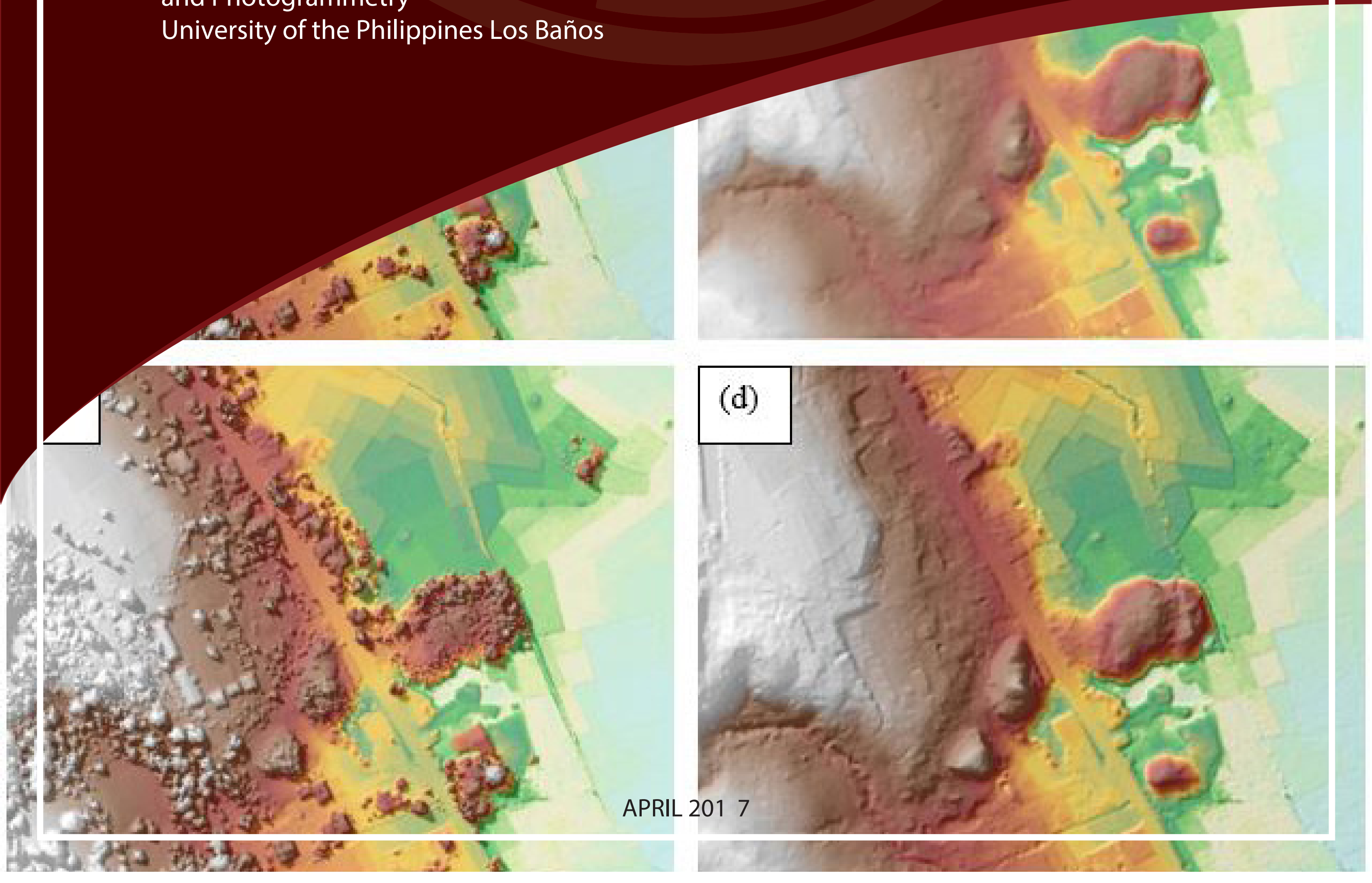
HAZARD MAPPING OF THE PHILIPPINES USING LIDAR ( PHIL-LIDAR 1 )

# LiDAR Surveys and Flood Mapping of Bulalacao River

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

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For questions/queries regarding this report, contact:

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

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

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# LIST OF ACRONYMS AND ABBREVIATIONS

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

*Enrico C. Paringit, Dr. Eng., and Dr. Edwin R. Abucay, Joan Pauline P. Talubo*

## 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 in 2014 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 University of the Philippines Los Baños (UPLB). UPLB is in charge of processing LiDAR data and conducting data validation reconnaissance, cross section, bathymetric survey, validation, river flow measurements, flood height and extent data gathering, flood modeling, and flood map generation for the 45 river basins in the Southern Luzon region. The university is located in Los Baños in the province of Laguna.

## 1.2 Overview of the Bulalacao River Basin

The Bulalacao River Basin is a 83,100-hectare watershed located in the Municipality of Bulalacao, Oriental Mindoro. It covers the barangays of Bagong Sikat, Benli, Cambunang, Campaasan, Nasukob, Poblacion and San Juan in Bulalacao municipality. It is situated in the southeastern point of the island of Mindoro, and northwest of Bulalacao Bay and Tablas Strait. It has an approximate land area of 6,461.35 has with the estimated run-off of 120 mcm according to DENR-RBCO.

The basin area has ten geological classifications including Paleocene-Eocene, Basement Complex, Jurrasic, Oligocene, Oligocene-Miocene, Oligocene-Miocene (Sedimentary and Metamorphic rocks), Pliocene-Pleistocene, Pliocene-Quaternary, Recent and some which are still unknown. The river basin is generally characterized by 30-50% slope and elevation of 300-2200 meters above mean sea level. About seven soil types can be found in the area including Alaminos loam, Bolinao clay, Buguay loamy sand, Maranlig gravelly sandy clay loam, San Manuel clay loam, San Manuel sandy loam, and Tagaytay sandy loam. Beach sand, hydrosol and rough mountain land (unclassified) can also be found in the area. The basin area is dominated by cultivated land mixed with brushland/grassland while the rest is occupied by arable land (crops mainly cereals and sugar), closed canopy (mature trees covering >50%), coconut plantations, coral reef, crop land mixed with coconut plantation, fishponds derived from mangrove, grassland (grass covering > 70%), open canopy (mature trees covering >70%) and some that are still unclassified.

Its main stem, Bulalacao River, also known as Cawacat River to some locals, is one of the main tributaries of the Bulalacao River Basin and is one of the 45 river systems under the University of the Philippines, Los Baños Phil-LIDAR Project. The river is connected to a larger stream network comprising of two (2) other rivers: the Maujao and Cavillan Rivers.

Bulalacao River passes through Bagong Sikat, Benli, Cambunang, Campaasan, Nasukob, Poblacion and San Juan in Bulalacao municipality.

The Bulalacao River is approximately 2.81 km in length and drains towards Bulalacao Bay. There is a total of 19,926 people living within the immediate vicinity of the river which is distributed among seven (7) barangays, namely: Bagong Sikat, Benli, Cambunang, Campaasan, Nasukob, Poblacion, and San Juan in the Municipality of Bulalacao according to the 2010 census conducted by NSO. Benli is considered to be the most populated barangay per record in the 2010 NSO Census of Population and Housing.

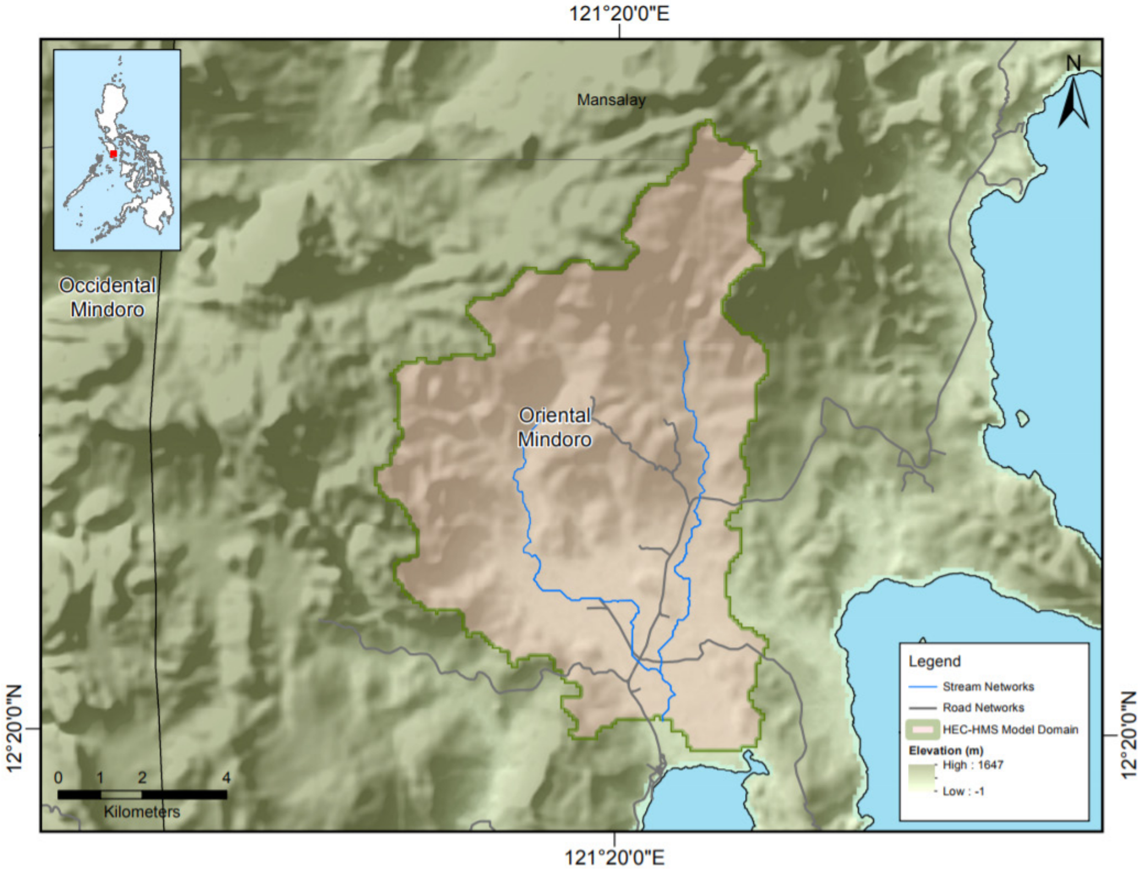



Figure 1. Map of Bulalacao River Basin

Most of the areas covered by the basin are cultivated for agricultural products such as coconut, cereal, and sugar. Aside from agriculture, aquaculture is also present along coastal communities. These livelihoods are able to continue to be sources of income for the communities near the river due to the conducive tropical climate in the river basin and the larger area where it is located. Climate Type I and III prevails in MIMAROPA and Laguna based on the Modified Corona Classification of climate. Type I has two pronounced seasons, dry from November to April, and wet the rest of the year with maximum rain period from June to September. On the other hand, Type III has no very pronounced maximum rain period and with short dry season lasting only from one to three months, during the period from December to February or from March to May.

Bulalacao River Basin is not without its threats of disaster. According to the Mines and Geosciences Bureau, the barangays of Bagong Sikat, Benli, Cabugao, Cambunang and San Juan of Bulalacao municipality are at a higher risk to landslides. Also, based on the field surveys conducted by the PHIL-LiDAR 1 validation team, a number of notable weather disturbances have caused flooding in 1995 (Rosing), 2004 (Unding), 2006 (Caloy), 2009 (Ondoy), 2013 (Yolanda), 2014 (Seniang), 2015 (Nona), and 2016 (Butchoy). Heavy rainfalls brought about by south west monsoon rains (habagat) caused flooding in 2013-2015. Flash floods occurred near the riverside last November 2 to 3, 2013 when Typhoon Haiyan hit most of Oriental Mindoro.

# CHAPTER 2: LIDAR DATA ACQUISITION OF THE BULALACAO FLOODPLAIN

*Engr. Louie P. Balicanta, Engr. Christopher Cruz, Lovely Gracia Acuña, Engr. Gerome Hipolito, Engr. Iro Niel D. Roxas, Ms. Rowena M. Gabua*

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

## 2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Bulalacao floodplain in Oriental Mindoro. These missions were planned for 16 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 is found in Table 1 and Table 2. Figure 2 shows the flight plan for Bulalacao floodplain.

Table 1. Flight planning parameters for Aquarius LiDAR system.

| Block Name | Flying Height (AGL) | Overlap (%) | Field of View | Pulse Repetition Frequency (PRF) (kHz) | Scan Frequency | Average Speed | Average Turn Time (Minutes) |
|---|---|---|---|---|---|---|---|
| BLK28N | 600 | 30 | 36 | 125 | 45 | 130 | 5 |
| BLK29B | 600 | 30 | 36 | 125 | 45 | 130 | 5 |

Table 2. Flight planning parameters for Gemini LiDAR system.

| Block Name | Flying Height (AGL) | Overlap (%) | Field of View | Pulse Repetition Frequency (PRF) (kHz) | Scan Frequency | Average Speed | Average Turn Time (Minutes) |
|---|---|---|---|---|---|---|---|
| BLK28J | 1000 | 30 | 50 | 125 | 50 | 130 | 5 |

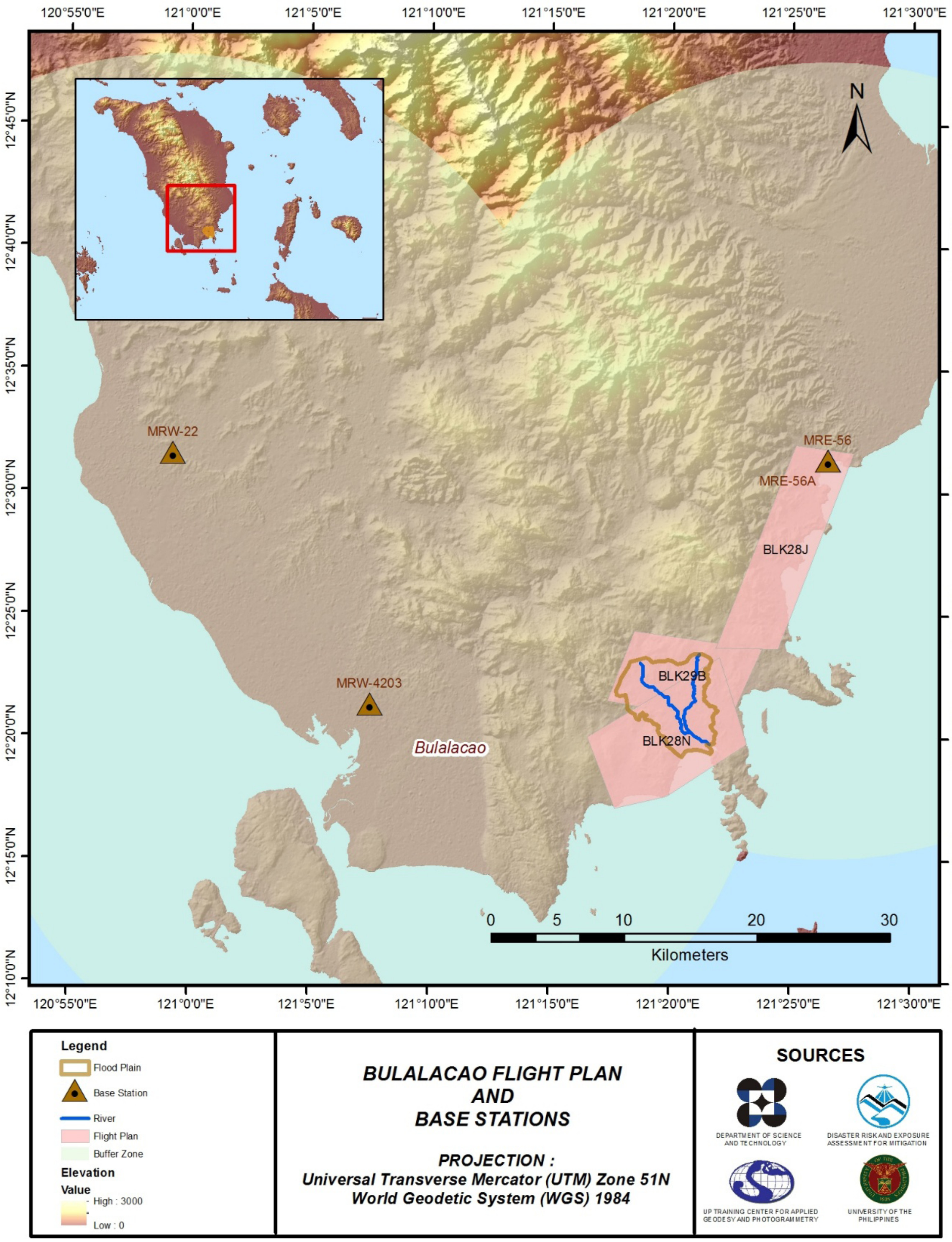



Figure 2. Flight plans and base stations used for Bulalacao Floodplain

## 2.2 Ground Base Station

The project team was able to recover two (2) NAMRIA ground control points: MRW-22 and MRE-56 which are of second (2nd) order accuracy. The project team also re-established ground control point MRW-4203 which is of third (3rd) order accuracy. The project team also established one (1) ground control point, MRE-56A. The certifications for the NAMRIA reference points are found in Annex 2 while the baseline processing report is in Annex 3. These were used as base stations during flight operations for the entire duration of the survey (March 3, 2014; October 26 - 28, 2015). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 852 and SPS 985. Flight plans and location of base stations used during the aerial LiDAR acquisition in Bulalacao floodplain are shown in Figure 2.The list of team members are shown in Annex 4.

Figure 3 to Figure 4 show the recovered NAMRIA reference points within the area, in addition Table 3 to Table 6 show the details about the following NAMRIA control stations and established points, Table 7 shows the list of all ground control points occupied during the acquisition together with the corresponding dates of utilization.

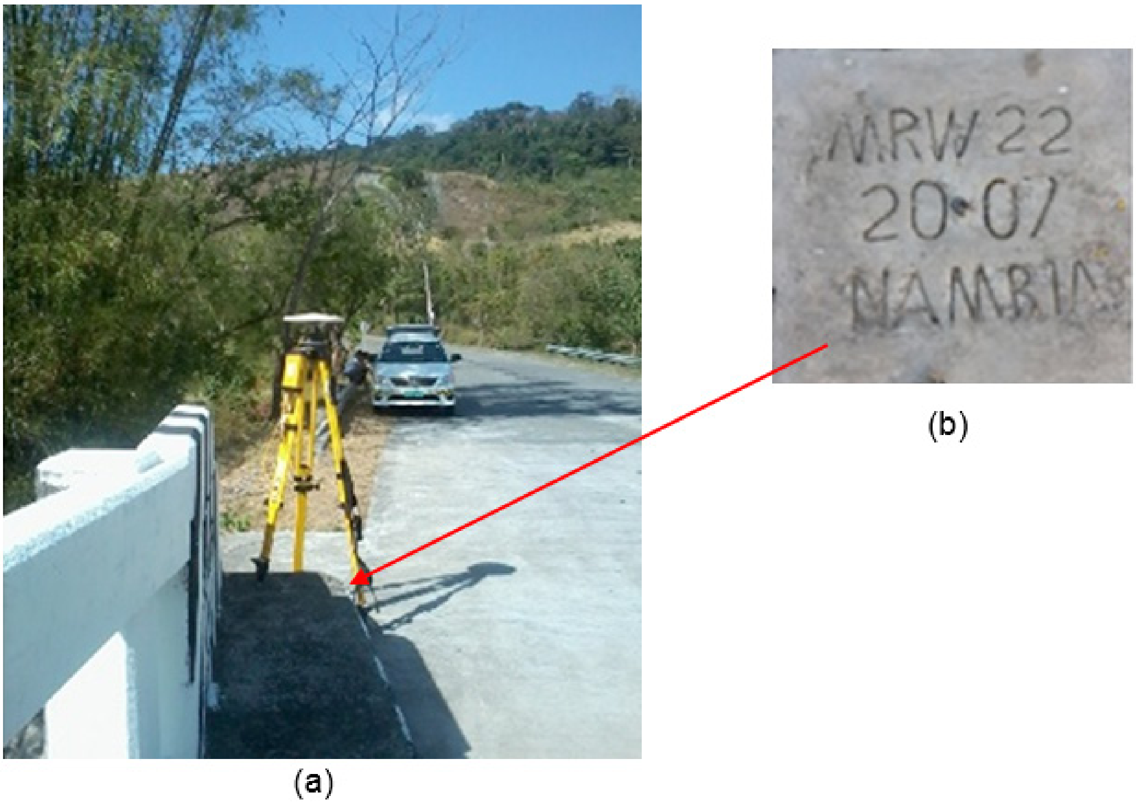



Figure 3. GPS set-up over MRW-22 as recovered in Lumintao Bridge in Brgy. Tanyag, municipality of Calintaan, Occidental Mindoro (a) and NAMRIA reference point MRW-22 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point MRW-22 used as base station for the LiDAR acquisition.

| Station Name | MRW-22 | |
|---|---|---|
| Order of Accuracy | 2nd | |
| Relative Error (horizontal positioning) | 1 in 50,000 | |
| Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92) | Latitude<br>Longitude<br>Ellipsoidal Height | 12°31'36.76881" North<br>120°59'13.46492" East<br>35.12700 meters |
| Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92) | Easting<br>Northing | 498595.125 meters<br>1385214.96 meters |
| Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84) | Latitude<br>Longitude<br>Ellipsoidal Height | 12°31'31.84278" North<br>120°59'18.53734" East<br>84.27100 meters |
| Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984) | Easting<br>Northing | 281265.62 meters<br>1385563.72 meters |

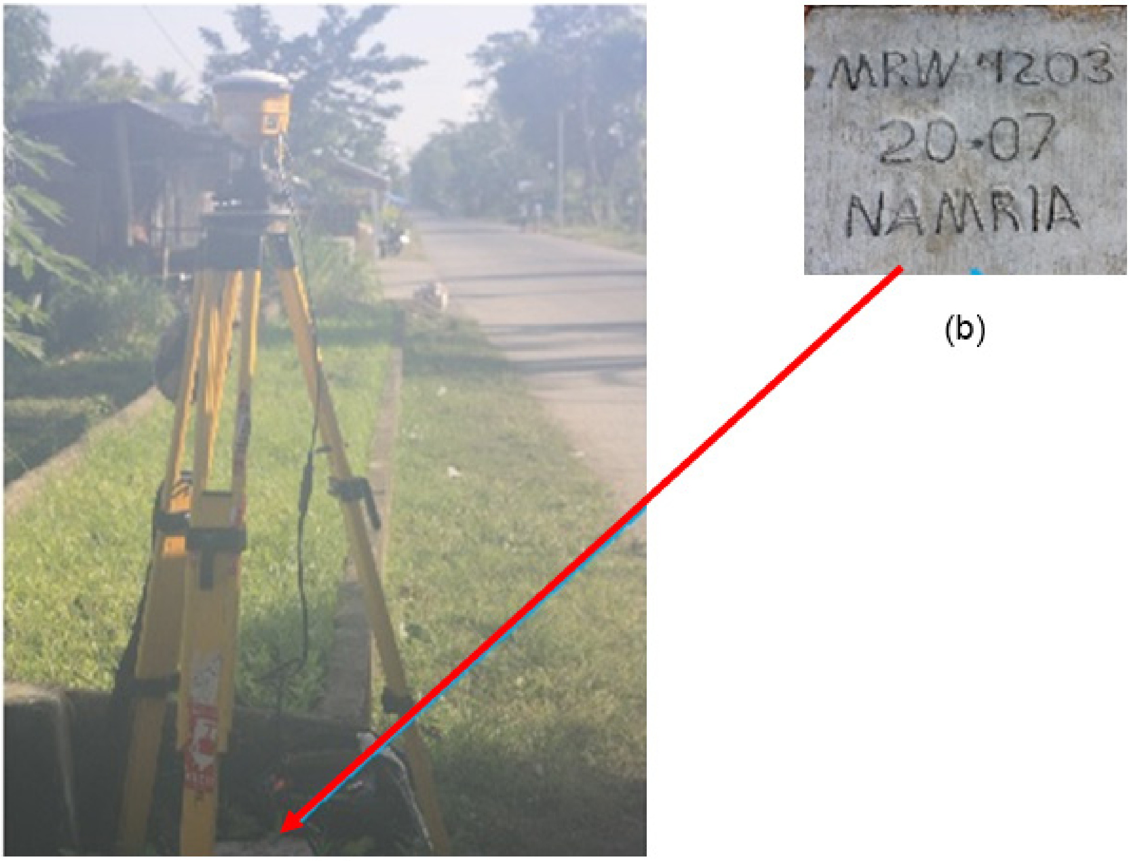



Figure 4. GPS set-up over MRW-4203 as recovered front of the barangay hall of Brgy. Mapaya, municipality of San Jose, Occidental Mindoro (a) and NAMRIA reference point MRW-4203 (b) as recovered by the field team.

Table 4. Details of the recovered NAMRIA horizontal control point MRE-4203 used as base station for the LiDAR acquisition with established coordinates.

| Station Name | MRW-4203 | |
|---|---|---|
| Order of Accuracy | 2nd | |
| Relative Error (horizontal positioning) | 1:50,000 | |
| Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92) | Latitude<br>Longitude<br>Ellipsoidal Height | 12°21’24.45021” North<br>121°07’26.92622” East<br>7.41400 meters |
| Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 5 PRS 92) | Easting<br>Northing | 296032.79 meters<br>1366637.32 meters |
| Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84) | Latitude<br>Longitude<br>Ellipsoidal Height | 12°21’19.57973” North<br>121°07’32.01059” East<br>57.32000 meters |

Table 5. Details of the recovered NAMRIA horizontal control point MRE-56 used as base station for the LiDAR acquisition.

| Station Name | MRE-56 | |
|---|---|---|
| Order of Accuracy | 2nd | |
| Relative Error (horizontal positioning) | 1 in 50,000 | |
| Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92) | Latitude<br>Longitude<br>Ellipsoidal Height | 12°31’25.76362’’ North<br>121°26’25.21109’’ East<br>7.8700 meters |
| Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 5 PRS 92) | Easting<br>Northing | 547857.861 meters<br>1383916.657 meters |
| Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84) | Latitude<br>Longitude<br>Ellipsoidal Height | 12°31’20.87629’’ North<br>121°26’30.28143’’ East<br>58.13600 meters |
| Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRD 1992) | Easting<br>Northing | 330530.08 meters<br>1384892.31 meters |

Table 6. Details of the established ground control point MRE-56A used as base station for the LiDAR acquisition.

| Station Name | MRE-56A | |
|---|---|---|
| Order of Accuracy | 2nd | |
| Relative Error (horizontal positioning) | 1:50,000 | |
| Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92) | Latitude<br>Longitude<br>Ellipsoidal Height | 12°31’20.59653’’ North<br>121°26’30.40791’’ East<br>57.601 meters |
| Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 5 PRS 92) | Easting<br>Northing | 330688.179 meters<br>1384818.639 meters |

Table 7. Ground control points used during LiDAR data acquisition

| Date Surveyed | Flight Number | Mission Name | Ground Control Points |
|---|---|---|---|
| 03-Mar-14 | 1164A | 3BLK29N61A | MRW-4203, MRW-22 |
| 26-Oct-15 | 8308G | 2BLK28J299A | MRE-56, MRE-56A |
| 28-Oct15 | 8312G | 2BLK28JKLS301A | MRE-56, MRE-56A |

## 2.3 Flight Missions

Three (3) missions were conducted to complete the LiDAR Data Acquisition in Bulalacao floodplain, for a total of twelve hours and two minutes (12+02) of flying time for RP-C9122 and RP-C9322. All missions were acquired using the Aquarius and Gemini LiDAR systems. Table 8 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 9 presents the actual parameters used during the LiDAR data acquisition.

Table 8. Flight missions for LiDAR data acquisition in Bulalacao Floodplain

| Date Surveyed | Flight Number | Flight Plan Area (km2) | Surveyed Area (km2) | Area Surveyed within the Floodplain (km2) | Area Surveyed Outside the Floodplain (km2) | No. of Images (Frames) | Flying Hours | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Hr | Min |
| 03-Mar-14 | 1164A | 128.92 | 112.10 | 25.28 | 86.82 | 311 | 4 | 53 |
| 26-Oct-15 | 8308G | 144.96 | 103.41 | 25.07 | 78.34 | NA | 3 | 41 |
| 28-Oct-15 | 8312G | 69.40 | 75.52 | 11.37 | 64.15 | NA | 3 | 28 |
| TOTAL | | 343.28 | 291.03 | 61.72 | 229.31 | 311 | 12 | 02 |

Table 9. Actual parameters used during LiDAR data acquisition

| Flight Number | Flying Height (AGL) | Overlap (%) | Field of View (θ) | Pulse Repetition Frequency (PRF) (kHz) | Scan Frequency (Hz) | Average Speed (kts) | Average Turn Time (Minutes) |
|---|---|---|---|---|---|---|---|
| 1164A | 600 | 30 | 36 | 50 | 40 | 130 | 5 |
| 8308G | 1000 | 30 | 36 | 100 | 50 | 130 | 5 |
| 2117P | 1000 | 30 | 36 | 100 | 50 | 130 | 5 |

## 2.4 Survey Coverage

Bulalacao floodplain is located in the province of Oriental Mindoro, with majority of the floodplain situated within the municipality of Bulalacao. The list of municipalities and cities surveyed with at least one (1) square kilometer coverage, is shown in Table 10. The actual coverage of the LiDAR acquisition for Bulalacao floodplain is presented in Figure 5.

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

| Province | Municipality/City | Area of Municipality/City (km2) | Total Area Surveyed (km2) | Percentage of Area Surveyed |
|---|---|---|---|---|
| Occidental Mindoro | Magsaysay | 256.56 | 10.12 | 4% |
| | San Jose | 449.82 | 10.69 | 2% |
| Oriental Mindoro | Bulalacao | 365.58 | 161.52 | 44% |
| | Mansalay | 477.24 | 30.61 | 6% |
| | Bansud | 197.00 | 9.87 | 5% |
| | Roxas | 90.14 | 2.67 | 3% |
| | Bongabong | 493.74 | 4.13 | 1% |
| | Gloria | 327.28 | 1.64 | 1% |
| Total | | 2657.36 | 231.25 | 8.70% |

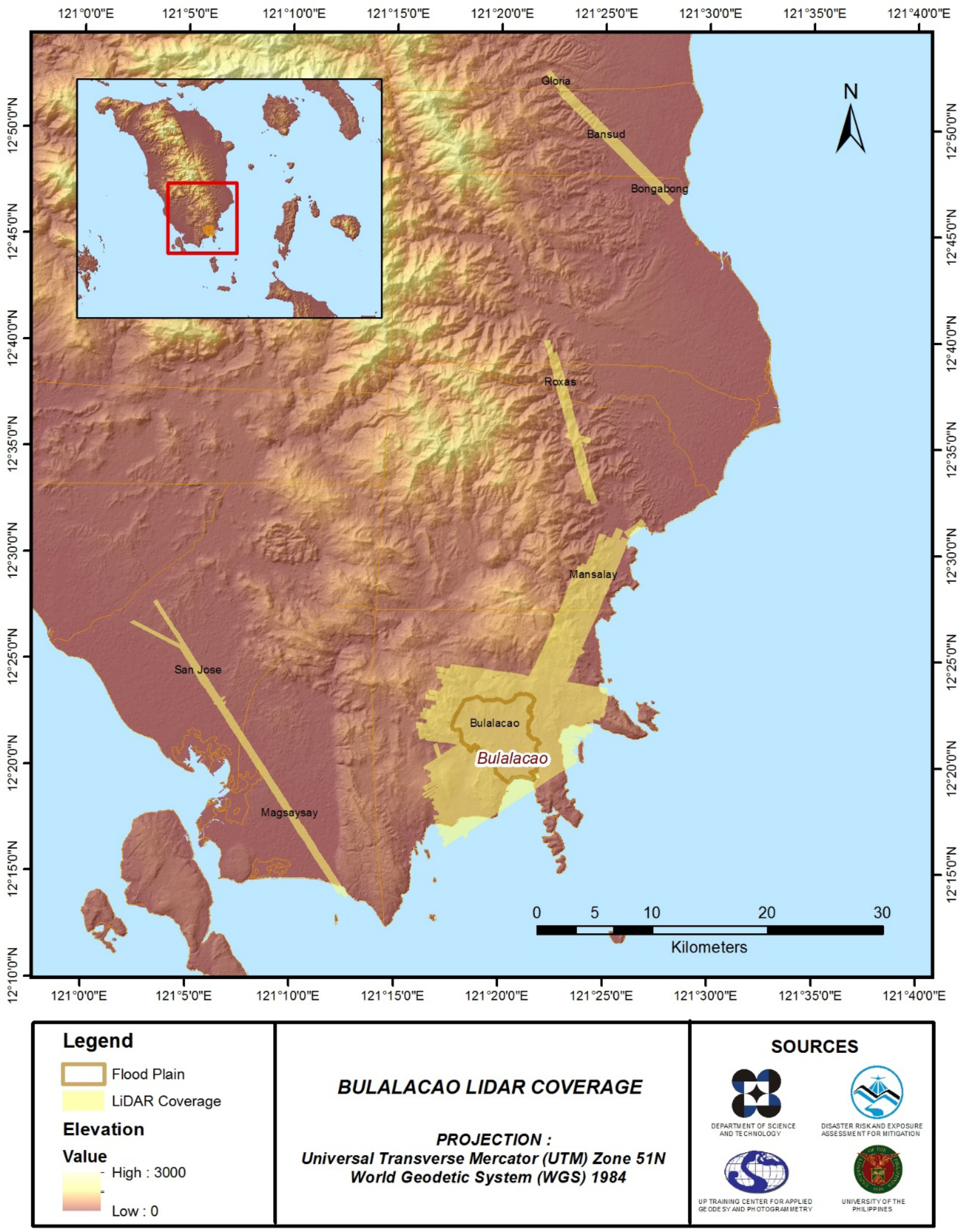



Figure 5. Actual LiDAR survey coverage for Bulalacao Floodplain.

# CHAPTER 3: LIDAR DATA PROCESSING OF THE BULALACAO FLOODPLAIN

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

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

## 3.1 Overview of the LIDAR Data Pre-Processing

The data transmitted by the Data Acquisition Component 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.

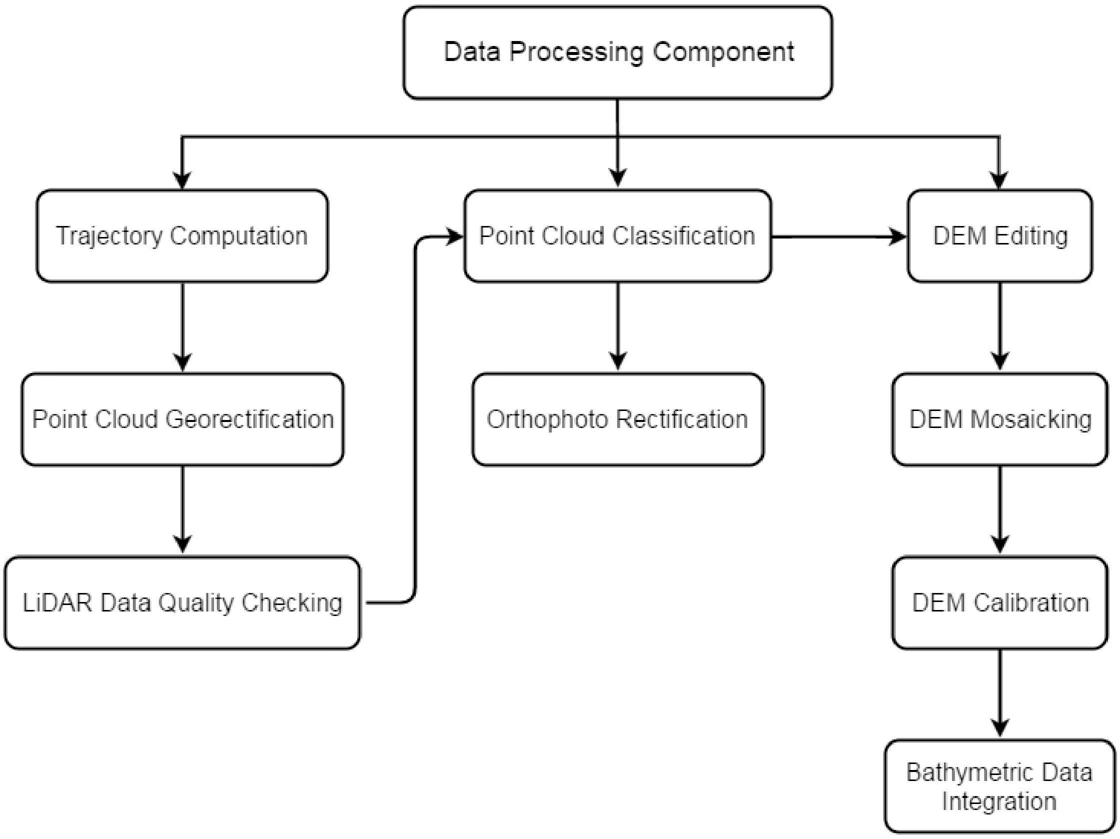



Figure 6. Schematic Diagram for Data Pre-Processing Component

## 3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Bulalacao floodplain can be found in Annex 5. Missions flown during the first survey conducted on March 2014 and second survey conducted on October 2015 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Aquarius system and Gemini system respectively over Municipality of Bulalacao, Oriental Mindoro.

The Data Acquisition Component (DAC) transferred a total of 38.60 Gigabytes of Range data, 743 Megabytes of POS data, 34.29 Megabytes of GPS base station data, and 22.50 Gigabytes of raw image data to the data server on November 09, 2015. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Bulalacao was fully transferred on November 12, 2015, as indicated on the Data Transfer Sheets for Bulalacao floodplain.

## 3.3 Trajectory Computation

The Smoothed Performance Metric parameters of the computed trajectory for flight 8308G, one of the Bulalacao flights, which is the North, East, and Down position RMSE values are shown in Figure 7. 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 October 25, 2015 00:00AM. The y-axis is the RMSE value for that particular position.


Figure 7. Smoothed Performance Metric Parameters of Bulalacao Flight 8308G.

The time of flight was from 87,500 seconds to 94,000 seconds, which corresponds to morning of October 26, 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 minimized the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values correspond to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 8 shows that the North position RMSE peaks at 1.44 centimeters, the East position RMSE peaks at 1.15 centimeters, and the Down position RMSE peaks at 3.05 centimeters, which are within the prescribed accuracies described in the methodology.


Figure 8. Solution Status Parameters of Bulalacao Flight 8308G.

The Solution Status parameters of flight 8308G, one of the Bulalacao flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 8. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Majority of the time, the number of satellites tracked was between 6 and 10. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode stayed at the value of 0 for majority of the survey with some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Bulalacao flights is shown in Figure 9.

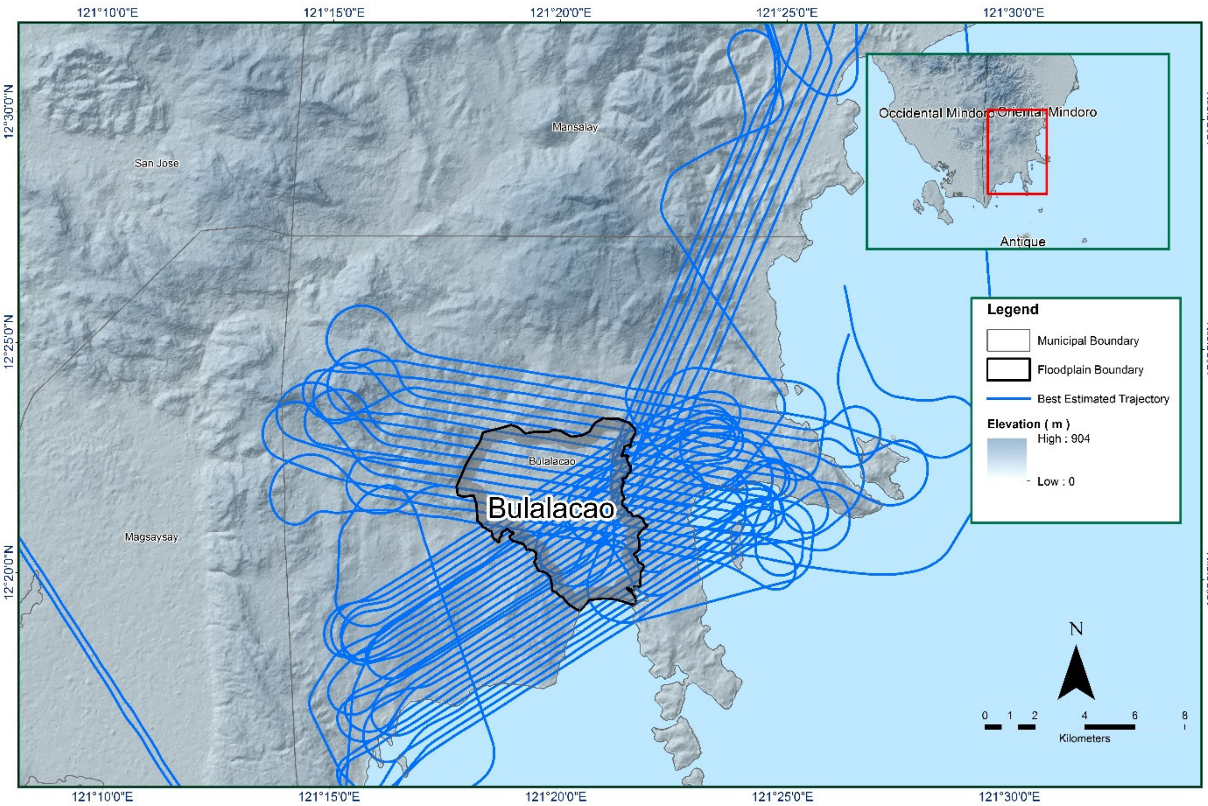



Figure 9. Best Estimated Trajectory for Bulalacao Floodplain.

## 3.4 LiDAR Point Cloud Computation

The produced LAS data contains 55 flight lines, with each flight line containing one channel, since the Gemini and Aquarius systems both contain one channel only. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Bulalacao floodplain are given in Table 11.

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

| Parameter | Computed Value |
|---|---|
| Boresight Correction stdev (<0.001degrees) | 0.000970 |
| IMU Attitude Correction Roll and Pitch Corrections stdev (<0.001degrees) | 0.000762 |
| GPS Position Z-correction stdev (<0.01meters) | 0.0019 |

The optimum accuracy is obtained for all Bulalacao 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 8: Mission Summary Reports.

## 3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Bulalacao Floodplain is shown in Figure 10. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

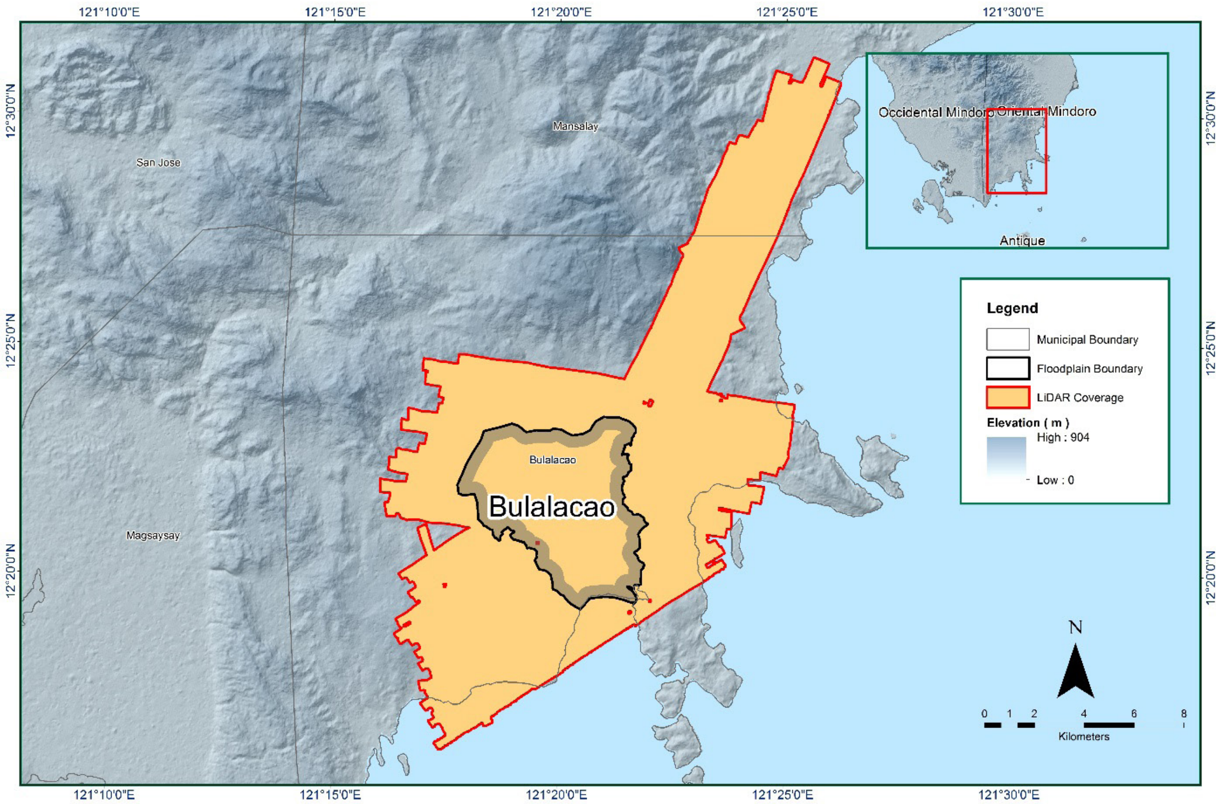



Figure 10. Boundary of the processed LiDAR data over Bulalacao Floodplain

The total area covered by the Bulalacao missions is 231.50 sq.km that is comprised of three (3) flight acquisitions grouped and merged into four (4) blocks as shown in Table 12.

Table 12. List of LiDAR blocks for Bulalacao Floodplain.

| LiDAR Blocks | Flight Numbers | Area (sq. km) |
|---|---|---|
| OccidentalMindoro_Blk29N | 1164A | 87.14 |
| OccidentalMindoro_Blk29N_additional | 1164A | 4.91 |
| OrientalMindoro_Reflights_Blk28J | 8312G | 44.55 |
| OrientalMindoro_Reflights_Blk28K | 8308G | 94.90 |
| | 8312G | |
| | TOTAL | 231.50 sq.km |

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 11. Since the Gemini and Aquarius systems both employ one channel, we would expect an average value of 1 (blue) for areas where there is limited overlap, and a value of 2 (yellow) or more (red) for areas with three or more overlapping flight lines.

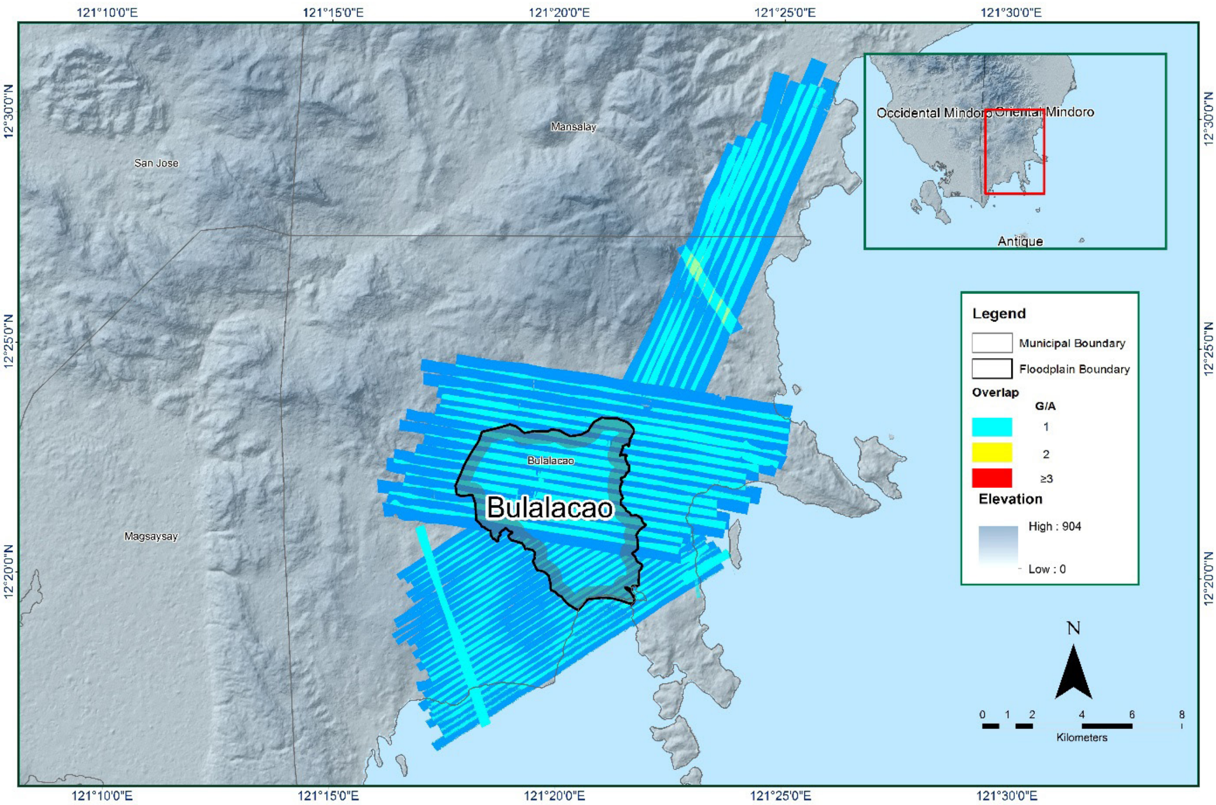



Figure 11. Image of data overlap for Bulalacao Floodplain.

The overlap statistics per block for the Bulalacao floodplain can be found in Annex 8. One pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 35.59% and 39.98% 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 12. It was determined that all LiDAR data for Bulalacao floodplain satisfy the point density requirement, and the average density for the entire survey area is 3.74 points per square meter.

