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

# LiDAR Surveys and Flood Mapping of Baua River


University of the Philippines Training Center for Applied Geodesy and Photogrammetry
Isabela State University



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# LIST OF ACRONYMS AND ABBREVIATIONS

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

CHAPTER 1: OVERVIE E PROGRAM
AND BAU

## 1.1 Background of the Phil-LIDAR 1 Program

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

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

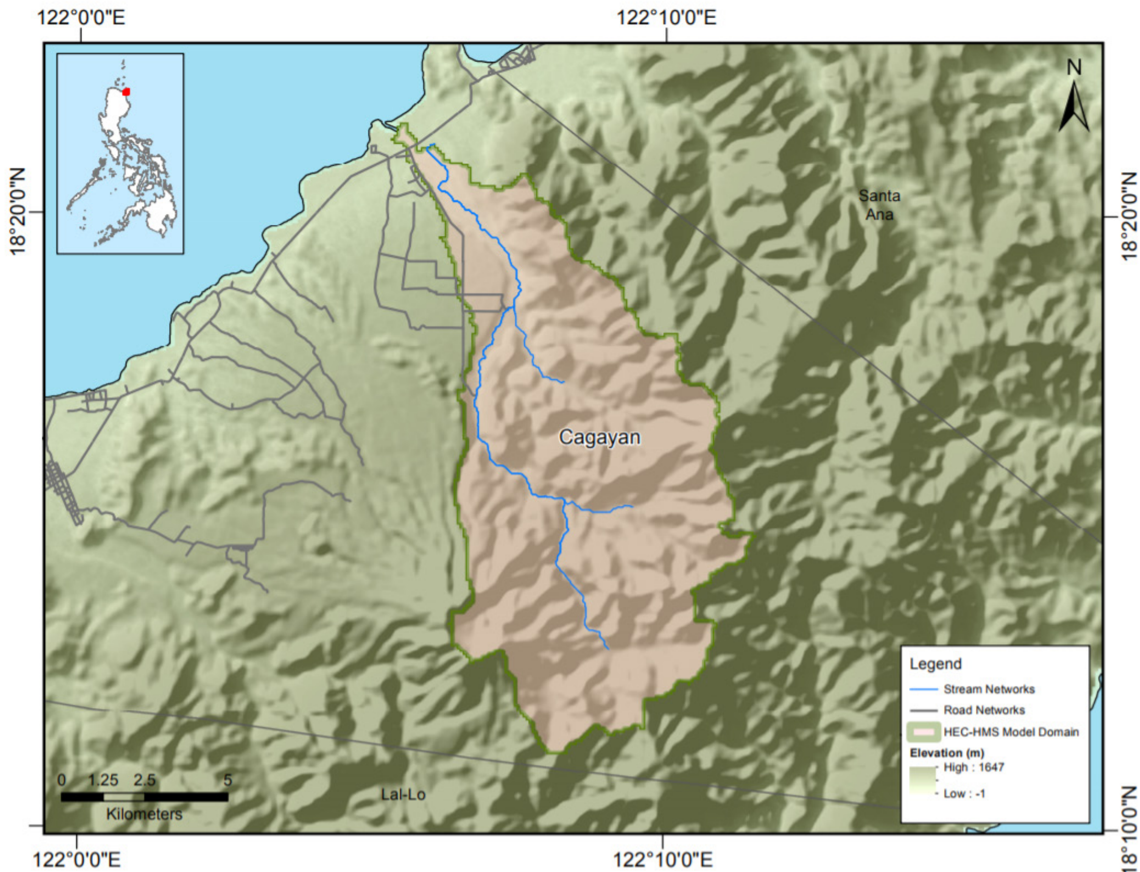
The implementing partner university for the Phil-LiDAR 1 Program is the Isabela State University (ISU). ISU is in charge of processing LiDAR data and conducting data validation reconnaissance, cross section, bathymetric survey, validation, river flow measurements, flood height and extent data gathering, flood modeling, and flood map generation for the eight (8) river basins in the Northeastern Luzon Region. The university is located in the Municipality of Echague in the province of Isabela.

## 1.2 Overview of the Baua River Basin

The Baua River Basin covers the Municipality of Gonzaga in Cagayan. The DENR River Basin Control Office (RBCO) states that the Baua Basin has a drainage are of 110 km$^2$ and an estimated 233 cubic meter (MCM) annual run-off (RBCO, 2015).

The Baua River Basin has a tropical climate and experiences significant rainfall most months with a short dry season. The climate here is classified as Am by the Köppen-Geiger system. The temperature averages 25.9 °C and the amount of precipitation is around 2361 mm. The least amount of rainfall occurs in April. In November, the precipitation reaches its peak and the temperatures are highest in June. January is the coldest month of the year.

Its main stem, Baua River, is among the ten (10) river systems in Cagayan Valley. The Baua River is located at Gonzaga, Cagayan. According to the 2015 national census of PSA, a total of 8,737 persons are residing within the immediate vicinity of the river, which is distributed among barangays Amunitan, Cabiraoan, Sta. Maria, and Baua in the Municipality of Gonzaga.




The water of Baua River is used mainly for irrigation. In fact, the economy of Cagayan Province, as well as the source of livelihood of communities along Baua River, largely rests on agriculture with rice, corn, and banana as the main crops and products (Philippine Statistics Authority, 2017). The Baua river is also used for other purposes such as fishery, transport and recreation. Another major use of the river and its bank is for sand and gravel extraction for concrete aggregates.

Meanwhile, Gonzaga, where the Baua River passes through, is a first class municipality located at the northeastern tip of the province of Cagayan, bordered by the municipality of Santa Ana to the northeast, to the west is the municipality of Santa Teresita, and the municipality of Lal-lo to the south. It has a total land area of 56,743 hectares. Only the northwestern part of the municipality has been settled in by constituents. Larger portions of the municipality are classified as forest. The highest elevation of the municipality is believed to be at Mount Cagua in barangay Magrafil. It is being considered as a potential source of geothermal energy.

Similar to the rest of Cagayan province, Gonzaga is an agricultural municipality with more than half of the workforce employed primarily as either farmers or fishers. It is bestowed with forest and aquatic resources. It is a haven of rivers flow down to irrigation structures allowing a regular two-cropping season for rice farming, the main industry.

The municipality of Gonzaga was among the areas devastated by Typhoon Angela (Local Code Name: Rubing) on October 8, 1989 as well as Typhoon Haima (Local Code Name: Lawin) on October 20, 2016. Last November 17, 2016, Quibal-Nanguillatan-Baggao provincial road in Cagayan and Abusag Bridge in Baggao Town were not passable due to floods due to heavy rains brought on by the tail-end of a cold front (Visaya, 2016).

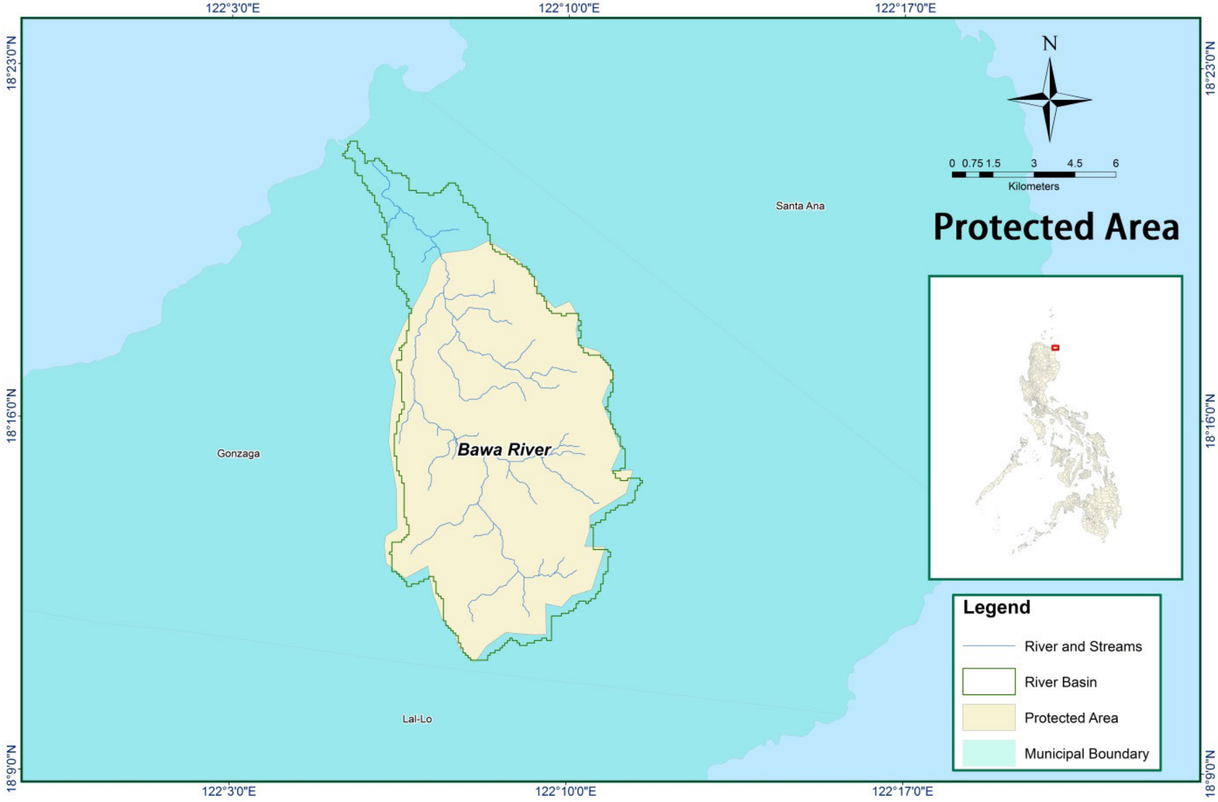



Figure 2. Protected Areas within Baua River Basin.

In addition, there are two (2) Watershed Reserves situated in the municipality of Gonzaga and Lallo. The Baua Watershed was proclaimed as Watershed Forest Reserve by virtue of Presidential Proclamation No. 108 on May 13, 1987 to protect the area from deforestation and degradation. Baua Watershed Forest Reserve covers a total area of 8, 995 hectares. It composed of Baua River - one of the major river systems in the municipality of Gonzaga. The other one is Wangag Watershed Forest Reserve.

Sources:
*https://en.climate-data.org*
*http://cagayan.gov.ph*
*http://www.gonzaga.gov.ph/?page_id=17*
*http://www.phivolcs.dost.gov.ph/html/update_VMEPD/Volcano/VolcanoList/cagua.htm*
*https://www.silent-gardens.com/climate.php*
*Philippine Statistics Authority, 2010*

# CHAPTER 2: LIDAR DATA ACQUISITION OF THE BAUA FLOODPLAIN

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 Baua floodplain in Cagayan province. These missions were planned for 21 lines and ran for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameters for the LiDAR system is found in Table 1. Figure 3 shows the flight plan for Baua floodplain.

Table 1. Flight planning parameters for Pegasus LiDAR system.

| Block Name | Flying Height (m AGL) | Overlap (%) | Field of View (θ) | Pulse Repetition Frequency (PRF) (kHz) | Scan Frequency (Hz) | Average Speed (kts) | Average Turn Time (Minutes) |
|---|---|---|---|---|---|---|---|
| BLK3B | 850 | 35 | 50 | 200 | 30 | 130 | 5 |

Table 2. Flight planning parameters for Gemini LiDAR system

| Block Name | Flying Height (m AGL) | Overlap (%) | Field of View (θ) | Pulse Repetition Frequency (PRF) (kHz) | Scan Frequency (Hz) | Average Speed (kts) | Average Turn Time (Minutes) |
|---|---|---|---|---|---|---|---|
| BLK3A | 850 | 35 | 50 | 125 | 40 | 130 | 5 |
| BLK3B | 900 | 35 | 125 | 200 | 40 | 130 | 5 |

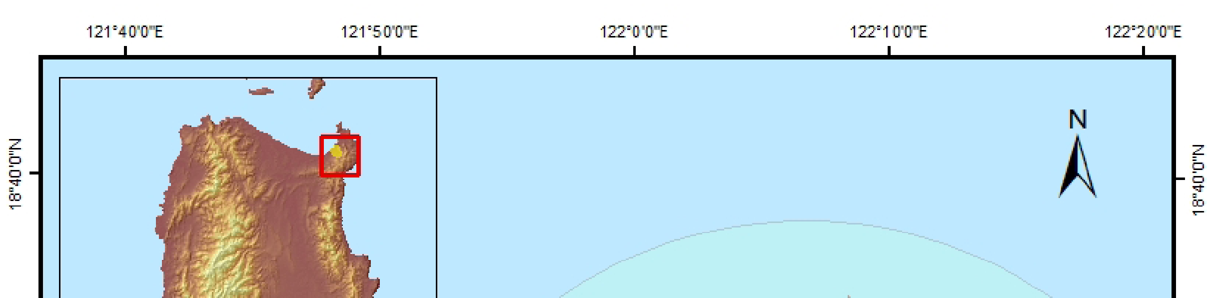


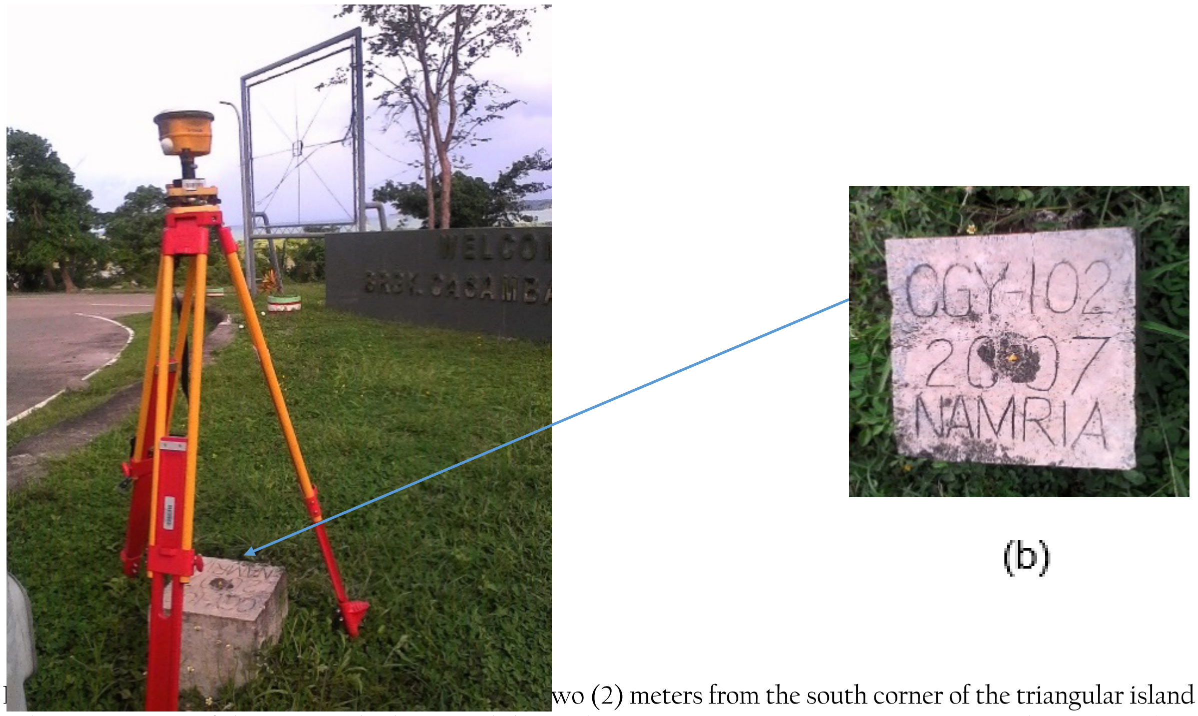
Figure 3. Flight plans and base stations used for Baua Floodplain

## 2.2 Ground Base Station

The project team was able to recover two (2) NAMRIA horizontal control points, CGY-102 and CGY-92 which are of second (2nd) order accuracy. The field team also recovered one (1) NAMRIA benchmark, CG-258, which was reprocessed as a horizontal ground control point. The certifications for the NAMRIA reference points are found in Annex 2 and the baseline processing report for CG-258 is found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey (November 30, 2015 and April 28 to May 6, 2016). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 882 and SPS 852. Flight plans and location of base stations used during the aerial LiDAR acquisition in Baua floodplain are shown in Figure 2. The list of LiDAR acquisition team members are found in Annex 4.

Figure 4 to Figure 6 show the recovered NAMRIA reference points within the area. In addition, Table 3 to

Table 5show the details about the following NAMRIA control stations, while Table 6 shows the list of all ground control points occupied during the acquisition together with the corresponding dates of utilization.




(b)

(a)

I wo (2) meters from the south corner of the triangular island at the intersection of the national highway and the road to Port Irene in Santa Ana, Cagayan, and CGY-102 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point CGY-102 used as base station for the LiDAR acquisition.

| Station Name | CGY-102 | |
|---|---|---|
| Order of Accuracy | $2^{nd}$ | |
| Relative Error (horizontal positioning) | 1 in 50,000 | |
| Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92) | Latitude<br>Longitude<br>Ellipsoidal Height | 18°22'15.98573" North<br>122°6'41.74346" East<br>22.60800 meters |
| Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92) | Easting<br>Northing | 617476.569 meters<br>2032192.366 meters |
| Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84) | Latitude<br>Longitude<br>Ellipsoidal Height | 18°22'9.81367" North<br>122°6'46.31361" East<br>57.19500 meters |
| Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992) | Easting<br>Northing | 406145.45 meters<br>203135134 meters |

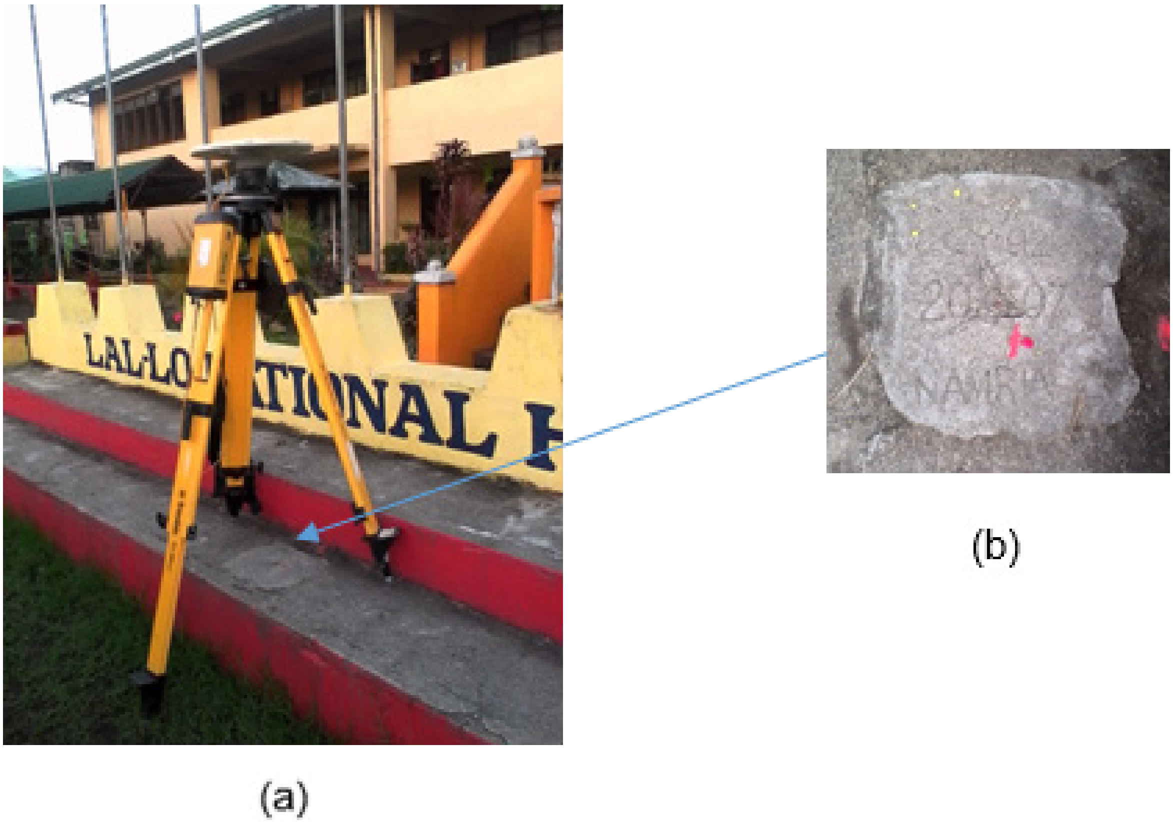
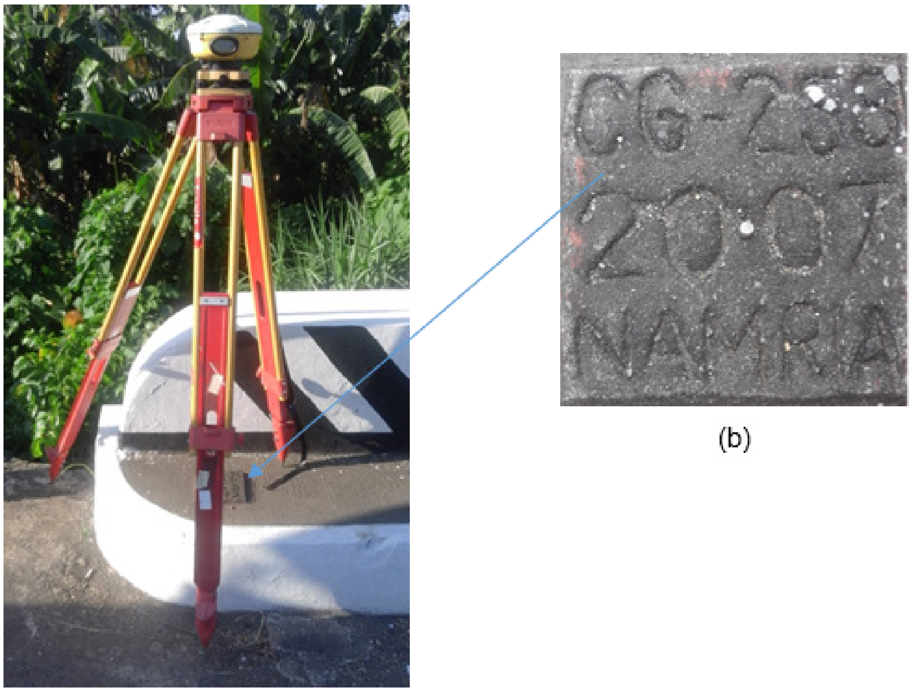



Figure 5. GPS set-up over CGY-92 located inside the Lal-lo National High School, about five (5) meters west of the flagpole (a), and CGY-92 (b) as recovered by the field team.

Table 4. Details of the recovered NAMRIA horizontal control point CGY-92 used as base station for the LiDAR acquisition.

| Station Name | **CGY-92** | |
|---|---|---|
| **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 | 18° 12’ 11.42361”North<br>121° 39’ 42.14392”East<br>14.47400 meters |
| **Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 5 PRS 92)** | Easting<br>Northing | 569996.115 meters<br>2013373.807 meters |
| **Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)** | Latitude<br>Longitude<br>Ellipsoidal Height | 18° 12’ 5.25321” North<br>21° 39’ 46.73084” East<br>48.54000 meters |
| **Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)** | Easting<br>Northing | 358475.41meters<br>2013059.26 meters |




(a) (b)

Figure 6. GPS set-up over CG-258 located along the national road and about 200 meters northeast of kilometer post no. 608 in Gonzaga, Cagayan (a) and NAMRIA benchmark CG-258 (b) as recovered by the field team.

Table 5. Details of point CG-258 used as vertical reference point and established base station for the LiDAR acquisition.

| Station Name | CG-258 | |
|---|---|---|
| Order of Accuracy | 2nd | |
| Elevation | 6.5266 +/- 0.0455 meters | |
| Relative Error (horizontal positioning) | 1:50,000 | |
| Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92) | Latitude | 18°17’21.328997” North |
| | Longitude | 122°01’21.83970” East |
| | Ellipsoidal Height | 12.774 meters |
| Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84) | Latitude | 18°17’15.16762” North |
| | Longitude | 122°01’26.41723” East |
| | Ellipsoidal Height | 47.419 meters |
| Grid Coordinates, Universal Transverse Mercator Zone 51 North UTM 51N PRS 92) | Easting | 396708.418 meters |
| | Northing | 2022343.154 meters |

Table 6. Ground control used during LiDAR data acquisition

| Date Surveyed | Flight Number | Mission Name | Ground Control Points |
|---|---|---|---|
| November 30, 2015 | 2916P | 1BLK21AB323A | CGY-102, CGY-92 |
| April 28, 2016 | 3971G | 2BLK3CAG2MQR119A | CGY-102, CG-258 |
| May 3, 2016 | 3991G | 2BLK3CAG2MSQS124B | CGY-102, CG-258 |
| May 6, 2016 | 4001G | 2BLK3CAG2MRS127A | CGY-102, CG-258 |

## 2.3 Flight Missions

Four (4) missions were conducted to complete the LiDAR data acquisition in Baua floodplain, for a total of 13 hours and ten minutes (13+10) of flying time for RP-C9122 and RP-C9022. All missions were acquired using the Pegasus and Gemini LiDAR systems. Table 7 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 8 presents the actual parameters used during the LiDAR data acquisition.

Table 7. Flight missions for LiDAR data acquisition in Baua 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 |
| **November 30, 2015** | 2916P | 229.33 | 111.30 | 19.29 | 92.01 | - | 2 | 29 |
| **April 28, 2016** | 3971G | 401.86 | 162.97 | 23.53 | 139.44 | - | 4 | 15 |
| **May 3, 2016** | 3991G | 401.86 | 121.82 | 24.69 | 97.13 | - | 2 | 26 |
| **May 6, 2016** | 4001G | 401.86 | 127.08 | 0.54 | 126.54 | - | 4 | 00 |
| **TOTAL** | | 631.19 | 523.17 | 68.05 | 455.12 | - | 13 | 10 |

Table 8. Actual parameters used during LiDAR data acquisition

| Flight Number | Flying Height (m AGL) | Overlap (%) | FOV (θ) | PRF (kHz) | Scan Frequency (Hz) | Average Speed (kts) | Average Turn Time (Minutes) |
|---|---|---|---|---|---|---|---|
| 2916P | 900 | 30 | 50 | 200 | 30 | 130 | 5 |
| 3971G | 850 | 30 | 50 | 125 | 50 | 130 | 5 |
| 3991G | 800 | 30 | 50 | 125 | 50 | 130 | 5 |
| 4001G | 800 | 30 | 50 | 125 | 50 | 130 | 5 |

## 2.4. Survey Coverage

Baua floodplain is located in the province of Cagayan. The survey covered the municipalities of Santa Ana and Gonzaga. The details of the survey coverage in these municipalities are shown in Table 9. The actual coverage of the LiDAR acquisition for Baua Floodplain is presented in Figure 7.

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

| Province | Municipality/City | Area of Municipality/City ($km^2$) | Total Area Surveyed ($km^2$) | Percentage of Area Surveyed |
|---|---|---|---|---|
| Cagayan | Santa Ana | 437.13 | 167.47 | 38.31% |
| | Gonzaga | 497.62 | 175.18 | 35.20% |
| | **Total** | **934.75** | **342.65** | **36.66%** |

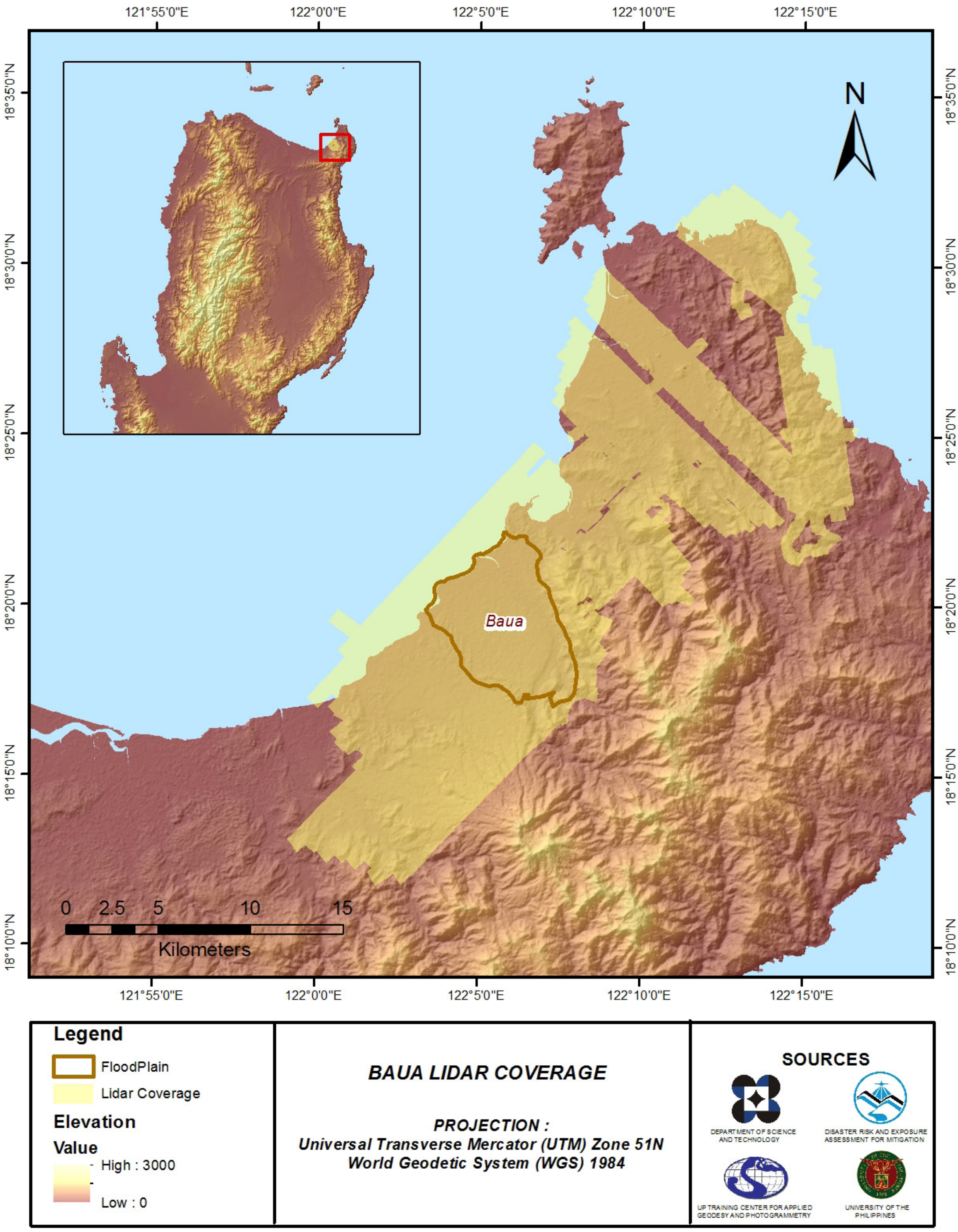



Figure 7. Actual LiDAR survey coverage for Baua Floodplain.

# CHAPTER 3: LIDAR DATA PROCESSING OF THE BAUA FLOODPLAIN

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

## 3.1 Overview of the LIDAR Data Pre-Processing

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

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

These processes are summarized in the flowchart shown in Figure 8.

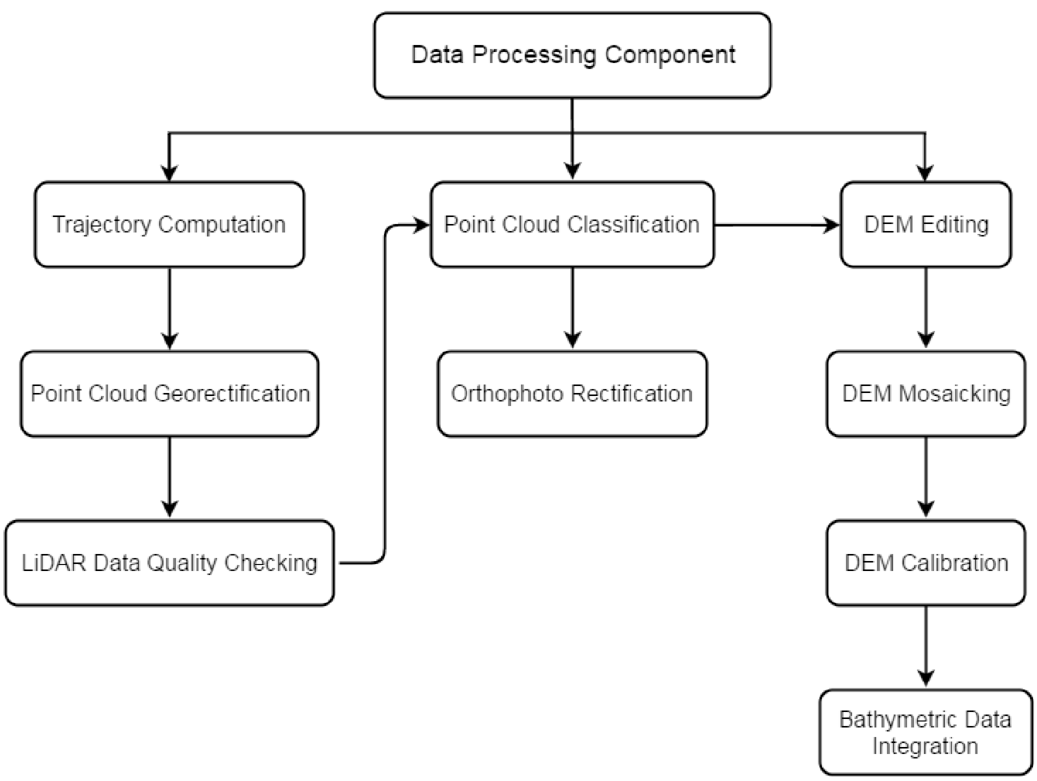



Figure 8. Schematic Diagram for Data Pre-Processing Component

## 3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Baua floodplain can be found in Annex 5. Missions flown during the first survey conducted on September 2015 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Gemini and Pegasus systems while missions acquired during the second survey on June 2016 were flown using the Gemini system over Gonzaga, Cagayan.

The Data Acquisition Component (DAC) transferred a total of 57.55 Gigabytes of Range data, 7.90 Gigabytes of POS data, 130.83 Megabytes of GPS base station data, and 17.9 Gigabytes of raw image data to the data server on September 22, 2015 for the first survey and June 21, 2016 for the second survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Baua was fully transferred on June 21, 2016, as indicated on the Data Transfer Sheets for Baua floodplain.

## 3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 3991G, one of the Baua flights, which is the North, East, and Down position RMSE values are shown in Figure 9. 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 May 03, 2016 00:00AM. The y-axis is the RMSE value for that particular position.


Figure 9. Smoothed Performance Metrics of Baua Flight 3991G.

The time of flight was from 195500 seconds to 200500 seconds, which corresponds to afternoon of May 03, 2016. 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 9 shows that the North position RMSE peaks at 2.50 centimeters, the East position RMSE peaks at 1.70 centimeters, and the Down position RMSE peaks at 2.40 centimeters, which are within the prescribed accuracies described in the methodology.


Figure 10. Solution Status Parameters of Baua Flight 3991G.

The Solution Status parameters of flight 3991G, one of the Baua flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 10. 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 1 for majority of the survey with some peaks up to 2 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 Baua flights is shown in Figure 11.

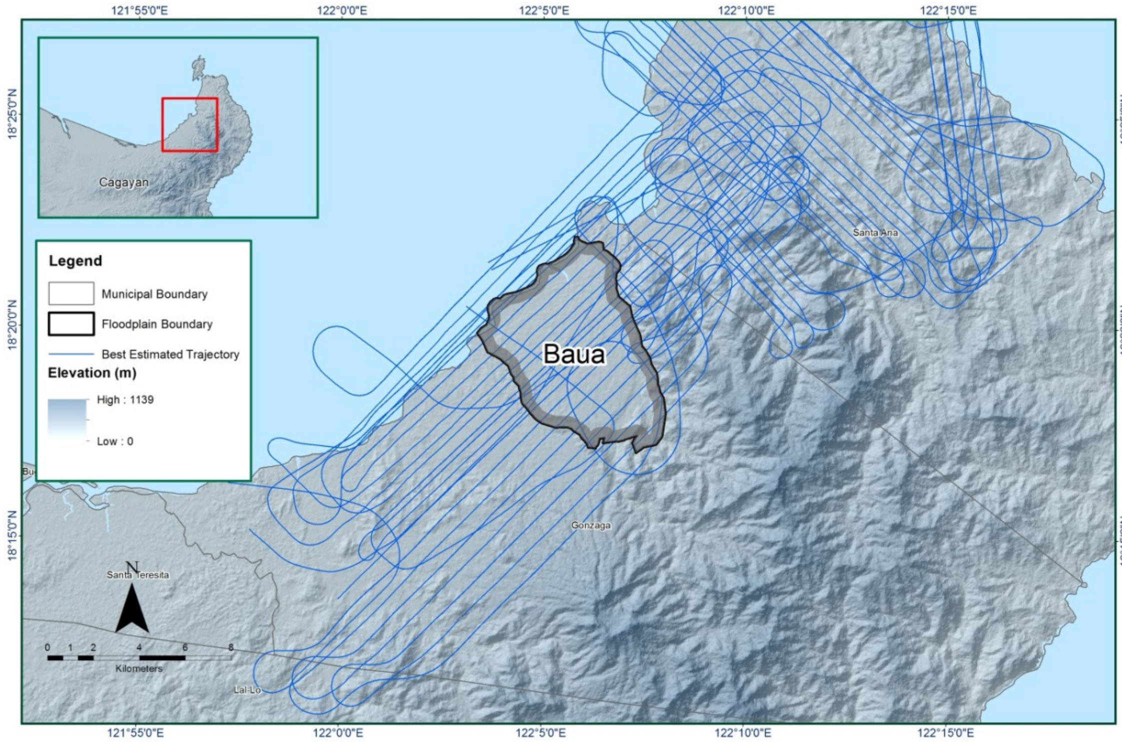



Figure 11. Best Estimated Trajectory for Baua Floodplain.

## 3.4 LiDAR Point Cloud Computation

The produced LAS data contains 46 flight lines, with each flight line containing one or two channels, since the Gemini system contains one channel and the Pegasus system contains two channels. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Baua floodplain are given in Table 10.

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

| Parameter | Computed Value |
|---|---|
| Boresight Correction stdev (<0.001degrees) | 0.000876 |
| IMU Attitude Correction Roll and Pitch Corrections stdev (<0.001degrees) | 0.015089 |
| GPS Position Z-correction stdev (<0.01meters) | 0.0024 |

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

## 3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Baua Floodplain is shown in Figure 12. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

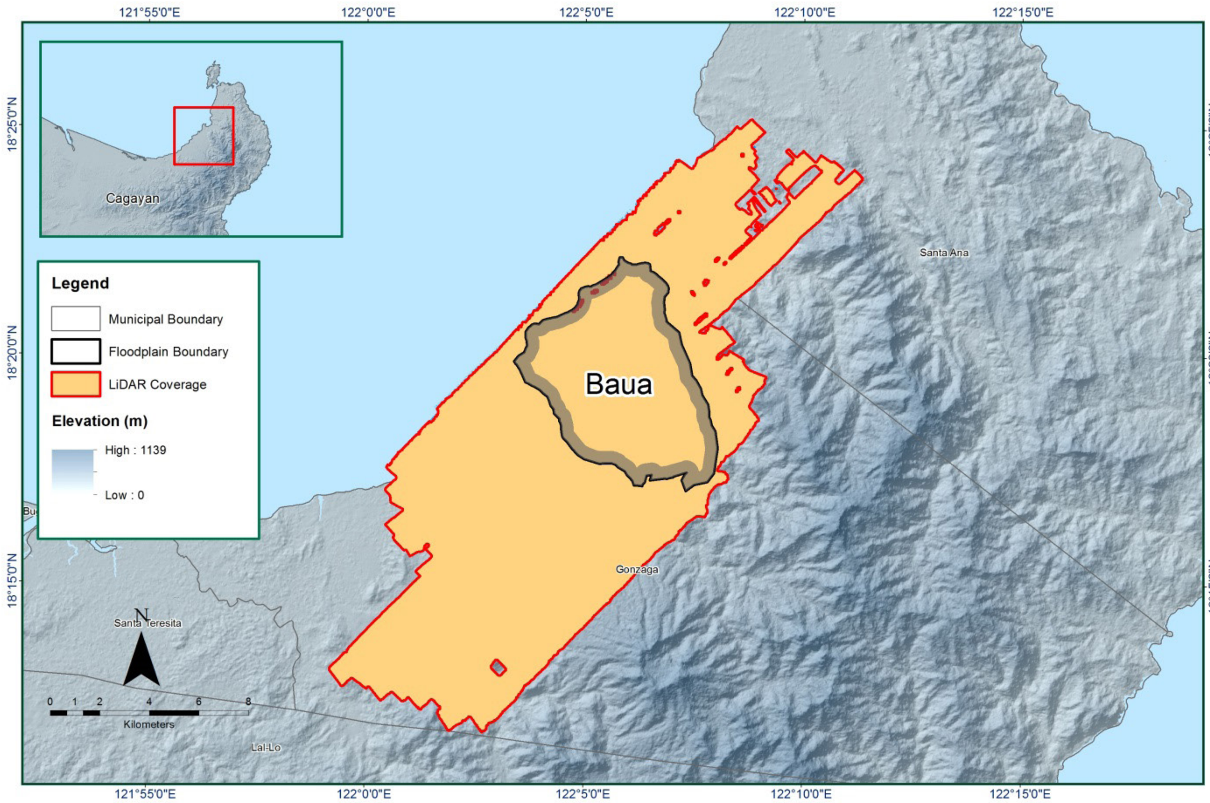



Figure 12. Boundary of the processed LiDAR data over Baua Floodplain

The total area covered by the Baua missions is 217.07 sq.km that is comprised of four (4) flight acquisitions grouped and merged into two (2) blocks as shown in Table 11.

Table 11. List of LiDAR blocks for Baua Floodplain.

| LiDAR Blocks | Flight Numbers | Area (sq.km) |
|---|---|---|
| Cagayan_reflights_Blk3A | 3971G | 108.73 |
| | 3991G | |
| | 4001G | |
| Cagayan_reflights_Tugegarao_Blk3A | 2916P | 108.34 |
| | **TOTAL** | **217.07 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 13. Since the Gemini system employs one channel and the Pegasus system employs two channels, we would expect an average value of 1 (blue) for Gemini and 2 for Pegasus for areas where there is limited overlap, and a value of 2 (yellow) or more (red) for Gemini and 3 for Pegasus for areas with three or more overlapping flight lines.

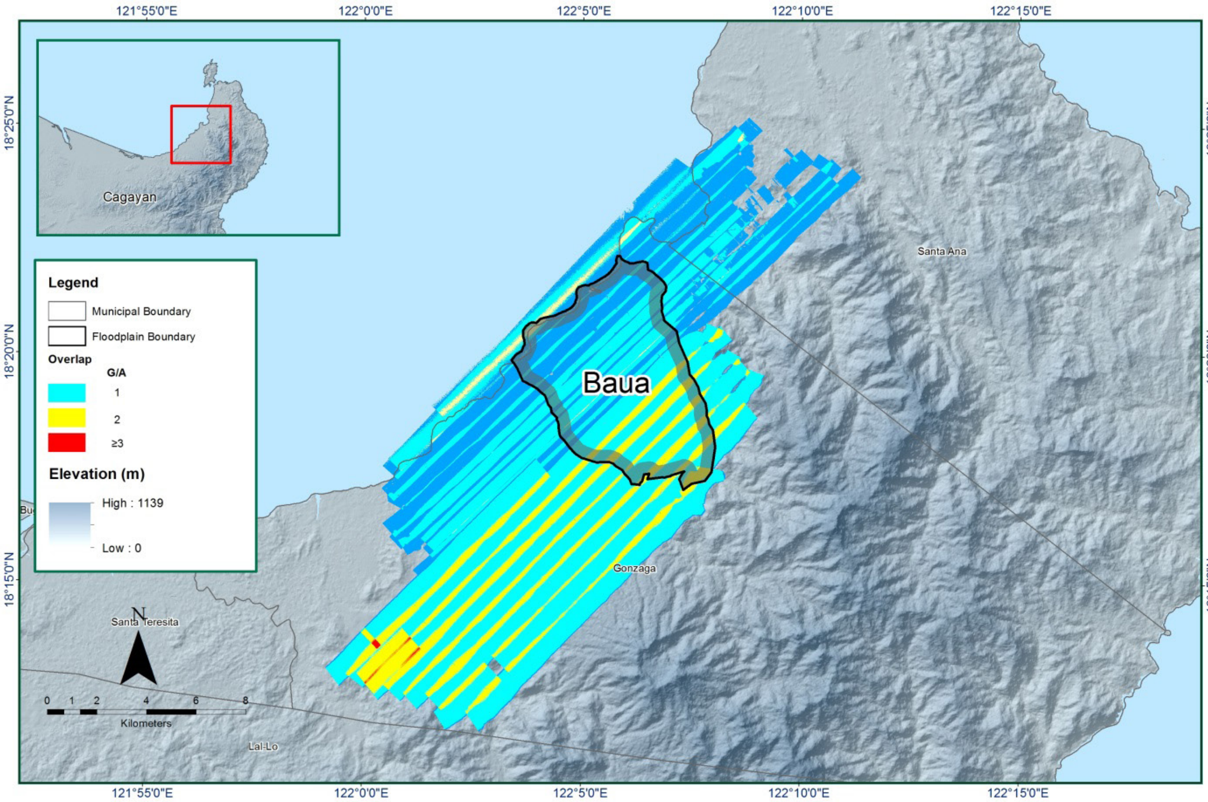



Figure 13. Image of data overlap for Baua Floodplain.

The overlap statistics per block for the Baua floodplain can be found in Annex B-1. One pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 30.46% and 42.36% 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 14. It was determined that all LiDAR data for Baua floodplain satisfy the point density requirement, and the average density for the entire survey area is 3.28 points per square meter.

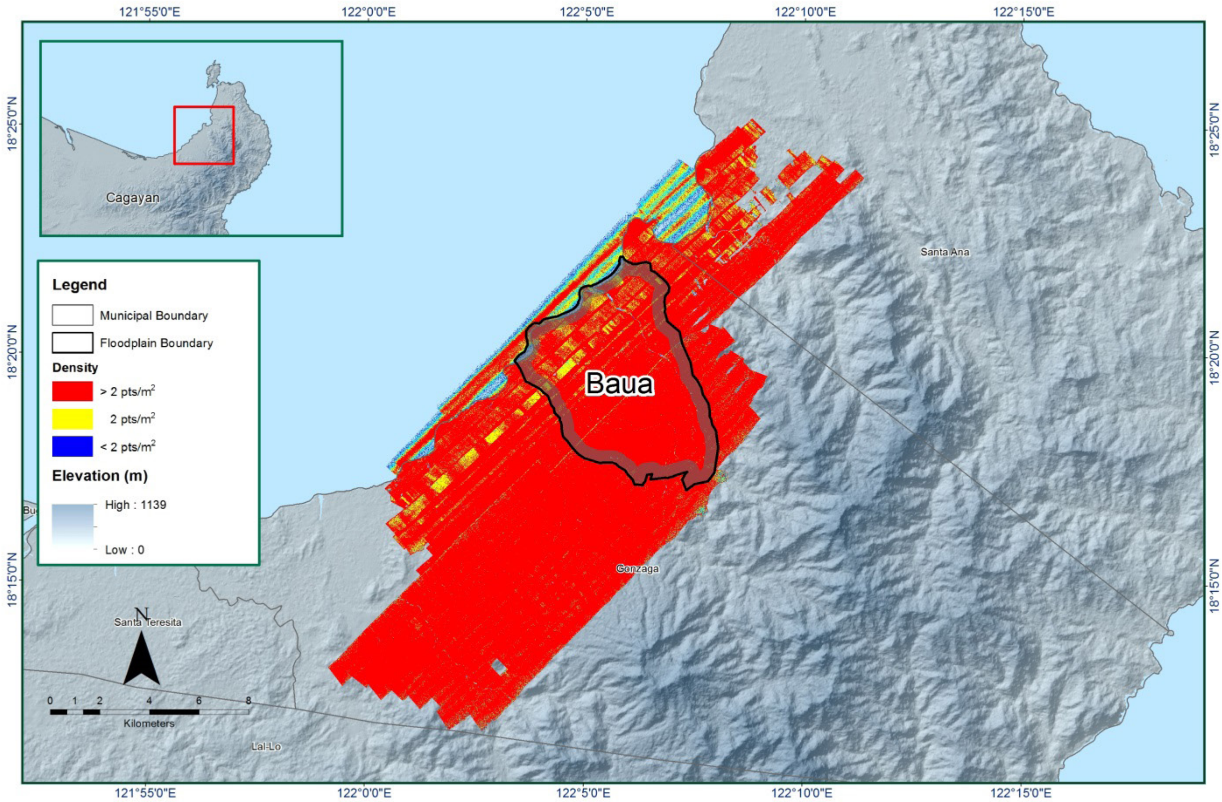



Figure 14. Pulse density map of merged LiDAR data for Baua Floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 15. 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.

