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

# LiDAR Surveys and Flood Mapping of Calbiga River

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

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

# Chapter 1: Overview of the Program and the Calbiga River Basin

## 1.1 Background of the Phil-LiDAR 1 Program

The University of the Philippines Training Center for Applied Geodesy and Photogrammetry (UP-TCAGP) launched a research program in 2014 entitled “Nationwide Hazard Mapping using LiDAR” or Phil-LiDAR 1, supported by the Department of Science and Technology (DOST) Grants-in-Aid (GiA) Program. The program was primarily aimed at acquiring a national elevation and resource dataset at sufficient resolution to produce information necessary to support the different phases of disaster management. Particularly, it targeted to operationalize the development of flood hazard models that would produce updated and detailed flood hazard maps for the major river systems in the country.

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

The implementing partner university for the Phil-LiDAR 1 Program is the Visayas State University (VSU). Acronym 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 28 river basins in the Eastern Visayas Region . The university is located in Baybay City in the province of Leyte.

## 1.2 Overview of the Calbiga River Basin

The Calbiga River Basin covers four (4) municipalities in Samar namely, Hinabangan, Calbiga, Basey, and Pinabacdao; and Borongan City in Easter Samar. According to DENR -River Basin Control Office, it has a drainage area of 283 km2 and an estimated annual run-off of 538 million cubic meter (MCM) (RBCO, 2015).

Its main stem, Calbiga River is part of the 19 river systems under the PHIL-LiDAR 1 partner HEI, Visayas State University. According to the 2010 national census of NSO, a total of 8,364 locals are residing in the immediate vicinity of the river which are distributed among the ten (10) barangays in Municipality of Calbiga. Farming and fishing are the two

major sources of income in the area. Many natural attractions are located here such as Langun-Gonbingob Caves, Lulugayan Falls and Rapids, etc. The most recent and significant flooding in the area was on November 2013 cause by typhoon Haiyan “Yolanda”.

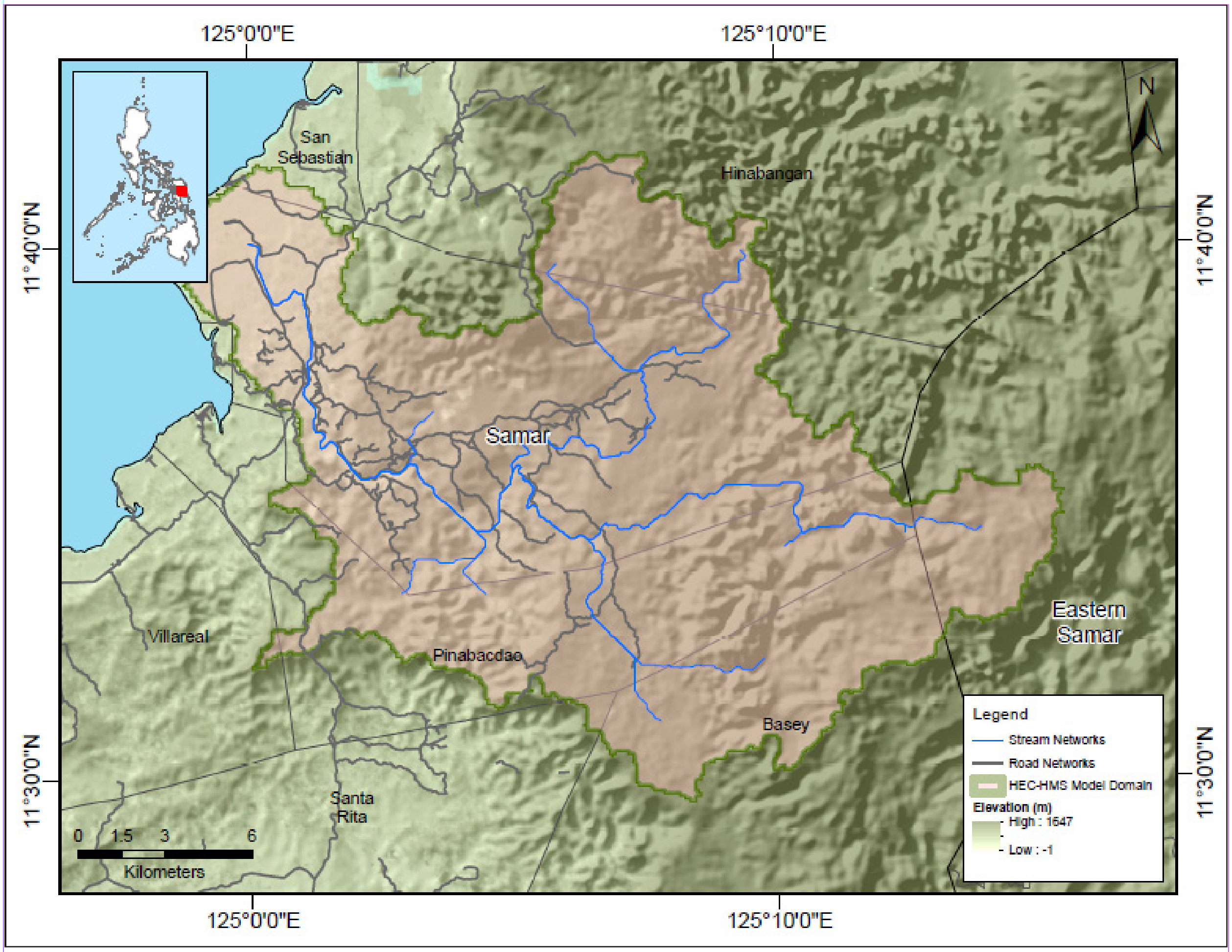


Figure 1. Location Map of the Calbiga River Basin (in brown)

# CHAPTER 2: LIDAR ACQUISITION IN CALBIGA FLOODPLAIN

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

## 2.1 Flight plans

Plans were made to acquire LiDAR data within the delineated priority area for Calbiga floodplain in Samar province. These missions were planned for 20 lines that run for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameters for the Pegasus LiDAR system used are found in Table 1. Figure 2 shows the flight plan for Calbiga floodplain. Annex 1 shows the technical specification of the Pegasus LiDAR system and aerial camera.

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) |
|---|---|---|---|---|---|---|---|
| BLK34H | 650 | 30 | 40 | 100 | 50 | 120 | 5 |
| BLK34I | 600 | 30 | 50 | 100 | 40 | 120 | 5 |
| BLK34J | 600 | 30 | 50 | 100 | 40 | 120 | 5 |
| BLK34J (2) | 650 | 30 | 40 | 100 | 50 | 120 | 5 |

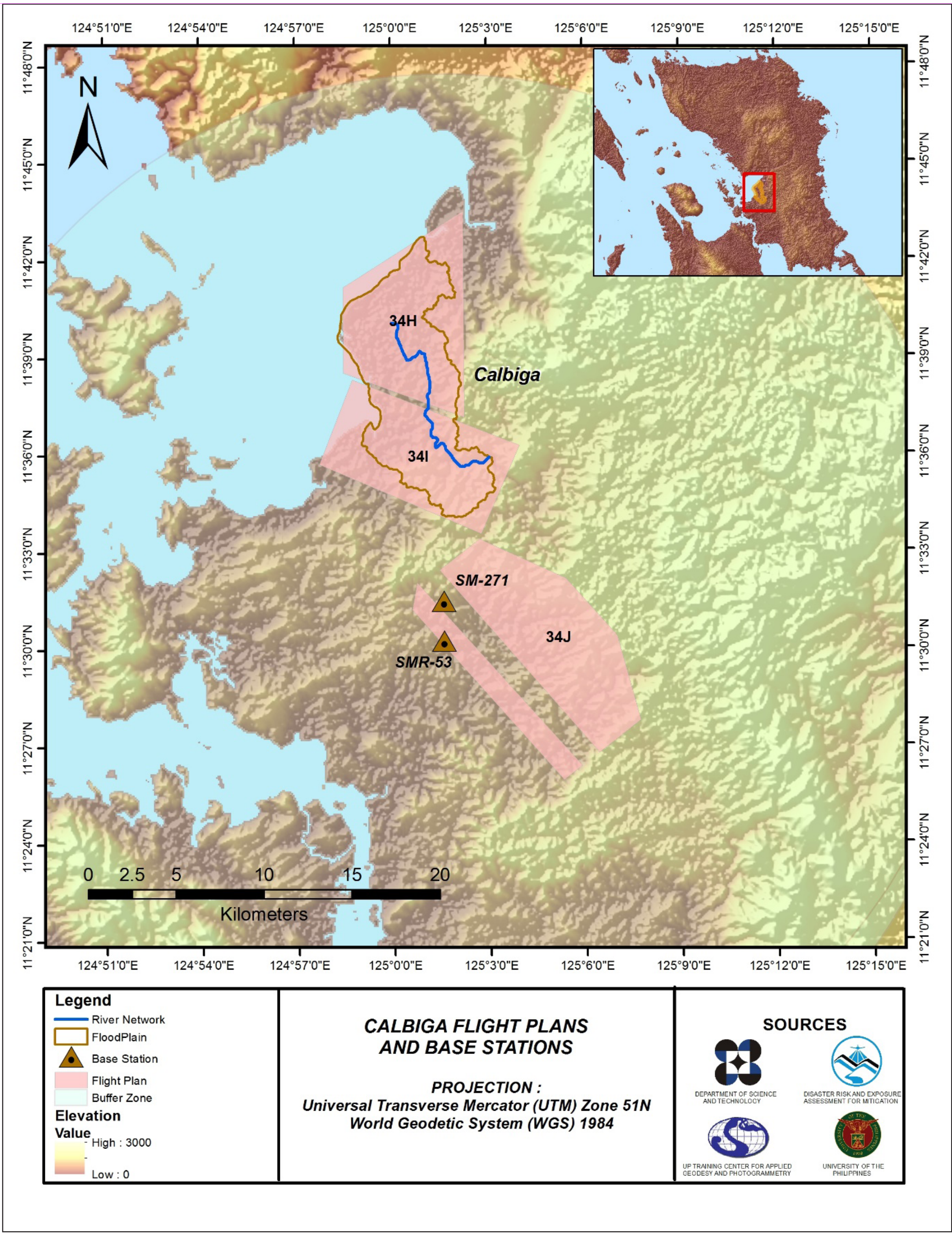


Figure 2. Flight plans and base stations used for Calbiga floodplain

## 2.2 Ground Base Station

Two (2) NAMRIA second order accuracy ground control points (GCP): SMR-53 was recovered for use as base station during the survey. LYT-104 is a 3rd order NAMRIA GCP and was re-processed as 2nd order GCP to satisfy the project's accuracy requirement. Also, SM-271 which is a high-accuracy benchmark was used and also re-processed as 2nd order horizontal control point for the project's accuracy. The certifications for the NAMRIA reference points are found in Annex 2 while the baseline processing reports are found in Annex 3. These were used as base stations or reference points during flight operations for the entire duration of the survey (January 29 to 30, 2016). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 852 and SPS 882. Flight plans and location of base stations used during the aerial LiDAR acquisition in Calbiga floodplain are shown in Figure 2 above.

Figure 3 to Figure 5 show the recovered NAMRIA reference points within the area, while Table 2 to Table 4 show the corresponding details about the following NAMRIA control stations and established points. In addition, Table 5 shows the list of all ground control points occupied in line with their respective mission names and flight numbers, together with the dates of acquisition.


(b)

(a)

Figure 3. GPS set-up over SMR-53 located near the school building flag pole of San Isidro Elementary, Brgy. San Isidro, Santa Rita (a) and NAMRIA reference point SMR-53 (b) as recovered by the field team.

Table 2. Details of the recovered NAMRIA horizontal control point SMR-53 used as base station for the LiDAR data acquisition.

| Station Name | SMR-53 | |
|---|---|---|
| Order of Accuracy | 2nd Order | |
| Relative Error (horizontal positioning) | 1 in 50,000 | |
| Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92) | Latitude | 11° 30' 17.85657" North |
| | Longitude | 125° 1' 29.837339" East |
| | Ellipsoidal Height | 26.13400 meters |
| Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92) | Easting | 502,722.403 meters |
| | Northing | 1,272,180.079 meters |
| Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84) | Latitude | 11° 30' 13.52495" North |
| | Longitude | 125° 1' 34.96980" East |
| | Ellipsoidal Height | 87.78700 meters |
| Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992) | Easting | 720,874.14 meters |
| | Northing | 1,272,513.40 meters |

(a) (b)

Figure 4. GPS set-up over LYT-104 located and re-established along rice paddy trail, approximately 90 meters from the centerline, east side of Pastrana-Santa Fe Road, District IV, Pastrana, Leyte (a) and NAMRIA reference point LYT-104 (b) as recovered by the field team.

Table 3. Details of the recovered and re-established NAMRIA horizontal control point LYT-104 used as base station for the LiDAR data acquisition.

| | | |
|---|---|---|
| Station Name | LYT-104 | |
| Order of Accuracy | 2nd order | |
| Relative Error (horizontal positioning) | 1 in 50,000 | |
| Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92) | Latitude | 11° 08’ 38.92234” North |
| | Longitude | 124° 53’ 13.52786” East |
| | Ellipsoidal Height | 33.659 meters |
| Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84) | Easting | 11° 08’ 34.67033” North |
| | Northing | 124° 53’ 18.69323” East |
| | Ellipsoidal Height | 95.861 meters |
| Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992) | Latitude | 706,089.510m |
| | Longitude | 1,232,496.838 |


(a) (b)

Figure 5. GPS set-up over SM-271 located beside kilometer post 864 along right side of the national highway, Bgry. Laygayon, Pinabacdao (a) and NAMRIA reference point SM-271 (b) as recovered by the field team.

Table 4. Details of the recovered NAMRIA vertical control point SM-271 used as base station for the LiDAR data acquisition with established coordinates.

| | | |
|---|---|---|
| Station Name | SM-271 | |
| Order of Accuracy (vertical) | 2nd order | |
| Relative Error (horizontal positioning) | 1 in 50,000 | |
| Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92) | Latitude<br>Longitude<br>Ellipsoidal Height | 11° 31’ 31.48945” North<br>125° 01’ 36.88429” East<br>82.083 meters |
| Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84) | Latitude<br>Longitude<br>Ellipsoidal Height | 125° 01’ 34.96980” East<br>143.69 meters |
| Grid Coordinates, Universal Transverse Mercator Zone 51 North<br>(UTM 51N PRS 1992) | Easting<br>Northing | 721,071.742 meters<br>1,274,777.721 meters |

Table 5. Ground control points used during LiDAR data acquisition.

| Date Surveyed | Flight Number | Mission Name | Ground Control Points |
|---|---|---|---|
| 29 JAN 2016 | 3727G | 2BLK34IJ029B | SMR-53 & SM-271 |
| 30 JAN 2016 | 3729G | 2BLK34HJ030A | SMR-53 & LYT-104 |

## 2.3 Flight Missions

Two (2) missions were conducted to complete LiDAR data acquisition in Calbiga Floodplain, for a total of eight hours and sixteen minutes (08+16) of flying time for RP-C9022. All missions were acquired using Gemini LiDAR system. The team line-up is shown in Annex 4. Table 6 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 7 presents the actual parameters used during the LiDAR data acquisition. The data transfer sheet, flight logs and flight status reports of each mission are shown in Annex 5, 6 and 7 respectively.

Table 6. Flight missions for LiDAR data acquisition in Calbiga floodplain.

| Date Surveyed | Flight Number | Flight Plan Area ($km^2$) | Surveyed Area ($km^2$) | Area Surveyed within the Floodplain ($km^2$) | Area Surveyed Outside the Floodplain ($km^2$) | Flying Hours | |
|---|---|---|---|---|---|---|---|
| | | | | | | Hr | Min |
| 29-Jan-16 | 3727G | 114.102 | 149.016 | 32.325 | 116.691 | 4 | 5 |
| 30-Jan-16 | 2729G | 74.081 | 113.571 | 44.901 | 68.67 | 4 | 11 |
| TOTAL | | 188.183 | 262.587 | 77.226 | 185.361 | 8 | 16 |

Table 7. 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) |
|---|---|---|---|---|---|---|---|
| 3727G | 600 | 30 | 50 | 100 | 40 | 120 | 5 |
| 2729G | 650 | 30 | 40 | 100 | 50 | 120 | 5 |

## 2.4 Survey Coverage

Calbiga floodplain is located in the province of Samar situated in the municipality of Calbiga. LiDAR swath coverage for these flights also covers the municipality of San Sebastian. The list of municipalities and/or cities surveyed with at least one (1) square kilometer coverage is shown in Table 8. The actual coverage of the LiDAR acquisition for Calbiga Floodplain is presented in Figure 6.

