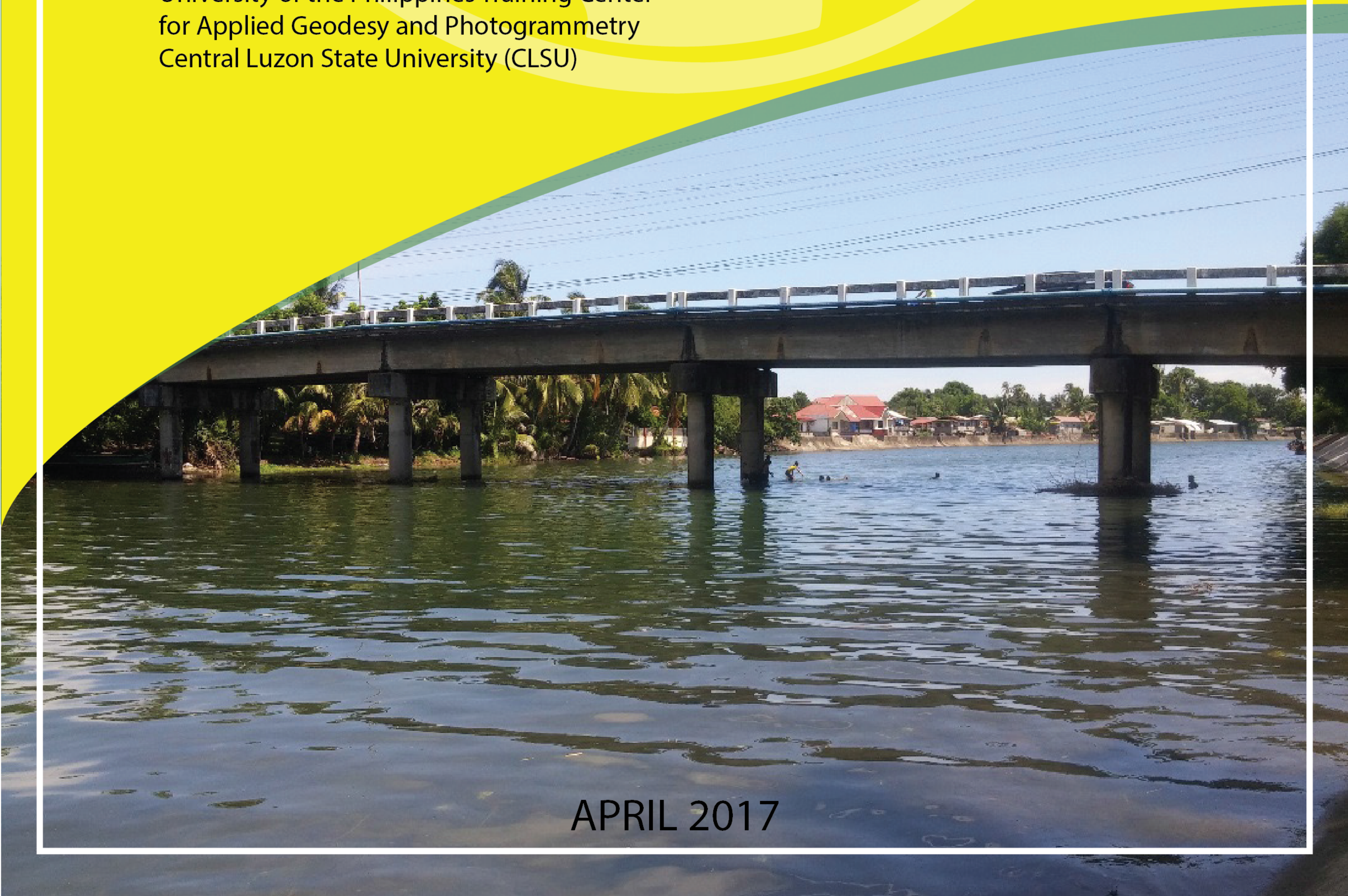
Hazard Mapping of the Philippines Using LIDAR ( Phil-LIDAR 1 )

# LiDAR Surveys and Flood Mapping of Morong River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
Central Luzon State University (CLSU)



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# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AAC | Asian Aerospace Corporation |
| Ab | abutment |
| ALTM | Airborne LiDAR Terrain Mapper |
| ARG | automatic rain gauge |
| ATQ | Antique |
| BA | Bridge Approach |
| BM | benchmark |
| CAD | Computer-Aided Design |
| 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 | Land Analysis System |
| 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 |
| NAMRIA | National Mapping and Resource Information Authority |
| NSTC | Northern Subtropical Convergence |
| PAF | Philippine Air Force |
| PAGASA | Philippine Atmospheric Geophysical and Astronomical Services Administration |
| PDOP | Positional Dilution of Precision |
| PPK | Post-Processed Kinematic [technique] |
| PRF | Pulse Repetition Frequency |
| PTM | Philippine Transverse Mercator |
| QC | Quality Check |
| QT | Quick Terrain [Modeler] |
| RA | Research Associate |
| RIDF | Rainfall Intensity Duration Frequency |
| RMSE | Root Mean Square Error |
| SAR | Synthetic Aperture Radar |
| SCS | Sun Canopy Sensor |
| SRTM | Shuttle Radar Topography Mission |
| SRS | Science Research Specialist |
| SSG | Special Service Group |
| TBC | Thermal Barrier Coatings |
| UPC | University of the Philippines Cebu |
| UP-TCAGP | University of the Philippines – Training Center for Applied Geodesy and Photogrammetry |
| UTM | Universal Transverse Mercator |
| WGS | World Geodetic System |

# CHAPTER 1 OVERVIEW OF THE PROGRAM AND MORONG RIVER

Enrico C. Paringit, Dr. Eng., Dr. Annie Melinda Paz-Alberto, and Gloria N. Ramos

## 1.1 Background of the Phil-LIDAR 1 Program

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

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

The implementing partner university for the Phil-LiDAR 1 Program is the Central Luzon State University (CLSU). CLSU 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 8 river basins in Central Luzon. The university is located in Munoz City in the province of Nueva Ecija.

## 1.2 Morong River Basin

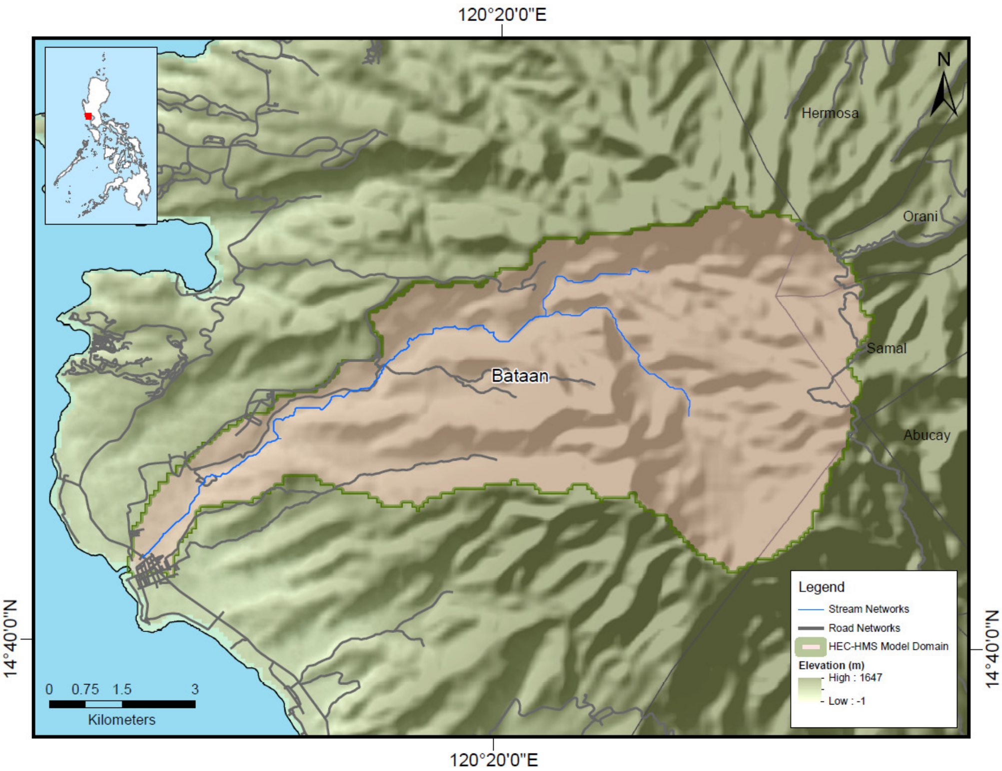



Figure 1. Map of Morong River Basin

Morong River is one of the five (5) rivers out of twelve (12) waterways that drains the municipality of Morong and can be found in Barangay Poblacion according to the Municipal Planning Development

Office of Management Plan (2015-2025). The river is located at 14° 40' 55.41" N 120° 15' 58.16" E, within the municipality of Morong, the second largest municipality in the province of Bataan, Central Luzon, Philippines. According to the 2015 national census of NSO, a total of 18,923 persons are residing within the immediate vicinity of the river which is distributed among three barangays namely: Sabang, Poblacion and Binaritan, in Morong, Bataan. Fishing is the primary source of livelihood for the majority of its population although there are also few areas are utilized for tourism and recreation such as the Pawikan Conservation Center in Brgy. Nagbalayong. (http://www.bataan.gov.ph/home/about-bataan/fast-facts/socio-economic-attribute.html, 2016). The city is also the center for trade, commerce, services and education in the Province of Bataan. On August 19, 2016 it has been reported that heavy monsoon rains have caused death to three persons in Bataan, one of whom is from Morong (http://newsinfo.inquirer.net/807678/state-of-calamity-up-in-flooded-areas, 2016).

Morong River Basin covers majority of Municipality of Morong; and minor portions of Municipalities of Bagac, Orani and Samal in Bataan. The DENR River Basin Control Office identified the basin to have a drainage area of 66km2 and an estimated 74 million cubic meter (MCM) annual run-off (RBCO, 2015).

The estimated terrain elevation above sea level is 3 meters and the watershed boundary was estimated at 64.44 square kilometer. Variant forms of spelling for Morong River or in other languages: Moran River, Moron River, Morong River, Morong, Moran River, Moron River, Morong, Morong River.

The prevailing climate in Morong is categorized under Type 1 of the Modified Corona's Classification. Rainy season starts in May and ends up around October. The rest of the year is dry with occasional rains dispersed widely throughout the province. Adjunct to this relatively hot and humid climate are the major climate cyclones largely controlled by the seasonal winds (Southwest and Northeast Monsoons) and topography. The Southwest monsoon prevails in the area from June to October whereas the Northeast monsoon prevails from November to March.

Morong has a rugged mountainous terrain. The relatively flat areas are found along the coasts facing West Philippine Sea. The largest among these is the narrow strip that spans the rice lands of Nagbalayong to Poblacion, Eman Point and to the north by Mayagao Point. Great portions of the municipality are rugged and mountainous terrain dominated by Mt. Natib's Peak (1,253 masl) towards southeast. Other landforms of considerable heights are Bataan Peak (1,026 masl) and Mt. Silanganan (910 masl). Major tributaries such as Tawawa, Bisay, Bayandati and Morong River drain the slopes of these mountainous terrains toward the West Philippine Sea and Subic Bay.

Morong municipality is a 3rd class municipality of Bataan Province. The municipality has a total population of 29,901 as of 2015 PSA census distributed among the five (5) barangays namely: Biniratan, Mabayao (with least number of population with only 4,771), Nagbalayong (the less dense barangay with only 0.62), Poblacion (the densest barangay having 13 persons per hectare) and Sabang, the barangay that was recorded as the most populated having 7,446.

Having low densities, Morong is considered as rural municipality. It is a distant municipality and mountinous land mass of which large portion belong to protected areas that is only small percent is devoted to residential, commercial and industrial purposes . The municipality of Morong although densely populated has been identified as a Special Economic Zone with the presence of Bataan Technology Park and a tourist destination as evidenced by its pristine beaches. It also serves as an alternate access to Subic Bay Freeport Zone and often called the back gate of SBFZ. Through these, Morong is also considered as a Secondary Urban Center A.

Morong has a land area of 219.20 square kilometers with forested areas cover at least 9000 hectares excluding Subic Bay Freeport Zone. These are mainly dipterocarp species vegetation and residual growths. Almost all of the forests in Morong are part of the Bataan National Park (BNP), a protected area covered by the NIPAS Law (Republic Act 7586) (SWMP-MPDO, 2015).

# CHAPTER 2 LIDAR ACQUISITION IN MORONG FLOODPLAIN

Engr. Louie P. Balicanta, Engr. Christopher Cruz, Lovely Gracia Acuña, Engr. Gerome Hipolito, Engr. Christopher L. Joaquin, and Ms. Jasmin M. Domingo
"

## 2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Morong floodplain in Bataan. These missions were planned for nine (9) lines that run 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 are found in Table 1 and Table 2. Figure 2 and Figure 3 show the flight plans and base stations used for Morong floodplain survey.

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) |
|---|---|---|---|---|---|---|---|
| BTN | 1000 | 30 | 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) |
|---|---|---|---|---|---|---|---|
| BAL E | 1000 | 30 | 40 | 100 | 50 | 120 | 5 |
| BTN C | 800 | 30 | 50 | 200 | 40 | 120 | 5 |
| BTN D | 800 | 30 | 50 | 200 | 40 | 120 | 5 |

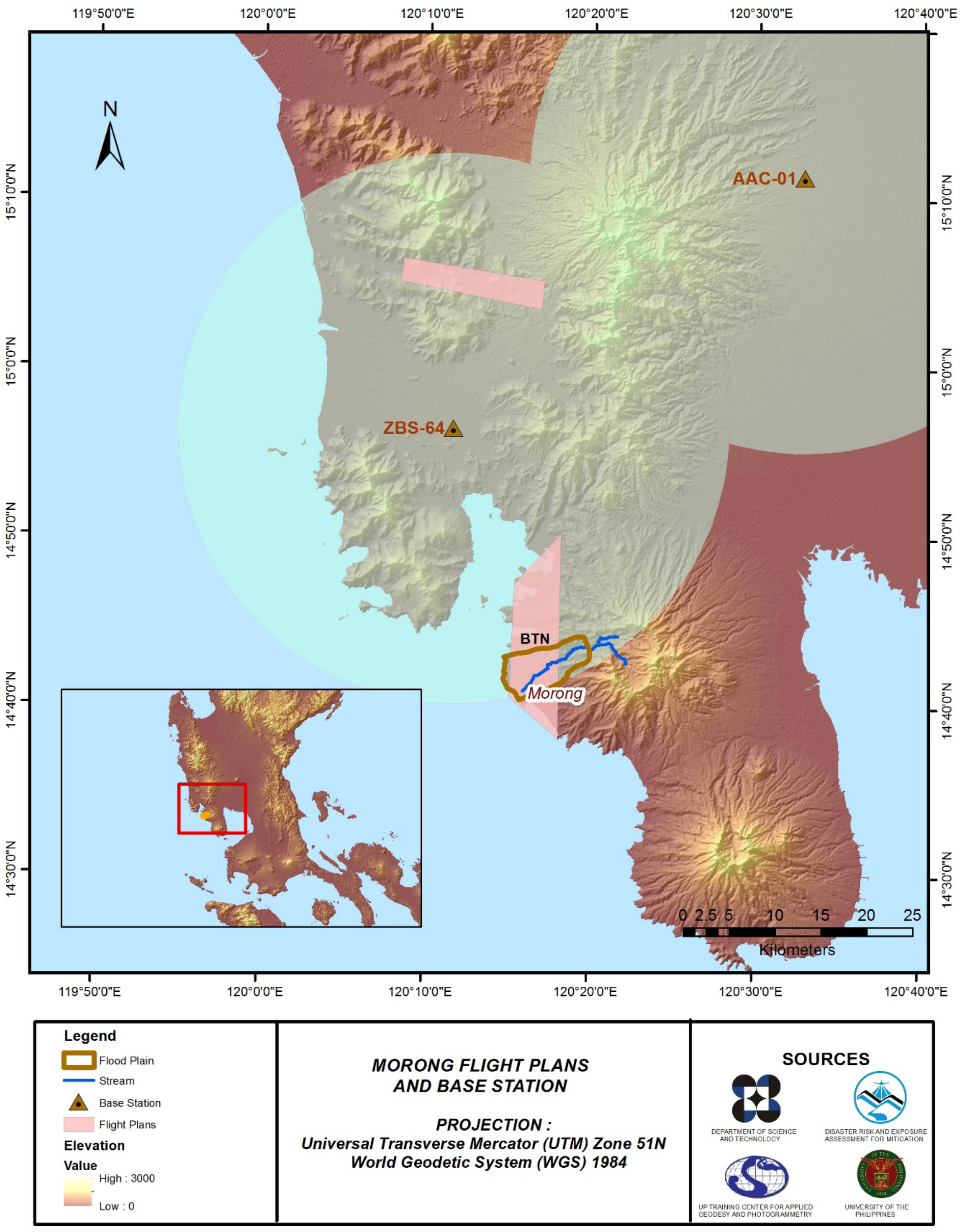



Figure 2. Flight plans and base stations used for Morong floodplain using Pegasus Sensor

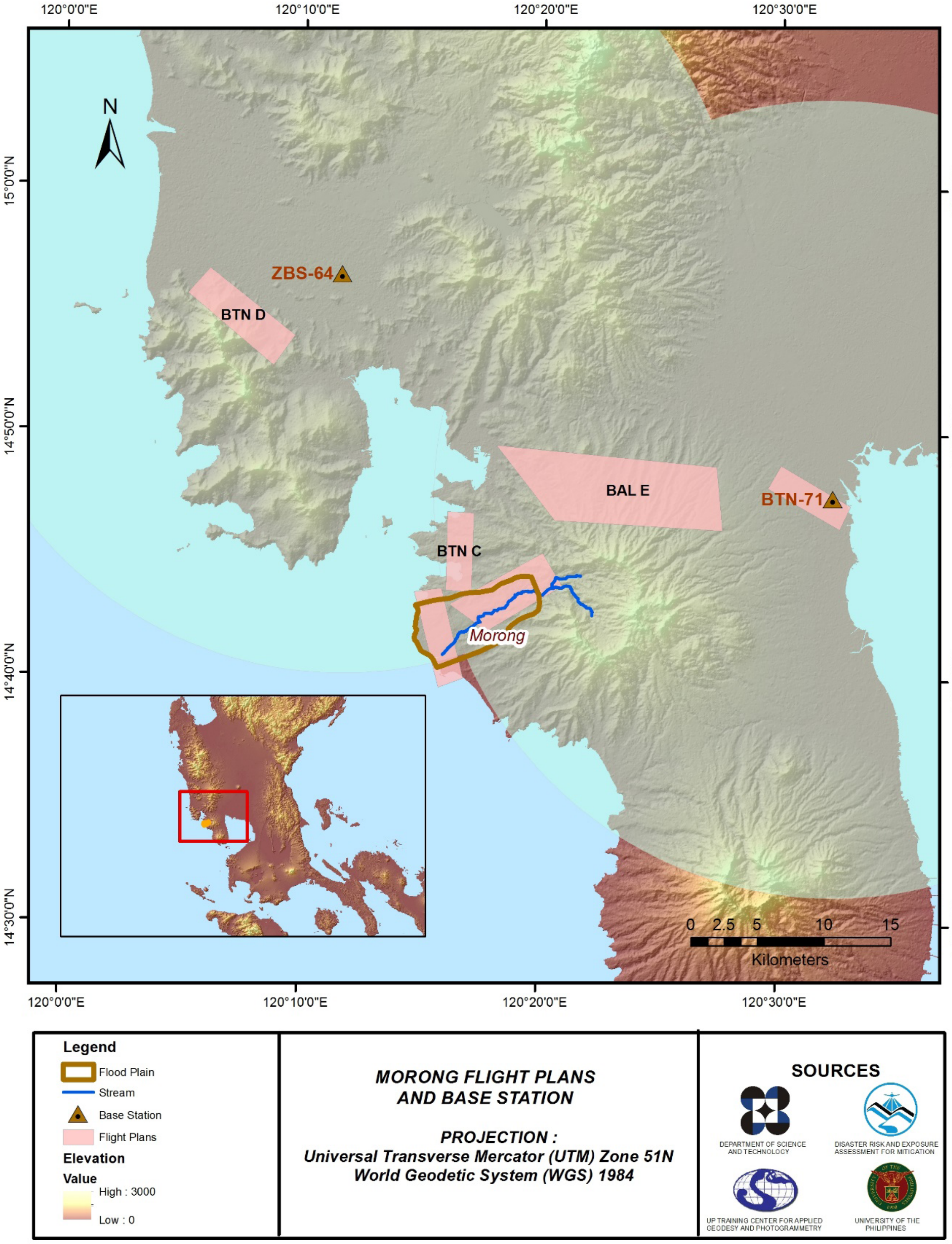
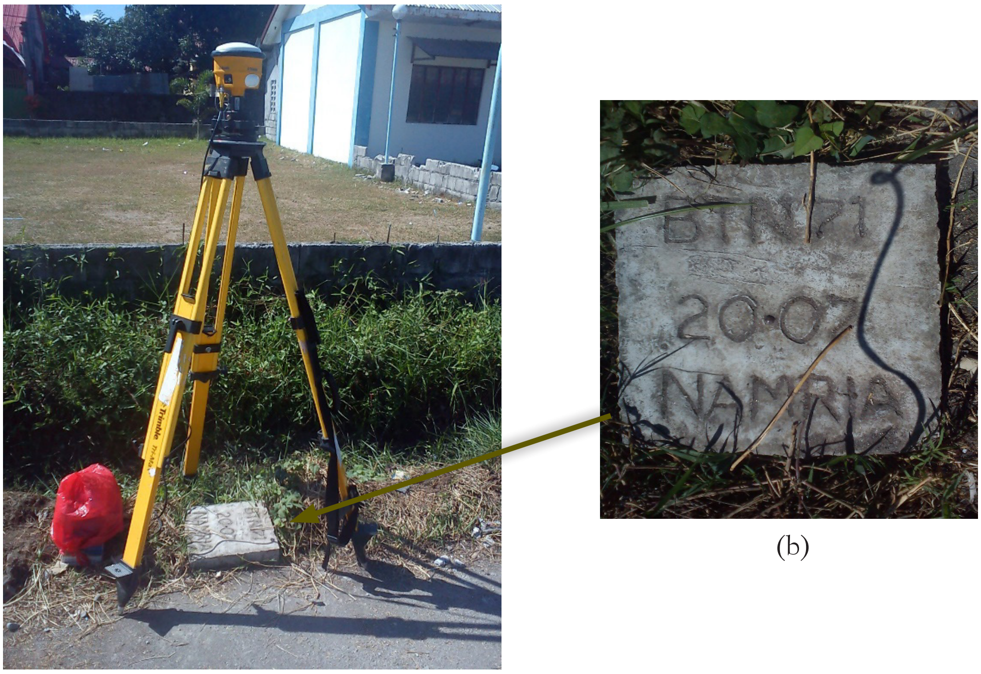



Figure 3. Flight plans and base stations used for Morong floodplain using Gemini Sensor

## 2.2 Ground Base Station

The project team was able to recover two (2) NAMRIA horizontal ground control points: BTN-71 and ZBS-64which are both of second (2nd) order accuracy. The project team also established one ground control point (AAC-01). The certification for the NAMRIA reference points and benchmarks are found in ANNEX A-2 while the baseline processing of the ground control points are found in ANNEX A-3. These were used as base stations during flight operations for the entire duration of the survey (January 2, 2014, January 23, 2015, and August 26, 2015). Base stations were observed using dual frequency GPS receivers, TOPCON GR5 and TRIMBLE SPS985. Flight plans and location of base stations used during the aerial LiDAR Acquisition in Morong floodplain are shown in Figure 2 and Figure 3.

Figure 4 to Figure 5 show the recovered NAMRIA reference points within the area. In addition, Table 3 to Table 5 show the details about the following NAMRIA control stations and established points, while Table 6 shows the list of all ground control points occupied during the acquisition with the corresponding dates of utilization.

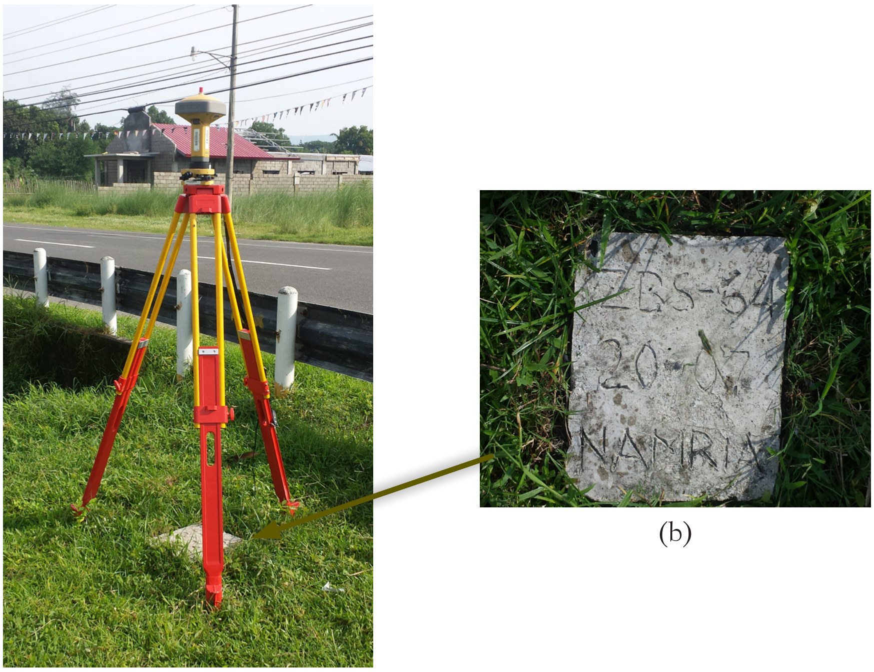



(a) (b)

Figure 4. GPS set-up over BTN-71 located in Brgy. Maria Fe, Orani, 30 meters southwest of the Day Care Center, 20 meters southeast of the basketball court and 15 meters of the chapel (a) and NAMRIA reference point BTN-71 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point BTN-71 used as base station for the LiDAR acquisition.

| Station Name | BTN-71 | |
|---|---|---|
| Order of Accuracy | 2nd | |
| Relative Error (horizontal positioning) | 1:50,000 | |
| Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92) | Latitude | 14°47' 30.18239" North |
| | Longitude | 120°32' 9.95860" East |
| | Ellipsoidal Height | 7.56300 meters |
| Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92) | Easting | 450060.675 meters |
| | Northing | 1635812.88 meters |
| Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84) | Latitude | 14°47' 24.68277" North |
| | Longitude | 120° 32' 14.83855" East |
| | Ellipsoidal Height | 49.42500 meters |
| Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992) | Easting | 234,782.54 meters |
| | Northing | 1,636,645.28 meters |




(b)

(a)

Figure 5. GPS set-up over ZBS-64 located in Brgy. Magsaysay which is about one (1) kilometer of Castillejos Municipal Hall (a) and NAMRIA reference point ZBS-64 (b) as recovered by the field team.

Table 4. Details of the recovered NAMRIA horizontal control point ZBS-64 used as base station for the LiDAR acquisition.

| Station Name | | ZBS-64 |
|---|---|---|
| Order of Accuracy | | 2nd |
| Relative Error (horizontal positioning) | | 1:50,000 |
| Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92) | Latitude | 14°56’ 28.82886” North |
| | Longitude | 120°11’ 31.25386” East |
| | Ellipsoidal Height | 52.07500 meters |
| Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92) | Easting | 413077.841 meters |
| | Northing | 1652473.038 meters |
| Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84) | Latitude | 14°56’ 23.26711” North |
| | Longitude | 120° 11’ 36.12262” East |
| | Ellipsoidal Height | 92.66800 meters |
| Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992) | Easting | 197, 928.90 meters |
| | Northing | 1,653,646.25 meters |

Table 5. Details of the established NAMRIA horizontal control point AAC-01 used as base station for the LiDAR acquisition.

| | | |
|---|---|---|
| Station Name | AAC-01 | |
| Order of Accuracy | 1st | |
| Relative Error (horizontal positioning) | 1:100,000 | |
| Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92) | Latitude | 15°11’ 27.81685” North |
| | Longitude | 120°32’ 43.37833” East |
| | Ellipsoidal Height | 154.260 meters |
| Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92) | Easting | 2366272.483 meters |
| | Northing | 1680836.256 meters |
| Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84) | Latitude | 15°11’ 22.22626” North |
| | Longitude | 120° 32’ 48.22418” East |
| | Ellipsoidal Height | 194.988 meters |

Table 6. Ground control points used during LiDAR data acquisition.

| Date Surveyed | Flight Number | Mission Name | Ground Control Points |
|---|---|---|---|
| January 2, 2014 | 926G | 2BALE002A | BTN-71 |
| January 23, 2015 | 2481P | 1BTN023A | AAC-01 and ZBS-64 |
| August 27, 2015 | 2658G | 2BTNCD239A | ZBS-64 |

## 2.3 Flight Missions

Three (3) missions were conducted to complete LiDAR data acquisition in Morong Floodplain, for a total of twelve hours and twenty seven minutes (12+27) of flying time for RP-C9122, RP-C9022 and RP-9322. All missions were acquired using Gemini and Pegasus LiDAR systems. Table 7 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 8 presents the actual parameters used during the LiDAR data acquisition.

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

| Date Surveyed | Flight Number | Flight Plan Area ($km^2$) | Surveyed Area ($km^2$) | Area Surveyed within the Floodplain ($km^2$) | Area Surveyed Outside the Floodplain ($km^2$) | No. of Images (Frames) | Flying Hours | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Hr | Min |
| January 2, 2014 | 926G | 85.47 | 88.41 | 0 | 88.41 | 402 | 4 | 05 |
| January 23, 2015 | 2481P | 133.76 | 164.91 | 24.17 | 140.74 | 0 | 4 | 23 |
| August 27, 2015 | 2658G | 69.96 | 84.98 | 28.47 | 56.51 | 347 | 3 | 59 |
| TOTAL | | 289.19 | 338.3 | 52.64 | 285.66 | 749 | 12 | 27 |

Table 8. Actual parameters used during LiDAR data acquisition

| Flight Number | Flying Height (m AGL) | Overlap (%) | FOV (θ) | PRF (khz) | Scan Frequency (Hz) | Average Speed (kts) | Average Turn Time (Minutes) |
|---|---|---|---|---|---|---|---|
| 926G | 1000 | 30 | 40 | 100 | 50 | 120 | 5 |
| 2481P | 1000 | 30 | 50 | 200 | 30 | 120 | 5 |
| 2658G | 800 | 30 | 50 | 100 | 40 | 120 | 5 |

## 2.4 Survey Coverage

Morong floodplain is located in the municipality of Morong, Bataan. Municipalities of Morong, Hermosa, San Marcelino, and San Antonio are mostly covered by the survey. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 9. The actual coverage of the LiDAR acquisition for Morong Floodplain is presented in Figure 6.

Table 9. List of municipalities and cities surveyed during Morong floodplain LiDAR survey.

| Province | Municipality/City | Area of Municipality/ City($km^2$) | Total Area Surveyed ($km^2$) | Percentage of Area Surveyed |
|---|---|---|---|---|
| Bataan | Morong | 240.57 | 114.86 | 48% |
| | Hermosa | 135.27 | 46.01 | 34% |
| | Orani | 53.25 | 12.067 | 23% |
| Zambales | San Felipe | 96.23 | 10.02 | 10% |
| | San Antonio | 179.70 | 18.21 | 10% |
| | Olongapo City | 178.25 | 14.31 | 8% |
| | San Marcelino | 337.57 | 26.40 | 8% |
| | Cabangan | 231.28 | 15.87 | 7% |
| | Subic | 253.59 | 5.54 | 2% |
| | Castillejos | 72.10 | 1.10 | 2% |
| | Botolan | 649.68 | 7.82 | 1% |

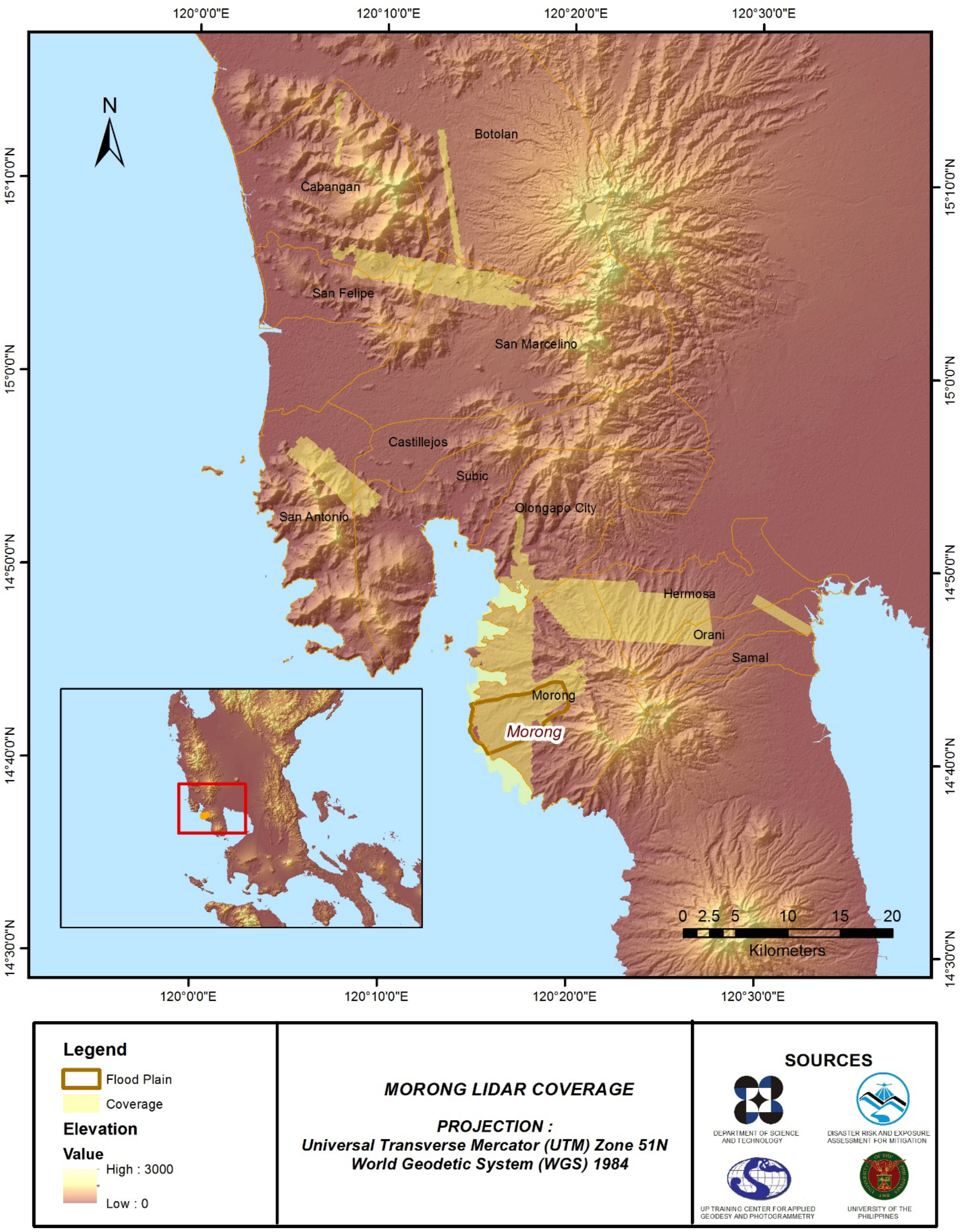



Figure 6. Actual LiDAR survey coverage for Morong floodplain.

# CHAPTER 3 LIDAR DATA PROCESSING FOR MORONG FLOODPLAIN

Engr. Ma. Rosario Concepcion O. Ang, Engr. John Louie D. Fabila, Engr. Sarah Jane D. Samalburo , Engr. Gladys Mae Apat , Engr. Elainne R. Lopez , Aljon Rie V. Araneta, Engr. Vincent Louise DL. Azucena, Engr. Abigail C. Ching , Engr. Jommer M. Medina, John Andrew B. Cruz, Gloria N. Ramos, Hanna Mae T. Carganilla, Cenon Conrado C. Divina, Jeremy Joel J. Barza, Kathrina Mapanao, Melissa Joy Sison, Kevin Christian Manipon

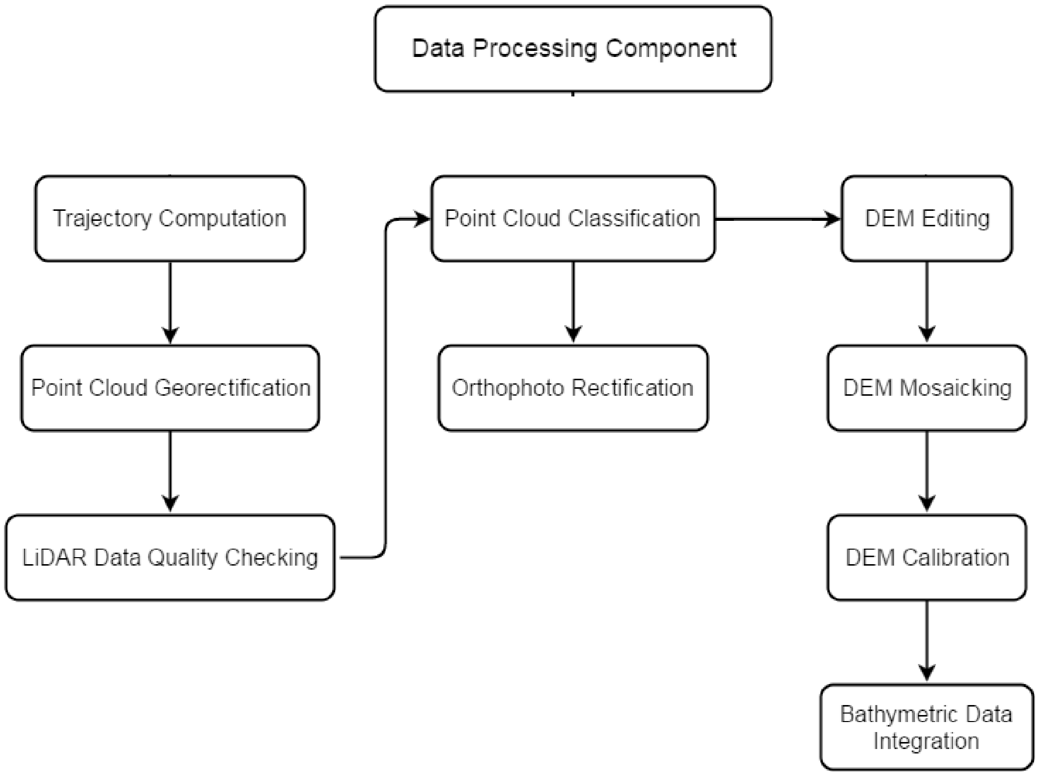



Figure 7. Schematic Diagram for Data Pre-Processing Component

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

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

These processes are summarized in the flowchart shown in Figure 7.

## 3.1 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Morong floodplain can be found in ANNEX A-5. Data Transfer Sheets. Missions flown during the first survey conducted on January 2014 and second survey conducted on January 2015 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc. ) both Pegasus and Gemini system over Municipality of Morong, Bataan. The Data Acquisition Component (DAC) transferred a total of 51.0 Gigabytes of Range data, 748 Megabytes of POS data, 105.85 Megabytes of GPS base station data, and 38.80 Gigabytes of raw image data to the data server on September 10, 2015. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Morong was fully transferred on October 05, 2015 as indicated on the Data Transfer Sheets for Morong floodplain.

## 3.2 Trajectory Computation

The *Smoothed Performance Metric* parameters of the computed trajectory for flight 2658G, one of the Morong flights, which is the North, East, and Down position RMSE values are shown in Figure 8. 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 August 23, 2015 00:00AM. The y-axis is the RMSE value for that particular position.

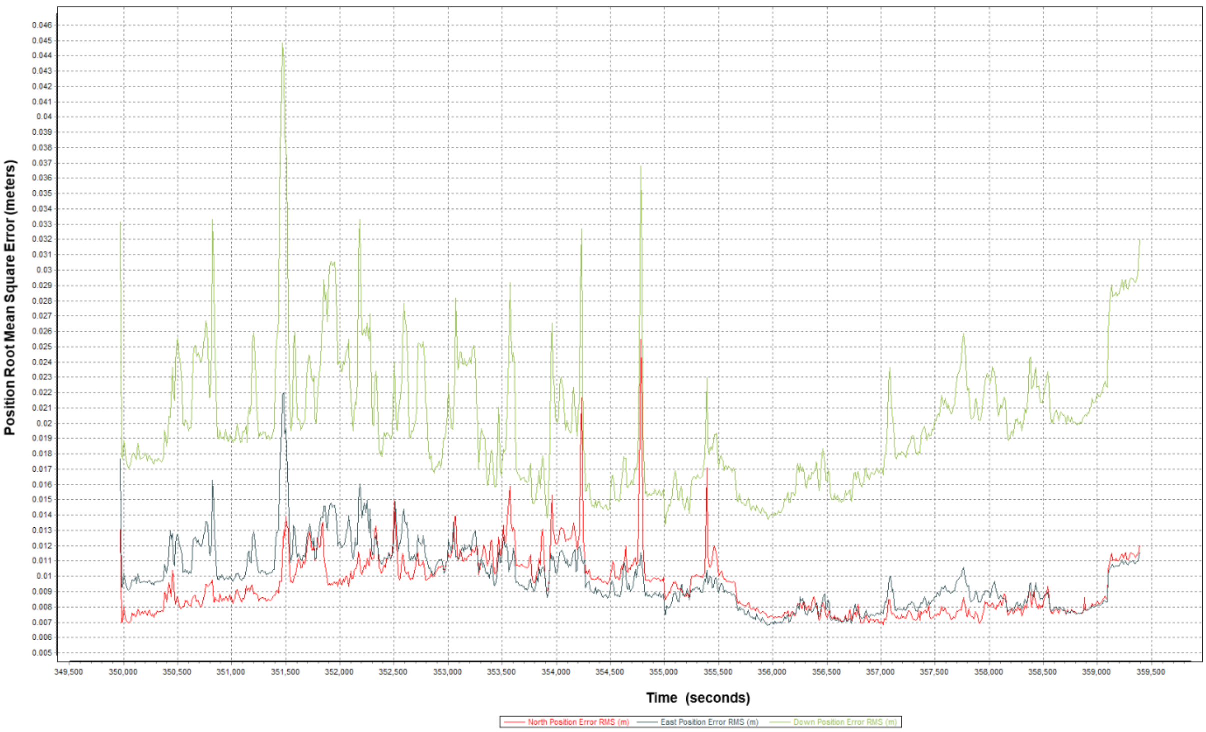



Figure 8. Smoothed Performance Metrics of a Morong Flight 2658G.

The time of flight was from 350,000 seconds to 359,500 seconds, which corresponds to morning of August 27, 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 POS system starts computing for the position and orientation of the aircraft. Redundant measurements from the POS system quickly minimize the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values correspond to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 8 shows that the North position RMSE peaks at 2.55 centimeters, the East position RMSE peaks at 2.20 centimeters, and the Down position RMSE peaks at 4.49 centimeters, which are within the prescribed accuracies described in the methodology.

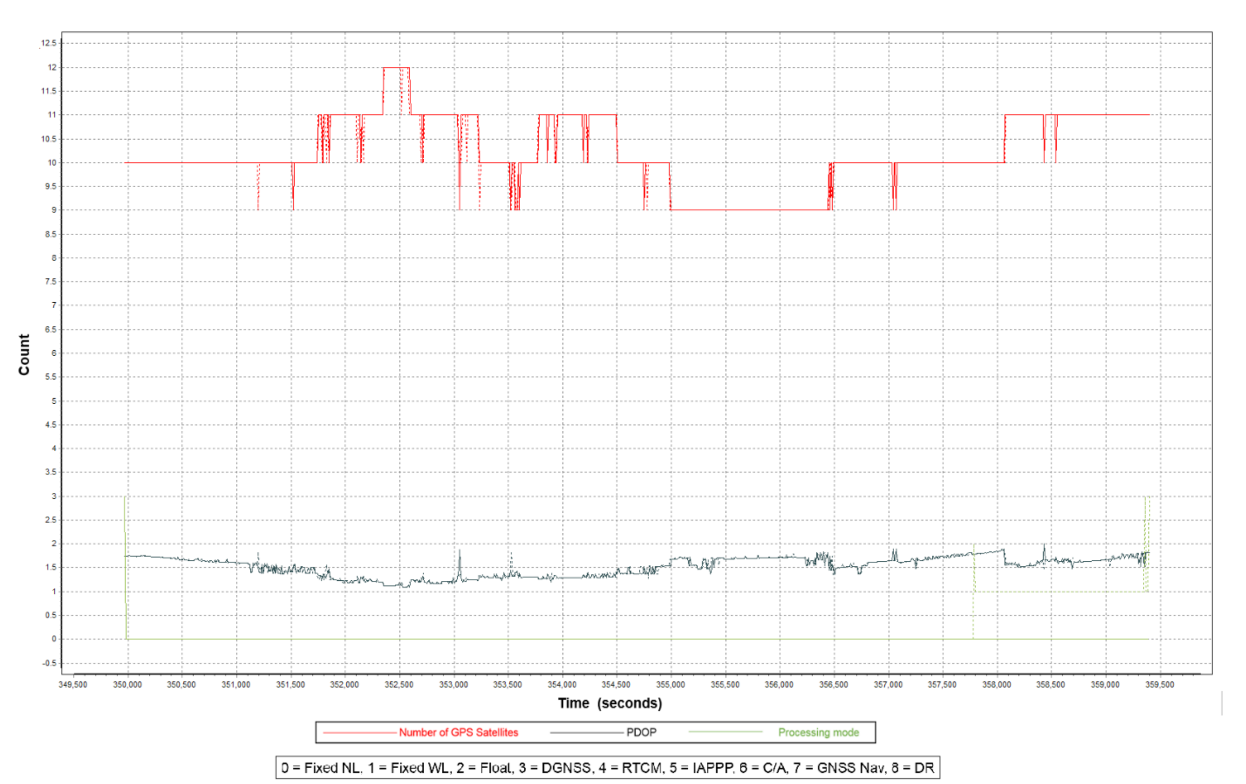



Figure 9. Solution Status Parameters of Morong Flight 2658G.