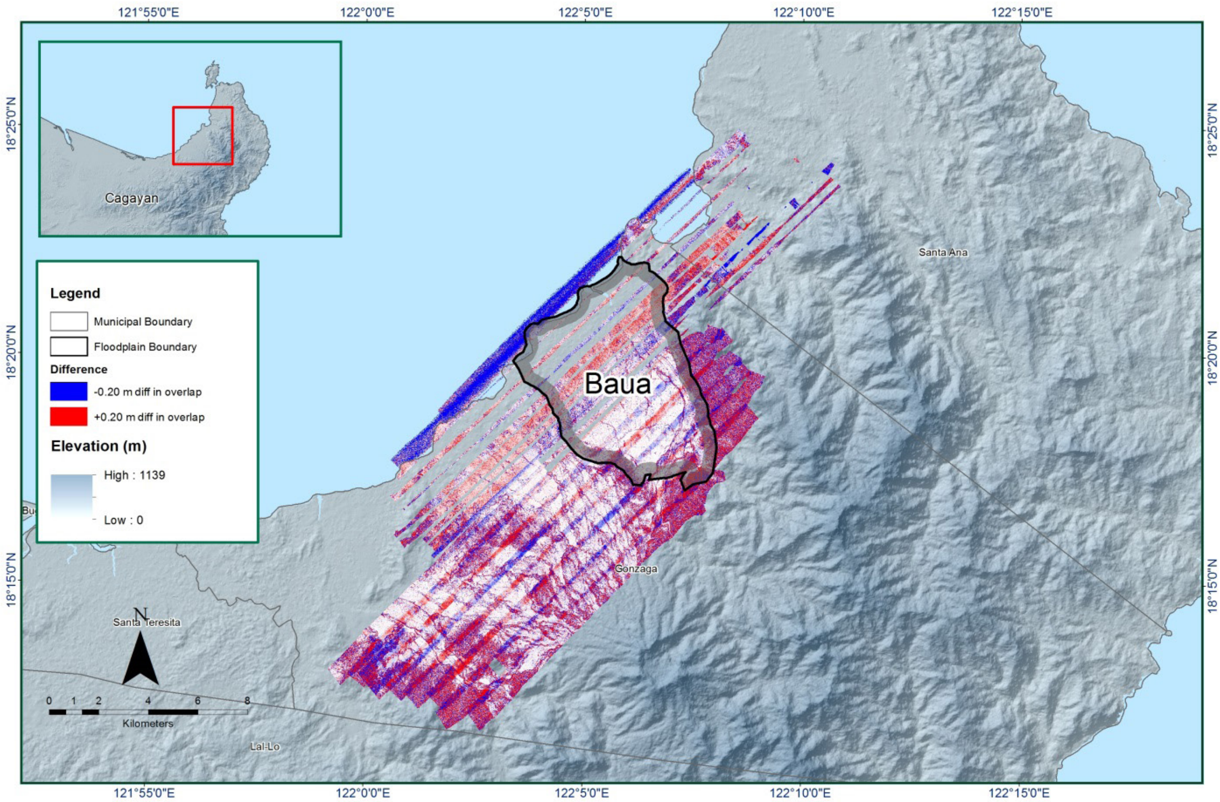



Figure 15. Elevation difference map between flight lines for Baua Floodplain.

A screen capture of the processed LAS data from a Baua flight 3991G loaded in QT Modeler is shown in Figure 16. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed red line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

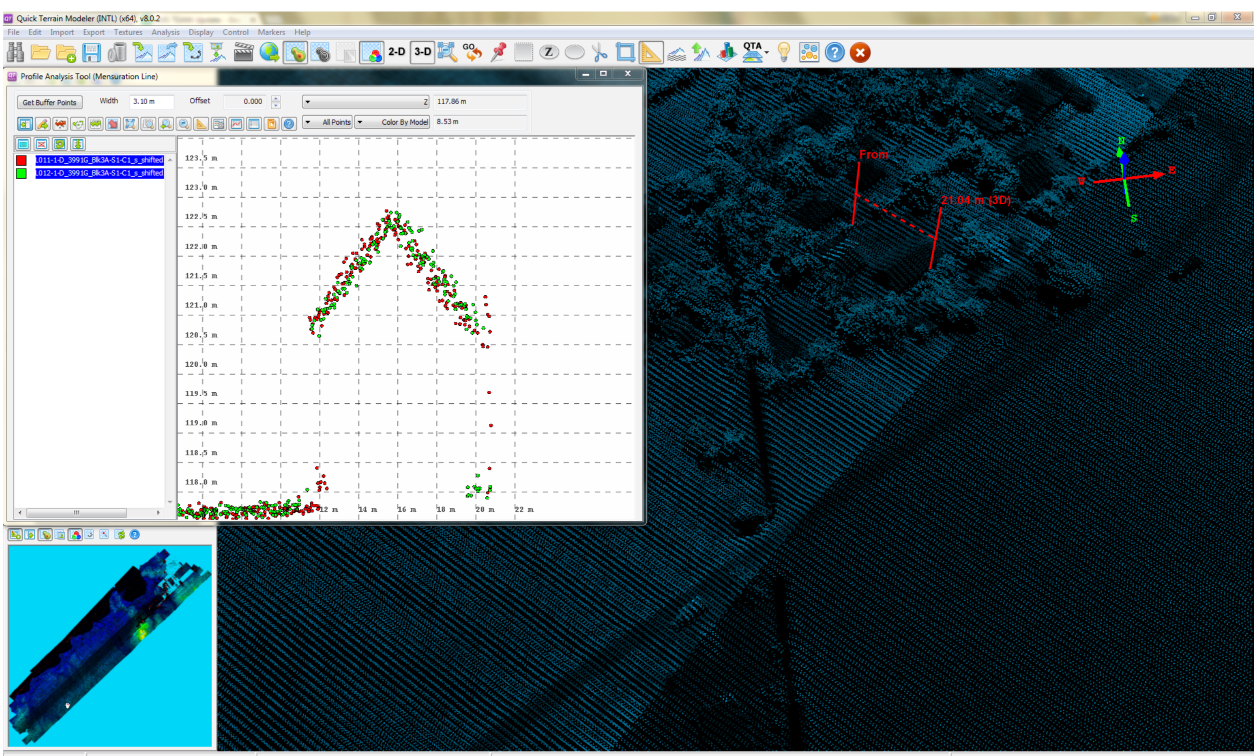



Figure 16. Quality checking for Baua Flight 3991G using the Profile Tool of QT Modeler.

## 3.6 LiDAR Point Cloud Classification and Rasterization

Table 12. Baua classification results in TerraScan.

| Pertinent Class | Total Number of Points |
|---|---:|
| Ground | 179,691,005 |
| Low Vegetation | 147,015,389 |
| Medium Vegetation | 332,562,577 |
| High Vegetation | 409,934,706 |
| Building | 14,197,860 |

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Baua floodplain is shown in Figure 17. A total of 294 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 12. The point cloud has a maximum and minimum height of 677.25 meters and 38.95 meters respectively.

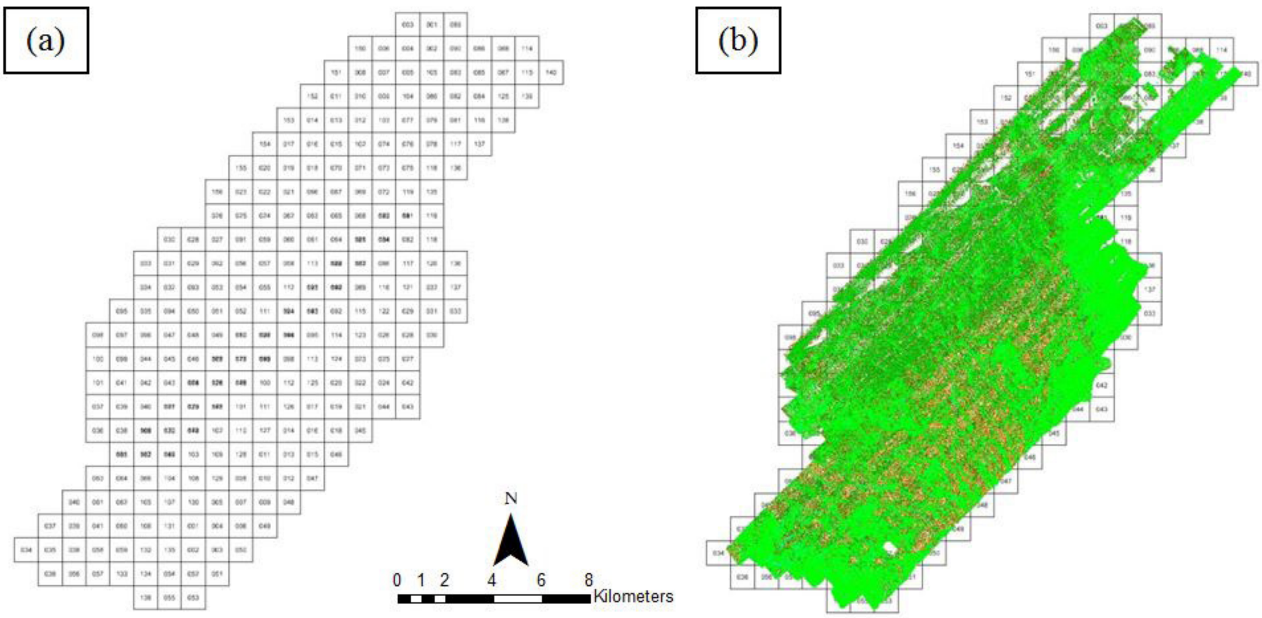



Figure 17. Tiles for Baua Floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 18. 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.

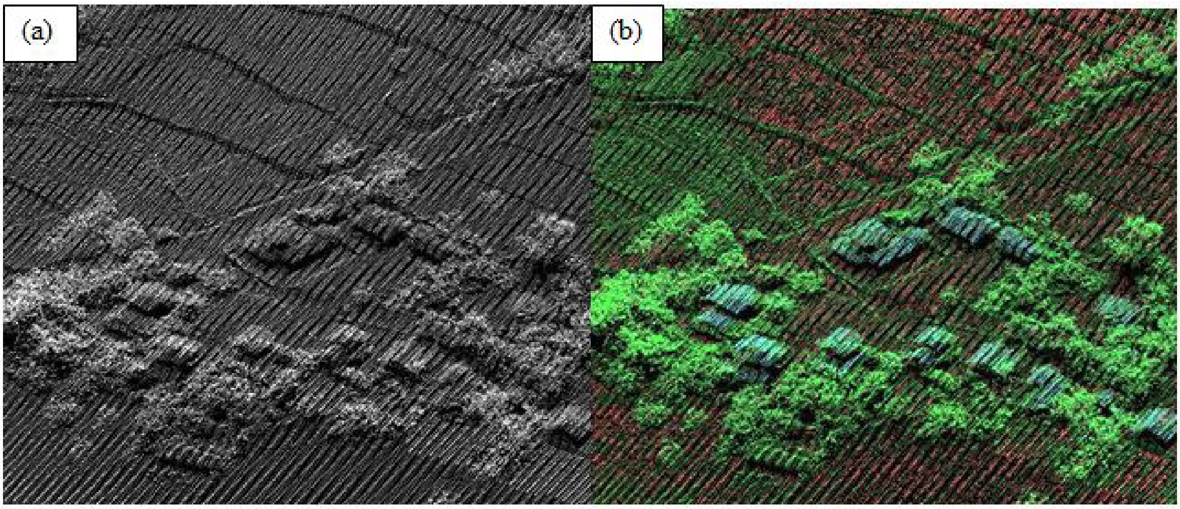



Figure 18. Point cloud before (a) and after (b) classification.

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

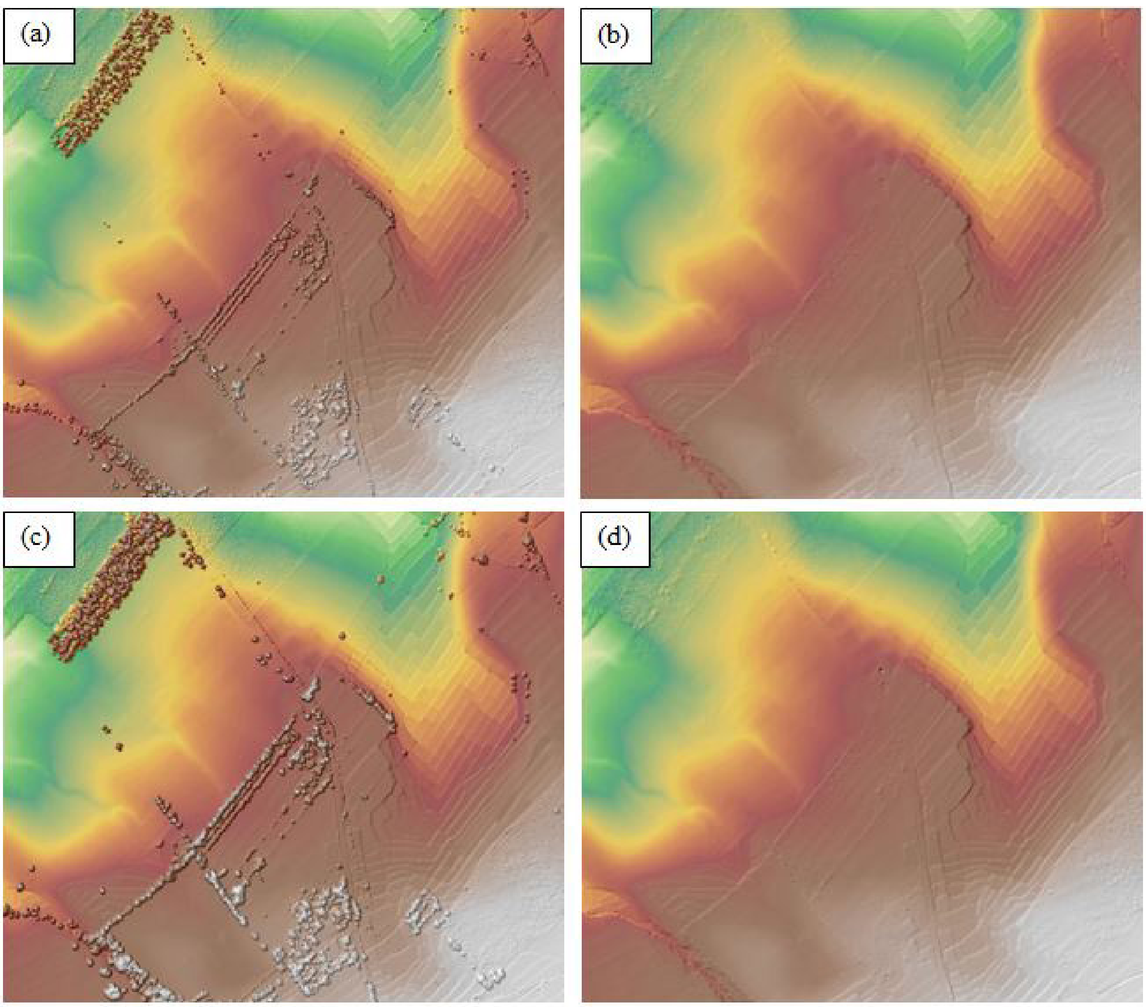



Figure 19. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Baua Floodplain.

## 3.7 LiDAR Image Processing and Orthophotograph Rectification

The 114 1km by 1km tiles area covered by Baua floodplain is shown in Figure 20. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Baua floodplain has a total of 85.78 sq.km orthophotogaph coverage comprised of 216 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 21.

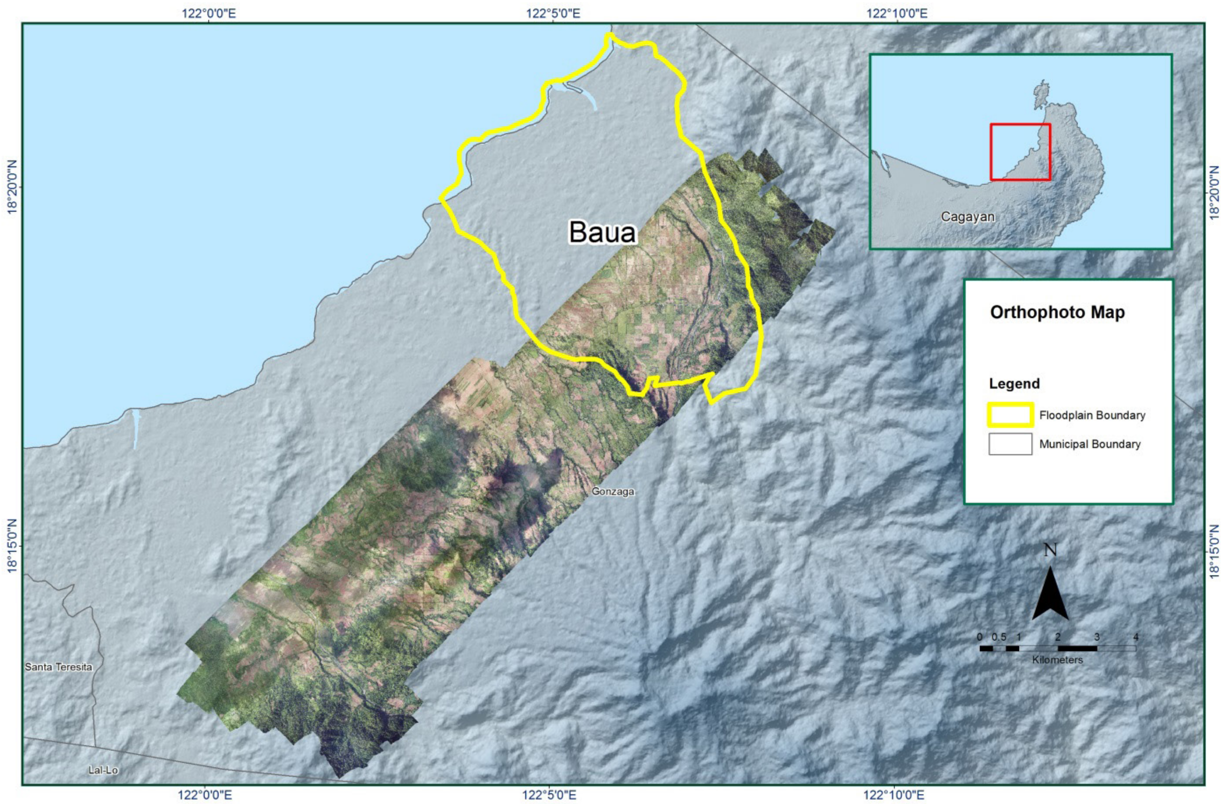



Figure 20. Baua Floodplain with available orthophotographs.

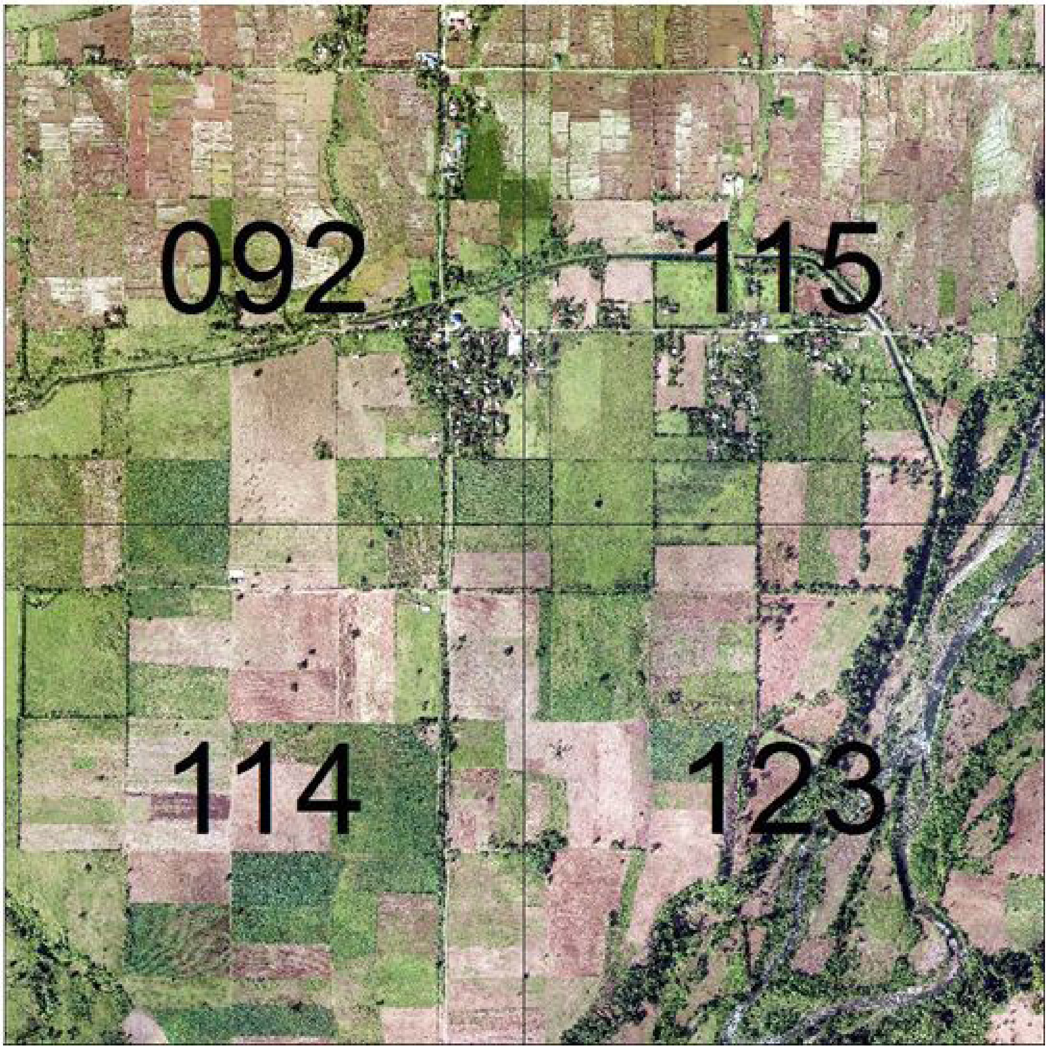



Figure 21. Sample orthophotograph tiles for Baua Floodplain.

## 3.8 DEM Editing and Hydro-Correction

Two (2) mission blocks were processed for Baua flood plain. These blocks are composed of Cagayan reflights and Cagayan reflights Tugegarao blocks with a total area of 217.07 square kilometers. Table 13 shows the name and corresponding area of each block in square kilometers.

Table 13. LiDAR blocks with its corresponding area

| LiDAR Blocks | Area (sq.km) |
|---|---|
| Cagayan_reflights_Blk3A | 108.73 |
| Cagayan_reflights_Tugegarao_Blk3A | 108.34 |
| **TOTAL** | **217.07 sq.km** |

Portions of DTM before and after manual editing are shown in Figure 22. The bridge (Figure 22a) is also considered to be an impedance to the flow of water along the river and has to be removed (Figure 22b) in order to hydrologically correct the river. An interpolated base of a mountain (Figure 22c) was retrieved (Figure 22d) in order to hydrologically correct the surrounding river system. Another example is an interpolated ridge (Figure 22e) has to be retrieved using object retrieval to achieve the actual surface (Figure 22f). Another example is a building that is still present in the DTM after classification (Figure 22g) and has to be removed through manual editing (Figure 22h).

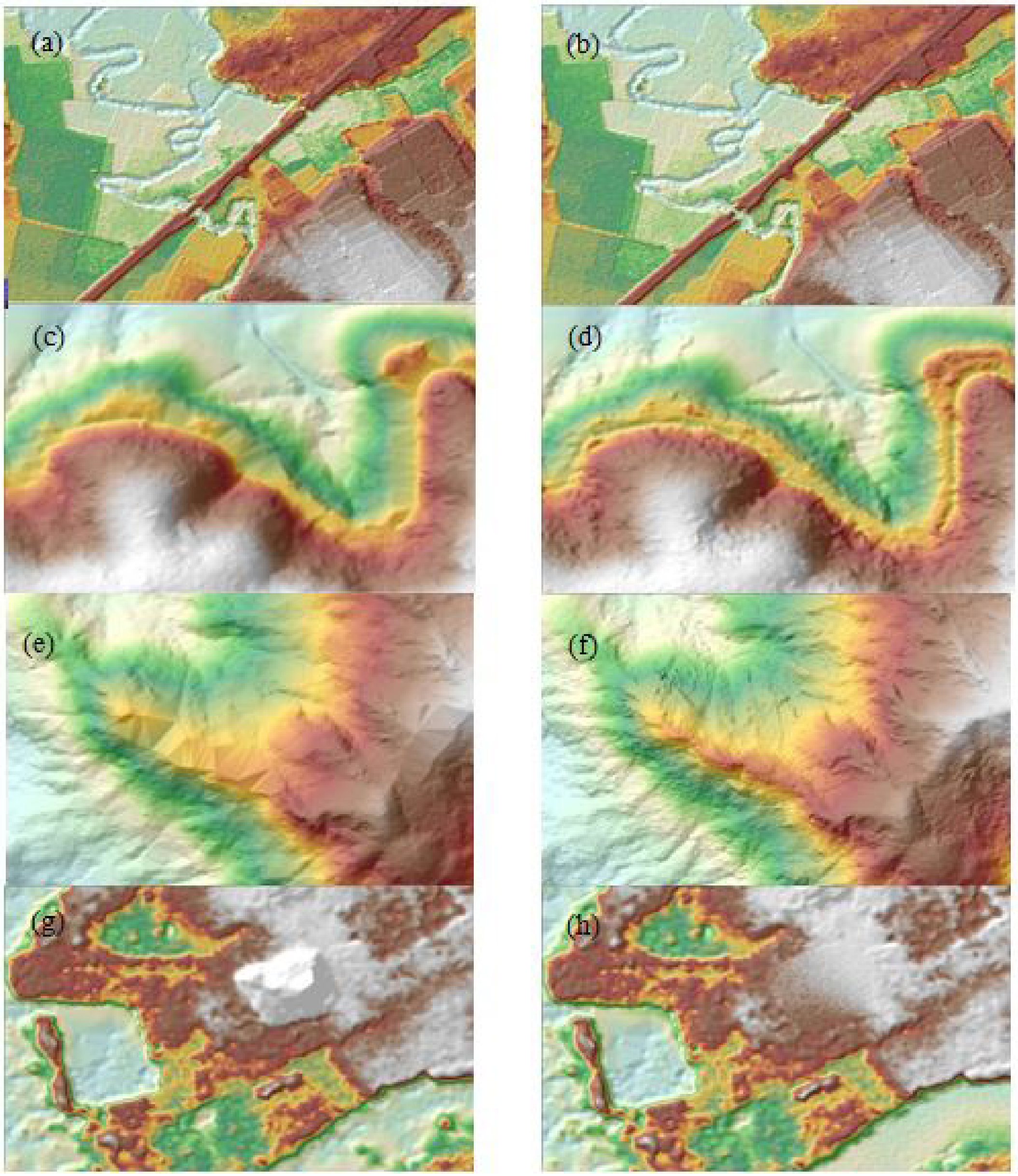



Figure 22. Portions in the DTM of Baua Floodplain – a bridge before (a) and after (b) manual editing; a mountain base before (c) and after object retrieval (d); interpolated ridge before (e) and after (f) object retrieval; and a building before (g) and after (h) manual editing.

## 3.9 Mosaicking of Blocks

No assumed reference block was used in mosaicking because the identified reference for shifting was an existing Aunugay DEM which was calibrated using Cagayan DEM overlapping with the blocks to be mosaicked. Table 14 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Baua floodplain is shown in Figure 23. It can be seen that the entire Baua floodplain is 100% covered by LiDAR data.

Table 14. Shift Values of each LiDAR Block of Baua Floodplain.

| Mission Blocks | Shift Values (meters) | | |
|---|---|---|---|
| | x | y | z |
| Cagayan_reflights_Blk3A | 6.32 | 1.18 | -4.72 |
| Cagayan_reflights_Tugegarao_Blk3A | 5.69 | -0.32 | -4.95 |

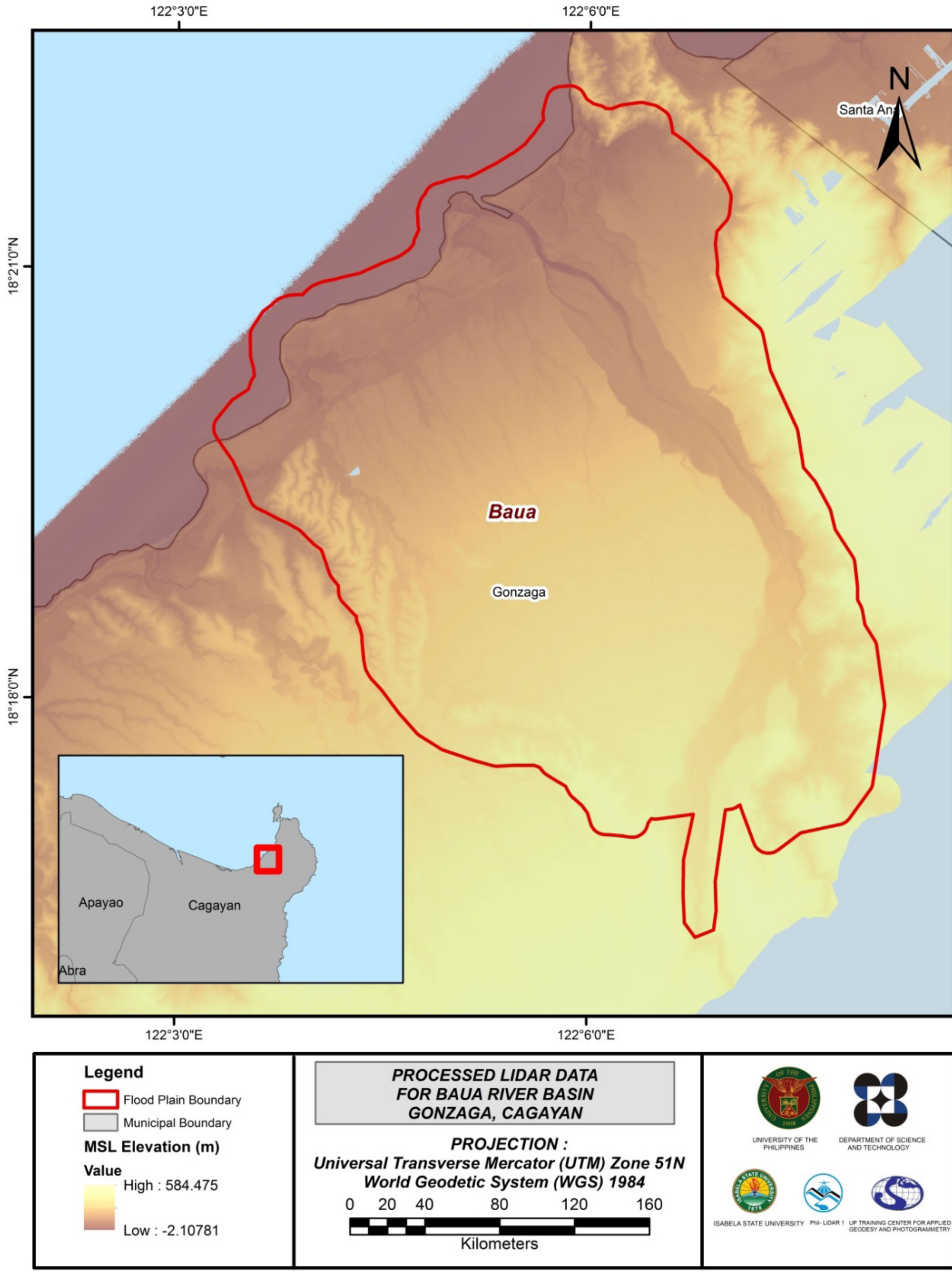



Figure 23. Map of Processed LiDAR Data for Baua Floodplain.

## 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 Cagayan to collect points with which the LiDAR dataset is validated is shown in Figure 24. A total of 6,209 survey points were gathered for all the floodplains within Cagayan wherein the Baua is located. However, the point dataset was not used for the calibration of the LiDAR data for Baua because during the mosaicking process, each LiDAR block was referred to the calibrated Cagayan DEM. Therefore, the mosaicked DEM of Baua can already be considered as a calibrated DEM.

A good correlation between the uncalibrated Cagayan LiDAR DTM and ground survey elevation values is shown in Figure 25. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration points is 4.07 meters with a standard deviation of 0.14 meters. Calibration of Cagayan LiDAR data was done by subtracting the height difference value, 4.07 meters, to Cagayan mosaicked LiDAR data. Table 15 shows the statistical values of the compared elevation values between Cagayan LiDAR data and calibration data. These values were also applicable to the Baua DEM.

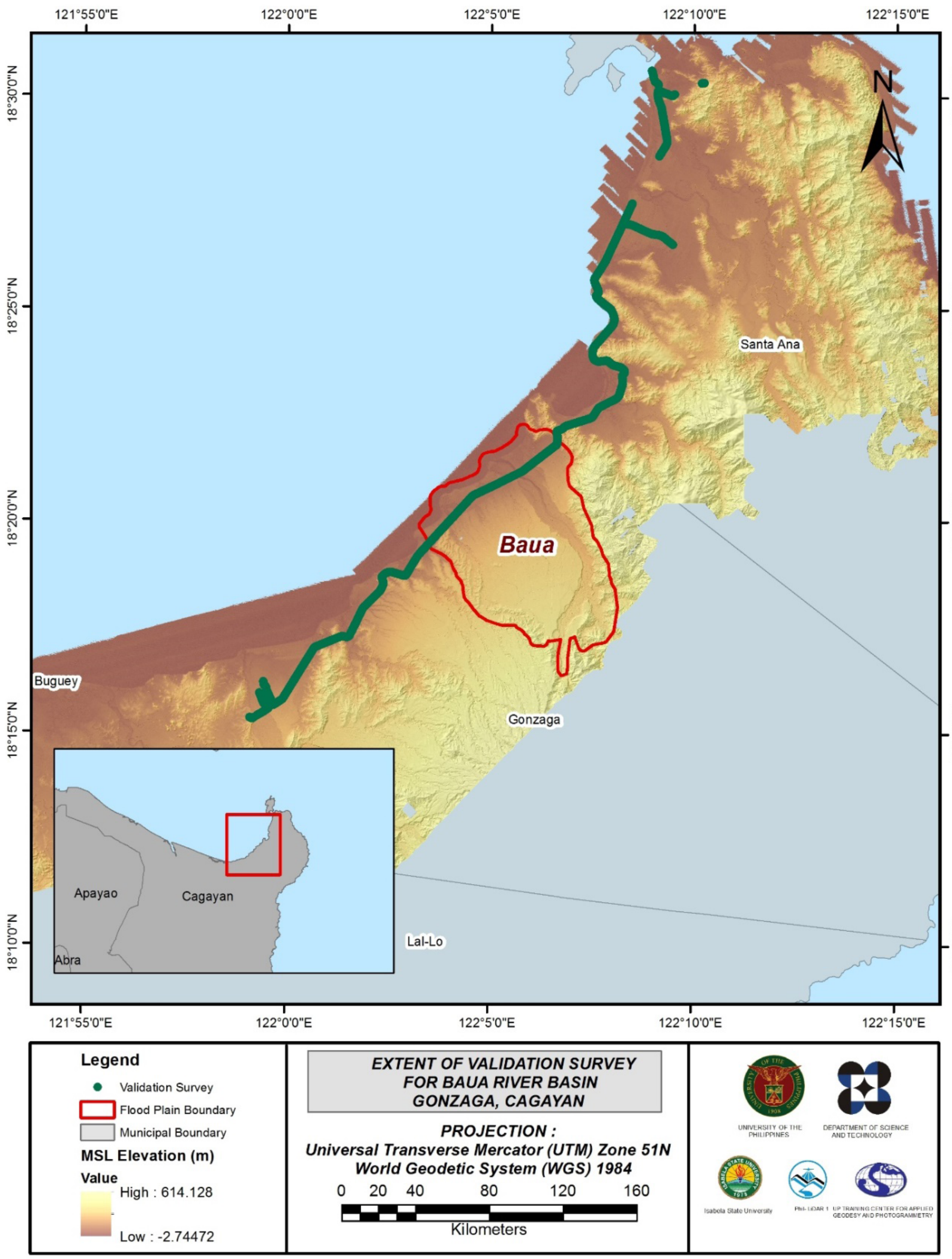



Figure 24. Map of Baua Floodplain with validation survey points in green.

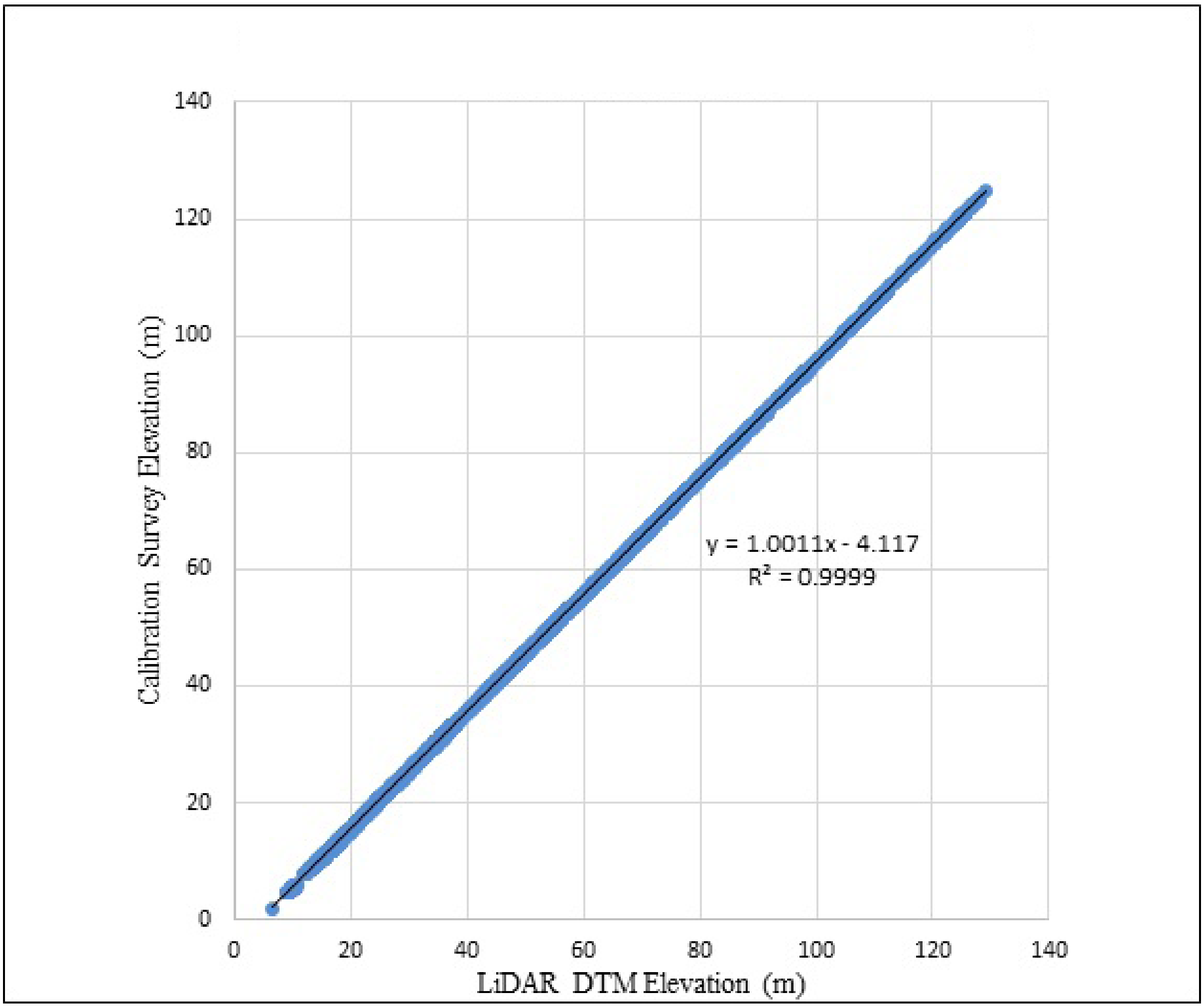



Figure 25. Correlation plot between calibration survey points and LiDAR data.

Table 15. Calibration Statistical Measures.

| Calibration Statistical Measures | Value (meters) |
|---|---|
| Height Difference | 4.07 |
| Standard Deviation | 0.14 |
| Average | -4.07 |
| Minimum | -4.50 |
| Maximum | -3.77 |

The remaining 20% of the total survey points, resulting to 186 points, were used for the validation of calibrated Baua DTM. The 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 26. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.198 meters with a standard deviation of 0.07 meters, as shown in Table 16.

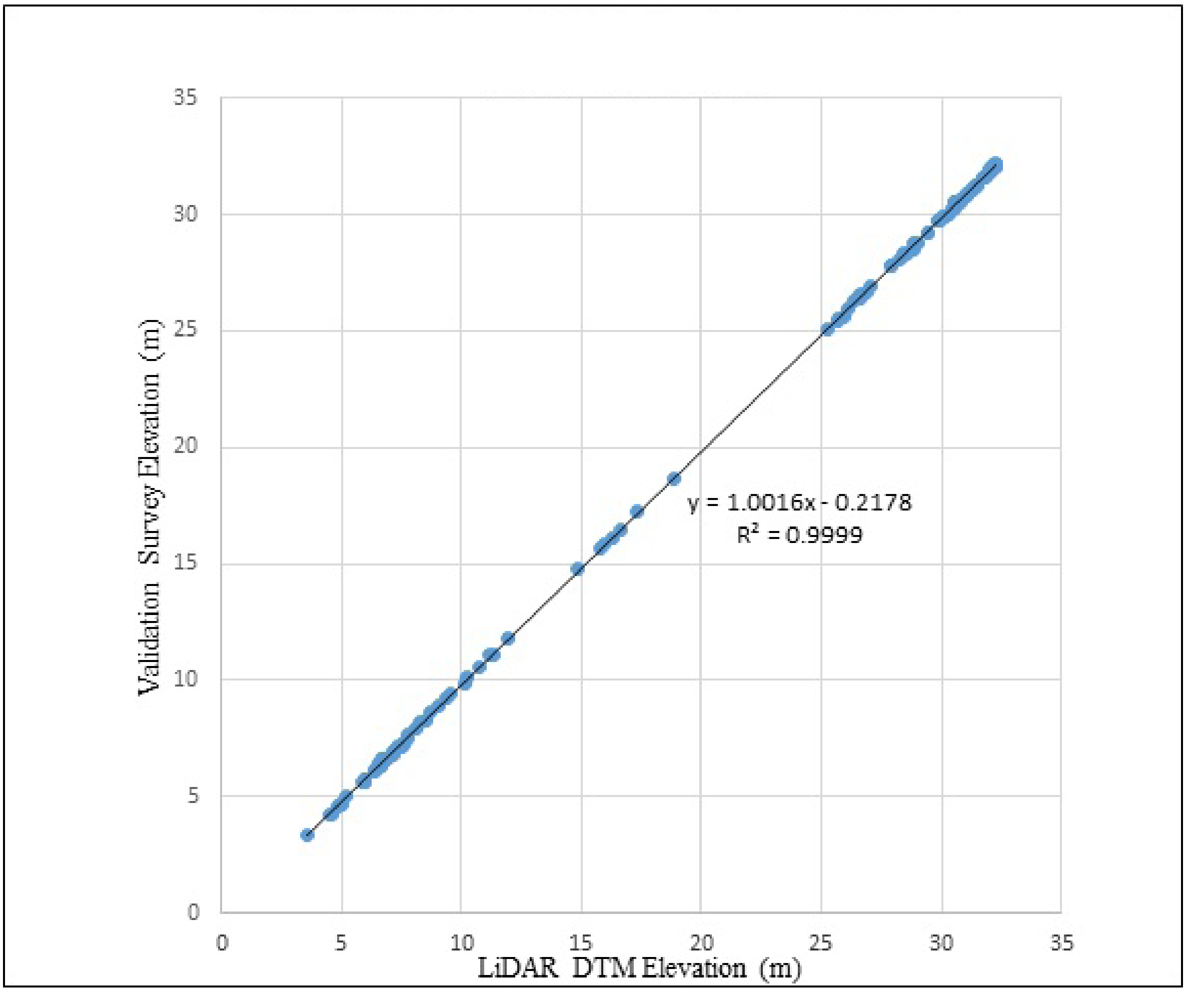



Figure 26. Correlation plot between validation survey points and LiDAR data.

Table 16. Validation Statistical Measures.

| Validation Statistical Measures | Value (meters) |
|---|---|
| RMSE | 0.48 |
| Standard Deviation | 0.09 |
| Average | 0.47 |
| Minimum | 0.14 |
| Maximum | 0.65 |

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

For bathy integration, only zigzag data was available for Baua with 2,516 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 0.07 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Baua integrated with the processed LiDAR DEM is shown in Figure 27.

