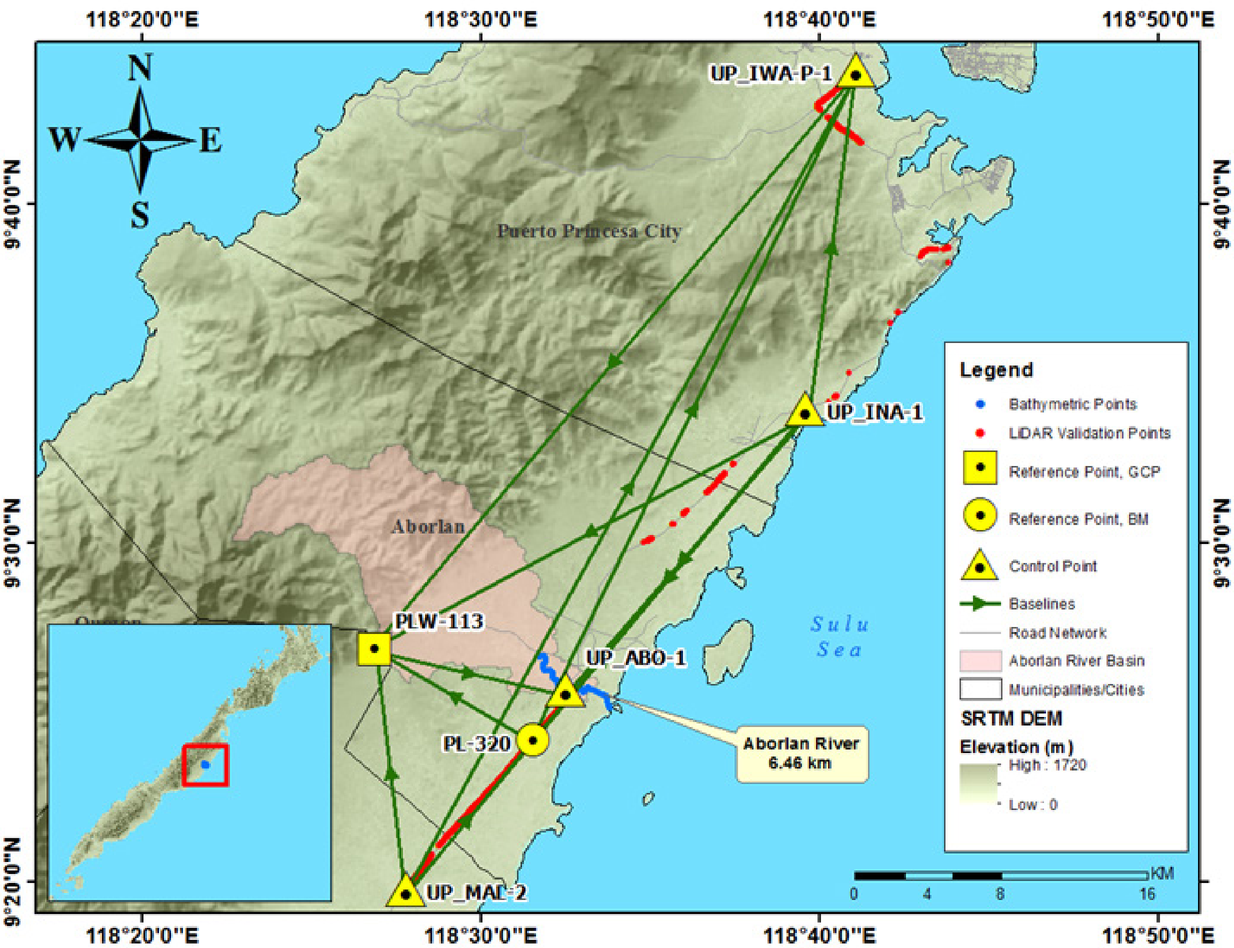



Figure 31. Extent of the bathymetric survey (in blue) in Aborlan River and the LiDAR data validation (in red) .

## 4.2 Control Survey

The GNSS network used for Aborlan River is composed of nine (9) loops established on August 25, 2016 occupying the following reference points: PLW-113, a second-order GCP in Brgy. Dumagueña, Narra, Palawan, and PL-320, a first-order BM in Brgy. Ramon Magsaysay, Aborlan, Palawan.

Four (4) control points established in the area by ABSD were also occupied: UP_MAL-2 at the approach of Malatgao Bridge in Brgy. Tinagong Dagat, Narra, Province of Palawan, UP_IWA-P-1 at the approach of Iwahig Penal Bridge in Brgy. Iwahig, Puerto Princesa City, Palawan, UP_ABO-1 located beside the approach of Aborlan Bridge in Brgy. Gogognan, Aborlan, Palawan, and UP_INA-1 located beside the approach of Inagauan Bridge in Brgy. Inagauan Sub-Colony, Puerto Princesa City, Palawan.

The summary of reference and control points and its location is summarized in Table 25 while GNSS network established is illustrated in Figure 32.

Table 25. List of reference and control points used during the survey in Aborlan River (Source: NAMRIA, UP-TCAGP).

| Control Point | Order of Accuracy | Geographic Coordinates (WGS 84) | | | | |
|---|---|---|---|---|---|---|
| | | Latitude | Longitude | Ellipsoid Height (m) | Elevation (MSL) (m) | Date of Establishment |
| Control Survey on December 10, 2016 | | | | | | |
| PLW-113 | 2nd order, GCP | 9° 26' 50.78624" N | 118° 26' 52.23491"E | 144.388 | 93.784 | 2007 |
| PL-320 | 1st order, BM | 9° 24' 10.67926" N | 118° 31' 31.30061"E | 58.025 | 7.089 | 2008 |
| UP_MAL-2 | Established | 9° 19' 47.08536"N | 118° 27' 48.23703"E | 67.449 | 16.469 | 11-27-15 |
| UP_ IWA-P-1 | Established | 9° 43' 58.38961"N | 118° 41' 03.58218"E | 55.529 | 5.044 | 11-25-15 |
| UP_ABO-1 | Established | 9° 25' 39.66712"N | 118° 32' 29.34660"E | 59.322 | 8.415 | 11-26-15 |
| UP_INA-1 | Established | 9° 33' 58.62160"N | 118° 39' 34.84567"E | 56.382 | 5.672 | 11-27-15 |

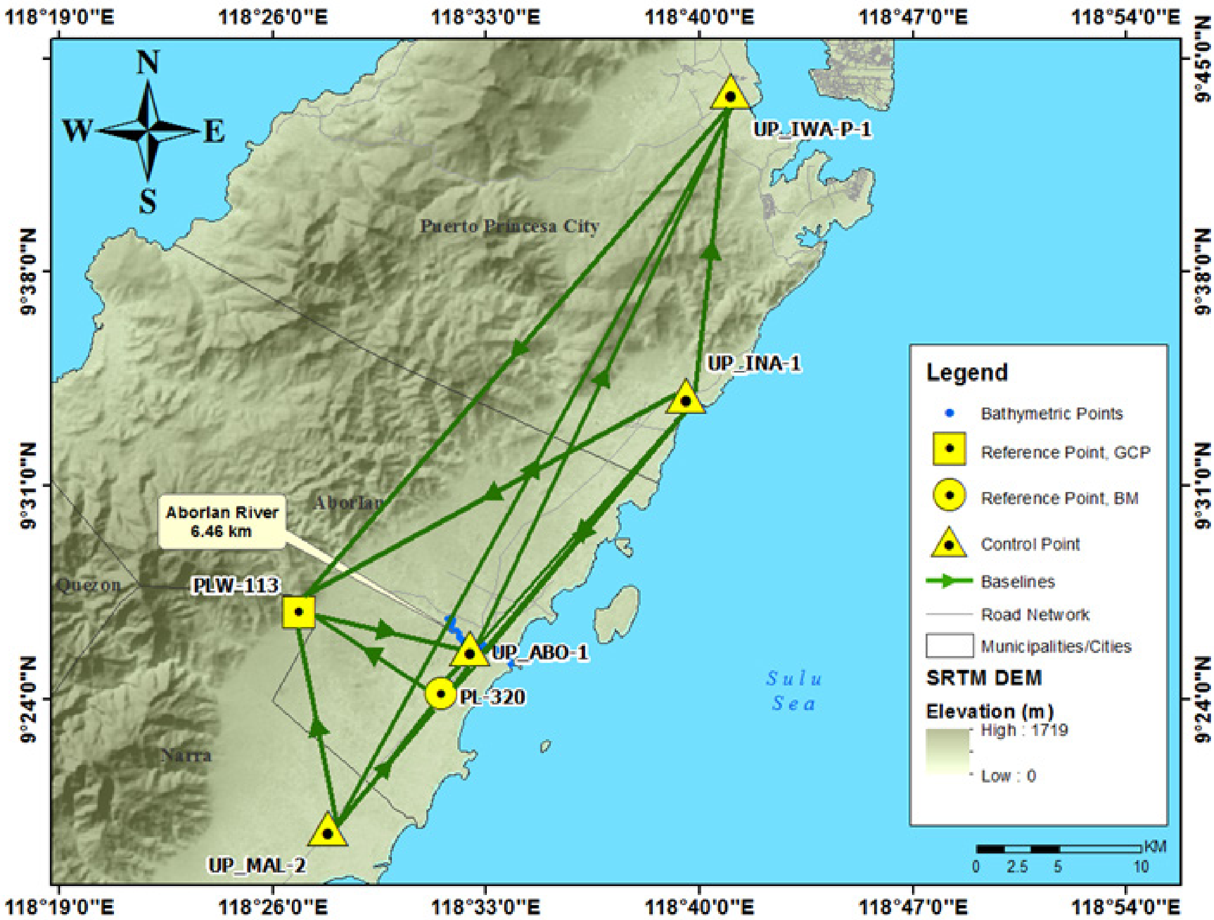



Figure 32. Aborlan River Basin control survey extent .

The GNSS set-ups on recovered reference points and established control points in Aborlan River are shown from Figure 33 to Figure 38.

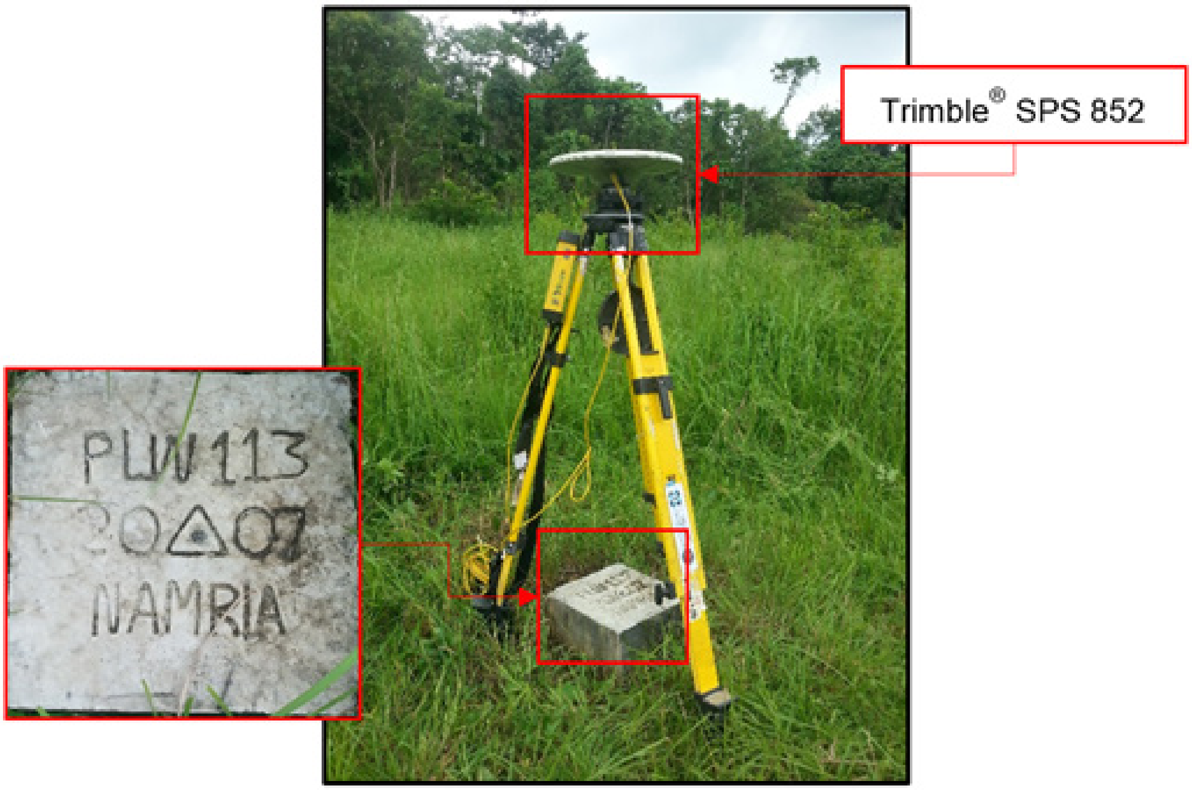



Figure 33. GNSS base set-up, Trimble® SPS 852, at PLW-113, located southwest of Aborlan Water System in Brgy. Dumagueña, Narra, Province of Palawan.

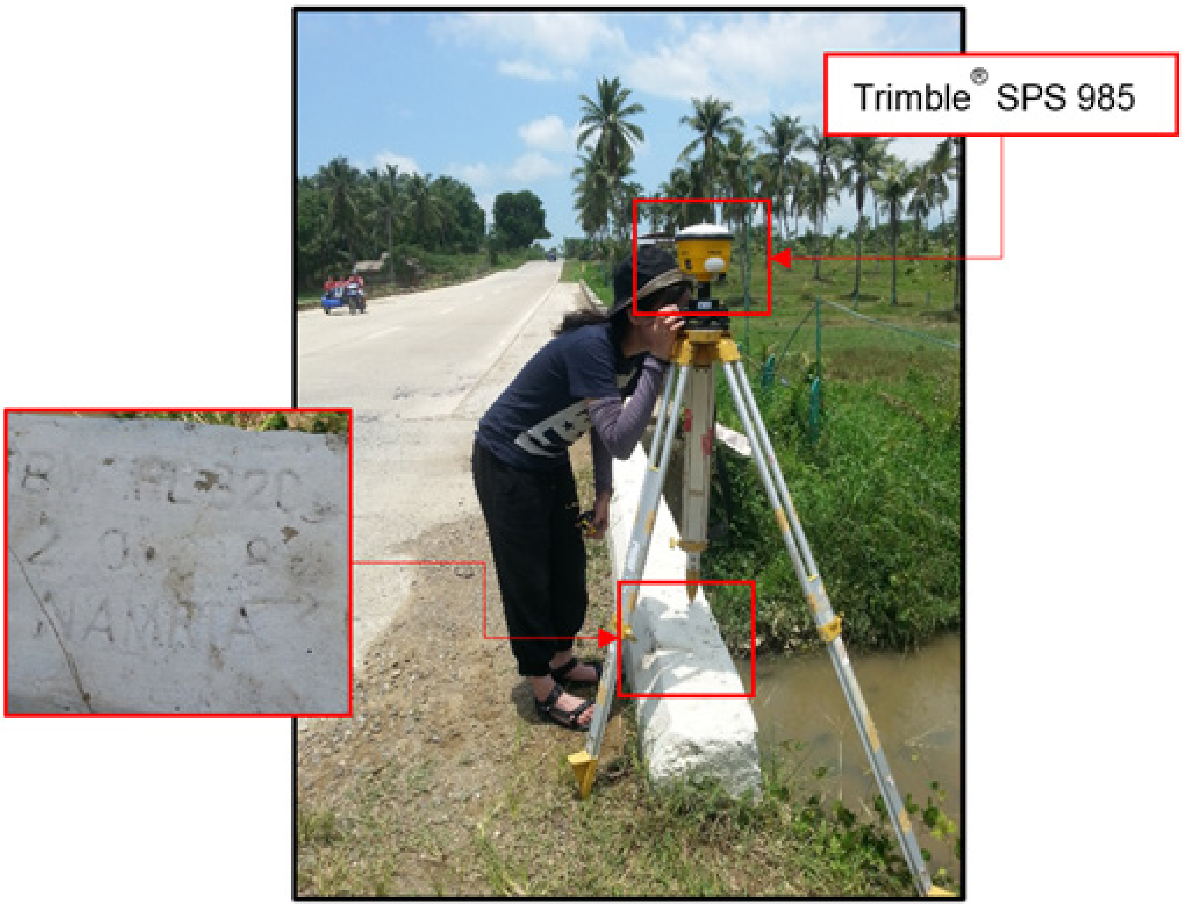



Figure 34. GNSS receiver set=up, Trimble® SPS 985, at PL-320, located on top of a culvert headwall along the National Road in Brgy. Ramon Magsaysay, Aborlan, Province of Palawan.


Figure 35. GNSS receiver set-up, Trimble® SPS 882, at UP_MAL-2, located at the approach of Malatgao Bridge in Brgy. Tinagong Dagat, Narra, Province of Palawan.


Figure 36. GNSS receiver set-up, Trimble® SPS 982, at UP_IWA-P-1, located at the approach of Iwahig Penal Bridge in Brgy. Iwahig, Puerto Princesa City, Palawan.


Figure 37. GNSS receiver set-up, Trimble® SPS 852, at UP_ABO-1, an established control point, beside the approach of Aborlan Bridge in Brgy. Gogognan, Aborlan, Palawan.


Figure 38. GNSS receiver set-up, Trimble® SPS 882, at UP_INA-1, located beside the approach of Inagauan Bridge in Brgy. Inagauan Sub-Colony, Puerto Princesa City, Palawan.

## 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 was 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 Aborlan River Basin is summarized in Table 26 as generated by TBC software.

Table 26. Baseline processing report for Aborlan River static survey.

| Observation | Date of Observation | Solution Type | H. Prec. (Meter) | V. Prec. (Meter) | Geodetic Az. | Ellipsoid Dist. (Meter) | ΔHeight (Meter) |
|---|---|---|---|---|---|---|---|
| PLW-113 --- UP_ABO-1 | 8-25-2016 | Fixed | 0.009 | 0.023 | 101°59'15" | 10513.593 | -85.092 |
| UP_IWA-P-1 --- PLW-113 | 8-25-2016 | Fixed | 0.004 | 0.024 | 219°26'55" | 40874.066 | 88.833 |
| PL-320 --- PLW- 113 | 8-25-2016 | Fixed | 0.018 | 0.029 | 300°01'31" | 9832.467 | 86.391 |
| PL-320 --- UP_IWA-P-1 | 8-25-2016 | Fixed | 0.004 | 0.018 | 205°34'21" | 40449.118 | 2.530 |
| UP_MAL-2 --- PL- 320 | 8-25-2016 | Fixed | 0.010 | 0.021 | 220°02'59" | 10578.751 | 9.435 |
| UP_INA-1 --- UP_ABO-1 | 8-25-2016 | Fixed | 0.008 | 0.025 | 220°15'41" | 20085.570 | 2.974 |
| UP_INA-1 --- PLW-113 | 8-25-2016 | Fixed | 0.005 | 0.025 | 240°32'45" | 26716.978 | 88.012 |
| UP_INA-1 --- PL-320 | 8-25-2016 | Fixed | 0.010 | 0.019 | 219°14'35" | 23320.185 | 1.618 |
| UP_INA-1 --- UP_IWA-P-1 | 8-25-2016 | Fixed | 0.005 | 0.019 | 188°21'15" | 18624.653 | 0.847 |
| UP_MAL-2 --- UP_INA-1 | 8-25-2016 | Fixed | 0.005 | 0.014 | 39°28'10" | 33898.188 | -11.058 |
| UP_MAL-2 --- UP_IWA-P-1 | 8-25-2016 | Fixed | 0.024 | 0.024 | 208°33'52" | 50759.890 | 11.894 |
| UP_MAL-2 --- PLW-113 | 8-25-2016 | Fixed | 0.005 | 0.021 | 352°31'24" | 13129.154 | 76.935 |

As shown in Table 26, a total of twelve (12) baselines were processed with coordinate and elevation values of UP_IWA-P-1 and the coordinate values of PLW-113 held fixed. All of them passed the required accuracy.

## 4.4 Network Adjustment

After the baseline processing procedure, network adjustment was 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:

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

where:

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

for each control point. See the Network Adjustment Report shown from Table 27 to Table 29 for the complete details. Refer to ANNEX 11 for the computation for the accuracy of ABSD.

The six (6) control points, PLW-113, PL-320, UP-MAL-2, UP-IWA-P-1, UP_ABO-1, and UP_INA-1 were occupied and observed simultaneously to form a GNSS loop. The coordinates and elevation of UP_IWA-P-1 and the coordinates of PLW-113 were held fixed during the processing of the control points as presented in Table 27. Through these reference points, the coordinates and elevations of the unknown control points would be computed.

Table 27. Control point constraints.

| Point ID | Type | East σ (Meter) | North σ (Meter) | Height σ (Meter) | Elevation σ (Meter) |
|---|---|---|---|---|---|
| PLW-113 | Global | Fixed | Fixed | | |
| UP_IWA-P-1 | Grid | | | | Fixed |
| UP_IWA-P-1 | Global | Fixed | Fixed | | |
| Fixed = 0.000001(Meter) | | | | | |

The list of adjusted grid coordinates, i.e., Northing, Easting, Elevation, and computed standard errors of the control points in the network is indicated in Table 28. All fixed control points have no values for grid errors and elevation error.

Table 28. Adjusted grid coordinates.

| Point ID | Easting (Meter) | Easting Error (Meter) | Northing (Meter) | Northing Error (Meter) | Elevation (Meter) | Elevation Error (Meter) | Constraint |
|---|---|---|---|---|---|---|---|
| PL-320 | 667487.736 | 0.013 | 1039767.829 | 0.008 | 7.089 | 0.049 | |
| PLW-113 | 658953.945 | ? | 1044650.284 | ? | 93.784 | 0.054 | LL |
| UP_ABO-1 | 669246.540 | 0.018 | 1042509.427 | 0.016 | 8.415 | 0.080 | |
| UP_INA-1 | 682153.657 | 0.009 | 1057898.445 | 0.007 | 5.672 | 0.047 | |
| UP_IWA-P-1 | 684768.852 | ? | 1076338.886 | ? | 5.044 | ? | LLe |
| UP_MAL-2 | 660716.408 | 0.012 | 1031641.078 | 0.009 | 16.469 | 0.047 | |

The results of the computation for accuracy are as follows:

**PL-320**

horizontal accuracy = $\sqrt{((1.3)^2 + (0.8)^2}$
= $\sqrt{(1.69 + 0.64)}$
= 2.33 < 20 cm
vertical accuracy = 4.9 < 10 cm

**PLW-113**

horizontal accuracy = Fixed
vertical accuracy = Fixed

**UP_ABO-1**

horizontal accuracy = $\sqrt{((1.8)^2 + (1.6)^2}$
= $\sqrt{(3.24 + 2.56)}$
= 5.8 < 20 cm
vertical accuracy = 8.0 < 10 cm

**UP_INA-1**

horizontal accuracy = $\sqrt{((0.9)^2 + (0.7)^2}$
= $\sqrt{(0.81 + 0.49)}$
= 1.30 < 20 cm
vertical accuracy = 4.7 < 10 cm

**UP_IWA-P-1**

horizontal accuracy = Fixed
vertical accuracy = Fixed

**UP_MAL-2**

horizontal accuracy = $\sqrt{((1.2)^2 + (0.9)^2}$
= $\sqrt{(1.44 + 0.81)}$
= 2.25 < 20 cm
vertical accuracy = 4.7 < 10 cm

Following the given formula, the horizontal and vertical accuracy result of the four (4) occupied control points are within the required precision.

Table 29. Adjusted geodetic coordinates.

| Point ID | Latitude | Longitude | Ellipsoid Height (Meter) | Height Error (Meter) | Constraint |
|---|---|---|---|---|---|
| PL-320 | N9°24'10.67926" | E118°31'31.30061" | 58.025 | 0.049 | |
| PLW-113 | N9°26'50.78624" | E118°26'52.23491" | 144.388 | 0.054 | LL |
| UP_ABO-1 | N9°25'39.66712" | E118°32'29.34660" | 59.322 | 0.080 | |
| UP_INA-1 | N9°33'58.62160" | E118°39'34.84567" | 56.382 | 0.047 | |
| UP_IWA-P-1 | N9°43'58.38961" | E118°41'03.58218" | 55.529 | ? | LLe |
| UP_MAL-2 | N9°19'47.08511" | E118°27'48.23731" | 67.449 | 0.047 | |

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 29. Based on the result of the computation, the accuracy conditions are satisfied; hence, the required accuracy for the program was met.

The summary of reference control points used is indicated in Table 30.

Table 30. Reference and control points used and its location (Source: NAMRIA, UP-TCAGP).

| Control Point | Order of Accuracy | Geographic Coordinates (WGS 84) | | | UTM ZONE 51 N | | |
|---|---|---|---|---|---|---|---|
| | | Latitude | Longitude | Ellipsoidal Height (m) | Northing (m) | Easting (m) | BM Ortho (m) |
| PLW-113 | 2nd order, GCP | 9° 26' 50.78624" N | 118° 26' 52.23491"E | 144.388 | 1044650.284 | 658953.945 | 93.784 |
| PL-320 | 1st order, BM | 9° 24' 10.67926" N | 118° 31' 31.30061"E | 58.025 | 1039767.829 | 667487.736 | 7.089 |
| UP_MAL-2 | Established | 9° 19' 47.08536"N | 118° 27' 48.23703"E | 67.449 | 1031641.078 | 660716.408 | 16.469 |
| UP_IWA-P-1 | Established | 9° 43' 58.38961"N | 118° 41' 03.58218"E | 55.529 | 1076338.886 | 684768.852 | 5.044 |
| UP_ABO-1 | Established | 9° 25' 39.66712"N | 118° 32' 29.34660"E | 59.322 | 1042509.427 | 669246.54 | 8.415 |
| UP_INA-1 | Established | 9° 33' 58.62160"N | 118° 39' 34.84567"E | 56.382 | 1057898.445 | 682153.657 | 5.672 |

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

Cross-section and as-built surveys were conducted on November 27, 2015 at the downstream side of Aborlan Bridge in Brgy. Gogognan, Municipality of Aborlan as shown in Figure 39. A total station was utilized for this survey as shown in Figure 40.

Figure 39. Aborlan Bridge facing upstream.


Figure 40. As-built survey of Aborlan Bridge.

The cross-sectional line of Aborlan Bridge is about 203 m with forty-four (44) cross-sectional points using the control points UP_ABO-1 and UP_ABO-2 as the GNSS base stations. The cross-section diagram and the bridge data form are shown in Figure 42 and Figure 43.

Gathering of random points for the checking of ABSD's bridge cross-section and bridge points data was performed by DVBC on August 24, 2016 using a survey grade GNSS Rover receiver attached to a 2-m pole, as seen in Figure 41.


Figure 41. Gathering of random cross-section points along the approach of Aborlan Bridge.

Linear square correlation (R2) and RMSE analysis were performed on the two (2) datasets. The linear square coefficient range was 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 0.980 was obtained by comparing the data of the contractor and DVBC; signifying a strong correlation between the two (2) datasets.

In addition to the Linear Square correlation, Root Mean Square (RMSE) analysis was 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 cross-section data, a computed value of 0.170 was acquired. The computed R2 and RMSE values are within the accuracy requirement of the program.

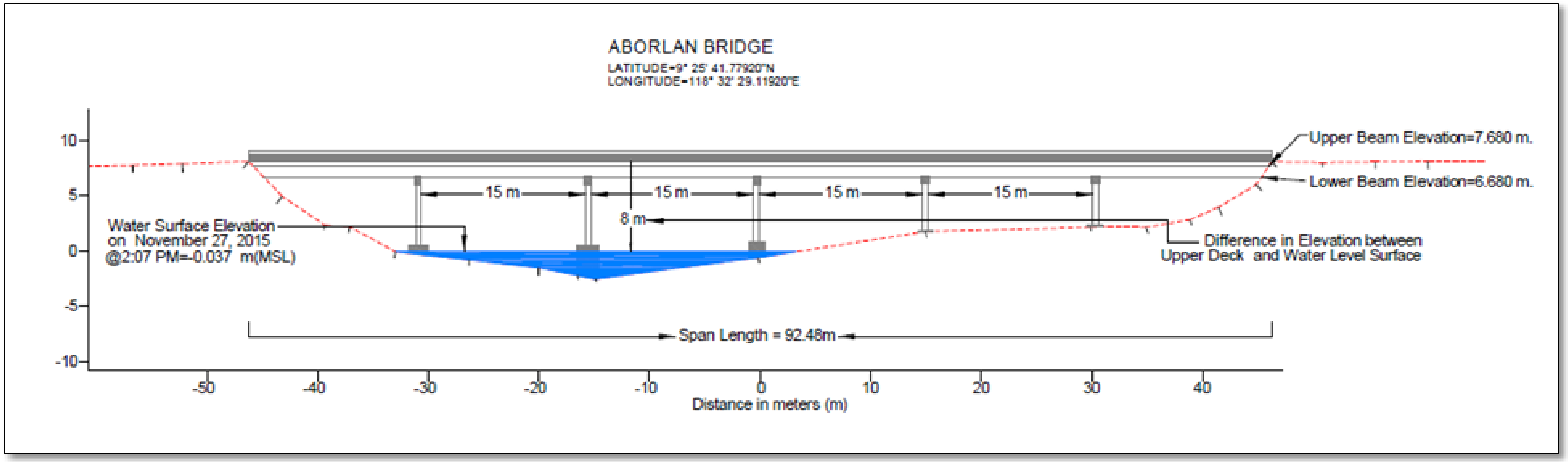



Figure 42. Aborlan Bridge cross-section diagram.

**Bridge Data Form**

Bridge Name: ABORLAN BRIDGE

River Name: ABORLAN RIVER

Location (Brgy, City, Region): Brgy. Gogognan, Aborlan, Palawan

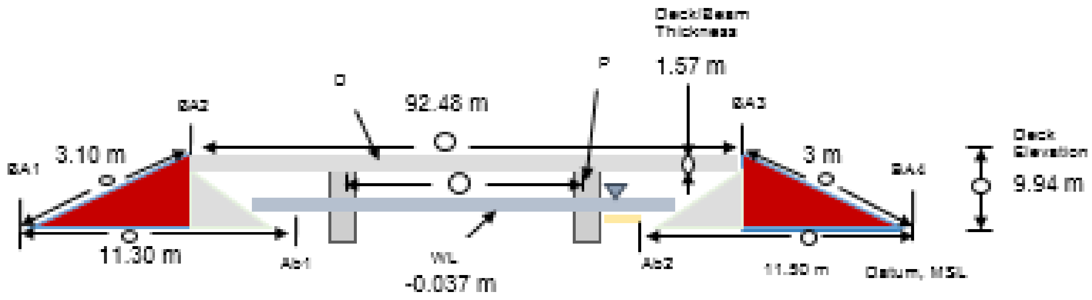
Survey Team: Jayson Illustre, Local Aide

Date and Time: November 27, 2015, 2:07 P.M.

Flow Condition: low ✔normal high

Weather Condition: fair ✔rainy

Cross-sectional View (not to scale)




Legend:
BA = Bridge Approach
P = Pier
Ab = Abutment
D = Deck
WL = Water Level/Surface
MSL = Mean Sea Level
◯ = Measurement Value

| Line Segment | Measurement (m) | Remarks |
|---|---|---|
| 1. BA1-BA2 | 3.10 m | |
| 2. BA2-BA3 | 92.48 m | |
| 3. BA3-BA4 | 3 m | |
| 4. BA1-Ab1 | 11.30 m | |
| 5. Ab2-BA4 | 11.50 m | |
| 6. Deck/beam thickness | 1.57 m | |
| 7. Deck elevation | 9.94 m | |

Note: Observer should be facing downstream

Figure C- 13 Aborlan Bridge Data Sheet

Figure 43. Aborlan Bridge data sheet.

Water surface elevation of Aborlan River was determined by a Horizon® Total Station on November 27, 2015 at 2:07 PM at Aborlan Bridge area with a value of -0.037 m in MSL as shown in Figure 44. This was translated into marking on the bridge's pier as shown in Figure 44. The marking will serve as reference for flow data gathering and depth gauge deployment of the partner HEI responsible for Aborlan River, the University of the Philippines Los Baños.

Figure 44. Water-level markings on Aborlan Bridge.

## 4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted by DVBC from August 16-28, 2016 using a survey grade GNSS Rover receiver, Trimble® SPS 985, mounted on a range pole which was attached on the side of the vehicle as shown in Figure 45. It was secured with cable ties and ropes to ensure that it was horizontally and vertically balanced. The antenna height was 2.590 m and measured from the ground up to the bottom of the quick release of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with UP_ABO-1 occupied as the GNSS base station in the conduct of the survey.


Figure 45. Validation points acquisition survey set-up for Aborlan River.

The survey started from Brgy. Kamuning, City of Puerto Princesa, Palawan going southwest along the national highway, covering seven (7) barangays in the Municipality of Aborlan and ended in Brgy. Malatgao, Municipality of Narra, Palawan. The survey gathered a total of 2,499 points with approximate length of 30.38 km using UP_ABO-1 as GNSS base station for the entire extent of validation points acquisition survey as illustrated in the map in Figure 46.

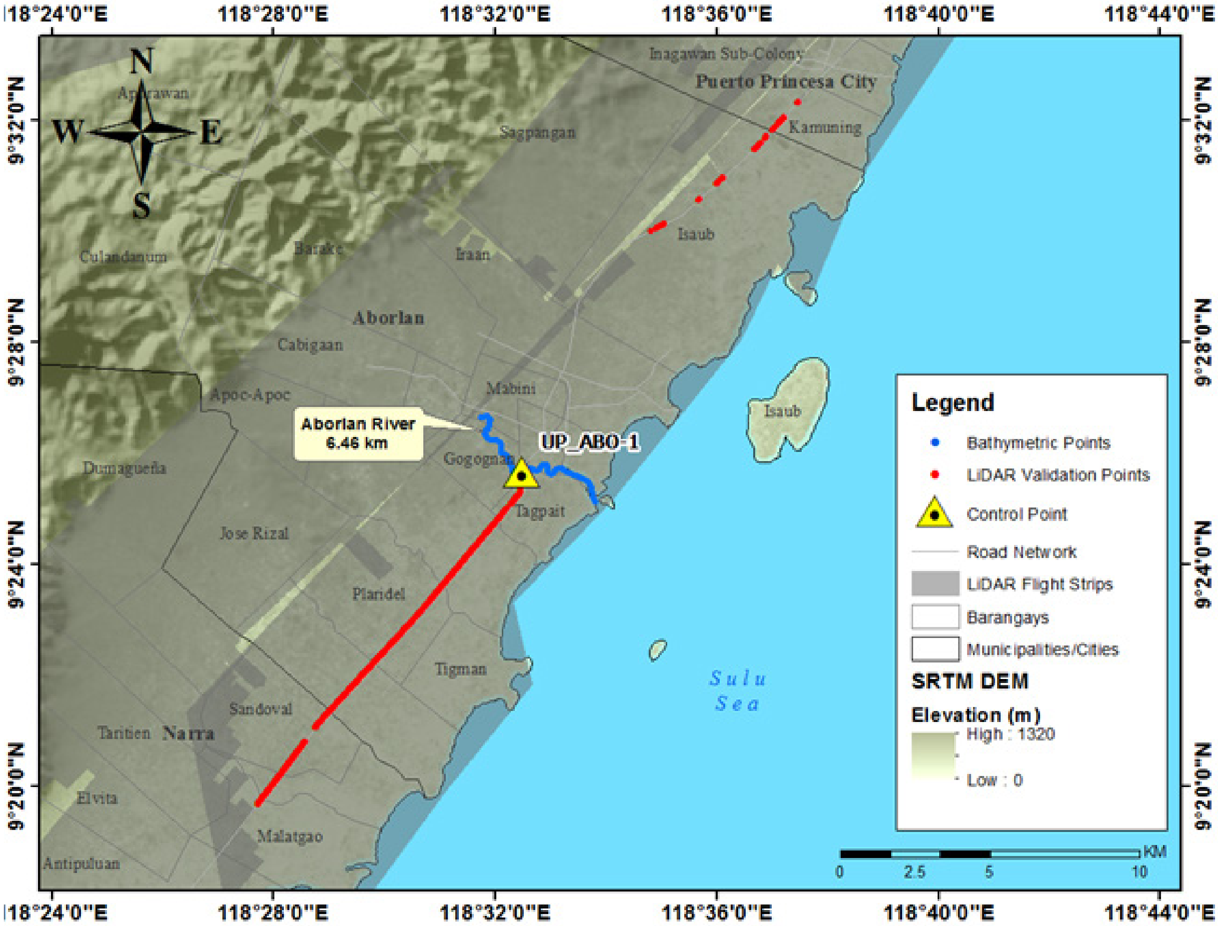



Figure 46. Validation points acquisition covering the Aborlan River Basin area.

## 4.7 River Bathymetric Survey

Bathymetric survey was executed manually on April 26, 2016 as seen in Figure C- 17 and on May 28, 2016 using a single-beam echo sounder as illustrated in Figure C- 18. The survey started in Brgy. Gogognan, Municipality of Aborlan, Palawan with coordinates 9° 26' 35.66196"N, 118° 31' 40.06602"E and ended at the mouth of the river in Brgy. Tagpait, Municipality of Aborlan, with coordinates 9° 25' 8.72409"N, 118° 33' 44.17628"E. The control point UP_ABO-0, UP_ABO-1, and UP_ABO-2 were used as GNSS base stations all throughout the entire survey.

Gathering of random points for the checking of ABSD's bathymetric data was performed by DVBC on August 27, 2016 using a survey grade GNSS Rover receiver attached to a boat, see Figure 48. A map showing the DVBC bathymetric checking points is shown in Figure 51.

Linear square correlation (R2) and RMSE analysis were also performed on the two (2) datasets. A computed R2 value of 0.873 and 0.900 for the centerline and zigzag line bathymetric data, respectively, were acquired which is within the 0.85 to 1 required range for R2 value. Additionally, RMSE values of 0.279 and 0.406 for the centerline and zigzag line bathymetric data, respectively, were obtained. Both the computed R2 and RMSE values are within the accuracy required by the program.


Figure 47. Manual bathymetric survey of ABSD at Aborlan River using Horizon® Total Station.


Figure 48. Bathymetric survey of ABSD at Aborlan River using Hi-Target™ Echo Sounder.


Figure 49. Gathering of random bathymetric points along Aborlan River.

The bathymetric survey for Aborlan River gathered a total of 2,844 points covering 6.46 km of the river traversing barangays Gogognan, Mabini, Poblacion, San Juan, and Tagpait in the Municipality of Aborlan. A CAD drawing was also produced to illustrate the riverbed profile of Aborlan River. As shown in Figure 52, the highest and lowest elevation has a 6-m difference. The highest elevation observed was 2.640 m above MSL located in Brgy. Dumagueña, Municipality of Narra while the lowest was -4.065 m below MSL located in Brgy. San Juan, Municipality of Aborlan.

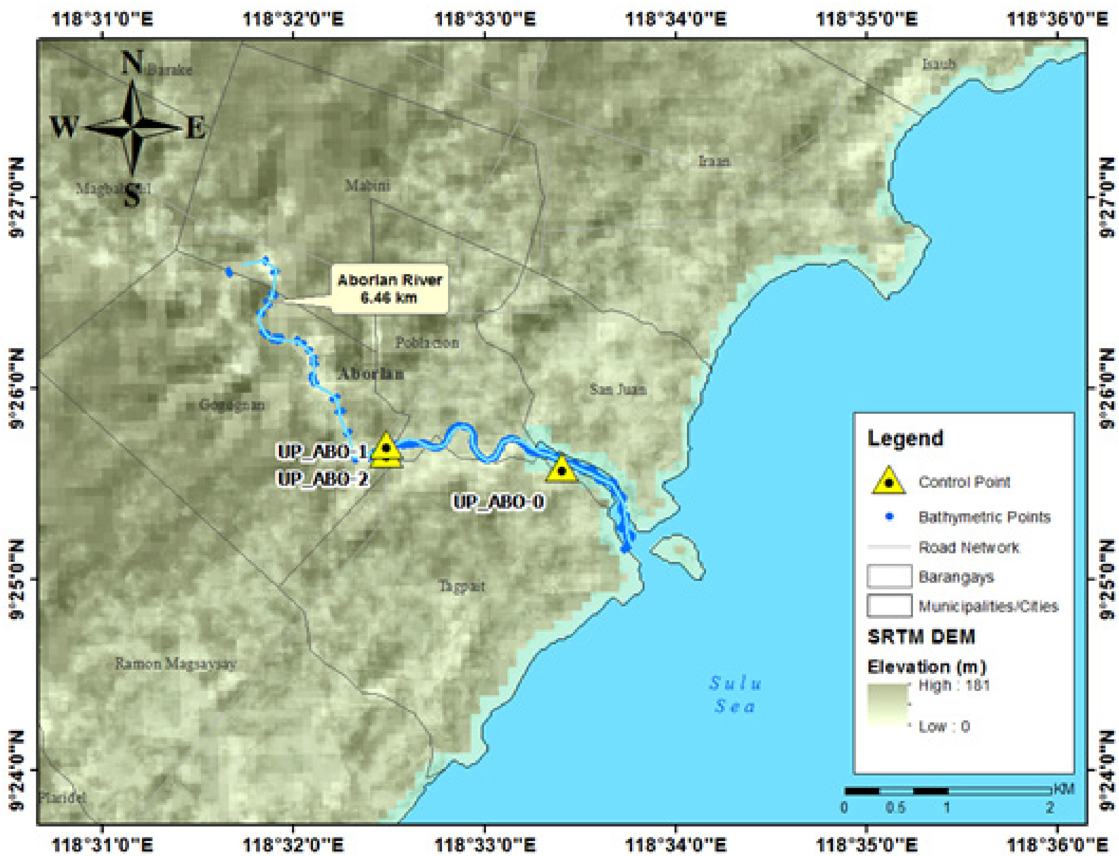



Figure 50. Bathymetric survey of Aborlan River.