The *Solution Status* parameters of flight 2658G, one of the Morong flights, which are the number of GPS satellites, Positional Dilution of Precision, and the GPS processing mode used, are shown in Figure 9. The graphs indicate that the number of satellites during the acquisition did not go down below 9. Majority of the time, the number of satellites tracked was between 9 and12.  The PDOP value also 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 Morong flights is shown in Figure 10.

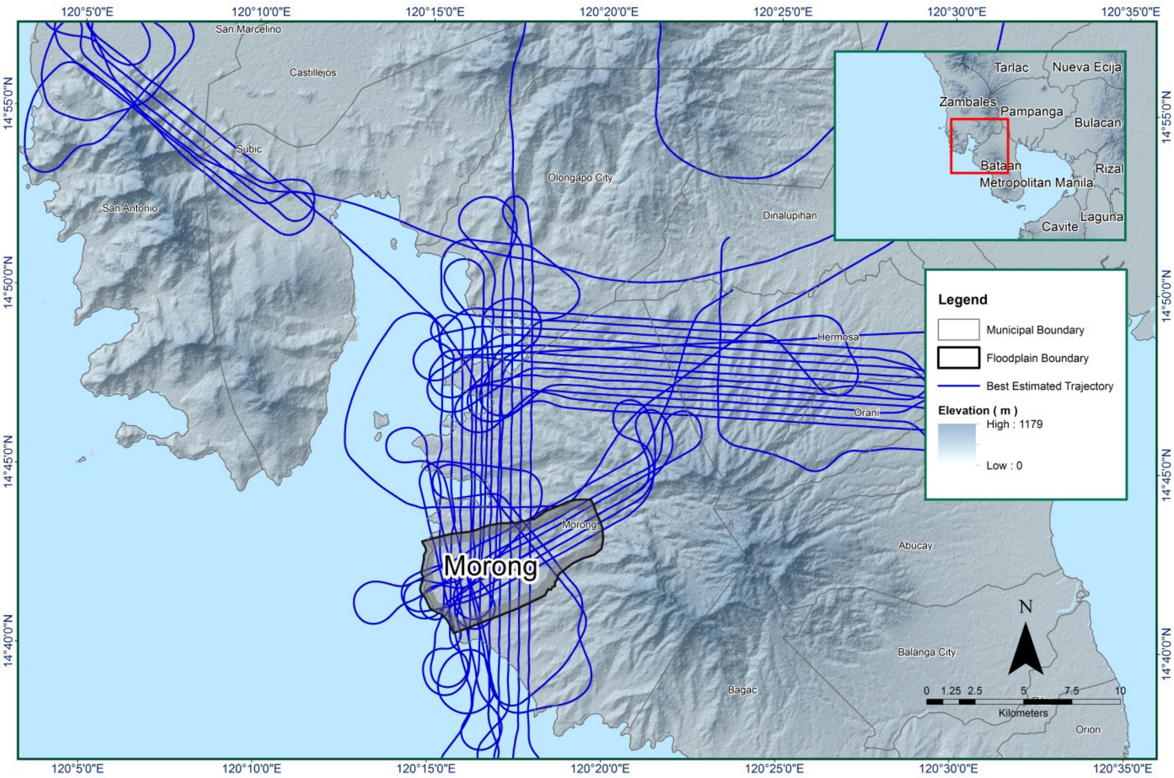



Figure 10. Best Estimated Trajectory for Morong floodplain.

## 3.3 LiDAR Point Cloud Computation

The produced LAS data contains 49 flight lines, thirteen (13) of those flight lines contains only one (1) channel for the Gemini system,and the remaining 36 flight lines contains two channels since the Pegasus system contains two channels. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Morong floodplain are given in Table 10.

Table 10. Self-Calibration Results values for Morong flights.

| Parameter | Value |
|---|---|
| Boresight Correction stdev (<0.001degrees) | 0.000479 |
| IMU Attitude Correction Roll and Pitch Corrections stdev (<0.001degrees) | 0.000981 |
| GPS Position Z-correction stdev (<0.01meters) | 0.0092 |

The optimum accuracy is obtained for all Morong flights based on the computed standard deviations of the corrections of the orientation parameters. Standard deviation values for individual blocks are available in the ANNEX A-8.

## 3.4 LiDAR Data Quality Checking

The boundary of the processed LiDAR data is shown in Figure 11. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

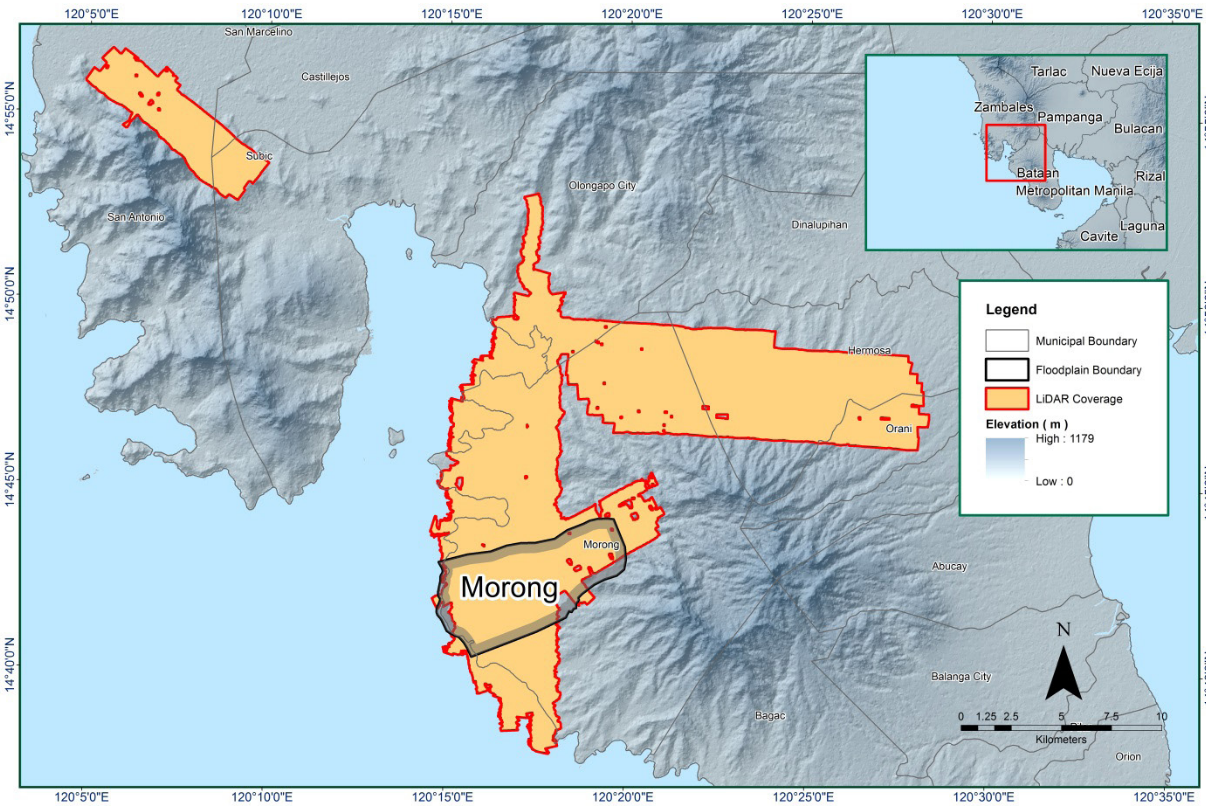



Figure 11. Boundary of the processed LiDAR data over Morong Floodplain

The total area covered by the Morong missions is 278.08 sq.km that is comprised of three (3) flight acquisitions grouped and merged into three (3) blocks as shown in Table 11.

Table 11. List of LiDAR blocks for Morong floodplain.

| LiDAR Blocks | Flight Numbers | Area (sq. km) |
|---|---|---|
| Bataan_Bal_BlkE | 926G | 89.95 |
| Bataan_Reflights_Bal_BlkE_additional | 2481P | 107.25 |
| Clark_reflights_BTNCD | 2658G | 80.88 |
| **TOTAL** | | **278.08** |

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 12. Since the Pegasus system employs two channels and the Gemini system employs one channel, we would expect an average value of 2 (blue) for areas where there is limited overlap, and a value of 3 (yellow) or more (red) for areas with three or more overlapping flight lines.

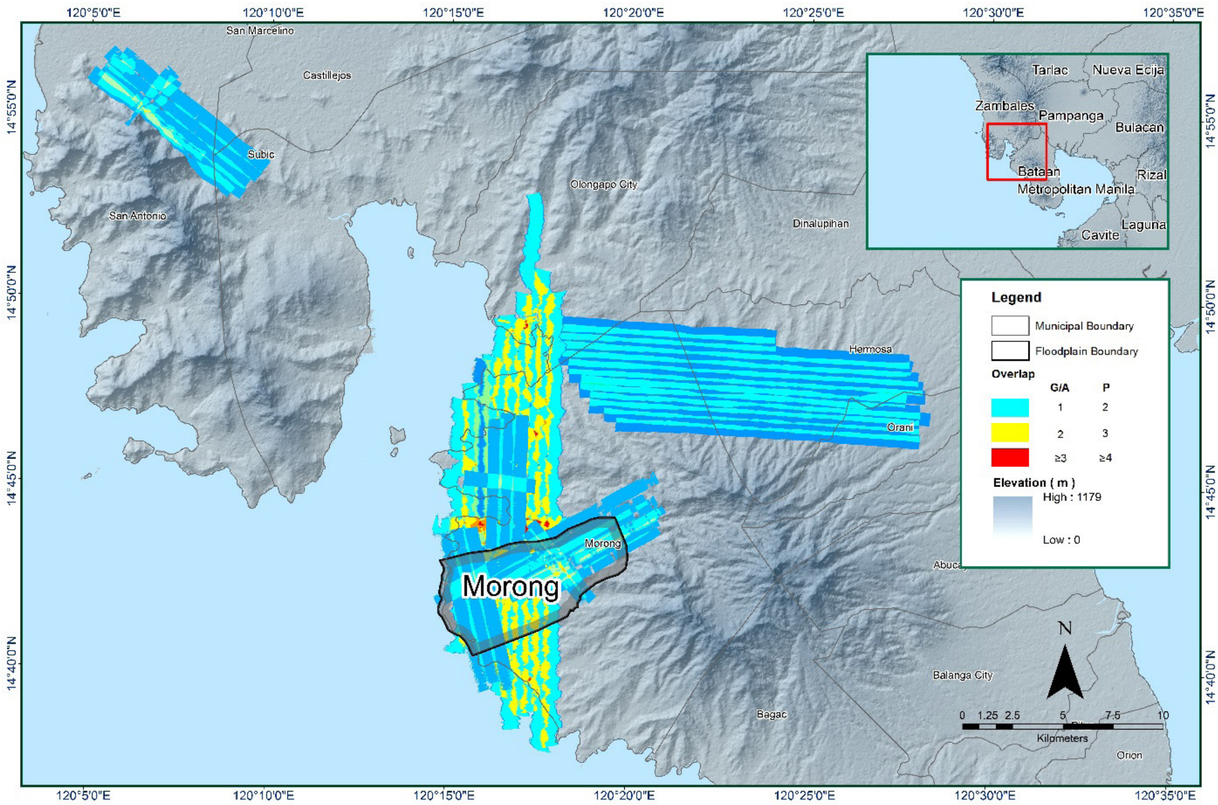



Figure 12. Image of data overlap for Morong floodplain.

The overlap statistics per block for the Morong floodplain can be found in ANNEX A-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 31.52% and 50.11% 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 13. It was determined that all LiDAR data for Morong floodplain satisfy the point density requirement, and the average density for the entire survey area is 4.12 points per square meter.

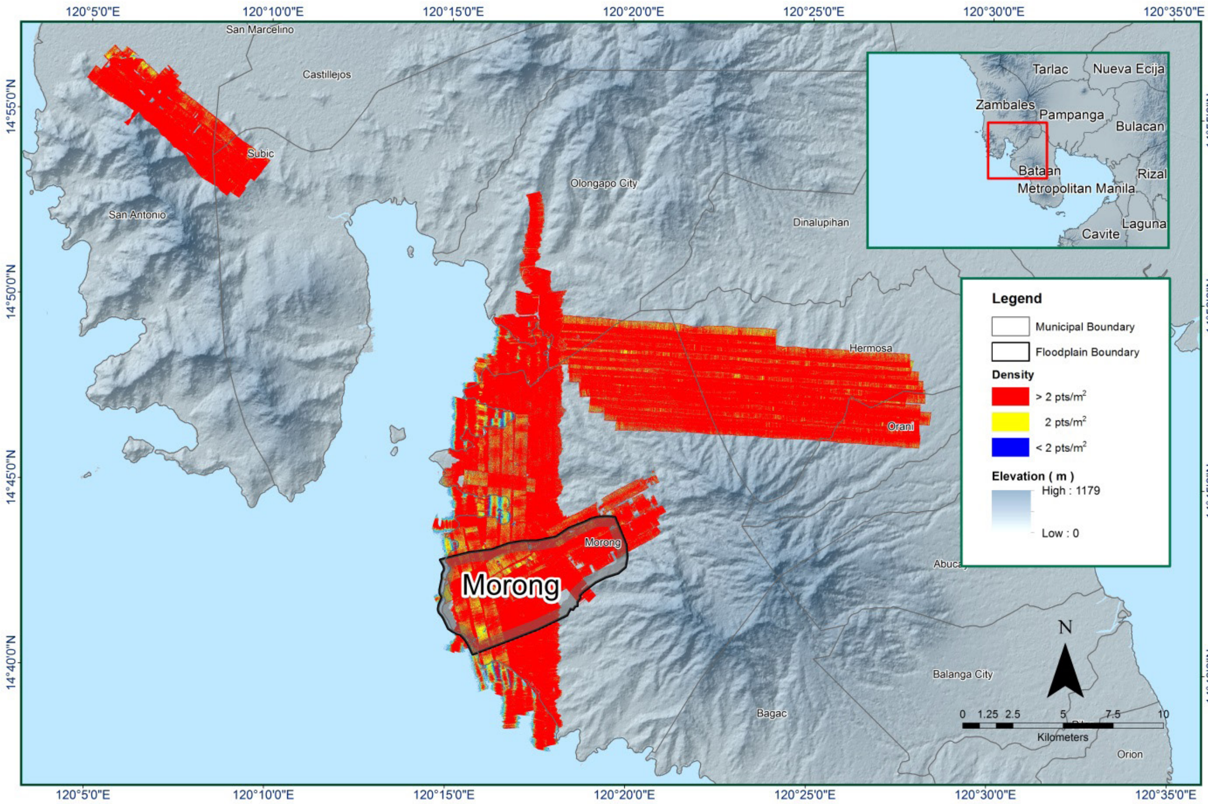



Figure 13. Pulse Density map of merged LiDAR data for Morong floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 14. The default color range is from blue to red, where bright blue areas correspond to portions where elevations of a previous flight line, identified by its acquisition time are higher by more than 0.20m relative to elevations of its adjacent flight line. Bright red areas indicate portions where elevations of a previous flight line are lower by more than 0.20m relative to elevations of its adjacent flight line. Areas with bright red or bright blue need to be investigated further using Quick Terrain Modeler software.

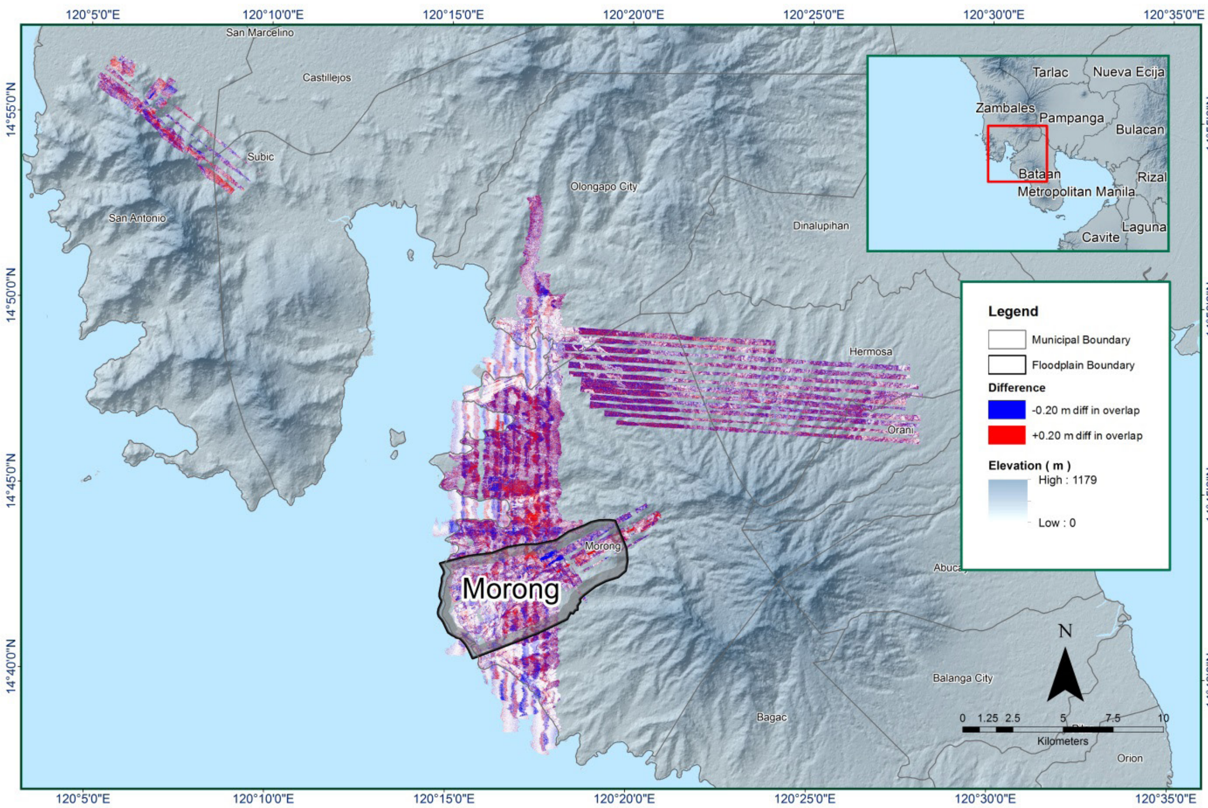



Figure 14. Elevation difference map between flight lines for Morong floodplain.

A screen capture of the processed LAS data from a Morong flight 2658G loaded in QT Modeler is shown in Figure 15. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed red line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

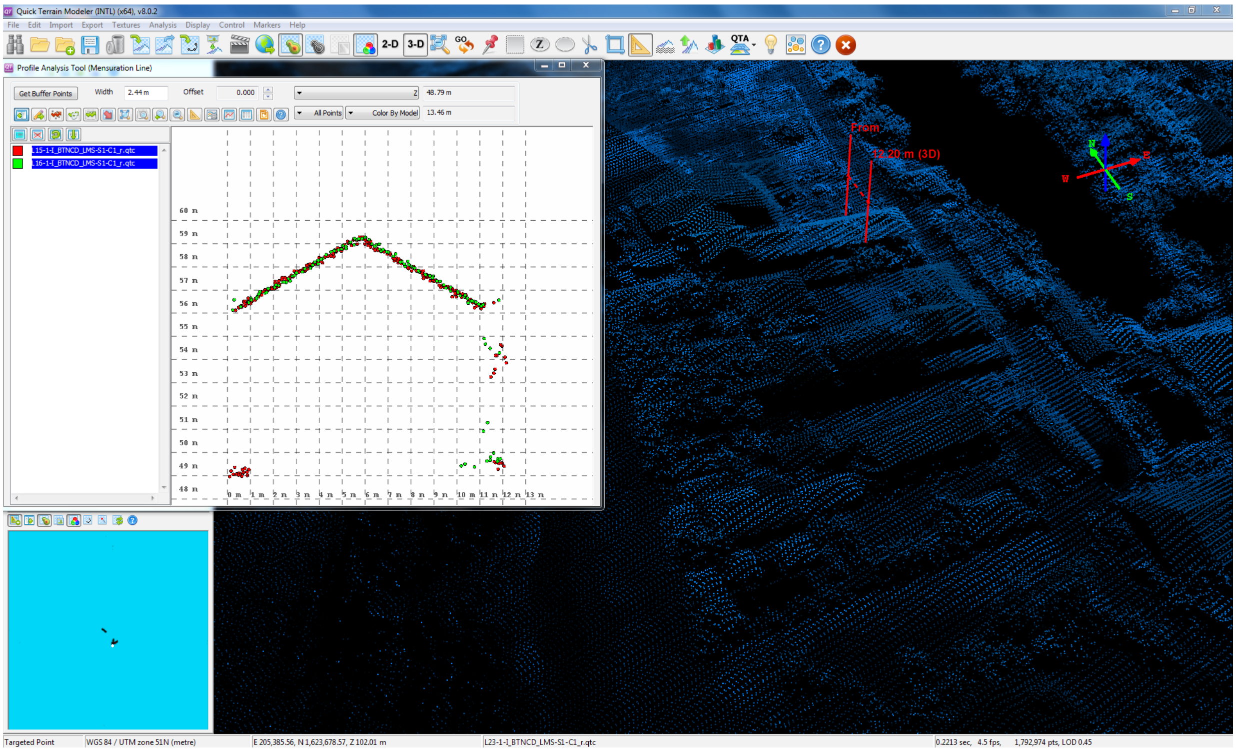


Figure 15. Quality checking for a Morong flight 2658G using the Profile Tool of QT Modeler.

## 3.5 LiDAR Point Cloud Classification and Rasterization

Table 12. Morong classification results in TerraScan.

| Pertinent Class | Total Number of Points |
|---|---|
| Ground | 193,857,135 |
| Low Vegetation | 160,000,845 |
| Medium Vegetation | 367,952,671 |
| High Vegetation | 680,792,010 |
| Building | 29,975,320 |

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Morong floodplain is shown in Figure 16. A total of 401 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 12. The point cloud has a maximum and minimum height of 756.92 meters and 29.33 meters respectively.

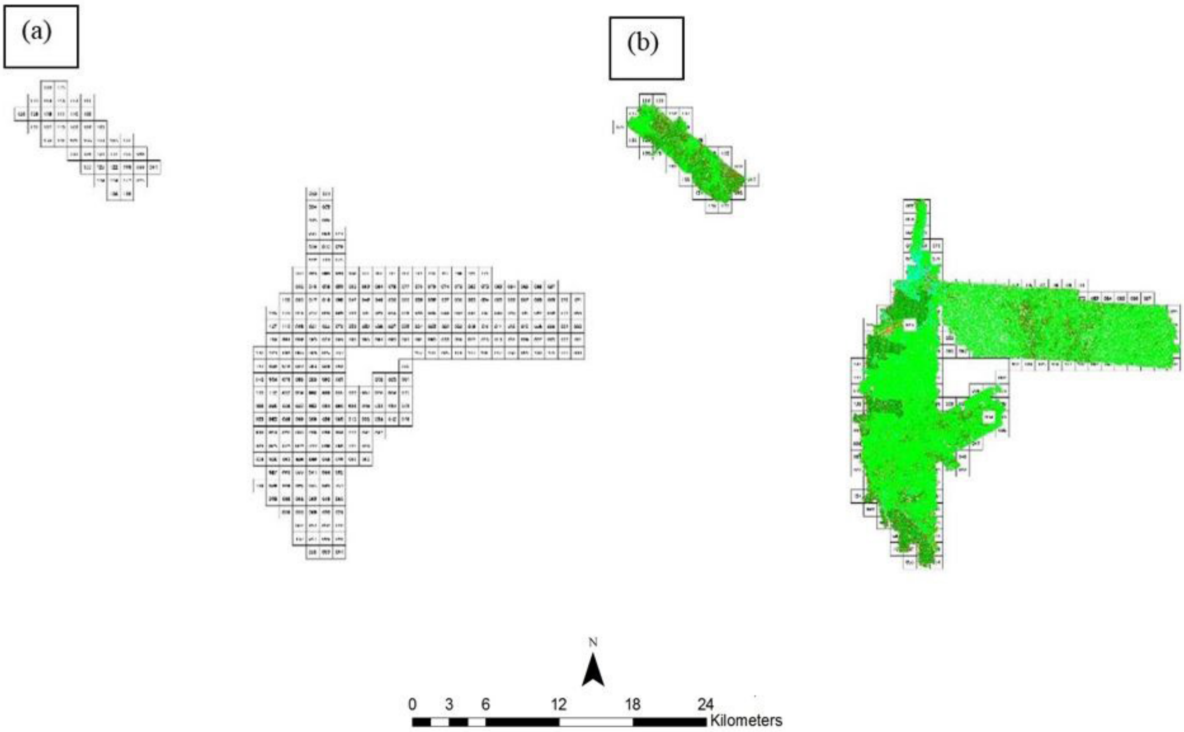



Figure 16. Tiles for Morong floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 17. 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.

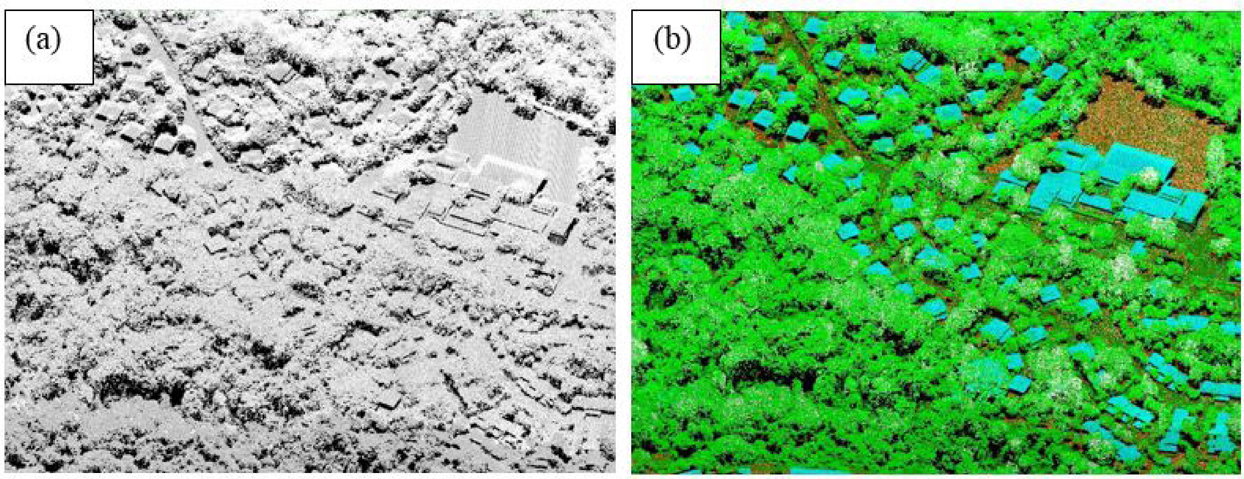



Figure 17. Point cloud before (a) and after (b) classification.

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

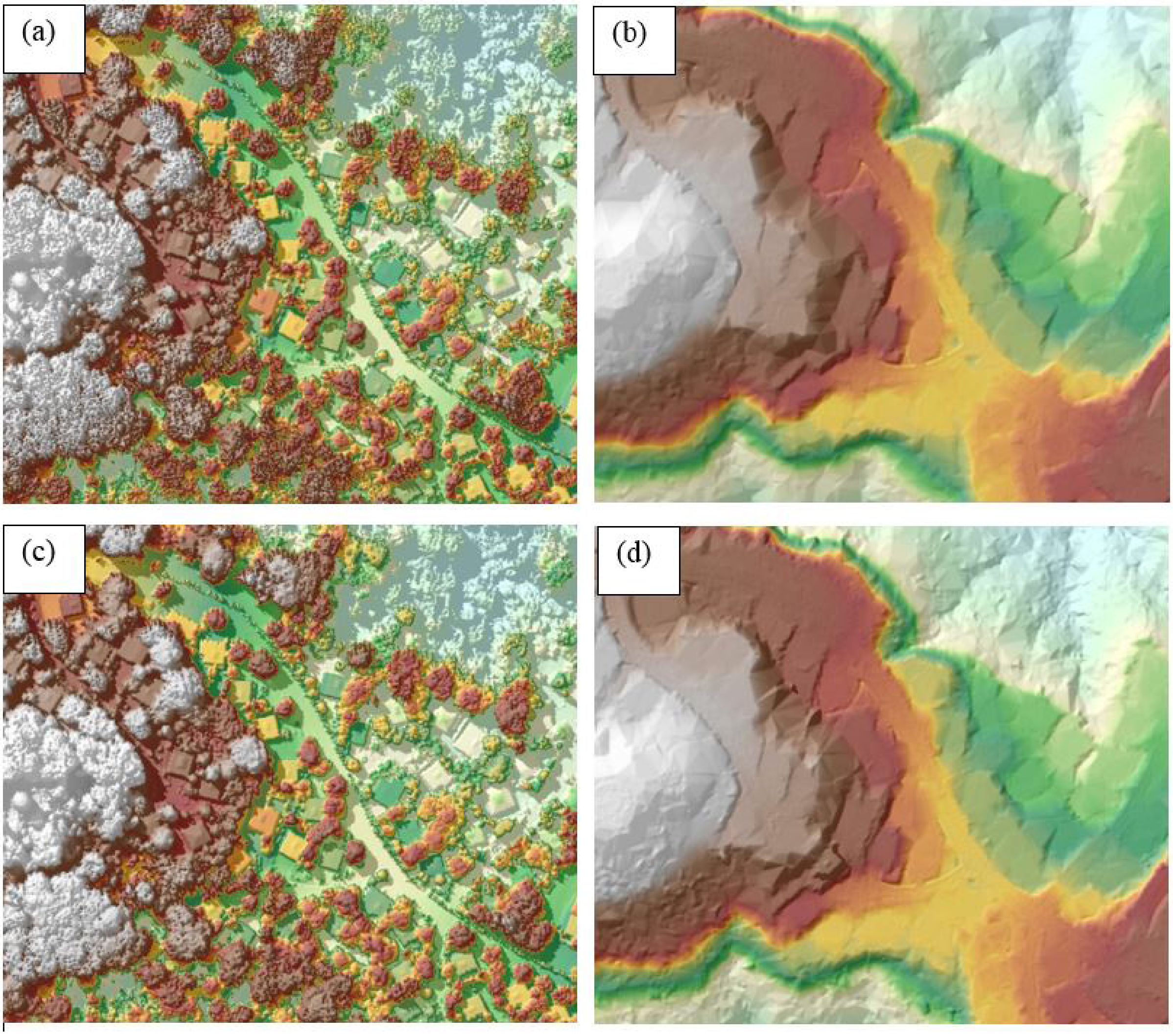



Figure 18. The Production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Morong floodplain.

## 3.6 LiDAR Image Processing and Orthophotograph Rectification

The 117 1km by 1km tiles area covered by Morong floodplain is shown in Figure 19. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Morong floodplain has a total of 91.26 sq.km orthophotogaph coverage comprised of 388 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 20.

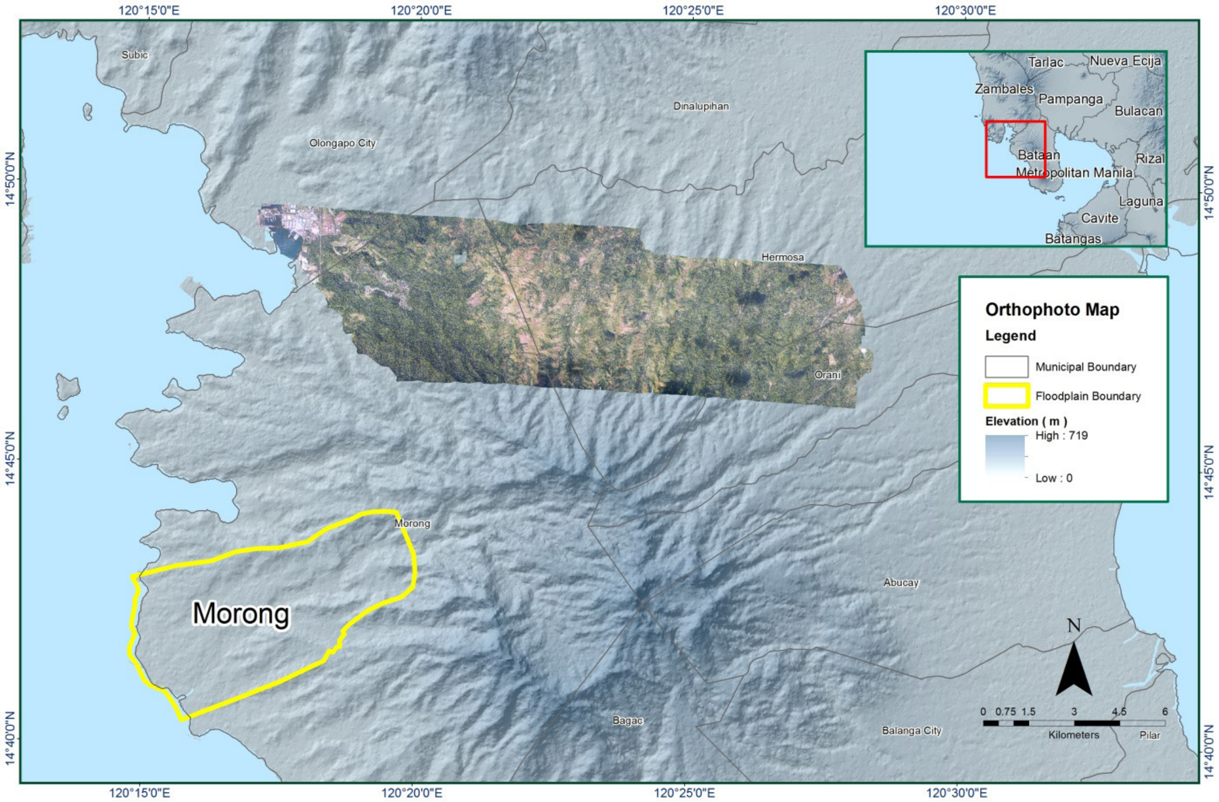



Figure 19. Morong floodplain with available orthophotographs.


Figure 20. Sample orthophotograph tiles for Morong floodplain.

## 3.7 DEM Editing and Hydro-Correction

Three (3) mission blocks were processed for Morong flood plain. These blocks are composed of Bataan, Bataan Reflights and Clark Reflights blocks with a total area of 278.08 square kilometers. Table 13 shows the name and corresponding area of each block in square kilometers.

Table 13. LiDAR blocks with its corresponding area.

| LiDAR Blocks | Area (sq. km) |
|---|---|
| Bataan_Bal_BlkE | 89.95 |
| Bataan_Reflights_Bal_BlkE_additional | 107.25 |
| Clark_reflights_BTNCD | 80.88 |
| **TOTAL** | **278.08** |

Portions of DTM before and after manual editing are shown in Figure 21. The bridge (Figure 21a) is considered to be an impedance to the flow of water along the river and has to be removed (Figure 21b) in order to hydrologically correct the river. Embankments (Figure 21c) have been misclassified and removed during classification process and has to be retrieved to complete the surface (Figure 21d) to allow the correct flow of water. Another example is a building that is still present in the DTM after classification (Figure 21e) and has to be removed through manual editing (Figure 21f).

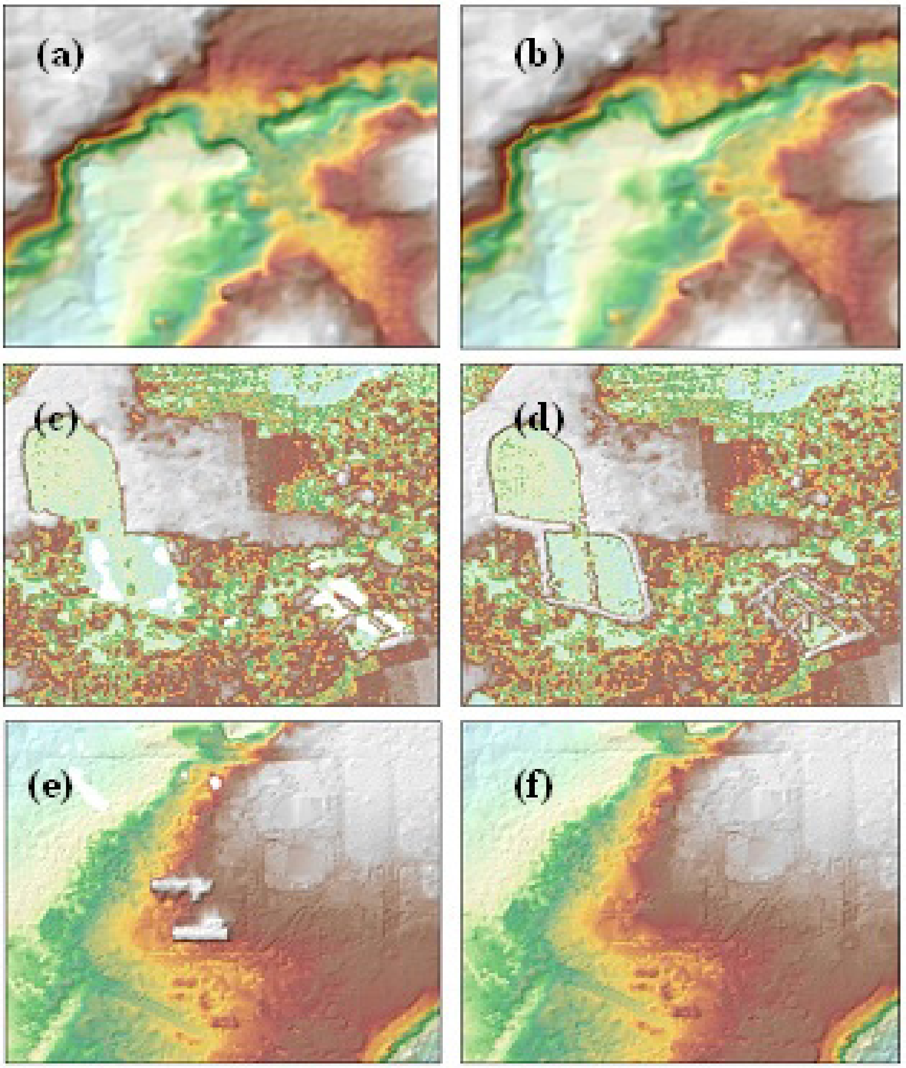



Figure 21. Portions in the DTM of Morong floodplain – a bridge before (a) and after (b) manual editing; a fish ponds before (c) and after (d) data retrieval; and a building before (e) and after (f) manual editing.

## 3.8 Mosaicking of Blocks

Clark_reflights Block BTNCD was used as the reference block at the start of mosaicking because it have the bigger area coveringthe flood plain.

Mosaicked LiDAR DTM for Morong floodplain is shown in Figure 22. The entire Morong floodplain is 89.92% covered by LiDAR data while portions with no Lidar data were patched with the available IFSAR data.

Table 14. Shift Values of each LiDAR Block of Morong floodplain.

| Mission Blocks | Shift Values (m) | | |
|---|---|---|---|
| | x | y | z |
| Bataan_Bal_BlkE | 0.07 | 2.91 | 1.90 |
| Bataan_Reflights_Bal_BlkE_additional | 0.00 | 0.00 | -0.40 |
| Clark_reflights_BtnCD | 0.00 | 0.00 | 0.45 |

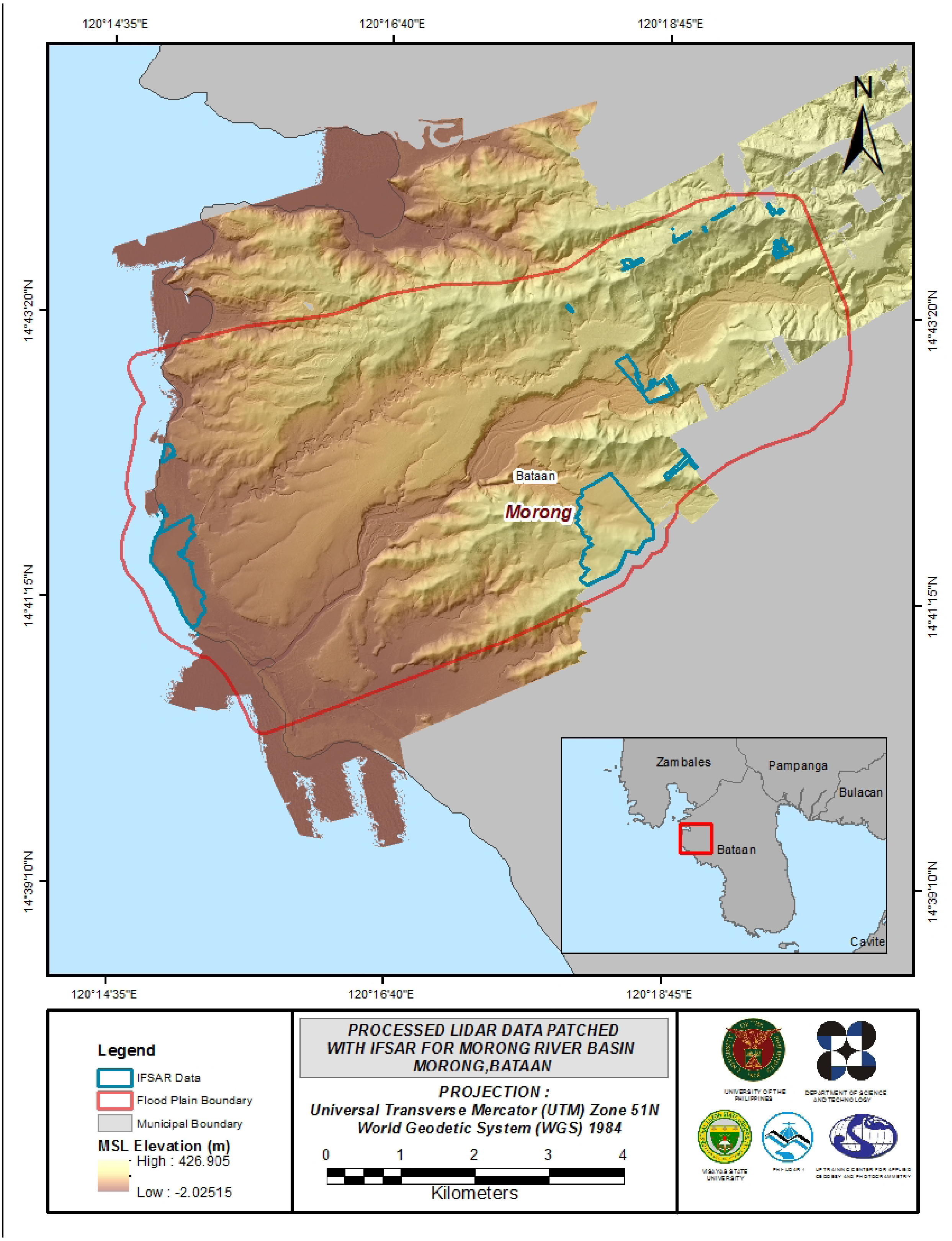



Figure 22. Map of Processed LiDAR Data for Morong Flood Plain.

## 3.9 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Morong to collect points with which the LiDAR dataset is validated is shown in Figure 23, with the validation survey points highlighted in green. Morong LiDAR data was calibrated using the validation survey points provided for BataanZambales area to be consistent with the other floodplains covered by the mosaicked blocks. A total of 30,472 survey points were gathered within BataanZambales wherein the Morong floodplain is located. Random selection of 80% of the survey points, resulting to 24,377 points, were used for calibration.

A good correlation between the uncalibrated BataanZambales LiDAR DTM and ground survey elevation values is shown in Figure 24. 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 points is 4.15 meters with a standard deviation of 0.15 meters. Calibration of Morong LiDAR data was done by subtracting the height difference value, 4.15 meters, to BataanZambales mosaicked LiDAR data. Table 15 shows the statistical values of the compared elevation values between BataanZambales LiDAR data and calibration data.