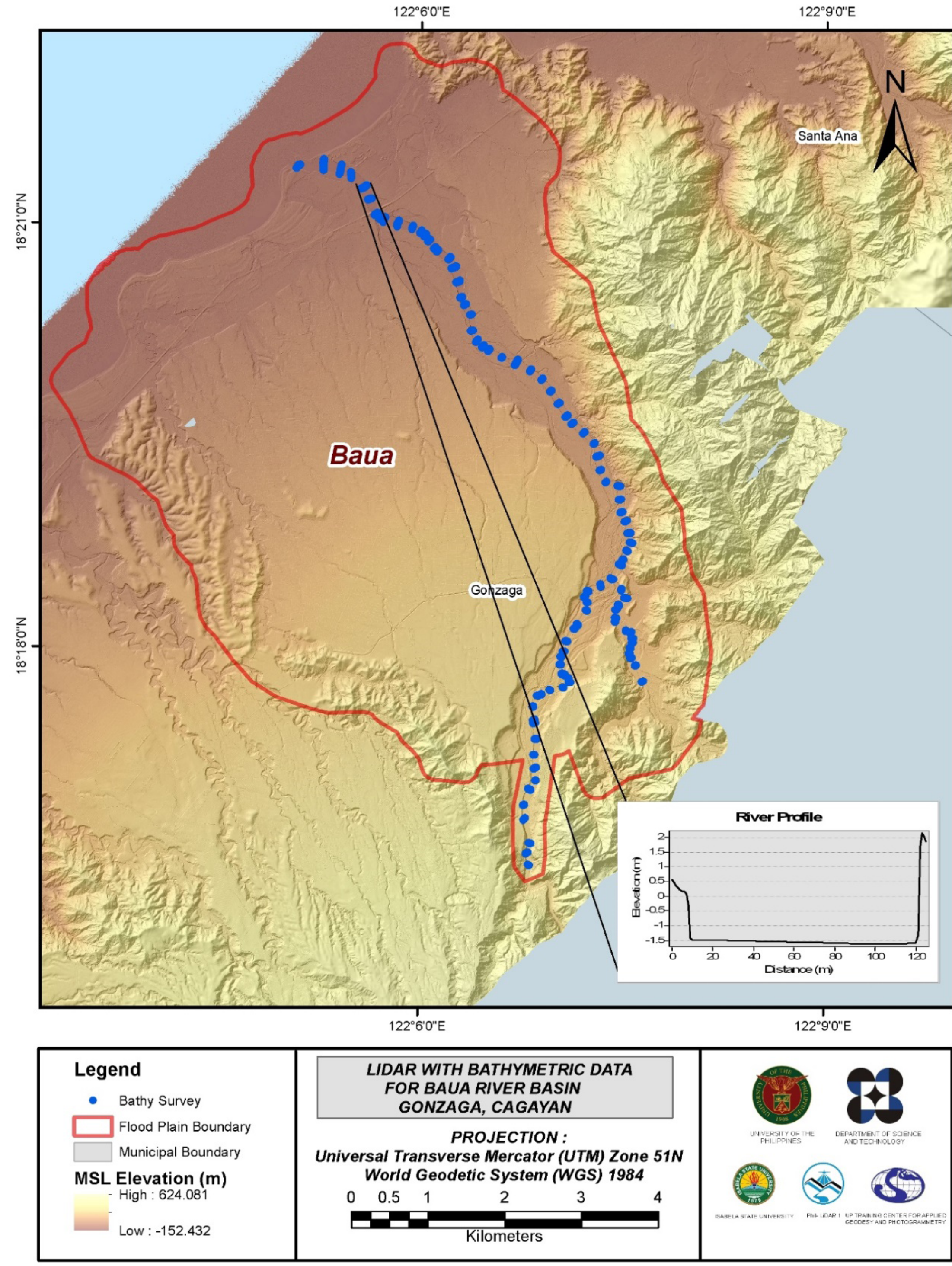



Figure 27. Map of Baua Floodplain with bathymetric survey points shown in blue.

## 3.12 Feature Extraction

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

### 3.12.1 Quality Checking of Digitized Features' Boundary

Baua floodplain, including its 200 m buffer, has a total area of 51.78 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 560 building features, are considered for QC. Figure 28 shows the QC blocks for Baua floodplain.

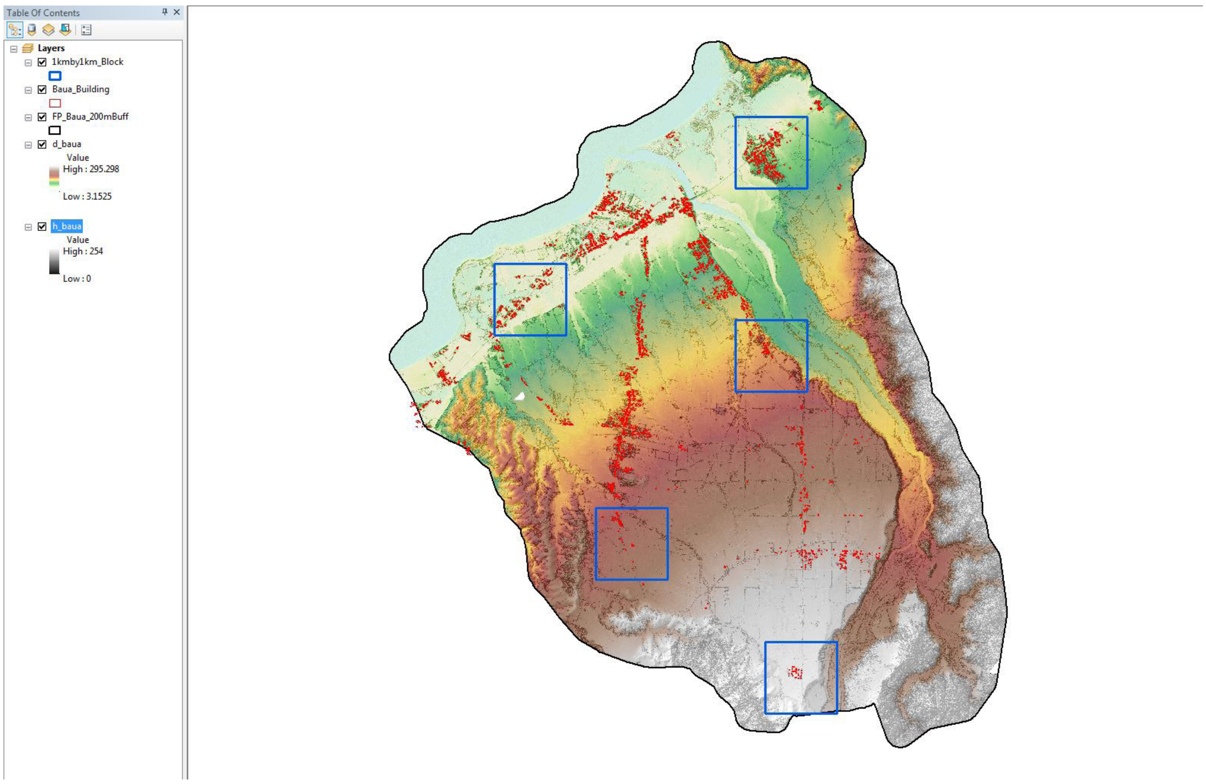



Figure 28. QC blocks for Baua building features.

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

Table 17. Quality Checking Ratings for Baua Building Features.

| FLOODPLAIN | COMPLETENESS | CORRECTNESS | QUALITY | REMARKS |
|---|---|---|---|---|
| Baua | 97.56 | 100 | 93.93 | PASSED |

### 3.12.2 Height Extraction

Height extraction was done for 3,043 building features in Baua floodplain. Of these building features, none was filtered out after height extraction, resulting to 3,043 buildings with height attributes. The lowest building height is at 2.86 m, while the highest building is at 12.87 m.

### 3.12.3 Feature Attribution

The digitized features were identified using participatory mapping. Stakeholders (preferably barangay officials) were invited in a forum and were given maps of their respective barangays. They attributed first non-residential buildings like barangay hall, schools, churches, commercial buildings, etc. then other building left were then coded as residential. An nDSM was generated using the LiDAR DEMs to extract the heights of the buildings. A minimum height of 2 meters was used to filter out the terrain features that were digitized as buildings. Buildings that were not yet constructed during the time of LiDAR acquisition were noted as new buildings in the attribute table.

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

Table 18. Building Features Extracted for Baua Floodplain.

| Facility Type | No. of Features |
|---|---|
| Residential | 2,918 |
| School | 77 |
| Market | 6 |
| Agricultural/Agro-Industrial Facilities | 0 |
| Medical Institutions | 0 |
| Barangay Hall | 5 |
| Military Institution | 0 |
| Sports Center/Gymnasium/Covered Court | 3 |
| Telecommunication Facilities | 0 |
| Transport Terminal | 0 |
| Warehouse | 0 |
| Power Plant/Substation | 0 |
| NGO/CSO Offices | 0 |
| Police Station | 0 |
| Water Supply/Sewerage | 0 |
| Religious Institutions | 19 |
| Bank | 0 |
| Factory | 0 |
| Gas Station | 8 |
| Fire Station | 0 |
| Other Government Offices | 6 |
| Other Commercial Establishments | 1 |
| **Total** | **3,043** |

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

| Floodplain | Road Network Length (km) | | | | | Total |
|---|---|---|---|---|---|---|
| | Barangay Road | City/Municipal Road | Provincial Road | National Road | Others | |
| Baua | 41.08 | 0.00 | 5.11 | 7.96 | 43.32 | **97.49** |

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

| Floodplain | Water Body Type | | | | | Total |
|---|---|---|---|---|---|---|
| | Rivers/Streams | Lakes/Ponds | Sea | Dam | Fish Pen | |
| Baua | 7 | 0 | 0 | 0 | 0 | **7** |

A total of 12 bridges and culverts over small channels that are part of the river network were also extracted for the floodplain.

### 3.12.4 Final Quality Checking of Extracted Features

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

Figure 29 shows the Digital Surface Model (DSM) of Baua floodplain overlaid with its ground features.

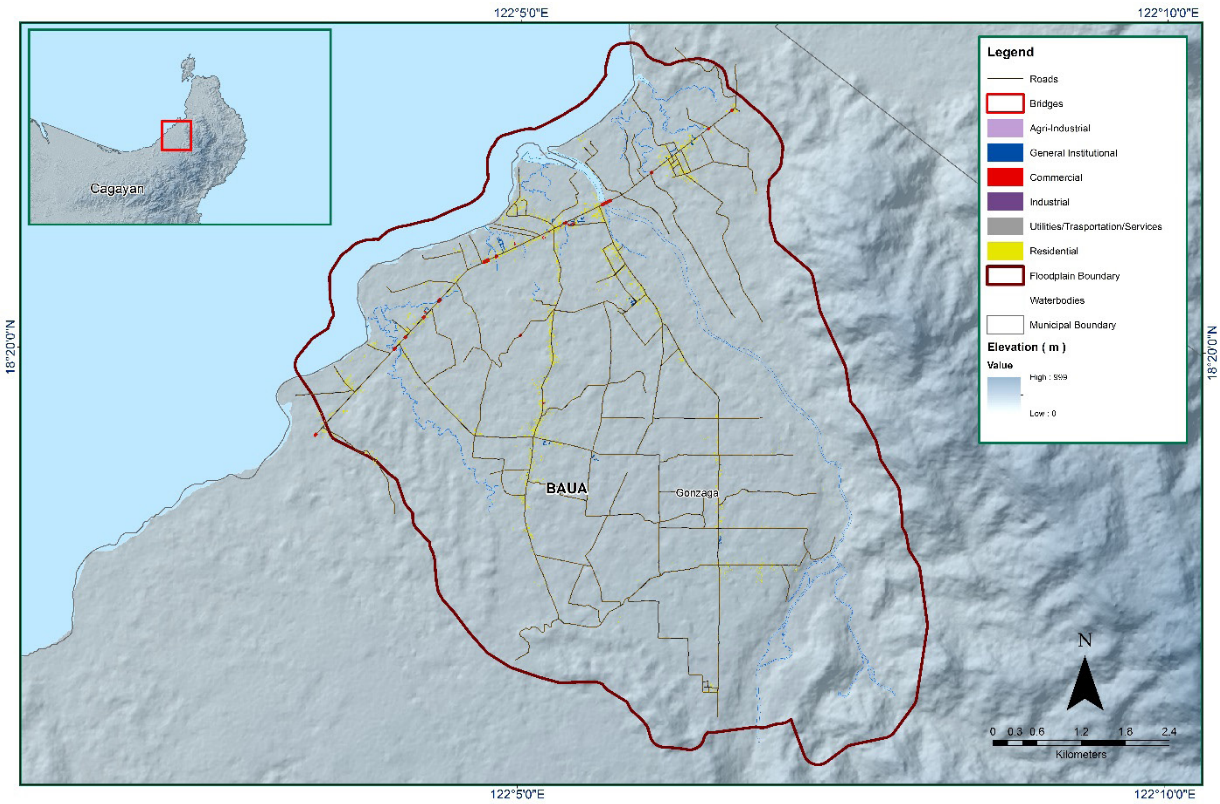



Figure 29. Extracted features for Baua Floodplain.

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

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

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

## 4.1 Summary of Activities

H.O. Noveloso Surveying (HONS) conducted a field survey in Baua River on Jan. 20-21, 2017, on Jan 23, 2017, on Jan. 30, 2017, on Feb. 4, 2017, on Feb. 6, 2017, on Feb. 11, 2017, on Feb. 14, 2017, and on Feb. 23 to 26, 2017 with the following scope: reconnaissance; control survey; cross-section and as-built survey of Baua Bridge in Brgy. Baua, Gonzaga, Cagayan; and bathymetric survey of the river from the upstream in Brgy. Amunitan to the mouth of the river in Brgy. Baua, Gonzaga, Cagayan with an approximate length of 15.62 km. Random checking points for the contractor's cross-section and bathymetry data were gathered by DVBC on October 11-22, 2016 using an Ohmex™ Single Beam Echo Sounder and Trimble® SPS 985 GNSS PPK survey technique. In addition to this, validation points acquisition survey was conducted covering the Baua River Basin area. The entire survey extent is illustrated in Figure 30.

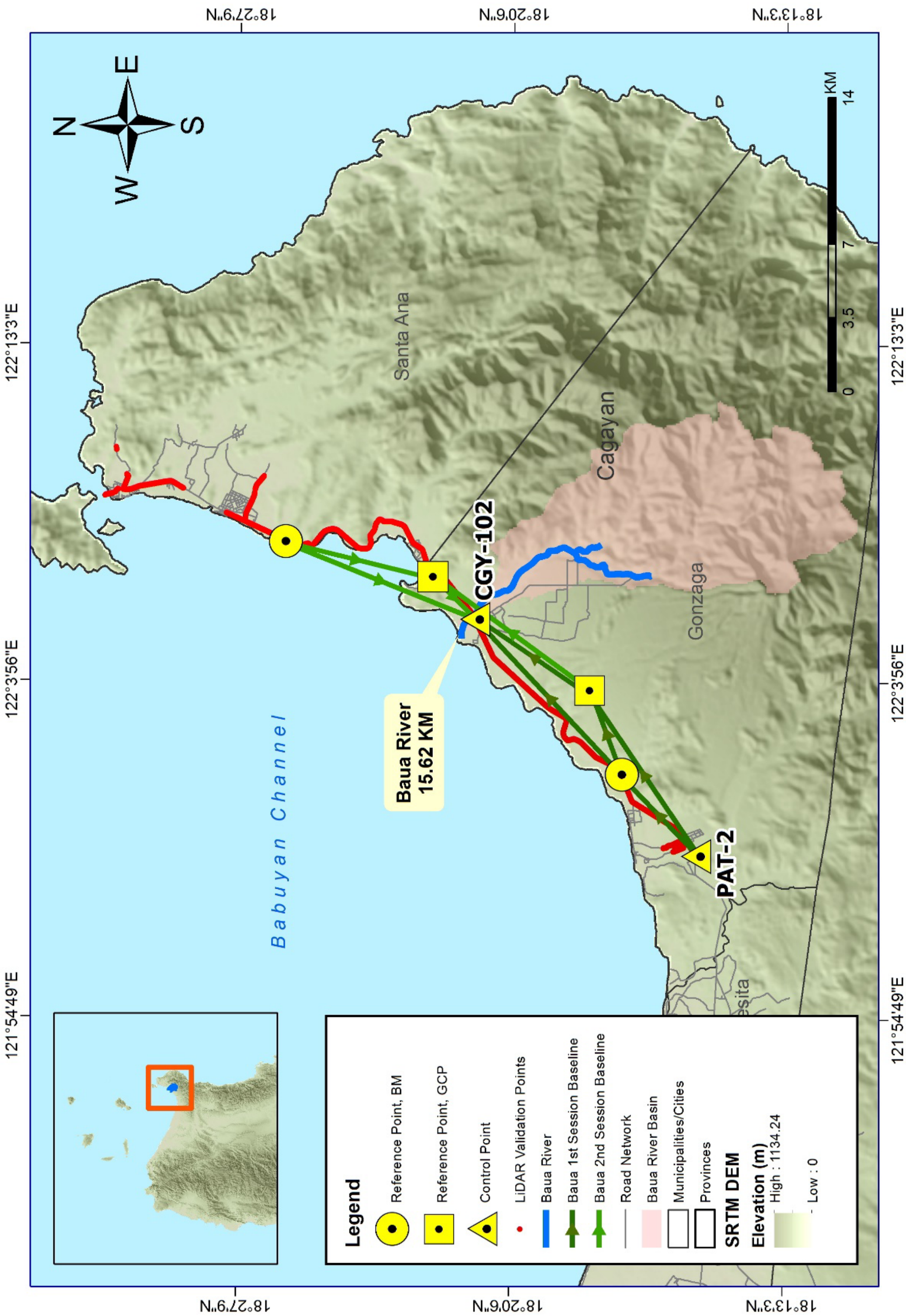



Figure 30. Baua River Survey Extent

## 4.2 Control Survey

The GNSS network used for Baua River is composed of two (2) networks. The 1st session is composed of two (2) loops established on October 12, 2016 occupying the following reference point: PAT-2, a DREAM-DVC established point last November 13-20, 2014, in Brgy. Pateng, Gonzaga, Cagayan.

Two (2) NAMRIA established control points, CGY-101, a second-order GCP in Brgy. Magrafil, Gonzaga, Cagayan and CG-258, a first-order BM in Brgy. Tapel, Gonzaga, Cagayan were used as markers along with one (1) established point in the area: UP-BAU-1 in Brgy. Baua, Gonzaga, Cagayan.

The 2nd session is also composed of two (2) loops established on October 13, 2016 occupying the following reference points: CGY-101 and UP-BAU-1.

Two (2) NAMRIA established control points, CGY-102, a second-order GCP in Brgy. San Jose, Gonzaga, Cagayan and CG-234, a first-order BM in Brgy. Diora-Zinungan, Sta. Ana, Cagayan were used as markers.

The summary of reference and control points and its location is summarized in Table 21 while the GNSS network established is illustrated in Figure 31.


Figure 31. GNSS Network covering Baua River

Table 21. List of reference and control points used in Baua River Basin survey
(Source: NAMRIA, UP-TCAGP)

| Control Point | Order of Accuracy | Geographic Coordinates (WGS 84) | | | | |
|---|---|---|---|---|---|---|
| | | Latitude | Longitude | Ellipsoid Height (m) | Elevation (MSL) (m) | Date of Establishment |
| 1st session | | | | | | |
| PAT-2 | Established | 18°15'20.41664"N | 121°59'13.60140"E | - | 21.505 | 2014 |
| CGY-101 | Used as marker | - | - | - | - | 2007 |
| CG-258 | Used as marker | - | - | - | - | 2007 |

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

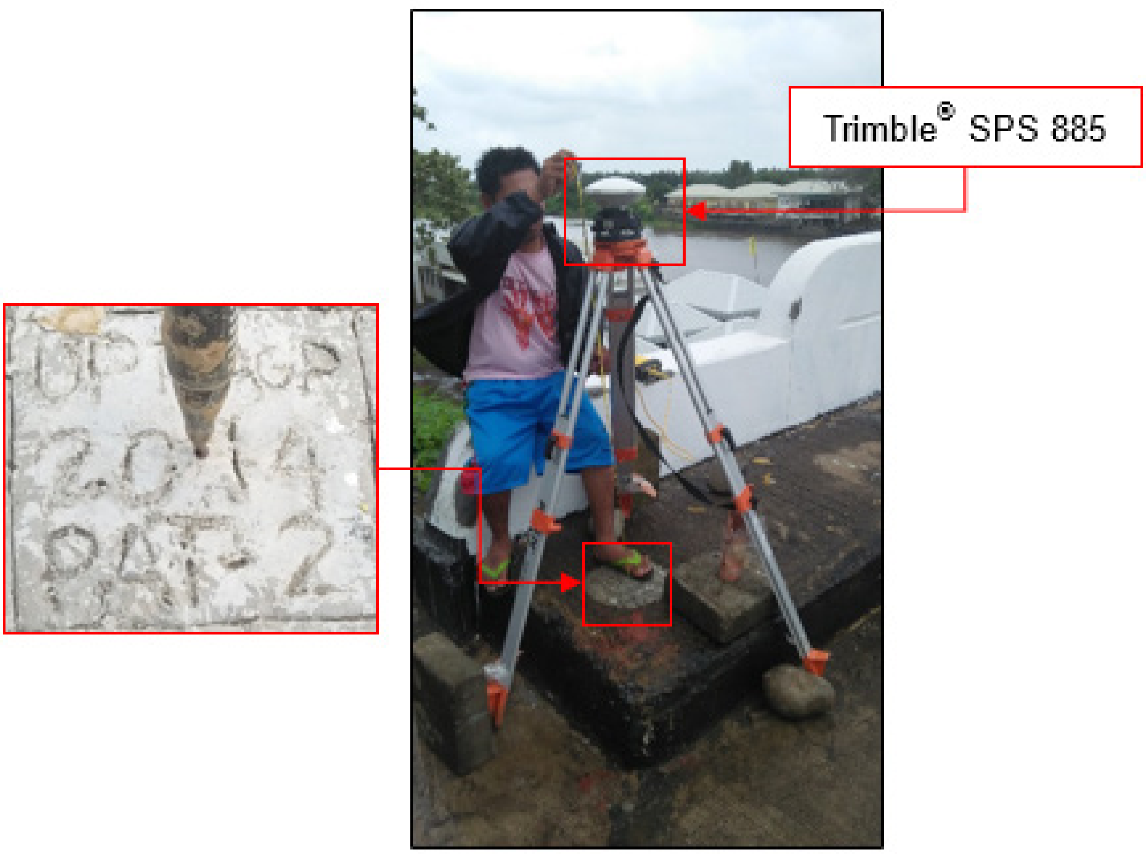



Figure 32. GNSS base set up, Trimble® SPS 885, at PAT-2, located at the approach of Pateng Bridge in Brgy. Pateng, Gonzaga, Cagayan

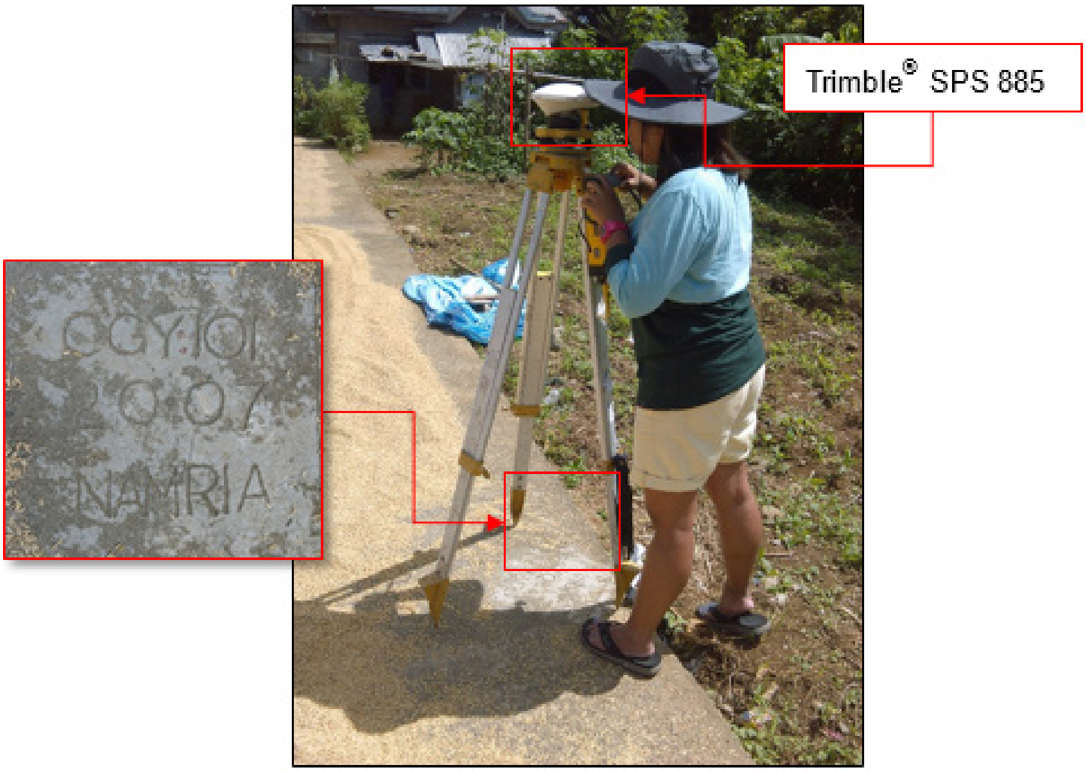



Figure 33. GNSS receiver set up, Trimble® SPS 885, at CGY-101, located at the side of the basketball court in Brgy. Magrafil, Gonzaga, Cagayan


Figure 34. GNSS receiver set up, Trimble® SPS 985, at CG-258, located at the approach of the bridge near the welcome arch of Brgy. Tapel, Gonzaga, Cagayan


Figure 35. GNSS receiver set up, Trimble® SPS 885, at UP-BAU-1, located at the approach of Baua Bridge in Brgy. Baua, Gonzaga, Cagayan


Figure 36. GNSS receiver set-up, Trimble® SPS 885, at CGY-102, located at the center island in front of the barangay marker of Brgy. Casambalangan in Brgy. San Jose, Gonzaga, Cagayan


Figure 37. GNSS receiver set-up, Trimble® SPS 885, at CG-234, located at the approach of Diora Bridge in Brgy. Diora-Zinungan, Sta. Ana, Cagayan

## 4.3 Baseline Processing

GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/- 20 cm and +/- 10 cm requirement, respectively. In case where one or more baselines did not meet all of these criteria, masking is performed. Masking is done by removing/masking portions of these baseline data using the same processing software. It is repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, resurvey is initiated. Baseline processing result of control points in Baua River Basin is summarized in Table 22 and Table 23 generated by TBC software.

Table 22. 1st Session Baseline Processing Report for Baua River Static Survey
(Source: NAMRIA, UP-TCAGP)

| Observation | Date of Observation | Solution Type | H. Prec. (Meter) | V. Prec. (Meter) | Geodetic Az. | Ellipsoid Dist. (Meter) | Height (m) |
|---|---|---|---|---|---|---|---|
| CGY-101 --- CG-258 | 10-12-2016 | Fixed | 0.003 | 0.017 | 68°41’13” | 4298.952 | 39.432 |
| CGY-101--- PAT-2 | 10-12-2016 | Fixed | 0.004 | 0.036 | 57°12’53” | 9404.155 | 23.252 |
| CG-258--- PAT-2 | 10-12-2016 | Fixed | 0.004 | 0.020 | 47°52’13” | 5260.711 | -16.180 |
| UP-BAU-1 --- CGY-101 | 10-12-2016 | Fixed | 0.003 | 0.015 | 31°30’31” | 6423.441 | -36.889 |
| UP-BAU-1 --- CG-258 | 10-12-2016 | Fixed | 0.004 | 0.028 | 226°18’00” | 10185.210 | -2.561 |
| UP-BAU-1 --- CGY-101 | 10-12-2016 | Fixed | 0.006 | 0.034 | 31°30’32” | 6423.433 | -36.919 |

Table 23. 2nd Session Baseline Processing Report for Baua River Static Survey
(Source: NAMRIA, UP-TCAGP)

| Observation | Date of Observation | Solution Type | H. Prec. (Meter) | V. Prec. (Meter) | Geodetic Az. | Ellipsoid Dist. (Meter) | Height (m) |
|---|---|---|---|---|---|---|---|
| UP-BAU-1 --- CGY-101 | 10-13-2016 | Fixed | 0.003 | 0.015 | 211°31'07" | 6423.441 | 36.890 |
| CGY-102--- CGY-101 | 10-13-2016 | Fixed | 0.005 | 0.033 | 35°41'58" | 9232.606 | -29.695 |
| CG-234--- CGY-102 | 10-13-2016 | Fixed | 0.003 | 0.017 | 13°22'55" | 7169.699 | -12.718 |
| CGY-102 --- UP-BAU-1 | 10-13-2016 | Fixed | 0.003 | 0.021 | 45°08'22" | 2865.049 | 7.194 |
| UP-BAU-1 --- CGY-101 | 10-13-2016 | Fixed | 0.006 | 0.035 | 211°31'07" | 6423.432 | 36.915 |
| CG-234 --- UP-BAU-1 | 10-13-2016 | Fixed | 0.005 | 0.029 | 22°17'57" | 9723.343 | -5.507 |

As shown Table 22 and Table 23, a total of twelve (12) baselines were processed with coordinate and elevation values of PAT-2 held fixed for the 1st session and the coordinate and elevation values of CGY-101 and UP-BAU-1 held fixed for the 2nd session. All of them passed the required accuracy.

## 4.4 Network Adjustment

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

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

Where:

$x_e$ is the Easting Error,
$y_e$ is the Northing Error, and
$z_e$ is the Elevation Error

for each control point. See the Network Adjustment Report shown in Table 24 to Table 29 for the complete details.

The four (4) control points, PAT-2, CGY-101, CG-258, and UP-BAU-1, were occupied and observed simultaneously to form a GNSS loop for the 1st session and the four (4) control points, CGY-101, UP-BAU-1, CGY-102, and CG-234, were also occupied and observed simultaneously to form a GNSS loop for the 2nd session. The coordinate and elevation values of PAT-2 held fixed for the 1st session and the coordinate and elevation values of CGY-101 and UP-BAU-1 held fixed for the 2nd session are presented in Table 24 and Table 25, respectively. Through this reference point, the coordinates and elevations of the unknown control points will be computed.

Table 24. 1st Session Control Point Constraints

| Point ID | Type | East σ (Meter) | North σ (Meter) | Height σ (Meter) | Elevation σ (Meter) |
|---|---|---|---|---|---|
| PAT-2 | Grid | | | | Fixed |
| PAT-2 | Global | Fixed | Fixed | | |
| **Fixed = 0.000001(Meter)** | | | | | |

Table 25. 2nd Session Control Point Constraints

| Point ID | Type | East σ (Meter) | North σ (Meter) | Height σ (Meter) | Elevation σ (Meter) |
|---|---|---|---|---|---|
| CGY-101 | Grid | | | | Fixed |
| CGY-101 | Global | Fixed | Fixed | | |
| UP-BAU-1<br>Grid<br>Fixed | | | | | |
| UP-BAU-1 | Global | Fixed | Fixed | | |
| **Fixed = 0.000001(Meter)** | | | | | |

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 26 and Table 27.

Table 26. 1st Session Adjusted Grid Coordinates

| Point ID | Easting (Meter) | Easting Error (Meter) | Northing (Meter) | Northing Error (Meter) | Elevation (Meter) | Elevation Error (Meter) | Constraint |
|---|---|---|---|---|---|---|---|
| CG-258 | 396844.016 | 0.009 | 2022275.238 | 0.007 | 5.558 | 0.070 | |
| CGY-101 | 400856.162 | 0.009 | 2023815.895 | 0.007 | 45.099 | 0.081 | |
| PAT-2 | 392924.044 | ? | 2018768.902 | ? | 21.505 | ? | LLe |
| UP-BAU-1 | 404240.430 | 0.011 | 2029273.374 | 0.009 | 8.626 | 0.090 | |

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

a. **CG-258**
horizontal accuracy = √((0.9)² + (0.7)²
= √ (0.81 + 0.49)
= 1.14 < 20 cm
vertical accuracy = 7.0 < 10 cm

b. **CGY-101**
horizontal accuracy = √((0.9)² + (0.7)²
= √ (0.81 + 0.49)
= 1.14 < 20 cm
vertical accuracy = 8.1 < 10 cm

c. **PAT-2**
horizontal accuracy = Fixed
vertical accuracy = Fixed

d. **UP-BAU-1**
horizontal accuracy = √((1.1)² + (0.9)²
= √ (1.21 + 0.81)
= 1.42 < 20 cm
vertical accuracy = 9.0 < 10 cm

Table 27. 2nd Session Adjusted Grid Coordinates

| Point ID | Easting (Meter) | Easting Error (Meter) | Northing (Meter) | Northing Error (Meter) | Elevation (Meter) | Elevation Error (Meter) | Constraint |
|---|---|---|---|---|---|---|---|
| CG-234 | 407973.653 | 0.011 | 2038248.421 | 0.009 | 3.769 | 0.051 | |
| CGY-101 | 400856.162 | ? | 2023815.895 | ? | 45.099 | ? | LLe |
| CGY-102 | 406280.704 | 0.007 | 2031283.618 | 0.005 | 15.970 | 0.043 | |
| UP-BAU-1 | 404240.430 | ? | 2029273.374 | ? | 8.626 | ? | LLe |

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

a. CG-234
horizontal accuracy = √((1.1)² + (0.9)²
= √ (1.21 + 0.81)
= 1.42 < 20 cm
vertical accuracy = 5.1 < 10 cm

b. CGY-101

horizontal accuracy = Fixed
vertical accuracy = Fixed

c. CGY-102
horizontal accuracy = $\sqrt{(0.7)^2 + (0.5)^2}$
= $\sqrt{(0.49 + 0.25)}$
= 0.86 < 20 cm
vertical accuracy = 4.3 < 10 cm

d. UP-BAU-1
horizontal accuracy = Fixed
vertical accuracy = Fixed

Following the given formula, the horizontal and vertical accuracy result of the three (3) occupied control points for the 1st session and two (2) occupied control points for the 2nd session are within the required precision.

Table 28. 1st Session Adjusted Geodetic Coordinates

| Point ID | Latitude | Longitude | Height (Meter) | Height Error (Meter) | Constraint |
|---|---|---|---|---|---|
| CG-258 | N18°17'15.18320" | E122°01'26.44115" | 43.357 | 0.070 | |
| CGY-101 | N18°18'05.99072" | E122°03'42.81396" | 82.793 | 0.081 | |
| PAT-2 | N18°15'20.41664" | E121°59'13.60140" | 59.538 | ? | LLe |
| UP-BAU-1 | N18°21'04.10030" | E122°05'37.15852" | 45.903 | 0.090 | |

Table 29. 2nd Session Adjusted Geodetic Coordinates

| Point ID | Latitude | Longitude | Height (Meter) | Height Error (Meter) | Constraint |
|---|---|---|---|---|---|
| CG-234 | N18°25'56.68760" | E122°07'42.88310" | 40.384 | 0.051 | |
| CGY-101 | N18°18'05.99072" | E122°03'42.81396" | 82.793 | ? | LLe |
| CGY-102 | N18°22'09.82860" | E122°06'46.33709" | 53.100 | 0.043 | |
| UP-BAU-1 | N18°21'04.10030" | E122°05'37.15852" | 45.903 | ? | LLe |

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 28 and Table 29. Based on the result of the computation, the equation is satisfied; hence, the required accuracy for the program was met.

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

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

| Control Point | Order of Accuracy | Geographic Coordinates (WGS 84) | | | UTM ZONE 51 N | | |
|---|---|---|---|---|---|---|---|
| | | Latitude | Longitude | Ellipsoidal Height (Meter) | Northing (m) | Easting (m) | BM Ortho (m) |
| 1st session | | | | | | | |
| PAT-2 | Established | 18°15'20.41664"N | 121°59'13.60140"E | 62.912 | 2018768.902 | 392924.044 | 21.505 |
| CGY-101 | Used as marker | 18°18'05.99063"N | 122°03'42.81382"E | 86.168 | 2023815.893 | 400856.157 | 45.1 |
| CG-258 | Used as marker | 18°17'15.18313"N | 122°01'26.44108"E | 46.732 | 2022275.236 | 396844.013 | 5.559 |
| UP-BAU-1 | Established | 18°21'04.10012"N | 122°05'37.15832"E | 49.278 | 2029273.368 | 404240.424 | 8.627 |
| 2nd session | | | | | | | |
| CGY-101 | 1st order, GCP | 18°18'05.99063"N | 122°03'42.81382"E | 86.168 | 2023815.893 | 400856.157 | 45.1 |
| UP-BAU-1 | Established | 18°21'04.10012"N | 122°05'37.15832"E | 49.278 | 2029273.368 | 404240.424 | 8.627 |
| CGY-102 | Used as marker | 18°22'09.82839"N | 122°06'46.33686"E | 56.475 | 2031283.611 | 406280.697 | 15.971 |
| CG-234 | Used as marker | 18°25'56.68727"N | 122°07'42.88284"E | 43.759 | 2038248.411 | 407973.645 | 3.77 |

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

Cross-section and as-built surveys were conducted on February 11, 2017 at the downstream side of Baua Bridge in Brgy. Baua, Gonzaga, Cagayan as shown in Figure 38. A Sokkia™ Set CX Total Station was utilized for this survey as shown in Figure 39. The Automated Water Level System (AWLS) is located on the upstream side of the bridge and its elevation was measured 10.510 m above MSL.

Figure 38. Baua Bridge facing upstream


Figure 39. As-built survey of Baua Bridge

Gathering of random points for the checking of HONS's bridge cross-section and bridge points data was performed by DVBC on October 17, 2016 using a survey grade GNSS Rover receiver attached to a 2-m pole as seen in Figure 40.

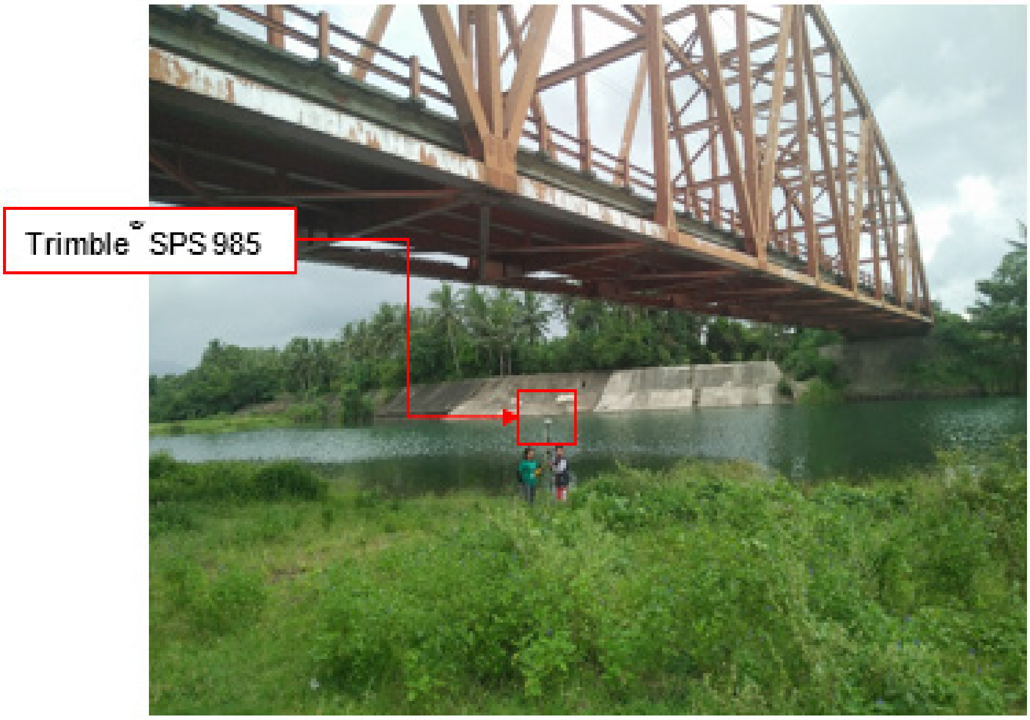



Figure 40. Gathering of random cross-section points along Baua Bridge

Linear square correlation ($R^2$) and RMSE analysis were performed on the two (2) datasets. The linear square coefficient range is determined to ensure that the submitted data of the contractor is within the accuracy standard of the project which is ±20 cm and ±10 cm for horizontal and vertical, respectively. The $R^2$ value must be within 0.85 to 1. An $R^2$ approaching 1 signifies a strong correlation between the vertical (elevation values) of the two datasets. A computed $R^2$ value of 0.963 was obtained by comparing the data of the contractor and DVBC; signifying a strong correlation between the two (2) datasets.

In addition to the Linear Square correlation, Root Mean Square (RMSE) analysis is also performed in order to assess the difference in elevation between the DVBC checking points and the contractor's. The RMSE value should only have a maximum radial distance of 5 m and the difference in elevation within the radius of 5 meters should not be beyond 0.50 m. For the bridge cross-section data, a computed value of 0.365 was acquired while a computed value of 0.227 was computed for the bridge points data. The computed $R^2$ and RMSE values are within the accuracy requirement of the program.

The cross-sectional line of Baua Bridge is about 131 m with two hundred fifty-nine (259) cross-sectional points using the control points UP-BAU-1 and UP-BAU-2 as the GNSS base stations. The location map, cross-section diagram, and the bridge data form are shown in Figure 41 to Figure 43.

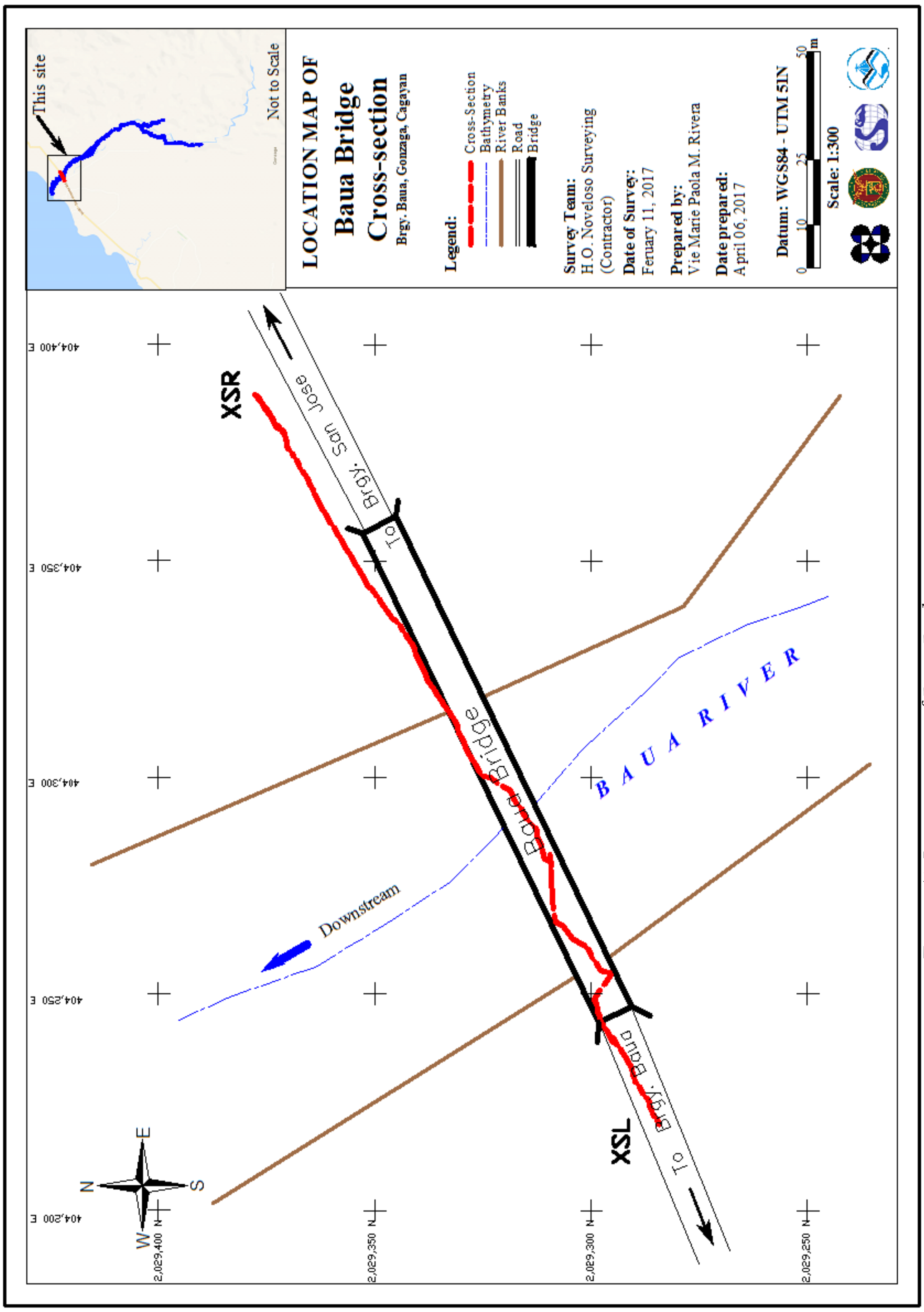



Figure 41. Location map of Baua Bridge cross-section survey

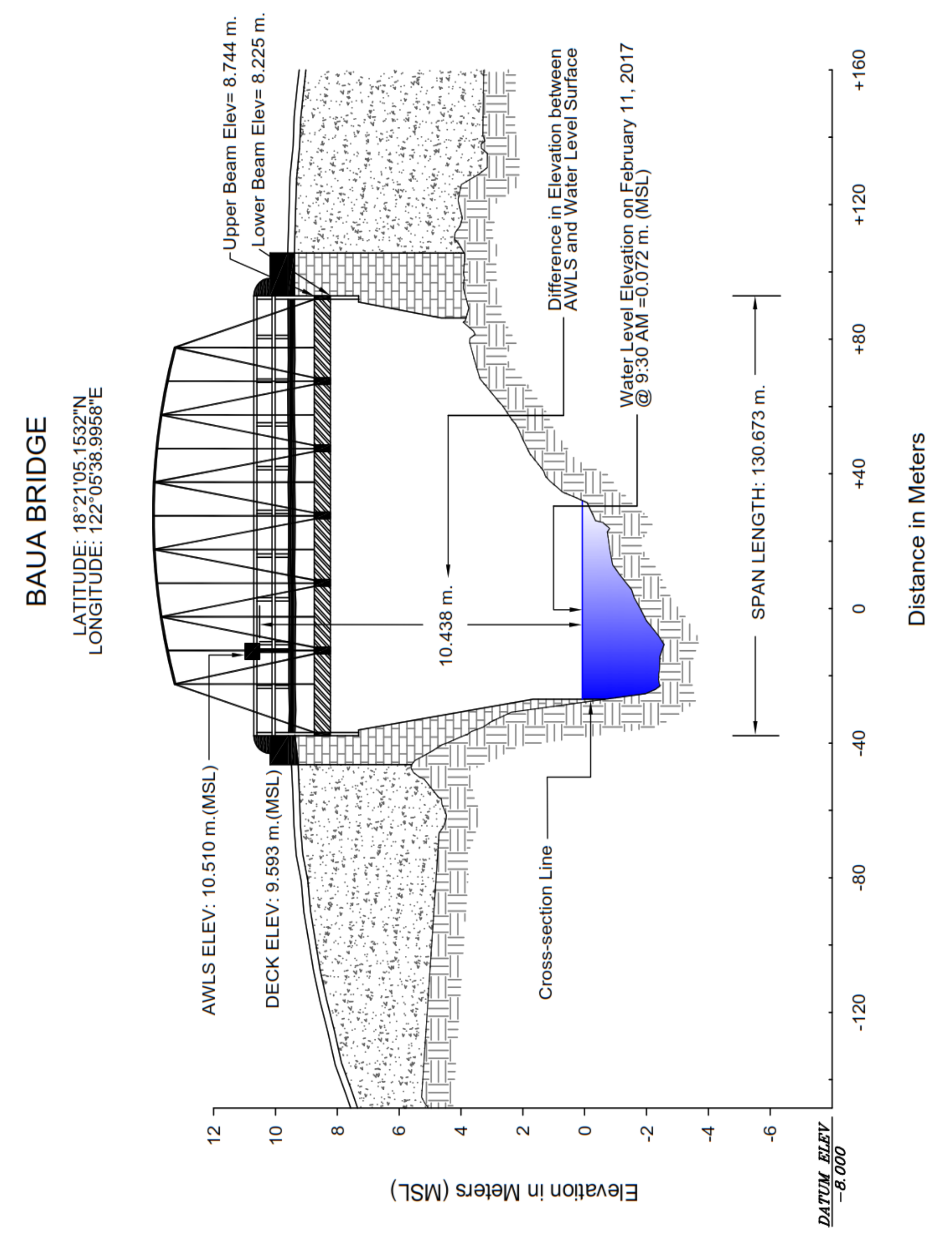



Figure 42. Baua Bridge Cross-section Diagram

**BRIDGE DATA FORM**

Bridge Name: Baua Bridge

River Name: Baua River

Location (Brgy., City, Region): Brgy. Baua, Gonzaga, Cagayan

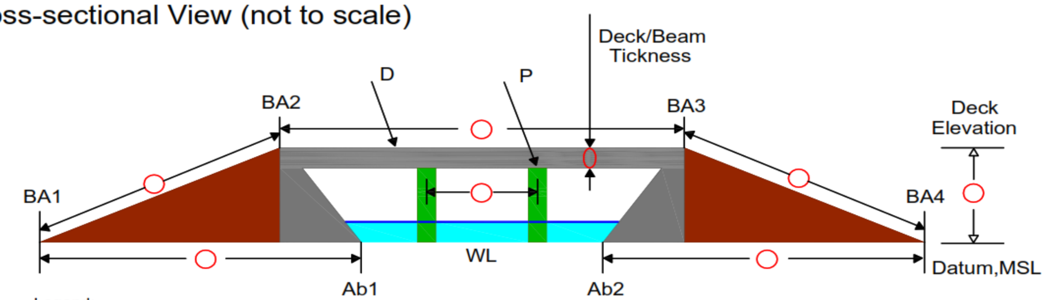
Survey Team: Jesus De Tagle, Alfie Paras, Isidro Basco, Mardy Feria, Rogelio Itorma and Myton Obaña

Date and Time: February 11, 2017 @ 9:30 am

Flow Condition: Low Normal High

Weather Condition: Fair Rainy

Cross-sectional View (not to scale)




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

| Line Segment | Measurement, m | Remarks |
|---|---|---|
| 1. BA1-BA2 | 8.651 m. | Concrete |
| 2. BA2-BA3 | 130.673 m. | Concrete |
| 3. BA3-BA4 | 12.751 m. | Concrete |
| 4. BA1-Ab1 | 19.425 m. | Concrete |
| 5. Ab2-BA4 | 19.289 m. | Concrete |
| 6. Deck/Beam thickness | 0.519 m. | Steel Truss |
| 7. Deck Elevation | 9.593 m. MSL | Concrete |

Note: Observer should be facing downstream

Figure 43. Baua Bridge Data Form

Water surface elevation of Baua River was determined by a Sokkia™ Set CX Total Station on February 11, 2017 at 9:30 AM at Baua Bridge area in Brgy. Baua, Gonzaga, Cagayan with a value of 0.072 m in MSL as shown in Figure 42. This was translated into marking on the bridge's riprap as shown in Figure 44. The marking will serve as reference for flow data gathering and depth gauge deployment of the partner HEI responsible for Baua River, the Isabela State University.