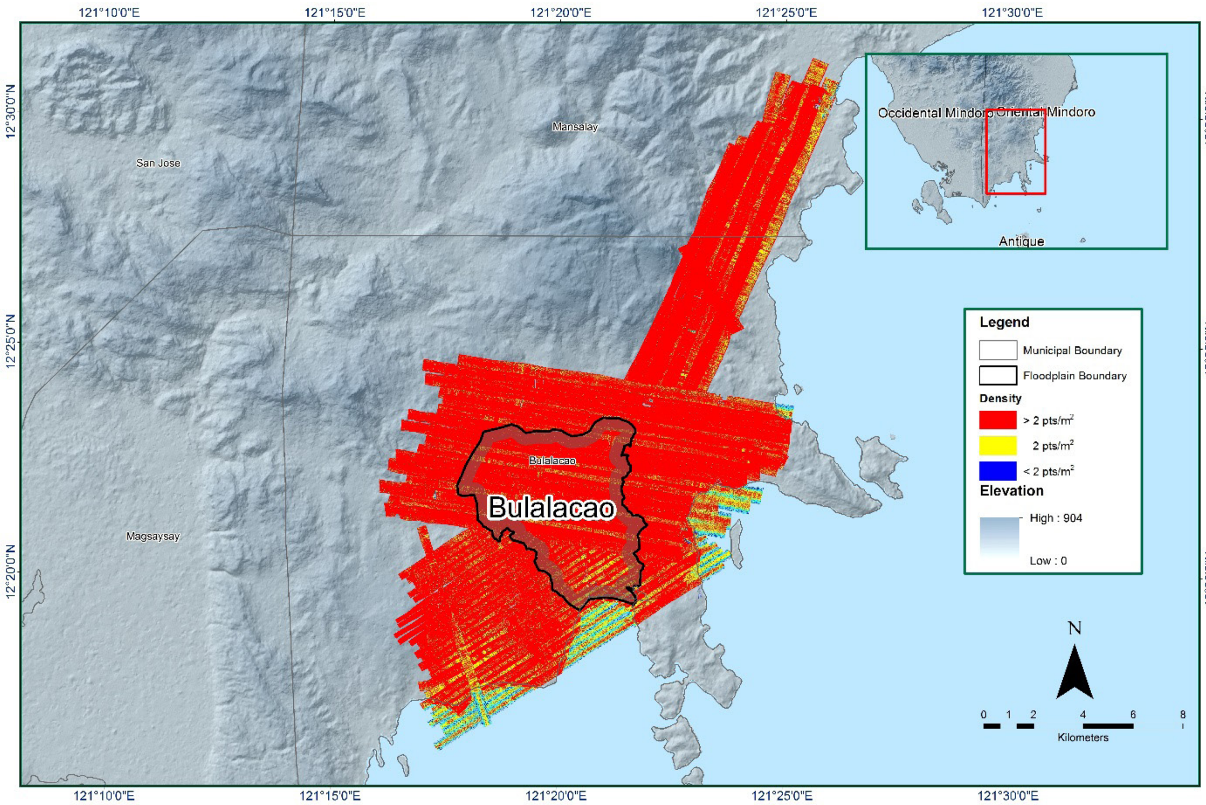



Figure 12. Pulse density map of merged LiDAR data for Bulalacao Floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 13. 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.

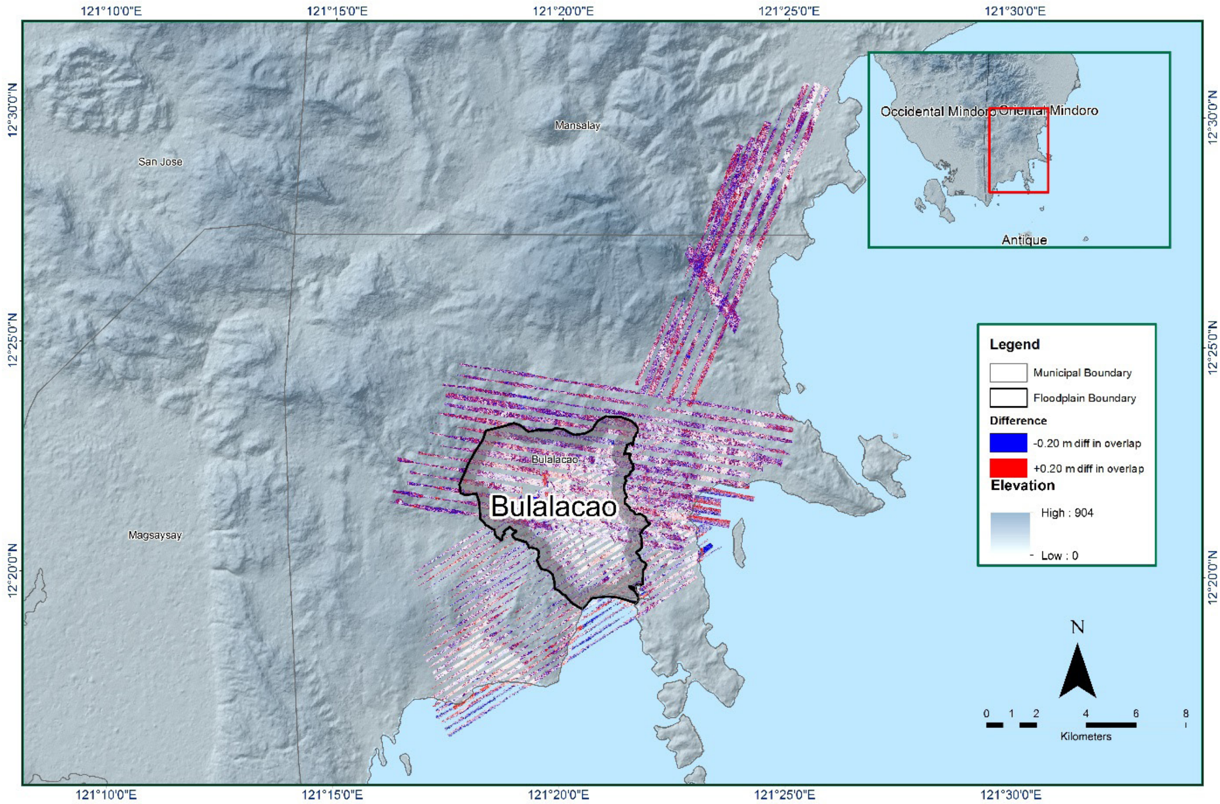



Figure 13. Elevation difference map between flight lines for Bulalacao Floodplain.

A screen capture of the processed LAS data from a Bulalacao flight 8308G loaded in QT Modeler is shown in Figure 14. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed yellow line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

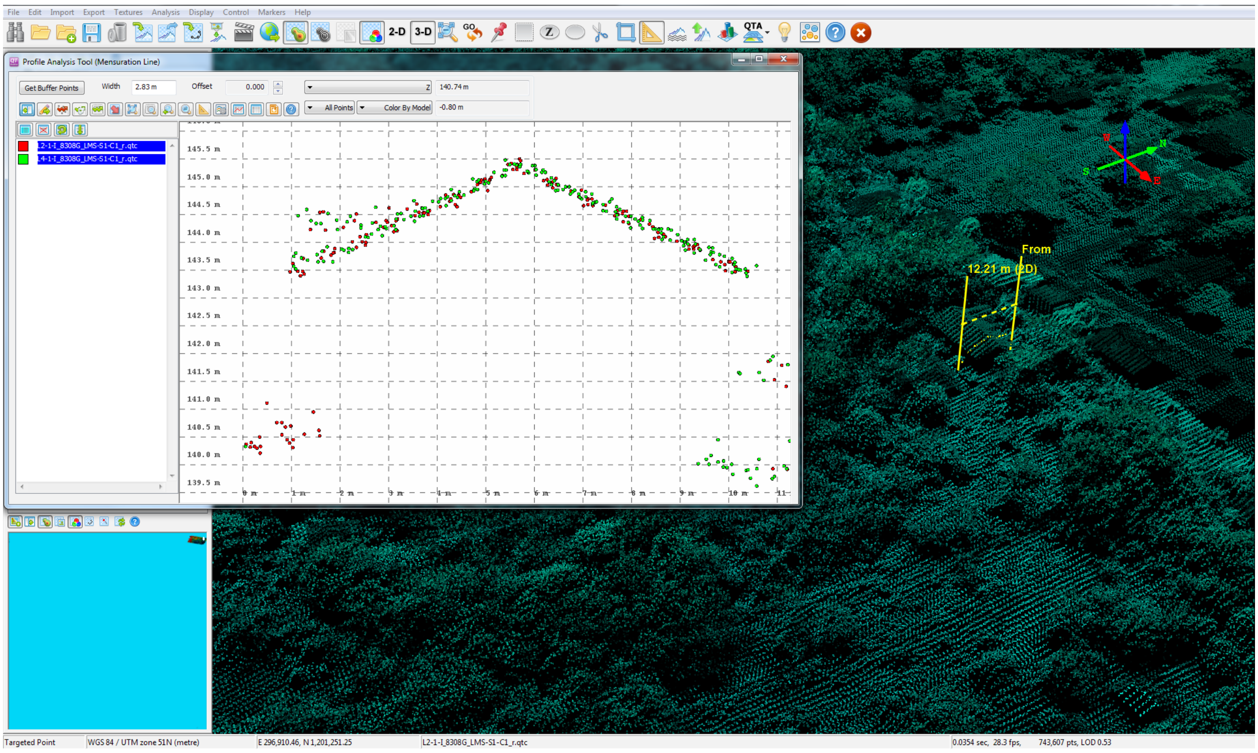



Figure 14. Quality checking for Bulalacao flight 8308G using the Profile Tool of QT Modeler.

## 3.6 LiDAR Point Cloud Classification and Rasterization

Table 13. Bulalacao classification results in TerraScan.

| Pertinent Class | Total Number of Points |
|---|---|
| Ground | 121,982,525 |
| Low Vegetation | 121,364,908 |
| Medium Vegetation | 256,627,802 |
| High Vegetation | 298,030,073 |
| Building | 4,761,961 |

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Bulalacao floodplain is shown in Figure 15. A total of 344 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 13. The point cloud has a maximum and minimum height of 687.61 meters and 38.91 meters respectively.

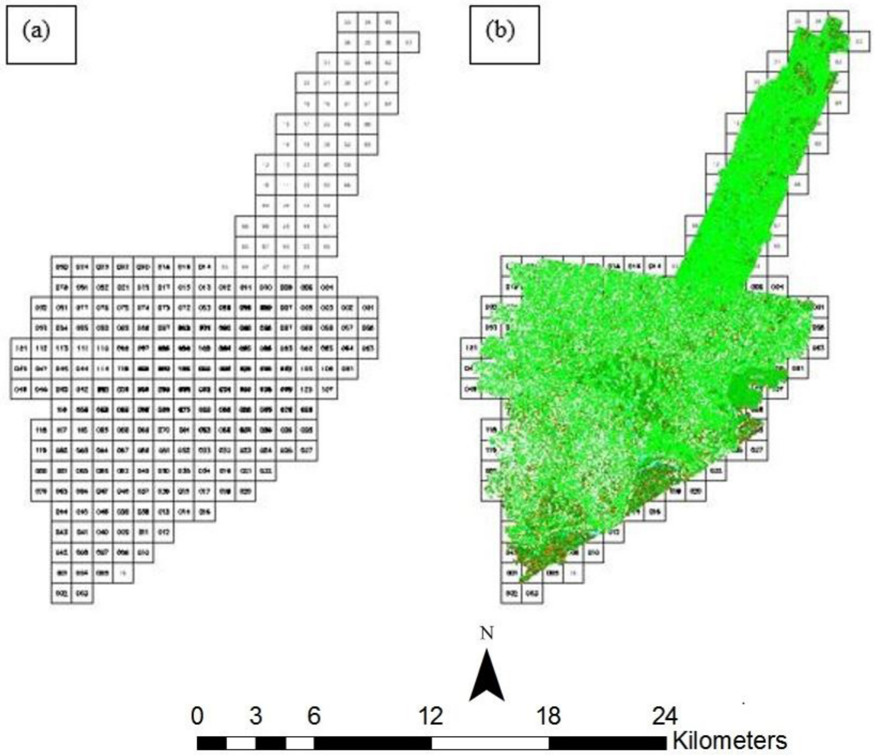



Figure 15. Tiles for Bulalacao Floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 16. 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.

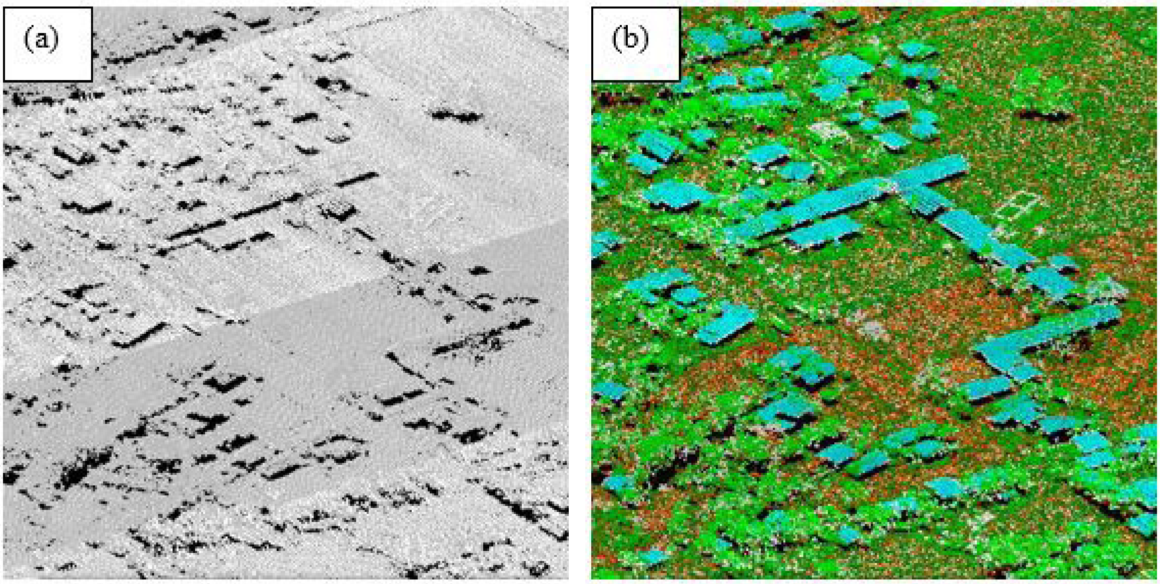



Figure 16. Point cloud before (a) and after (b) classification.

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

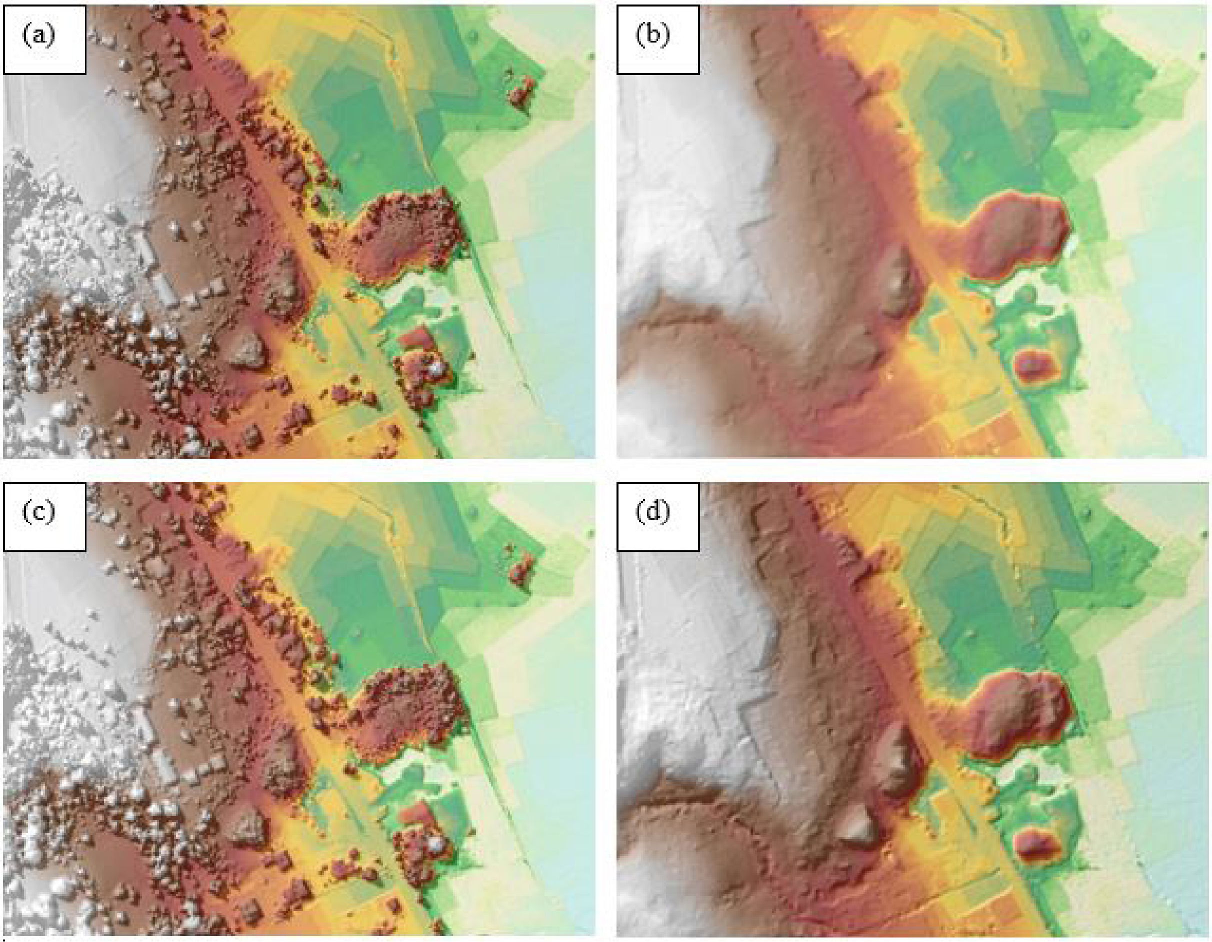



Figure 17. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Bulalacao floodplain.

## 3.7 LiDAR Image Processing and Orthophotograph Rectification

The 63 1km by 1km tiles area covered by Bulalacao floodplain is shown in Figure B-13. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Bulalacao floodplain has a total of 23.83 sq.km orthophotogaph coverage comprised of 176 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 18.

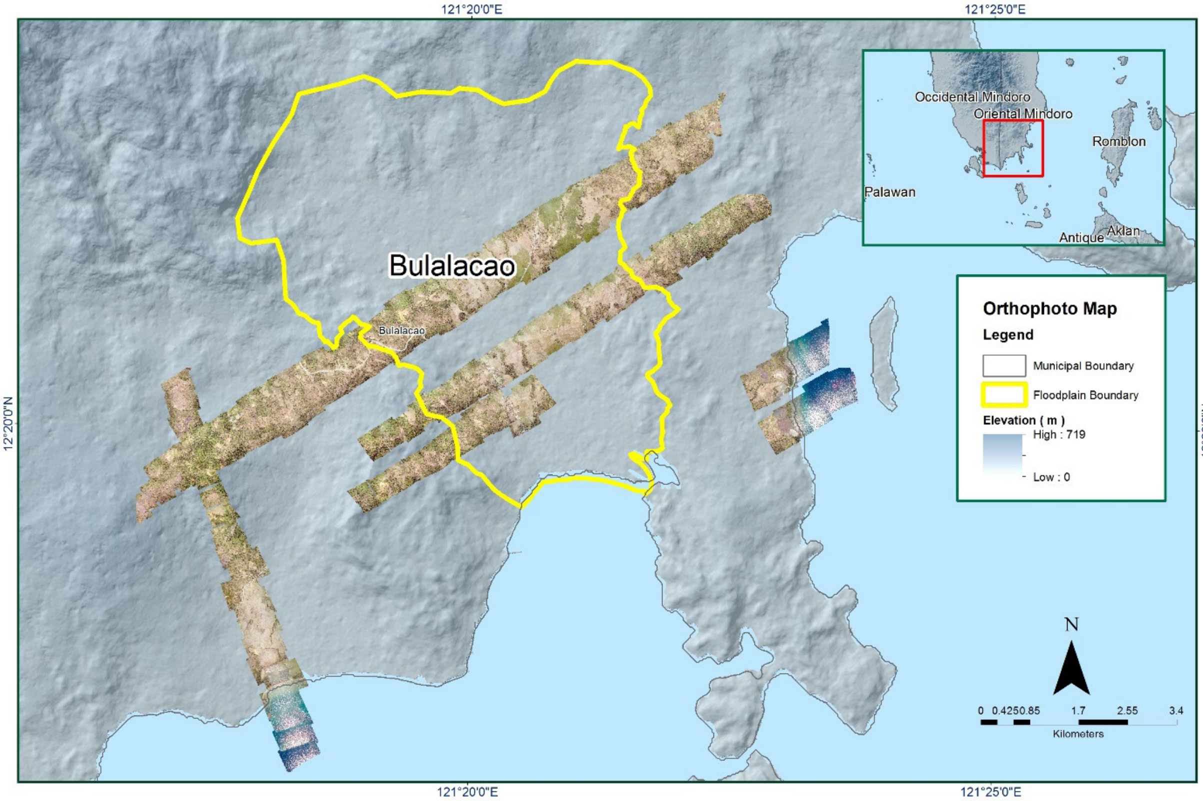



Figure 18. Bulalacao floodplain with available orthophotographs


Figure 19. Sample orthophotograph tiles for Bulalacao Floodplain

## 3.8 DEM Editing and Hydro-Correction

Four (4) mission blocks were processed for Bulalacao flood plain. These blocks are composed of Mindoro and Oriental Mindoro Reflight blocks with a total area of 231.50 square kilometers. Table 14 shows the name and corresponding area of each block in square kilometers.

Table 14. LiDAR blocks with its corresponding area.

| LiDAR Blocks | Area (sq. km) |
|---|---|
| OccidentalMindoro_Blk29N | 87.14 |
| OccidentalMindoro_Blk29N_additional | 4.91 |
| OrientalMindoro_Reflights_Blk28J | 44.55 |
| OrientalMindoro_Reflights_Blk28K | 94.90 |
| TOTAL | 231.50 sq.km |

Portions of DTM before and after manual editing are shown in Figure 20. The bridge (Figure 20a) is considered to be an impedance to the flow of water along the river and has to be removed (Figure 20b) in order to hydrologically correct the river. The paddy field (Figure 20c) has been misclassified and removed during classification process and has to be retrieved to complete the surface (Figure 20d) to allow the correct flow of water. Another example is a surface that has been misclassified due to thick vegetation, such as in this case, a highland. The surface appears to have been interpolated in the DTM after classification (Figure 20e) and has to be retrieved back from secondary DTM during manual editing (Figure 20f).

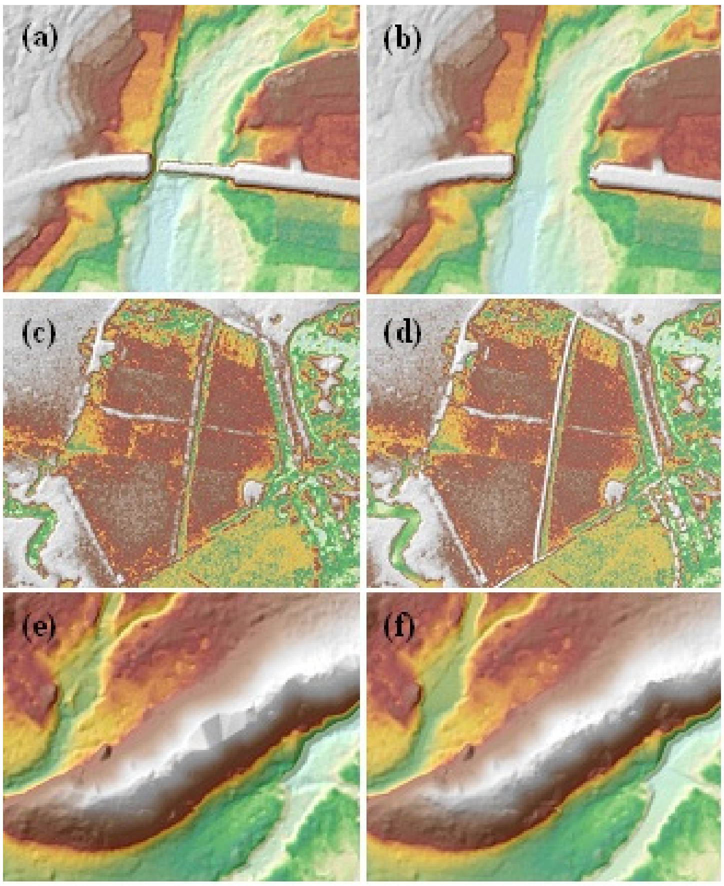



Figure 20. Portions in the DTM of Bulalacao floodplain – a bridge before (a) and after (b) manual editing; a paddy field before (c) and after (d) data retrieval; a highland before (e) and after (f) manual editing.

## 3.9 Mosaicking of Blocks

Mindoro_Blk29N was used as the reference block at the start of mosaicking because it was referred to a base station with an acceptable order of accuracy. Table 15 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Bulalacao floodplain is shown in Figure 21. It can be seen that the entire Bulalacao floodplain is 100% covered by LiDAR data.

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

| Mission Blocks | Shift Values (meters) | | |
|---|---|---|---|
| | x | y | z |
| OccidentalMindoro_Blk29N | 0.00 | 0.00 | 0.00 |
| OccidentalMindoro_Blk29N_additional | 0.00 | 0.00 | 0.00 |
| OrientalMindoro_Reflights_Blk28J | 0.00 | 0.00 | -0.77 |
| OrientalMindoro_Reflights_Blk28K | 0.00 | 0.00 | -0.85 |

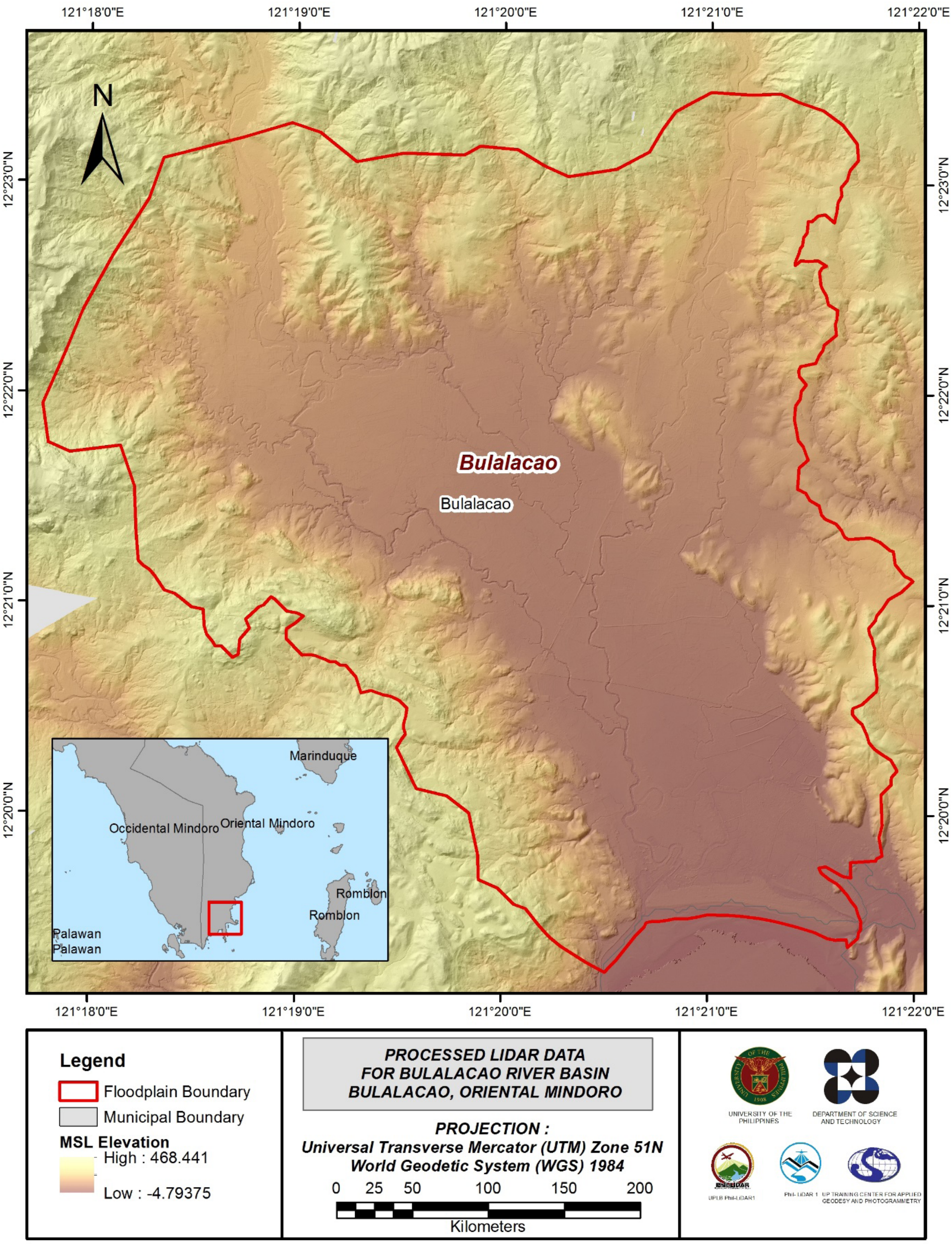



Figure 21. Map of Processed LiDAR Data for Bulalacao Floodplain.

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

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Bulalacao to collect points with which the LiDAR dataset is validated is shown in Figure 22. A total of 1,722 survey points were used for calibration and validation of Bulalacao LiDAR data. Random selection of 80% of the survey points, resulting to 1,377 points, were used for calibration.

A good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values is shown in Figure 23. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration elevation values is 1.54 meters with a standard deviation of 0.20 meters. Calibration of Bulalacao LiDAR data was done by subtracting the height difference value, 1.54 meters, to Bulalacao mosaicked LiDAR data. Table 16 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

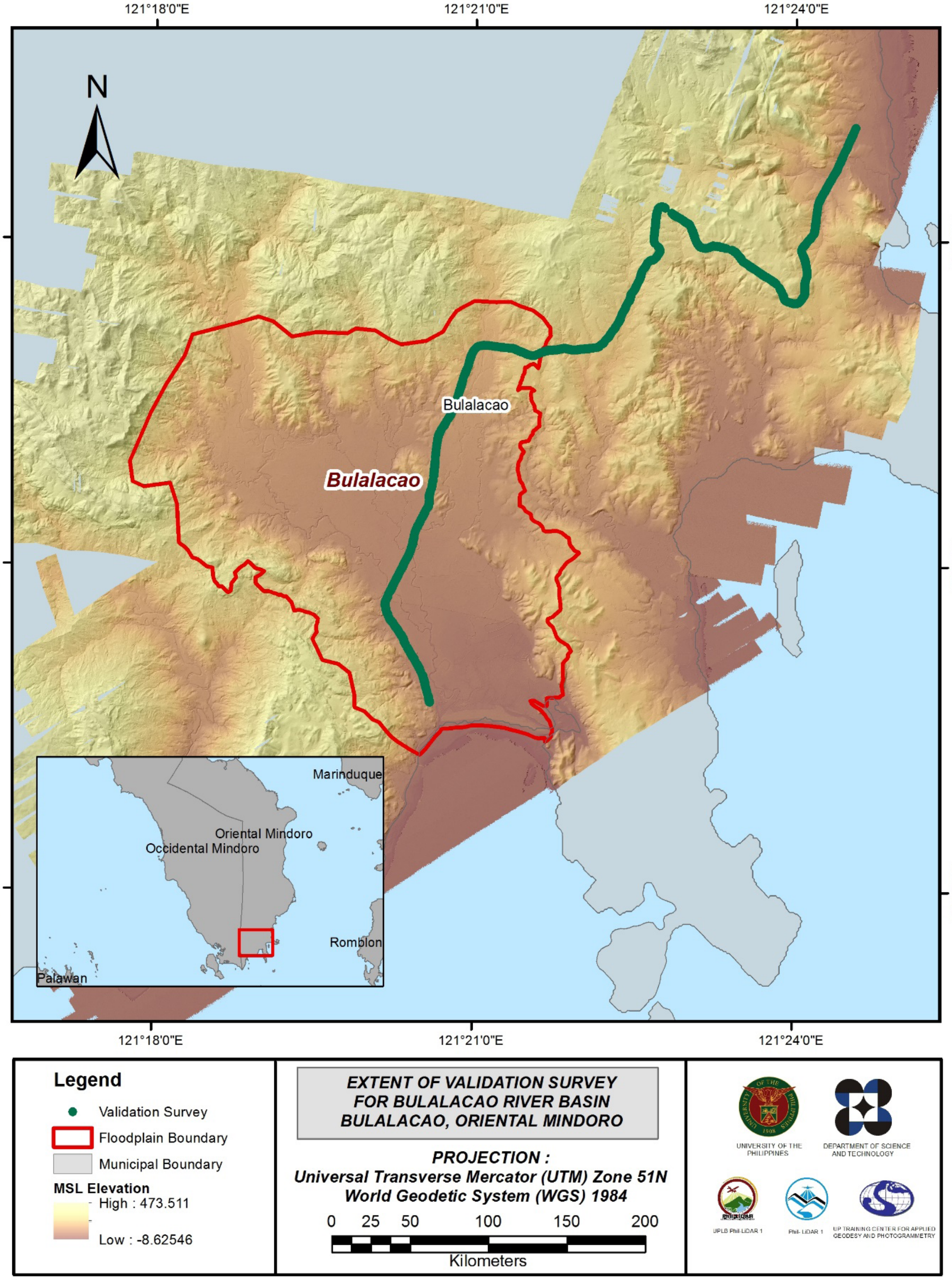



Figure 22. Map of Bulalacao Floodplain with validation survey points in green.

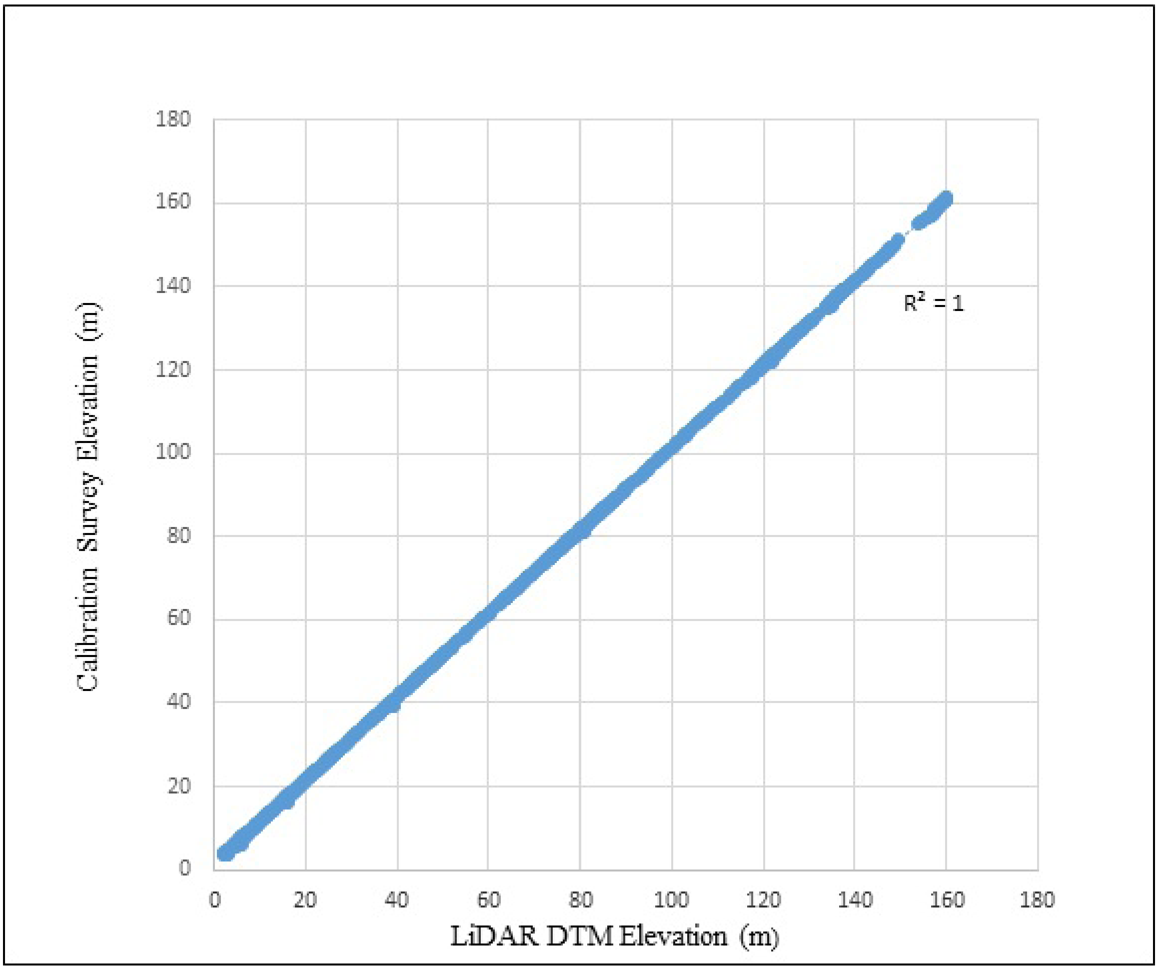



Figure 23. Correlation plot between calibration survey points and LiDAR data.

Table 16. Shift Values of each LiDAR Block of Bulalacao Floodplain.

| Calibration Statistical Measures | Value (meters) |
|---|---|
| Height Difference | 1.54 |
| Standard Deviation | 0.20 |
| Average | -1.53 |
| Minimum | -1.85 |
| Maximum | -0.03 |

The remaining 20% of the total survey points, resulting to 345 points, were used for the validation of calibrated Bulalacao 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 24. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.19 meters with a standard deviation of 0.19 meters, as shown in Table 17.

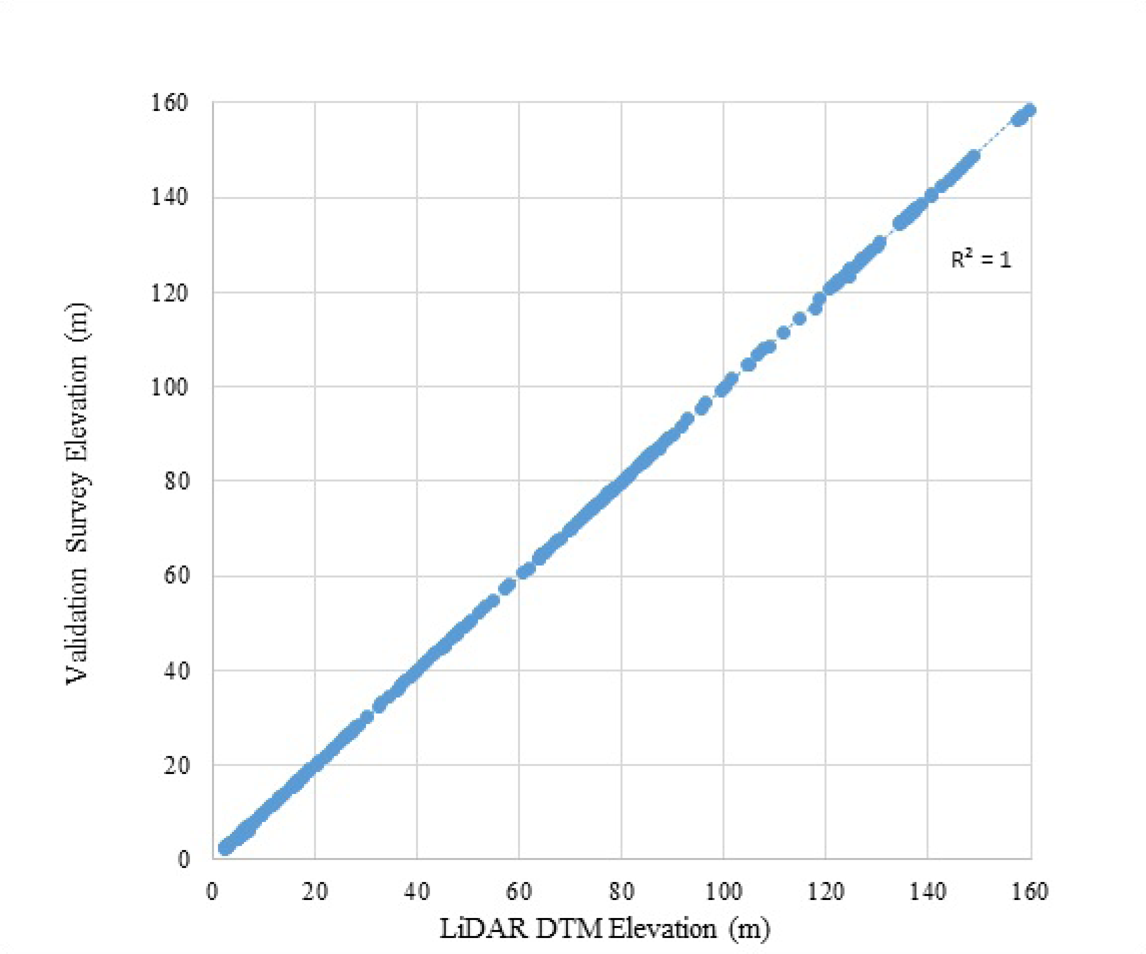



Figure 24. Correlation plot between validation survey points and LiDAR data.

Table 17. Validation Statistical Measures.

| Validation Statistical Measures | Value (meters) |
|---|---|
| RMSE | 0.19 |
| Standard Deviation | 0.19 |
| Average | 0.01 |
| Minimum | -0.23 |
| Maximum | 1.16 |

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

For bathy integration, only centerline data was available for Bulalacao with 1,946 bathymetric survey points. The resulting raster surface produced was done by Inverse Distance Weighted (IDW) interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.38 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Bulalacao integrated with the processed LiDAR DEM is shown in Figure 25.

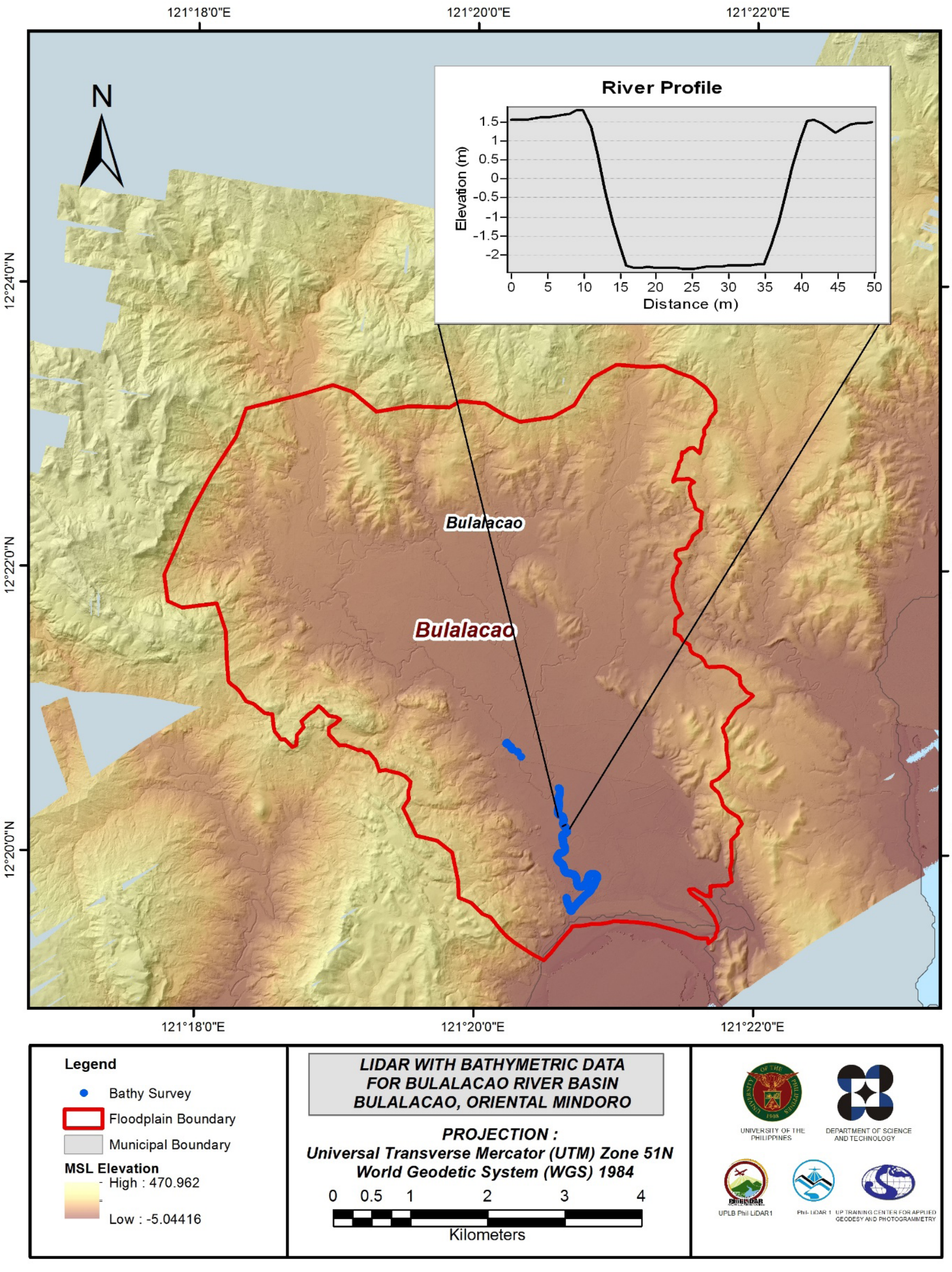



Figure 25. Map of Bulalacao Floodplain with bathymetric survey points shown in blue.

# CHAPTER 4: LIDAR VALIDATION SURVEY AND MEASUREMENTS OF BULALACAO RIVER BASIN

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

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

## 4.1 Summary of Activities

The Data Validation and Bathymetry Component (DVBC) conducted a field survey in Cawacat River starting from October 8 to October 23, 2013 in partnership with the University of The Philippines Los Baños which covered as-built and cross-section surveys in Cawacat Bridge. Another survey was conducted from May 30 to June 11, 2014 for the bathymetry and cross-section of the Cawacat River. Finally, an additional survey was done from October 27 to 31, 2014 for the validation points acquisition survey of Bulalacao River Basin. The bathymetric survey was conducted using an echo sounder to determine the depth of the river while a Trimble® SPS 882 rover GPS gathered the coordinates and elevation values of the survey points. The entire survey extent is illustrated in Figure 26.

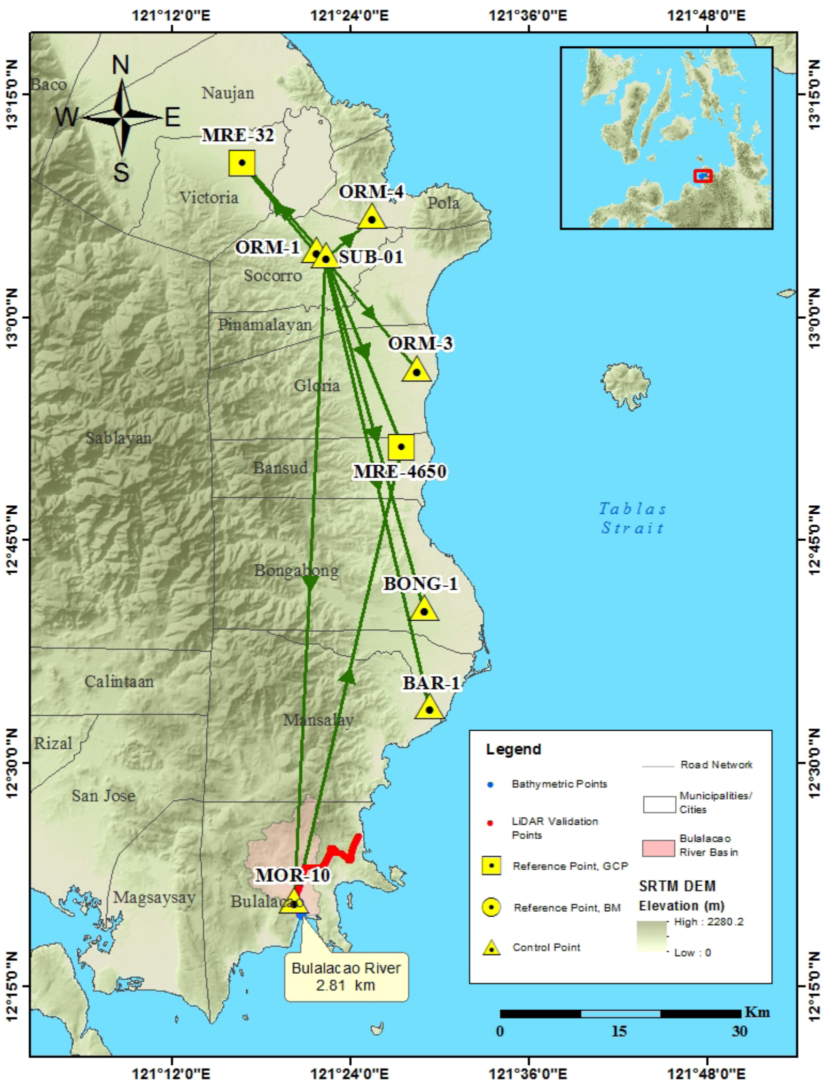



Figure 26. Bulalacao River Survey Extent

## 4.2 Control Survey

A GNSS network was established for previous PHIL-LiDAR fieldwork in Mindoro on February 28 – March 11, 2013 occupying MR-178, a first-order BM located at the approach of Panggalaan Bridge in Brgy. Bucayao, Calapan City, Oriental Mindoro; and MRE-32, a second order GCP in Brgy. Poblacion 1, Mun. of Victoria, Oriental Mindoro.

The GNSS network used for Bulalacao River Basin is composed of two (2) loops and four (4) baselines established on May 30 and May 31, 2014 occupying the reference point MRE-32, a second-order GCP fixed from the previous field survey in Mindoro Oriental for Mag Asawang Tubig river.