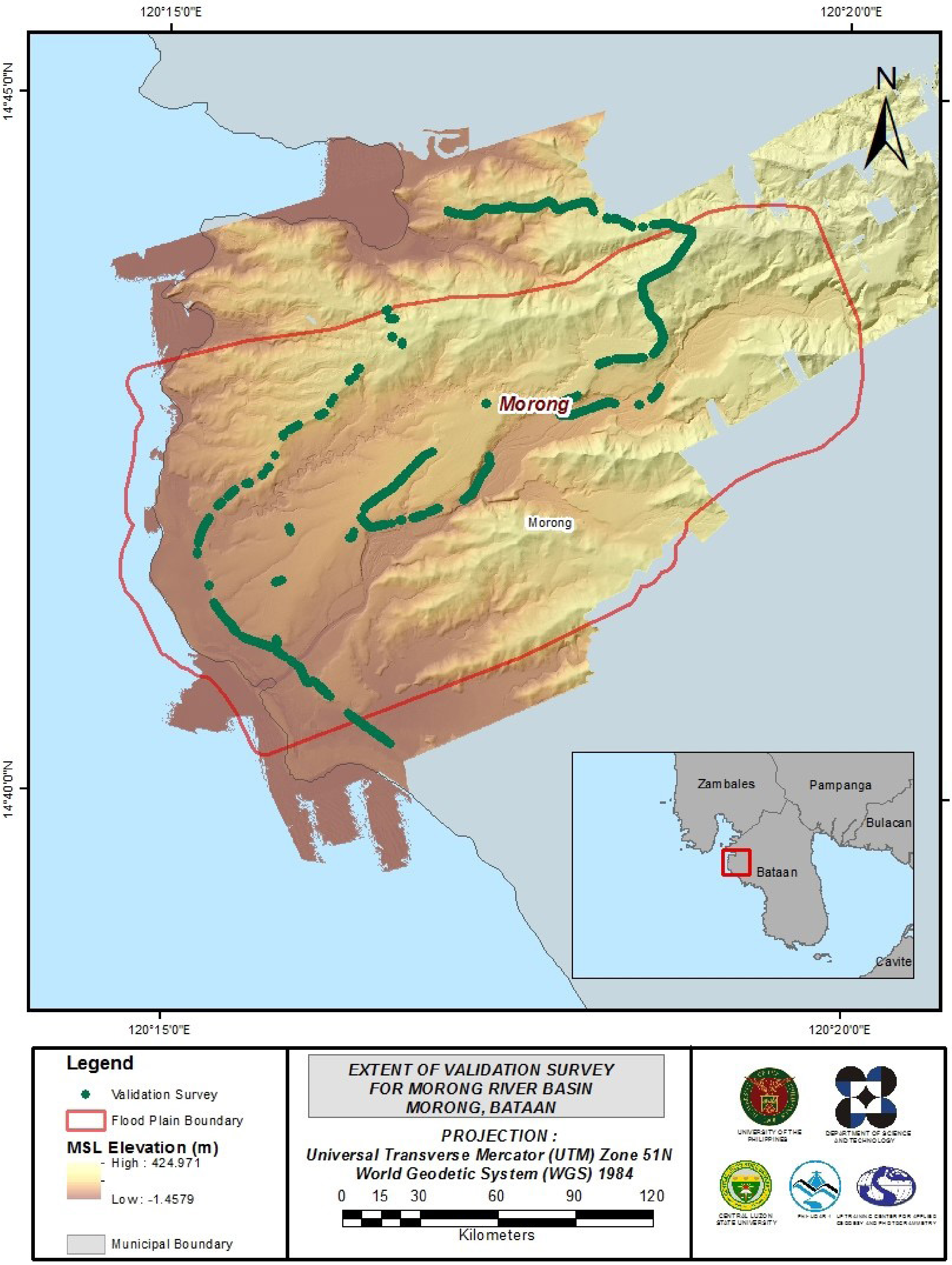



Figure 23. Map of Morong Flood Plain with validation survey points in green.

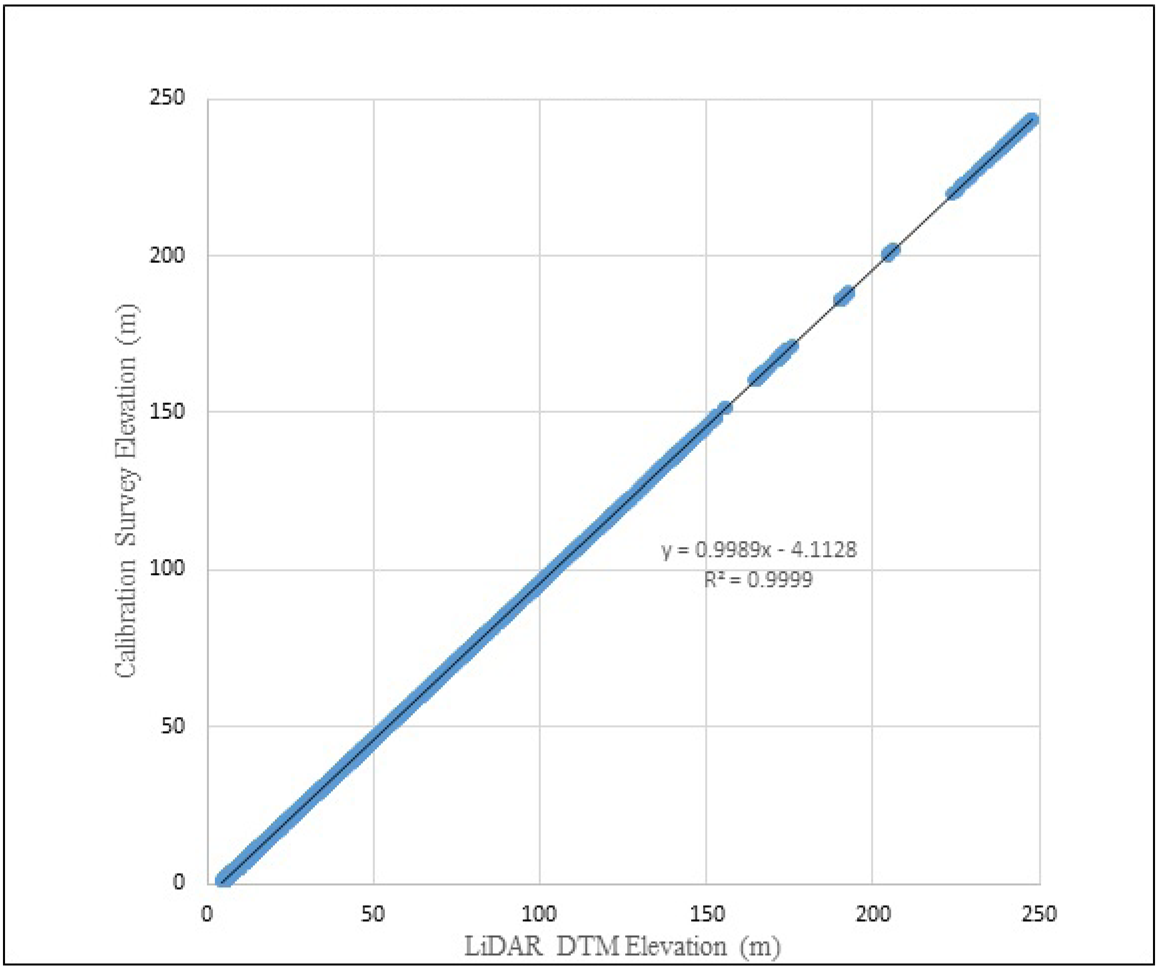



Figure 24. Correlation plot between calibration survey points and LiDAR data.

Table 15. Calibration Statistical Measures.

| Calibration Statistical Measures | Value (meters) |
|---|---|
| Height Difference | 4.15 |
| Standard Deviation | 0.15 |
| Average | -4.14 |
| Minimum | -4.50 |
| Maximum | -3.85 |

A total of 282 points, were used for the validation of calibrated Morong 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 25. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.12 meters with a standard deviation of 0.12 meters, as shown in Table 16.

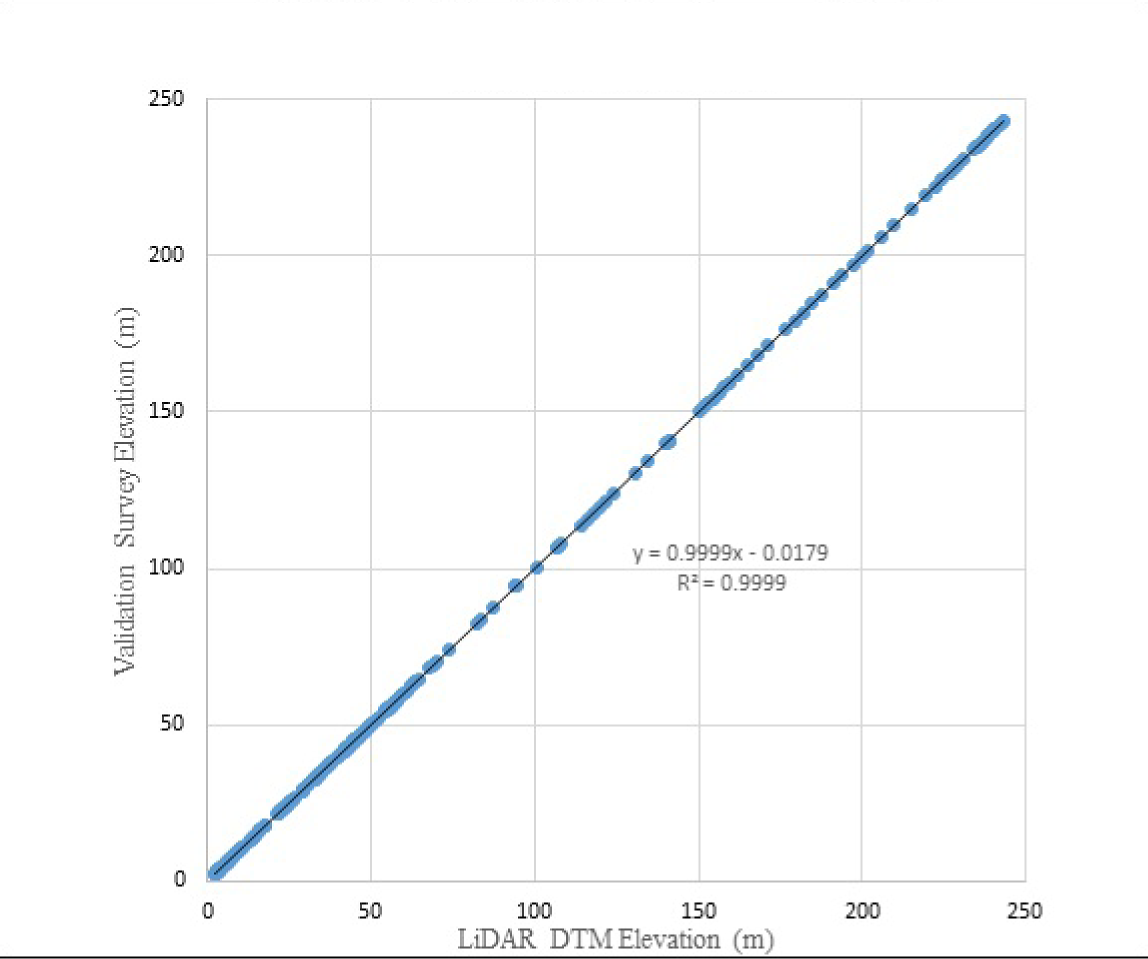



Figure 25. Correlation plot between validation survey points and LiDAR data.

Table 16. Validation Statistical Measures

| Validation Statistical Measures | Value (meters) |
|---|---|
| RMSE | 0.12 |
| Standard Deviation | 0.12 |
| Average | -0.03 |
| Minimum | -0.38 |
| Maximum | 0.28 |

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

For bathy integration, merged centerline and zigzag data were available for Morong with 20,129 bathymetric survey points. The resulting raster surface produced was done by Kernel Interpolation with Barriers (KIB) interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.21 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Morong integrated with the processed LiDAR DEM is shown in Figure 26.

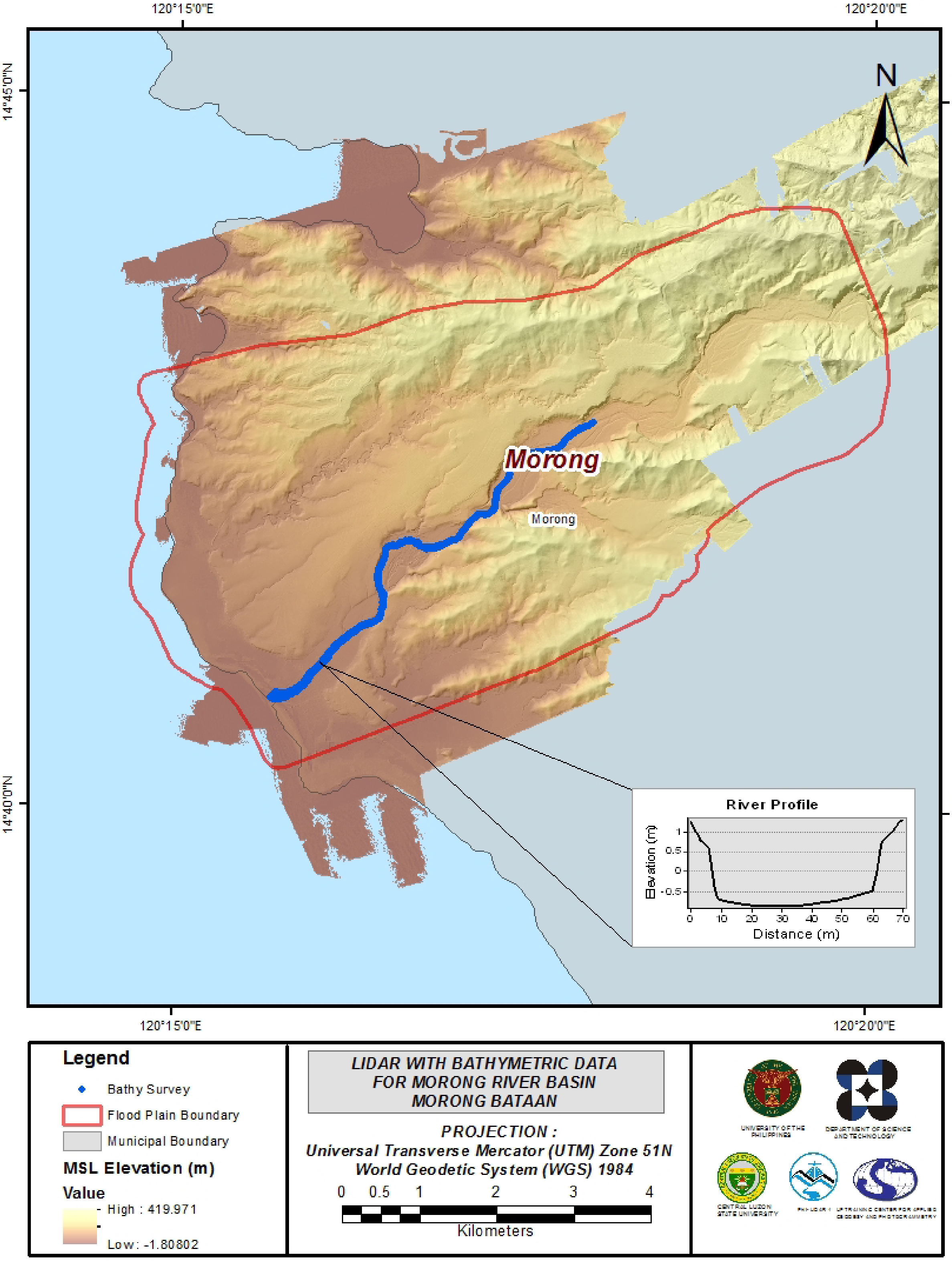



Figure 26. Map of Morong Flood Plain with bathymetric survey points shown in blue.

## 3.11 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.

### 3.11.1 Quality Checking of Digitized Features' Boundary

Morong floodplain, including its 200 m buffer, has a total area of 42.73sq km. For this area, a total of 5.00 sq km, corresponding to a total of 366 building features, are considered for QC. Figure 27 shows the QC blocks for Morong floodplain.

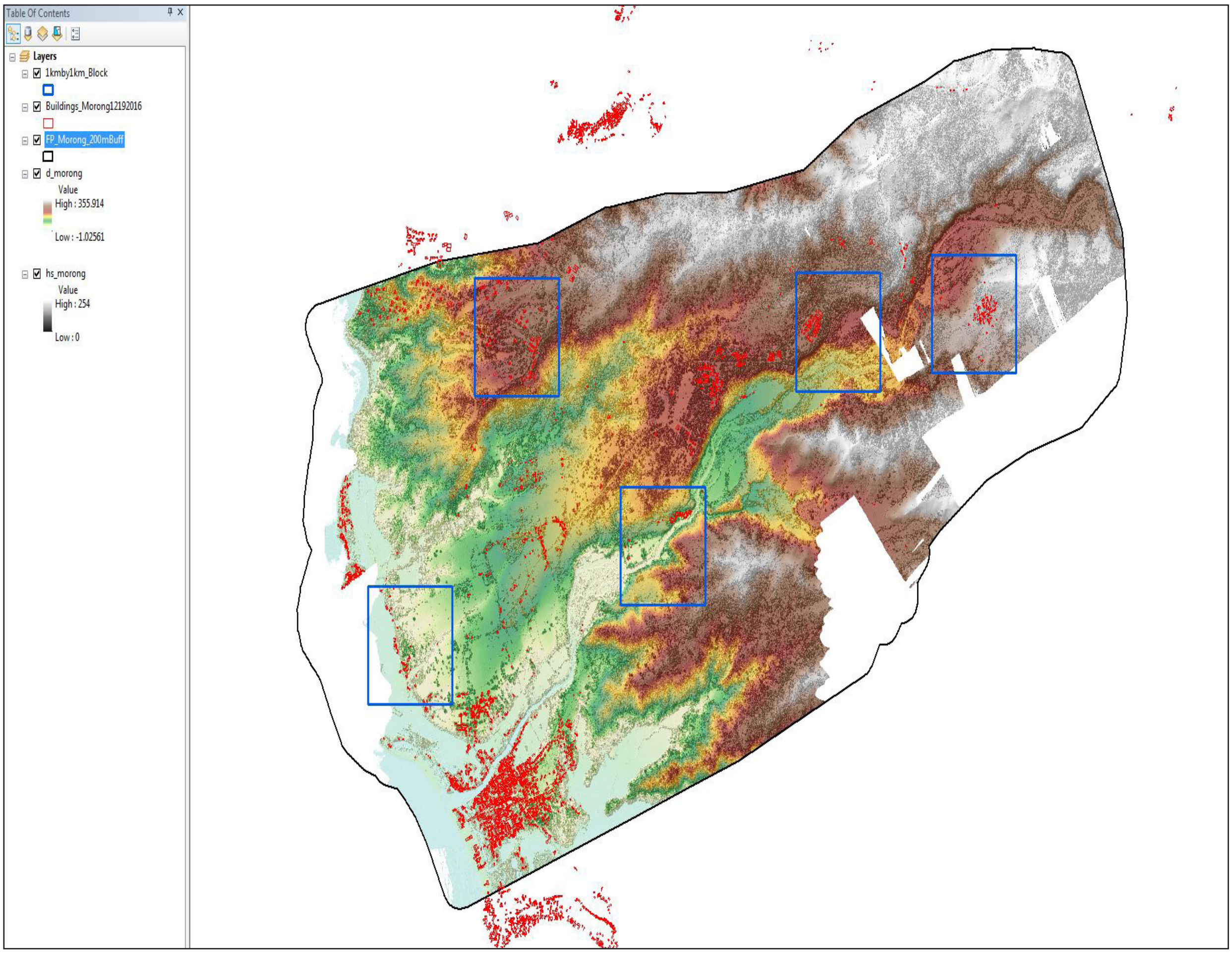



Figure 27. QC blocks for Morong building features.

Quality checking of Morong building features resulted in the ratings shown in Table 17.

Table 17. Quality Checking Ratings for Morong Building Features.

| FLOODPLAIN | COMPLETENESS | CORRECTNESS | QUALITY | REMARKS |
|---|---|---|---|---|
| Morong | 100.00 | 100.00 | 89.07 | PASSED |

### 3.11.2 Height Extraction

Height extraction was done for 4,700 building features in Morong floodplain. Of these building features, 28 was filtered out after height extraction, resulting to 4,672 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 11.95 m.

### 3.11.3 Feature Attribution

Field data gathering and ground verification were conducted in order to correct and complete the information needed in the attribution of the digitized features in the flood plains of the river basins.

The team used the video tagging/capture device installed in a vehicle that roamed around the floodplains to capture and tag the buildings, bridges, roads and water bodies. Courtesy call to the municipal officials and request for their approval at the same time were performed before the video tagging was conducted.

Table 18 summarizes the number of building features per type. On the other hand, Table 19 shows the total length of each road type, while Table 20 shows the number of water features extracted per type.

Table 18. Number of Building Features Extracted for Morong Floodplain.

| Facility Type | No. of Features |
|---|---|
| Residential | 4,024 |
| School | 42 |
| Market | 11 |
| Agricultural/Agro-Industrial Facilities | 2 |
| Medical Institutions | 1 |
| Barangay Hall | 3 |
| Military Institution | 0 |
| Sports Center/Gymnasium/Covered Court | 2 |
| Telecommunication Facilities | 0 |
| Transport Terminal | 12 |
| Warehouse | 1 |
| Power Plant/Substation | 7 |
| NGO/CSO Offices | 0 |
| Police Station | 1 |
| Water Supply/Sewerage | 3 |
| Religious Institutions | 23 |
| Bank | 0 |
| Factory | 0 |
| Gas Station | 6 |
| Fire Station | 0 |
| Other Government Offices | 5 |
| Other Commercial Establishments | 529 |
| **Total** | **4,672** |

Table 19. Total Length of Extracted Roads for Morong Floodplain.

| Floodplain | Road Network Length (km) | | | | | Total |
|---|---|---|---|---|---|---|
| | Barangay Road | City/ Municipal Road | Provincial Road | National Road | Others | |
| Morong | 36.25 | 4.64 | 6.91 | 11.98 | 0.00 | **59.73** |

Table 20. Number of Extracted Water Bodies for Morong Floodplain.

| Floodplain | Water Body Type | | | | | Total |
|---|---|---|---|---|---|---|
| | Rivers/Streams | Lakes/Ponds | Sea | Dam | Fish Pen | |
| Morong | 5 | 9 | 0 | 0 | 0 | **14** |

A total of 10 bridges and culverts over small channels that are part of the river network were also extracted for the floodplain.

### 3.11.4 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 28 shows the Digital Surface Model (DSM) of Morong floodplain overlaid with its ground features.

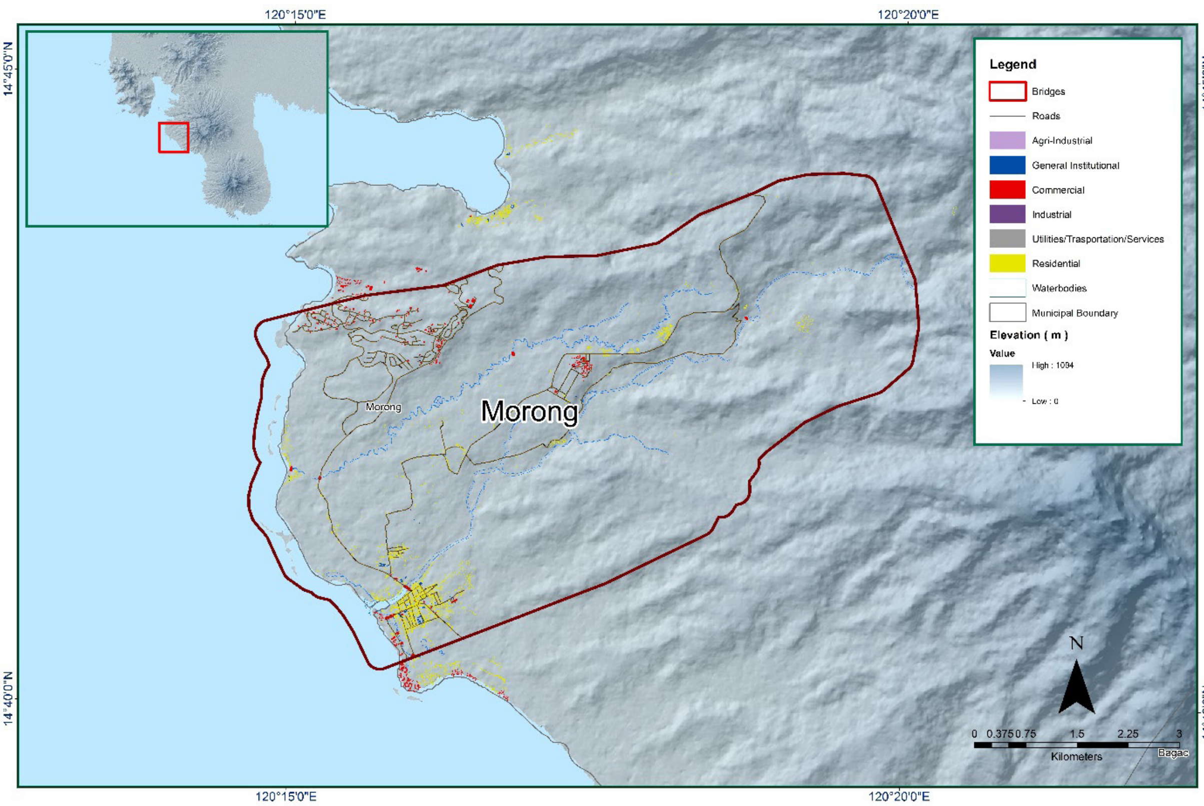



Figure 28. Extracted features for Morong floodplain.

# CHAPTER 4: SURVEY AND MEASUREMENTS IN THE MORONG RIVER BASIN

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

## 4.1 Summary of Activities

The Data Validation and Bathymetry Component (DVBC) conducted a field survey in Morong River on July 22 – Aug 3, 2016 with the following scope of work: reconnaissance; control survey; cross-section and as-built survey at MorongBridge in Brgy. Binaritan, Municipality of Morong, Bataan; validation points acquisition of about 25 km covering the Morong River Basin area; and bathymetric survey from its upstream in Brgy. Binaritan down to the mouth of the river located in Brgy. Poblacion, both in Municipality of Morong, with an approximate length of 6.505km using Ohmex™ single beam echo sounder and Trimble® SPS 882 GNSS PPK survey technique (Figure 29).

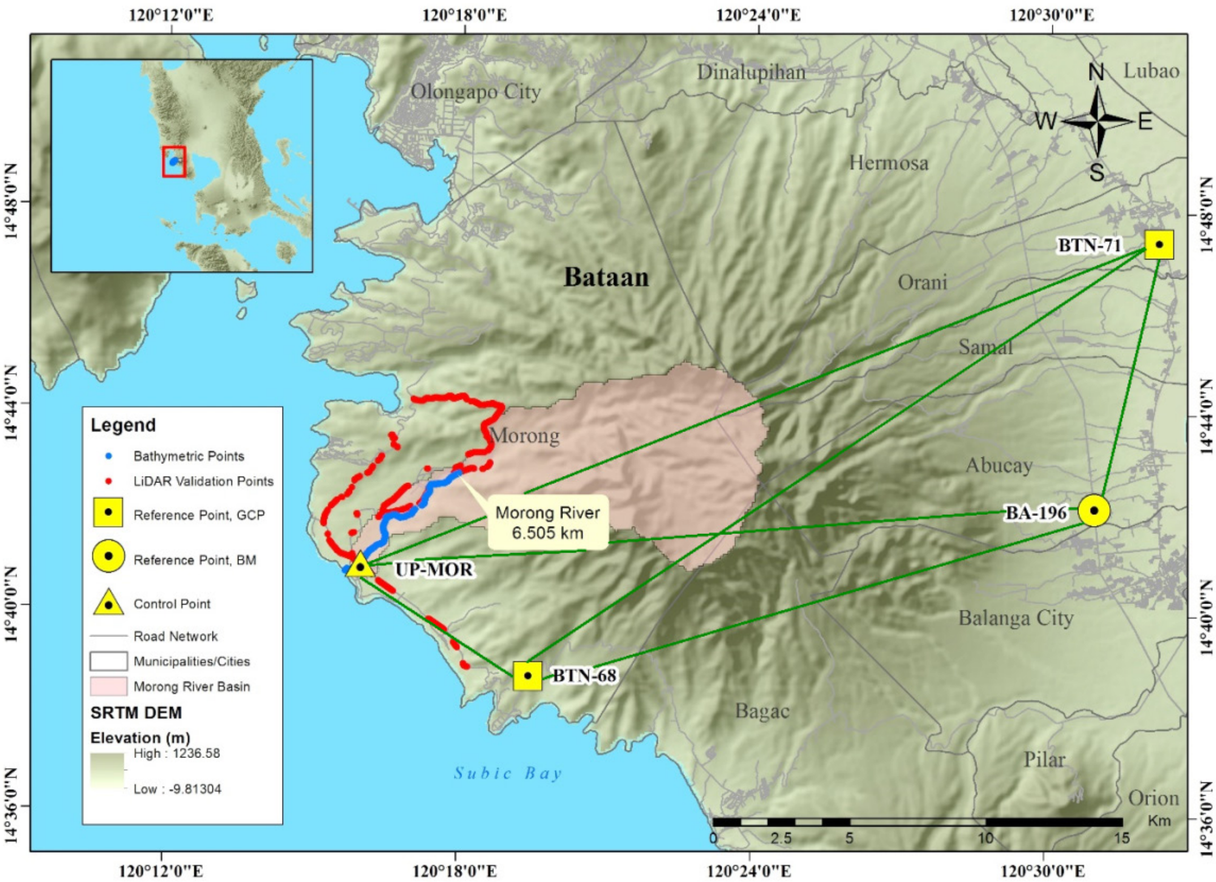



Figure 29. Morong River Survey Extent

## 4.2 Control Survey

The GNSS network used for Morong River Basin is composed of four (4) loops established on July 24, 2016 occupying the following reference points: BTN-68, a second-order GCP in Brgy. Nagbalayong, Municipality of Morong;BTN-71, a second order GCP, in Brgy. Apollo, Municipality of Orani; and BA-196, a first order BM, located in Brgy. Capitangan, Municipality of Abucay; all in Bataan.

A control pointwas established along the approach of Morong Bridge namely: UP-MOR, located in Brgy. Poblacion, Municipality of Morong, Bataan.

The summary of reference and control points and its location is summarized in Table 21 while the GNSS network established is illustrated in Figure 30.

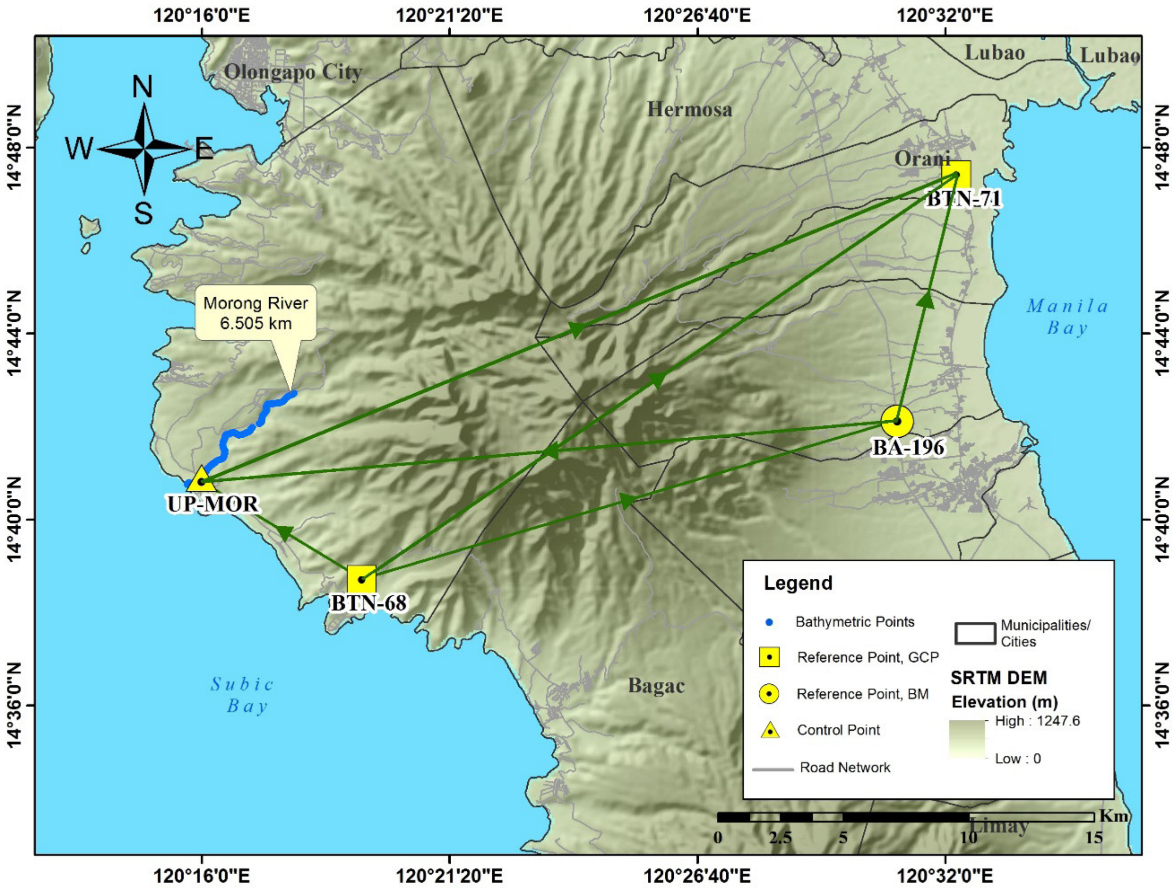



Figure 30. GNSS Network covering Morong River

Table 21. List of Reference and Control Points occupied for Morong River Survey (Source: NAMRIA; UP-TCAGP)

| Control Point | Order of Accuracy | Geographic Coordinates (WGS 84) | | | | |
|---|---|---|---|---|---|---|
| | | Latitude | Longitude | Ellipsoidal Height (m) | MSL Elevation (m) | Date Established |
| BTN-68 | 2nd order, GCP | 14°38'42.29096"N | 120°19'26.94802"E | 136.52 | - | 2016 |
| BTN-71 | 2nd order, GCP | 14°47'24.68277"N | 120°32'14.83855"E | 45.996 | - | 2014 |
| BA-196 | 1st order, BM | - | - | 65.611 | 22.836 | 2016 |
| UP-MOR | UP Established | - | - | - | - | Jul 24, 2016 11:17 AM |

The GNSS set-ups on recovered reference points and established control points in Morong River are shown in Figure 31 to Figure 34.

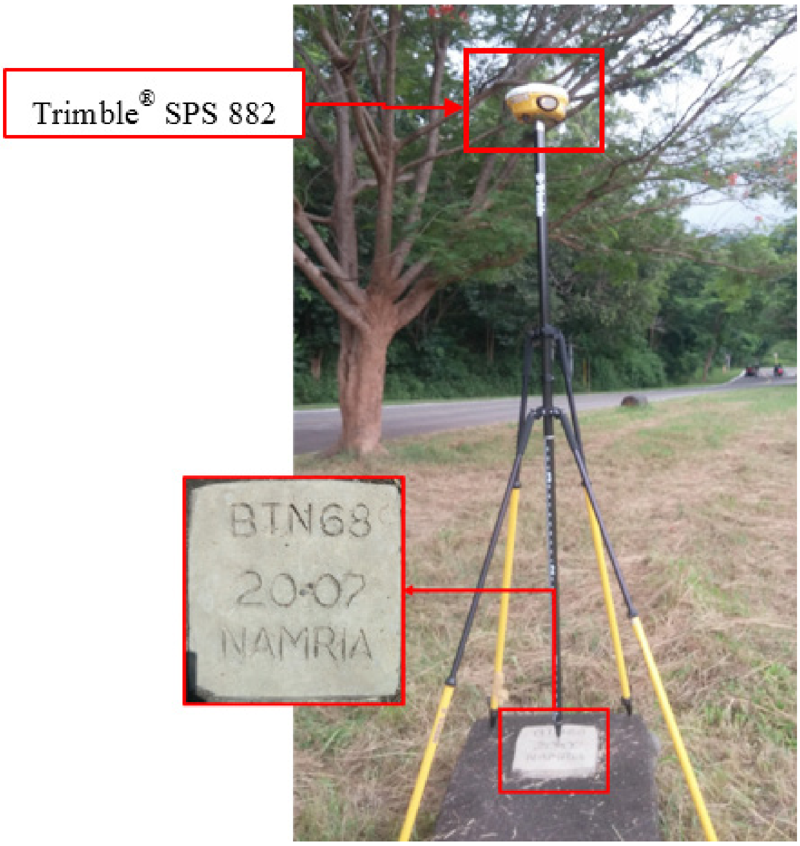



Figure 31. GNSS base set up, Trimble® SPS 882, atBTN-68 located just outside the Bataan Nuclear Power Plant along National High Way, Brgy. Nagbalayong, Municipality of Morong, Bataan

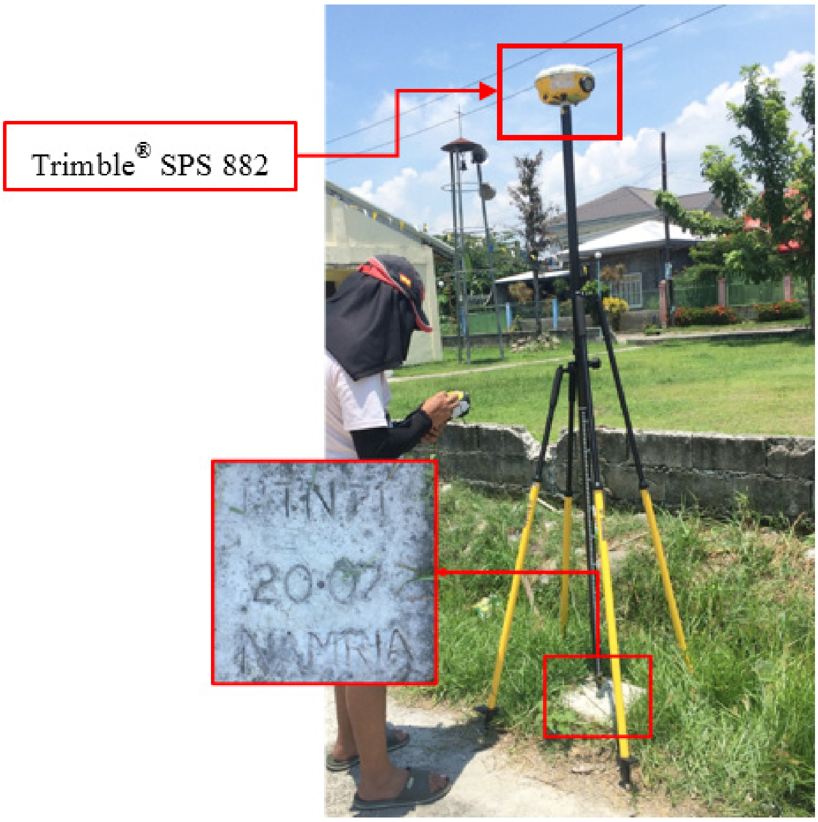



Figure 32. GNSS receiver setup, Trimble® SPS 882, atBTN-71 located at the middle of a basketball court, Barangay Day Care Center and Barangay Chapel in Brgy. Apollo, Municipality of Orani, Bataan


Figure 33. GNSS receiver setup, Trimble® SPS 852, at BA-196 located at the approach of CapitanganBridge in Brgy. Capitangan, Municipality of Abucay, Bataan

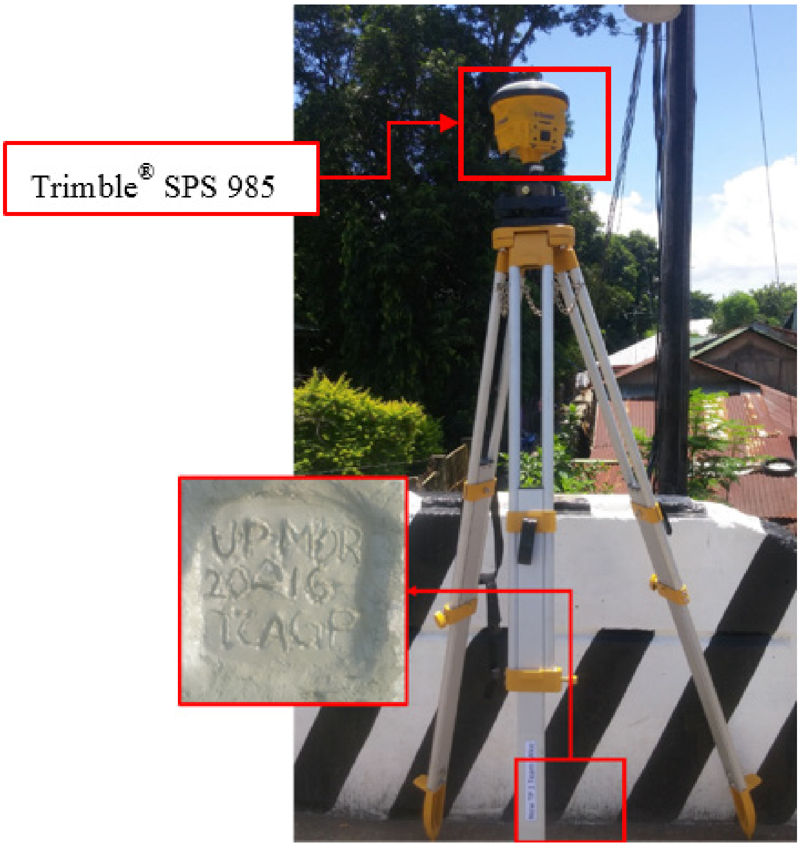



Figure 34. GNSS receiver setup, Trimble® SPS 985, at UP-MOR located at the approach of Morong Bridge in Brgy. Poblacion, Municipality of Morong, Bataan

## 4.3 Baseline Processing

GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/- 20 cm and +/- 10 cm requirement, respectively. In case where one or more baselines did not meet all of these criteria, masking is performed. Masking is done by removing/masking portions of these baseline data using the same processing software. It is repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, resurvey is initiated. Baseline processing result of control points in Morong River Basin is summarized in Table 22 generated by TBC software.

Table 22. Baseline Processing Summary Report for MorongRiver Survey

| Observation | Date of Observation | Solution Type | H.Prec. (Meter) | V.Prec. (Meter) | Geodetic Az. | Ellipsoid Dist. (Meter) | Height (Meter) |
|---|---|---|---|---|---|---|---|
| BA196 --- BTN68 | 07-24-2016 | Fixed | 0.005 | 0.018 | 73°05’46” | 21610.115 | -70.921 |
| BTN68 --- UPMOR | 07-24-2016 | Fixed | 0.004 | 0.015 | 303°13’37” | 7409.089 | -87.926 |
| BA196 --- BTN71 | 07-24-2016 | Fixed | 0.003 | 0.015 | 13°12’16” | 10046.745 | -19.625 |
| BA196 --- UPMOR | 07-24-2016 | Fixed | 0.003 | 0.013 | 265°19’07” | 26966.019 | -17.016 |
| UPMOR --- BTN71 | 07-24-2016 | Fixed | 0.003 | 0.016 | 67°36’23” | 31535.946 | -2.587 |
| BTN68 --- BTN71 | 07-24-2016 | Fixed | 0.005 | 0.022 | 55°01’14” | 28025.680 | -90.506 |

As shown Table 22 a total of six(6) baselines were processed with reference points BTN-68 and BTN-71 held fixed for coordinate values; and BA-196 fixed for elevation values. All of them passed the required accuracy.

## 4.4 Network Adjustment

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

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

Where:

$x_e$ is the Easting Error,

$y_e$ is the Northing Error, and

$z_e$ is the Elevation Error

for each control point. See the Network Adjustment Report shown in Table C-3 to Table C-6 for complete details.

The four (4) control points, BTN-68, BTN-71, BA-196 and UP-MOR were occupied and observed simultaneously to form a GNSS loop. Coordinates of BTN-68 and BTN-71;and elevation value of BA-196 were held fixed during the processing of the control points as presented in Table 23. Through these reference points, the coordinates and elevation of the unknown control points will be computed.

Table 23. Control Point Constraints

| Point ID | Type | East σ (Meter) | North σ (Meter) | Height σ (Meter) | Elevation σ (Meter) |
|---|---|---|---|---|---|
| BTN-68 | Local | Fixed | Fixed | | |
| BTN-71 | Local | Fixed | Fixed | | |
| BA-196 | Grid | | | | 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 24. The fixed controlsBTN-68 and BTN-71 have no values for grid errors while BA-68has no value for elevation error.

Table 24. Adjusted Grid Coordinates

| Point ID | Easting (Meter) | Easting Error (Meter) | Northing (Meter) | Northing Error (Meter) | Elevation (Meter) | Elevation Error (Meter) | Constraint |
|---|---|---|---|---|---|---|---|
| BTN-68 | 211765.363 | ? | 1620773.573 | ? | 93.217 | 0.044 | LL |
| BTN-71 | 234930.205 | ? | 1636575.052 | ? | 3.465 | 0.041 | LL |
| BA-196 | 232526.227 | 0.006 | 1626815.229 | 0.005 | 22.836 | ? | e |
| UP-MOR | 205612.090 | 0.008 | 1624909.162 | 0.007 | 5.340 | 0.039 | |

With the mentioned equation, for horizontal and  for the vertical; the computation for the accuracy are as follows:

a. **BTN-68**

horizontal accuracy = Fixed

vertical accuracy = 4.4 cm < 10 cm

b. **BTN-71**

horizontal accuracy = Fixed

vertical accuracy = 4.1 cm < 10 cm

c. **BA-196**

horizontal accuracy = $\sqrt{((0.6)^2 + (0.5)^2}$

= $\sqrt{(0.36 + 0.25)}$

= 0.78 < 20 cm

vertical accuracy = Fixed

d. **UP-MOR**

horizontal accuracy = $\sqrt{((0.8)^2 + (0.7)^2}$

= $\sqrt{(0.64 + 0.49)}$

= 1.06 < 20 cm

vertical accuracy = 3.9 cm < 10 cm

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

Table 25. Adjusted Geodetic Coordinates

| Point ID | Latitude | Longitude | Ellipsoidal Height (Meter) | Height Error (Meter) | Constraint |
|---|---|---|---|---|---|
| BTN-68 | N14°38’42.29096” | E120°19’26.94802” | 136.520 | 0.044 | LL |
| BTN-71 | N14°47’24.68277” | E120°32’14.83855” | 45.996 | 0.041 | LL |
| BA-196 | N14°42’06.44710” | E120°30’58.09376” | 65.611 | ? | e |
| UP-MOR | N14°40’54.35855” | E120°15’59.79638” | 48.592 | 0.039 | |

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 25. Based on the result of the computation, the equation is satisfied; hence, the required accuracy for the program was met.

The summary of reference and control points used is indicated in Table 26.

Table 26. 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) |
| BTN-68 | 2nd order, GCP | 13°55’14.18695” | 122°36’12.89833” | 59.636 | 1538981.558 | 457175.646 | 10.059 |
| BTN-71 | 2nd order, GCP | 13°49’14.33596” | 122°47’41.49841” | 60.994 | 1527900.59 | 477829.729 | 10.576 |
| BA-196 | 1st order, BM | 14°09’12.36125” | 122°49’52.53365” | 64.661 | 1564701.975 | 481789.697 | 14.905 |
| UP-MOR | UP Established | 14°03’52.37147” | 122°58’30.23146” | 55.501 | 1554865.116 | 497307.927 | 5.214 |

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

Cross-section andas-built survey were conducted on July 29, and August 1, 2016 at the upstream side of Morong Bridge in Brgy. Binarian, Municipality of Morong, Bataanas shown in Figure 35. A Trimble® SPS 882 GNSS PPK survey technique were utilized for this survey.