Figure 44. Water level markings on the riprap of Baua Bridge

## 4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted by DVBC on October 16, 2016 using a survey grade GNSS Rover receiver, Trimble® SPS 985, mounted on a range pole which was attached on the side of the vehicle as shown in Figure 45. It was secured with cable ties and ropes to ensure that it was horizontally and vertically balanced. The antenna height was 2.460 m and measured from the ground up to the bottom of the antenna mount of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with CGY-102 occupied as the GNSS base station in the conduct of the survey.

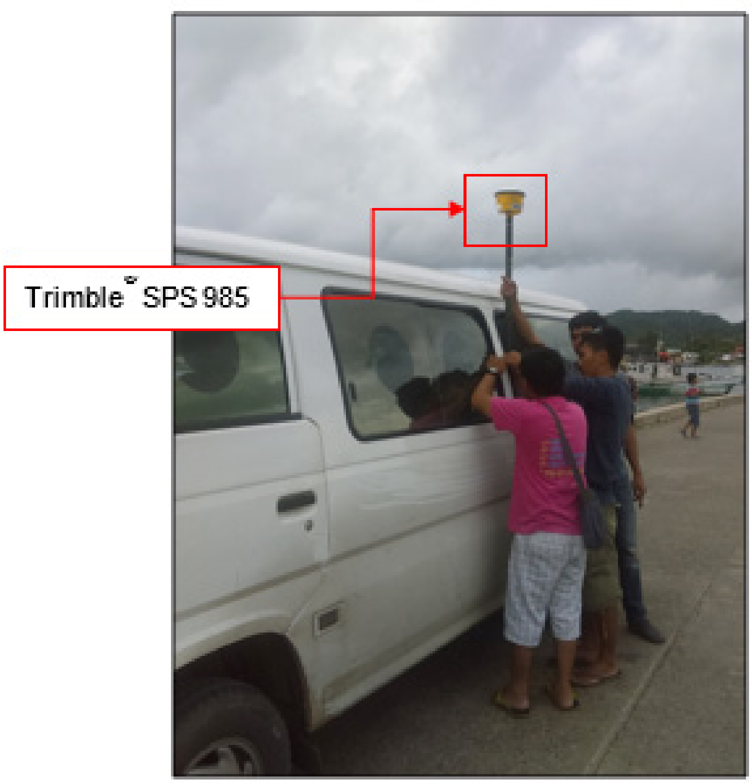



Figure 45. Validation points acquisition survey set-up for Baua River

The survey started from Brgy. Pateng, Gonzaga, Cagayan going northeast along the national highway, covering eleven (11) barangays in Gonzaga, eight (8) barangays in Sta. Ana, and ended in Brgy. San Vicente, Sta. Ana, Cagayan. The survey gathered a total of 8,092 points with approximate length of 44.91 km using CGY-102 and PAT-2 as GNSS base stations for the entire extent of validation points acquisition survey as illustrated in the map in Figure 46.


Figure 46. LiDAR Validation points acquisition survey for Baua River Basin

## 4.7 Bathymetric Survey

Manual bathymetric survey was executed on February 23 to 26, 2017 using a Sokkia™ Set CX Total Station as illustrated in Figure 47. The control points UP-BAU-1, UP-BAU-3, UP-BAU-4, UP-BAU-5, UP-BAU-6, and UP-BAU-7 were used as GNSS base stations all throughout the entire survey.

For the main river, the survey started in Brgy. Amunitan, Gonzaga, Cagayan, with coordinates 18°16'27.8247"N, 122°06'49.0628"E and ended at the mouth of the river in Brgy. Baua, also in Gonzaga, with coordinates 18°21'24.0195"N, 122°05'05.1713"E.

For the tributary, the survey started in Brgy. Cabiraoan, Gonzaga, Cagayan, with coordinates 18°17'46.0715"N, 122°07'39.0679"E and ended also in Brgy. Cabiraoan, with coordinates 18°18'29.3917"N, 122°07'25.7885"E.

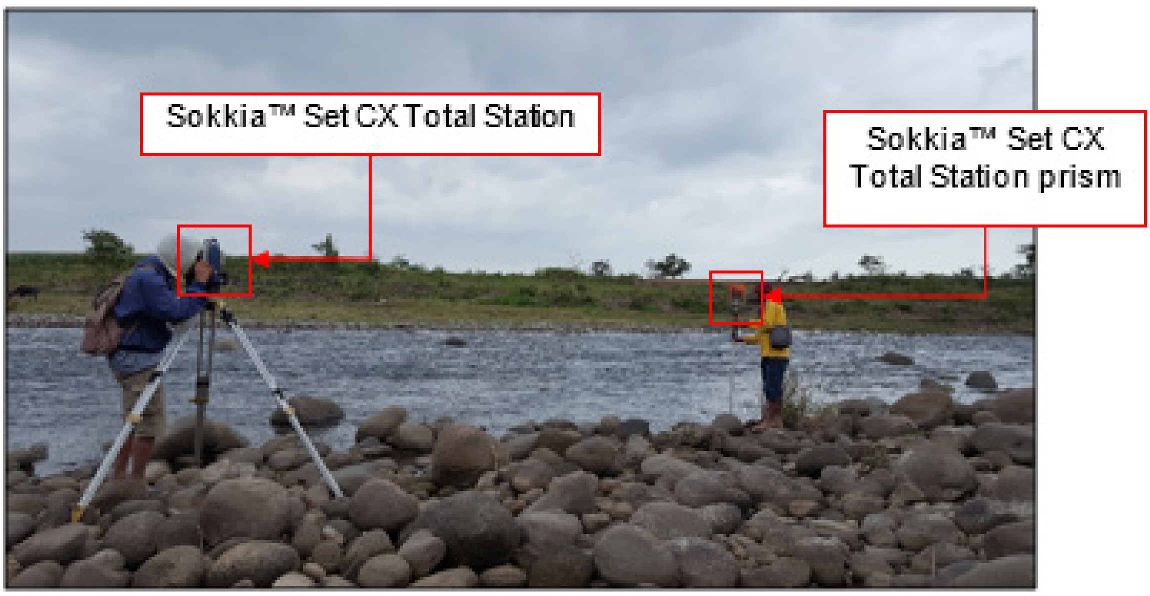



Figure 47. Manual bathymetric survey of HONS along Baua River

Gathering of random points for the checking of HONS's bathymetric data was performed by DVBC on October 14, 2016 using a survey grade GNSS Rover receiver attached to a boat as seen in Figure 48. The entire bathymetric survey extent of Baua River is illustrated in Figure 49. A map showing the DVBC bathymetric checking points is shown in Figure 50.


Figure 48. Gathering of random bathymetric points along Baua River

Linear square correlation ($R^2$) and RMSE analysis were also performed on the two (2) datasets and a computed $R^2$ value of 0.884 for the bathymetric data is within the required range for $R^2$, which is 0.85 to 1. Additionally, an RMSE value of 0.291 for the bathymetric data was obtained. Both the computed $R^2$ and RMSE values are within the accuracy required by the program.

The bathymetric survey for Baua River gathered a total of 4,503 points covering 13.791 km of the river traversing barangays Amunitan, Cabiraoan, Sta. Maria, and Baua in the Municipality of Gonzaga.

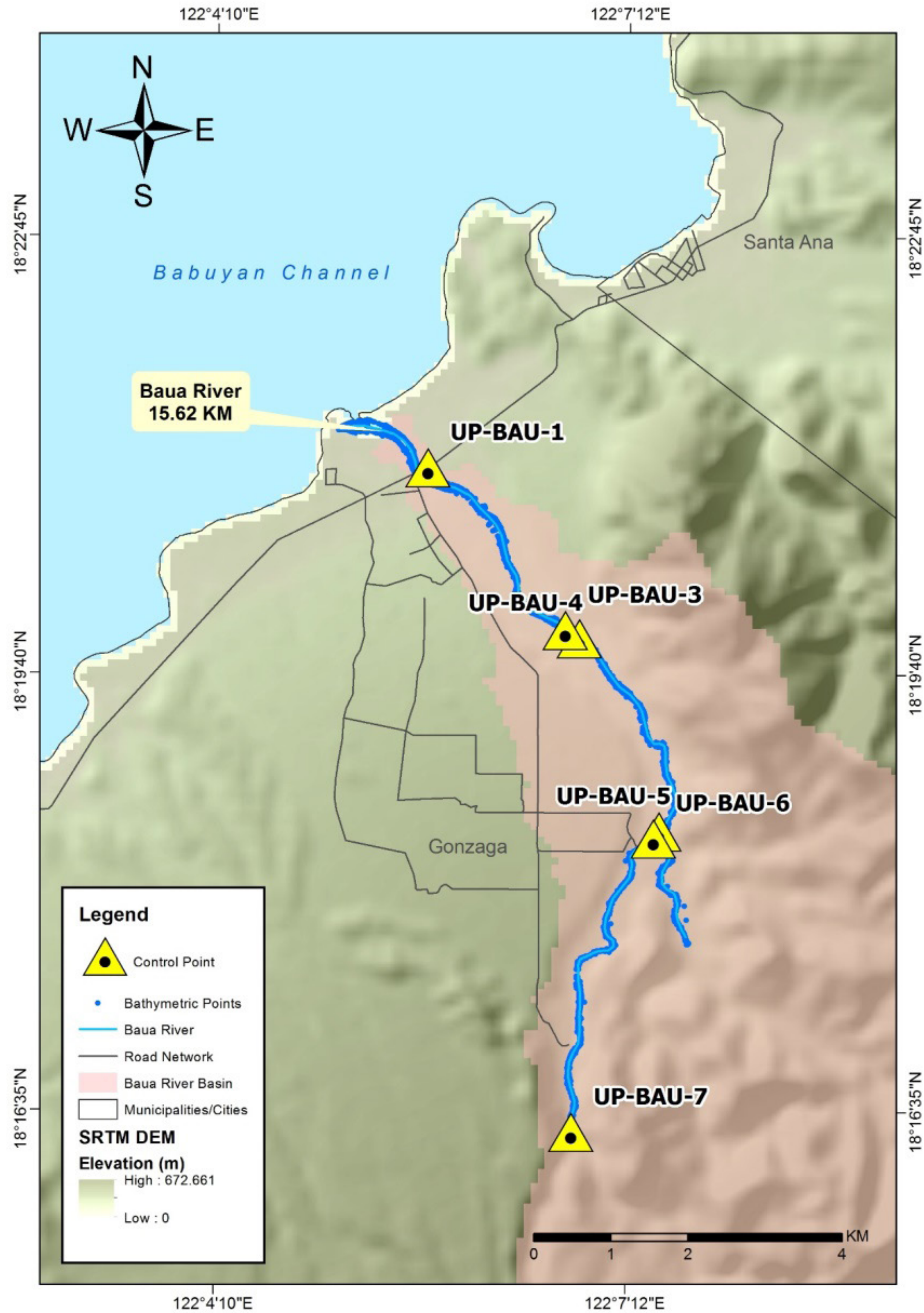



Figure 49. Bathymetric survey of Baua River

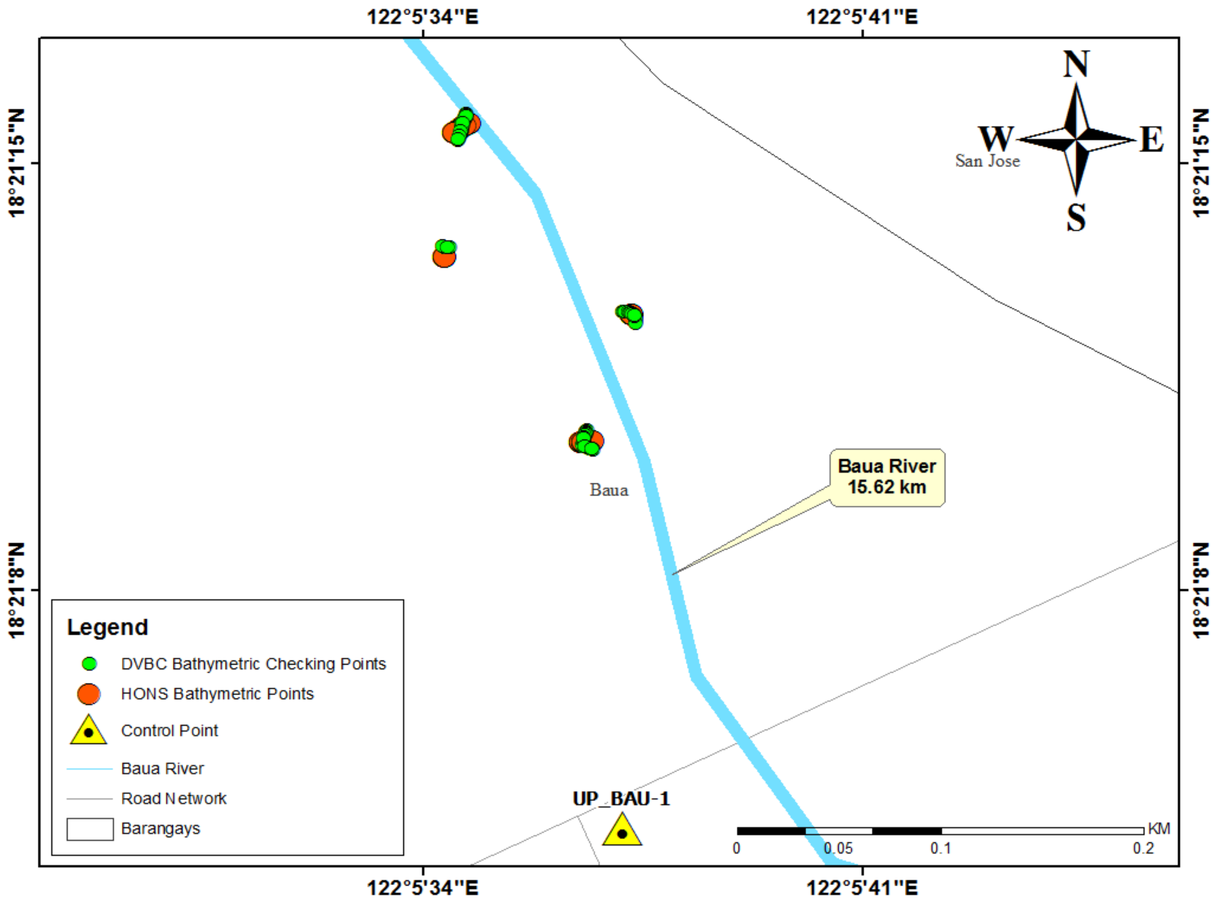



Figure 50. Quality checking points gathered along Baua River by DVBC

A CAD drawing was also produced to illustrate the riverbed profile of Baua River. As shown in Figure 51 and Figure 52, the highest and lowest elevation has a 117-m difference. The highest elevation observed was 115.060 m above MSL located in Brgy. Amunitan, Gonzaga, Cagayan while the lowest was -2.434 m below MSL located in Brgy. Baua, Gonzaga, Cagayan.

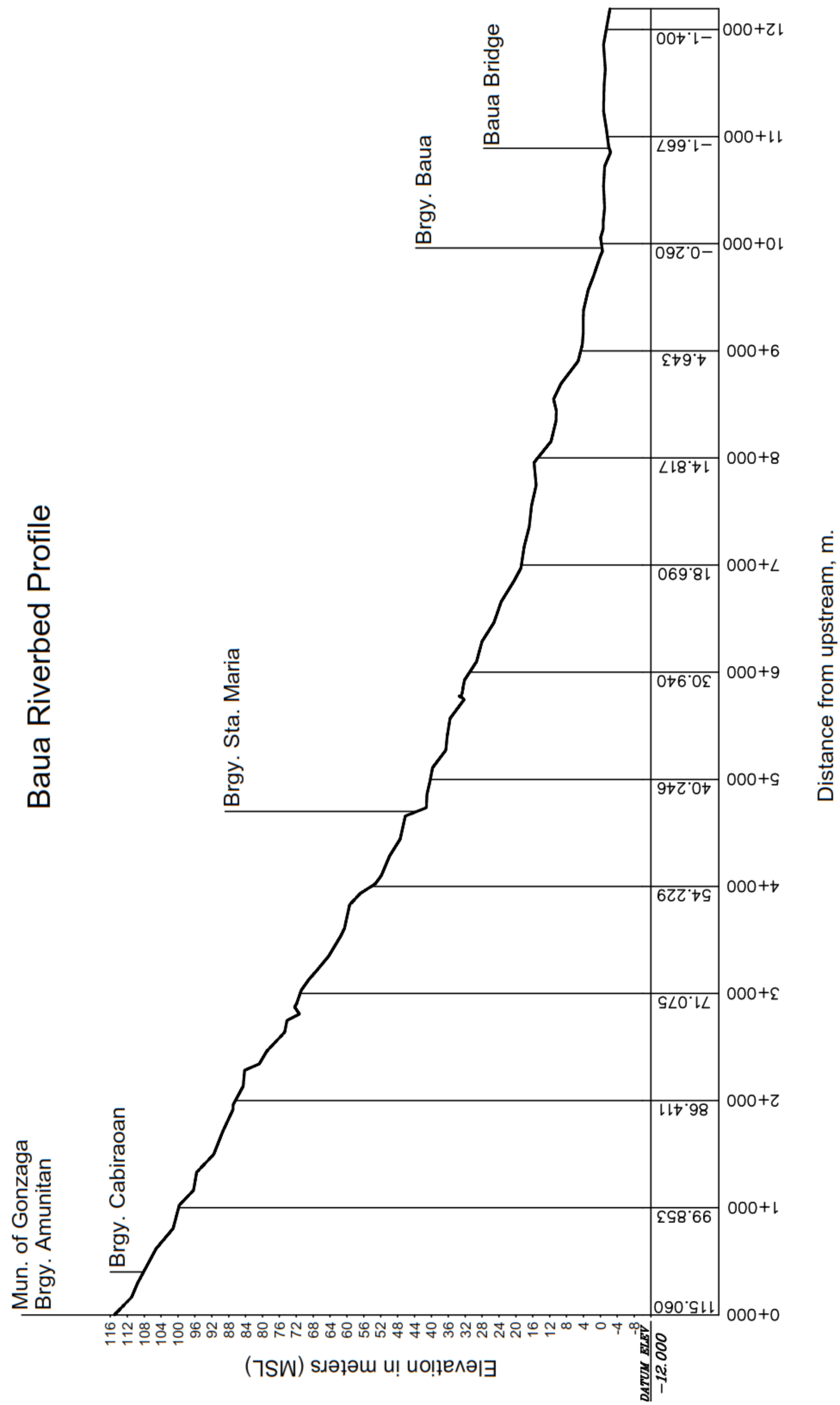



Figure 51. Baua Riverbed Profile

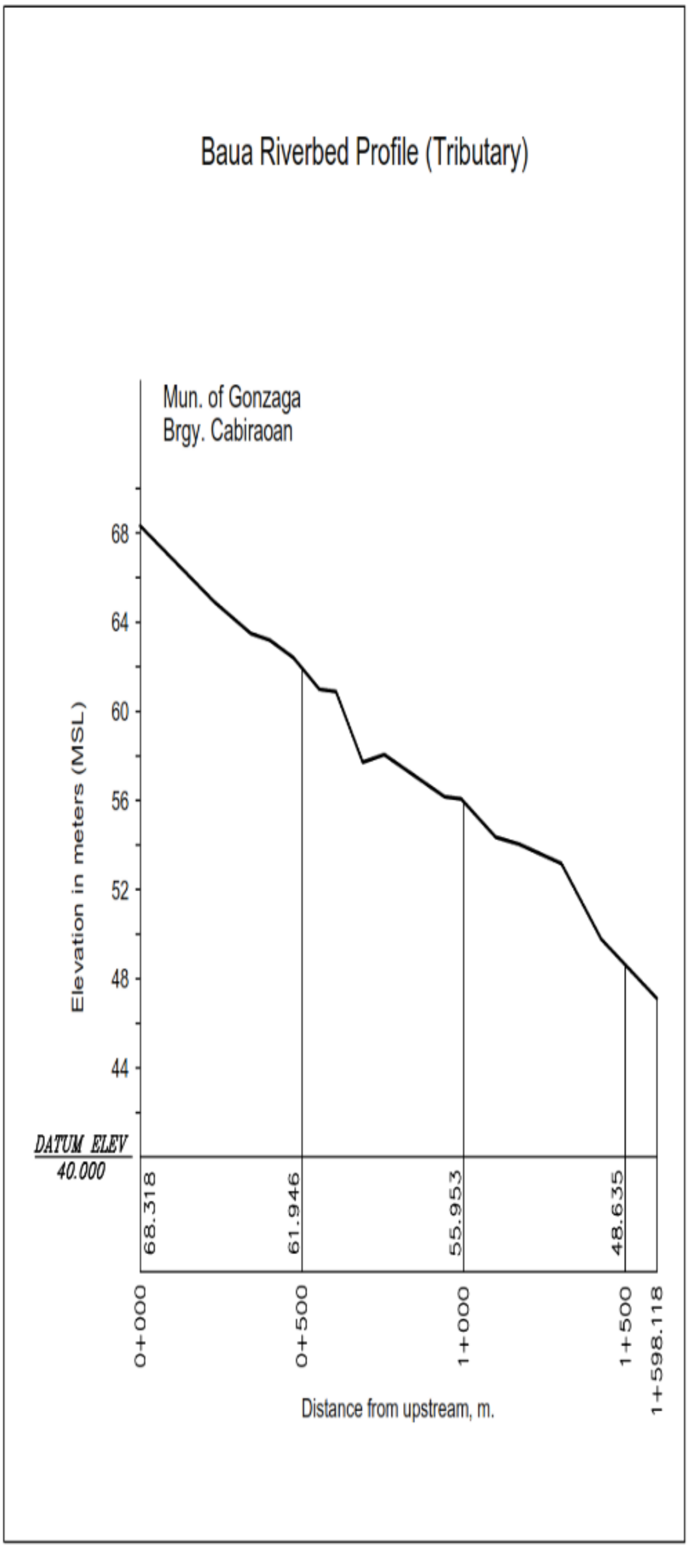



Figure 52. Baua Riverbed Profile (tributary)

# 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, Mariel Monteclaro

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 Baua 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 Baua River Basin were monitored, collected, and analyzed.

### 5.1.2 Precipitation

Cagayan, including the Baua River basin, experienced heavy and long term rain such as Monsoon Rain during the month of December. The hydrologic data collection covered the period 2:00 P.M. on 27 December 2016 until 8:40 P.M. on 28 December 2016. Hydrologic data include the river velocity, water depth and rain collected from data logging sensors (mechanical velocity meter, depth gauge and rain gauges) in specific time period. Precipitation data was taken from the Brgy. San Jose, Cagayan ARG. The location of the rain gauge is seen in Figure 7. Rainfall data were downloaded from the web portal of Philippine E-Science Grid-ASTI (http://fmon.asti.dost.gov.ph/weather/predict/).

Total rain from the Brgy. San Jose, Cagayan ARG is 85 mm. It peaked to 2.5 mm. on 28 December 2016 2:00 A.M. The lag time between the peak rainfall and discharge is 16 hours and 30 minutes. The ARG for Baua River Basin is shown Figure 53.

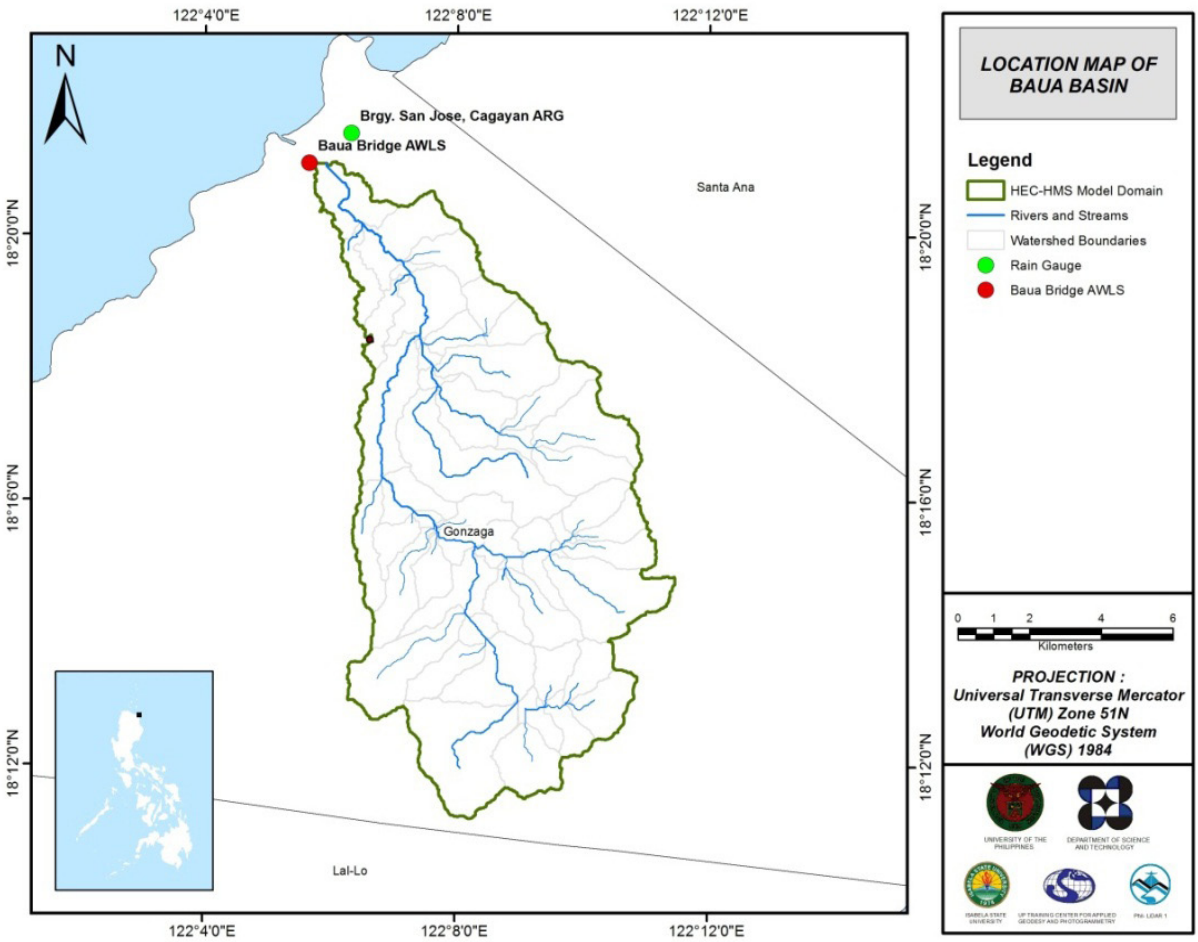



**Figure 53. Location map** of Baua HEC-HMS model used for calibration.

## 5.1.3 Rating Curve and River Outflow

Monsoon rain that occurred on 27 December 2016 – 28 December 2016 contributed to a (-) 0.258 meter water level rise with peak discharge of 177.8 $m^3/s$ recorded at 9:10 AM on 28 December 2016 with accumulated rainfall 85 mm. These hydrologic data is the actual event of Baua River and inputted to hydrologic modeling. Hydrologic measurements were taken from Baua Bridge, Gonzaga, Cagayan.

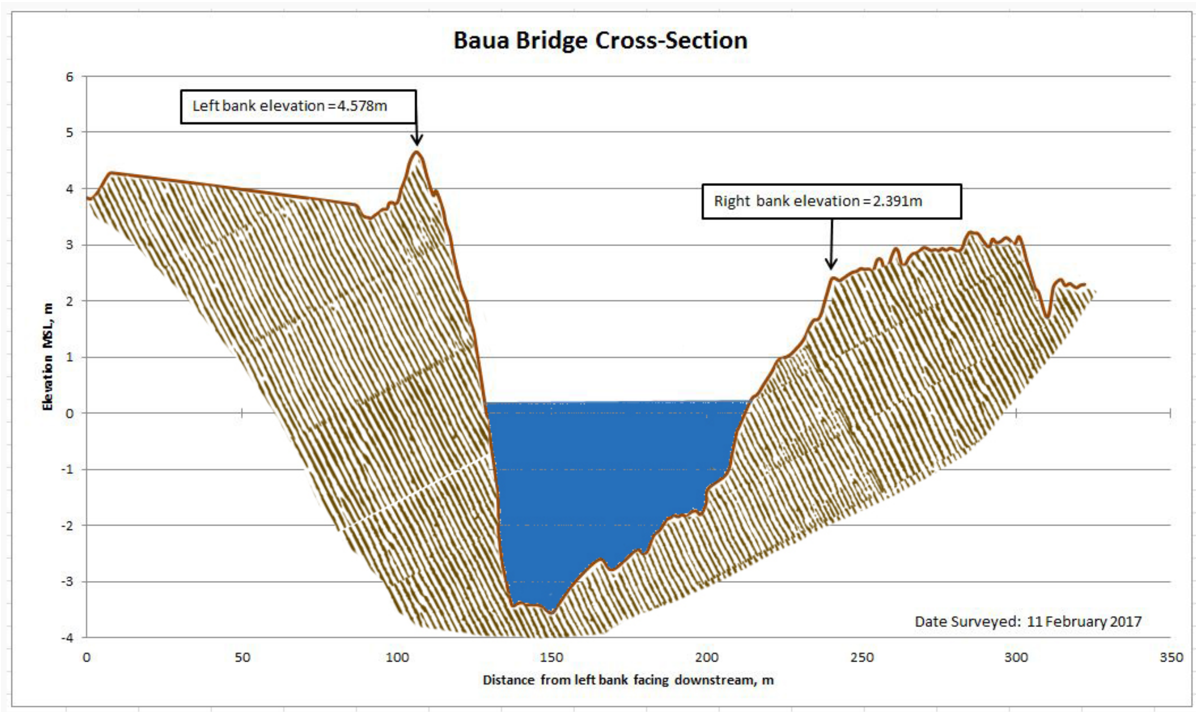



Figure 54. Cross-Section Plot of Baua Bridge

A rating curve was generated for the observed flow and water level. It shows the relationship of the two hydrologic data. It is expressed in the form of the following equation:

$$Q=a^{nh}$$

where, Q : Discharge ($m^3/s$),
h : Gauge height (reading from Baua Bridge depth gauge sensor), and
a and n : Constants.

The Baua River Rating Curve measured at Baua Bridge is expressed as $Q = 73.115e^{3.4448x}$ (Figure 55).

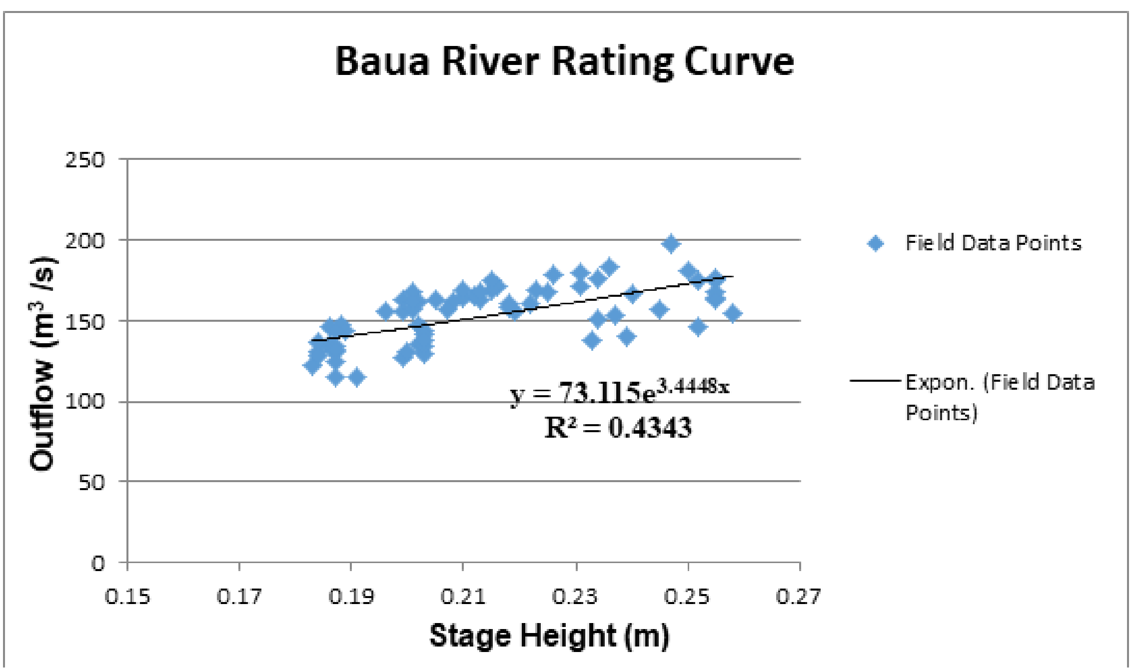



Figure 55. Rating curve at Baua Bridge, Gonzaga, Cagayan

This rating curve equation was used to compute the river outflow at Baua Bridge for the calibration of the HEC-HMS model shown in Figure 56.

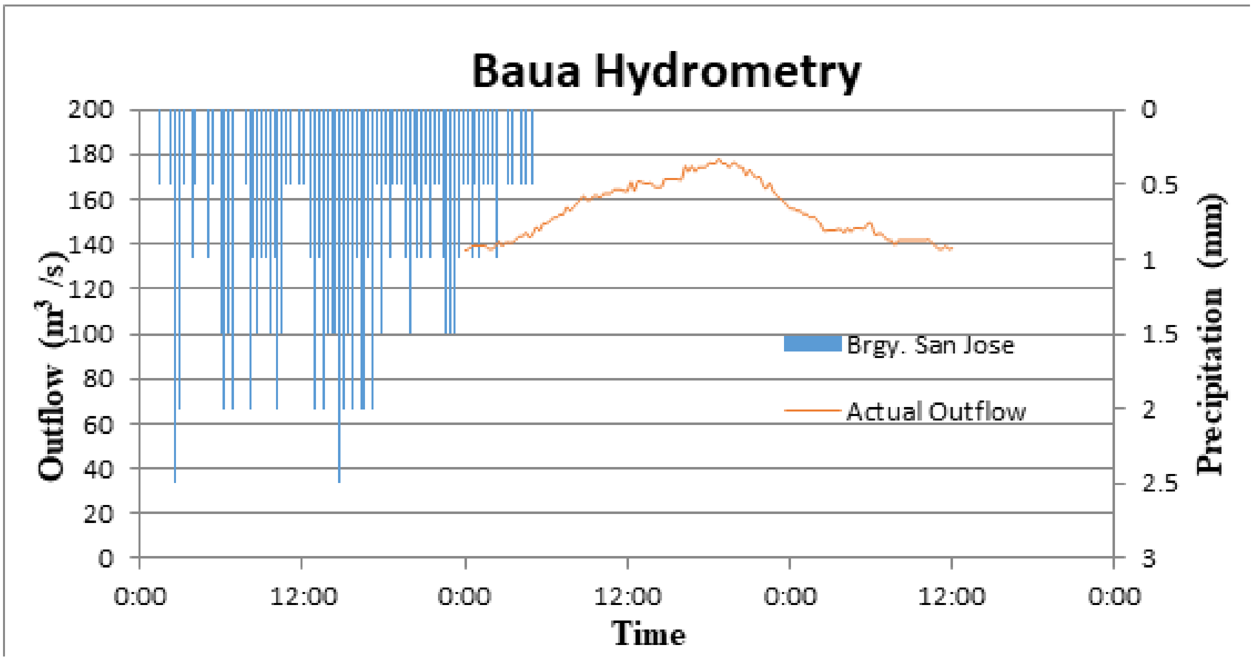



Figure 56. Rainfall and outflow data at Baua Bridge used for modeling

## 5.2 RIDF Station

The Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed for Rainfall Intensity Duration Frequency (RIDF) values for the Aparri Rain Gauge. The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the values in such a way a certain peak value will be attained at a certain time. This station is chosen based on its proximity to the Baua watershed. The extreme values for this watershed were computed based on a 47-year record, shown in Table 31.

Table 31. RIDF values for Aparri Rain Gauge computed by PAGASA

| COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| T (yrs) | 10 mins | 20 mins | 30 mins | 1 hr | 2 hrs | 3 hrs | 6 hrs | 12 hrs | 24 hrs |
| 2 | 20.1 | 31.4 | 39.4 | 53.3 | 75.6 | 92.2 | 119.4 | 147.7 | 167.9 |
| 5 | 28.5 | 44.9 | 55.8 | 78.7 | 110.4 | 137 | 173.6 | 221.2 | 252.5 |
| 10 | 34.1 | 53.8 | 66.6 | 95.6 | 133.4 | 166.6 | 209.5 | 269.9 | 308.5 |
| 15 | 37.2 | 58.8 | 72.7 | 105.1 | 146.5 | 183.4 | 229.7 | 297.4 | 340.2 |
| 20 | 39.4 | 62.3 | 77 | 111.8 | 155.6 | 195.1 | 243.9 | 316.6 | 362.3 |
| 25 | 41.1 | 65 | 80.3 | 116.9 | 162.6 | 204.1 | 254.8 | 331.4 | 379.3 |
| 50 | 46.3 | 73.4 | 90.5 | 132.7 | 184.2 | 231.9 | 288.4 | 377.1 | 431.9 |
| 100 | 51.4 | 81.7 | 100.6 | 148.4 | 205.6 | 259.5 | 321.7 | 422.4 | 484 |

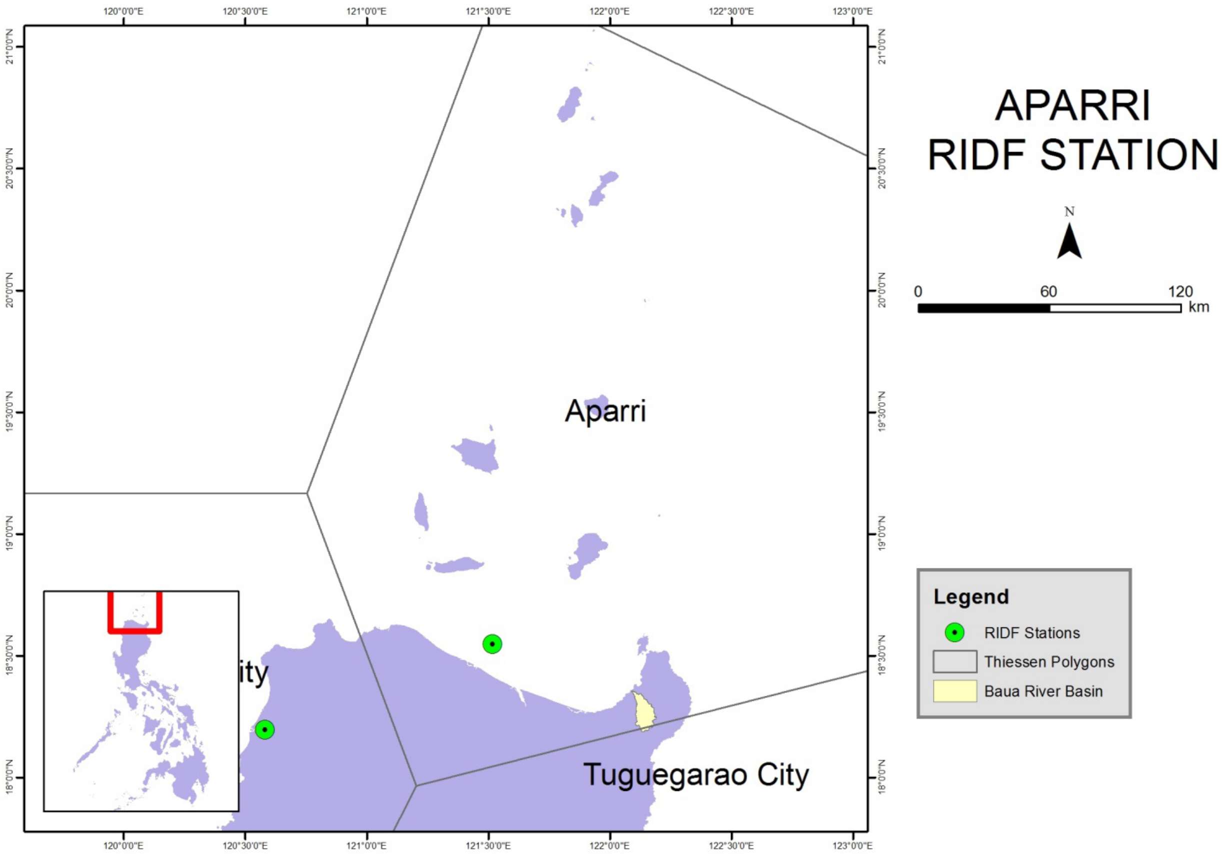



Figure 57.Location of Aparri RIDF Station relative to Baua River Basin

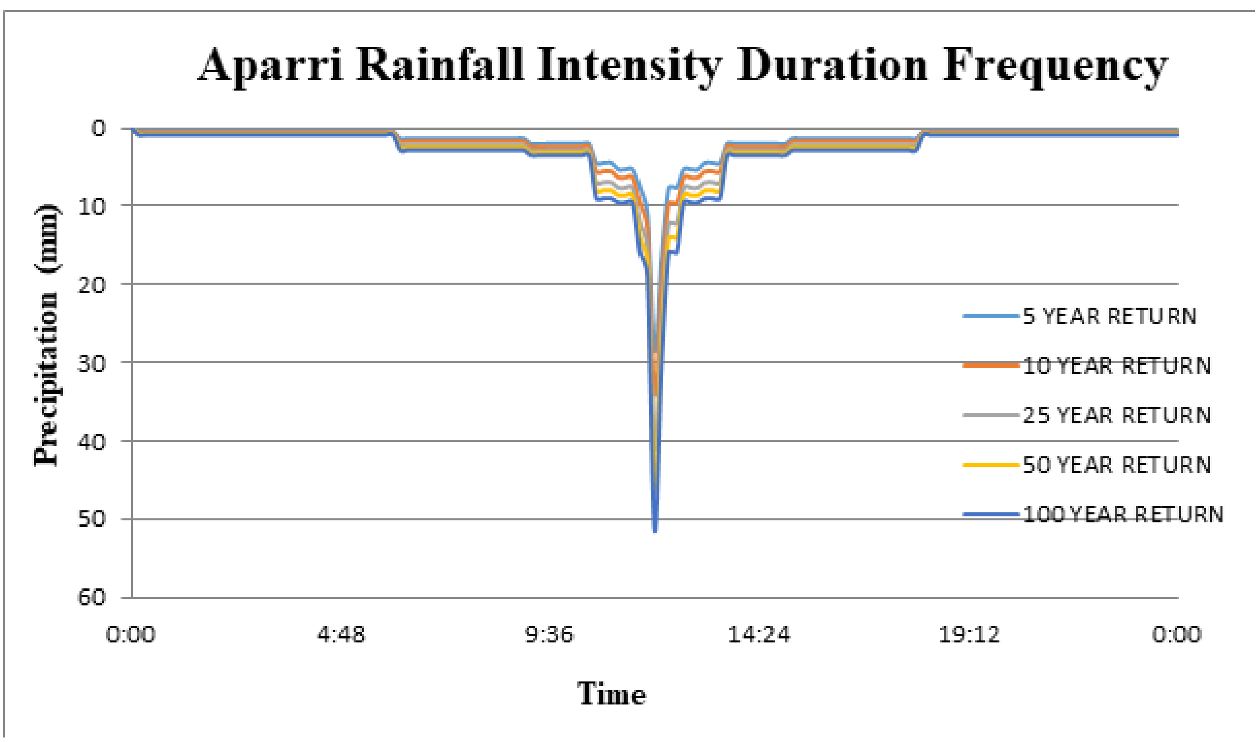



Figure 58. Synthetic storm generated for a 24-hr period rainfall for various return periods.