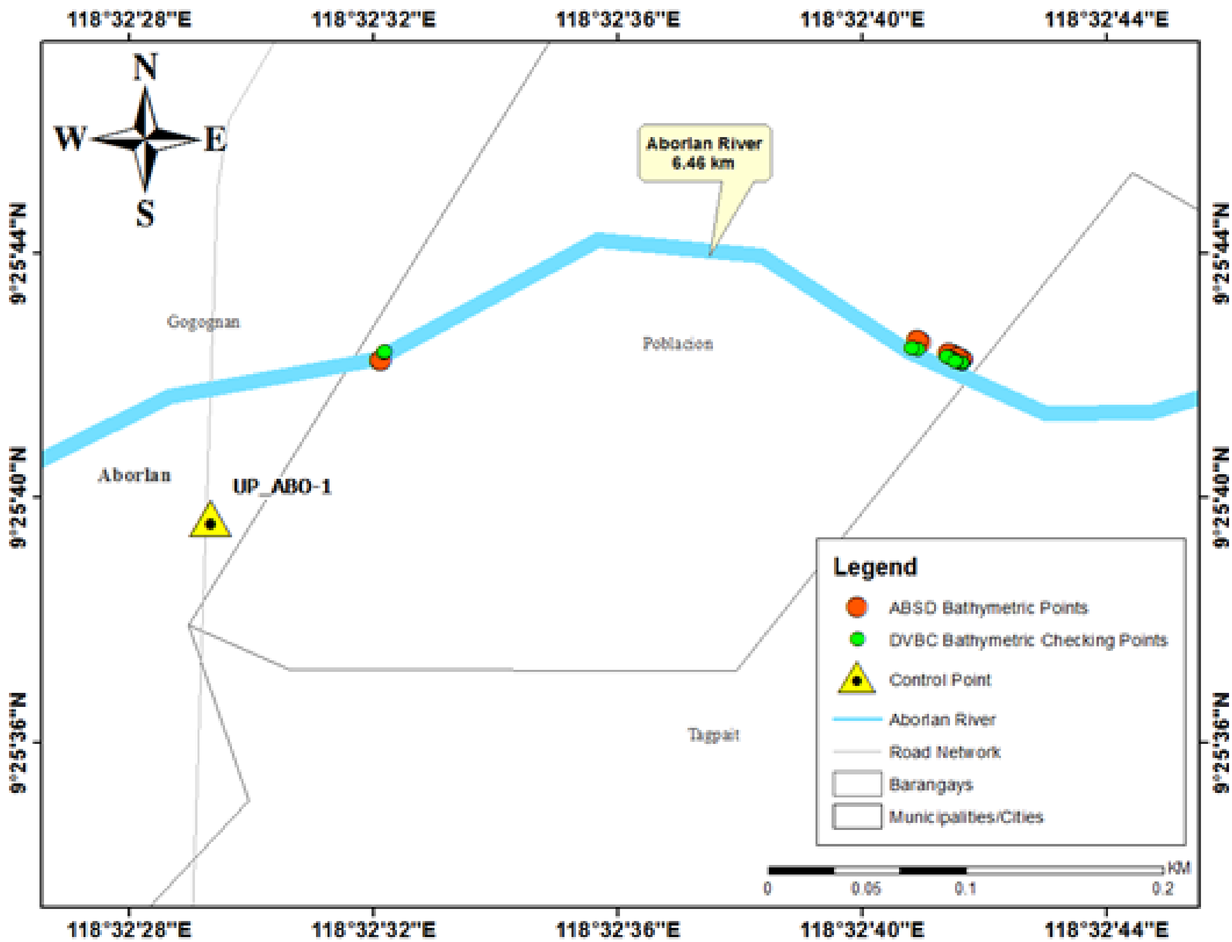



Figure 51. Quality checking points gathered along Aborlan River by DVBC

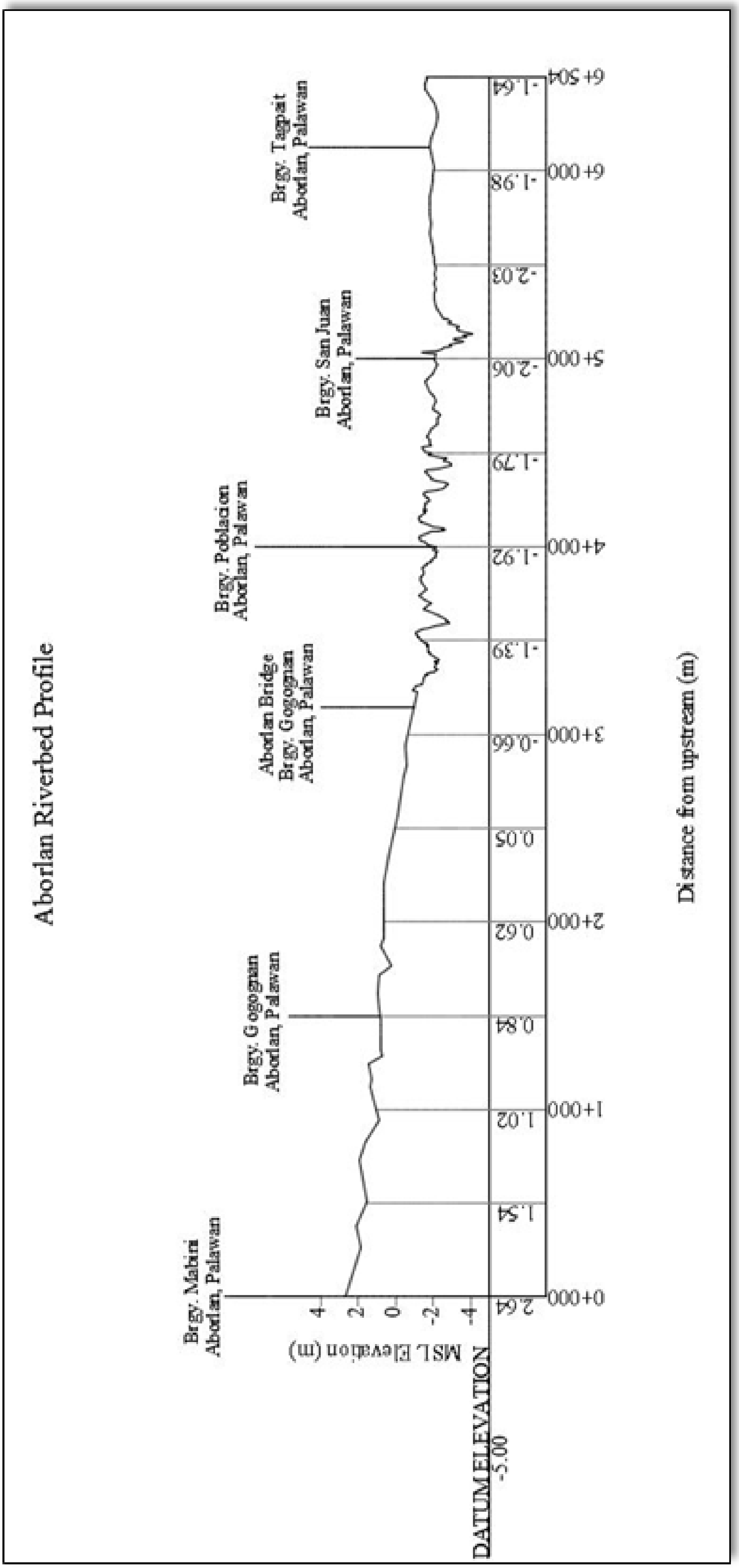



Figure 52. Aborlan Riverbed Profile.

# CHAPTER 5: FLOOD MODELING AND MAPPING

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

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

## 5.1 Data Used for Hydrologic Modeling

### 5.1.1 Hydrometry and Rating Curves

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

### 5.1.2 Precipitation

Precipitation data was taken from a portable rain gauge deployed on a strategic location within the river basin (9.428366˚ N, 118.540607˚ E). The location of the rain gauge is seen in Figure 53.

The total precipitation for this event is 115.40 mm. It has a peak rainfall of 13.20 mm on January 11, 2017 at 8:30 am. The lag time between the peak rainfall and discharge is 1 hour and 20 minutes, as seen in Figure 56.

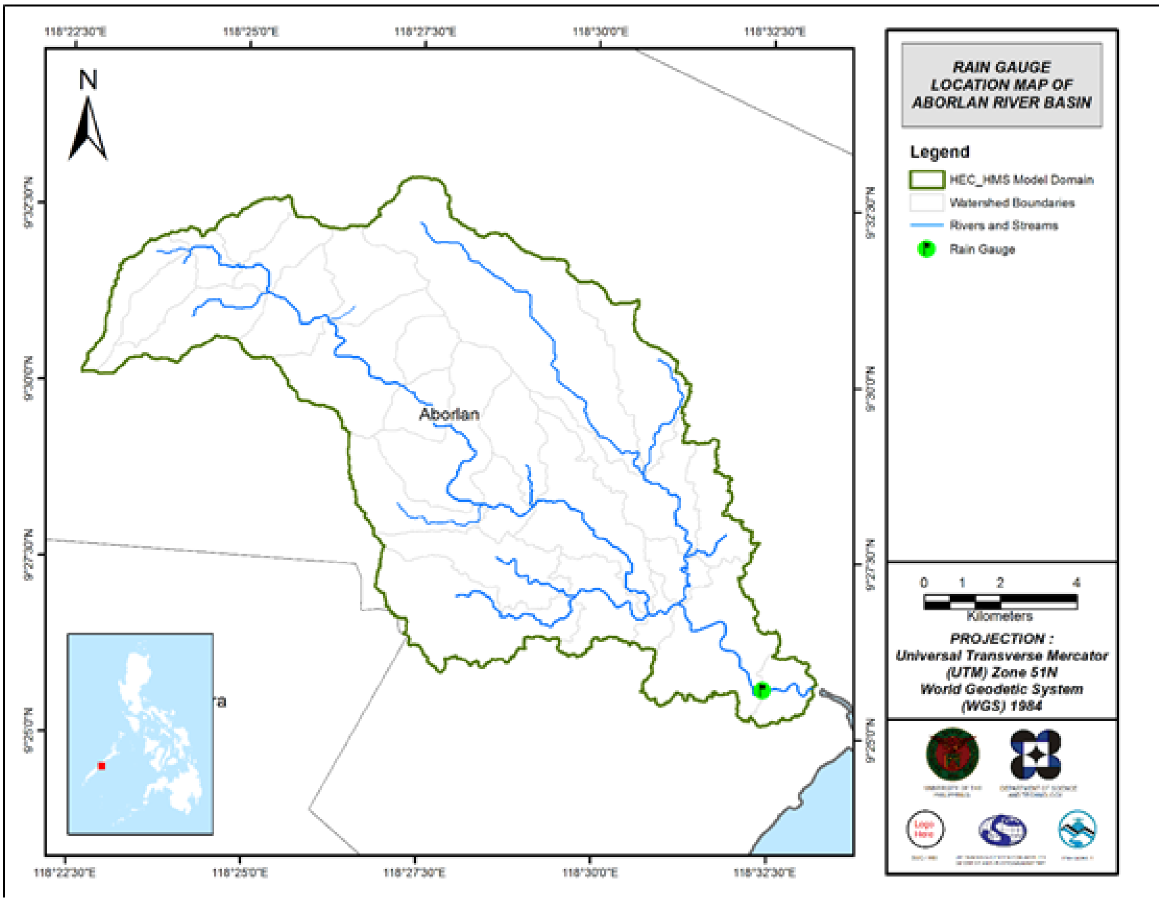



Figure 53. The location map of Aborlan HEC-HMS model used for calibration.

### 5.1.3 Rating Curves and River Outflow

A rating curve was developed at Aborlan Bridge, Aborlan, Palawan (9.428272° N, 118.541422° E). It gives the relationship between the observed water levels from the Aborlan Bridge and outflow of the watershed at this location using Bankful Method in Manning's Equation.

For Aborlan Bridge, the rating curve is expressed as Q = 0.7567x2 +1.0795x -0.1641 as shown in Figure 54.

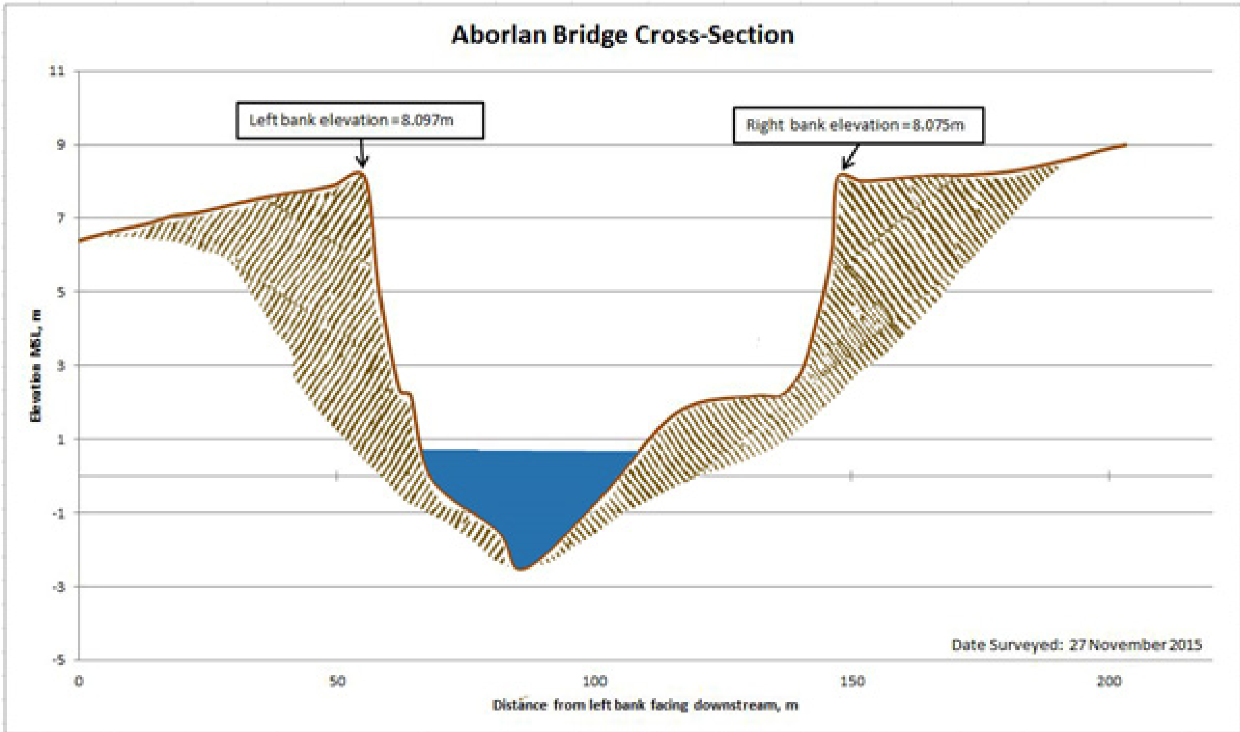



Figure 54. Cross-section plot of Aborlan Bridge.

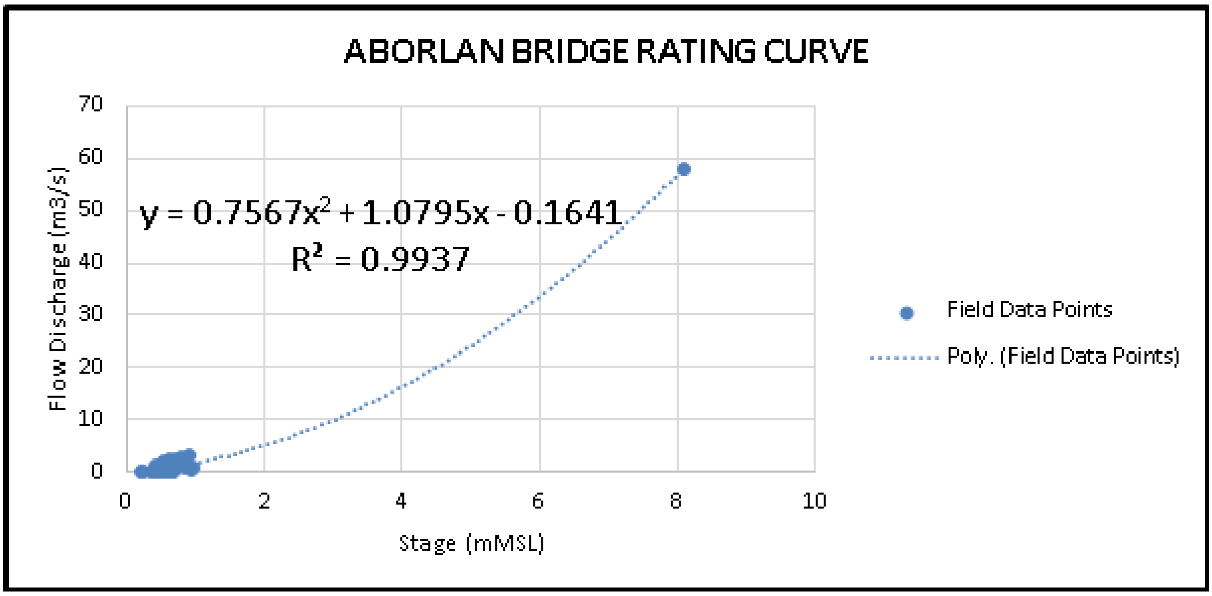



Figure 55. Rating curve at Aborlan Bridge, Aborlan, Palawan.

For the calibration of the HEC-HMS model, shown in Figure 56, actual flow discharge during a rainfall event was collected in the Aborlan bridge. Peak discharge is 18.39 m3/s on January 11, 2017 at 9:50 am.

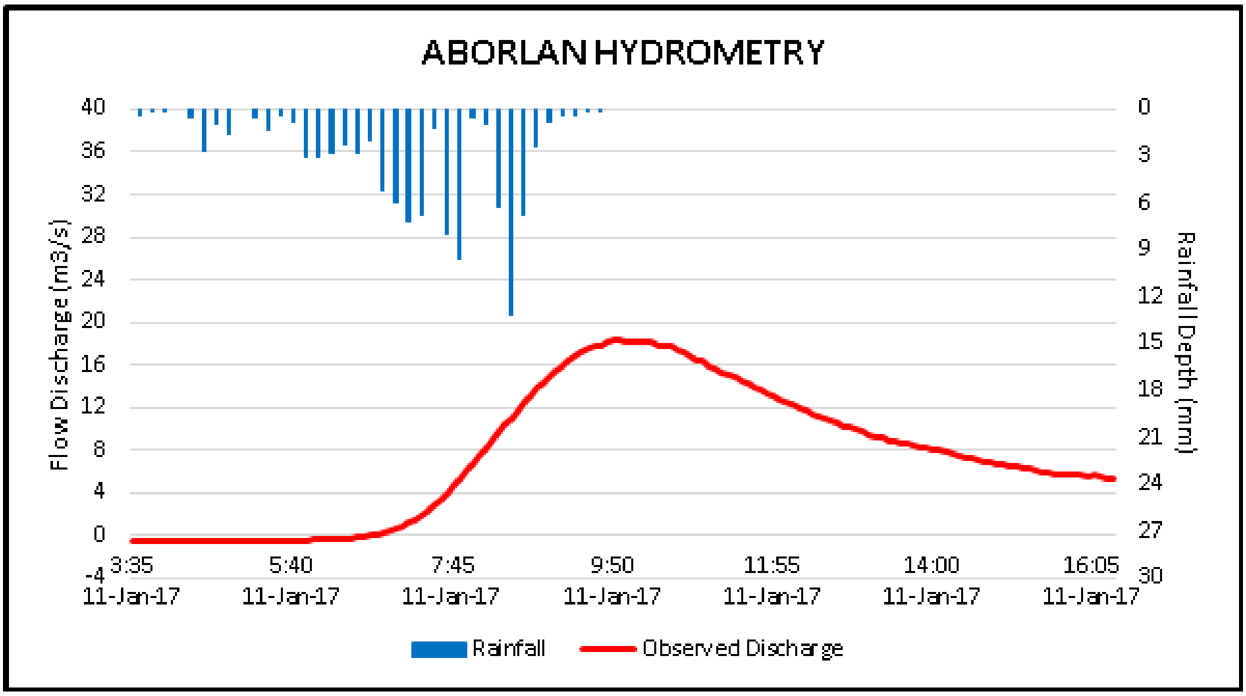



Figure 56. Rainfall and outflow data at Aborlan used for modeling.

## 5.2 RIDF Station

The Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Puerto Princesa 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 was chosen based on its proximity to the Aborlan watershed. The extreme values for this watershed were computed based on a 58-year record.

Table 31. RIDF values for Puerto Princesa Rain Gauge computed by PAGASA.

| COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **T (yrs)** | **10 mins** | **20 mins** | **30 mins** | **1 hr** | **2 hrs** | **3 hrs** | **6 hrs** | **12 hrs** | **24 hrs** |
| **2** | 14.8 | 22 | 27.3 | 36.2 | 49.8 | 58.8 | 75.1 | 88 | 104.1 |
| **5** | 21.3 | 31.9 | 39.7 | 52.3 | 73 | 86.9 | 112.8 | 135.4 | 156.4 |
| **10** | 25.6 | 38.5 | 48 | 63 | 88.4 | 105.5 | 137.8 | 166.8 | 191.1 |
| **15** | 28.1 | 42.2 | 52.6 | 69 | 97 | 116 | 151.9 | 184.5 | 210.6 |
| **20** | 29.8 | 44.7 | 55.9 | 73.3 | 103.1 | 123.4 | 161.7 | 196.8 | 224.3 |
| **25** | 31.1 | 46.7 | 58.4 | 76.5 | 107.8 | 129.1 | 169.3 | 206.4 | 234.9 |
| **50** | 35.2 | 52.9 | 66.1 | 86.5 | 122.2 | 146.5 | 192.7 | 235.8 | 267.3 |
| **100** | 39.2 | 59 | 73.7 | 96.4 | 136.5 | 163.8 | 216 | 265 | 299.6 |

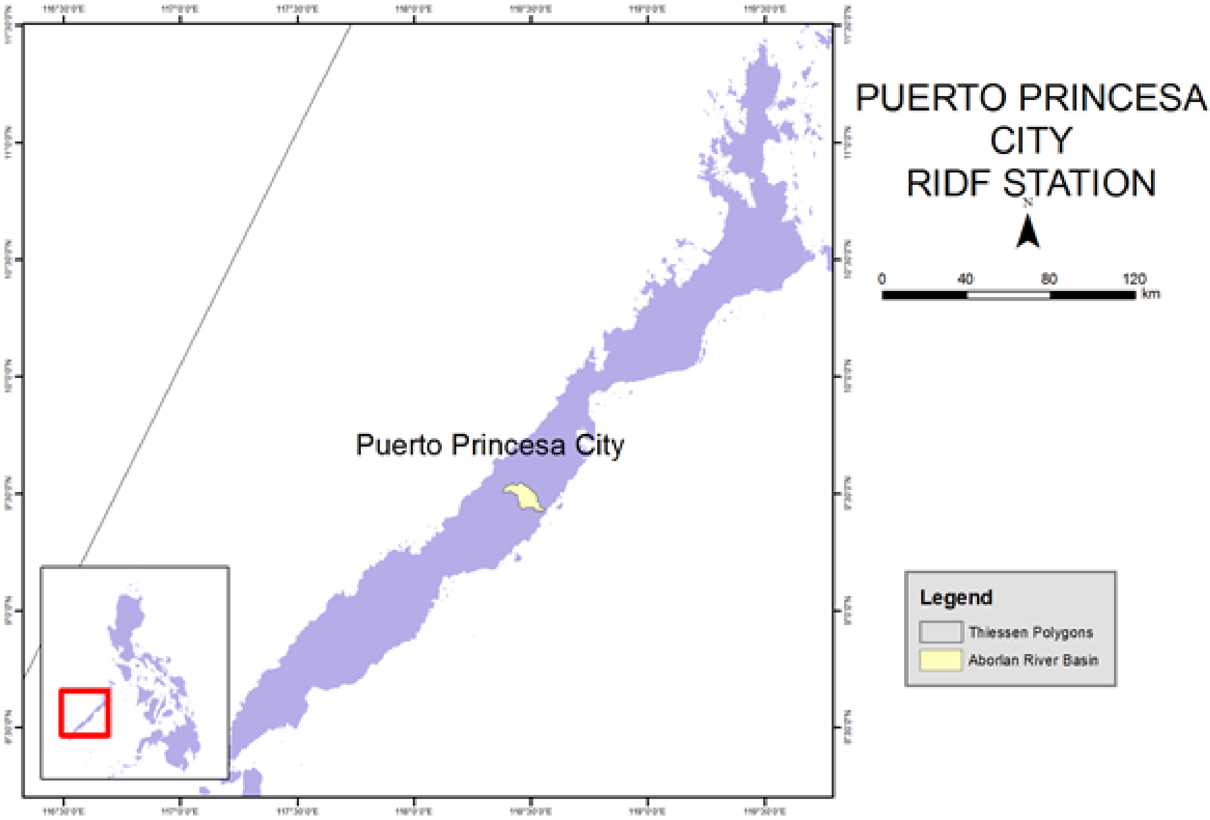



Figure 57. Location of Puerto Princesa RIDF relative to Aborlan River Basin.

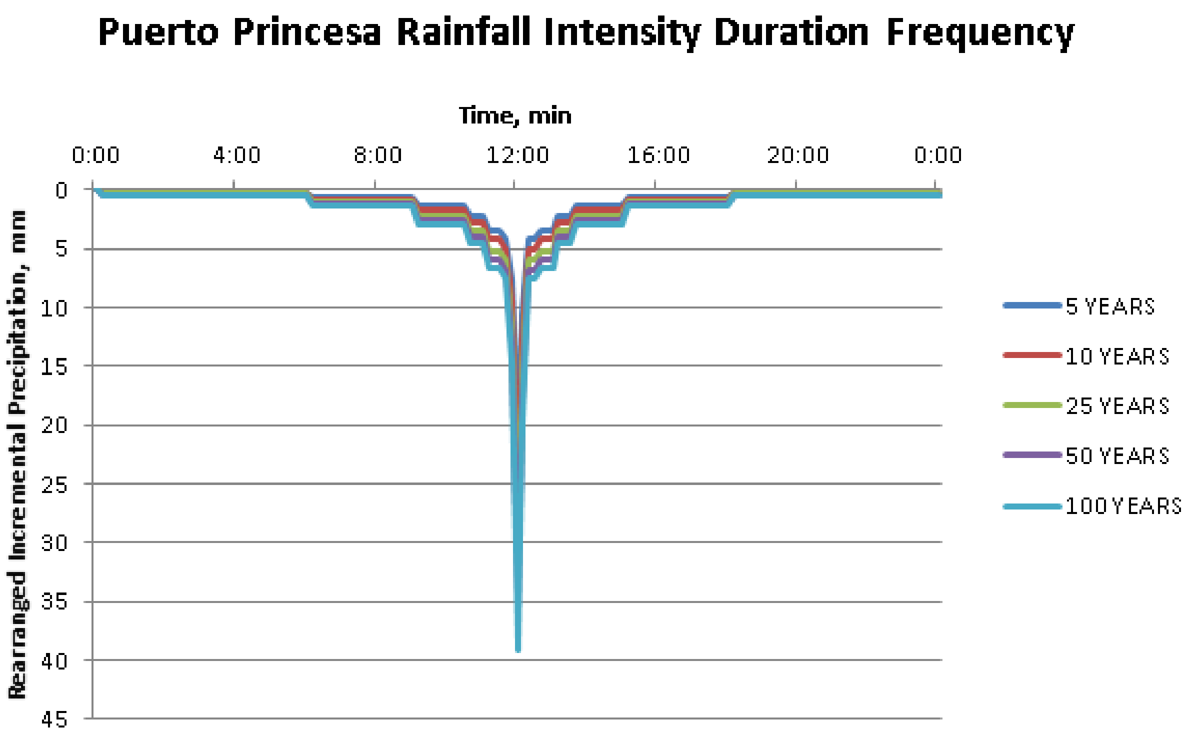



Figure 58. Synthetic storm generated for a 24-hour period rainfall for various return periods.

## 5.3 HMS Model

The soil dataset was taken from and generated by the Bureau of Soils and Water Management (BSWM) under the Agriculture (DA). The land cover dataset was from the National Mapping and Resource Information Authority (NAMRIA).

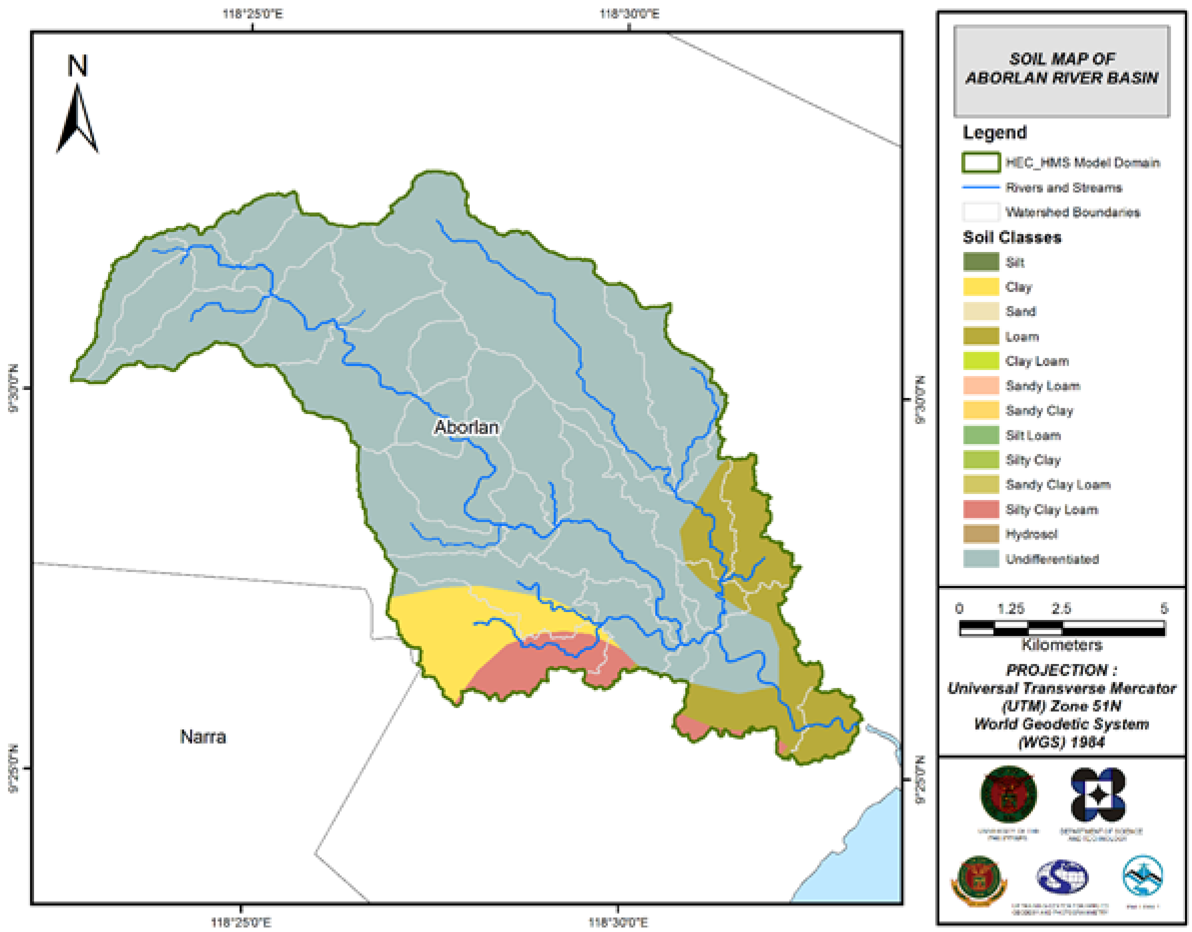



Figure 59. Soil map of the Aborlan River Basin used for the estimation of the CN parameter (Source: DA-BSWM).

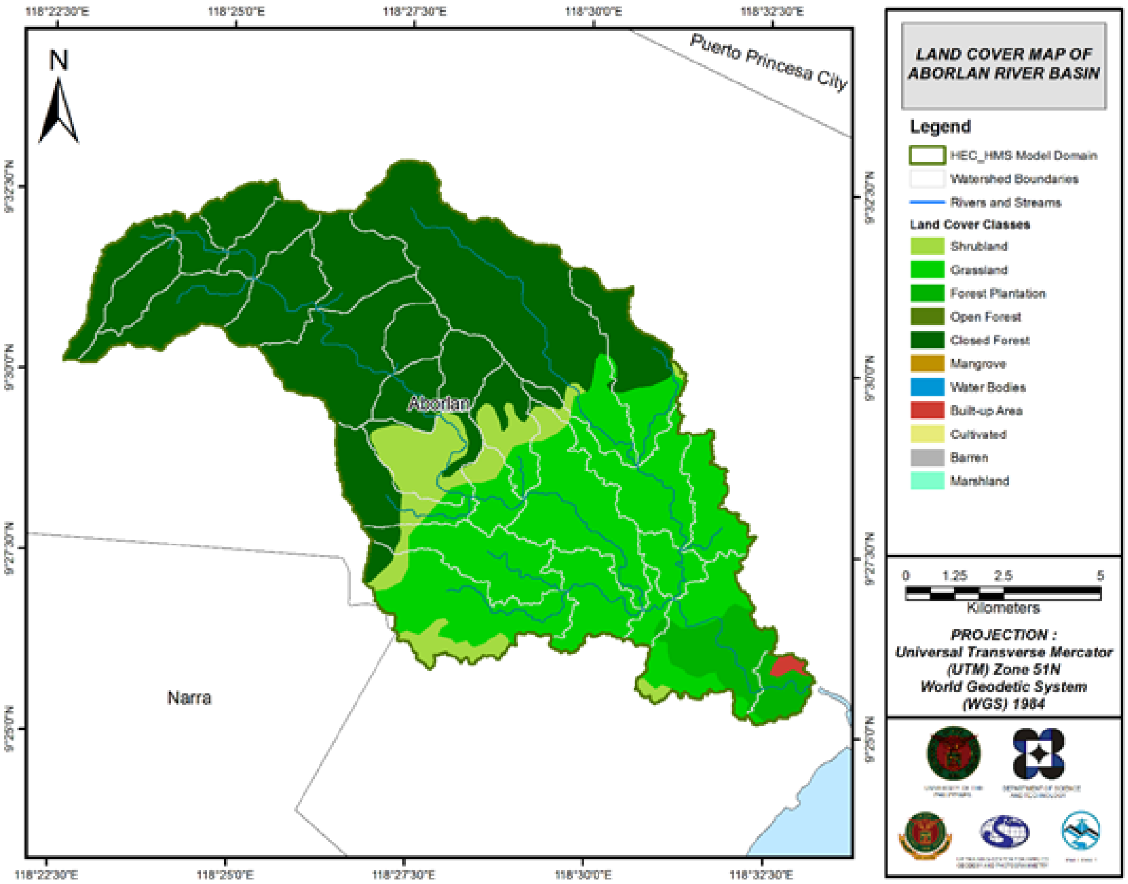



Figure 60. Land cover map of the Aborlan River Basin used for the estimation of the CN and watershed lag parameters of the rainfall-runoff model (Source: NAMRIA).

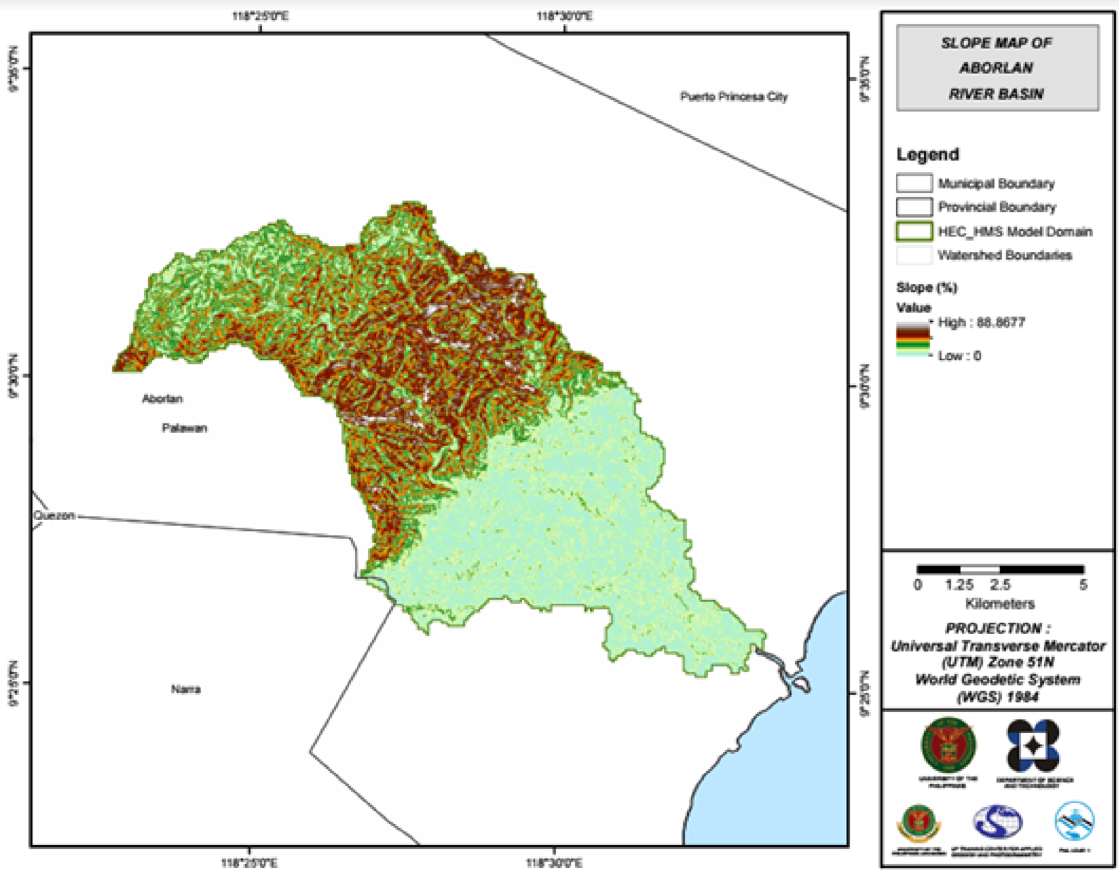



Figure 61. Slope map of the Aborlan River Basin.

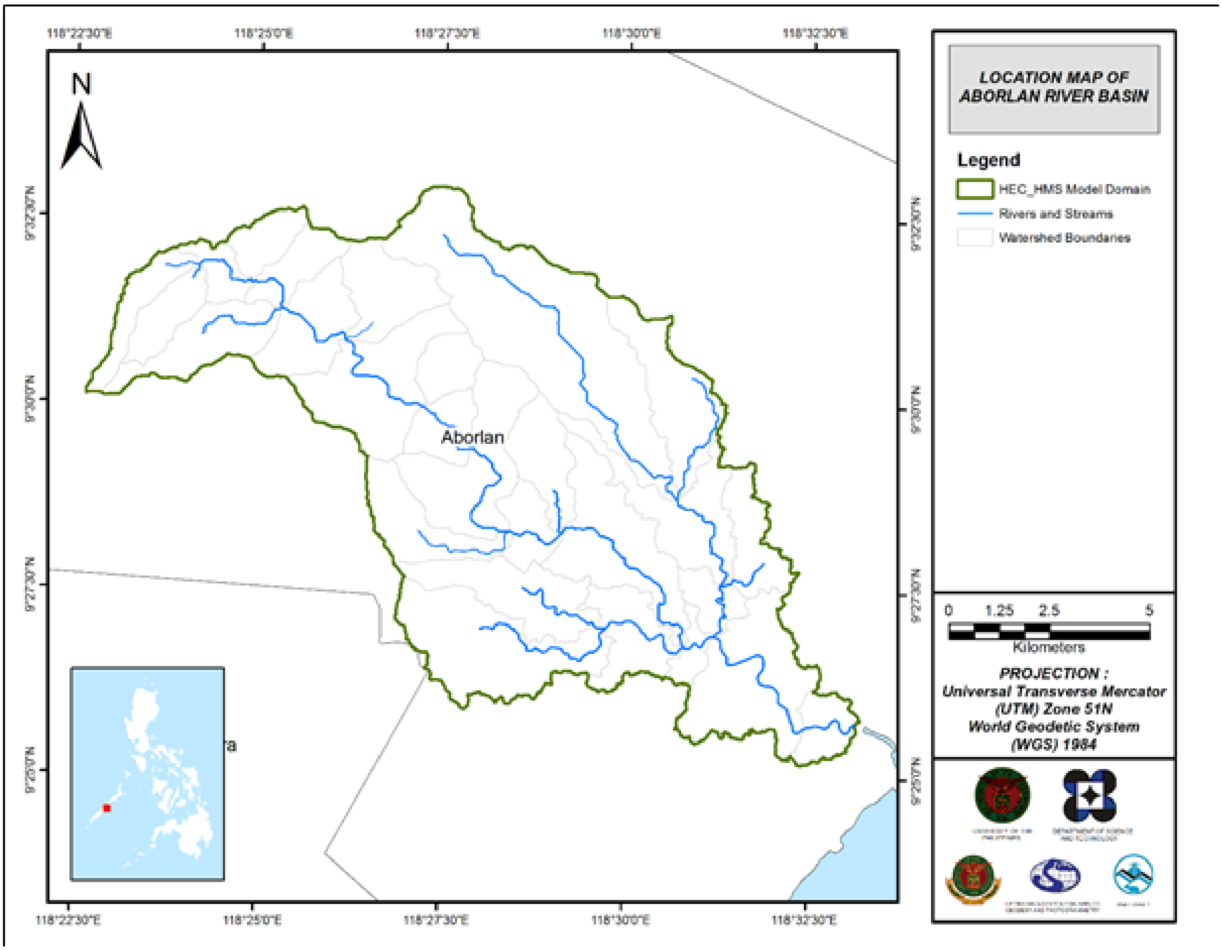



Figure 62. Stream delineation map of the Aborlan River Basin.

Using SAR-based DEM, the Aborlan Basin was delineated and further subdivided into subbasins. The model consists of 28 subbasins, 14 reaches, and 14 junctions. The main outlet is labeled as 90. 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 portable rain gauge set up by the Data Validation team of UPLB (DVC-UPLB) on a strategic point within the river basin. Finally, it was calibrated using the flow data collected from the Aborlan Bridge.

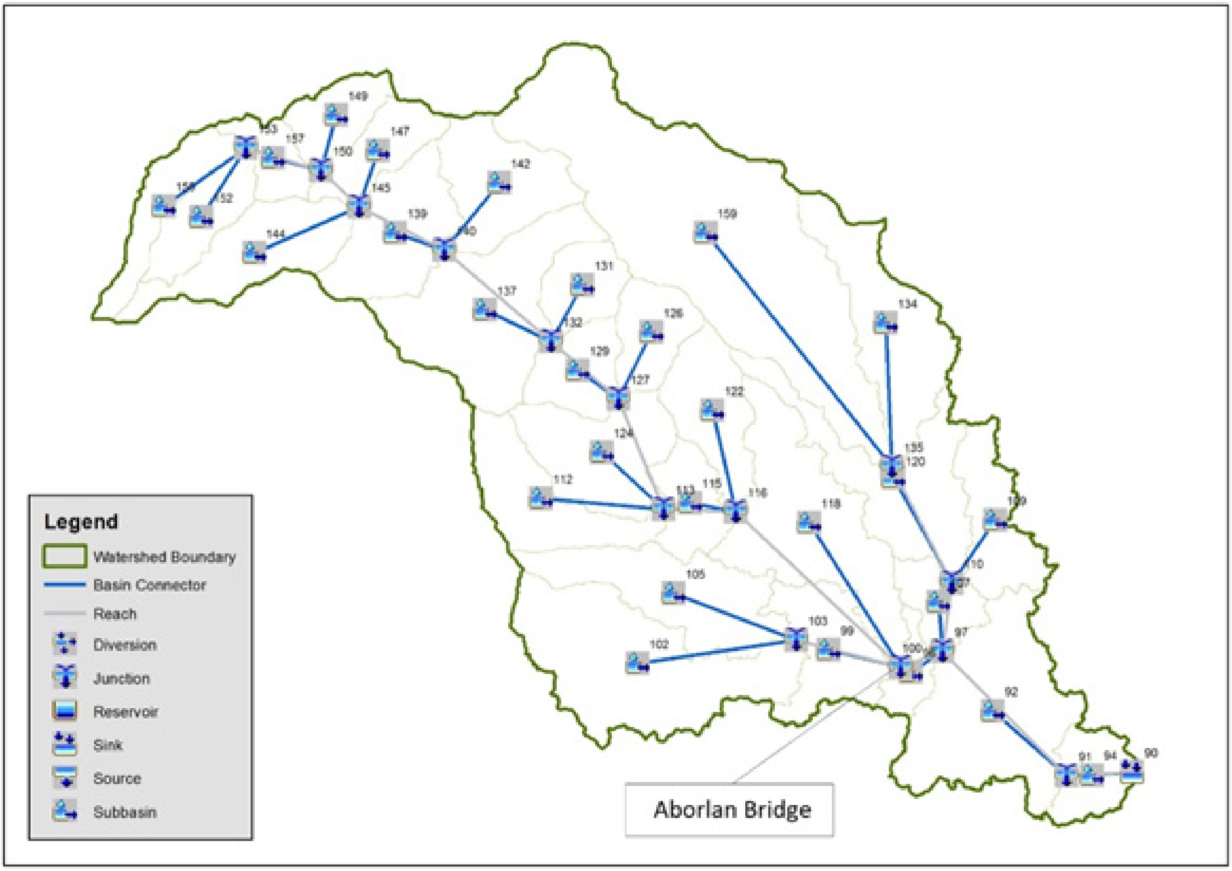



Figure 63. The Aborlan River Basin model generated using HEC-HMS

## 5.4 Cross-section Data

Riverbed cross-sections of the watershed are crucial in the HEC-RAS model set-up. 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.

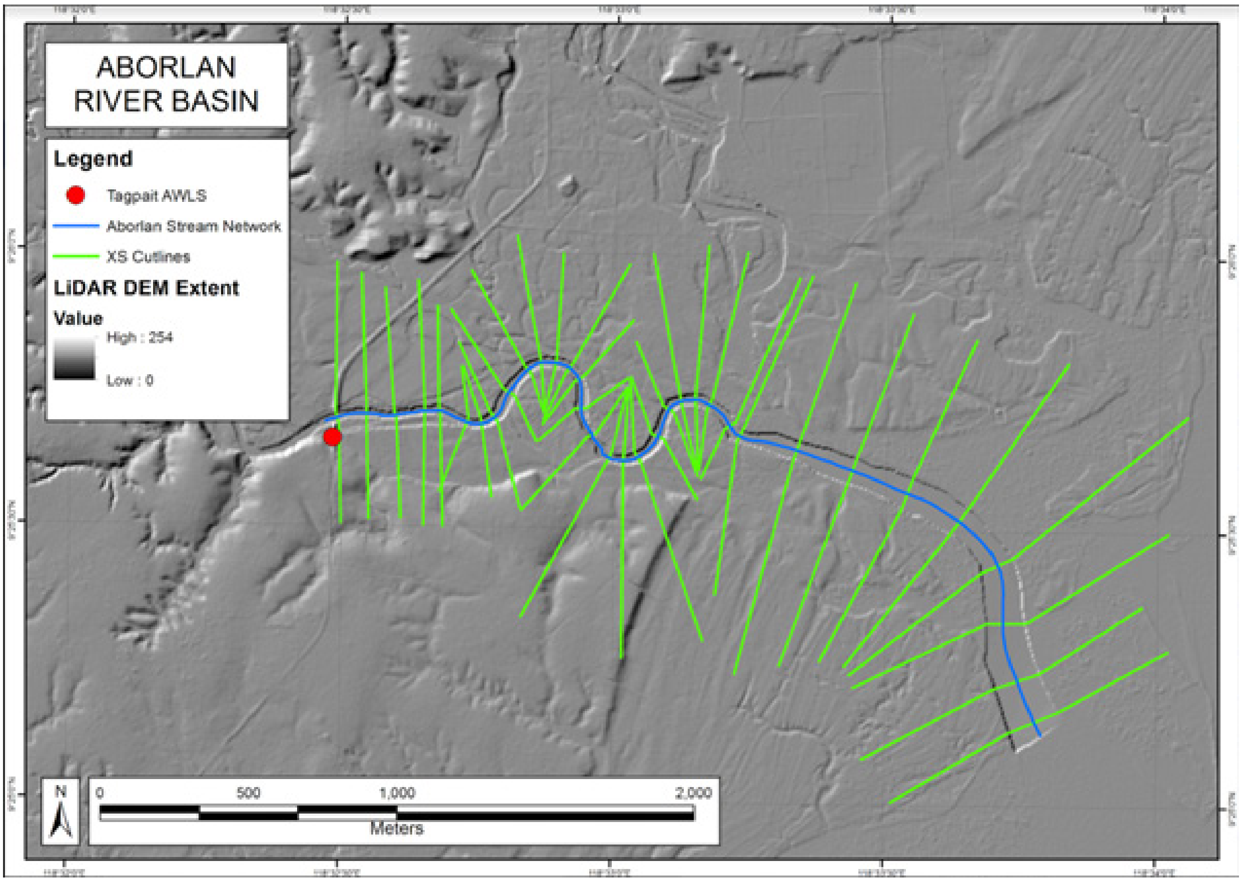



Figure 64. River cross-section of Aborlan River generated through Arcmap HEC GeoRAS tool.