Figure 35. Morong Bridge facing downstream

The cross-sectional line of Morong Bridge is about 117.55m with one hundred seventeen (117) cross-sectional points using the control point UP-MOR as the GNSS base station. The cross-section diagram, bridge planimetric map, and the bridge data form are shown in Figure 36 and Figure 38, respectively.

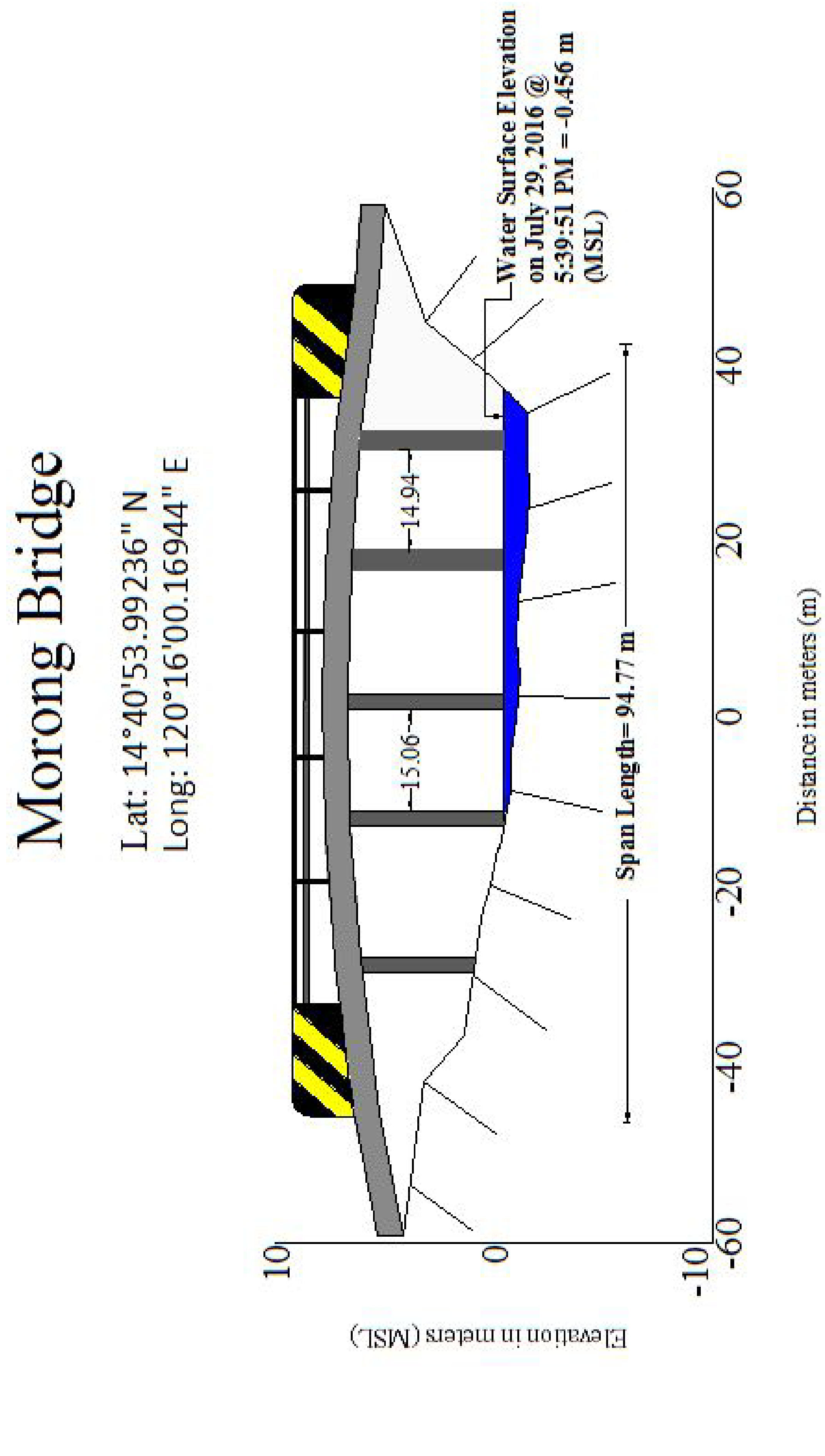



Figure 36. MorongBridge cross-section diagram

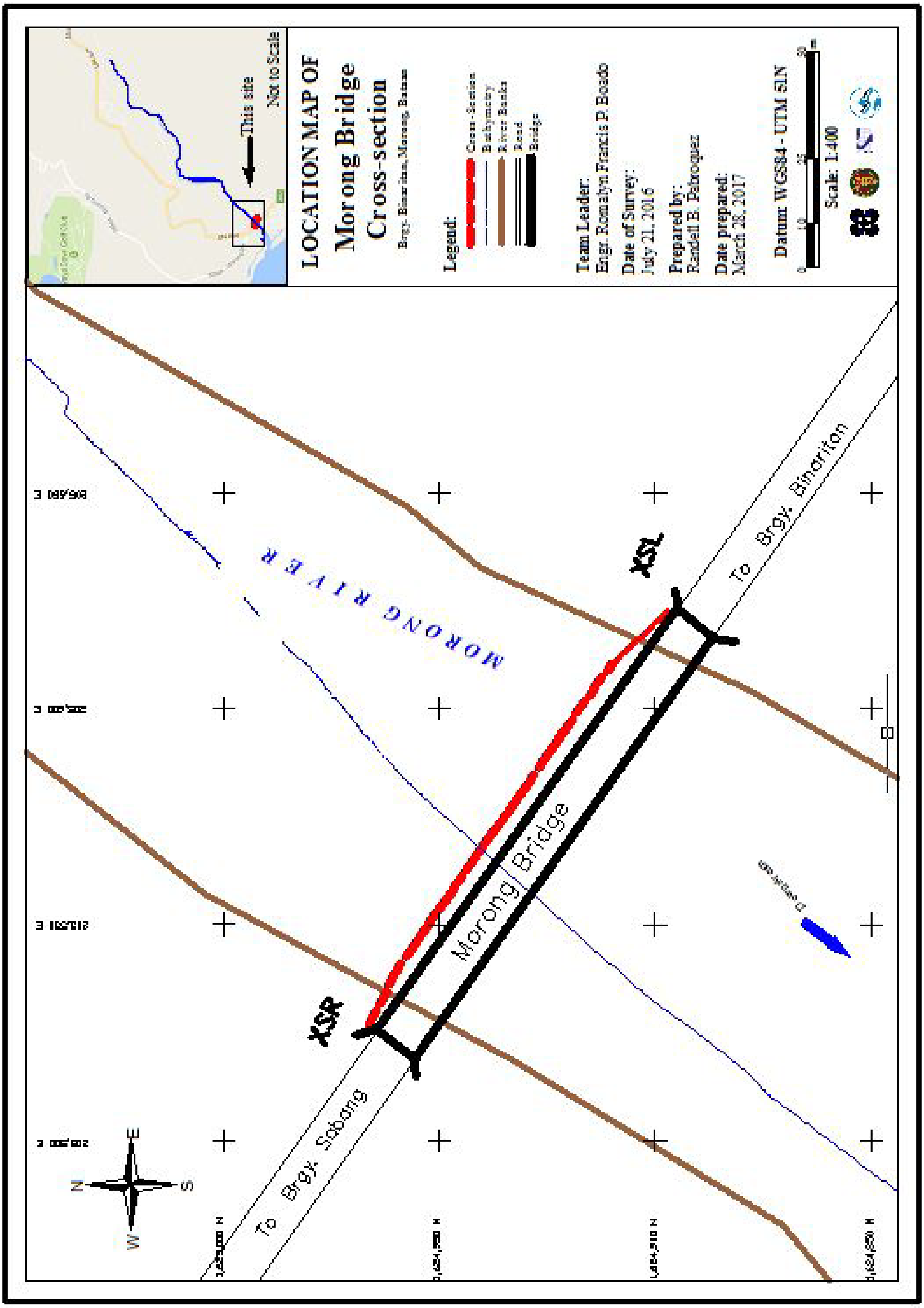
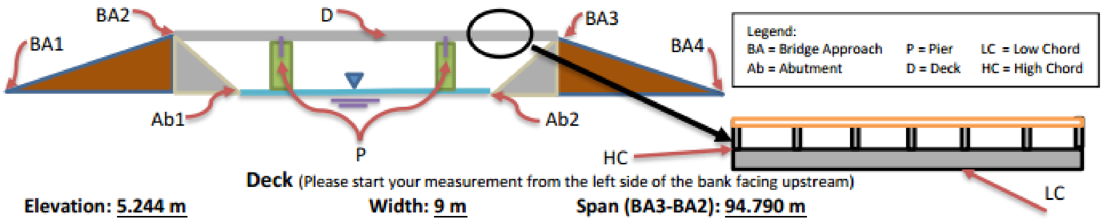



Figure 37. Morong bridge cross-section planimetric map

**Bridge Data Form**

| | |
|---|---|
| **Bridge Name:** Morong Bridge | **Date:** July 29 and Aug 1, 2016 |
| **River Name:** Morong River | **Time:** 5:39 PM |
| **Location (Brgy, City,Region):** Brgy. Binaritan, Municipality of Morong, Bataan | |
| **Survey Team:** Romalyn Boado, Lorenz Taguse, Marion Dimain | |
| **Flow condition:** normal | **Weather Condition:** fair |
| **Latitude:** 14°40'54.32642" N | **Longitude:** 120°15'59.84449" E |




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

**Elevation:** 5.244 m **Width:** 9 m **Span (BA3-BA2):** 94.790 m

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

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

| | Station(Distance from BA1) | Elevation | | Station(Distance from BA1) | Elevation |
|---|---|---|---|---|---|
| BA1 | 0 | 4.097 m | BA3 | 108.923 m | 5.228 m |
| BA2 | 14.133 m | 5.233 m | BA4 | 117.542 m | 4.971 m |

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

| | Station (Distance from BA1) | Elevation |
|---|---|---|
| Ab1 | NA | NA |
| Ab2 | NA | NA |

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

Shape: Cylindrical Number of Piers: 5 Height of column footing: N/A

| | Station (Distance from BA1) | Elevation | Pier Diameter |
|---|---|---|---|
| Pier 1 | 31.767 m | 6.103 m | NA |
| Pier 2 | 46.737 m | 6.552 m | NA |
| Pier 3 | 61.829 m | 6.699 m | NA |
| Pier 4 | 76.787 m | 6.512 m | NA |
| Pier 5 | 91.747 m | 6.099 m | NA |

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

Figure 38. Bridge as-built form of Morong Bridge

Water surface elevation of Morong River was determined using a survey grade GNSS receiver Trimble® SPS 882 in PPK survey technique on July 29, 2016 at 5:39PM with a value of -0.456m in MSL as shown in Figure C-8. This was translated into marking on one of the bridge's abutment using the same technique as shown in Figure 39. This will serve as reference for flow data gathering and depth gauge deployment of partner HEI responsible for Morong river, the Central Luzon State University.

Figure 39. Water-level markings on Morong Bridge

## 4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on August 1, 2016 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted in front of a vehicle as shown in Figure 40. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The antenna heights were 1.588 m and 1.945 m and measured from the ground up to the bottom of notch of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with UP-MOR occupied as the GNSS base station.


Figure 40. Validation points acquisition survey set up along MorongRiver Basin

The survey started from Morong Bridge in Brgy. Binaritan, Municipality of Morong, going south traversing Brgy. Poblacion, Brgy. Binaritan, which ended in Brgy. Nagbalayaong; and going north traversing Brgy. Sabang and ending in Brgy. Mabayo; all in Municipality of Morong, Bataan.Atotal of 2,746 points were gathered with approximate length of 25km using UP-MOR as GNSS base station for the entire extent validation points acquisition survey as illustrated in the map in Figure 41.


Figure 41. Validation point acquisition survey ofMorongRiver Basin

## 4.7 Bathymetric Survey

Bathymetric survey was executed on July 29, 2016 using an Ohmex™ single beam echosounder and Trimble® SPS 882 in GNSSPPK survey technique in continuous topo mode as illustrated in Figure 42.The survey started at the upper part of Morong Bridge in Brgy. Binaritan, with coordinates 14°40'58.38854"N, 120°16'01.04799"E, and ended at the mouth of the river in Brgy. Poblacion with coordinates 14°40'45.41536"N, 120°15'41.93778"E.

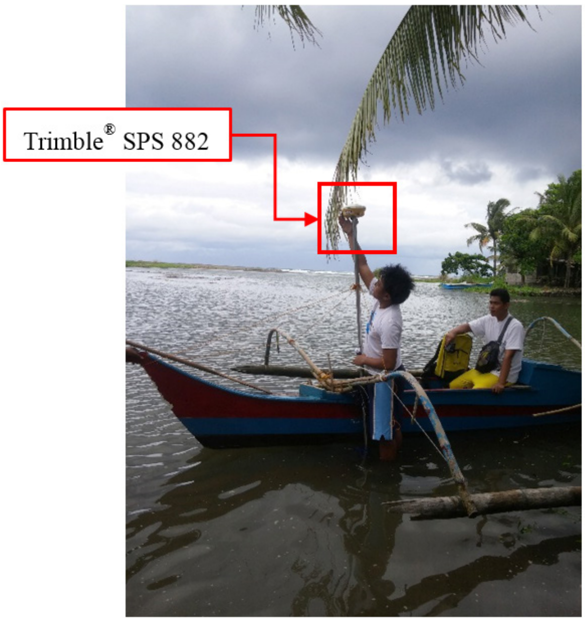



Figure 42. Bathymetric survey using Ohmex™ single beam echo sounder in MorongRiver

Manual bathymetric survey was executed on July 29, Aug 1 and 2, 2016 using Trimble® SPS 882 in GNSS PPK survey technique in continuous topo mode as shown in Figure 43. The survey started in the uppermost part of the river in Brgy. Binaritan, Municipality of Morong, with coordinates 14°42'43.20225"N, 120°17'59.87425"E, and ended at the starting point of the bathymetric using boat. The control point UP-MOR was used as the GNSS base station throughout the entire survey.


Figure 43. Manual Bathymetric Survey

The bathymetric survey for Morong River gathered a total of 18,621 points covering 6.505 km of the river traversing Brgy Sabang, Brgy. Binaritan, and Brgy. Polacion. A CAD drawing was also produced to illustrate the riverbed profile of Morong River. As shown in Figure 45, the highest and lowest elevation has a 38-m difference. The highest elevation observed was 36.241 m in MSL located at Brgy. Binaritan, while the lowest was -2.425m below MSL located at the downstream portion of the river in Brgy. Pobacion, both in Municipality of Morong. Approximately 4 kilometers was not surveyed since the upstream portion of the river have available LiDAR data as advised by the Data Pre-Processing Component.


Figure 44. Bathymetric survey of MorongRiver

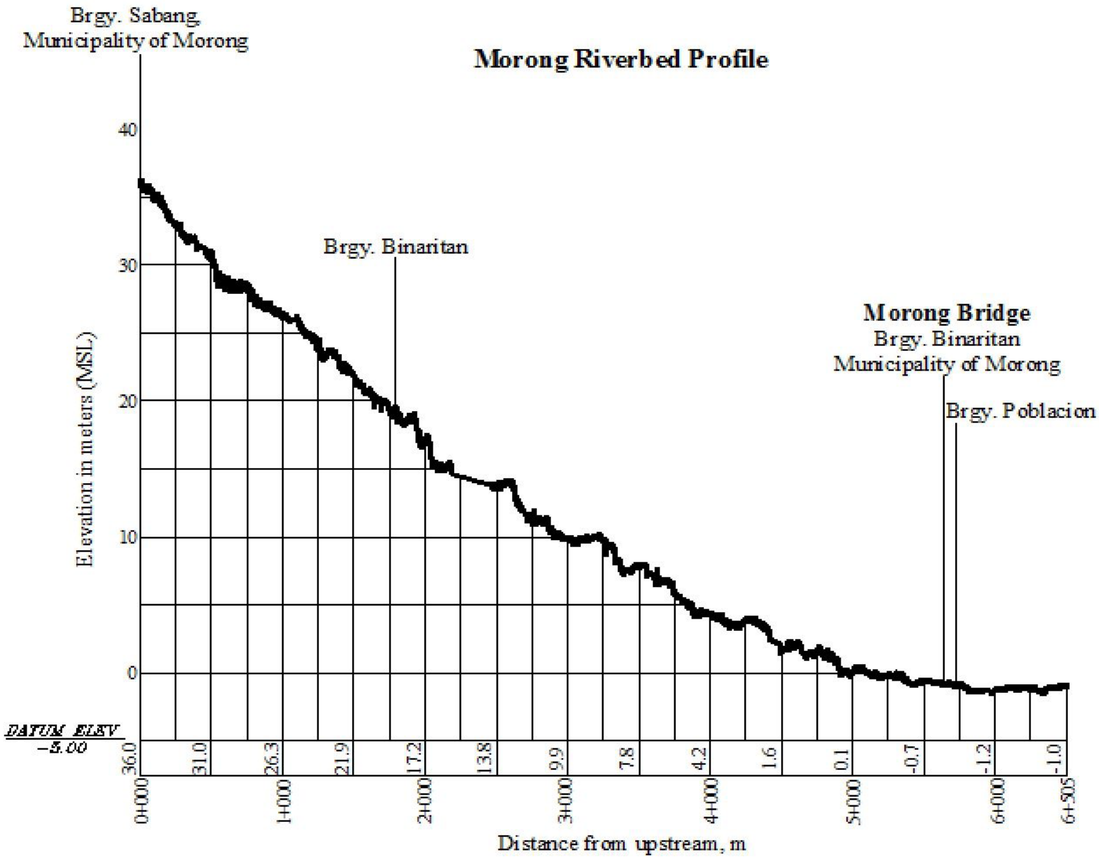



Figure 45. MorongRiverbed Profile

# 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, Girlie David, Mariel Monteclaro, Eleazar Raneses, Jr. and Jose T. Gavino

## 5.1 Data Used for Hydrologic Modeling

### 5.1.1 Hydrometry and Rating Curves

Components and data that affect the hydrologic cycle of the river basin was monitored, collected, and analyzed. These include the rainfall, water level, and flow in a certain period of time.

### 5.1.2 Precipitation

In the absence of automatic rain gauge in Morong, precipitation data was recorded through manual reading in an 8 inches standard rain gauge installed in the study area. The rain gauge was installed one (1) kilometer upstream from the flow measurement site.

The total rain recorded in this event from the rain gauge is 197.29 mm. It peaked to 14.923 mm. on 09 July 2016 at 14:30. The lag time between the peak rainfall and discharge is 2 hours.

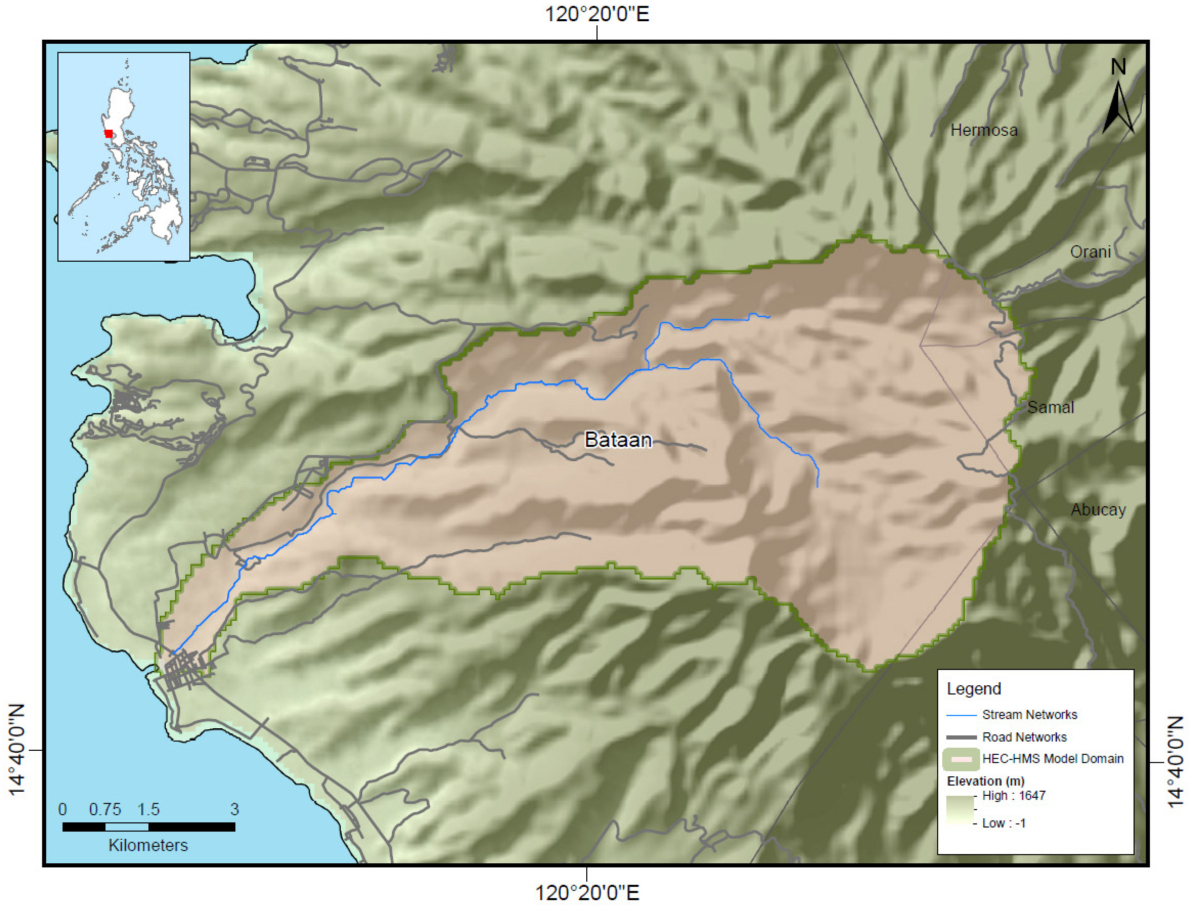



Figure 46. The location map of Morong HEC-HMS model used for calibration.

### 5.1.3 Rating Curves and River Outflow

A rating curve was developed at Morong Bridge, Morong, Bataan (14°40' 55.416"N, 120°15' 58.167"E). It gives the relationship between the observed water levels at Morong Bridge and outflow of the watershed at this location.

For Morong Bridge, the rating curve is expressed as $Q = 8.8636e^{1.4753h}$ as shown in Figure 47.

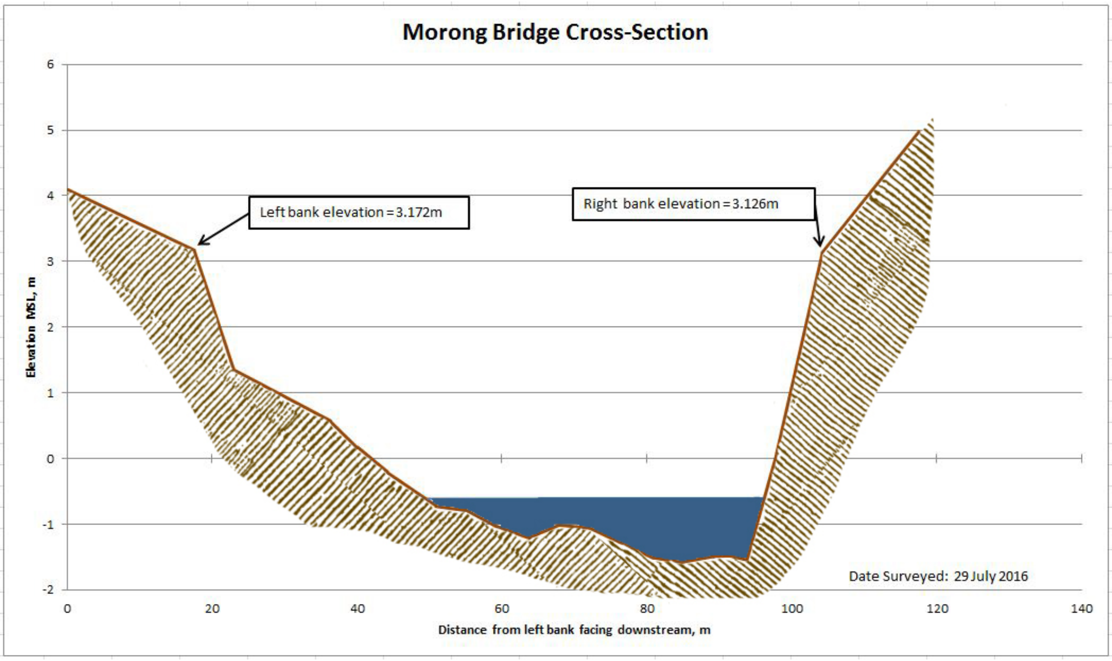



Figure 47. Cross-Section Plot of Morong Bridge

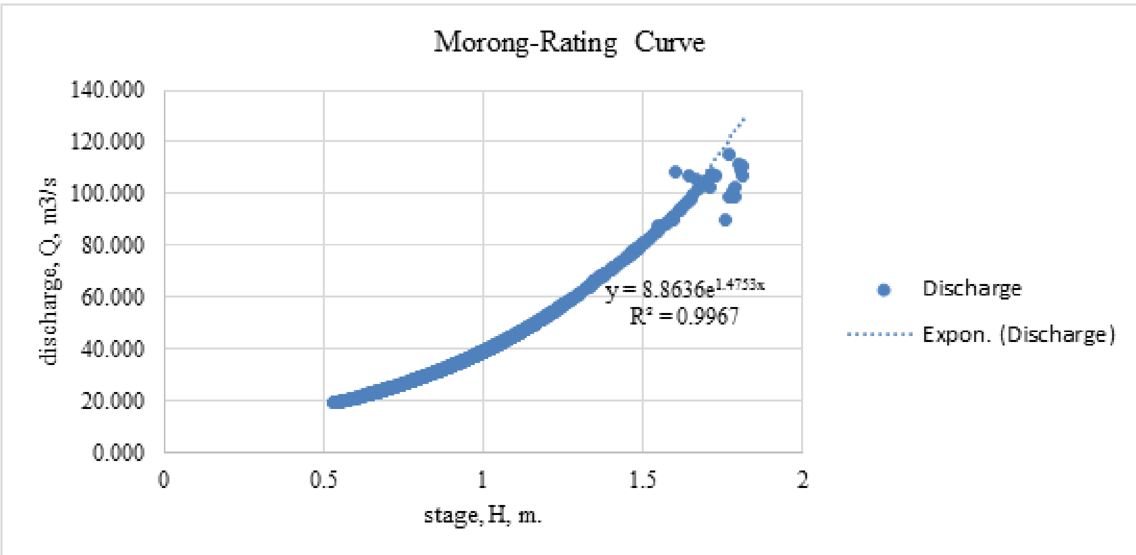



Figure 48. Rating Curve at Morong Bridge, Morong, Bataan

This rating curve equation was used to compute the river outflow at Morong Bridge for the calibration of the HEC-HMS model shown in Figure 48. Peak discharge is 96.016 cms at 16:30 AM, July 09, 2016.

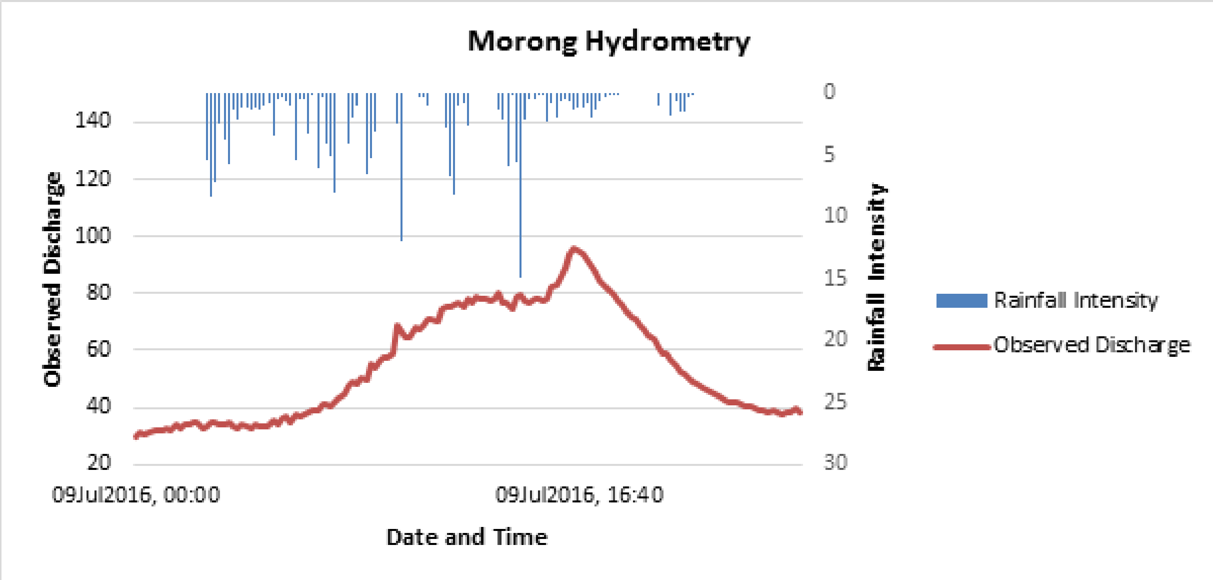



Figure 49. Rainfall and outflow data at Morong used for modeling

## 5.2 RIDF Station

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

Table 27. RIDF values for Sangley Point 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 | 20.3 | 30 | 36.6 | 46.4 | 63.2 | 74.6 | 96.6 | 119.6 | 147.9 |
| 5 | 28.3 | 41.8 | 50.8 | 64.6 | 89.8 | 106.8 | 140.3 | 174 | 209.4 |
| 10 | 33.6 | 49.7 | 60.2 | 76.7 | 107.3 | 128.2 | 169.2 | 210 | 250.1 |
| 15 | 36.6 | 54.1 | 65.5 | 83.5 | 117.2 | 140.3 | 185.6 | 230.3 | 273.1 |
| 20 | 38.7 | 57.2 | 69.2 | 88.3 | 124.2 | 148.7 | 197 | 244.6 | 289.1 |
| 25 | 40.3 | 59.6 | 72.1 | 91.9 | 129.5 | 155.2 | 205.8 | 255.5 | 301.5 |
| 50 | 45.3 | 66.9 | 80.9 | 103.3 | 146 | 175.2 | 233 | 289.3 | 339.7 |
| 100 | 50.3 | 74.2 | 89.7 | 114.5 | 162.3 | 195.1 | 259.9 | 322.8 | 377.6 |

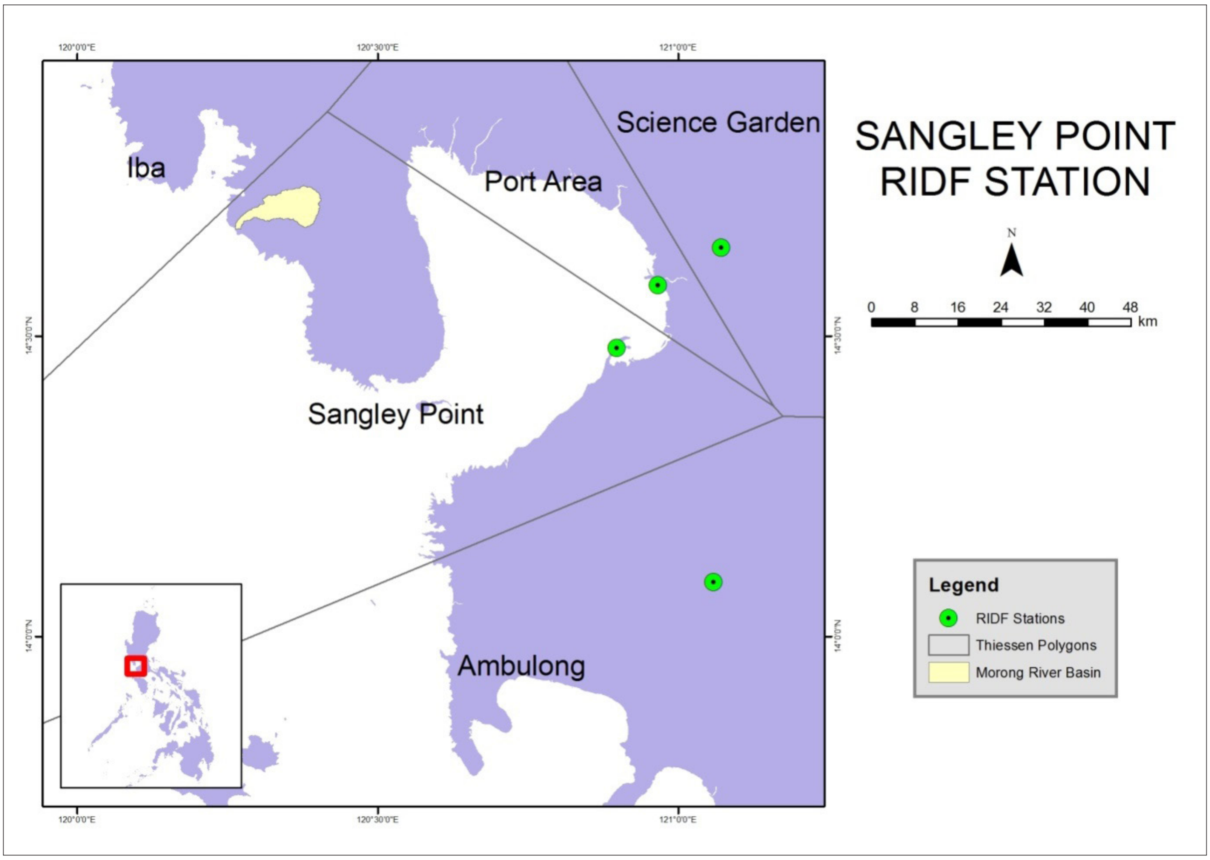



Figure 50. Sangley Point RIDF location relative to Morong River Basin

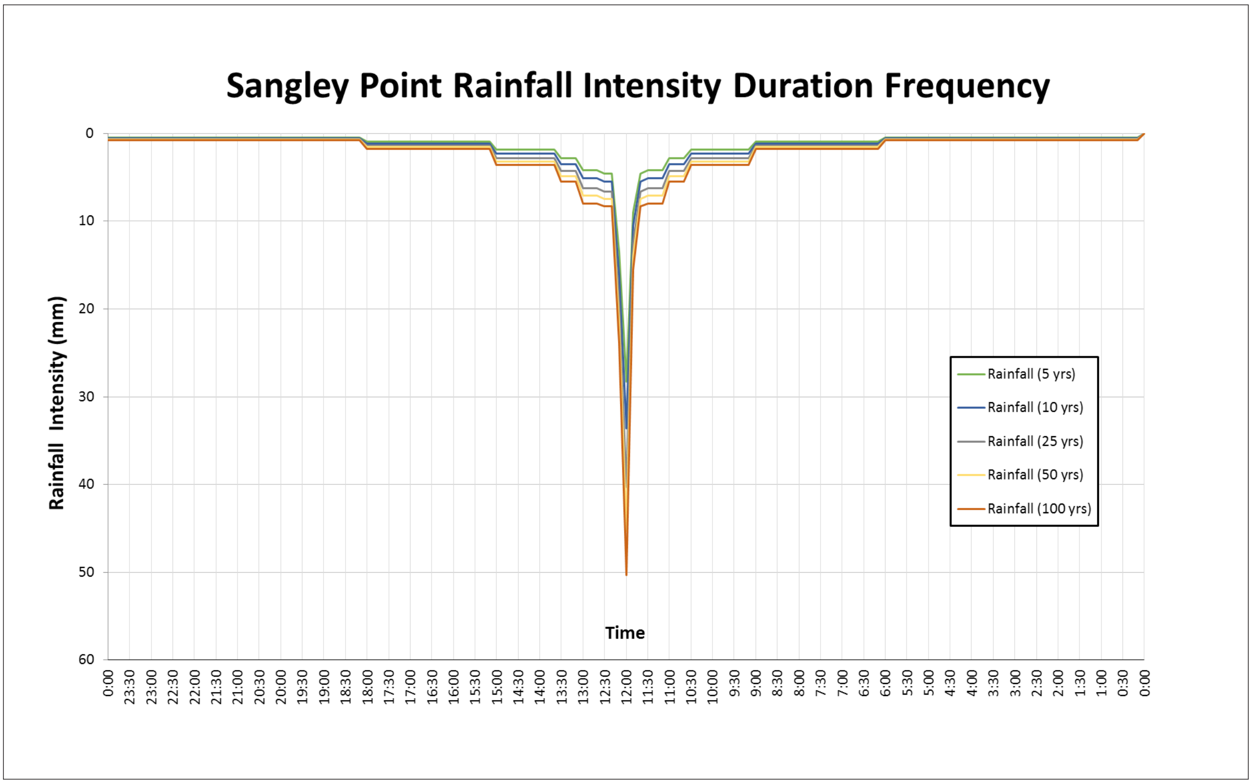



Figure 51. Synthetic storm generated for a 24-hr period rainfall for various return periods

## 5.3 HMS Model

Using the SAR-based DEM, the Morong basin was delineated and further subdivided into subbasin. The Morong basin model consists of 5 sub basins, 2 reaches, and 2 junctions as shown in Figure 52. Finally, it was calibrated using depth gauge installed in Morong Bridge.

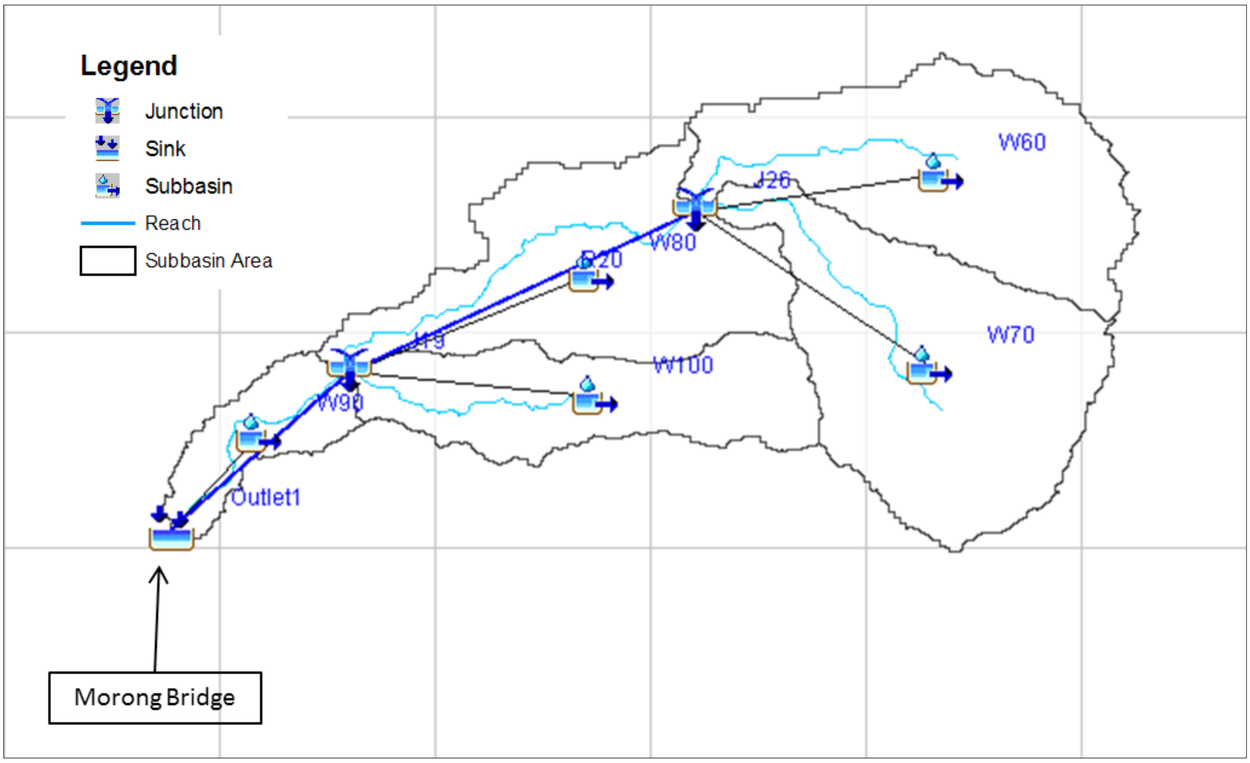



Figure 52. The Morong river basin model generated using HEC-HMS

## 5.4 Cross-section Data

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

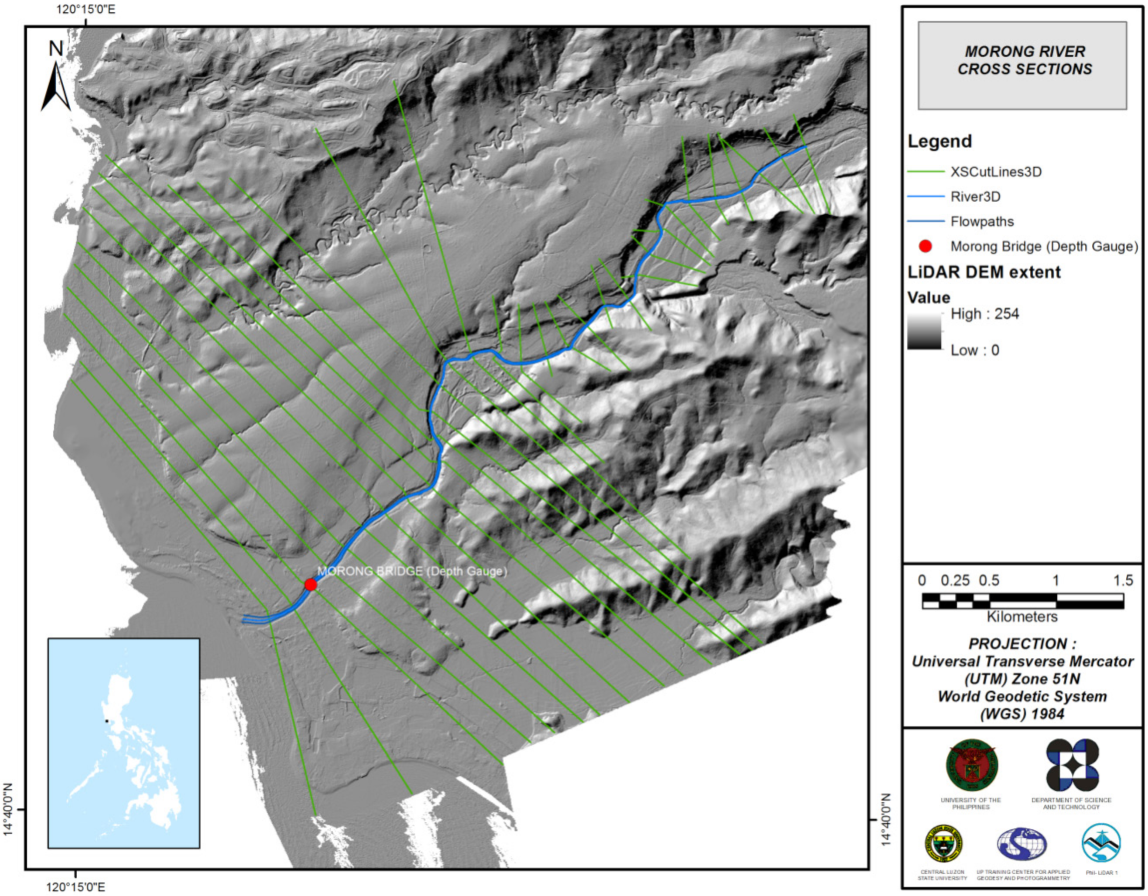



Figure 53. River cross-section of MorongRiver generated through Arcmap HEC GeoRAS tool

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

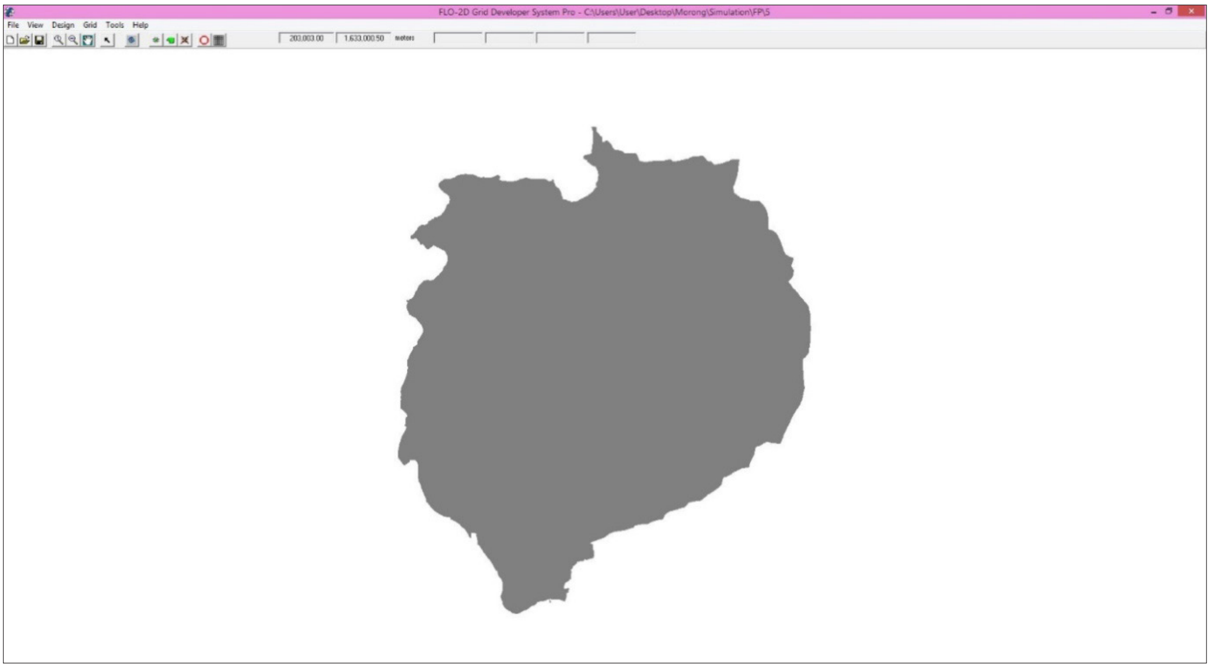



Figure 54**.** Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 39.55225 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 $m^2/s$.