## 5.3 HMS Model

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

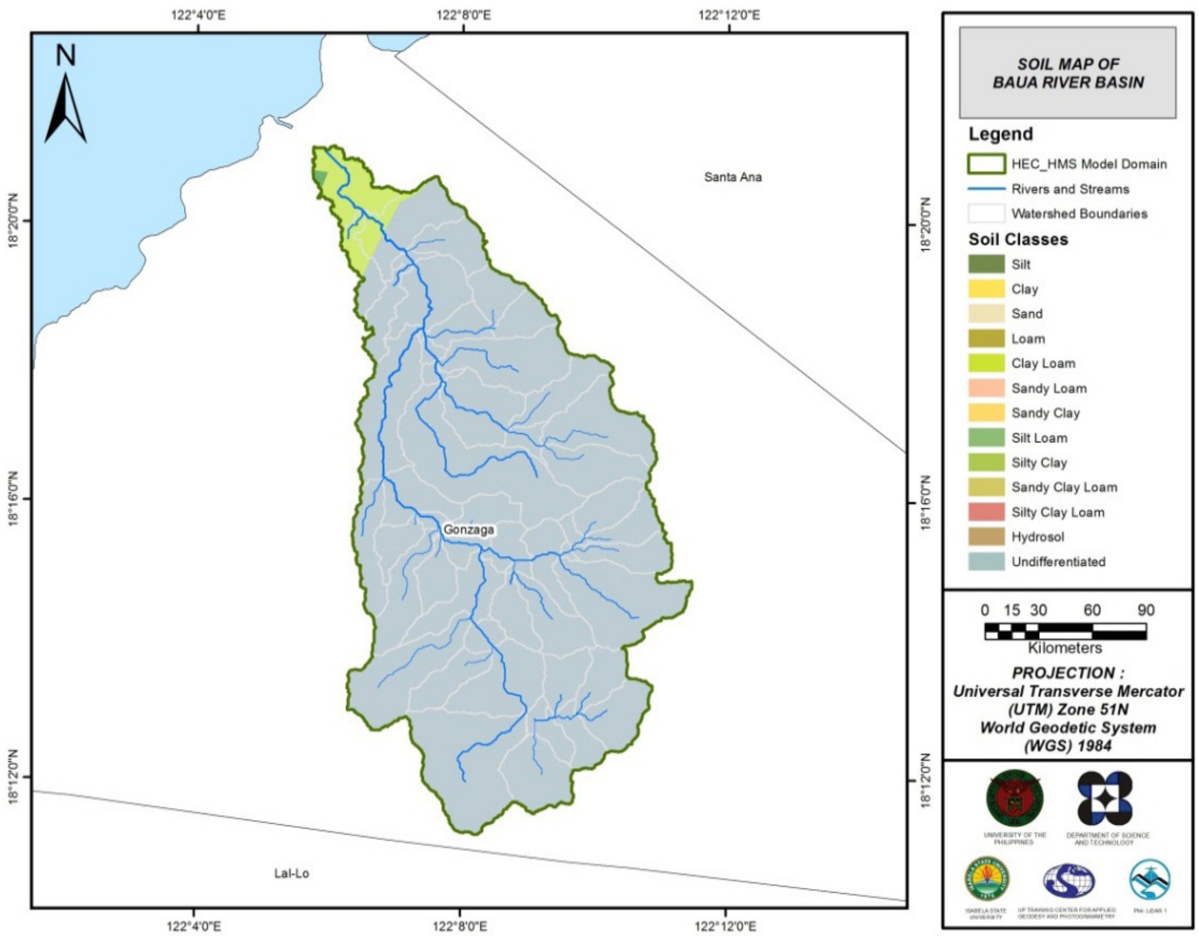



Figure 59. Soil map of the Baua River Basin used for the estimation of the CN parameter.
(Source: DA)

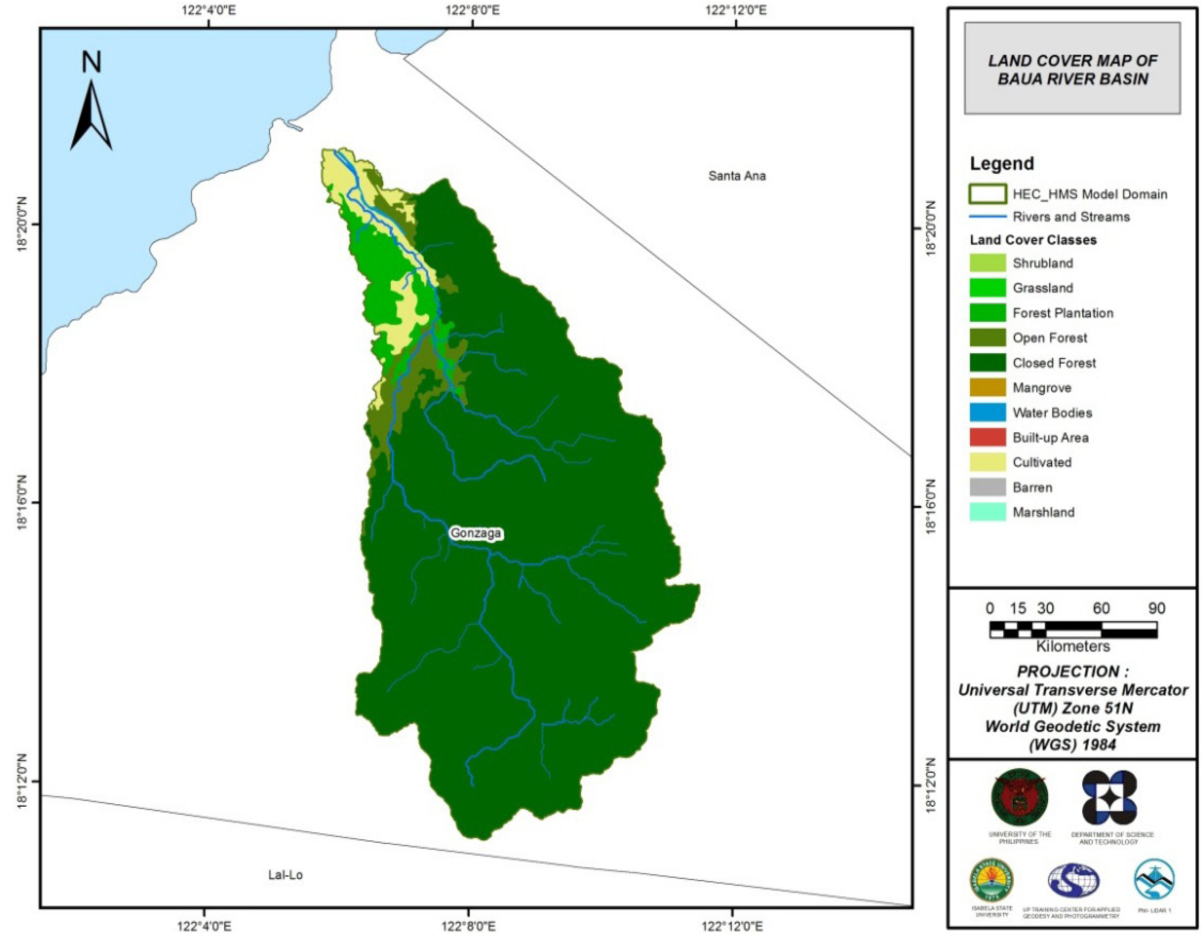



Figure 60. Land cover map of Baua River Basin used for the estimation of the Curve Number (CN) and the watershed lag parameters of the rainfall-runoff model. (Source: NAMRIA)

For the Baua river basin, three (3) soil classes were identified. The Baua river basin has portions of clay loam and silt loam, while the rest is undifferentiated. Moreover, four (4) land cover classes were identified. Most of the Baua river basin is largely closed forest, and small parts are open forest, forest plantation, and cultivated areas.

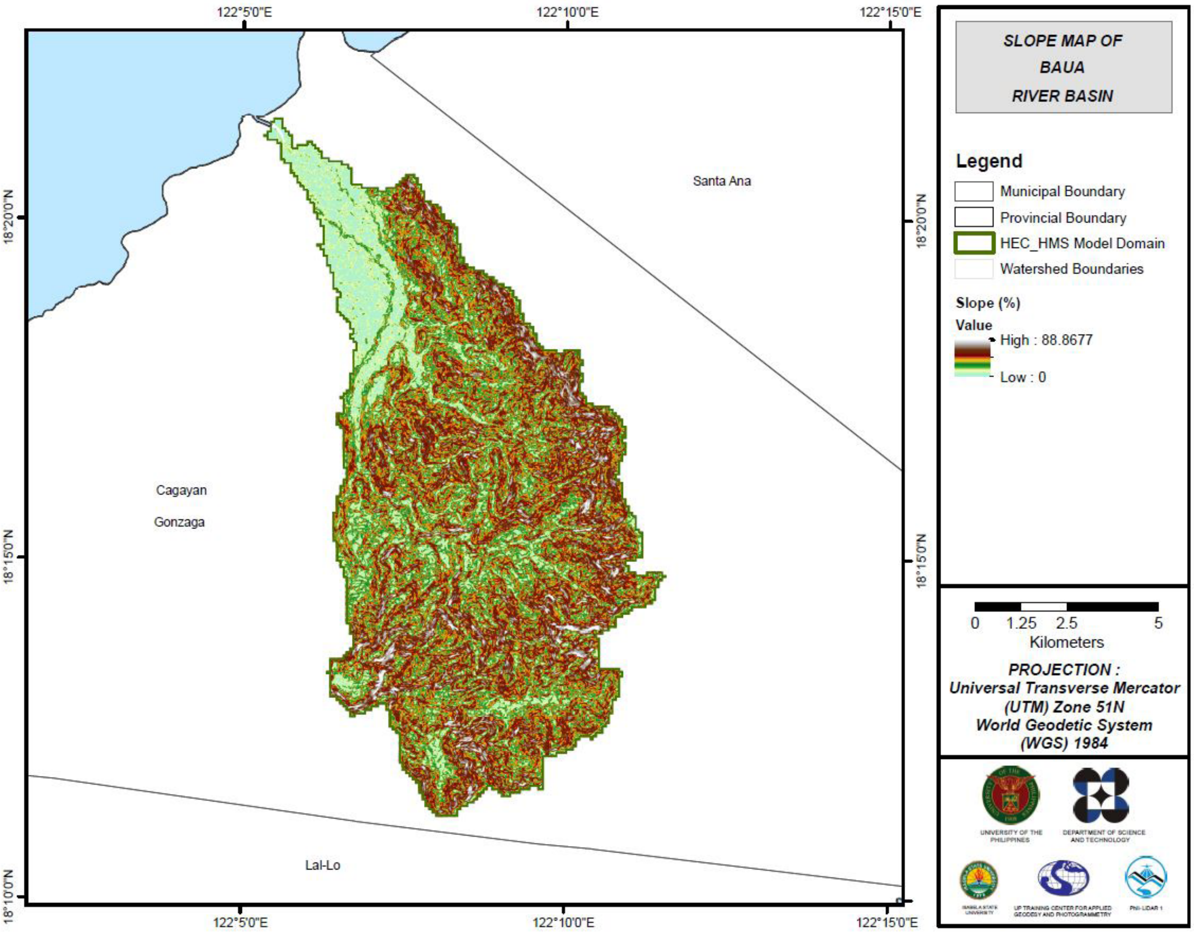



Figure 61. Slope map of Baua River Basin

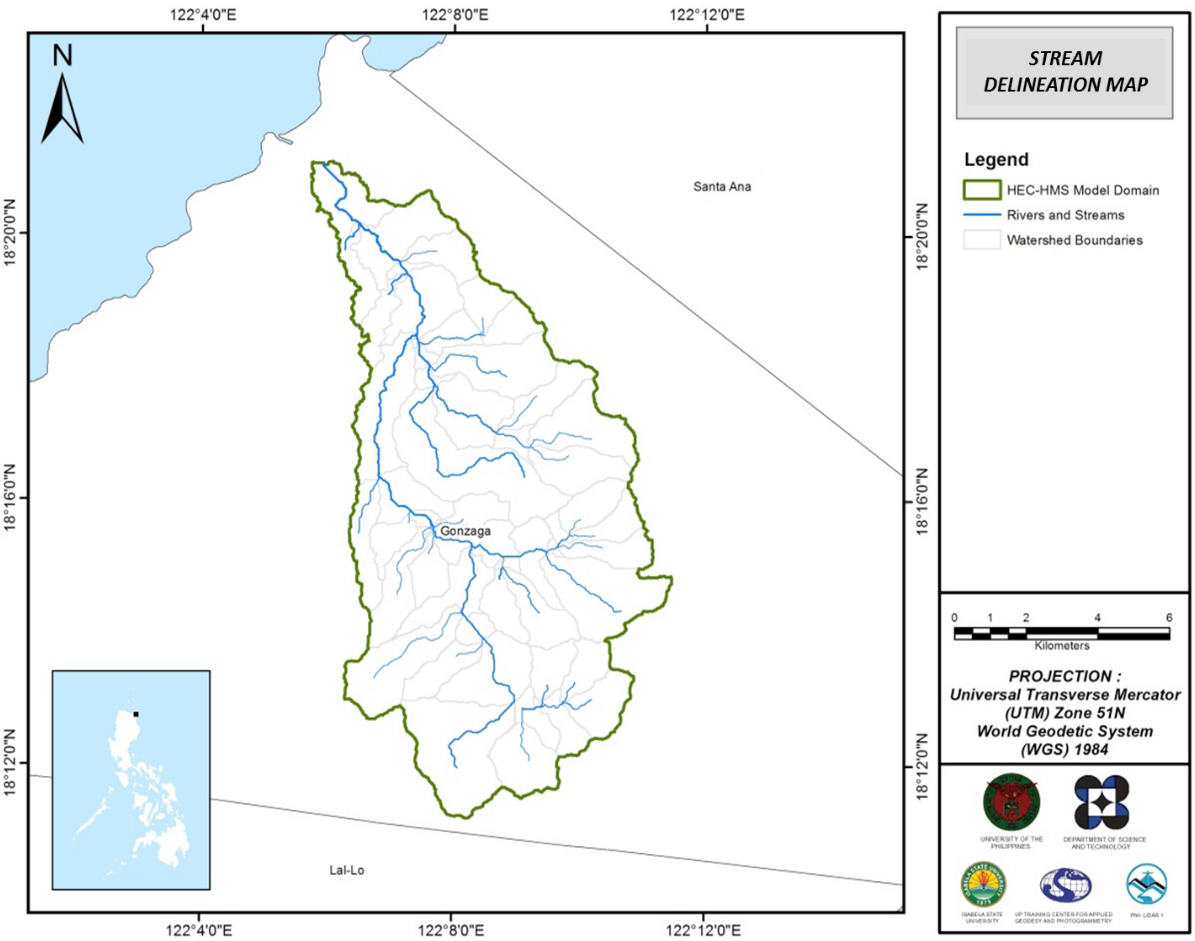



Figure 62. Stream delineation map of Baua River Basin

A drainage system includes the basin boundary, subbasin and the stream networks of the basin. Using ArcMap 10.2 with HEC-GeoHMS version 10.2 extension, the Baua River centerline and SAR-DEM 10m resolution served as primary data, delineating the drainage system of the Baua river basin. The river centerline was digitized starting from upstream towards downstream in Google Earth (2014). Default threshold area used is 140 hectares.

Using the SAR-based DEM, the Baua basin was delineated and further subdivided into subbasins. The Baua basin model consists of 55 subbasins, 27 reaches, and 27 junctions. The main outlet is at Outlet 1. This basin model is illustrated in Figure 63. The basins were identified based on soil and land cover characteristics of the area. Precipitation from the 27 December 2016 to 28 December 2016 (Monsoon Rain) was taken from Brgy. San Jose, Cagayan ARG. Finally, it was calibrated using data from the Baua depth gauge sensor.

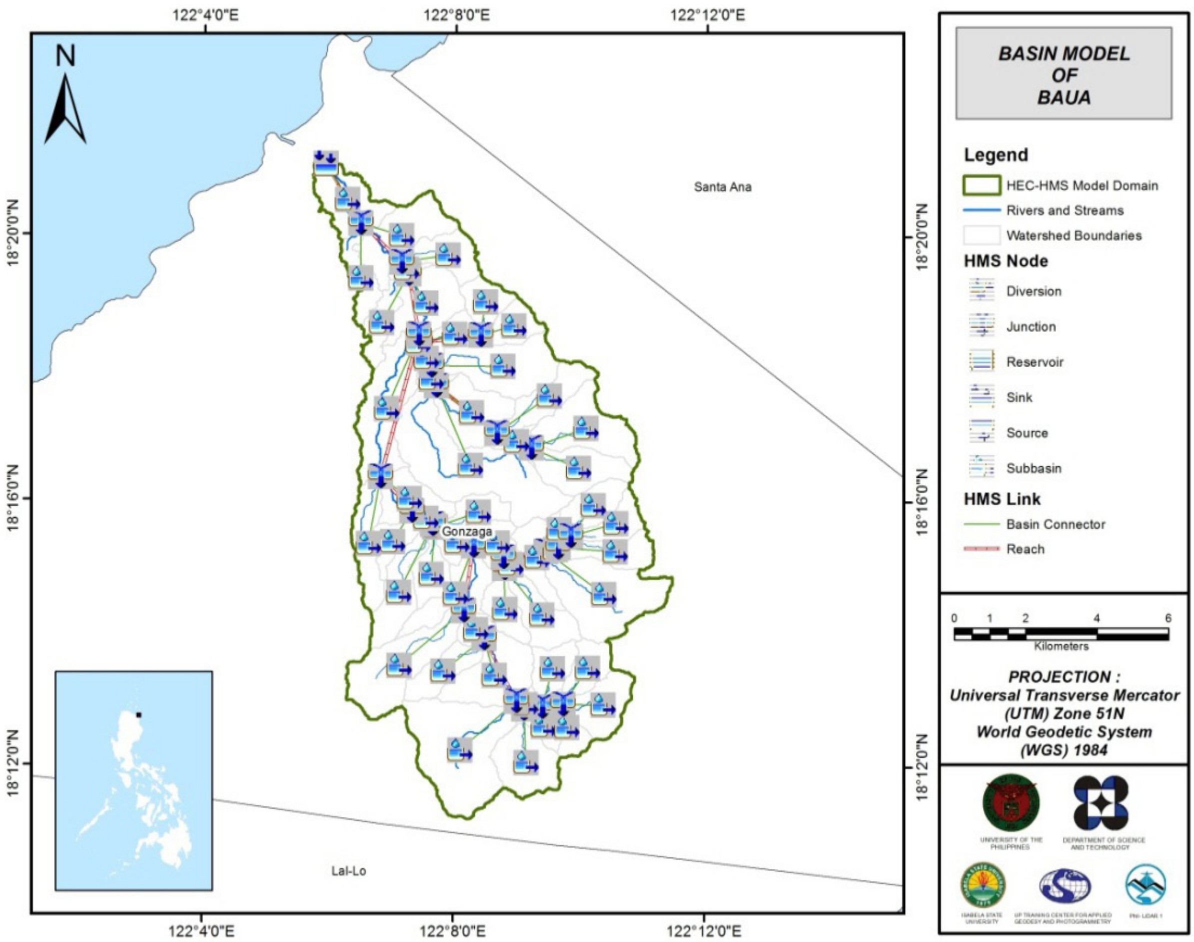



Figure 63. HEC-HMS generated Baua River Basin Model.

## 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.

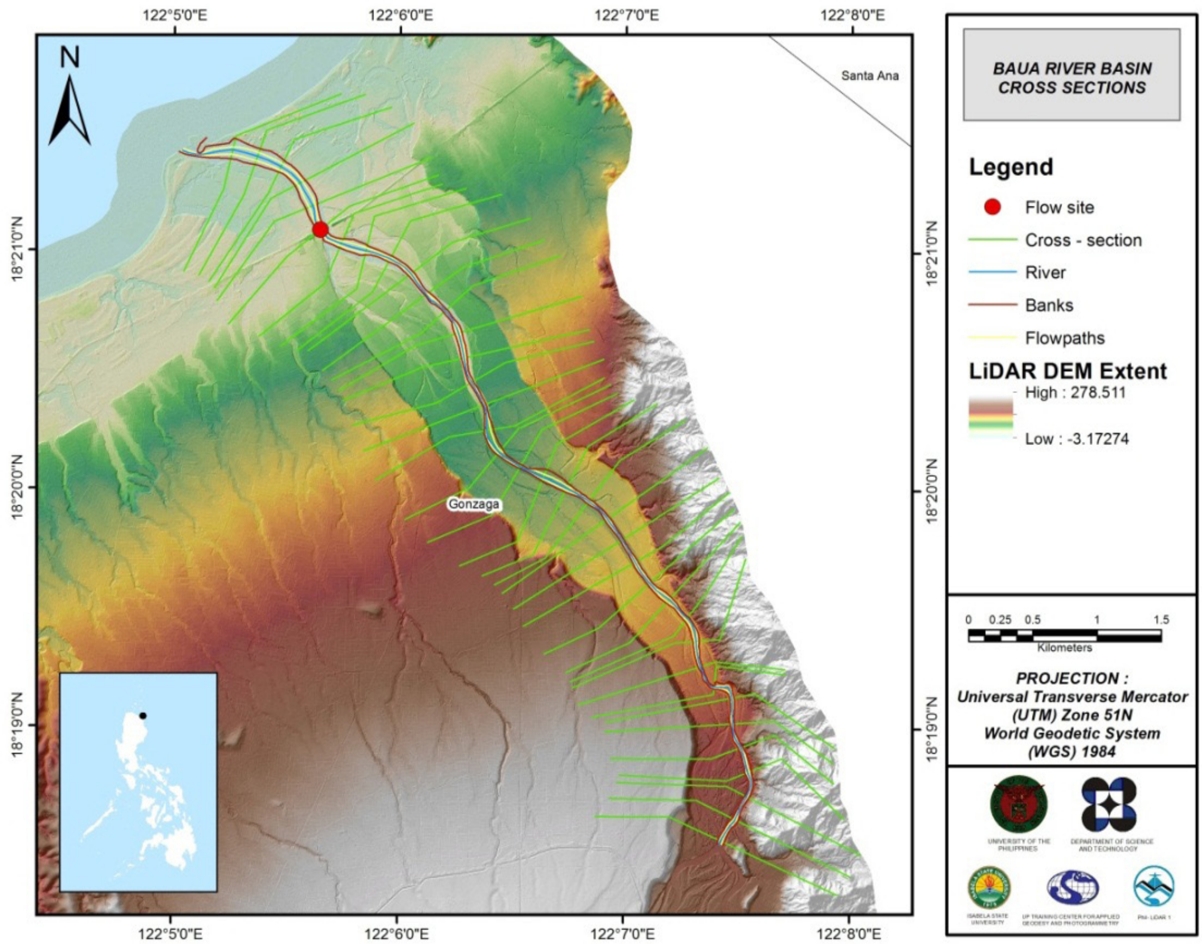



Figure 64. River cross-section of Baua River generated through Arcmap HEC GeoRAS tool

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

Figure 65. Screenshot of subcatchment with 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 28.67212 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 $m^2/s$.

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 45299400.00 $m^2$.

There is a total of 52789084.78 $m^3$ of water entering the model. Of this amount, 20034425.58 $m^3$ is due to rainfall while 32754659.20 $m^3$ is inflow from other areas outside the model. 4674584.50 $m^3$ of this water is lost to infiltration and interception, while 2563791.01 $m^3$ is stored by the flood plain. The rest, amounting up to 45550705.86 $m^3$, is outflow.

## 5.6 Results of HMS Calibration

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

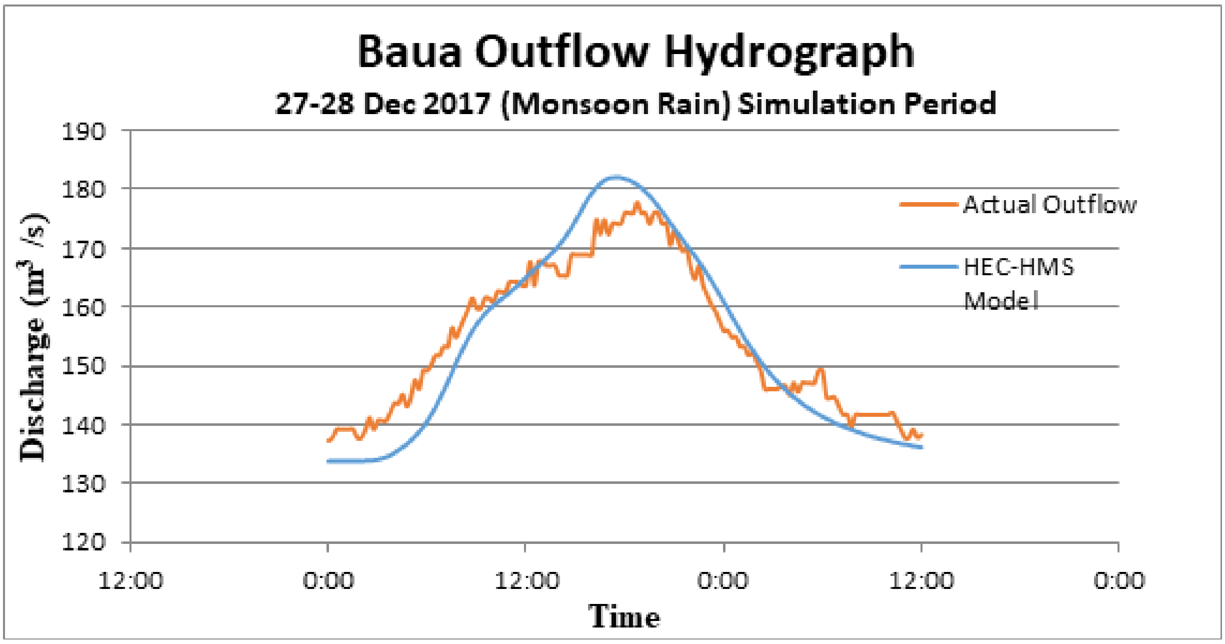



Figure 66. Outflow Hydrograph of Baua produced by the HEC-HMS model compared with observed outflow.

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

Table 32. Range of calibrated values for Baua Watershed

| Hydrologic Element | Calculation Type | Method | Parameter | Range of Calibrated Values |
|---|---|---|---|---|
| Basin | Loss | SCS Curve number | Initial Abstraction (mm) | 1.98 – 12.47 |
| | | | Curve Number | 77 - 99 |
| | Transform | Clark Unit Hydrograph | Time of Concentration (hr) | 0.29 – 4.34 |
| | | | Storage Coefficient (hr) | 0.40 – 5.9 |
| | Baseflow | Recession | Recession Constant | 1 |
| | | | Ratio to Peak | 0.2 |
| Reach | Routing | Muskingum-Cunge | Manning's Coefficient | 0.035 |

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 1.98 mm to 12.47 mm signifies that there is minimal amount of infiltration or rainfall interception by vegetation.

The curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range for the curve number of Baua River Basin is 77 to 99. For Baua, the basin mostly consists of closed forest and the soil mostly consists of undifferentiated soil.

The time of concentration and storage coefficient are the travel time and index of temporary storage of runoff in a watershed. The range of calibrated values from 0.29 hour to 5.9 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, while ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant of 1 indicates that the basin is highly unlikely to quickly go back to its original discharge and instead, will be higher. Ratio to peak of 0.2 indicates a steeper receding limb of the outflow hydrograph.

Manning's roughness coefficient of 0.035 corresponds to the common roughness in Baua watershed, which is determined to be cultivated with mature row crops (Brunner, 2010).

Table 33. Summary of the Efficiency Test of Baua HMS Model

| Accuracy measure | Value |
|---|---|
| RMSE | 4.8 |
| $r^2$ | 0.956 |
| NSE | 0.85 |
| PBIAS | 0.56 |
| RSR | 0.38 |

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 4.8 ($m^3/s$).

The Pearson correlation coefficient ($r^2$) 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 0.956.

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 0.85.

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 0.56.

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 0.38.

## 5.7 Calculated Outflow hydrographs and Discharge Values for different Rainfall Return Periods

### 5.7.1 Hydrograph using the Rainfall Runoff Model

The summary graph (Figure 67) shows the Baua River outflow using the Aparri 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.

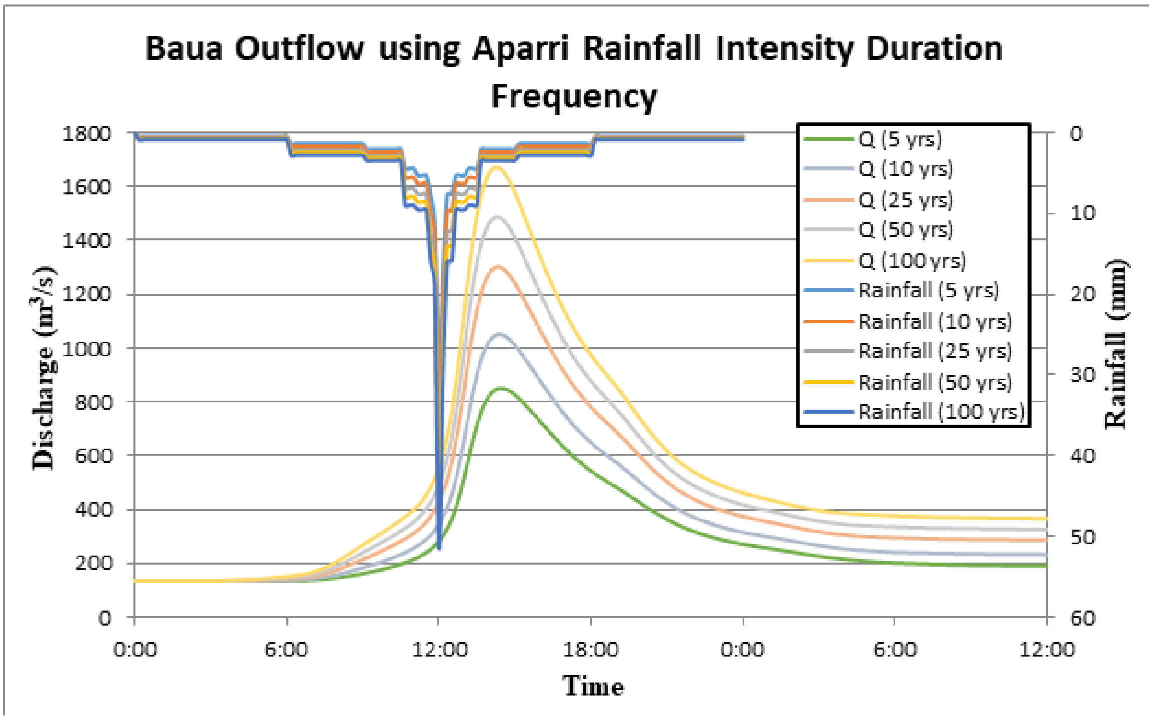



Figure 67. Outflow hydrograph at Baua Station generated using Aparri RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of the Baua discharge using the Aparri Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 34.

Table 34. Peak values of the Baua HEC-HMS Model outflow using the Aparri RIDF

| RIDF Period | Total Precipitation (mm) | Peak Rainfall (mm) | Peak Outflow | Time to Peak |
|---|---|---|---|---|
| 5-year RIDF | 252.5 | 28.5 | 851.1 | 2 hours, 30 minutes |
| 10-year RIDF | 308.5 | 34.1 | 1050.0 | 2 hours, 20 minutes |
| 25-year RIDF | 379.3 | 41.1 | 1301.7 | 2 hours, 20 minutes |
| 50-year RIDF | 431.9 | 46.3 | 1486.2 | 2 hours, 20 minutes |
| 100-year RIDF | 484 | 51.4 | 1670.2 | 2 hours, 20 minutes |

## 5.8 River Analysis Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. For this publication, only a sample output map river was to be shown. The sample generated map of Baua River using the calibrated HMS is shown in Figure 68.


Figure 68. Sample output of Baua RAS Model

## 5.9 Flood Hazard and Flow Depth Map

The resulting hazard and flow depth maps have a 10m resolution. The generated flood hazard maps for the Baua Floodplain were used to assess the vulnerability of the educational and medical institutions in the floodplain. Using the flood depth units of PAGASA for hazard maps - “Low”, “Medium”, and “High” - the affected institutions were given their individual assessment for each Flood Hazard Scenario (5 yr, 25 yr, and 100 yr). Figure 69 to Figure 74 shows the 5-, 25-, and 100-year rain return scenarios of the Baua floodplain. The floodplain, with an area of 57.04 sq. km., covers one municipality namely Gonzaga. Table 35 shows the percentage of area affected by flooding in the municipality.

Table 35. Municipalities affected in Baua Floodplain

| Municipality | Total Area | Area Flooded | % Flooded |
|---|---|---|---|
| Gonzaga | 497.62 | 57.04 | 11% |

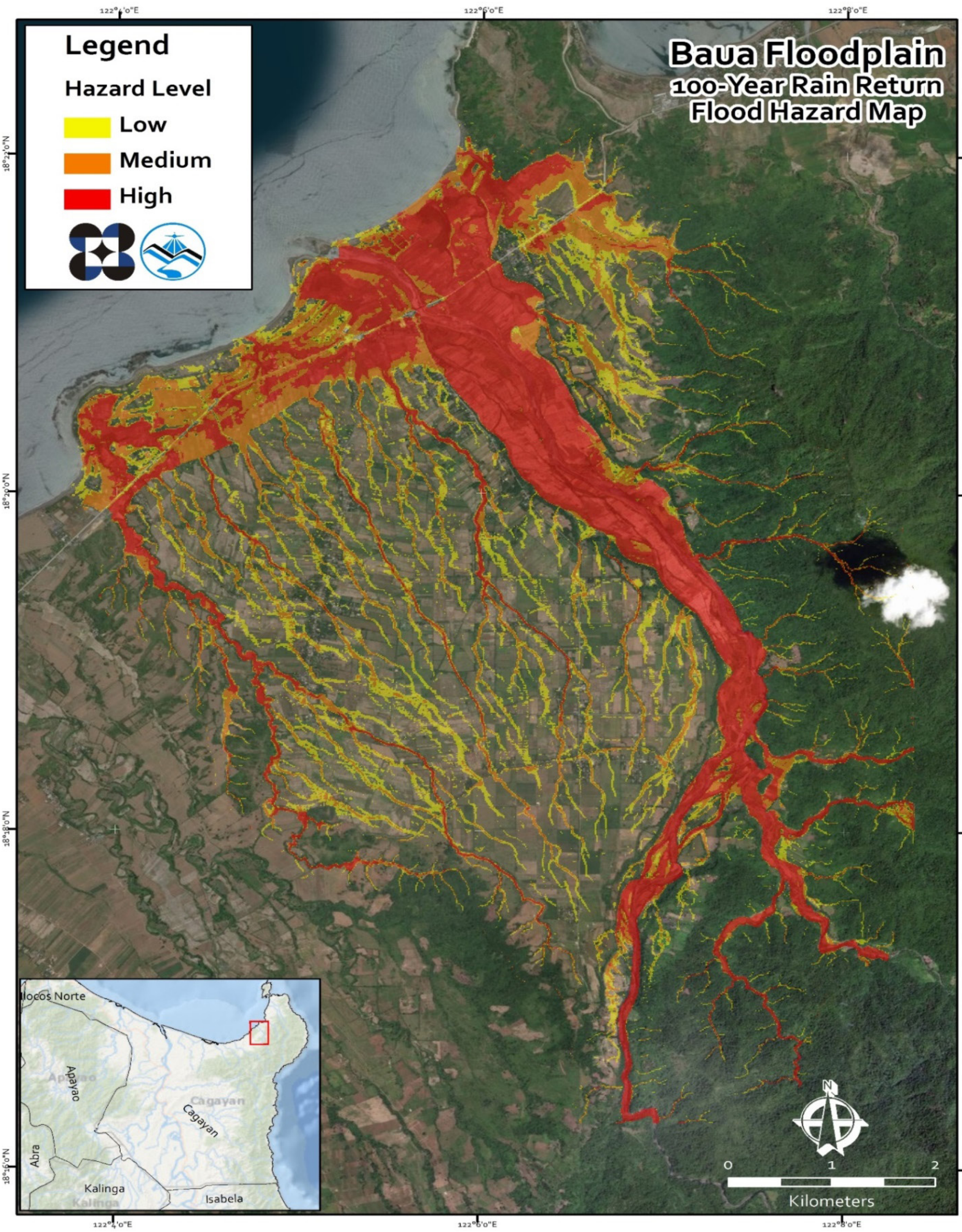



Figure 69. 100-year Flood Hazard Map for Baua Floodplain overlaid on Google Earth imagery

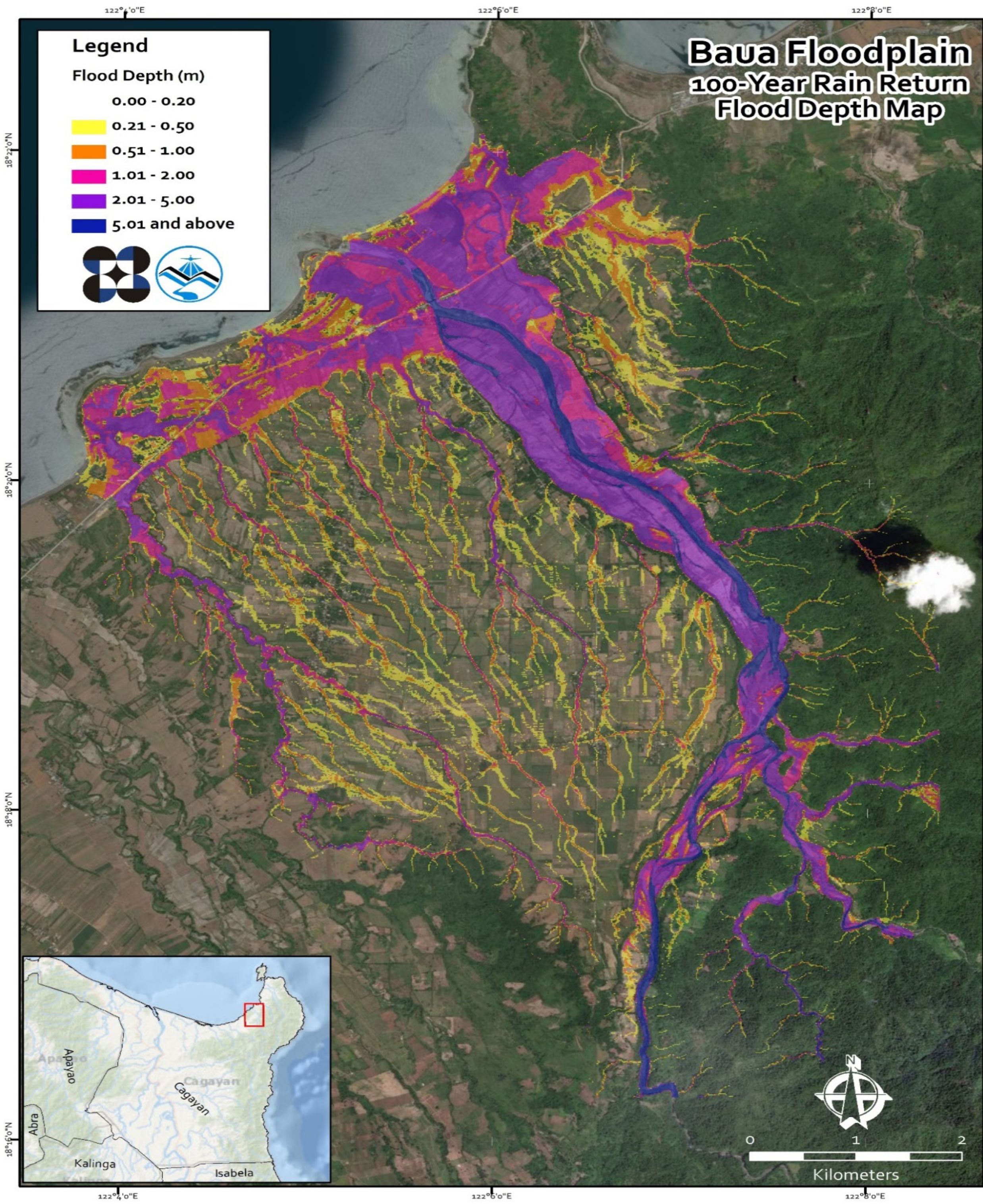



Figure 70. 100-year Flow Depth Map for Baua Floodplain overlaid on Google Earth imagery

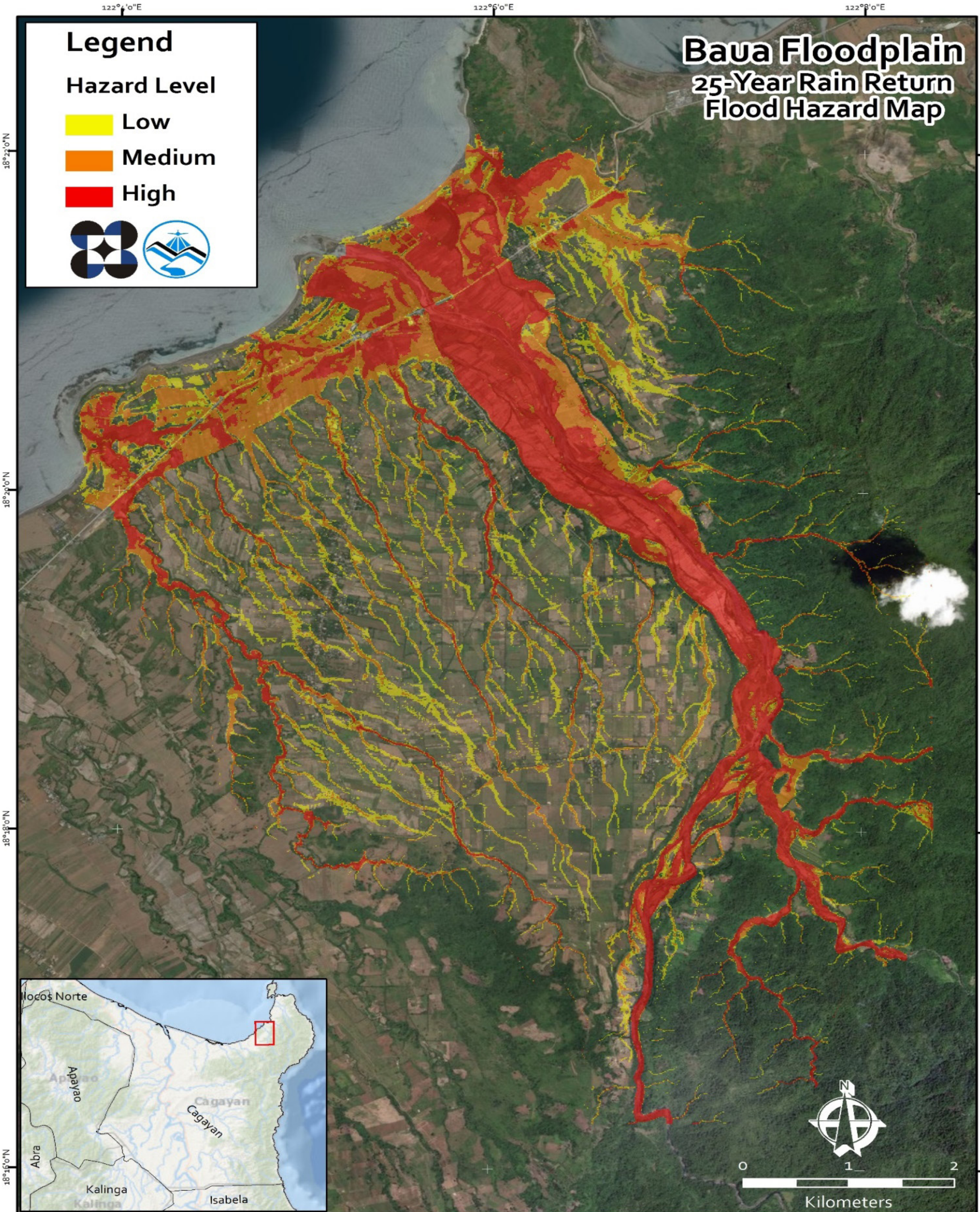



Figure 71. 25-year Flood Hazard Map for Baua Floodplain overlaid on Google Earth imagery

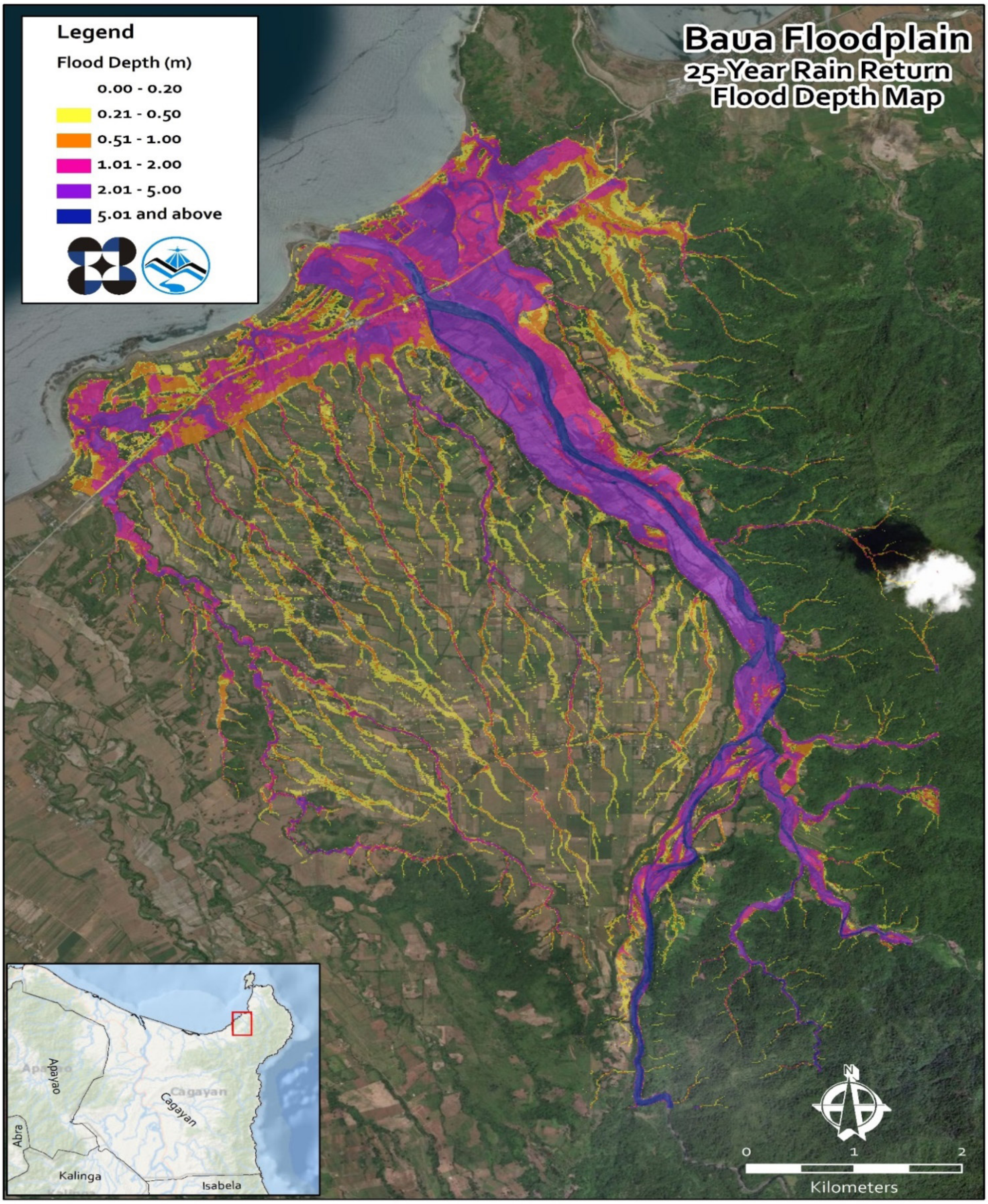



Figure 72. 25-year Flow Depth Map for Baua Floodplain overlaid on Google Earth imagery

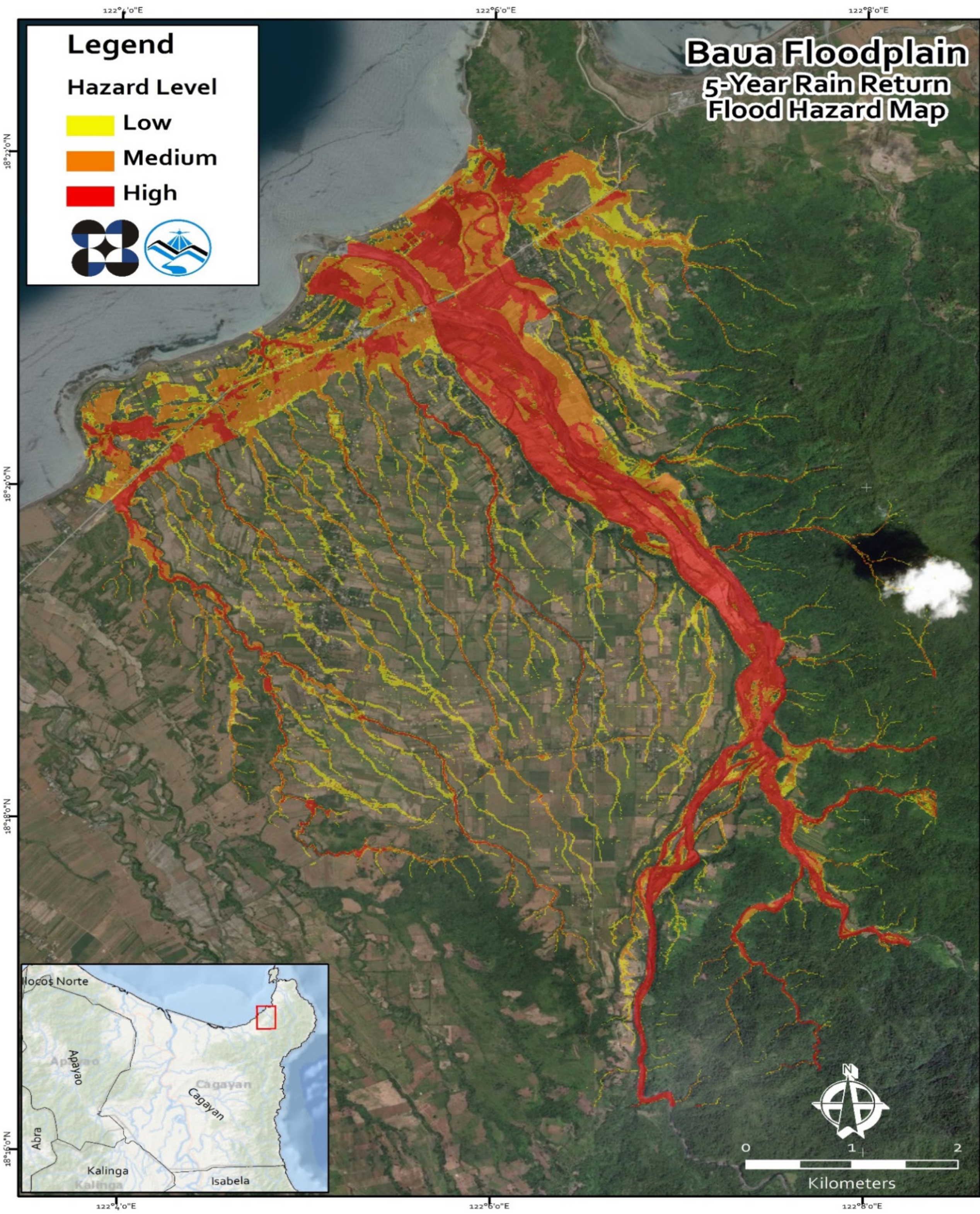



Figure 73. 5-year Flood Hazard Map for Baua Floodplain overlaid on Google Earth imagery

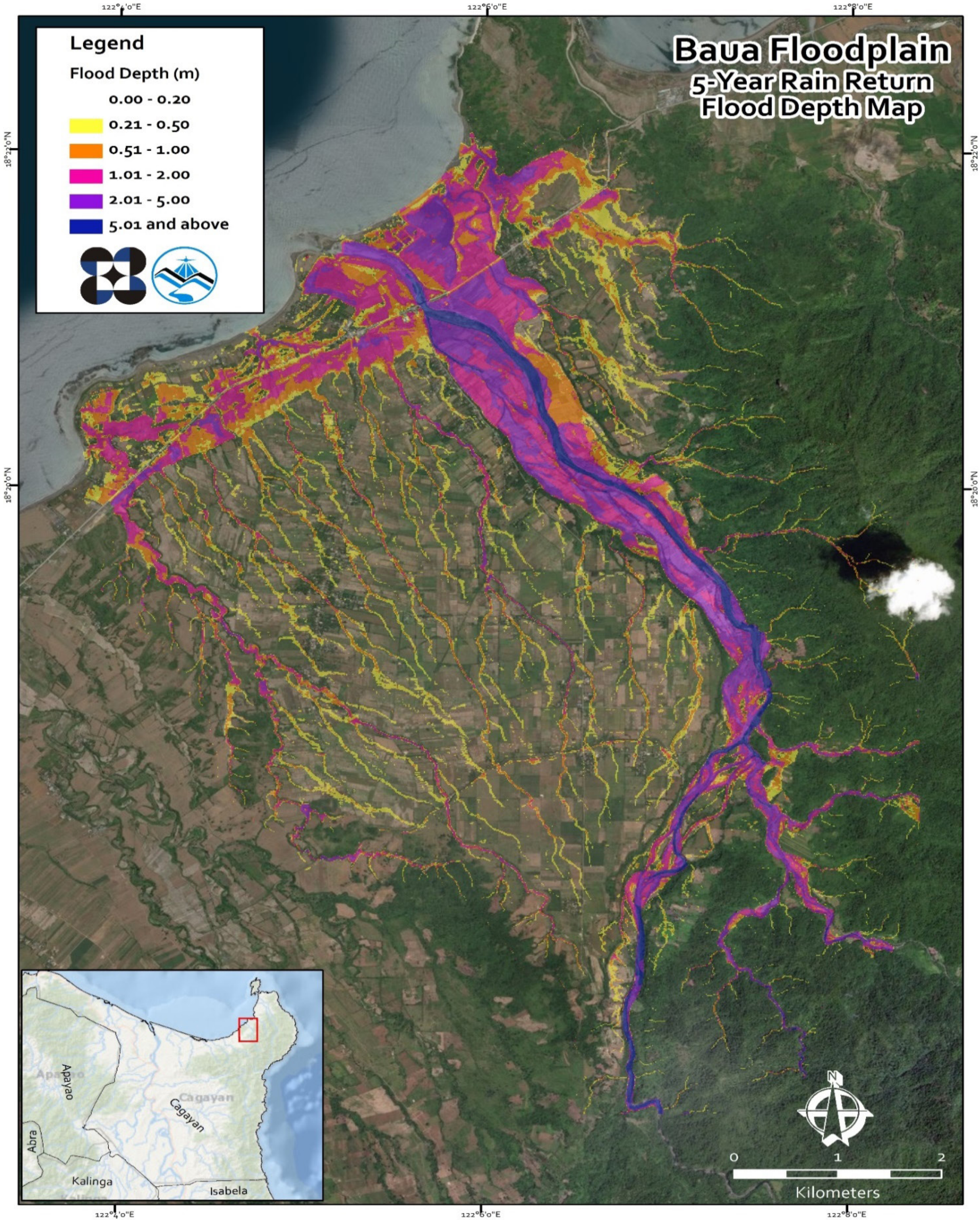



Figure 74. 5-year Flood Depth Map for Baua Floodplain overlaid on Google Earth imagery

## 5.10 Areas Exposed to Flooding

Affected barangays in Baua river basin, grouped by municipality, are listed below. For the said basin, one (1) municipality consisting of 6 barangays are expected to experience flooding when subjected to 5-, 25-, and 100-yr rainfall return period.