## 5.5 Flo 2D Model

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

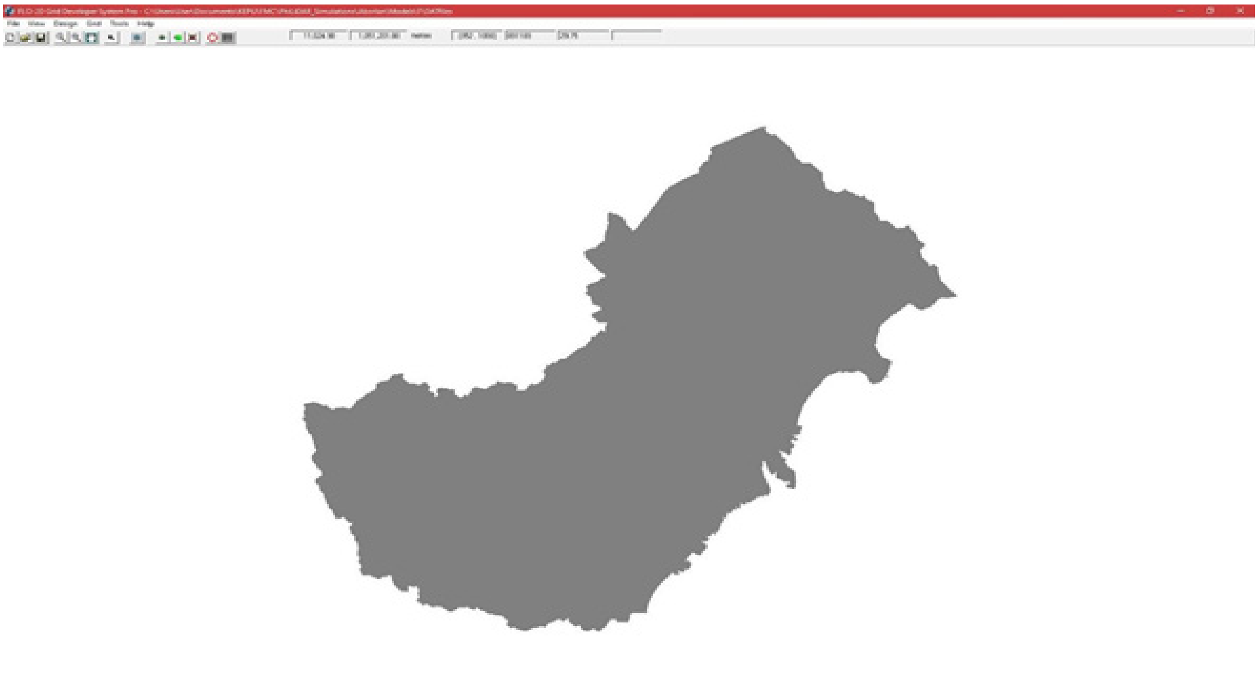


Figure 65. Screenshot of subcatchment with computational area to be modeled in FLO-2D GDS Pro

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 73.96387 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 94531680.00 m2.

There is a total of 72189906.41 m3 of water entering the model. Of this amount, 28764141.00 m3 is due to rainfall while 43425765.41 m3 is inflow from other areas outside the model. 9977180.00 m3 of this water is lost to infiltration and interception, while 11940530.71 m3 is stored by the flood plain. The rest, amounting up to 50272211.84 m3, is outflow.

## 5.6 Results of HMS Calibration

After calibrating the Aborlan HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 65 shows the comparison between the two discharge data.

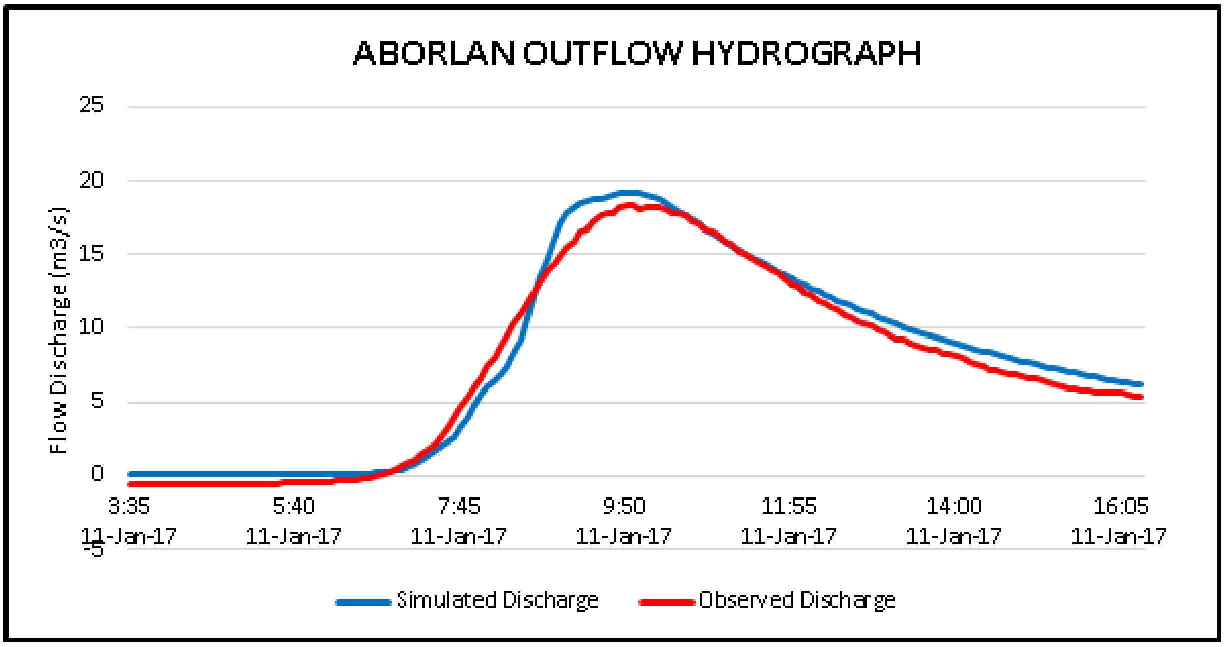



Figure 66. Outflow hydrograph of Aborlan produced by the HEC-HMS model compared with observed outflow.

Enumerated in Table 32 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 32. Range of calibrated values for Aborlan.

| Hydrologic Element | Calculation Type | Method | Parameter | Range of Calibrated Values |
|---|---|---|---|---|
| Basin | Loss | SCS Curve Number | Initial Abstraction (mm) | 5 - 119 |
| | | | Curve Number | 35 - 71 |
| | Transform | Clark Unit Hydrograph | Time of Concentration (hr) | 0.2 - 2 |
| | | | Storage Coefficient (hr) | 1 - 56 |
| | Baseflow | Recession | Recession Constant | 0.01 – 0.05 |
| | | | Ratio to Peak | 0 – 0.5 |
| Reach | Routing | Muskingum-Cunge | Manning's Coefficient | 0.0001 – 0.002 |

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 5 mm to 119 mm means that there is a diverse amount of infiltration or rainfall interception by vegetation depending on the subbasin.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 35 to 71 for curve number is lower than the advisable for Philippine watersheds.

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 0.2 hours to 56 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant of 0.01 indicates that the basin is likely to quickly go back to its original discharge and instead, will be higher. Ratio to peak of 0 to 0.5 indicates a steeper range of receding limb of the outflow hydrograph.

Manning's roughness coefficient of 0.0001 to 0.002 is relatively low compared to the common roughness of watersheds (Brunner, 2010).

Table 33. Summary of the efficiency test of Aborlan HMS Model.

| Accuracy measure | Value |
|---|---|
| RMSE | 0.909 |
| r2 | 0.993 |
| NSE | 0.980 |
| PBIAS | -6.213 |
| RSR | 0.142 |

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 0.909.

The Pearson correlation coefficient (r2) assesses the strength of the linear relationship between the observations and the model. A value 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 0.993.

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 0.980.

A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate bias towards over-prediction. Again, the optimal value is 0. In the model, the PBIAS is -6.213.

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 0.142.

## 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 66) shows the Aborlan outflow using the Puerto Princesa RIDF curves in 5 different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on PAGASA data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

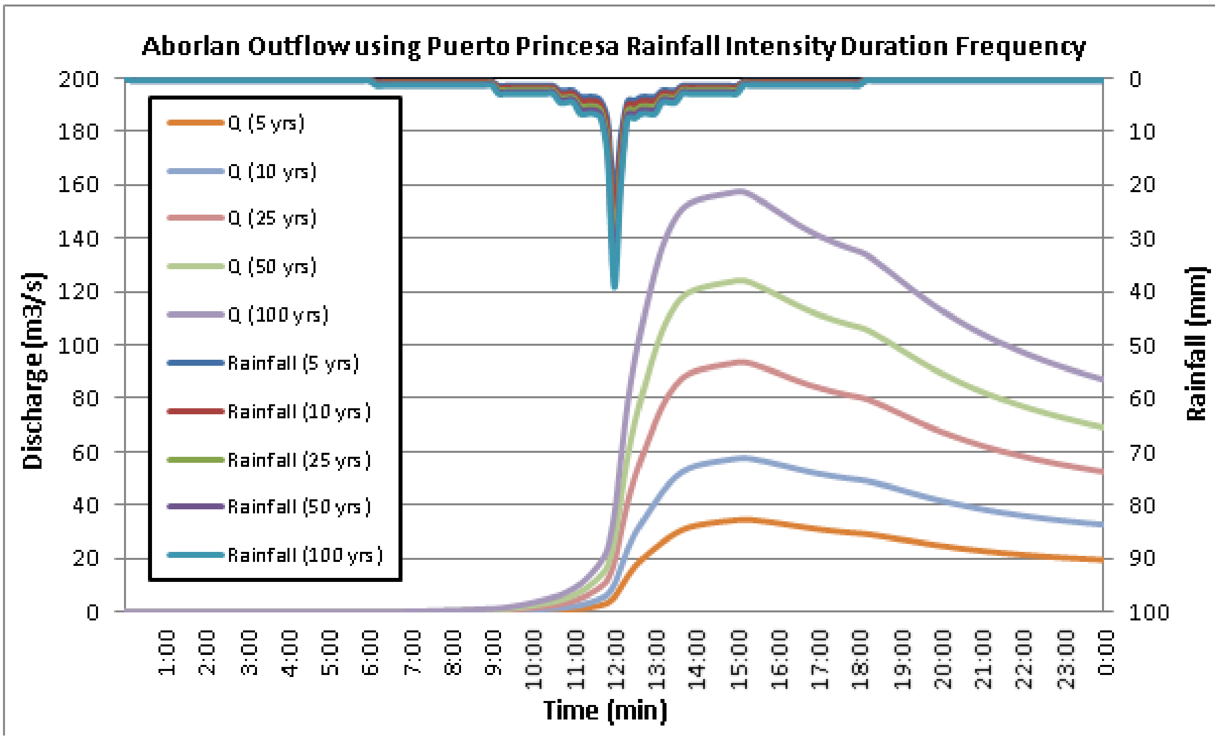



Figure 67. Outflow hydrograph at Aborlan Station generated using Puerto Princesa RIDF simulated in HEC-HMS.

A summary of the total precipitation, peak rainfall, peak outflow, time to peak, and lag time of the Aborlan discharge using the Puerto Princesa RIDF in five different return periods is shown in Table 34.

Table 34. Peak values of the Aborlan HEC-HMS Model outflow using the Puerto Princesa RIDF.

| RIDF Period | Total Precipitation (mm) | Peak rainfall (mm) | Peak outflow (m 3/s) | Time to Peak |
|---|---|---|---|---|
| 5-Year | 156.40 | 21.30 | 34.541 | 3 hours 10 minutes |
| 10-Year | 191.10 | 25.60 | 57.602 | 3 hours 10 minutes |
| 25-Year | 234.90 | 31.10 | 93.581 | 3 hours 10 minutes |
| 50-Year | 267.30 | 35.20 | 124.231 | 3 hours 10 minutes |
| 100-Year | 299.60 | 39.20 | 157.447 | 3 hours |

## 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 Aborlan River using the HMS base flow is shown on Figure 67 below.

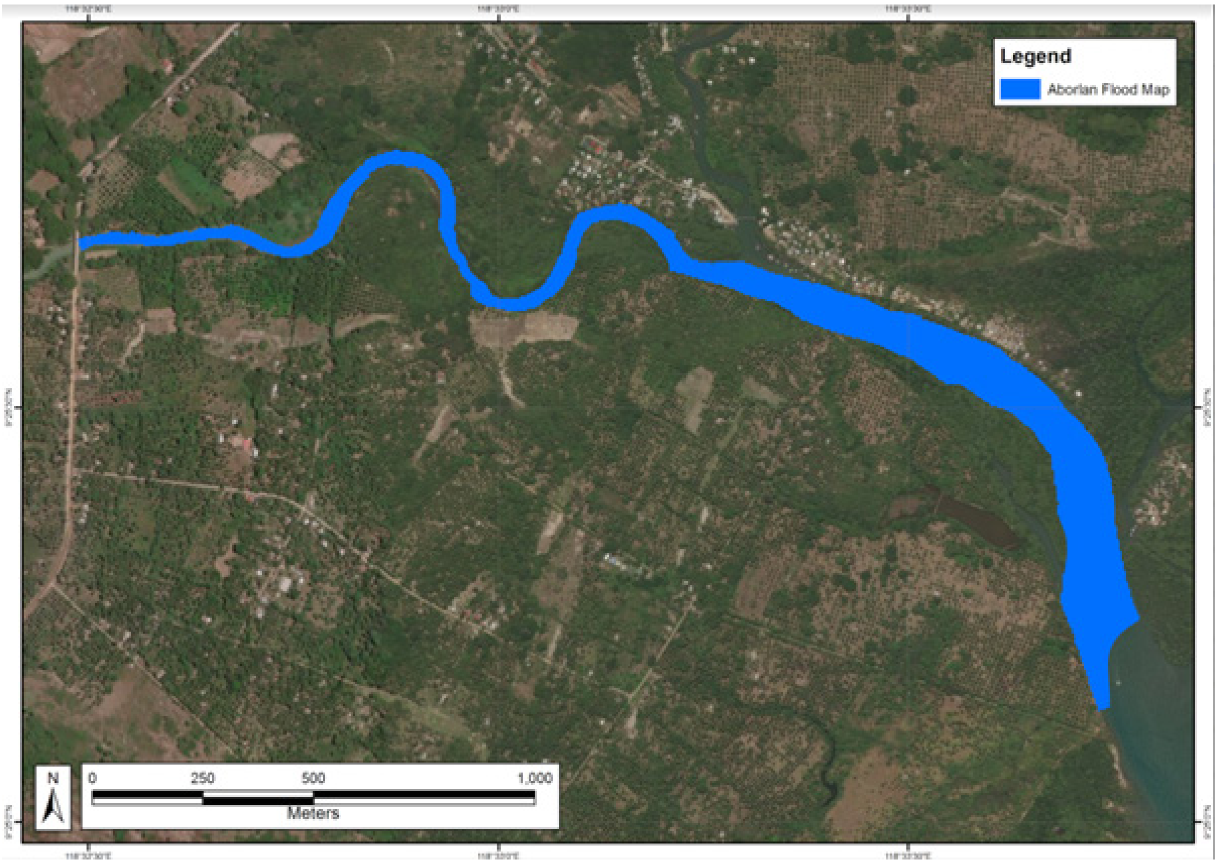



Figure 68. Sample output map of the Aborlan RAS Model.

## 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 Aborlan Floodplain are shown in Figure 68 to Figure 73. The floodplain, with an area of 280.72 sq km, covers two municipalities namely Aborlan and Narra. Table 35 shows the percentage of area affected by flooding per municipality.

Table 35. Municipalities affected in Aborlan Floodplain.

| Municipality | Total Area | Area Flooded | % Flooded |
|---|---|---|---|
| Aborlan | 645.111 | 269.9301 | 41.84243 |
| Narra | 831.19 | 10.33013 | 1.242812 |

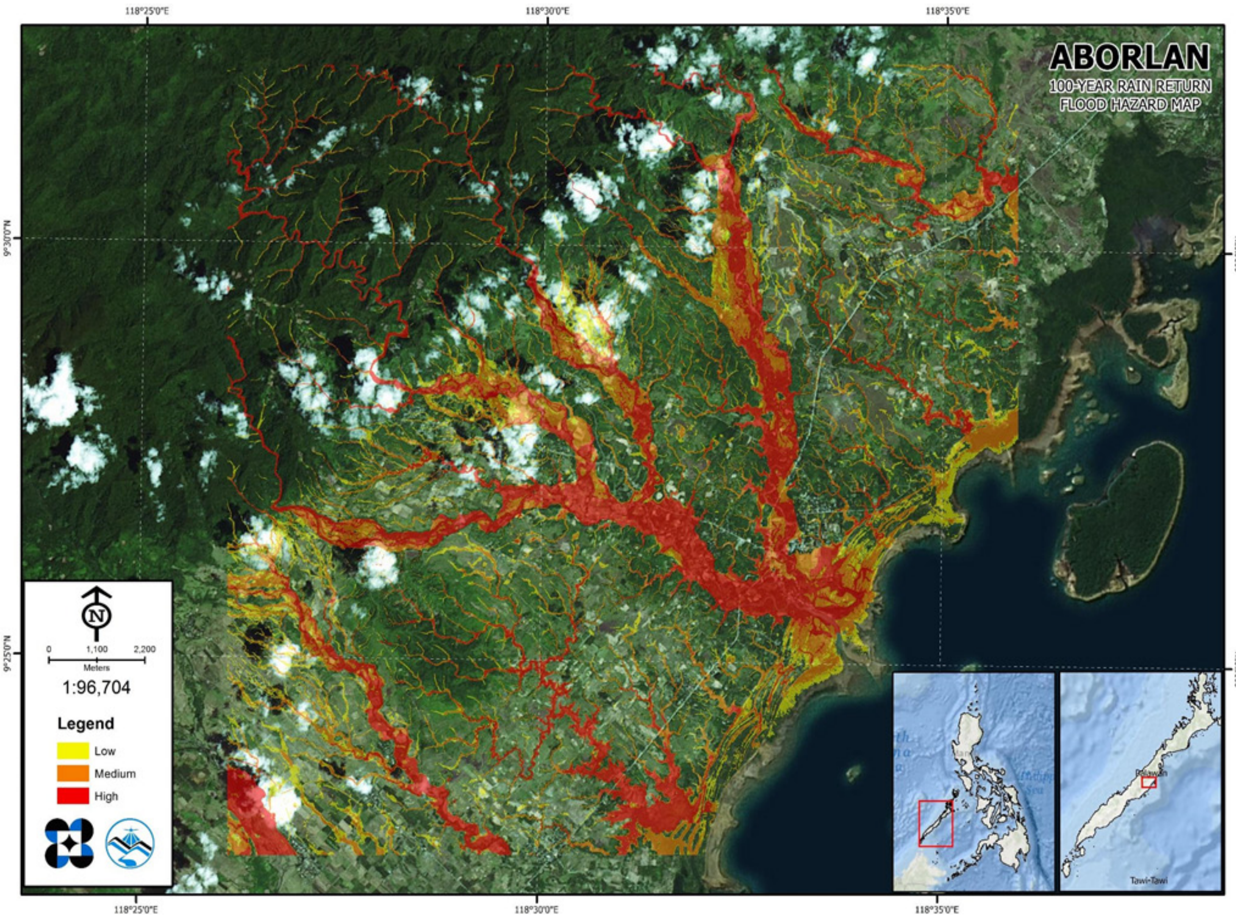



Figure 69. 100-year Flood Hazard Map for Aborlan Floodplain.

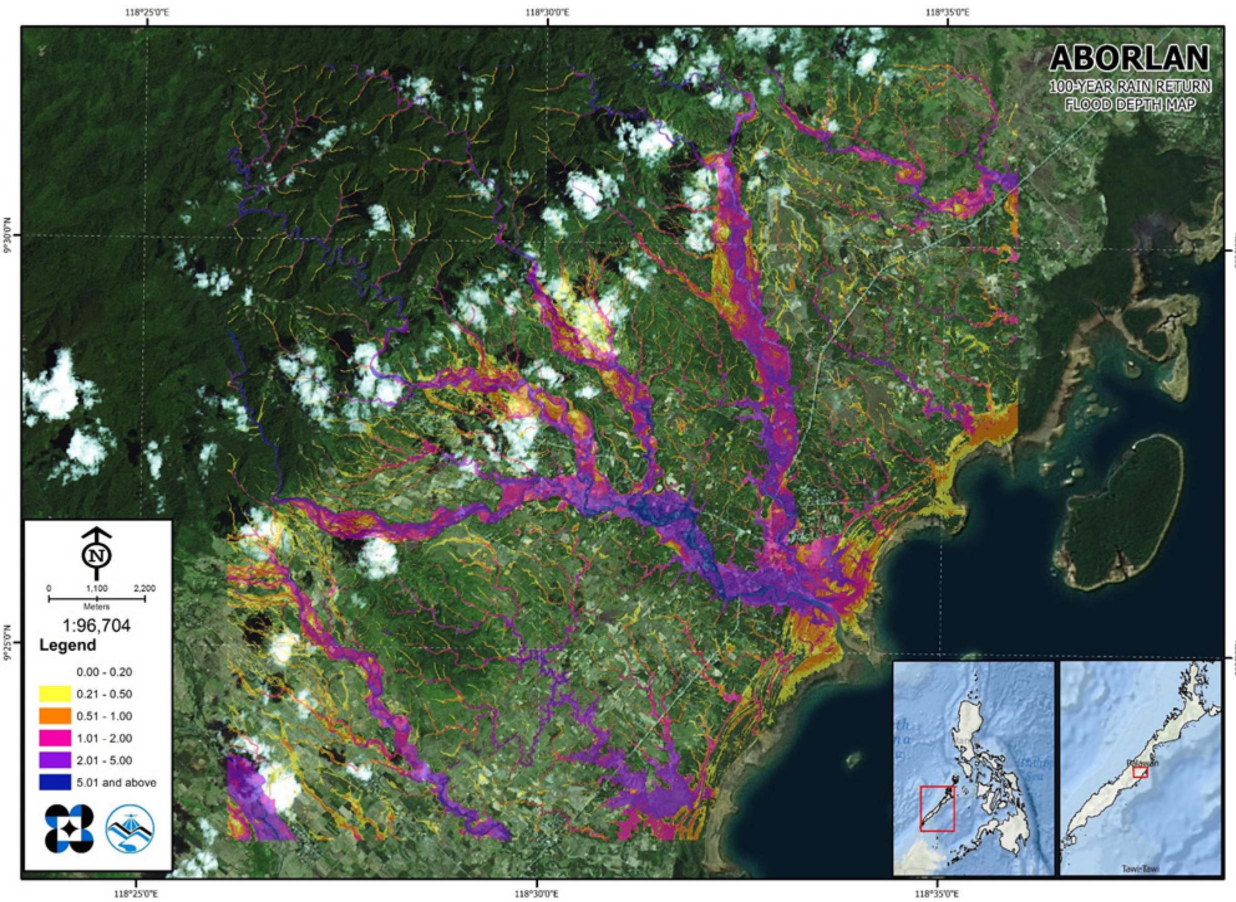



Figure 70. 100-year Flow Depth Map for Aborlan Floodplain.

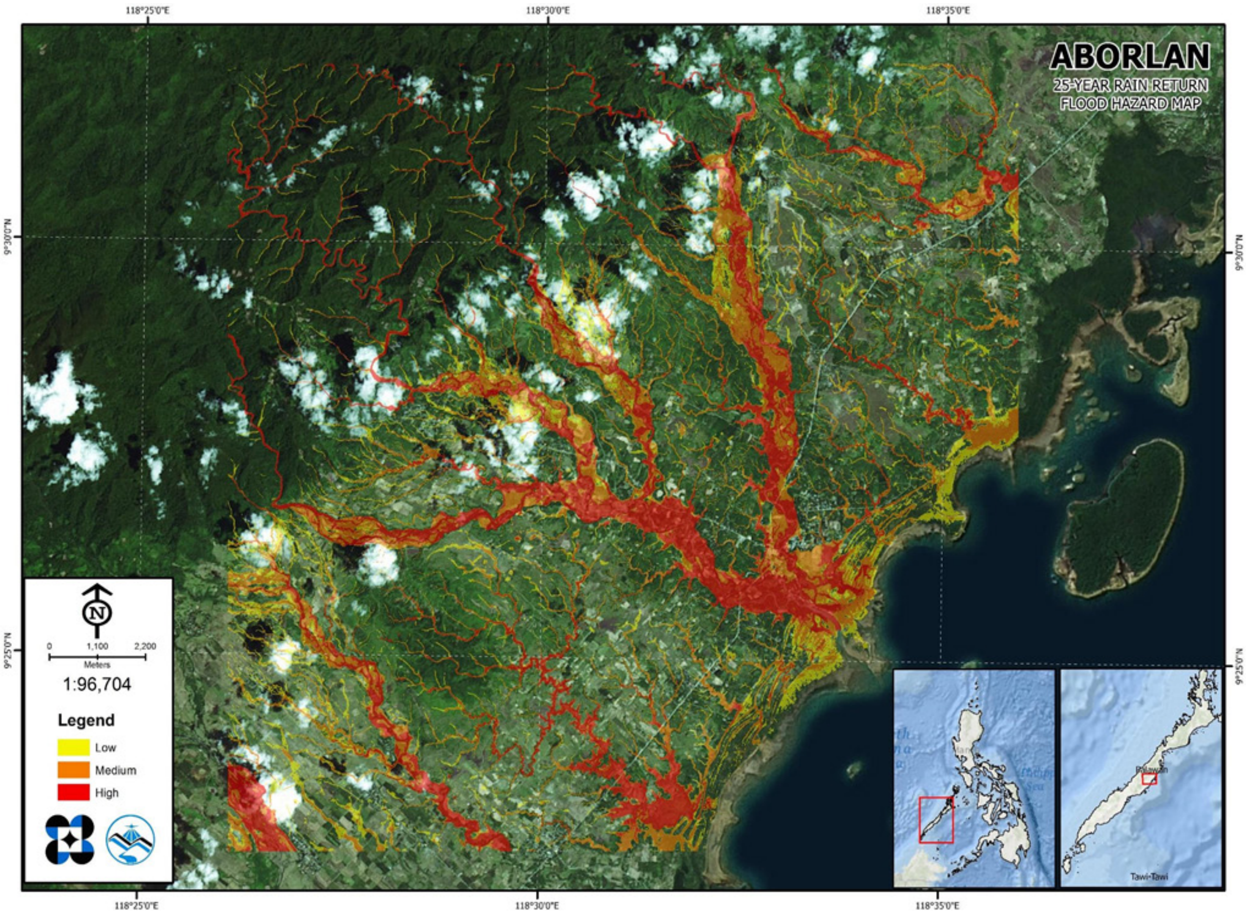



Figure 71. 25-year Flood Hazard Map for Aborlan Floodplain.

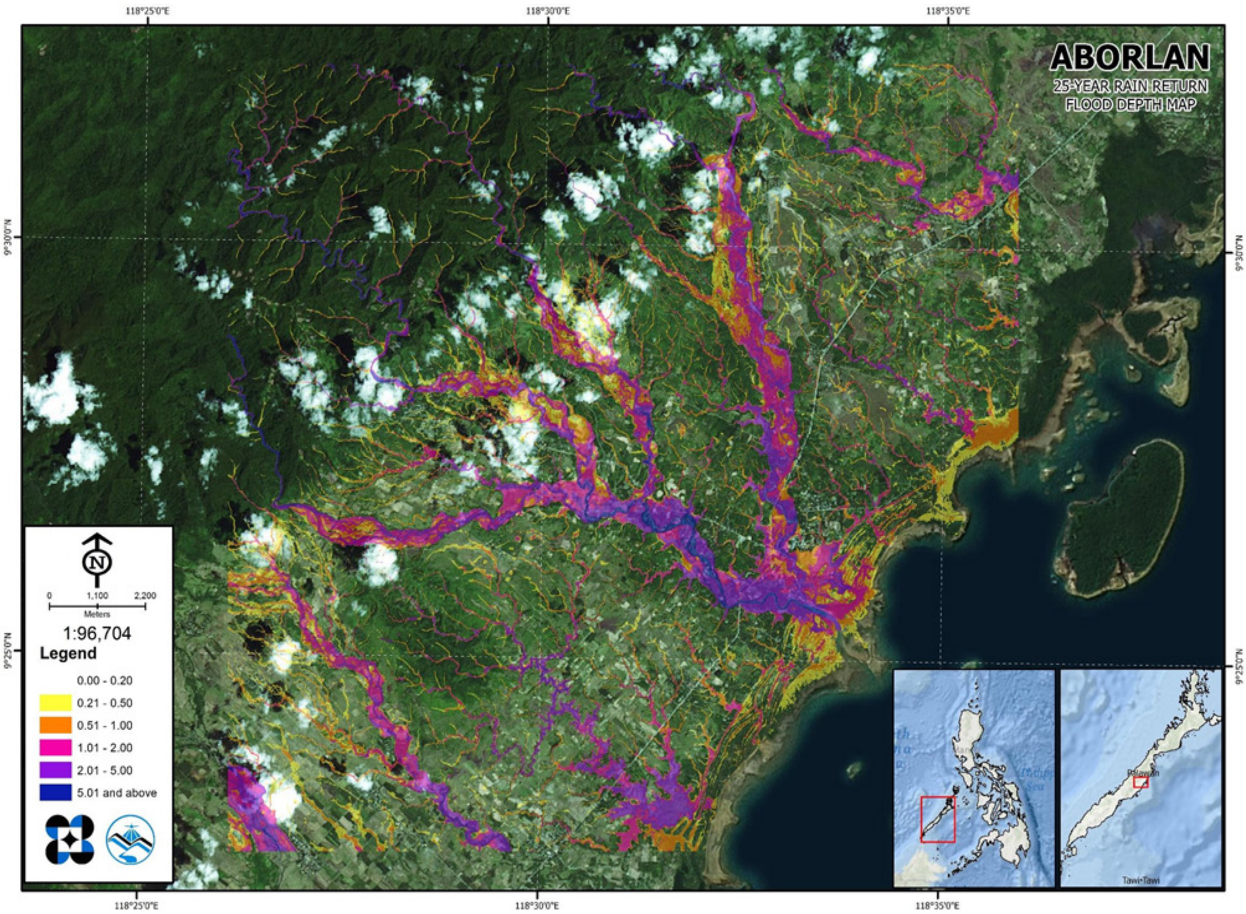



Figure 72. 25-year Flow Depth Map for Aborlan Floodplain.

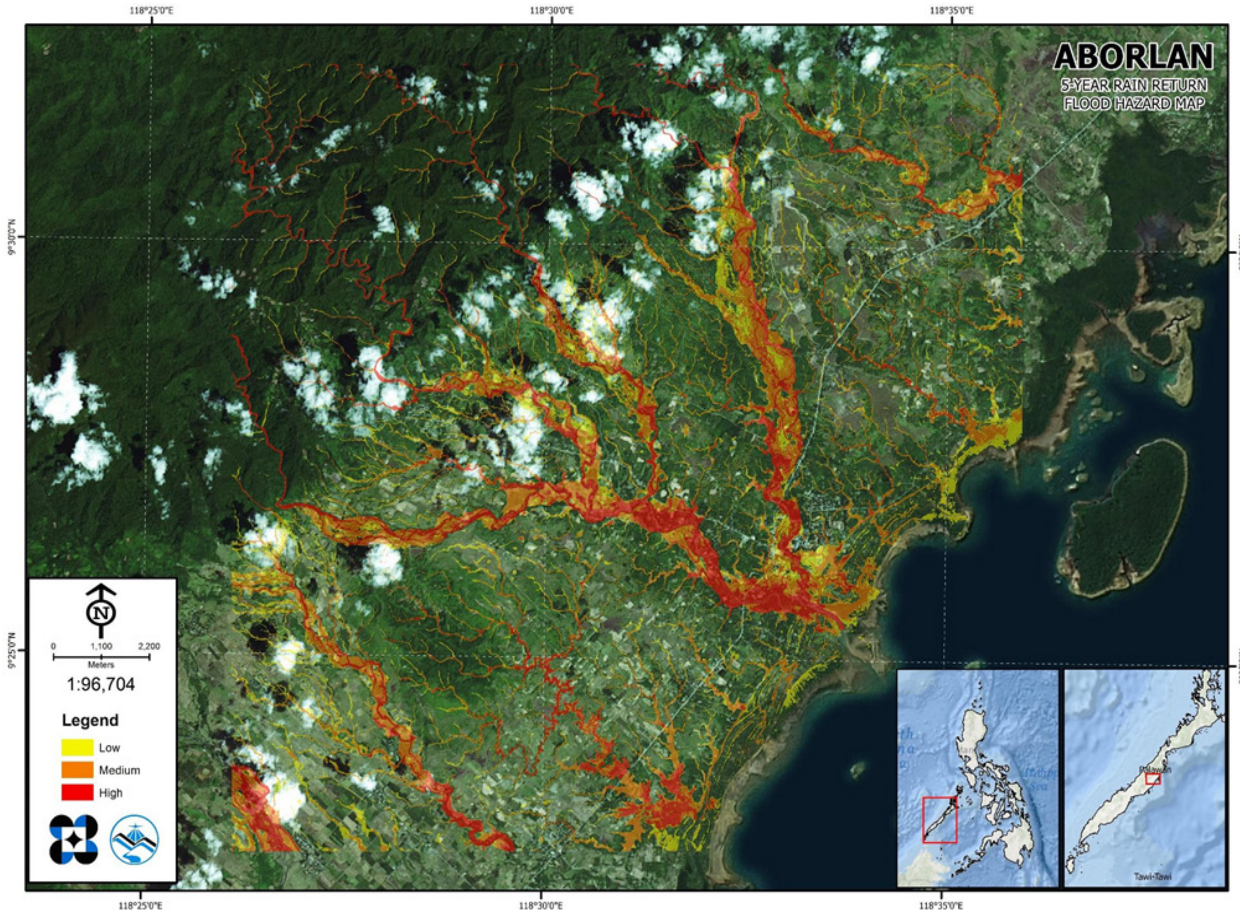



Figure 73. 5-year Flood Hazard Map for Aborlan Floodplain.

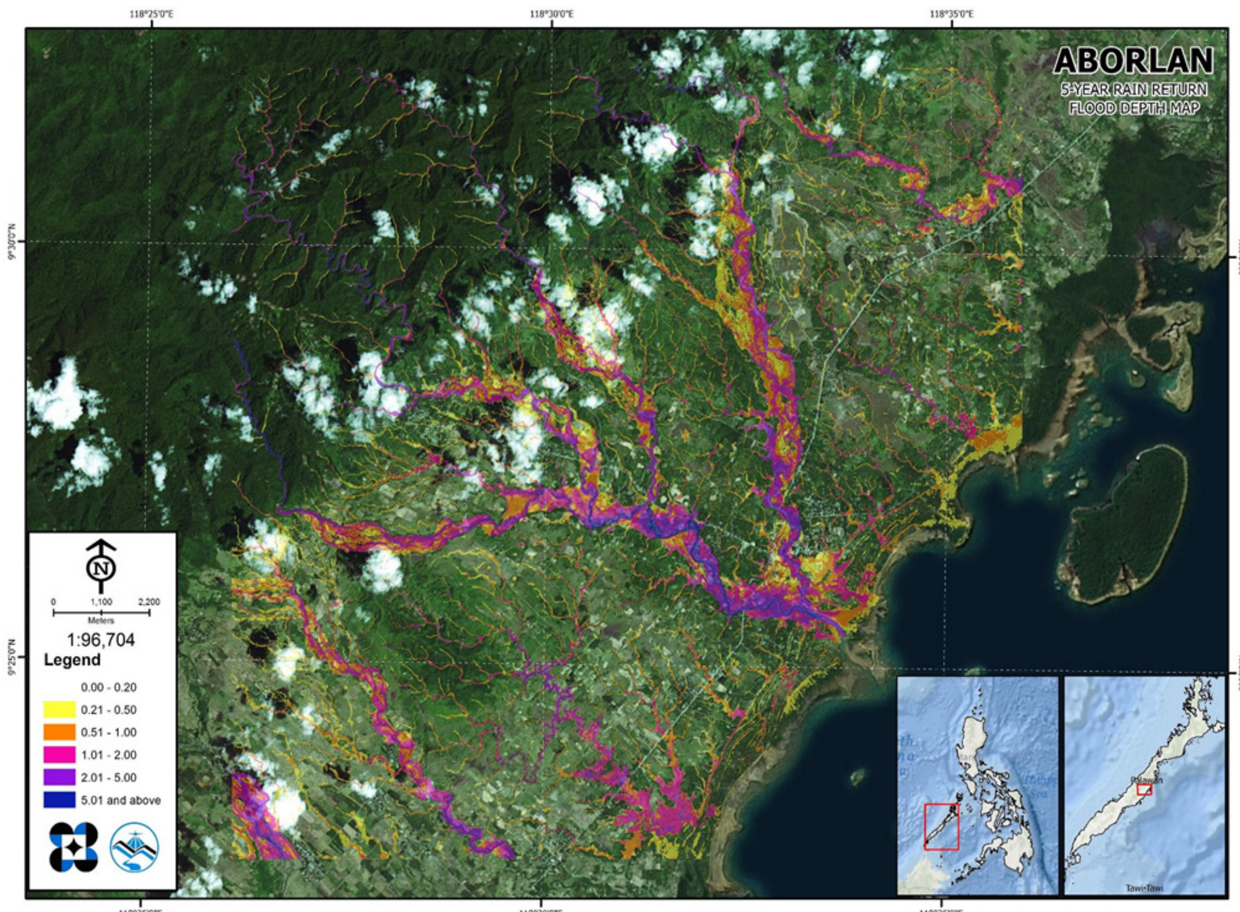



Figure 74. 5-year Flow Depth Map for Aborlan Floodplain.

## 5.10 Inventory of Areas Exposed to Flooding

Listed below are the barangays affected by the Aborlan River Basin, grouped accordingly by municipality. For the said basin, two (2) municipalities consisting of 21 barangays are expected to experience flooding when subjected to a 5-year rainfall return period.

For the 5-year return period, 33.79% of the municipality of Aborlan with an area of 645.11 sq km will experience flood levels of less 0.20 meters; 2.45% of the area will experience flood levels of 0.21 to 0.50 meters; while 2.29%, 2.12%, 1.10%, and 0.13% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Table 36 and Table 37 depict the areas affected in Aborlan in square kilometers by flood depth per barangay.

Table 36. Affected areas in Aborlan, Palawan during a 5-year rainfall return period.

| Affected area (sq. km.) by flood depth (in m.) | Area of affected barangays in Aborlan (in sq km.) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Apo-Aporawan | Apoc-Apoc | Aporawan | Barake | Cabigaan | Culandanum | Gogognan | Iraan | Isaub |
| 0.03-0.20 | 3.33 | 9.88 | 5.27 | 32.13 | 14.47 | 9.03 | 4.33 | 27.1 | 21.75 |
| 0.21-0.50 | 0.35 | 0.62 | 0.12 | 1.76 | 1.3 | 0.13 | 0.24 | 2.14 | 1.82 |
| 0.51-1.00 | 0.17 | 0.75 | 0.062 | 1.52 | 1.24 | 0.088 | 0.4 | 2.12 | 1.6 |
| 1.01-2.00 | 0.13 | 0.64 | 0.047 | 1.14 | 1.19 | 0.099 | 0.49 | 1.47 | 1.06 |
| 2.01-5.00 | 0.083 | 0.23 | 0.031 | 0.6 | 0.64 | 0.18 | 0.63 | 0.5 | 0.3 |
| > 5.00 | 0.0013 | 0.069 | 0.0025 | 0.094 | 0.035 | 0.078 | 0.18 | 0.0063 | 0 |

Table 37. Affected areas in Aborlan, Palawan during a 5-year rainfall return period.

| Affected area (sq. km.) by flood depth (in m.) | Area of affected barangays in Aborlan (in sq km.) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Jose Rizal | Mabini | Magbabadil | Plaridel | Poblacion | Ramon Magsaysay | Sagpangan | San Juan | Tagpait | Tigman |
| 0.03-0.20 | 16.85 | 3.96 | 2.65 | 11.6 | 1.15 | 20.53 | 27.64 | 1.19 | 4.7 | 0.44 |
| 0.21-0.50 | 1.52 | 0.25 | 0.26 | 0.55 | 0.3 | 1.22 | 1.88 | 0.48 | 0.63 | 0.24 |
| 0.51-1.00 | 1.2 | 0.3 | 0.42 | 0.65 | 0.35 | 1.23 | 1.45 | 0.68 | 0.38 | 0.18 |
| 1.01-2.00 | 0.97 | 0.4 | 0.59 | 1.11 | 0.47 | 1.73 | 1.14 | 0.59 | 0.3 | 0.079 |
| 2.01-5.00 | 0.15 | 0.54 | 0.54 | 0.65 | 0.47 | 0.55 | 0.68 | 0.16 | 0.11 | 0.022 |
| > 5.00 | 0.0003 | 0.076 | 0.13 | 0.0037 | 0.067 | 0.0014 | 0.063 | 0.0058 | 0.0055 | 0 |

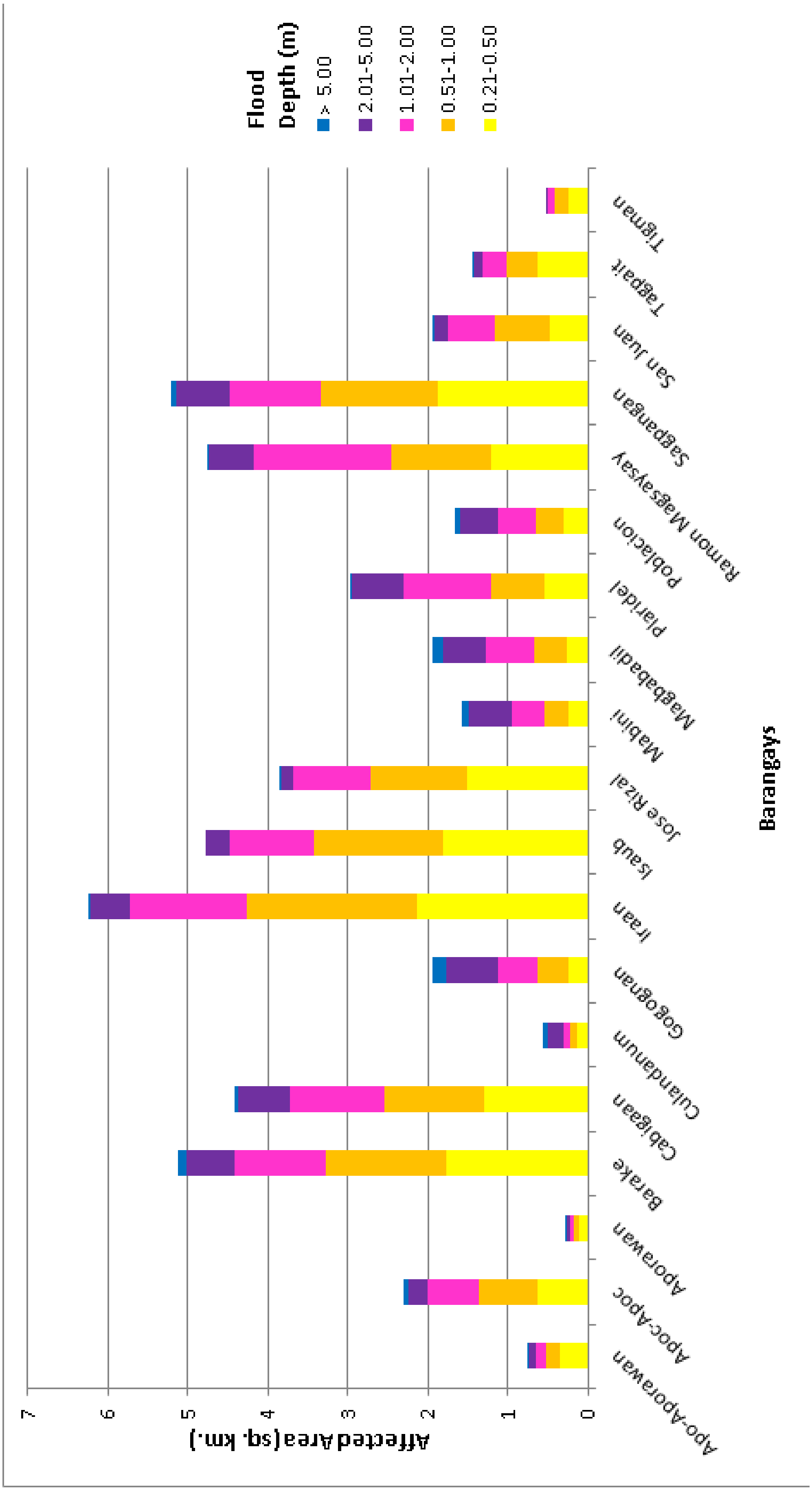



Figure 75. Affected areas in Aborlan, Palawan during a 5-year rainfall return period.

For the municipality of Narra, with an area of 831.19 sq km, 0.82% will experience flood levels of less 0.20 meters; 0.14% of the area will experience flood levels of 0.21 to 0.50 meters; while 0.11%, 0.11%, 0.06%, and 0.003% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Table 38 depicts the affected areas in square kilometers by flood depth per barangay.