Seven (7) control points were established namely: BAR-1 located at the approach of Baroc Bridge in Brgy. San Isidro, Municipality of Mansalay; BONG-01 located near Bongabong Bridge in Brgy. San Isidro, Municipality of Luna; MOR-10, located at the approach of Cawacat Bridge in Brgy. Campaasan, Municipality of Bulalacao; ORM-1, located in Subaan Bridge in Barangay Subaan, Municipality of Socorro; ORM-3 located in Balete bridge in Brgy. Balete, Municipality of Gloria; ORM-4 in Pola Bridge, Brgy. Casiligan, Municipality of Pola; and SUB-01, located within the Maramot Residence in Brgy. Subaan, Municipality of Socorro. An LMS-established control point namely MRE-4650, located at Bansud Bridge, Brgy. Pagasa, Municipality of Bansud, Oriental Mindoro was also occupied to use as marker in the survey.

The summary of references and control points and its location is summarized in Table 18 while the GNSS network established is illustrated in Figure 27.

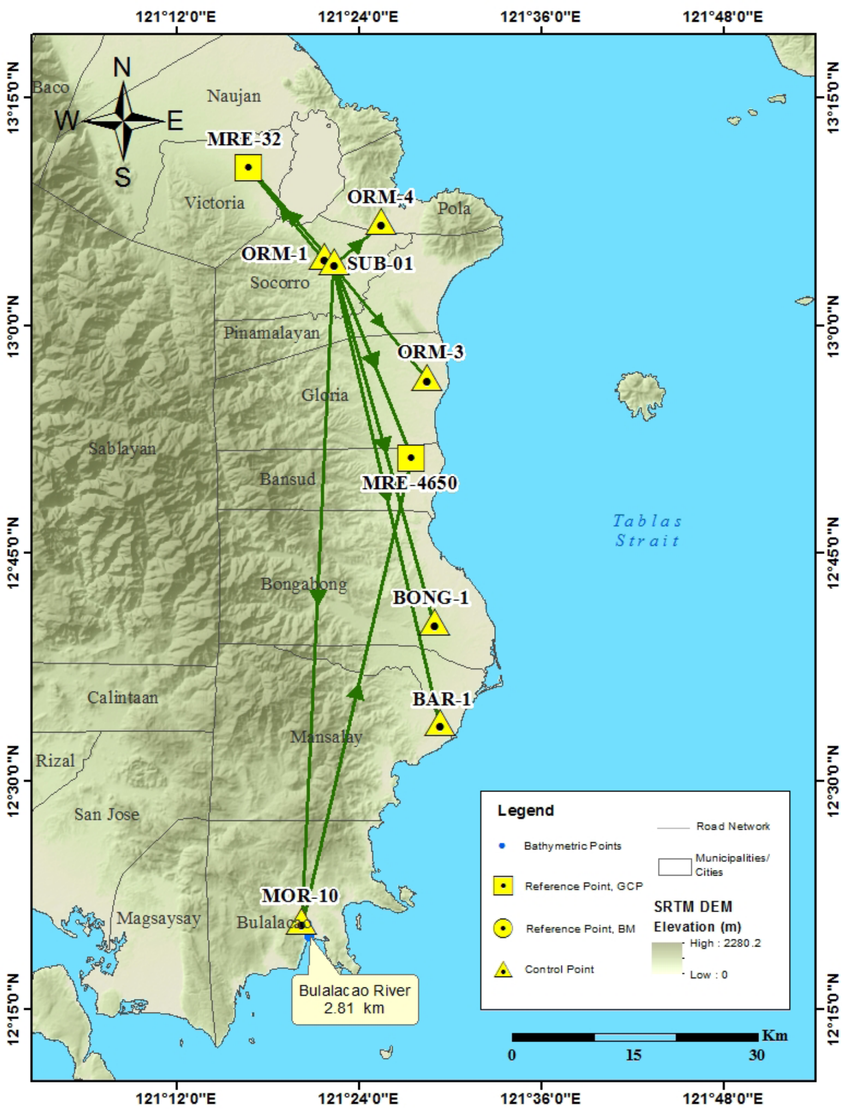



Figure 27. GNSS Network covering Bulalacao River

Table 18. List of reference and control points used during the survey in Bulalacao River (Source: NAMRIA, UP-TCAGP)

| Control Point | Order of Accuracy | Geographic Coordinates (WGS 84) | | | | |
|---|---|---|---|---|---|---|
| | | Latitude | Longitude | Ellipsoidal Height (Meter) | Elevation in MSL (Meter) | Date Established |
| MRE-32 | 2nd order, GCP | 13°10'23.79251" | 121°16'43.46244" | 65.638 | 17.175 | 2007 |
| MRE-4650 | Used as marker | - | - | - | - | 2011 |
| BAR-1 | UP Established | - | - | - | - | June 7, 2015 |
| BONG-01 | UP Established | - | - | - | - | 6-1-2014 |
| MOR-10 | UP Established | - | - | - | - | 6-1-2014 |
| ORM-1 | UP Established | - | - | - | - | 5-31-2014 |
| ORM-3 | UP Established | - | - | - | - | 5-30-2014 |
| ORM-4 | UP Established | - | - | - | - | 5-31-2014 |
| SUB-01 | UP Established | - | - | - | - | 5-31-2014 |

The GNSS set ups made in the location of the reference and control points are exhibited in Figure 28 to Figure 32.


Figure 28. GPS setup of Trimble® SPS 882 at MRE-32, located at the Municipal Park of Victoria, in Brgy. Poblacion 1, Oriental Mindoro

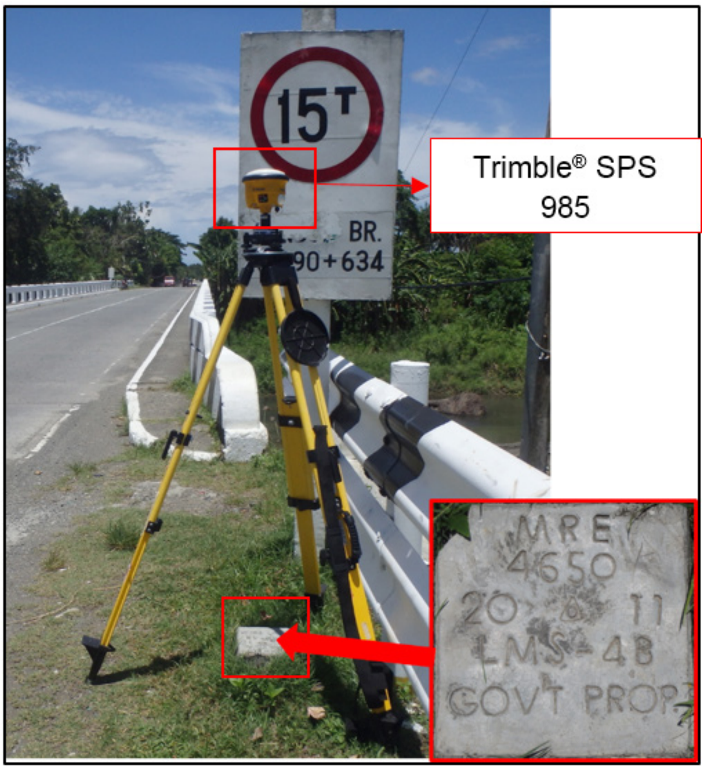



Figure 29. The GPS setup of Trimble® SPS 985 at MRE-4650, an LMS control point located at the approach of Bansud Bridge, in Brgy. Pagasa, Municipality of Bansud, Oriental Mindoro


Figure 30. GNSS setup of Trimble® SPS 882 on BONG-01 in Brgy. San Isidro, Municipality of Bongabong, Oriental Mindoro

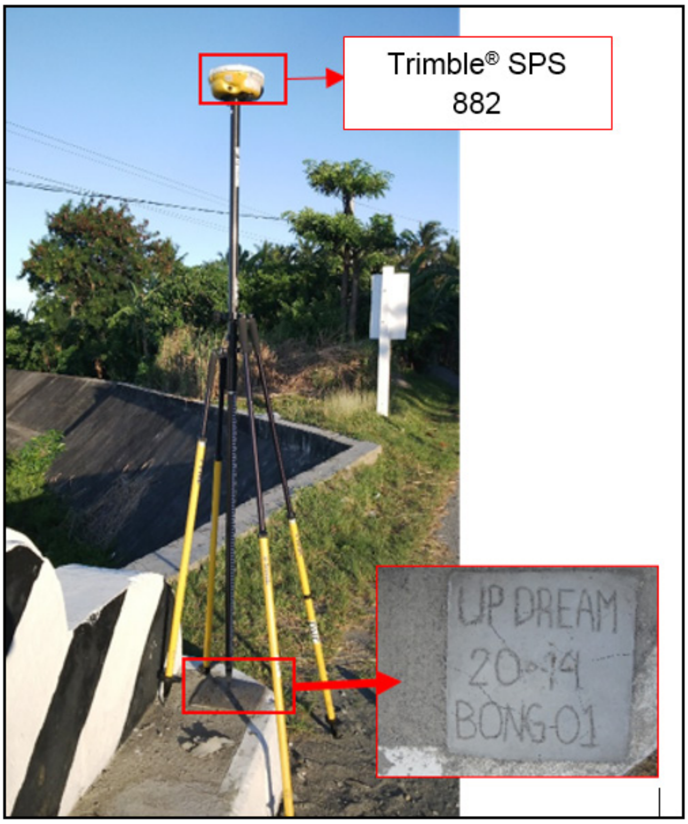



Figure 31. GNSS setup of Trimble® SPS 882 on BONG-01 in Brgy. San Isidro, Municipality of Bongabong, Oriental Mindoro


Figure 32. GPS setup of Trimble® SPS 852 at MOR-10, located in the approach of the Cawacat Bridge, in Bry. Campasaan, Municipality of Bulalacao, Oriental Mindoro


Figure 33. GPS setup of Trimble® SPS 852 at ORM-1, located on Subaan Bridge, Brgy. Subaan, Municipality of Socorro, Oriental Mindoro

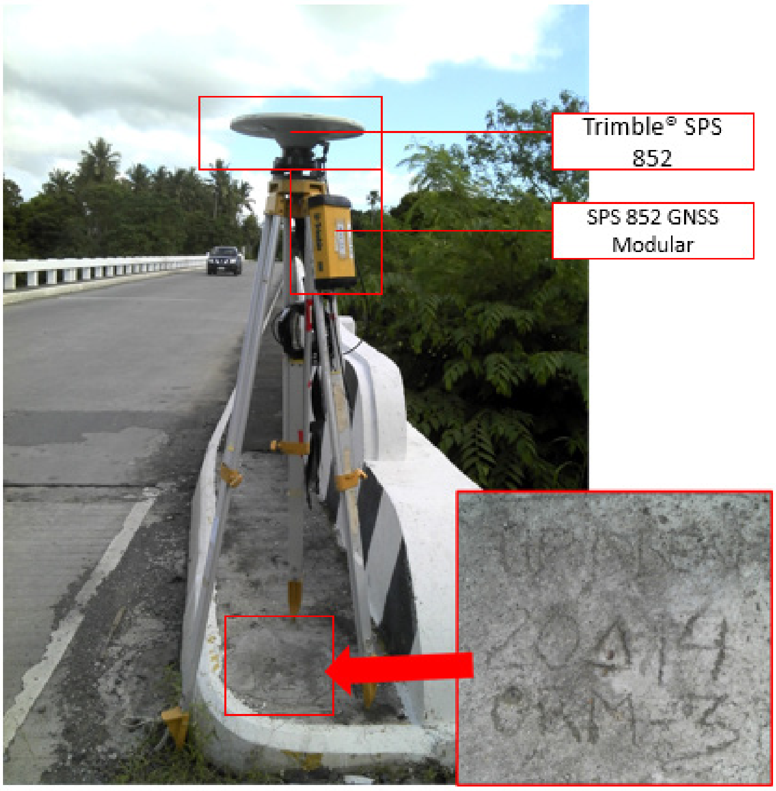



Figure 34. Trimble® SPS 985 setup at ORM-3 located at the approach of Balete Bridge, Brgy. Balete, Municipality of Gloria, Oriental Mindoro

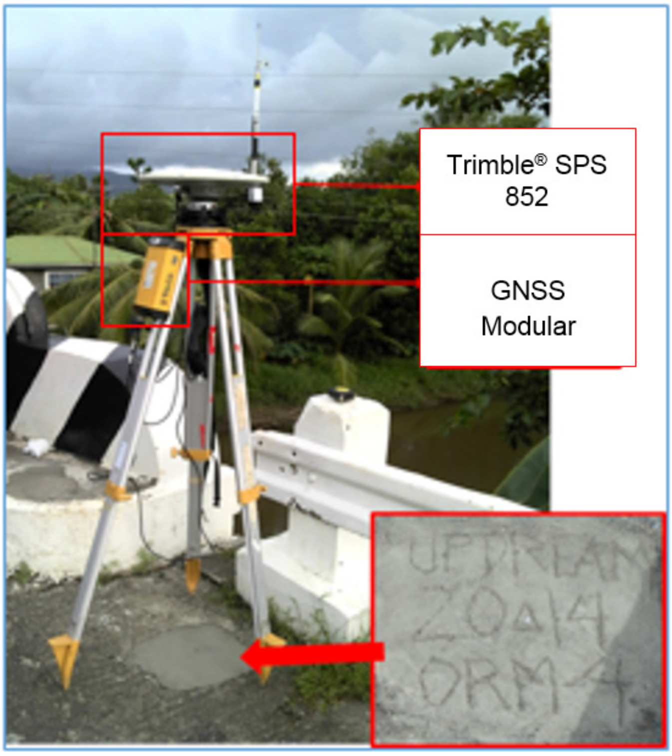



Figure 35. GNSS receiver Trimble® SPS 852 setup at ORM-4, located at the right side of the approach of Pola Bridge in Barangay Casiligan, Municipality of Pola, Oriental Mindoro

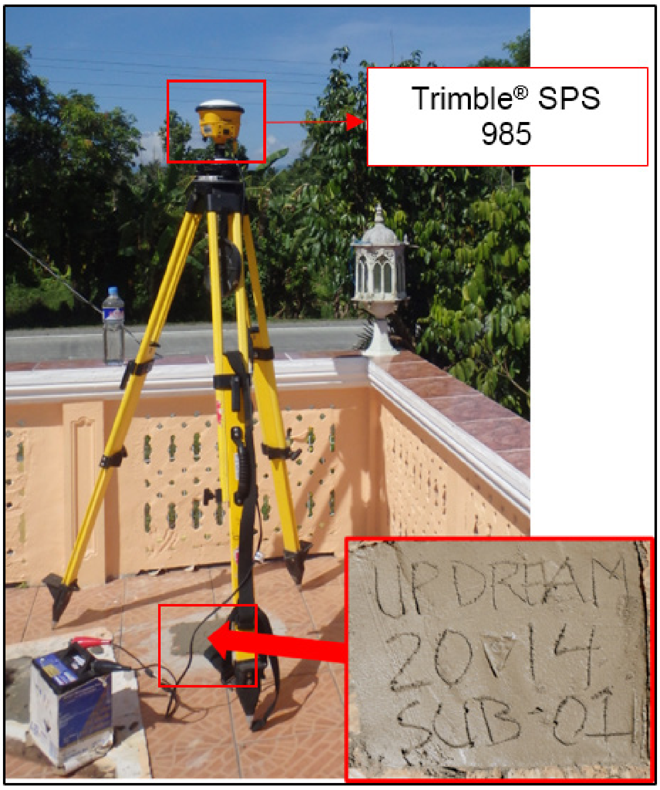



Figure 36. GPS setup of Trimble® SPS 985 at SUB-1, an established control point located at Maramot Residence in Brgy. Subaan, Municipality of Socorro, Oriental Mindoro

## 4.3 Baseline Processing

GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/-20cm and +/-10cm 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 Baroc River Basin is summarized in Table 19 generated by TBC software.

Table 19. Baseline Processing Report for Bulalacao River Static Survey (Source: NAMRIA, UP-TCAGP)

| Observation | Date of Observation | Solution Type | H. Prec. (Meter) | V. Prec. (Meter) | Geodetic Az. | Ellipsoid Dist. (Meter) | ΔHeight (Meter) |
|---|---|---|---|---|---|---|---|
| ORM-1 --- SUB-01 | 05-30-2014 | Fixed | 0.004 | 0.006 | 301°40’27” | 1466.251 | 4.823 |
| SUB-01 --- MRE-32 | 05-30-2014 | Fixed | 0.010 | 0.031 | 318°11’52” | 15342.18 | -9.283 |
| SUB-01 --- MOR-10 | 05-31-2014 | Fixed | 0.014 | 0.044 | 182°47’52” | 80162.62 | -16.502 |
| SUB-01 --- MRE-4650 | 05-31-2014 | Fixed | 0.006 | 0.038 | 158°49’08” | 25506.78 | -9.971 |
| SUB-01 --- ORM-3 | 5-31-2014 | Fixed | 0.007 | 0.028 | 141°48’05” | 17755.532 | -12.886 |
| SUB-01 --- ORM-4 | 6-1-2014 | Fixed | 0.003 | 0.022 | 48°43’17” | 7475.934 | -19.149 |
| SUB-01 --- BAR-1 | 6-1-2014 | Fixed | 0.024 | 0.107 | 167°15’17” | 57308.832 | -16.370 |
| SUB-01 --- BONG-01 | 6-1-2014 | Fixed | 0.021 | 0.035 | 164°45’51” | 45313.95 | 0.212 |
| ORM-1 --- MRE 32 | 05-30-2014 | Fixed | 0.010 | 0.032 | 319°54’33” | 13942.72 | -14.146 |
| MOR-10 --- MRE 4650 | 05-31-2014 | Fixed | 0.012 | 0.051 | 13°07’21” | 57794.34 | 6.484 |

As shown in Table 19, a total of ten (10) baselines were processed and all of them passed the required accuracy set by the project.

## 4.4 Network Adjustment

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

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

Where:

Xe is the Easting Error,
Ye is the Northing Error, and
Ze is the Elevation Error

for each control point. See the Network Adjustment Report shown in Table 20 to Table 22 for complete details.

The five (5) control points, MRE-32, ORM-1, MOR-10, MRE-4650 and SUB-01 were occupied and observed simultaneously to form a GNSS loop. Coordinates and elevation values of MRE-32 were held fixed during the processing of the control points as presented in Table 20. Through these reference points, the coordinates and elevation of the unknown control points were computed.

Table 20. Control Point Constraints

| Point ID | Type | East σ (Meter) | North σ (Meter) | Height σ (Meter) | Elevation σ (Meter) |
|---|---|---|---|---|---|
| MRE-32 | Grid | Fixed | Fixed | Fixed | Fixed |
| Fixed = 0.000001(Meter) | | | | | |

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 21. All fixed control points have no values for grid and elevation errors.

Table 21. Adjusted Grid Coordinates

| Point ID | Easting | Easting Error (Meter) | Northing (Meter) | Northing Error (Meter) | Elevation (Meter) | Elevation Error (Meter) | Constraint |
|---|---|---|---|---|---|---|---|
| MOR-10 | 319188.891 | 0.010 | 1365393.240 | 0.010 | 6.868 | 0.052 | |
| MRE-32 | 313449.201 | ? | 1456936.499 | ? | 17.175 | ? | ENe |
| MRE-4650 | 332665.789 | 0.008 | 1421592.819 | 0.006 | 14.627 | 0.049 | |
| ORM-1 | 322358.982 | 0.007 | 1421592.819 | 0.003 | 30.565 | 0.028 | |
| SUB-01 | 323601.847 | 0.007 | 1445433.872 | 0.003 | 25.687 | 0.028 | |

The network is fixed at reference points. The list of adjusted grid coordinates of the network is shown in Table 22. Using the equation $\sqrt{((x_e)^2 + (y_e)^2)} < 20cm$ for horizontal and $z_e < 10\ cm$ for the vertical; below is the computation for accuracy that passed the required precision:

a. **MRE-32**

Horizontal accuracy = Fixed
Vertical accuracy = Fixed

b. **MOR-10**

Horizontal accuracy = $\sqrt{((1.0)^2 + (1.0)^2}$
= $\sqrt{(1.0 + 1.0)}$
= 1.1 cm < 20 cm
Vertical accuracy = 1.4 cm< 10 cm

c. **MRE-4650**

Horizontal accuracy = $\sqrt{((0.8)^2 + (0.6)^2}$
= $\sqrt{(0.64 + 0.36)}$
= 1.0 cm < 20 cm
Vertical accuracy = 4.9 cm < 10 cm

d. **ORM-1**

Horizontal accuracy = $\sqrt{((0.7)^2 + (0.3)^2}$
= $\sqrt{(0.49 + 0.90)}$
= 1.2 cm < 20 cm
Vertical accuracy = 2.8 cm < 10 cm

e. **SUB-01**

Horizontal accuracy = $\sqrt{((0.7)^2 + (0.3)^2}$
= $\sqrt{(0.49 + 0.90)}$
= 1.2 cm < 20 cm
Vertical accuracy = 2.8 cm < 10 cm

Following the given formula, the horizontal and vertical accuracy result of the five (5) occupied control points are within the required accuracy of the project.

Table 22. Adjusted Geodetic Coordinates

| Point ID | Latitude | Longitude | Ellipsoidal Height (Meter) | Height Error (Meter) | Constraint |
|---|---|---|---|---|---|
| MOR-10 | N12°20’46.18547” | E121°20’13.54772” | 58.186 | 0.052 | |
| MRE-32 | N13°10’23.79251” | E121°16'43.46244" | 65.368 | ? | ENe |
| MRE-4650 | N12°51’17.70515” | E121°27’28.71020” | 64.693 | 0.049 | |
| ORM-1 | N13°04’36.74731” | E121°21’41.63863” | 79.500 | 0.028 | |
| SUB-01 | N13°04’11.69491” | E121°22’23.06063” | 74.676 | 0.028 | |

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 22. Based on the result of the computation, the accuracy condition is satisfied; hence, the required accuracy for the program was met.

The summary of reference and control points used is indicated in Table 23.

Table 23. Reference and control points 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 | Easting | Elevation in MSL (m) |
| MRE-32 | 2nd order, GCP | 13°10'23.79251" | 121°16'43.46244" | 65.368 | 1456936.499 | 313449.201 | 17.175 |
| MRE-4650 | Used as Marker | 12°51'17.70515" | 121°27'28.71020" | 64.693 | 1421592.819 | 332665.789 | 14.627 |
| BAR-1 | UP Established | 12°33'52.65149" | 121°29'21.90040" | 58.344 | 1389460.775 | 335892.131 | 6.953 |
| BONG-01 | UP Established | 12°40'28.89755" | 121°28'57.71173" | 74.917 | 1401640.553 | 335232.485 | 23.974 |
| MOR-10 | UP Established | 12°20'46.18547" | 121°20'13.54772" | 58.186 | 1365393.24 | 319188.891 | 6.868 |
| ORM-1 | UP Established | 13°04'36.74731" | 121°21'41.63863" | 79.5 | 1446211.774 | 322358.982 | 30.565 |
| ORM-3 | UP Established | 12°56'37.56304" | 121°28'27.33712" | 61.799 | 1431410.893 | 334491.821 | 12.031 |
| ORM-4 | UP Established | 13°06'52.16736" | 121°25'29.58456" | 55.523 | 1450329.531 | 329251.554 | 6.585 |
| SUB-01 | UP Established | 13°04'11.69491" | 121°22'23.06063" | 74.676 | 1445433.872 | 323601.847 | 25.687 |

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

Cross-section and as-built survey was done on October 10, 2013 at the downstream side of Cawacat Bridge using a GNSS receiver Trimble® SPS 882 in PPK survey technique. Bridge as-built features determination was also performed to get the distance of piers and abutments from the bridge approach as shown on Figure 37. The bridge deck was measured to get the high chord, and meter tapes to get its low chord elevation.


Figure 37. (a) View of Cawacat Bridge from the approach and (b) as-built and cross section survey of Cawacat Bridge

The cross-sectional line for the Cawacat Bridge is about 206.68 m with 30 cross-sectional points gathered using MOR-10 as the GNSS base station. Figure 38 to Figure 40 show the location map, cross-sectional diagram, and as-built bridge data form for Cawacat Bridge.

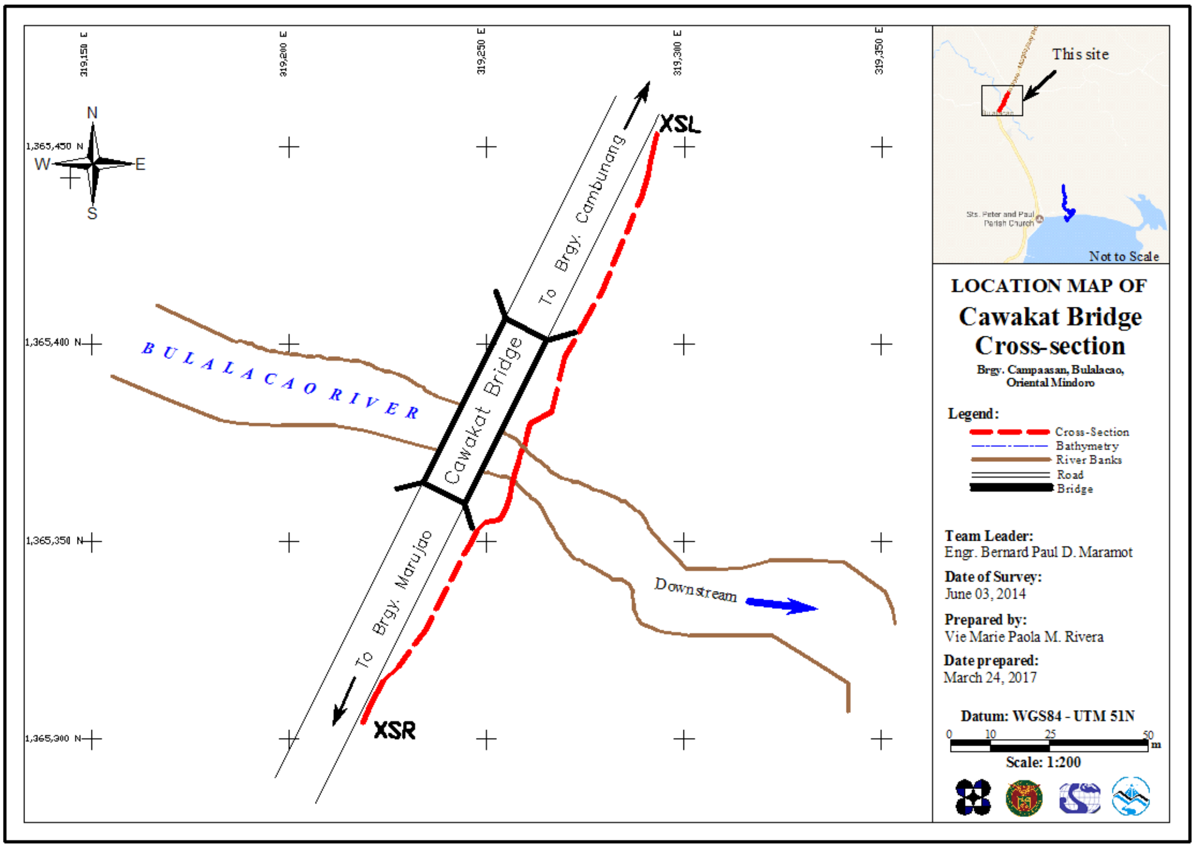



Figure 38. Location Map of Cawakat Bridge River Cross-Section survey

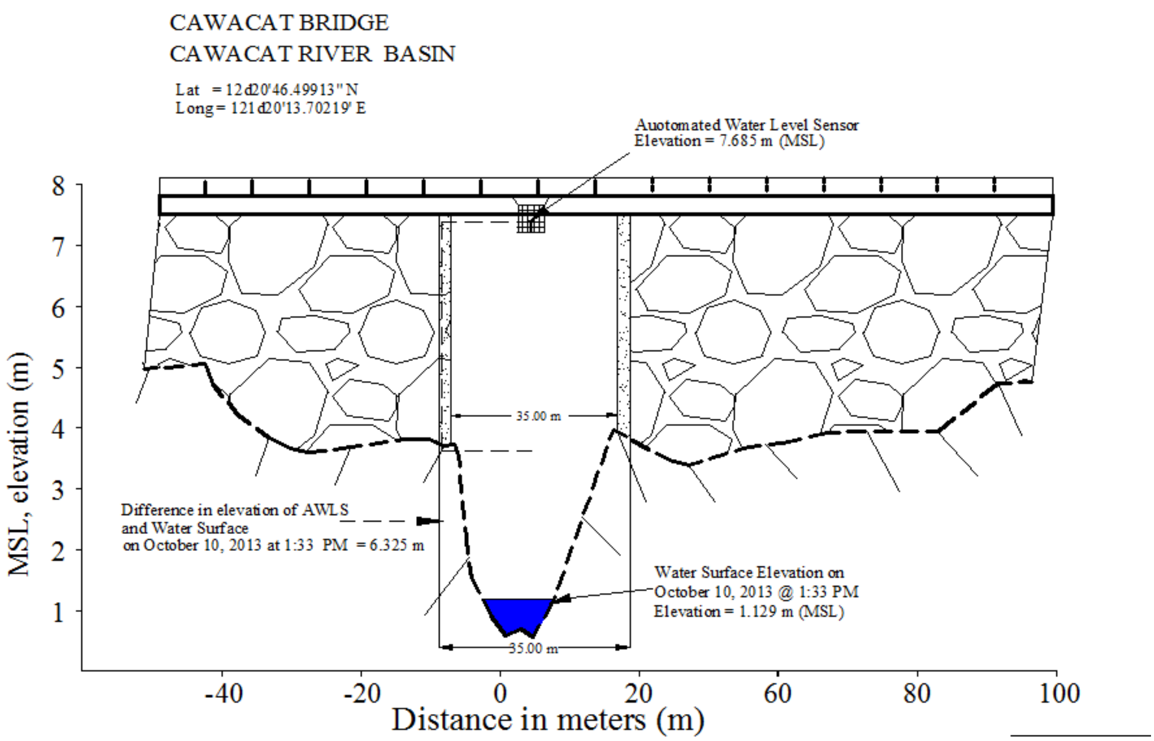



Figure 39. Cawacat Bridge cross-section diagram

**Bridge Data Form**

Bridge Name: CAWACAT BRIDGE Date: October 29, 2014

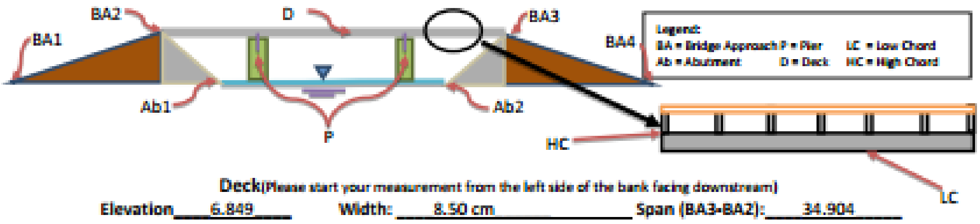
River Name: BULALACAO RIVER Time: 2:55 pm

Location (Brgy, City,Region): Brgy. Cawacat, Municipality of Bulalacao, Oriental Mindoro,

Survey Team: Team Bernard

Flow condition: low normal high Weather Condition: fair rainy

Latitude: 12d20'46.18699"N Longitude: 121d20'13.54758"E




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

Elevation 6.849 Width: 8.50 cm Span (BA3-BA2): 34.904

| | Station | High Chord Elevation | Low Chord Elevation |
|---|---|---|---|
| 1 | | 6.825 m | 5.360 m |
| 2 | | | |
| 3 | | | |
| 4 | | | |

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

| | Station(Distance from BA1) | Elevation | | Station(Distance from BA1) | Elevation |
|---|---|---|---|---|---|
| BA1 | 0 | 4.941 m | BA3 | 118.852 | 6.811 m |
| BA2 | 83.949 | 6.779 m | BA4 | 179.875 | 5.670 m |

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

| | Station(Distance from BA1) | Elevation |
|---|---|---|
| Ab1 | 92.248 | 3.488 m |
| Ab2 | 109.860 | 1.079 m |

**Pier** (Please start your measurement from the left side of the bankfacing downstream)

Shape: CYLINDRICAL Number of Piers: 3 Height of column footing: ________

| | Station (Distance from BA1) | Elevation | Pier Width |
|---|---|---|---|
| Pier 1 | 86.23186426 | 6.803 m | |
| Pier 2 | 100.7108607 | 6.794 m | |
| Pier 3 | 111.218161 | 6.770 m | |
| Pier 4 | | | |
| Pier 5 | | | |
| Pier 6 | | | |
| Pier 7 | | | |

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

Figure 40. Bridge as-built form of Cawacat Bridge

Water surface elevation of Cawacat River was determined using Trimble® SPS 882 in PPK mode technique on October 10, 2013 at 1:33 PM along the banks of Cawacat Bridge. The water surface elevation was translated onto marking the bridge's pier using a Digital Level. The right side of the pier was marked using red and white paints, as shown in Figure 41. The marked pier shall serve as reference for flow data gathering and depth gauge deployment by the accompanying HEI, UPLB, who is responsible for Cawacat River as shown in Figure 42.

Figure 41. Water Level marking at the right pier of Cawacat Bridge


Figure 42. Finished markings

## 4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on October 31, 2014 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted on a pole which was attached in front of the vehicle (Figure 43). It was secured with a cable tie to ensure that it is horizontally and vertically balanced. The antenna height of 1.498 m was measured from the ground up to the bottom of the notch of the GNSS Rover receiver. The activity started from Brgy. San Roque to Brgy. Poblacion in the Municipality of Bulalacao.


Figure 43. Validation points acquisition survey setup for Cawacat River Basin


Figure 44. Validation point acquisition survey of Bulalacao River Basin

## 4.7 Bathymetric Survey

Bathymetric survey of Cawacat River was conducted on June 3, 2014 starting from the upstream Brgy. Campasaan down to the mouth of the river in Brgy. Campasaan. The bathymetric survey utilized a GNSS Rover receiver, Trimble® SPS 882 in PPK survey technique mounted on top of a pole with Ohmex™ Single Beam Echo Sounder. The control point MOR-10 was used as the base station. The setup of instruments is shown in Figure 45 and Figure 46 shows the coverage of the bathymetric survey.

A total of 1,901 bathymetric points were acquired with an approximate length of 2.81 km as illustrated in the map in Figure 46.

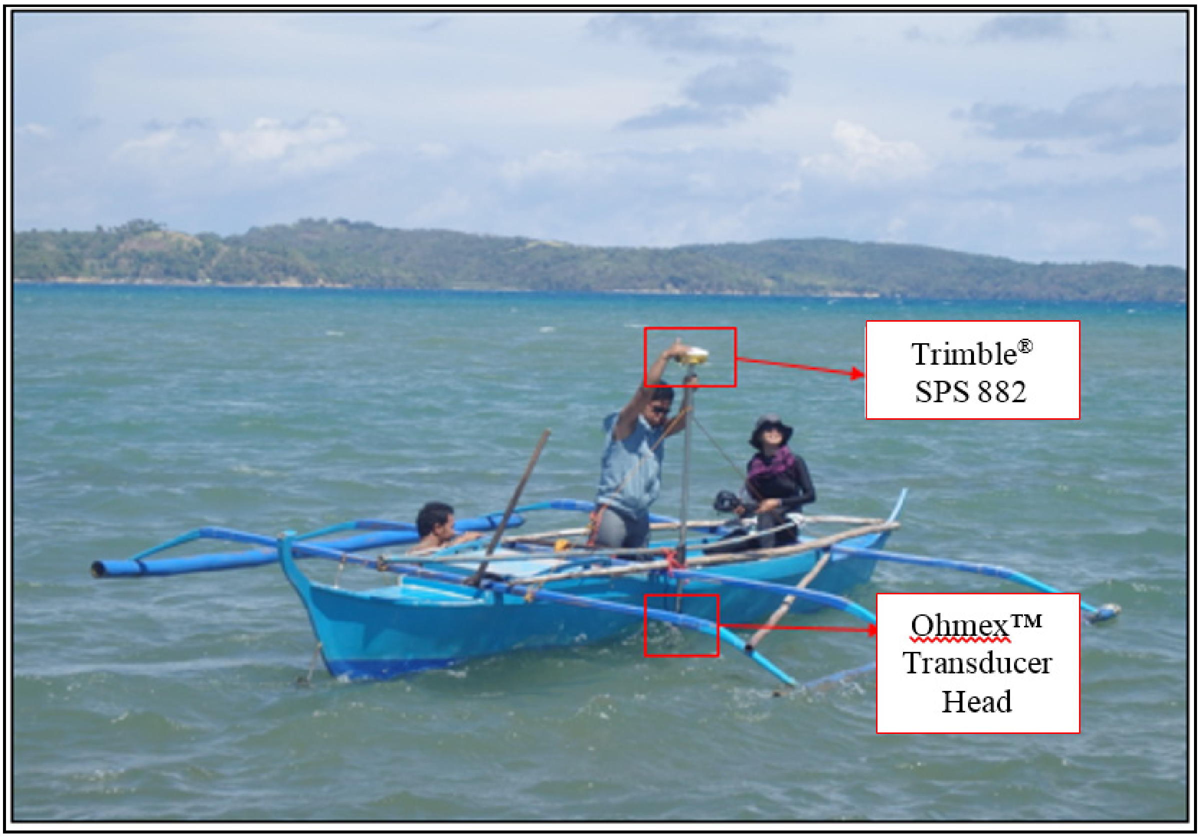



Figure 45. Bathymetric survey conducted in Bulalacao River using Trimble SPS 882 and Ohmex Transducer Head

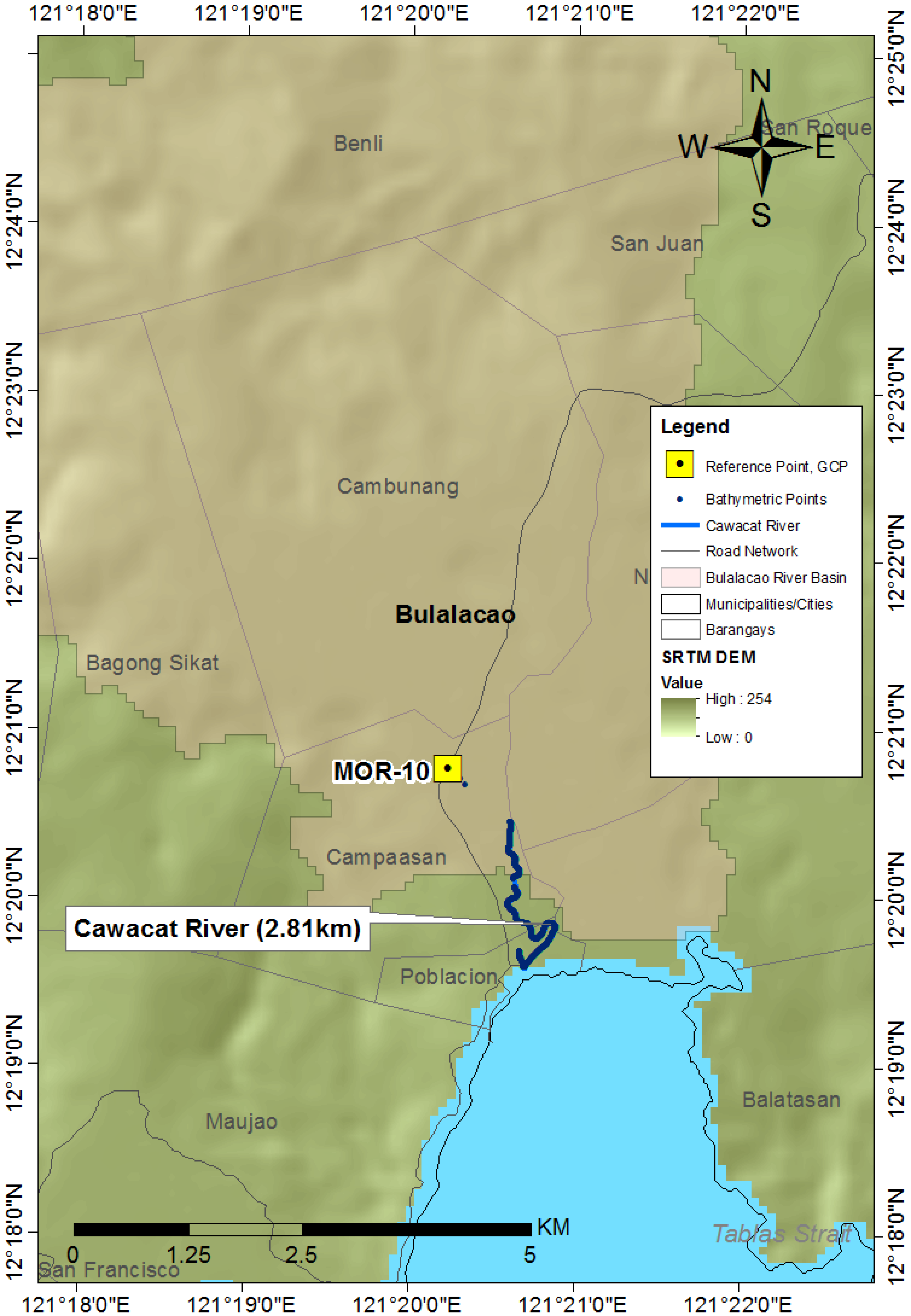



Figure 46. Bathymetric survey of Bulalacao River

A CAD drawing was also produced to illustrate the Bulalacao (also known as Cawacat) riverbed profile from Brgy. Campasaan down to Brgy. Poblacion, as shown in Figure 47. An elevation drop of 1.8 m with respect to MSL was observed within the approximated distance of 2.8 km.

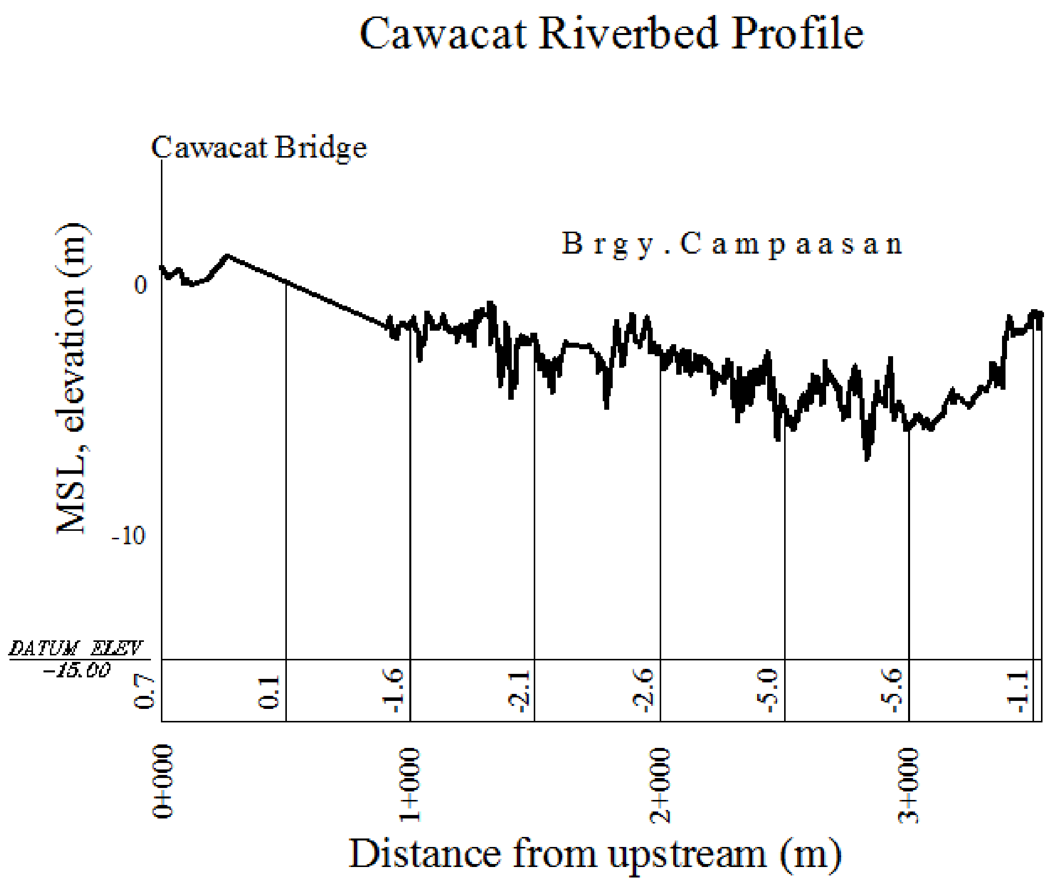



Figure 47. Bulalacao (also known as Cawacat) Riverbed Profile

# CHAPTER 5: FLOOD MODELING AND MAPPING

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

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

## 5.1 Data used in Hydrologic Modeling

### 5.1.1 Hydrometry and Rating Curves

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

### 5.1.2 Precipitation

Precipitation data was taken from the rain gauge station installed in Brgy. Nasucob, Bulalacao, Oriental Mindoro (12.335817° N, 121.35000° E). The location of the rain gauge is seen in Figure 48.

The total precipitation for this event in Nasucob ARG was 34.2mm. It has a peak rainfall of 7.2 mm on

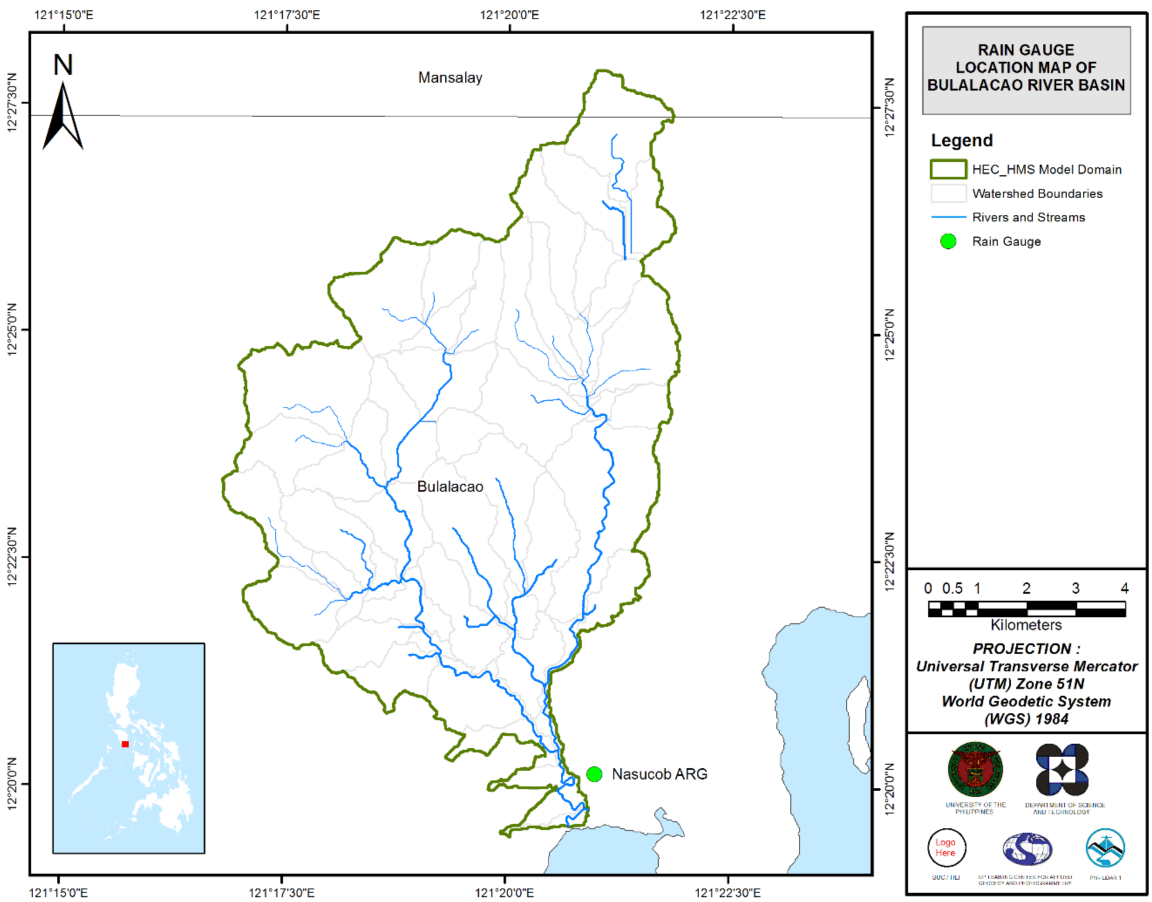



Figure 48. The location map of Bulalacao HEC-HMS model used for calibration

### 5.1.3 Rating Curve and River Outflow

A rating curve was developed at Cawacat Bridge, Bulalacao, Oriental Mindoro (12.346350° N, 121.337133° E). It gives the relationship between the observed water levels from the Cawacat Bridge and outflow of the watershed at this location using Bankfull Method in Manning's Equation.

For Cawacat Bridge, the rating curve is expressed as Q = 0.0418e2.0469x as shown in Figure 50.