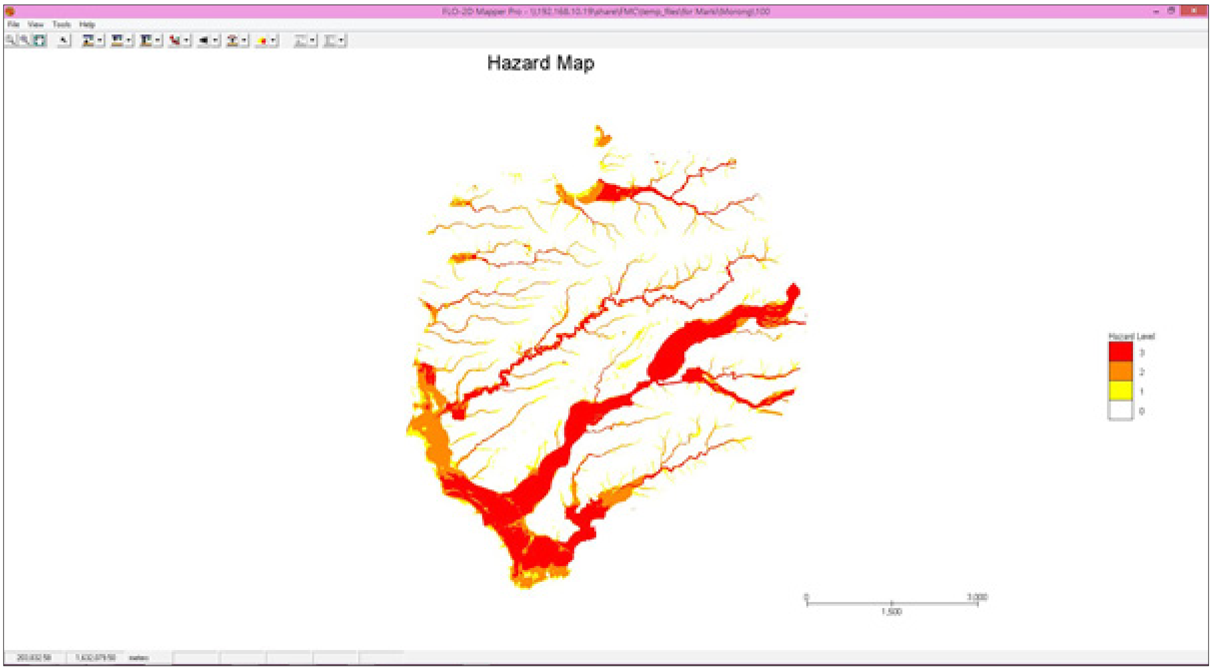



Figure 55. Generated 100-year rain return hazard map from FLO-2D Mapper

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 39 385 900.00 m$^2$.

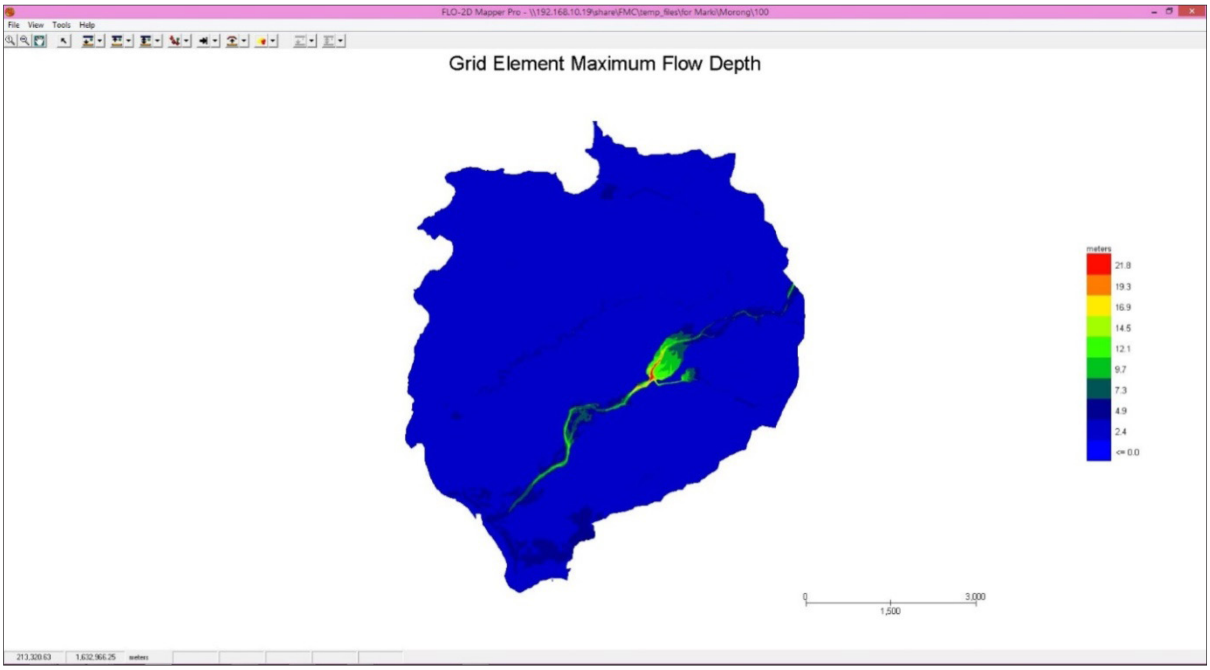



Figure 56. Generated 100-year rain return flow depth map from FLO-2D Mapper

There is a total of 18 419 757.72 m$^3$ of water entering the model. Of this amount, 10 725 727.85 m$^3$ is due to rainfall while 7 694 029.87 m$^3$ is inflow from other areas outside the model. 3 960 626.75 m$^3$ of this water is lost to infiltration and interception, while 12 447 417.07 m$^3$ is stored by the flood plain. The rest, amounting up to 2 011 714.06 m$^3$,is outflow.

## 5.6 Results of HMS Calibration

After calibrating the Morong HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 57 shows the comparison between the two discharge data.

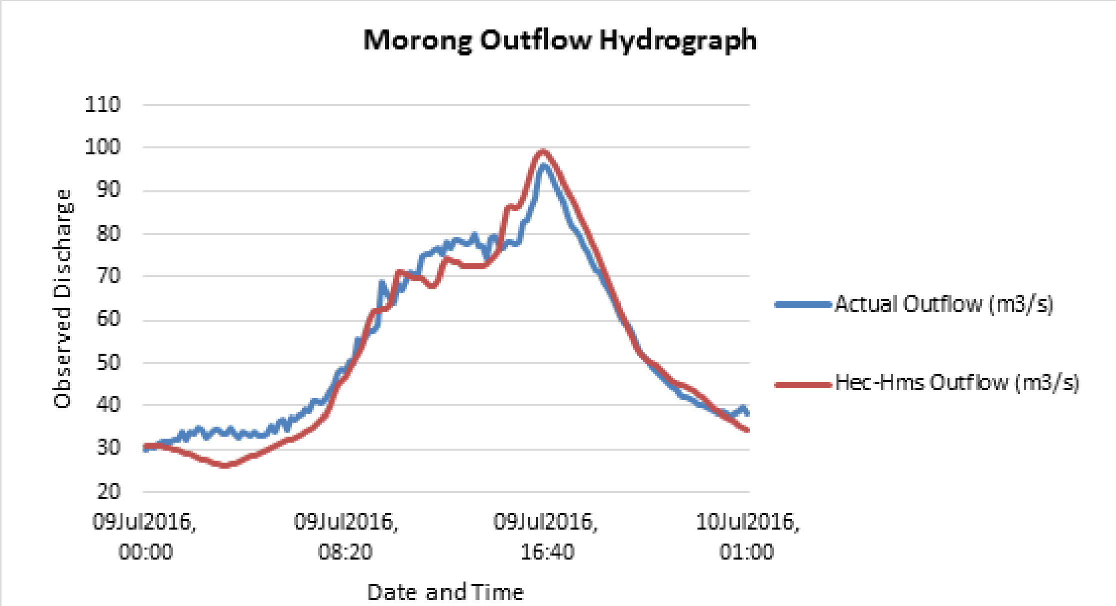



Figure 57. Outflow Hydrograph of Morong produced by the HEC-HMS model compared with observed outflow

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

Table 28. Range of Calibrated Values for Morong

| Hydrologic Element | Calculation Type | Method | Parameter | Range of Calibrated Values |
|---|---|---|---|---|
| Basin | Loss | SCS Curve number | Initial Abstraction (mm) | 4.50 – 6.66 |
| | | | Curve Number | 35.175 – 39.25 |
| | Transform | Clark Unit Hydrograph | Time of Concentration (hr) | 0.232 – 3.953 |
| | | | Storage Coefficient (hr) | 0.99 – 3.63 |
| | Baseflow | Recession | Recession Constant | 0.119 – 0.175 |
| | | | Ratio to Peak | 0.272 – 0.423 |
| Reach | Routing | Muskingum-Cunge | Manning's Coefficient | 0.025 – 0.057 |

Initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as initial abstraction decreases. The range of values from 4.55mm to 6.66mm means that there is minimal amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 35.175 – 39.25 for curve number is lower than the advisable for Philippine watersheds depending on the soil and land cover of the area. For Morong, the basin mostly consists of brushlands and closed canopy and the soil consists of clay and undifferentiated soil.

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 0.232 hours to 3.953 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 0.119 – 0.175 indicates that the basin will quickly go back to its original discharge. Ratio to peak of 0.272 – 0.423 indicates a steeper receding limb of the outflow hydrograph.

Manning's roughness coefficient of values 0.025 – 0.057 are close to the common roughness of Philippine watersheds which is 0.04.

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

| Accuracy Measure | Value |
|---|---|
| RMSE | 4.4 |
| $r^2$ | 4.4 |
| NSE | 0.97 |
| PBIAS | 1.89 |
| RSR | 0.15 |

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computedat 4.4 m3/s.

The Pearson correlation coefficient (r2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. A value of r2 = 0.97 was computed for this model. This means that the degree of collinearity between simulated and measured data is relatively high

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 0.98 which means that the model has a very good performance rating in simulating discharge.

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 negative 1.89 which implies that the model was underestimated at 1.89 percent difference in streamflow volume between simulated and measured data for a particular period.

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 are quantified. The model has an RSR value of 0.15 which indicates that the model has a better simulation performance due to low value of computed RSR.

## 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 58) shows the Morong outflow using the Sangley Point Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAG-ASA) data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

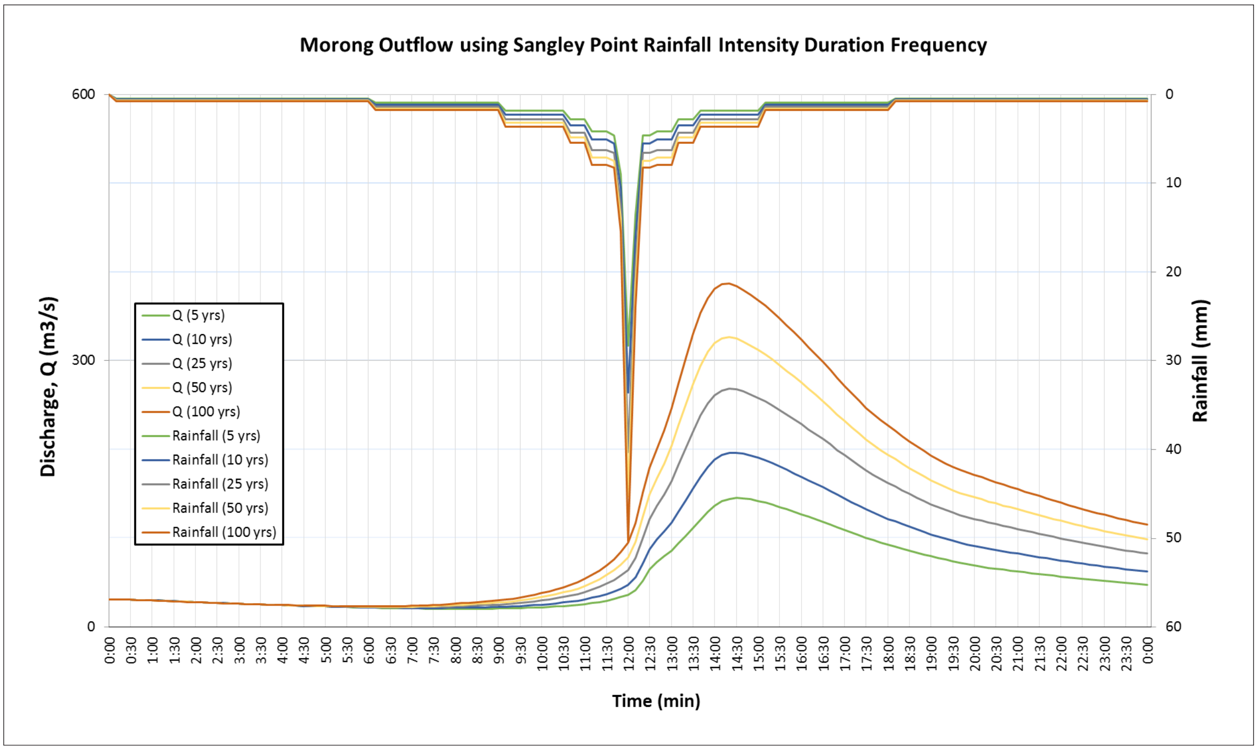



Figure 58. Outflow hydrograph at Morong Station generated using Sangley Point RIDF simulated in HEC HMS

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

Table 30. Peak values of the Morong HEC-HMS Model outflow using the Sangley Point RIDF

| RIDF Period | Total Precipitation (mm) | Peak rainfall (mm) | Peak outflow ($m^3/s$) | Time to Peak |
|---|---|---|---|---|
| 5-Year | 209.4 | 28.3 | 145.5 | 2 hours 30 minutes |
| 10-Year | 250.1 | 33.6 | 196.6 | 2 hours 30 minutes |
| 25-Year | 301.5 | 40.3 | 268.6 | 2 hours 20 minutes |
| 50-Year | 339.7 | 45.3 | 326.6 | 2 hours 20 minutes |
| 100-Year | 377.6 | 50.3 | 386.9 | 2 hours 20 minutes |

## 5.8 River Analysis Model Simulation

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

The Morong model has a minimum and maximum flow discharge of 30.07 and 96.016 m3/s, respectively and this was needed for unsteady flow analysis as input file. The simulation results also showed that there is no overflow of water along the banks of the river. However, some floodplain areas were being filled with water due to its elevation like agricultural areas located in Barangay Nagbalayong, Poblacion, Binaritan and Sabang (located at the downstream portion of the river). The sample 1D flood hazard map using the calibrated discharge of Morong river from HMS model is shown in Figure 59.


Figure 59. Sample output of Morong RAS Model

## 5.9 Flood Hazard and Flow Depth Map

The resulting hazard and flow depth maps for the 5-, 25-, and 100-year rain return scenarios of the Morong floodplain are shown in Figure 60 to Figure 65.

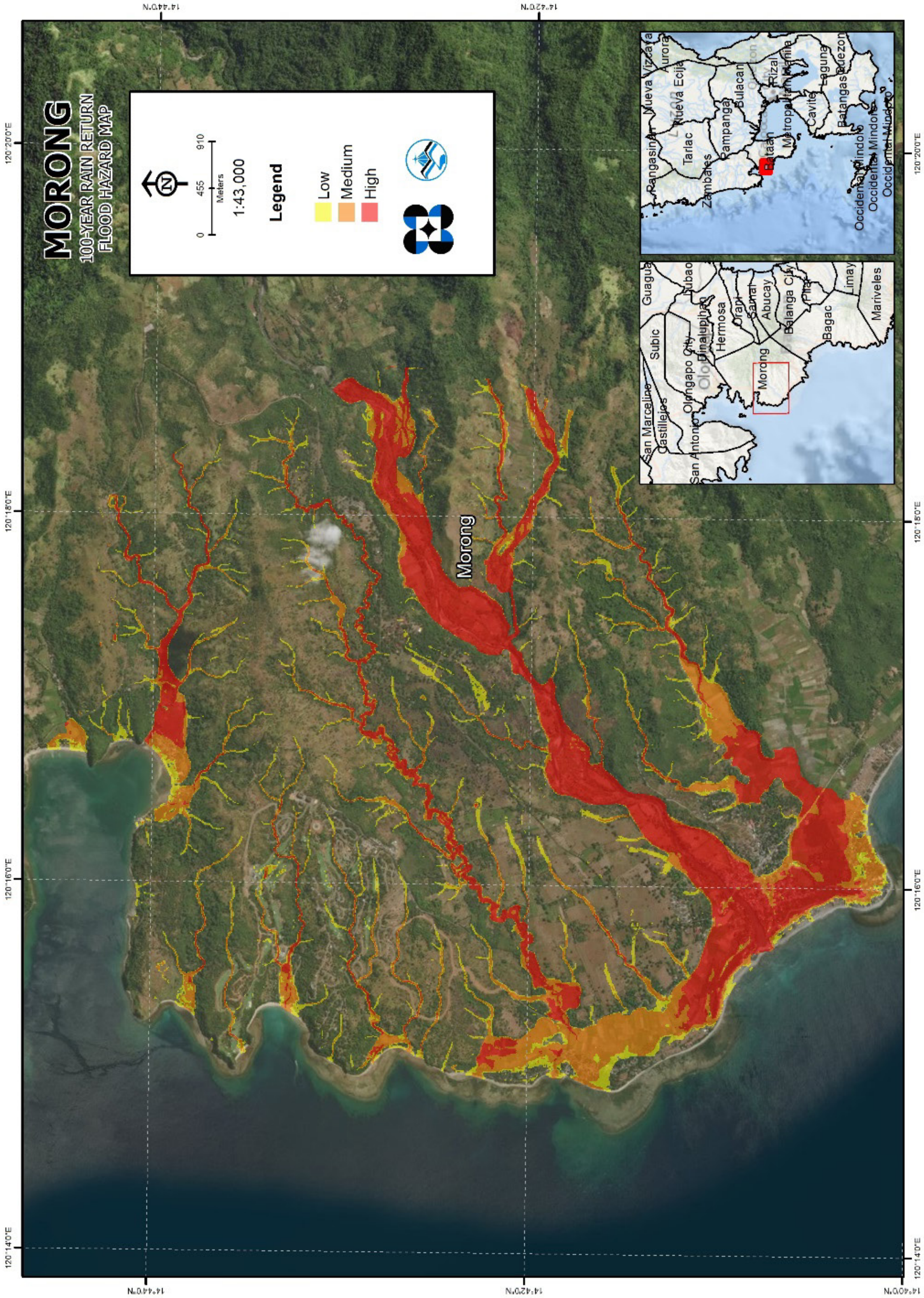



Figure 60. 100-year Flood Hazard Map for Bucao Floodplain

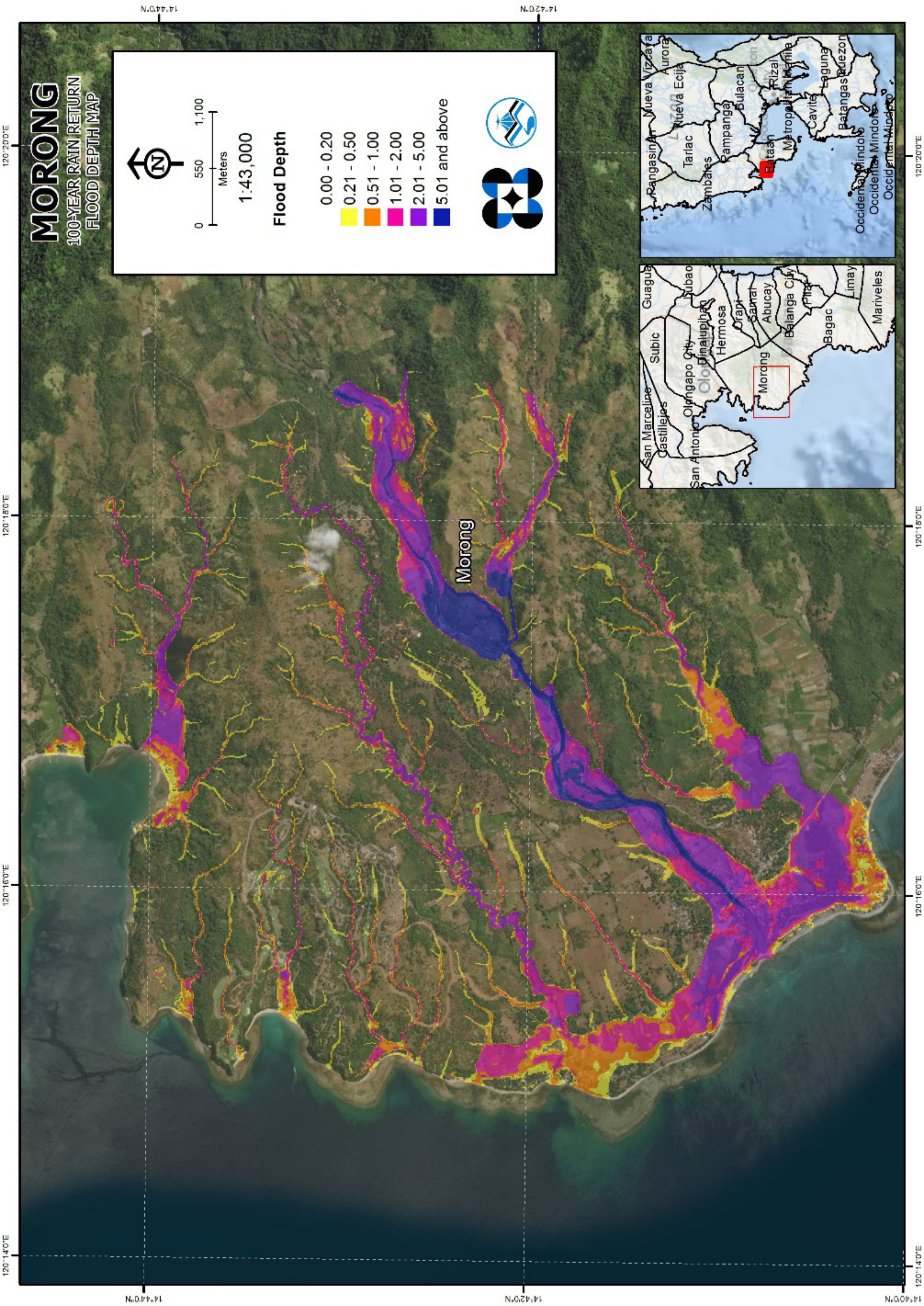



Figure 61. 100-year Flow Depth Map for Bucao Floodplain

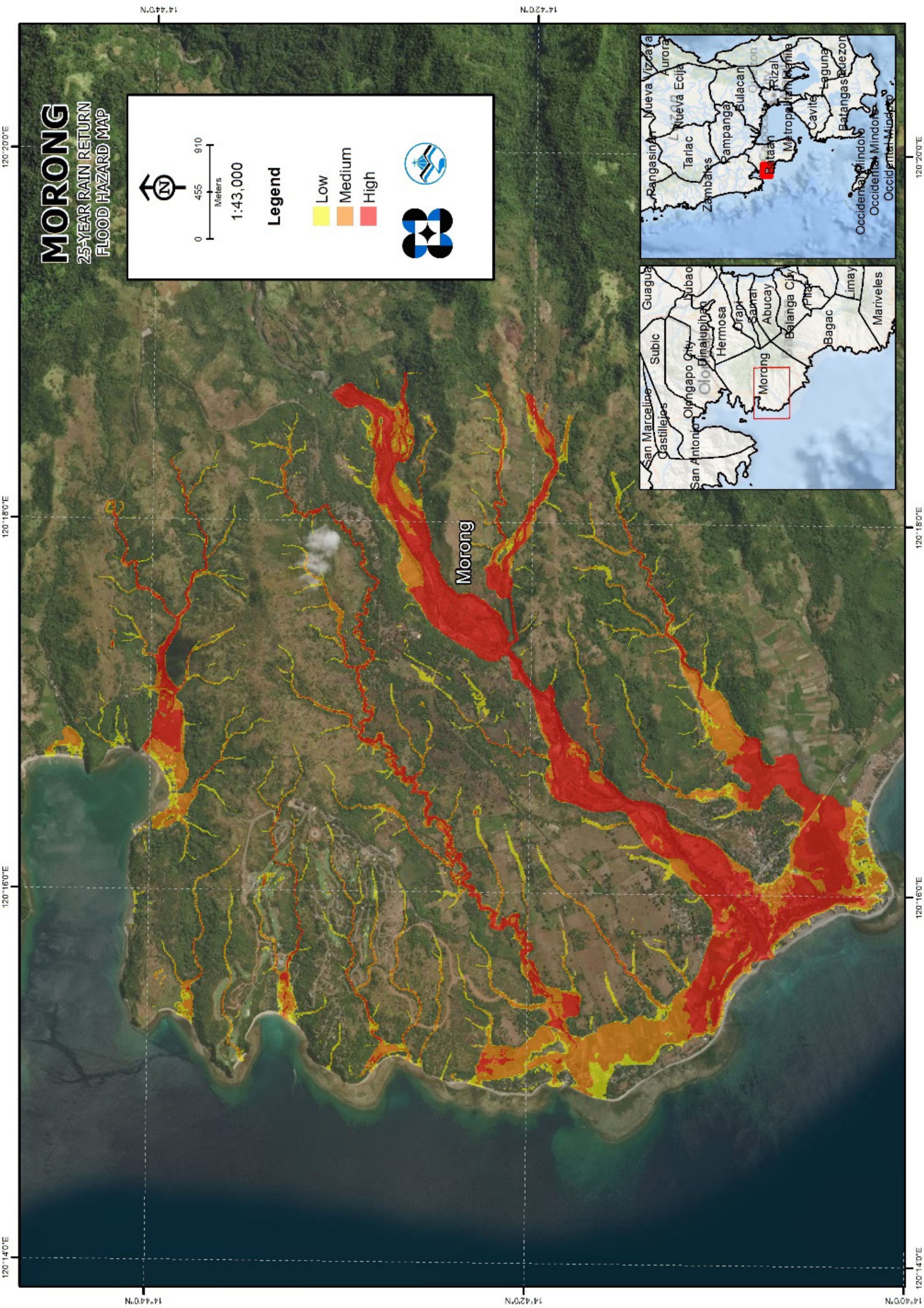



Figure 62. 25-year Flood Hazard Map for Bucao Floodplain

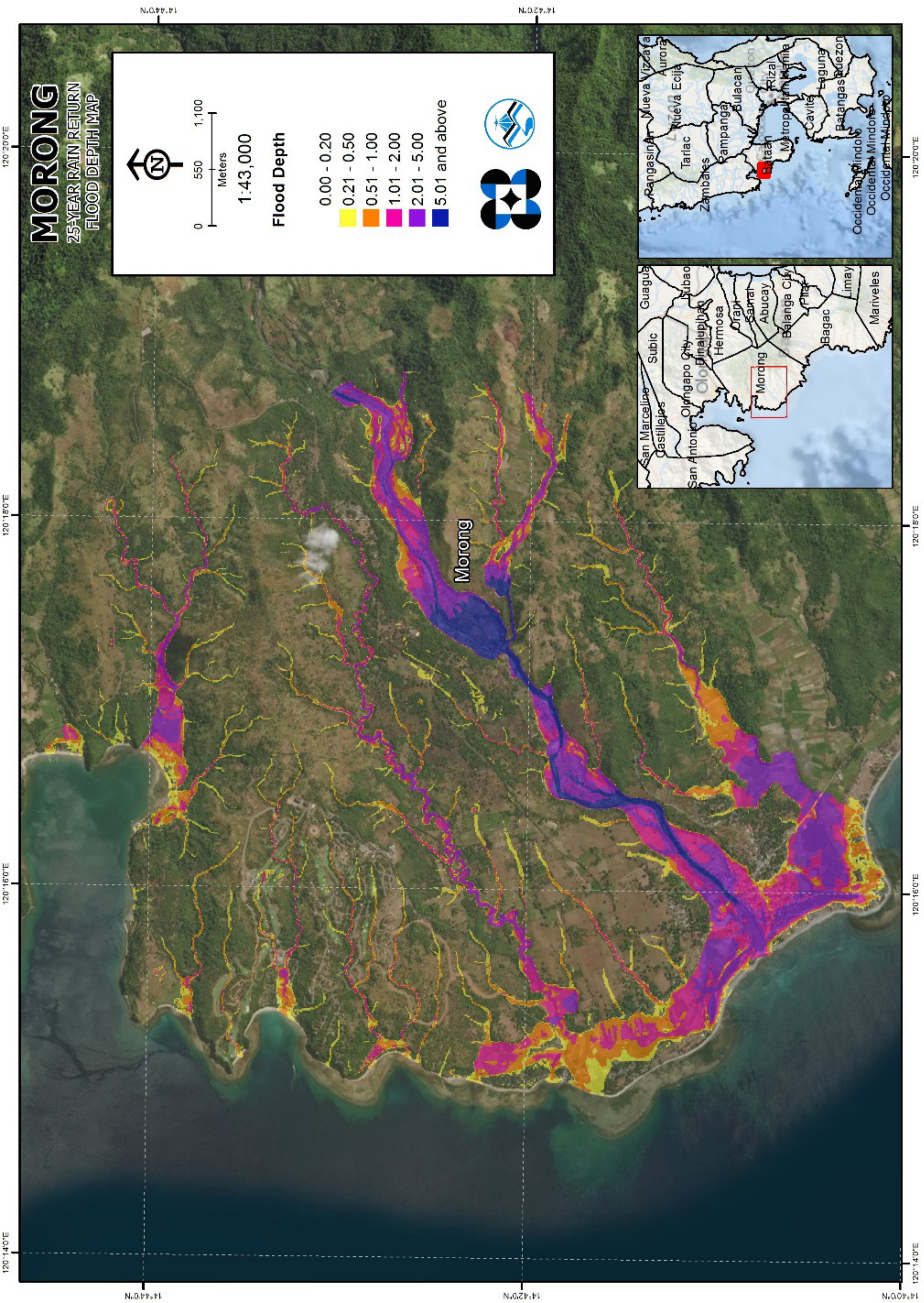



Figure 63. 25-year Flow Depth Map for Bucao Floodplain

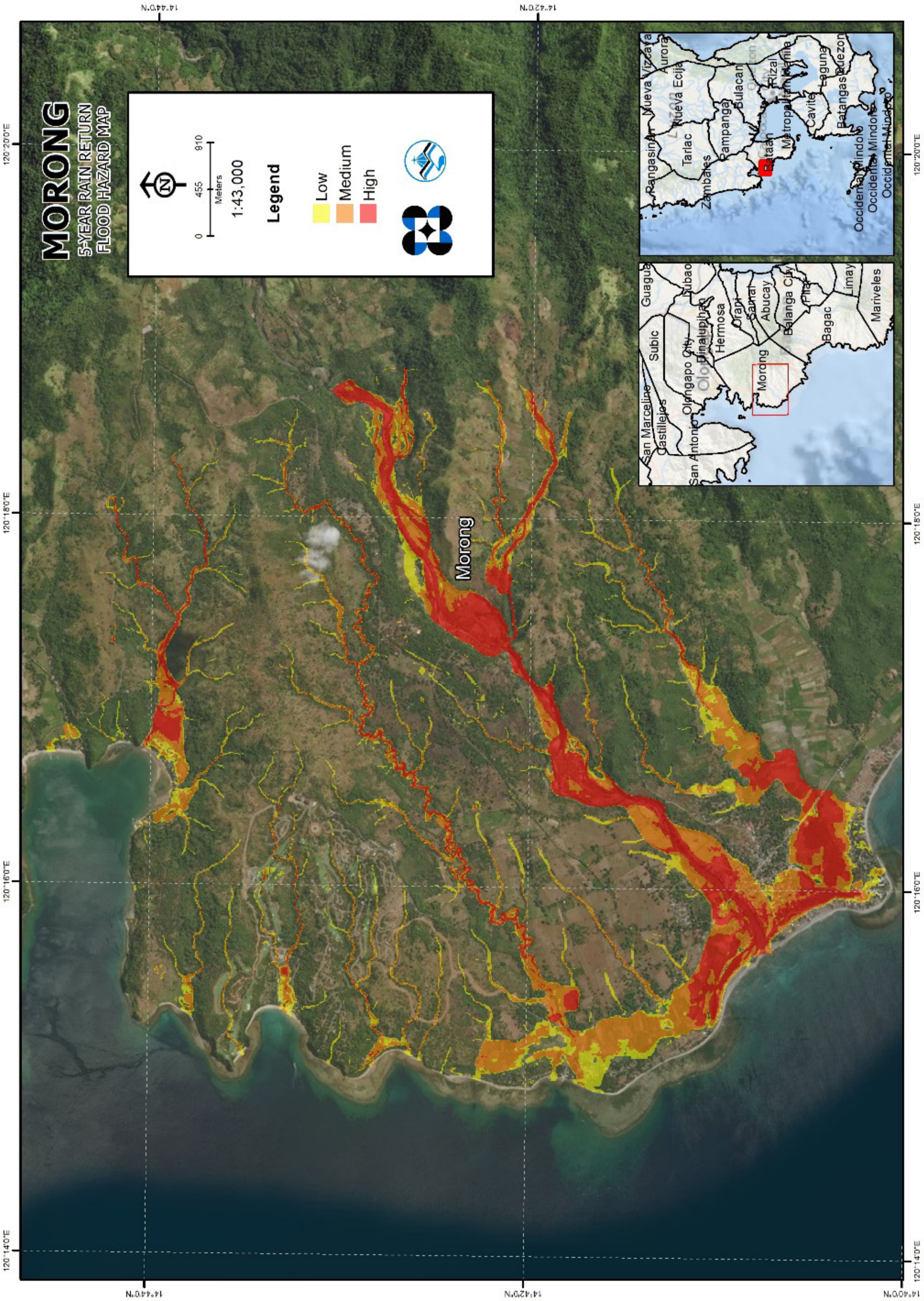



Figure 64. 5-year Flood Hazard Map for Bucao Floodplain

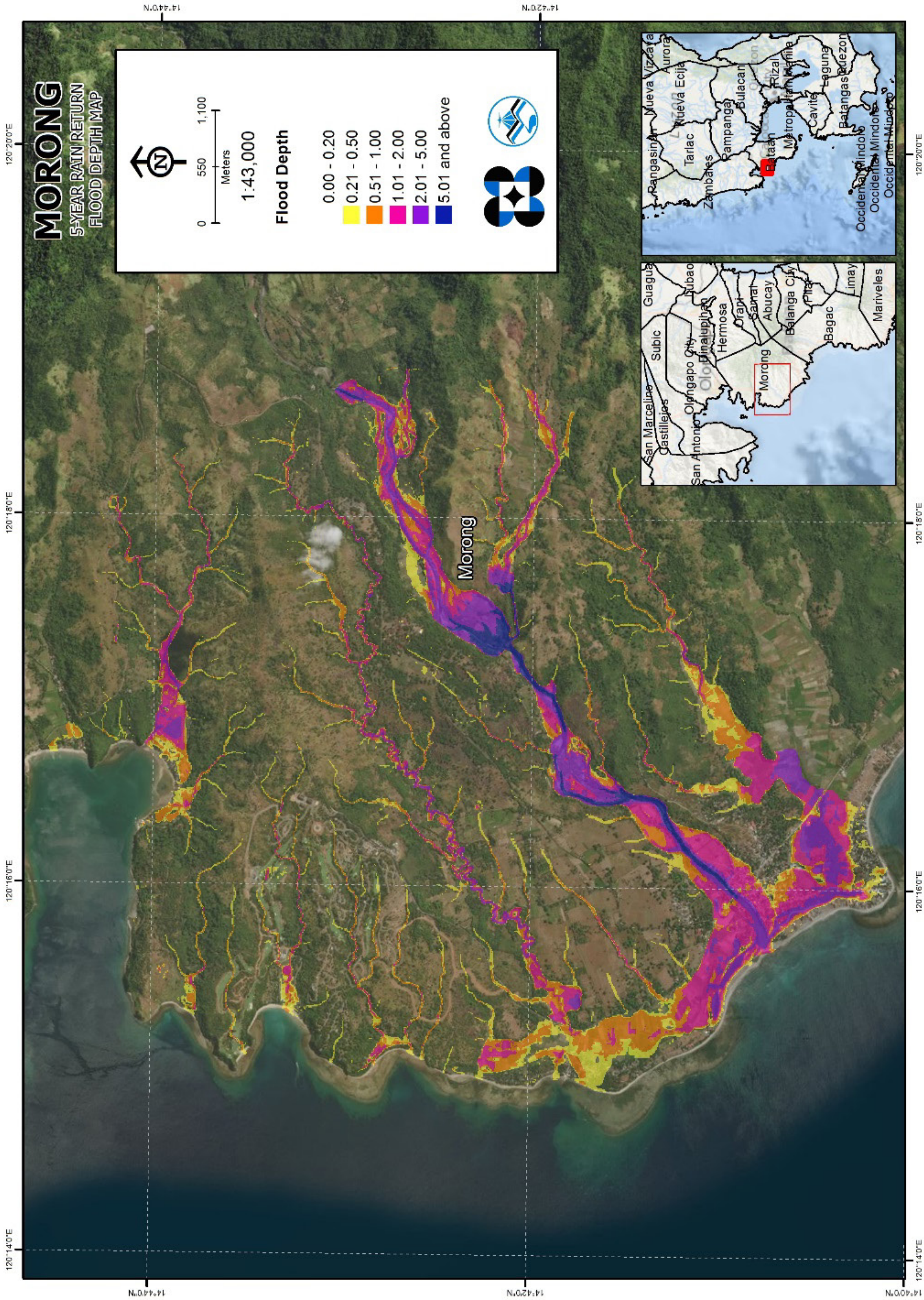



Figure 65. 5-year Flood Depth Map for Bucao Floodplain

## 5.10 Inventory of Areas Exposed to Flooding

Affected barangays in Morong river basin are listed below. For the said basin, one municipality consisting of five barangays are expected to experience flooding when subjected to 5-yr rainfall return period.

For the 5-year return period, 48.08% of the municipality of Morong with an area of 64.44 sq. km. will experience flood levels of less than 0.20 meters. 2.71% of the area will experience flood levels of 0.21 to 0.50 meters while 2.92%, 3.51%, 2.02%, and 0.46% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in the table are the affected areas in square kilometers by flood depth per barangay.

Table 31. Affected Areas in Morong, Bataan during 5-Year Rainfall Return Period

| Affected Area (sq. km.) by flood depth (in m.) | Affected Barangays in Morong (in sq. km.) | | | | |
|---|---|---|---|---|---|
| | Binaritan | Mabayo | Nagbalayong | Poblacion | Sabang |
| **0.03-0.20** | 3.39 | 7.58 | 2.53 | 0.17 | 17.3 |
| **0.21-0.50** | 0.2 | 0.34 | 0.2 | 0.041 | 0.96 |
| **0.51-1.00** | 0.28 | 0.28 | 0.16 | 0.094 | 1.07 |
| **1.01-2.00** | 0.5 | 0.22 | 0.21 | 0.25 | 1.09 |
| **2.01-5.00** | 0.36 | 0.053 | 0.18 | 0.16 | 0.55 |
| **> 5.00** | 0.2 | 0 | 0 | 0.00032 | 0.1 |

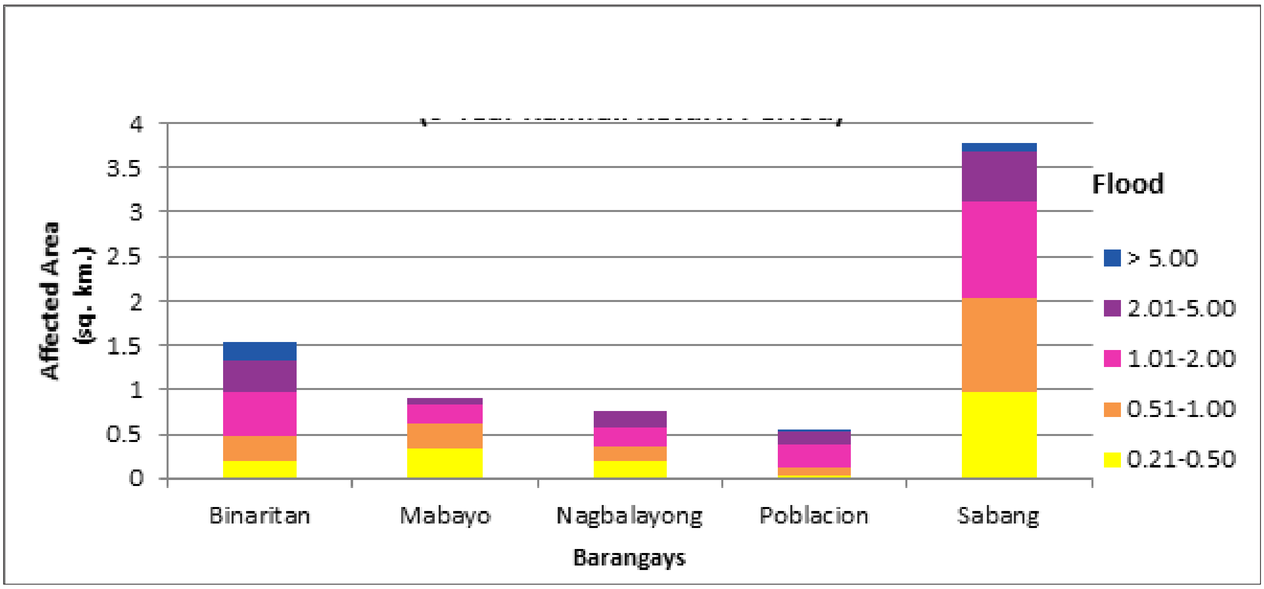



Figure 66. Affected Areas in Morong, Bataan during 5-Year Rainfall Return Period

For the 25-year return period, 46.30% of the municipality of Morong with an area of 64.435501 sq. km. will experience flood levels of less than 0.20 meters. 2.55% of the area will experience flood levels of 0.21 to 0.50 meters while 2.86%, 3.67%, 3.43%, and 0.90% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in the table are the affected areas in square kilometers by flood depth per barangay.

Table 32. Affected Areas in Morong, Bataan during 25-Year Rainfall Return Period

| Affected Area (sq. km.) by flood depth (in m.) | Affected Barangays in Morong (in sq. km.) | | | | |
|---|---|---|---|---|---|
| | Binaritan | Mabayo | Nagbalayong | Poblacion | Sabang |
| **0.03-0.20** | 3.28 | 7.38 | 2.33 | 0.13 | 16.72 |
| **0.21-0.50** | 0.13 | 0.38 | 0.23 | 0.026 | 0.88 |
| **0.51-1.00** | 0.21 | 0.32 | 0.25 | 0.05 | 1 |
| **1.01-2.00** | 0.38 | 0.28 | 0.19 | 0.22 | 1.29 |
| **2.01-5.00** | 0.64 | 0.11 | 0.28 | 0.28 | 0.89 |
| **> 5.00** | 0.29 | 0 | 0 | 0.0017 | 0.29 |

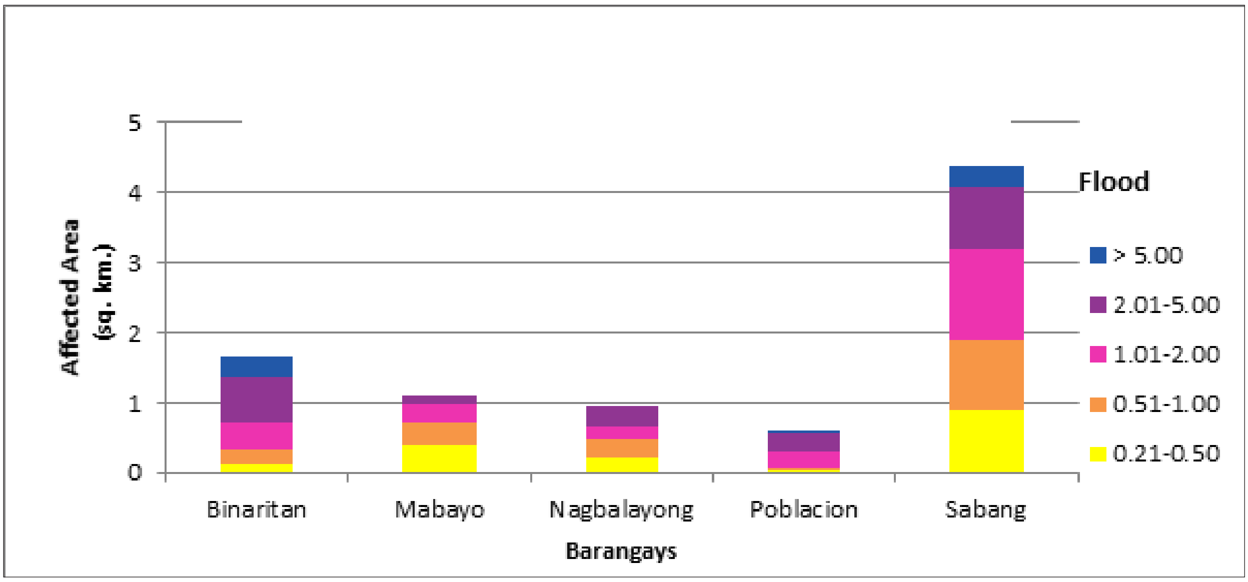



Figure 67. Affected Areas in Morong, Bataan during 25-Year Rainfall Return Period

For the 100-year return period, 45.35% of the municipality of Morong with an area of 64.435501 sq. km. will experience flood levels of less than 0.20 meters. 2.55% of the area will experience flood levels of 0.21 to 0.50 meters while 2.73%, 3.58%, 4.26%, and 1.23% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in the table are the affected areas in square kilometers by flood depth per barangay.