Table 38. Affected areas in Narra, Palawan during a 5-year rainfall return period.

| Affected area (sq. km.) by flood depth (in m.) | Areas of affected Barangays in Narra (in sq.km.) | |
|---|---|---|
| | Bagong Sikat | Dumagueña |
| 0.03-0.20 | 1.07 | 5.77 |
| 0.21-0.50 | 0.21 | 0.96 |
| 0.51-1.00 | 0.37 | 0.54 |
| 1.01-2.00 | 0.67 | 0.24 |
| 2.01-5.00 | 0.44 | 0.039 |
| > 5.00 | 0.021 | 0.0045 |

Figure 68. Affected Areas in Aborlan, Ilocos Norte during 5-Year Rainfall Return Period.

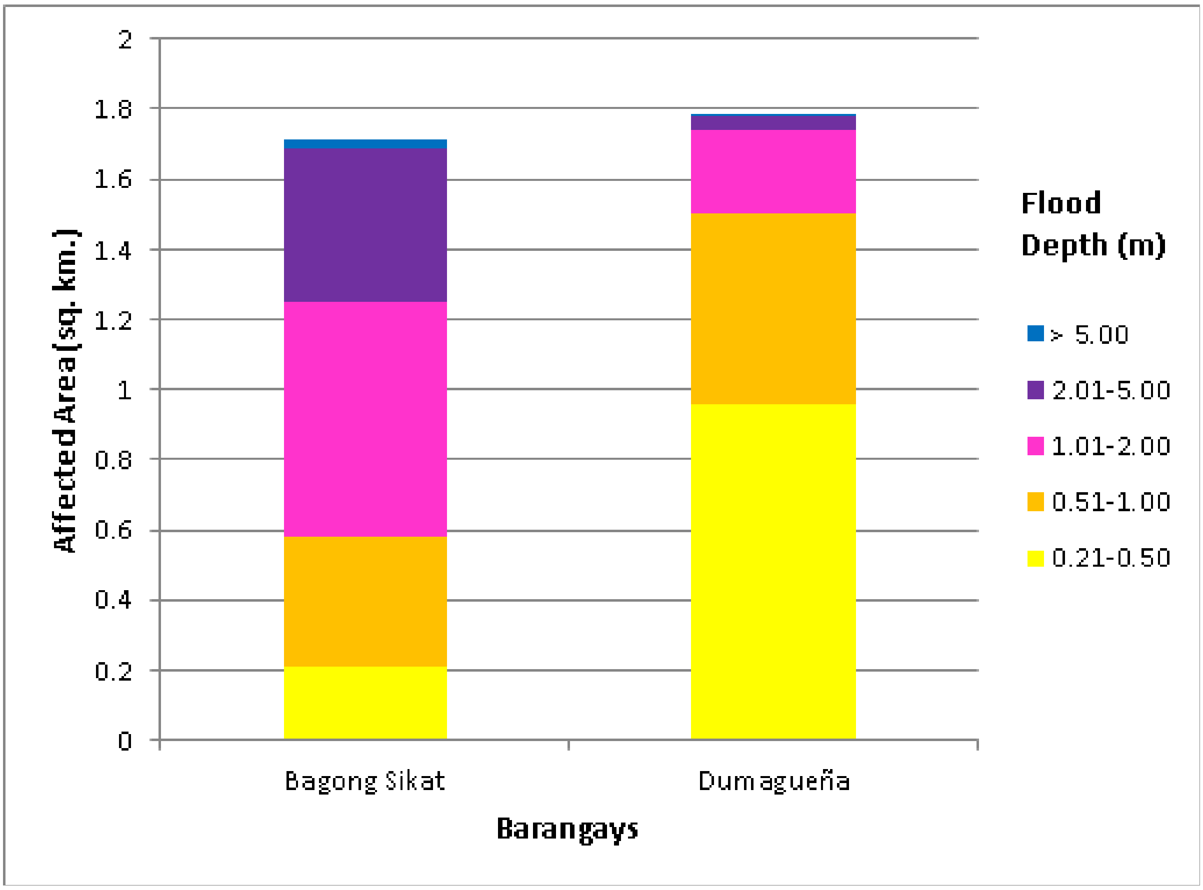



Figure 76. Affected areas in Narra, Palawan during a 5-year rainfall return period.

For the 25-year return period, 32.12% of the municipality of Aborlan with an area of 645.11 sq km will experience flood levels of less 0.20 meters; 2.46% of the area will experience flood levels of 0.21 to 0.50 meters; while 2.31%, 2.69%, 2.05%, and 2.26% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Table 39 and Table 40 depict the areas affected in Aborlan in square kilometers by flood depth per barangay.

Table 39. Affected areas in Aborlan, Palawan during a 25-year rainfall return period

| Affected area (sq. km.) by flood depth (in m.) | Area of affected barangays in Aborlan (in sq km.) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Apo-Aporawan | Apoc-Apoc | Aporawan | Barake | Cabigaan | Culandanum | Gogognan | Iraan | Isaub |
| 0.03-0.20 | 3.13 | 9.65 | 5.22 | 31.05 | 13.58 | 8.9 | 4.08 | 25.98 | 20.83 |
| 0.21-0.50 | 0.41 | 0.55 | 0.13 | 1.84 | 1.33 | 0.16 | 0.18 | 2.08 | 1.67 |
| 0.51-1.00 | 0.22 | 0.65 | 0.071 | 1.65 | 1.3 | 0.086 | 0.23 | 1.93 | 1.87 |
| 1.01-2.00 | 0.16 | 0.89 | 0.056 | 1.62 | 1.61 | 0.11 | 0.45 | 2.31 | 1.51 |
| 2.01-5.00 | 0.14 | 0.36 | 0.05 | 0.88 | 0.98 | 0.17 | 0.96 | 1.04 | 0.66 |
| > 5.00 | 0.0066 | 0.093 | 0.0053 | 0.2 | 0.072 | 0.19 | 0.35 | 0.012 | 0.0031 |

Table 40. Affected areas in Aborlan, Palawan during a 55-year rainfall return period

| Affected area (sq. km.) by flood depth (in m.) | Area of affected barangays in Aborlan (in sq km.) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Jose Rizal | Mabini | Magbabadil | Plaridel | Poblacion | Ramon Magsaysay | Sagpangan | San Juan | Tagpait | Tigman |
| 0.03-0.20 | 16.06 | 3.72 | 2.42 | 11.22 | 0.94 | 19.68 | 26.32 | 0.51 | 3.61 | 0.31 |
| 0.21-0.50 | 1.72 | 0.19 | 0.17 | 0.58 | 0.049 | 1.3 | 1.92 | 0.4 | 1.14 | 0.061 |
| 0.51-1.00 | 1.19 | 0.31 | 0.26 | 0.5 | 0.25 | 1.15 | 1.58 | 0.65 | 0.71 | 0.29 |
| 1.01-2.00 | 1.35 | 0.35 | 0.68 | 0.9 | 0.57 | 1.34 | 1.75 | 1.04 | 0.4 | 0.24 |
| 2.01-5.00 | 0.37 | 0.78 | 0.87 | 1.34 | 0.9 | 1.78 | 1.09 | 0.5 | 0.26 | 0.071 |
| > 5.00 | 0.0014 | 0.17 | 0.2 | 0.032 | 0.091 | 0.021 | 0.19 | 0.011 | 0.0073 | 0 |

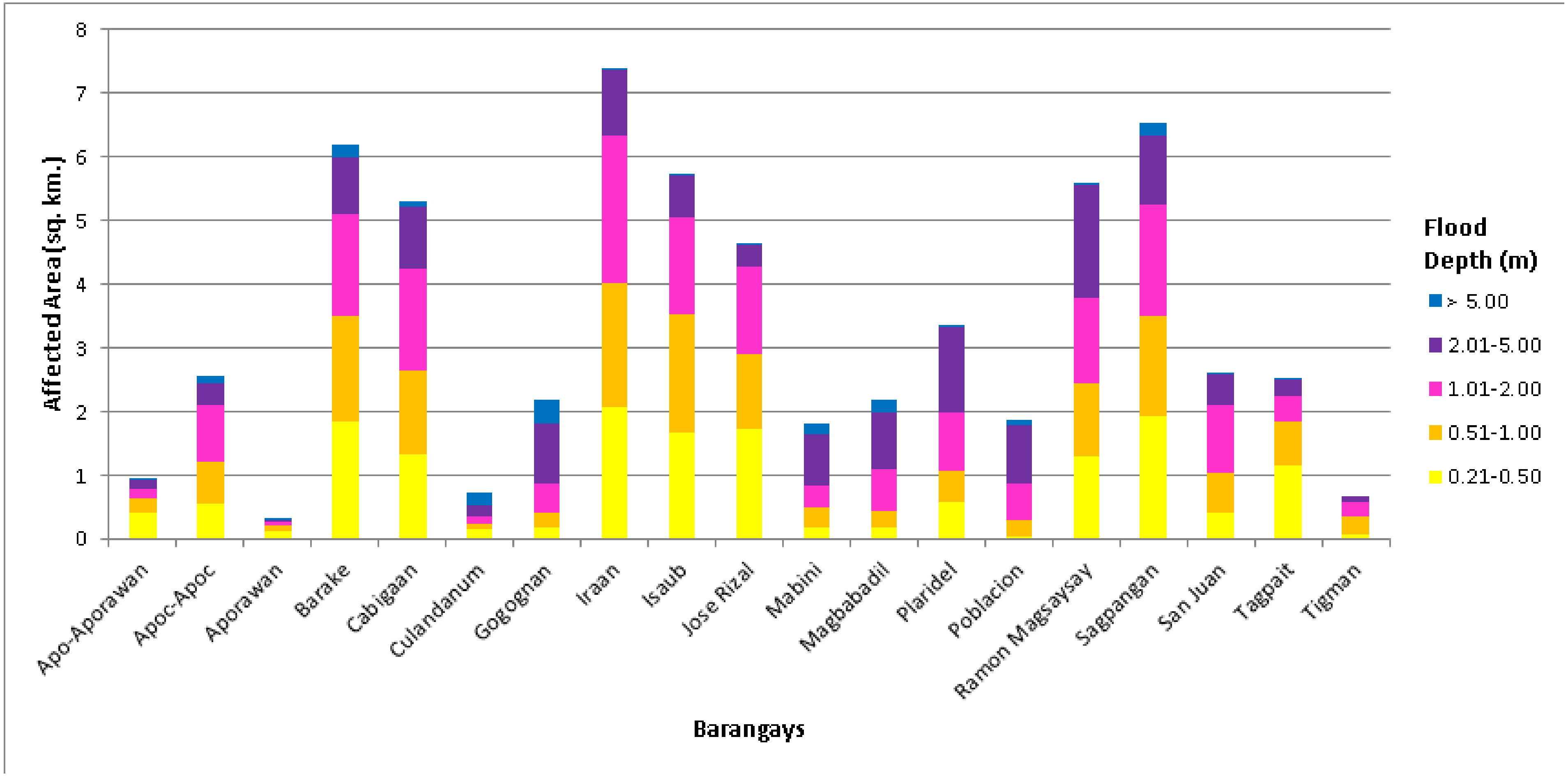



Figure 77. Affected areas in Aborlan, Palawan during a 25-year rainfall return period .

For the municipality of Narra, with an area of 831.19 sq km, 0.75% will experience flood levels of less 0.20 meters; 0.15% of the area will experience flood levels of 0.21 to 0.50 meters; while 0.11%, 0.13%, 0.10%, and 0.006% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Table 41 depicts the affected areas in square kilometers by flood depth per barangay.

Table 41. Affected areas in Narra, Palawan during a 25-year rainfall return period.

| Affected area (sq. km.) by flood depth (in m.) | Areas of affected Barangays in Narra (in sq.km.) | |
|---|---|---|
| | Bagong Sikat | Dumagueña |
| 0.03-0.20 | 0.94 | 5.29 |
| 0.21-0.50 | 0.15 | 1.12 |
| 0.51-1.00 | 0.21 | 0.69 |
| 1.01-2.00 | 0.68 | 0.37 |
| 2.01-5.00 | 0.75 | 0.075 |
| > 5.00 | 0.039 | 0.0073 |

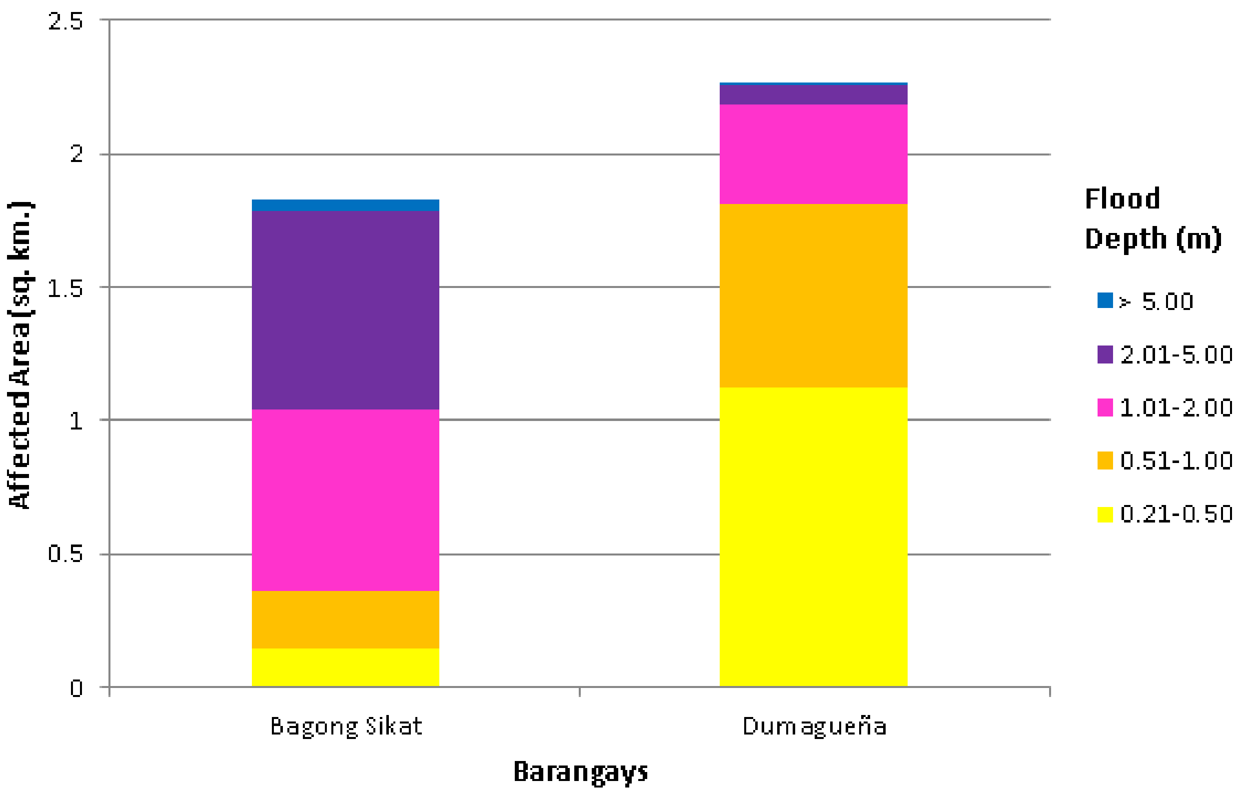



Figure 78. Affected areas in Narra, Palawan during a 25-year rainfall return period.

For the 100-year return period, 31.21% of the municipality of Aborlan with an area of 645.11 sq km will experience flood levels of less 0.20 meters; 2.51% of the area will experience flood levels of 0.21 to 0.50 meters; while 2.29%, 2.84%, 2.64%, and 0.40% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Table 42 and Table 43 depict the areas affected in Aborlan in square kilometers by flood depth per barangay.

Table 42. Affected areas in Aborlan, Palawan during a 100-year rainfall return period

| Affected area (sq. km.) by flood depth (in m.) | Area of affected barangays in Aborlan (in sq km.) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Apo-Aporawan | Apoc-Apoc | Aporawan | Barake | Cabigaan | Culandanum | Gogognan | Iraan | Isaub |
| 0.03-0.20 | | | | | | | | | |
| 0.21-0.50 | | | | | | | | | |
| 0.51-1.00 | | | | | | | | | |
| 1.01-2.00 | | | | | | | | | |
| 2.01-5.00 | | | | | | | | | |
| > 5.00 | | | | | | | | | |

Table 43. Affected areas in Aborlan, Palawan during a 100-year rainfall return period.

| Affected area (sq. km.) by flood depth (in m.) | Area of affected barangays in Aborlan (in sq km.) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Jose Rizal | Mabini | Magbabadil | Plaridel | Poblacion | Ramon Magsaysay | Sagpangan | San Juan | Tagpait | Tigman |
| 0.03-0.20 | 16.06 | 3.72 | 2.42 | 11.22 | 0.94 | 19.68 | 26.32 | 0.51 | 3.61 | 0.31 |
| 0.21-0.50 | 1.72 | 0.19 | 0.17 | 0.58 | 0.049 | 1.3 | 1.92 | 0.4 | 1.14 | 0.061 |
| 0.51-1.00 | 1.19 | 0.31 | 0.26 | 0.5 | 0.25 | 1.15 | 1.58 | 0.65 | 0.71 | 0.29 |
| 1.01-2.00 | 1.35 | 0.35 | 0.68 | 0.9 | 0.57 | 1.34 | 1.75 | 1.04 | 0.4 | 0.24 |
| 2.01-5.00 | 0.37 | 0.78 | 0.87 | 1.34 | 0.9 | 1.78 | 1.09 | 0.5 | 0.26 | 0.071 |
| > 5.00 | 0.0014 | 0.17 | 0.2 | 0.032 | 0.091 | 0.021 | 0.19 | 0.011 | 0.0073 | 0 |

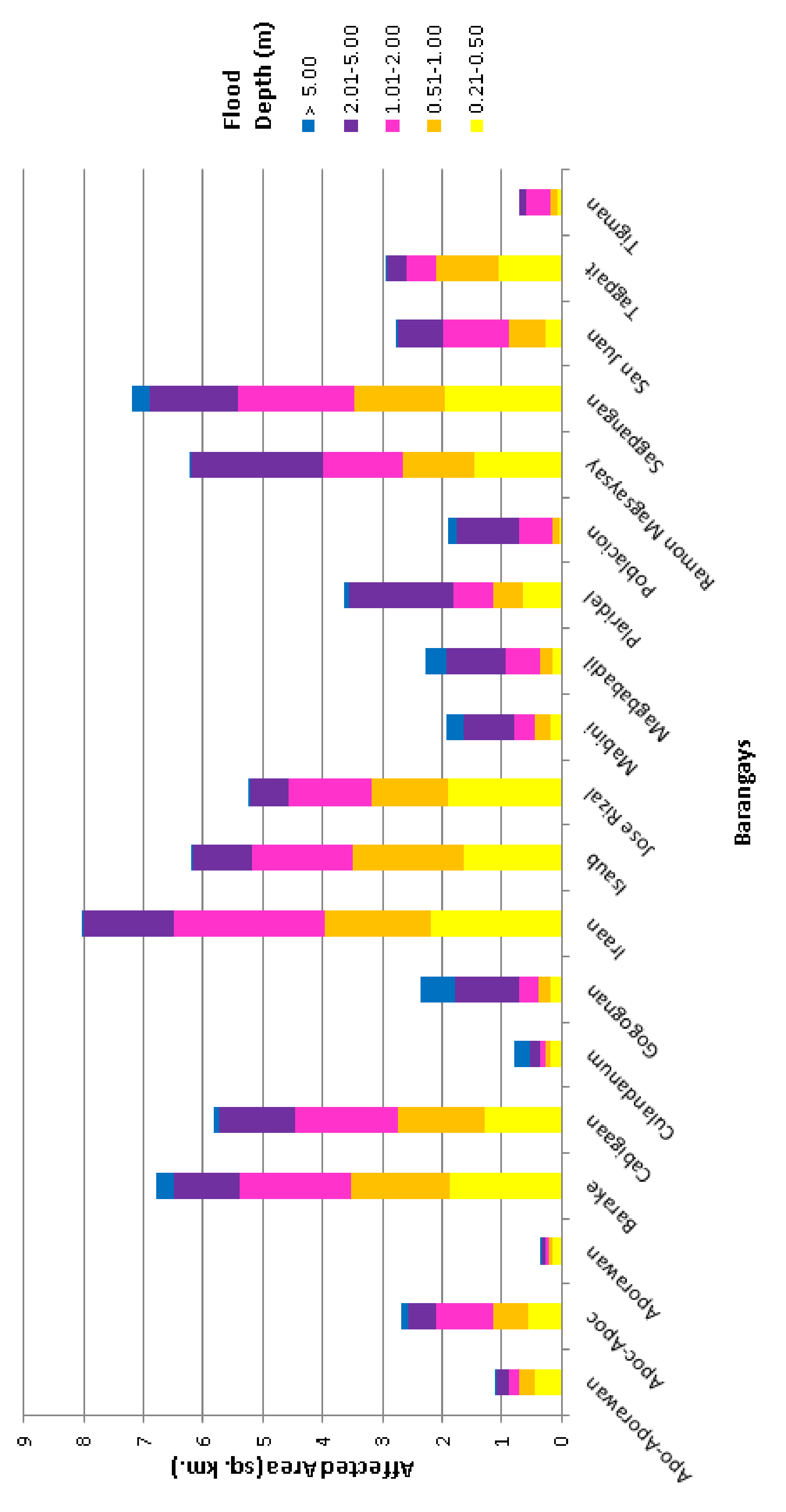



Figure 79. Affected areas in Aborlan, Palawan during a 100-year rainfall return period .

For the municipality of Narra, with an area of 831.19 sq km, 0.70% will experience flood levels of less 0.20 meters; 0.16% of the area will experience flood levels of 0.21 to 0.50 meters; while 0.12%, 0.10%, 0.15%, and 0.01% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Table 44 depicts the affected areas in square kilometers by flood depth per barangay.

Table 44. Affected areas in Narra, Palawan during a 100-year rainfall return period.

| Affected area (sq. km.) by flood depth (in m.) | Areas of affected Barangays in Narra (in sq.km.) | |
|---|---|---|
| | Bagong Sikat | Dumagueña |
| 0.03-0.20 | 0.84 | 4.95 |
| 0.21-0.50 | 0.14 | 1.21 |
| 0.51-1.00 | 0.17 | 0.81 |
| 1.01-2.00 | 0.39 | 0.47 |
| 2.01-5.00 | 1.16 | 0.11 |
| > 5.00 | 0.085 | 0.0084 |

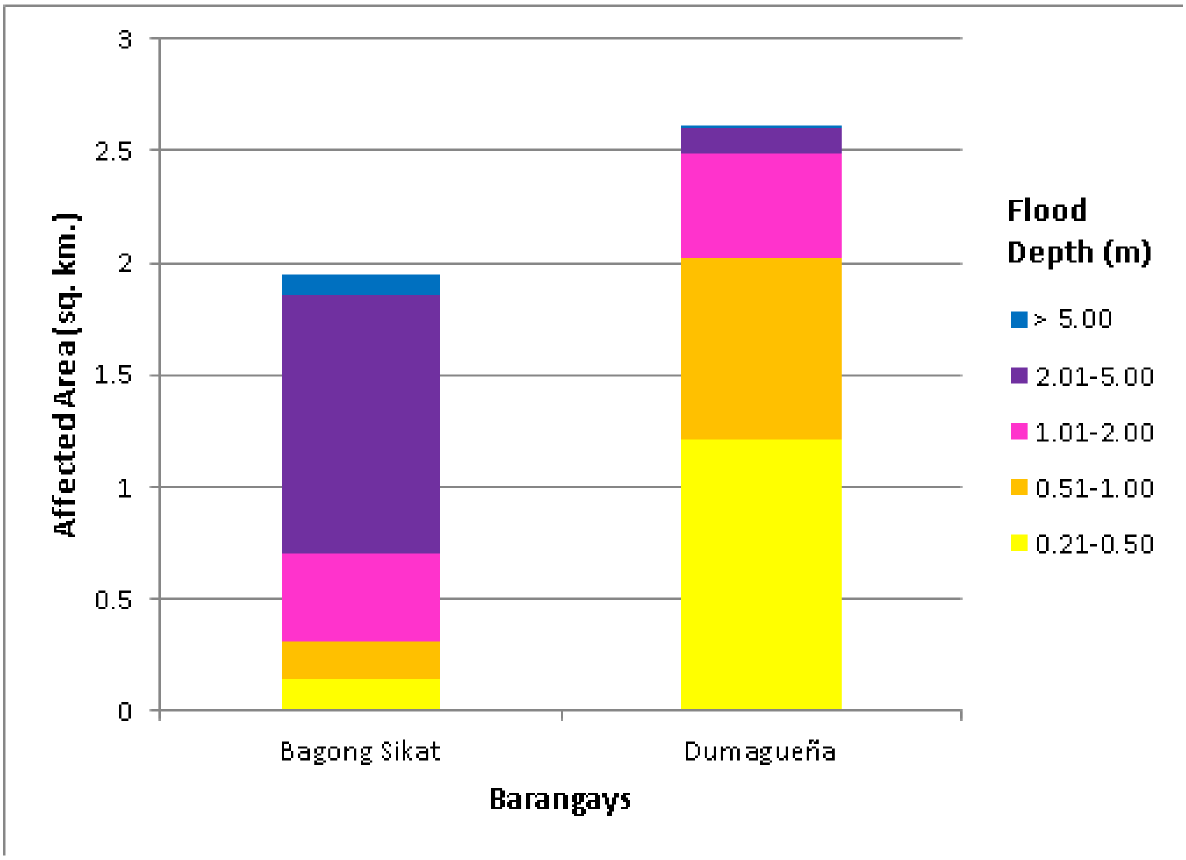



Figure 79. Affected areas in Narra, Palawan during a 100-year rainfall return period.

Among the barangays in the municipality of Aborlan, Barake is projected to have the highest percentage of area that will experience flood levels of at 5.77%. On the other hand, Iraan posted the percentage of area that may be affected by flood depths of at 5.17%.

Among the barangays in the municipality of Narra, Dumagueña is projected to have the highest percentage of area that will experience flood levels of at 0.91%. On the other hand, Bagong Sikat posted the percentage of area that may be affected by flood depths of at 0.33%.

## 5.11 Flood Validation

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

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

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

After which, the actual data from the field will be 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 88

.

The flood validation consists of 70 points randomly selected all over the Aborlan flood plain. Comparing it with the flood depth map of the nearest storm event, the map has an RMSE value of 1.604m. Table 42 shows a contingency matrix of the comparison.

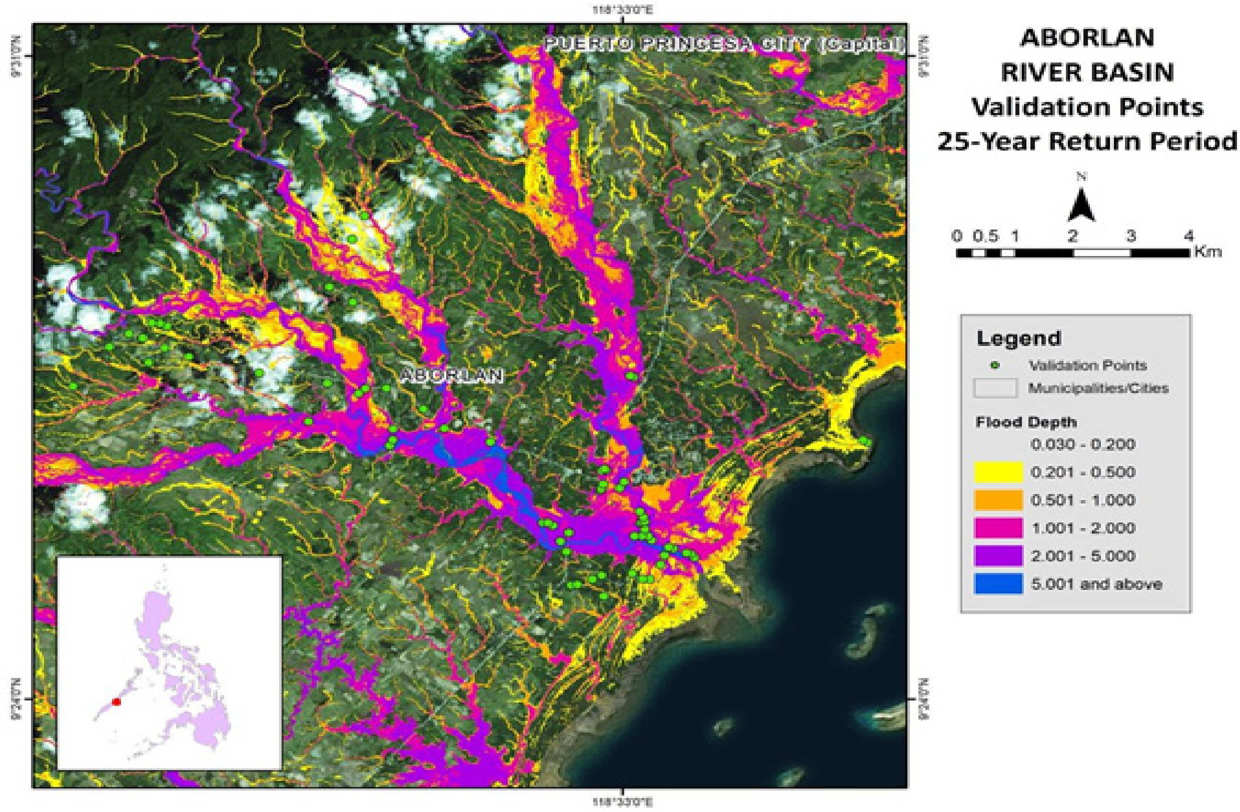



Figure 80. Validation points for 25-year Flood Depth Map of Aborlan Floodplain

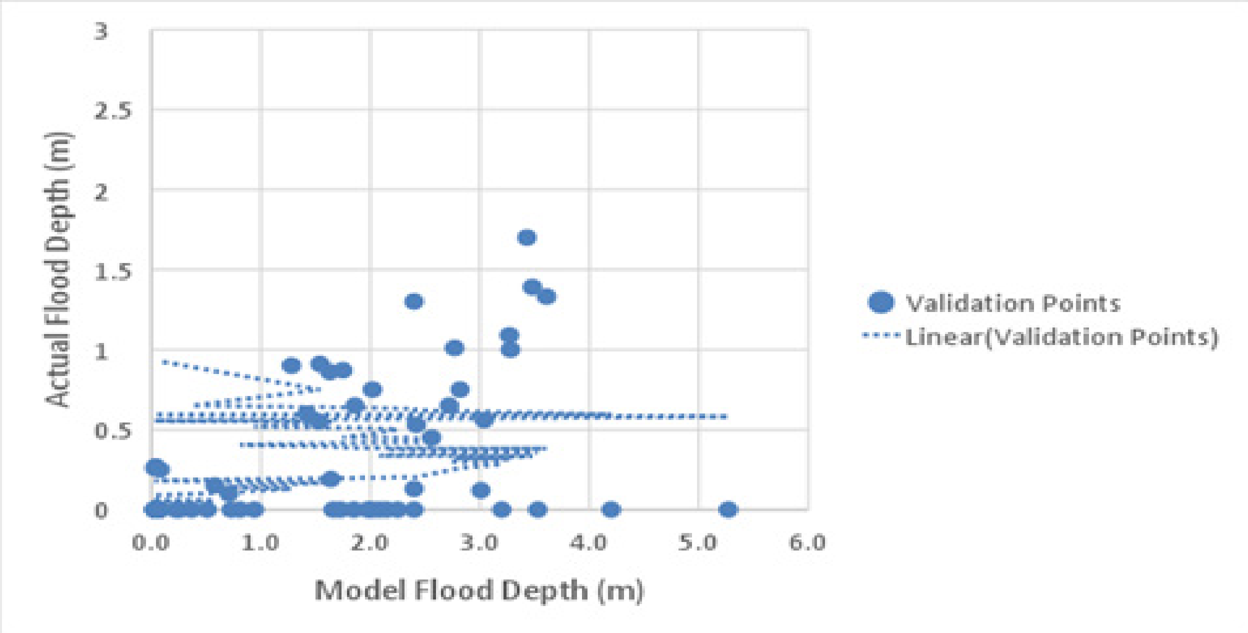



Figure 81. Flood map depth vs actual flood depth

Table 45. Actual Flood Depth vs Simulated Flood Depth at different levels in the Aborlan River Basin.

| ABORLAN | | Modeled Flood Depth (m) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **180** | **10** | **11** | **1** | **0** | **0** | 202 |
| **Actual Flood Depth (m)** | **0-0.20** | 22 | 3 | 6 | 5 | 10 | 1 | 47 |
| | **0.21-0.50** | 3 | 0 | 0 | 0 | 1 | 0 | 4 |
| | **0.51-1.00** | 0 | 0 | 0 | 7 | 6 | 0 | 13 |
| | **1.01-2.00** | 0 | 0 | 0 | 0 | 6 | 0 | 6 |
| | **2.01-5.00** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **> 5.00** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Total** | 25 | 3 | 6 | 12 | 23 | 1 | 70 |

The overall accuracy generated by the flood model is estimated at 31.43% with 22 points correctly matching the actual flood depths. In addition, there were 19 points estimated one level above and below the correct flood depths while there were 12 points and 17 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 3 points were underestimated in the modelled flood depths of Aborlan. Table 46 depicts the summary of the Accuracy Assessment in the Aborlan River Basin Survey.

Table 46. Summary of Accuracy Assessment in the Aborlan River Basin Survey

| LANANG | No. of Points | % |
|---|---|---|
| Correct | 22 | **31.43** |
| Overestimated | 45 | 64.29 |
| Underestimated | 3 | 4.29 |
| Total | 70 | 100.00 |

# REFERENCES

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

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

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

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

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

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

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

# ANNEXES

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

1. Pegasus Sensor

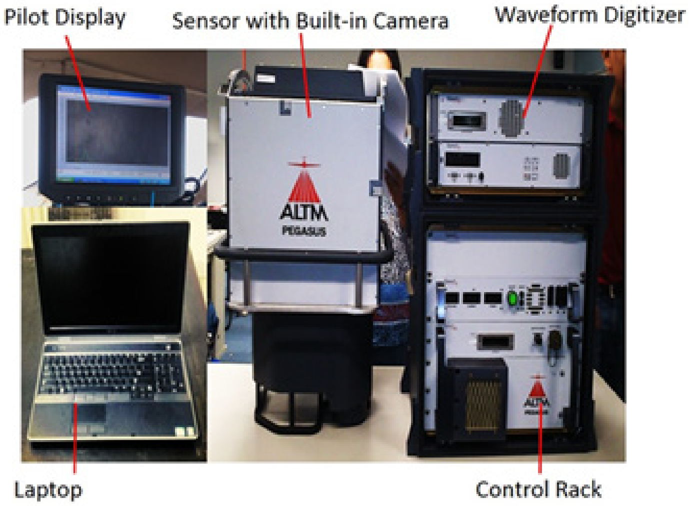



Figure A-1.1. Pegasus Sensor

Table A-1.1. Parameters and Specifications of 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, 1Ó |
| Elevation accuracy (2) | < 5-20 cm, 1Ó |
| 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 (optional) |
| 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 |

2. Gemini Sensor

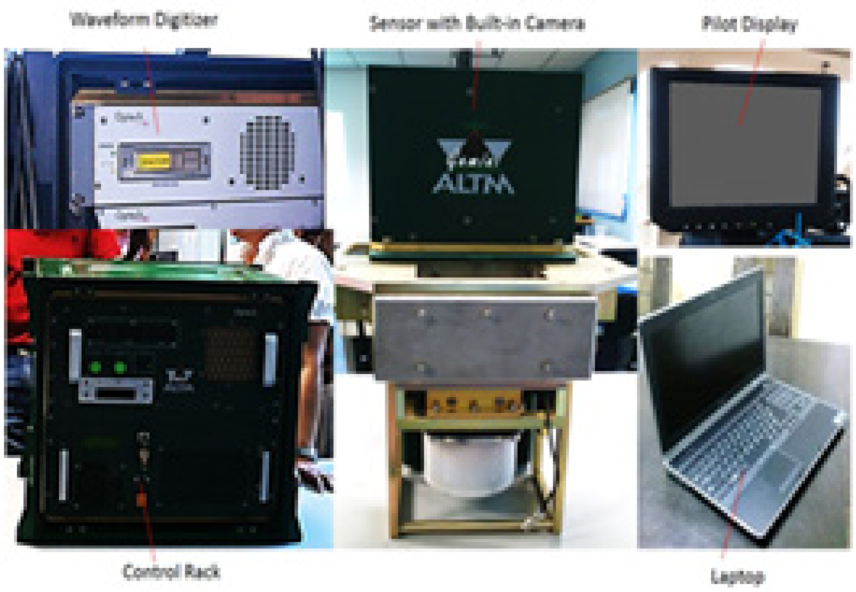



Figure A-1.2. Gemini Sensor

Table A-1.2. Parameters and Specifications of Gemini Sensor

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

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

1. PLW-50

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

June 23, 2015

**CERTIFICATION**

To whom it may concern:

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

| | | |
|---|---|---|
| | Province: **PALAWAN** | |
| | Station Name: **PLW-50** | |
| | Order: **2nd** | |
| Island: **LUZON** | Barangay: **IWAHIG** | |
| Municipality: **PUERTO PRINCESA CITY (CAPITAL)** | MSL Elevation: | |
| | ***PRS92 Coordinates*** | |
| Latitude: **9° 44' 42.16318"** | Longitude: **118° 39' 28.02050"** | Ellipsoidal Hgt: **16.81300 m.** |
| | ***WGS84 Coordinates*** | |
| Latitude: **9° 44' 37.72390"** | Longitude: **118° 39' 33.34598"** | Ellipsoidal Hgt: **66.85300 m.** |
| | ***PTM / PRS92 Coordinates*** | |
| Northing: **1077537.527 m.** | Easting: **517311.956 m.** | Zone: **1A** |
| | ***UTM / PRS92 Coordinates*** | |
| Northing: **1,077,601.73** | Easting: **681,851.72** | Zone: **50** |

Location Description

PLW-50
From Puerto Princesa City Proper, travel along the National Highway S bound, until reaching Iwahig Penal Farm at about 15 km. The station is located inside the vicinity of Iwahig Penal Farm, situated at the base of the fountain 20 m. NW of Administration Building and 50 m W of Iwahig Elem. School. Station mark is a brass plate 10" in diameter with inscription "Corps of Engineers, U.S. Army Survey control mark circle station".

Requesting Party: **UP-DREAM**
Purpose: **Reference**
OR Number: **8083538 I**
T.N.: **2015-1337**

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

99062320151114335

CP/4701/13/09/814

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.1. PLW-50

2. PLW-71

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

June 23, 2015

CERTIFICATION

To whom it may concern:

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

Province: PALAWAN
Station Name: PLW-71 (PAL-14)
Order: 2nd

| | | | |
|---|---|---|---|
| Island: LUZON | Barangay: BERONG, SO. BADLESAN | | |
| Municipality: PUERTO PRINCESA CITY (CAPITAL) | MSL Elevation: | | |
| | *PRS92 Coordinates* | | |
| Latitude: 9° 27' 39.91263" | Longitude: 118° 12' 4.53547" | Ellipsoidal Hgt: | 3.87100 m. |
| | *WGS84 Coordinates* | | |
| Latitude: 9° 27' 35.50449" | Longitude: 118° 12' 9.88716" | Ellipsoidal Hgt: | 53.39400 m. |
| | *PTM / PRS92 Coordinates* | | |
| Northing: 1046143.749 m. | Easting: 467194.901 m. | Zone: | 1A |
| | *UTM / PRS92 Coordinates* | | |
| Northing: 1,045,990.79 | Easting: 631,874.59 | Zone: | 50 |

Location Description

PLW-71 (PAL-14)
From Puerto Princesa City travel south bound by a shuttle van going to the municipality of Quezon for almost 3 to 4 hours. The station is located near the house of Ex Brgy. Capt. Victorino Danglong in sitio Badlesan at the back of the house of Mr. Tranquilino (June) Talo Jr. Mark is a 4" copper nail centered on top of a 30 x 30 x 100 cm concrete monument, 80 cm embedded on the ground and 20 cm protruding on the ground with inscription PAL-14 2005 NCIP.

Requesting Party: UP-DREAM
Purpose: Reference
OR Number: 8083538 I
T.N.: 2015-1343

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

9906232015114604

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.2. PLW-71

3. PLW-113

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

June 23, 2015

**CERTIFICATION**

To whom it may concern:

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

Province: **PALAWAN**
Station Name: **PLW-113**
Order: **2nd**

| | | | |
|---|---|---|---|
| Island: **LUZON** | Barangay: **CABIGAAN** | | |
| Municipality: **PUERTO PRINCESA CITY (CAPITAL)** | MSL Elevation: | | |
| | ***PRS92 Coordinates*** | | |
| Latitude: **9° 26' 55.17200"** | Longitude: **118° 26' 46.88314"** | Ellipsoidal Hgt: | **95.70958 m.** |
| | ***WGS84 Coordinates*** | | |
| Latitude: **9° 26' 50.78858"** | Longitude: **118° 26' 52.23545"** | Ellipsoidal Hgt: | **145.86900 m.** |
| | ***PTM / PRS92 Coordinates*** | | |
| Northing: **1044755.711 m.** | Easting: **494109.133 m.** | Zone: | **1A** |
| | ***UTM / PRS92 Coordinates*** | | |
| Northing: **1,044,718.65** | Easting: **658,792.04** | Zone: | **50** |

Location Description

PLW-113
From Poblacion Aborlan approximately 500 m. turn W at the junction going to Brgy. Cabigaan. Travel approximately 14 kms. up to Aborlan Water System. Station is located outside, SE of Aborlan Water System. Mark is the head of a 4 in. copper nail flushed in a cement putty 30cm x 30cm x 120cm embedded 1m on the ground with inscriptions "PLW-113 2007 NAMRIA."