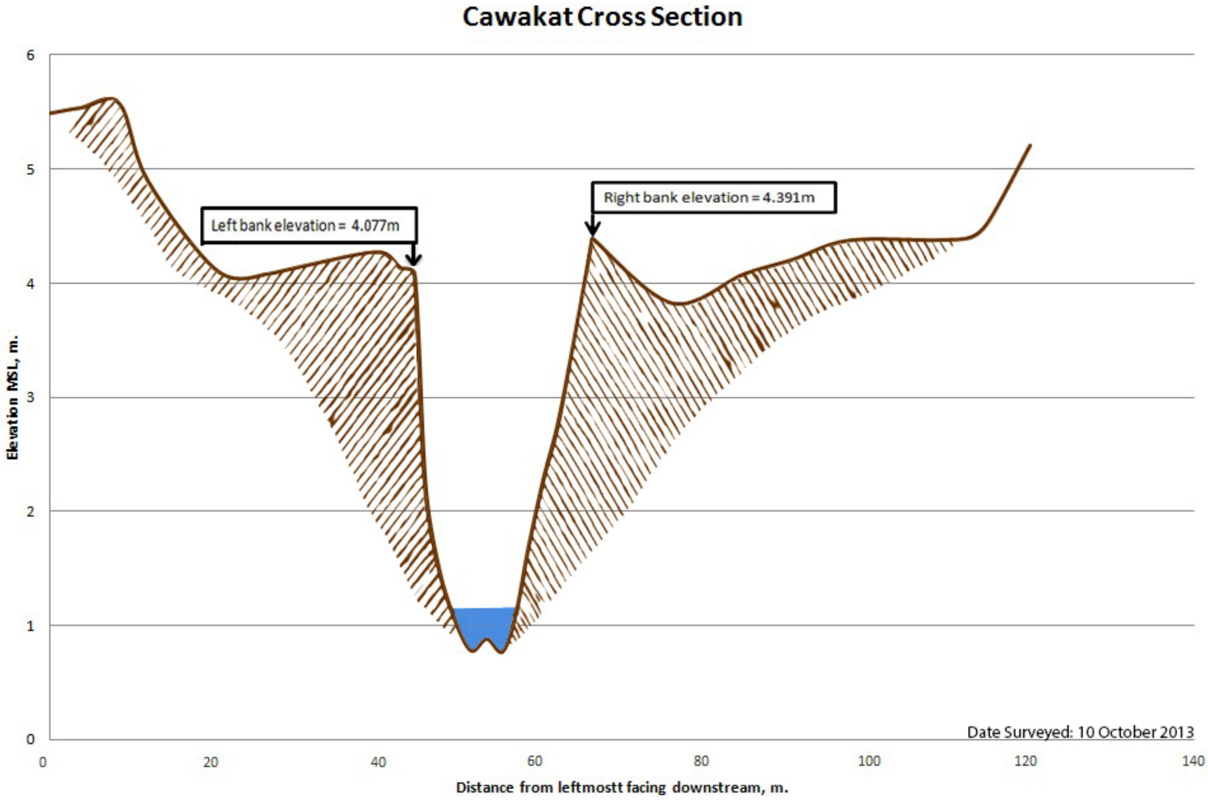



Figure 49. Cross-Section Plot of Bulalacao Bridge

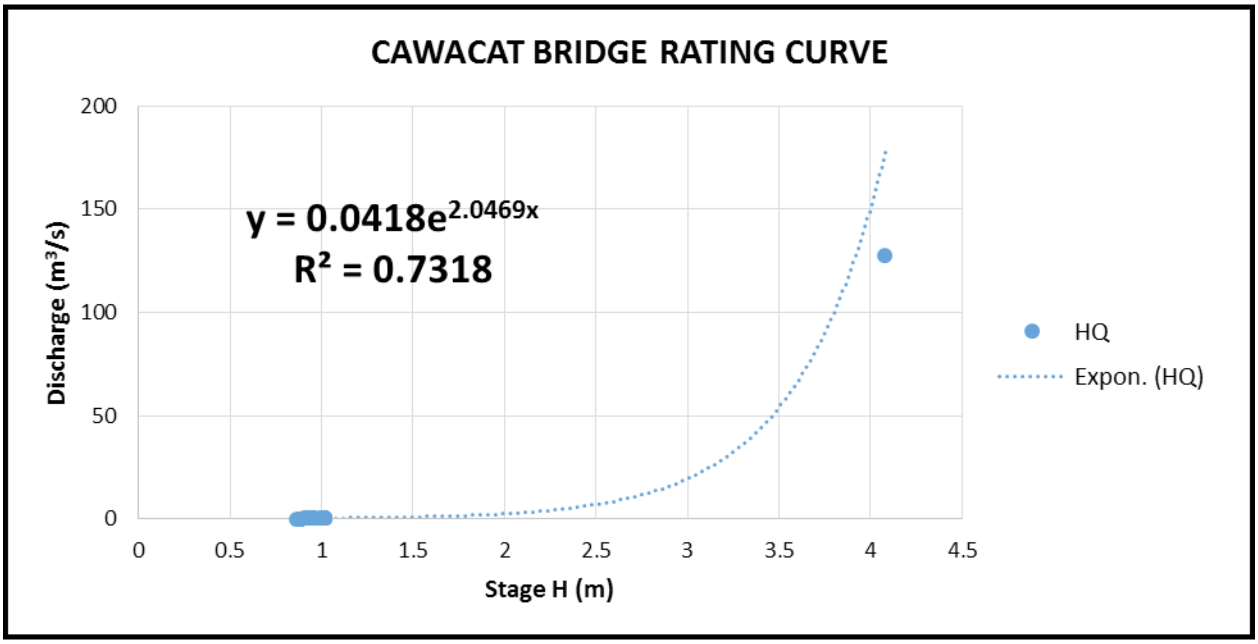



Figure 50. Rating curve at Cawacat Bridge, Bulalacao, Oriental Mindoro

For the calibration of the HEC-HMS model, shown in Figure 51, actual flow discharge during a rainfall event was collected in the Cawacat bridge. Peak discharge is 31.42 cu.m/s at 1100H, December 12, 2013.

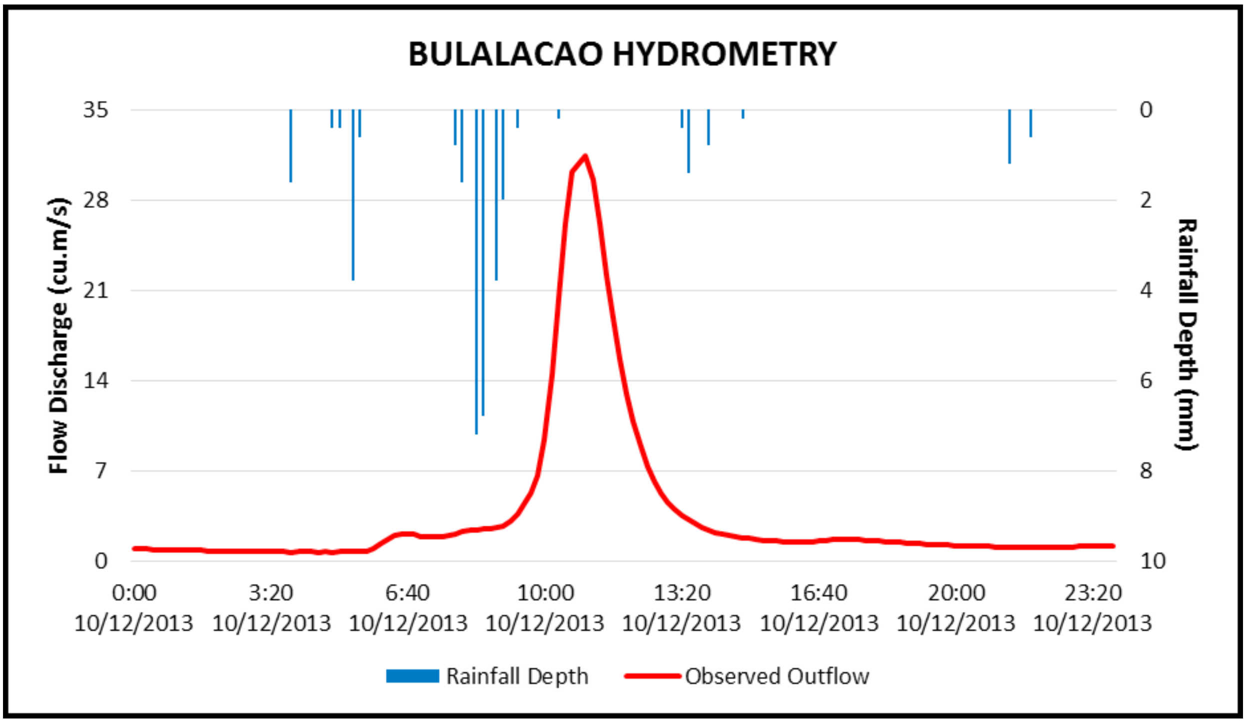



Figure 51. Rainfall and outflow data at Bulalacao River Basin used for modeling

## 5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Romblon Rain Gauge. This station chosen based on its proximity to the Bulalacao watershed. The extreme values for this watershed were computed based on a 48-year record, with the computed extreme values shown in Table 24.

Table 24. RIDF values for Romblon 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 | 18.2 | 27 | 33.5 | 44.3 | 59.5 | 70.4 | 89.5 | 107 | 119.8 |
| 5 | 26 | 37.7 | 46.5 | 60.7 | 82.2 | 97.6 | 125.5 | 152.9 | 171.6 |
| 10 | 31.1 | 44.8 | 55 | 71.5 | 97.3 | 115.7 | 149.3 | 183.4 | 205.9 |
| 15 | 34 | 48.8 | 59.9 | 77.7 | 105.8 | 125.8 | 162.8 | 200.5 | 225.2 |
| 20 | 36 | 51.6 | 63.3 | 82 | 111.8 | 133 | 172.2 | 212.6 | 238.8 |
| 25 | 37.6 | 53.8 | 65.9 | 85.3 | 116.4 | 138.4 | 179.4 | 221.8 | 249.2 |
| 50 | 42.4 | 60.4 | 74 | 95.4 | 130.5 | 155.3 | 201.8 | 250.3 | 281.4 |
| 100 | 47.2 | 67 | 81.9 | 105.5 | 144.5 | 172.1 | 223.9 | 278.6 | 313.3 |

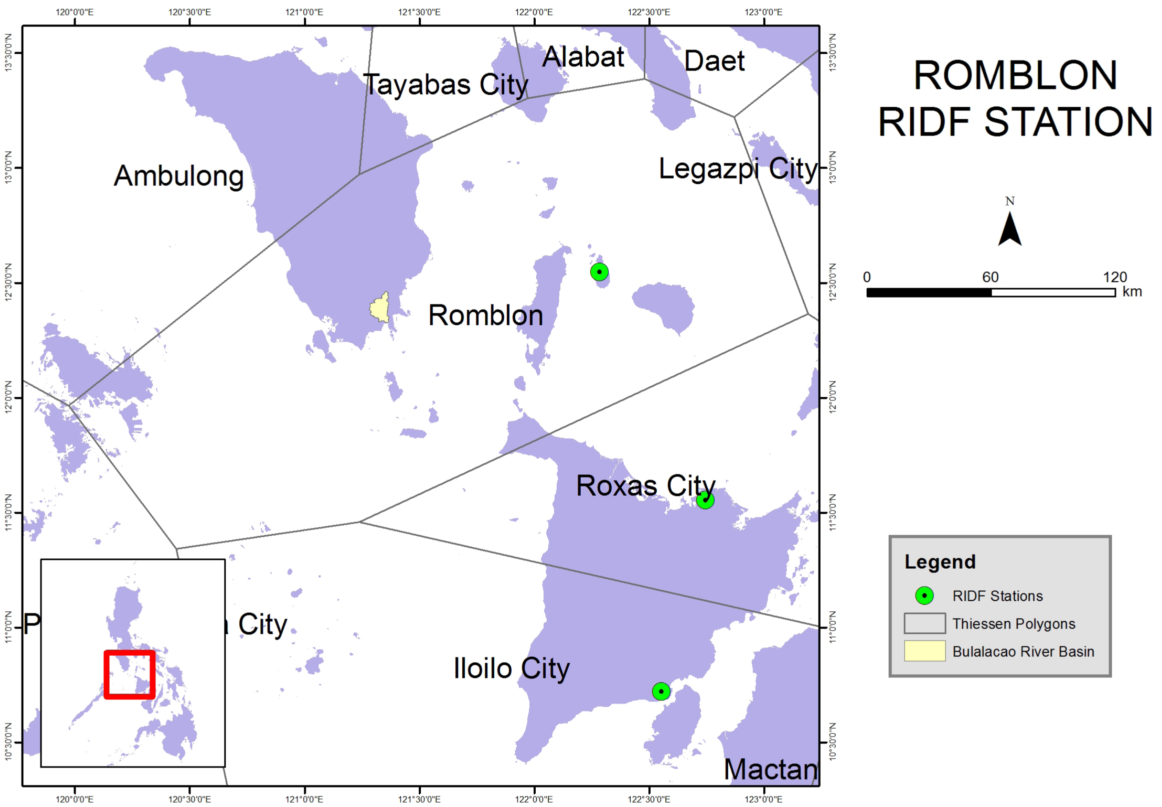



Figure 52. Location of Romblon RIDF relative to Bulalacao River Basin

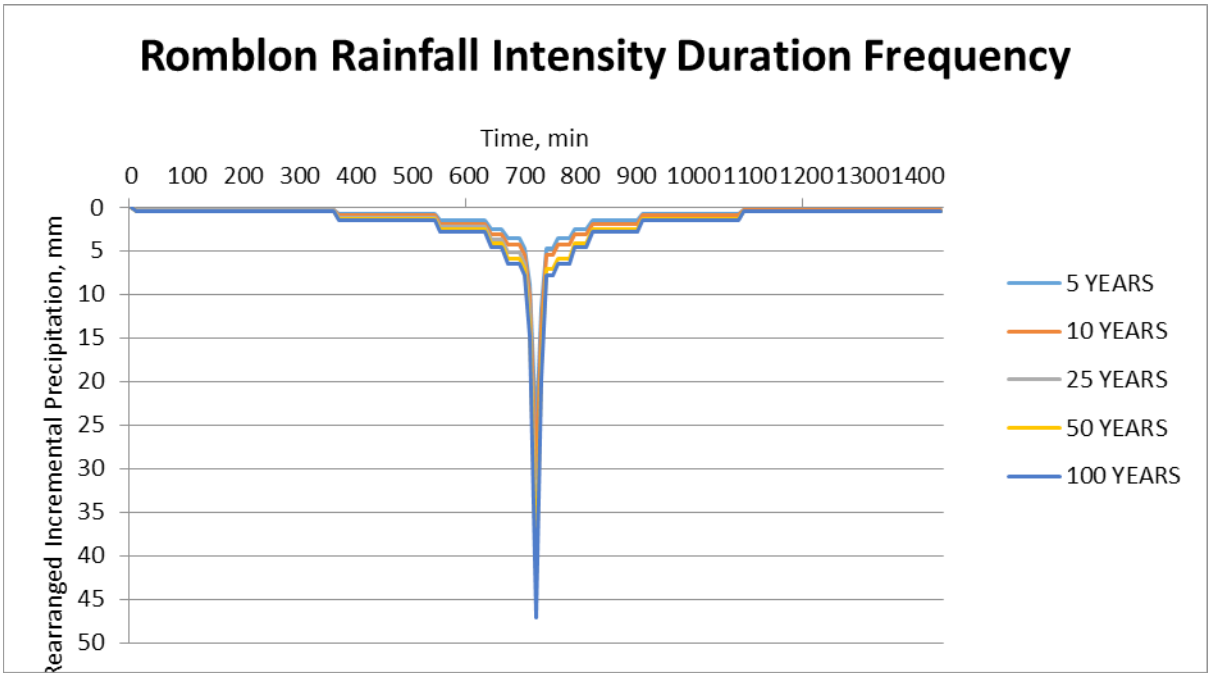



Figure 53. Synthetic storm generated for a 24-hr period rainfall for various return periods.

## 5.3 HMS Model

The soil dataset was generated before 2004 by the Bureau of Soils and Water Management under the Department of Agriculture (DA-BSWM). The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Bulalacao River Basin are shown in Figure 54 and Figure 55, respectively.

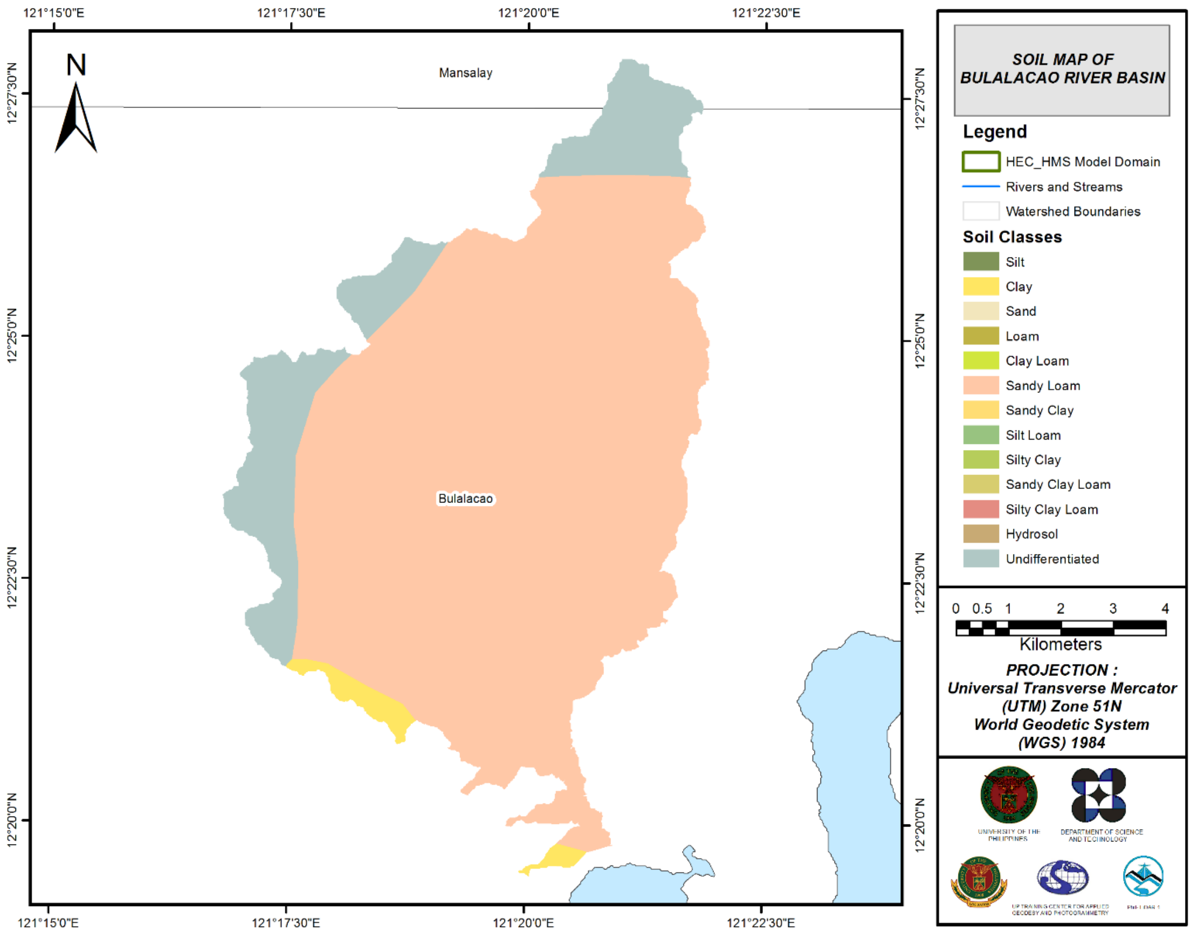



Figure 54. Soil map of Bulalacao River Basin used for the estimation of the CN parameter. (Source: DA)

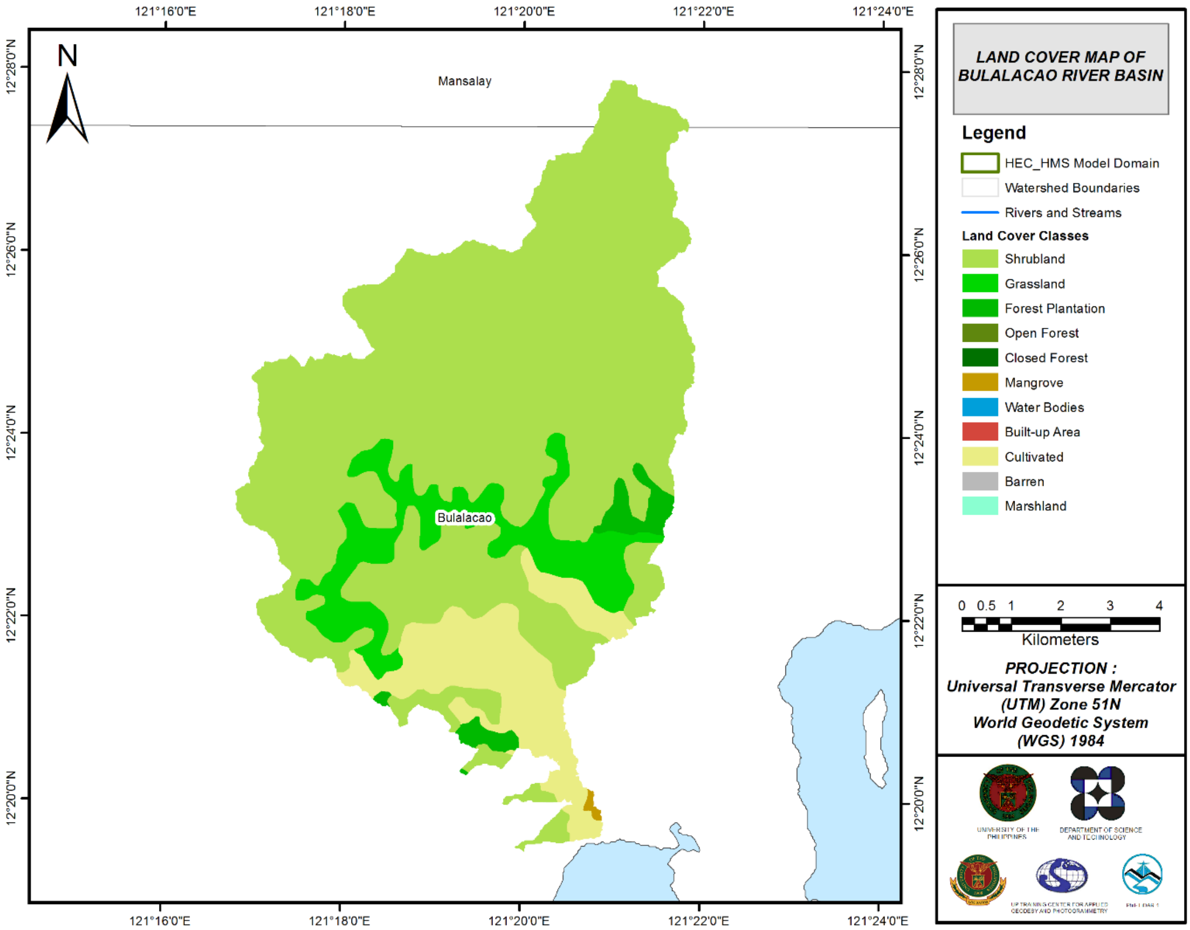



Figure 55. Land cover map of Bulalacao River Basin used for the estimation of the CN and watershed lag parameters of the rainfall-runoff model. (Source: NAMRIA)

For Bulalacao, the three (3) soil classes identified were mostly sandy loam, with some portions of clay and undifferentiated soil class. The land cover types identified in the Bulalacao river basin was largely shrubland, while the rest is grassland, forest plantation, mangrove, and cultivated areas.

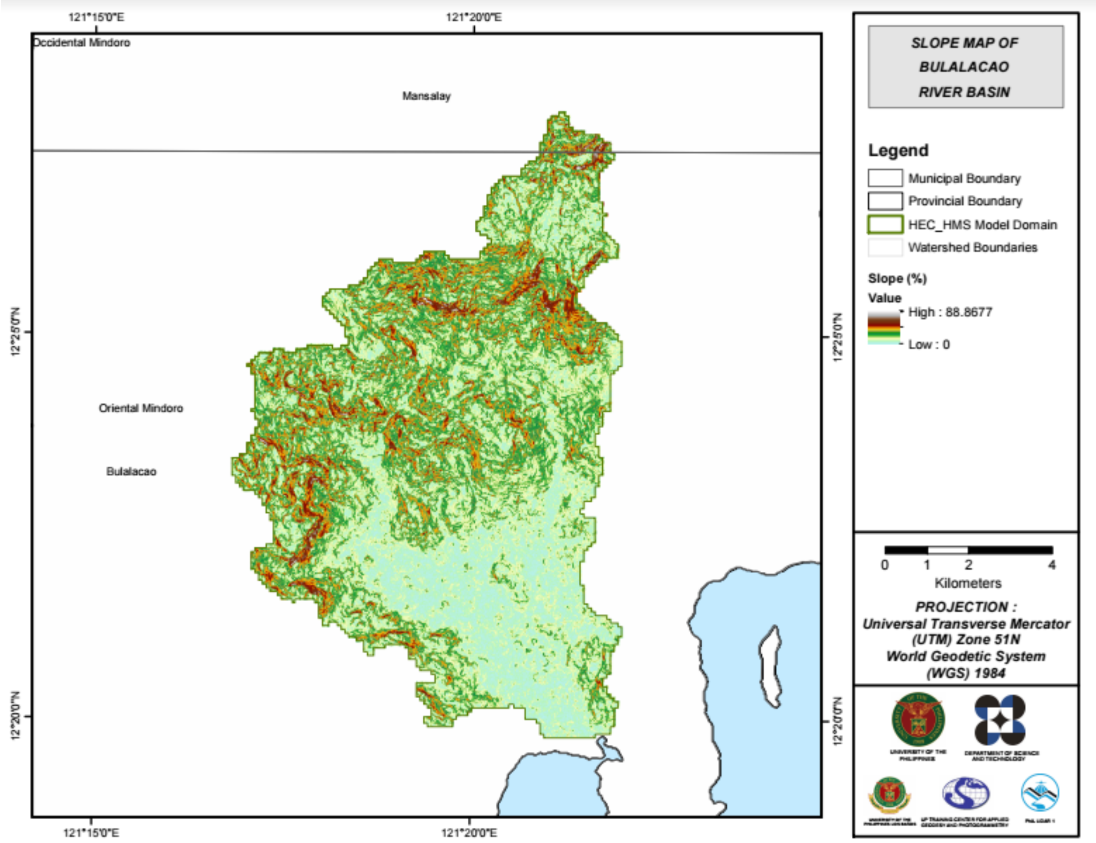



Figure 56. Slope map of Bulalacao River Basin

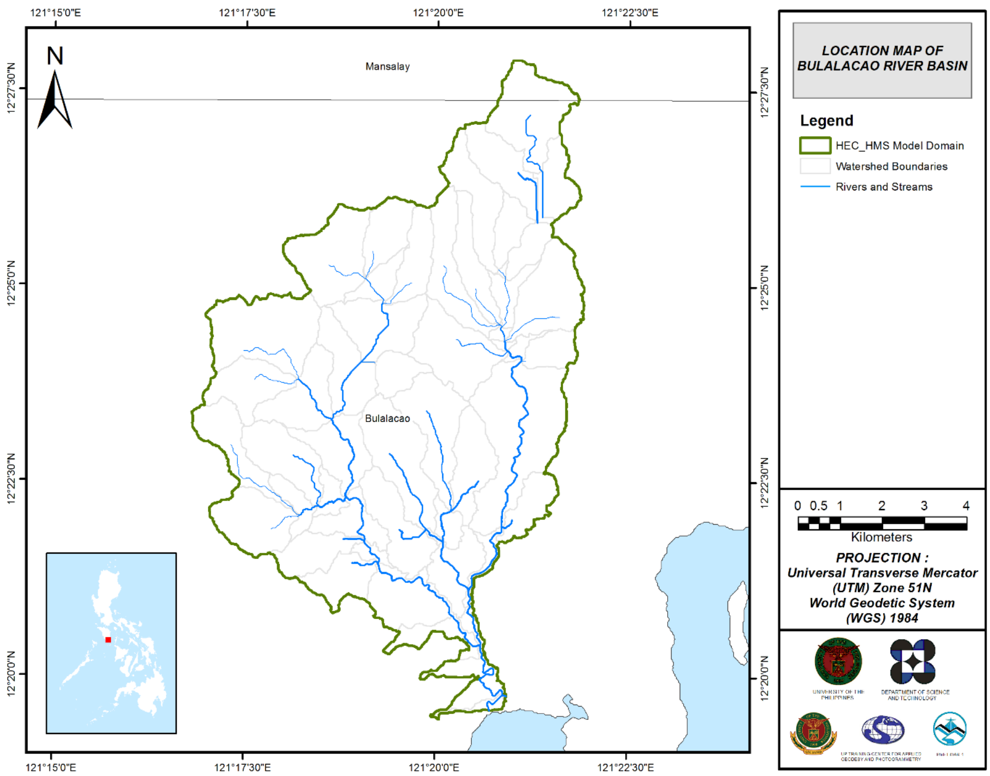



Figure 57. Stream delineation map of Bulalacao River Basin

Using the SAR-based DEM, the Bulalacao basin was delineated and further subdivided into subbasins. The model consists of 55 sub basins, 32 reaches, and 28 junctions as shown in Figure 58. The main outlet is at Bulalacao Bridge

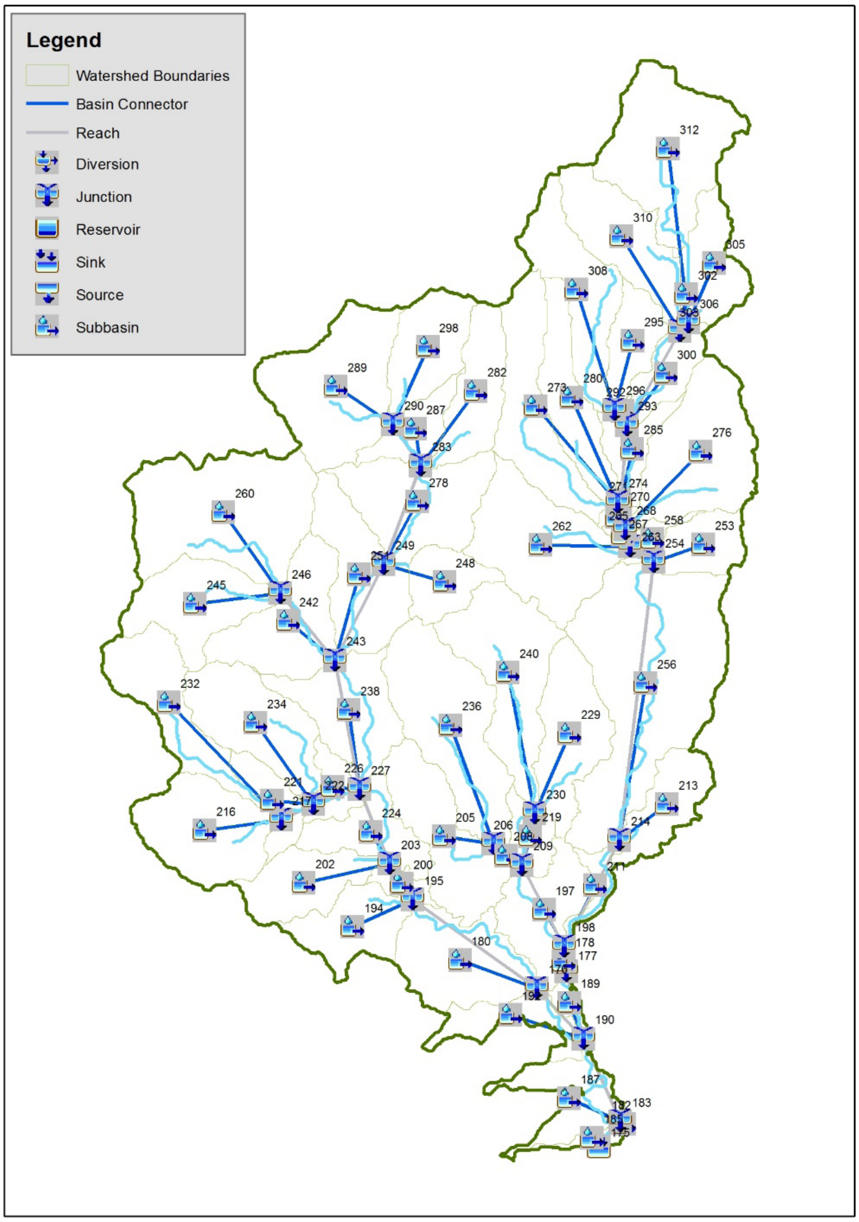



Figure 58. HEC-HMS generated Bulalacao River Basin Model.

## 5.4 Cross-section Data

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

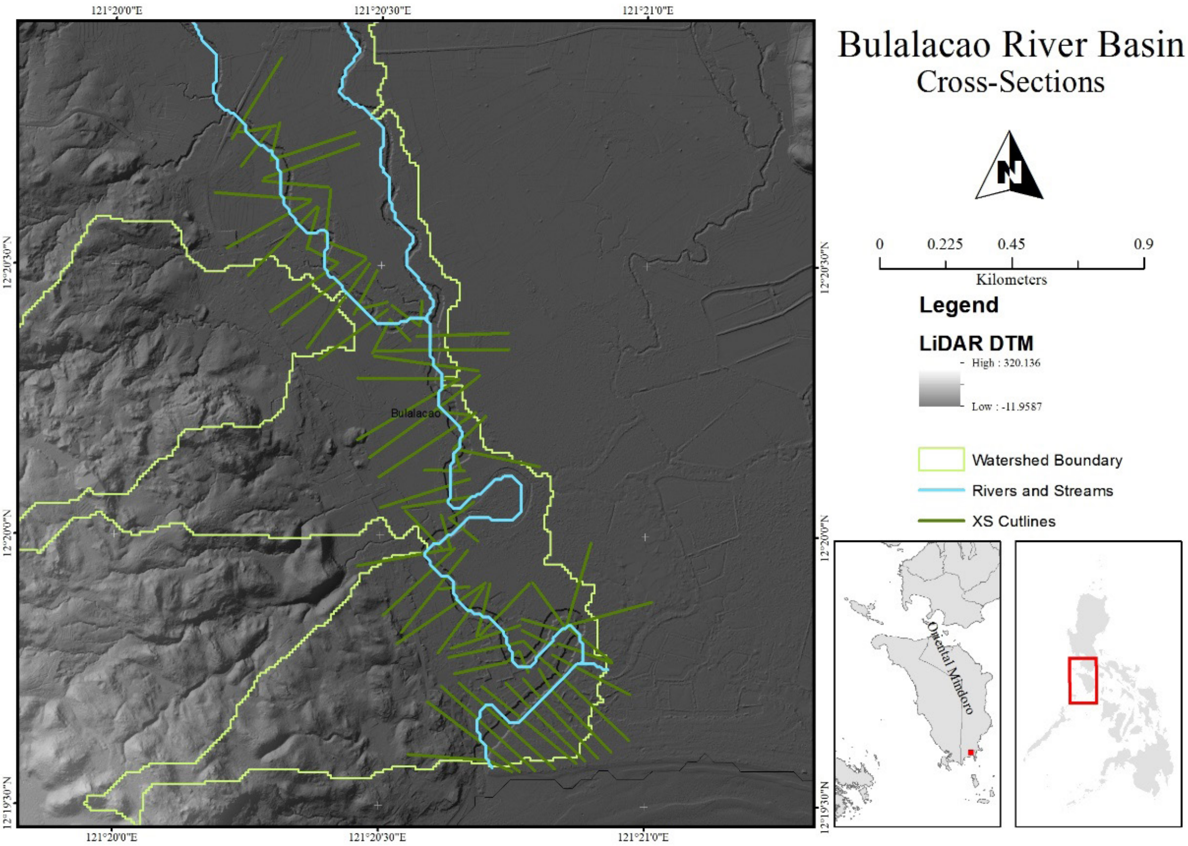



Figure 59. River cross-section of Bulalacao River generated through Arcmap HEC GeoRAS tool

## 5.5 Flo 2D Model

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

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

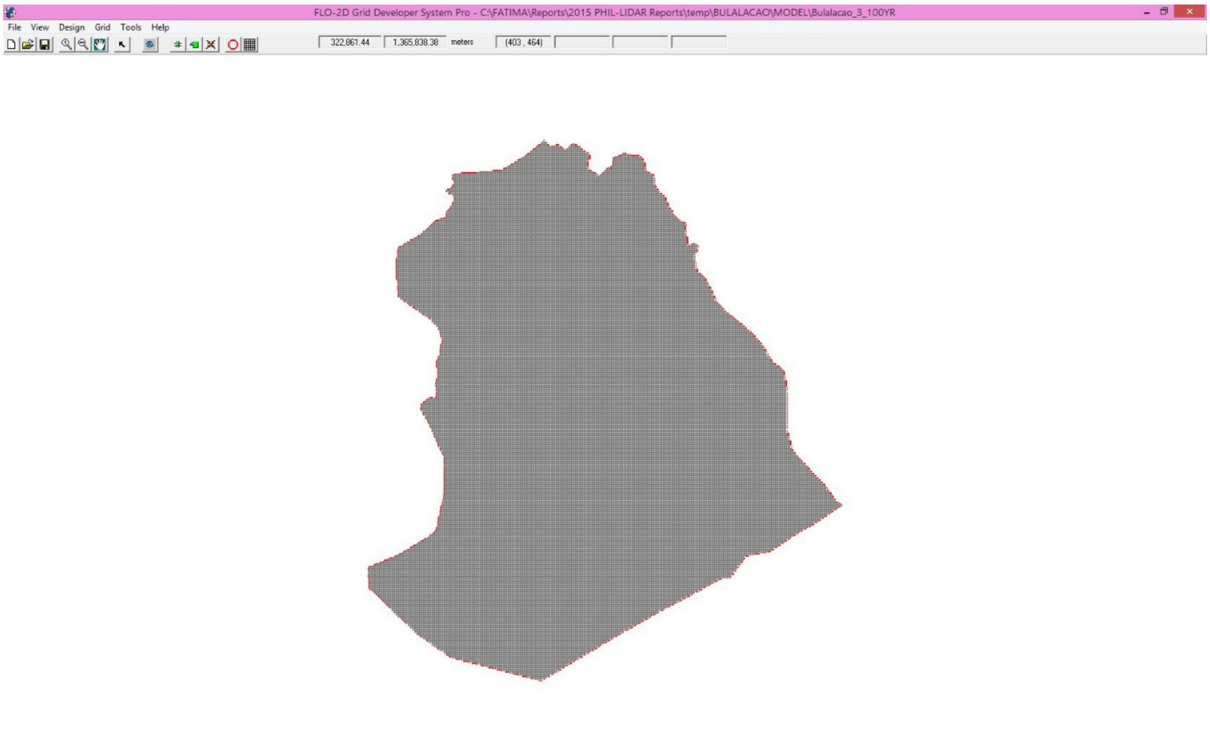



Figure 60. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 9.53955 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m2/s.

The creation of a flood hazard map from the model also automatically creates a flow depth map depicting the maximum amount of inundation for every grid element. The legend used by default in Flo-2D Mapper is not a good representation of the range of flood inundation values, so a different legend is used for the layout. In this particular model, the inundated parts cover a maximum land area of 13110100.00 m2.

There is a total of 11856976.87 m3 of water entering the model. Of this amount, 4093604.46 m3 is due to rainfall while 7763372.41 m3 is inflow from other areas outside the model. 2238198.00 m3 of this water is lost to infiltration and interception, while 2318733.48 m3 is stored by the flood plain. The rest, amounting up to 7300045.18 m3, is outflow.

## 5.6 Results of HMS Calibration

After calibrating the Bulalacao HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 61 shows the comparison between the two discharge data.

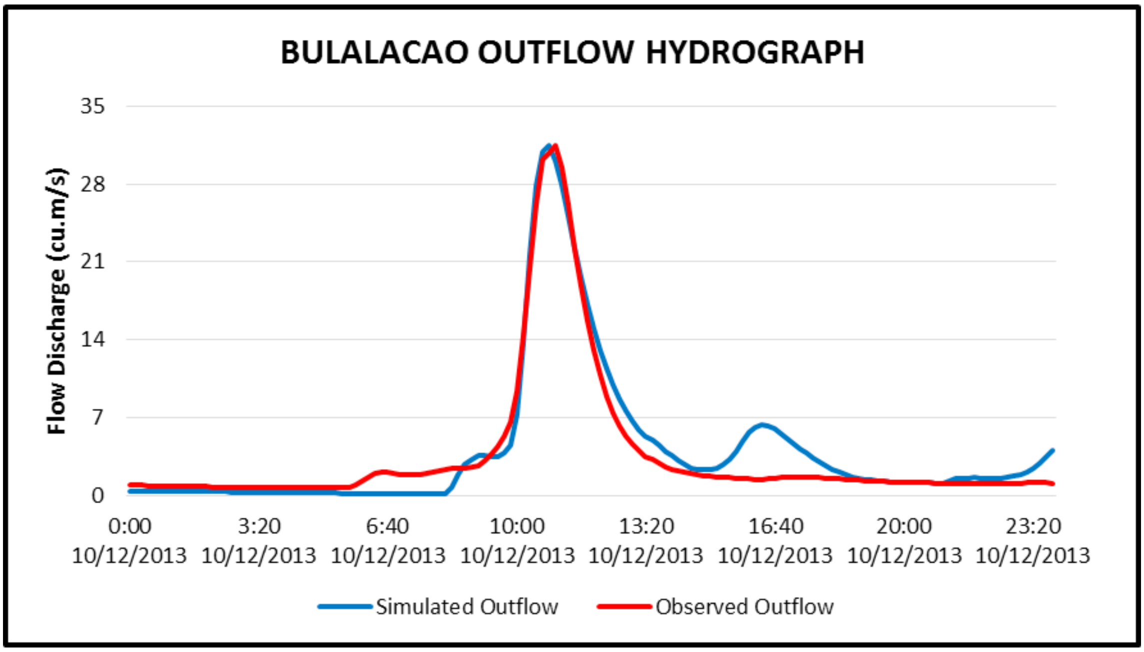



Figure 61. Outflow Hydrograph of Bulalacao produced by the HEC-HMS model compared with observed outflow.

Enumerated in Table 25 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 25. Range of calibrated values for Bulalacao River Basin

| Hydrologic Element | Calculation Type | Method | Parameter | Range of Calibrated Values |
|---|---|---|---|---|
| Basin | Loss | SCS Curve number | Initial Abstraction (mm) | 3 - 47 |
| | | | Curve Number | 58 - 99 |
| | Transform | Clark Unit Hydrograph | Time of Concentration (hr) | 0.5 - 12 |
| | | | Storage Coefficient (hr) | 0.8 - 14 |
| | Baseflow | Recession | Recession Constant | 0.008 - 1 |
| | | | Ratio to Peak | 0.007 – 0.05 |
| Reach | Routing | Muskingum-Cunge | Manning's Coefficient | 0.03 - 0.14 |

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 3mm to 47mm means that there is an average to high amount of infiltration or rainfall interception by vegetation per subbasin.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 58 to 99 for curve number is advisable for Philippine watersheds depending on the soil and land cover of the area. For Bulalacao, the basin mostly consists of brushlan and cultivated areas, and the soil consists mostly of sandy loam.
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 0.5 to 14 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. For Bulalacao, the range of values of the recession constant and ratio to peak varies wherein we can stay that each subbasin behaves in a different way.

Manning's roughness coefficient of 0.03 to 0.14 indicates that the basin consist of cultivated areas as well as trees and forest plantation which is consistent to its land cover. (Brunner, 2010).

Table 26. Summary of the Efficiency Test of Bulalacao HMS Model

| Accuracy measure | Value |
|---|---|
| RMSE | 6.9878 |
| r2 | 0.9543 |
| NSE | 0.7501 |
| PBIAS | -19.783 |
| RSR | 0.4999 |

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 6.9878.

The Pearson correlation coefficient (r2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.9543.

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 0.7501.

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 -19.7829.

The Observation Standard Deviation Ratio, RSR, is an error index. A perfect model attains a value of 0 when the error in the units of the valuable a quantified. The model has an RSR value of 0.4999.

## 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 62) shows the Bulalacao outflow using the Romblon 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.

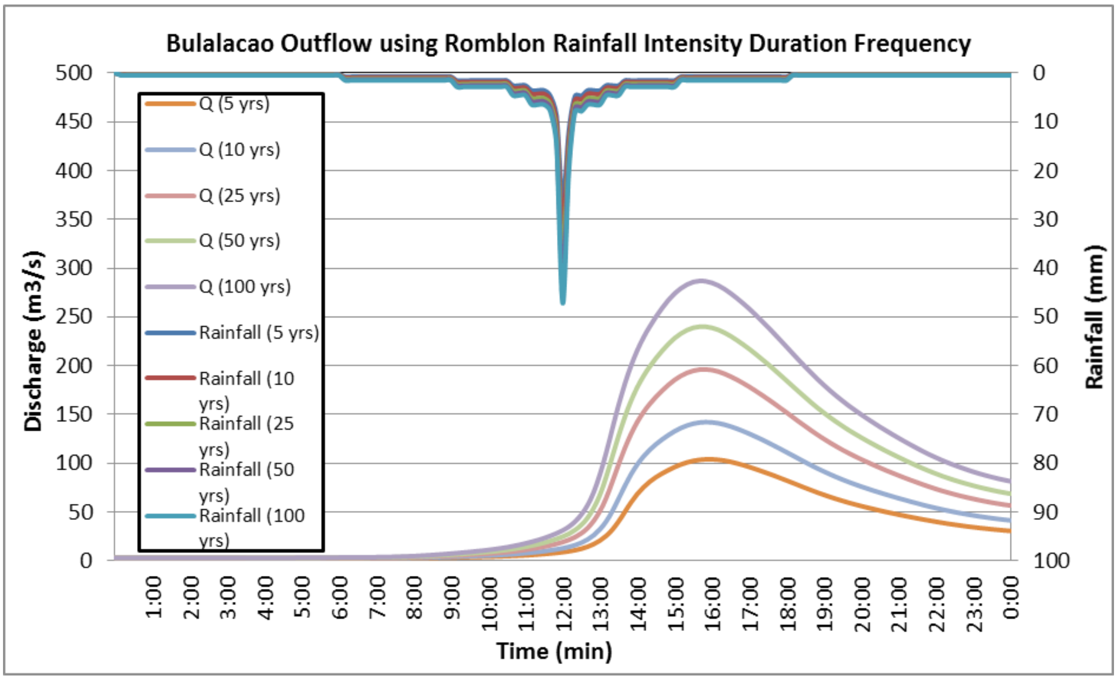



Figure 62. Outflow hydrograph at Bulalacao Station generated using Romblon RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow, time to peak and lag time of the Bulalacao discharge using the Romblon Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 27.

Table 27. Summary of the Efficiency Test of Bulalacao HMS Model

| RIDF Period | Total Precipitation (mm) | Peak rainfall (mm) | Peak outflow (m 3/s) | Time to Peak | Lag Time |
|---|---|---|---|---|---|
| 5-Year | 152.9 | 26 | 229.231 | 13 hours 50 minutes | 1 hours 50 minutes |
| 10-Year | 183.4 | 31.1 | 279.436 | 13 hours 50 minutes | 1 hours 50 minutes |
| 25-Year | 221.8 | 37.6 | 342.441 | 13 hours 40 minutes | 1 hours 40 minutes |
| 50-Year | 250.3 | 42.4 | 389.688 | 13 hours 40 minutes | 1 hours 40 minutes |
| 100-Year | 278.6 | 47.2 | 436.997 | 13 hours 40 minutes | 1 hours 40 minutes |

### 5.7.2 Discharge data using Dr. Horritt's recommended hydrologic method

The river discharges for the three rivers entering the floodplain are shown in Figure 63 to Figure 64 and the peak values are summarized in Table 28 to Table 29.

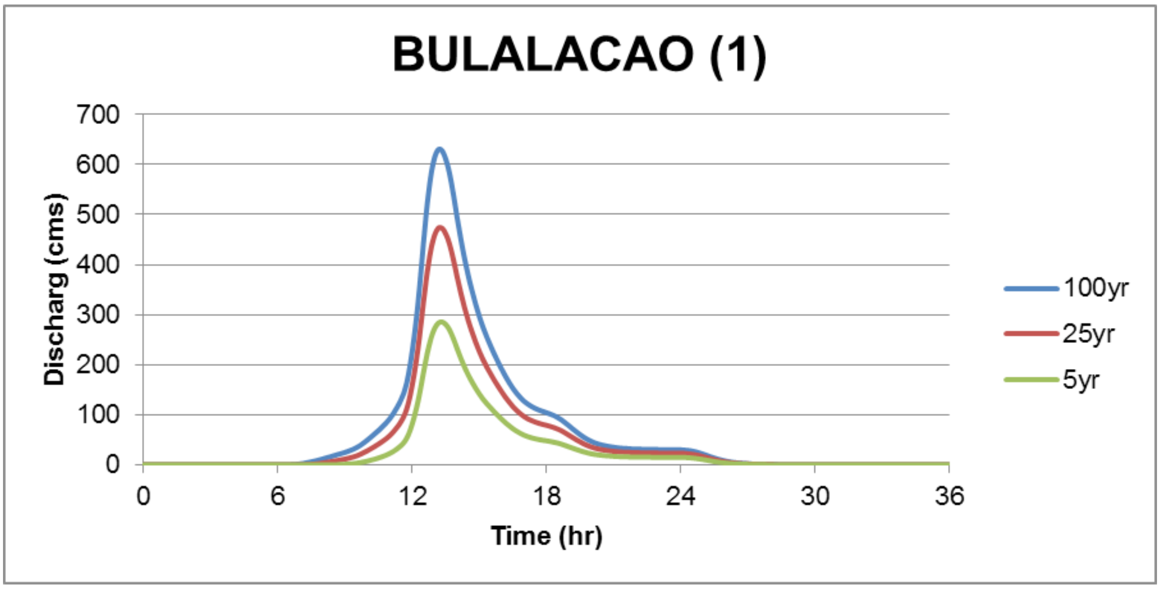



Figure 63. Bulalacao river (1) generated discharge using 5-, 25-, and 100-year Romblon rainfall intensity-duration-frequency (RIDF) in HEC-HMS

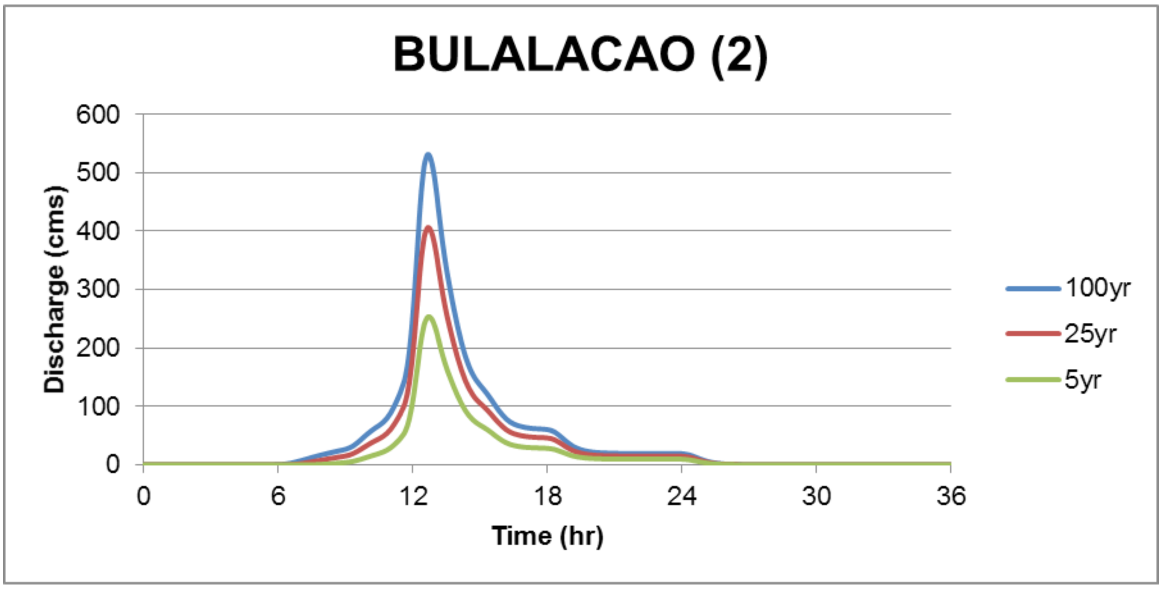



Figure 64. Bulalacao river (2) generated discharge using 5-, 25-, and 100-year Romblon rainfall intensity-duration-frequency (RIDF) in HEC-HMS

Table 28. Summary of Bulalacao river (1) discharge generated in HEC-HMS

| RIDF Period | Peak discharge (cms) | Time-to-peak |
|---|---|---|
| 100-Year | 630.0 | 13 hours, 10 minutes |
| 25-Year | 472.9 | 13 hours, 10 minutes |
| 5-Year | 285.6 | 13 hours, 20 minutes |

Table 29. Summary of Bulalacao river (2) discharge generated in HEC-HMS

| RIDF Period | Peak discharge (cms) | Time-to-peak |
|---|---|---|
| 100-Year | 531.9 | 12 hours, 40 minutes |
| 25-Year | 406.6 | 12 hours, 40 minutes |
| 5-Year | 253.3 | 12 hours, 40 minutes |

The comparison of the discharge results using Dr. Horritt's recommended hydrological method against the bankful and specific discharge estimates is shown in Table 30.