Table 33. Affected Areas in Morong, Bataan during 100-Year Rainfall Return Period

| Affected Area (sq. km.) by flood depth (in m.) | Affected Barangays in Morong (in sq. km.) | | | | |
|---|---|---|---|---|---|
| | Binaritan | Mabayo | Nagbalayong | Poblacion | Sabang |
| **0.03-0.20** | 3.22 | 7.27 | 2.26 | 0.11 | 16.36 |
| **0.21-0.50** | 0.12 | 0.39 | 0.2 | 0.024 | 0.91 |
| **0.51-1.00** | 0.18 | 0.34 | 0.27 | 0.041 | 0.92 |
| **1.01-2.00** | 0.27 | 0.31 | 0.22 | 0.18 | 1.33 |
| **2.01-5.00** | 0.77 | 0.17 | 0.33 | 0.35 | 1.13 |
| **> 5.00** | 0.37 | 0 | 0 | 0.003 | 0.42 |

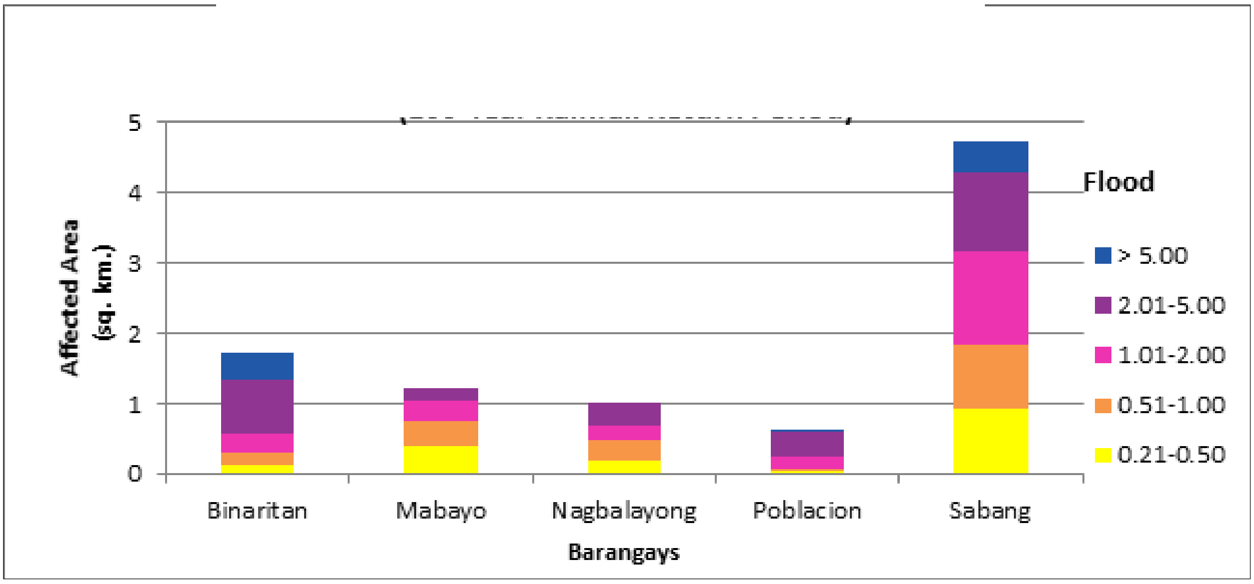



Figure 68. Affected Areas in Morong, Bataan during 100-Year Rainfall Return Period

Among the barangays in the municipality of Morong, Sabang is projected to have the highest percentage of area that will experience flood levels at 32.71%. Meanwhile, Mabayo posted the second highest percentage of area that may be affected by flood depths at 13.15%.

Moreover, the generated flood hazard maps for the Morong Floodplain were used to assess the vulnerability of the educational and medical institutions in the floodplain. Using the flood depth units of PAG-ASA for hazard maps - "Low", "Medium", and "High" - the affected institutions were given their individual assessment for each Flood Hazard Scenario (5 yr, 25 yr, and 100 yr).

Table 34. Area covered by each warning level with respect to the rainfall scenario

| Warning Level | Area Covered in sq. km. | | |
|---|---|---|---|
| | 5 year | 25 year | 100 year |
| Low | 1.7573 | 1.6701 | 1.6907 |
| Medium | 3.0407 | 2.9457 | 2.8419 |
| High | 2.8065 | 4.1475 | 4.8648 |

As seen in Annex 12 Of the 42 identified Education Institute in Morong Flood plain, 7 schools were assessed to be exposed to the Low level flooding during a 5 year scenario while 15 schools were assessed to be exposed to medium level flooding and 5 schools were assessed to be exposed to high level floodingin the same scenario. In the 25 year scenario, 6 schools were assessed to be exposed to the Low level flooding while 22 schools were assessed to be exposed to medium level flooding and 5 schools were assessed to be exposed to high level flooding. For the 100 year scenario, 2 school was assessed for low level flooding and 18 schools for medium level flooding. In the same scenario, 13 schools were assessed to be exposed to high level flooding.

One (1) Medical Institutions were identified in Morong Floodplain and was assessed to be exposed to medium level flooding in the 5 and 25 year scenario and to high level flooding in the 100 year scenario.

## 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 flood validation consists of 180 points randomly selected all over the Morong flood plain. It has an RMSE value of 0.68.

The flood validation data were obtained on January 10-14, 2017

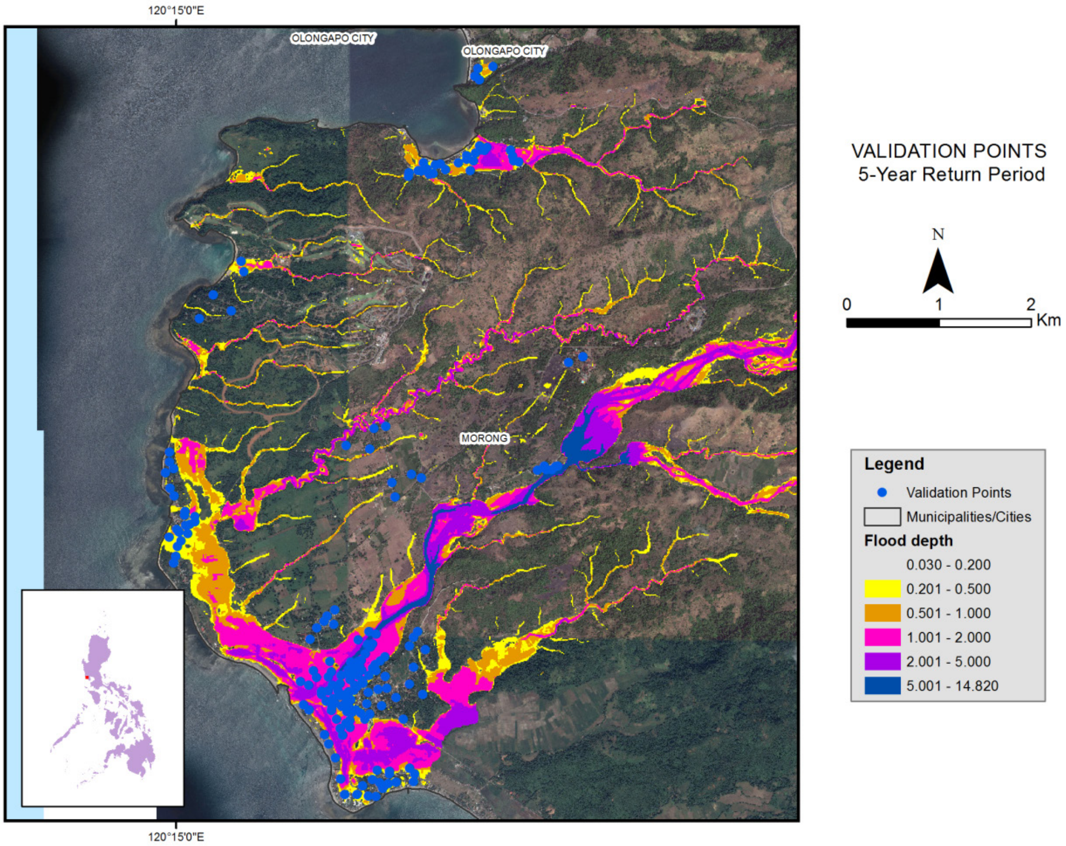



Figure 69. Validation points for 5-year Flood Depth Map of Morong Floodplain

Table 35. Actual Flood Depth vs Simulated Flood Depth in Morong

| MORONG BASIN | | Modeled Flood Depth (m) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0-0.20 | 0.21-0.50 | 0.51-1.00 | 1.01-2.00 | 2.01-5.00 | > 5.00 | Total |
| Actual Flood Depth (m) | 0-0.20 | 52 | 13 | 14 | 0 | 0 | 0 | 79 |
| | 0.21-0.50 | 4 | 17 | 7 | 5 | 3 | 0 | 36 |
| | 0.51-1.00 | 1 | 0 | 11 | 14 | 2 | 0 | 28 |
| | 1.01-2.00 | 1 | 1 | 5 | 22 | 8 | 0 | 37 |
| | 2.01-5.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | > 5.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Total | 58 | 31 | 37 | 41 | 13 | 0 | 180 |

The overall accuracy generated by the flood model is estimated at 56.67%, with 102 points correctly matching the actual flood depths. In addition, there were 51 points estimated one level above and below the correct flood depths while there were 23 points and 4 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 66 points were overestimated while a total of 12 points were underestimated in the modelled flood depths of Morong.

Table 36. Summary of Accuracy Assessment in Morong

| | No. of Points | % |
|---|---|---|
| Correct | 102 | **56.67** |
| Overestimated | 66 | **36.67** |
| Underestimated | 12 | **6.67** |
| Total | 180 | **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 Specification of the Optech Sensors Used in the LiDAR Survey

1. Pegasus


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

1 Target reflectivity ≥20%

2 Dependent on selected operational parameters using nominal FOV of up to 40° in standard atmospheric conditions with 24-km visibility

3 Angle of incidence ≤20˚

4 Target size ≥ laser footprint5 Dependent on system configuration

2. Gemini


| 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><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><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 Certificates of Reference Points Used

1. BTN-71

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

January 02, 2014

## CERTIFICATION

To whom it may concern:

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

Province: **BATAAN**
Station Name: **BTN-71**
Order: **2nd**

| | | |
|---|---|---|
| Island: **LUZON** | | Barangay: **MARIA FE** |
| Municipality: **ORANI** | | |
| | *PRS92 Coordinates* | |
| Latitude: **14° 47' 30.18239"** | Longitude: **120° 32' 9.95860"** | Ellipsoidal Hgt: **7.56300 m.** |
| | *WGS84 Coordinates* | |
| Latitude: **14° 47' 24.68277"** | Longitude: **120° 32' 14.83855"** | Ellipsoidal Hgt: **49.42500 m.** |
| | *PTM Coordinates* | |
| Northing: **1635812.88 m.** | Easting: **450060.675 m.** | Zone: **3** |
| | *UTM Coordinates* | |
| Northing: **1,636,645.28** | Easting: **234,782.54** | Zone: **51** |

Location Description

BTN-71
Is located in Brgy. Maria Fe, 30 m Sw of the Day Care Center, 20 m SE of the basketball court and 15 m NE of the chapel of the said barangay. It is also situated on the W edge of the concrete pavement used as volleyball court. Mark is the head of a 4" copper nail centered on a 30 cm x 30 cm concrete monument flushed on the ground with inscriptions BTN-71 2007 NAMRIA.

Requesting Party: **UP DREAM**
Pupose: **Reference**
OR Number: **8794989 A**
T.N.: **2014-4**

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

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

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

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

2. ZBS-64

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

September 04, 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: **ZAMBALES** | |
| | Station Name: **ZBS-64** | |
| | Order: **2nd** | |
| Island: **LUZON** | Barangay: **MAGSAYSAY** | |
| Municipality: **CASTILLEJOS** | MSL Elevation: | |
| | ***PRS92 Coordinates*** | |
| Latitude: **14° 56' 28.82886"** | Longitude: **120° 11' 31.25386"** | Ellipsoidal Hgt: **52.07500 m.** |
| | ***WGS84 Coordinates*** | |
| Latitude: **14° 56' 23.26711"** | Longitude: **120° 11' 36.12262"** | Ellipsoidal Hgt: **92.66800 m.** |
| | ***PTM / PRS92 Coordinates*** | |
| Northing: **1652473.038 m.** | Easting: **413077.841 m.** | Zone: **3** |
| | ***UTM / PRS92 Coordinates*** | |
| Northing: **1,653,646.25** | Easting: **197,928.90** | Zone: **51** |

Location Description

ZBS-64
From San Fernando City, travel toward Castillejos Proper via Olongapo City. The station is situated at Barangay Magsaysay which is about 1 km NW of Castillejos Municipal Hall. Mark is located at the left shoulder of the road and is measured 2m from the culvert parapet. Mark is the head of a 4 inch copper nail, centered on a 30 cm x 30 cm concrete block flushed on the ground with inscription "ZBS-64, 2007, NAMRIA".

Requesting Party: **Christopher Cruz**
Purpose: **Reference**
OR Number: **8087195 I**
T.N.: **2015-2551**

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

9 9 0 9 0 4 2 0 1 5 1 5 5 5 0 8

CIF/4701/12/09/814

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

# Annex 3. Baseline Processing Reports of Reference Points Used

1. AAC-01

Vector Components (Mark to Mark)

| From: | TRC-01 | | | | |
|---|---|---|---|---|---|
| Grid | | Local | | Global | |
| Easting | 242278.307 m | Latitude | N15°28'44.13767" | Latitude | N15°28'38.48550" |
| Northing | 1712636.202 m | Longitude | E120°35'52.67202" | Longitude | E120°35'57.49329" |
| Elevation | 44.420 m | Height | 46.891 m | Height | 86.902 m |

| To: | AAC-01 | | | | |
|---|---|---|---|---|---|
| Grid | | Local | | Global | |
| Easting | 236272.483 m | Latitude | N15°11'27.81685" | Latitude | N15°11'22.22626" |
| Northing | 1680836.256 m | Longitude | E120°32'43.37833" | Longitude | E120°32'48.22418" |
| Elevation | 151.882 m | Height | 154.260 m | Height | 194.988 m |

| Vector | | | | | |
|---|---|---|---|---|---|
| ΔEasting | -6005.824 m | NS Fwd Azimuth | 190°03'34" | ΔX | 523.697 m |
| ΔNorthing | -31799.946 m | Ellipsoid Dist. | 32347.854 m | ΔY | 10213.192 m |
| ΔElevation | 107.461 m | ΔHeight | 107.369 m | ΔZ | -30689.417 m |

Standard Errors

| Vector errors: | | | | | |
|---|---|---|---|---|---|
| σ ΔEasting | 0.002 m | σ NS fwd Azimuth | 0°00'00" | σ ΔX | 0.006 m |
| σ ΔNorthing | 0.002 m | σ Ellipsoid Dist. | 0.002 m | σ ΔY | 0.011 m |
| σ ΔElevation | 0.013 m | σ ΔHeight | 0.013 m | σ ΔZ | 0.004 m |

Aposteriori Covariance Matrix (Meter²)

| | X | Y | Z |
|---|---|---|---|
| X | 0.0000413905 | | |
| Y | -0.0000661260 | 0.0001225849 | |
| Z | -0.0000191610 | 0.0000334556 | 0.0000154812 |

## Annex 4. The LiDAR Survey Team Composition

| Data Acquisition Component Sub-Team | Designation | Name | Agency/ Affiliation |
|---|---|---|---|
| PHIL-LIDAR 1 | Program Leader | ENRICO C. PARINGIT, D.ENG | UP-TCAGP |
| Data Acquisition Component Leader | Data Component Project Leader - I | ENGR. CZAR JAKIRI SARMIENTO | UP-TCAGP |
| | Data Component Project Leader – I | ENGR. LOUIE P. BALICANTA | UP-TCAGP |
| Survey Supervisor | Chief Science Research Specialist (CSRS) | ENGR. CHRISTOPHER CRUZ | UP-TCAGP |
| | Supervising Science Research Specialist (Supervising SRS) | LOVELY GRACIA ACUÑA | UP-TCAGP |
| | | LOVELYN ASUNCION | UP-TCAGP |
| FIELD TEAM | | | |
| LiDAR Operation | Senior Science Research Specialist (SSRS) | AUBREY PAGADOR | UP-TCAGP |
| | Senior Science Research Specialist (SSRS) 2016/ RA (2014) | JASMINE ALVIAR | UP-TCAGP |
| | Research Associate (RA) | ENGR. DAN CHRISTOFFER ALDOVINO | UP-TCAGP |
| | RA | FOR. REGINA FELISMINO | UP-TCAGP |
| | RA | MA. CATHERINE ELIZABETH BALIGUAS | UP-TCAGP |
| LiDAR Operation/ Ground Survey, Data Download and Transfer | RA | ENGR. RENAN PUNTO | UP-TCAGP |
| | RA | ENGR. LARAH KRISELLE PARAGAS | UP-TCAGP |
| | RA | ENGR. IRO NIEL ROXAS | UP-TCAGP |
| LiDAR Operation | Airborne Security | SSG DIOSCORO SOBERANO | PHILIPPINE AIR FORCE (PAF) |
| | | SSG MARION TORRE | PAF |
| | | SSG PRADYUMA DAS RAMIREZ | PAF |
| | Pilot | CAPT. ALBERT PAUL LIM | ASIAN AEROSPACE CORPORATION (AAC) |
| | | CAPT. JEFF JEREMY ALAJAR | AAC |
| | | CAPT. F. DE OCAMPO | AAC |
| | | CAPT. JERICHO JECIEL | AAC |

# Annex 5. Data Transfer Sheet for Morong Floodplain

DATA TRANSFER SHEET

Jan 10, 2013

| DATE | FLIGHT NO. | MISSION NAME | SENSOR | RAW LAS | | LOGS | POS | RAW IMAGES | MISSION LOG FILE | RANGE | DIGITIZER | BASE STATION(S) | | OPERATOR LOGS (OPLOG) | FLIGHT PLAN | | SERVER LOCATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Output LAS | KML (swath) | | | | | | | BASE STATION(S) | Base Info (.txt) | | Actual | KML | |
| Jan 2 2014 | 926G | 2BALE002A | GEMINI | N/A | N/A | 4.05 MB | 243 MB | 27.2 GB | 201 KB | 13.3 GB | 101 GB | 8.23 MB | 174 BYTES | 471 BYTES | 4.68 KB | 101 KB | Y:\Airborne_Raw\926G |
| Jan 3 2014 | 930G | 2BUCE003A | GEMINI | N/A | N/A | 848 KB | 277 MB | 35.2 GB | 245 KB | 18.9 GB | 1.29 GB | 27.7 MB | 376 BYTES | 485 BYTES | 5.77 KB | 432 KB | Y:\Airborne_Raw\930G |
| Jan 3 2014 | 932G | 2BUCES003A | GEMINI | N/A | N/A | 329 KB | 86.8 MB | N/A | N/A | 809 MB | N/A | 27.7 MB | 376 BYTES | 438 BYTES | 5.77 KB | 432 KB | Y:\Airborne_Raw\932G |
| Jan 4 2014 | 934G | 2BUCF004A | GEMINI | N/A | N/A | 0.99 MB | 299 MB | 7.19 GB | N/A | 27.6 GB | 189 GB | 21.3 MB | 278 BYTES | 527 BYTES | 5.63 KB | 664 KB | Y:\Airborne_Raw\934G |
| Jan 2 2014 | 935P | 1BALAS002A | PEGASUS | 970 KB | 1124 KB | 9.79 MB | 265 MB | N/A | N/A | 18.5 GB | 87.3 GB | 8.23 MB | 174 BYTES | 604 BYTES | 19.0 KB | 145 KB | Y:\Airborne_Raw\935G |
| Jan 4 2014 | 943P | 1BUCABC004A | PEGASUS | 1415 KB | 1152 KB | 11.6 MB | 274 MB | N/A | N/A | 21.6 GB | 78.2 GB | 21.3 MB | 278 BYTES | 616 BYTES | 47.6 KB | 60.7 KB | Y:\Airborne_Raw\943P |
| Jan 3 2014 | 941P | 1BUCBS003B | PEGASUS | 574 KB | 699 KB | 6.43 MB | 205 MB | N/A | N/A | 10.8 GB | 36.3 GB | 27.7 MB | 376 BYTES | 320 BYTES | 22.6 KB | 53.4 KB | Y:\Airborne_Raw\941P |
| Jan 4 2014 | 945P | 1BUCCS004B | PEGASUS | 211 KB | 258 KB | 5.52 MB | 172 MB | N/A | N/A | 4.69 GB | 562 MB | 21.3 MB | 278 BYTES | 374 BYTES | 29.2 KB | 53.4 KB | Y:\Airborne_Raw\945P |
| Jan 3 2014 | 939P | 1PLGA003A | PEGASUS | 1.38 MB | 1.68 MB | 10.0 MB | 295 MB | N/A | N/A | 26.1 GB | 121 GB | 27.7 MB | 376 BYTES | 524 BYTES | 29.6 KB | 18.6 KB | Y:\Airborne_Raw\939P |
| Jan 5 2014 | 949P | 1BUCGS005B | PEGASUS | 671 KB | 823 KB | 7.24 MB | 228 MB | N/A | N/A | 12.9 GB | 42.9 GB | 16.1 MB | 222 BYTES | 558 BYTES | 23.8 KB | 243 KB | Y:\Airborne_Raw\949P |
| Jan 6 2014 | 951P | 1BALF006A | PEGASUS | 420 KB | 528 KB | 6.41 MB | 178 MB | N/A | N/A | 9.51 GB | 41.5 GB | 12.8 MB | 221 BYTES | 442 BYTES | 19 KB | 158 KB | Y:\Airborne_Raw\951P |

# { 924G
947P
963P

**Received from**

Name Pat Alcantara
Position RA
Signature [signature]

**Received by**

Name JOIDA PRIETO
Position SSRS
Signature [signature]

**Verified by**

Name JOIDA PRIETO
Position SSRS
Signature [signature] 01/10/2014 2013

13-21

DATA TRANSFER SHEET
03/09/2015(Clark)

| 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 | |
| 20-Jan | 2471P | 1BUC020A | pegasus | 847 | na | 7.8 | 192 | 25.1 | 217 | 15.5 | na | 5.41 | 1KB | 1KB | 50 | na | Z:\DAC\RAW DATA |
| 21-Jan | 2473P | 1BUC021A | pegasus | 1.69 | na | 10.3 | 252 | 31 | 208 | 16 | na | 4.14 | 1KB | 1KB | 44 | na | Z:\DAC\RAW DATA |
| 22-Jan | 2477P | 1NEJ022A | pegasus | 1.04 | na | 7.5 | 197 | na | na | 10.2 | na | 4.16 | 1KB | 1KB | na | na | Z:\DAC\RAW DATA |
| 23-Jan | 2481P | 1BTN023A | pegasus | 2.44 | na | 11.7 | 273 | na | na | 24.4 | na | 2.82 | 1KB | 1KB | 113 | na | Z:\DAC\RAW DATA |
| 26-Jan | 2493P | 1BUC026A | pegasus | 2.44 | na | 11.7 | 273 | 18.7/11.1 | 13682.4q | 6.71 | na | 8.56 | 1KB | 1KB | 113 | na | Z:\DAC\RAW DATA |
| 27-Jan | 2497P | 1BUC027A | pegasus | 631 | na | 6.73 | 195 | 21 | 170 | 7.47 | na | 2.41 | 1KB | 1KB | 63 | na | Z:\DAC\RAW DATA |
| 28-Jan | 2501P | 1BUC028A | pegasus | 1.9 | na | 8.65 | 184 | 22.5 | 161 | 20.7 | na | 5.3 | 1KB | 1KB | 89 | na | Z:\DAC\RAW DATA |

Received from

Name C JOAQUIN
Position
Signature [signature]

Received by

Name AC Bongat 3/9/15
Position CSRS
Signature [signature]

15-13

DATA TRANSFER SHEET
~~Calabarzon~~ 9/10/15 CLARK

| 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 | |
| 26-Aug-15 | 2656G | 2BTNAB238B | gemini | na | 202 | 385 | 185 | 9.17/1.8/361 | 81/15/4 | 9.15 | 1.22 | 175 | 1KB | 1KB | 8 | 7 | Z:\DAC\RAW DATA |
| 27-Aug-15 | 2658G | 2BTNCD239A | gemini | na | 298 | 623 | 232 | 11.6/9.83 | 1/1/1 | 13.3 | 537 | 94.8 | 1KB | 1KB | 10 | 17 | Z:\DAC\RAW DATA |
| 28-Aug-15 | 2662G | 2UMYA240A | gemini | na | 273 | 482 | 231 | 134/25.1 | 2/198 | 8.59 | 0 | 137 | 1KB | 1KB | 12 | 30 | Z:\DAC\RAW DATA |
| 29-Aug-15 | 2666G | 2UMYAB241A | gemini | na | 301 | 554 | 238 | 17.6 | 139 | 12.5 | 673 | 104 | 1KB | 1KB | 12 | na | Z:\DAC\RAW DATA |
| 30-Aug-15 | 2670G | 2CLBUMYABS242A | gemini | na | 379 | 635 | 247 | 29.1 | 233 | 16.4 | 321 | 84.5 | 1KB | 1KB | 5 | 7 | Z:\DAC\RAW DATA |

**Received from**

Name C. Joaquin
Position RA
Signature [signature]

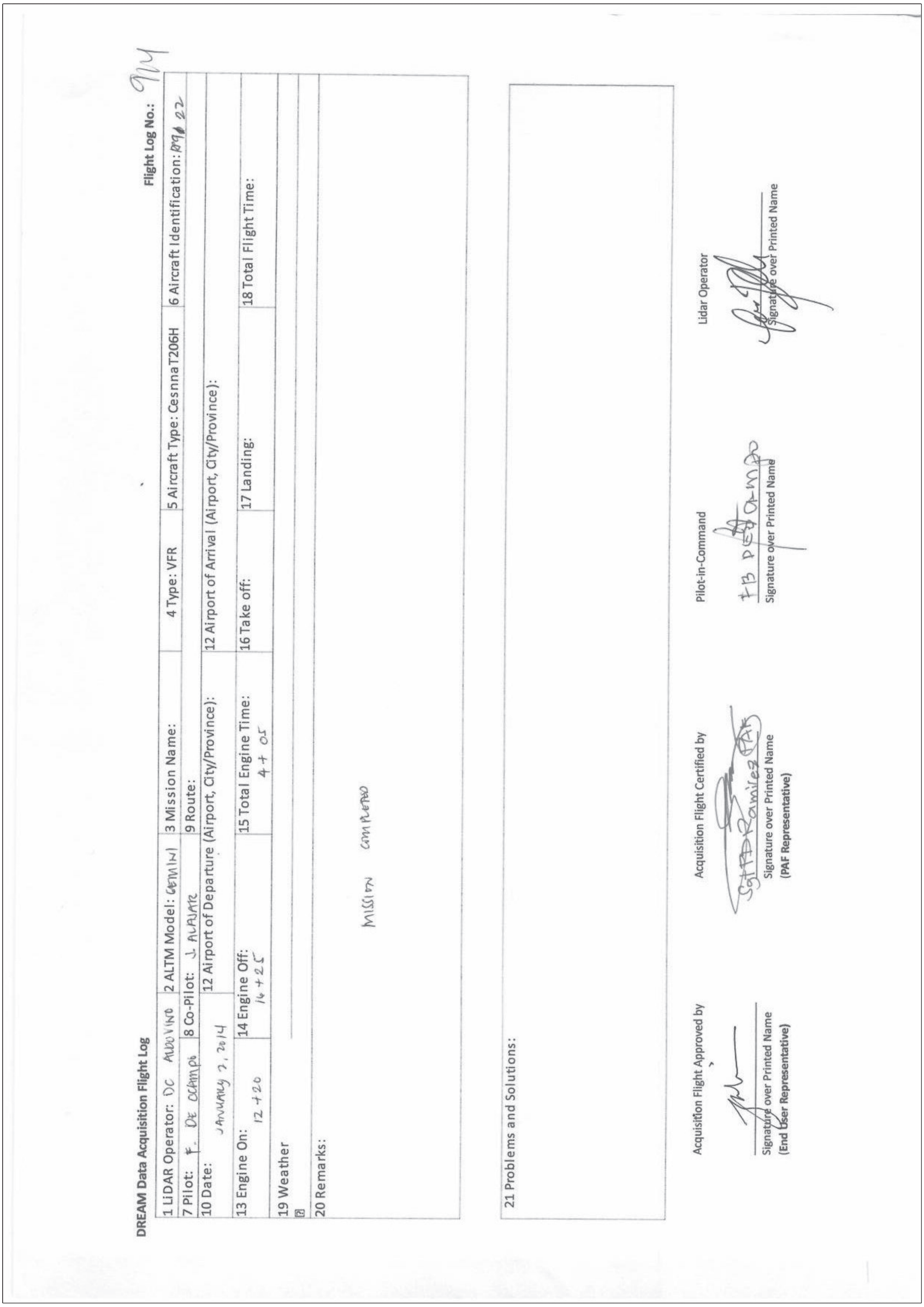
**Received by**

Name AC Bongat 9/11/15 Calib: 10/5/15
Position SSRS
Signature ACBongat

15-26

# Annex 6. Flight Logs

1. Flight Log for 926G Mission


DREAM Data Acquisition Flight Log

Flight Log No.: 914

| | | | | | |
|---|---|---|---|---|---|
| 1 LiDAR Operator: DC ALDOVINO | 2 ALTM Model: GEMINI | 3 Mission Name: | 4 Type: VFR | 5 Aircraft Type: Cesnna T206H | 6 Aircraft Identification: RP9022 |
| 7 Pilot: F. DE OCAMPO | 8 Co-Pilot: J. ALFONSO | 9 Route: | | | |
| 10 Date: JANUARY 7, 2014 | 12 Airport of Departure (Airport, City/Province): | | 12 Airport of Arrival (Airport, City/Province): | | |
| 13 Engine On: 12+20 | 14 Engine Off: 16+25 | 15 Total Engine Time: 4+05 | 16 Take off: | 17 Landing: | 18 Total Flight Time: |
| 19 Weather | | | | | |
| 20 Remarks: MISSION COMPLETED | | | | | |
| 21 Problems and Solutions: | | | | | |

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

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

Pilot-in-Command — FB DE OCAMPO — Signature over Printed Name

Lidar Operator — Signature over Printed Name

2. Flight Log for 2481P Mission

**DREAM Data Acquisition Flight Log**

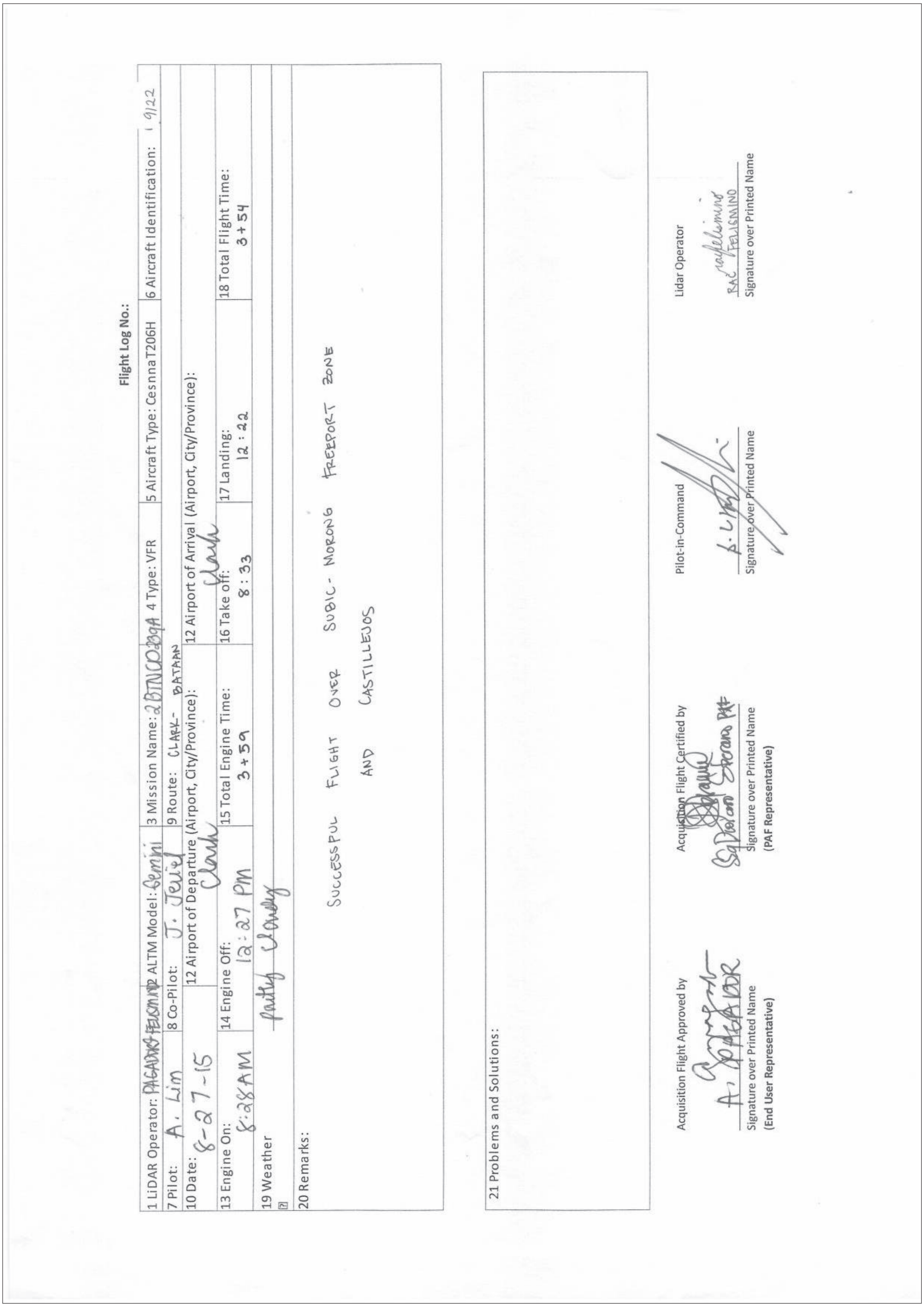
**Flight Log No.:** 2481

| | | | | | |
|---|---|---|---|---|---|
| 1 LiDAR Operator: I. Roxas | 2 ALTM Model: Pegasus | 3 Mission Name: 1BTN023A | 4 Type: VFR | 5 Aircraft Type: CesnnaT206H | 6 Aircraft Identification: RP-C9022 |
| 7 Pilot: J. Alajar | 8 Co-Pilot: A. Lim | 9 Route: Clark – Clark | | | |
| 10 Date: Jan 23, 2015 | 12 Airport of Departure (Airport, City/Province): Clark | | 12 Airport of Arrival (Airport, City/Province): Clark | | |
| 13 Engine On: 1205H | 14 Engine Off: 1628H | 15 Total Engine Time: 4+23 | 16 Take off: 1200H | 17 Landing: 1623H | 18 Total Flight Time: 4+13 |
| 19 Weather | | | | | |
| 20 Remarks: Successful flight | | | | | |

21 Problems and Solutions:

| Acquisition Flight Approved by | Acquisition Flight Certified by | Pilot-in-Command | Lidar Operator |
|---|---|---|---|
| J. Alviar | Marlon Torre | JJ Alajar | I. Roxas |
| Signature over Printed Name (End User Representative) | Signature over Printed Name (PAF Representative) | Signature over Printed Name | Signature over Printed Name |

Flight Log for 2658G



**Flight Log No.:**

| | | | | | |
|---|---|---|---|---|---|
| 1 LiDAR Operator: PAGADUAN-FELISMINO | 2 ALTM Model: Gemini | 3 Mission Name: 2BTNCO239A | 4 Type: VFR | 5 Aircraft Type: CesnnaT206H | 6 Aircraft Identification: 9122 |
| 7 Pilot: A. Lim | 8 Co-Pilot: J. Jeriel | 9 Route: CLARK- BATAAN | | | |
| 10 Date: 8-27-15 | 12 Airport of Departure (Airport, City/Province): Clark | | 12 Airport of Arrival (Airport, City/Province): Clark | | |
| 13 Engine On: 8:28AM | 14 Engine Off: 12:27 PM | 15 Total Engine Time: 3+59 | 16 Take off: 8:33 | 17 Landing: 12:22 | 18 Total Flight Time: 3+54 |
| 19 Weather: Partly Cloudy | | | | | |
| 20 Remarks: SUCCESSFUL FLIGHT OVER SUBIC-MORONG FREEPORT ZONE AND CASTILLEJOS | | | | | |

21 Problems and Solutions:

| Acquisition Flight Approved by | Acquisition Flight Certified by | Pilot-in-Command | Lidar Operator |
|---|---|---|---|
| A. PAGADOR | SgDivan Ebrano PAF | A. LIM | RAC FELISMINO |
| Signature over Printed Name (End User Representative) | Signature over Printed Name (PAF Representative) | Signature over Printed Name | Signature over Printed Name |

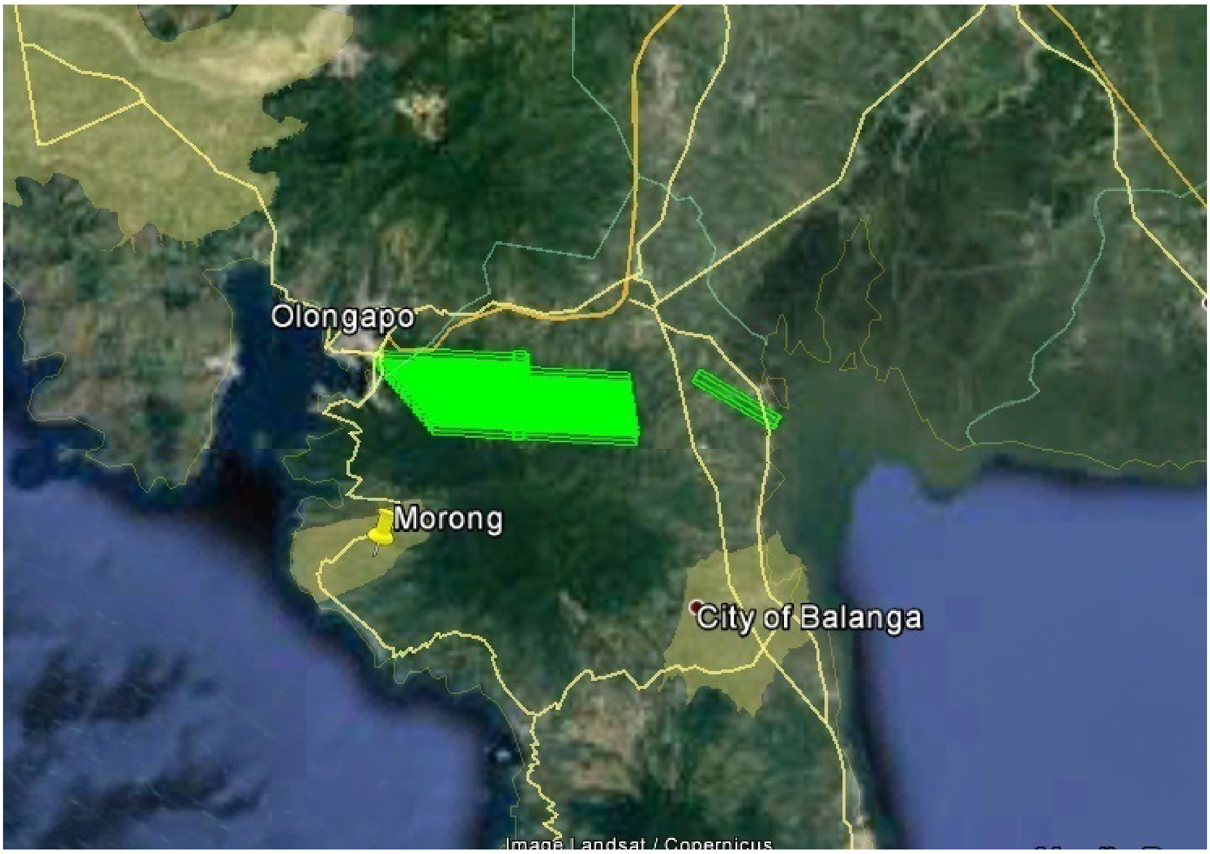
# Annex 7. Flight Status

| FLIGHT STATUS REPORT<br>Bataan and Umiray; Clark Reflights<br>January 2, 2014, January 23, 2015, and August 26, 2015 | | | | | |
|---|---|---|---|---|---|
| **FLIGHT NO.** | **AREA** | **MISSION** | **OPERATOR** | **DATE FLOWN** | **REMARKS** |
| 926G | BALE | 2BALE002A | DC ALDOVINO | January 2, 2014 | Surveyed BALE |
| 2481P | BTN | 1BTN023A | I ROXAS | January 23, 2015 | Filled up gaps in Bucao, surveyed Morong |
| 2658G | BTNCD | 2BTNCD239A | AM PAGADOR & MCE BALIGUAS | August 27, 2015 | Successful flight over Subic-Morong Freeport Zone and Castillejos |

## SWATH/LAS PER MISSION

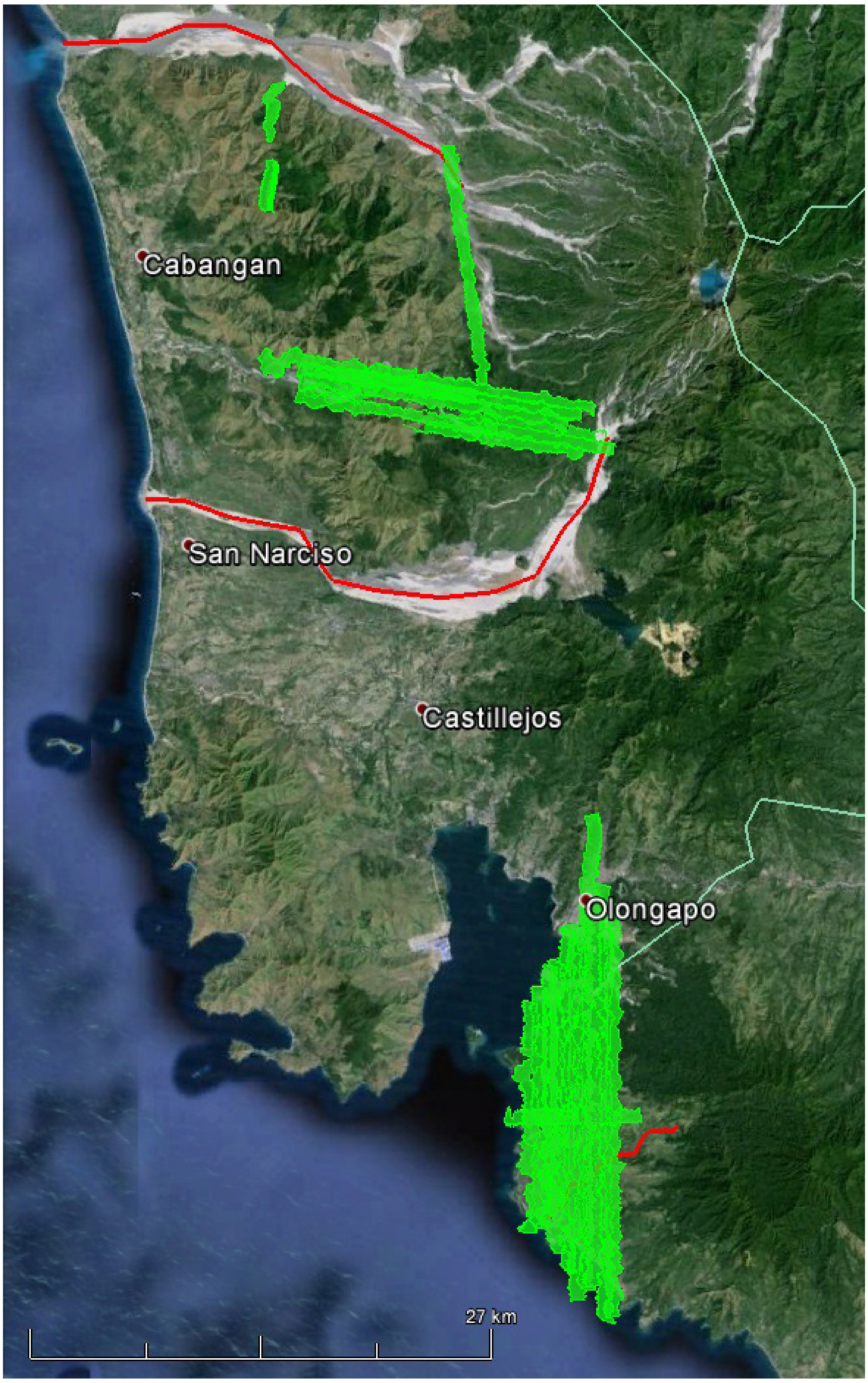
Flight No. : 926G
Area: BALE
Mission Name: 2BALE002A
Parameters: Altitude: 1000 Scan Frequency: 50
Scan Angle: 20 Overlap: 30