For the 5-year return period, 8.50% of the municipality of Gonzaga with an area of 497.62 sq. km. will experience flood levels of less than 0.20 meters. 0.77% of the area will experience flood levels of 0.21 to 0.50 meters while 0.63%, 0.82%, 0.59%, and 0.14% 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 36 and shown in Figure 75 are the affected areas in square kilometers by flood depth per barangay.

Table 36. Affected Areas in Gonzaga, Cagayan during 5-Year Rainfall Return Period

| Affected Area (sq. km.) by flood depth (in m.) | Area of affected barangays in Gonzaga (in sq. km) | | | | | |
|---|---|---|---|---|---|---|
| | Amunitan | Baua | Cabiraoan | San Jose | Santa Cruz | Santa Maria |
| **0.03-0.20** | 4.65 | 1.35 | 17.18 | 3.78 | 2.68 | 12.68 |
| **0.21-0.50** | 0.29 | 0.33 | 1.24 | 0.56 | 0.45 | 0.98 |
| **0.51-1.00** | 0.25 | 0.54 | 0.59 | 0.56 | 0.51 | 0.7 |
| **1.01-2.00** | 0.3 | 0.78 | 0.56 | 0.93 | 0.46 | 1.07 |
| **2.01-5.00** | 0.074 | 0.47 | 0.56 | 0.58 | 0.076 | 1.16 |
| **> 5.00** | 0.048 | 0.12 | 0.17 | 0 | 0 | 0.37 |

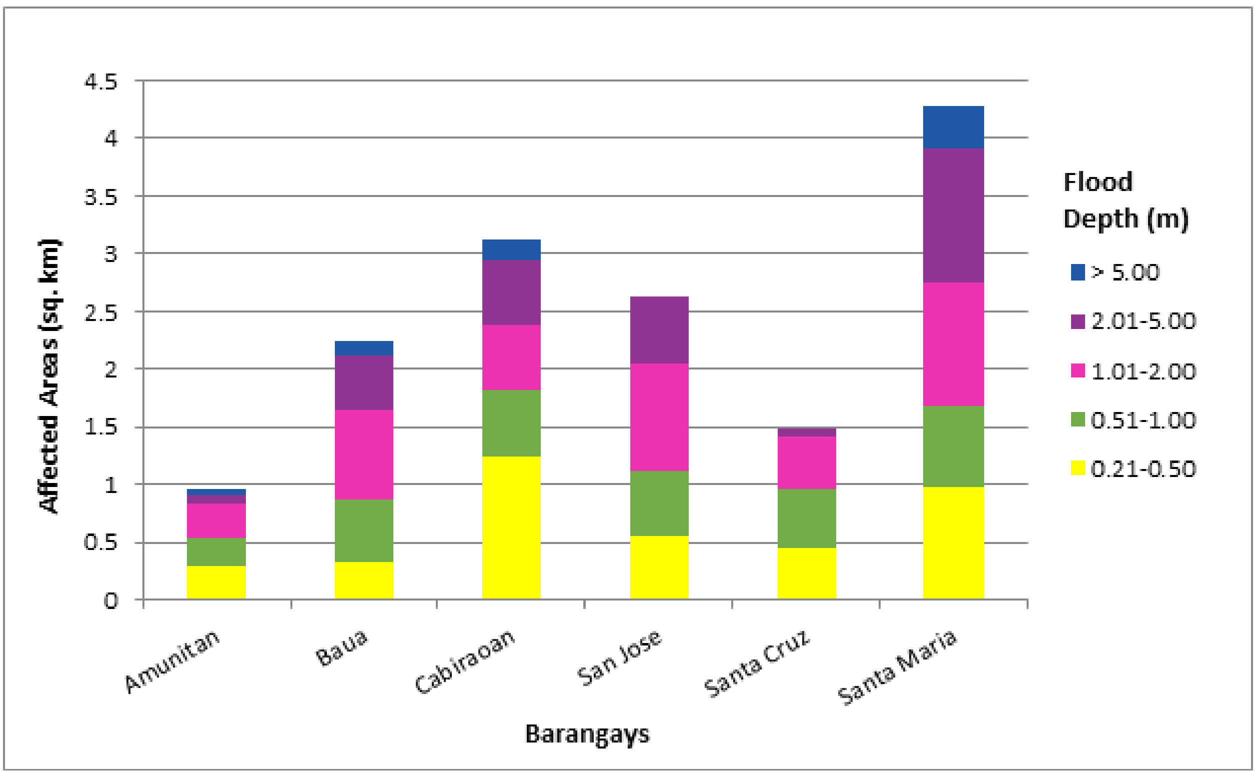



Figure 75. Affected Areas in Gonzaga, Cagayan during 5-Year Rainfall Return Period

For the 25-year return period, 8.04% of the municipality of Gonzaga with an area of 497.62 sq. km. will experience flood levels of less than 0.20 meters. 0.87% of the area will experience flood levels of 0.21 to 0.50 meters while 0.61%, 0.84%, 0.92%, and 0.18% 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 37 and shown in Figure 76 are the affected areas in square kilometers by flood depth per barangay.

Table 37. Affected Areas in Gonzaga, Cagayan during 25-Year Rainfall Return Period

| Affected Area (sq. km.) by flood depth (in m.) | Area of affected barangays in Gonzaga (in sq. km) | | | | | |
|---|---|---|---|---|---|---|
| | Amunitan | Baua | Cabiraoan | San Jose | Santa Cruz | Santa Maria |
| 0.03-0.20 | 4.48 | 1.08 | 16.44 | 3.48 | 2.38 | 12.17 |
| 0.21-0.50 | 0.3 | 0.27 | 1.56 | 0.6 | 0.45 | 1.14 |
| 0.51-1.00 | 0.25 | 0.44 | 0.69 | 0.54 | 0.55 | 0.56 |
| 1.01-2.00 | 0.32 | 0.92 | 0.6 | 0.93 | 0.56 | 0.84 |
| 2.01-5.00 | 0.2 | 0.74 | 0.75 | 0.86 | 0.23 | 1.81 |
| > 5.00 | 0.066 | 0.14 | 0.26 | 0.0001 | 0 | 0.43 |

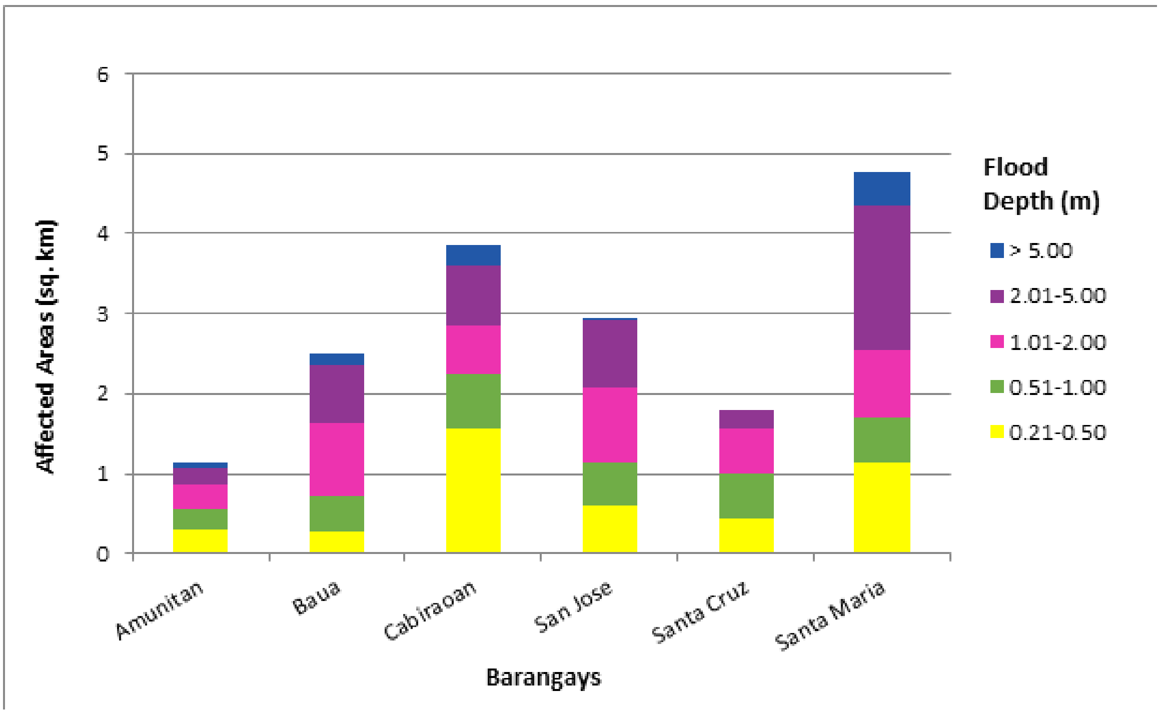



Figure 76. Affected Areas in Gonzaga, Cagayan during 25-Year Rainfall Return Period

For the 100-year return period, 7.73% of the municipality of Gonzaga with an area of 497.62 sq. km. will experience flood levels of less than 0.20 meters. 0.95% of the area will experience flood levels of 0.21 to 0.50 meters while 0.62%, 0.79%, 1.15%, and 0.22% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 38 and shown in Figure 77 are the affected areas in square kilometers by flood depth per barangay.

Table 38. Affected Areas in Gonzaga, Cagayan during 100-Year Rainfall Return Period

| Affected Area (sq. km.) by flood depth (in m.) | Area of affected barangays in Gonzaga (in sq. km) | | | | | |
|---|---|---|---|---|---|---|
| | Amunitan | Baua | Cabiraoan | San Jose | Santa Cruz | Santa Maria |
| 0.03-0.20 | 4.37 | 0.9 | 15.86 | 3.32 | 2.2 | 11.81 |
| 0.21-0.50 | 0.31 | 0.28 | 1.83 | 0.59 | 0.45 | 1.28 |
| 0.51-1.00 | 0.26 | 0.36 | 0.78 | 0.56 | 0.55 | 0.58 |
| 1.01-2.00 | 0.29 | 0.92 | 0.61 | 0.84 | 0.65 | 0.64 |
| 2.01-5.00 | 0.31 | 0.97 | 0.9 | 1.1 | 0.32 | 2.11 |
| > 5.00 | 0.072 | 0.17 | 0.32 | 0.0001 | 0 | 0.53 |

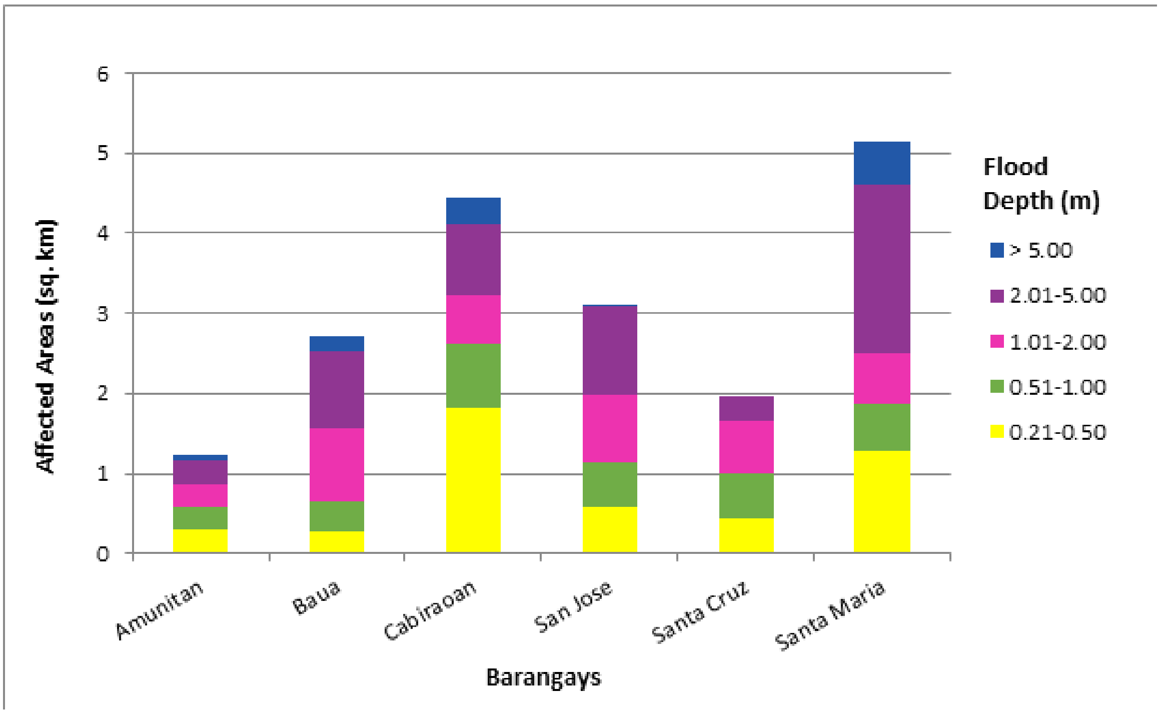



Figure 77. Affected Areas in Gonzaga, Cagayan during 100-Year Rainfall Return Period

Among the barangays in the municipality of Gonzaga in Cagayan, Cabiraoan is projected to have the highest percentage of area that will experience flood levels at 4.08%. Meanwhile, Santa Maria posted the second highest percentage of area that may be affected by flood depths at 3.41%.

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

Table 39. Area covered by each warning level with respect to the rainfall scenario

| Warning Level | Area Covered in sq. km. | | |
|---|---|---|---|
| | 5 year | 25 year | 100 year |
| Low | 3.92 | 4.43 | 4.87 |
| Medium | 5.20 | 5.21 | 5.06 |
| High | 5.87 | 7.69 | 9.02 |
| Total | 14.99 | 17.33 | 18.95 |

Of the 15 identified educational institutions in Baua Flood Plain, two (2) schools were discovered exposed to low-level flooding while three (3) schools were found exposed to medium-level flooding, both during the 5-year scenario.

For the 25-year scenario, one (1) school was discovered exposed to low-level flooding while two (2) schools were found exposed to medium-level flooding. In the same scenario, two (2) schools were discovered exposed to high-level flooding.

For the 100-year scenario, two (2) schools were discovered exposed to low-level flooding while one (1) school was found exposed to medium-level flooding. In the same scenario, three (3) schools were discovered exposed to high-level flooding.
The educational institutions exposed to flooding are shown in Annex 12.

No medical institutions were identified to be affected by flooding in Baua Floodplain.

## 5.11 Flood Validation

Survey was done along the floodplain of Baua River to validate the generated flood maps. The team gathered secondary data regarding flood occurrence in the area. Ground validation points were acquired as well as the other necessary details like date of occurrence, name of typhoon and actual flood depth.

During validation, the team was assisted by the local Disaster Risk Reduction and Management representative. Residents along the floodplain were interviewed of the historical flood events they experiences.

Actual flood depth acquired from the ground validation were then computed and compared to the flood depth simulated by the model (Figure 79). The flood validation consists of 160 points randomly selected all over the Baua flood plain. It has an RMSE value of 1.208.

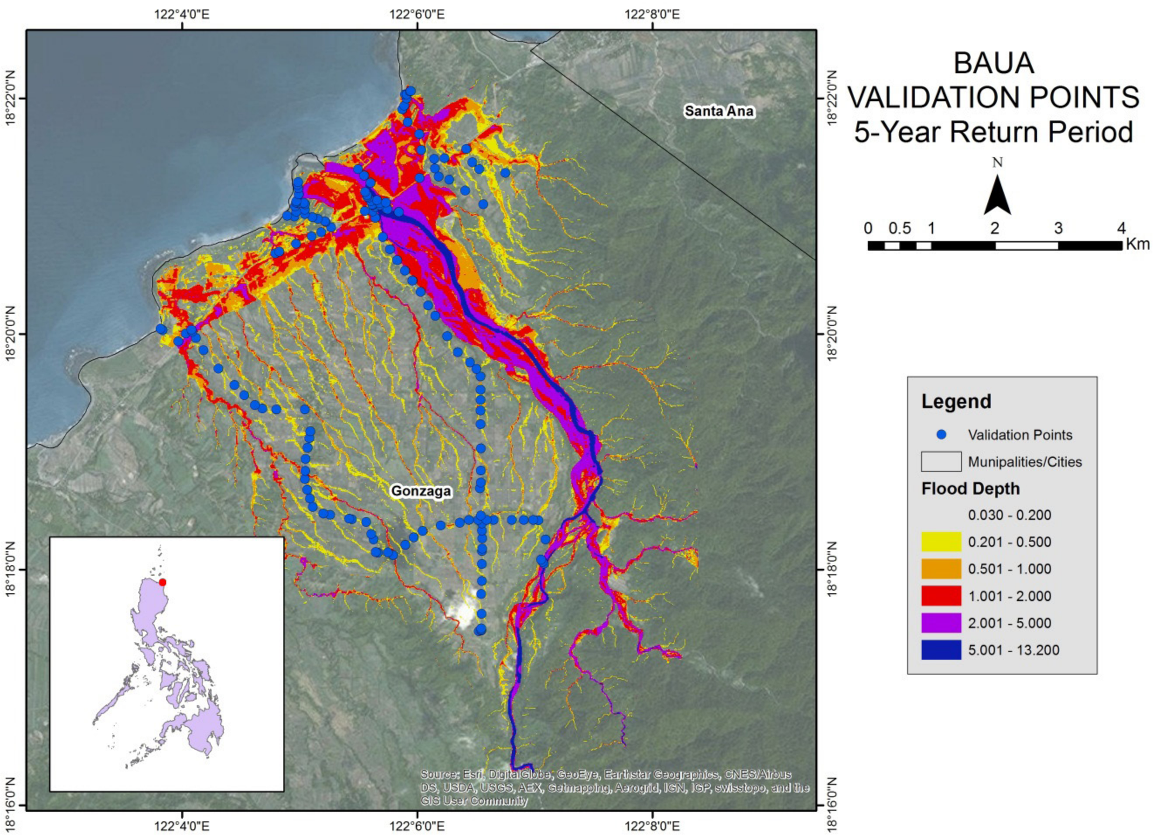



Figure 78. Validation points for 5-year Flood Depth Map of Baua Floodplain

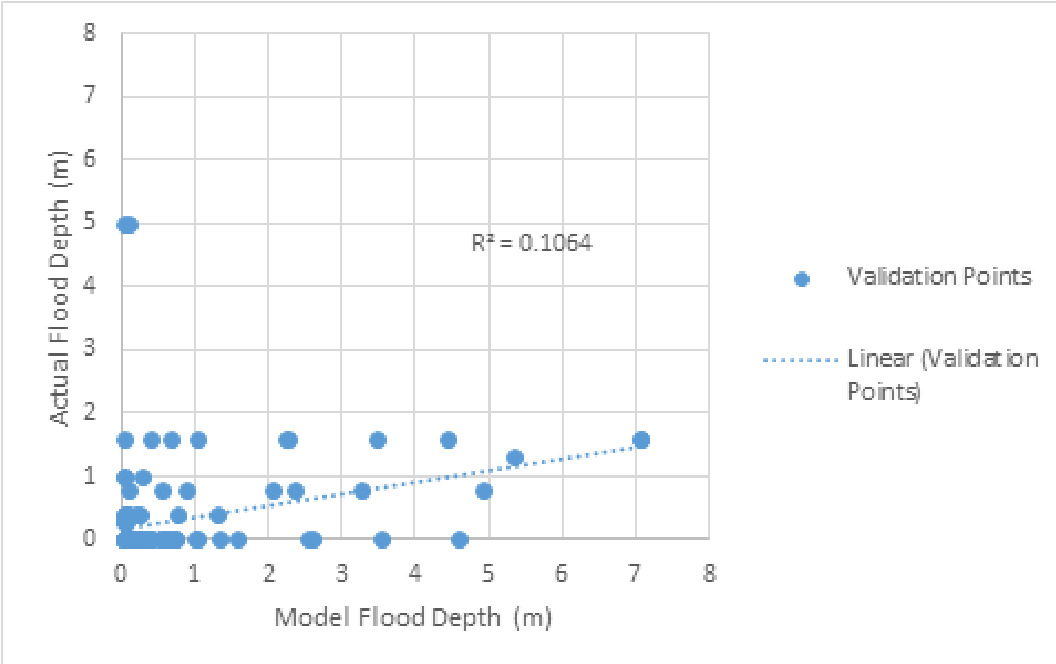



Figure 79. Flood map depth vs. actual flood depth

Table 40. Actual flood vs simulated flood depth of Baua 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** | 82 | 17 | 10 | 4 | 4 | 0 | 117 |
| **0.21-0.50** | 16 | 2 | 1 | 1 | 0 | 0 | 20 |
| **0.51-1.00** | 3 | 1 | 2 | 0 | 4 | 0 | 10 |
| **1.01-2.00** | 1 | 1 | 1 | 1 | 4 | 3 | 11 |
| **2.01-5.00** | 2 | 0 | 0 | 0 | 0 | 0 | 2 |
| **> 5.00** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total** | 104 | 21 | 14 | 6 | 12 | 3 | 160 |

The overall accuracy generated by the flood model is estimated at 54.38% with 87 points correctly matching the actual flood depths. In addition, there were 39 points estimated one level above and below the correct flood depths while there were 22 points and 11 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 4 points were overestimated while a total of 25 points were underestimated in the modelled flood depths of Baua. The summary of the accuracy assessment is presented in Table 41.

Table 41. Summary of the Accuracy Assessment in the Baua River Basin Survey

| | No. of Points | % |
|---|---|---|
| Correct | 87 | **54.38** |
| Overestimated | 48 | **30.00** |
| Underestimated | 25 | **15.63** |
| Total | 160 | **100.00** |

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# ANNEXES

## Annex 1. Optech Technical Specification of the Pegasus and Gemini Sensors

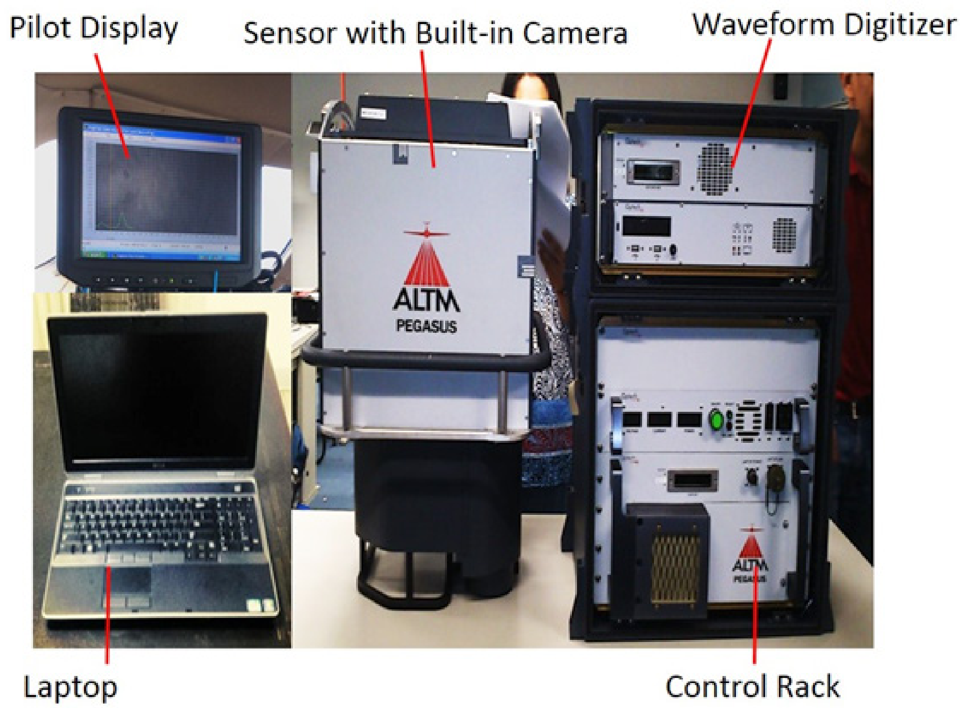



Figure A-1.1 Pegasus Sensor

Table A-1.1 Parameters and Specifications of the Pegasus Sensor

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

1 Target reflectivity ≥20%
2 Dependent on selected operational parameters using nominal FOV of up to 40° in standard atmospheric conditions with 24-km visibility
3 Angle of incidence ≤20°
4 Target size ≥ laser footprint5 Dependent on system configuration


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 Certificates of Reference Points Used

1. CGY-102

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

December 02, 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: CAGAYAN | |
| | Station Name: CGY-102 | |
| | Order: 2nd | |
| Island: LUZON | Barangay: CASAMBALANGAN | |
| Municipality: SANTA ANA | MSL Elevation: | |
| | *PRS92 Coordinates* | |
| Latitude: 18° 22' 15.98573" | Longitude: 122° 6' 41.74346" | Ellipsoidal Hgt: 22.60800 m. |
| | *WGS84 Coordinates* | |
| Latitude: 18° 22' 9.81367" | Longitude: 122° 6' 46.31361" | Ellipsoidal Hgt: 57.19500 m. |
| | *PTM / PRS92 Coordinates* | |
| Northing: 2032192.366 m. | Easting: 617476.569 m. | Zone: 3 |
| | *UTM / PRS92 Coordinates* | |
| Northing: 2,031,351.34 | Easting: 406,145.45 | Zone: 51 |

Location Description

CGY-102
From Gonzaga, travel along the nat'l. highway to Santa Ana. Station is located about 2 m. from the S corner of the triangular isalnd at the intersection of the nat'l. highway and the road to Port Irene. Mark is the head of a copper nail centered and flushed on a 30 cm. x 30 cm. concrete monument, with inscriptions "CGY-102 2007 NAMRIA".

Requesting Party: UP DREAM
Purpose: Reference
OR Number: 8088735 I
T.N.: 2015-3961

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.1 CGY-102

2. CGY-92

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

October 29, 2013

**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: **CAGAYAN** | |
| | Station Name: **CGY-92** | |
| Island: **LUZON** | Order: **2nd** | Barangay: **POBLACION** |
| Municipality: **LAL-LO** | | |
| | ***PRS92 Coordinates*** | |
| Latitude: **18° 12' 11.42361"** | Longitude: **121° 39' 42.14392"** | Ellipsoidal Hgt: **14.47400 m.** |
| | ***WGS84 Coordinates*** | |
| Latitude: **18° 12' 5.25321"** | Longitude: **121° 39' 46.73084"** | Ellipsoidal Hgt: **48.54000 m.** |
| | ***PTM Coordinates*** | |
| Northing: **2013373.807 m.** | Easting: **569996.115 m.** | Zone: **3** |
| | ***UTM Coordinates*** | |
| Northing: **2,013,059.26** | Easting: **358,475.41** | Zone: **51** |

Location Description

CGY-92
Is located inside the Lal-lo Nat'l. High School, about 5 m. W of the flagpole. Said school is 95 m. E of the Tuguegarao-Aparri nat'l. road, between Km Posts 562 and 563 and about 40 m. N of Lal-lo Mun. Hall. Mark is the head of a copper nail centered and flushed on a 30 cm. x 30 cm. cement putty, with inscriptions "CGY-92 2007 NAMRIA".

Requesting Party: **UP-DREAM**
Pupose: **Reference**
OR Number: **3947103 B**
T.N.: **2013-1171**

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

9 9 1 0 2 9 2 0 1 3 1 2 4 7 0 7

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

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

Figure A-2.2 CGY-92

3. CG-258

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

May 17, 2016

**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: **CAGAYAN**
Station Name: **CG-258**

| | | |
|---|---|---|
| Island: **Luzon** | Municipality: **GONZAGA** | Barangay: **TAPEL** |
| Elevation: **6.5266 +/- 0.0455 m.** | Accuracy Class at 95% C.L: **4 cm** | Datum: **Mean Sea Level** |
| Latitude: **18° 17' 15.50000"** | Longitude: **122° 1' 26.40000"** | |

The accuracy standards reported herein (FGDC-STD-007-1998) supersedes and replace the previous accuracy standards found in FGCC 1984 and FGCC 1988. Classified control points are verified as being consistent w/ all other points in the network, not merely those within that particular survey.

Location Description

BM CG-258 is in the Province of Cagayan, Municipality of Gonzaga, Brgy. of Tapel, along the national road and about 200 m NE of Kilometer post no. 608, It is embedded in a hole drilled on top of and near the West end of the North sidewalk of a concrete bridge. It is 0.22 m above the bridge floor, almost 4.33 m North of the centerline of the bridge. It is located at the right side of the national road going to Aparri, almost 37.7 m North post of the Tapel Brgy. marker.

Mark is a 1/2" x 2" brass rod embedded in a drilled hole, with an inscription on the cement putty placed around the mark as shown; CG-258; 2007; NAMRIA

| | |
|---|---|
| Requesting Party: | **UP-DREAM** |
| Purpose: | **Reference** |
| OR Number: | **8090370 I** |
| T.N.: | **2016-1109** |

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

9905172016095807

CERTIFICATION INTERNATIONAL ISO 9001:2008
ACCREDITED
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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.3 CG-258

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

1. CGY-102

Vector Components (Mark to Mark)

| From: | CGY-102 | | | | |
|---|---|---|---|---|---|
| Grid | | Local | | Global | |
| Easting | 406145.451 m | Latitude | N18°22'15.98572" | Latitude | N18°22'09.81367" |
| Northing | 2031351.336 m | Longitude | E122°06'41.74346" | Longitude | E122°06'46.31361" |
| Elevation | 20.066 m | Height | 22.609 m | Height | 57.195 m |

| To: | CG-258 | | | | |
|---|---|---|---|---|---|
| Grid | | Local | | Global | |
| Easting | 396708.418 m | Latitude | N18°17'21.32897" | Latitude | N18°17'15.16762" |
| Northing | 2022343.154 m | Longitude | E122°01'21.83970" | Longitude | E122°01'26.41723" |
| Elevation | 9.620 m | Height | 12.774 m | Height | 47.419 m |

| Vector | | | | | |
|---|---|---|---|---|---|
| ΔEasting | -9437.033 m | NS Fwd Azimuth | 226°03'09" | ΔX | 6452.377 m |
| ΔNorthing | -9008.183 m | Ellipsoid Dist. | 13049.913 m | ΔY | 7393.391 m |
| ΔElevation | -10.445 m | ΔHeight | -9.835 m | ΔZ | -8602.642 m |

Standard Errors

| Vector errors: | | | | | |
|---|---|---|---|---|---|
| σ ΔEasting | 0.001 m | σ NS fwd Azimuth | 0°00'00" | σ ΔX | 0.005 m |
| σ ΔNorthing | 0.001 m | σ Ellipsoid Dist. | 0.001 m | σ ΔY | 0.007 m |
| σ ΔElevation | 0.009 m | σ ΔHeight | 0.009 m | σ ΔZ | 0.003 m |

Aposteriori Covariance Matrix (Meter²)

| | X | Y | Z |
|---|---|---|---|
| X | 0.0000235542 | | |
| Y | -0.0000335823 | 0.0000546286 | |
| Z | -0.0000130276 | 0.0000212981 | 0.0000098327 |

Figure A-3.1 CGY-102

# Annex 4. The LiDAR Survey Team Composition

Table A-4.1 LiDAR Survey Team Composition

<table>
<tr><th>Data Acquisition Component Sub -Team</th><th>Designation</th><th>Name</th><th>Agency / Affiliation</th></tr>
<tr><td>PHIL-LIDAR 1</td><td>Program Leader</td><td>ENRICO C. PARINGIT, D.ENG</td><td>UP-TCAGP</td></tr>
<tr><td>Data Acquisition Component Leader</td><td>Data Component Project Leader – I</td><td>ENGR. CZAR JAKIRI SARMIENTO</td><td>UP-TCAGP</td></tr>
<tr><td rowspan="3">Survey Supervisor</td><td>Chief Science Research Specialist (CSRS)</td><td>ENGR. CHRISTOPHER CRUZ</td><td>UP-TCAGP</td></tr>
<tr><td rowspan="2">Supervising Science Research Specialist (Supervising SRS)</td><td>LOVELY GRACIA ACUÑA</td><td>UP-TCAGP</td></tr>
<tr><td>LOVELYN ASUNCION</td><td>UP-TCAGP</td></tr>
<tr><td colspan="4">FIELD TEAM</td></tr>
<tr><td rowspan="6">LiDAR Operation</td><td rowspan="2">Senior Science Research Specialist (SSRS)</td><td>JASMINE ALVIAR</td><td>UP-TCAGP</td></tr>
<tr><td>ENGR. IRO NIEL ROXAS</td><td>UP-TCAGP</td></tr>
<tr><td>Research Associate (RA)</td><td>ENGR. KENNETH QUISADO</td><td>UP-TCAGP</td></tr>
<tr><td>RA</td><td>KRISTINE JOY ANDAYA</td><td>UP-TCAGP</td></tr>
<tr><td>RA</td><td>JONATHAN ALMALVEZ</td><td>UP-TCAGP</td></tr>
<tr><td>RA</td><td>SANDRA POBLETE</td><td>UP-TCAGP</td></tr>
<tr><td rowspan="2">Ground Survey, Data Download and Transfer</td><td>RA</td><td>MA. REMEDIOS VILLANUEVA</td><td>UP-TCAGP</td></tr>
<tr><td>RA</td><td>DARRYL AUSTRIA</td><td>UP-TCAGP</td></tr>
<tr><td rowspan="5">LiDAR Operation</td><td rowspan="2">Airborne Security</td><td>SSG. ERWIN DELOS SANTOS</td><td>PHILIPPINE AIR FORCE (PAF)</td></tr>
<tr><td>SSG. JOHN ERIC CACANINDIN</td><td>PHILIPPINE AIR FORCE</td></tr>
<tr><td rowspan="3">Pilot</td><td>CAPT. CESAR ALFONSO III</td><td>ASIAN AEROSPACE CORPORATION (AAC)</td></tr>
<tr><td>CAPT. JERICO JECIEL</td><td>AAC</td></tr>
<tr><td>CAPT. JEROME MOONEY</td><td>AAC</td></tr>
</table>

# Annex 5. Data Transfer Sheets

DATA TRANSFER SHEET
cagayan2 12/2/15

| 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 | |
| 18-Nov | 2866P | 1BLK2G322A | pegasus | 2.33 | na | 11.8 | 266 | 34.7 | 258 | 22.8 | na | 15.6 | 1KB | 1KB | 129 | NA | Z:\DAC\RAW DATA |
| 18-Nov | 2868P | 1BLK2H322B | pegasus | 1.87 | na | 7.94 | 157 | 27.7 | 207 | 18 | na | 15.6 | 1KB | 1KB | 74 | NA | Z:\DAC\RAW DATA |
| 19-Nov | 2870P | 1BLK21AB323A | pegasus | 2.11 | na | 11.6 | 255 | 23.2 | 211 | 22.8 | na | 10.3 | 1KB | 1KB | 46 | NA | Z:\DAC\RAW DATA |
| 20-Nov | 2874P | 1BLK21C324A | pegasus | 1.22 | na | 8.12 | 195 | 7.3 | 80 | 12 | na | 10.8 | 1KB | 1KB | 57/90 | NA | Z:\DAC\RAW DATA |
| 21-Nov | 2880P | 1BLK2HS325A | pegasus | 1.76 | na | 12.2 | 231 | 30 | 240/1 | 17.7 | na | 11.4 | 1KB | 1KB | 84/76/74 | NA | Z:\DAC\RAW DATA |

Received from

Name [illegible]
Position
Signature

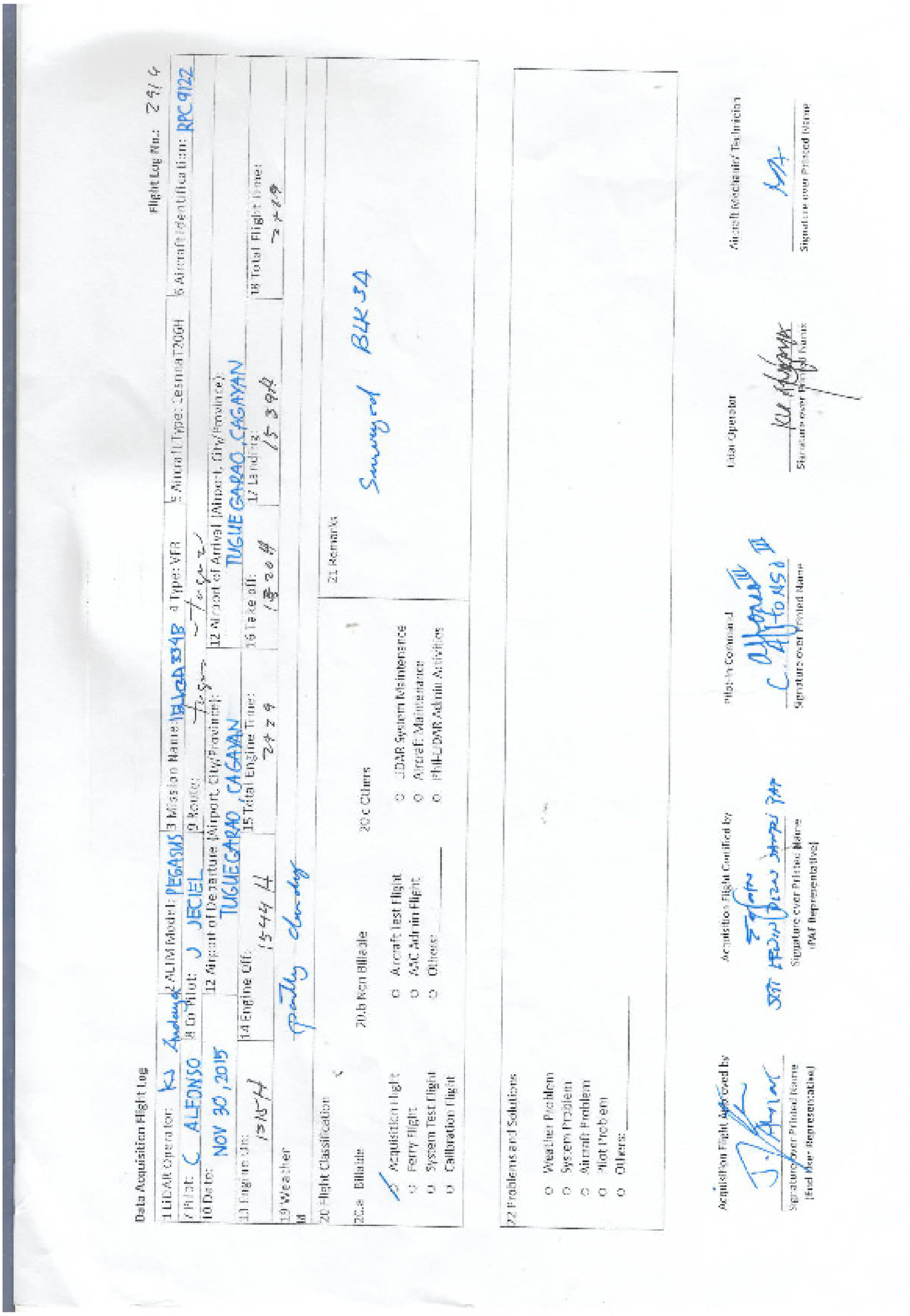
Received by

Name AC Bongat 12/4/15
Position
Signature

Figure A-5.1 Data Transfer Sheet for Baua Floodplain - A

# Annex 6. Flight Logs

1. Flight Log for 2916P Mission



Data Acquisition Flight Log

Flight Log No.: 2916

1 LiDAR Operator: KJ Andaya | 2 ALTM Model: PEGASUS | 3 Mission Name: 1BLK3A334B | 4 Type: VFR | 5 Aircraft Type: Cesnna T206H | 6 Aircraft Identification: RPC9122

7 Pilot: C ALFONSO | 8 Co-Pilot: J JECIEL | 9 Route:

10 Date: NOV 30, 2015 | 12 Airport of Departure (Airport, City/Province): TUGUEGARAO, CAGAYAN | 12 Airport of Arrival (Airport, City/Province): TUGUEGARAO, CAGAYAN

13 Engine On: 1315H | 14 Engine Off: 1544H | 15 Total Engine Time: 2+29 | 16 Take off: 1320H | 17 Landing: 1539H | 18 Total Flight Time: 2+19

19 Weather: Partly cloudy

20 Flight Classification

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

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

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

21 Remarks: Surveyed BLK 3A

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

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

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

Pilot-in-Command: C Alfonso III, Signature over Printed Name

Lidar Operator: KJ Andaya, Signature over Printed Name

Aircraft Mechanic/Technician: Signature over Printed Name

Figure A-6.1 Flight Log for 2916P Mission

2. Flight Log for 3971G Mission

UP DREAM **Data Acquisition Flight Log**

**Flight Log No.:** 3971

| | | | | | |
|---|---|---|---|---|---|
| 1 LiDAR Operator: J. ALMALVEZ | 2 ALTM Model: GEMINI | 3 Mission Name: 2BLK3CAG2MQR119A | 4 Type: VFR | 5 Aircraft Type: Cesnna T206H | 6 Aircraft Identification: RP-C9022 |
| 7 Pilot: J. MOONEY | 8 Co-Pilot: D. CORPUZ | 9 Route: TUGUEGARAO - TUGUEGARAO | | | |
| 10 Date: APRIL 28, 2016 | 12 Airport of Departure (Airport, City/Province): TUGUEGARAO | | 12 Airport of Arrival (Airport, City/Province): TUGUEGARAO | | |
| 13 Engine On: 1009 H | 14 Engine Off: 1424 H | 15 Total Engine Time: 04 + 15 | 16 Take off: 1014 H | 17 Landing: 1419 H | 18 Total Flight Time: 04 + 05 |
| 19 Weather: FAIR | | | | | |

**20 Flight Classification**

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

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

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

**21 Remarks**

SUCCESSFUL FLIGHT

Covered Baua, Casambalangan & Palawig floodplains

**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/ LiDAR Technician |
|---|---|---|---|---|
| I. ROXAS | SSC PACAYNON | J. MOONEY | J. ALMALVEL | – |
| 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 3971G Mission

3. Flight Log for 3991G Mission

UP DREAM Data Acquisition Flight Log

Flight Log No.: 3991

| | | | | | |
|---|---|---|---|---|---|
| 1 LiDAR Operator: J. ALMALVEZ | 2 ALTM Model: GEMINI | 3 Mission Name: 2BLK3CAG2MS124B | 4 Type: VFR | 5 Aircraft Type: Cesnna T206H | 6 Aircraft Identification: RP-C9022 |
| 7 Pilot: J. MOONEY | 8 Co-Pilot: D. CORPUZ | 9 Route: TUGUEGARAO - TUGUEGARAO | | | |
| 10 Date: MAY 3, 2016 | 12 Airport of Departure (Airport, City/Province): TUGUEGARAO | | 12 Airport of Arrival (Airport, City/Province): TUGUEGARAO | | |
| 13 Engine On: 1334 H | 14 Engine Off: 1600 H | 15 Total Engine Time: 2+26 | 16 Take off: 1339 H | 17 Landing: 1555 H | 18 Total Flight Time: 2+16 |
| 19 Weather: PARTLY CLOUDY | | | | | |