Table 30. Validation of river discharge estimates

| Discharge Point | QMED(SCS), cms | QBANKFUL, cms | QMED(SPEC), cms | VALIDATION | |
|---|---|---|---|---|---|
| | | | | Bankful Discharge | Specific Discharge |
| Bulalacao (1) | 251.328 | 242.960 | 340.432 | Pass | Pass |
| Bulalacao (2) | 222.904 | 267.270 | 245.794 | Pass | Pass |

The two values from the HEC-HMS river discharge estimates were able to satisfy the conditions for validation using the bankful and specific discharge methods. The calculated values are based on theory but are supported using other discharge computation methods so they were good to use flood modeling. However, these values will need further investigation for the purpose of validation. It is therefore recommended to obtain actual values of the river discharges for higher-accuracy modeling.

## 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 sample map of Bulalacao River using the HMS base flow is shown on Figure 65 below.

Figure 65. Sample output of Bulalacao RAS Model

## 5.9 Flood Hazard and Flow Depth Map

The resulting hazard and flow depth maps for 5-, 25-, and 100-year rain return scenarios of the Bulalacao floodplain are shown in Figure 66 to Figure 71. The floodplain, with an area of 53.44 sq. km., covers one municipality namely Bulalacao. Table 31 shown the percentage of area affected by flooding per municipality.

Table 31. Municipalities affected in Bulalacao Floodplain

| Municipality | Total Area | Area Flooded | % Flooded |
|---|---|---|---|
| Bulalacao | 365.584 | 53.24789 | 14.56516 |

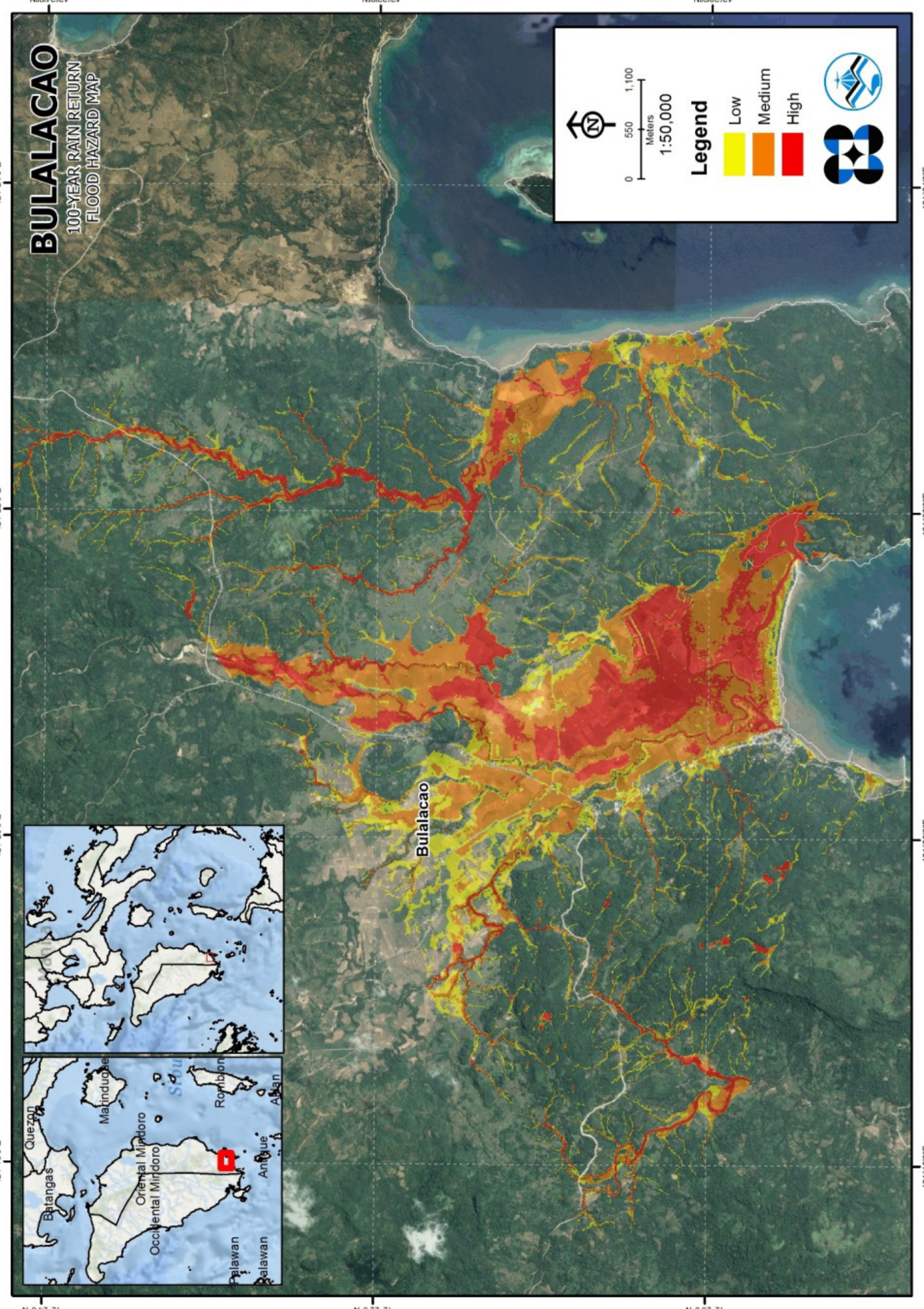



Figure 66. 100-year Flood Hazard Map for Bulalacao Floodplain overlaid on Google Earth imagery

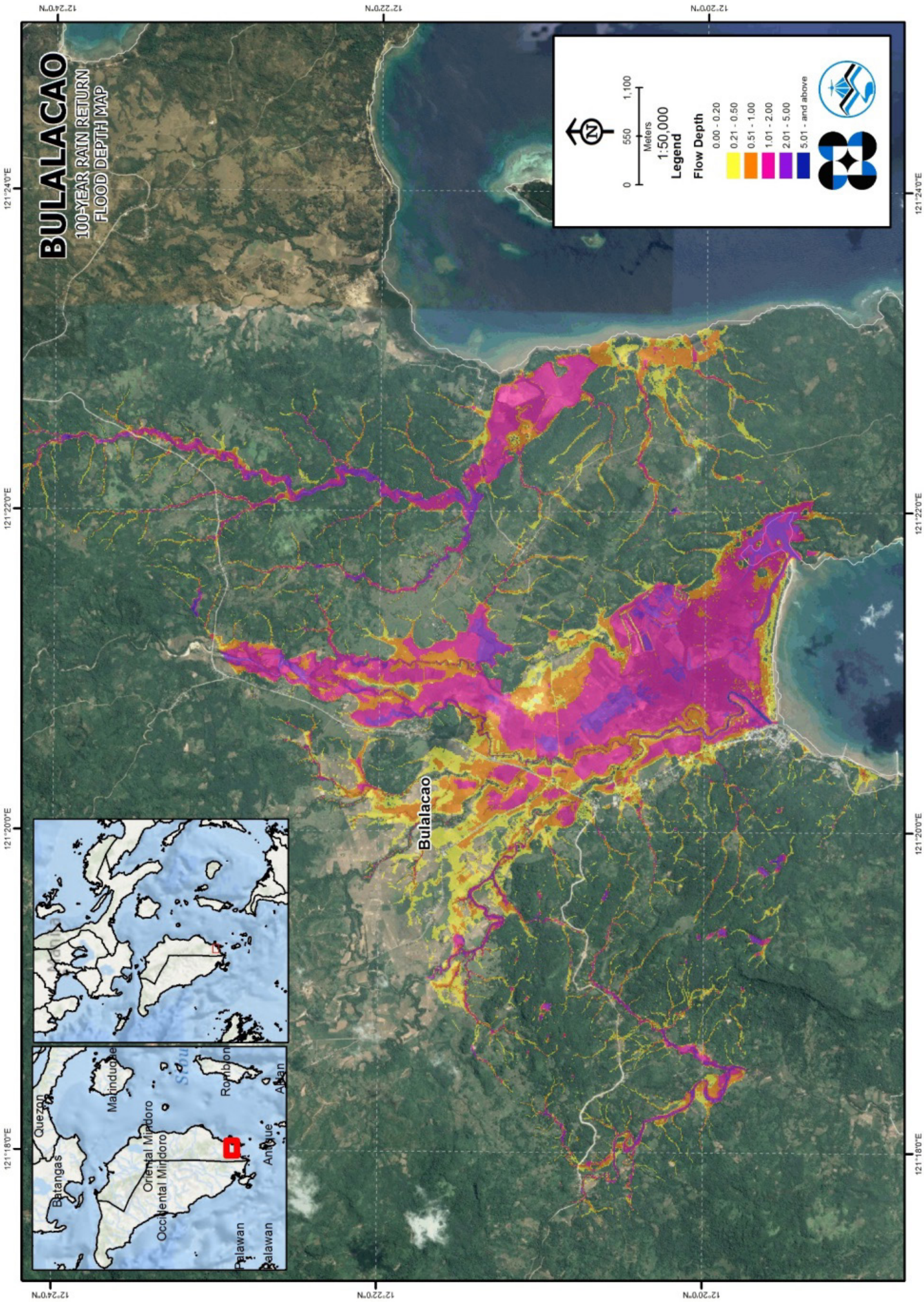



Figure 67. 100-year Flow Depth Map for Bulalacao Floodplain overlaid on Google Earth imagery

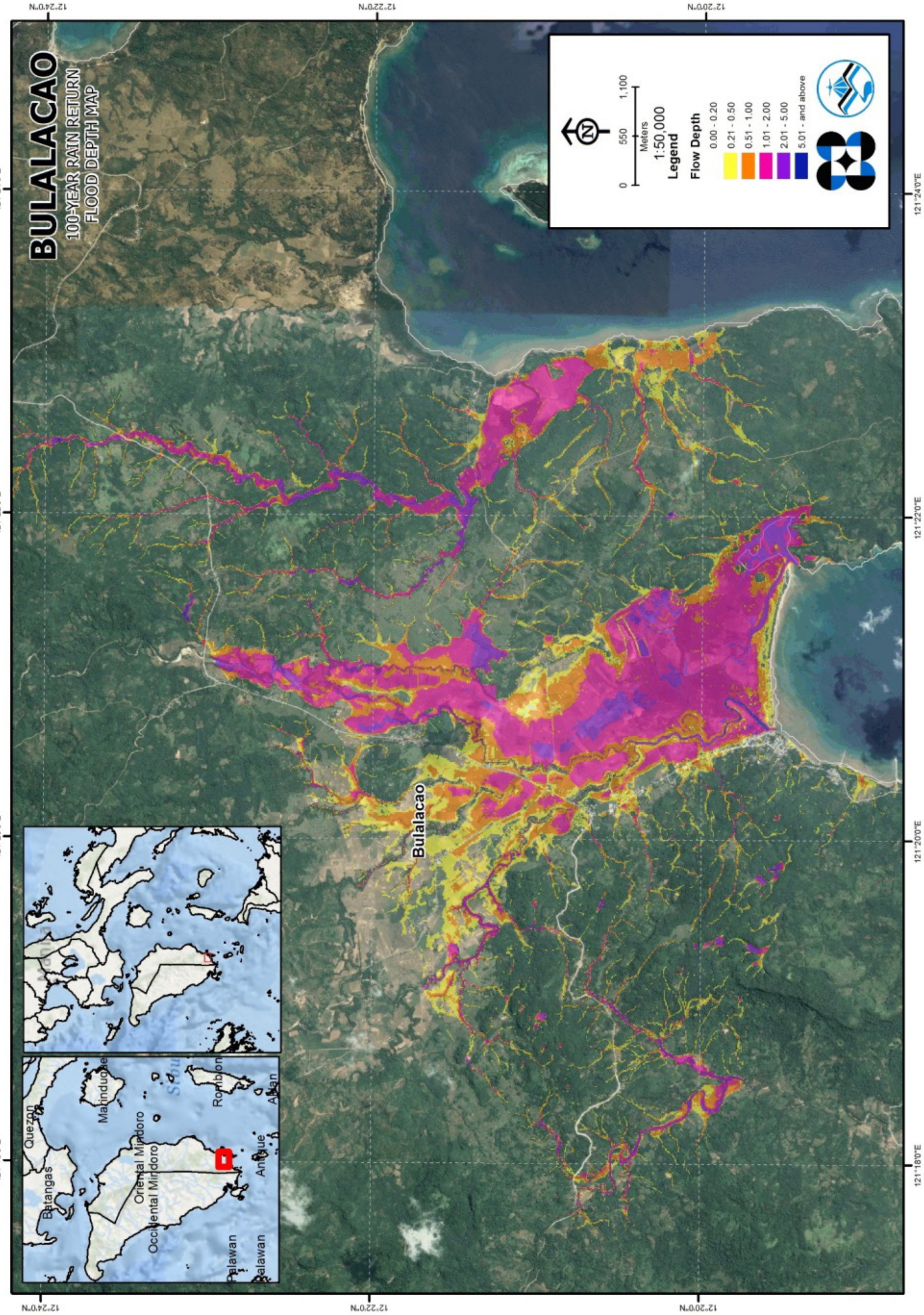



Figure 68. 25-year Flood Hazard Map for Bulalacao Floodplain overlaid on Google Earth imagery

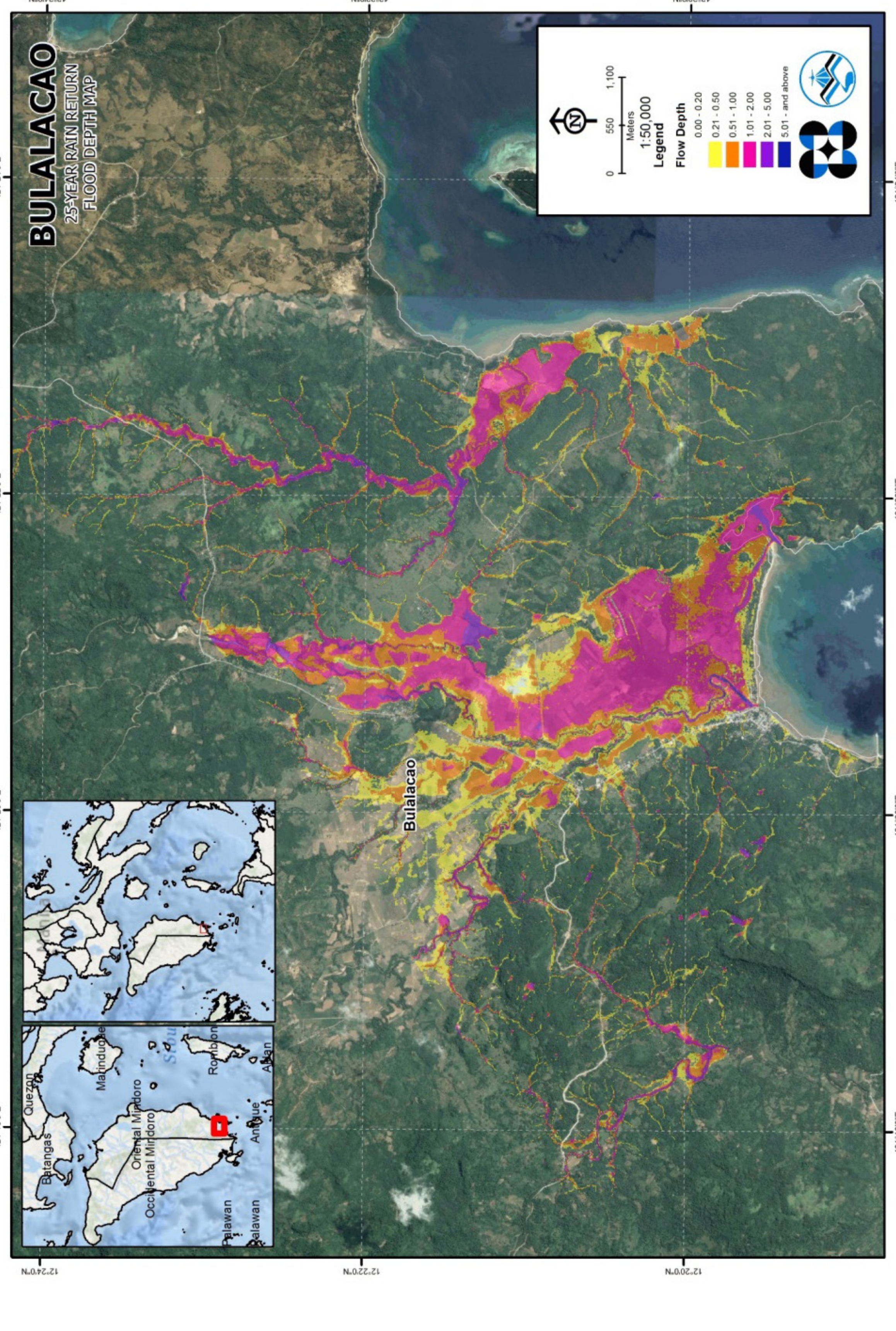



Figure 69. 25-year Flow Depth Map for Bulalacao Floodplain overlaid on Google Earth imagery

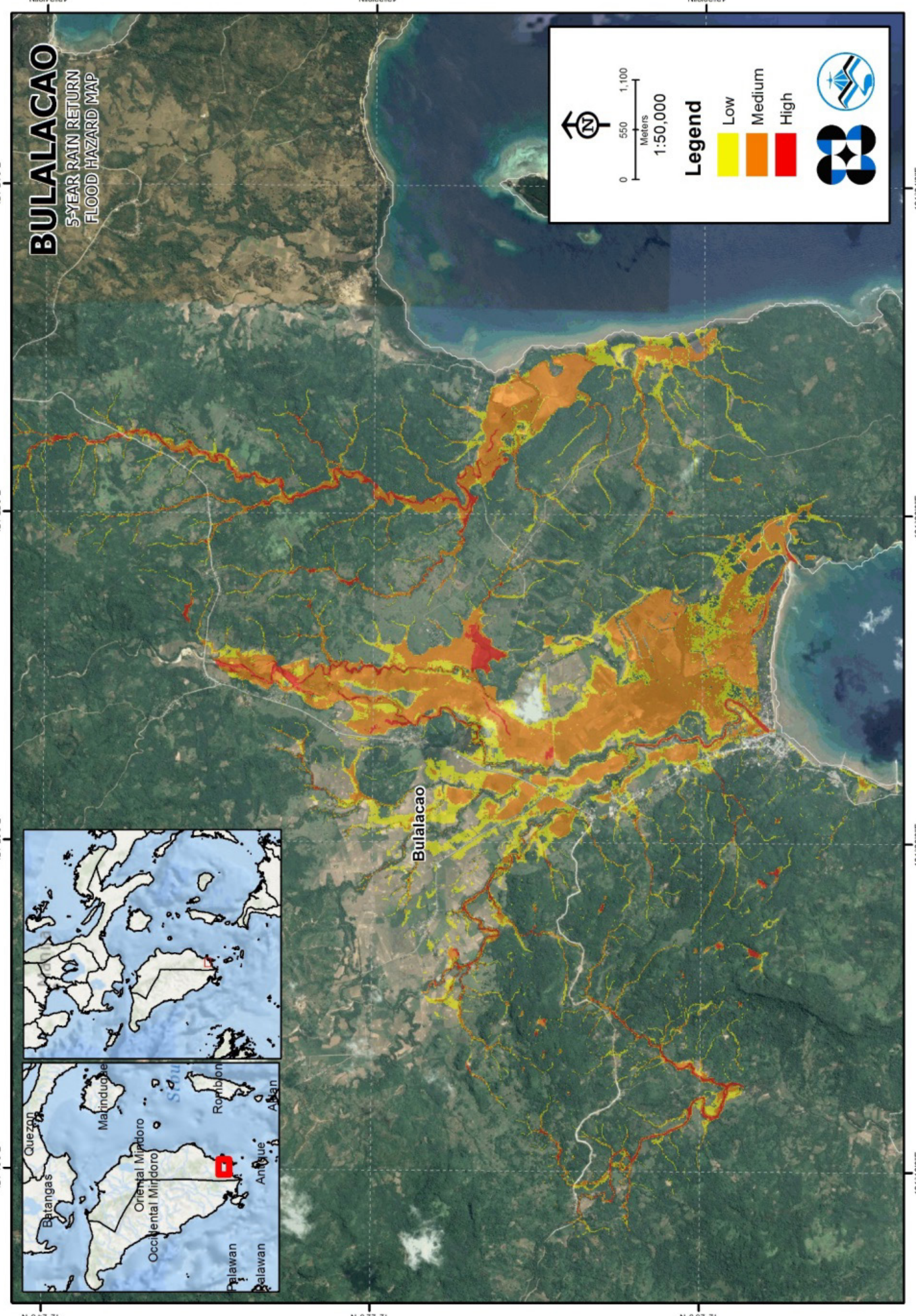



Figure 70. 5-year Flood Hazard Map for Bulalacao Floodplain overlaid on Google Earth imagery

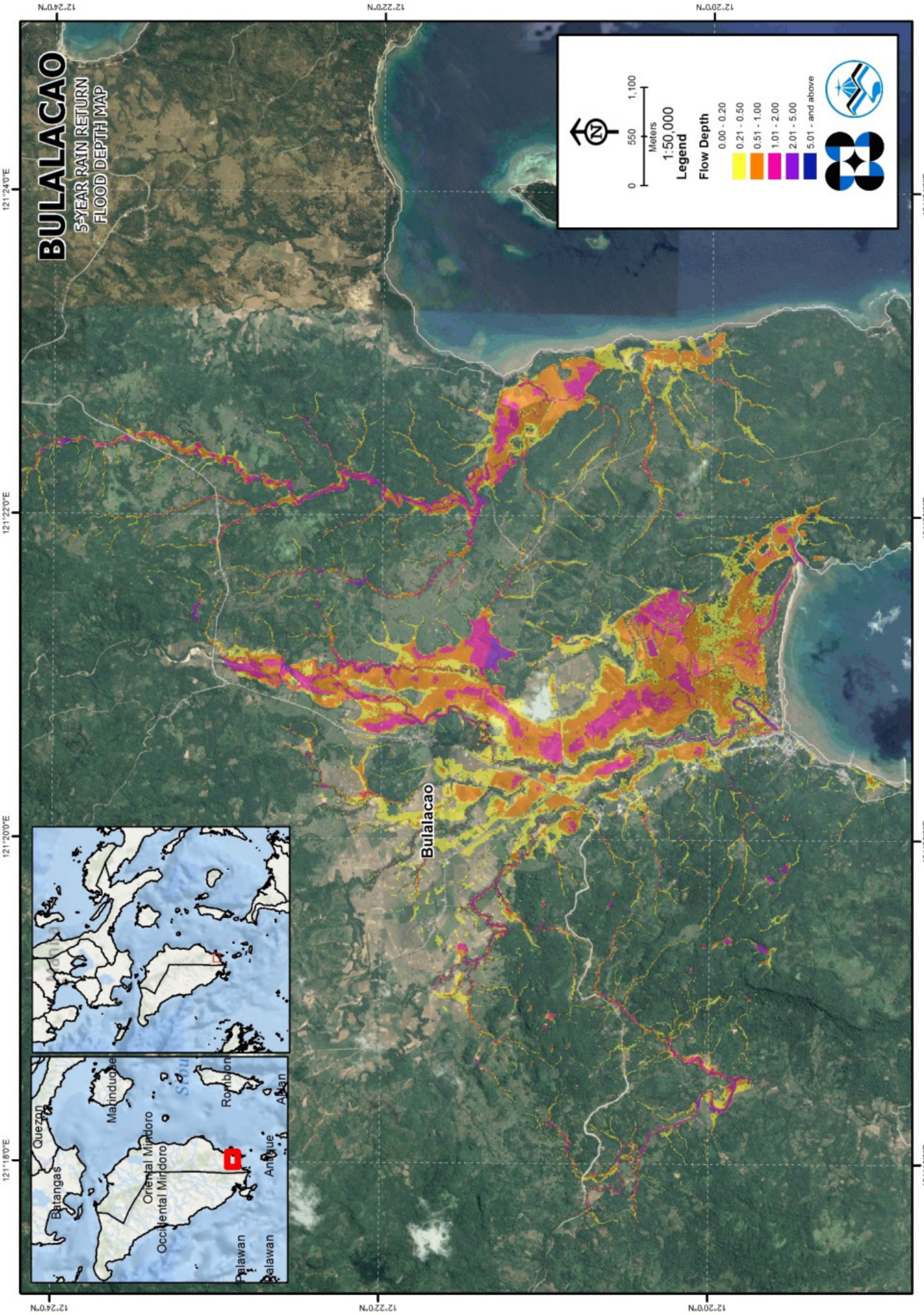



Figure 71. 5-year Flood Depth Map for Bulalacao Floodplain overlaid on Google Earth imagery

## 5.10 Inventory of Areas Exposed to Flooding

Affected barangays in Bulalacao river basin, grouped by municipality, are listed below. For the said basin, one (1) municipality consisting of 10 barangays are expected to experience flooding when subjected to 5-yr rainfall return period.

For the 5-year return period, 11.37% of the municipality of Bulalacao with an area of 365.58 sq. km. will experience flood levels of less 0.20 meters. 1.18% of the area will experience flood levels of 0.21 to 0.50 meters while 1.36%, 0.58%, 0.09%, and 0.003% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 32 and shown in Figure 72 are the affected areas in Bulalacao in square kilometres by flood depth per barangay.

Table 32. Affected Areas in Bulalacao, Oriental Mindoro during 5-Year Rainfall Return Period

| Affected area (sq. km.) by flood depth (in m.) | Area of affected barangays in Bulalacao (in sq. km.) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Bagong Sikat | Balatasan | Cab-ugao | Cambu-nang | Cam-paasan | Maujao | Nasukob | Poblacion | San Juan | San Roque |
| 0.03-0.20 | 5.81 | 1.18 | 0.27 | 5.48 | 6.2 | 0.6 | 8.52 | 1.08 | 12.4 | 0.0037 |
| 0.21-0.50 | 0.3 | 0.055 | 0.0081 | 1.16 | 0.64 | 0.031 | 0.77 | 0.095 | 1.24 | 0.000003 |
| 0.51-1.00 | 0.17 | 0.034 | 0.0039 | 1.1 | 0.52 | 0.0076 | 1.08 | 0.085 | 1.97 | 0 |
| 1.01-2.00 | 0.12 | 0.00071 | 0.0021 | 0.41 | 0.17 | 0.0009 | 0.69 | 0.012 | 0.71 | 0 |
| 2.01-5.00 | 0.045 | 0.000001 | 0 | 0.066 | 0.041 | 0.0002 | 0.12 | 0.017 | 0.032 | 0 |
| > 5.00 | 0.0002 | 0 | 0 | 0.0001 | 0.0007 | 0 | 0.0006 | 0.0056 | 0.0023 | 0 |

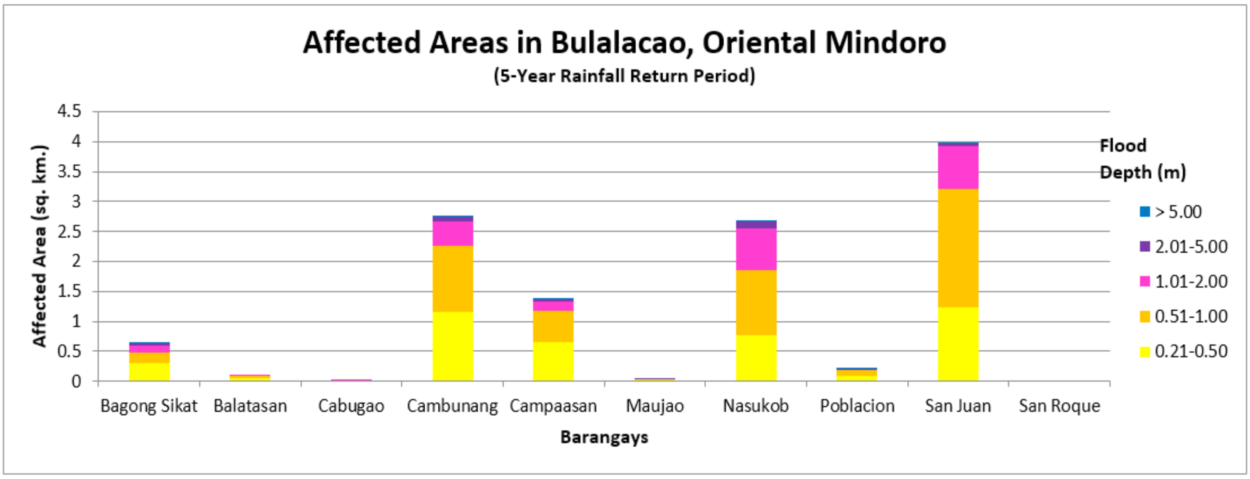



Figure 72. Affected Areas in Bulalacao, Oriental Mindoro during 5-Year Rainfall Return Period

For the 25-year return period, 10.60% of the municipality of Bulalacao with an area of 365.58 sq. km. will experience flood levels of less 0.20 meters. 1.17% of the area will experience flood levels of 0.21 to 0.50 meters while 1.16%, 1.49%, 0.16%, and 0.005% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 33 and shown in Figure 73 are the affected areas in square kilometres by flood depth per barangay.

Table 33. Affected Areas in Bulalacao, Oriental Mindoro during 25-Year Rainfall Return Period

| Affected area (sq. km.) by flood depth (in m.) | Area of affected barangays in Bulalacao (in sq. km.) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Bagong Sikat | Balatasan | Cab-ugao | Cambu-nang | Cam-paasan | Maujao | Nasukob | Poblacion | San Juan | San Roque |
| 0.03-0.20 | 5.61 | 1.14 | 0.26 | 4.73 | 5.71 | 0.58 | 7.96 | 0.98 | 11.77 | 0.0037 |
| 0.21-0.50 | 0.36 | 0.052 | 0.01 | 1.33 | 0.71 | 0.042 | 0.72 | 0.099 | 0.97 | 0.000003 |
| 0.51-1.00 | 0.24 | 0.042 | 0.0055 | 1.12 | 0.66 | 0.01 | 0.83 | 0.066 | 1.26 | 0 |
| 1.01-2.00 | 0.17 | 0.046 | 0.003 | 0.91 | 0.45 | 0.0017 | 1.45 | 0.13 | 2.3 | 0 |
| 2.01-5.00 | 0.075 | 0.00042 | 0.00012 | 0.13 | 0.06 | 0.0003 | 0.23 | 0.017 | 0.063 | 0 |
| > 5.00 | 0.0007 | 0 | 0 | 0.0002 | 0.0013 | 0 | 0.0017 | 0.01 | 0.0037 | 0 |

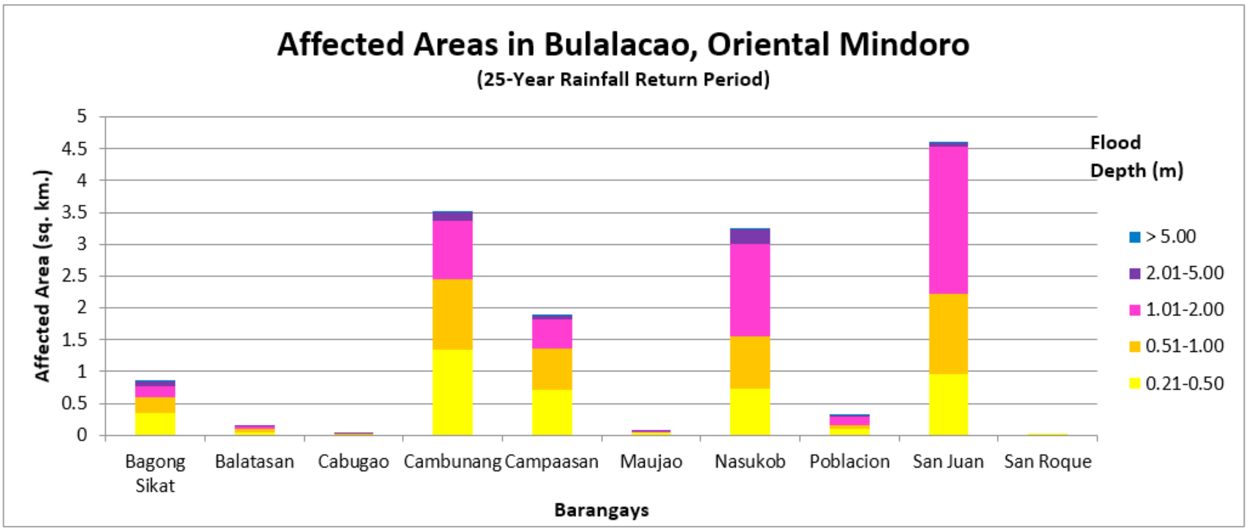



Figure 73. Affected Areas in Bulalacao, Oriental Mindoro during 25-Year Rainfall Return Period

For the 100-year return period, 1.11% of the municipality of Bulalacao with an area of 365.58 sq. km. will experience flood levels of less 0.20 meters. 1.10% of the area will experience flood levels of 0.21 to 0.50 meters while 1.74%, 0.32%, and 0.007% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, and more than 2 meters, respectively. Listed in Table 34 and shown in Figure 74 are the areas affected in Bulalacao in square kilometers by flood depth per barangay.

Table 34. Affected Areas in Bulalacao, Oriental Mindoro during 100-Year Rainfall Return Period

| Affected area (sq. km.) by flood depth (in m.) | Area of affected barangays in Bulalacao (in sq. km.) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Bagong Sikat | Ba-latasan | Cabugao | Cambu-nang | Campaas-an | Maujao | Nasukob | Poblacion | San Juan | San Roque |
| 0.03-0.20 | 0.26 | 0.05 | 0.013 | 1.39 | 0.62 | 0.052 | 0.6 | 0.091 | 0.96 | 0.000003 |
| 0.21-0.50 | 0.2 | 0.04 | 0.0059 | 1.16 | 0.68 | 0.014 | 0.82 | 0.08 | 1.02 | 0 |
| 0.51-1.00 | 0.1 | 0.015 | 0.003 | 1.21 | 0.7 | 0.0022 | 1.53 | 0.16 | 2.64 | 0 |
| 1.01-2.00 | 0.0009 | 0 | 0.00062 | 0.2 | 0.11 | 0.0003 | 0.53 | 0.023 | 0.3 | 0 |
| 2.01-5.00 | 0 | 0 | 0 | 0 | 0.003 | 0 | 0.0028 | 0.014 | 0.005 | 0 |
| > 5.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

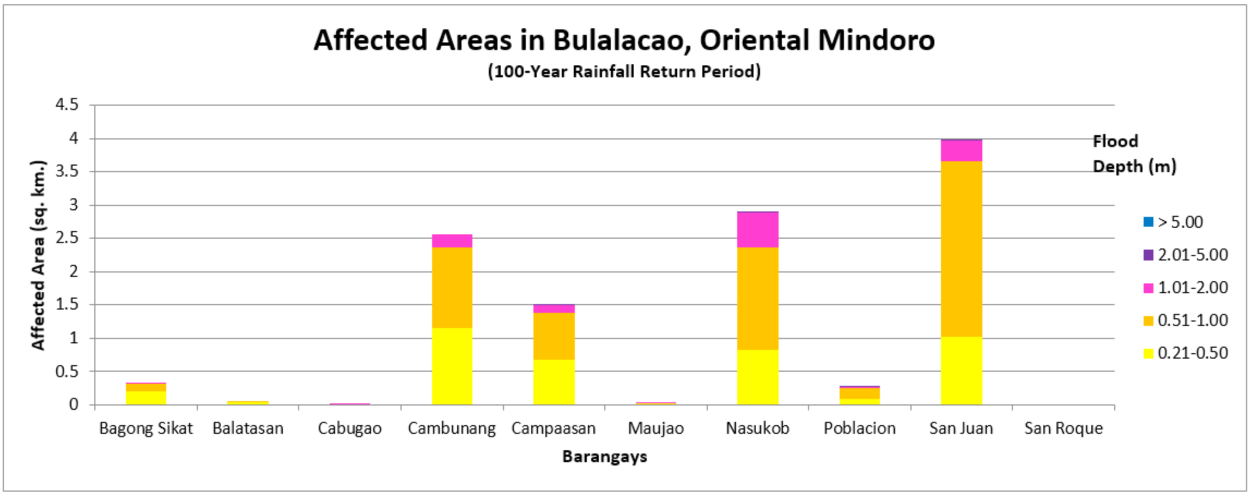



Figure 74. Affected areas in Bulalacao, Oriental Mindoro during the 100-Year Rainfall Return Period

Among the barangays in the municipality of Bulalacao, San Juan is projected to have the highest percentage of area that will experience flood levels at 4.47%. Meanwhile, Nasukob posted the second highest percentage of area that may be affected by flood depths at 3.06%.

## 5.11 Flood Validation

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

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

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

After which, the actual data from the field was compared to the simulated data to assess the accuracy of the Flood Depth Maps produced and to improve on what is needed. The points in the flood map versus its corresponding validation depths are shown in Figure 75.

The flood validation consisted of 102 points randomly selected all over the Clarin flood plain. It has an RMSE value of 0.40. Table 38 shows a contingency matrix of the comparison.

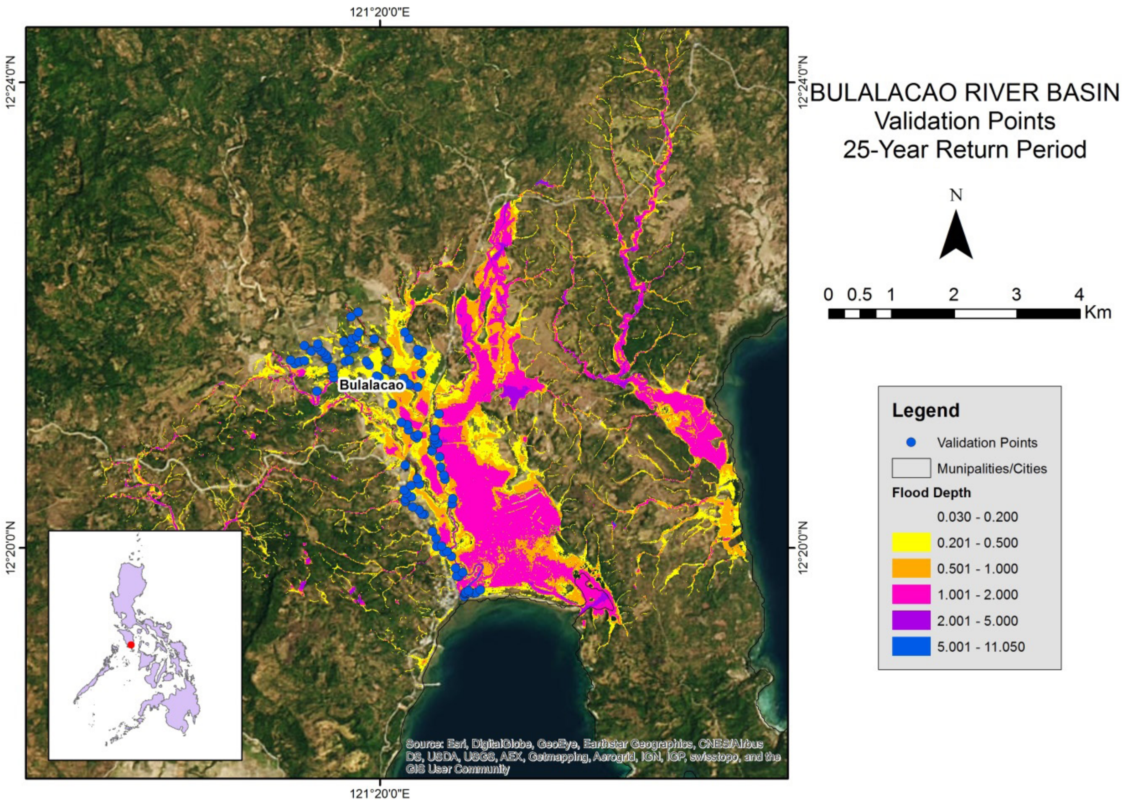



Figure 75. Validation points for 25-year Flood Depth Map of Bulalacao Floodplain

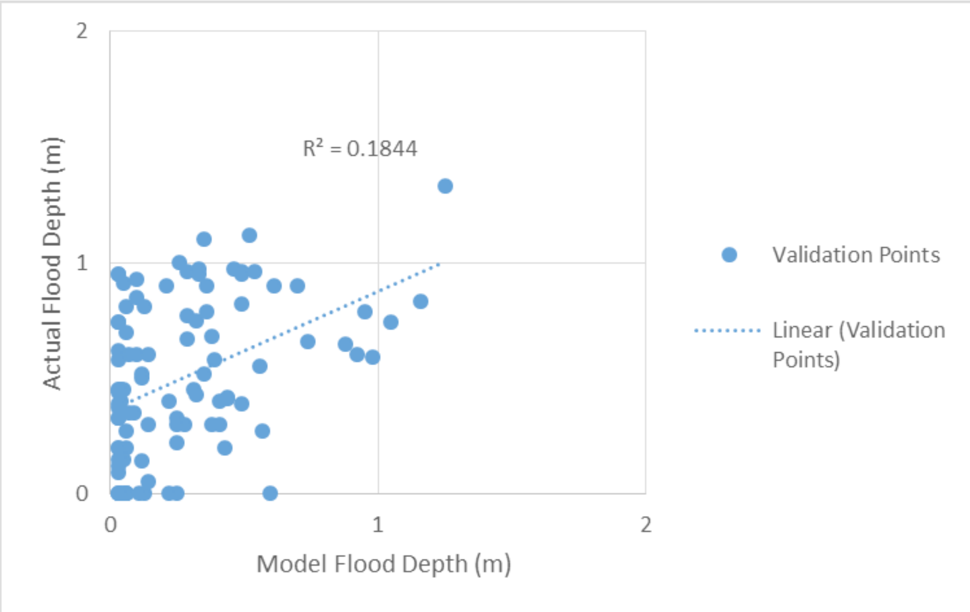



Figure 76. Flood map depth vs. actual flood depth

Table 35. Actual flood vs simulated flood depth at different levels in the Bulalacao River Basin.

| Actual Flood Depth (m) | Modeled Flood Depth (m) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0-0.20 | 0.21-0.50 | 0.51-1.00 | 1.01-2.00 | 2.01-5.00 | > 5.00 | Total |
| 0-0.20 | 21 | 3 | 1 | 0 | 0 | 0 | 25 |
| 0.21-0.50 | 16 | 13 | 1 | 0 | 0 | 0 | 30 |
| 0.51-1.00 | 16 | 17 | 9 | 2 | 0 | 0 | 44 |
| 1.01-2.00 | 0 | 1 | 1 | 1 | 0 | 0 | 3 |
| 2.01-5.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| > 5.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 53 | 34 | 12 | 3 | 0 | 0 | 102 |

The overall accuracy generated by the flood model is estimated at 43.14%, with 44 points correctly matching the actual flood depths. In addition, there were 40 points estimated one level above and below the correct flood depths while there were 18 points estimated two levels above and below the correct flood. A total of 7 points were overestimated while a total of 51 points were underestimated in the modelled flood depths of Bulalacao. Table 39 depicts the summary of the Accuracy Assessment in the Bulalacao River Basin Survey.

Table 36. Summary of the Accuracy Assessment in the Bulalacao River Basin Survey

| | No. of Points | % |
|---|---|---|
| Correct | 44 | **43.14** |
| Overestimated | 7 | 6.86 |
| Underestimated | 51 | 50.00 |
| Total | 102 | 100 |

# REFERENCES

Ang M.C., 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.C., Lagmay, A.F., 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.J.S., Paringit E.C., et al. 2014. DREAM Data Aquisition 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)

# ANNEXES

## Annex 1. Technical Specifications of the LiDAR Sensors used in the Bulalacao Floodplain Survey

Table A-1.1 Technical Specifications of the LiDAR Sensors used in the Bulalacao Floodplain Survey

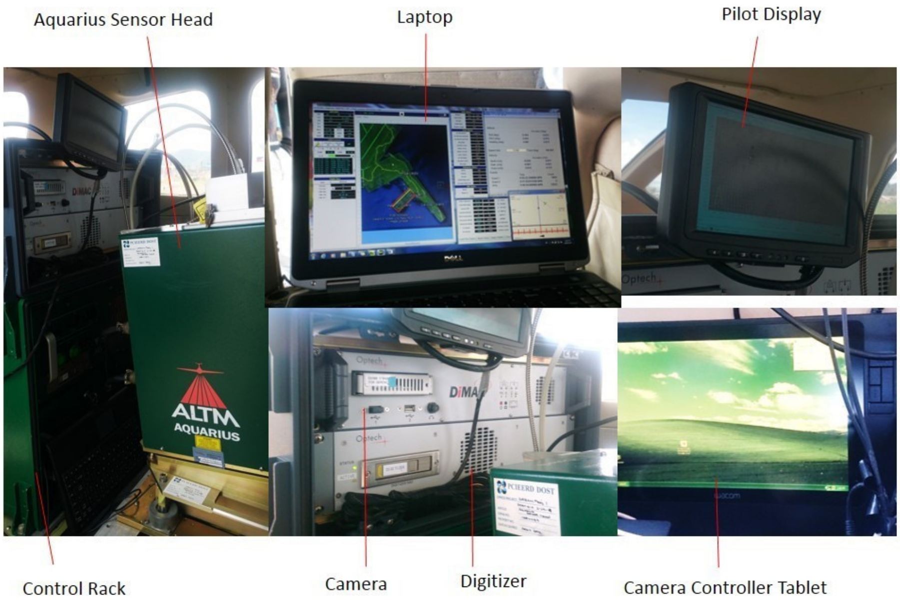



Figure A-1:1 Aquarius Sensor

Table A-1.1 Parameters and Specifications of the Aquarius Sensor

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


Figure A-1.2 Gemini Sensor

Table A-1.2 Parameters and Specifications of the Gemini Sensor

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

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

Table A-2.1. NAMRIA Certification of Reference Points used in the LiDAR Survey

1. MRW-22

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

March 04, 2014

**CERTIFICATION**

To whom it may concern:

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

Province: **OCCIDENTAL MINDORO**
Station Name: **MRW-22**
Order: **2nd**

| | | |
|---|---|---|
| Island: **LUZON** | | Barangay: **TANYAG** |
| Municipality: **CALINTAAN** | | |
| | ***PRS92 Coordinates*** | |
| Latitude: **12° 31' 36.76881"** | Longitude: **120° 59' 13.46492"** | Ellipsoidal Hgt: **35.12700 m.** |
| | ***WGS84 Coordinates*** | |
| Latitude: **12° 31' 31.84278"** | Longitude: **120° 59' 18.53734"** | Ellipsoidal Hgt: **84.27100 m.** |
| | ***PTM Coordinates*** | |
| Northing: **1385214.96 m.** | Easting: **498595.125 m.** | Zone: **3** |
| | ***UTM Coordinates*** | |
| Northing: **1,385,563.72** | Easting: **281,265.62** | Zone: **51** |

Location Description

MRW-22

From Abra de Ilog to San Jose, along Nat'l Road, approx. 9 Km. from Calintaan Town Proper, located Lumintao Bridge at Brgy. Tanyag, Sitio Marilao, Calintaan, Occ. Mindoro. Station is located at the N end of the catwalk of Lumintao Bridge. Mark is the head of a 4 in. copper nail flushed in a cement block embedded in the ground with inscriptions, "MRW-22, 2007, NAMRIA".

Requesting Party: **UP-DREAM**
Pupose: **Reference**
OR Number: **8795470 A**
T.N.: **2014-446**

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

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

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

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

Figure A-2.1. MRW-22

2. MRE-56

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

October 28, 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: **ORIENTAL MINDORO**
Station Name: **MRE-56**
Order: **2nd**

| | | |
|---|---|---|
| Island: **LUZON** | Barangay: | |
| Municipality: **MANSALAY** | MSL Elevation: | |
| | ***PRS92 Coordinates*** | |
| Latitude: **12° 31' 25.76362"** | Longitude: **121° 26' 25.21109"** | Ellipsoidal Hgt: **7.87000 m.** |
| | ***WGS84 Coordinates*** | |
| Latitude: **12° 31' 20.87629"** | Longitude: **121° 26' 30.28143"** | Ellipsoidal Hgt: **58.13600 m.** |
| | ***PTM / PRS92 Coordinates*** | |
| Northing: **1384916.657 m.** | Easting: **547857.861 m.** | Zone: **3** |
| | ***UTM / PRS92 Coordinates*** | |
| Northing: **1,384,892.31** | Easting: **330,530.08** | Zone: **51** |

Location Description

MRE-56

From Calapan City to Bulalacao, along Nat'l Road approx. 4 Km. from Roxas Proper is an intersection of Roxas, Mansalay, Bongabong Road, turn left, approx. 14 Km. travel, right side of Nat'l Road located Mun. Hall of Mansalay, Oriental Mindoro, in front of Mansalay Hospital. Station is located in corner wall of Mun. Park in front of Mun. Hall. Mark is the head of a 4 in. copper nail flushed in a cement block embedded in the ground with inscritions, "MRE-56, 2007, NAMRIA".