## SWATH



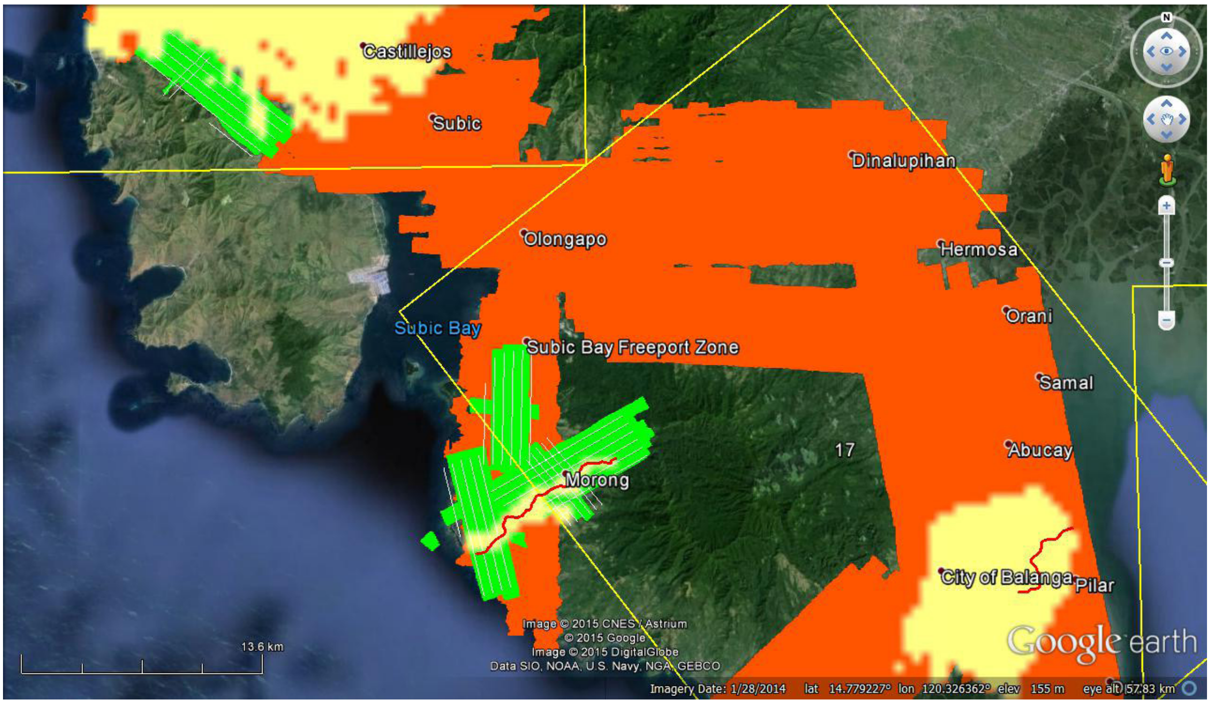
Flight No. : 2481P
Area: BTN
Mission Name: 1BTN023A
Parameters: Altitude: 1000 Scan Frequency: 30
Scan Angle: 25 Overlap: 30

**LAS**



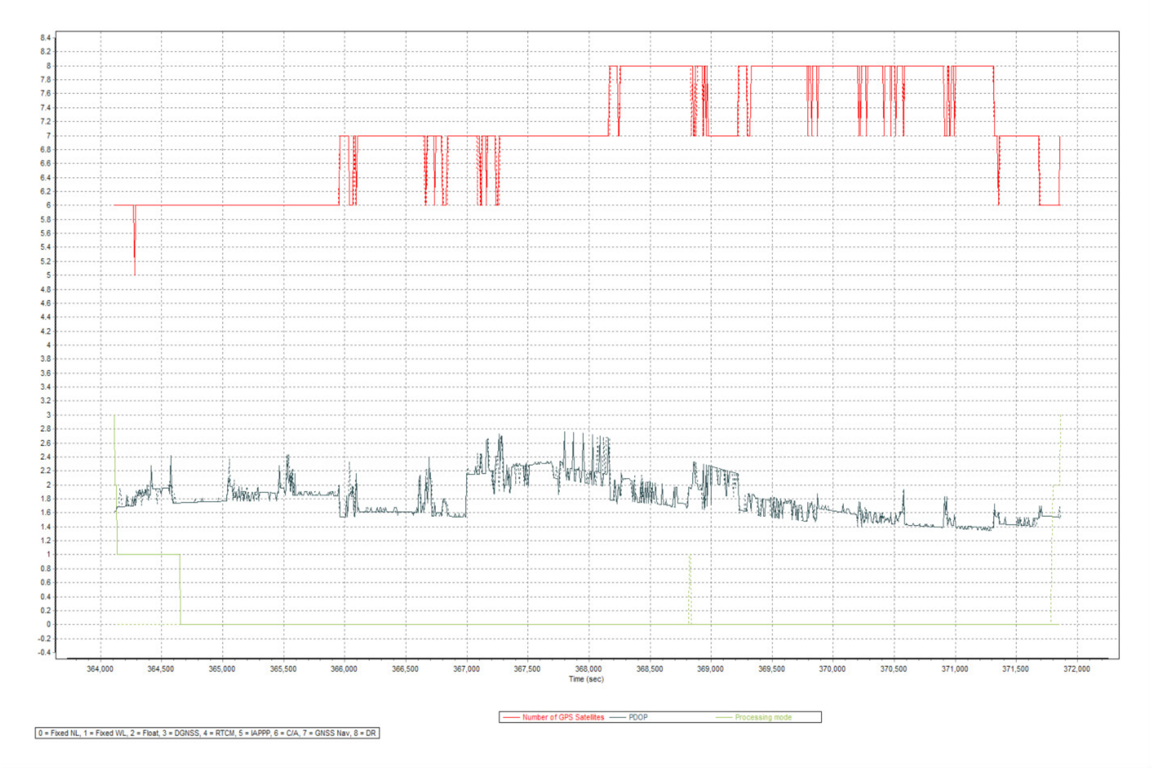
Flight No. : 2658G
Area: BTNCD
Mission Name: 2BTNCD239A
Parameters: Altitude: 800 Scan Frequency: 40
Scan Angle: 25 Overlap: 30

**SWATH**

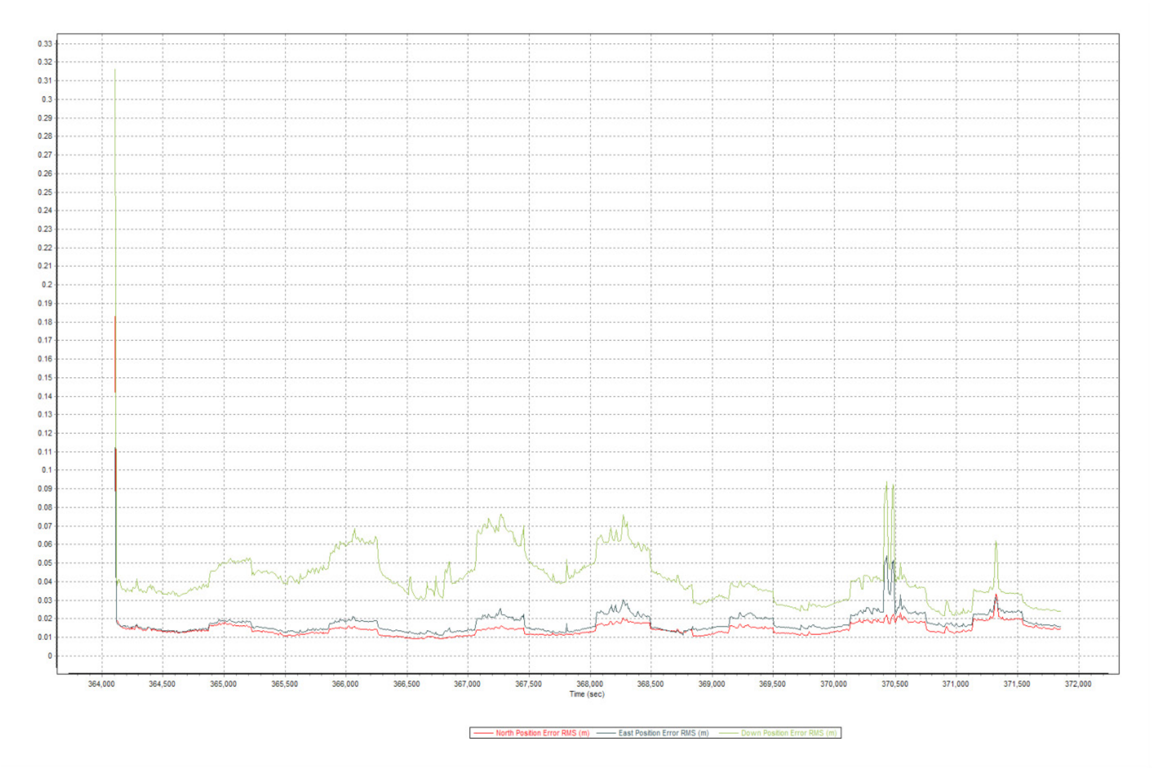


# Annex 8. Mission Summary Report

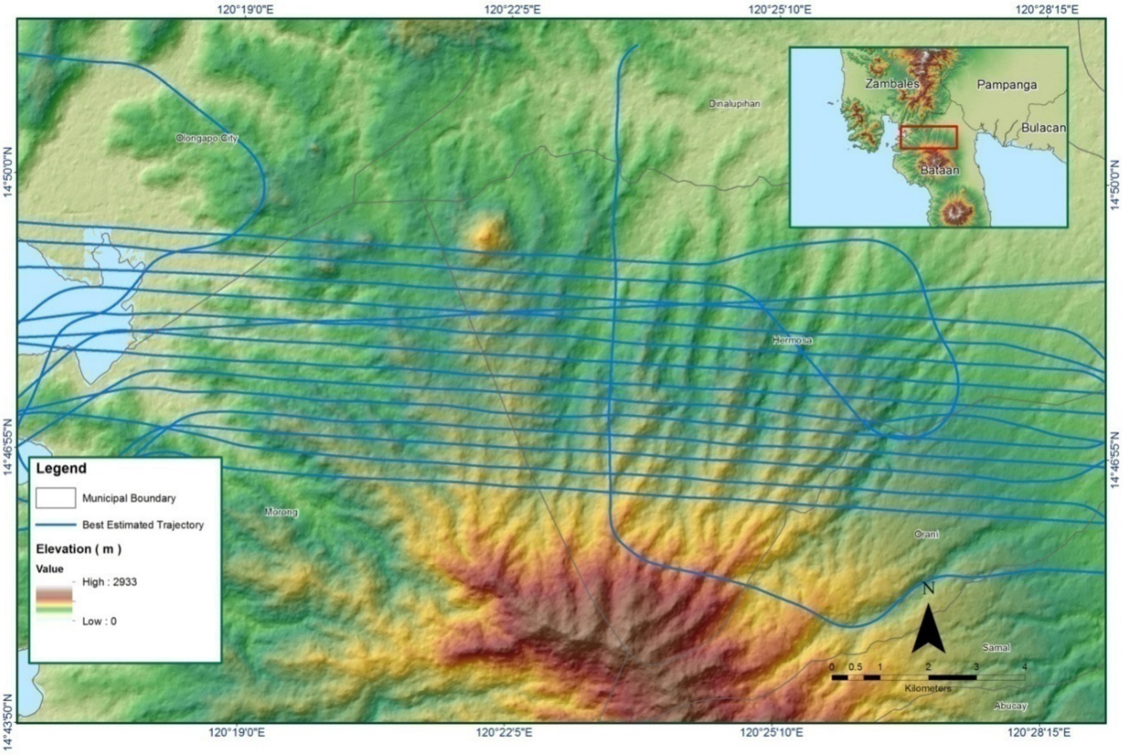
| **Flight Area** | **Bataan** |
|---|---|
| Mission Name | **BataanZambales_BalE** |
| Inclusive Flights | 926G |
| Range data size | 13.3 GB |
| POS | 243 MB |
| Image | 27.2 GB |
| Base | N/A |
| Transfer date | January 10, 2014 |
| | |
| *Solution Status* | |
| Number of Satellites (>6) | Yes |
| PDOP (<3) | Yes |
| Baseline Length (<30km) | Yes |
| Processing Mode (<=1) | Yes |
| | |
| *Smoothed Performance Metrics* (in cm) | |
| RMSE for North Position (<4.0 cm) | 3.0 |
| RMSE for East Position (<4.0 cm) | 5.0 |
| RMSE for Down Position (<8.0 cm) | 8.5 |
| | |
| Boresight correction stdev (<0.001deg) | 0.000148 |
| IMU attitude correction stdev (<0.001deg) | 0.000709 |
| GPS position stdev (<0.01m) | 0.0068 |
| | |
| Minimum % overlap (>25) | |
| Ave point cloud density per sq.m. (>2.0) | |
| Elevation difference between strips (<0.20 m) | Yes |
| | |
| Number of 1km x 1km blocks | 119 |
| Maximum Height | 473.01 m |
| Minimum Height | 41.26 m |
| | |
| *Classification (# of points)* | |
| Ground | 34,074,245 |
| Low vegetation | 27,623,561 |
| Medium vegetation | 85,714,678 |
| High vegetation | 178,053,916 |
| Building | 5,464,959 |
| | |
| Orthophoto | Yes |
| Processed by | Engr. Charmaine Cruz, Engr. Elainne Lopez |



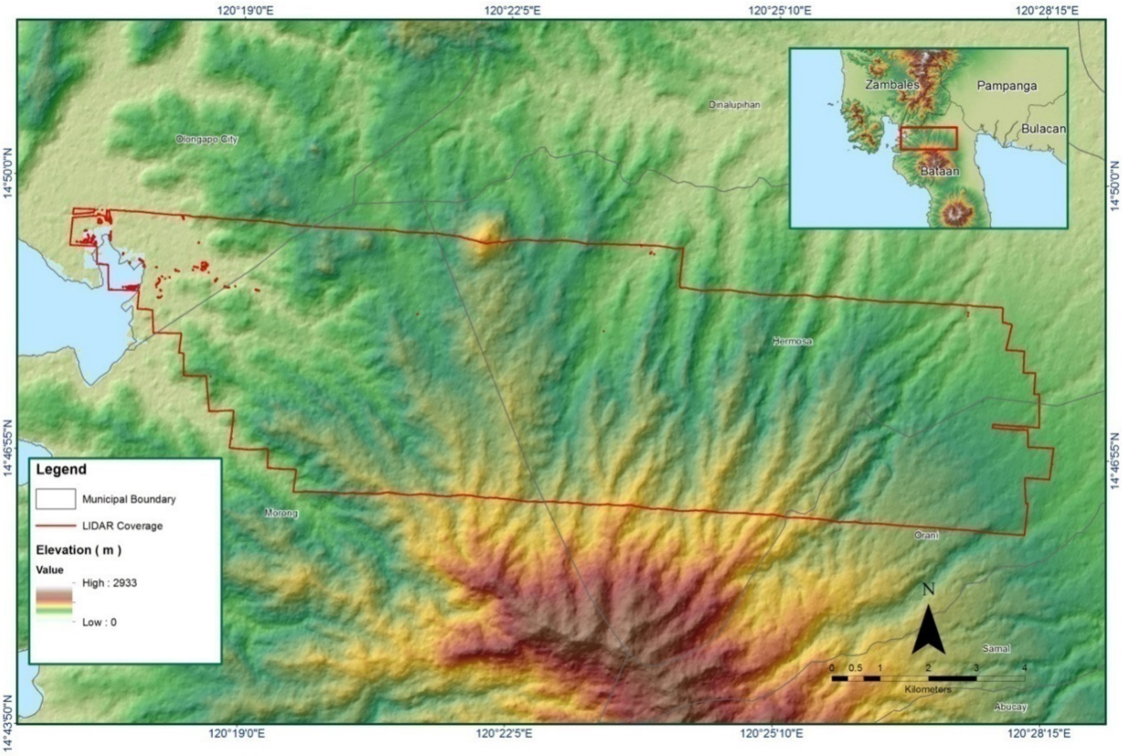

Solution Status




Smoothed Performance Metric Parameters




Best Estimated Trajectory




Coverage of LiDAR Data

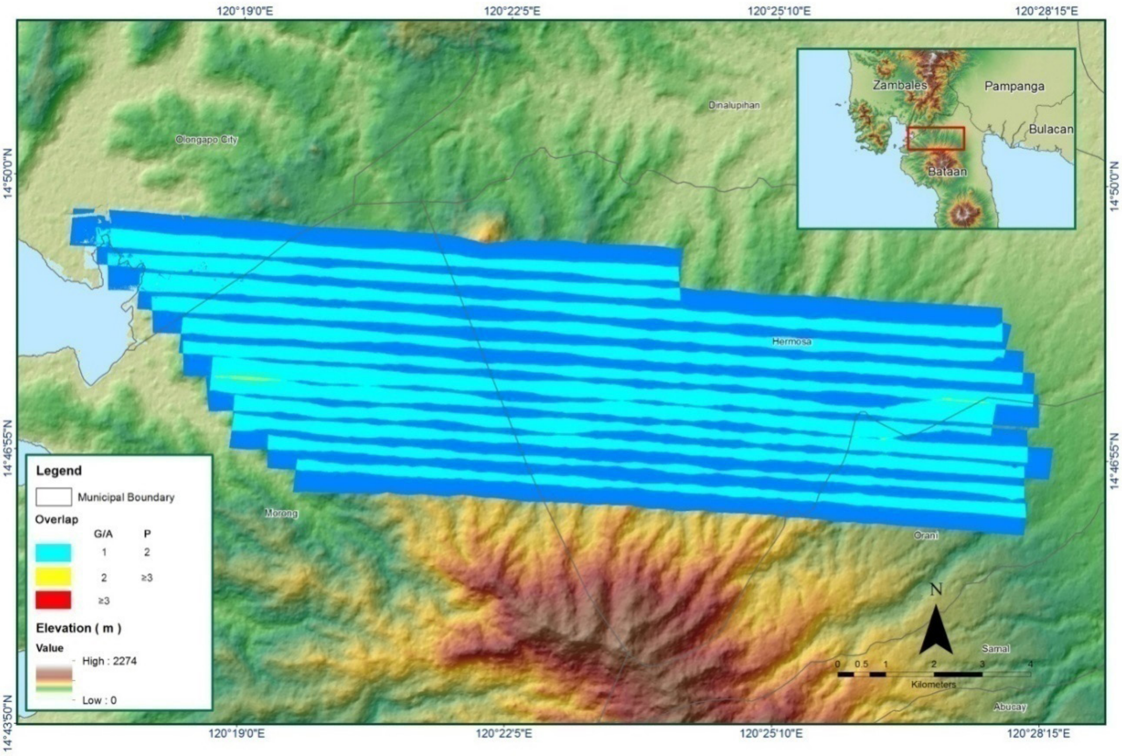
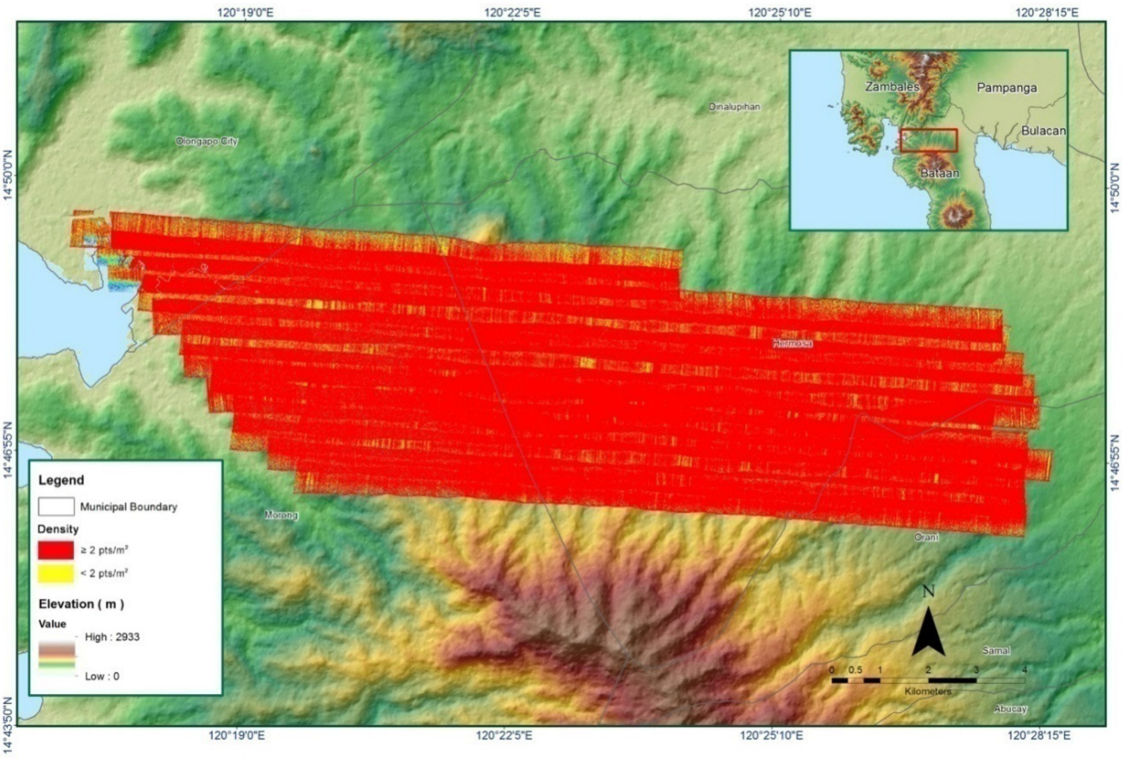
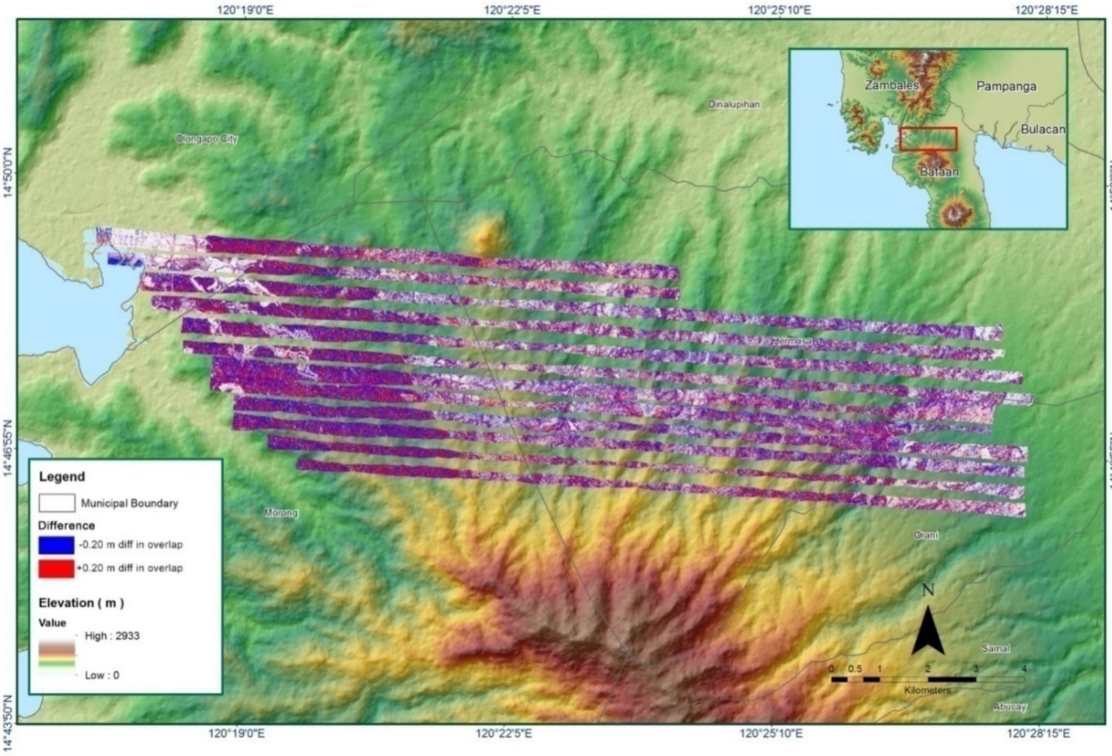



Image of data overlap



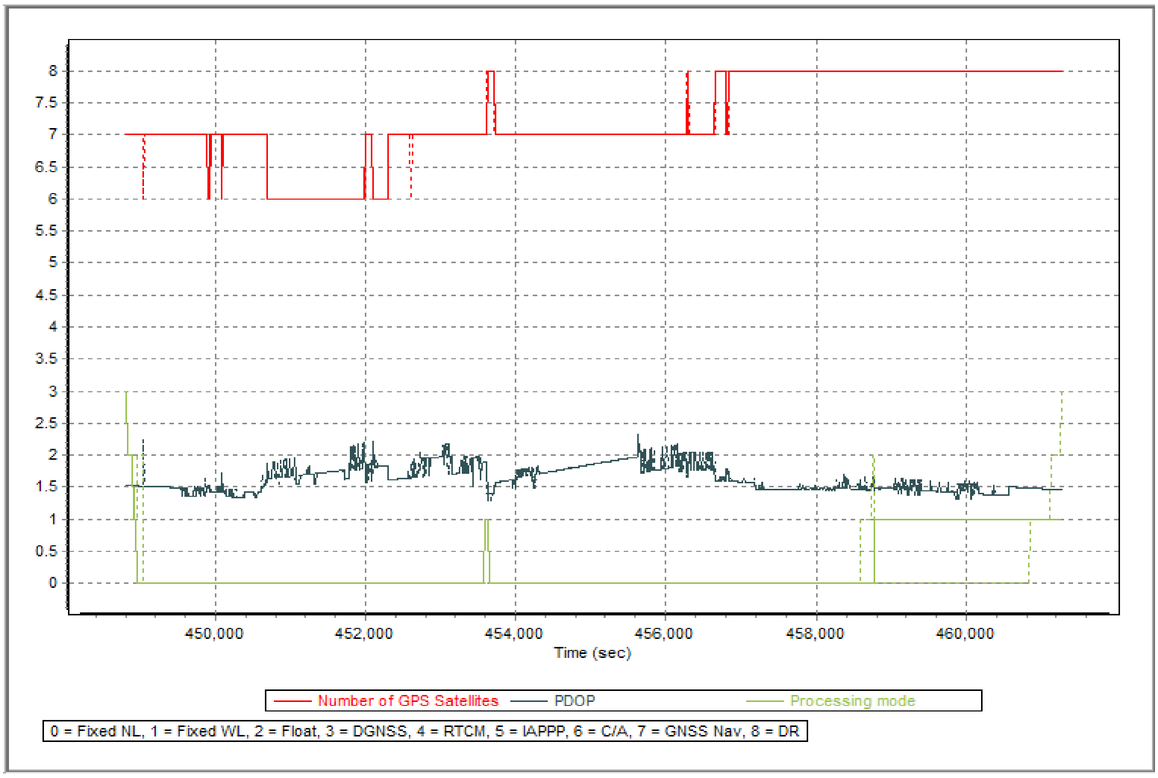

Pulse Density map of merged LiDAR data



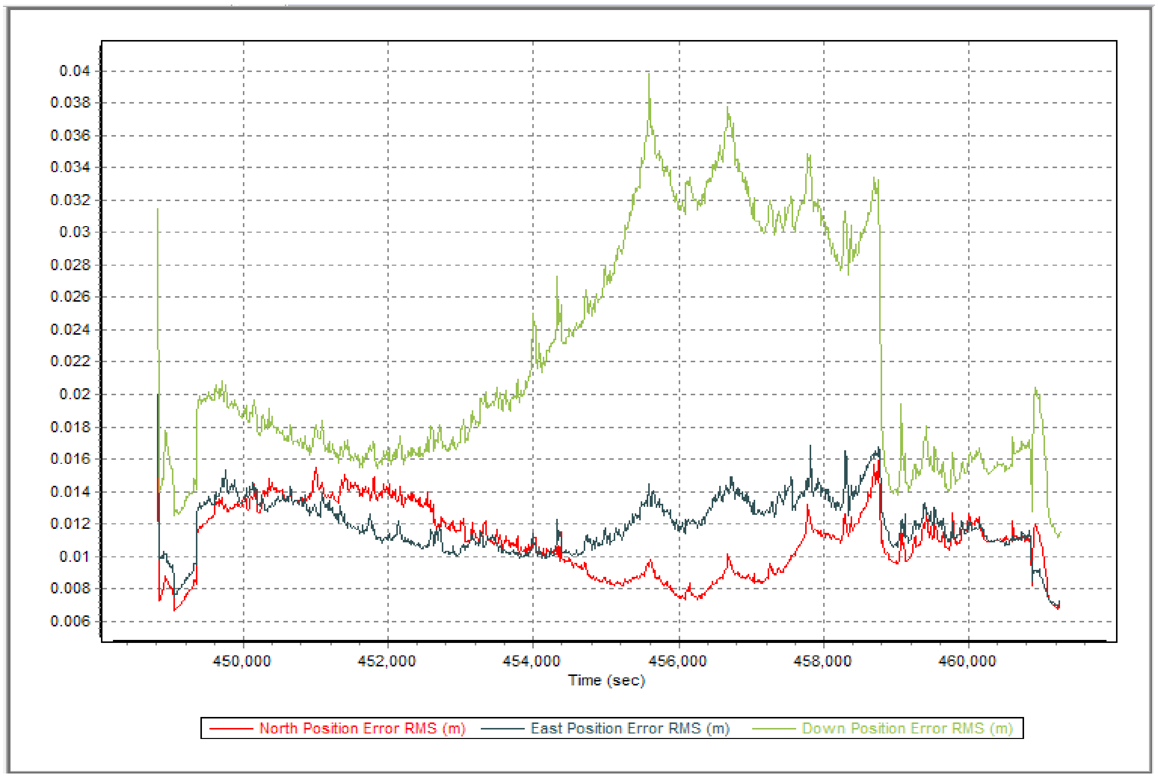

Elevation difference between flight lines

| **Flight Area** | **Bataan_Reflights** |
|---|---|
| Mission Name | **Bal_E_Additional** |
| Inclusive Flights | 2481P |
| Range data size | 24.4 GB |
| POS | 273 MB |
| Image | NA |
| Base | 2.82 |
| Transfer date | March 9, 2015 |
| | |
| *Solution Status* | |
| Number of Satellites (>6) | Yes |
| PDOP (<3) | Yes |
| Baseline Length (<30km) | No |
| Processing Mode (<=1) | Yes |
| | |
| *Smoothed Performance Metrics* (in cm) | |
| RMSE for North Position (<4.0 cm) | 1.60 |
| RMSE for East Position (<4.0 cm) | 1.69 |
| RMSE for Down Position (<8.0 cm) | 3.98 |
| | |
| Boresight correction stdev (<0.001deg) | 0.000241 |
| IMU attitude correction stdev (<0.001deg) | 0.000948 |
| GPS position stdev (<0.01m) | 0.0117 |
| | |
| Minimum % overlap (>25) | 29.32 |
| Ave point cloud density per sq.m. (>2.0) | 3.87 |
| Elevation difference between strips (<0.20 m) | Yes |
| | |
| Number of 1km x 1km blocks | 144 |
| Maximum Height | 382.64 m |
| Minimum Height | 29.33 m |
| | |
| *Classification (# of points)* | |
| Ground | 121,193,806 |
| Low vegetation | 103,902,742 |
| Medium vegetation | 151,989,087 |
| High vegetation | 377,494,365 |
| Building | 22,763,644 |
| | |
| Orthophoto | No |

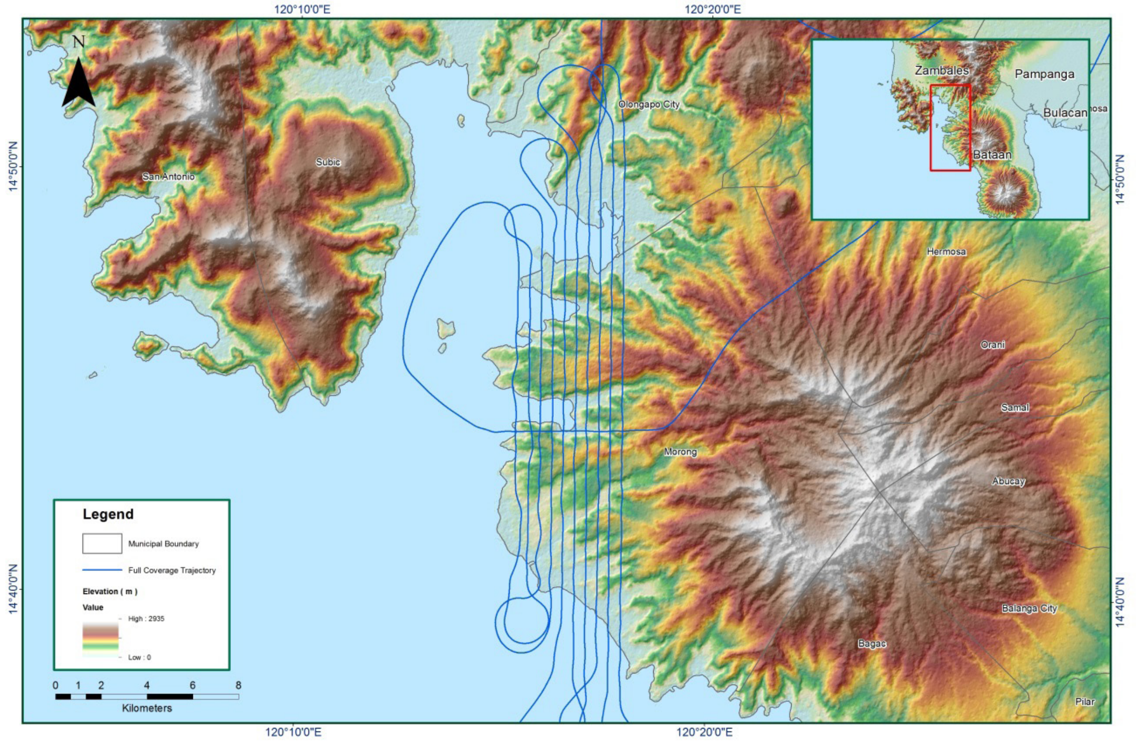
| Processed by | Engr. Charmaine Cruz, Engr. Melissa Fernandez |
|---|---|



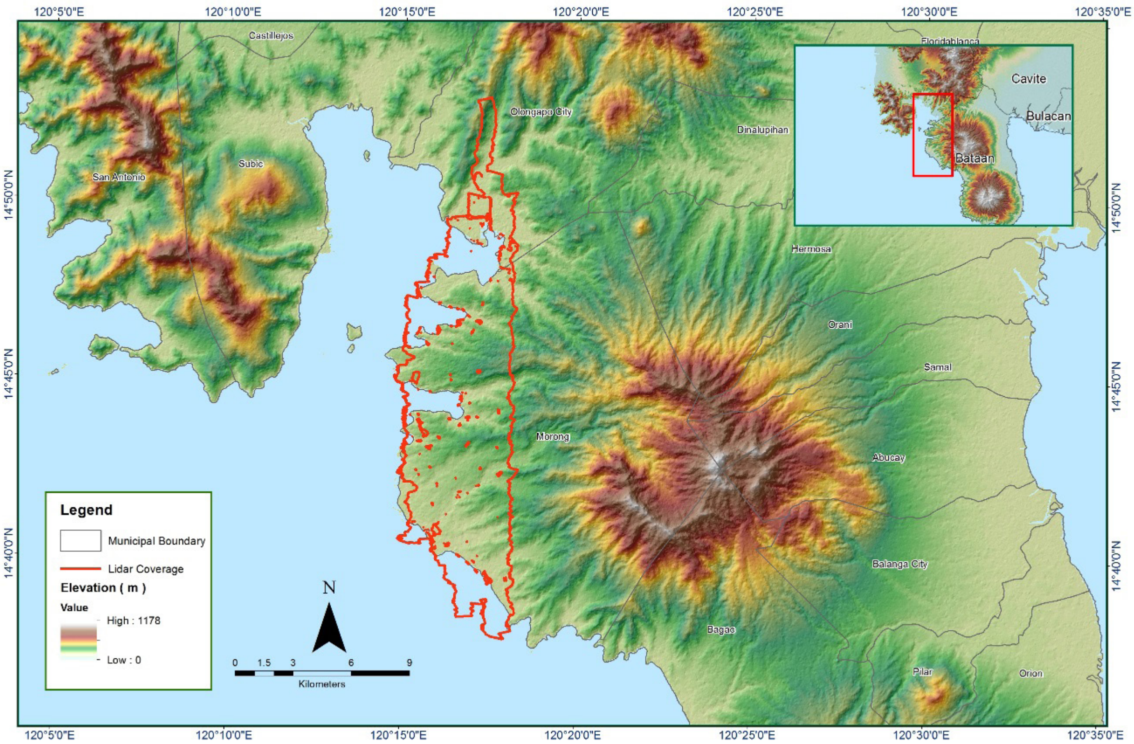

Solution Status




Smoothed Performance Metric Parameters




Best Estimate Trajectory




Coverage of LiDAR data

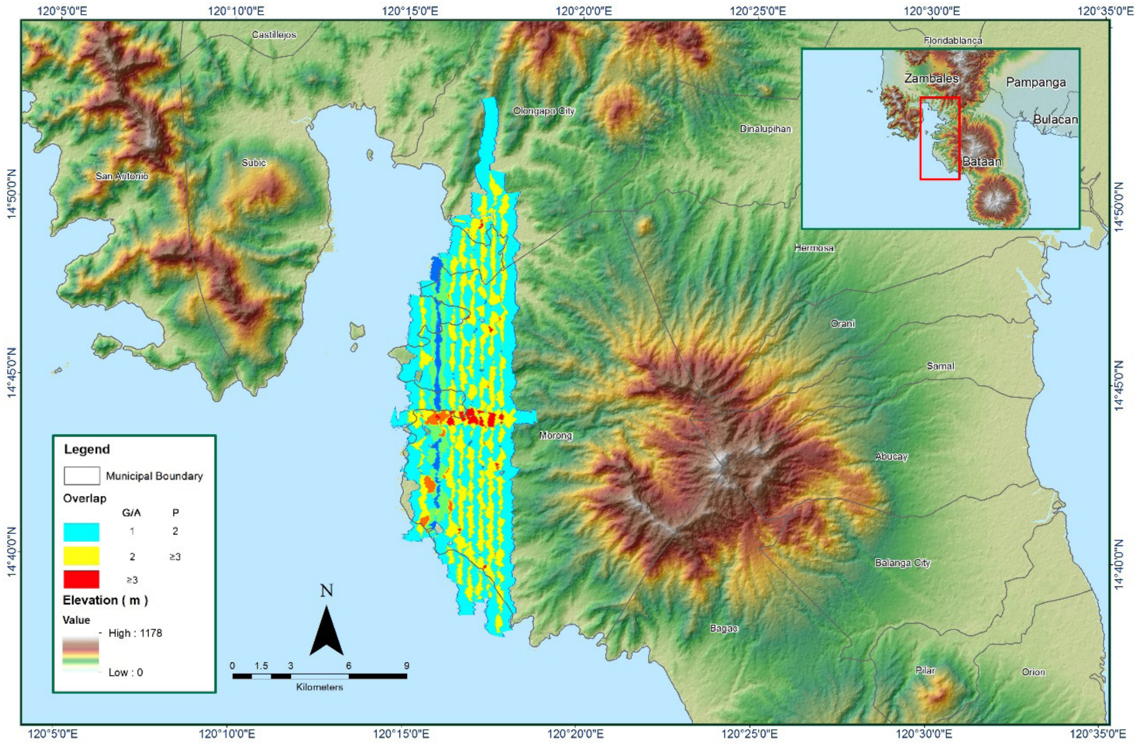
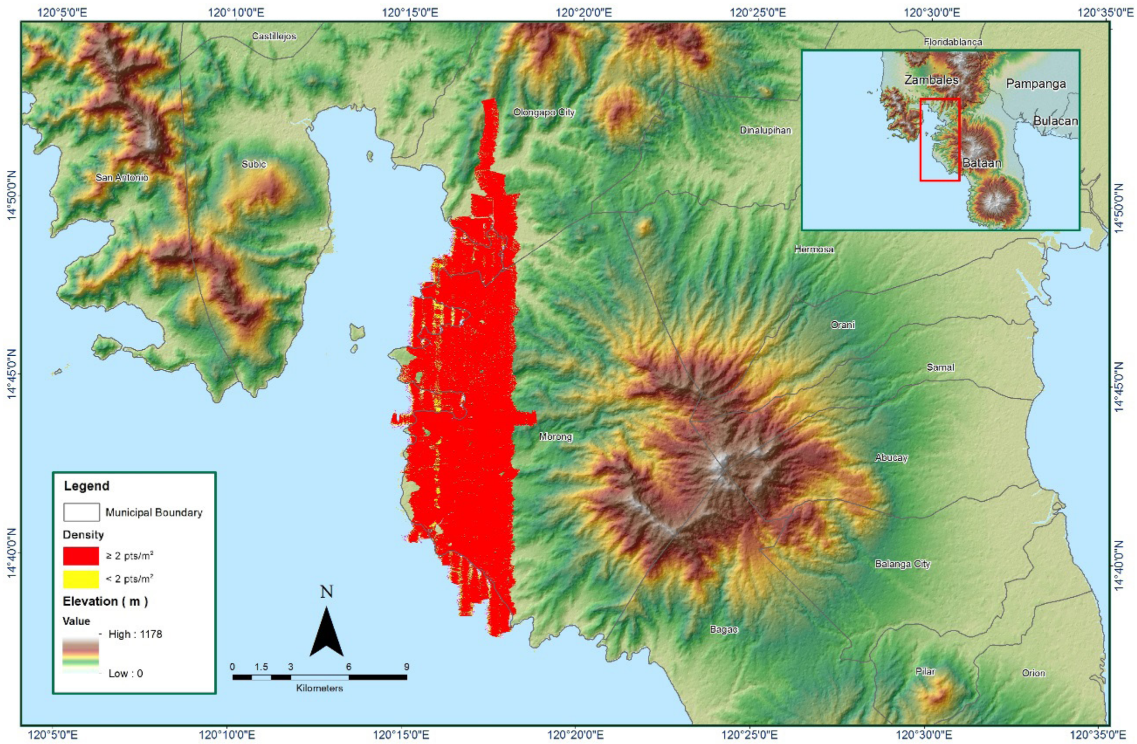
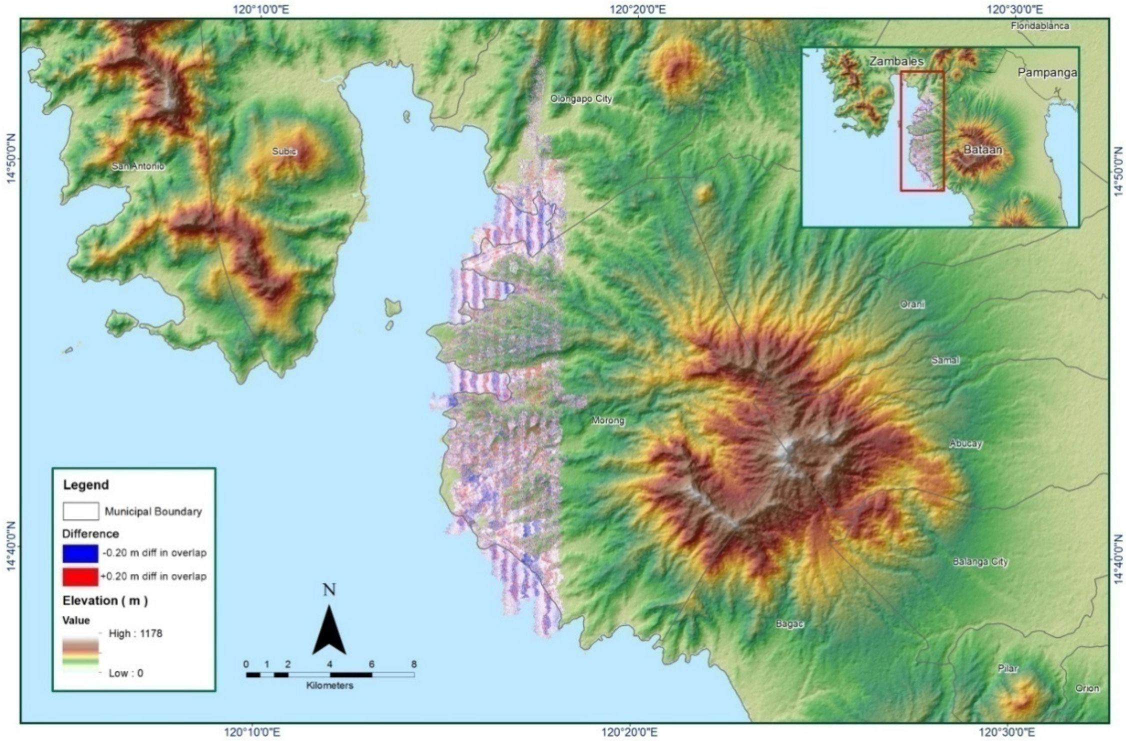