20 Flight Classification

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

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

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

21 Remarks

Successful flight

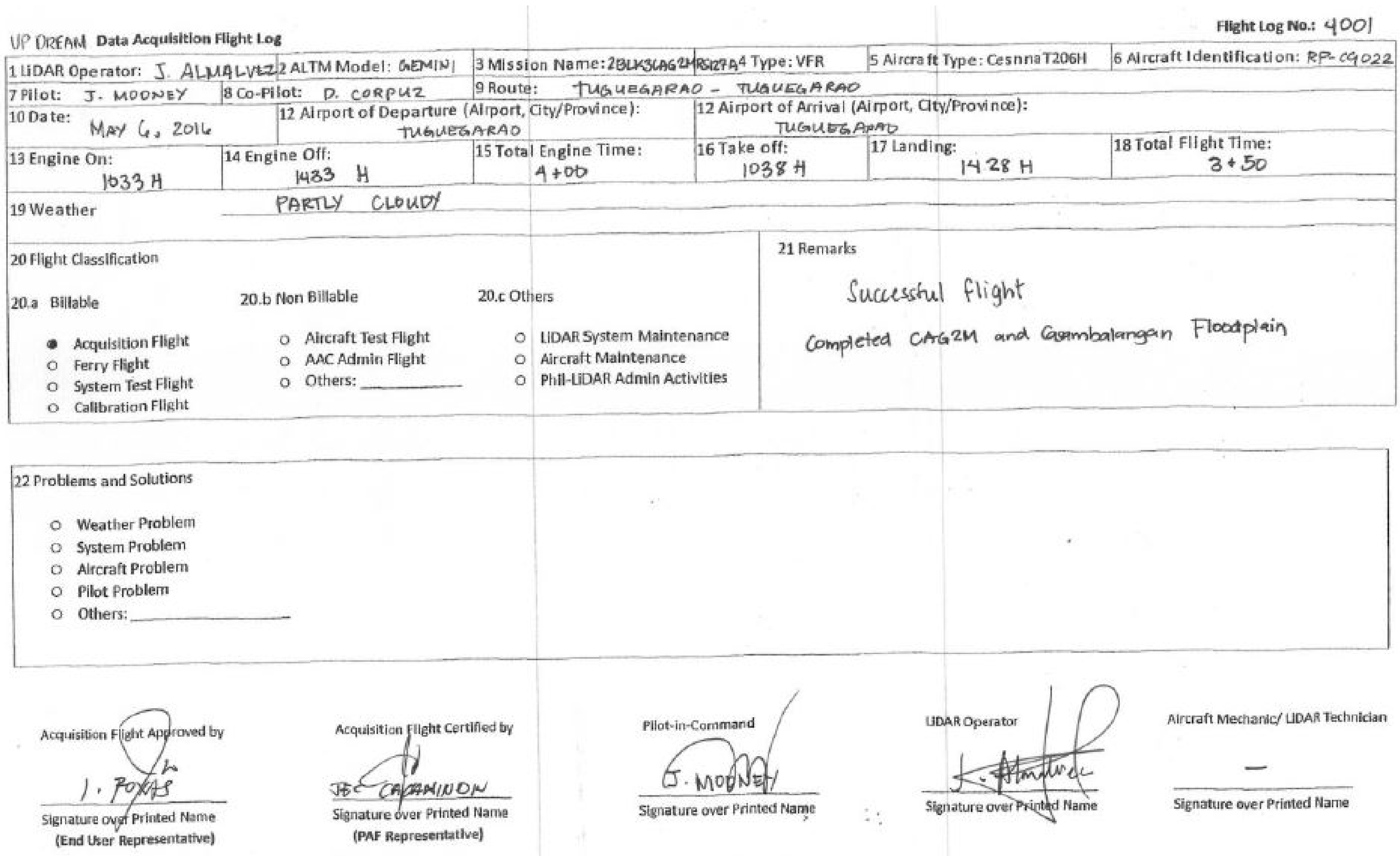
Covered CAG2M and O

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/ LiDAR Technician |
|---|---|---|---|---|
| J. POKLAS | TSC ALDANA PAF | J. MOONEY | J. Almalvez | — |
| 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 3991G Mission



UP DREAM Data Acquisition Flight Log

Flight Log No.: 4001

| | | | | | |
|---|---|---|---|---|---|
| 1 LiDAR Operator: J. ALMALVEZ | 2 ALTM Model: GEMINI | 3 Mission Name: 2BLK3CAG2MRS127A | 4 Type: VFR | 5 Aircraft Type: Cesnna T206H | 6 Aircraft Identification: RP-C9022 |
| 7 Pilot: J. MOONEY | 8 Co-Pilot: D. CORPUZ | 9 Route: TUGUEGARAO - TUGUEGARAO | | | |
| 10 Date: MAY 6, 2016 | 12 Airport of Departure (Airport, City/Province): TUGUEGARAO | | 12 Airport of Arrival (Airport, City/Province): TUGUEGARAO | | |
| 13 Engine On: 1033 H | 14 Engine Off: 1433 H | 15 Total Engine Time: 4+00 | 16 Take off: 1038 H | 17 Landing: 1428 H | 18 Total Flight Time: 3+50 |
| 19 Weather | PARTLY CLOUDY | | | | |

20 Flight Classification

20.a Billable

- ● Acquisition Flight
- ○ Ferry Flight
- ○ System Test Flight
- ○ Calibration Flight

20.b Non Billable

- ○ Aircraft Test Flight
- ○ AAC Admin Flight
- ○ Others: ____________

20.c Others

- ○ LiDAR System Maintenance
- ○ Aircraft Maintenance
- ○ Phil-LiDAR Admin Activities

21 Remarks

Successful flight

Completed CAG2M and Gambalangan Floodplain

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/ LiDAR Technician |
|---|---|---|---|---|
| I. ROXAS | JBC CABANINON | J. MOONEY | | — |
| Signature over Printed Name (End User Representative) | Signature over Printed Name (PAF Representative) | Signature over Printed Name | Signature over Printed Name | Signature over Printed Name |

Figure A-6.4 Flight Log for 4001G Mission

# Annex 7. Flight Status Report

Table A-7.1 Flight Status Report

| CAGAYAN REFLIGHTS (NOVEMBER 30, 2015, APRIL 28 – MAY 6, 2016) | | | | | |
|---|---|---|---|---|---|
| **FLIGHT NO** | **AREA** | **MISSION** | **OPERATOR** | **DATE FLOWN** | **REMARKS** |
| 2916P | BLK 3A AUNUGAY FP, BAUA FP | 1BLK3A334B | KJ ANDAYA | NOV 30, 2015 | SURVEYED AUNUGAY AND BAUA FPs120.97 SQ.KM |
| 3971G | CAG2M, CAG2Q, CAG2R | 2BLK3CAG2MQR119A | J. ALMALVEZ | APRIL 28, 2016 | COVERED BAUA, CASAMBALANGAN AND PALAWIG FLOODPLAINS |
| 3991G | CAG2M, CAG2Q, CAG2R | 2BLK3CAG2MSQS124B | J. ALMALVEZ | May 3, 2016 | COVERED CAG2Q AND R |
| 4001G | CAG2M, CAG2R | 2BLK3CAG2MRS127A | J. ALMALVEZ | May 6, 2016 | COMPLETED CAG2M AND |

**LAS BOUNDARIES PER FLIGHT**

| | | | | | |
|---|---|---|---|---|---|
| Flight No. : | 2916P | | | | |
| Area: | BLK 3A | | | | |
| Mission Name: | 1BLK3A334B | | | | |
| Parameters: | PRF 200 | SF | 30 | FOV | 50 |

**LAS/SWATH**

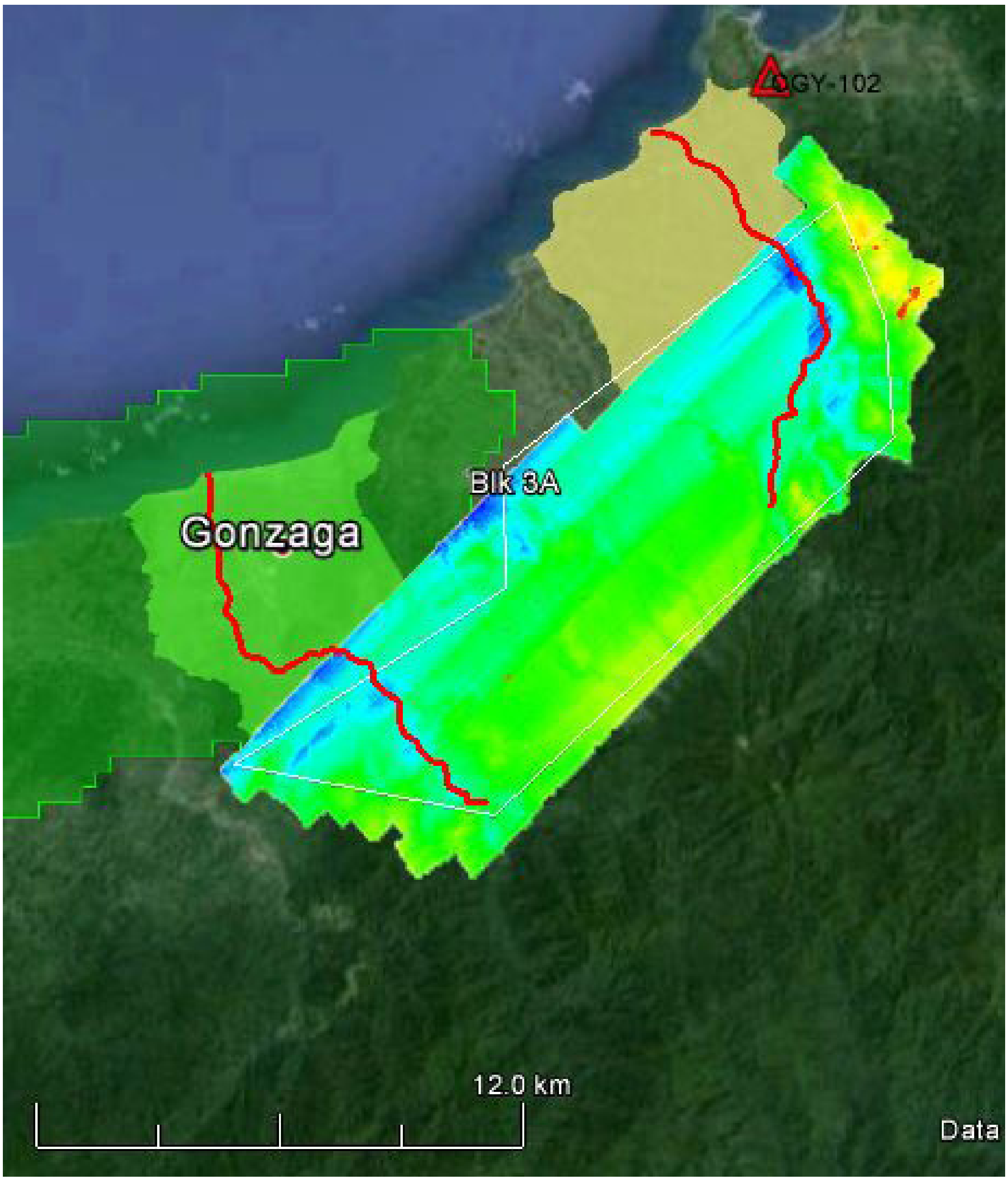



Figure A-7.1 Swath for Flight No. 2916P

FLIGHT NO.: 3971G
AREA: CAG2M, CAG2Q, CAG2R
MISSION NAME: 2BLK3CAG2MQR119A

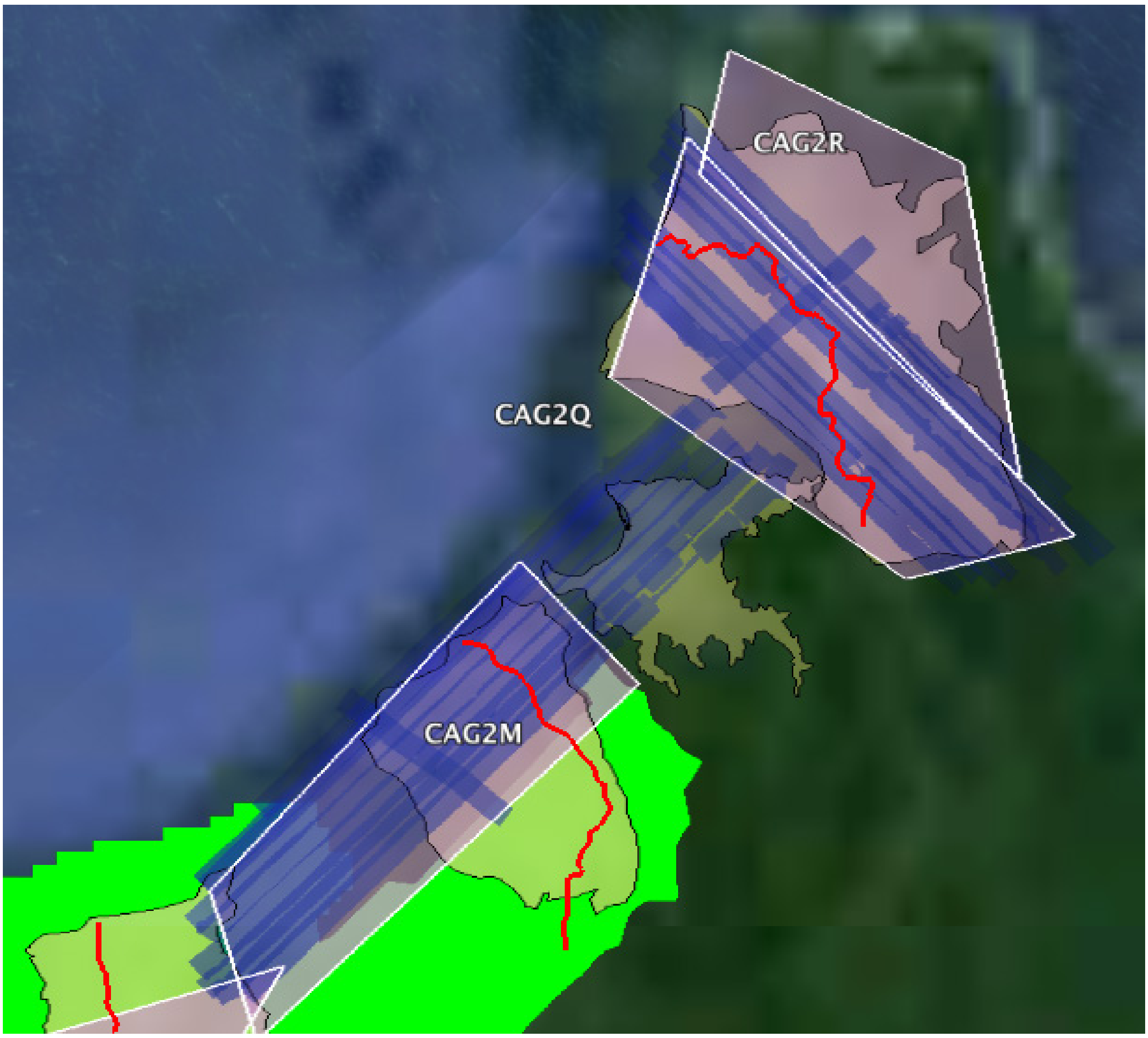



Figure A-7.2 Swath for Flight No. 3971G

FLIGHT NO.: 3991G
AREA: CAG2M, CAG2Q, CAG2R
MISSION NAME: 2BLK3CAG2MSQS124B

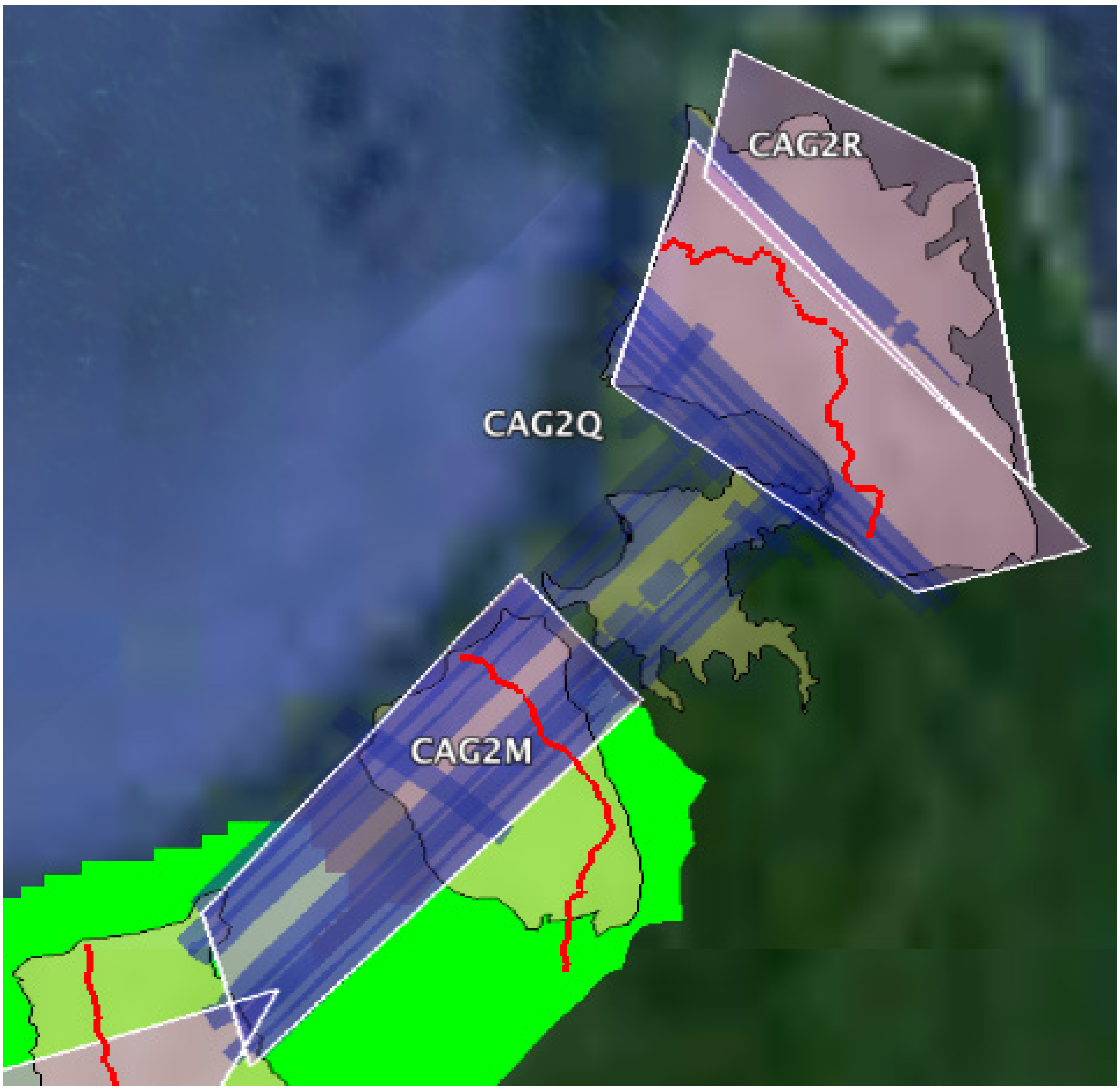



Figure A-7.3 Swath for Flight No. 3991G

FLIGHT NO.: 4001G
AREA: CAG2M, CAG2R
MISSION NAME: 2BLK3CAG2MRS127A

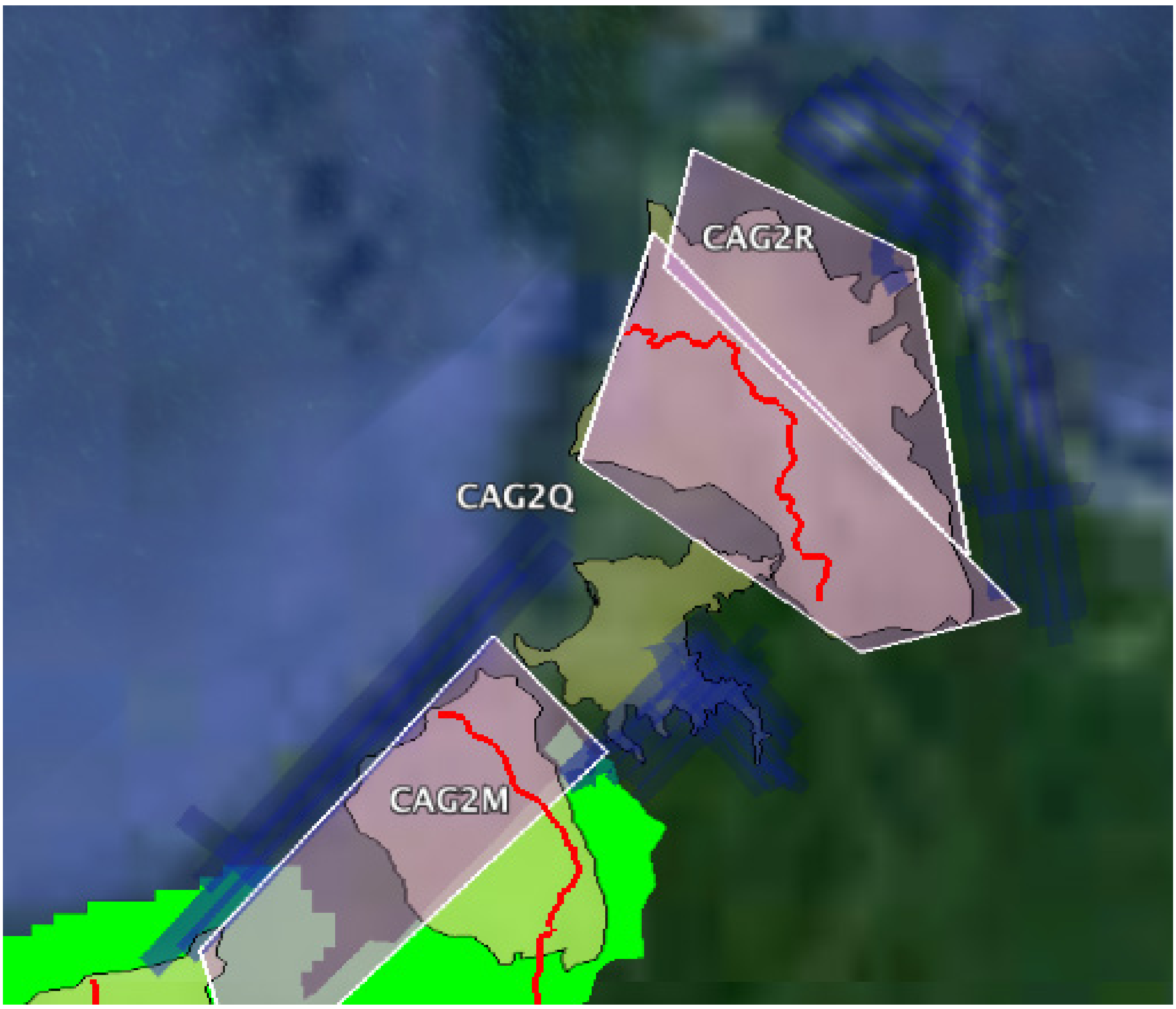



Figure A-7.4 Swath for Flight No. 4001G

## Annex 8. Mission Summary Report

Table A-8.1 Mission Summary Report for Mission Blk3A

| **Flight Area** | **Cagayan Reflights(Tuguegarao)** |
| --- | --- |
| Mission Name | **Blk3A** |
| Inclusive Flights | 2916P |
| Range data size | 11.8GB |
| POS | 150MB |
| Image | 17.9MB |
| Transfer date | December 8, 2015 |
| | |
| *Solution Status* | |
| Number of Satellites (>6) | Yes |
| PDOP (<3) | Yes |
| Baseline Length (<30km) | Yes |
| Processing Mode (<=1) | No |
| | |
| *Smoothed Performance Metrics* (in cm) | |
| RMSE for North Position (<4.0 cm) | 1.87 |
| RMSE for East Position (<4.0 cm) | 1.65 |
| RMSE for Down Position (<8.0 cm) | 2.61 |
| | |
| Boresight correction stdev (<0.001deg) | 0.000319 |
| IMU attitude correction stdev (<0.001deg) | 0.001384 |
| GPS position stdev (<0.01m) | 0.0023 |
| | |
| Minimum % overlap (>25) | 30.46 |
| Ave point cloud density per sq.m. (>2.0) | |
| Elevation difference between strips (<0.20 m) | Yes |
| | |
| Number of 1km x 1km blocks | 138 |
| Maximum Height | 677.25 m |
| Minimum Height | 57.52 m |
| | |
| *Classification (# of points)* | |
| Ground | 109,071,592 |
| Low vegetation | 74,643,090 |
| Medium vegetation | 133,250,063 |
| High vegetation | 287,388,029 |
| Building | 8,589,940 |
| | |
| Orthophoto | Yes |
| Processed by | Engr. Angelo Carlo Bongat, Engr. Ma. Joanne Balaga, Jovy Narisma |

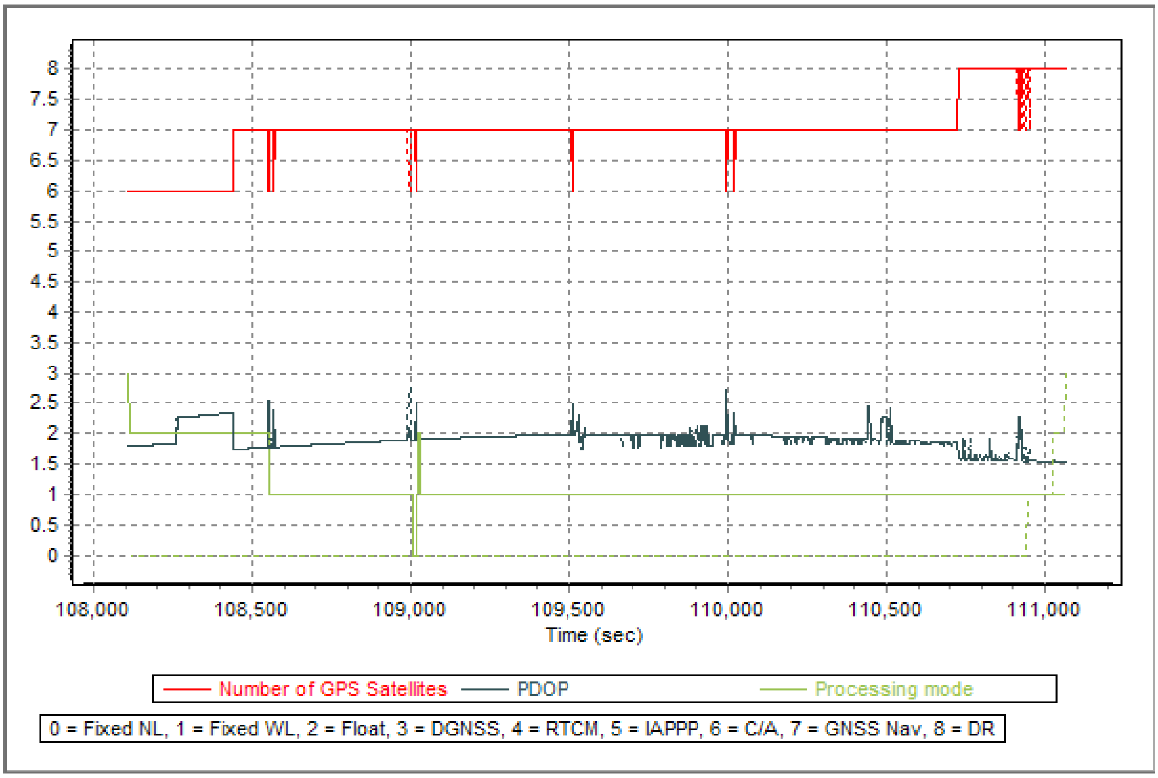



Figure A-8.1. Solution Status

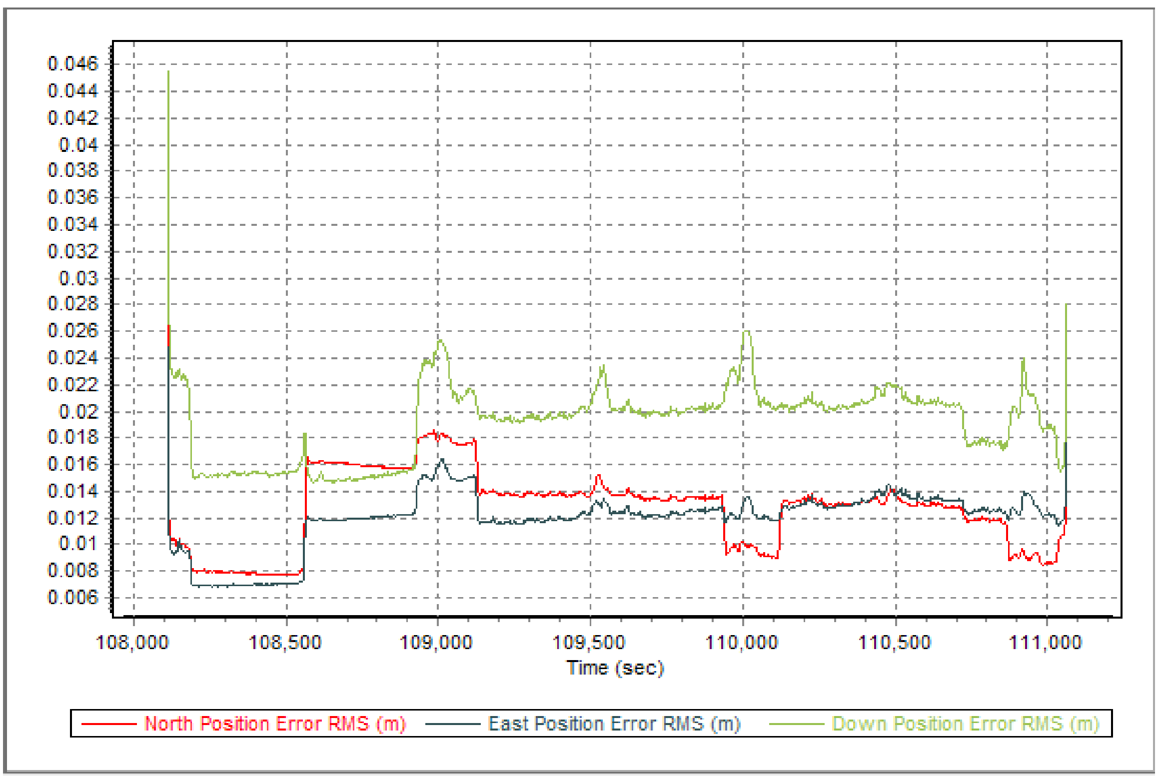



Figure A-8.2. Smoothed Performance Metric Parameters

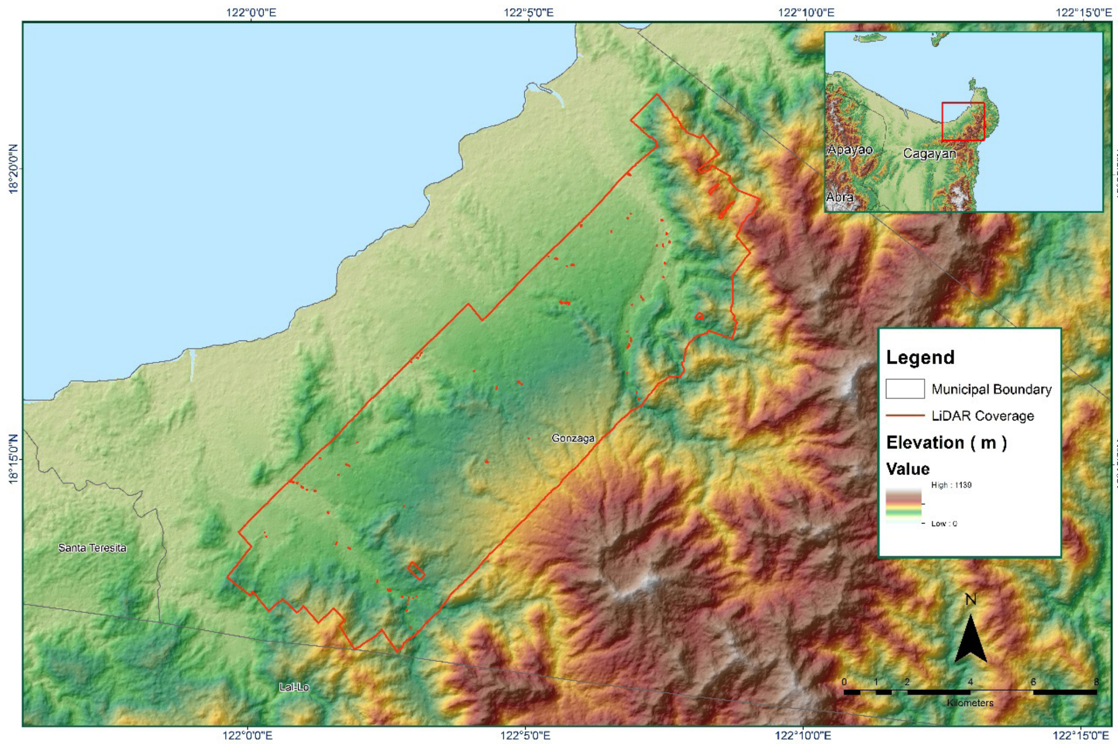



Figure A-8.3 Best Estimated Trajectory

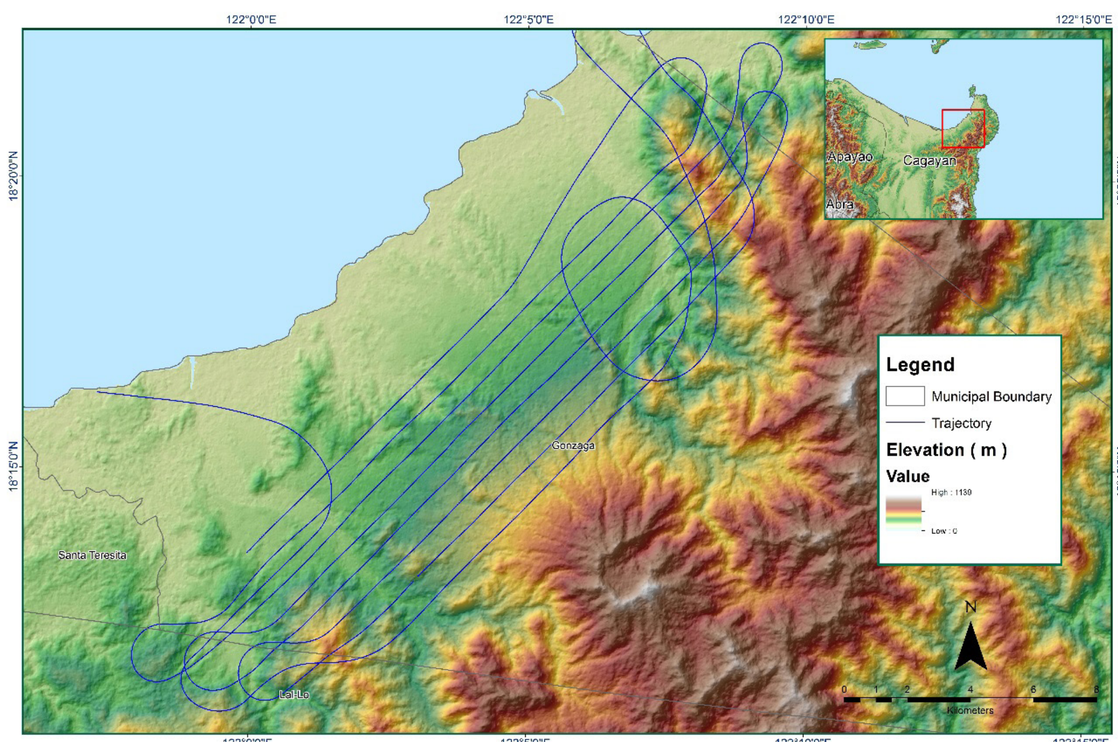



Figure A-8.4. Coverage of LiDAR data

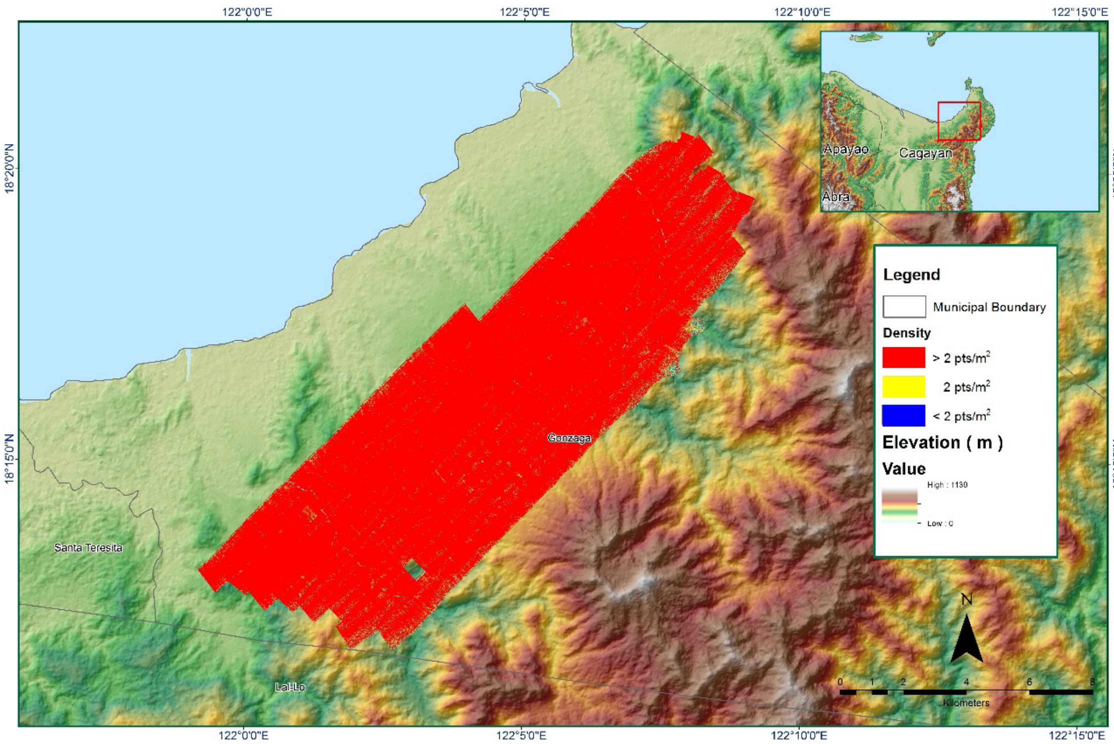



Figure A-8.5 Image of data overlap

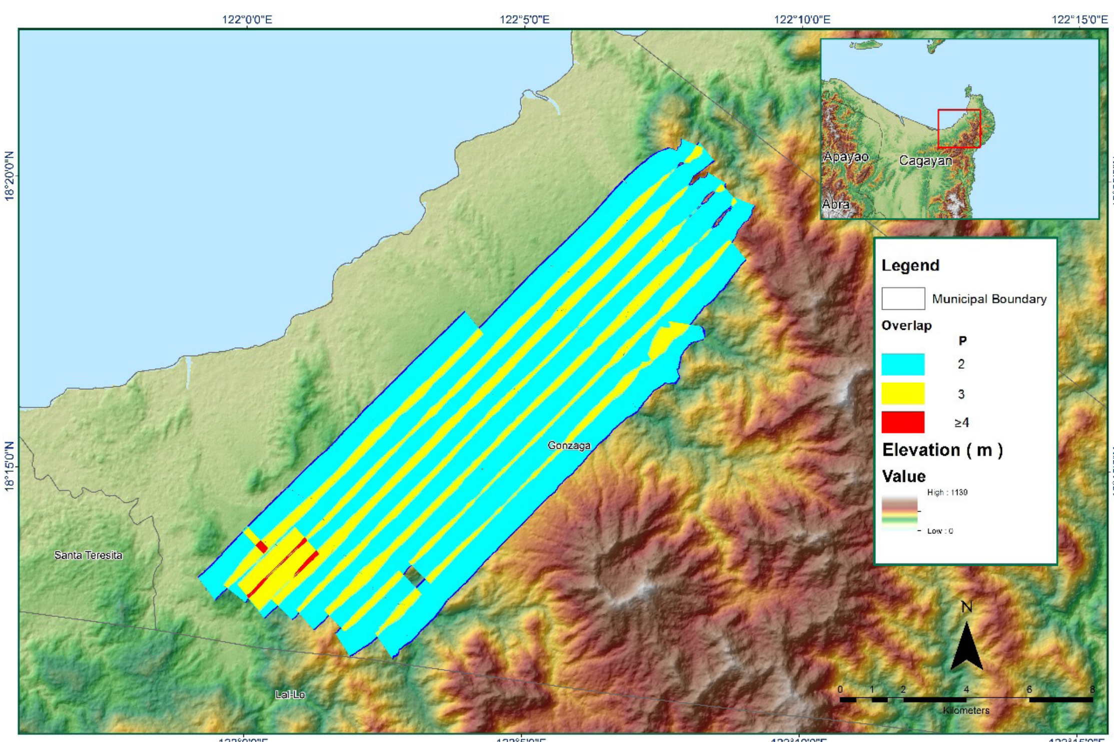



Figure A.8.6 Image of data overlap

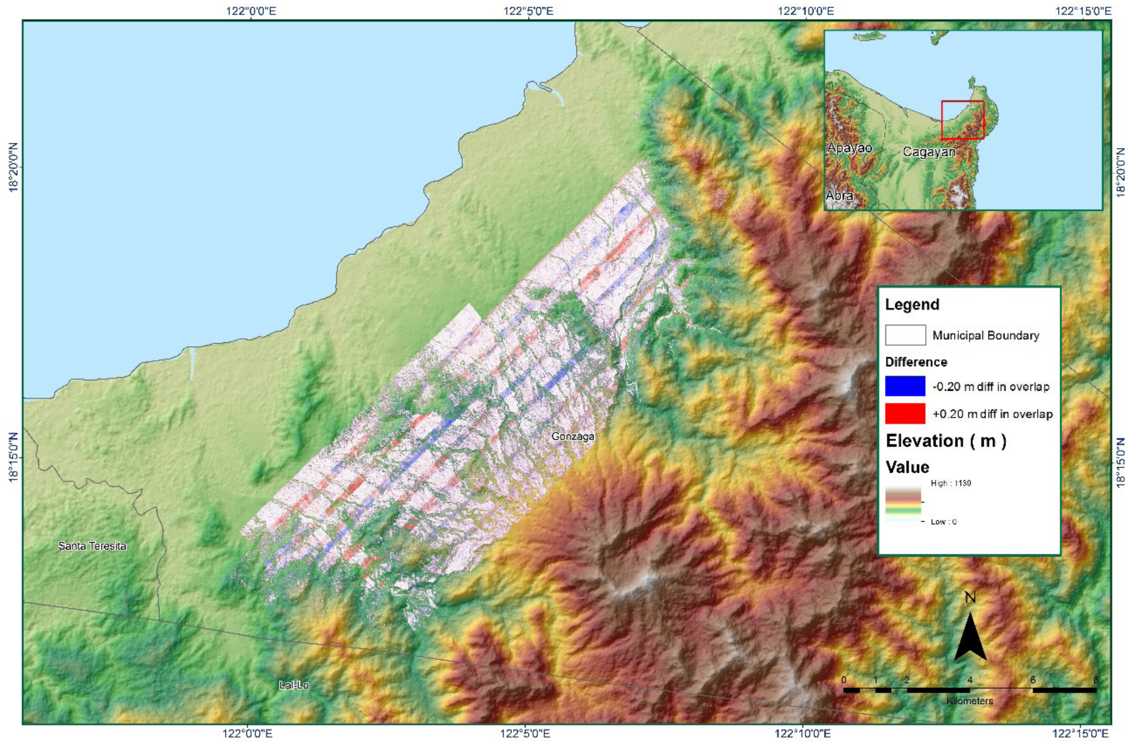



Figure A-8.7 Elevation Difference Between flight lines

Table A-8.2 Mission Summary Report for Mission Cagayan_reflights_Blk3A

| Flight Area | Cagayan |
|---|---|
| Mission Name | Cagayan_reflights_Blk3A |
| Inclusive Flights | 3971G, 3991G, 4001G |
| Range data size | 45.75 GB |
| POS data size | 640 MB |
| Base data size | 33.73 MB |
| Image | NA |
| Transfer date | June 21, 2016 |
| | |
| *Solution Status* | |
| Number of Satellites (>6) | No |
| PDOP (<3) | Yes |
| Baseline Length (<30km) | Yes |
| Processing Mode (<=1) | No |
| | |
| *Smoothed Performance Metrics* (in cm) | |
| RMSE for North Position (<4.0 cm) | 2.5 |
| RMSE for East Position (<4.0 cm) | 1.7 |
| RMSE for Down Position (<8.0 cm) | 2.4 |
| | |
| Boresight correction stdev (<0.001deg) | 0.000876 |
| IMU attitude correction stdev (<0.001deg) | 0.015089 |
| GPS position stdev (<0.01m) | 0.0024 |
| | |
| Minimum % overlap (>25) | 42.36% |
| Ave point cloud density per sq.m. (>2.0) | 3.56 |
| Elevation difference between strips (<0.20 m) | Yes |
| | |
| Number of 1km x 1km blocks | 156 |
| Maximum Height | 526.96 m |
| Minimum Height | 39.41 m |
| | |
| *Classification (# of points)* | |
| Ground | 70,619,413 |
| Low vegetation | 72,372,299 |
| Medium vegetation | 199,312,514 |
| High vegetation | 122,546,677 |
| Building | 5,607,920 |
| | |
| Orthophoto | No |
| Processed by | Engr. Don Matthew Banatin, Engr. Christy Lubiano, Engr. Karl Adrian Vergara |