Requesting Party: **ENGR. CHRISTOPHER CRUZ**
Purpose: **Reference**
OR Number: **8088472 I**
T.N.: **2015-3523**

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

9 9 1 0 2 8 2 0 1 5 1 3 4 8 1 7

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

CIF/4701/12/07/814

Figure A-2.2. MRE-56

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

Table A-3.1. Baseline Processing Reports of Control Points used in the LiDAR Survey

1. MRW-4203

**Vector Components (Mark to Mark)**

| From: | MRW-22 | | | | |
|---|---|---|---|---|---|
| Grid | | Local | | Global | |
| Easting | 281265.629 m | Latitude | N12°31'36.76881" | Latitude | N12°31'31.84278" |
| Northing | 1385563.717 m | Longitude | E120°59'13.46492" | Longitude | E120°59'18.53734" |
| Elevation | 35.076 m | Height | 35.127 m | Height | 84.271 m |

| To: | MRW-4203 | | | | |
|---|---|---|---|---|---|
| Grid | | Local | | Global | |
| Easting | 296032.858 m | Latitude | N12°21'24.45021" | Latitude | N12°21'19.57700" |
| Northing | 1366637.239 m | Longitude | E121°07'26.92622" | Longitude | E121°07'32.01274" |
| Elevation | 6.991 m | Height | 7.414 m | Height | 57.334 m |

| Vector | | | | | |
|---|---|---|---|---|---|
| ΔEasting | 14767.230 m | NS Fwd Azimuth | 141°36'12" | ΔX | -14844.540 m |
| ΔNorthing | -18926.478 m | Ellipsoid Dist. | 24002.218 m | ΔY | -4238.929 m |
| ΔElevation | -28.085 m | ΔHeight | -27.712 m | ΔZ | -18378.800 m |

Figure A-3.1. Baseline Processing Report - A

2. MRE-56a

| Project information | | Coordinate System | |
|---|---|---|---|
| Name: | | Name: | UTM |
| Size: | | Datum: | WGS 1984 |
| Modified: | 10/12/2012 4:40:11 PM (UTC:-6) | Zone: | 51 North (123E) |
| Time zone: | Mountain Standard Time | Geoid: | EGM96 (Global) |
| Reference number: | | Vertical datum: | |
| Description: | | | |

## Baseline Processing Report

### Processing Summary

| Observation | From | To | Solution Type | H. Prec. (Meter) | V. Prec. (Meter) | ΔX (Meter) | ΔY (Meter) | ΔZ (Meter) | Geodetic Az. | Ellipsoid Dist. (Meter) | ΔHeight (Meter) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MRE56 - 26 --- MRE56a - 26 (B1) | MRE56 - 26 | MRE56a - 26 | Fixed | 0.001 | 0.002 | -3.920 | -0.909 | -8.525 | 156°03'00" | 9.407 | -0.535 |

### Acceptance Summary

| Processed | Passed | Flag | Fail |
|---|---|---|---|
| 1 | 1 | 0 | 0 |

Figure A-3.2. Baseline Processing Report – B

3. MRE-56a (continuation)

**MRE56 - 26 - MRE56a - 26 (6:52:03 AM-10:24:32 AM) (S1)**

| | |
|---|---|
| **Baseline observation:** | MRE56 - 26 --- MRE56a - 26 (B1) |
| **Processed:** | 11/5/2015 5:05:12 PM |
| **Solution type:** | Fixed |
| **Frequency used:** | Dual Frequency (L1, L2) |
| **Horizontal precision:** | 0.001 m |
| **Vertical precision:** | 0.002 m |
| **RMS:** | 0.000 m |
| **Maximum PDOP:** | 12.356 |
| **Ephemeris used:** | Broadcast |
| **Antenna model:** | NGS Absolute |
| **Processing start time:** | 10/26/2015 6:52:03 AM (Local: UTC+8hr) |
| **Processing stop time:** | 10/26/2015 10:24:32 AM (Local: UTC+8hr) |
| **Processing duration:** | 03:32:29 |
| **Processing interval:** | 1 second |

**Vector Components (Mark to Mark)**

| **From:** | MRE56 - 26 | | | | |
|---|---|---|---|---|---|
| **Grid** | | **Local** | | **Global** | |
| **Easting** | 330684.411 m | **Latitude** | N12°31'20.87629" | **Latitude** | N12°31'20.87629" |
| **Northing** | 1384827.258 m | **Longitude** | E121°26'30.28143" | **Longitude** | E121°26'30.28143" |
| **Elevation** | 7.925 m | **Height** | 58.136 m | **Height** | 58.136 m |

| **To:** | MRE56a - 26 | | | | |
|---|---|---|---|---|---|
| **Grid** | | **Local** | | **Global** | |
| **Easting** | 330688.179 m | **Latitude** | N12°31'20.59653" | **Latitude** | N12°31'20.59653" |
| **Northing** | 1384818.639 m | **Longitude** | E121°26'30.40791" | **Longitude** | E121°26'30.40791" |
| **Elevation** | 7.390 m | **Height** | 57.601 m | **Height** | 57.601 m |

| **Vector** | | | | | |
|---|---|---|---|---|---|
| **ΔEasting** | 3.768 m | **NS Fwd Azimuth** | 156°03'00" | **ΔX** | -3.958 m |
| **ΔNorthing** | -8.619 m | **Ellipsoid Dist.** | 9.407 m | **ΔY** | -0.847 m |
| **ΔElevation** | -0.535 m | **ΔHeight** | -0.535 m | **ΔZ** | -8.509 m |

| | | |
|---|---|---|
| 11/5/2015 5:06:23 PM | | Business Center - HCE |

Figure A-3.3. Baseline Processing Report – C

# Annex 4. The LiDAR Survey Team Composition

Table A-4.1. The LiDAR Survey Team Composition

| Data Acquisition Component | Designation | Name | Agency/ Affiliation |
| --- | --- | --- | --- |
| PHIL-LIDAR 1 | Program Leader | ENRICO C. PARINGIT, D.ENG | UP-TCAGP |
| Data Acquisition Component Leader | Data Component Project Leader – I | ENGR. CZAR JAKIRI SARMIENTO | UP-TCAGP |
| Survey Supervisor | Chief Science Research Specialist (CSRS) | ENGR. CHRISTOPHER CRUZ | UP-TCAGP |
| | Supervising Science Research Specialist (Supervising SRS) | LOVELY GRACIA ACUÑA | UP-TCAGP |
| | | LOVELYN ASUNCION | UP-TCAGP |
| FIELD TEAM | | | |
| LiDAR Operation | Senior Science Research Specialist | ENGR. LOVELYN ASUNCION | UP-TCAGP |
| | Research Associate (RA) | ENGR. LARAH KRISELLE PARAGAS | UP-TCAGP |
| | RA | PATRICIA YSABEL ALCANTARA | UP-TCAGP |
| Ground Survey, Data Download and Transfer | RA | GRACE SINADJAN | UP-TCAGP |
| LiDAR Operation | Airborne Security | SSG. ERIC CACANINDIN | PHILIPPINE AIR FORCE (PAF) |
| | Pilot | CAPT. JEFFREY JEREMY ALAJAR | ASIAN AEROSPACE CORPORATION (AAC) |
| | | CAPT. JACKSON JAVIER | AAC |

# Annex 5. Data Transfer Sheets for the Bulalacao Floodplain

Table A-5.1. Data Transfer Sheet for the Bulalacao Floodplain

DATA TRANSFER SHEET
3/19/2014(OCCMIIN)

| 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 | |
| Feb 27, 2014 | 1152A | 3BLK29GSDS8A | AQUARIUS | NA | NA | 1.12MB | 255MB | 73GB | 544KB | 12.6GB | 53.8GB | 15.9MB | 1KB | 1KB | 339KB | 135/556KB | Z:\Airborne_Raw\1152A |
| Feb 27, 2014 | 1154A\ | 3BLK29DS58B | AQUARIUS | NA | NA | NA | 214MB | 39.9GB | 283/29KB | 44.5GB | 9.42GB | 15.9MB | 1KB | 2KB | 687KB | NA | Z:\Airborne_Raw\1154A |
| Feb 28, 2014 | 1156A | 3BLK29F59A | AQUARIUS | NA | NA | 1.72MB | 268MB | 69.5GB | NA | 14.3GB | 69.8GB | 17.1MB | 1KB | 1KB | 352KB | 813KB | Z:\Airborne_Raw\1156A |
| Feb 28, 2014 | 1158A | 3BLK29AS9B | AQUARIUS | NA | NA | 683 KB | 210 MB | 38GB | 95/199KB | 8.14GB | 13.7GB | 17.1MB | 1KB | 1KB | 6/144KB | 424KB | Z:\Airborne_Raw\1158A |
| Mar 1, 2014 | 1160A | 3BLK29C60A | AQUARIUS | NA | NA | 1.03MB | 268MB | 13.5GB | 10/50/40KB | 14.1GB | 57GB | 17.8MB | 1KB | 1KB | 519KB | 399/16KB | Z:\Airborne_Raw\1160A |
| Mar 1, 2014 | 1162A | 3BLK29AS60B | AQUARIUS | NA | NA | 759KB | 199MB | 34.6GB | 147/88KB | 9.54GB | 87.2GB | 17.8MB | 1KB | 1KB | 11/176KB | 445KB | Z:\Airborne_Raw\1162A |
| Mar 2, 2014 | 1164A | 3BLK29N61A | AQUARIUS | NA | NA | 878KB | 293MB | 22.5GB | 147KB | 13.6GB | 73.8GB | 18.4MB | 1KB | 1KB | 237KB | 76/44KB | Z:\Airborne_Raw\1164A |
| Mar 2, 2014 | 1166A | 3BLK29B61B | AQUARIUS | NA | NA | 1.16MB | 230MB | NA | NA | 12.5GB | 144GB | 18.4MB | 1KB | 1KB | 9/242KB | 714/714KB | Z:\Airborne_Raw\1166A |
| Mar 3, 2014 | 1168A | 3BLK29BS62A | AQUARIUS | NA | NA | 2.37MB | 268MB | NA | NA | 12.3GB | 15.7GB | 10.8MB | 1KB | 1KB | 184KB | 300/686/670KB | Z:\Airborne_Raw\1168A |

Received from

Name CHRIS JOAQUIN

Position RA

Signature 042114

Received by

Name JOIDA F. PRIETO

Position SSRS

Signature 042314

Figure A-5.1. Data Transfer Sheet for Bulalacao Floodplain - A

DATA TRANSFER SHEET
Calapan 11/9/15

| 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 | |
| Oct. 22, 2015 | 8300 | 2BLK28ABC295A | Gemini | na | 400 | 675 | 236 | 28.5 | 214 | 18.2 | 247 | 15.6 | 1KB | 1KB | 24 | na | Z:\DAC\RAW DATA |
| Oct. 22, 2015 | 8301 | 2BLK28CSD295B | Gemini | na | 587 | 947 | 249 | 39.1/10.5 | 307/87 | 22.7 | na | 15.6 | 1KB | 1KB | 22/24 | na | Z:\DAC\RAW DATA |
| Oct. 23, 2015 | 8302 | 2BLK28ASEHI296A | Gemini | na | 343 | 593 | 228 | 28.2 | 223 | 14.5 | na | 11.5 | 1KB | 1KB | 22/24 | na | Z:\DAC\RAW DATA |
| Oct. 24, 2015 | 8304 | 2BLK28FHS297A | Gemini | na | 315 | 519 | 214 | 24.8 | 187 | 14.2 | 221 | 8.92 | 1KB | 1KB | 5/11/24/14/13 | na | Z:\DAC\RAW DATA |
| Oct. 25, 2015 | 8306 | 2CALIBBLK28FSGS298A | Gemini | na | 136 | 366 | 220 | na | na | 10.7 | 4.29 | 8.28 | 1KB | 1KB | 28/27 | na | Z:\DAC\RAW DATA |
| Oct. 26, 2015 | 8308 | 2BLK28J299A | Gemini | na | 312 | 356 | 235 | na | na | 14 | 153 | 8.39 | 1KB | 1KB | 7/5/2 | na | Z:\DAC\RAW DATA |
| Oct. 28, 2015 | 8312 | 2BLK28JKLS301A | Gemini | na | 40 | 292 | 215 | na | na | 11 | 427 | 7.5 | 1KB | 1KB | 7 | 270 | Z:\DAC\RAW DATA |

Received from
Name C. JOAQUIN
Position RA
Signature

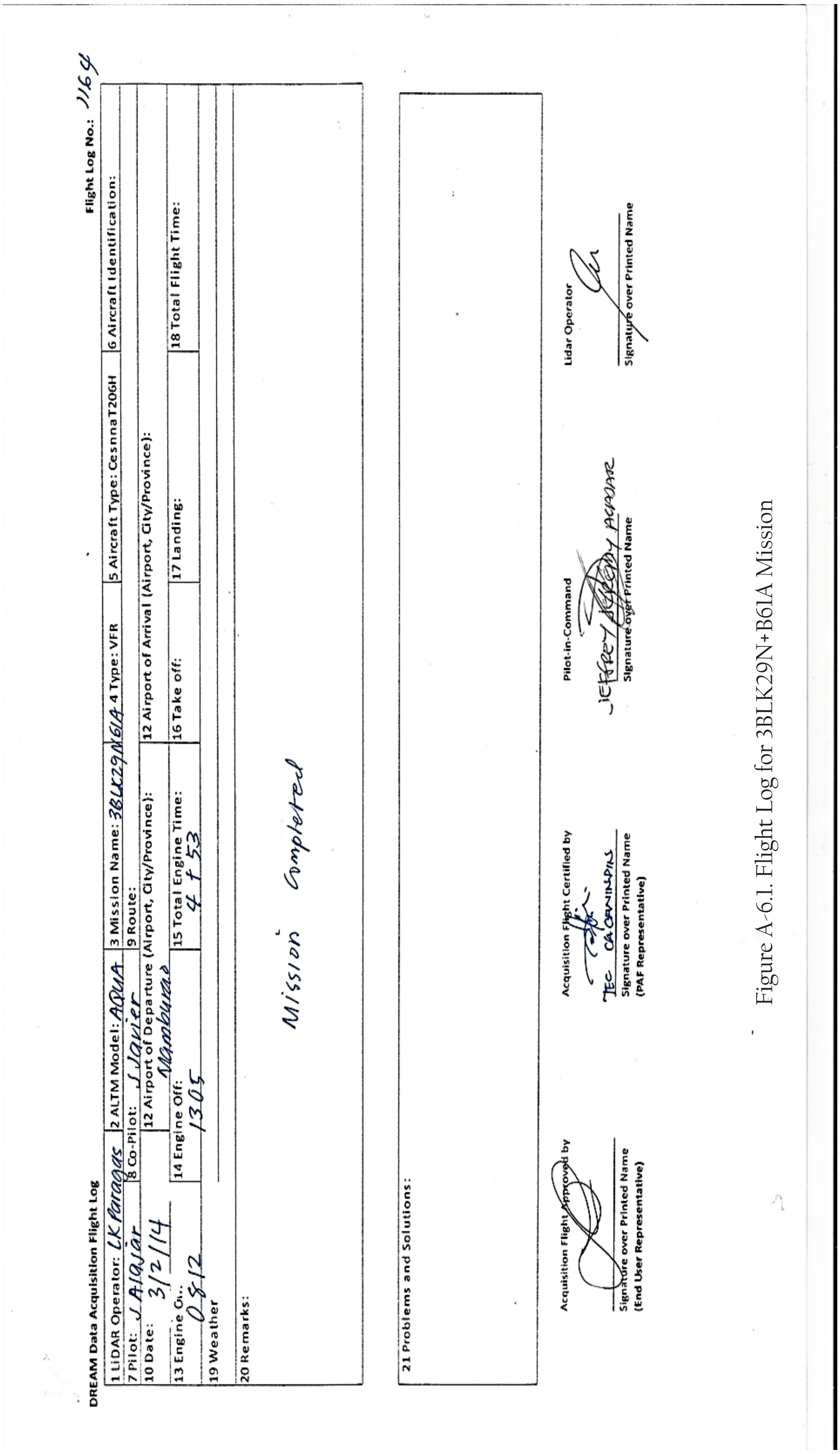
Received by
Name AC Bongat
Position SSRS
Signature 11/12/15

Figure A-5.2. Data Transfer Sheet for Bulalacao Floodplain - B

# Annex 6. FLIGHT LOGS

Table A-6.1. Flight Logs for the Flight Missions

1. Flight Log for 3BLK29N+B61A Mission



Flight Log No.: 1164

**DREAM Data Acquisition Flight Log**

| | | | | | |
|---|---|---|---|---|---|
| 1 LiDAR Operator: LK Paragas | 2 ALTM Model: AQUA | 3 Mission Name: 3BLK29N61A | 4 Type: VFR | 5 Aircraft Type: CesnnaT206H | 6 Aircraft Identification: |
| 7 Pilot: J Alajar | 8 Co-Pilot: J Javier | 9 Route: | | | |
| 10 Date: 3/2/14 | 12 Airport of Departure (Airport, City/Province): Mambucao | | 12 Airport of Arrival (Airport, City/Province): | | |
| 13 Engine On: 0812 | 14 Engine Off: 1305 | 15 Total Engine Time: 4+53 | 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 — TEC CACANINDIN — Signature over Printed Name (PAF Representative)

Pilot-in-Command — JEFFREY ALAJAR — Signature over Printed Name

Lidar Operator — Signature over Printed Name

Figure A-6.1. Flight Log for 3BLK29N+B61A Mission

## 2. Flight Log for 2BLK28J299A Mission

**Data Acquisition Flight Log**

Flight Log No.: 83086

| | | | | | |
|---|---|---|---|---|---|
| 1 LiDAR Operator: MS REYES | 2 ALTM Model: Gemini | 3 Mission Name: 2BLK28J299A | 4 Type: VFR | 5 Aircraft Type: Cesnna T206H | 6 Aircraft Identification: 9322 |
| 7 Pilot: M Tangonan | 8 Co-Pilot: J Mooney | 9 Route: Calapan- Calapan | | | |
| 10 Date: Oct. 26, 2015 | 12 Airport of Departure (Airport, City/Province): Calapan | | 12 Airport of Arrival (Airport, City/Province): Calapan | | |
| 13 Engine On: 0712 | 14 Engine Off: 1103 | 15 Total Engine Time: 3+51 | 16 Take off: 0717 | 17 Landing: 1058 | 18 Total Flight Time: 3+41 |
| 19 Weather: Cloudy | | | | | |

**20 Flight Classification**

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

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

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

**21 Remarks**

Supplemental flight for Blk 28F and covered BLK28J with voids due to clouds. Experienced digitizer hard drive writing error

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

| Acquisition Flight Approved by | Acquisition Flight Certified by | Pilot-in-Command | Lidar Operator | Aircraft Mechanic/ Technician |
|---|---|---|---|---|
| Signature over Printed Name (End User Representative) | Signature over Printed Name (PAF Representative) | Signature over Printed Name | Signature over Printed Name | Signature over Printed Name |

Figure A-6.2. Flight Log for 2BLK28J299A Mission

3. Flight Log for 2BLK28JKLS301A Mission

**Data Acquisition Flight Log** — **Flight Log No.:** 83126

| | | | | | |
|---|---|---|---|---|---|
| 1 LiDAR Operator: MCE BALIGUAS | 2 ALTM Model: Gemini | 3 Mission Name: 2BLK28JKLS 301A | 4 Type: VFR | 5 Aircraft Type: CesnnaT206H | 6 Aircraft Identification: 9322 |
| 7 Pilot: M TANGONAN | 8 Co-Pilot: J MOONEY | 9 Route: Calapan- Calapan | | | |
| 10 Date: Oct. 28, 2015 | 12 Airport of Departure (Airport, City/Province): Calapan | | 12 Airport of Arrival (Airport, City/Province): Calapan | | |
| 13 Engine On: 0840 | 14 Engine Off: 1218 | 15 Total Engine Time: 3+38 | 16 Take off: 0845 | 17 Landing: 1213 | 18 Total Flight Time: 3+28 |
| 19 Weather: Cloudy | | | | | |

20 Flight Classification

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

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

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

21 Remarks

Completed Blk28J and covered additional areas

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

| Acquisition Flight Approved by | Acquisition Flight Certified by | Pilot-in-Command | Lidar Operator | Aircraft Mechanic/ Technician |
|---|---|---|---|---|
| [signature] | AWC CHARLITA NAVARRO PAF | M.C. TANGONAN | [signature] | G. ANTONIO |
| Signature over Printed Name (End User Representative) | Signature over Printed Name (PAF Representative) | Signature over Printed Name | Signature over Printed Name | Signature over Printed Name |

Figure A-6.3. Flight Log for 2BLK28JKLS301A Mission

# Annex 7. Flight Status Report

Table A-7.1. Flight Status Reports

BULALACAO FLOODPLAIN
March 3, 2014; October 26-28, 2015

| FLIGHT NO | AREA | MISSION | OPERATOR | DATE FLOWN | REMARKS |
|---|---|---|---|---|---|
| 1164A | BLK29B & BLK28N | 3BLK29N+B61A | L. PARAGAS | 03-Mar-14 | Mission Complete |
| 8308G | BLK28F & 28J | 2BLK28J299A | S. REYES | 26-Oct-15 | Supplemental flight for BLK28F and covered BLK28J with voids due to clouds. |
| 8312G | BLK28J | 2BLK28JKLS301A | C. BALIGUAS | 28-Oct-15 | Completed BLK28J and covered additional areas. |

**LAS/SWATH BOUNDARIES PER MISSION FLIGHT**

FLIGHT LOG NO. 1164A
AREA: BLK29N AND BLK29B
MISSION NAME: 3BLK29N+B61A

Scan Freq: 40 kHz
Scan Angle: 18 deg
Alt: 600

SURVEY COVERAGE:


Figure A-7.1. Swath for Flight No. 1164A

FLIGHT LOG NO. 8308G
AREA: BLK28F and BLK28J
MISSION NAME: 2BLK28J299A

Scan Freq: 50 kHz
Scan Angle: 18 deg
Alt: 1000

SURVEY COVERAGE:

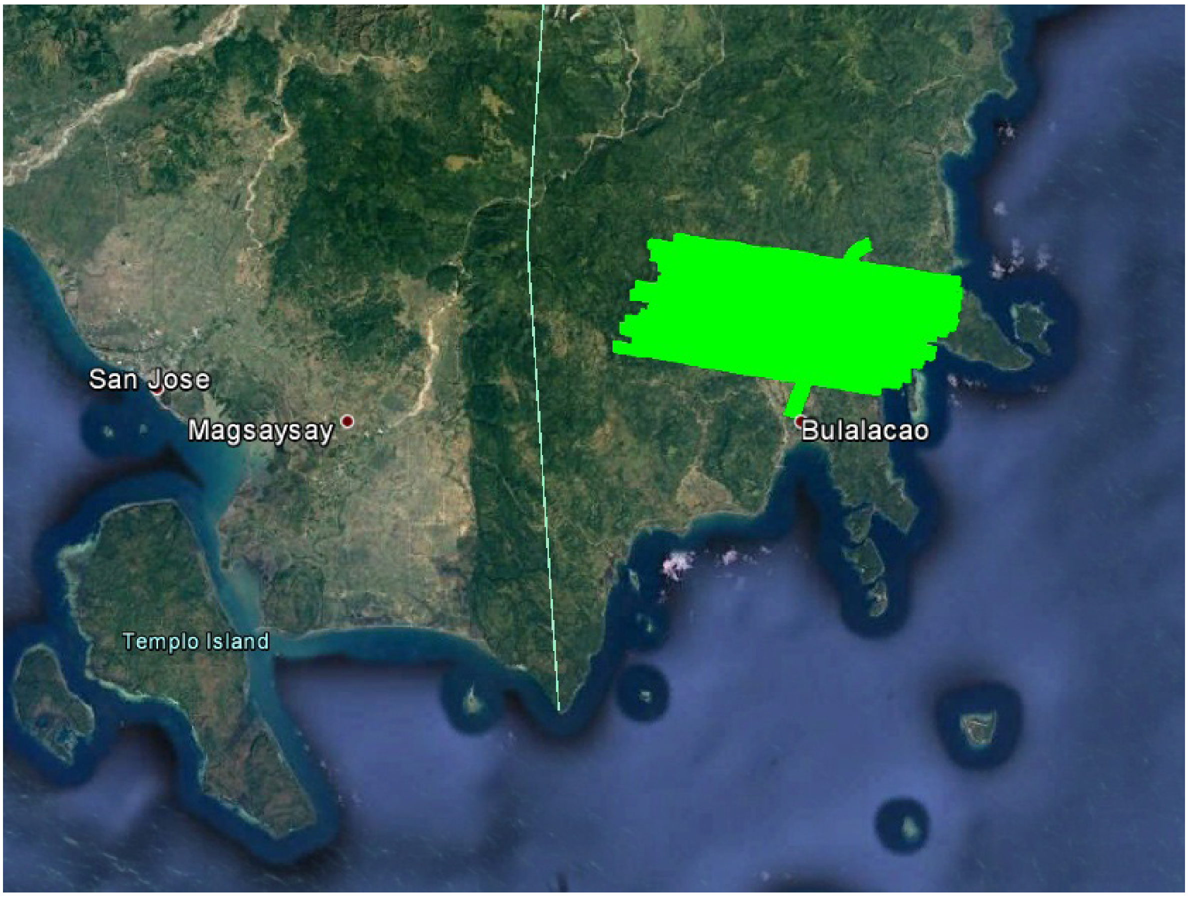



Figure A-7.2. Swath for Flight No. 8308G

FLIGHT LOG NO. 8312G
AREA: BLK28J
MISSION NAME: 2BLK28JKLS301A

Scan Freq: 30 kHz
Scan Angle: 25 deg
Alt: 1000

SURVEY COVERAGE:

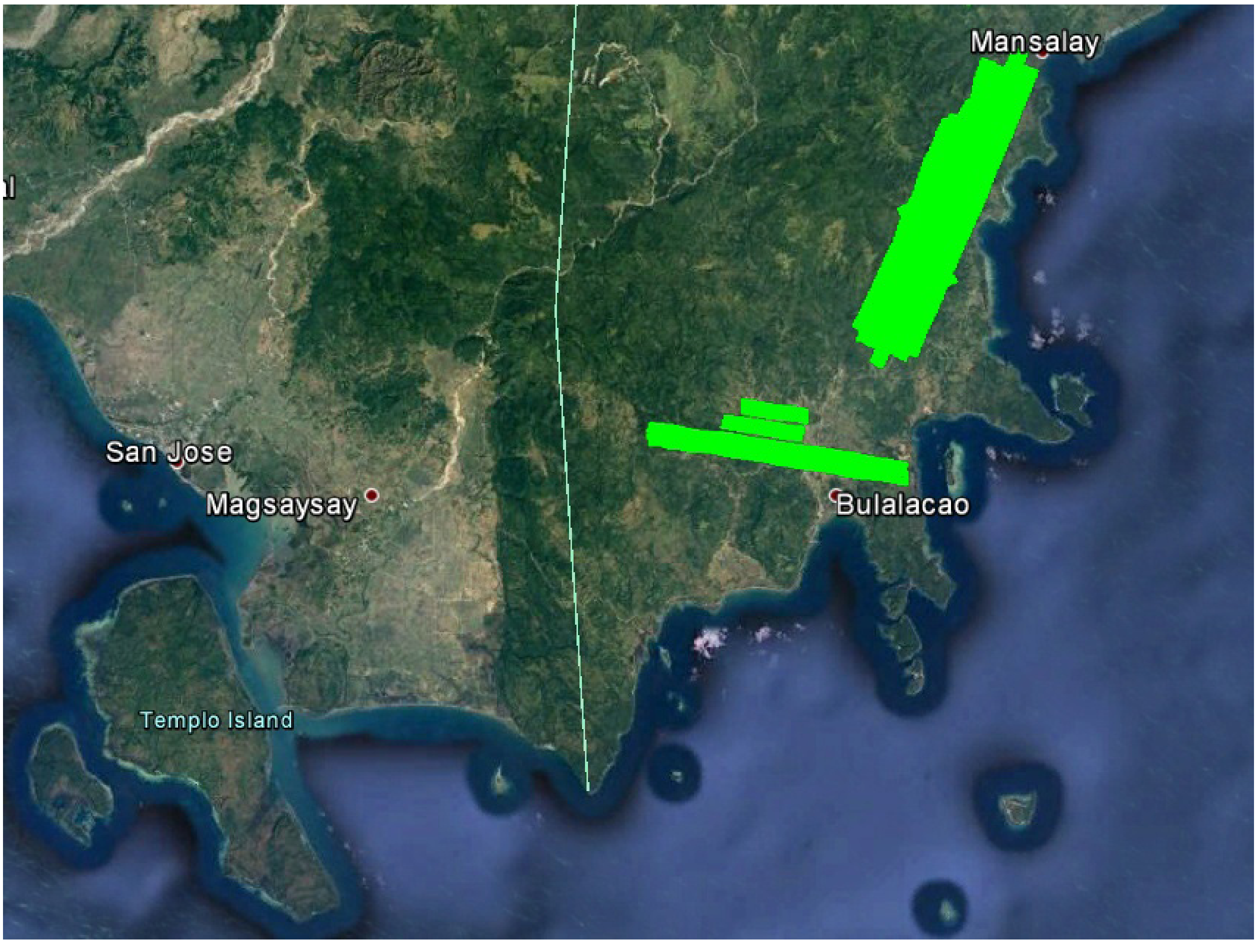



Figure A-7.3. Swath for Flight No. 8312G

## Annex 8. Mission Summary Report

Table A-8.1 Mission Summary Report for Mission Blk29N

| **Flight Area** | **Occidental Mindoro** |
|---|---|
| Mission Name | Blk29N |
| Inclusive Flights | 1164A |
| Range data size | 13.6 GB |
| Base data size | 18.4 MB |
| POS | 293 MB |
| Image | 22.5 GB |
| Transfer date | 04/23/2014 |
| | |
| *Solution Status* | |
| Number of Satellites (>6) | No |
| PDOP (<3) | No |
| Baseline Length (<30km) | No |
| Processing Mode (<=1) | No |
| | |
| *Smoothed Performance Metrics (in cm)* | |
| RMSE for North Position (<4.0 cm) | 8 |
| RMSE for East Position (<4.0 cm) | 4.5 |
| RMSE for Down Position (<8.0 cm) | 7.6 |
| | |
| Boresight correction stdev (<0.001deg) | 0.000267 |
| IMU attitude correction stdev (<0.001deg) | 0.024537 |
| GPS position stdev (<0.01m) | 0.0335 |
| | |
| Minimum % overlap (>25) | 35.59% |
| Ave point cloud density per sq.m. (>2.0) | 3.31 |
| Elevation difference between strips (<0.20 m) | Yes |
| | |
| Number of 1km x 1km blocks | 122 |
| Maximum Height | 437.8 m |
| Minimum Height | 42.88 m |

| | |
|---|---|
| *Classification (# of points)* | |
| Ground | 61887640 |
| Low vegetation | 62034376 |
| Medium vegetation | 66935608 |
| High vegetation | 40368994 |
| Building | 1397397 |
| | |
| Orthophoto | Yes |
| Processed by | Engr. Jeffrey Delica, Engr. Charmaine Cruz, Ma. Victoria Rejuso |

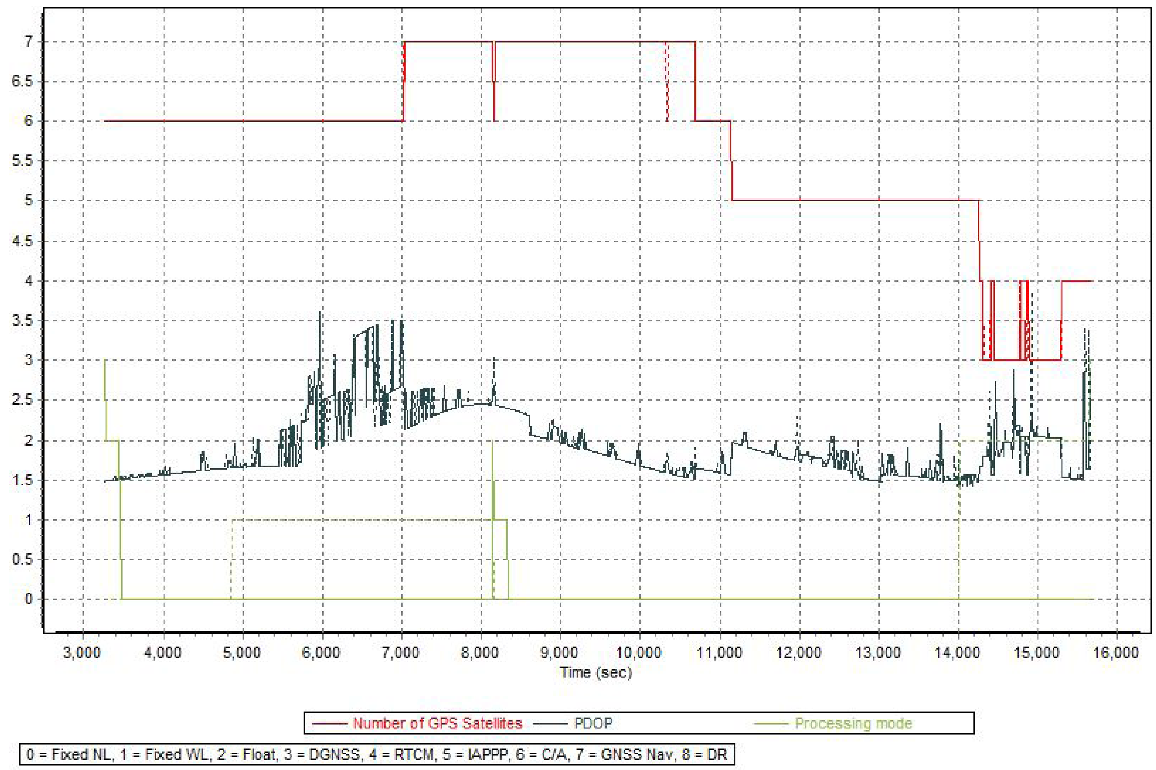



Figure A-8.1 Solution Status

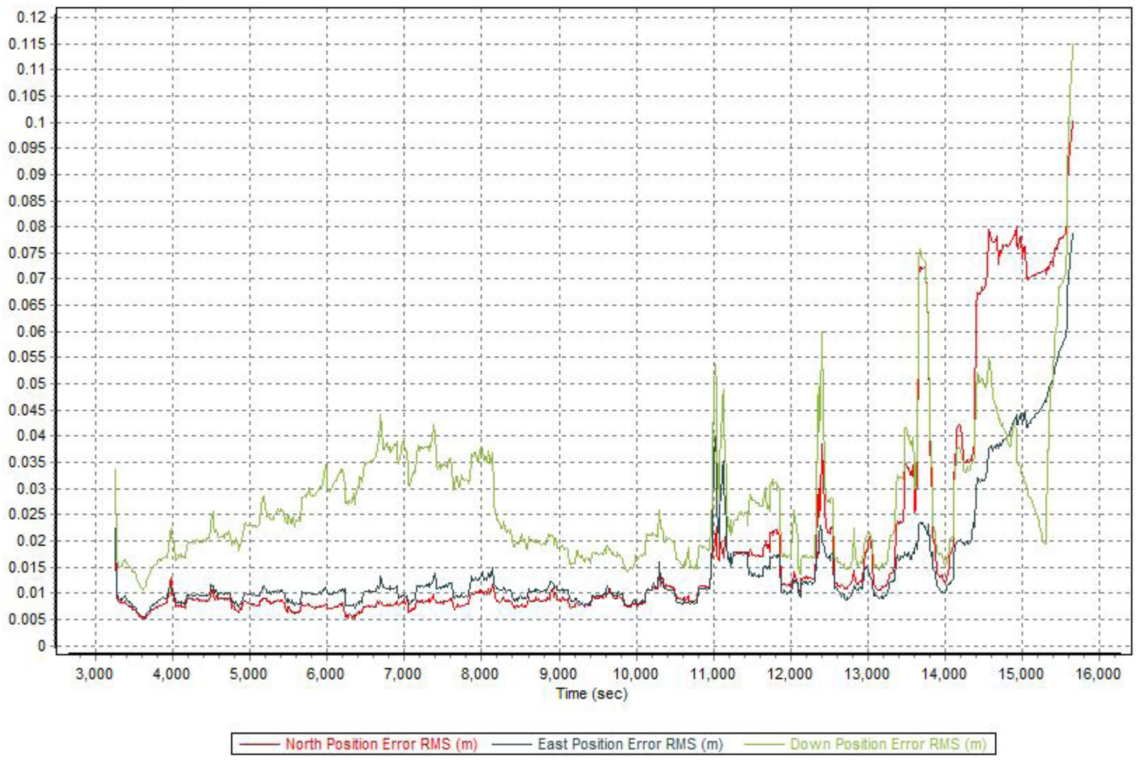



Figure A-8.2 Smoothed Performance Metrics Parameters

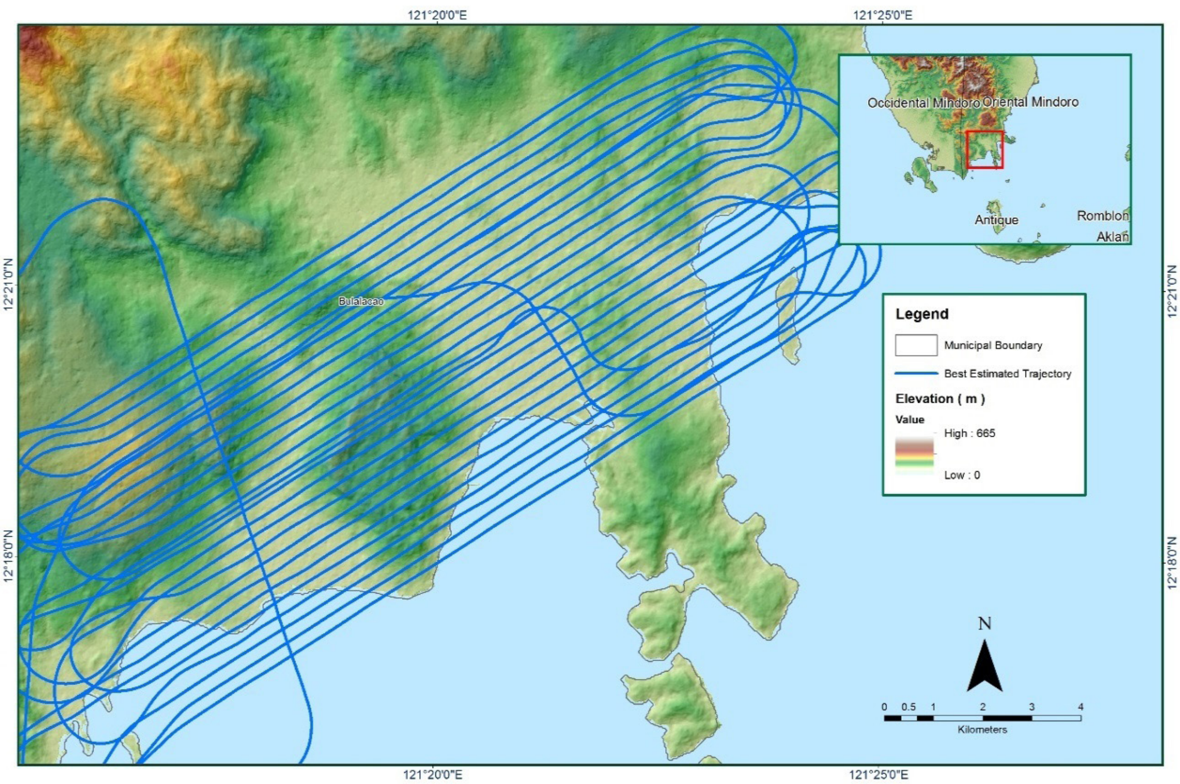



Figure A-8.3 Best Estimated Trajectory

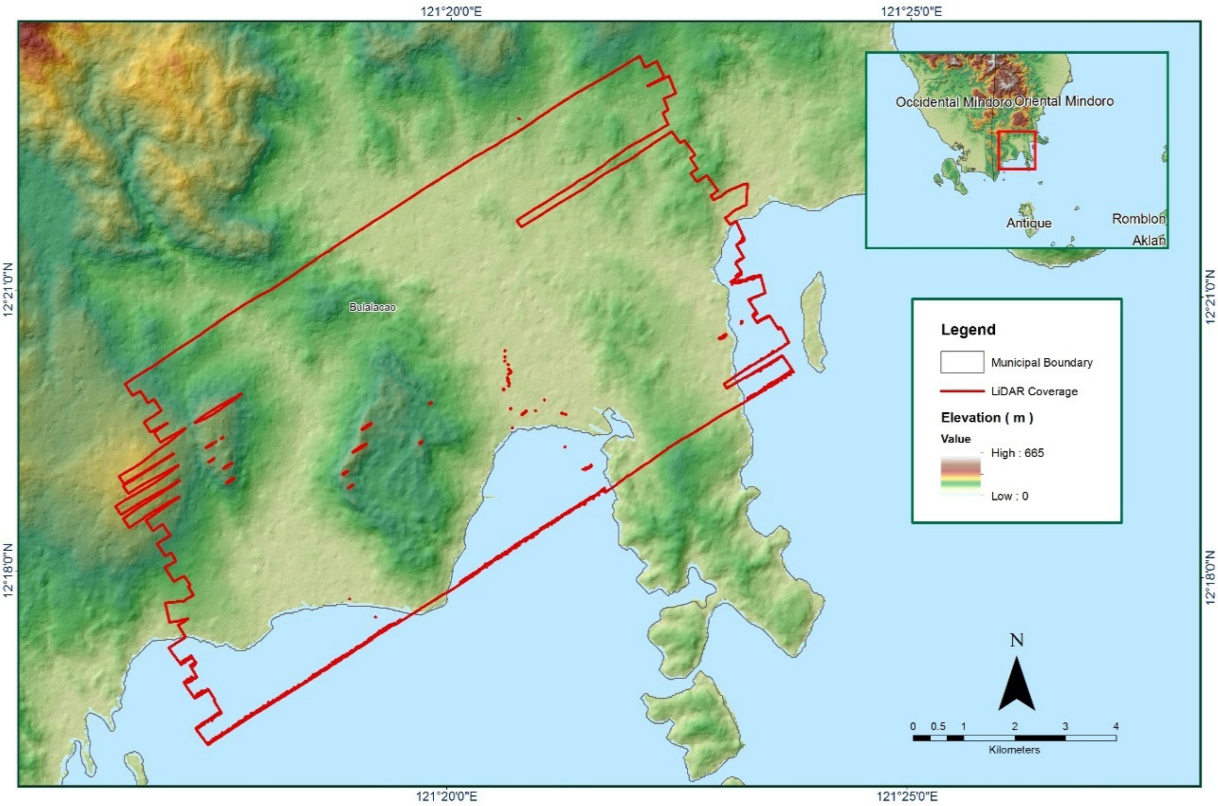



Figure A-8.4. Coverage of LiDAR data

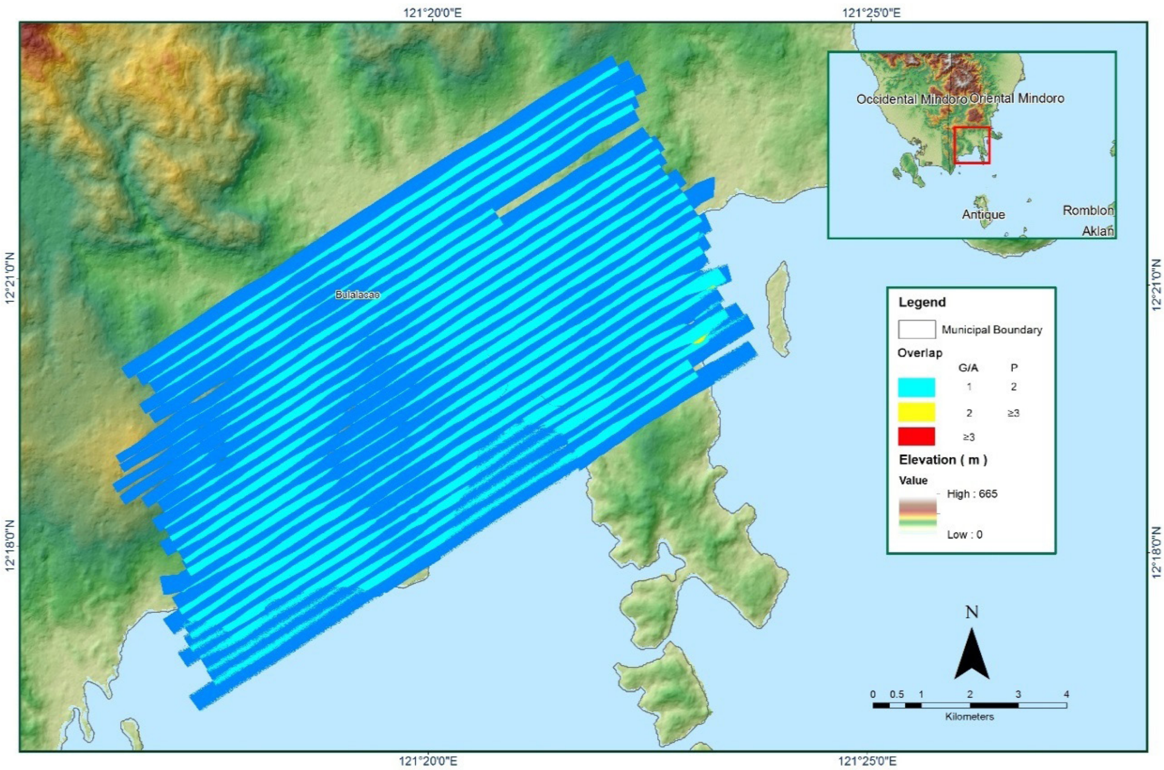



Figure A-8.5. Image of data overlap

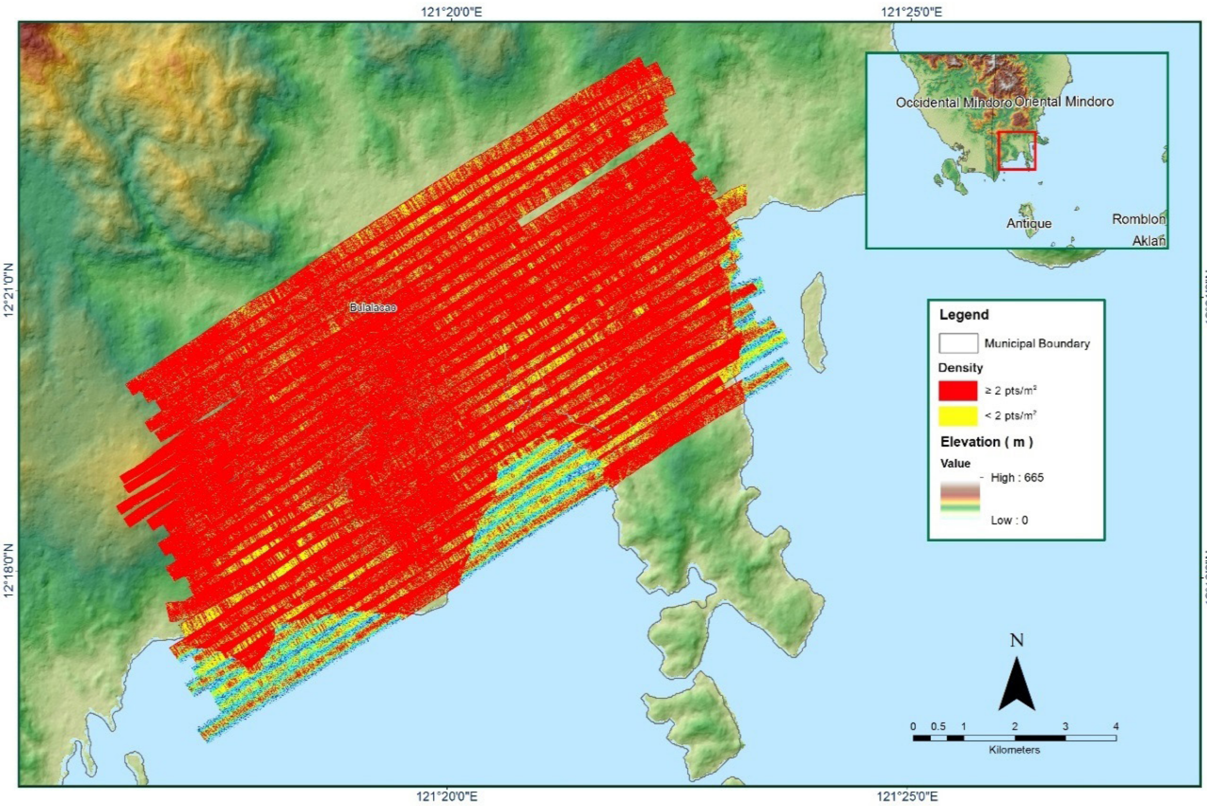



Figure A-8.6 Density of merged LiDAR data

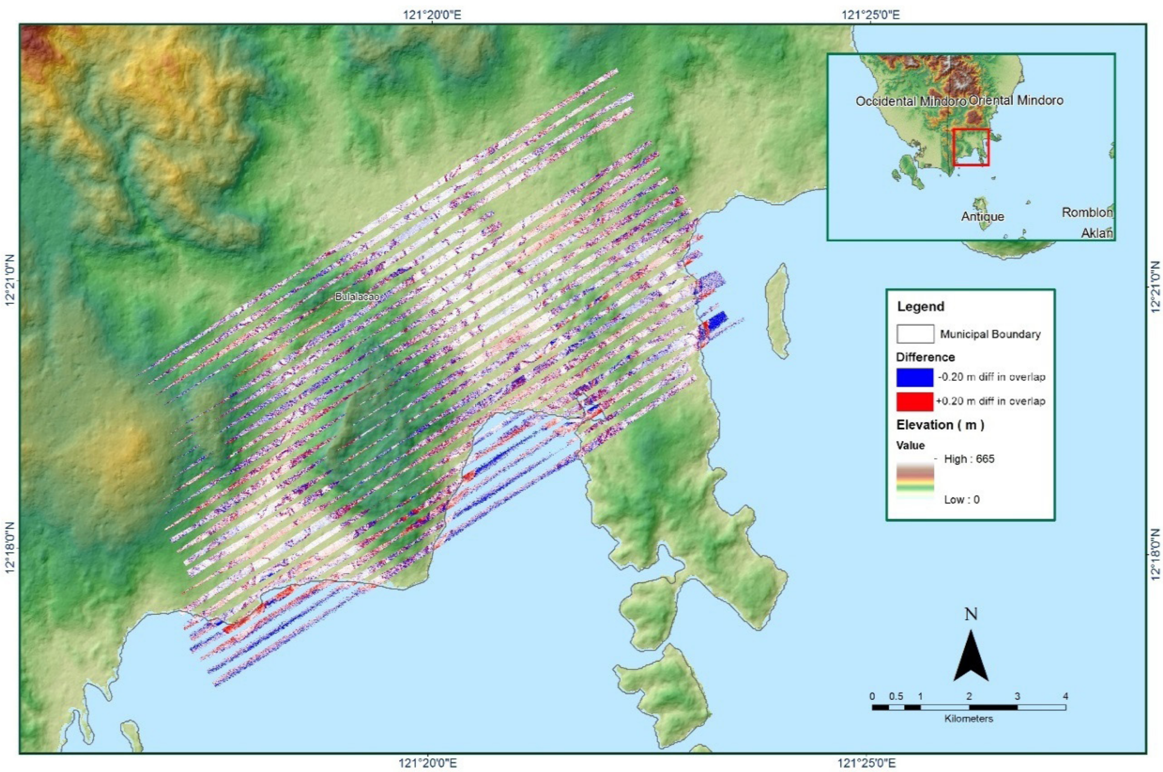



Figure A-8.7. Elevation difference between flight lines

Table A-8.2 Mission Summary Report for Mission Blk29N_Additional

| Flight Area | Occidental Mindoro |
|---|---|
| Mission Name | Blk29N_Additional |
| Inclusive Flights | 1164A |
| Range data size | 13.6 GB |
| Base data size | 18.4 MB |
| POS | 293 MB |
| Image | 22.5 GB |
| Transfer date | 04/23/2014 |
| | |
| *Solution Status* | |
| Number of Satellites (>6) | No |
| PDOP (<3) | No |
| Baseline Length (<30km) | No |
| Processing Mode (<=1) | No |
| | |
| *Smoothed Performance Metrics (in cm)* | |
| RMSE for North Position (<4.0 cm) | 8 |
| RMSE for East Position (<4.0 cm) | 4.5 |
| RMSE for Down Position (<8.0 cm) | 7.6 |
| | |
| Boresight correction stdev (<0.001deg) | 0.000267 |
| IMU attitude correction stdev (<0.001deg) | 0.024537 |
| GPS position stdev (<0.01m) | 0.0335 |
| | |
| Minimum % overlap (>25) | 0% |
| Ave point cloud density per sq.m. (>2.0) | 2.42 |
| Elevation difference between strips (<0.20 m) | Yes |
| | |
| Number of 1km x 1km blocks | 30 |
| Maximum Height | 335.92 m |
| Minimum Height | 45.5 m |

| | |
|---|---|
| *Classification (# of points)* | |
| Ground | 3201396 |
| Low vegetation | 2462935 |
| Medium vegetation | 2699860 |
| High vegetation | 1313234 |
| Building | 39009 |
| Orthophoto | No |
| Processed by | Ma. Victoria Rejuso, Engr. Christy Lubiano, Kathryn Claudyn Zarate |
| Processed by | Engr. Jeffrey Delica, Engr. Charmaine Cruz, Ma. Victoria Rejuso |