Table 8. List of municipalities and/or cities surveyed during Calbiga floodplain LiDAR survey.

| Province | City/ Municipality | Area of Municipality/ City ($km^2$) | Total Area Surveyed ($km^2$) | Percentage of Area Surveyed |
|---|---|---|---|---|
| Samar | Basey | 627.969 | 30.667 | 5% |
| Samar | Calbiga | 216.76 | 71.983 | 33% |
| Samar | Hinabangan | 378.667 | 3.733 | 1% |
| Samar | Pinabacdao | 118.375 | 55.756 | 47% |
| Samar | San Sebastian | 15.838 | 15.175 | 96% |
| Samar | Santa Rita | 250.369 | 45.238 | 18% |
| Samar | Villareal | 130.22 | 6.311 | 5% |
| TOTAL | | 1738.20 | 228.86 | 13.17% |

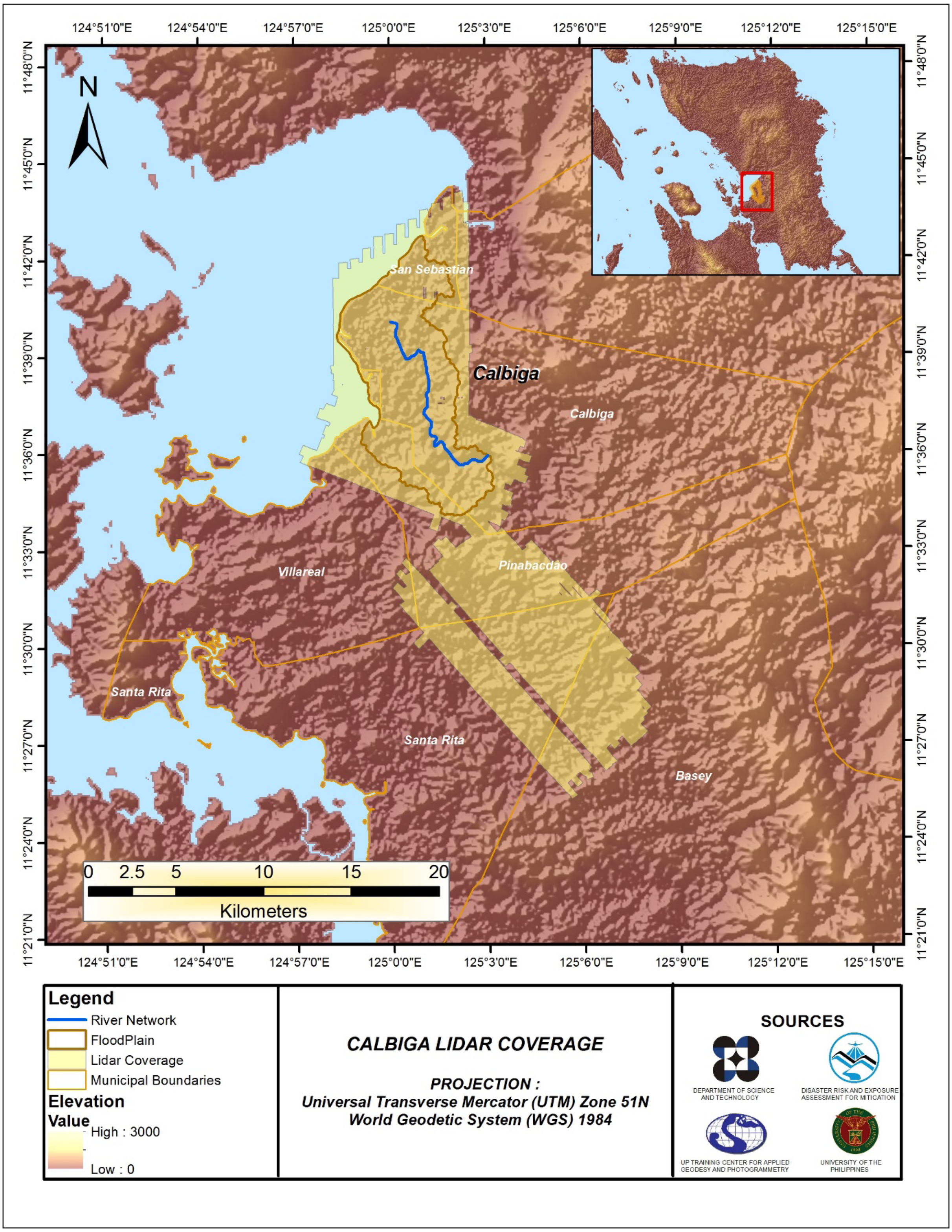


Figure 6. Actual LiDAR survey coverage for Calbiga floodplain

# CHAPTER 3: LiDAR DATA PROCESSING FOR CALBIGA 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).

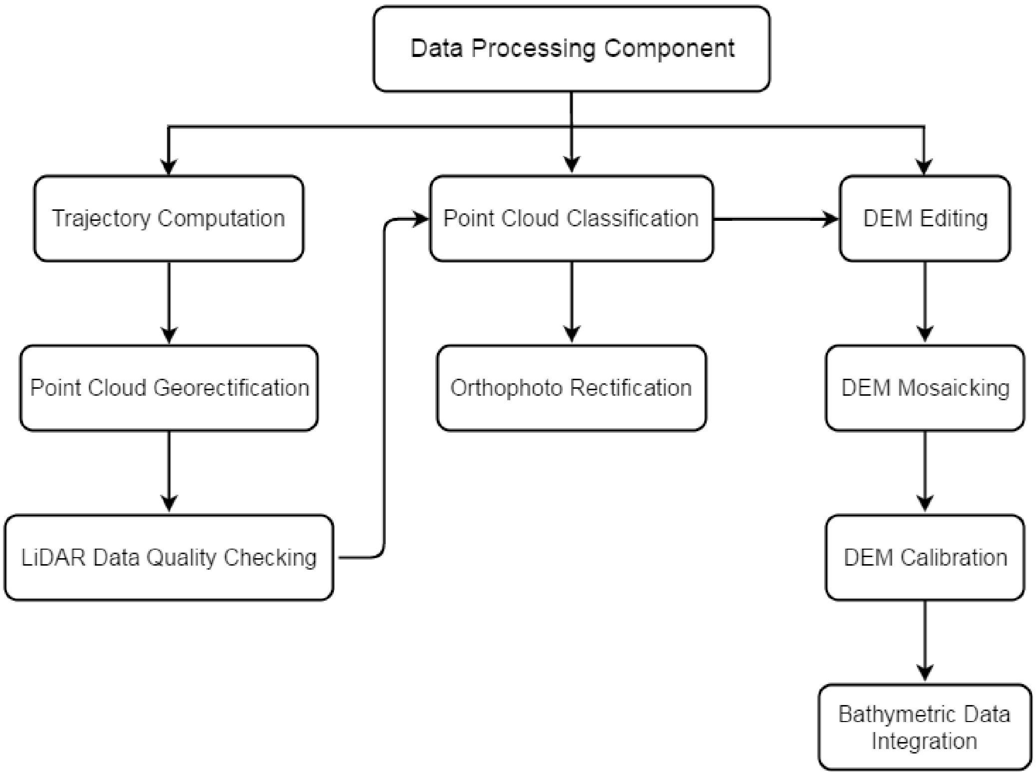


Figure 7. Schematic Diagram for Data Pre-Processing Component

## 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 7.

## 3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Calbiga floodplain can be found in Annex 5. Missions flown during the first survey conducted on February 2016 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Gemini system over Calbiga, Samar. The Data Acquisition Component (DAC) transferred a total of 43.10 Gigabytes of Range data, 0.49 Gigabytes of POS data, 10.28 Megabytes of GPS base station data, and 0 Gigabytes of raw image data to the data server on February 23, 2016 for the first survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Calbiga was fully transferred on February 26, 2016, as indicated on the Data Transfer Sheets for Calbiga floodplain.

## 3.3 Trajectory Computation

The *Smoothed Performance Metric* parameters of the computed trajectory for flight 3729G, one of the Calbiga flights, which is the North, East, and Down position RMSE values are shown in Figure 8. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on February 23, 2106 00:00AM. The y-axis is the RMSE value for that particular position.

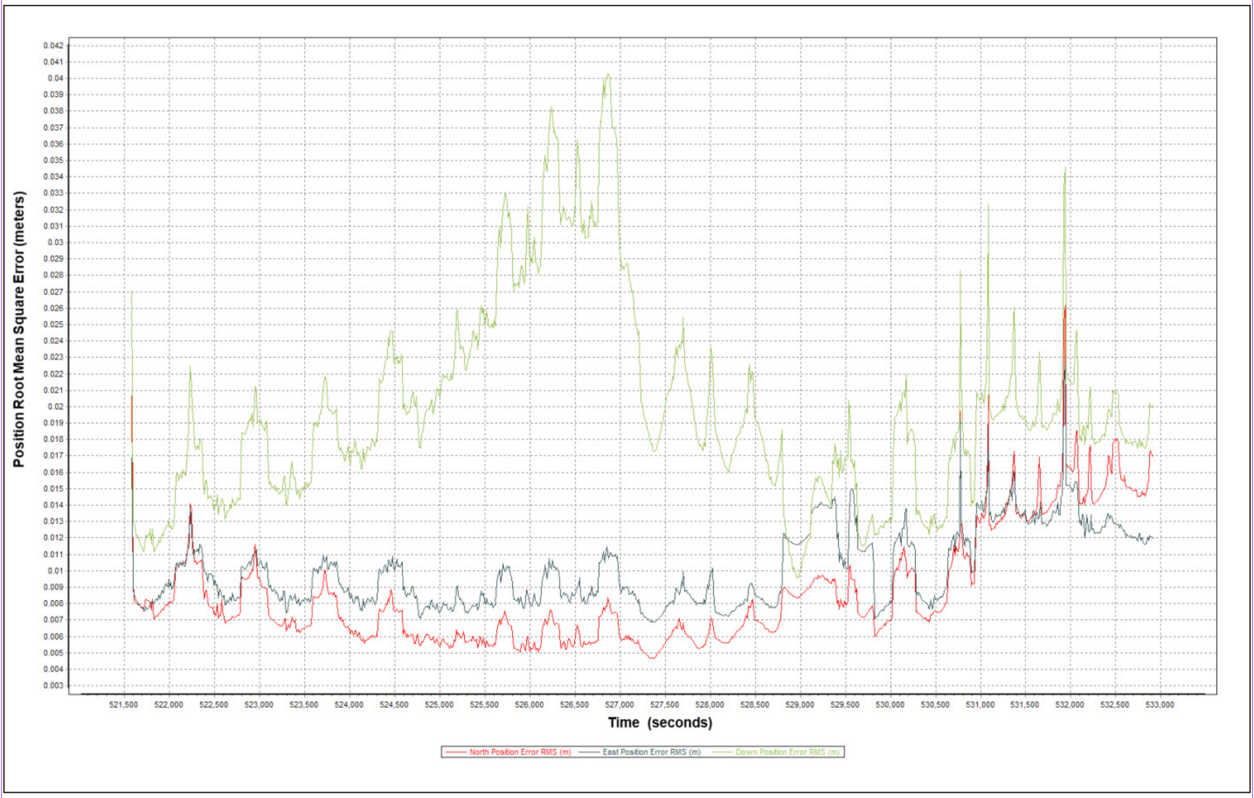


Figure 8. Smoothed Performance Metric Parameters of a Calbiga Flight 3729G.

The time of flight was from 521,600 seconds to 532,900 seconds, which corresponds to morning of February 23, 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 8 shows that the North position RMSE peaks at 2.60 centimeters, the East position RMSE peaks at 2.20 centimeters, and the Down position RMSE peaks at 4.00 centimeters, which are within the prescribed accuracies described in the methodology.

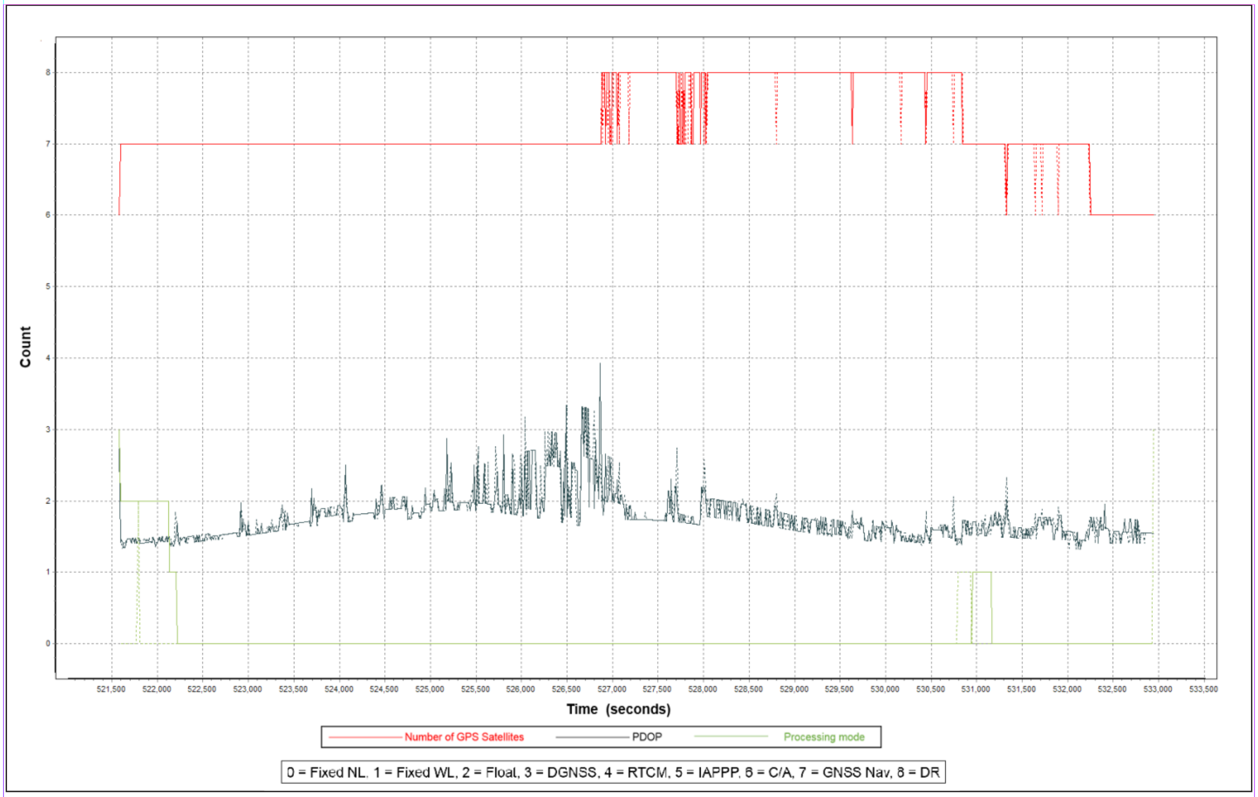


Figure 9. Solution Status Parameters of Calbiga Flight 3729G.

The *Solution Status* parameters of flight 3729G, one of the Calbiga flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 9. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Majority of the time, the number of satellites tracked was between 6 and 8. Majority of the time, the PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode stayed at the value of 0 for majority of the survey with some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Calbiga flights is shown in Figure 10.

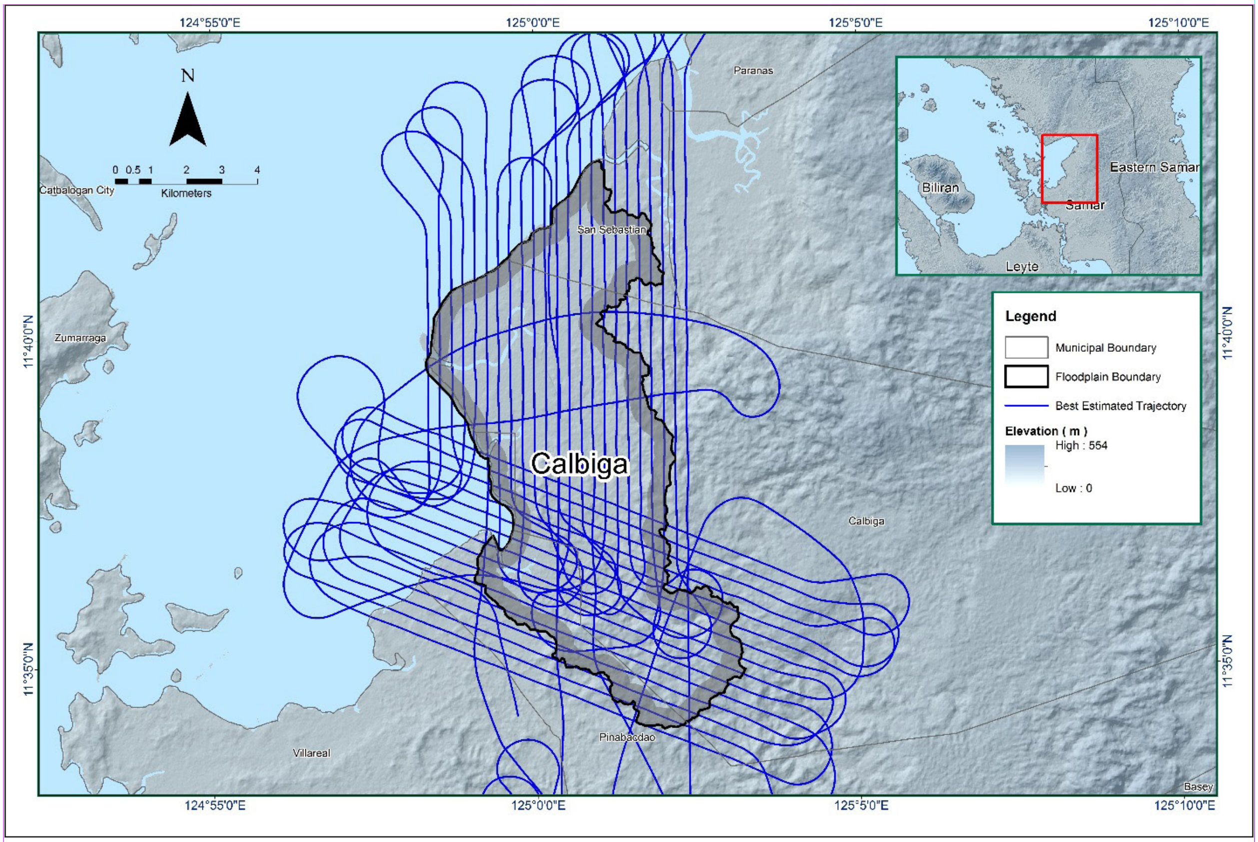


Figure 10. Best Estimated Trajectory for Calbiga floodplain.

## 3.4 LiDAR Point Cloud Computation

The produced LAS data contains 38 flight lines, with each flight line containing one channel, since the Gemini system contains one channel only. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Calbiga floodplain are given in Table 9.