Requesting Party: **UP-DREAM**
Purpose: **Reference**
OR Number: **8083538 I**
T.N.: **2015-1339**

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.3. PLW-113

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

1. PLW-113 and PL-46

**Vector Components (Mark to Mark)**

| From: | PLW 113 | | | | |
|---|---|---|---|---|---|
| Grid | | Local | | Global | |
| Easting | -385.117 m | Latitude | N9°26'55.17199" | Latitude | N9°26'50.78858" |
| Northing | 1047659.012 m | Longitude | E118°26'46.88318" | Longitude | E118°26'52.23545" |
| Elevation | 95.265 m | Height | 95.710 m | Height | 145.869 m |

| To: | PL 46 | | | | |
|---|---|---|---|---|---|
| Grid | | Local | | Global | |
| Easting | 10678.747 m | Latitude | N9°26'56.28696" | Latitude | N9°26'51.91226" |
| Northing | 1047550.297 m | Longitude | E118°32'48.62908" | Longitude | E118°32'53.98117" |
| Elevation | 15.378 m | Height | 15.833 m | Height | 66.241 m |

| Vector | | | | | |
|---|---|---|---|---|---|
| ΔEasting | 11063.863 m | NS Fwd Azimuth | 89°48'50" | ΔX | -9658.079 m |
| ΔNorthing | -108.715 m | Ellipsoid Dist. | 11035.352 m | ΔY | -5339.316 m |
| ΔElevation | -79.887 m | ΔHeight | -79.877 m | ΔZ | 20.985 m |

**Standard Errors**

| Vector errors: | | | | | |
|---|---|---|---|---|---|
| σ ΔEasting | 0.006 m | σ NS fwd Azimuth | 0°00'00" | σ ΔX | 0.009 m |
| σ ΔNorthing | 0.003 m | σ Ellipsoid Dist. | 0.006 m | σ ΔY | 0.012 m |
| σ ΔElevation | 0.014 m | σ ΔHeight | 0.014 m | σ ΔZ | 0.003 m |

**Aposteriori Covariance Matrix (Meter²)**

| | X | Y | Z |
|---|---|---|---|
| X | 0.0000858869 | | |
| Y | -0.0000752793 | 0.0001329191 | |
| Z | 0.0000004586 | 0.0000135321 | 0.0000100914 |

Figure A-3.1. PLW-113 and PL-46

2. c

**Vector Components (Mark to Mark)**

| From: | PLW 50 | | | | |
|---|---|---|---|---|---|
| Grid | | Local | | Global | |
| Easting | 23307.331 m | Latitude | N9°44'42.16318" | Latitude | N9°44'37.72390" |
| Northing | 1080218.190 m | Longitude | E118°39'28.02050" | Longitude | E118°39'33.34598" |
| Elevation | 16.338 m | Height | 16.813 m | Height | 66.853 m |

| To: | PL 92 | | | | |
|---|---|---|---|---|---|
| Grid | | Local | | Global | |
| Easting | 26049.752 m | Latitude | N9°44'04.01581" | Latitude | N9°43'59.58138" |
| Northing | 1079008.192 m | Longitude | E118°40'58.28065" | Longitude | E118°41'03.60701" |
| Elevation | 7.859 m | Height | 8.218 m | Height | 58.344 m |

| Vector | | | | | |
|---|---|---|---|---|---|
| ΔEasting | 2742.421 m | NS Fwd Azimuth | 113°04'19" | ΔX | -2504.878 m |
| ΔNorthing | -1209.998 m | Ellipsoid Dist. | 2990.326 m | ΔY | -1153.405 m |
| ΔElevation | -8.479 m | ΔHeight | -8.595 m | ΔZ | -1156.451 m |

**Standard Errors**

| Vector errors: | | | | | |
|---|---|---|---|---|---|
| σ ΔEasting | 0.001 m | σ NS fwd Azimuth | 0°00'00" | σ ΔX | 0.002 m |
| σ ΔNorthing | 0.001 m | σ Ellipsoid Dist. | 0.001 m | σ ΔY | 0.004 m |
| σ ΔElevation | 0.005 m | σ ΔHeight | 0.005 m | σ ΔZ | 0.001 m |

**Aposteriori Covariance Matrix (Meter²)**

| | X | Y | Z |
|---|---|---|---|
| X | 0.0000048259 | | |
| Y | -0.0000079489 | 0.0000161587 | |
| Z | -0.0000016287 | 0.0000033073 | 0.0000011240 |

Figure A-3.2. PLW-113 and PL-46

3. PLW-318 and PLW-3043

**Vector Components (Mark to Mark)**

| From: | PLW-3043 | | | | |
|---|---|---|---|---|---|
| Grid | | Local | | Global | |
| Easting | 8789.146 m | Latitude | N9°21'42.33800" | Latitude | N9°21'37.98382" |
| Northing | 1037903.794 m | Longitude | E118°31'50.87908" | Longitude | E118°31'56.23900" |
| Elevation | 7.628 m | Height | 8.199 m | Height | 58.756 m |

| To: | PL-318 | | | | |
|---|---|---|---|---|---|
| Grid | | Local | | Global | |
| Easting | 9337.208 m | Latitude | N9°24'58.83705" | Latitude | N9°24'54.46952" |
| Northing | 1043949.629 m | Longitude | E118°32'06.27533" | Longitude | E118°32'11.63035" |
| Elevation | 17.219 m | Height | 17.702 m | Height | 68.152 m |

| Vector | | | | | |
|---|---|---|---|---|---|
| ΔEasting | 548.062 m | NS Fwd Azimuth | 4°26'57" | ΔX | 53.384 m |
| ΔNorthing | 6045.835 m | Ellipsoid Dist. | 6054.978 m | ΔY | -1081.262 m |
| ΔElevation | 9.591 m | ΔHeight | 9.503 m | ΔZ | 5957.428 m |

**Standard Errors**

| Vector errors: | | | | | |
|---|---|---|---|---|---|
| σ ΔEasting | 0.014 m | σ NS fwd Azimuth | 0°00'00" | σ ΔX | 0.016 m |
| σ ΔNorthing | 0.007 m | σ Ellipsoid Dist. | 0.006 m | σ ΔY | 0.013 m |
| σ ΔElevation | 0.015 m | σ ΔHeight | 0.015 m | σ ΔZ | 0.007 m |

**Aposteriori Covariance Matrix (Meter²)**

| | X | Y | Z |
|---|---|---|---|
| X | 0.0002480993 | | |
| Y | -0.0000479049 | 0.0001678494 | |
| Z | 0.0000251507 | 0.0000322887 | 0.0000465177 |

Figure A-3.3. PLW-318 and PLW-3043

# 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 |
|---|---|---|---|
| Data Acquisition Component Leader | Data Component Program Leader | ENRICO C. PARINGIT | UP-TCAGP |
| Data Acquisition Component Leader | Data Component Project Leader -I | ENGR. CZAR JAKIRI S. SARMIENTO<br>ENGR. LOUIE P. BALICANTA | UP-TCAGP |
| Survey Supervisor | Chief Science Research Specialist (CSRS) | ENGR. CHRISTOPHER CRUZ | UP TCAGP |
| LiDAR Operation | Senior Science\ Research Specialist | JASMINE ALVIAR<br>ENGR. GEROME HIPOLITO | UP TCAGP |
| LiDAR Operation | Research Associate | ENGR. LARAH KRISELLE PARAGAS<br>MARY CATHERINE ELIZABETH BALIGUAS | UP TCAGP |
| | Research Associate | ENGR. GRACE SINADJAN<br>JONATHAN ALMALVEZ | UP TCAGP |
| Ground Survey | Research Associate | JERIEL PAUL ALAMBAN, GEOL.<br>ENGR. IRO ROXAS | UP TCAGP |
| Data Download and Transfer | Senior Science Research Specialist | ENGR. LARAH KRISELLE PARAGAS<br>MARY CATHERINE ELIZABETH BALIGUAS | UP TCAGP |
| LiDAR Operation | Airborne Security | SSG. ARIES TORNO<br>SSG PRADYUMNA DAS RAMIREZ<br>AT2C JUNMAR PARANGUE | PILIPPINE AIR FORCE (PAF) |
| LiDAR Operation | Pilot | CAPT. MARK TANGONAN<br>CAPT. ALBERT PAUL LIM | ASIAN AEROSPACE CORPORATION (AAC) |
| LiDAR Operation | Co-Pilot | CAPT. JUSTINE JOYA<br>CAPT. RANDY LAGCO | AAC |

# Annex 5. Data Transfer Sheet for Aborlan Floodplain

DATA TRANSFER SHEET
7/9/2015(Palawan)

| 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 | |
| 18-Jun | 3065P | 1BLK42Ac169A | pegasus | 1.09 | na | 7.83 | 187 | 37.7 | 288 | 20.6 | 60.1 | 3.9 | 1kb | na | 96/15 | na | Z:\DAC\RAW DATA |
| 28-Jun | 3105P | 1BLK42QR179A | pegasus | 1.45 | na | 9.25 | 213 | 36.9 | 40 | 20.4 | 59.3 | 9.17 | 1KB | na | 108 | na | Z:\DAC\RAW DATA |
| 29-Jun | 3109P | 1BLK42QR180A | pegasus | 988 | na | 6 | 147 | na | na | 18.3 | 16.3 | 6.79 | 1KB | na | 108/117 | 6 | Z:\DAC\RAW DATA |

Received from

Name

Position

Signature

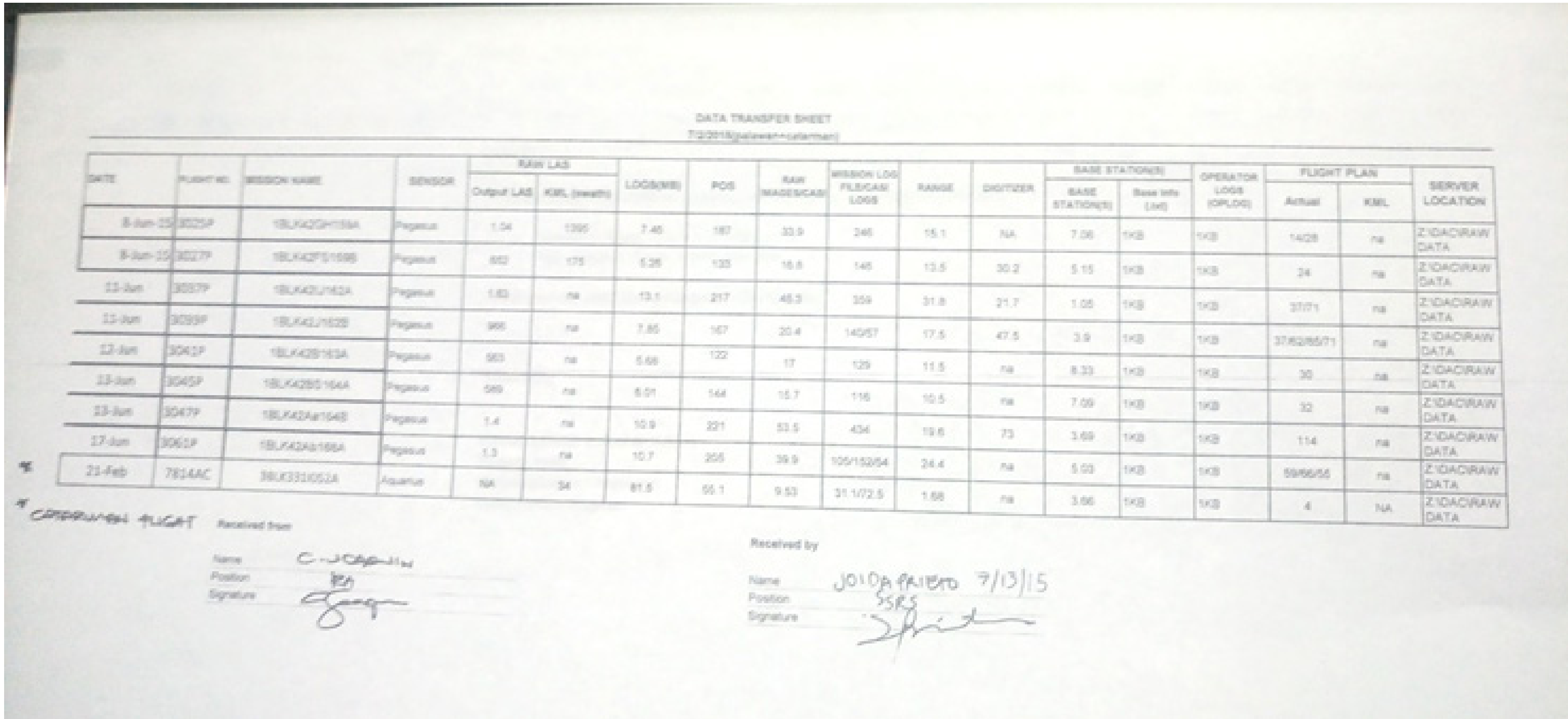
Received by

Name

Position

Signature

Figure A-5.1. Transfer Sheet for Aborlan Floodplain (A)



DATA TRANSFER SHEET
7/2/2015(palawan+calamian)

| 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 | |
| 8-Jun-15 | 3025P | 1BLK42GH159A | Pegasus | 1.04 | 1390 | 7.46 | 187 | 33.9 | 246 | 15.1 | NA | 7.06 | 1KB | 1KB | 14/28 | na | Z:\DAC\RAW DATA |
| 8-Jun-15 | 3027P | 1BLK42FS159B | Pegasus | 652 | 175 | 5.28 | 133 | 16.8 | 146 | 13.5 | 30.2 | 5.15 | 1KB | 1KB | 24 | na | Z:\DAC\RAW DATA |
| 11-Jun | 3037P | 1BLK42IJ162A | Pegasus | 1.83 | na | 13.1 | 217 | 45.3 | 359 | 31.8 | 21.7 | 1.05 | 1KB | 1KB | 37/71 | na | Z:\DAC\RAW DATA |
| 11-Jun | 3039P | 1BLK42J162B | Pegasus | 966 | na | 7.85 | 167 | 20.4 | 140/57 | 17.5 | 47.5 | 3.9 | 1KB | 1KB | 37/62/65/71 | na | Z:\DAC\RAW DATA |
| 12-Jun | 3041P | 1BLK42B163A | Pegasus | 563 | na | 5.68 | 122 | 17 | 129 | 11.5 | na | 8.33 | 1KB | 1KB | 30 | na | Z:\DAC\RAW DATA |
| 13-Jun | 3045P | 1BLK42BS164A | Pegasus | 569 | na | 6.01 | 144 | 15.7 | 116 | 10.5 | na | 7.09 | 1KB | 1KB | 32 | na | Z:\DAC\RAW DATA |
| 13-Jun | 3047P | 1BLK42Aa164B | Pegasus | 1.4 | na | 10.9 | 221 | 53.5 | 434 | 19.6 | 73 | 3.69 | 1KB | 1KB | 114 | na | Z:\DAC\RAW DATA |
| 17-Jun | 3061P | 1BLK42Ab168A | Pegasus | 1.3 | na | 10.7 | 205 | 39.9 | 105/152/54 | 24.4 | na | 5.03 | 1KB | 1KB | 59/66/56 | na | Z:\DAC\RAW DATA |
| * 21-Feb | 7814AC | 3BLK331I052A | Aquarius | NA | 34 | 81.5 | 55.1 | 9.53 | 31.1/72.5 | 1.68 | na | 3.66 | 1KB | 1KB | 4 | NA | Z:\DAC\RAW DATA |

* CALAMIAN FLIGHT

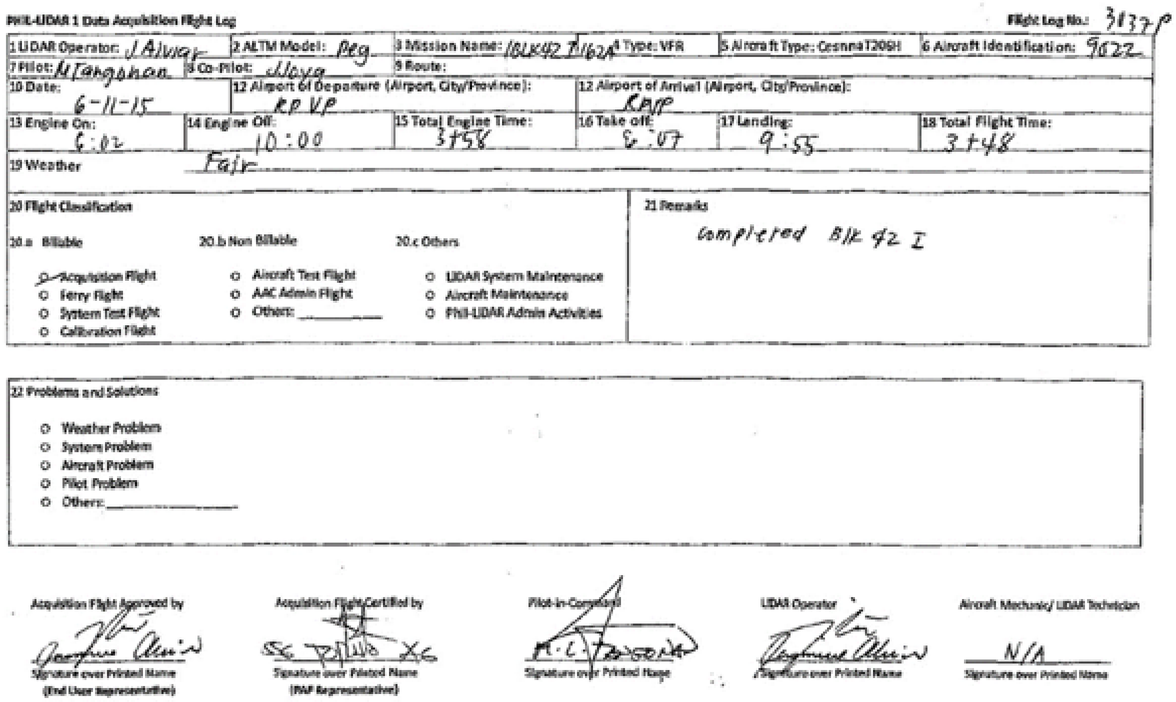
Received from
Name: C. JOAQUIN
Position: RA
Signature:

Received by
Name: JOIDA PRIETO 7/13/15
Position: SSRS
Signature:

Figure A-5.2. Transfer Sheet for Aborlan Floodplain (B)

# Annex 6. Flight logs for the flight missions

1. Flight Log for 3037P Mission


PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 3137P

| | | | | | |
|---|---|---|---|---|---|
| 1 LIDAR Operator: J Alviar | 2 ALTM Model: Peg | 3 Mission Name: 1BLK42I162A | 4 Type: VFR | 5 Aircraft Type: CesnnaT206H | 6 Aircraft Identification: 9022 |
| 7 Pilot: M Tangonan | 8 Co-Pilot: J Loyo | 9 Route: | | | |
| 10 Date: 6-11-15 | 12 Airport of Departure (Airport, City/Province): RPVP | | 12 Airport of Arrival (Airport, City/Province): RPVP | | |
| 13 Engine On: 6:02 | 14 Engine Off: 10:00 | 15 Total Engine Time: 3+58 | 16 Take off: 6:07 | 17 Landing: 9:55 | 18 Total Flight Time: 3+48 |
| 19 Weather: Fair | | | | | |

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

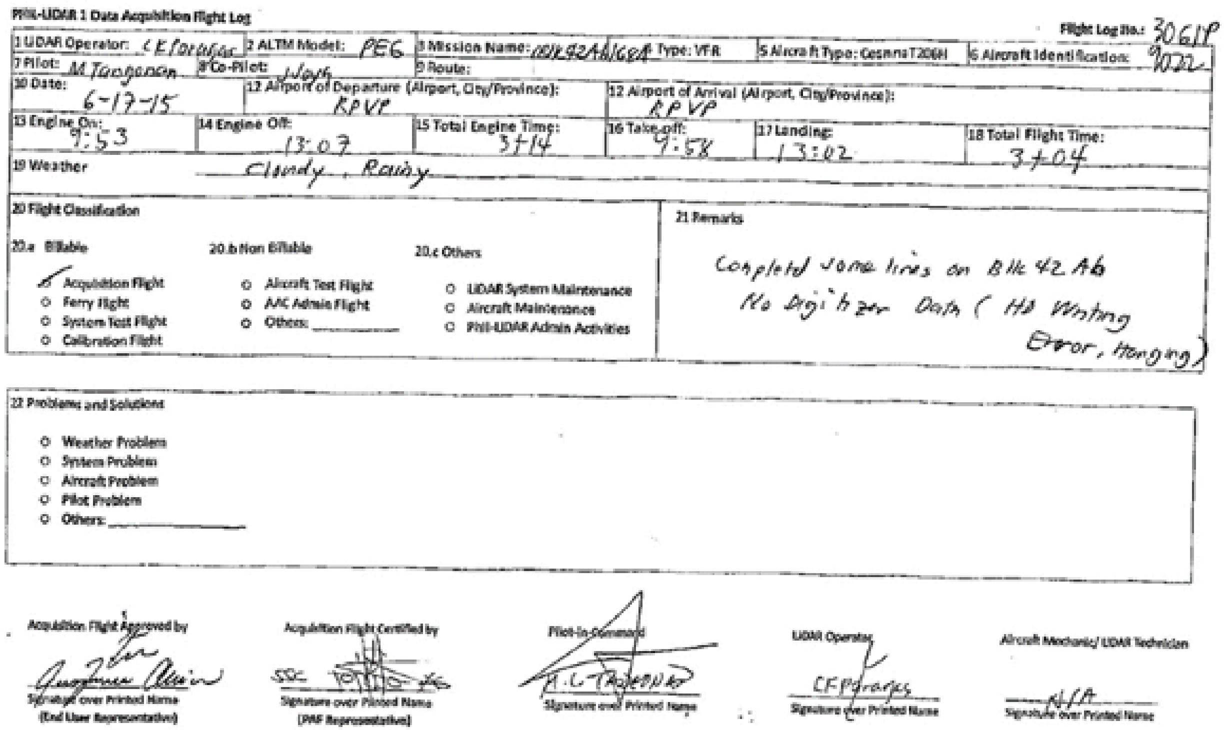
Completed Blk 42 I

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/ LIDAR Technician |
|---|---|---|---|---|
| Signature over Printed Name (End User Representative) | Signature over Printed Name (PAF Representative) | M. L. Tangonan Signature over Printed Name | Signature over Printed Name | N/A Signature over Printed Name |

Figure A-6.1. Flight Log for Mission 3037P

2. Flight log for 3061P Mission


PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 3061P

| | | | | | |
|---|---|---|---|---|---|
| 1 LiDAR Operator: C.F. Paragas | 2 ALTM Model: PEG | 3 Mission Name: 1BLK42A168A | 4 Type: VFR | 5 Aircraft Type: Cessna T206H | 6 Aircraft Identification: 9022 |
| 7 Pilot: M. Tangonan | 8 Co-Pilot: | 9 Route: | | | |
| 10 Date: 6-17-15 | 12 Airport of Departure (Airport, City/Province): RPVP | | 12 Airport of Arrival (Airport, City/Province): RPVP | | |
| 13 Engine On: 9:53 | 14 Engine Off: 13:07 | 15 Total Engine Time: 3+14 | 16 Take off: 9:58 | 17 Landing: 13:02 | 18 Total Flight Time: 3+04 |
| 19 Weather: Cloudy, Rainy | | | | | |

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

Completed some lines on Blk 42 Ab. No Digitizer Data (HD Writing Error, Hanging)

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

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

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

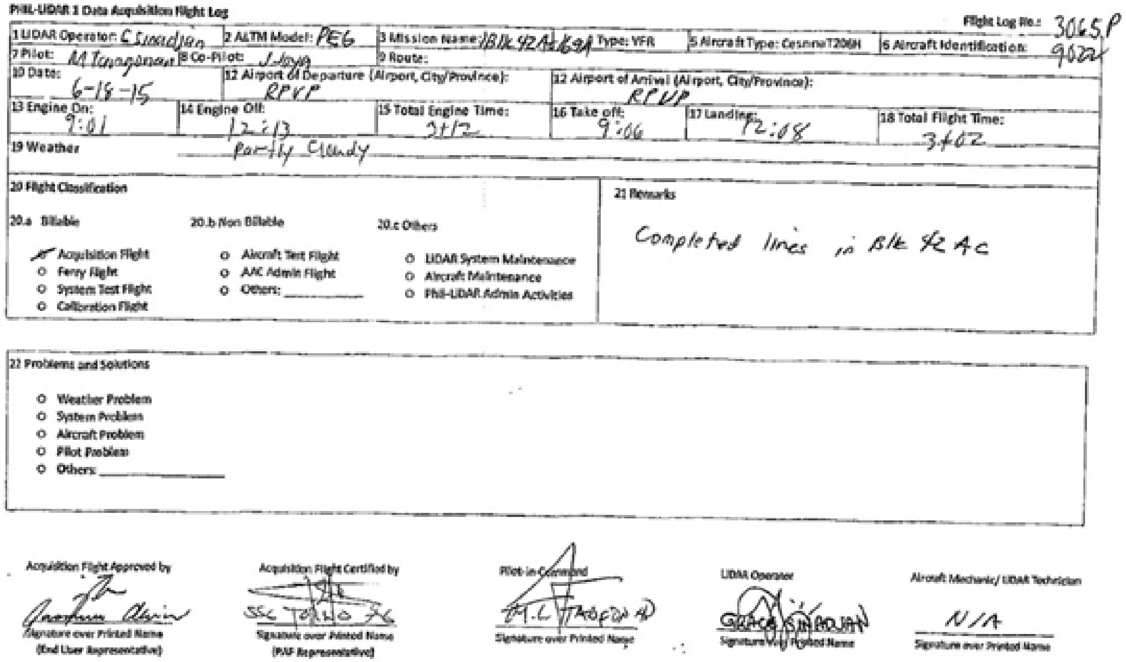
Pilot-in-Command — A.C. Tabenas — Signature over Printed Name

LiDAR Operator — C.F. Paragas — Signature over Printed Name

Aircraft Mechanic/ LiDAR Technician — N/A — Signature over Printed Name

Figure A-6.2. Flight log for Mission 3061P

3. Flight log for 3065P Mission


PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 3065P

| | | | | | |
|---|---|---|---|---|---|
| 1 LIDAR Operator: C Sinadjan | 2 ALTM Model: PEG | 3 Mission Name: 1BLK42A&63A | 4 Type: VFR | 5 Aircraft Type: CesnnaT206H | 6 Aircraft Identification: 9022 |
| 7 Pilot: M Tangonan | 8 Co-Pilot: J Joya | 9 Route: | | | |
| 10 Date: 6-18-15 | 12 Airport of Departure (Airport, City/Province): RPVP | | 12 Airport of Arrival (Airport, City/Province): RPVP | | |
| 13 Engine On: 9:01 | 14 Engine Off: 12:13 | 15 Total Engine Time: 3+12 | 16 Take off: 9:06 | 17 Landing: 12:08 | 18 Total Flight Time: 3+02 |
| 19 Weather | Partly Cloudy | | | | |

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

Completed lines in Blk 42Ac

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

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

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

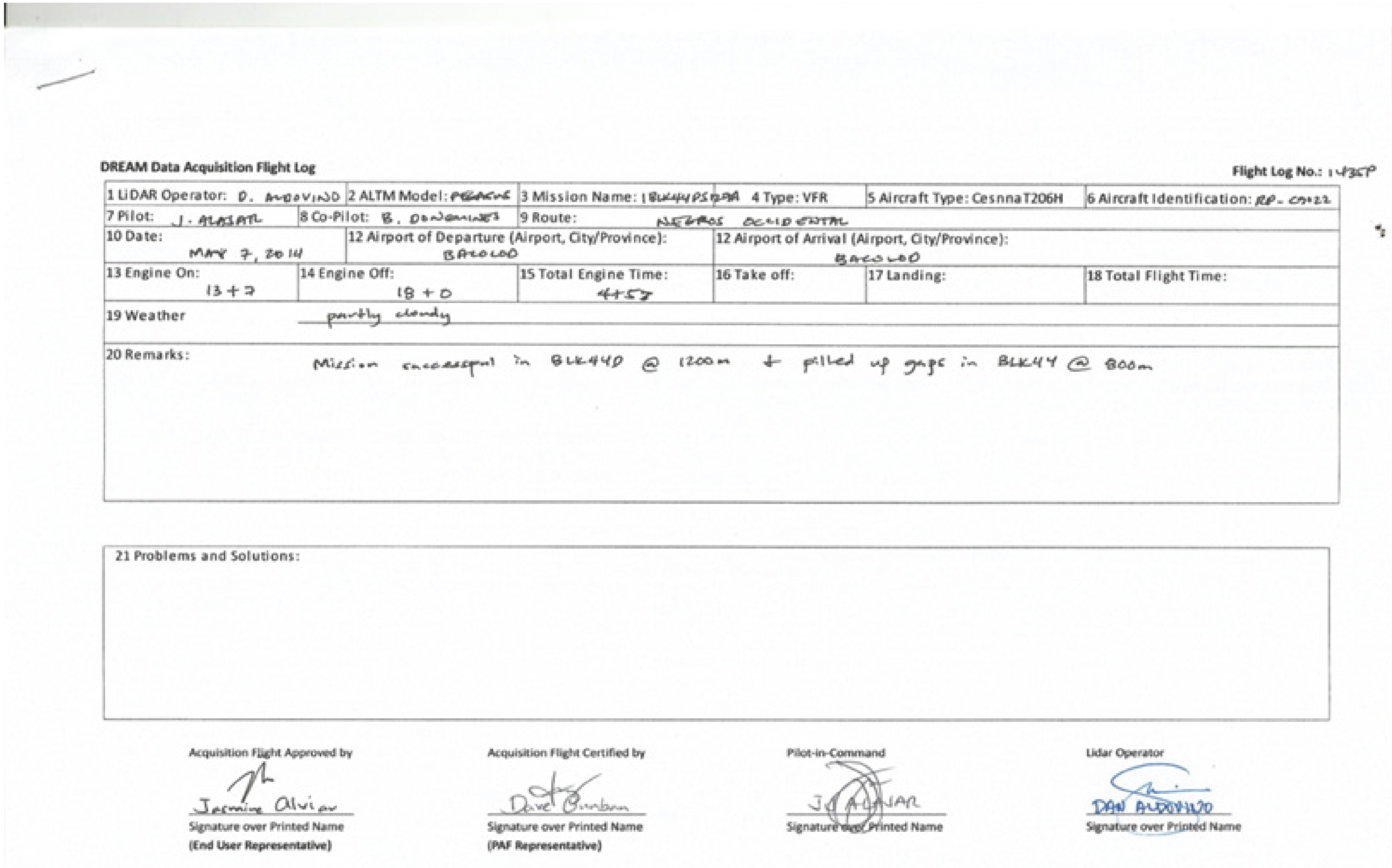
Pilot-in-Command — M.L Tangonan — Signature over Printed Name

LIDAR Operator — Grace Sinadjan — Signature over Printed Name

Aircraft Mechanic/ LIDAR Technician — N/A — Signature over Printed Name

Figure A-6.3. Flight log for Mission 3065P

4. Flight log for 3537G Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 1435P

| | | | | | |
|---|---|---|---|---|---|
| 1 LiDAR Operator: D. ALDOVINO | 2 ALTM Model: PEGASUS | 3 Mission Name: 1BLK44PS128A | 4 Type: VFR | 5 Aircraft Type: CesnnaT206H | 6 Aircraft Identification: RP-C9022 |
| 7 Pilot: J. ALAJAR | 8 Co-Pilot: B. DONGUINES | 9 Route: NEGROS OCCIDENTAL | | | |
| 10 Date: MAY 7, 2014 | 12 Airport of Departure (Airport, City/Province): BACOLOD | | 12 Airport of Arrival (Airport, City/Province): BACOLOD | | |
| 13 Engine On: 13+7 | 14 Engine Off: 18+0 | 15 Total Engine Time: 4+53 | 16 Take off: | 17 Landing: | 18 Total Flight Time: |
| 19 Weather | partly cloudy | | | | |
| 20 Remarks: | Mission successful in BLK44D @ 1200m + filled up gaps in BLK44 @ 800m | | | | |

21 Problems and Solutions:

| Acquisition Flight Approved by | Acquisition Flight Certified by | Pilot-in-Command | Lidar Operator |
|---|---|---|---|
| Jasmine Alviar | Dave Bunban | J. ALAJAR | DAN ALDOVINO |
| Signature over Printed Name (End User Representative) | Signature over Printed Name (PAF Representative) | Signature over Printed Name | Signature over Printed Name |

Figure A-6.4. Flight Log for Mission 7091G

5. Flight log for 3553G Mission

Flight Log No.: 3573

**Data Acquisition Flight Log**

1 LIDAR Operator: J. Almalvez
2 ALTM Model: Gem
3 Mission Name: 2BLK42H/333A2A
4 Type: VFR
5 Aircraft Type: Cesnna T206H
6 Aircraft Identification: 9022
7 Pilot: A. Lim
8 Co-Pilot: F. Lago
9 Route: PPS - PPS
10 Date: Nov 30, 2015
12 Airport of Departure (Airport, City/Province): PPS
12 Airport of Arrival (Airport, City/Province): PPS
13 Engine On: 0451H
14 Engine Off: 1020H
15 Total Engine Time: 3+29
16 Take off: 0456H
17 Landing: 1015H
18 Total Flight Time: 00+10
19 Weather: Cloudy

20 Flight Classification

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

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

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

21 Remarks

Surveyed 4 lines of BLK42K & 8 lines of BLK42A & covered voids

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 |
|---|---|---|---|---|
| S. Hizon, Jr | T Ramirez PAF | A. Lim | J. Almalvez | N/A |
| Signature over Printed Name (End User Representative) | Signature over Printed Name (PAF Representative) | Signature over Printed Name | Signature over Printed Name | Signature over Printed Name |

Figure A-6.5. Flight log for Mission 3553G

6. Flight log for 3557G Mission

**Data Acquisition Flight Log**

Flight Log No.: 3557G

| | | | | | |
|---|---|---|---|---|---|
| 1 LiDAR Operator: MCE BALICVAS | 2 ALTM Model: GEM | 3 Mission Name: 2BLK42H s335A | 4 Type: VFR | 5 Aircraft Type: Cesnna T206H | 6 Aircraft Identification: 9022 |
| 7 Pilot: A. LIM | 8 Co-Pilot: K. LACCO | 9 Route: PPS – PPS | | | |
| 10 Date: DEC 01, 2015 | 12 Airport of Departure (Airport, City/Province): PPS | | 12 Airport of Arrival (Airport, City/Province): PPS | | |
| 13 Engine On: 0920 | 14 Engine Off: 1301 | 15 Total Engine Time: 3+41 | 16 Take off: 0925 H | 17 Landing: 1256 H | 18 Total Flight Time: 3+31 |
| 19 Weather: Cloudy | | | | | |

20 Flight Classification

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

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

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

21 Remarks

Supplementary flight for data gap over BLK42H ; completed BLK42L . No camera, with digitizer.

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 |
|---|---|---|---|---|
| G. Hipolito | Sgt P Ramirez PAF | A. Lim | MCE BALICVAS | G. Antonio |
| 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-6.6. Flight log for Mission 3557G

# Annex 7. Flight status reports

Aborlan Mission
February 18, 2014 to March 14, 2014

Table A-7.1. Flight Status Report

| FLIGHT STATUS REPORT<br>ABORLAN<br>(May to June 2015 and December 2015) | | | | | |
|---|---|---|---|---|---|
| **FLIGHT NO** | **AREA** | **MISSION** | **OPERATOR** | **DATE FLOWN** | **REMARKS** |
| 3037P | BLK 42IJ | 1BLK42IJ162A | J. Alviar | June 11 | CHANGED PLAN ORIENTATION DUE TO TERRAIN AND CLOUD COVER |
| 3061P | BLK 42ES, BLK 42Ab | 1BLK42Ab168A | L. Paragas | June 17 | SURVEYED VOIDS IN BLK 42F AND BLK 42AbS, EAST COAST |
| 3065P | BLk 42Ac | 1BLK42Ac169A | G. Sinadjan | June 18 | SURVEYED BLK 42Ac, EAST COAST; PRECIPITATION IN SOME PARTS OF AREA |
| 3537 | BLK42 eH,eJ | 2BLK42HJ330A | MCE Baligu-as | 26-Nov-15 | Cloudy; Multiple POS and range data due to several system restarts by task dead problem (TDP); 2 lines in eJ, no tie line due to tdp, pls use 3553 & 3555's tie line then integrate |
| 3553 | BLK42 eH, eJ | 2BLK42HJ334A | JM Almalvez | 30-Nov-15 | Surveyed 4 lines of BLK42eJ and 8 lines of BLK42eH and covered voids from previous flight. |
| 3557 | BLK42 eH, Ks | 2BLK42HsL335A | MCE Baligu-as | 01-Dec-15 | Supplementary flight for data gap over BLK42eH and completed BLK42Ks. No camera, with digitizer. |

## LAS BOUNDARIES PER MISSION FLIGHT

Flight No. : 3037P
Area: BLK 42IJ
Mission Name: 1BLK42IJ162A
Parameters: PRF 200 SF 30 FOV 50
Area Surveyed: 284.99 sq km.

**LAS**

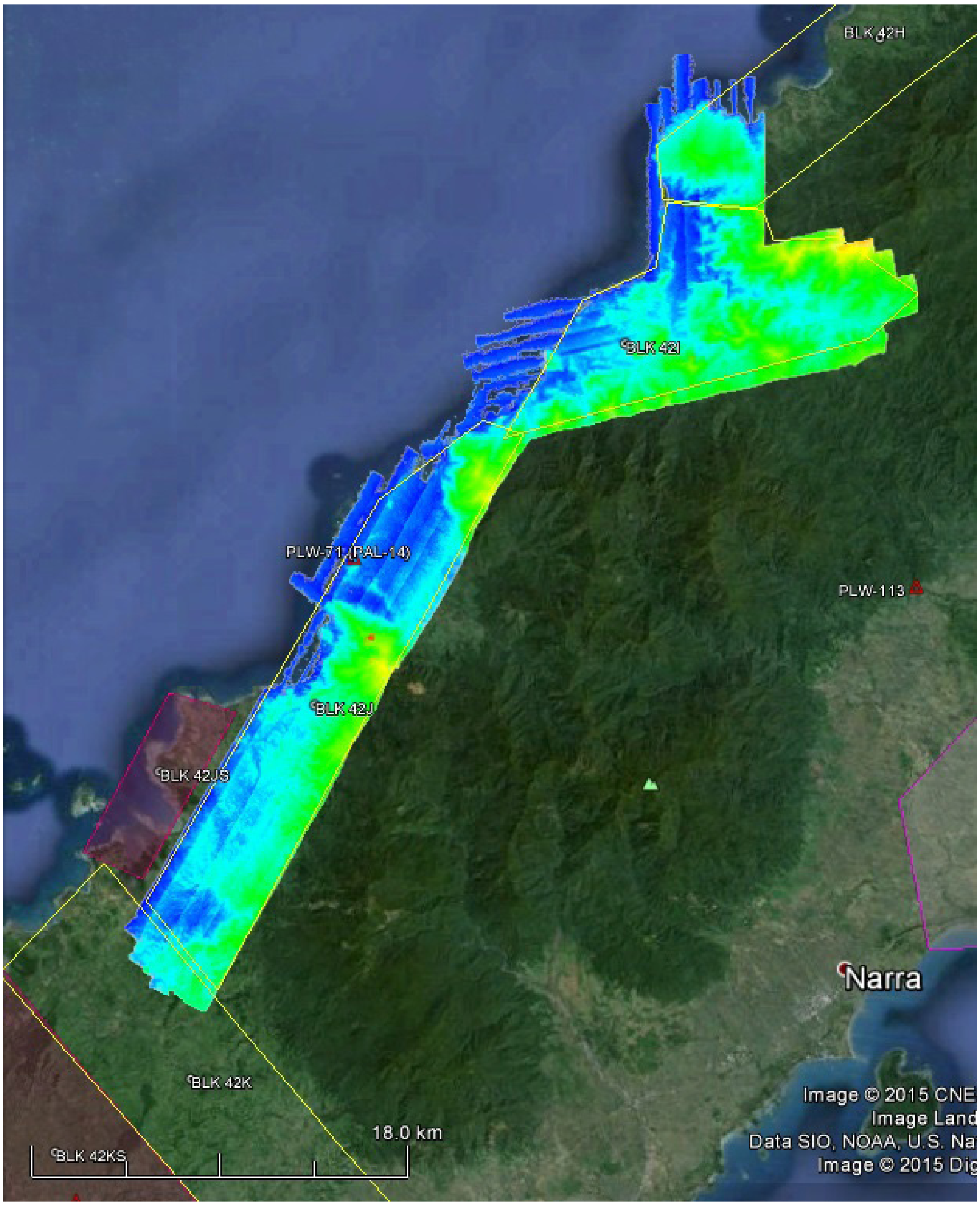



Figure A-7.1. Swath for Flight No.3037P

Flight No. : 3061P
Area: BLK 42 E, BLK 42Ab
Mission Name: 1BLK42Ab168A
Parameters: PRF 200 SF 30 FOV 50
Area Surveyed: 179.65 sq km.

LAS

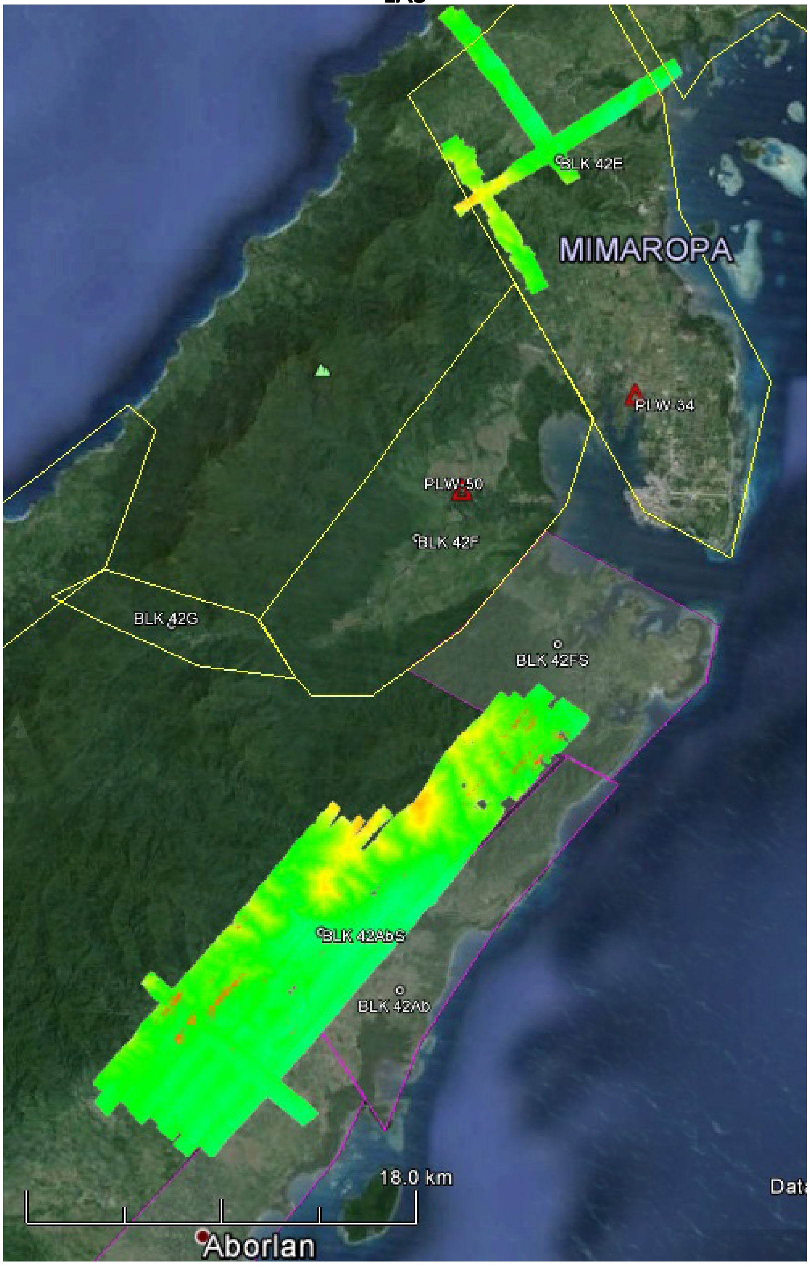



Figure A-7.2. Swath for Flight No. 3061P

| | |
|---|---|
| Flight No. : | 3065P |
| Area: | BLK 42Ac |
| Mission Name: | 1BLK42Ac169A |
| Parameters: | PRF 200 SF 30 FOV 50 |
| Area Surveyed: | 224.25 sq km. |

LAS

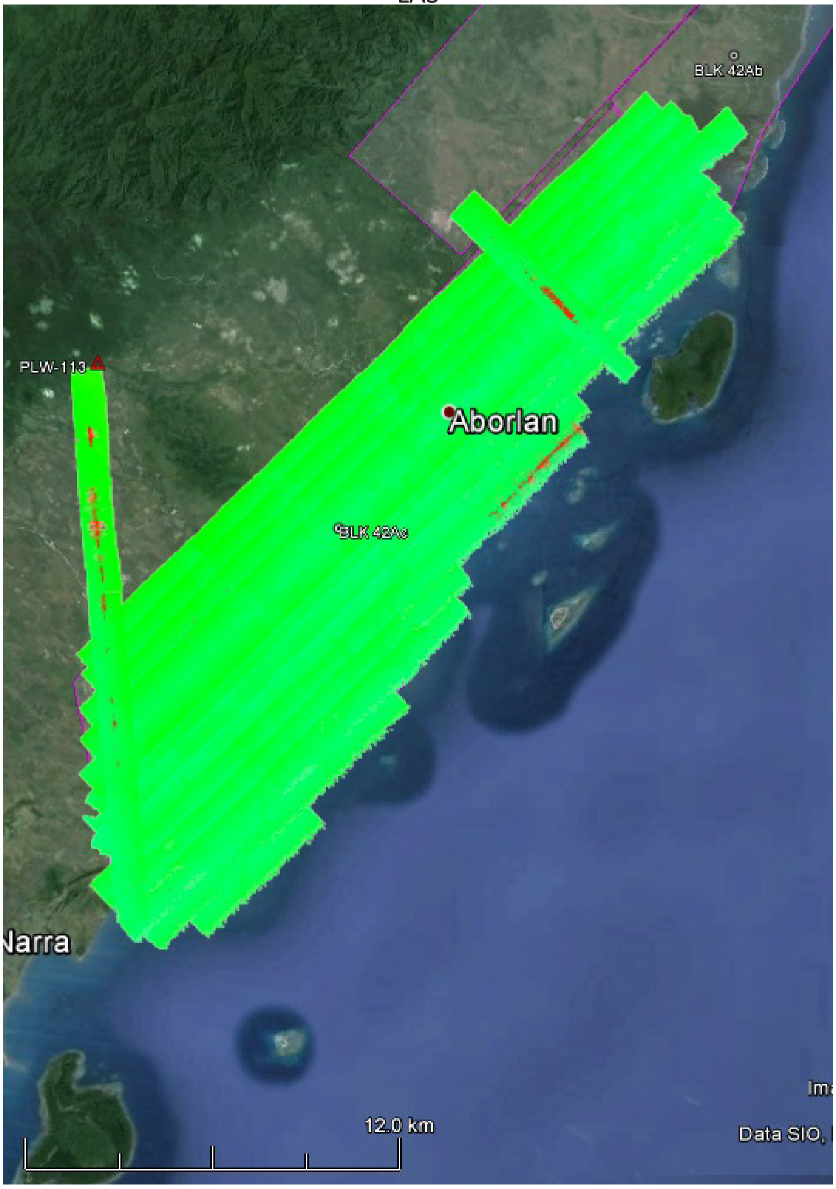



Figure A-7.3. Swath for Flight No. 3065P

Flight No. : 3537
Area: BLK 42 eH,eJ
Mission Name: 2BLK42HJ330A
Total Area Surveyed: 81.054 sq km