Image of data overlap



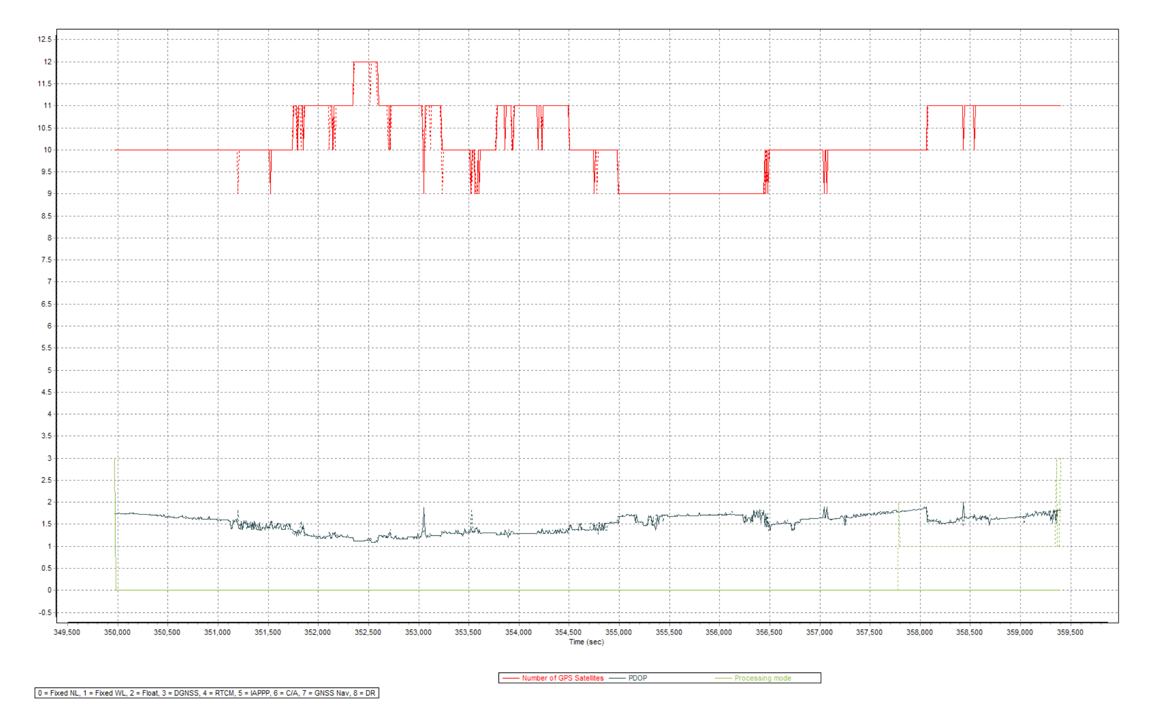

Density Map of merged LiDAR data



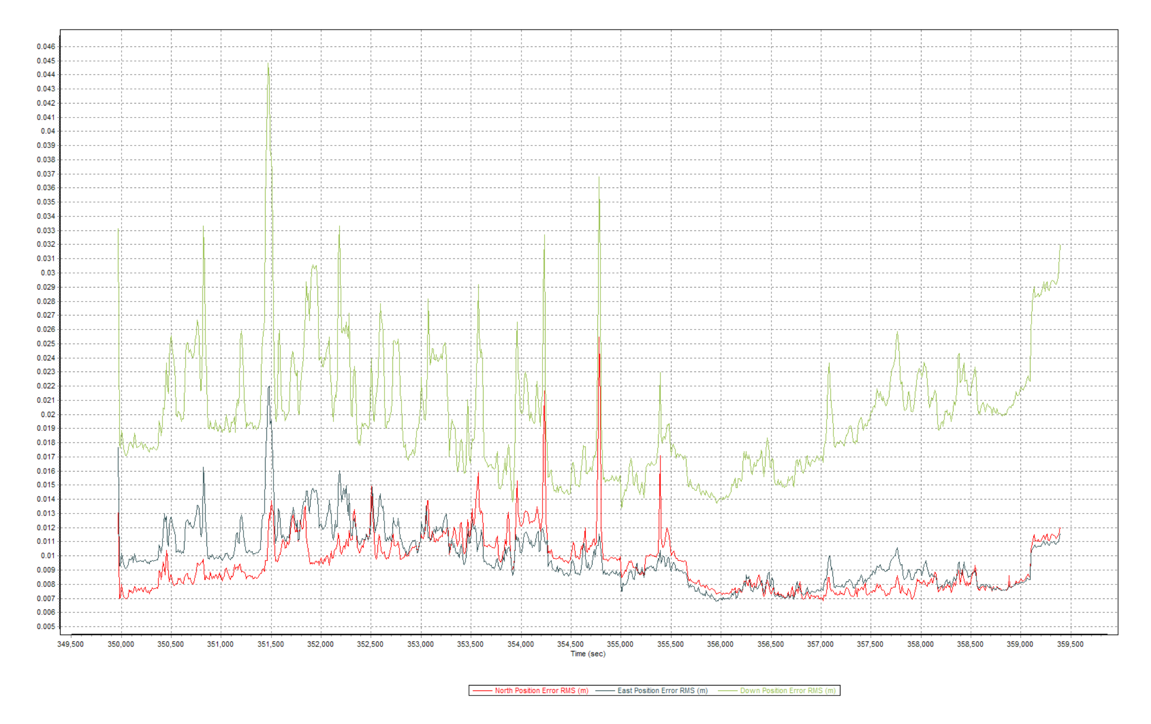

Elevation Difference Between flight lines

| Flight Area | Clark Reflights |
|---|---|
| Mission Name | BlkBtn_CD |
| Inclusive Flights | 2658G |
| Range data size | 13.3 GB |
| POS | 232 MB |
| Image | 11.6 GB |
| Base | 94.8 |
| Transfer date | August 27, 2015 |
| | |
| *Solution Status* | |
| Number of Satellites (>6) | Yes |
| PDOP (<3) | Yes |
| Baseline Length (<30km) | Yes |
| Processing Mode (<=1) | Yes |
| | |
| *Smoothed Performance Metrics* (in cm) | |
| RMSE for North Position (<4.0 cm) | 2.55 |
| RMSE for East Position (<4.0 cm) | 2.20 |
| RMSE for Down Position (<8.0 cm) | 4.50 |
| | |
| Boresight correction stdev (<0.001deg) | 0.000479 |
| IMU attitude correction stdev (<0.001deg) | 0.001994 |
| GPS position stdev (<0.01m) | 0.0252 |
| | |

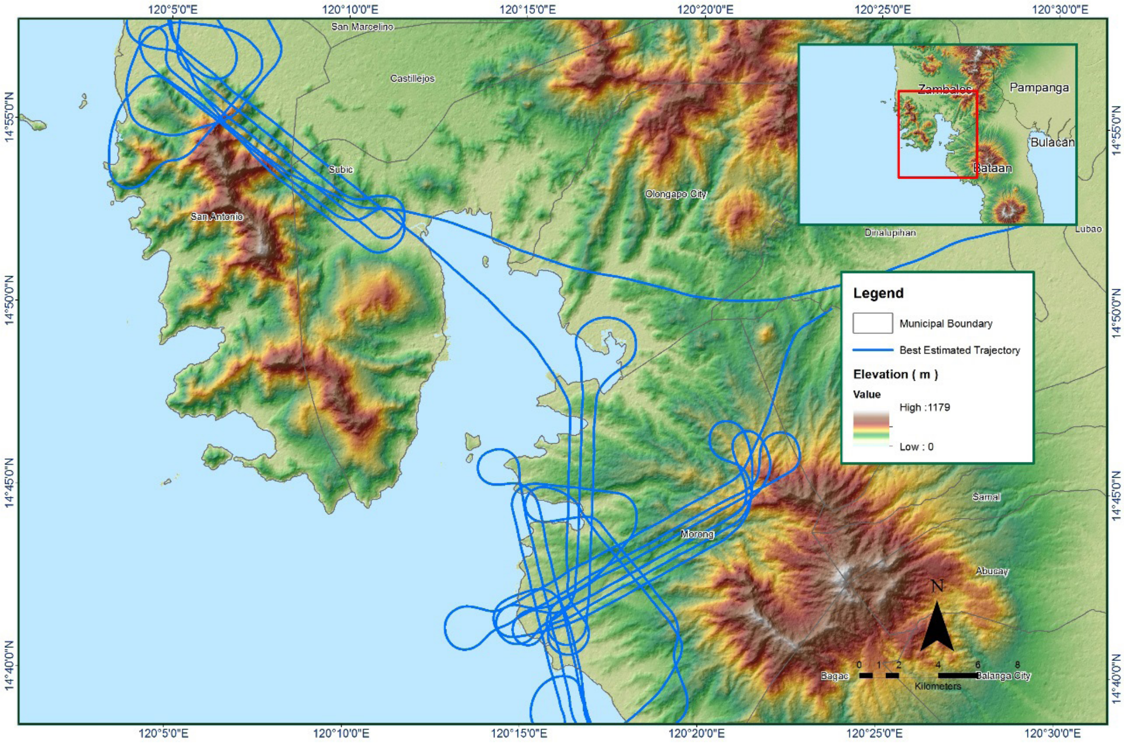
| | |
|---|---|
| Minimum % overlap (>25) | 31.52% |
| Ave point cloud density per sq.m. (>2.0) | 4.47 |
| Elevation difference between strips (<0.20 m) | Yes |
| | |
| Number of 1km x 1km blocks | 138 |
| Maximum Height | 756.92 m |
| Minimum Height | 42.19 m |
| | |
| *Classification (# of points)* | |
| Ground | 38,589,084 |
| Low vegetation | 28,474,542 |
| Medium vegetation | 130,248,906 |
| High vegetation | 125,243,729 |
| Building | 1,746,717 |
| | |
| Orthophoto | No |
| Processed by | Engr. Edgardo Gubatanga, Jr., Kathryn Claudyn Zarate |



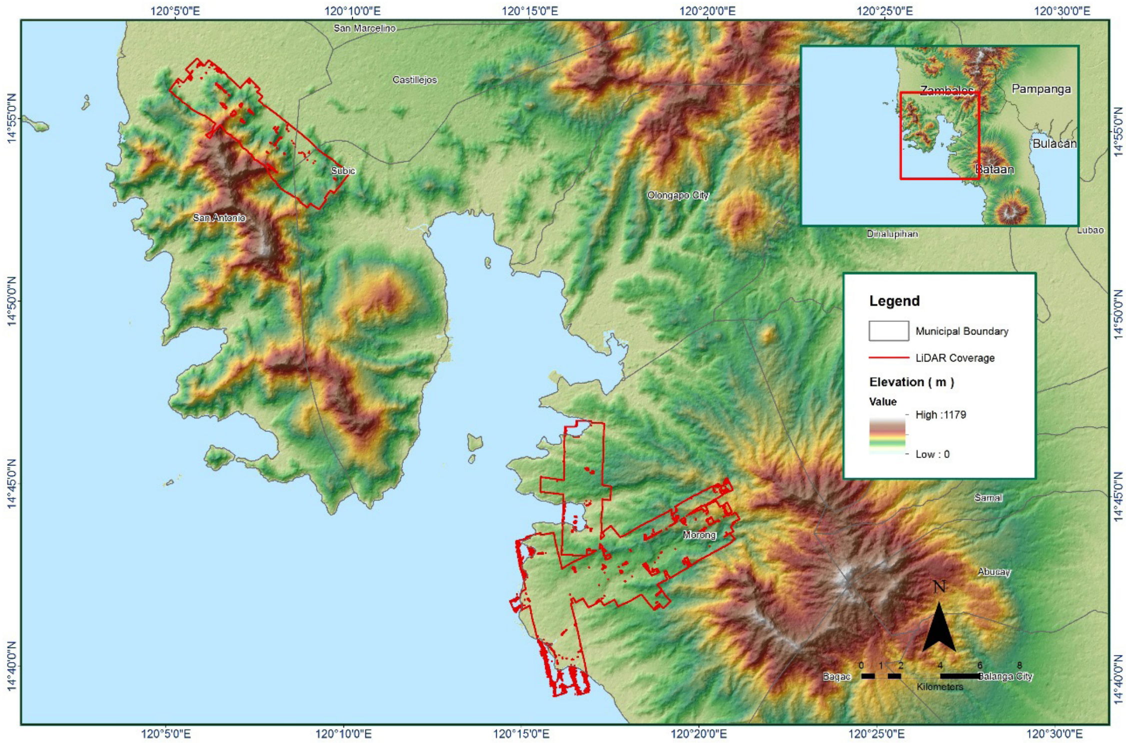

Solution Status




Smoothed Performance Metric Parameters




Best Estimated Trajectory




Coverage of LiDAR data

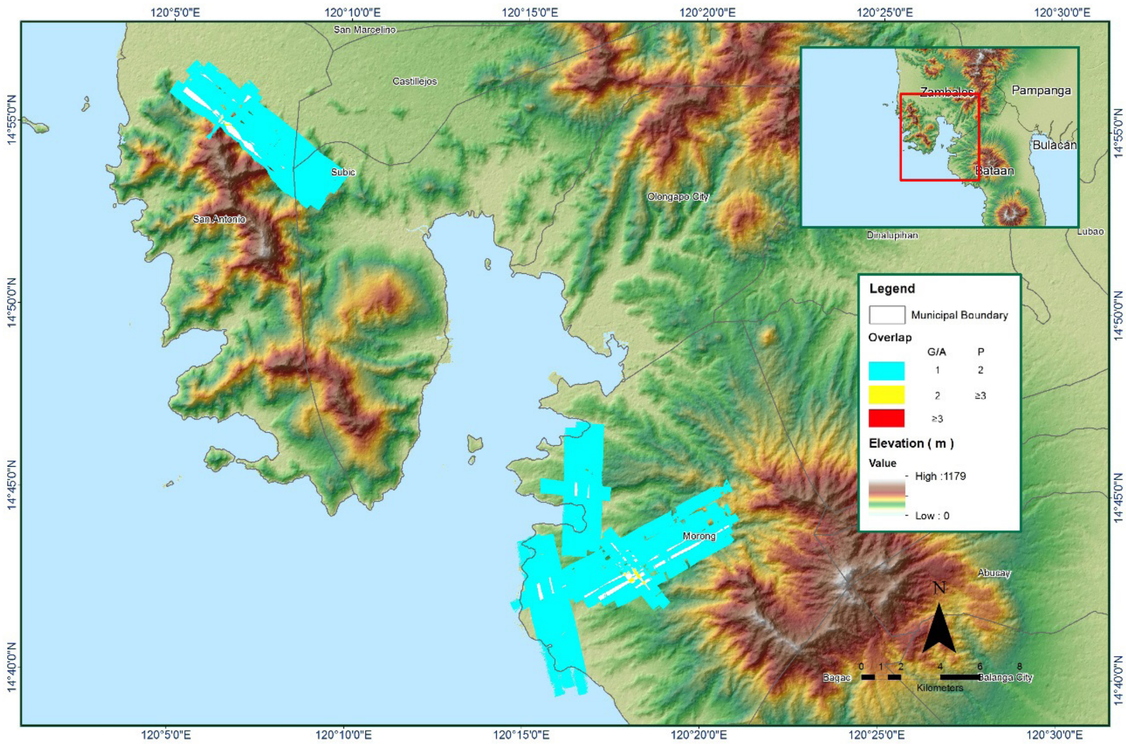
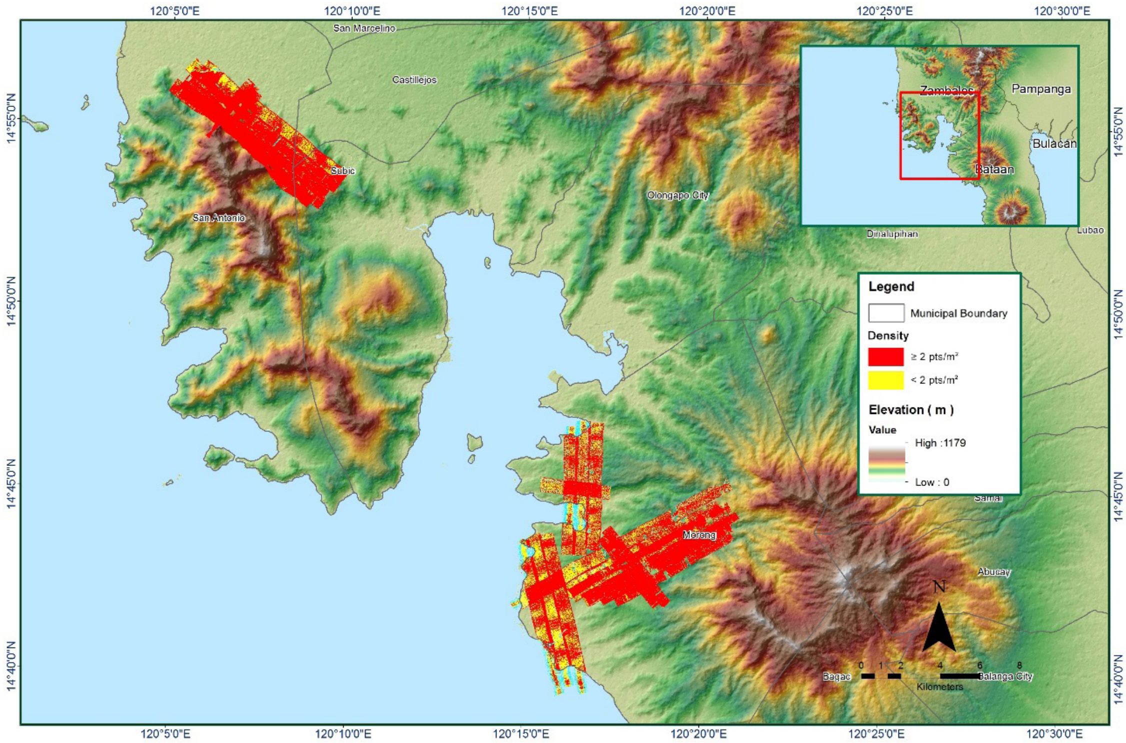
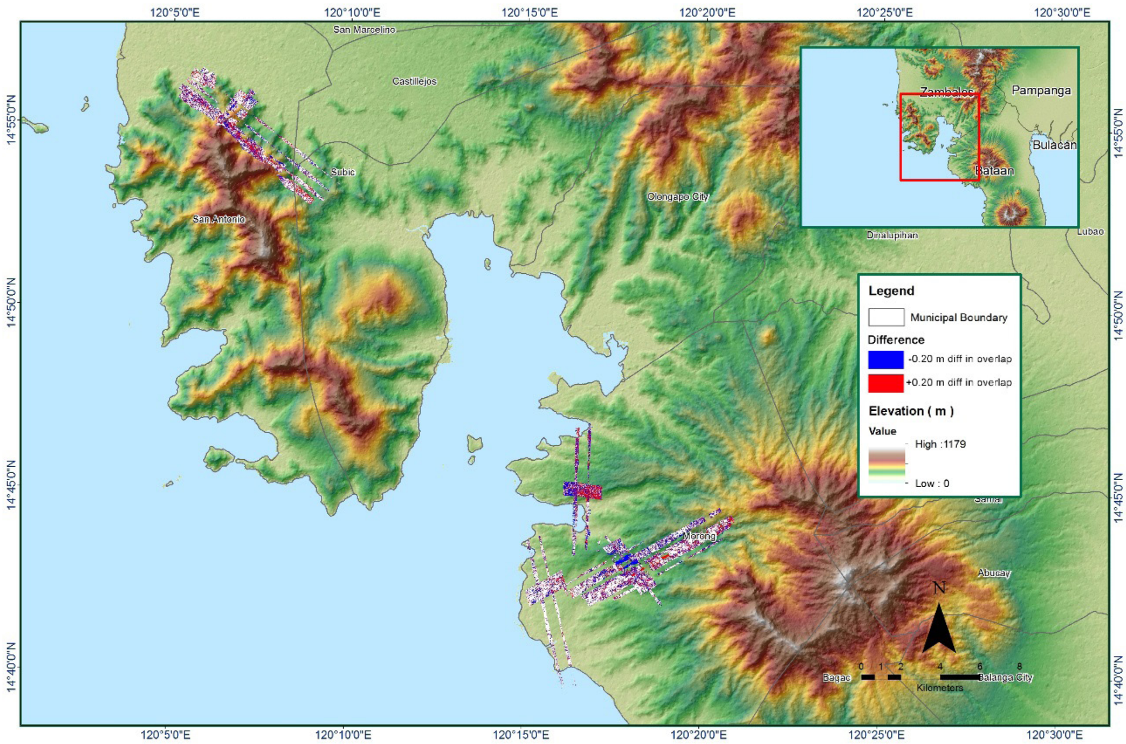



Image of data overlap




Density map of merged LiDAR data




Elevation difference between flight lines

## Annex 9. Morong Model Basin Parameter

| Basin Number | SCS Curve Number Loss | | | Clark Unit Hydrograph Transform | | Recession Baseflow | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Initial Abstraction (mm) | Curve Number | Impervious (%) | Time of Concentration (HR) | Storage Coefficient (HR) | Initial Type | Initial Discharge (M3/S) | Recession Constant | Threshold Type | Ratio to Peak |
| W100 | 5.1877 | 39.25 | 0 | 0.23232 | 1.7425 | Discharge | 4.9508 | 0.17502 | Ratio to Peak | 0.27236 |
| W60 | 6.6019 | 35.286 | 0 | 1.7944 | 1.4011 | Discharge | 7.7596 | 0.17498 | Ratio to Peak | 0.28372 |
| W70 | 4.5047 | 35.175 | 0 | 3.9539 | 3.6286 | Discharge | 9.0348 | 0.17495 | Ratio to Peak | 0.28952 |
| W80 | 5.4138 | 35.223 | 0 | 1.6685 | 2.5532 | Discharge | 7.2759 | 0.17499 | Ratio to Peak | 0.42354 |
| W90 | 6.6594 | 35.233 | 0 | 2.1623 | 0.99034 | Discharge | 1.979 | 0.11909 | Ratio to Peak | 0.27671 |

## Annex 10. Morong Model Reach Parameters

| Reach Number | Muskingum Cunge Channel Routing | | | | | | |
|---|---|---|---|---|---|---|---|
| | Time Step Method | Length (m) | Slope | Manning's n | Shape | Width | Side Slope |
| R20 | Automatic Fixed Interval | 7767.7 | 0.01704 | 0.0570478 | Trapezoid | 35.05 | 1 |
| R50 | Automatic Fixed Interval | 4457.5 | 0.01 | 0.0253546 | Trapezoid | 54.04 | 1 |

# Annex 11. Morong Field Validation

| Point Number | Validation Coordinates | | Model Var (m) | Validation Points (m) | Error | Event/Date | Rain Return /Scenario |
|---|---|---|---|---|---|---|---|
| | Lat | Long | | | | | |
| 1 | 14.70127 | 120.28538 | 0.05 | 0 | -0.05 | Habagat, 2016 | 5 -Year |
| 2 | 14.70169 | 120.28599 | 0.06 | 0 | -0.06 | Habagat, 2016 | 5 -Year |
| 3 | 14.70055 | 120.27399 | 0.03 | 0.1 | 0.07 | Habagat, 2016 | 5 -Year |
| 4 | 14.70088 | 120.27306 | 0.13 | 0 | -0.13 | Habagat, 2016 | 5 -Year |
| 5 | 14.70011 | 120.27111 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 6 | 14.69868 | 120.27143 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 7 | 14.68706 | 120.2648 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 8 | 14.68591 | 120.26382 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 9 | 14.68625 | 120.26545 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 10 | 14.68119 | 120.27048 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 11 | 14.67995 | 120.2698 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 12 | 14.68211 | 120.27324 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 13 | 14.67833 | 120.27015 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 14 | 14.67751 | 120.26897 | 0.11 | 0 | -0.11 | Habagat, 2016 | 5 -Year |
| 15 | 14.68379 | 120.27438 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 16 | 14.69223 | 120.24981 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 17 | 14.6929 | 120.25004 | 0.14 | 0 | -0.14 | Habagat, 2016 | 5 -Year |
| 18 | 14.71608 | 120.25234 | 0.03 | 0.4 | 0.37 | Habagat, 2016 | 5 -Year |
| 19 | 14.71683 | 120.25544 | 0.06 | 0.25 | 0.19 | Habagat, 2016 | 5 -Year |
| 20 | 14.71839 | 120.25367 | 0.03 | 0.25 | 0.22 | Habagat, 2016 | 5 -Year |
| 21 | 14.70338 | 120.26896 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 22 | 14.70535 | 120.2694 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 23 | 14.70557 | 120.27054 | 0.04 | 0 | -0.04 | Habagat, 2016 | 5 -Year |
| 24 | 14.70373 | 120.26664 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 25 | 14.71237 | 120.28977 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 26 | 14.7118 | 120.28836 | 0.03 | 0.4 | 0.37 | Habagat, 2016 | 5 -Year |
| 27 | 14.67054 | 120.26829 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 28 | 14.67084 | 120.26995 | 0.04 | 0 | -0.04 | Habagat, 2016 | 5 -Year |
| 29 | 14.66947 | 120.26959 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 30 | 14.67088 | 120.27152 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 31 | 14.67096 | 120.27325 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 32 | 14.69387 | 120.25017 | 0.26 | 0 | -0.26 | Habagat, 2016 | 5 -Year |
| 33 | 14.69441 | 120.25051 | 0.31 | 0 | -0.31 | Habagat, 2016 | 5 -Year |
| 34 | 14.69476 | 120.24938 | 0.4 | 0.25 | -0.15 | Habagat, 2016 | 5 -Year |
| 35 | 14.69512 | 120.25118 | 0.46 | 0 | -0.46 | Habagat, 2016 | 5 -Year |
| 36 | 14.6779 | 120.26763 | 0.45 | 0.5 | 0.05 | Habagat, 2016 | 5 -Year |
| 37 | 14.67857 | 120.26663 | 0.49 | 0.5 | 0.01 | Habagat, 2016 | 5 -Year |
| 38 | 14.67983 | 120.26742 | 0.41 | 0.25 | -0.16 | Habagat, 2016 | 5 -Year |
| 39 | 14.6786 | 120.26554 | 0.44 | 0.5 | 0.06 | Habagat, 2016 | 5 -Year |
| 40 | 14.66967 | 120.26771 | 0.28 | 0.3 | 0.02 | Habagat, 2016 | 5 -Year |
| 41 | 14.67171 | 120.27333 | 0.23 | 0 | -0.23 | Habagat, 2016 | 5 -Year |

| Point Number | Validation Coordinates | | Model Var (m) | Validation Points (m) | Error | Event/Date | Rain Return /Scenario |
|---|---|---|---|---|---|---|---|
| | Lat | Long | | | | | |
| 42 | 14.72164 | 120.25643 | 0.22 | 0 | -0.22 | Habagat, 2016 | 5 -Year |
| 43 | 14.69627 | 120.25189 | 0.46 | 0.46 | 0 | Habagat, 2016 | 5 -Year |
| 44 | 14.69692 | 120.25089 | 0.32 | 0.3 | -0.02 | Habagat, 2016 | 5 -Year |
| 45 | 14.67073 | 120.2708 | 0.24 | 0 | -0.24 | Habagat, 2016 | 5 -Year |
| 46 | 14.66952 | 120.26883 | 0.39 | 0 | -0.39 | Habagat, 2016 | 5 -Year |
| 47 | 14.66969 | 120.26653 | 0.37 | 0 | -0.37 | Habagat, 2016 | 5 -Year |
| 48 | 14.67117 | 120.26609 | 0.54 | 0.3 | -0.24 | Habagat, 2016 | 5 -Year |
| 49 | 14.68265 | 120.26508 | 0.42 | 0.3 | -0.12 | Habagat, 2016 | 5 -Year |
| 50 | 14.68148 | 120.26681 | 0.5 | 0 | -0.5 | Habagat, 2016 | 5 -Year |
| 51 | 14.68055 | 120.26833 | 0.43 | 0 | -0.43 | Habagat, 2016 | 5 -Year |
| 52 | 14.73124 | 120.27421 | 0.48 | 0.46 | -0.02 | Habagat, 2016 | 5 -Year |
| 53 | 14.73103 | 120.27536 | 0.27 | 0.46 | 0.19 | Habagat, 2016 | 5 -Year |
| 54 | 14.73018 | 120.27513 | 0.49 | 0.3 | -0.19 | Habagat, 2016 | 5 -Year |
| 55 | 14.73114 | 120.27586 | 0.41 | 0.3 | -0.11 | Habagat, 2016 | 5 -Year |
| 56 | 14.73125 | 120.27763 | 0.25 | 0.3 | 0.05 | Habagat, 2016 | 5 -Year |
| 57 | 14.73158 | 120.27843 | 0.24 | 0.3 | 0.06 | Habagat, 2016 | 5 -Year |
| 58 | 14.73219 | 120.27926 | 0.27 | 0.3 | 0.03 | Habagat, 2016 | 5 -Year |
| 59 | 14.73292 | 120.2797 | 0.45 | 1.25 | 0.8 | Habagat, 2016 | 5 -Year |
| 60 | 14.72995 | 120.27272 | 0.27 | 0 | -0.27 | Habagat, 2016 | 5 -Year |
| 61 | 14.68176 | 120.26956 | 0.43 | 0 | -0.43 | Habagat, 2016 | 5 -Year |
| 62 | 14.68202 | 120.26923 | 0.85 | 0.25 | -0.6 | Habagat, 2016 | 5 -Year |
| 63 | 14.68127 | 120.26889 | 0.85 | 0.25 | -0.6 | Habagat, 2016 | 5 -Year |
| 64 | 14.6808 | 120.26821 | 0.89 | 1.07 | 0.18 | Habagat, 2016 | 5 -Year |
| 65 | 14.68019 | 120.26774 | 0.86 | 0 | -0.86 | Habagat, 2016 | 5 -Year |
| 66 | 14.68089 | 120.26703 | 0.83 | 0.91 | 0.08 | Habagat, 2016 | 5 -Year |
| 67 | 14.67937 | 120.26642 | 0.79 | 0 | -0.79 | Habagat, 2016 | 5 -Year |
| 68 | 14.67891 | 120.26713 | 0.69 | 0 | -0.69 | Habagat, 2016 | 5 -Year |
| 69 | 14.67694 | 120.26703 | 0.67 | 0 | -0.67 | Habagat, 2016 | 5 -Year |
| 70 | 14.67817 | 120.26695 | 0.7 | 0 | -0.7 | Habagat, 2016 | 5 -Year |
| 71 | 14.677 | 120.26847 | 0.86 | 0.25 | -0.61 | Habagat, 2016 | 5 -Year |
| 72 | 14.67778 | 120.2667 | 0.68 | 0 | -0.68 | Habagat, 2016 | 5 -Year |
| 73 | 14.67816 | 120.26523 | 0.71 | 0 | -0.71 | Habagat, 2016 | 5 -Year |
| 74 | 14.69601 | 120.2514 | 0.52 | 1.07 | 0.55 | Habagat, 2016 | 5 -Year |
| 75 | 14.69526 | 120.25034 | 0.56 | 0 | -0.56 | Habagat, 2016 | 5 -Year |
| 76 | 14.69551 | 120.25012 | 0.67 | 0 | -0.67 | Habagat, 2016 | 5 -Year |
| 77 | 14.6959 | 120.25101 | 0.6 | 0.91 | 0.31 | Habagat, 2016 | 5 -Year |
| 78 | 14.69676 | 120.25188 | 0.56 | 1.07 | 0.51 | Habagat, 2016 | 5 -Year |
| 79 | 14.69726 | 120.25092 | 0.81 | 0.91 | 0.1 | Habagat, 2016 | 5 -Year |
| 80 | 14.72063 | 120.25667 | 0.57 | 0 | -0.57 | Habagat, 2016 | 5 -Year |
| 81 | 14.73064 | 120.27456 | 0.6 | 0.91 | 0.31 | Habagat, 2016 | 5 -Year |
| 82 | 14.73015 | 120.27474 | 0.56 | 0.91 | 0.35 | Habagat, 2016 | 5 -Year |
| 83 | 14.73027 | 120.2728 | 0.63 | 0.91 | 0.28 | Habagat, 2016 | 5 -Year |

| Point Number | Validation Coordinates | | Model Var (m) | Validation Points (m) | Error | Event/Date | Rain Return /Scenario |
|---|---|---|---|---|---|---|---|
| | Lat | Long | | | | | |
| 84 | 14.73059 | 120.27637 | 0.8 | 1.37 | 0.57 | Habagat, 2016 | 5 -Year |
| 85 | 14.7305 | 120.27876 | 0.66 | 0.91 | 0.25 | Habagat, 2016 | 5 -Year |
| 86 | 14.73146 | 120.27908 | 0.82 | 0.91 | 0.09 | Habagat, 2016 | 5 -Year |
| 87 | 14.7325 | 120.27977 | 0.85 | 0.3 | -0.55 | Habagat, 2016 | 5 -Year |
| 88 | 14.67766 | 120.26719 | 0.86 | 0.2 | -0.66 | Habagat, 2016 | 5 -Year |
| 89 | 14.67761 | 120.26809 | 0.71 | 0 | -0.71 | Habagat, 2016 | 5 -Year |
| 90 | 14.67225 | 120.27284 | 0.78 | 0 | -0.78 | Habagat, 2016 | 5 -Year |
| 91 | 14.73196 | 120.27843 | 0.53 | 0.91 | 0.38 | Habagat, 2016 | 5 -Year |
| 92 | 14.73048 | 120.27371 | 1.42 | 1.37 | -0.05 | Habagat, 2016 | 5 -Year |
| 93 | 14.73044 | 120.274 | 1.27 | 1.37 | 0.1 | Habagat, 2016 | 5 -Year |
| 94 | 14.73274 | 120.2804 | 1.34 | 0.76 | -0.58 | Habagat, 2016 | 5 -Year |
| 95 | 14.73245 | 120.28012 | 1.08 | 0.5 | -0.58 | Habagat, 2016 | 5 -Year |
| 96 | 14.73252 | 120.2827 | 1.63 | 0.5 | -1.13 | Habagat, 2016 | 5 -Year |
| 97 | 14.73188 | 120.28288 | 1.78 | 0.3 | -1.48 | Habagat, 2016 | 5 -Year |
| 98 | 14.73134 | 120.2835 | 1.59 | 1.3 | -0.29 | Habagat, 2016 | 5 -Year |
| 99 | 14.73144 | 120.28298 | 1.04 | 1.37 | 0.33 | Habagat, 2016 | 5 -Year |
| 100 | 14.68275 | 120.2681 | 1.69 | 1.22 | -0.47 | Habagat, 2016 | 5 -Year |
| 101 | 14.68239 | 120.26737 | 1.67 | 1.37 | -0.3 | Habagat, 2016 | 5 -Year |
| 102 | 14.68181 | 120.26815 | 1.67 | 1.22 | -0.45 | Habagat, 2016 | 5 -Year |
| 103 | 14.68237 | 120.26948 | 1.4 | 0.6 | -0.8 | Habagat, 2016 | 5 -Year |
| 104 | 14.6831 | 120.27045 | 1.51 | 0.6 | -0.91 | Habagat, 2016 | 5 -Year |
| 105 | 14.68033 | 120.26749 | 1.16 | 0.91 | -0.25 | Habagat, 2016 | 5 -Year |
| 106 | 14.67969 | 120.26687 | 1.14 | 1.07 | -0.07 | Habagat, 2016 | 5 -Year |
| 107 | 14.68048 | 120.26606 | 1.31 | 0.3 | -1.01 | Habagat, 2016 | 5 -Year |
| 108 | 14.67933 | 120.26604 | 1.29 | 1.22 | -0.07 | Habagat, 2016 | 5 -Year |
| 109 | 14.67901 | 120.26541 | 1.45 | 0.91 | -0.54 | Habagat, 2016 | 5 -Year |
| 110 | 14.67977 | 120.26491 | 1.43 | 1.37 | -0.06 | Habagat, 2016 | 5 -Year |
| 111 | 14.67877 | 120.26471 | 1.47 | 1.07 | -0.4 | Habagat, 2016 | 5 -Year |
| 112 | 14.67785 | 120.2652 | 1.64 | 0.8 | -0.84 | Habagat, 2016 | 5 -Year |
| 113 | 14.67661 | 120.26662 | 1.41 | 0.6 | -0.81 | Habagat, 2016 | 5 -Year |
| 114 | 14.67548 | 120.26632 | 1.61 | 1.22 | -0.39 | Habagat, 2016 | 5 -Year |
| 115 | 14.68174 | 120.26345 | 1.11 | 0.91 | -0.2 | Habagat, 2016 | 5 -Year |
| 116 | 14.6811 | 120.26376 | 1.49 | 1.37 | -0.12 | Habagat, 2016 | 5 -Year |
| 117 | 14.68034 | 120.263 | 1.6 | 0.91 | -0.69 | Habagat, 2016 | 5 -Year |
| 118 | 14.68067 | 120.26218 | 1.13 | 0.91 | -0.22 | Habagat, 2016 | 5 -Year |
| 119 | 14.68113 | 120.26492 | 1.61 | 1.37 | -0.24 | Habagat, 2016 | 5 -Year |
| 120 | 14.68163 | 120.26521 | 1.46 | 1.52 | 0.06 | Habagat, 2016 | 5 -Year |
| 121 | 14.67978 | 120.26588 | 1.38 | 1.22 | -0.16 | Habagat, 2016 | 5 -Year |
| 122 | 14.68436 | 120.26921 | 1.75 | 1.83 | 0.08 | Habagat, 2016 | 5 -Year |
| 123 | 14.68406 | 120.26903 | 2.56 | 1.68 | -0.88 | Habagat, 2016 | 5 -Year |
| 124 | 14.68339 | 120.2685 | 1.85 | 1.07 | -0.78 | Habagat, 2016 | 5 -Year |
| 125 | 14.6827 | 120.26998 | 1.55 | 0.9 | -0.65 | Habagat, 2016 | 5 -Year |

| Point Number | Validation Coordinates | | Model Var (m) | Validation Points (m) | Error | Event/Date | Rain Return /Scenario |
|---|---|---|---|---|---|---|---|
| | Lat | Long | | | | | |
| 126 | 14.68266 | 120.26785 | 2.32 | 1.68 | -0.64 | Habagat, 2016 | 5 -Year |
| 127 | 14.68213 | 120.26797 | 1.83 | 0.3 | -1.53 | Habagat, 2016 | 5 -Year |
| 128 | 14.68183 | 120.26688 | 2.01 | 1.68 | -0.33 | Habagat, 2016 | 5 -Year |
| 129 | 14.68166 | 120.26732 | 1.42 | 1.83 | 0.41 | Habagat, 2016 | 5 -Year |
| 130 | 14.68129 | 120.26776 | 1.3 | 1.83 | 0.53 | Habagat, 2016 | 5 -Year |
| 131 | 14.68129 | 120.26618 | 2.69 | 0.3 | -2.39 | Habagat, 2016 | 5 -Year |
| 132 | 14.70172 | 120.28729 | 2.5 | 0.3 | -2.2 | Habagat, 2016 | 5 -Year |
| 133 | 14.70165 | 120.28709 | 3.03 | 1.25 | -1.78 | Habagat, 2016 | 5 -Year |
| 134 | 14.70135 | 120.28678 | 3.94 | 1.5 | -2.44 | Habagat, 2016 | 5 -Year |
| 135 | 14.70134 | 120.28623 | 2.17 | 0.5 | -1.67 | Habagat, 2016 | 5 -Year |
| 136 | 14.67943 | 120.26423 | 1.69 | 1.37 | -0.32 | Habagat, 2016 | 5 -Year |
| 137 | 14.6761 | 120.26606 | 1.5 | 0.91 | -0.59 | Habagat, 2016 | 5 -Year |
| 138 | 14.67619 | 120.267 | 1.52 | 0.75 | -0.77 | Habagat, 2016 | 5 -Year |
| 139 | 14.70209 | 120.24944 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 140 | 14.70143 | 120.24984 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 141 | 14.70105 | 120.24903 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 142 | 14.69954 | 120.24948 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 143 | 14.69878 | 120.24986 | 0.08 | 0 | -0.08 | Habagat, 2016 | 5 -Year |
| 144 | 14.70303 | 120.24941 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 145 | 14.68046 | 120.27283 | 0.04 | 0 | -0.04 | Habagat, 2016 | 5 -Year |
| 146 | 14.68005 | 120.27064 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 147 | 14.67914 | 120.27153 | 0.04 | 0 | -0.04 | Habagat, 2016 | 5 -Year |
| 148 | 14.67701 | 120.27226 | 0.05 | 0 | -0.05 | Habagat, 2016 | 5 -Year |
| 149 | 14.67965 | 120.26883 | 0.05 | 0 | -0.05 | Habagat, 2016 | 5 -Year |
| 150 | 14.67945 | 120.27417 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 151 | 14.68558 | 120.27366 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 152 | 14.685 | 120.27325 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 153 | 14.68416 | 120.27283 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 154 | 14.67853 | 120.26867 | 0.04 | 0 | -0.04 | Habagat, 2016 | 5 -Year |
| 155 | 14.67701 | 120.26572 | 1.26 | 0.6 | -0.66 | Habagat, 2016 | 5 -Year |
| 156 | 14.67167 | 120.27088 | 0.24 | 0.3 | 0.06 | Habagat, 2016 | 5 -Year |
| 157 | 14.67115 | 120.26924 | 0.16 | 0 | -0.16 | Habagat, 2016 | 5 -Year |
| 158 | 14.67203 | 120.26967 | 0.71 | 0 | -0.71 | Habagat, 2016 | 5 -Year |
| 159 | 14.67027 | 120.27023 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 160 | 14.67843 | 120.26251 | 0.89 | 0.46 | -0.43 | Habagat, 2016 | 5 -Year |
| 161 | 14.67792 | 120.26302 | 0.66 | 0.61 | -0.05 | Habagat, 2016 | 5 -Year |
| 162 | 14.67552 | 120.26454 | 0.07 | 0 | -0.07 | Habagat, 2016 | 5 -Year |
| 163 | 14.67462 | 120.26495 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 164 | 14.67327 | 120.26563 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 165 | 14.74066 | 120.28099 | 0.29 | 0 | -0.29 | Habagat, 2016 | 5 -Year |
| 166 | 14.73968 | 120.2792 | 0.06 | 1.37 | 1.31 | Habagat, 2016 | 5 -Year |
| 167 | 14.73936 | 120.27967 | 0.05 | 0.61 | 0.56 | Habagat, 2016 | 5 -Year |

| Point Number | Validation Coordinates | | Model Var (m) | Validation Points (m) | Error | Event/Date | Rain Return /Scenario |
|---|---|---|---|---|---|---|---|
| | Lat | Long | | | | | |
| 168 | 14.74047 | 120.27954 | 0.04 | 0 | -0.04 | Habagat, 2016 | 5 -Year |
| 169 | 14.67827 | 120.26621 | 0.63 | 0.75 | 0.12 | Habagat, 2016 | 5 -Year |
| 170 | 14.68034 | 120.26529 | 2.59 | 0.61 | -1.98 | Habagat, 2016 | 5 -Year |
| 171 | 14.68474 | 120.2678 | 0.95 | 1.52 | 0.57 | Habagat, 2016 | 5 -Year |
| 172 | 14.68531 | 120.26956 | 4.25 | 1.75 | -2.5 | Habagat, 2016 | 5 -Year |
| 173 | 14.68431 | 120.26873 | 4.67 | 1.85 | -2.82 | Habagat, 2016 | 5 -Year |
| 174 | 14.68557 | 120.26888 | 1.93 | 1.68 | -0.25 | Habagat, 2016 | 5 -Year |
| 175 | 14.68479 | 120.26314 | 0.09 | 0 | -0.09 | Habagat, 2016 | 5 -Year |
| 176 | 14.68659 | 120.26451 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 177 | 14.68769 | 120.26554 | 0.03 | 0 | -0.03 | Habagat, 2016 | 5 -Year |
| 178 | 14.68258 | 120.26711 | 4.4 | 1.85 | -2.55 | Habagat, 2016 | 5 -Year |
| 179 | 14.67973 | 120.26426 | 2.73 | 0.76 | -1.97 | Habagat, 2016 | 5 -Year |
| 180 | 14.67194 | 120.27088 | 0.93 | 0.34 | -0.59 | Habagat, 2016 | 5 -Year |

## Annex 12. Educational Institutions Affected in Morong Floodplain

| Bataan | | | | |
|---|---|---|---|---|
| Morong | | | | |
| Building Name | Barangay | Rainfall Scenario | | |
| | | 5-year | 25-year | 100-year |
| Binaritan Elementary School 1 | Binaritan | High | High | High |
| Binaritan Elementary School 2 | Binaritan | High | High | High |
| Binaritan Elementary School 3 | Binaritan | High | High | High |
| Binaritan Elementary School 4 | Binaritan | High | High | High |
| Binaritan Elementary School 5 | Binaritan | High | High | High |
| Binaritan Elementary School 6 | Binaritan | | | |
| Mabayo Elementary School 1 | Mabayo | Medium | Medium | Medium |
| Mabayo Elementary School 2 | Mabayo | Medium | Medium | Medium |
| Mabayo Elementary School 3 | Mabayo | Medium | Medium | High |
| Mabayo Elementary School 4 | Mabayo | Medium | Medium | High |
| Mabayo Elementary School 5 | Mabayo | Medium | Medium | Medium |
| Mabayo Elementary School 6 | Mabayo | Medium | Medium | Medium |
| Mabayo High School 1 | Mabayo | | | |
| Mabayo High School 2 | Mabayo | Low | Low | Low |
| Mabayo High School 3 | Mabayo | Low | Low | Medium |
| Mabayo High School 4 | Mabayo | Low | Medium | Medium |
| Mabayo High School 5 | Mabayo | Low | Medium | Medium |
| Mabayo High School 6 | Mabayo | | | |
| Minanga Elementary School 1 | Mabayo | | Low | Medium |
| Minanga Elementary School 2 | Mabayo | | Low | Medium |
| Minanga Elementary School 3 | Mabayo | | Low | Low |
| Minanga Elementary School 4 | Mabayo | | Low | Medium |
| Minanga Elementary School 5 | Mabayo | | Medium | Medium |
| Morong Elementary School 1 | Poblacion | Low | Medium | Medium |
| Morong Elementary School 10 | Poblacion | Low | Medium | Medium |
| Morong Elementary School 11 | Poblacion | Medium | Medium | Medium |
| Morong Elementary School 12 | Poblacion | Medium | Medium | Medium |
| Morong Elementary School 13 | Poblacion | Medium | Medium | High |
| Morong Elementary School 2 | Poblacion | | Medium | Medium |
| Morong Elementary School 3 | Poblacion | Medium | Medium | Medium |
| Morong Elementary School 4 | Poblacion | Medium | Medium | High |
| Morong Elementary School 5 | Poblacion | Medium | Medium | High |
| Morong Elementary School 6 | Poblacion | Medium | Medium | High |
| Morong Elementary School 7 | Poblacion | Medium | Medium | High |
| Morong Elementary School 8 | Poblacion | Low | Medium | Medium |
| Morong Elementary School 9 | Poblacion | Medium | Medium | High |
| Maranhattta Christian Academy | Sabang | | | |
| Morong National High School 1 | Sabang | | | |

| Bataan | | | | |
|---|---|---|---|---|
| Morong | | | | |
| Building Name | Barangay | Rainfall Scenario | | |
| | | 5-year | 25-year | 100-year |
| Morong National High School 2 | Sabang | | | |
| Morong National High School 3 | Sabang | | | |
| Morong National High School 4 | Sabang | | | |
| Morong National High School 5 | Sabang | | | |

## Annex 13. Medical Institutions Affected in Morong Floodplain

| Bataan | | | | |
|---|---|---|---|---|
| Morong | | | | |
| Building Name | Barangay | Rainfall Scenario | | |
| | | 5-year | 25-year | 100-year |
| Morong Municipal Health Center | Poblacion | Medium | Medium | High |