Table 9. Self-Calibration Results values for Calbiga flights.

| Parameter | Computed Value |
|---|---|
| Boresight Correction stdev (<0.001degrees) | 0.003745 |
| IMU Attitude Correction Roll and Pitch Corrections stdev (<0.001degrees) | 0.001 |
| GPS Position Z-correction stdev (<0.01meters) | 0.0092 |

The optimum accuracy is obtained for all Calbiga 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 Calbiga Floodplain is shown in Figure 11. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

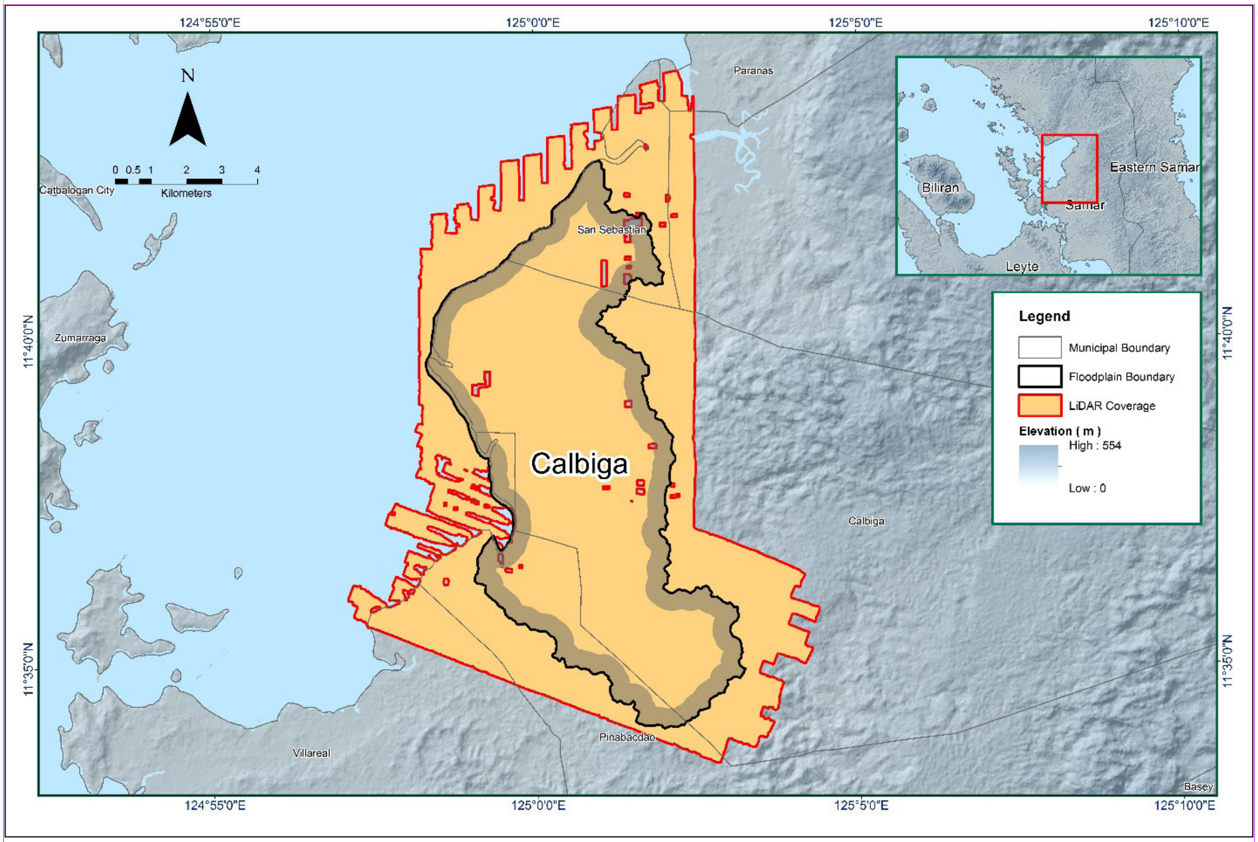


Figure 11. Boundary of the processed LiDAR data over Calbiga Floodplain

The total area covered by the Calbiga missions is 140.24 sq.km that is comprised of two (2) flight acquisitions grouped and merged into two (2) blocks as shown in Table 10.

Table 10. List of LiDAR blocks for Calbiga floodplain.

| LiDAR Blocks | Flight Numbers | Area (sq. km) |
|---|---|---|
| Leyte Blk33H_supplement | 3727G | 63.38 |
| Leyte Blk33I | 3729G | 76.86 |
| TOTAL | | 140.24 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 12. Since the Gemini system employs one channel, we would expect an average value of 1 (blue) for areas where there is limited overlap, and a value of 2 (yellow) or more (red) for areas with three or more overlapping flight lines.

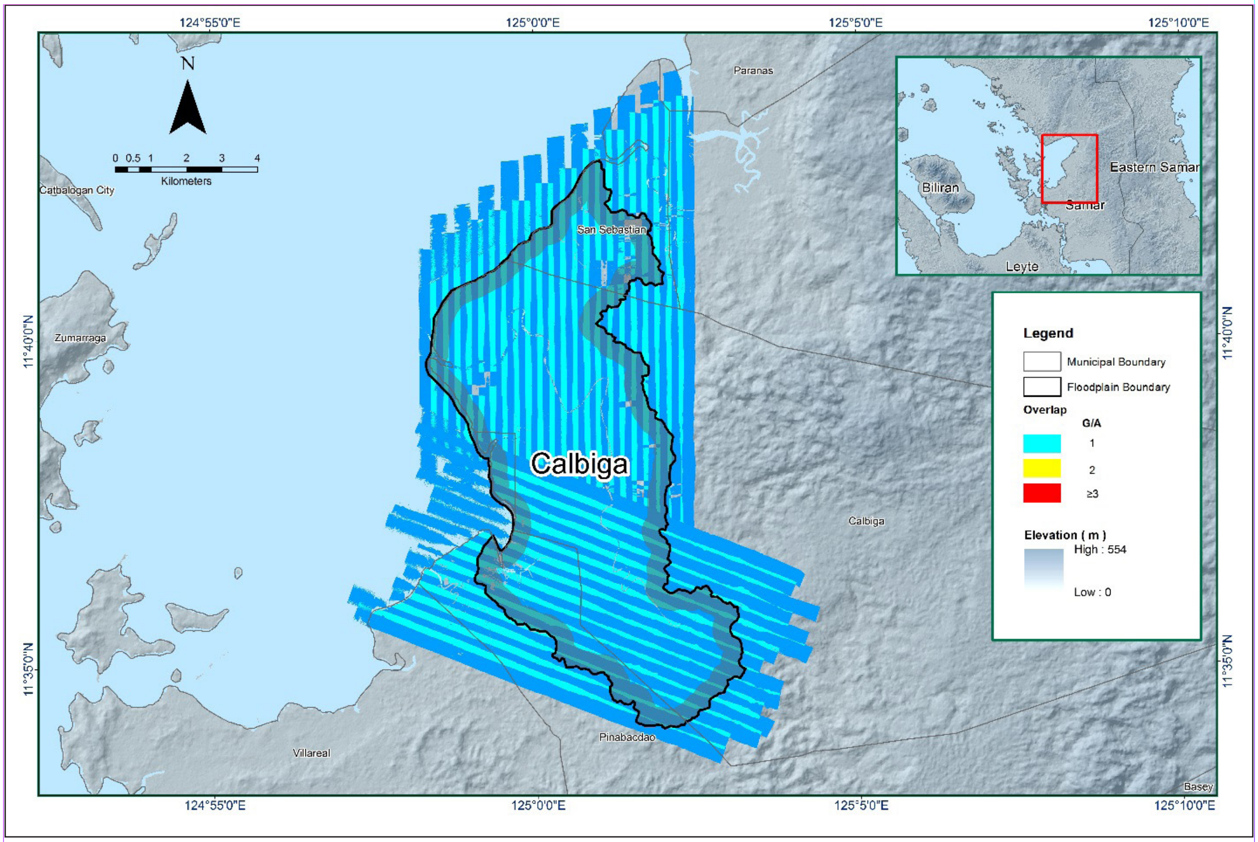


Figure 12. Image of data overlap for Calbiga floodplain.

The overlap statistics per block for the Calbiga 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 28.06% and 36.04% respectively, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 13. It was determined that all LiDAR data for Calbiga floodplain satisfy the point density requirement, and the average density for the entire survey area is 4.85 points per square meter.

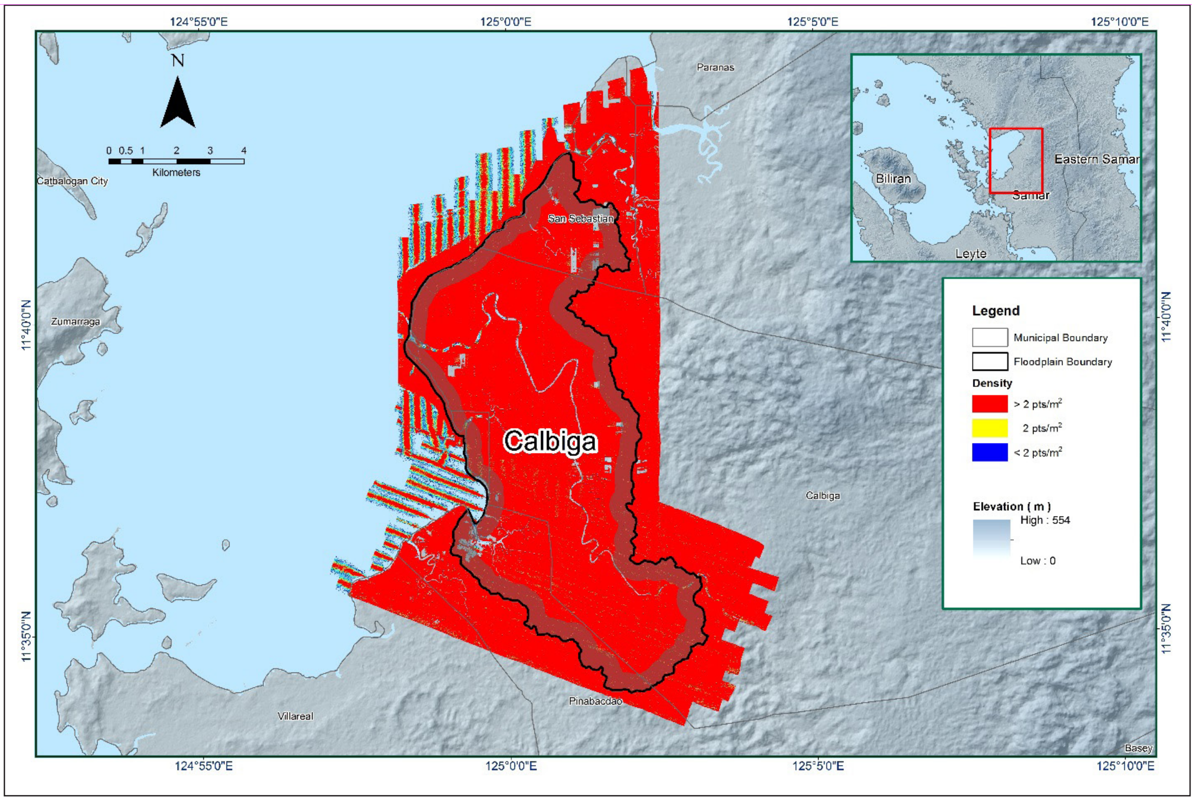


Figure 13. Pulse density map of merged LiDAR data for Calbiga floodplain.

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

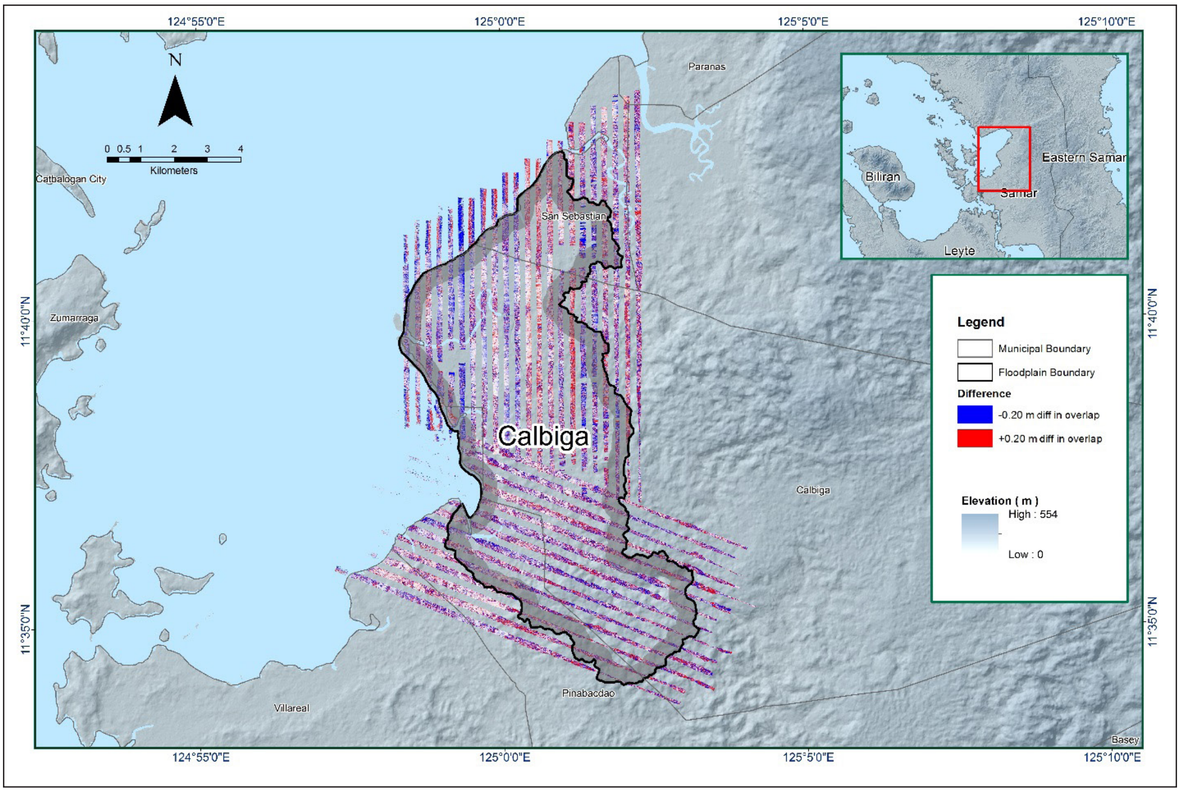


Figure 14. Elevation difference map between flight lines for Calbiga floodplain.

A screen capture of the processed LAS data from a Calbiga flight 3729G loaded in QT Modeler is shown in Figure 15. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed red line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

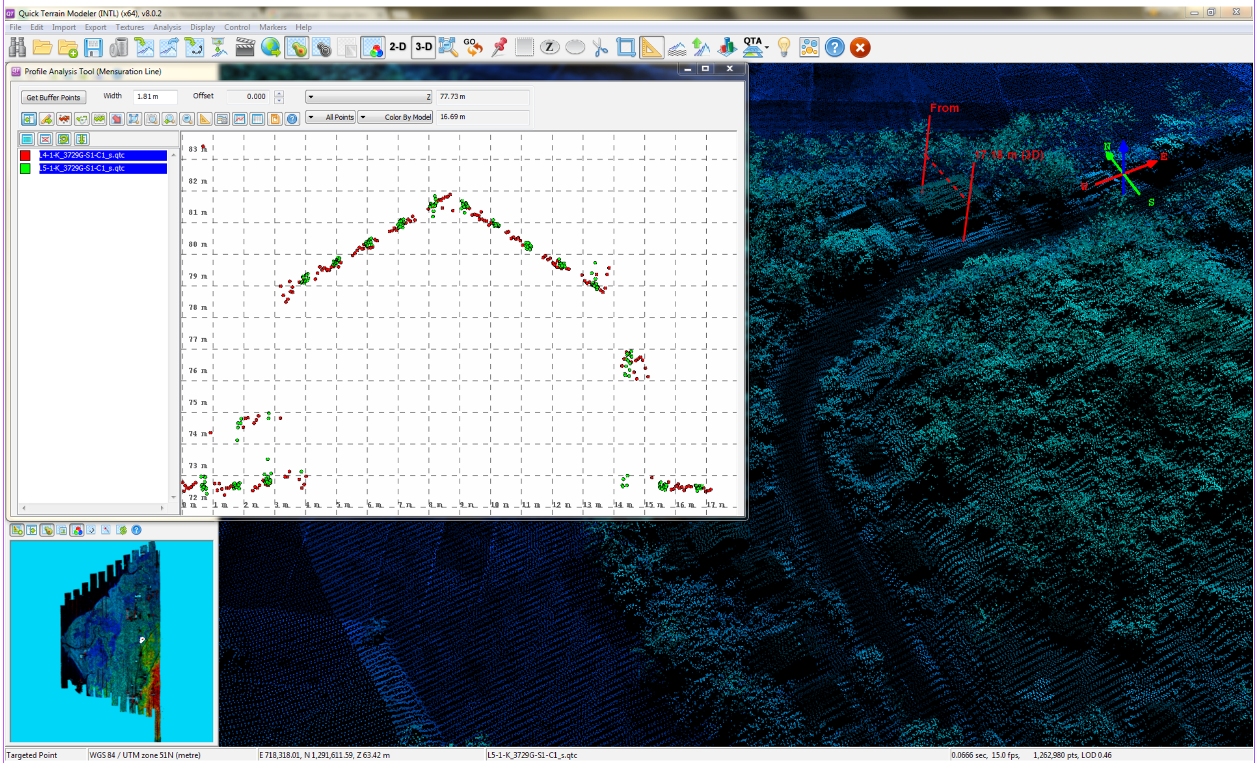

Figure 15. Quality checking for a Calbiga flight 3729G using the Profile Tool of QT Modeler.

## 3.6 LiDAR Point Cloud Classification and Rasterization

Table 11. Calbiga classification results in TerraScan.

| Pertinent Class | Total Number of Points |
|---|---|
| Ground | 104,211,750 |
| Low Vegetation | 64,804,379 |
| Medium Vegetation | 228,698,863 |
| High Vegetation | 133,626,398 |
| Building | 1,307,188 |

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Calbiga floodplain is shown in Figure 16. A total of 203 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 11. The point cloud has a maximum and minimum height of 298.19 meters and 40.33 meters respectively.