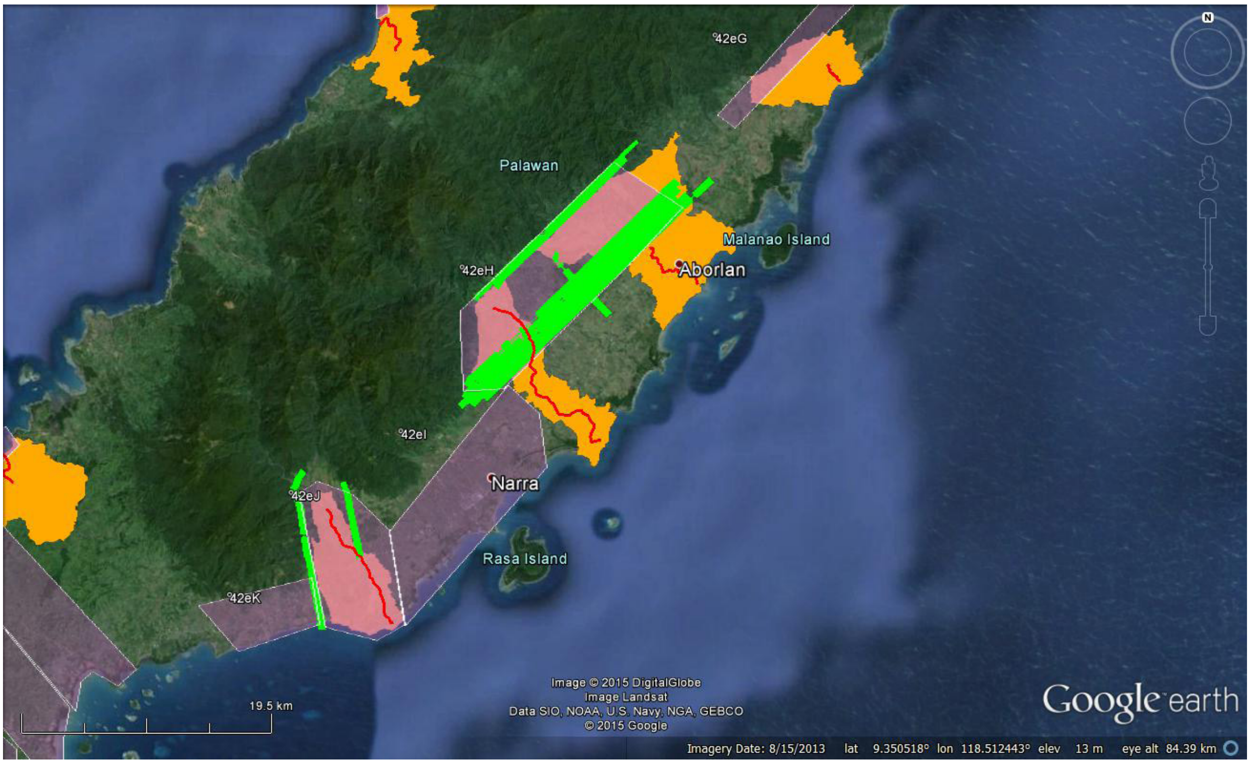



Figure A-7.4. Swath for Flight No. 3537

Flight No. : 3553
Area: BLK 42 eH,eJ
Mission Name: 2BLK42HJ334A
Total Area Surveyed: 107.096 sq km

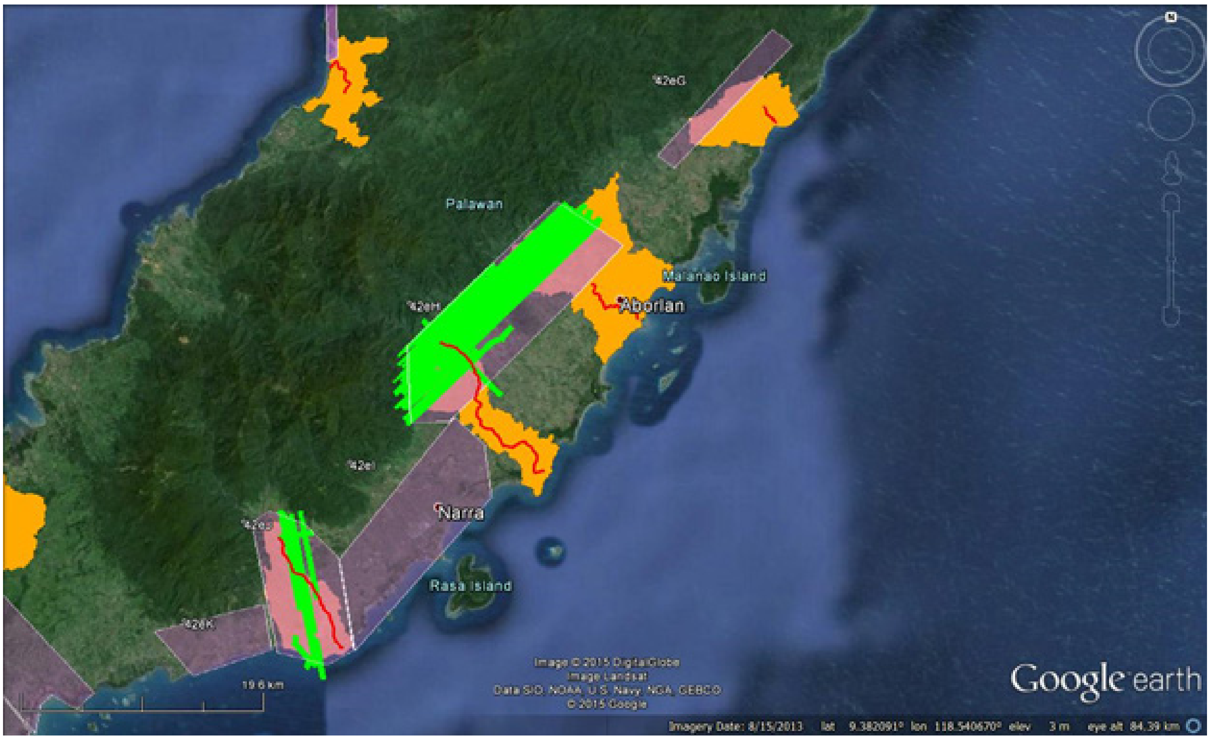



Figure A-7.5. Swath for Flight No. 3553

Flight No. : 3557
Area: BLK 42 eH,Ks
Mission Name: 2BLK45HsL335A
Total Area Surveyed: 129.929 sq km

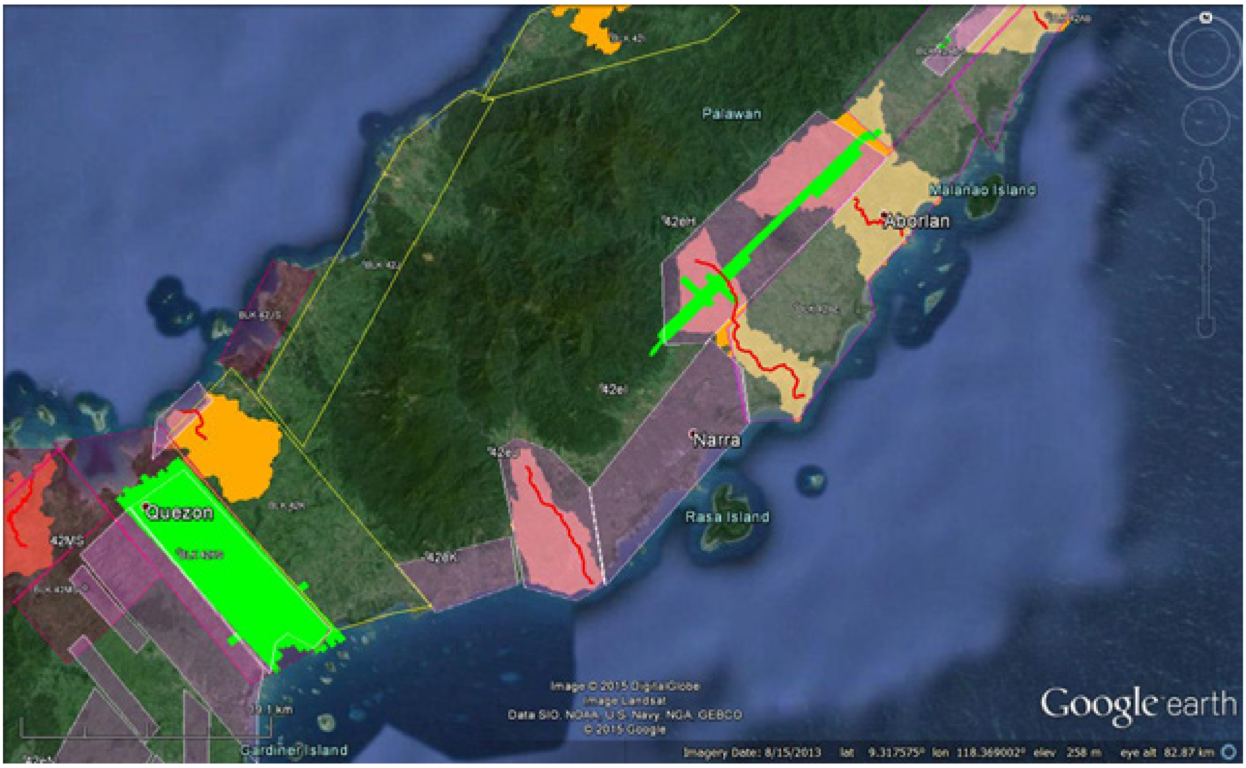



Figure A-7.6. Swath for Flight No. 3557

# Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Blk42Ab

| | |
|---|---|
| Flight Area | West Palawan |
| Mission Name | Blk42Ab |
| Inclusive Flights | 3061P |
| Range data size | 24.40 GB |
| POS | 205 MB |
| Image | 39.90 GB |
| Transfer date | July 13, 2015 |
| | |
| *Solution Status* | |
| Number of Satellites (>6) | No |
| PDOP (<3) | Yes |
| Baseline Length (<30km) | No |
| Processing Mode (<=1) | Yes |
| | |
| *Smoothed Performance Metrics* (in cm) | |
| RMSE for North Position (<4.0 cm) | 3.60 |
| RMSE for East Position (<4.0 cm) | 3.50 |
| RMSE for Down Position (<8.0 cm) | 5.00 |
| | |
| Boresight correction stdev (<0.001deg) | 0.000288 |
| IMU attitude correction stdev (<0.001deg) | 0.0.001931 |
| GPS position stdev (<0.01m) | 0.0024 |
| | |
| Minimum % overlap (>25) | 47.37 |
| Ave point cloud density per sq.m. (>2.0) | 5.32 |
| Elevation difference between strips (<0.20 m) | Yes |
| | |
| Number of 1km x 1km blocks | 191 |
| Maximum Height | 695 m |
| Minimum Height | 53.39 m |
| | |
| *Classification (# of points)* | |
| Ground | 119,527,355 |
| Low vegetation | 102,354,575 |
| Medium vegetation | 220,405,118 |
| High vegetation | 874,045,928 |
| Building | 5,413,679 |
| Orthophoto | Yes |
| Processed by | Engr. Irish Cortez, Engr. Mark Joshua Salvacion, Engr. Mark Sueden Lyle Magtalas |

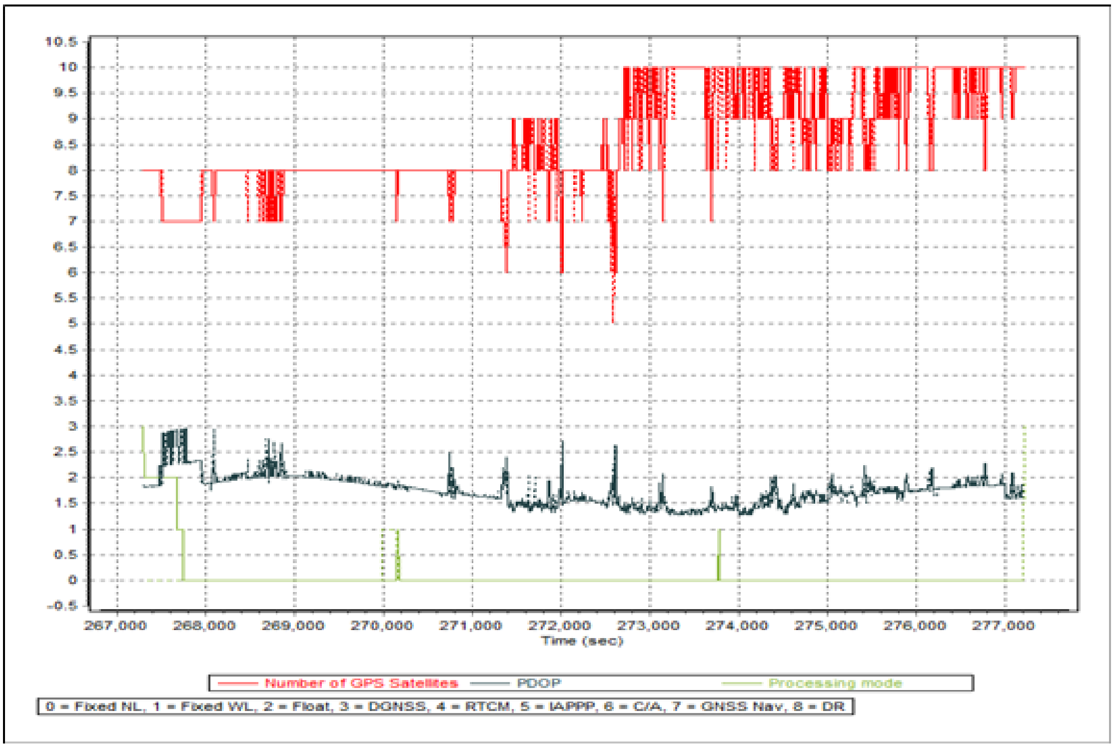



Figure A-8.1 Solution Status

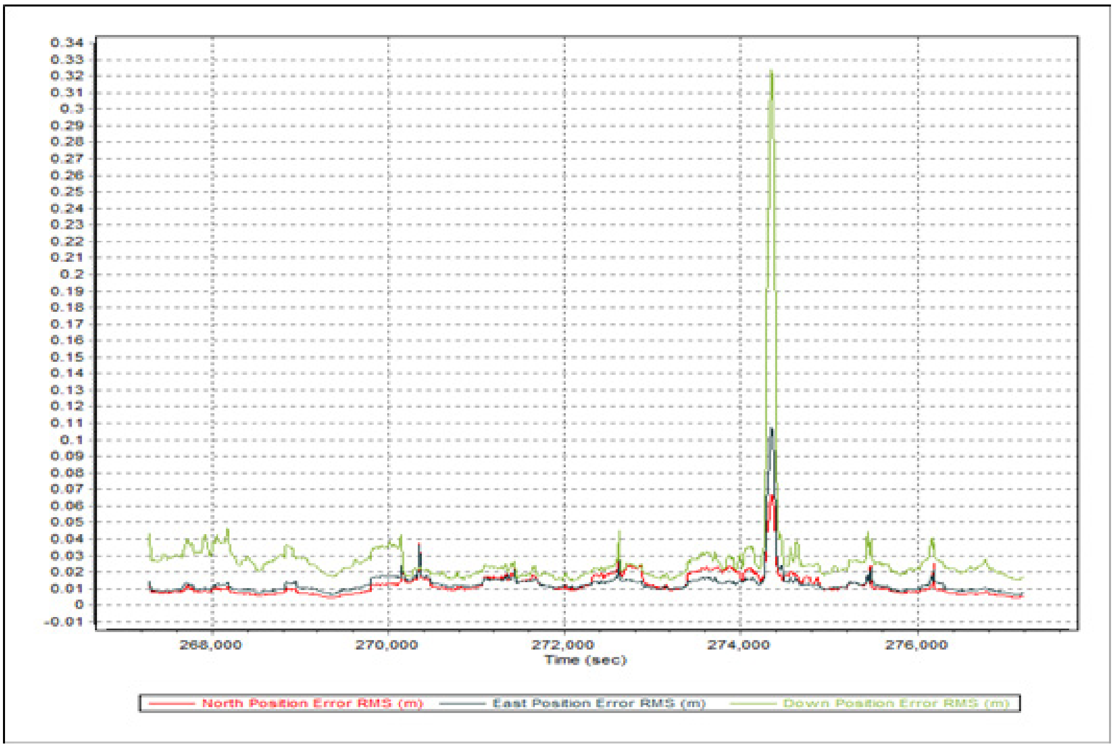



Figure A-8.2 Smoothed Performance Metric Parameters

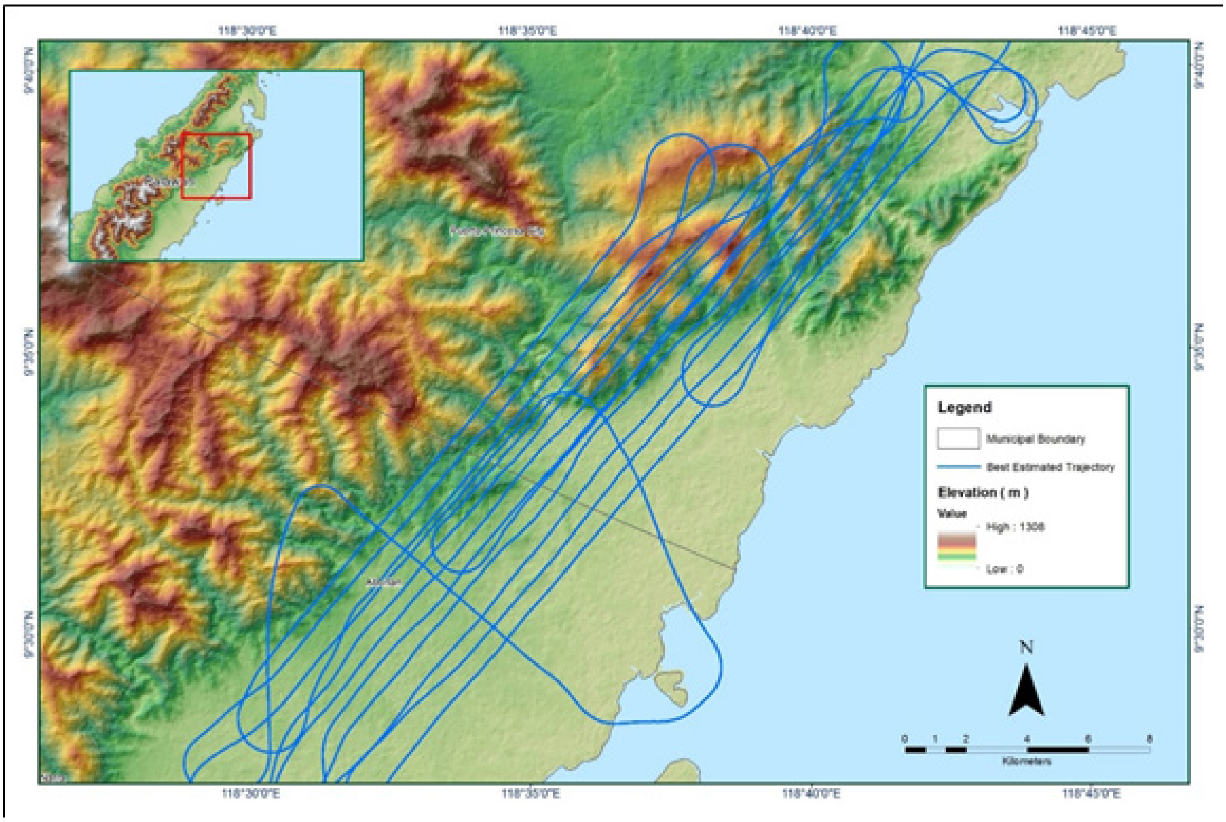



Figure A-8.3 Best Estimated Trajectory

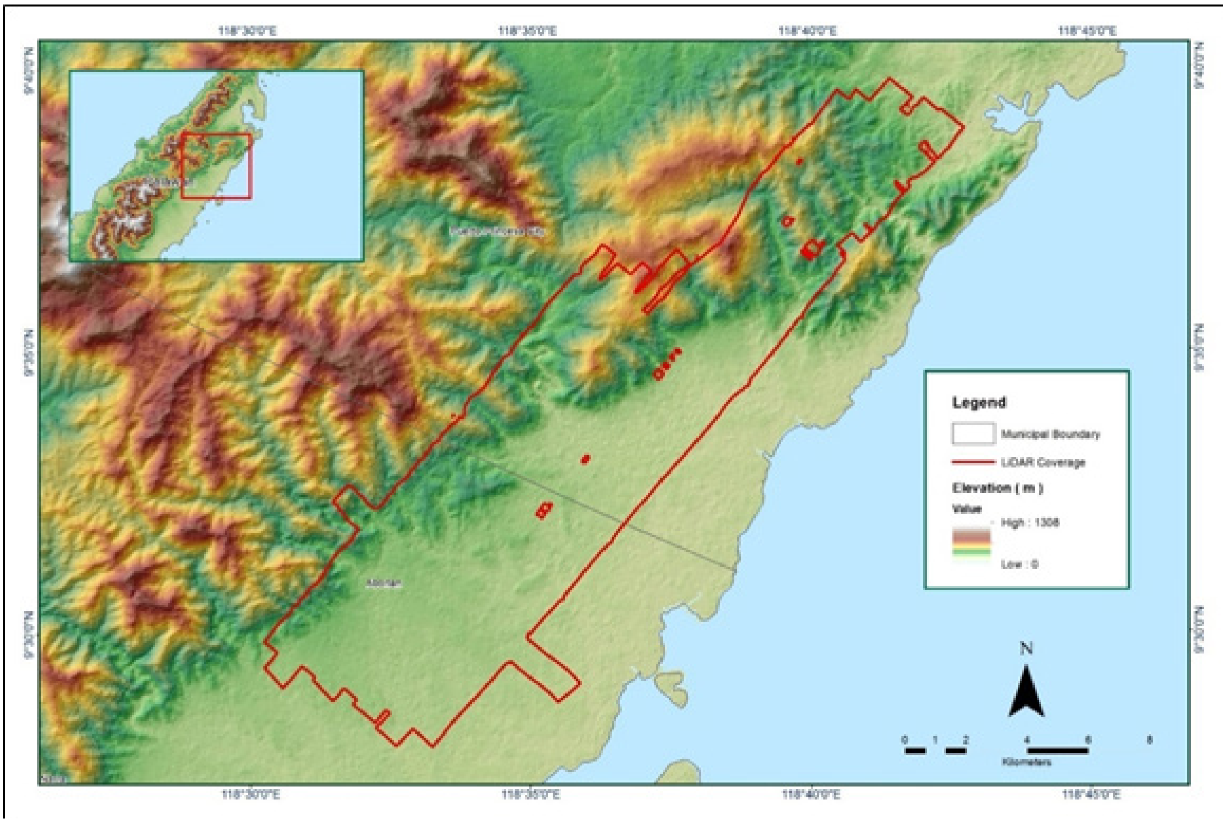



Figure A-8.4 Coverage of LiDAR data

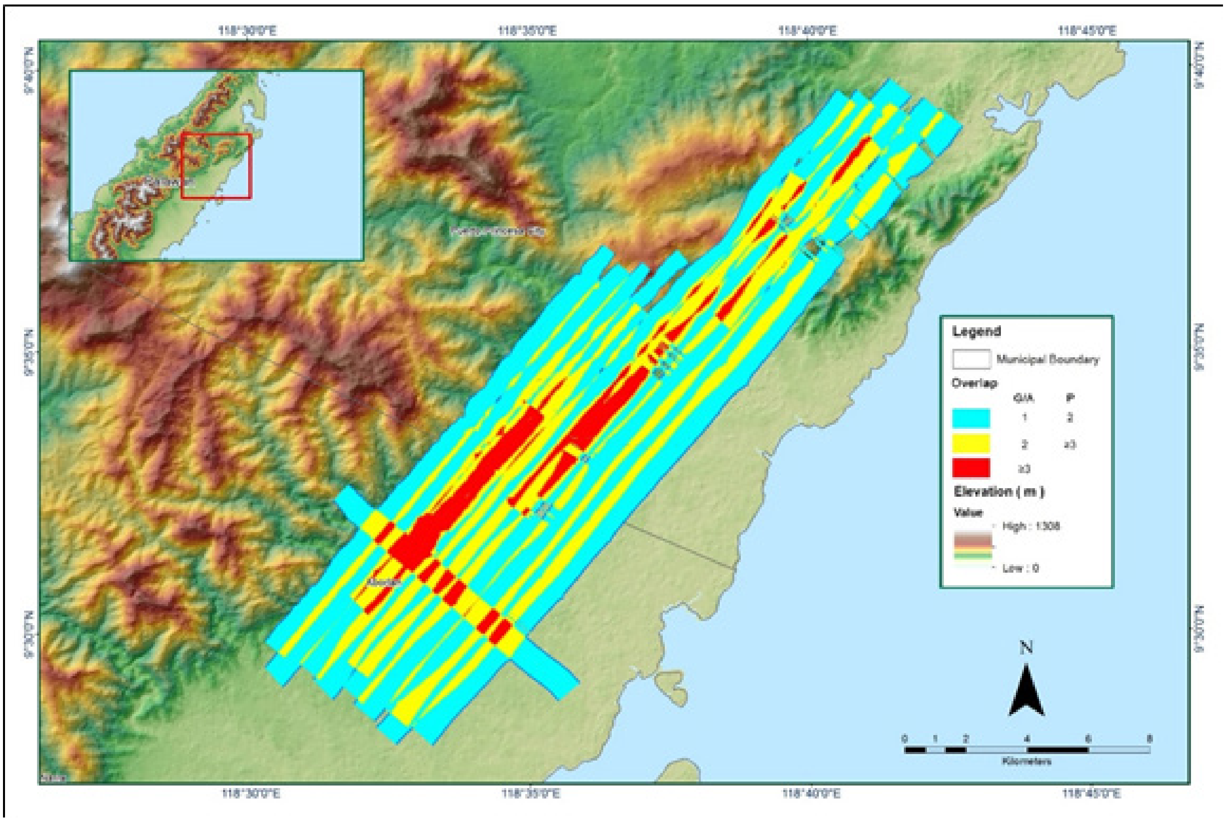



Figure A-8.5 Image of data overlap

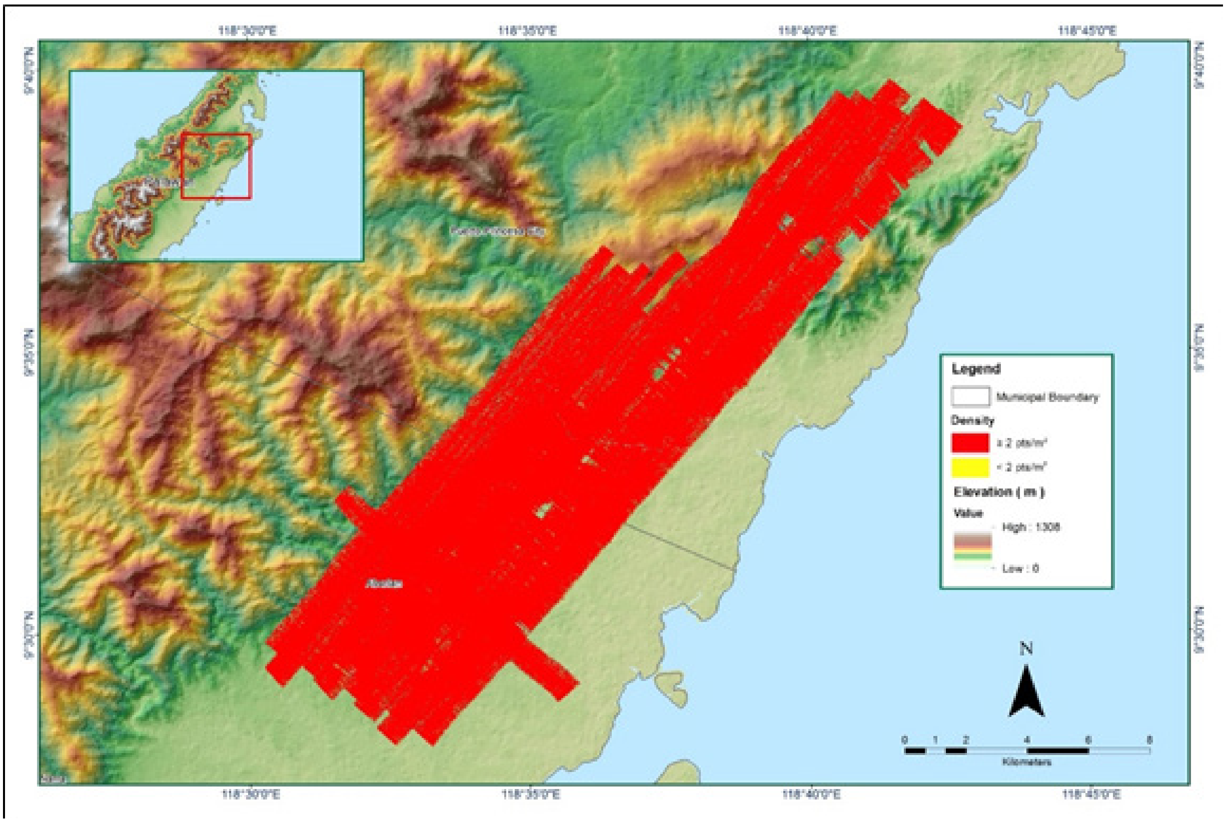



Figure A-8.6 Density map of merged LiDAR data

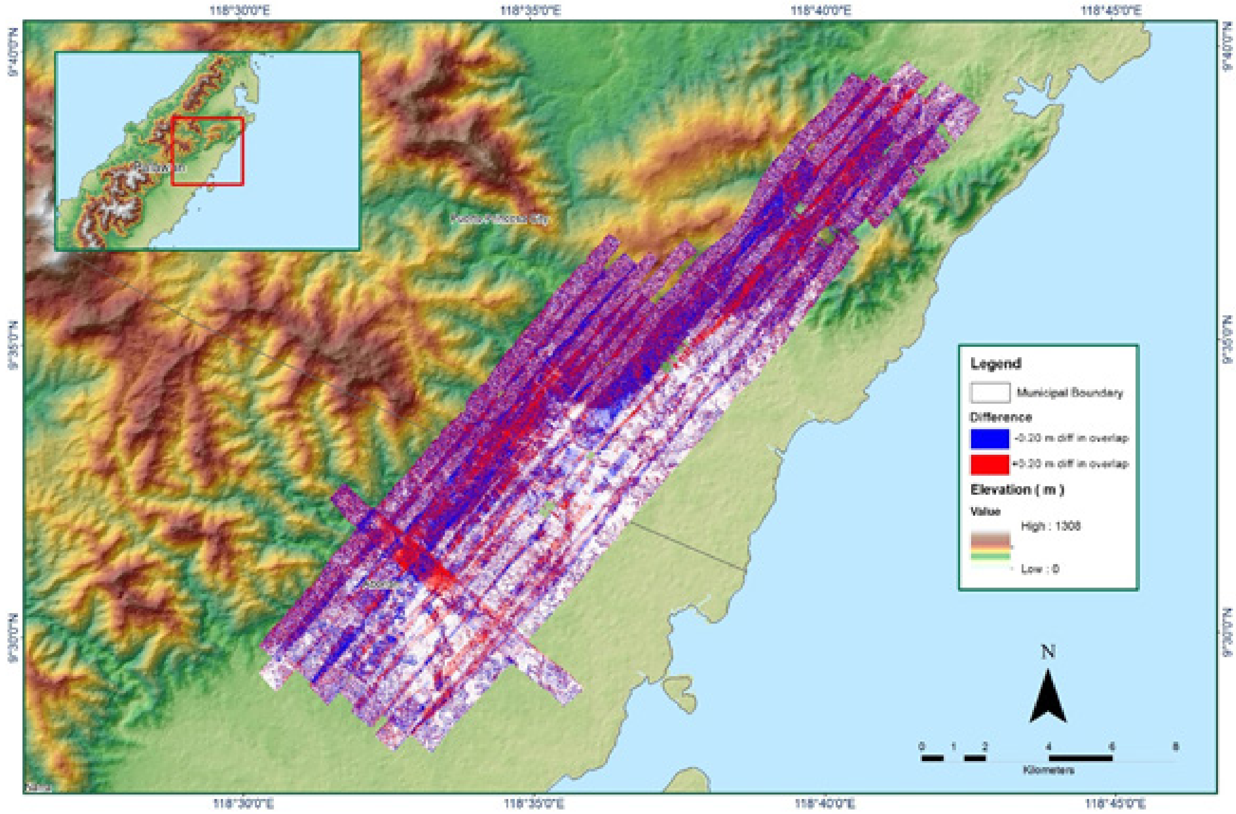



Figure A-8.7 Elevation difference between flight lines

Table A-8.2. Mission Summary Report for Mission Blk4C

| Flight Area | West Palawan |
|---|---|
| Mission Name | Blk42I |
| Inclusive Flights | 3037P |
| Range data size | 31.80 GB |
| POS | 217 MB |
| Image | 45.30 GB |
| Transfer date | July 13, 2015 |
| | |
| Solution Status | |
| Number of Satellites (>6) | Yes |
| PDOP (<3) | No |
| Baseline Length (<30km) | No |
| Processing Mode (<=1) | Yes |
| | |
| Smoothed Performance Metrics (in cm) | |
| RMSE for North Position (<4.0 cm) | 1.25 |
| RMSE for East Position (<4.0 cm) | 2.50 |
| RMSE for Down Position (<8.0 cm) | 4.44 |
| | |
| Boresight correction stdev (<0.001deg) | 0.000192 |
| IMU attitude correction stdev (<0.001deg) | 0.000209 |
| GPS position stdev (<0.01m) | 0.0020 |
| | |
| Minimum % overlap (>25) | 45.91 |
| Ave point cloud density per sq.m. (>2.0) | 3.51 |
| Elevation difference between strips (<0.20 m) | Yes |
| | |
| Number of 1km x 1km blocks | 227 |
| Maximum Height | 739.37 m |
| Minimum Height | 49.39 m |
| | |
| Classification (# of points) | |
| Ground | 74,111,411 |
| Low vegetation | 47,249,546 |
| Medium vegetation | 145,020,119 |
| High vegetation | 854,591,404 |
| Building | 2,268,737 |
| Orthophoto | Yes |
| Processed by | Engr. Regis Guhiting, Engr. Edgardo Gubatanga Jr., Alex John Escobido Engr. Carlyn Ann Ibanez, Engr. Melanie Hingpit |