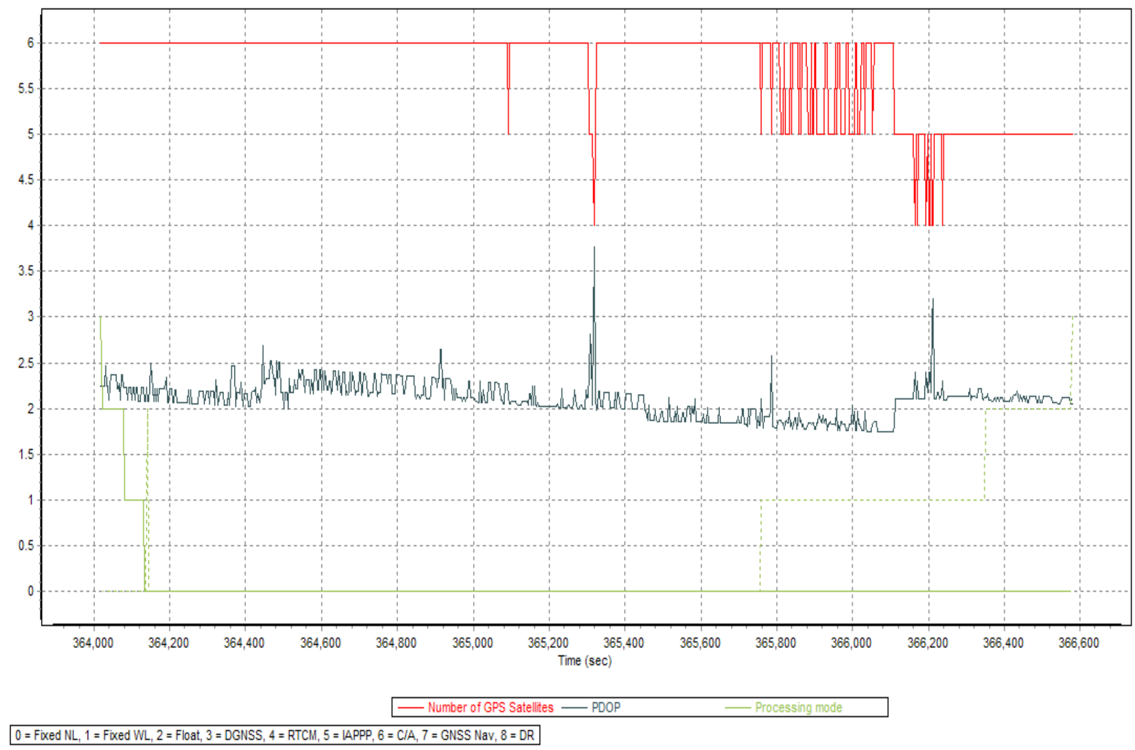



Figure A-8.8. Solution Status

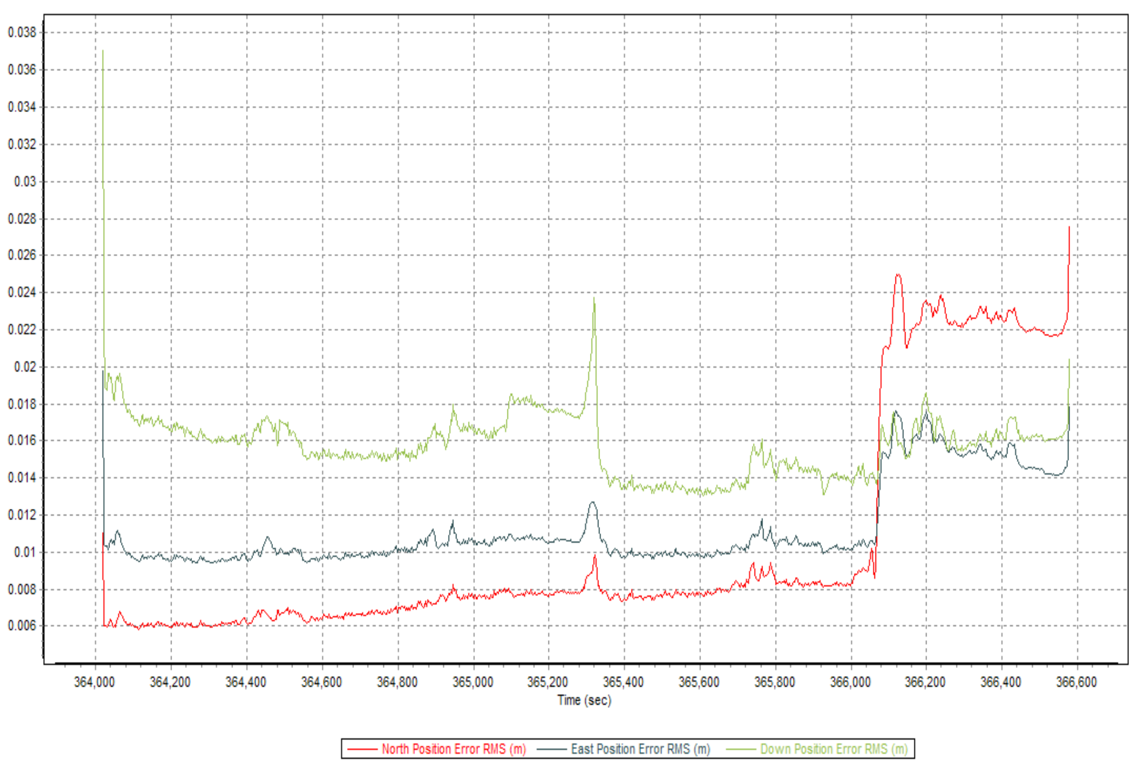



Figure A-8.9. Smoothed Performance Metric Parameters

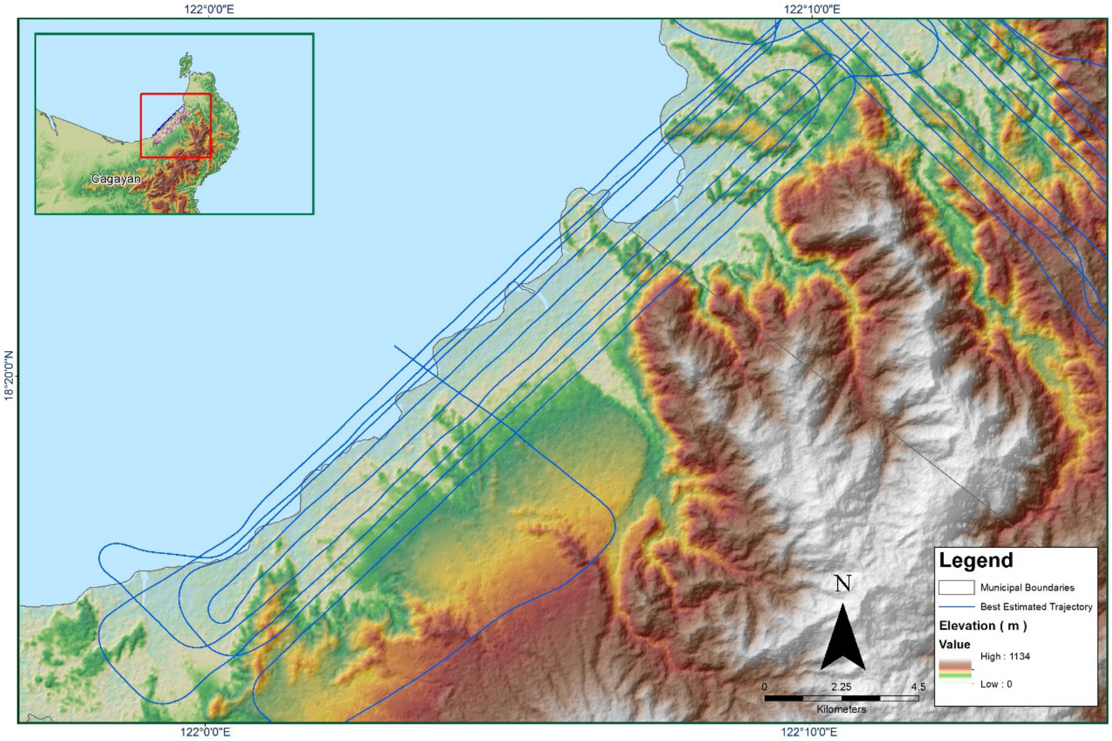



Figure A-8.10. Best Estimated Trajectory

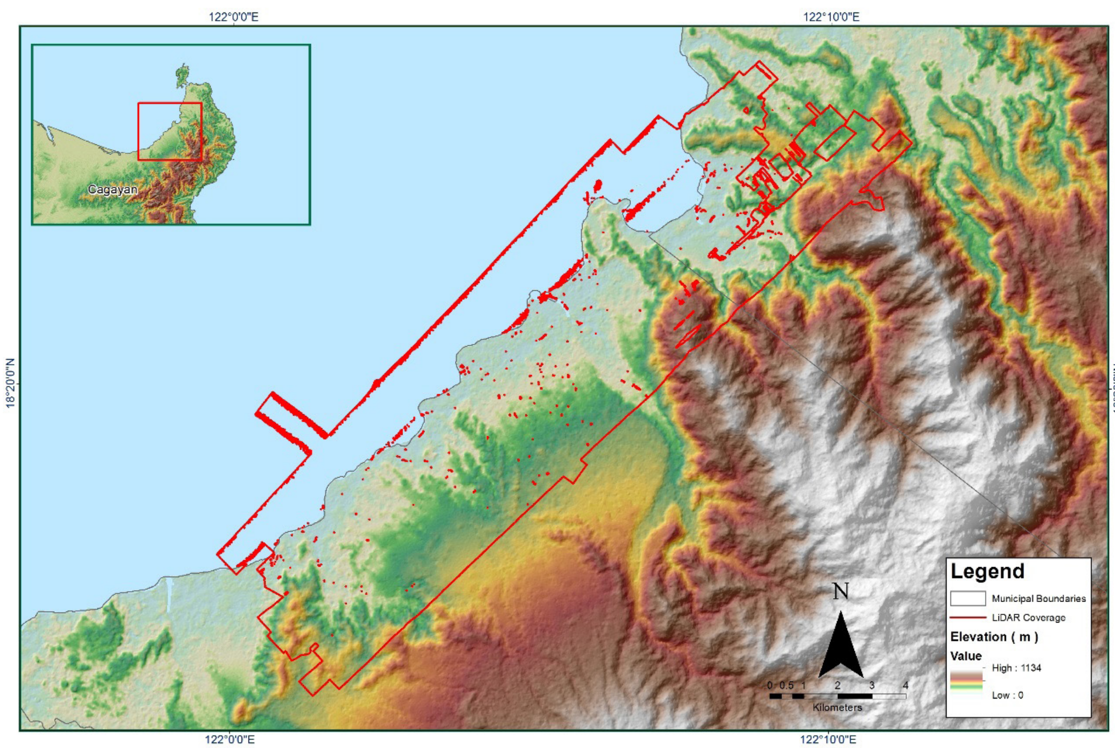



Figure A-8.11. Coverage of LiDAR Data

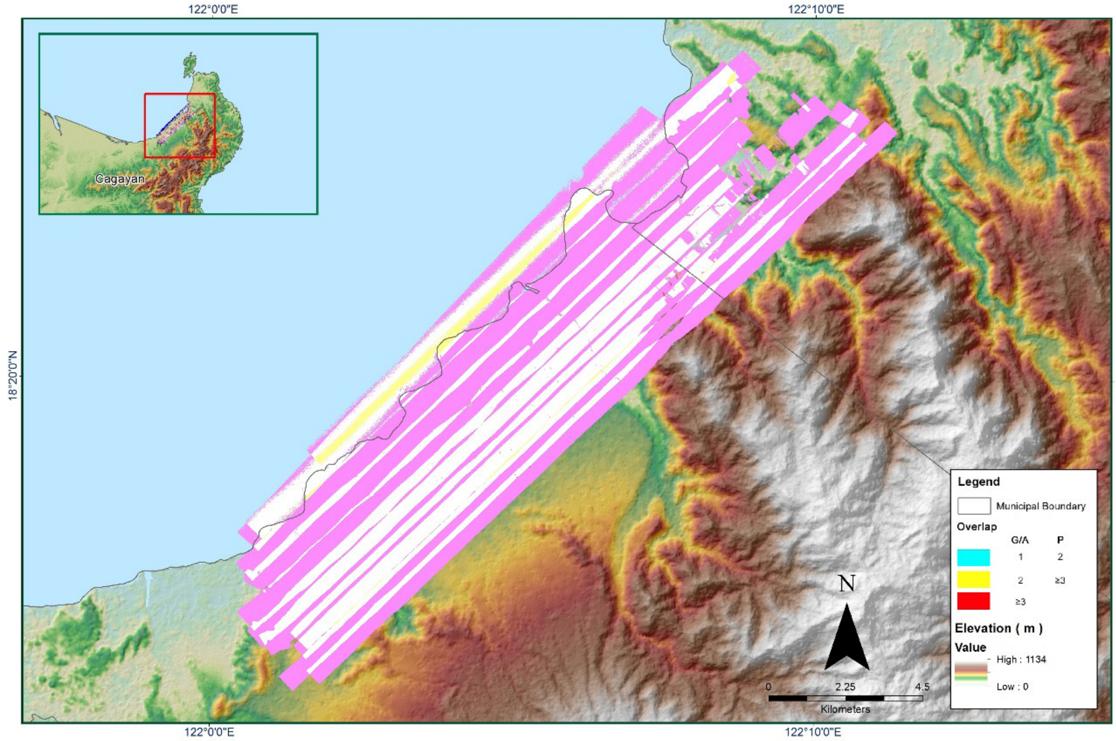



Figure A-8.12. Image of data overlap

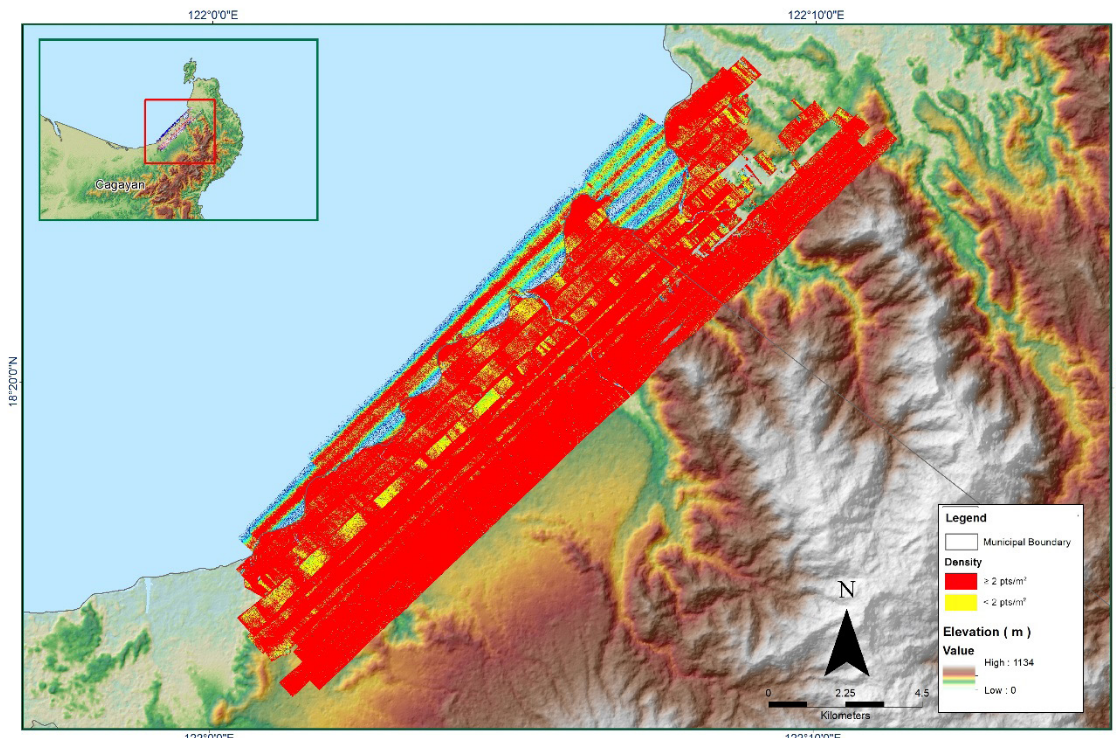



Figure A-8.13. Density map of merged LiDAR data

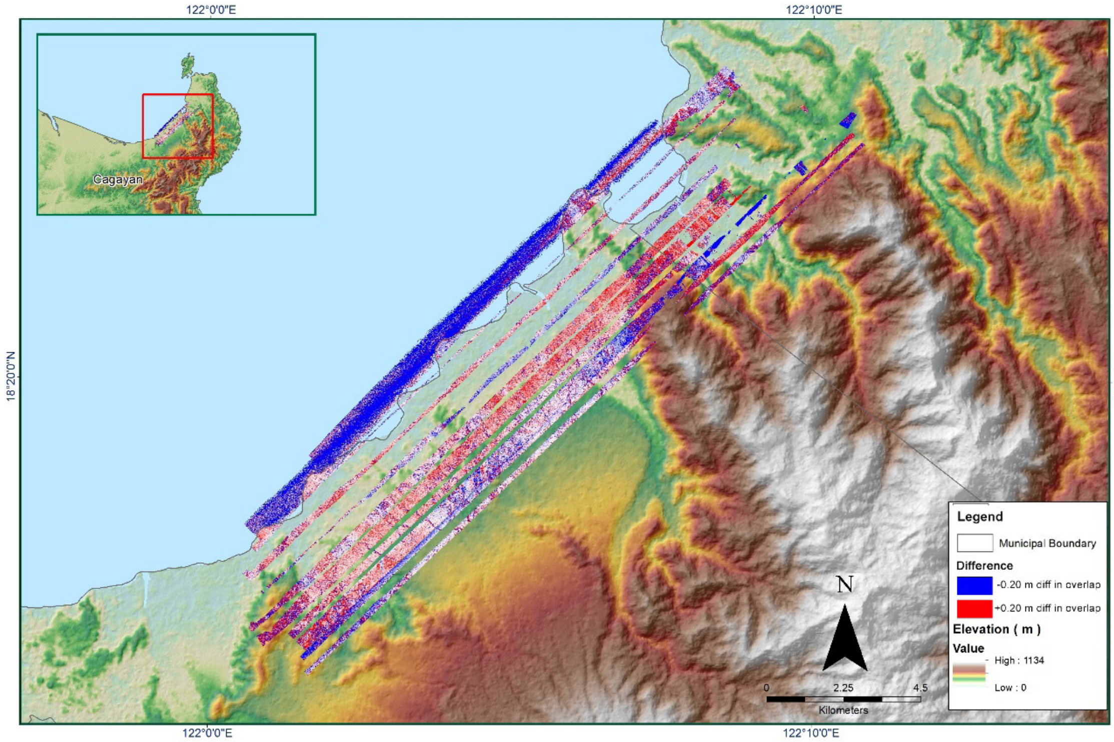



Figure A-8.14. Elevation difference between flight lines

# Annex 9. Baua Model Basin Parameters

Table A-9.1 Baua Model Basin Parameters

| Basin Number | SCS Curve Number Loss | | | Clark Unit Hydrograph Transform | | Recession Baseflow | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Initial Abstraction (mm) | Curve Number | Impervious (%) | Time of Concentration (HR) | Storage Coefficient (HR) | Initial Type | Initial Discharge (M3/S) | Recession Constant | Threshold Type | Ratio to Peak |
| W1000 | 12.469 | 77 | 0.0 | 2.6397 | 3.5900 | Discharge | 6.8750 | 1 | Ratio to Peak | 0.2 |
| W1010 | 12.469 | 77 | 0.0 | 1.4658 | 1.9935 | Discharge | 2.2387 | 1 | Ratio to Peak | 0.2 |
| W1020 | 12.469 | 77 | 0.0 | 2.2406 | 3.0472 | Discharge | 4.4983 | 1 | Ratio to Peak | 0.2 |
| W1030 | 12.469 | 77 | 0.0 | 1.3527 | 1.8396 | Discharge | 1.9409 | 1 | Ratio to Peak | 0.2 |
| W1040 | 12.469 | 77 | 0.0 | 1.1568 | 1.5733 | Discharge | 1.9254 | 1 | Ratio to Peak | 0.2 |
| W1050 | 12.469 | 77 | 0.0 | 1.5567 | 2.1171 | Discharge | 2.8718 | 1 | Ratio to Peak | 0.2 |
| W1060 | 12.469 | 77 | 0.0 | 2.5543 | 3.4738 | Discharge | 8.9623 | 1 | Ratio to Peak | 0.2 |
| W1070 | 12.469 | 77 | 0.0 | 0.66415 | 0.90324 | Discharge | 0.41189 | 1 | Ratio to Peak | 0.2 |
| W1080 | 12.469 | 77 | 0.0 | 1.2291 | 1.6716 | Discharge | 1.5667 | 1 | Ratio to Peak | 0.2 |
| W1090 | 12.469 | 77 | 0.0 | 0.87673 | 1.1923 | Discharge | 0.96269 | 1 | Ratio to Peak | 0.2 |
| W1100 | 12.469 | 77 | 0.0 | 1.4535 | 1.9767 | Discharge | 3.5938 | 1 | Ratio to Peak | 0.2 |
| W560 | 1.9759 | 99 | 0.0 | 2.0744 | 2.8212 | Discharge | 3.4096 | 1 | Ratio to Peak | 0.2 |
| W570 | 5.0930 | 99 | 0.0 | 2.4590 | 3.3443 | Discharge | 1.8168 | 1 | Ratio to Peak | 0.2 |
| W580 | 7.0690 | 95.638 | 0.0 | 1.4911 | 2.0279 | Discharge | 4.4083 | 1 | Ratio to Peak | 0.2 |
| W590 | 12.323 | 77.408 | 0.0 | 1.3622 | 1.8526 | Discharge | 2.3771 | 1 | Ratio to Peak | 0.2 |
| W600 | 7.2152 | 95.016 | 0.0 | 0.44883 | 0.61042 | Discharge | 0.36130 | 1 | Ratio to Peak | 0.2 |
| W610 | 7.1145 | 95.444 | 0.0 | 2.7401 | 3.7266 | Discharge | 1.7824 | 1 | Ratio to Peak | 0.2 |
| W620 | 8.0448 | 91.631 | 0.0 | 2.7096 | 3.6850 | Discharge | 3.9123 | 1 | Ratio to Peak | 0.2 |
| W630 | 12.469 | 77 | 0.0 | 1.0914 | 1.4843 | Discharge | 1.8112 | 1 | Ratio to Peak | 0.2 |
| W640 | 8.6244 | 89.405 | 0.0 | 3.5387 | 4.8126 | Discharge | 5.7059 | 1 | Ratio to Peak | 0.2 |
| W650 | 8.0378 | 91.658 | 0.0 | 0.54704 | 0.74397 | Discharge | 0.0633384 | 1 | Ratio to Peak | 0.2 |
| W660 | 12.469 | 77 | 0.0 | 1.0086 | 1.3717 | Discharge | 1.7506 | 1 | Ratio to Peak | 0.2 |

| Basin Number | SCS Curve Number Loss | | | Clark Unit Hydrograph Transform | | Recession Baseflow | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Initial Abstraction (mm) | Curve Number | Impervious (%) | Time of Concentration (HR) | Storage Coefficient (HR) | Initial Type | Initial Discharge (M3/S) | Recession Constant | Threshold Type | Ratio to Peak |
| W670 | 11.216 | 80.648 | 0.0 | 1.2631381 | 1.7179 | Discharge | 1.5705 | 1 | Ratio to Peak | 0.2 |
| W680 | 9.5269 | 86.1472883 | 0.0 | 0.85803 | 1.1669 | Discharge | 0.41007 | 1 | Ratio to Peak | 0.2 |
| W690 | 12.161 | 77.866 | 0.0 | 2.3031 | 3.1322 | Discharge | 5.2077 | 1 | Ratio to Peak | 0.2 |
| W700 | 10.210 | 83.8354049 | 0.0 | 0.86477 | 1.1761 | Discharge | 0.48343 | 1 | Ratio to Peak | 0.2 |
| W710 | 12.469 | 77 | 0.0 | 1.7106 | 2.3264 | Discharge | 2.6308 | 1 | Ratio to Peak | 0.2 |
| W720 | 12.003 | 78.318 | 0.0 | 2.0924 | 2.8456 | Discharge | 4.0213 | 1 | Ratio to Peak | 0.2 |
| W730 | 12.469 | 77 | 0.0 | 0.99365 | 1.3514 | Discharge | 0.85539 | 1 | Ratio to Peak | 0.2 |
| W740 | 12.469 | 77 | 0.0 | 1.8508 | 2.5171 | Discharge | 4.6748 | 1 | Ratio to Peak | 0.2 |
| W750 | 12.334 | 77.377 | 0.0 | 4.3414 | 5.9042 | Discharge | 9.9565 | 1 | Ratio to Peak | 0.2 |
| W760 | 12.469 | 77 | 0.0 | 1.4503 | 1.9724 | Discharge | 3.3941 | 1 | Ratio to Peak | 0.2 |
| W770 | 12.031 | 78.238 | 0.0 | 2.3506 | 3.1968 | Discharge | 2.8123 | 1 | Ratio to Peak | 0.2 |
| W780 | 12.454 | 77.042 | 0.0 | 1.8382 | 2.5000 | Discharge | 2.5761 | 1 | Ratio to Peak | 0.2 |
| W790 | 12.469 | 77 | 0.0 | 1.3949 | 1.8971 | Discharge | 1.5415 | 1 | Ratio to Peak | 0.2 |
| W800 | 12.469 | 77 | 0.0 | 1.0164 | 1.3823 | Discharge | 0.38614 | 1 | Ratio to Peak | 0.2 |

| Basin Number | SCS Curve Number Loss | | | Clark Unit Hydrograph Transform | | Recession Baseflow | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Initial Abstraction (mm) | Curve Number | Impervious (%) | Time of Concentration (HR) | Storage Coefficient (HR) | Initial Type | Initial Discharge (M3/S) | Recession Constant | Threshold Type | Ratio to Peak |
| W850 | 12.469 | 77 | 0.0 | 1.3968 | 1.8997 | Discharge | 1.8118 | 1 | Ratio to Peak | 0.2 |
| W860 | 12.469 | 77 | 0.0 | 0.29304 | 0.39853 | Discharge | 0.0045520 | 1 | Ratio to Peak | 0.2 |
| W870 | 12.469 | 77 | 0.0 | 1.2275 | 1.6694 | Discharge | 1.7762069 | 1 | Ratio to Peak | 0.2 |
| W880 | 12.469 | 77 | 0.0 | 0.66114 | 0.89915 | Discharge | 0.45442 | 1 | Ratio to Peak | 0.2 |
| W890 | 12.469 | 77 | 0.0 | 1.4683 | 1.9969 | Discharge | 1.2184 | 1 | Ratio to Peak | 0.2 |
| W900 | 12.469 | 77 | 0.0 | 1.7053 | 2.3192 | Discharge | 2.2152 | 1 | Ratio to Peak | 0.2 |
| W910 | 12.469 | 77 | 0.0 | 1.2336 | 1.6777 | Discharge | 1.4351 | 1 | Ratio to Peak | 0.2 |
| W920 | 12.469 | 77 | 0.0 | 2.0926 | 2.8459 | Discharge | 3.1297 | 1 | Ratio to Peak | 0.2 |
| W930 | 12.469 | 77 | 0.0 | 0.47228 | 0.64231 | Discharge | 0.17558 | 1 | Ratio to Peak | 0.2 |
| W940 | 12.469 | 77 | 0.0 | 1.2715 | 1.7292 | Discharge | 2.2172 | 1 | Ratio to Peak | 0.2 |
| W950 | 12.469 | 77 | 0.0 | 0.60102 | 0.81739 | Discharge | 0.28171 | 1 | Ratio to Peak | 0.2 |
| W960 | 12.469 | 77 | 0.0 | 1.4063 | 1.9126 | Discharge | 1.9056 | 1 | Ratio to Peak | 0.2 |
| W970 | 12.469 | 77 | 0.0 | 1.5676 | 2.1320 | Discharge | 2.8816 | 1 | Ratio to Peak | 0.2 |
| W980 | 12.469 | 77 | 0.0 | 2.7166 | 3.6946 | Discharge | 5.7635 | 1 | Ratio to Peak | 0.2 |
| W990 | 12.469 | 77 | 0.0 | 0.98610 | 1.3411 | Discharge | 0.97102 | 1 | Ratio to Peak | 0.2 |

# Annex 10. Baua Model Reach Parameters

Table A-10.1 Baua Model Reach Parameters

| Reach Number | MuskingumCunge Channel Routing | | | | | | |
|---|---|---|---|---|---|---|---|
| | Time Step Method | Length (m) | Slope | Manning's n | Shape | Width | Side Slope |
| R10 | Automatic Fixed Interval | 2570.0 | 0.0067295 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R100 | Automatic Fixed Interval | 246.57 | 0.0141973 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R110 | Automatic Fixed Interval | 1993.4 | 0.0594735 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R120 | Automatic Fixed Interval | 801.84 | 0.0167591 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R140 | Automatic Fixed Interval | 666.98 | 0.0164793 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R150 | Automatic Fixed Interval | 2686.2 | 0.0386112 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R170 | Automatic Fixed Interval | 1159.8 | 0.0758038 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R200 | Automatic Fixed Interval | 4956.1 | 0.0203050 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R220 | Automatic Fixed Interval | 1492.0 | 0.0168190 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R240 | Automatic Fixed Interval | 784.26 | 0.0107762 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R250 | Automatic Fixed Interval | 90.711 | 0.0140724 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R260 | Automatic Fixed Interval | 28.284 | 0.001 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R30 | Automatic Fixed Interval | 1895.5 | 0.0056477 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R310 | Automatic Fixed Interval | 1474.3 | 0.0442737 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R320 | Automatic Fixed Interval | 572.84 | 0.0604411 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R340 | Automatic Fixed Interval | 410.42 | 0.0718342 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R360 | Automatic Fixed Interval | 1067.1 | 0.0427851 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R370 | Automatic Fixed Interval | 1341.8 | 0.0444133 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R380 | Automatic Fixed Interval | 337.28 | 0.12654 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R410 | Automatic Fixed Interval | 2115.1 | 0.0396921 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R440 | Automatic Fixed Interval | 1029.5 | 0.0495979 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R470 | Automatic Fixed Interval | 2330.7 | 0.0451154 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R50 | Automatic Fixed Interval | 408.70 | 0.0170005 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R500 | Automatic Fixed Interval | 296.98 | 0.001 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R510 | Automatic Fixed Interval | 746.69 | 0.0625617 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R520 | Automatic Fixed Interval | 565.56 | 0.0443851 | 0.035 | Trapezoid | 78.73881 | 0.0564 |
| R70 | Automatic Fixed Interval | 2093.1 | 0.0081210 | 0.035 | Trapezoid | 78.73881 | 0.0564 |

# Annex 11. Baua Flood Validation Data

Table A-11.1 Baua Flood Validation Data

| Point Number | Validation Coordinates | | Model Var (m) | Validation Points (m) | Error | Event/Date | Rain Return/ Scenario |
|---|---|---|---|---|---|---|---|
| | Lat | Long | | | | | |
| 1 | 18.29129 | 122.10874 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 2 | 18.29138 | 122.10906 | 0.060 | 0.0 | -0.06 | | 5 Yr |
| 3 | 18.29143 | 122.10905 | 0.060 | 0.0 | -0.06 | | 5 Yr |
| 4 | 18.29168 | 122.10909 | 0.060 | 0.0 | -0.06 | | 5 Yr |
| 5 | 18.29372 | 122.10913 | 0.280 | 0.0 | -0.28 | | 5 Yr |
| 6 | 18.29654 | 122.10909 | 0.140 | 0.0 | -0.14 | | 5 Yr |
| 7 | 18.29835 | 122.10915 | 0.040 | 0.0 | -0.04 | | 5 Yr |
| 8 | 18.30077 | 122.10917 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 9 | 18.30083 | 122.11792 | 4.590 | 0.0 | -4.59 | | 5 Yr |
| 10 | 18.30108 | 122.11776 | 2.550 | 0.0 | -2.55 | | 5 Yr |
| 11 | 18.30141 | 122.11755 | 1.350 | 0.0 | -1.35 | | 5 Yr |
| 12 | 18.30203 | 122.09659 | 1.010 | 0.0 | -1.01 | | 5 Yr |
| 13 | 18.30239 | 122.09439 | 0.050 | 0.0 | -0.05 | | 5 Yr |
| 14 | 18.30243 | 122.09586 | 0.220 | 0.0 | -0.22 | | 5 Yr |
| 15 | 18.30248 | 122.09410 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 16 | 18.30262 | 122.10917 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 17 | 18.30293 | 122.10919 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 18 | 18.30348 | 122.09833 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 19 | 18.30427 | 122.11818 | 0.080 | 0.0 | -0.08 | | 5 Yr |
| 20 | 18.30425 | 122.09382 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 21 | 18.30438 | 122.10921 | 0.150 | 0.0 | -0.15 | | 5 Yr |
| 22 | 18.30455 | 122.09952 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 23 | 18.30504 | 122.09349 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 24 | 18.30544 | 122.10079 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 25 | 18.30553 | 122.10918 | 0.220 | 0.0 | -0.22 | | 5 Yr |
| 26 | 18.30623 | 122.10334 | 0.290 | 0.0 | -0.29 | | 5 Yr |
| 27 | 18.30653 | 122.10915 | 0.110 | 0.0 | -0.11 | | 5 Yr |
| 28 | 18.30662 | 122.10603 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 29 | 18.30670 | 122.09275 | 0.170 | 0.0 | -0.17 | | 5 Yr |
| 30 | 18.30694 | 122.11716 | 0.300 | 0.0 | -0.30 | | 5 Yr |
| 31 | 18.30698 | 122.11645 | 0.400 | 0.0 | -0.40 | | 5 Yr |
| 32 | 18.30698 | 122.11341 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 33 | 18.30700 | 122.11511 | 0.060 | 0.0 | -0.06 | | 5 Yr |
| 34 | 18.30698 | 122.11082 | 0.090 | 0.0 | -0.09 | | 5 Yr |
| 35 | 18.30699 | 122.10865 | 0.050 | 0.0 | -0.05 | | 5 Yr |
| 36 | 18.30700 | 122.10984 | 0.070 | 0.0 | -0.07 | | 5 Yr |
| 37 | 18.30700 | 122.10733 | 0.150 | 0.0 | -0.15 | | 5 Yr |
| 38 | 18.30710 | 122.09074 | 0.030 | 0.4 | 0.37 | TS Lawin/ October 2016 | 5 Yr |

| Point Number | Validation Coordinates | | Model Var (m) | Validation Points (m) | Error | Event/Date | Rain Return/ Scenario |
|---|---|---|---|---|---|---|---|
| | Lat | Long | | | | | |
| 39 | 18.30718 | 122.09038 | 0.030 | 0.4 | 0.37 | TS Lawin/ October 2016 | 5 Yr |
| 40 | 18.30764 | 122.10903 | 0.090 | 0.0 | -0.09 | | 5 Yr |
| 41 | 18.30773 | 122.08766 | 0.050 | 0.0 | -0.05 | | 5 Yr |
| 42 | 18.30792 | 122.08667 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 43 | 18.30883 | 122.08520 | 0.100 | 0.0 | -0.10 | | 5 Yr |
| 44 | 18.31003 | 122.08480 | 0.110 | 0.0 | -0.11 | | 5 Yr |
| 45 | 18.31127 | 122.08441 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 46 | 18.31150 | 122.10889 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 47 | 18.31232 | 122.10900 | 0.040 | 0.0 | -0.04 | | 5 Yr |
| 48 | 18.31280 | 122.08410 | 0.260 | 0.4 | 0.14 | TS Lawin/ October 2016 | 5 Yr |
| 49 | 18.31401 | 122.10901 | 0.220 | 0.0 | -0.22 | | 5 Yr |
| 50 | 18.31395 | 122.08412 | 0.090 | 0.0 | -0.09 | | 5 Yr |
| 51 | 18.31565 | 122.08419 | 0.070 | 0.0 | -0.07 | | 5 Yr |
| 52 | 18.31715 | 122.10901 | 0.070 | 0.0 | -0.07 | | 5 Yr |
| 53 | 18.31722 | 122.08447 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 54 | 18.31856 | 122.08473 | 0.200 | 0.4 | 0.20 | TS Lawin/ October 2016 | 5 Yr |
| 55 | 18.31954 | 122.08486 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 56 | 18.32054 | 122.10896 | 0.060 | 0.4 | 0.34 | TS Lawin/ October 2016 | 5 Yr |
| 57 | 18.32247 | 122.10898 | 0.050 | 0.0 | -0.05 | | 5 Yr |
| 58 | 18.32265 | 122.08408 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 59 | 18.32264 | 122.08003 | 0.060 | 0.3 | 0.24 | TS Lawin/ October 2016 | 5 Yr |
| 60 | 18.32280 | 122.07808 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 61 | 18.32326 | 122.07697 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 62 | 18.32399 | 122.10898 | 0.060 | 0.0 | -0.06 | | 5 Yr |
| 63 | 18.32467 | 122.07552 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 64 | 18.32542 | 122.10898 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 65 | 18.32609 | 122.07408 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 66 | 18.32729 | 122.10895 | 0.610 | 0.0 | -0.61 | | 5 Yr |
| 67 | 18.32837 | 122.10841 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 68 | 18.32841 | 122.07185 | 0.280 | 1.0 | 0.72 | every typhoon occurrence | 5 Yr |
| 69 | 18.32927 | 122.10748 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 70 | 18.33073 | 122.10575 | 0.040 | 0.0 | -0.04 | | 5 Yr |
| 71 | 18.33103 | 122.06973 | 0.030 | 1.0 | 0.97 | every typhoon occurrence | 5 Yr |
| 72 | 18.33227 | 122.06614 | 0.560 | 0.0 | -0.56 | | 5 Yr |
| 73 | 18.33276 | 122.06863 | 0.030 | 1.0 | 0.97 | every typhoon occurrence | 5 Yr |
| 74 | 18.33301 | 122.10424 | 0.030 | 0.0 | -0.03 | | 5 Yr |

| Point Number | Validation Coordinates | | Model Var (m) | Validation Points (m) | Error | Event/Date | Rain Return/ Scenario |
|---|---|---|---|---|---|---|---|
| | Lat | Long | | | | | |
| 75 | 18.33340 | 122.06722 | 0.390 | 0.0 | -0.39 | | 5 Yr |
| 76 | 18.33362 | 122.06813 | 2.070 | 0.8 | -1.27 | 2000 Typhoon | 5 Yr |
| 77 | 18.33389 | 122.06394 | 0.050 | 0.0 | -0.05 | | 5 Yr |
| 78 | 18.33393 | 122.06803 | 0.560 | 0.8 | 0.24 | 2000 Typhoon | 5 Yr |
| 79 | 18.33407 | 122.06364 | 0.100 | 0.8 | 0.70 | TS Lawin/ October 2016 | 5 Yr |
| 80 | 18.33590 | 122.10258 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 81 | 18.33736 | 122.10154 | 0.110 | 0.0 | -0.11 | | 5 Yr |
| 82 | 18.33925 | 122.10047 | 0.040 | 0.0 | -0.04 | | 5 Yr |
| 83 | 18.34087 | 122.09932 | 0.090 | 0.0 | -0.09 | | 5 Yr |
| 84 | 18.34088 | 122.09934 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 85 | 18.34226 | 122.09828 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 86 | 18.34374 | 122.09713 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 87 | 18.34473 | 122.07990 | 0.390 | 0.0 | -0.39 | | 5 Yr |
| 88 | 18.34498 | 122.08044 | 0.140 | 0.0 | -0.14 | | 5 Yr |
| 89 | 18.34528 | 122.09614 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 90 | 18.34608 | 122.08284 | 0.380 | 0.0 | -0.38 | | 5 Yr |
| 91 | 18.34705 | 122.09512 | 0.210 | 0.0 | -0.21 | | 5 Yr |
| 92 | 18.34711 | 122.08506 | 0.730 | 0.0 | -0.73 | | 5 Yr |
| 93 | 18.34773 | 122.08639 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 94 | 18.34841 | 122.08778 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 95 | 18.34915 | 122.08701 | 0.030 | 0.3 | 0.27 | TS Lawin/ October 2016 | 5 Yr |
| 96 | 18.34925 | 122.08691 | 0.360 | 0.0 | -0.36 | | 5 Yr |
| 97 | 18.34962 | 122.08590 | 0.100 | 0.0 | -0.10 | | 5 Yr |
| 98 | 18.34971 | 122.09406 | 0.720 | 0.0 | -0.72 | | 5 Yr |
| 99 | 18.34982 | 122.08516 | 0.030 | 0.3 | 0.27 | TS Lawin/ October 2016 | 5 Yr |
| 100 | 18.34985 | 122.08513 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 101 | 18.34993 | 122.08260 | 0.030 | 0.3 | 0.27 | TS Lawin/ October 2016 | 5 Yr |
| 102 | 18.35003 | 122.08159 | 0.050 | 0.3 | 0.25 | TS Lawin/ October 2016 | 5 Yr |
| 103 | 18.35024 | 122.08407 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 104 | 18.35057 | 122.09736 | 7.050 | 1.6 | -5.45 | TS Rubing/ October 5, 1989 | 5 Yr |
| 105 | 18.35057 | 122.09737 | 7.050 | 1.6 | -5.45 | TS Rubing/ October 5, 1989 | 5 Yr |
| 106 | 18.35066 | 122.09367 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 107 | 18.35061 | 122.08289 | 0.030 | 0.3 | 0.27 | TS Lawin/ October 2016 | 5 Yr |
| 108 | 18.35071 | 122.09258 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 109 | 18.35094 | 122.09567 | 2.240 | 1.6 | -0.64 | TS Rubing/ October 5, 1989 | 5 Yr |

| Point Number | Validation Coordinates | | Model Var (m) | Validation Points (m) | Error | Event/Date | Rain Return/ Scenario |
|---|---|---|---|---|---|---|---|
| | Lat | Long | | | | | |
| 110 | 18.35094 | 122.09580 | 2.270 | 1.6 | -0.67 | TS Rubing/ October 5, 1989 | 5 Yr |
| 111 | 18.35091 | 122.08410 | 0.540 | 0.0 | -0.54 | | 5 Yr |
| 112 | 18.35129 | 122.09407 | 3.540 | 0.0 | -3.54 | | 5 Yr |
| 113 | 18.35140 | 122.08268 | 0.040 | 0.3 | 0.26 | TS Lawin/ October 2016 | 5 Yr |
| 114 | 18.35154 | 122.09468 | 4.430 | 1.6 | -2.83 | TS Rubing/ October 5, 1989 | 5 Yr |
| 115 | 18.35159 | 122.09370 | 4.920 | 0.8 | -4.12 | TS Rubing/ October 5, 1989 | 5 Yr |
| 116 | 18.35168 | 122.10937 | 0.060 | 0.0 | -0.06 | | 5 Yr |
| 117 | 18.35164 | 122.09362 | 3.260 | 0.8 | -2.46 | TS Rubing/ October 5, 1989 | 5 Yr |
| 118 | 18.35168 | 122.08411 | 0.040 | 0.3 | 0.26 | TS Lawin/ October 2016 | 5 Yr |
| 119 | 18.35180 | 122.09469 | 2.610 | 0.0 | -2.61 | | 5 Yr |
| 120 | 18.35180 | 122.08311 | 0.590 | 0.0 | -0.59 | | 5 Yr |
| 121 | 18.35183 | 122.08332 | 0.030 | 0.3 | 0.27 | | 5 Yr |
| 122 | 18.35184 | 122.08393 | 0.040 | 0.0 | -0.04 | | 5 Yr |
| 123 | 18.35193 | 122.09555 | 0.030 | 1.6 | 1.57 | TS Rubing/ October 5, 1989 | 5 Yr |
| 124 | 18.35190 | 122.08281 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 125 | 18.35211 | 122.09342 | 3.470 | 1.6 | -1.87 | TS Rubing/ October 5, 1989 | 5 Yr |
| 126 | 18.35208 | 122.08288 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 127 | 18.35225 | 122.09432 | 5.350 | 1.3 | -4.05 | TS Lawin/ October 2016 | 5 Yr |
| 128 | 18.35259 | 122.09312 | 2.370 | 0.8 | -1.57 | TS Rubing/ October 5, 1989 | 5 Yr |
| 129 | 18.35274 | 122.09293 | 0.870 | 0.8 | -0.07 | TS Rubing/ October 5, 1989 | 5 Yr |
| 130 | 18.35296 | 122.09290 | 0.750 | 0.4 | -0.35 | TS Rubing/ October 5, 1989 | 5 Yr |
| 131 | 18.35307 | 122.08323 | 0.290 | 0.0 | -0.29 | | 5 Yr |
| 132 | 18.35308 | 122.08324 | 0.290 | 0.0 | -0.29 | | 5 Yr |
| 133 | 18.35341 | 122.09264 | 1.300 | 0.4 | -0.90 | TS Rubing/ October 5, 1989 | 5 Yr |
| 134 | 18.35357 | 122.10679 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 135 | 18.35391 | 122.08317 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 136 | 18.35441 | 122.08306 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 137 | 18.35469 | 122.09340 | 0.670 | 1.6 | 0.93 | TS Rubing/ October 5, 1989 | 5 Yr |
| 138 | 18.35478 | 122.08311 | 0.340 | 0.0 | -0.34 | TS Rubing/ October 5, 1989 | 5 Yr |
| 139 | 18.35515 | 122.10452 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 140 | 18.35539 | 122.10032 | 0.510 | 0.0 | -0.51 | | 5 Yr |

| Point Number | Validation Coordinates | | Model Var (m) | Validation Points (m) | Error | Event/Date | Rain Return/ Scenario |
|---|---|---|---|---|---|---|---|
| | Lat | Long | | | | | |
| 141 | 18.35558 | 122.10304 | 0.150 | 0.0 | -0.15 | | 5 Yr |
| 142 | 18.35572 | 122.09246 | 1.030 | 1.6 | 0.57 | TS Rubing/ October 5, 1989 | 5 Yr |
| 143 | 18.35608 | 122.11248 | 0.300 | 0.0 | -0.30 | | 5 Yr |
| 144 | 18.35662 | 122.10876 | 0.060 | 0.4 | 0.34 | every typhoon occurrence | 5 Yr |
| 145 | 18.35664 | 122.09160 | 0.390 | 1.6 | 1.21 | TS Rubing/ October 5, 1989 | 5 Yr |
| 146 | 18.35672 | 122.10253 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 147 | 18.35759 | 122.10779 | 0.060 | 0.4 | 0.34 | every typhoon occurrence | 5 Yr |
| 148 | 18.35809 | 122.10239 | 0.030 | 0.0 | -0.03 | | 5 Yr |
| 149 | 18.35816 | 122.10388 | 0.080 | 0.0 | -0.08 | | 5 Yr |
| 150 | 18.35933 | 122.10059 | 0.600 | 0.0 | -0.60 | | 5 Yr |
| 151 | 18.35949 | 122.10694 | 1.580 | 0.0 | -1.58 | | 5 Yr |
| 152 | 18.36160 | 122.10029 | 0.690 | 0.0 | -0.69 | | 5 Yr |
| 153 | 18.36329 | 122.09863 | 1.040 | 0.0 | -1.04 | | 5 Yr |
| 154 | 18.36507 | 122.09788 | 0.290 | 0.0 | -0.29 | | 5 Yr |
| 155 | 18.36560 | 122.09819 | 0.110 | 0.0 | -0.11 | | 5 Yr |
| 156 | 18.36663 | 122.09852 | 0.660 | 0.0 | -0.66 | | 5 Yr |
| 157 | 18.36721 | 122.09827 | 0.030 | 5.0 | 4.97 | 1972 | 5 Yr |
| 158 | 18.36722 | 122.09852 | 0.110 | 5.0 | 4.89 | 1973 | 5 Yr |
| 159 | 18.36764 | 122.09897 | 0.110 | 0.4 | 0.29 | TS Lawin/ October 2016 | 5 Yr |
| 160 | 18.36770 | 122.09906 | 0.220 | 0.4 | 0.18 | TS Lawin/ October 2016 | 5 Yr |

# Annex 12. Educational Institutions Affected in Baua Floodplain

Table A-12.1 Educational Institutions in Gonzaga, Cagayan affected by flooding in Baua Floodplain

| Cagayan | | | | |
|---|---|---|---|---|
| Gonzaga | | | | |
| Building Name | Barangay | Rainfall Scenario | | |
| | | 5-year | 25-year | 100-year |
| Baua Central School | Baua | Medium | Medium | High |
| Baua Day Care Center | Baua | Medium | High | High |
| Baua National High School | Baua | Medium | High | High |
| Cabiraoan Elemenetary School | Cabiraoan | | | |
| Baua National High School Extension | Cabiraoan | | | |
| Cabiraoan Day Care | Cabiraoan | | | |
| Cabiraoan Dela Cruz Elementary School | Cabiraoan | | | |
| Cabiraoan Elementary School | Cabiraoan | | | |
| Prince Aaron Christian School | San Jose | Low | Low | Low |
| San Jose Day Care Center | San Jose | | | |
| San Jose Elementary School | San Jose | | | |
| Sta Cruz Day Care Center | Santa Cruz | Low | Medium | Medium |
| Sta Cruz Elementary School | Santa Cruz | | | Low |
| Sta. Maria Day Care Center | Santa Maria | | | |
| Sta. Maria Elementary School | Santa Maria | | | |

# Annex 13. Health Institutions Affected in Baua Floodplain

No health institutions in Gonzaga, Cagayan are affected by flooding in Baua, Floodplain.