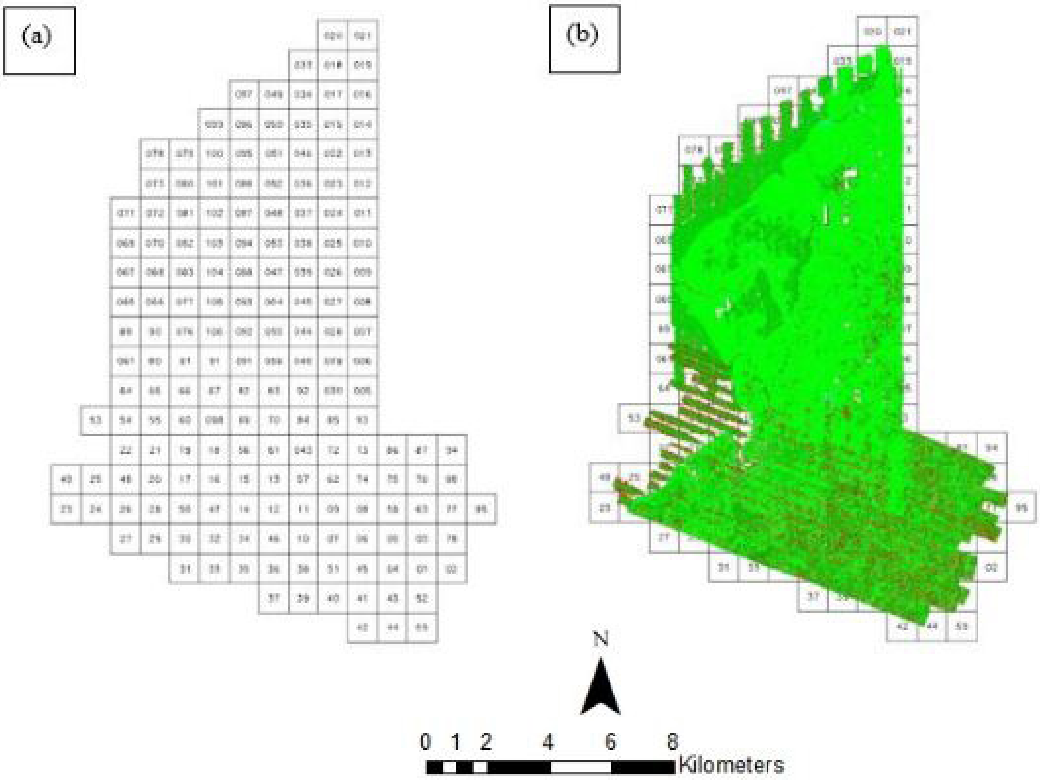


Figure 16. Tiles for Calbiga floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 17. The ground points are in orange, the vegetation is in different shades of green, and the buildings are in cyan. It can be seen that residential structures adjacent or even below canopy are classified correctly, due to the density of the LiDAR data.

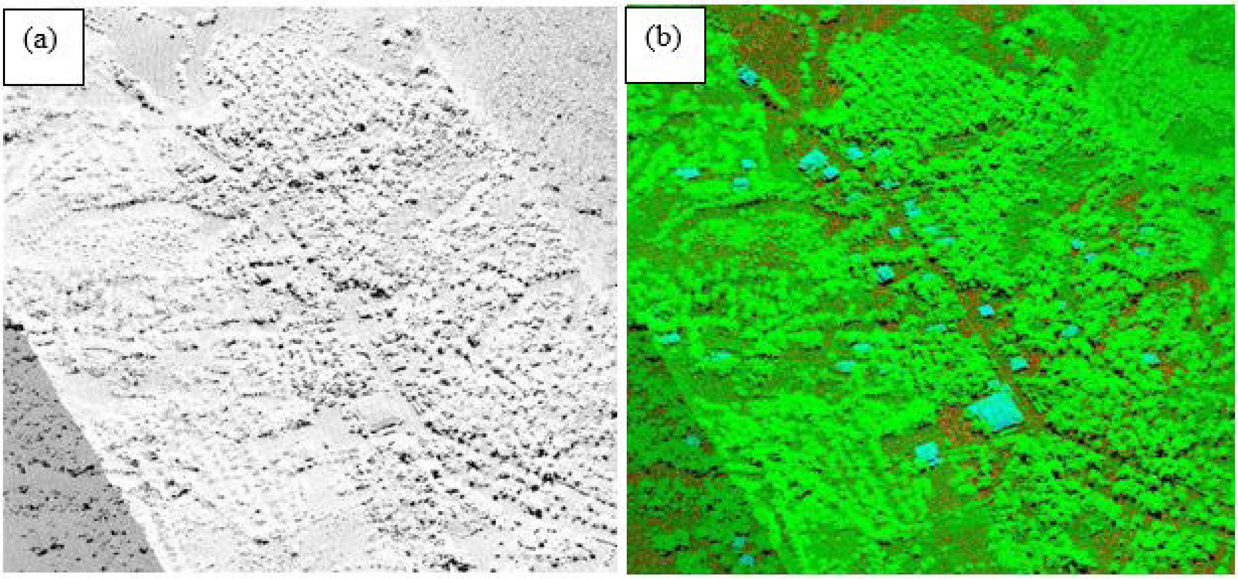


Figure 17. Point cloud before (a) and after (b) classification.

The production of last return (V_ASCII) and the secondary (T_ ASCII) DTM, first (S_ ASCII) and last (D_ ASCII) return DSM of the area in top view display are shown in Figure 18. It shows that DTMs are the representation of the bare earth while on the DSMs, all features are present such as buildings and vegetation.

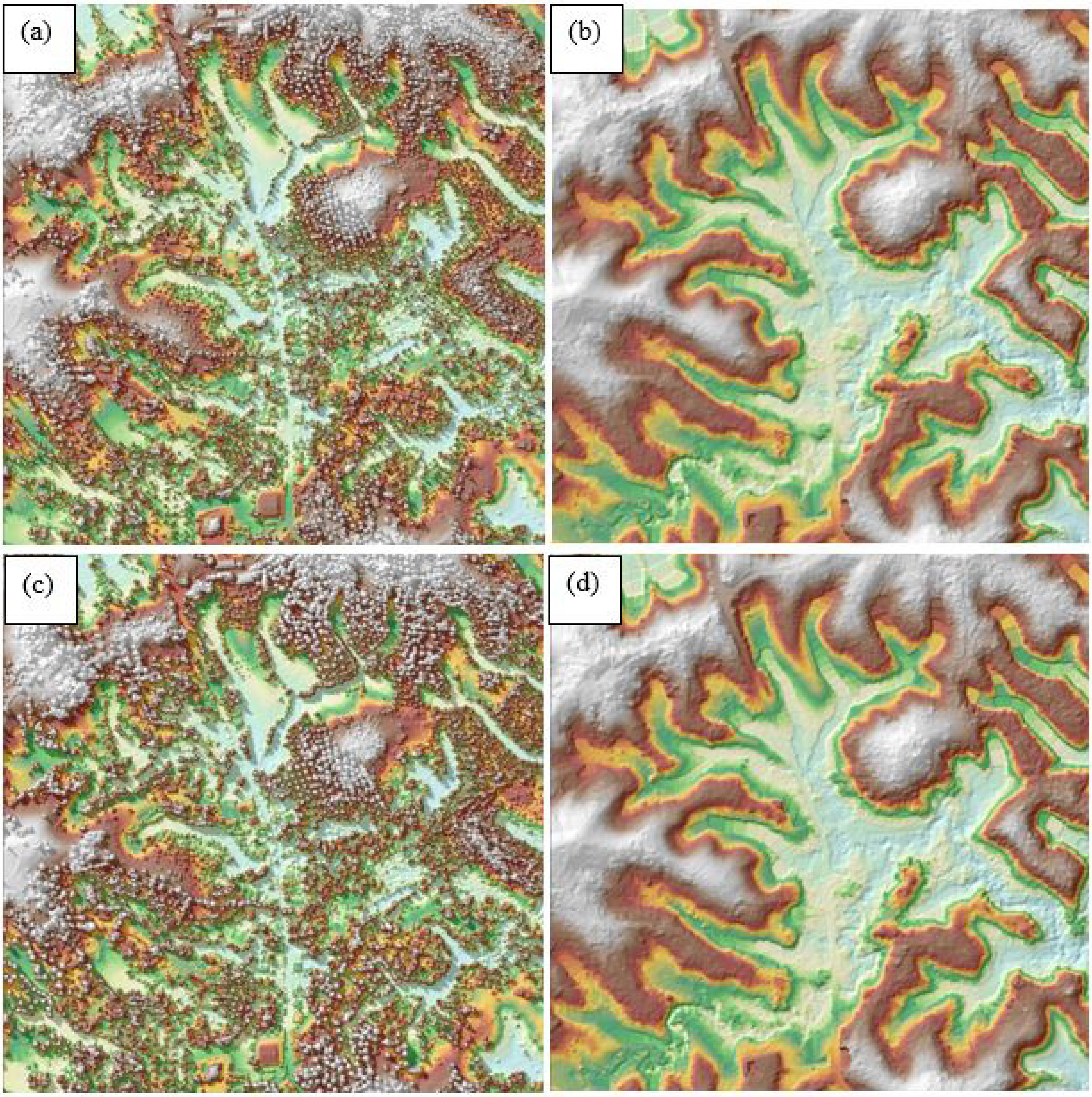


Figure 18. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Calbiga floodplain.

## 3.7 LiDAR Image Processing and Orthophotograph Rectification

There are no available orthophotographs for the Calbiga floodplain.

## 3.8 DEM Editing and Hydro-Correction

Two (2) mission blocks were processed for Calbiga flood plain. These blocks are composed of Leyte blocks with a total area of 140.24 square kilometers. Table 12 shows the name and corresponding area of each block in square kilometers.

Table 12. LiDAR blocks with its corresponding area.

| LiDAR Blocks | Area (sq.km) |
|---|---|
| Leyte_Blk33I | 76.86 |
| Leyte_Blk33H_supplement | 63.38 |
| TOTAL | 140.24 sq. km |

Portions of DTM before and after manual editing are shown in Figure 19. The bridge (Figure 19a) is considered to be an impedance to the flow of water along the river and has to be removed (Figure 19b) in order to hydrologically correct the river. The paddy field (Figure 19c) has been misclassified and removed during classification process and has to be retrieved to complete the surface (Figure 19d) to allow the correct flow of water.

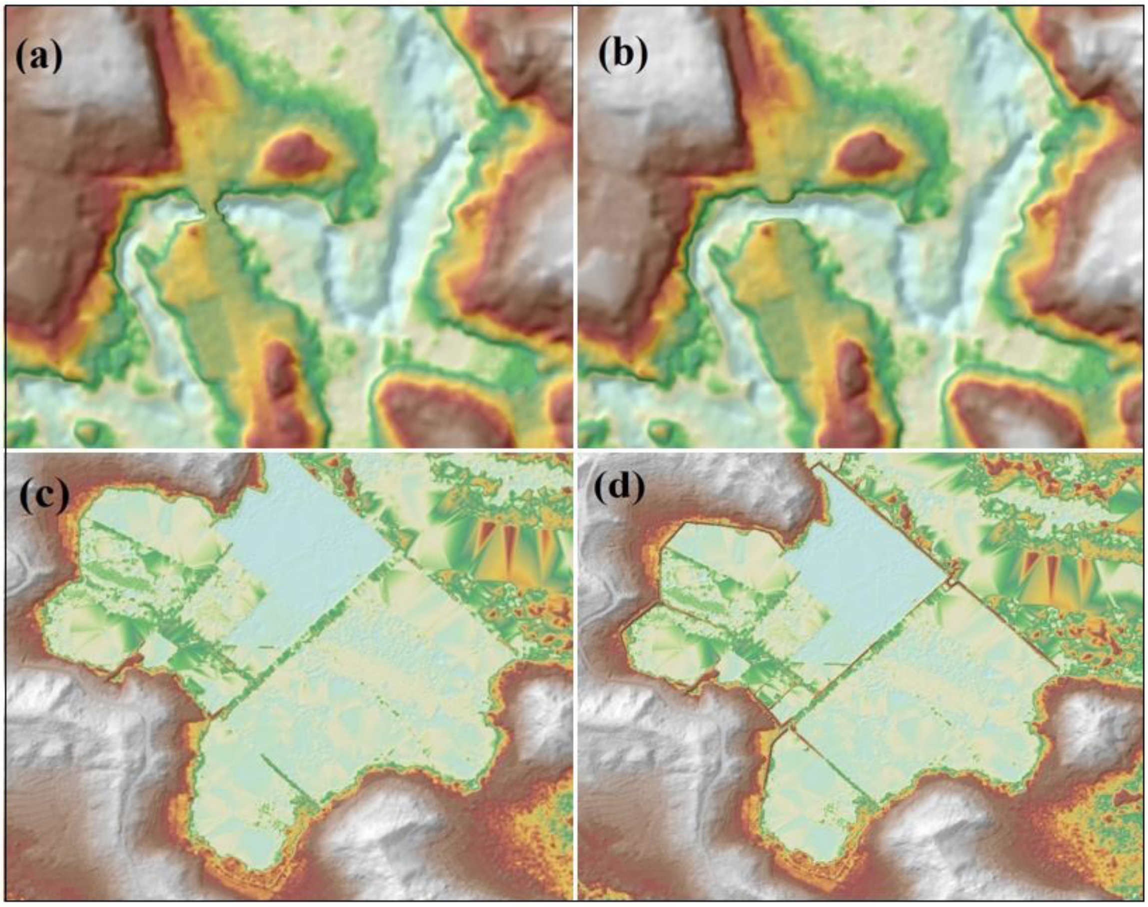


Figure 19. Portions in the DTM of Calbiga flood plain – a bridge before (a) and after (b) manual editing; a paddy field before (c) and after (d) data retrieval.

## 3.9 Mosaicking of Blocks

No assumed reference block was used in mosaicking because the identified reference for shifting was an existing calibrated Tacloban DEM overlapping with the blocks to be mosaicked. Table 13 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Calbiga flood plain is shown in Figure 20. The entire Calbiga floodplain is 98.76% covered by LiDAR data while portions with no Lidar data were patched with the available IFSAR data.

Table 13. Table 13. Shift Values of each LiDAR Block of Calbiga floodplain.

| Mission Blocks | Shift Values (meters) | | |
|---|---|---|---|
| | x | y | z |
| Leyte_33H_supp | 1.00 | 0.00 | -1.05 |
| Leyte_33I | 1.00 | 0.00 | -0.96 |

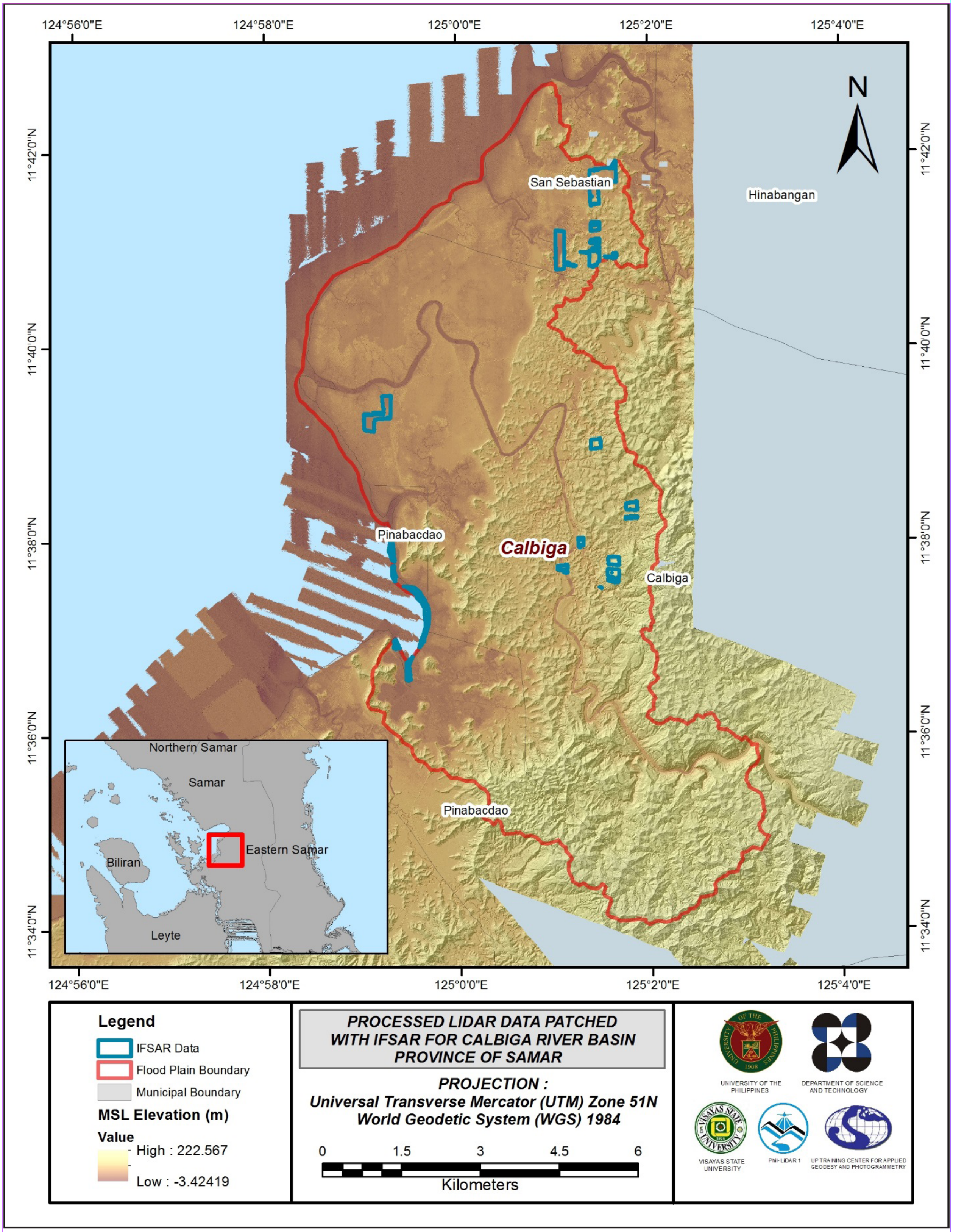


Figure 20. Map of Processed LiDAR Data for Calbiga Flood Plain.