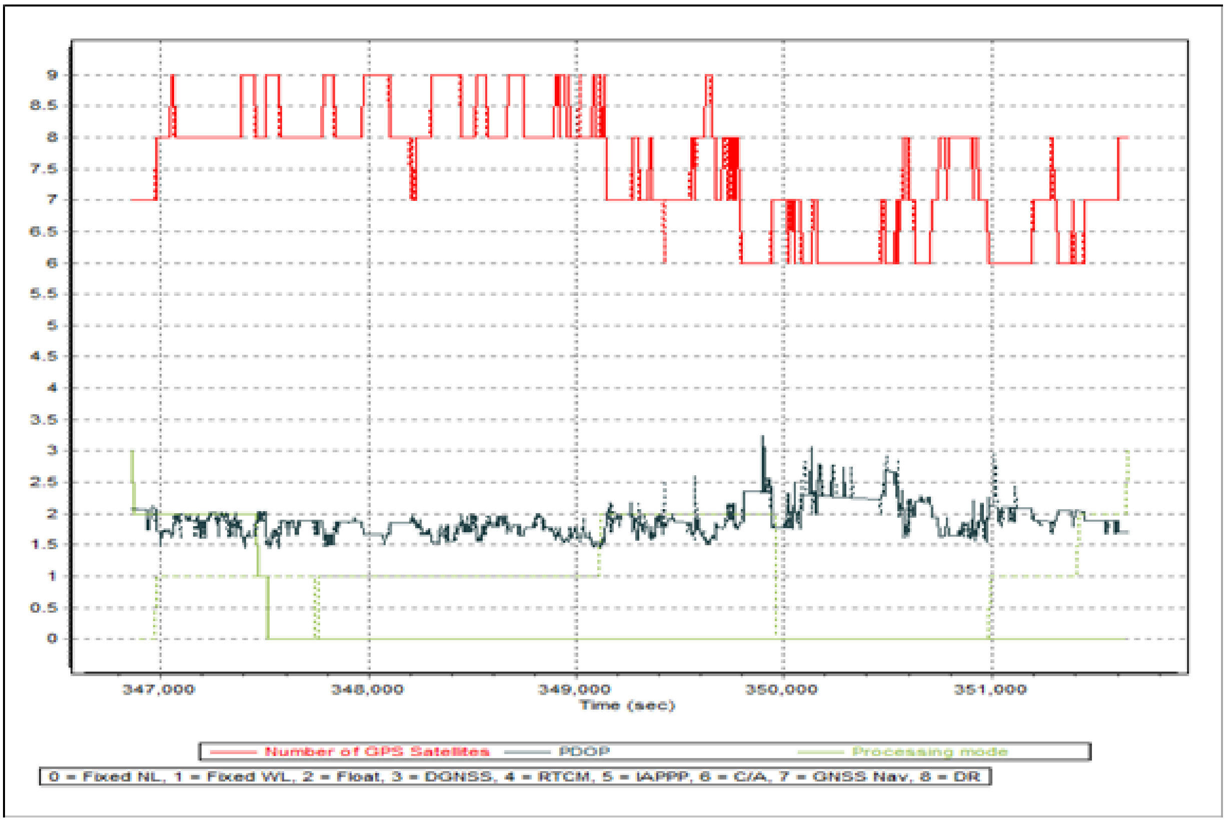



Figure A-8.8 Solution Status

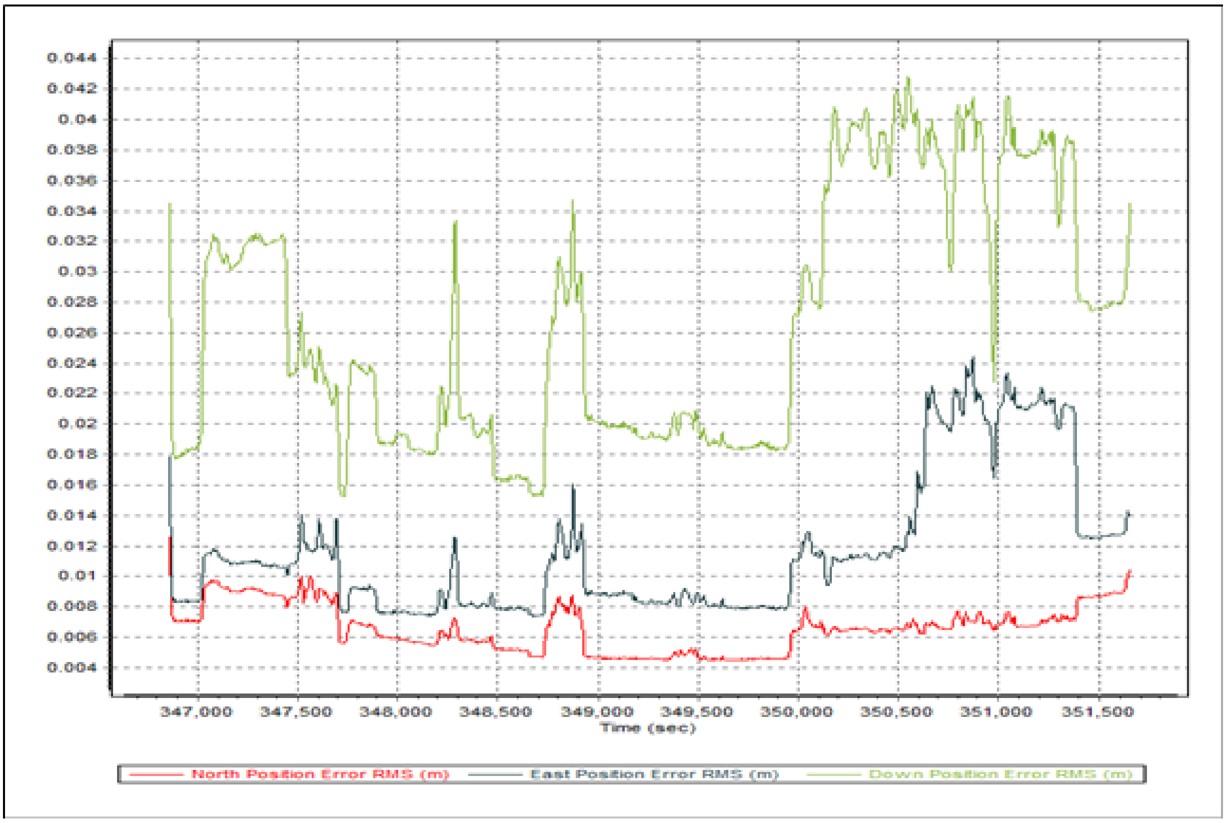



Figure A-8.9 Smoothed Performance Metric Parameters

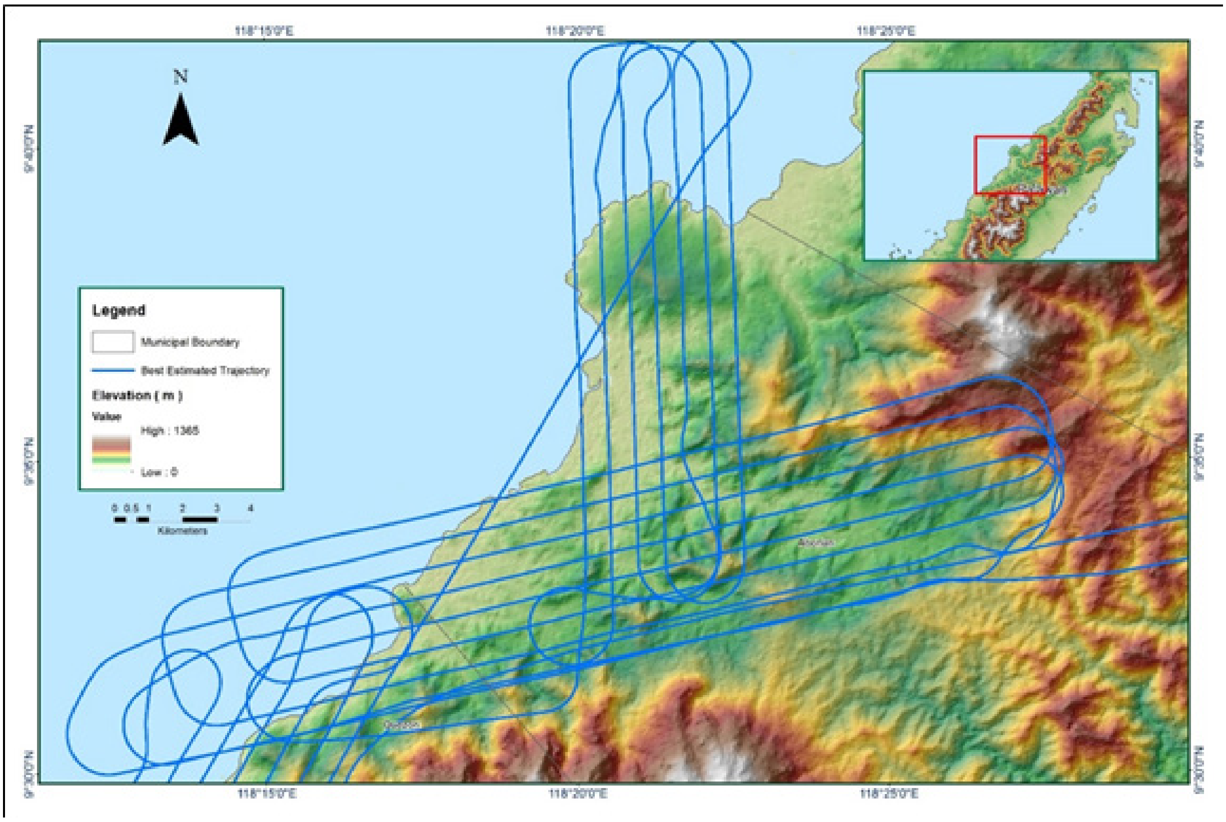



Figure A-8.10 Best Estimated Trajectory

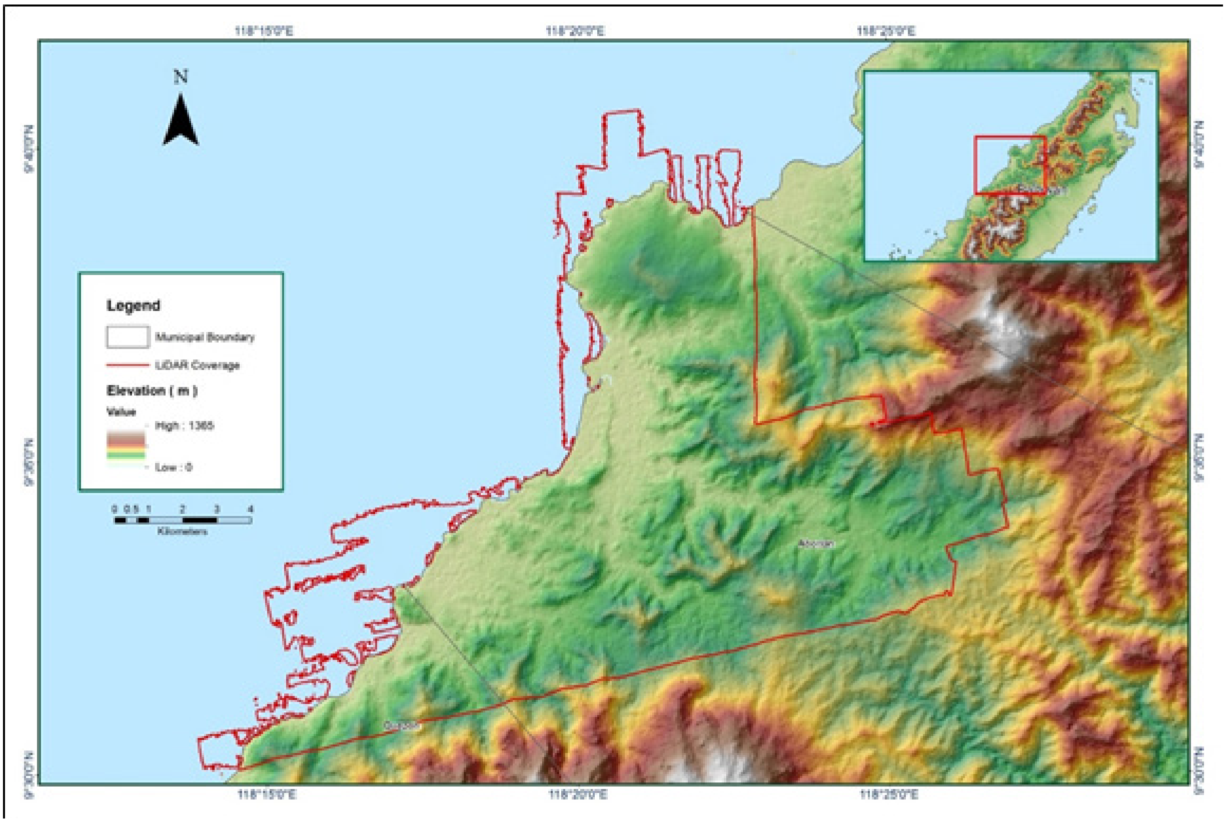



Figure A-8.11 Coverage of LiDAR data

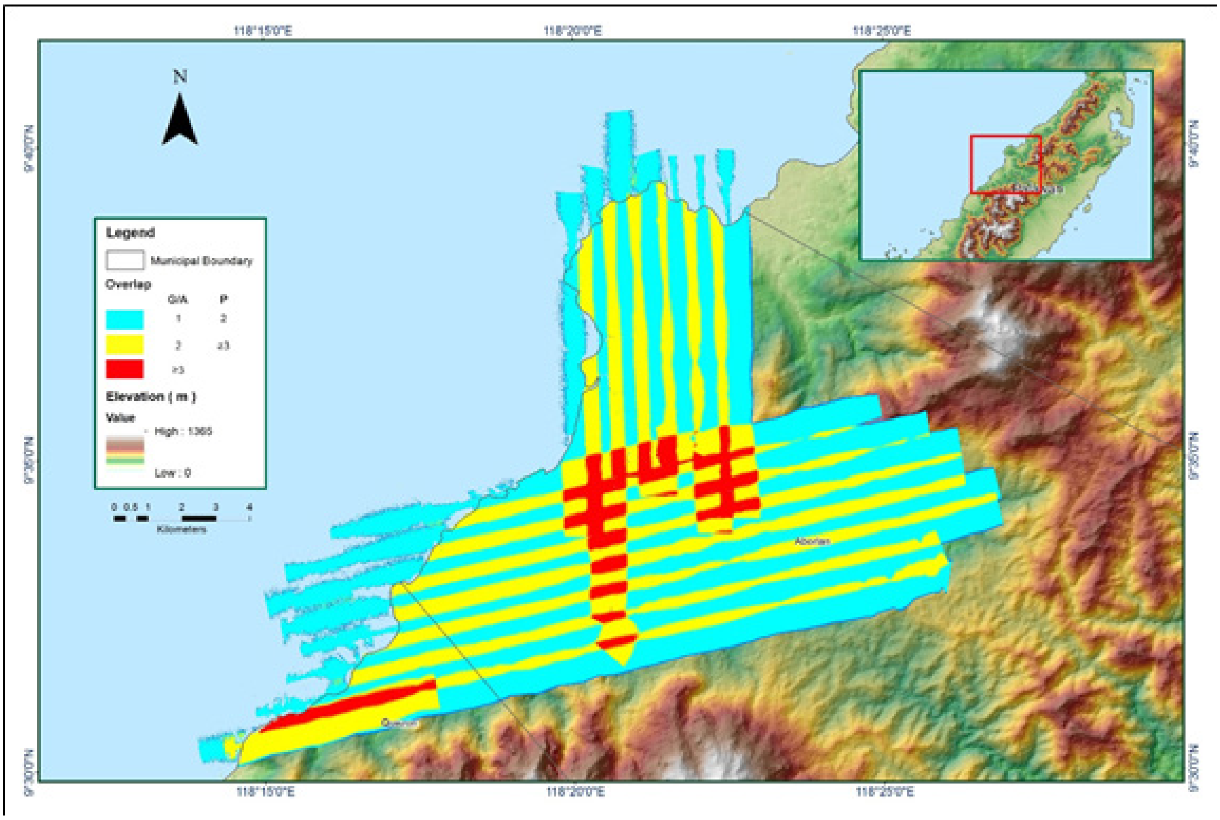



Figure A-8.12 Image of data overlap

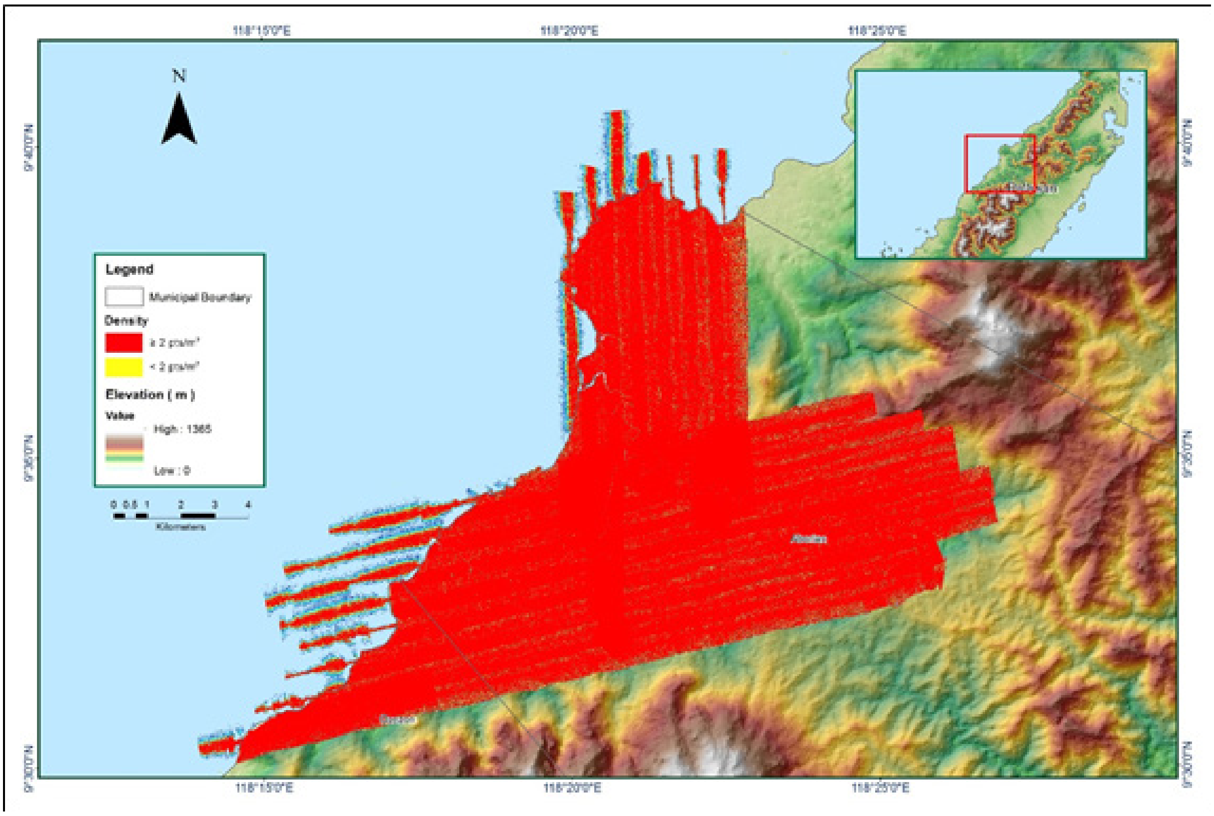



Figure A-8.13 Density map of merged LiDAR data

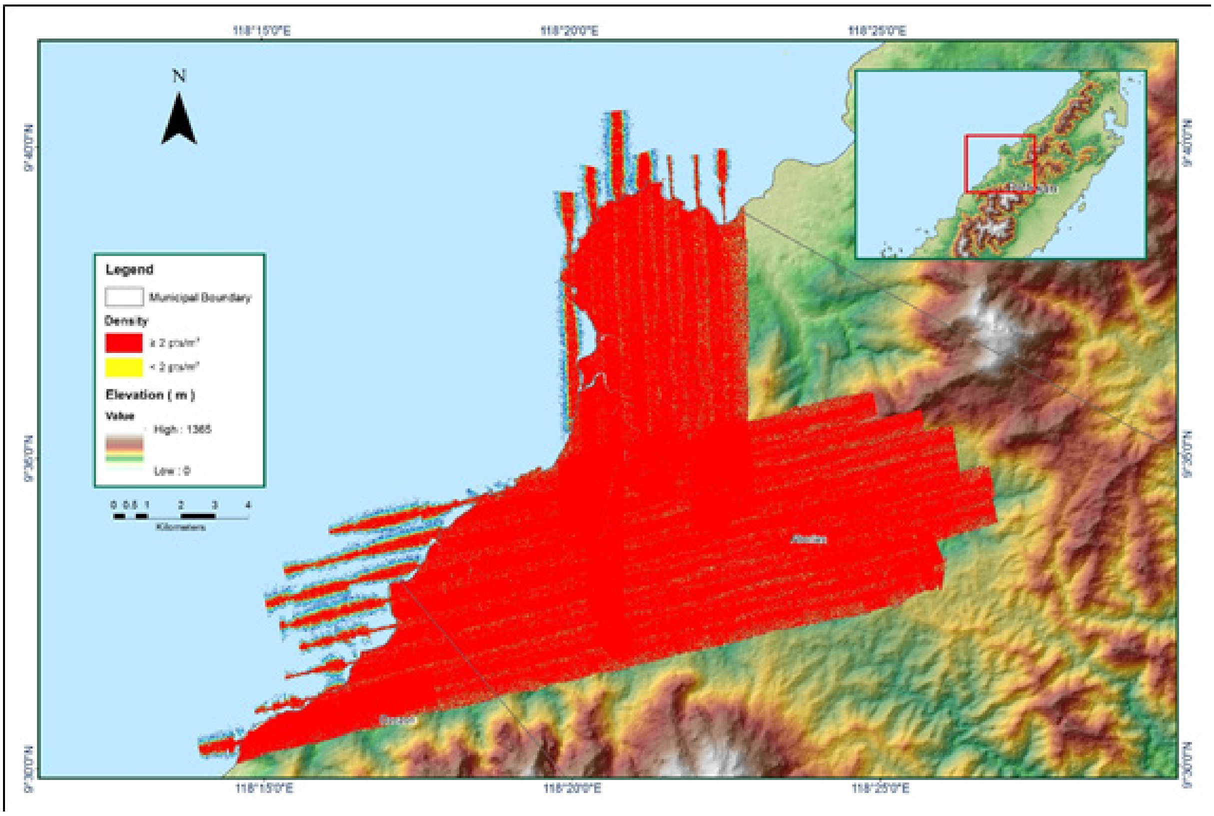



Figure A-8.14 Elevation difference between flight lines

Table A-8.3. Mission Summary Report for Mission Blk4Ac

| Flight Area | West Palawan |
|---|---|
| Mission Name | Blk42Ac |
| Inclusive Flights | 3065P |
| Range data size | 20.60 GB |
| POS | 187 MB |
| Image | 37.70 GB |
| Transfer date | June 18, 2015 |
| | |
| Solution Status | |
| Number of Satellites (>6) | Yes |
| PDOP (<3) | No |
| Baseline Length (<30km) | Yes |
| Processing Mode (<=1) | Yes |
| | |
| Smoothed Performance Metrics (in cm) | |
| RMSE for North Position (<4.0 cm) | 1.90 |
| RMSE for East Position (<4.0 cm) | 2.05 |
| RMSE for Down Position (<8.0 cm) | 4.80 |
| | |
| Boresight correction stdev (<0.001deg) | 0.00005 |
| IMU attitude correction stdev (<0.001deg) | 0.0.000120 |
| GPS position stdev (<0.01m) | 0.0070 |
| | |
| Minimum % overlap (>25) | 39.13 |
| Ave point cloud density per sq.m. (>2.0) | 2.56 |
| Elevation difference between strips (<0.20 m) | Yes |
| | |
| Number of 1km x 1km blocks | 167 |
| Maximum Height | 125.92 m |
| Minimum Height | 52.42 m |
| | |
| Classification (# of points) | |
| Ground | 241,211,903 |
| Low vegetation | 173,662,143 |
| Medium vegetation | 160,403,456 |
| High vegetation | 358,710,743 |
| Building | 6,348,454 |
| | |
| Orthophoto | Yes |
| Processed by | Engr. Kenneth Solidum, Engr. Velina Angela Bemida, Maria Tamsyn Malabanan |

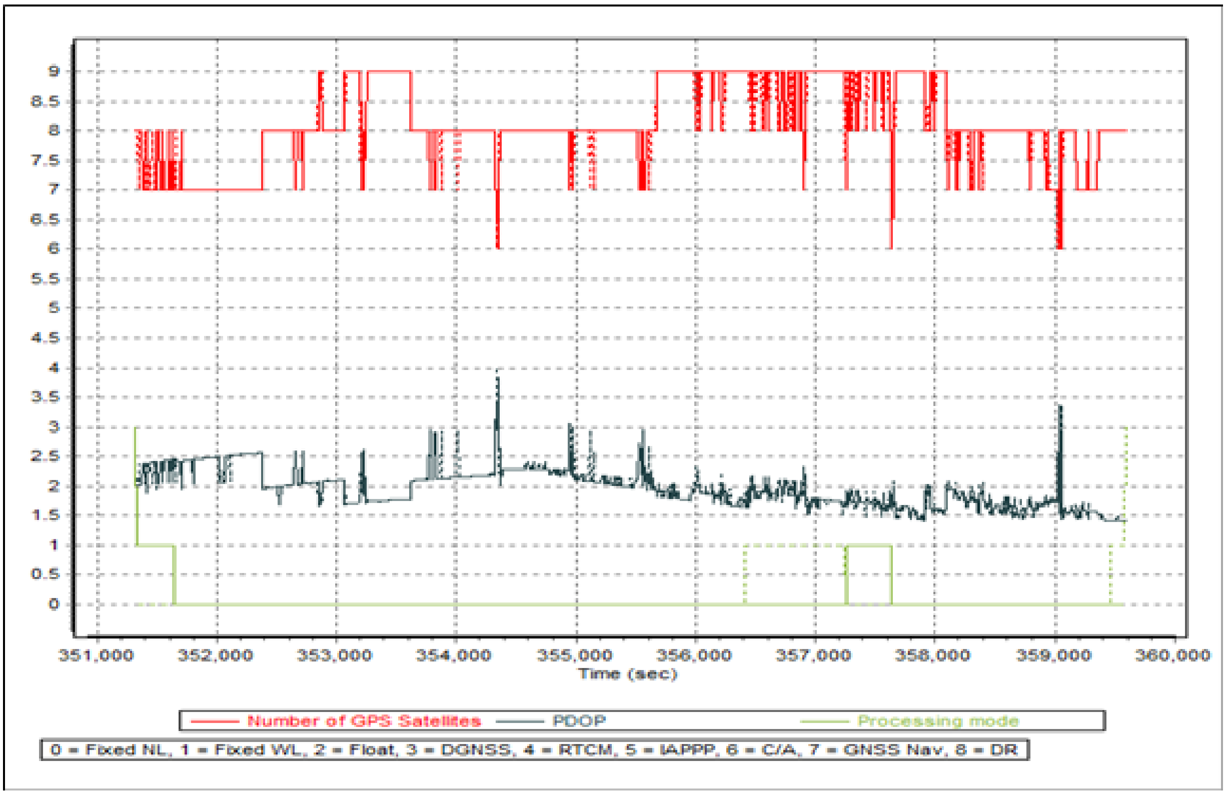



Figure A-8.15 Solution Status

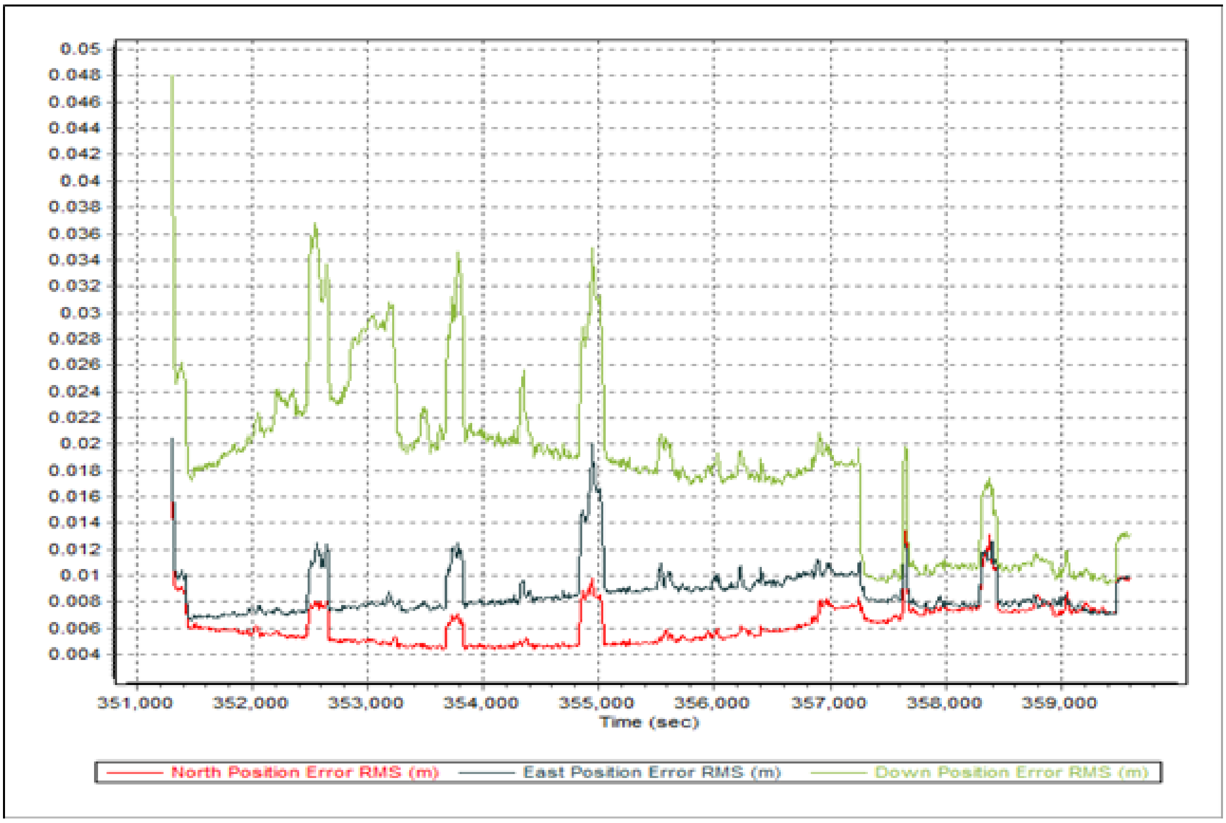



Figure A-8.16 Smoothed Performance Metric Parameters

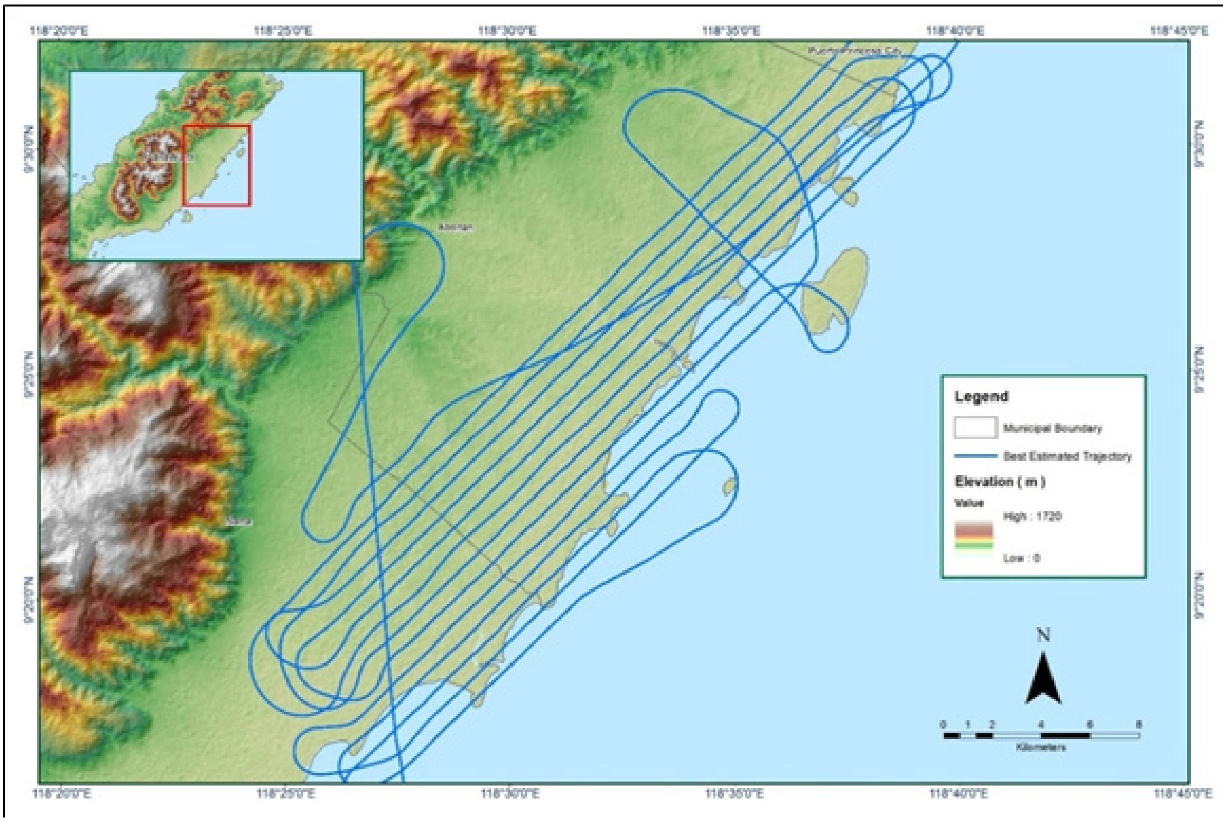



Figure A-8.17 Best Estimated Trajectory

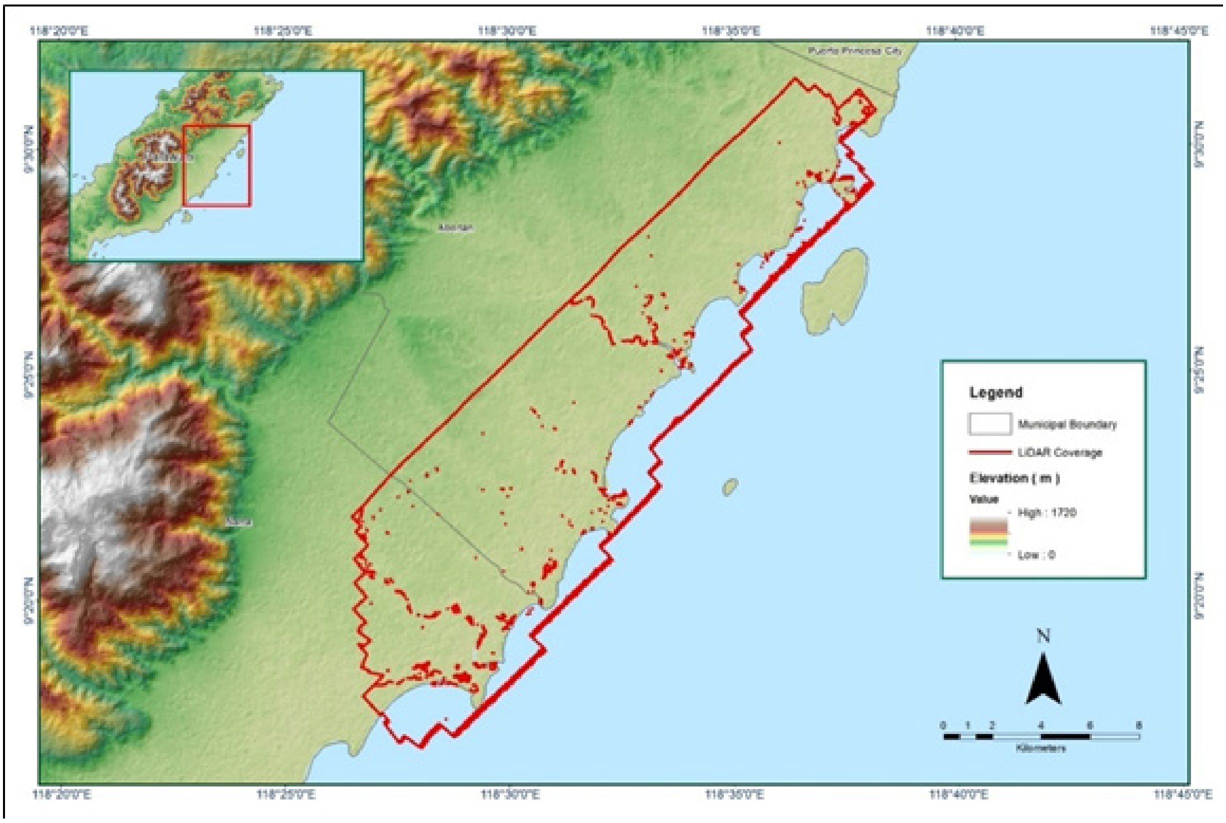



Figure A-8.18 Coverage of LiDAR data

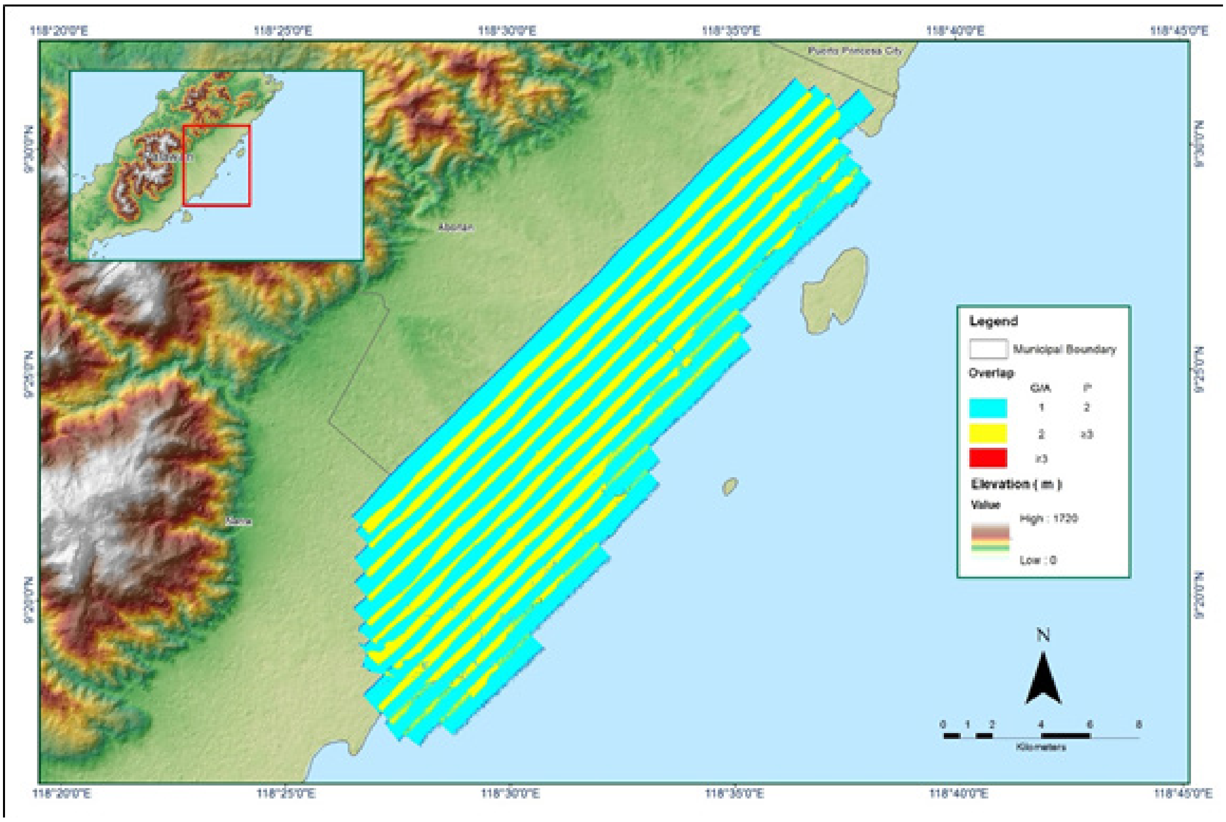



Figure A-8.19 Image of data overlap

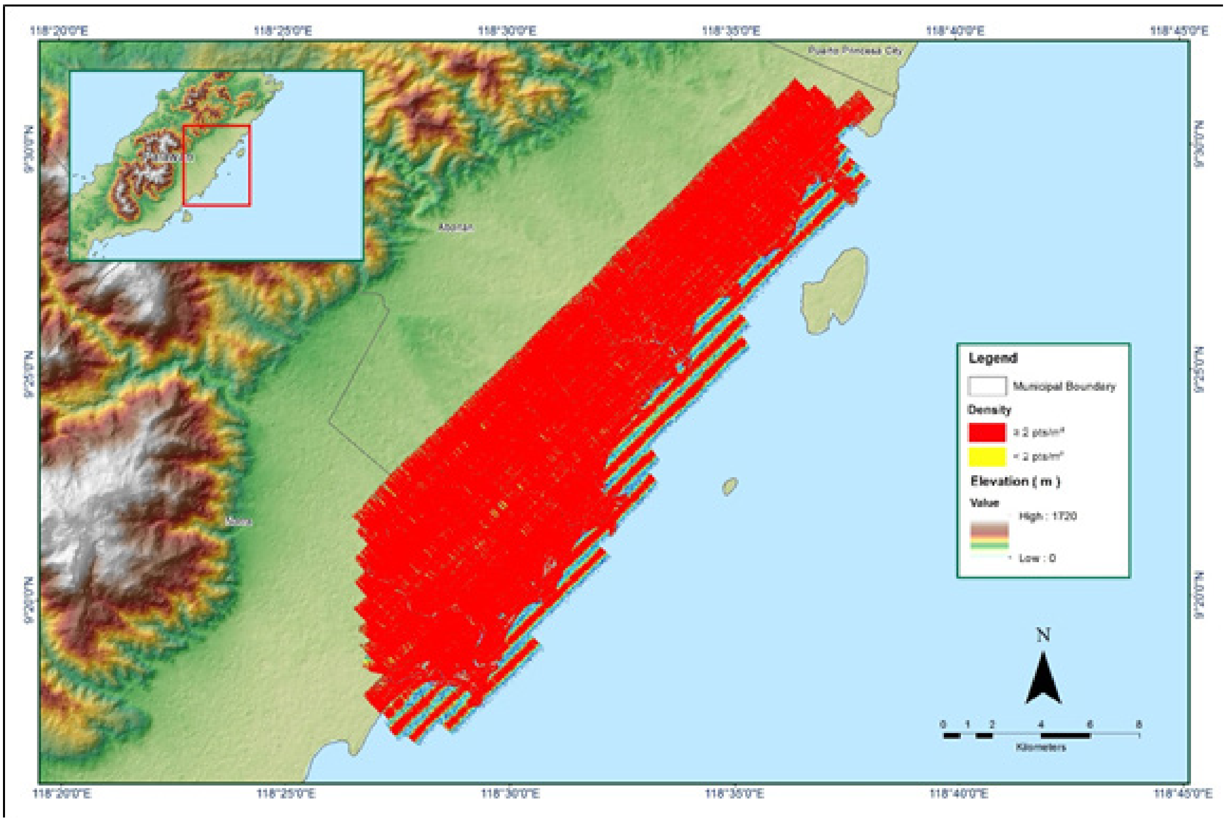



Figure A-8.20 Density map of merged LiDAR data

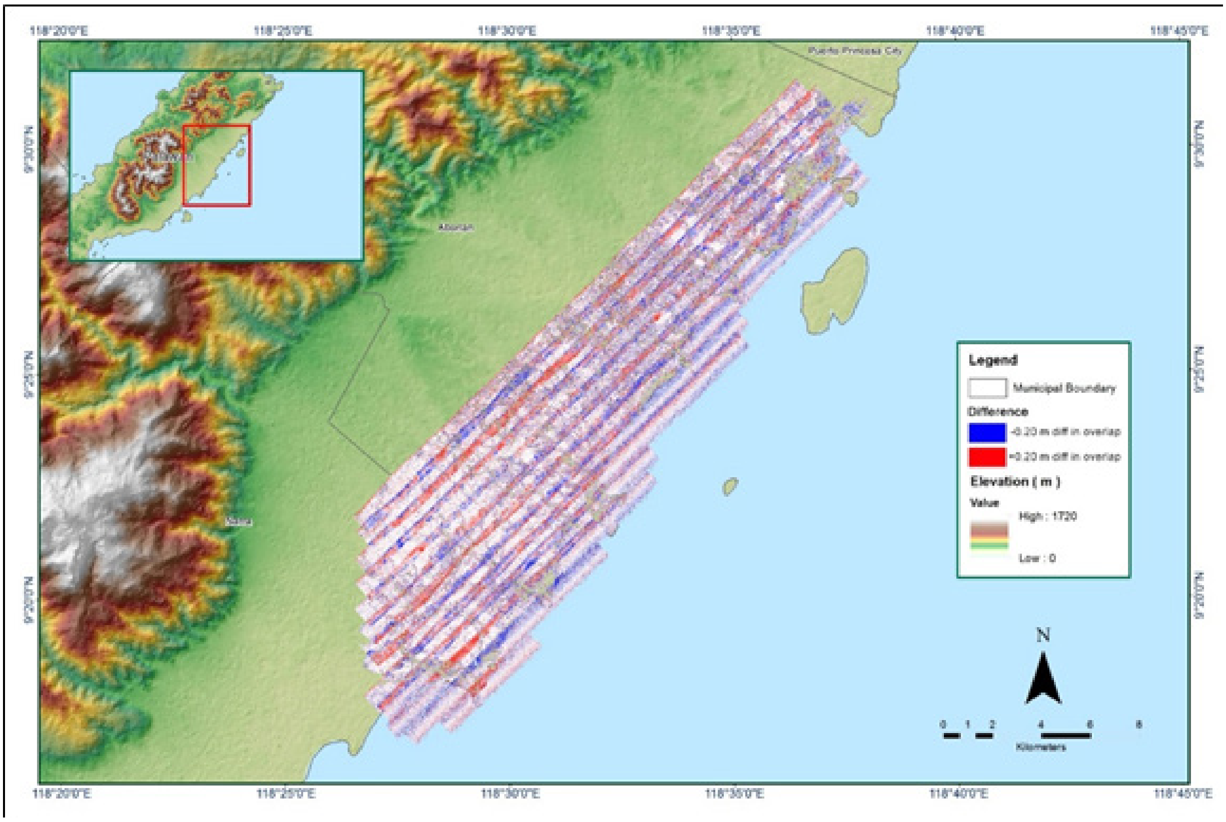



Figure A-8.21 Elevation difference between flight lines

Table A-8.4. Mission Summary Report for Mission Blk4F

| Flight Area | West Palawan |
|---|---|
| Mission Name | Blk42E_Additional |
| Inclusive Flights | 3061P |
| Range data size | 24.40 GB |
| POS | 205 MB |
| Image | 39.90 GB |
| Transfer date | July 13, 2015 |
| | |
| Solution Status | |
| Number of Satellites (>6) | No |
| PDOP (<3) | Yes |
| Baseline Length (<30km) | No |
| Processing Mode (<=1) | Yes |
| | |
| Smoothed Performance Metrics (in cm) | |
| RMSE for North Position (<4.0 cm) | 3.50 |
| RMSE for East Position (<4.0 cm) | 3.50 |
| RMSE for Down Position (<8.0 cm) | 6.00 |
| | |
| Boresight correction stdev (<0.001deg) | 0.000288 |
| IMU attitude correction stdev (<0.001deg) | 0.001790 |
| GPS position stdev (<0.01m) | 0.0024 |
| | |
| Minimum % overlap (>25) | 29.02 |
| Ave point cloud density per sq.m. (>2.0) | 4.80 |
| Elevation difference between strips (<0.20 m) | Yes |
| | |
| Number of 1km x 1km blocks | 68 |
| Maximum Height | 657.58 m |
| Minimum Height | 52.77 m |
| | |
| Classification (# of points) | |
| Ground | 27,095,789 |
| Low vegetation | 8,872,032 |
| Medium vegetation | 26,823,246 |
| High vegetation | 17,948,604 |
| Building | 0 |
| | |
| Orthophoto | Yes |
| Processed by | Engr. Irish Cortez, Aljon Rie Araneta, Maria Tamsyn Malabanan |