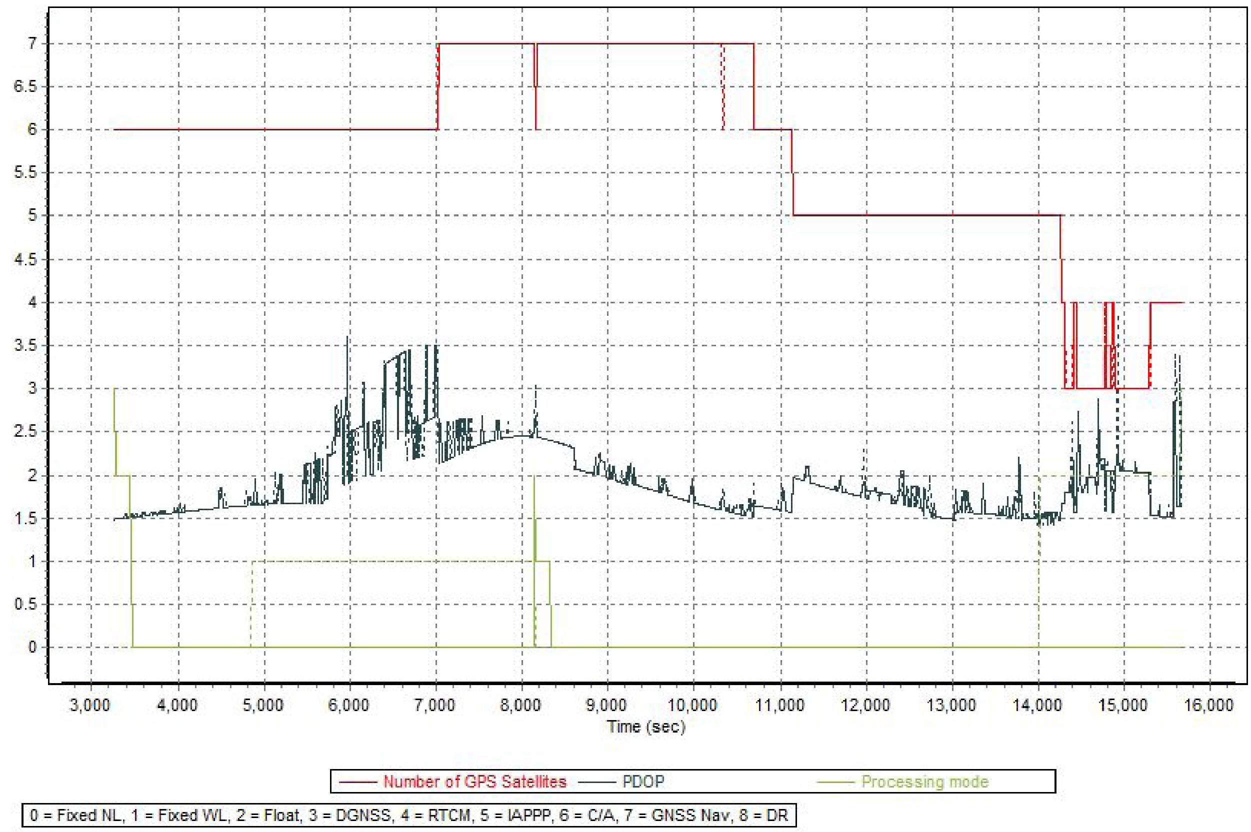



Figure A-8.8. Solution Status

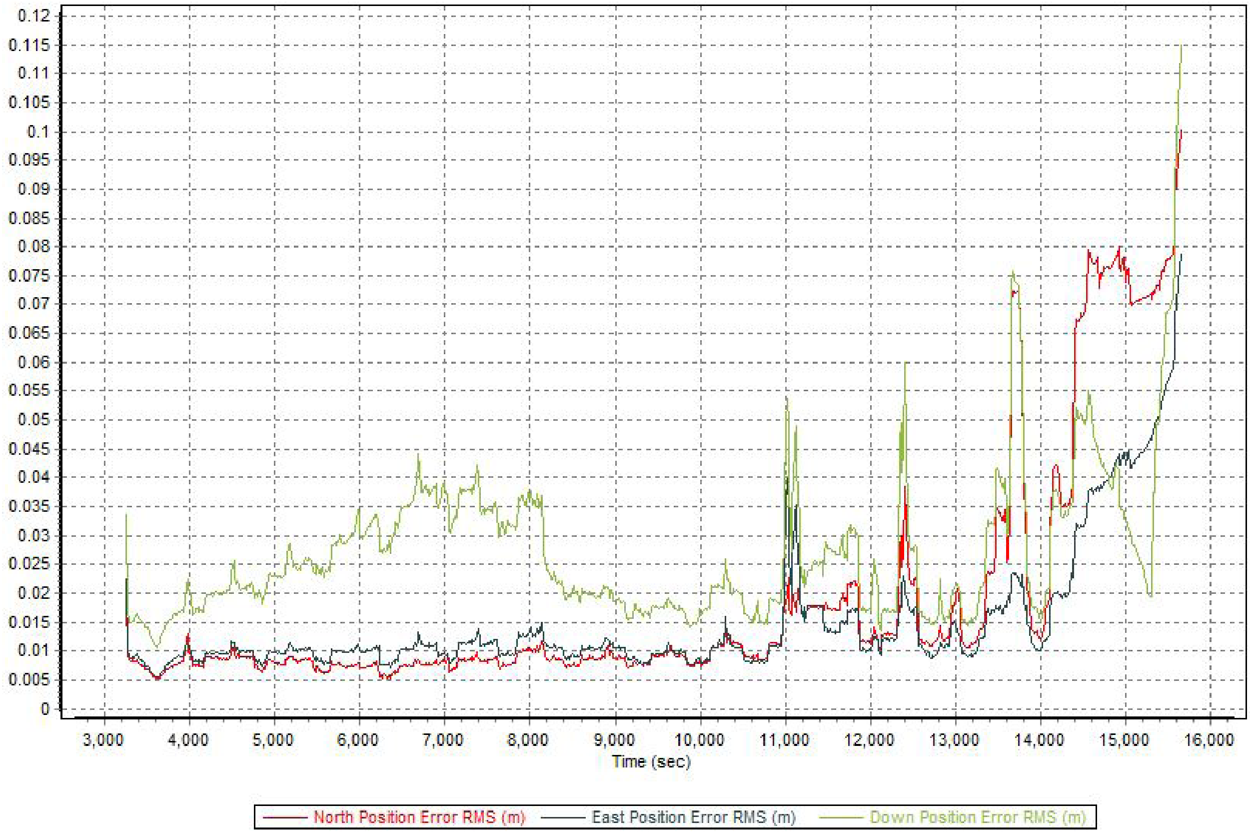



Figure A-8.9. Smoothed Performance Metrics Parameters

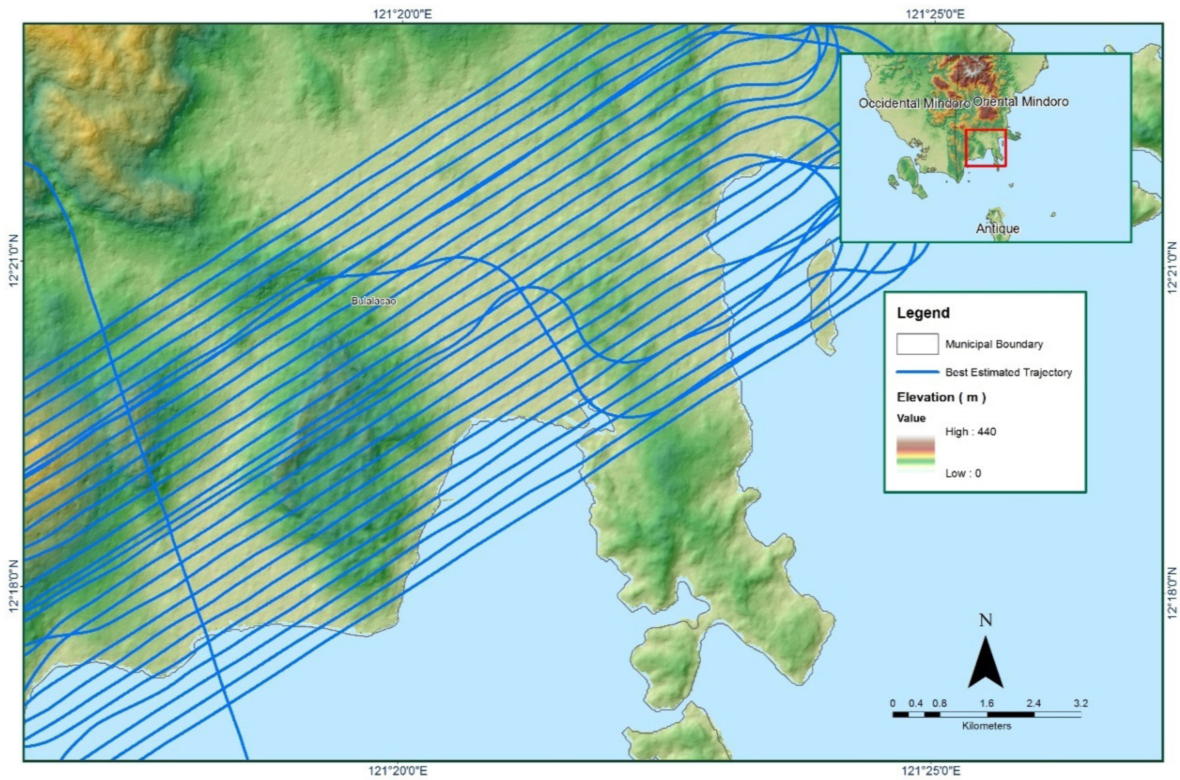



Figure A-8.10. Best Estimated Trajectory

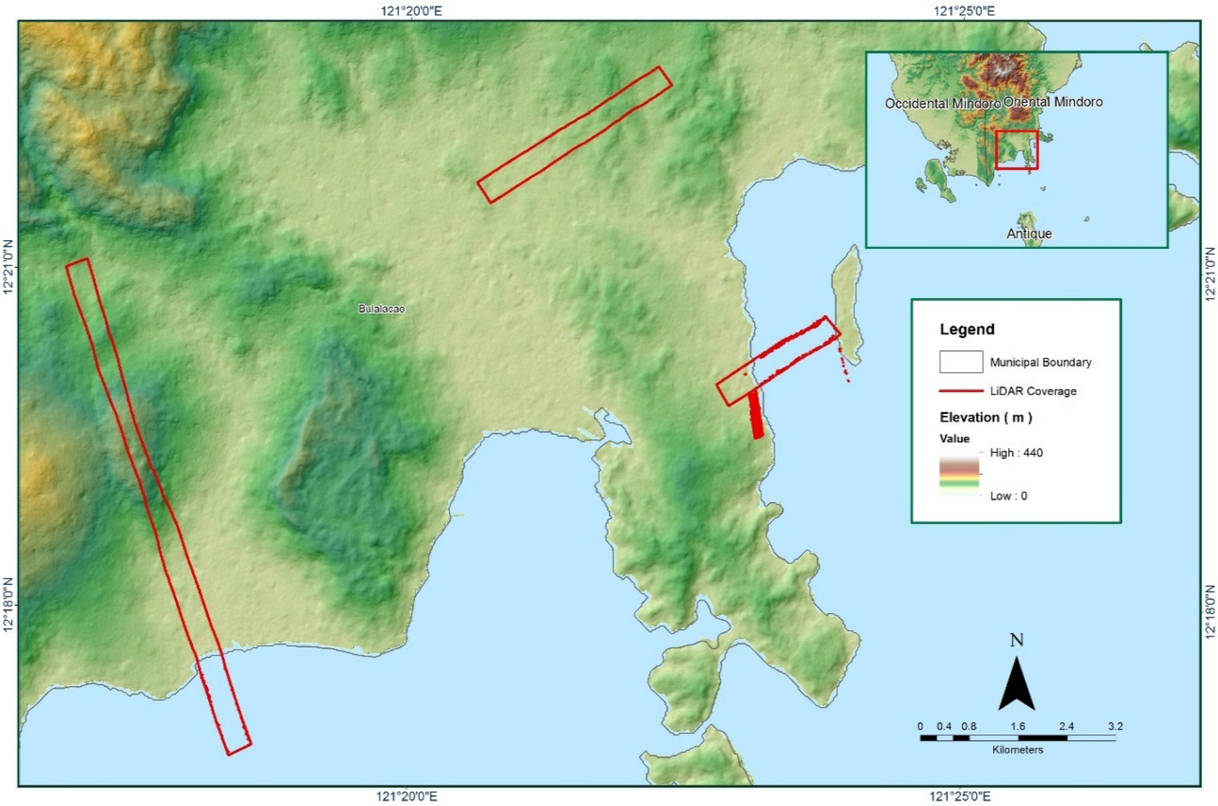



Figure A-8.11. Coverage of LiDAR data

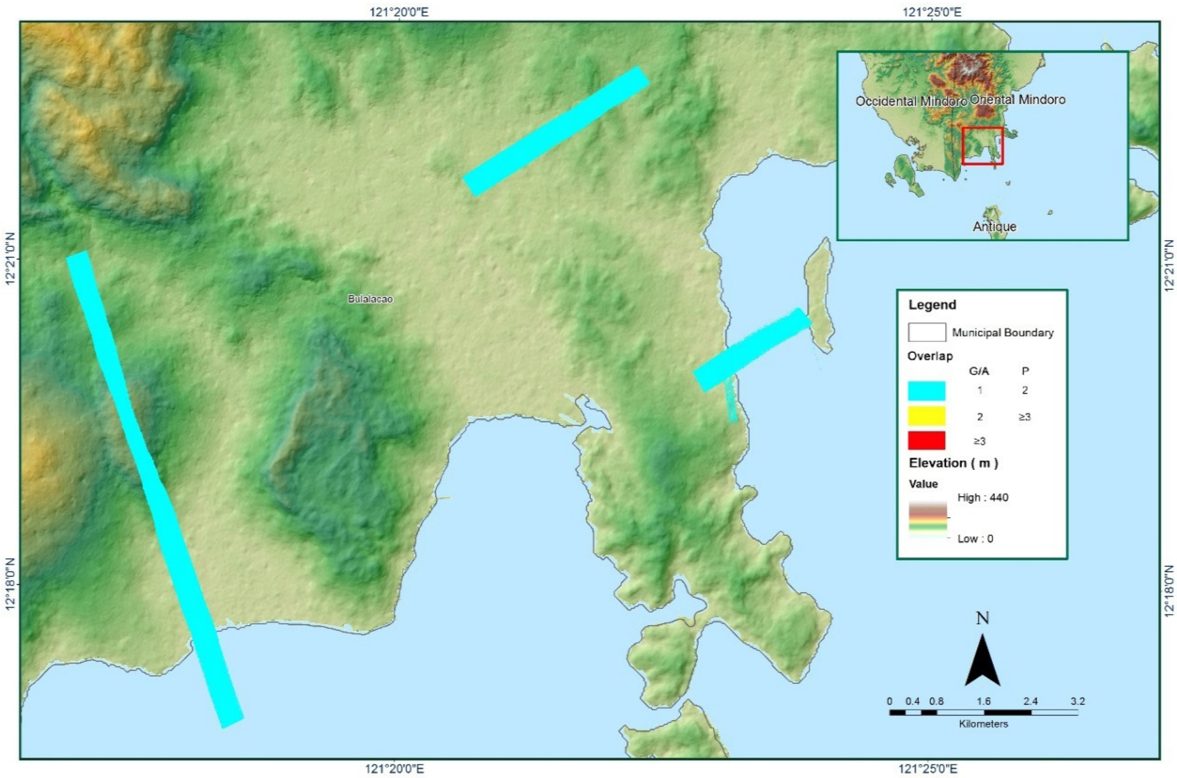



Figure A-8.12. Image of data overlap

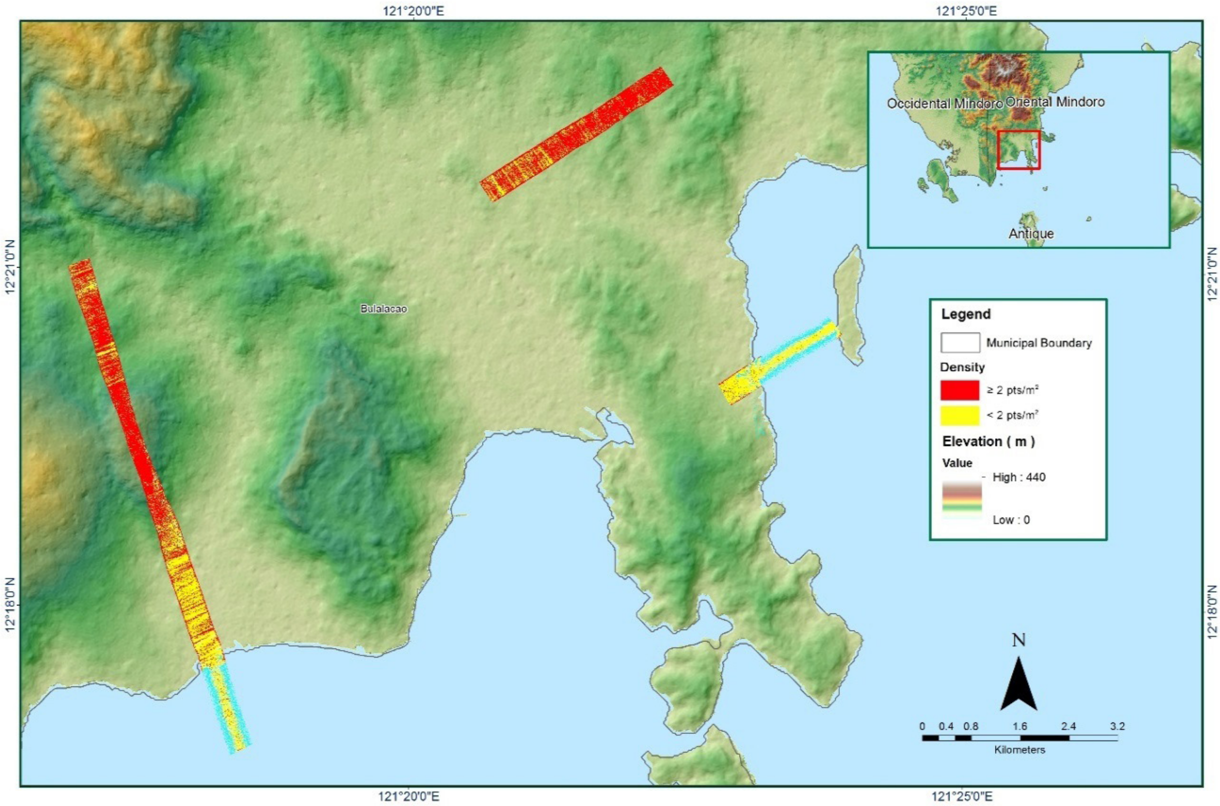



Figure A-8.13. Density of merged LiDAR data

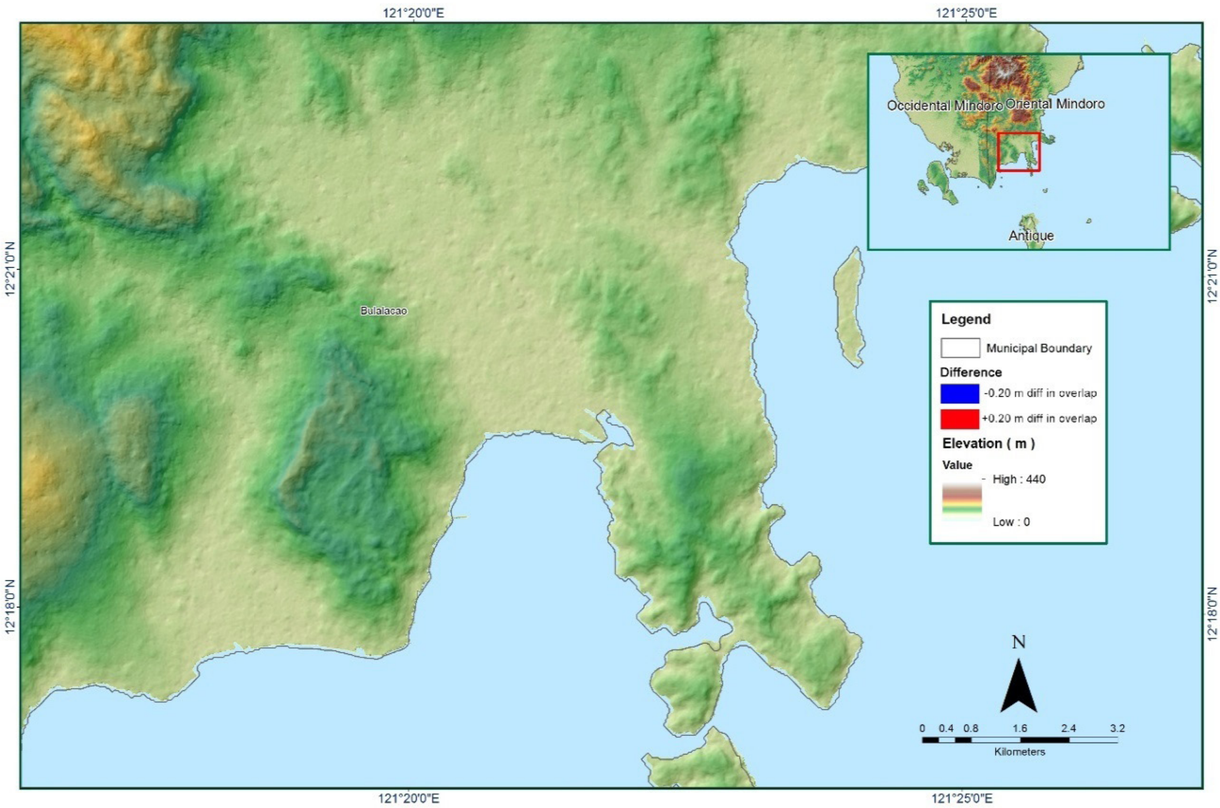



Figure A-8.14. Elevation difference between flight lines

Table A-8.3 Mission Summary Report for Mission Blk28J

| Flight Area | Occidental Mindoro |
|---|---|
| Mission Name | Blk28J |
| Inclusive Flights | 8312G |
| Range data size | 11 GB |
| Base data size | 7.5 MB |
| POS | 215 MB |
| Image | NA |
| Transfer date | November 12, 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) | 1.12 |
| RMSE for East Position (<4.0 cm) | 1.45 |
| RMSE for Down Position (<8.0 cm) | 3.38 |
| | |
| Boresight correction stdev (<0.001deg) | 0.00062 |
| IMU attitude correction stdev (<0.001deg) | 0.000960 |
| GPS position stdev (<0.01m) | 0.0023 |
| | |
| Minimum % overlap (>25) | 39.08 |
| Ave point cloud density per sq.m. (>2.0) | 5.00 |
| Elevation difference between strips (<0.20 m) | Yes |
| | |
| Number of 1km x 1km blocks | 69 |
| Maximum Height | 687.61 |
| Minimum Height | 52.94 |

| *Classification (# of points)* | |
|---|---|
| Ground | 18,058,835 |
| Low vegetation | 15,128,654 |
| Medium vegetation | 68,946,595 |
| High vegetation | 116,052,339 |
| Building | 1,828,719 |
| | |
| Orthophoto | No |
| Processed by | Engr. Irish Cortez, Engr. Chelou Prado, Kathryn Claudyn Zarate |

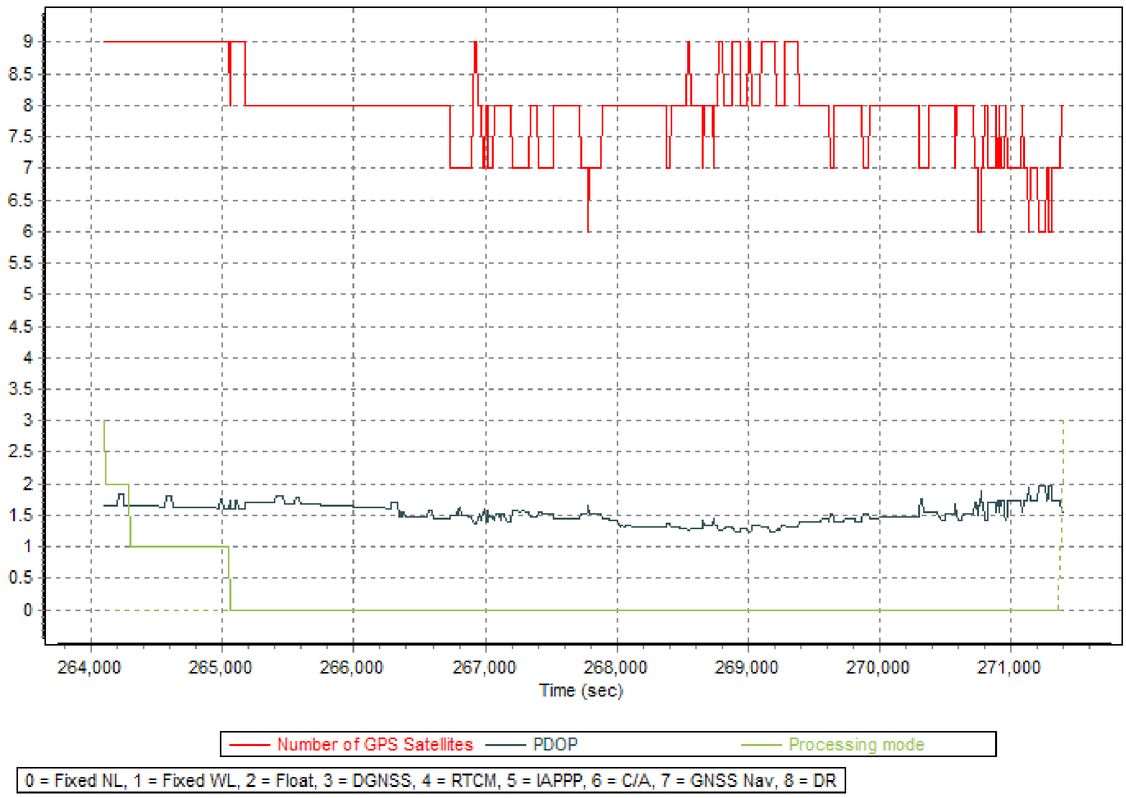



Figure A-8.15. Solution Status

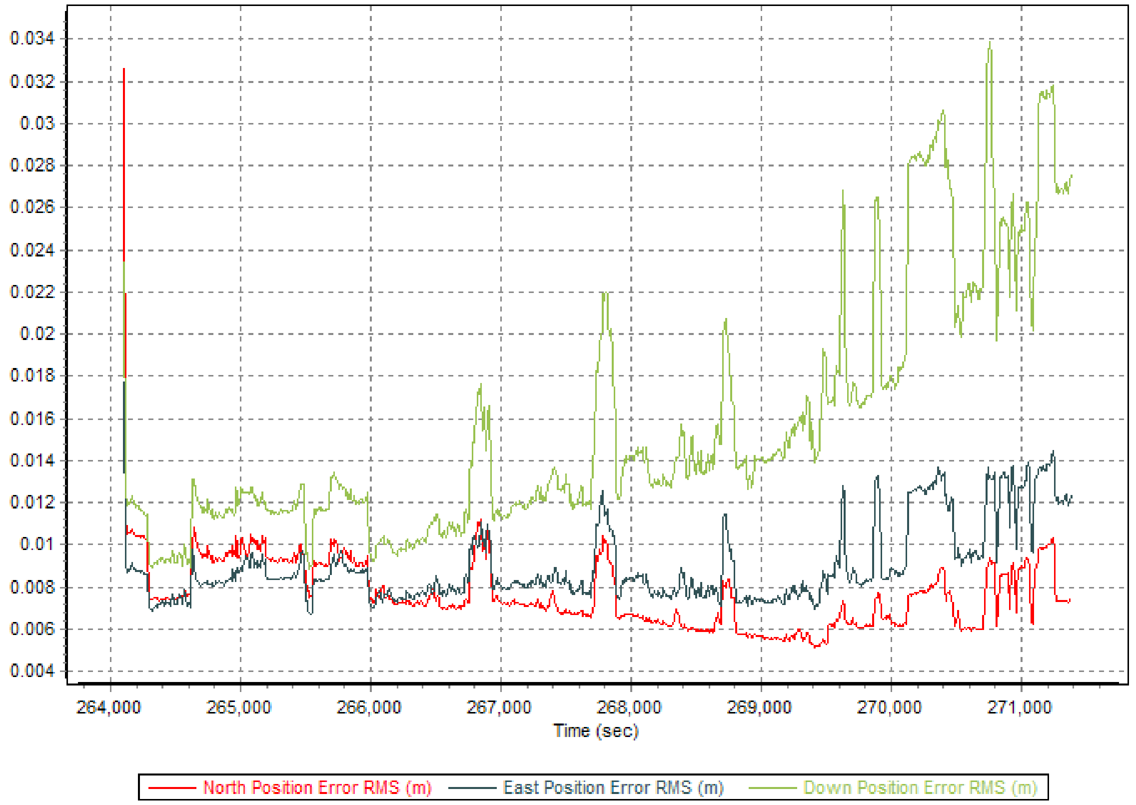



Figure A-8.16. Smoothed Performance Metrics Parameters

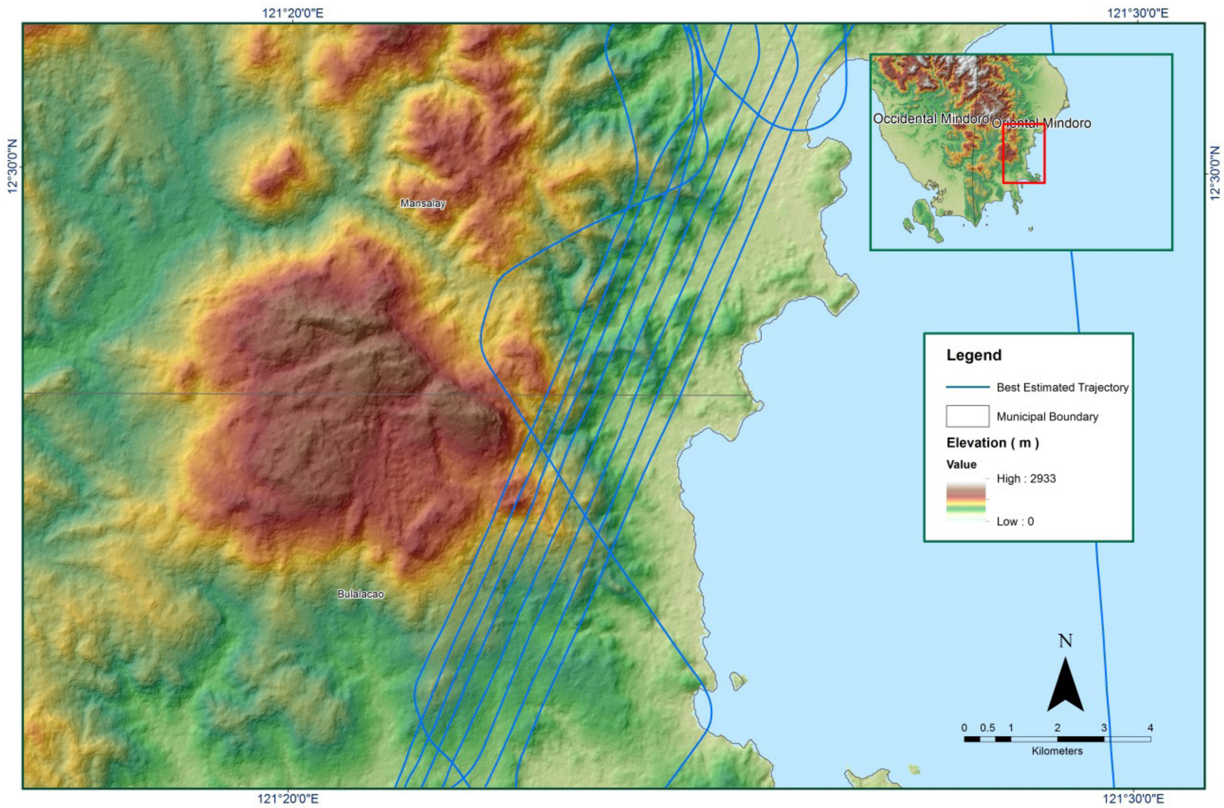



Figure A-8.17. Best Estimated Trajectory

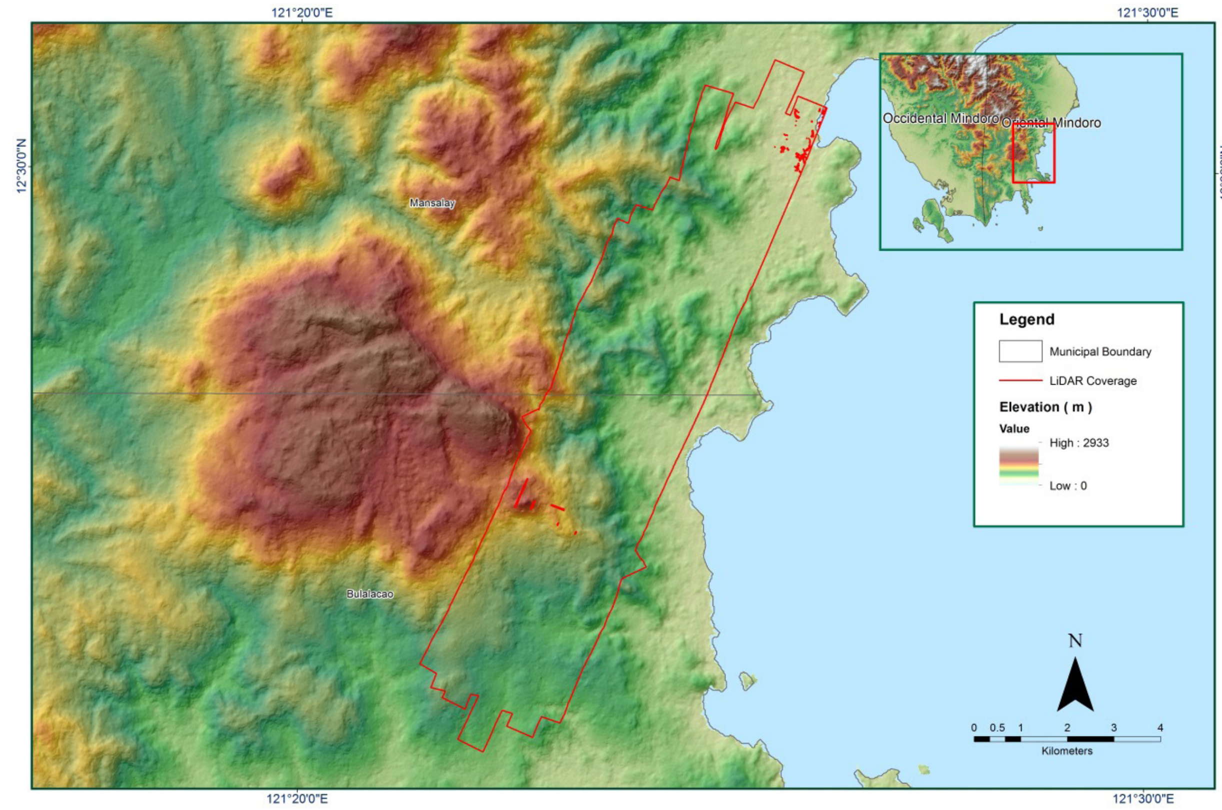



Figure A-8.18. Coverage of LiDAR data

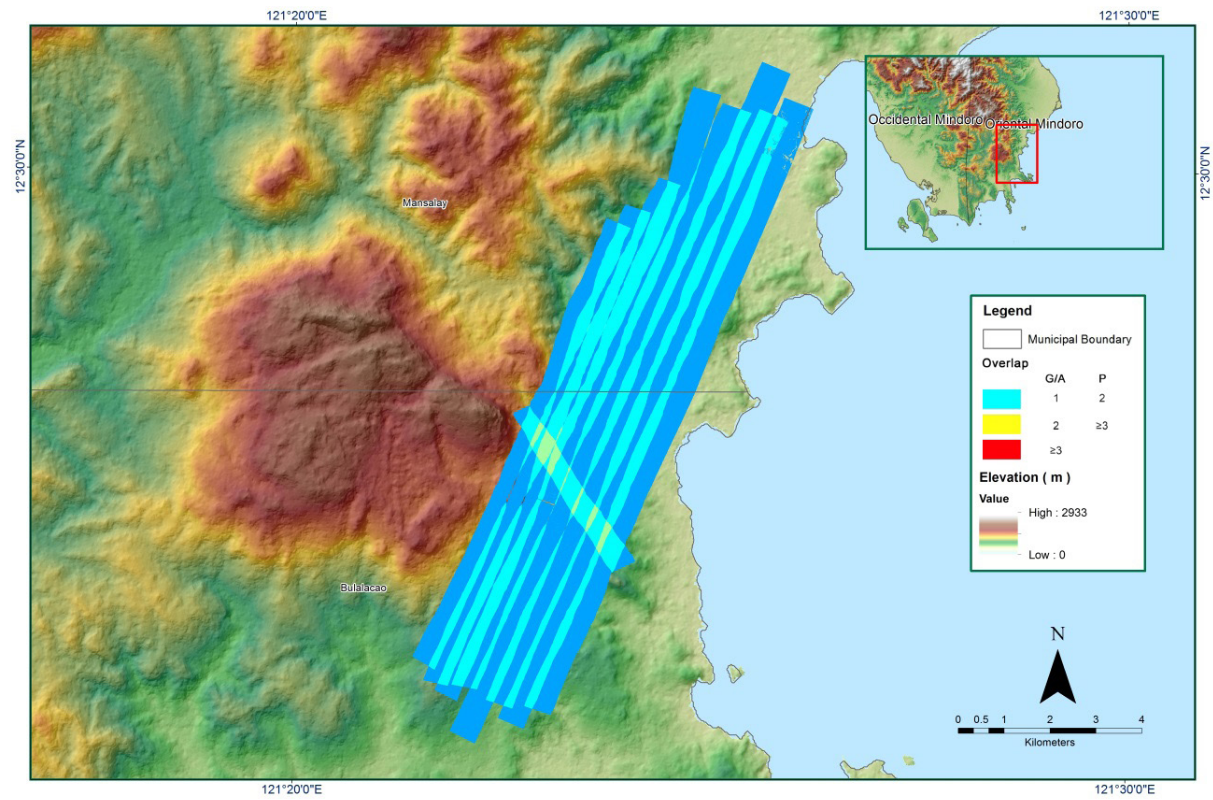



Figure A-8.19. Image of data overlap

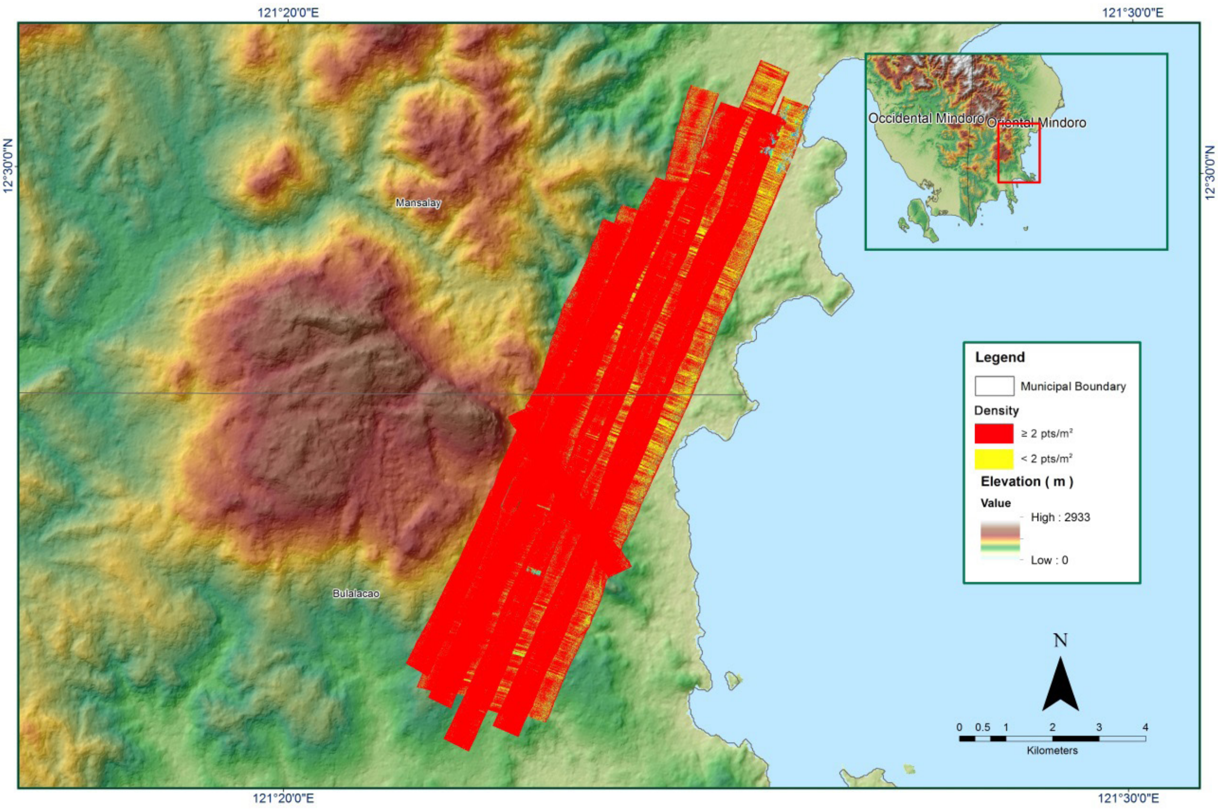



Figure A-8.20. Density of merged LiDAR data

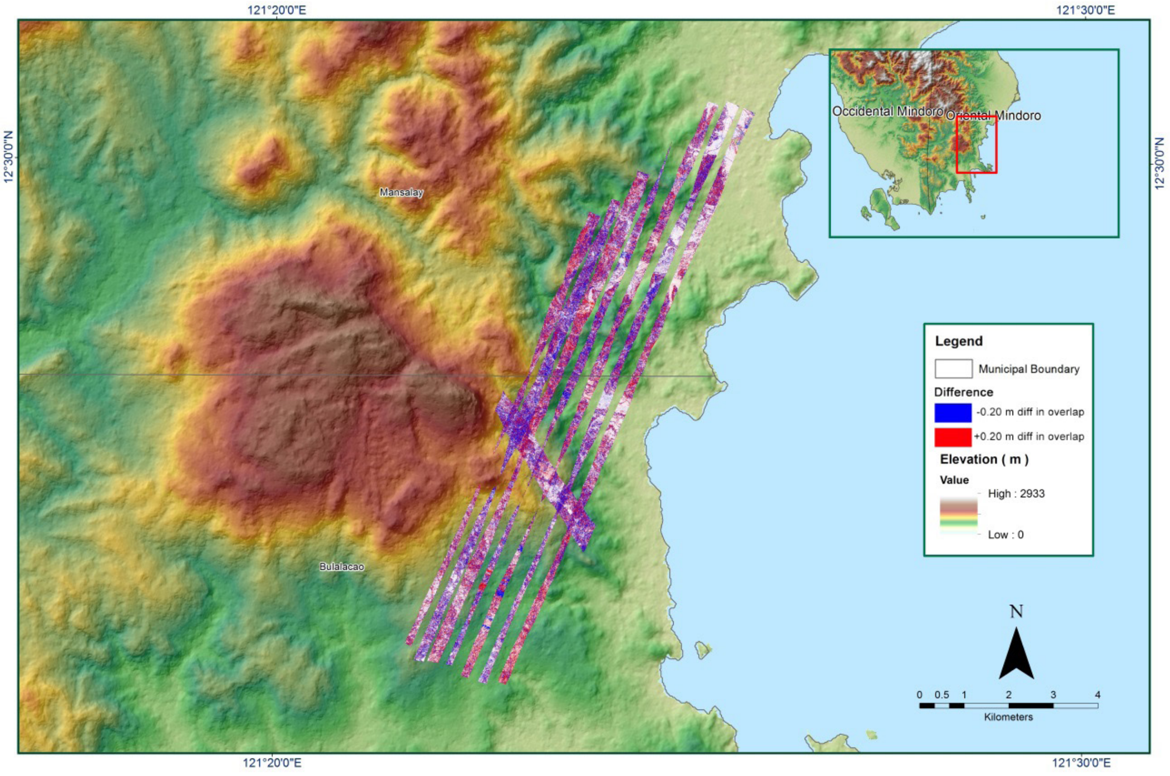



Figure A-8.21. Elevation difference between flight lines

Table A-8.4 Mission Summary Report for Mission Blk28K

| Flight Area | Oriental Mindoro Reflights |
|---|---|
| Mission Name | Blk28K |
| Inclusive Flights | 8308G |
| Range data size | 14 GB |
| Base data size | 8.39 MB |
| POS | 235 MB |
| Image | NA |
| Transfer date | November 12, 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) | 1.45 |
| RMSE for East Position (<4.0 cm) | 1.14 |
| RMSE for Down Position (<8.0 cm) | 3.04 |
| | |
| Boresight correction stdev (<0.001deg) | 0.000246 |
| IMU attitude correction stdev (<0.001deg) | 0.000970 |
| GPS position stdev (<0.01m) | 0.0019 |
| | |
| Minimum % overlap (>25) | 39.98 |
| Ave point cloud density per sq.m. (>2.0) | 4.23 |
| Elevation difference between strips (<0.20 m) | Yes |
| | |
| Number of 1km x 1km blocks | 123 |
| Maximum Height | 547.69 |
| Minimum Height | 38.91 |

| | |
|---|---|
| Classification (# of points) | |
| Ground | 38,834,654 |
| Low vegetation | 41,738,943 |
| Medium vegetation | 11,8045739 |
| High vegetation | 140,295,506 |
| Building | 1,496,836 |
| | |
| Orthophoto | No |
| Processed by | Engr. Irish Cortez, Engr. Edgardo Gubatanga, Jr., Alex John Escobido |