## 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 Calbiga to collect points with which the LiDAR dataset is validated is shown in Figure 21. A total of 1,057 survey points were gathered for the Calbiga flood plain. However, the point dataset was not used for the calibration of the LiDAR data for Calbiga because during the mosaicking process, each LiDAR block was referred to the calibrated Tacloban DEM. Therefore, the mosaicked DEM of Calbiga can already be considered as a calibrated DEM.

A good correlation between the uncalibrated Tacloban LiDAR DTM and ground survey elevation values is shown in Figure 22. 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 0.14 meters with a standard deviation of 0.13 meters. Calibration of Tacloban LiDAR data was done by subtracting the height difference value, 0.14 meters, to Tacloban mosaicked LiDAR data. Table 14 shows the statistical values of the compared elevation values between Tacloban LiDAR data and calibration data. These values were also applicable to the Calbiga DEM.

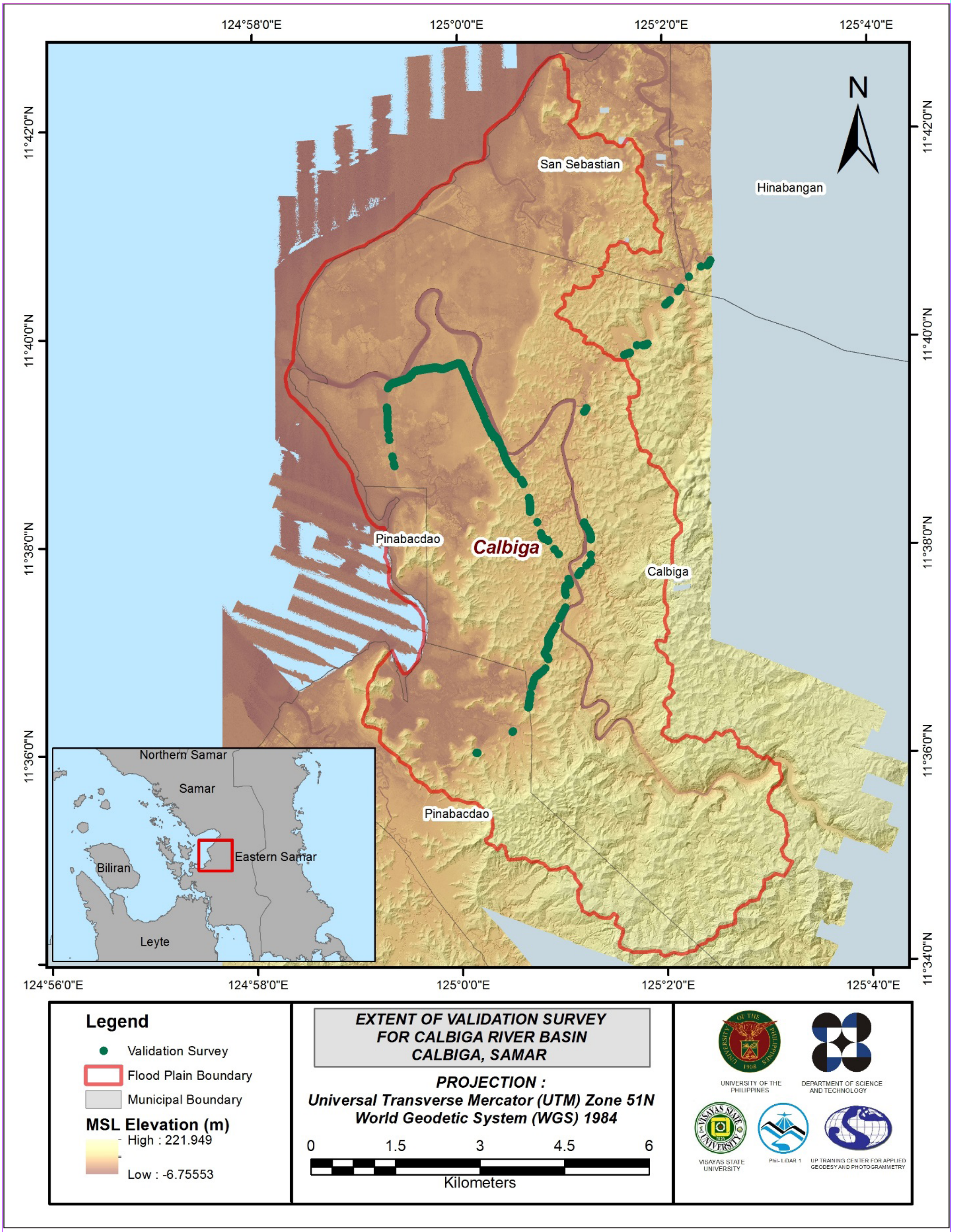


Figure 21. Map of Calbiga Flood Plain with validation survey points in green.

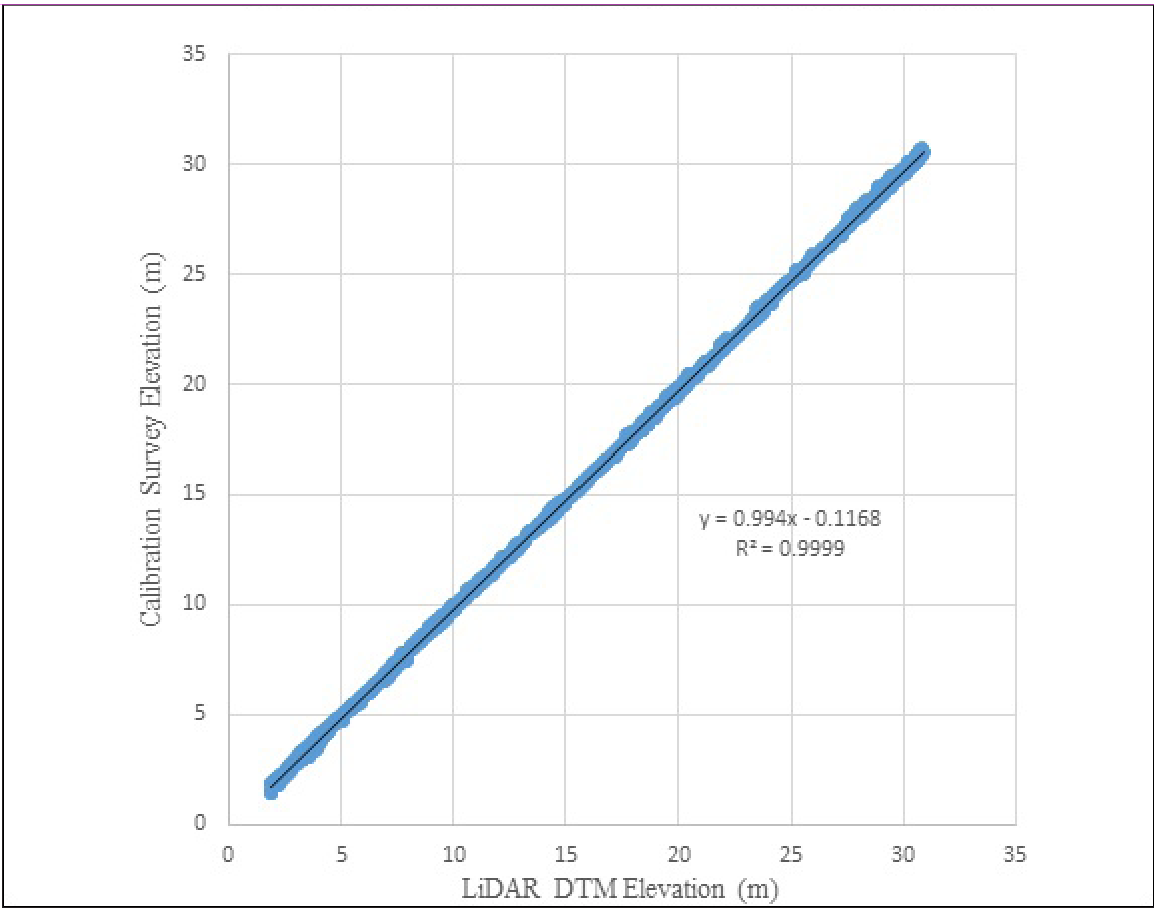


Figure 22. Correlation plot between calibration survey points and LiDAR data.

Table 14. Calibration Statistical Measures.

| Calibration Statistical Measures | Value (meters) |
|---|---|
| Height Difference | 0.14 |
| Standard Deviation | 0.13 |
| Average | -0.05 |
| Minimum | -0.32 |
| Maximum | 0.22 |

The remaining 20% of the total survey points, resulting to 1,009 points, were used for the validation of calibrated Calbiga DTM. A good correlation between the calibrated mosaicked LiDAR elevation values and the ground survey elevation, which reflects the quality of the LiDAR DTM is shown in Figure 23. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.20 meters with a standard deviation of 0.12 meters, as shown in Table 15.

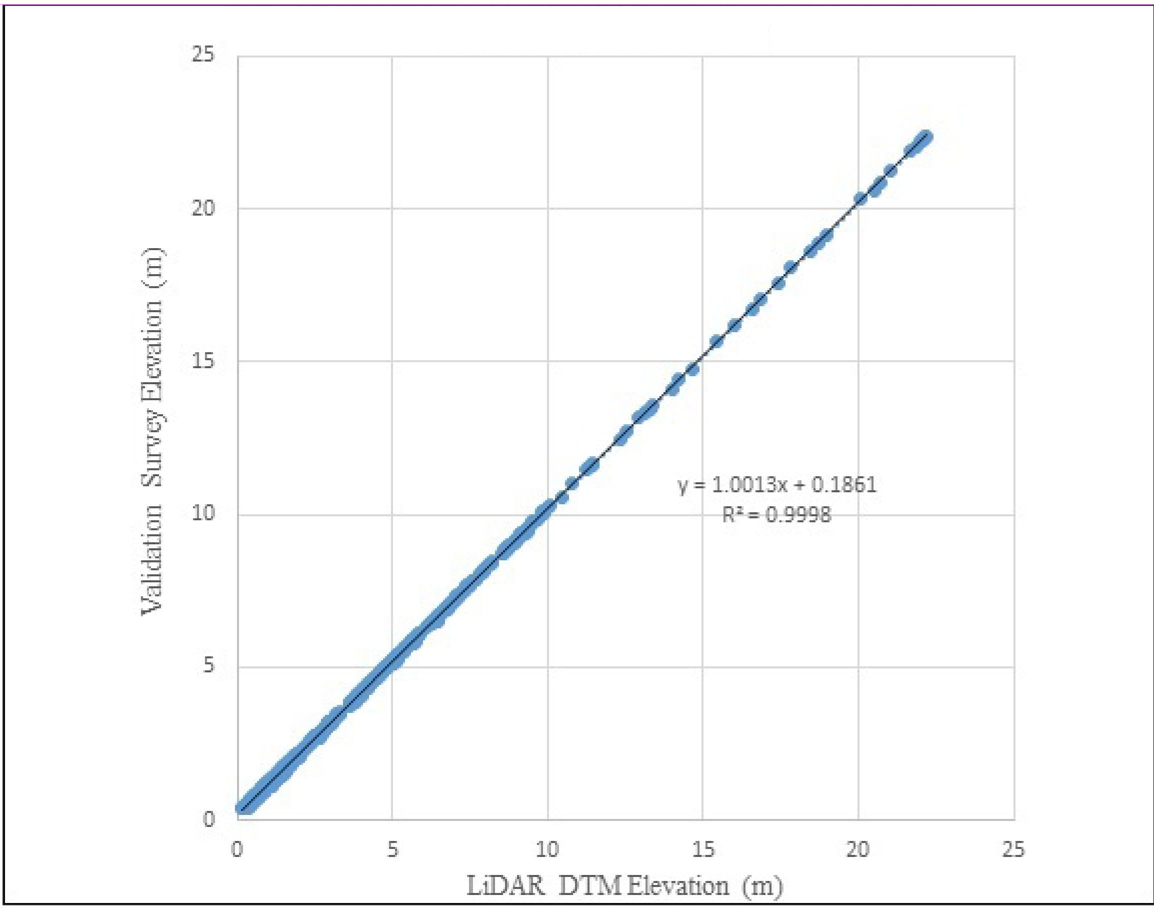


Figure 23. Correlation plot between validation survey points and LiDAR data.

Table 15. Validation Statistical Measures.

| Validation Statistical Measures | Value (meters) |
|---|---|
| RMSE | 0.20 |
| Standard Deviation | 0.05 |
| Average | 0.19 |
| Minimum | 0.03 |
| Maximum | 0.26 |

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

For bathy integration, centerline and zigzag data was available for Calbiga with 20,060 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 0.47 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Calbiga integrated with the processed LiDAR DEM is shown in Figure 24.

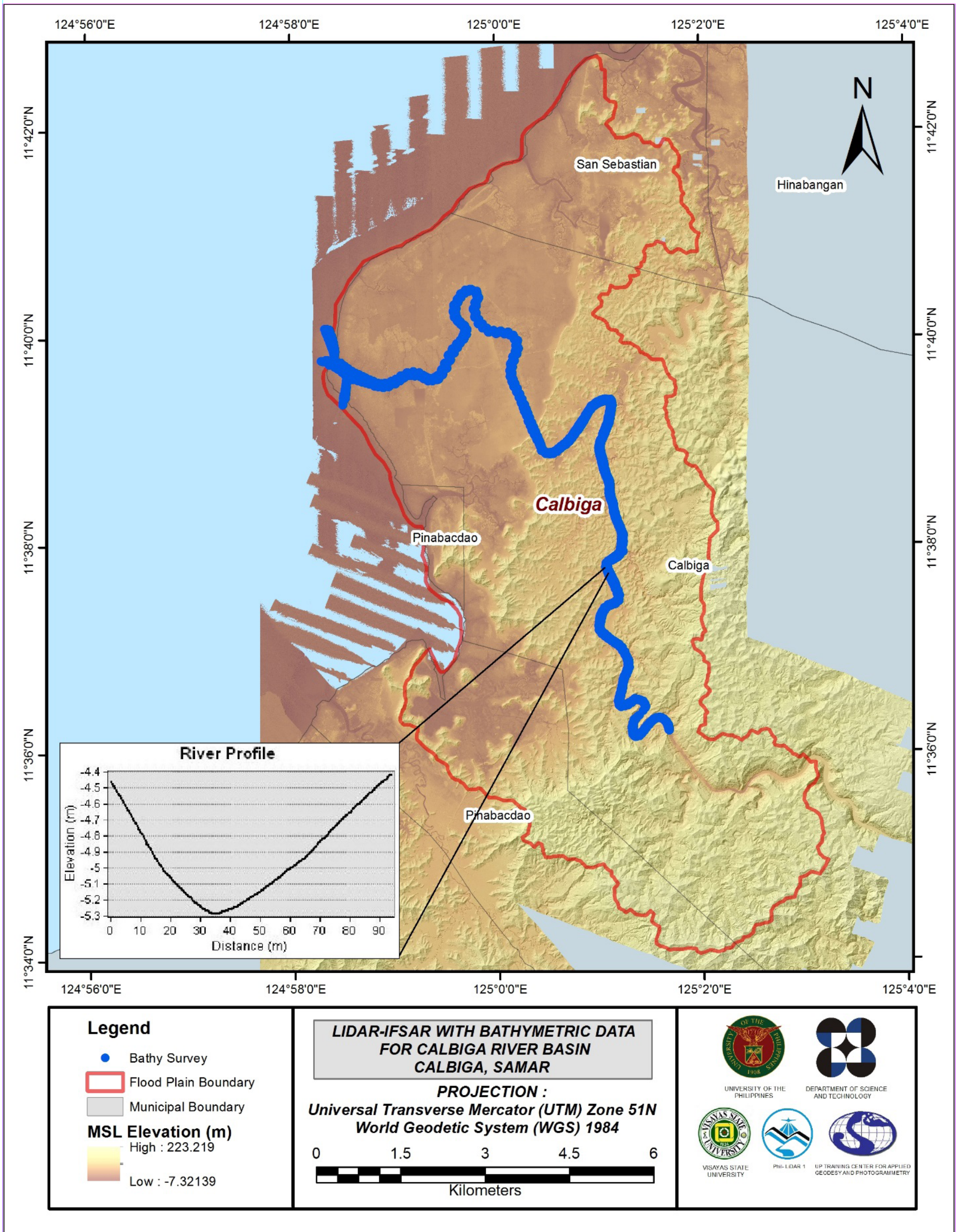


Figure 24. Map of Calbiga Flood Plain with bathymetric survey points shown in blue.

## 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

Calbiga floodplain, including its 200 m buffer, has a total area of 80.74 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 769 building features, are considered for QC. Figure 25 shows the QC blocks for Calbiga floodplain.