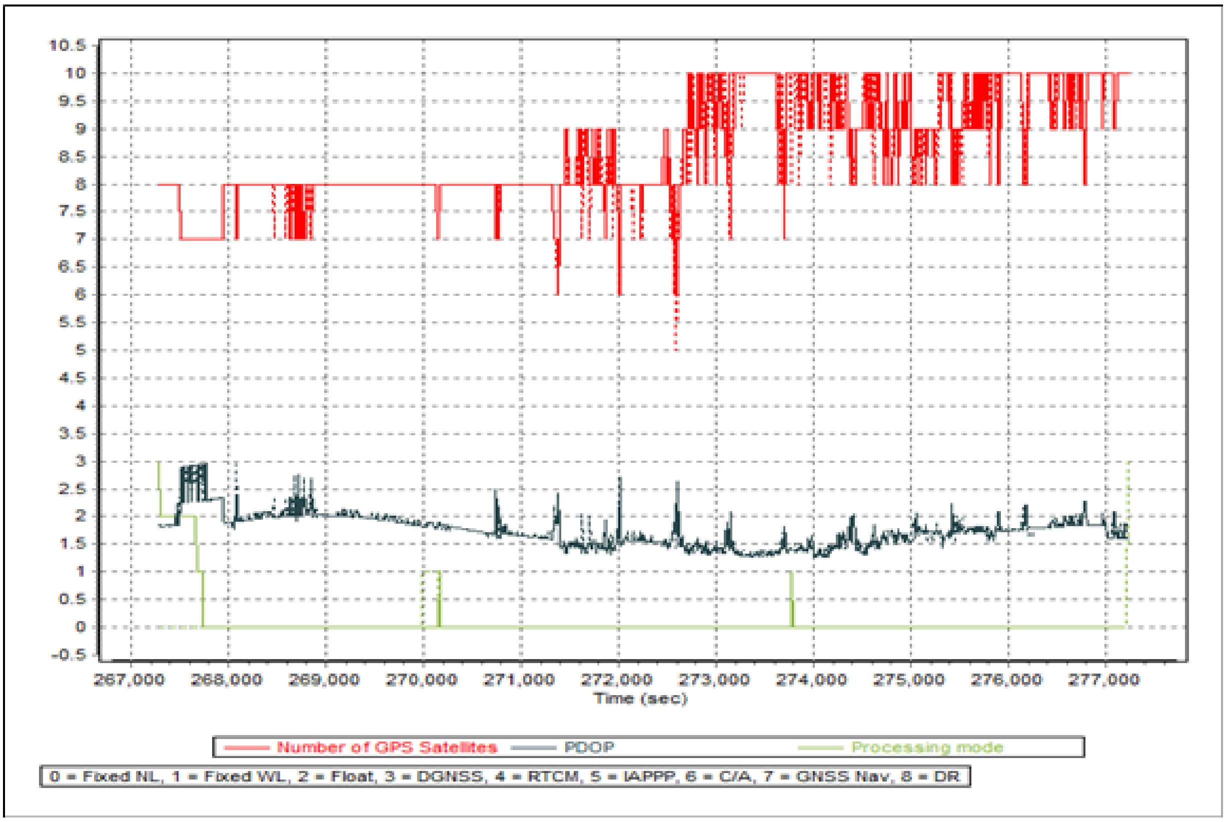



Figure A-8.22 Solution Status

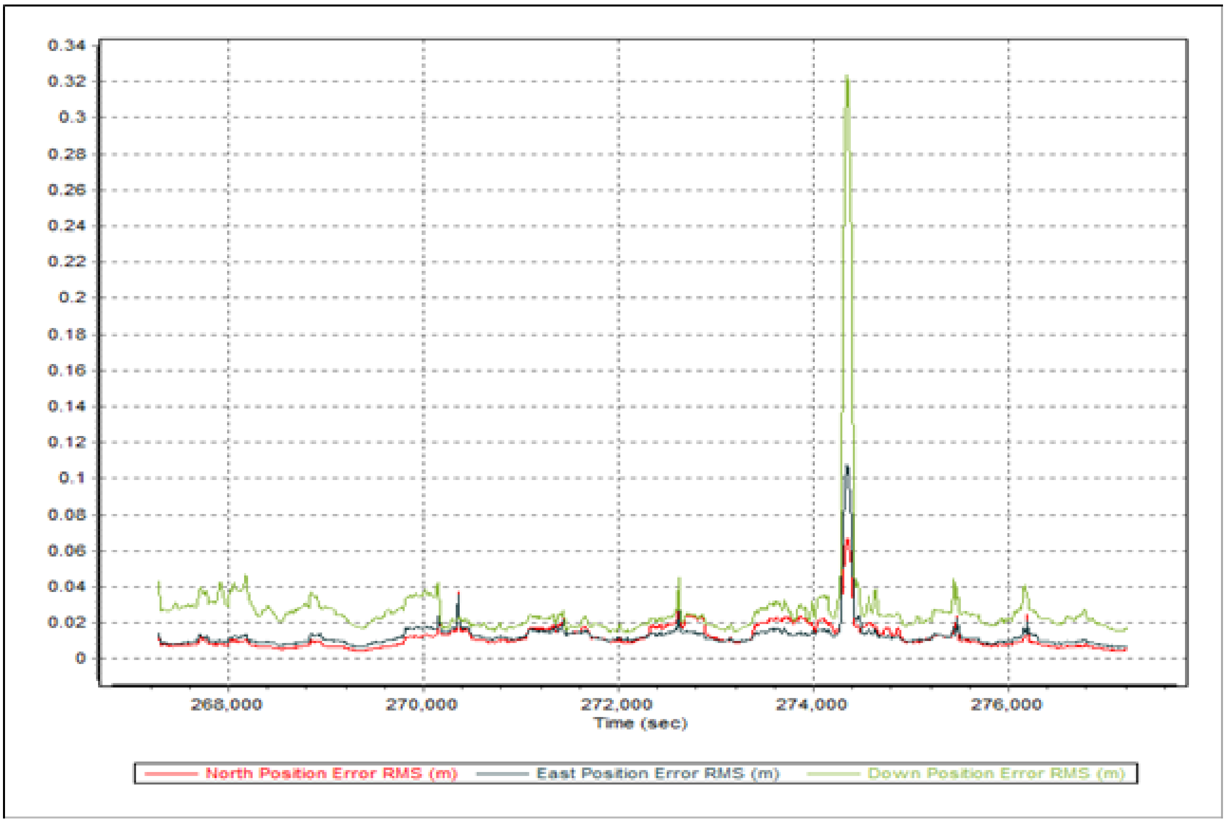



Figure A-8.23 Smoothed Performance Metric Parameters

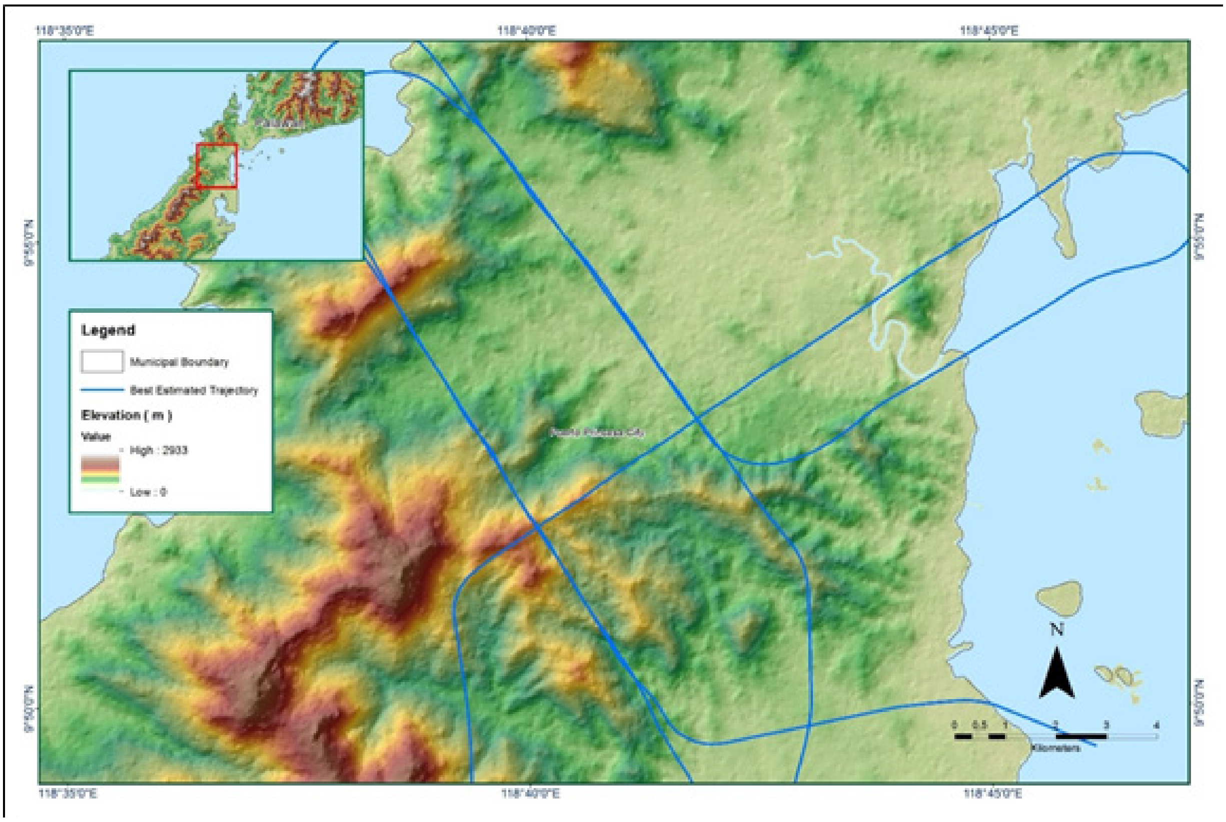



Figure A-8.24 Best Estimated Trajectory

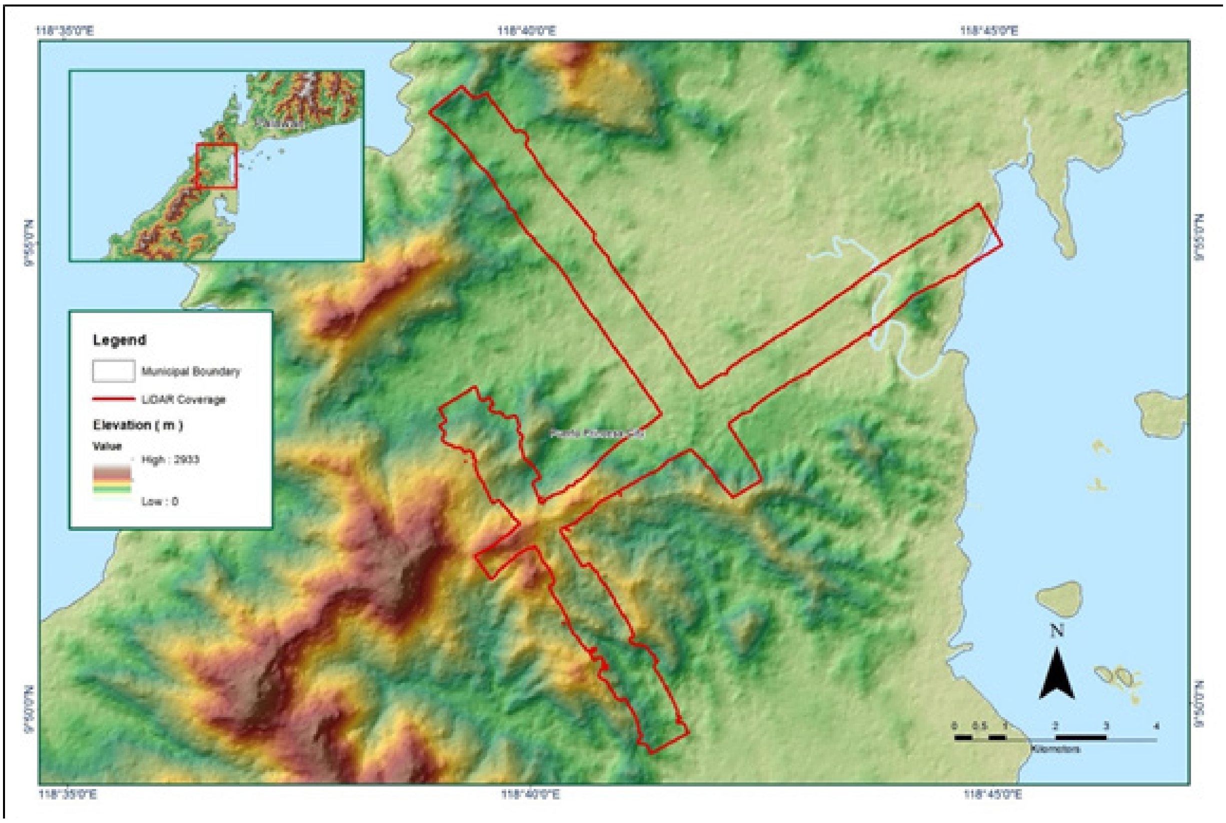



Figure A-8.25 Coverage of LiDAR data

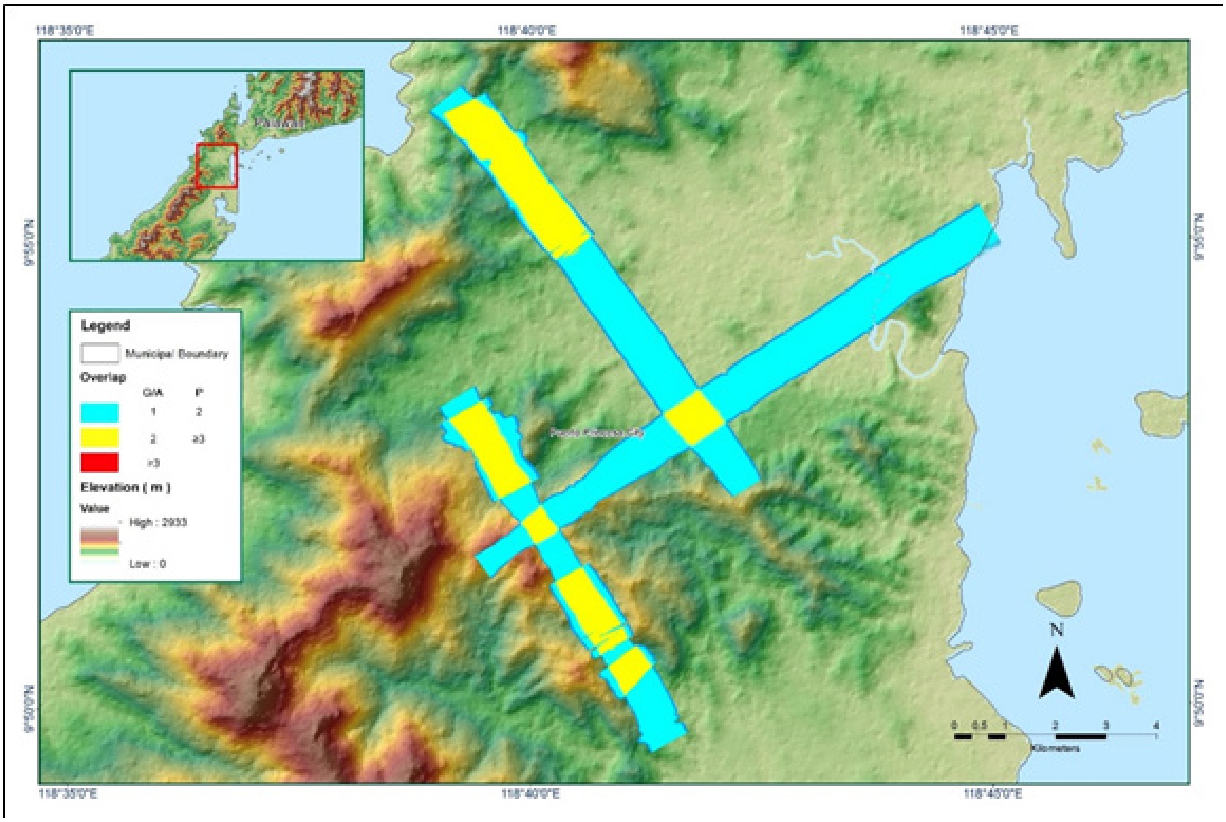



Figure A-8.26 Image of data overlap

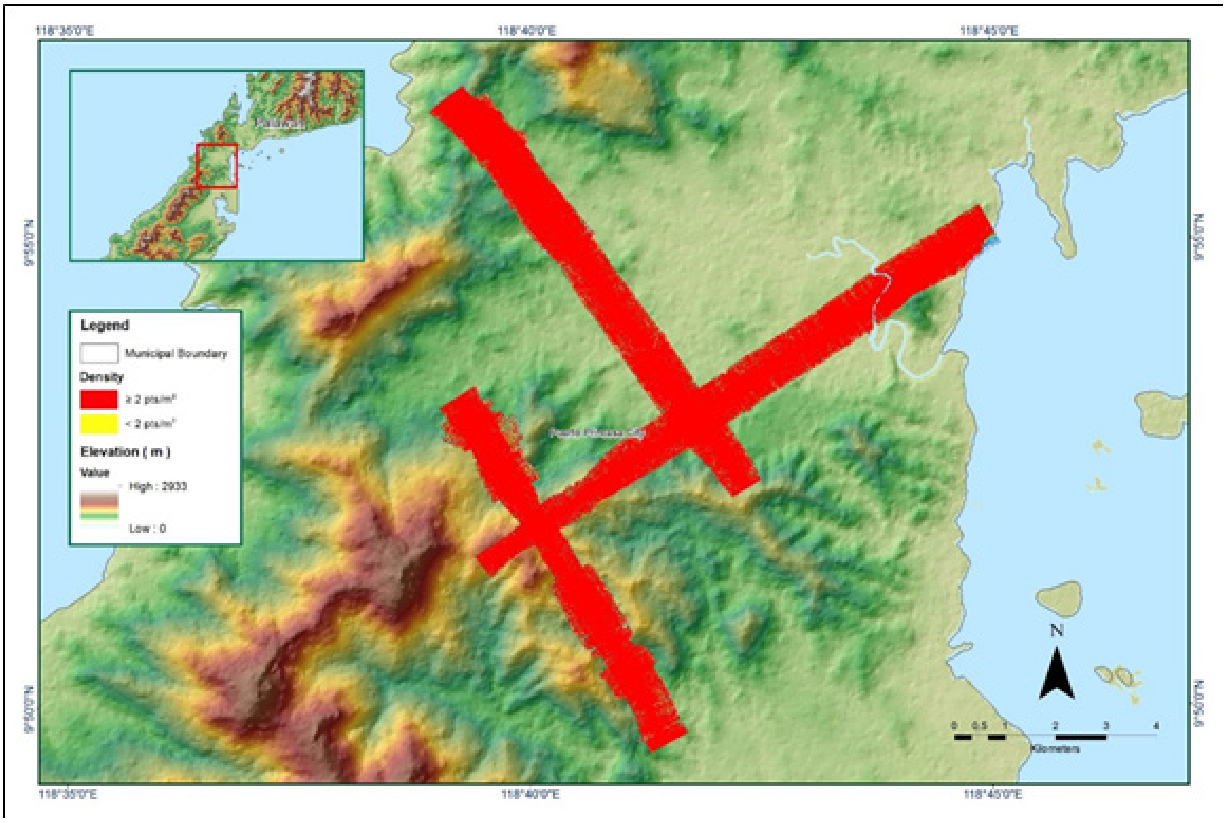



Figure A-8.27 Density map of merged LiDAR data

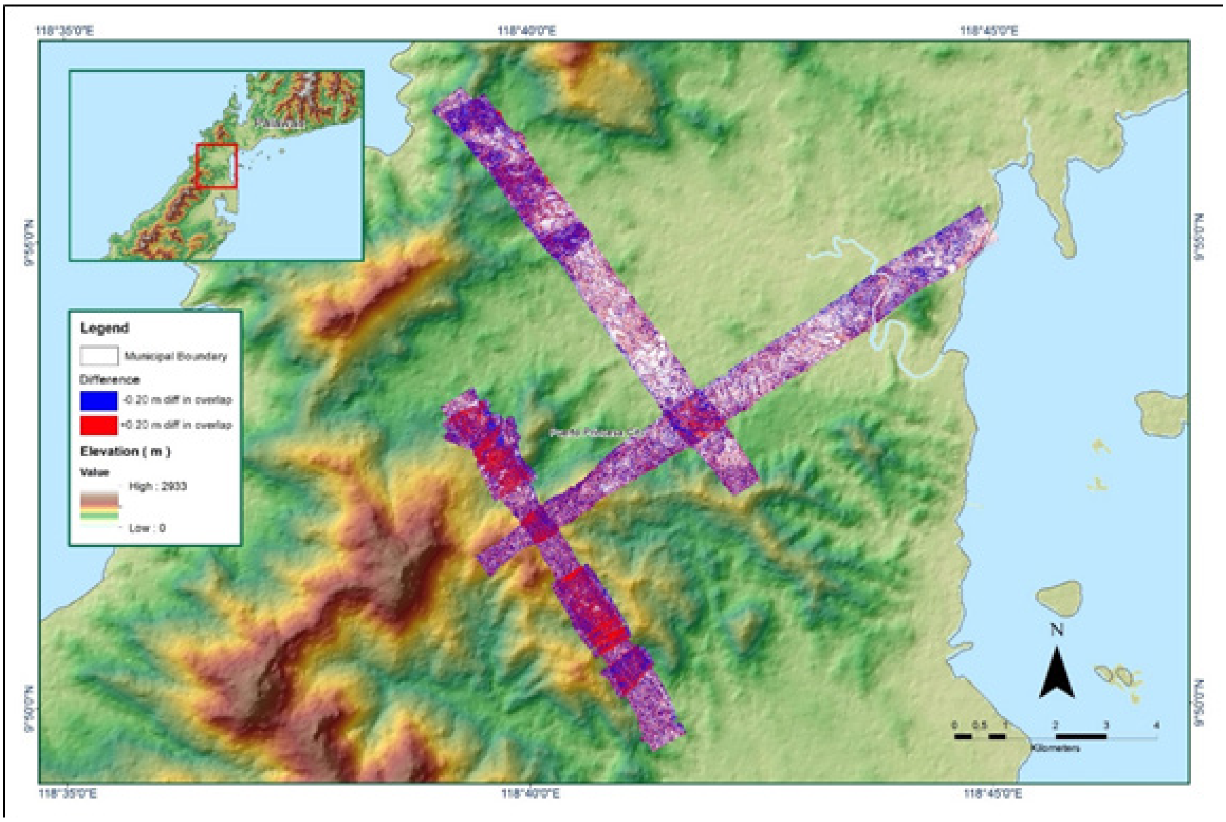



Figure A-8.28 Elevation difference between flight lines

Table A-8.5. Mission Summary Report for Mission Blk42eH

| **Flight Area** | **Palawan Reflights** |
|---|---|
| Mission Name | Blk42eH |
| Inclusive Flights | 3553G |
| Range data size | 16 GB |
| Base data size | 8.36 MB |
| POS | 187 MB |
| Image | NA |
| Transfer date | January 4, 2016 |
| | |
| Solution Status | |
| Number of Satellites (>6) | Yes |
| PDOP (<3) | Yes |
| Baseline Length (<30km) | Yes |
| Processing Mode (<=1) | No |
| | |
| Smoothed Performance Metrics (in cm) | |
| RMSE for North Position (<4.0 cm) | 2.36 |
| RMSE for East Position (<4.0 cm) | 2.86 |
| RMSE for Down Position (<8.0 cm) | 5.21 |
| | |
| Boresight correction stdev (<0.001deg) | NA |
| IMU attitude correction stdev (<0.001deg) | NA |
| GPS position stdev (<0.01m) | NA |
| | |
| Minimum % overlap (>25) | 36.04% |
| Ave point cloud density per sq.m. (>2.0) | 5.18 |
| Elevation difference between strips (<0.20 m) | Yes |
| | |
| Number of 1km x 1km blocks | 127 |
| Maximum Height | 814.62 m |
| Minimum Height | 53.00 m |
| | |
| Classification (# of points) | |
| Ground | 31,611,024 |
| Low vegetation | 48,277,717 |
| Medium vegetation | 162,535,879 |
| High vegetation | 188,860,178 |
| Building | 2,443,146 |
| | |
| Ortophoto | No |
| Processed by | Engr. Irish Cortez, Engr. Mark Joshua Salvacion, Marie Denise Bueno |

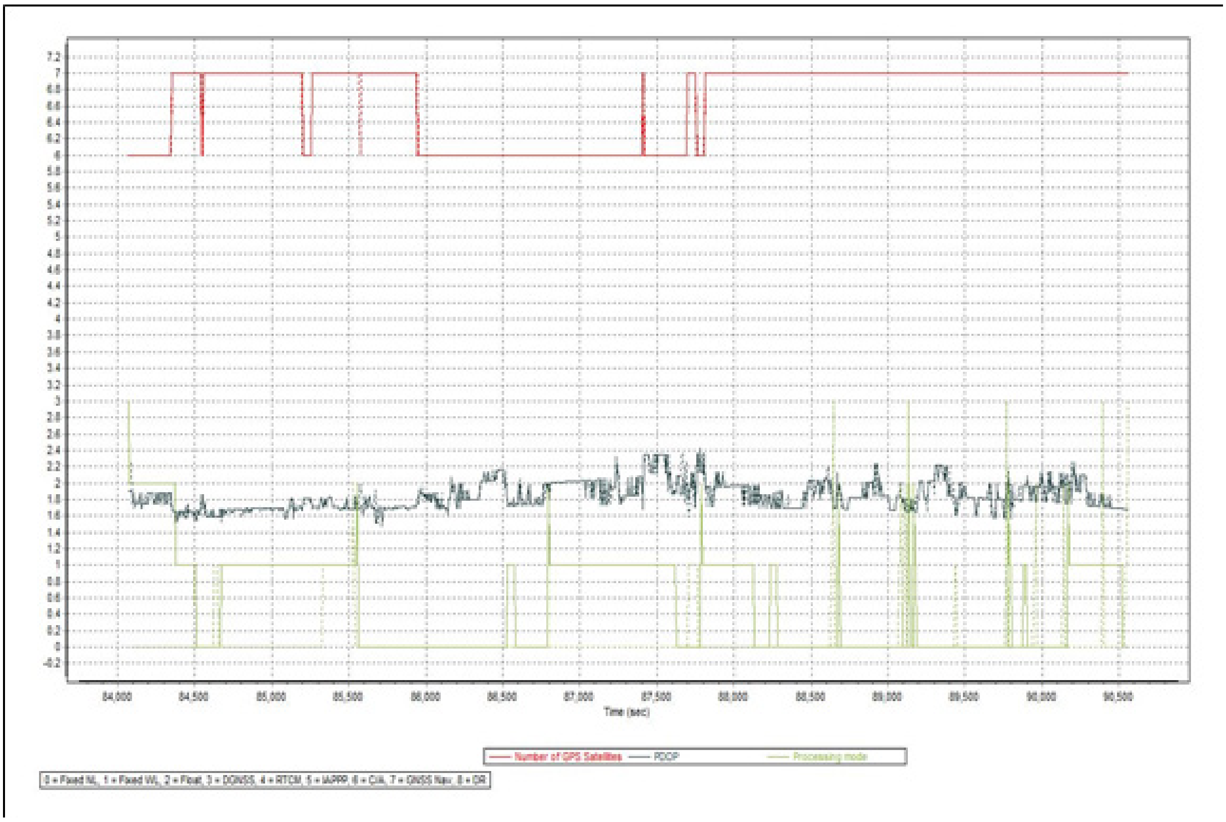



Figure A-8.29. Solution Status

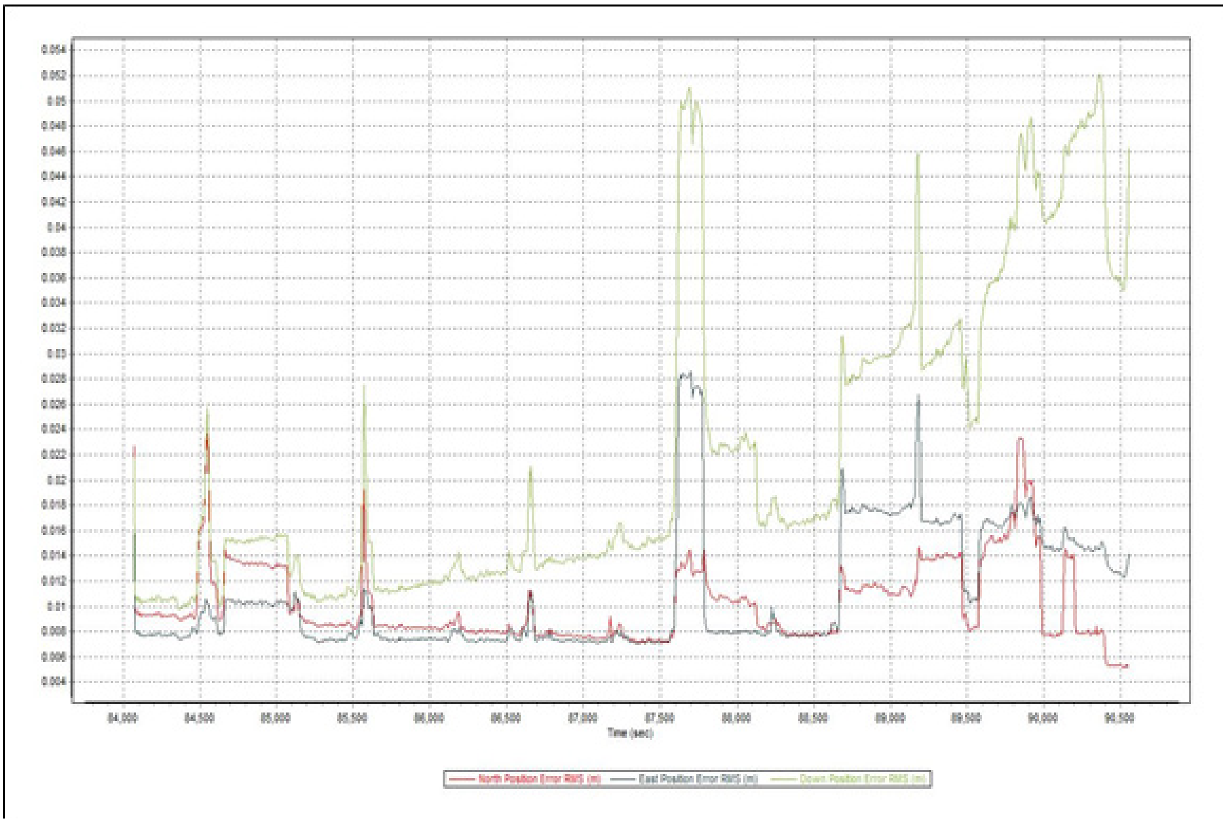



Figure A-8.30. Smoothed Performance Metric Parameters

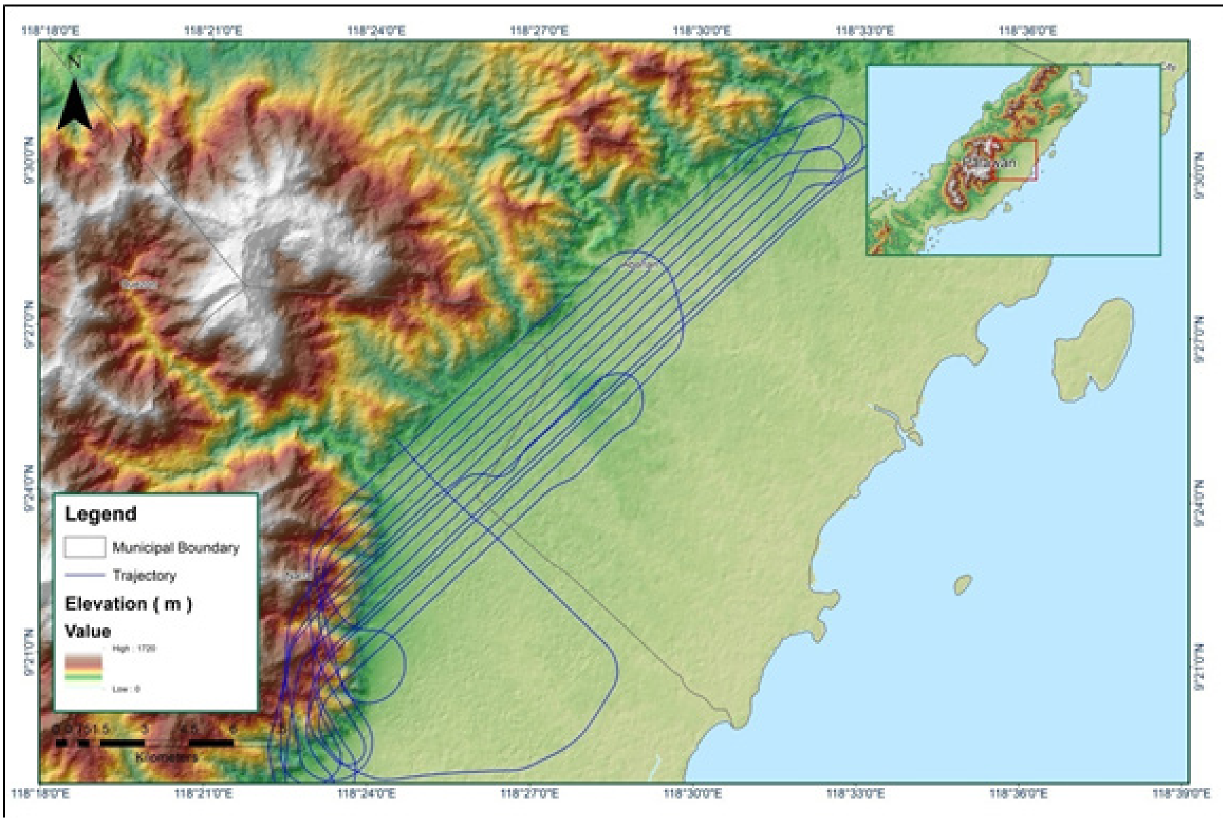



Figure A-8.31 Best Estimated Trajectory

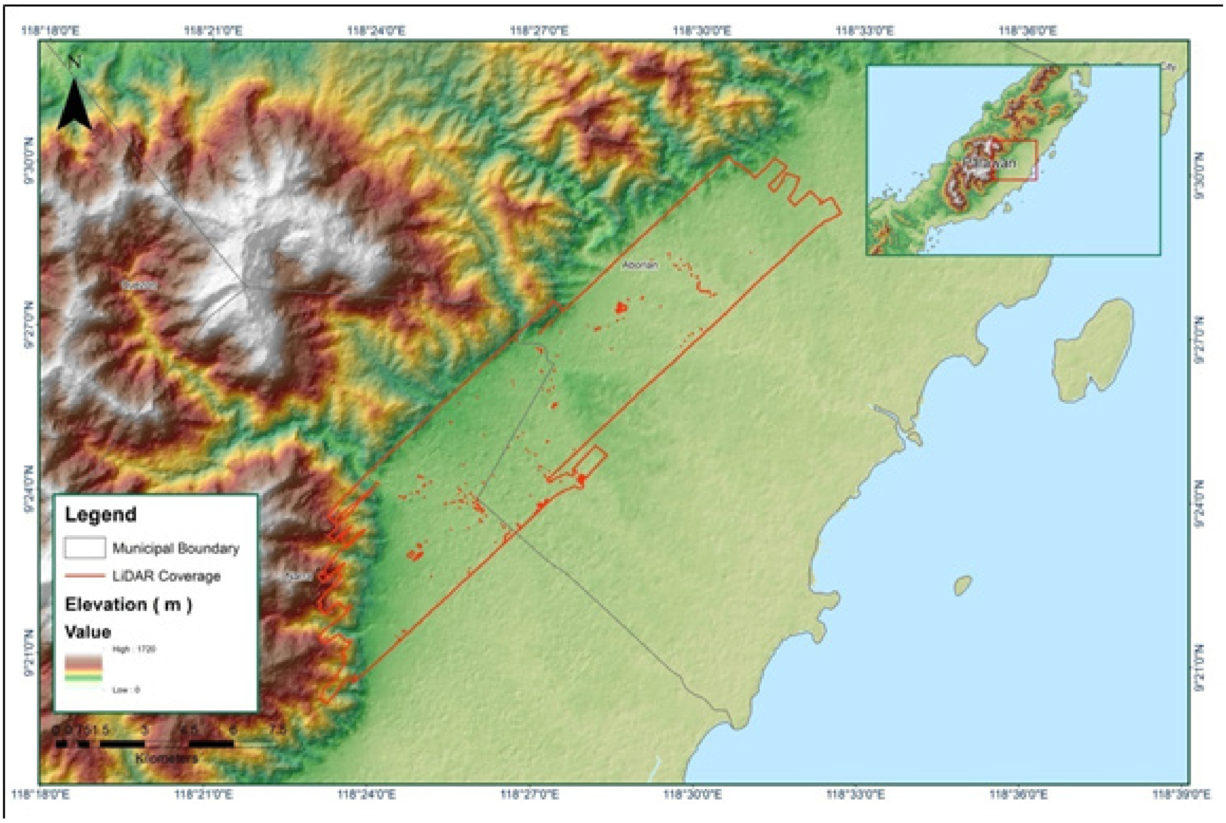



Figure A-8.32 Coverage of LiDAR data

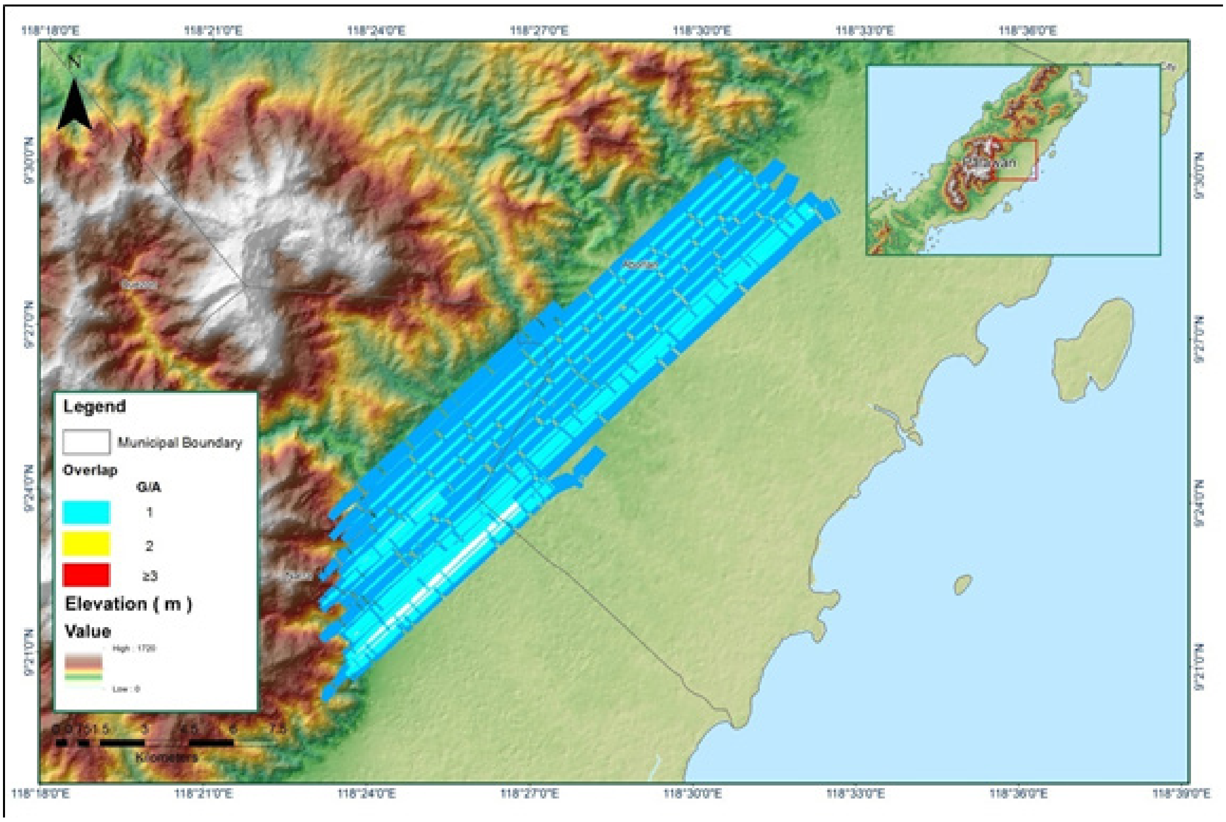



Figure A-8.33. Image of data overlap

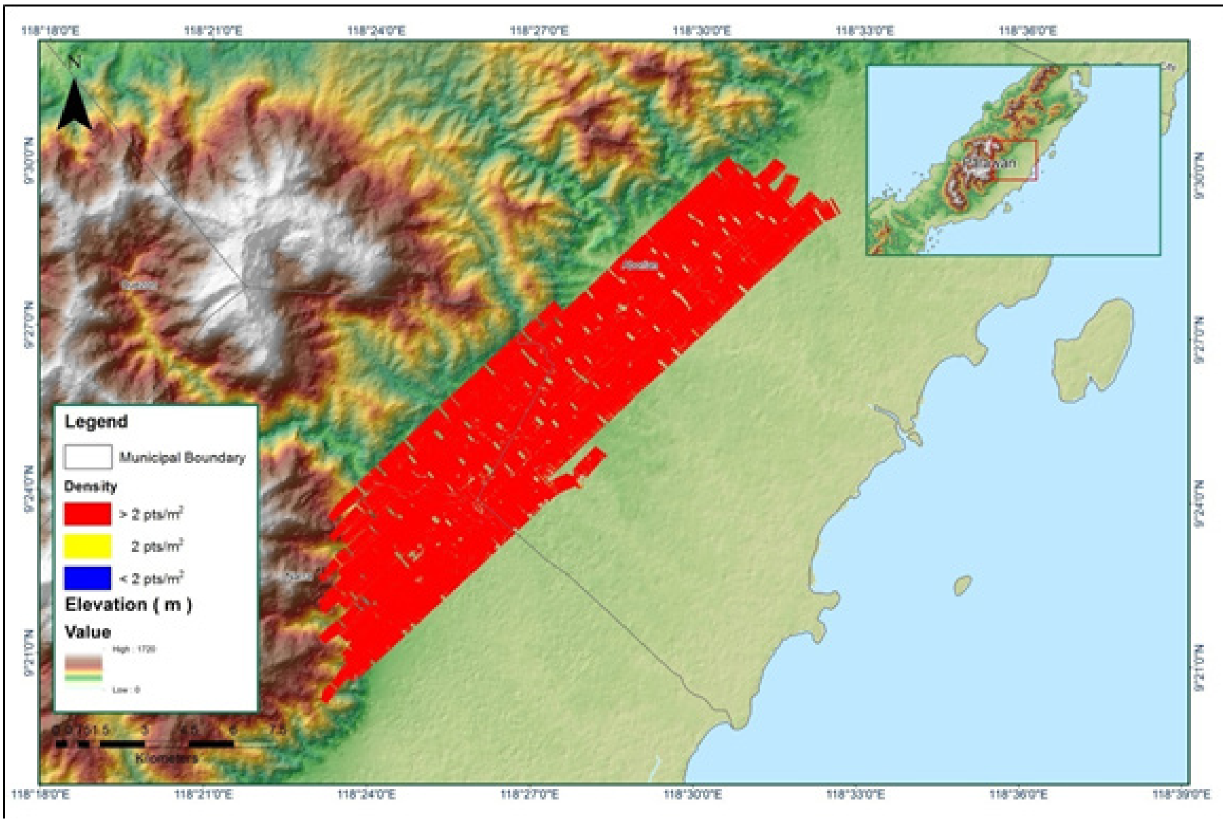



Figure A-8.34. Density Map of merged LiDAR data

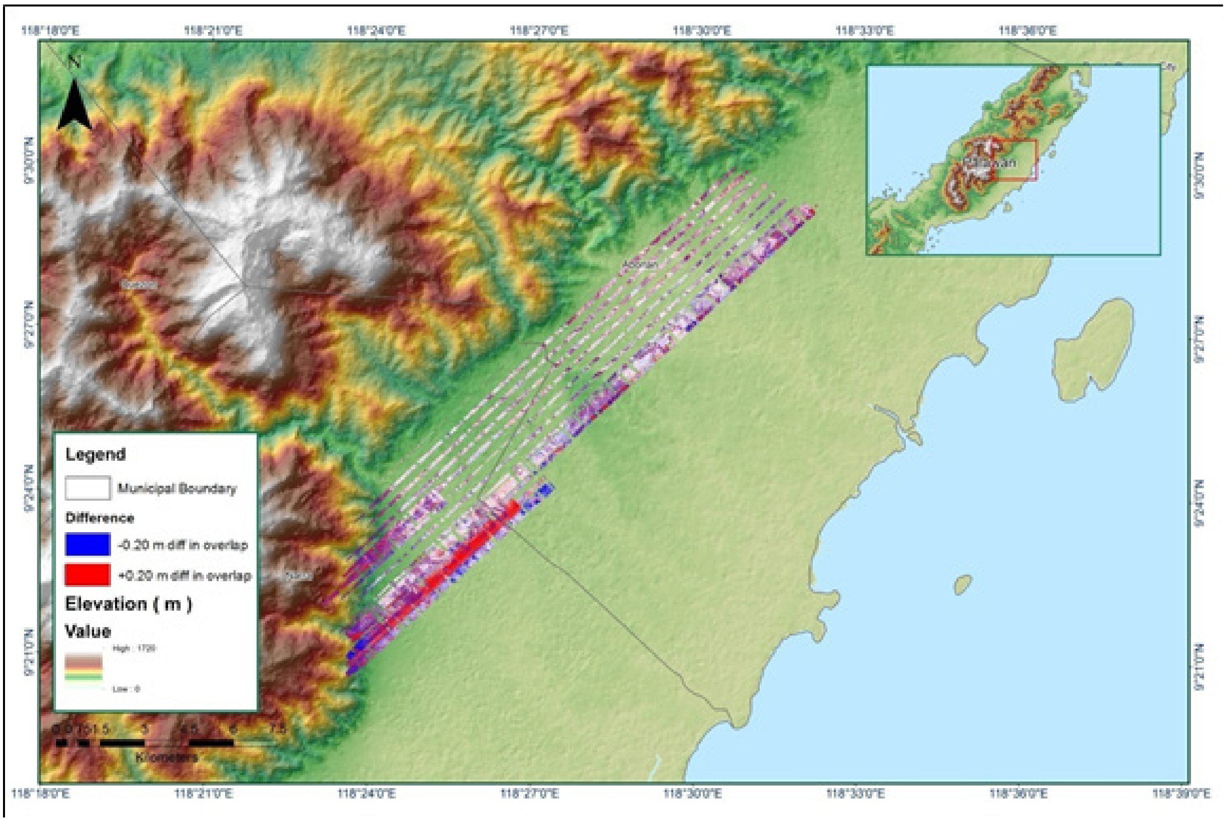



Figure A-8.35. Elevation Difference Between flight lines

# Annex 9. Aborlan Model Basin Parameters

Table A-9.1. Aborlan Model Basin Parameters

| Subbasin | SCS CURVE NUMBER LOSS | | | CLARK UNIT HYDROGRAPH TRANSFORM | | RECESSION BASEFLOW | | |
|---|---|---|---|---|---|---|---|---|
| | Initial Abstraction (MM) | Curve Number | Imperviousness (%) | Time of Concentration (HR) | Storage Coefficient (HR) | Initial Discharge (CU.M/S) | Recession Constant | Ratio to Peak |
| W280 | 113.335 | 35.176 | 0.0 | 1.0958 | 36.283 | 0.0154923 | 0.0251048 | 0.5 |
| W290 | 111.6725 | 52.77 | 0.0 | 0.14284 | 24.691 | 0.0012317 | 0.0245087 | 0.5 |
| W300 | 112.195 | 35.81 | 0.0 | 0.12652 | 14.616 | 0.0019873 | 0.0508381 | 0.5 |
| W310 | 65.5861 | 71.038 | 0.0 | 1.2722 | 1.9417 | 0.0019259 | 0.0345831 | 0 |
| W320 | 55.93125 | 35.176 | 0.0 | 0.84206 | 1.7297 | 0.0016119 | 0.0251052 | 0.13665 |
| W330 | 110.618 | 37.396 | 0.0 | 0.07876 | 8.6861 | 0.0018988 | 0.0378461 | 0.49 |
| W340 | 110.9695 | 52.767 | 0.0 | 0.15667 | 26.408 | 0.0034251 | 0.0251048 | 0.5 |
| W350 | 22.5929 | 35.173 | 0.0 | 0.07216 | 3.572 | 0.0033468 | 0.0116177 | 0.12861 |
| W360 | 113.05 | 35.176 | 0.0 | 0.39196 | 18.928 | 0.0035021 | 0.0156842 | 0.5 |
| W370 | 111.15 | 52.949 | 0.0 | 0.1103 | 19.069 | 0.0060054 | 0.0230558 | 0.5 |
| W380 | 108.699 | 35.176 | 0.0 | 0.14725 | 55.879 | 0.0045231 | 0.0251052 | 0.5 |
| W390 | 45.93155 | 35.176 | 0.0 | 0.13337 | 11.668 | 0.0016561 | 0.0170784 | 0.43406 |
| W400 | 111.891 | 52.949 | 0.0 | 0.0800267 | 13.302 | 0.0019118 | 0.0211737 | 0.4802 |
| W410 | 13.13945 | 35.175 | 0.0 | 0.0722733 | 3.3182 | 0.0018861 | 0.0170784 | 0.18906 |
| W420 | 39.40885 | 35.175 | 0.0 | 0.0166667 | 5.6119 | 0.0038192 | 0.0116177 | 0.41687 |
| W430 | 118.959 | 52.879 | 0.0 | 0.094439 | 6.5337 | 0.0027435 | 0.0170781 | 0.49 |
| W440 | 46.80365 | 35.176 | 0.0 | 0.12764 | 55.744 | 0.0044441 | 0.0173417 | 0.5 |
| W450 | 103.8445 | 35.254 | 0.0 | 0.1348 | 15.898 | 0.0061066 | 0.0170781 | 0.5 |
| W460 | 42.8868 | 35.176 | 0.0 | 0.0166667 | 5.2792 | 0.0017410 | 0.0170781 | 0.27792 |
| W470 | 71.611 | 35.157 | 0.0 | 0.11821 | 18.136 | 0.0032131 | 0.0170781 | 0.4706 |
| W480 | 86.04435 | 35.212 | 0.0 | 0.36447 | 41.162 | 0.0025558 | 0.0173417 | 0.5 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| W490 | 24.88525 | 35.176 | 0.0 | 0.0166667 | 6.0952 | 0.0013927 | 0.0170781 | 0.41687 |
| W500 | 43.966 | 35.099 | 0.0 | 0.0832434 | 6.9135 | 0.0042764 | 0.0116177 | 0.42538 |
| W510 | 13.5318 | 48.765 | 0.0 | 0.0826589 | 6.345 | 0.0071921 | 0.0174528 | 0.28359 |
| W520 | 37.39485 | 37.121 | 0.0 | 0.0832558 | 23.705 | 0.0029516 | 0.0170781 | 0.5 |
| W530 | 29.6875 | 35.364 | 0.0 | 0.0826546 | 24.353 | .000891479 | 0.0170781 | 0.5 |
| W560 | 5.2013 | 69.876 | 0.0 | 2.3434 | 3.8244 | 0.0016521 | 1 | 0.5 |
| W570 | 36.0962 | 37.587 | 0.0 | 0.0741667 | 20.241 | 0.0066160 | 0.0170781 | 0.5 |

# Annex 10. Aborlan Model Reach Parameters

Table A-10.1. Aborlan Model Reach Parameters

| REACH | MUSKINGUM CUNGE CHANNEL ROUTING | | | | | | |
|---|---|---|---|---|---|---|---|
| | Time Step Method | Length (M) | Slope(M/M) | Manning's n | Shape | Width (M) | Side Slope (xH:1V) |
| R110 | Automatic Fixed Interval | 2066.1 | 0.0230575 | .000610958 | Trapezoid | 40 | 1 |
| R150 | Automatic Fixed Interval | 3555.0 | 0.0108152 | .000901342 | Trapezoid | 40 | 1 |
| R170 | Automatic Fixed Interval | 1738.2 | 0.0062544 | .00040683 | Trapezoid | 40 | 1 |
| R190 | Automatic Fixed Interval | 3378.1 | 0.0051797 | .000605888 | Trapezoid | 40 | 1 |
| R220 | Automatic Fixed Inter-val | 2018.9 | 0.0013853 | .000606308 | Trapezoid | 40 | 1 |
| R230 | Automatic Fixed Interval | 5784.3 | 0.0043828 | 0.0013581 | Trapezoid | 40 | 1 |
| R240 | Automatic Fixed Interval | 1016.4 | 0.0043828 | .000116148 | Trapezoid | 40 | 1 |
| R250 | Automatic Fixed Interval | 2799.1 | 0.0036756 | .000116148 | Trapezoid | 40 | 1 |
| R270 | Automatic Fixed Interval | 1716.3 | 0.0036756 | 0.04 | Trapezoid | 40 | 1 |
| R40 | Automatic Fixed Interval | 1905.4 | 0.0156303 | .000908779 | Trapezoid | 40 | 1 |
| R50 | Automatic Fixed Interval | 1415.7 | 0.0097613 | 0.002025 | Trapezoid | 40 | 1 |
| R590 | Automatic Fixed Interval | 4716.2 | 0.0016318 | .00038416 | Trapezoid | 40 | 1 |
| R80 | Automatic Fixed Interval | 2316.9 | 0.0080094 | .000903277 | Trapezoid | 40 | 1 |
| R90 | Automatic Fixed Interval | 3580.5 | 0.0114666 | .000585808 | Trapezoid | 40 | 1 |

# Annex 11. Phil-LiDAR 1 UPLB Team Composition

**Project Leader**
Asst. Prof. Edwin R. Abucay (CHE, UPLB)

**Project Staffs/Study Leaders**
Asst. Prof. Efraim D. Roxas (CHE, UPLB)
Asst. Prof. Joan Pauline P. Talubo (CHE, UPLB)
Ms. Sandra Samantela (CHE, UPLB)
Dr. Cristino L. Tiburan (CFNR, UPLB)
Engr. Ariel U. Glorioso (CEAT, UPLB)
Ms. Miyah D. Queliste (CAS, UPLB)
Mr. Dante Gideon K. Vergara (SESAM, UPLB)

**Sr. Science Research Specialists**
Gillian Katherine L. Inciong
For. John Alvin B. Reyes

**Research Associates**
Alfi Lorenz B. Cura
Angelica T. Magpantay
Gemmalyn E. Magnaye
Jayson L. Arizapa
Kevin M. Manalo
Leendel Jane D. Punzalan
Maria Michaela A. Gonzales
Paulo Joshua U. Quilao
Sarah Joy A. Acepcion
Ralphael P. Gonzales

**Computer Programmers**
Ivan Marc H. Escamos
Allen Roy C. Roberto

**Information Systems Analyst**
Jan Martin C. Magcale

**Project Assistants**
Daisili Ann V. Pelegrina
Athena Mercado
Kaye Anne A. Matre
Randy P. Porciocula