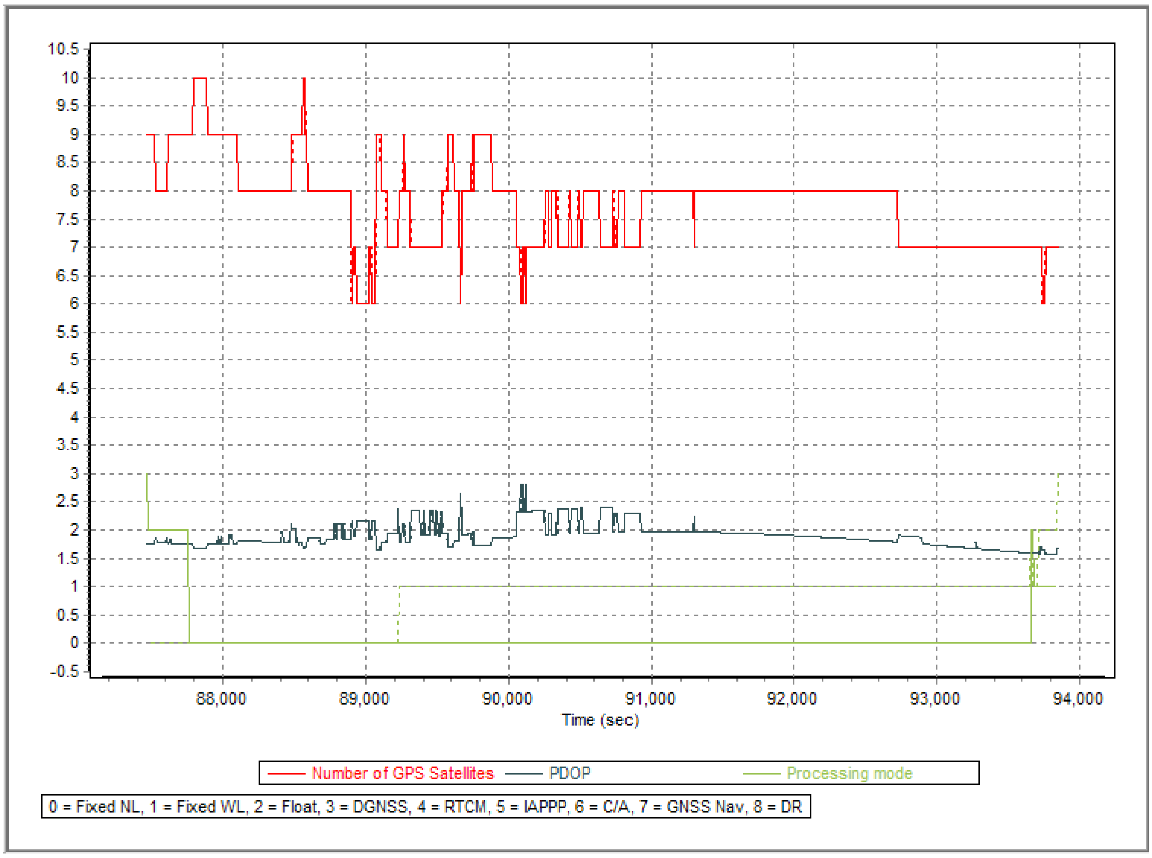



Figure A-8.22. Solution Status

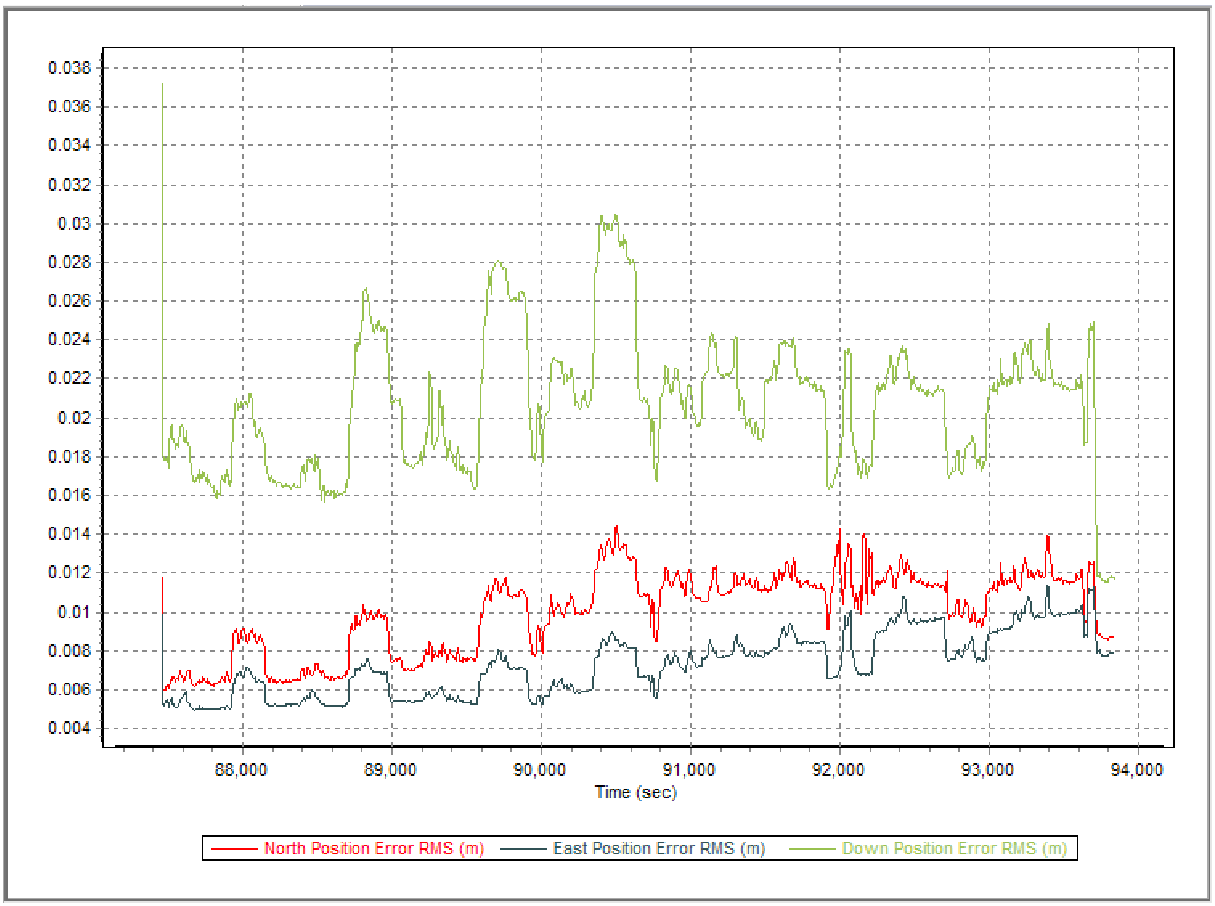



Figure A-8.23. Smoothed Performance Metrics Parameters

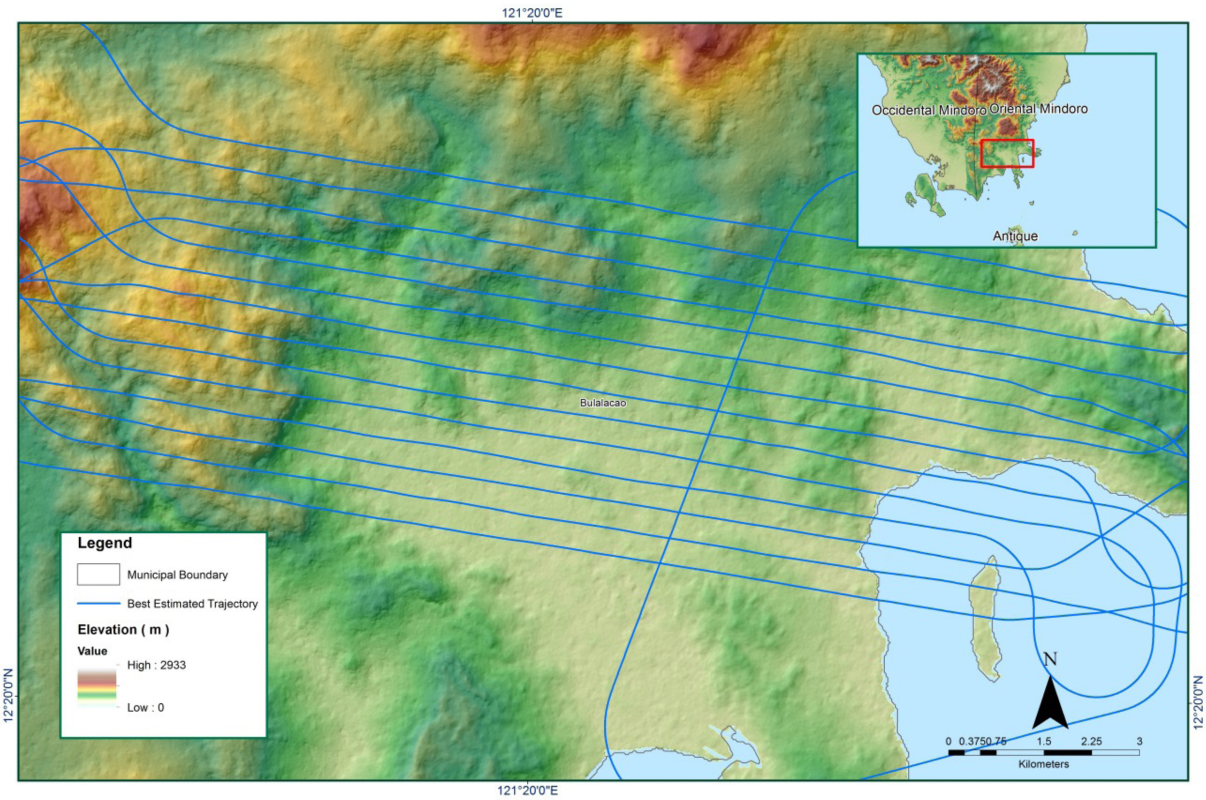



Figure A-8.24. Best Estimated Trajectory

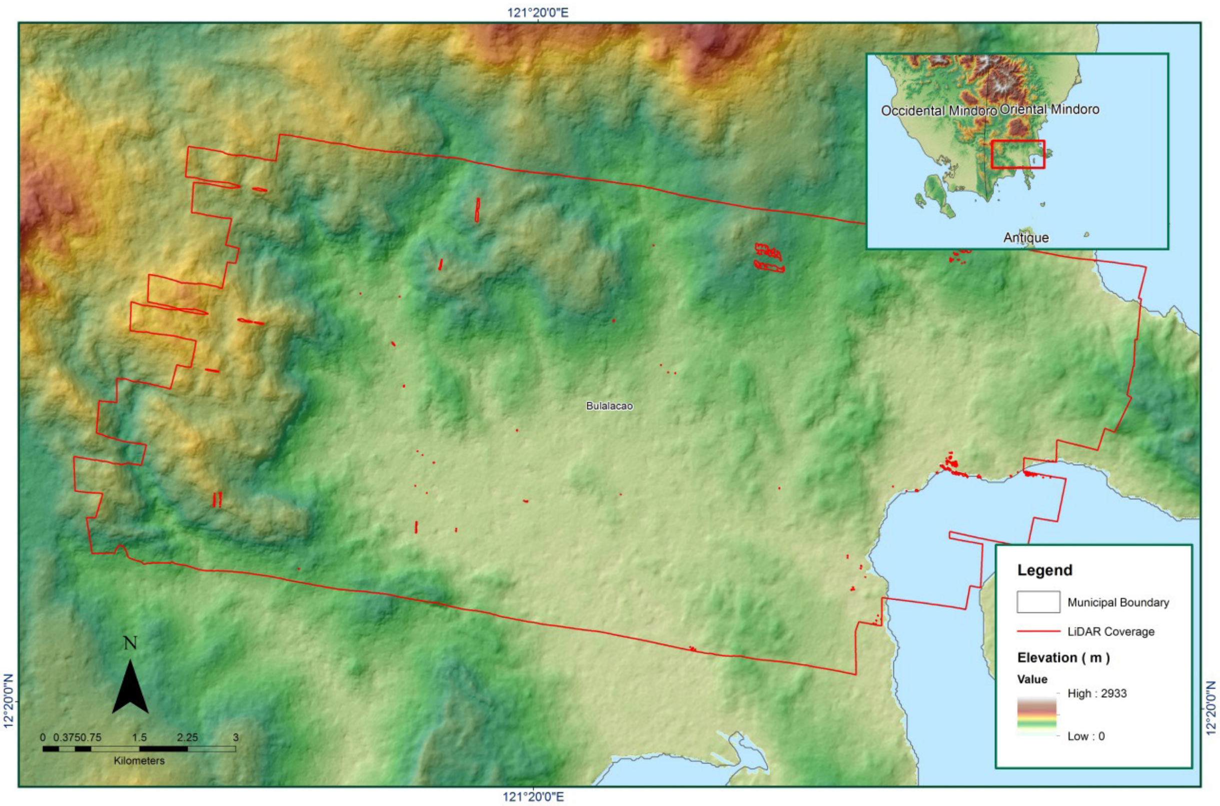



Figure A-8.25. Coverage of LiDAR data

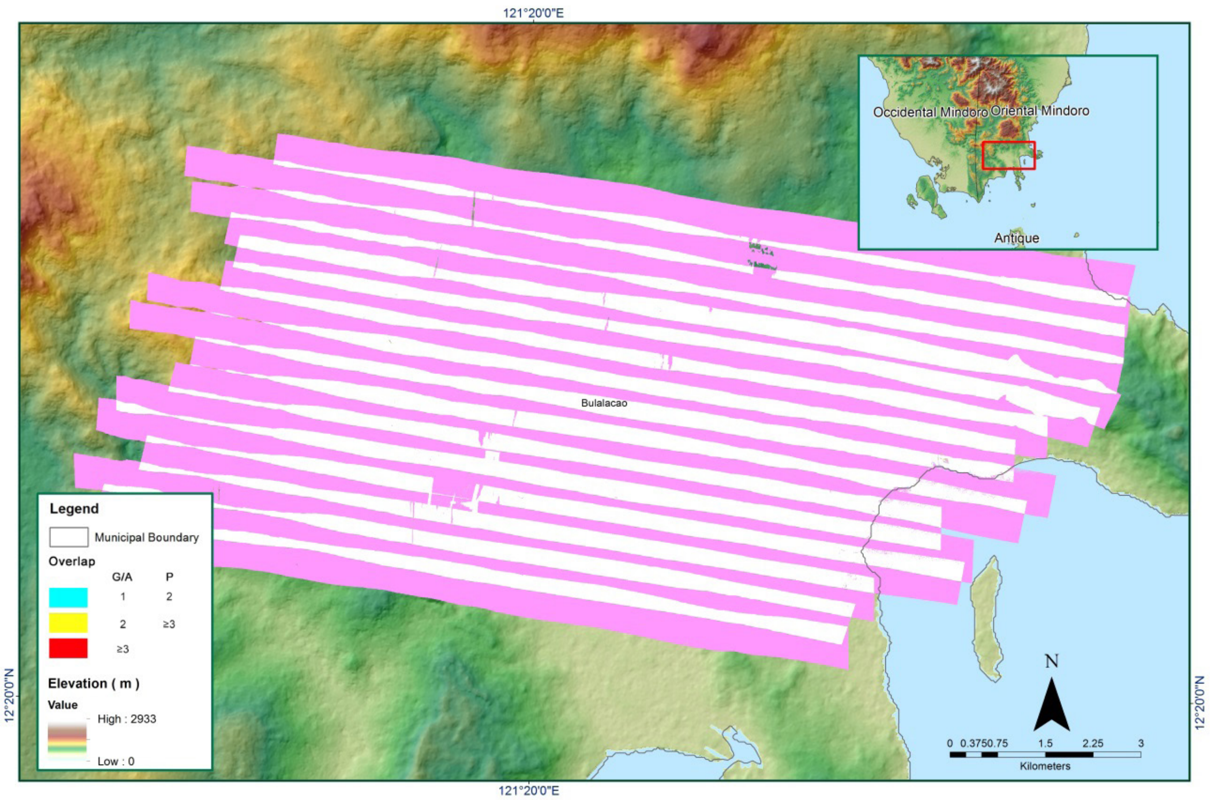



Figure A-8.26. Image of data overlap

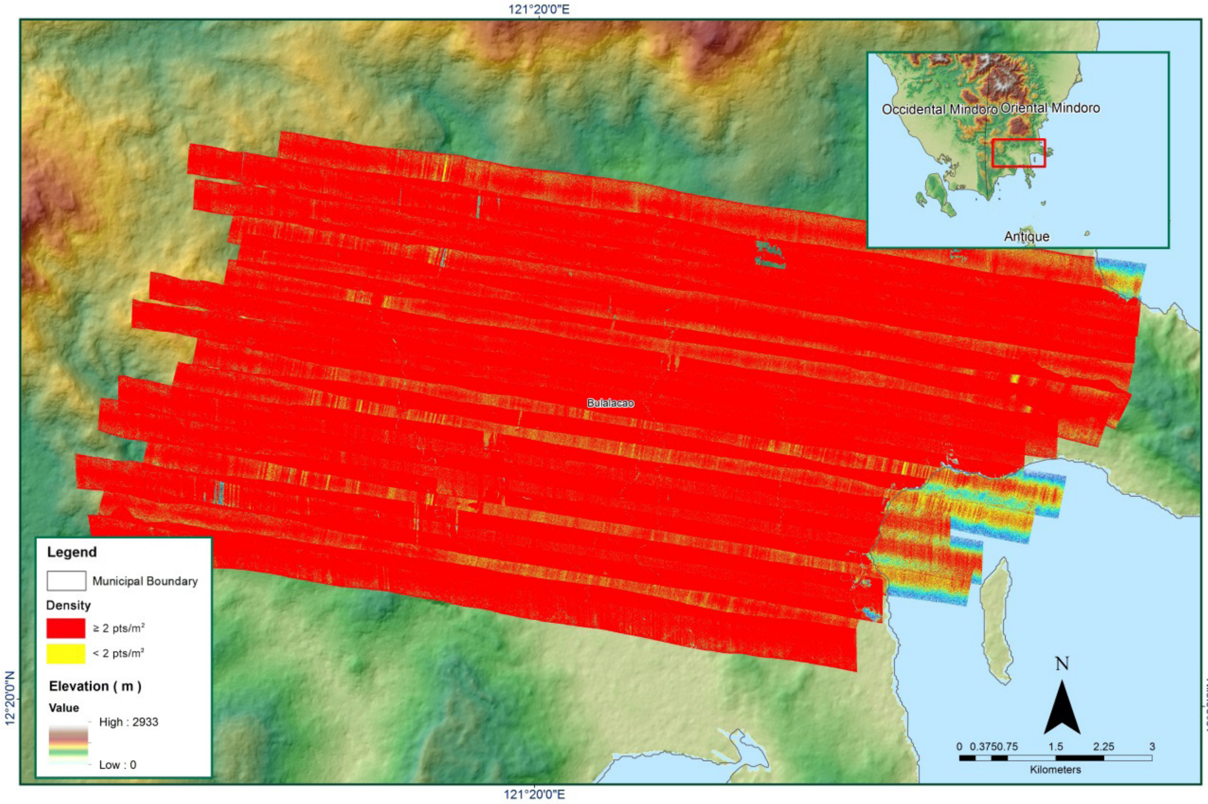



Figure A-8.27. Density of merged LiDAR data

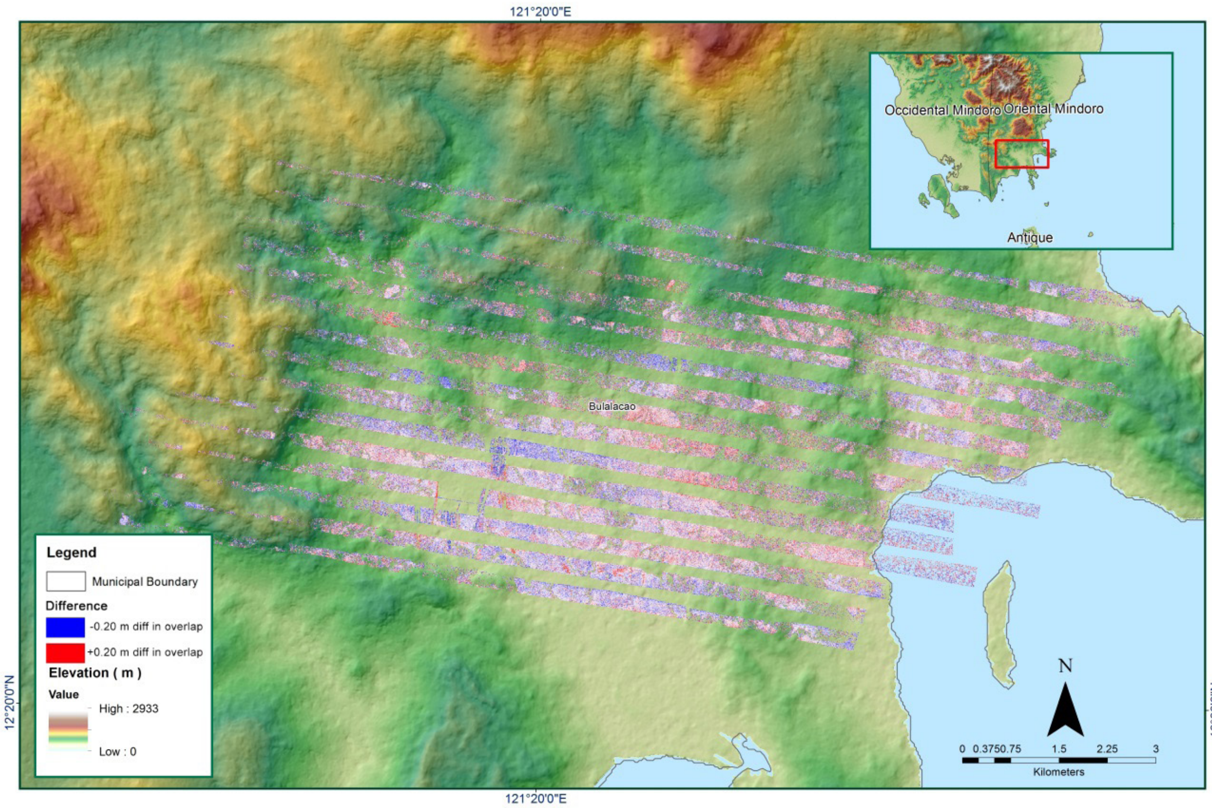



Figure A-8.24. Best Estimated Trajectory

# Annex 9. Bulalacao Model Basin Parameters

Table A-9.1 Bulalacao Model Basin Parameters

| Subbasin | SCS CURVE NUMBER LOSS | | | CLARK UNIT HYDROGRAPH TRANSFORM | | RECESSION BASEFLOW | | |
|---|---|---|---|---|---|---|---|---|
| | Initial Abstraction (MM) | Curve Number | Impervi-ousness (%) | Time of Concen-tration (HR) | Storage Coefficient (HR) | Initial Discharge (CU.M/S) | Recession Constant | Ratio to Peak |
| W1000 | 14.414 | 85.572 | 0 | 0.58307 | 0.95157 | 0.0057448 | 1 | 0.05 |
| W1010 | 12.085 | 97.807 | 0 | 1.5867 | 0.67984 | 0.0211495 | 0.0104563 | 0.0077073 |
| W1020 | 14.496 | 99 | 0 | 2.6656 | 4.3502 | 0.0123315 | 1 | 0.05 |
| W1030 | 14.181 | 99 | 0 | 2.9922 | 4.8832 | 0.0043718 | 1 | 0.05 |
| W1040 | 9.3458 | 99 | 0 | 1.1686 | 1.9072 | 0.0219593 | 1 | 0.05 |
| W1050 | 4.4014 | 99 | 0 | 0.10897 | 0.17785 | 0.000670988 | 1 | 0.05 |
| W1060 | 9.9585 | 99 | 0 | 2.5048 | 4.0878 | 0.0404457 | 1 | 0.05 |
| W1070 | 15.331 | 96.498 | 0 | 1.5525 | 0.81568 | 0.0129962 | 0.0077454 | 0.0113298 |
| W1080 | 4.2478 | 58.741 | 0 | 1.2929 | 0.84921 | 0.0027133 | 0.0246035 | 0.0077073 |
| W1090 | 7.0084 | 99 | 0 | 0.58051 | 0.94739 | 0.0160271 | 1 | 0.05 |
| W1100 | 13.976 | 58.465 | 0 | 0.15897 | 1.3165 | 0.0127168 | 0.016737 | 0.0166547 |
| W1130 | 4.4014 | 99 | 0 | 0.24829 | 0.4052 | 0.002044 | 1 | 0.05 |
| W1140 | 8.6331 | 99 | 0 | 2.5858 | 4.22 | 0.0161192 | 1 | 0.05 |
| W1150 | 13.885 | 99 | 0 | 1.5927 | 2.5992 | 0.0117982 | 1 | 0.05 |
| W1160 | 4.4014 | 99 | 0 | 0.13161 | 0.21478 | 0.0015211 | 1 | 0.05 |
| W1170 | 4.4014 | 99 | 0 | 0.0473058 | 0.077203 | 0.000257833 | 1 | 0.05 |
| W1180 | 4.5337 | 99 | 0 | 0.98789 | 1.6122 | 0.0283979 | 1 | 0.05 |
| W1190 | 8.7134 | 99 | 0 | 1.8006 | 2.9386 | 0.0062387 | 1 | 0.05 |
| W1200 | 5.5944 | 99 | 0 | 0.6695 | 1.0926 | 0.0148466 | 1 | 0.05 |
| W1210 | 5.6004 | 99 | 0 | 0.56183 | 0.91691 | 0.0062916 | 1 | 0.05 |
| W1220 | 3.3414 | 99 | 0 | 0.21198 | 0.34596 | 0.0021962 | 1 | 0.05 |
| W1240 | 8.2958 | 99 | 0 | 0.85117 | 1.3891 | 0.0076056 | 1 | 0.05 |
| W1250 | 17.269 | 94.966 | 0 | 0.15397 | 1.0763 | 0.0298059 | 0.0077454 | 0.0113298 |
| W1290 | 4.4014 | 99 | 0 | 0.0695166 | 0.11345 | 0.000518773 | 1 | 0.05 |
| W1300 | 4.4014 | 99 | 0 | 0.08003 | 0.13061 | 0.000684449 | 1 | 0.05 |
| W620 | 10.209 | 99 | 0 | 3.345 | 5.459 | 0.0328401 | 1 | 0.05 |
| W630 | 16.272 | 99 | 0 | 3.3441 | 5.4576 | 0.0190341 | 1 | 0.05 |
| W640 | 19.131 | 99 | 0 | 2.0497 | 3.3451 | 0.0205304 | 1 | 0.05 |
| W650 | 18.518 | 99 | 0 | 2.2676 | 3.7007 | 0.0120374 | 1 | 0.05 |
| W660 | 20.845 | 99 | 0 | 2.7821 | 4.5403 | 0.0018784 | 1 | 0.05 |
| W670 | 20.845 | 99 | 0 | 1.5352 | 2.5054 | 0.0081544 | 1 | 0.05 |
| W680 | 19.63 | 99 | 0 | 0.97354 | 0.69034 | 0.0127141 | 0.0113857 | 0.0077073 |
| W690 | 20.845 | 99 | 0 | 2.0575 | 3.3579 | 0.0229886 | 1 | 0.05 |
| W700 | 20.845 | 99 | 0 | 0.81819 | 1.3353 | 0.0095357 | 1 | 0.05 |
| W710 | 20.845 | 99 | 0 | 0.17603 | 0.28728 | 0.000546731 | 1 | 0.05 |
| W720 | 12.84 | 99 | 0 | 1.194 | 0.79491 | 0.0430626 | 0.0077454 | 0.0163216 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| W730 | 18.109 | 99 | 0 | 1.2353 | 0.61605 | 0.007483 | 0.0113858 | 0.0166547 |
| W740 | 20.845 | 99 | 0 | 1.4514 | 2.3687 | 0.0075735 | 1 | 0.05 |
| W750 | 46.901 | 99 | 0 | 1.2451 | 4.6652 | 0.0129653 | 0.0246034 | 0.0390183 |
| W760 | 20.845 | 99 | 0 | 1.5402 | 2.5137 | 0.0153768 | 1 | 0.05 |
| W770 | 32.23 | 99 | 0 | 8.4388 | 9.188 | 0.0209795 | 0.0246034 | 0.0390183 |
| W780 | 20.845 | 99 | 0 | 2.6381 | 4.3054 | 0.0281204 | 1 | 0.05 |
| W790 | 20.845 | 99 | 0 | 0.0641132 | 0.10463 | 6.94E-05 | 1 | 0.05 |
| W800 | 20.845 | 99 | 0 | 0.26195 | 0.42751 | 0.0014041 | 1 | 0.05 |
| W810 | 20.845 | 99 | 0 | 0.52593 | 0.85832 | 0.0019229 | 1 | 0.05 |
| W820 | 20.845 | 99 | 0 | 1.3141 | 2.1446 | 0.0289923 | 1 | 0.05 |
| W830 | 45.857 | 99 | 0 | 1.9307 | 7.3822 | 0.0364281 | 0.0245188 | 0.0390183 |
| W840 | 20.845 | 99 | 0 | 0.31585 | 0.51547 | 0.0018659 | 1 | 0.05 |
| W850 | 16.643 | 99 | 0 | 2.3895 | 3.8996 | 0.0595409 | 1 | 0.05 |
| W860 | 20.845 | 99 | 0 | 0.7206 | 1.176 | 0.0095647 | 1 | 0.05 |
| W870 | 22.748 | 80.54 | 0 | 1.4116 | 0.52634 | 0.0192352 | 0.0244825 | 0.0077073 |
| W880 | 47.131 | 99 | 0 | 1.2095 | 6.7658 | 0.0084828 | 0.0244825 | 0.0390183 |
| W890 | 21.981 | 96.357 | 0 | 1.2954 | 0.5544 | 0.0176323 | 0.0113298 | 0.0113298 |
| W900 | 18.627 | 99 | 0 | 1.5135 | 0.68651 | 0.0201182 | 0.0077073 | 0.0077073 |
| W910 | 20.473 | 99 | 0 | 1.6813 | 2.7439 | 0.0277373 | 1 | 0.05 |
| W920 | 19.96 | 98.954 | 0 | 1.3859 | 1.2728 | 0.0179614 | 0.0113298 | 0.0077073 |
| W930 | 19.949 | 99 | 0 | 1.9692 | 3.2138 | 0.0324363 | 1 | 0.05 |
| W940 | 20.506 | 99 | 0 | 11.874 | 6.5058 | 0.0199155 | 0.0249821 | 0.0390183 |
| W950 | 25.473 | 58.465 | 0 | 1.4962 | 13.504 | 0.0173665 | 0.0249821 | 0.0390183 |
| W960 | 15.508 | 99 | 0 | 1.303 | 2.1265 | 0.0194959 | 1 | 0.05 |
| W970 | 23.465 | 37.271 | 0 | 1.4948 | 1.0875 | 0.0047794 | 0.0359892 | 0.0251572 |
| W980 | 21.62 | 93.916 | 0 | 1.8774 | 2.2819 | 0.0078514 | 0.0244825 | 0.0260122 |
| W990 | 35.904 | 99 | 0 | 1.7769 | 4.3319 | 0.006562 | 0.0249821 | 0.05 |

## Annex 10. Bulalacao Model Reach Parameters

Table A-10.1 Bulalacao Model Reach Parameters

| Reach | MUSKINGUM CUNGE CHANNEL ROUTING | | | | | | |
|---|---|---|---|---|---|---|---|
| | Time Step Method | Length (M) | Slope (M/M) | Manning's n | Shape | Width (M) | Side Slope (xH:1V) |
| R100 | Automatic Fixed Interval | 1888.9 | 0.73284 | 0.04 | Trapezoid | 7.5 | 1 |
| R110 | Automatic Fixed Interval | 789.83 | 0.0384867 | 0.0897015 | Trapezoid | 7.5 | 1 |
| R1270 | Automatic Fixed Interval | 2886.6 | 0.0020785 | 0.045659 | Trapezoid | 7.5 | 1 |
| R1320 | Automatic Fixed Interval | 413.85 | 0.0096654 | 0.04 | Trapezoid | 7.5 | 1 |
| R150 | Automatic Fixed Interval | 52.426 | 0.0096654 | 0.04 | Trapezoid | 7.5 | 1 |
| R160 | Automatic Fixed Interval | 1319.8 | 0.0704638 | 0.04 | Trapezoid | 7.5 | 1 |
| R170 | Automatic Fixed Interval | 397.99 | 0.0376894 | 0.04 | Trapezoid | 7.5 | 1 |
| R190 | Automatic Fixed Interval | 264.85 | 0.0037757 | 0.04 | Trapezoid | 7.5 | 1 |
| R210 | Automatic Fixed Interval | 530.42 | 0.0056559 | 0.04 | Trapezoid | 7.5 | 1 |
| R230 | Automatic Fixed Interval | 1784.8 | 0.0168614 | 0.0304419 | Trapezoid | 7.5 | 1 |
| R270 | Automatic Fixed Interval | 1394.4 | 0.75171 | 0.12956 | Trapezoid | 7.5 | 1 |
| R280 | Automatic Fixed Interval | 1805.8 | 0.58963 | 0.0863772 | Trapezoid | 7.5 | 1 |
| R290 | Automatic Fixed Interval | 2311.1 | 0.0125483 | 0.13295 | Trapezoid | 7.5 | 1 |
| R310 | Automatic Fixed Interval | 886.69 | 0.0236504 | 0.13564 | Trapezoid | 7.5 | 1 |
| R350 | Automatic Fixed Interval | 612.13 | 0.0236504 | 0.12556 | Trapezoid | 7.5 | 1 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| R360 | Automatic Fixed Interval | 5059.4 | 0.0140332 | 0.04 | Trapezoid | 7.5 | 1 |
| R40 | Automatic Fixed Interval | 169.71 | 0.0051026 | 0.04 | Trapezoid | 7.5 | 1 |
| R420 | Automatic Fixed Interval | 1567.8 | 0.0051026 | 0.048902 | Trapezoid | 7.5 | 1 |
| R430 | Automatic Fixed Interval | 543.55 | 0.0036795 | 0.04 | Trapezoid | 7.5 | 1 |
| R440 | Automatic Fixed Interval | 963.55 | 0.0010378 | 0.04 | Trapezoid | 7.5 | 1 |
| R450 | Automatic Fixed Interval | 724.97 | 0.0010378 | 0.0274813 | Trapezoid | 7.5 | 1 |
| R470 | Automatic Fixed Interval | 1546.8 | 0.0010378 | 0.04 | Trapezoid | 7.5 | 1 |
| R480 | Automatic Fixed Interval | 2127.9 | 0.0023497 | 0.04 | Trapezoid | 7.5 | 1 |
| R490 | Automatic Fixed Interval | 347.99 | 0.0028736 | 0.04 | Trapezoid | 7.5 | 1 |
| R510 | Automatic Fixed Interval | 820.12 | 0.007316 | 0.04 | Trapezoid | 7.5 | 1 |
| R530 | Automatic Fixed Interval | 805.98 | 0.0012407 | 0.04 | Trapezoid | 7.5 | 1 |
| R540 | Automatic Fixed Interval | 346.27 | 0.0012407 | 0.04 | Trapezoid | 7.5 | 1 |
| R550 | Automatic Fixed Interval | 230.71 | 0.0031586 | 0.04 | Trapezoid | 7.5 | 1 |
| R570 | Automatic Fixed Interval | 1266.4 | 0.0031586 | 0.04 | Trapezoid | 7.5 | 1 |
| R590 | Automatic Fixed Interval | 968.11 | 0.0031586 | 0.04 | Trapezoid | 7.5 | 1 |
| R610 | Automatic Fixed Interval | 678.26 | 0.15278 | 0.04 | Trapezoid | 7.5 | 1 |
| R90 | Automatic Fixed Interval | 287.99 | 0.15278 | 0.04 | Trapezoid | 7.5 | 1 |
| W990 | 35.904 | 99 | 0 | 1.7769 | 4.3319 | 0.006562 | 0.0249821 |

# Annex 11. Bulalacao Flood Validation Data

Table A-11.1 Bulalacao Flood Validation Data

| Point Number | Validation Coordinates | | Model Var (m) | Valida-tion Points (m) | Error | Event/Date | Rain Return / Scenario |
|---|---|---|---|---|---|---|---|
| | Lat | Long | | | | | |
| 1 | 12.326383 | 121.345416 | 0.06 | 0.00 | -0.06 | | 25-Year |
| 2 | 12.326747 | 121.345591 | 0.05 | 0.00 | -0.05 | | 25-Year |
| 3 | 12.326857 | 121.346734 | 0.13 | 0.00 | -0.13 | | 25-Year |
| 4 | 12.326867 | 121.345584 | 0.25 | 0.00 | -0.25 | | 25-Year |
| 5 | 12.326891 | 121.347085 | 0.22 | 0.00 | -0.22 | | 25-Year |
| 6 | 12.326908 | 121.346024 | 0.32 | 0.43 | 0.11 | High Tide | 25-Year |
| 7 | 12.326968 | 121.345647 | 0.28 | 0.30 | 0.02 | High Tide | 25-Year |
| 8 | 12.327185 | 121.346049 | 0.6 | 0.00 | -0.60 | | 25-Year |
| 9 | 12.327339 | 121.34773 | 0.38 | 0.30 | -0.08 | Nona / Dec. 2015 | 25-Year |
| 10 | 12.329253 | 121.344629 | 0.74 | 0.66 | -0.08 | Yolanda / Nov. 8, 2013 | 25-Year |
| 11 | 12.329294 | 121.344348 | 0.95 | 0.79 | -0.16 | Ondoy / Sept. 26, 2009 | 25-Year |
| 12 | 12.329825 | 121.345187 | 0.31 | 0.45 | 0.14 | 2014 | 25-Year |
| 13 | 12.330419 | 121.344178 | 0.88 | 0.65 | -0.23 | 2015 | 25-Year |
| 14 | 12.332137 | 121.343584 | 0.7 | 0.90 | 0.20 | Seniang / Dec. 2014 | 25-Year |
| 15 | 12.33272 | 121.342528 | 0.25 | 0.33 | 0.08 | Nona / Dec. 15, 2015 | 25-Year |
| 16 | 12.332842 | 121.342979 | 0.61 | 0.90 | 0.29 | Habagat / July, 2013 | 25-Year |
| 17 | 12.333537 | 121.341472 | 0.43 | 0.20 | -0.23 | Seniang / Dec. 2014 | 25-Year |
| 18 | 12.333583 | 121.342208 | 0.32 | 0.75 | 0.43 | Seniang / Dec. 2014 | 25-Year |
| 19 | 12.334724 | 121.341379 | 0.14 | 0.60 | 0.46 | Butchoy / July, 2016 | 25-Year |
| 20 | 12.335666 | 121.340855 | 0.57 | 0.27 | -0.30 | Butchoy / July, 2016 | 25-Year |
| 21 | 12.338146 | 121.339716 | 0.03 | 0.33 | 0.30 | Butchoy / July, 2016 | 25-Year |
| 22 | 12.338174 | 121.339346 | 0.03 | 0.12 | 0.09 | Butchoy / July, 2016 | 25-Year |
| 23 | 12.338781 | 121.338919 | 0.03 | 0.20 | 0.17 | Butchoy / July, 2016 | 25-Year |
| 24 | 12.338781 | 121.338919 | 0.06 | 0.20 | 0.14 | Butchoy / July, 2016 | 25-Year |
| 25 | 12.339186 | 121.338036 | 0.03 | 0.37 | 0.34 | Butchoy / July, 2016 | 25-Year |
| 26 | 12.339635 | 121.34371 | 0.21 | 0.90 | 0.69 | | 25-Year |
| 27 | 12.339978 | 121.336985 | 0.56 | 0.55 | -0.01 | Seniang / Dec. 2014 | 25-Year |
| 28 | 12.340331 | 121.336997 | 0.41 | 0.40 | -0.01 | Caloy / May 2006 | 25-Year |
| 29 | 12.340413 | 121.343806 | 0.33 | 0.97 | 0.64 | Seniang / Dec. 2014 | 25-Year |
| 30 | 12.340626 | 121.337884 | 0.41 | 0.30 | -0.11 | Rosing / Nov. 1995 | 25-Year |
| 31 | 12.341164 | 121.33717 | 0.49 | 0.39 | -0.10 | Butchoy / July, 2016 | 25-Year |
| 32 | 12.341612 | 121.336849 | 0.25 | 0.22 | -0.03 | Butchoy / July, 2016 | 25-Year |
| 33 | 12.342289 | 121.337818 | 0.25 | 0.30 | 0.05 | Seniang / Dec. 2014 | 25-Year |
| 34 | 12.342456 | 121.339044 | 0.49 | 0.82 | 0.33 | Nona / Dec. 15, 2015 | 25-Year |
| 35 | 12.343183 | 121.342644 | 0.54 | 0.96 | 0.42 | Ondoy / Sept. 2009 | 25-Year |
| 36 | 12.343244 | 121.338697 | 0.03 | 0.45 | 0.42 | Seniang / Dec. 2014 | 25-Year |
| 37 | 12.343712 | 121.342501 | 0.49 | 0.96 | 0.47 | Ondoy / Sept. 2009 | 25-Year |

| Point Number | Validation Coordinates | | Model Var (m) | Validation Points (m) | Error | Event/Date | Rain Return / Scenario |
|---|---|---|---|---|---|---|---|
| | Lat | Long | | | | | |
| 38 | 12.344886 | 121.342064 | 0.35 | 0.52 | 0.17 | Ondoy / Sept. 2009 | 25-Year |
| 39 | 12.345209 | 121.336988 | 0.03 | 0.00 | -0.03 | Butchoy / July, 2016 | 25-Year |
| 40 | 12.346384 | 121.34192 | 0.46 | 0.97 | 0.51 | | 25-Year |
| 41 | 12.347187 | 121.340814 | 0.38 | 0.68 | 0.30 | Yolanda / Nov. 2013 | 25-Year |
| 42 | 12.348186 | 121.341279 | 0.39 | 0.58 | 0.19 | | 25-Year |
| 43 | 12.348333 | 121.341613 | 1.25 | 1.33 | 0.08 | October 19,2014 | 25-Year |
| 44 | 12.348805 | 121.341183 | 1.05 | 0.74 | -0.31 | Seniang / Nov. 2013 | 25-Year |
| 45 | 12.349074 | 121.338605 | 0.44 | 0.42 | -0.02 | Yolanda / Nov. 2013 | 25-Year |
| 46 | 12.349169 | 121.341173 | 1.16 | 0.83 | -0.33 | Yolanda / Nov. 2013 | 25-Year |
| 47 | 12.349339 | 121.33834 | 0.35 | 1.10 | 0.75 | Habagat / 2014 | 25-Year |
| 48 | 12.349493 | 121.338798 | 0.36 | 0.90 | 0.54 | October 19,2014 | 25-Year |
| 49 | 12.350134 | 121.341177 | 0.07 | 0.60 | 0.53 | Yolanda / Nov. 2013 | 25-Year |
| 50 | 12.350134 | 121.341177 | 0.92 | 0.60 | -0.32 | Yolanda / Nov. 2013 | 25-Year |
| 51 | 12.350235 | 121.337418 | 0.52 | 1.12 | 0.6 | Nov. 2015 | 25-Year |
| 52 | 12.350326 | 121.341288 | 0.98 | 0.59 | -0.39 | Yolanda / Nov. 2013 | 25-Year |
| 53 | 12.350975 | 121.337272 | 0.49 | 0.95 | 0.46 | Oct. 22, 2015 | 25-Year |
| 54 | 12.35131 | 121.336409 | 0.26 | 1.00 | 0.74 | Habagat / Oct. 2014 | 25-Year |
| 55 | 12.352536 | 121.341793 | 0.29 | 0.77 | 0.48 | October 19,2014 | 25-Year |
| 56 | 12.353922 | 121.335114 | 0.13 | 0.81 | 0.68 | Habagat / Oct. 2014 | 25-Year |
| 57 | 12.355766 | 121.324339 | 0.03 | 0.95 | 0.92 | Nov. 2014 | 25-Year |
| 58 | 12.356357 | 121.338738 | 0.36 | 0.79 | 0.43 | Ondoy / Sept. 2009 | 25-Year |
| 59 | 12.356644 | 121.337632 | 0.22 | 0.40 | 0.18 | | 25-Year |
| 60 | 12.356826 | 121.337389 | 0.29 | 0.67 | 0.38 | Ondoy / Sept. 2009 | 25-Year |
| 61 | 12.357586 | 121.336778 | 0.12 | 0.52 | 0.4 | | 25-Year |
| 62 | 12.357691 | 121.32672 | 0.33 | 0.95 | 0.62 | Yolanda / Nov. 8, 2013 | 25-Year |
| 63 | 12.357801 | 121.333218 | 0.1 | 0.93 | 0.83 | 2014 | 25-Year |
| 64 | 12.357949 | 121.332854 | 0.06 | 0.81 | 0.75 | Ondoy / Sept. 2009 | 25-Year |
| 65 | 12.358374 | 121.339265 | 0.06 | 0.70 | 0.64 | | 25-Year |
| 66 | 12.358417 | 121.326651 | 0.29 | 0.96 | 0.67 | Yolanda / Nov. 8, 2013 | 25-Year |
| 67 | 12.358543 | 121.334988 | 0.04 | 0.40 | 0.36 | 2014 | 25-Year |
| 68 | 12.358869 | 121.334129 | 0.03 | 0.74 | 0.71 | 2014 | 25-Year |
| 69 | 12.359131 | 121.326494 | 0.1 | 0.60 | 0.5 | Caloy / May 2006 | 25-Year |
| 70 | 12.359515 | 121.331775 | 0.05 | 0.91 | 0.86 | Yolanda / Nov. 8, 2013 | 25-Year |
| 71 | 12.359709 | 121.321155 | 0.03 | 0.33 | 0.3 | Ondoy / Sept. 26, 2009 | 25-Year |
| 72 | 12.360043 | 121.331416 | 0.03 | 0.39 | 0.36 | | 25-Year |
| 73 | 12.359988 | 121.321791 | 0.14 | 0.30 | 0.16 | Unding / Nov. 2004 | 25-Year |
| 74 | 12.360048 | 121.328402 | 0.05 | 0.45 | 0.4 | Ondoy / Sept. 26, 2009 | 25-Year |

| Point Number | Validation Coordinates | | Model Var (m) | Validation Points (m) | Error | Event/Date | Rain Return / Scenario |
|---|---|---|---|---|---|---|---|
| | Lat | Long | | | | | |
| 75 | 12.360149 | 121.322536 | 0.03 | 0.95 | 0.92 | Yolanda / Nov. 8, 2013 | 25-Year |
| 76 | 12.3602 | 121.328994 | 0.05 | 0.15 | 0.1 | Yolanda / Nov. 8, 2013 | 25-Year |
| 77 | 12.360226 | 121.320581 | 0.03 | 0.00 | -0.03 | Ondoy / Sept. 26, 2009 | 25-Year |
| 78 | 12.360443 | 121.325863 | 0.03 | 0.15 | 0.12 | Nov. 2014 | 25-Year |
| 79 | 12.360498 | 121.325637 | 0.07 | 0.35 | 0.28 | Habagat / Nov. 2015 | 25-Year |
| 80 | 12.360937 | 121.338897 | 0.03 | 0.62 | 0.59 | 2015 | 25-Year |
| 81 | 12.360926 | 121.325645 | 0.03 | 0.09 | 0.06 | Ondoy / Sept. 26, 2009 | 25-Year |
| 82 | 12.361348 | 121.334352 | 0.03 | 0.44 | 0.41 | Nona / Dec. 2015 | 25-Year |
| 83 | 12.36131 | 121.325217 | 0.03 | 0.45 | 0.42 | Yolanda / Nov. 8, 2013 | 25-Year |
| 84 | 12.361463 | 121.339459 | 0.12 | 0.5 | 0.38 | | 25-Year |
| 85 | 12.361507 | 121.323538 | 0.03 | 0 | -0.03 | Yolanda / Nov. 8, 2013 | 25-Year |
| 86 | 12.361554 | 121.324894 | 0.04 | 0.45 | 0.41 | Ondoy / Sept. 26, 2009 | 25-Year |
| 87 | 12.361601 | 121.328731 | 0.06 | 0 | -0.06 | | 25-Year |
| 88 | 12.361733 | 121.338755 | 0.03 | 0.58 | 0.55 | | 25-Year |
| 89 | 12.361911 | 121.329745 | 0.11 | 0 | -0.11 | | 25-Year |
| 90 | 12.362134 | 121.324423 | 0.04 | 0.15 | 0.11 | Yolanda / Nov. 8, 2013 | 25-Year |
| 91 | 12.362307 | 121.322541 | 0.06 | 0.27 | 0.21 | Yolanda / Nov. 8, 2013 | 25-Year |
| 92 | 12.362552 | 121.324478 | 0.09 | 0.35 | 0.26 | Ondoy / Sept. 26, 2009 | 25-Year |
| 93 | 12.362717 | 121.329186 | 0.14 | 0.05 | -0.09 | Ondoy / Sept. 2009 | 25-Year |
| 94 | 12.362902 | 121.328168 | 0.44 | 0.41 | -0.03 | Typhoon | 25-Year |
| 95 | 12.36325 | 121.332536 | 0.04 | 0.45 | 0.41 | Oct. 2014 | 25-Year |
| 96 | 12.363331 | 121.337503 | 0.03 | 0.2 | 0.17 | Nona / December, 2015 | 25-Year |
| 97 | 12.363308 | 121.329357 | 0.12 | 0.14 | 0.02 | October 19,2014 | 25-Year |
| 98 | 12.363578 | 121.330065 | 0.03 | 0.74 | 0.71 | October 19,2014 | 25-Year |
| 99 | 12.364174 | 121.330319 | 0.06 | 0 | -0.06 | | 25-Year |
| 100 | 12.364248 | 121.336911 | 0.1 | 0.85 | 0.75 | 2012 | 25-Year |
| 101 | 12.366416 | 121.329198 | 0.06 | 0 | -0.06 | | 25-Year |
| 102 | 12.367108 | 121.330252 | 0.04 | 0 | -0.04 | | 25-Year |

## Annex 12. Phil-LiDAR 1 UPLB Team Composition

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

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

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

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

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

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

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