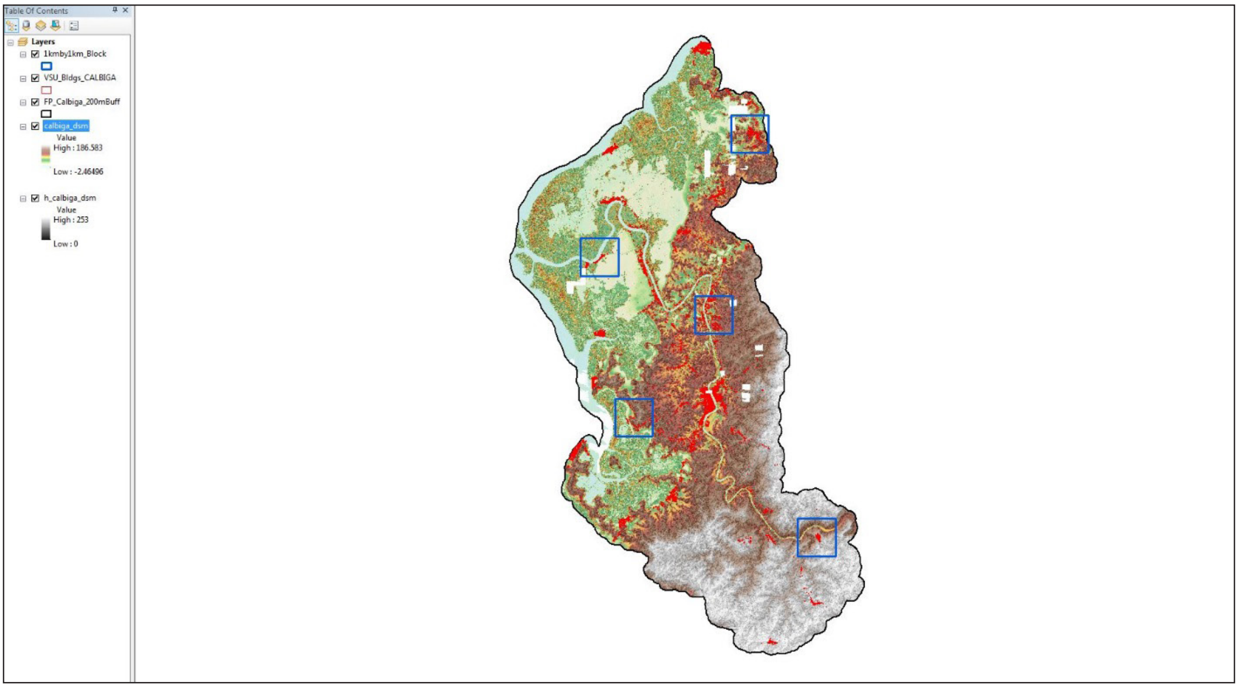


Figure 25. QC blocks for Calbiga building features.

Quality checking of Calbiga building features resulted in the ratings shown in Table 16.

Table 16. Quality Checking Ratings for Calbiga Building Features.

| FLOODPLAIN | COMPLETENESS | CORRECTNESS | QUALITY | REMARKS |
|---|---|---|---|---|
| Calbiga | 95.52 | 99.87 | 80.49 | PASSED |

### 3.12.2 Height Extraction

Height extraction was done for 6812 building features in Calbiga flood plain. Of these building features, 41 was filtered out after height extraction, resulting to 6,771 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 8.56 m.

### 3.12.3 Feature Attribution

The digitized features were marked and coded in the field using handheld GPS receivers. The attributes of non-residential buildings were first identified; all other buildings 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 17 summarizes the number of building features per type. On the other hand, Table 18 shows the total length of each road type, while Table 19 shows the number of water features extracted per type.

Table 17. Building Features Extracted for Calbiga Floodplain.

| Facility Type | No. of Features |
|---|---|
| Residential | 6,437 |
| School | 161 |
| Market | 3 |
| Agricultural/Agro-Industrial Facilities | 6 |
| Medical Institutions | 8 |
| Barangay Hall | 28 |
| Military Institution | 0 |
| Sports Center/Gymnasium/Covered Court | 6 |
| Telecommunication Facilities | 0 |
| Transport Terminal | 1 |
| Warehouse | 2 |
| Power Plant/Substation | 0 |
| NGO/CSO Offices | 0 |
| Police Station | 3 |
| Water Supply/Sewerage | 0 |
| Religious Institutions | 28 |
| Bank | 0 |
| Factory | 0 |
| Gas Station | 0 |
| Fire Station | 2 |
| Other Government Offices | 20 |
| Other Commercial Establishments | 26 |
| Cemetery | 40 |
| Total | 6,771 |

Table 18. Total Length of Extracted Roads for Calbiga Floodplain.

| Floodplain | Road Network Length (km) | | | | | Total |
|---|---|---|---|---|---|---|
| | Barangay Road | City/Municipal Road | Provincial Road | National Road | Others | |
| Calbiga | 49.04 | 21.82 | 0 | 10.171 | 0.00 | 81.03 |

Table 19. Number of Extracted Water Bodies for Calbiga Floodplain.

| Floodplain | Water Body Type | | | | | Total |
|---|---|---|---|---|---|---|
| | Rivers/Streams | Lakes/Ponds | Sea | Dam | Fish Pen | |
| Calbiga | 164 | 0 | 0 | 0 | 18 | 182 |

A total of 18 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 flood plain. This completes the feature extraction phase of the project.

Figure 26 shows the Digital Surface Model (DSM) of Calbiga flood plain overlaid with its ground features.

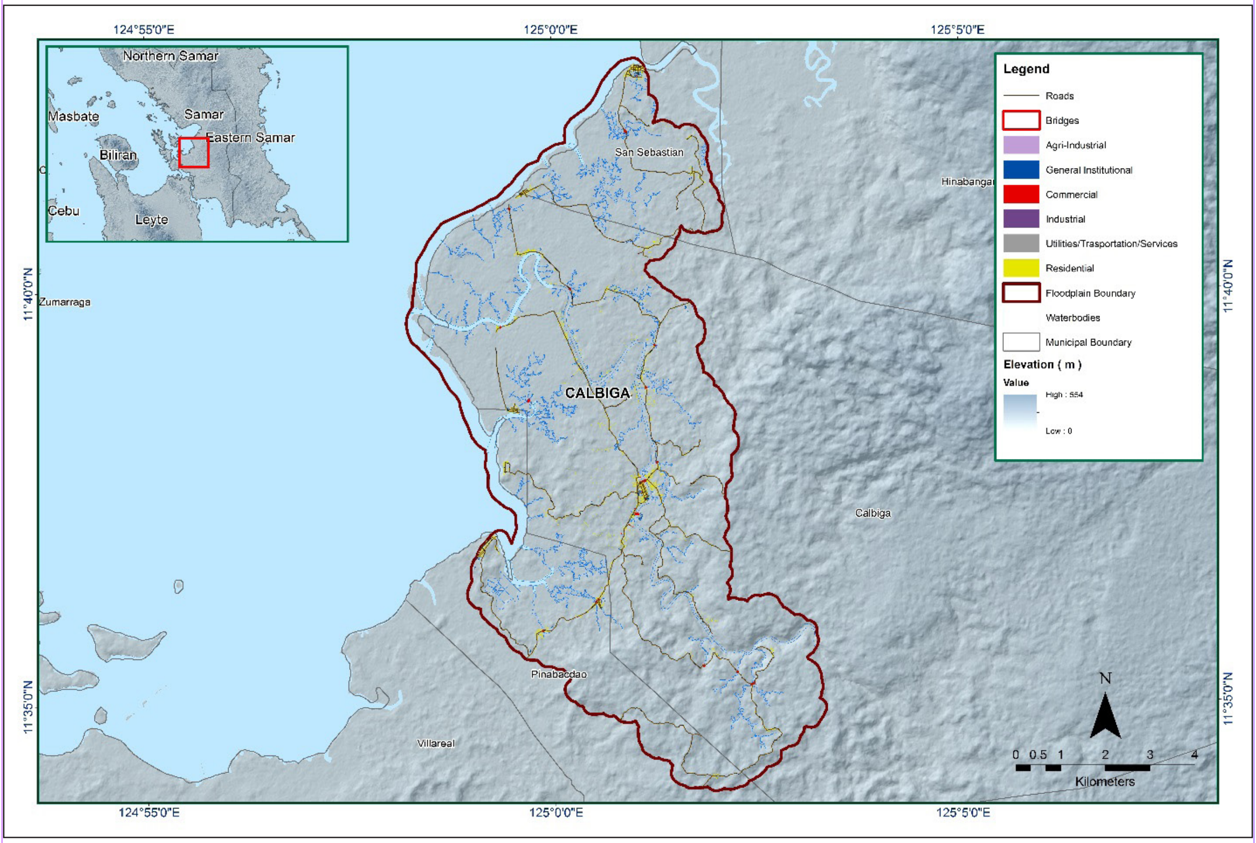


Figure 26. Extracted features for Calbiga floodplain.

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

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Engr. Kristine Ailene B. Borromeo

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

DVBC conducted a field survey in Calbiga River on April 8 to 17, 2016 with the following scope of work: reconnaissance; control survey; cross-section survey at the deployment site in Brgy. Macaalan; validation points acquisition of about 53 km covering the Calbiga River Basin area; and bathymetric survey from its upstream in Brgy. Otoc down to the mouth of the river in Brgy. Barobaybay, both in Municipality of Calbiga, with an approximate length of 17.346 km using Ohmex™ single beam echo sounder and Trimble® SPS 882 GNSS PPK survey technique (Figure 27).

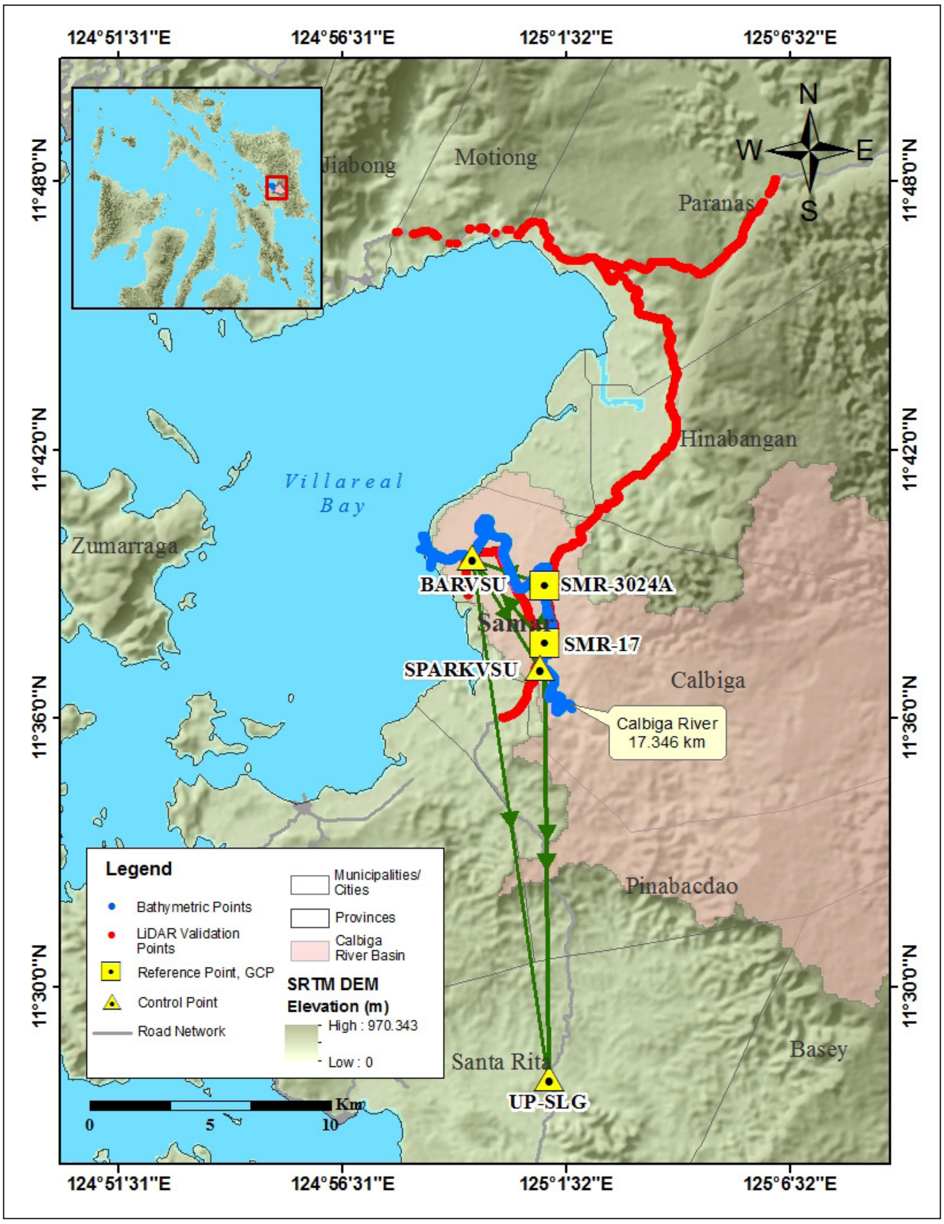



Figure 27. Survey extent for Calbiga River Basin

## 4.2 Control Survey

A GNSS network was established by VSU on September 7 and 10, 2015 occupying the control points SMR-17, UP-SLG, and BARVSU. The control point UP-SLG was used to give MSL value for this network. Its MSL value was derived from the benchmark SE-85 in Brgy. Tabok, Municipality of Llorente- from the network established by DVBC on September 10 to 24, 2014 for Silaga River Basin.

The GNSS network used for Calbiga River Basin is composed of three (3) loops established on April 14, 2016 occupying SMR-17, a second-order GCP, in Brgy. Macaalan, Municipality of Calbiga, as the reference point.

The UP established control point UP-SLG located at the approach of Silagan Bridge; VSU established control points BARVSU in Brgy. Patong and SPARKVSU, in Brgy, Macaalan; and a NAMRIA established control SMR-3024A in Brgy. Canticum, all in Municipality of Calbiga; were also occupied and used as marker for the network.

The summary of reference and control points and its location is summarized in Table 20 while GNSS network established is illustrated in Figure 28.

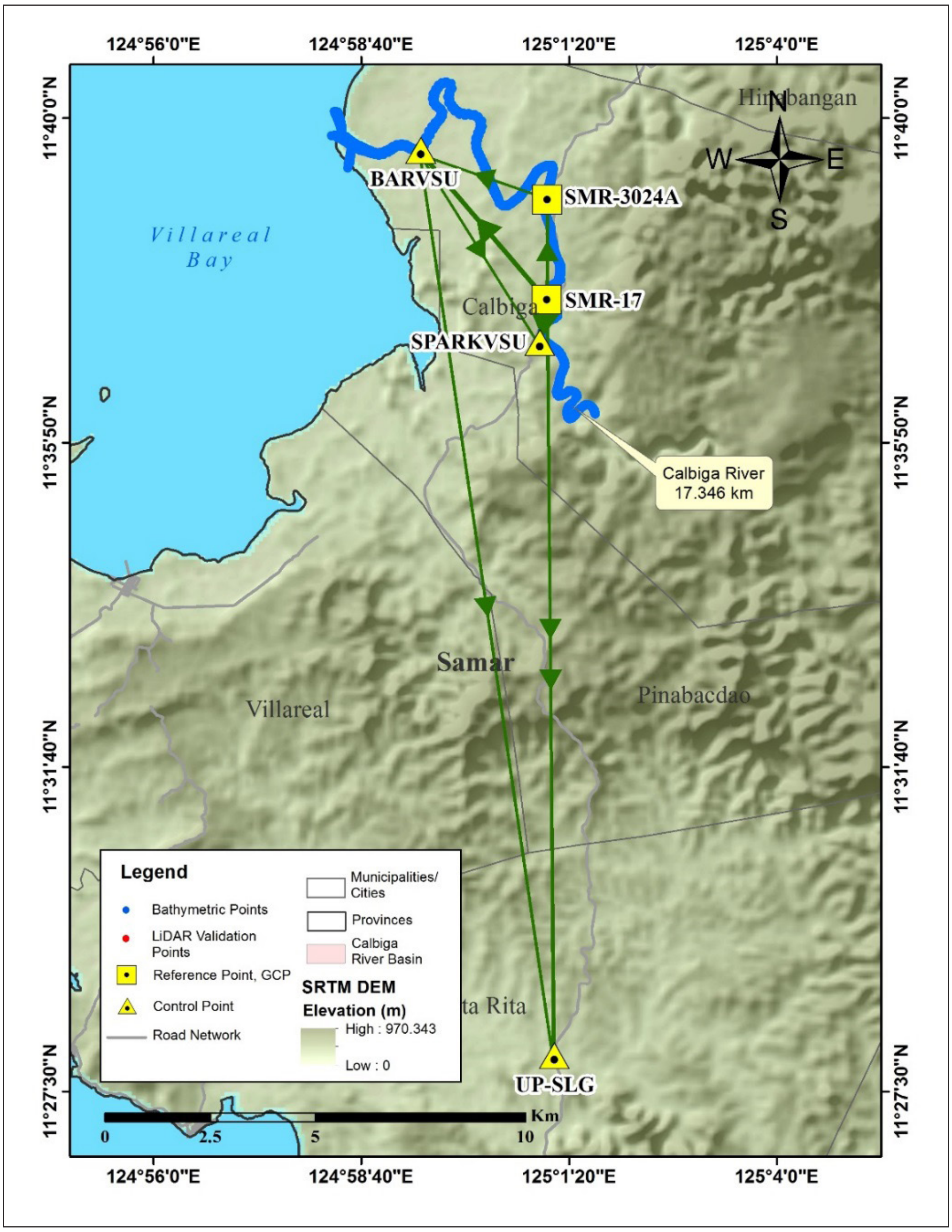



Figure 28. GNSS Network of Calbiga River field survey

Table 20. List of reference and control points occupied for Calbiga River Survey
(Source: NAMRIA, UP-TCAGP, VSU)

| Control Point | Order of Accuracy | Geographic Coordinates (WGS 84) | | | | |
|---|---|---|---|---|---|---|
| | | Latitude | Longitude | Ellipsoidal Height (m) | MSL Elevation (m) | Date Established |
| VSU Control Survey on September 7 & 10, 2015 | | | | | | |
| SMR-17 | 2sd Order, GCP | 11°37'39.96040 N | 125°01'03.14253" E | 72.351 | 10.153 | 2001 |
| UP-SLG | UP Established | 11°27'57.59924" | 125°01'08.87419" | 73.097 | 9.977 | 9-7-2015 |
| BARVSU | VSU Established | 11d39'35.28570" | 124d59'25.89204" | 64.121 | 1.636 | 9-7-2015 |
| Control Survey on April 14, 2016 | | | | | | |
| SMR-17 | 2sd Order, GCP | 11°37'39.96040 N | 125°01'03.14253" E | 72.351 | 10.153 | 2001 |
| UP-SLG | UP Established | - | - | 73.097 | 9.977 | 9-7-2015 |
| SMR-3024A | Used as Marker | - | - | - | - | 2001 |
| BARVSU | VSU Established | - | - | -- | - | 9-7-2015 |
| SPARKVSU | VSU Established | - | - | - | - | 9-7-2015 |

The GNSS set up made in the location of the reference and control points are exhibited are shown in Figure 29 to Figure 32.


Figure 29. GNSS base set up, Trimble® SPS 985, at SMR-17, located in Brgy. Macaalan, Municipality of Calbiga, Samar


Figure 30. GNSS base set up, Trimble® SPS 855, at UP-SLG, located at the approach of the left side of Silaga Bridge in Brgy. Tominamos, Municipality of Santa Rita, Samar


Figure 31. GNSS base set up, Trimble® SPS 855, at SMR-3024A, located at the approach of the entrance gate of Canticum Elementary School in Brgy. Canticum, Municipality of Calbiga, Samar


Figure 32. GNSS base set up, Trimble® SPS 855, at BARVSU, located at one of the corners of the Barangay Basketball Court in Brgy. Barobaybay, Municipality of Calbiga, Samar

## 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 Calbiga River Basin is summarized in Table 21 generated by TBC software.

Table 21. Baseline Processing Report for Calbiga River Basin Static Survey

| Observation | Date of Observation | Solution Type | H. Prec. (Meter) | V. Prec. (Meter) | Geodetic Az. | Ellipsoid Dist. (Meter) |
|---|---|---|---|---|---|---|
| SMR-3024A ---BARVSU | 4-14-2016 | Fixed | 0.004 | 0.021 | 291°38’52” | 3178.598 |
| SMR-3024A --- SMR-17 | 4-14-2016 | Fixed | 0.004 | 0.018 | 0°12’52” | 2371.243 |
| BARVSU --- UP-SLG | 4-14-2016 | Fixed | 0.006 | 0.035 | 171°42’58” | 21664.016 |
| BARVSU--- SPARKVSU | 4-14-2016 | Fixed | 0.005 | 0.018 | 148°36’53” | 5333.606 |
| SMR-17--- UP-SLG | 4-14-2016 | Fixed | 0.007 | 0.037 | 179°26’38” | 17895.306 |
| SPARKVSU --- SMR-17 | 4-14-2016 | Fixed | 0.003 | 0.005 | 189°27’45” | 1023.597 |
| SMR-17 --- BARVSU | 4-14-2016 | Fixed | 0.004 | 0.023 | 320°16’03” | 4608.119 |
| BARVSU--- SMR-17 | 4-14-2016 | Fixed | 0.006 | 0.009 | 320°16’03” | 4608.123 |
| SMR-3024A --- UP-SLG | 4-14-2016 | Fixed | 0.007 | 0.042 | 179°32’02” | 20266.356 |

As shown in Table 21, a total of nine (9) baselines were processed with reference points SMR-17 fixed for grid and elevation values. All of them passed the required accuracy.

## 4.4 Network Adjustment

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

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

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 22 to Table 24 for the complete details.

The four (5) control points, SMR-17, UP-SLG, SMR-3024A, BARVSU and SPARKVSU, were occupied and observed simultaneously to form a GNSS loop. Elevation value and coordinates of SMR-17 were held fixed during the processing of the control points as presented in Table 22. Through these reference points, the coordinates and elevation of the unknown control points will be computed.

Table 22. Control Point Constraints

| Point ID | Type | East σ (Meter) | North σ (Meter) | Height σ (Meter) | Elevation σ (Meter) |
|---|---|---|---|---|---|
| SMR-17 | Grid | Fixed | Fixed | | Fixed |
| Fixed = 0.000001(Meter) | | | | | |

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 23. The fixed control point SMR-17 has no values for grid and elevation errors.

Table 23. Adjusted Grid Coordinates

| Point ID | Easting (Meter) | Easting Error (Meter) | Northing (Meter) | Northing Error (Meter) | Elevation (Meter) | Elevation Error (Meter) | Constraint |
|---|---|---|---|---|---|---|---|
| BARVSU | 716995.085 | 0.004 | 1289697.624 | 0.003 | 1.592 | 0.019 | |
| SMR-17 | 719966.306 | ? | 1286174.169 | ? | 10.153 | ? | ENe |
| SMR-3024A | 719958.330 | 0.005 | 1288545.870 | 0.004 | 2.942 | 0.031 | |
| SPARKVSU | 719805.163 | 0.004 | 1285163.131 | 0.004 | 20.456 | 0.019 | |
| UP-SLG | 720266.262 | 0.007 | 1268277.803 | 0.005 | 9.977 | 0.048 | |

The network is fixed at reference point SMR-17 with known coordinates and with known elevation. As shown in Table 23, the standard errors ($x_e$ and $y_e$) of BARVSU are 0.40 cm and 0.30 cm; SMR-3024A are 0.50 cm and 0.40 cm; SPARKVSU are 0.40 cm and 0.40cm; and UP-SLG are 0.70 cm and 0.50 cm. With the mentioned equation, for horizontal and for the vertical; the computation for the accuracy are as follows:

a. **SMR-17**

horizontal accuracy = Fixed

vertical accuracy = Fixed

b. **UP-SLG**

horizontal accuracy = $\sqrt{((0.70)^2 + (0.50)^2}$

= $\sqrt{(0.49 + 0.25)}$

= 0.86 cm < 20 cm

vertical accuracy = 4.8 cm < 10 cm

c. **SMR-3024A**

horizontal accuracy = $\sqrt{((0.50)^2 + (0.40)^2}$

= $\sqrt{(0.25 + 0.16)}$

= 0.64cm < 20 cm

vertical accuracy = 3.1cm < 10 cm

d. **BARVSU**

horizontal accuracy = $\sqrt{((0.40)^2 + (0.30)^2}$

= $\sqrt{(0.16 + 0.09)}$

= 0.5 cm < 20 cm

vertical accuracy = 1.9 < 10 cm

e. **SPARKVSU**

horizontal accuracy = $\sqrt{((0.40)^2 + (0.40)^2}$

= $\sqrt{(0.16 + 0.16)}$

= 0.57 cm < 20 cm

vertical accuracy = 1.9 cm < 10 cm

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

Table 24. Adjusted Geodetic Coordinates

| Point ID | Latitude | Longitude | Ellipsoidal Height (Meter) | Height Error (Meter) | Constraint |
|---|---|---|---|---|---|
| SMR-17 | N11°37'39.96040" | E125°01'03.14253" | 72.836 | ? | ENe |
| UP-SLG | N11°27'57.59924" | E125°01'08.87419" | 73.097 | 0.048 | |
| SMR-3204A | N11°38'57.12960" | E125°01'03.43562" | 65.558 | 0.031 | |
| BARVSU | N11°39'35.28567" | E124°59'25.89214" | 64.076 | 0.019 | |
| SPARKVSU | N11°37'07.10168" | E125°00'57.58733" | 83.162 | 0.019 | |

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 24. Based on the result of the computation, the equation is satisfied; hence, the required accuracy for the program was met.

The summary of reference and control points used is indicated in Table 25.

Table 25. Reference and control points used and its location (Source: NAMRIA, UP-TCAGP and VSU)

| Control Point | Order of Accuracy | Geographic Coordinates (WGS 84) | | | UTM ZONE 51 N | | |
|---|---|---|---|---|---|---|---|
| | | Latitude | Longitude | Ellipsoidal Height (m) | Northing (m) | Easting (m) | BM Ortho (m) |
| SMR-17 | 2sd Order, GCP | 11°37'39.9604"N | 125°01'03.1425"E | 72.836 | 1286226.990 | 719812.920 | 10.153 |
| UP-SLG | UP Established | 11°27'57.5992"N | 125°01'08.8741"E | 73.097 | 1268277.803 | 720266.262 | 9.977 |
| SMR-3204A | Used as Marker | 11°38'57.1296"N | 125°01'03.4356"E | 65.558 | 1288545.870 | 719958.330 | 2.942 |
| BARVSU | VSU Established | 11°39'35.2856"N | 124°59'25.8921"E | 64.076 | 1289697.624 | 716995.085 | 1.592 |
| SPARKVSU | VSU Established | 11°37'07.1016"N | 125°00'57.5873"E | 83.162 | 1285163.131 | 719805.163 | 20.456 |

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

Cross-section survey was conducted at the deployment site in Brgy. Macaalan, Municipality of Calbiga, on April 12, 2016 using a GNSS receiver, Trimble® SPS 882, in PPK survey technique. The area identified by Visayas State University for their flow data gathering is a non-bridge location as shown in Figure 33.


Figure 33. Cross-Section Survey for Calbiga River

The cross-sectional line length of the deployment site is about 95.843 m with 60 cross-sectional points acquired using SMR-17 as the GNSS base station. The location map of the Calbiga cross-section survey and cross-section diagram are illustrated in Figure 34 and Figure 35.

Water surface elevation in MSL of Calbiga River was determined using Trimble® SPS 882 in PPK mode technique on April 12, 2016 at 12:13 PM with a value of 0.464 m in MSL. This will be translated onto marking by the VSU after the renovation of the dike. The markings will serve as their reference for flow data gathering and depth gauge deployment for Calbiga River.

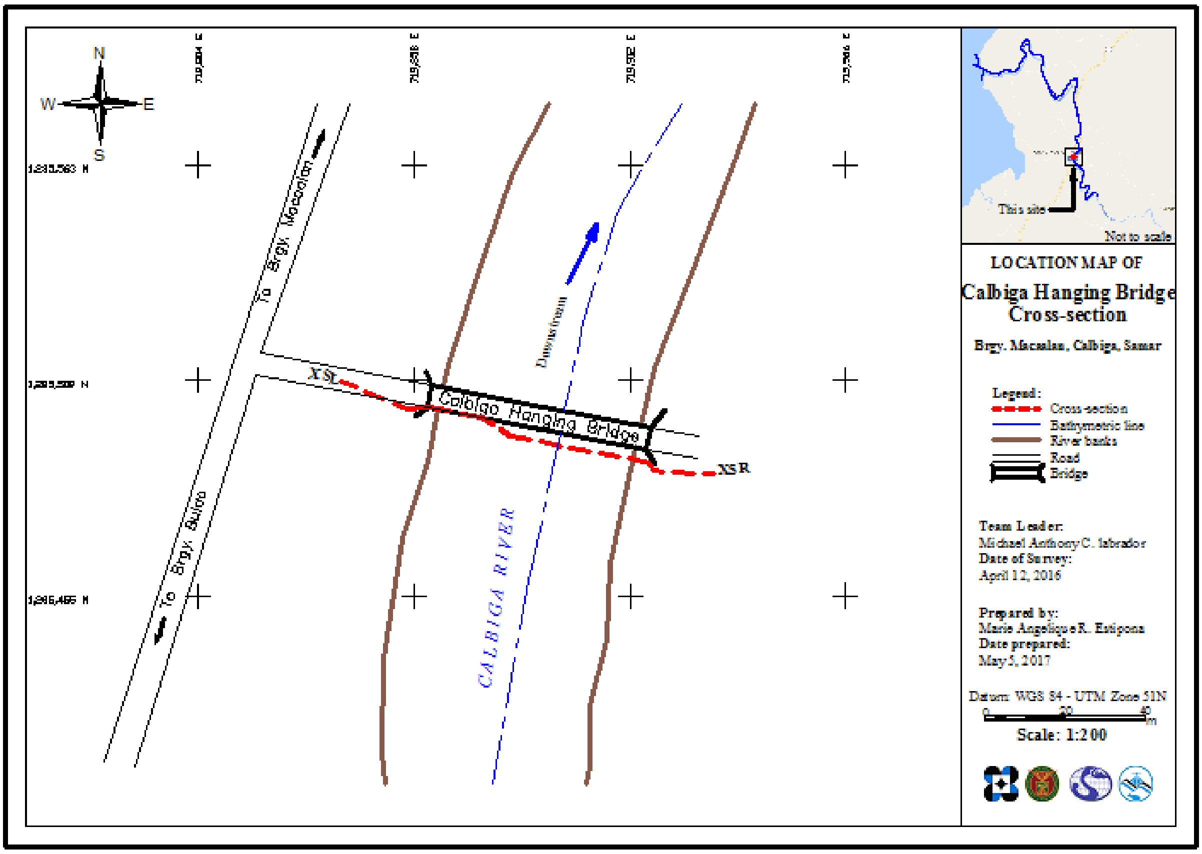



Figure 34. Location map of Calbiga cross-section survey

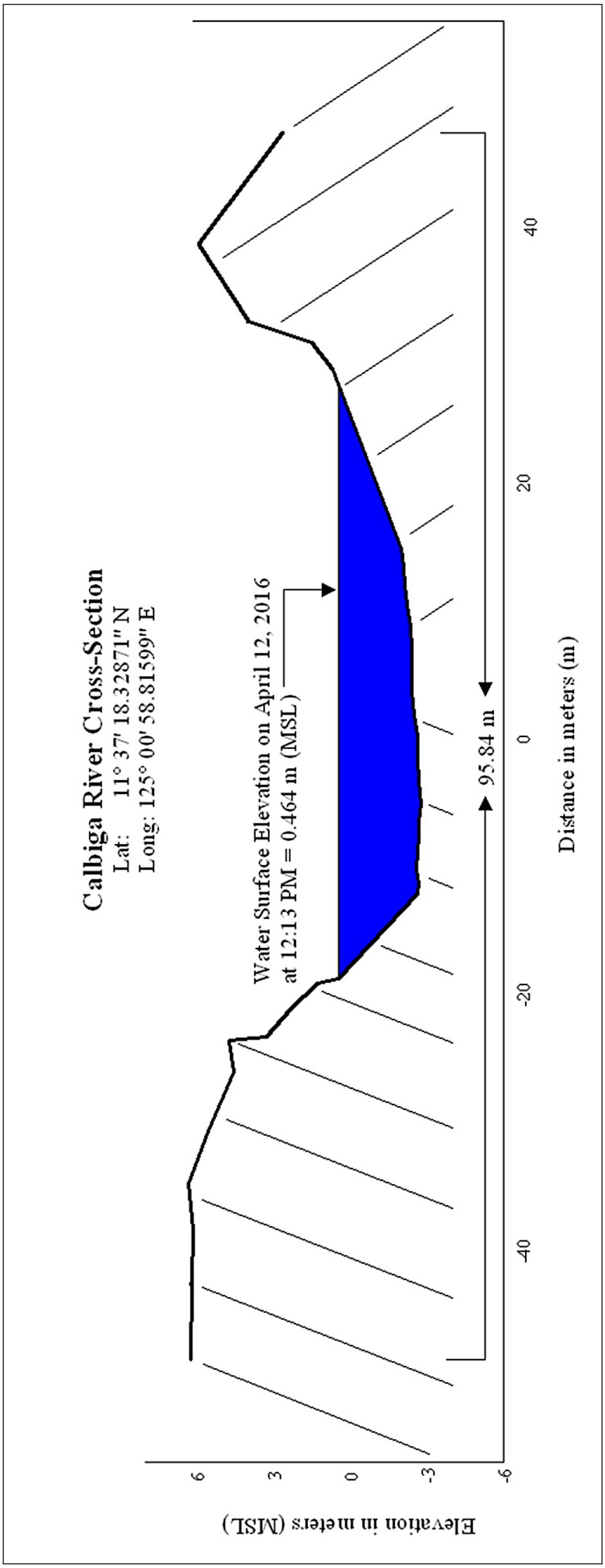



Figure 35. Calbiga River Cross-section Diagram

## 4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on April 11, 2016 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted on a pole which was attached to the side of vehicle as shown in Figure C-10. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The antenna height was 2.089 m and measured from the ground up to the bottom of notch of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with SMR-17 occupied as the GNSS base stations in the conduct of the survey.


Figure 36. Validation points acquisition survey set up

The survey started from Brgy. Patag in the Municipality of Paranas, going south towards the municipalities of Hinabangan, Hinundayan, Calbiga and ended in Brgy. Pasigay, Municipality of Calbiga. This route aims to cut flight strips perpendicularly. The survey gathered 6,176 points with approximate length of 53.44 km using SMR-17 as GNSS base for the entire extent validation points acquisition survey, as illustrated in the map in Figure 37.

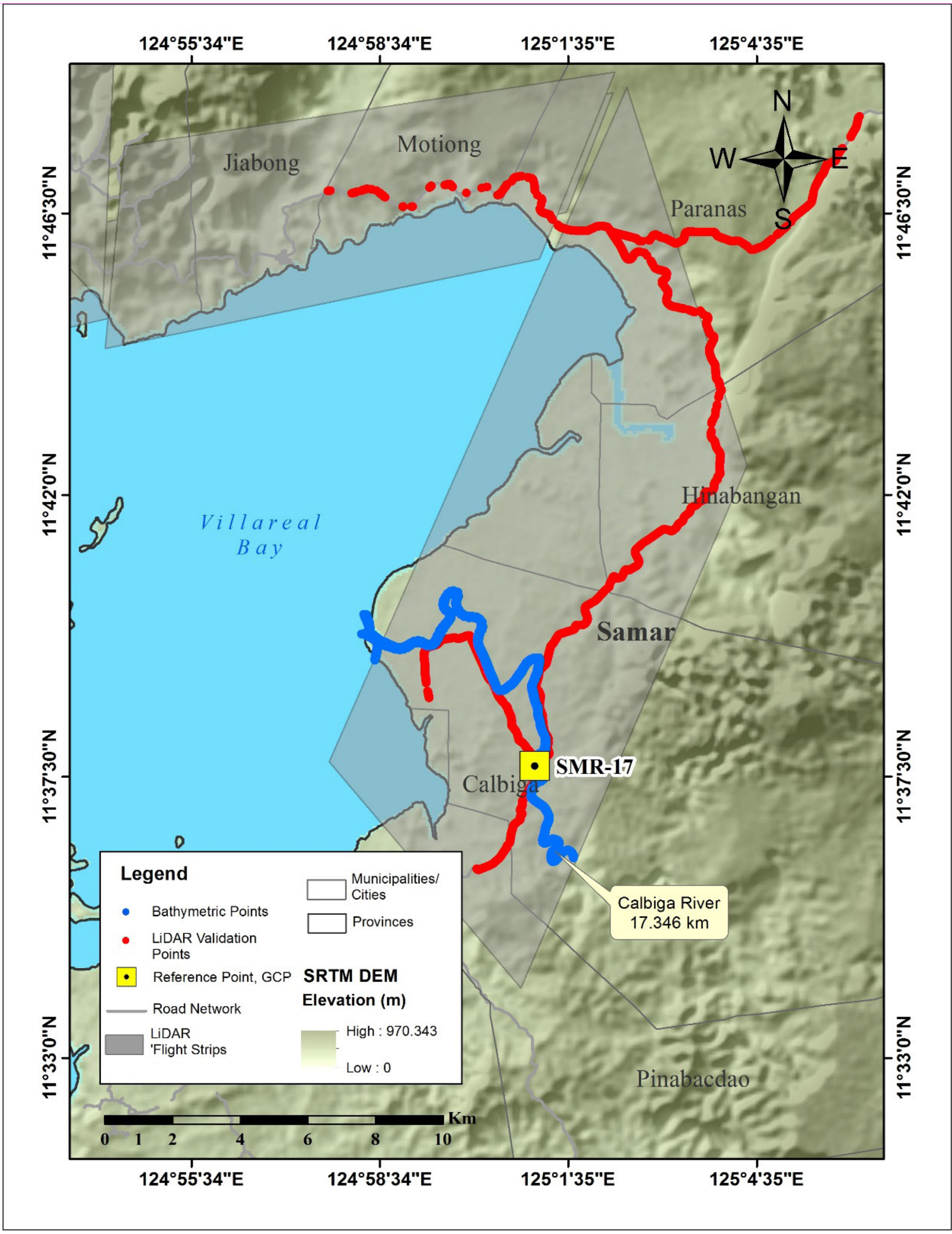



Figure 37. Validation point acquisition survey for the Calbiga River Basin

## 4.7 Bathymetric Survey

Bathymetric survey was executed on September 8-10, 2015 using a Trimble® SPS 882 in GNSS PPK survey technique and Ohmex™ single beam echo sounder, as illustrated in Figure C-12. The extent of the survey is from the upstream in Brgy Otoc, Municipality of Calbiga with coordinates 11°36’11.89402”N, 125°01’40.33722”E, down to the mouth of the river in Brgy. Barabaybau, also in Calbiga with coordinates 11°39’46.73581”N, 124°58’17.13663”E, as shown in the map in Figure 39.


Figure 38. Bathymetry by boat set up for Calbiga River survey

A CAD drawing was also produced to illustrate the riverbed profile of Calbiga River. As shown in Figure 40 and Figure 41, the highest and lowest elevation has a 26-meter difference. The highest elevation observed was -0.528 m above MSL located at the upstream portion of the river in Brgy. Otoc while the lowest was -11.592 m below MSL located at the mid portion of the river in Brgy. Macaalan, both in Municipality of Calbiga. The bathymetric survey gathered a total of 23,457 points covering 17.346 km of the river traversing ten barangays in Municipality of Calbiga. The survey extended the planned bathymetric lines up to Brgy. Otoc as requested by VSU to include the flood prone areas.

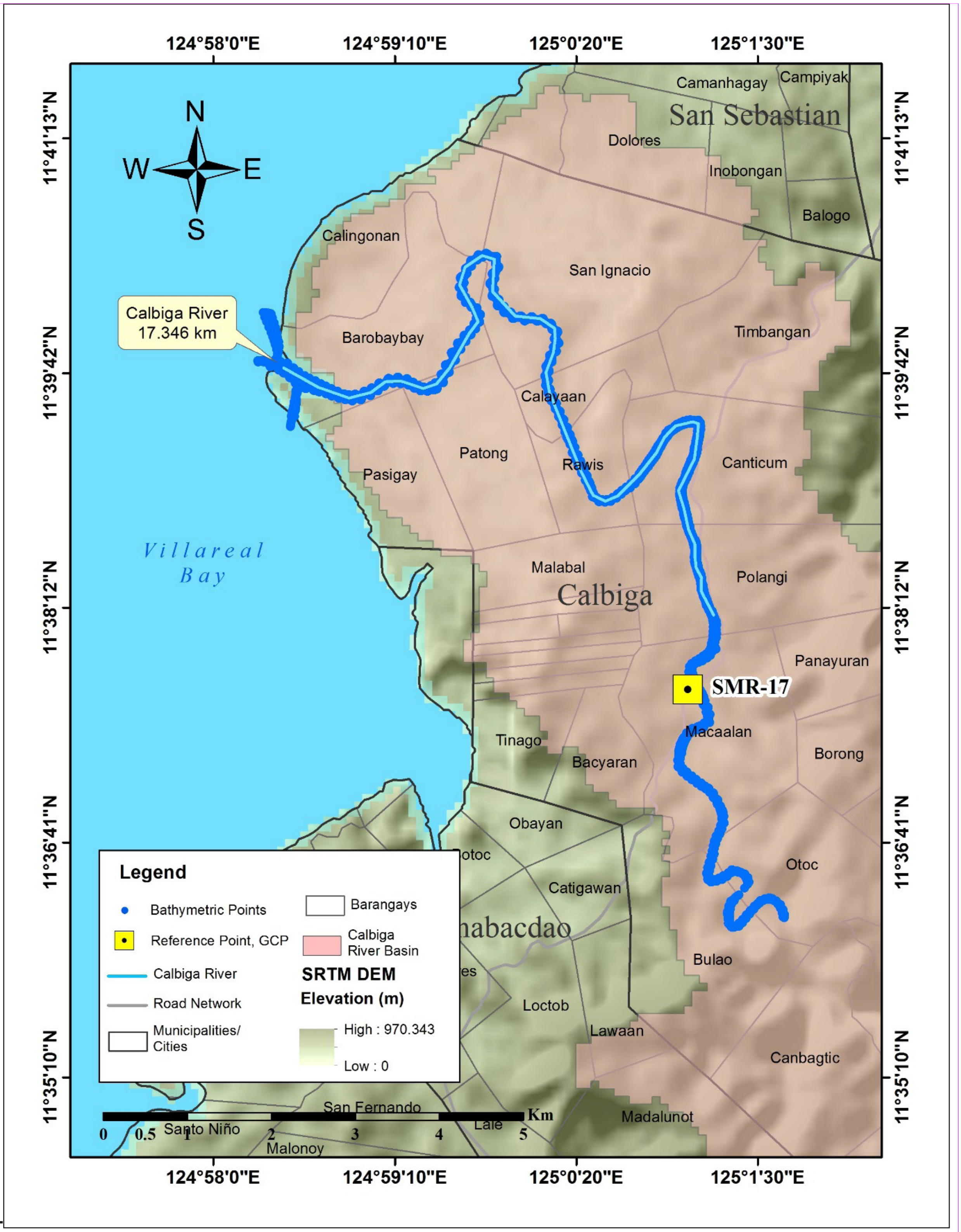



Figure 39. Bathymetric survey of Calbiga River

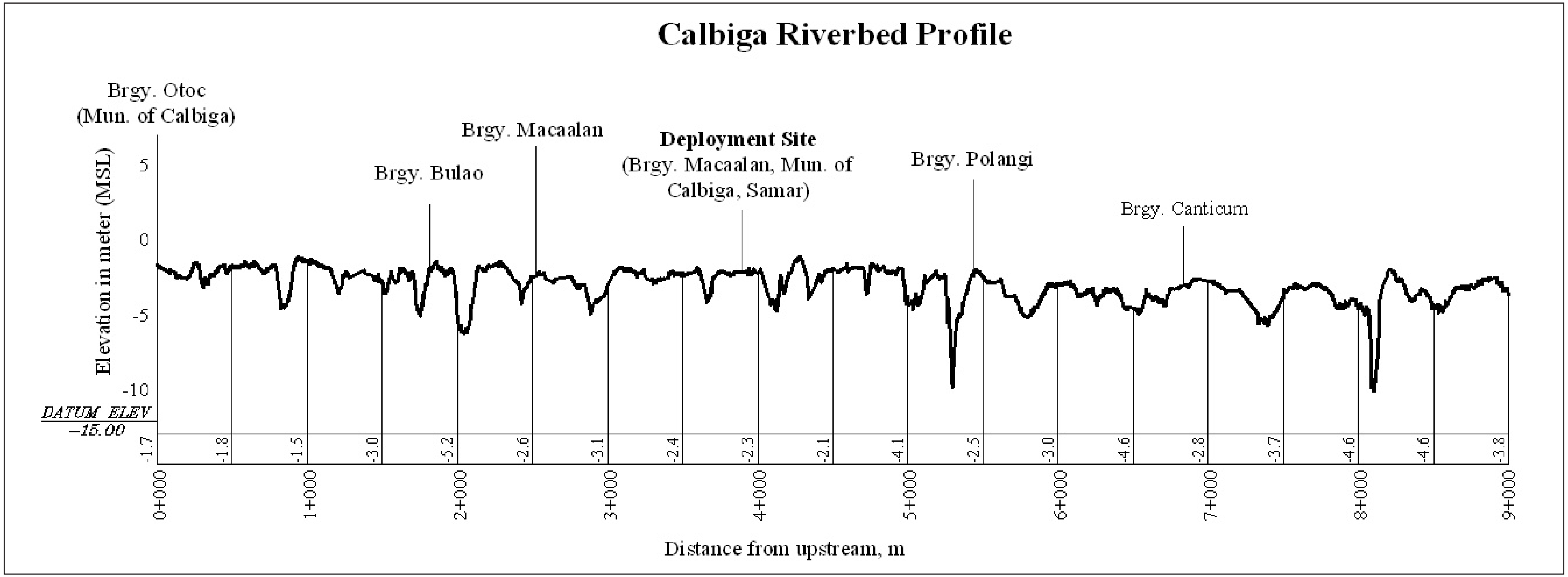



Figure 40. Riverbed profile of Calbiga River (1 of 2)

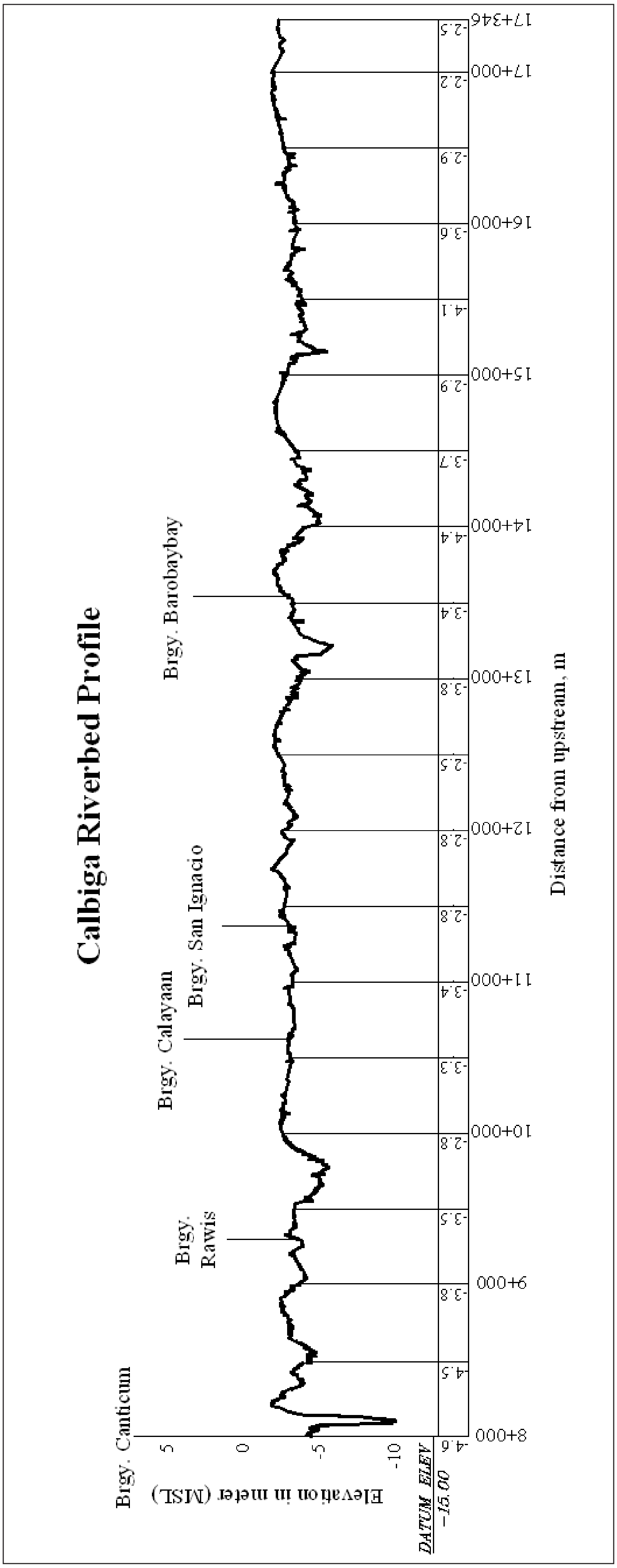



Figure 41. Riverbed profile of Calbiga River (2 of 2)

# 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

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

## 5.1 Data Used for Hydrologic Modeling

### 5.1.1 Hydrometry and Rating Curves

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

### 5.1.2 Precipitation

Precipitation data was taken from the installed rain gauge in Calbiga Eco-Lodge, Calbiga. The location of the rain gauge is seen in Figure 42.

Total rain from Calbiga rain gauge is 138 mm. It peaked to 6.6mm on 06 December 2014, 14:30. A summary of the data is seen in Table 26. The lag time between the peak rainfall and discharge is seven hours and thirty minutes.

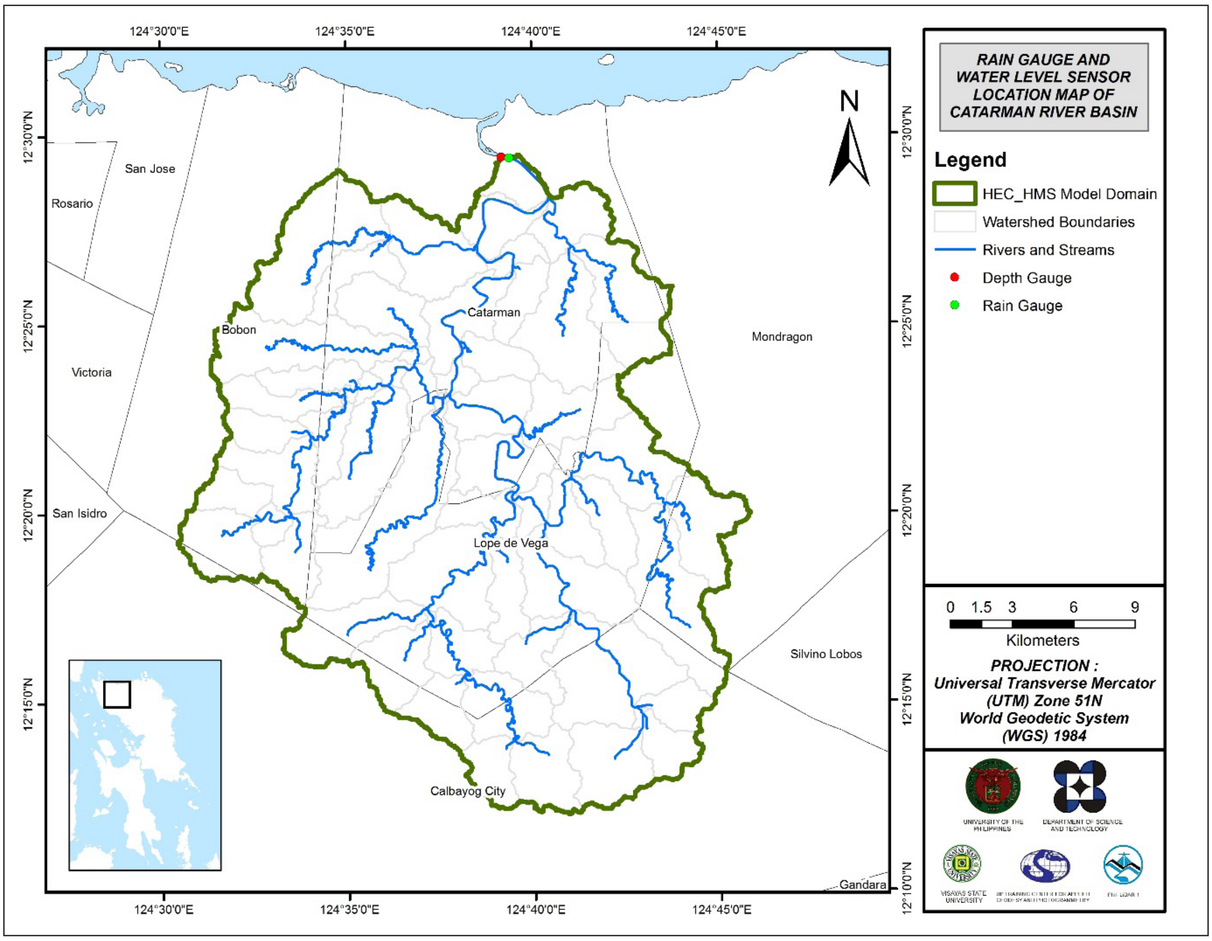



Figure 42. The location map of Calbiga HEC-HMS model used for calibration

### 5.1.3 Rating Curves and River Outflow

A rating curve was developed at Calbiga Hanging Bridge, Calbiga, Samar (11° 37'41.7"N, 125°01'06"E). It gives the relationship between the observed water levels from the Calbiga Bridge Automatic Water Level Sensor (AWLS) and the combined discharge from baseflow and bankfull.

For Calbiga Bridge, the rating curve is expressed as $Q = 0.0688e^{0.7968h}$ as shown in Figure 44.

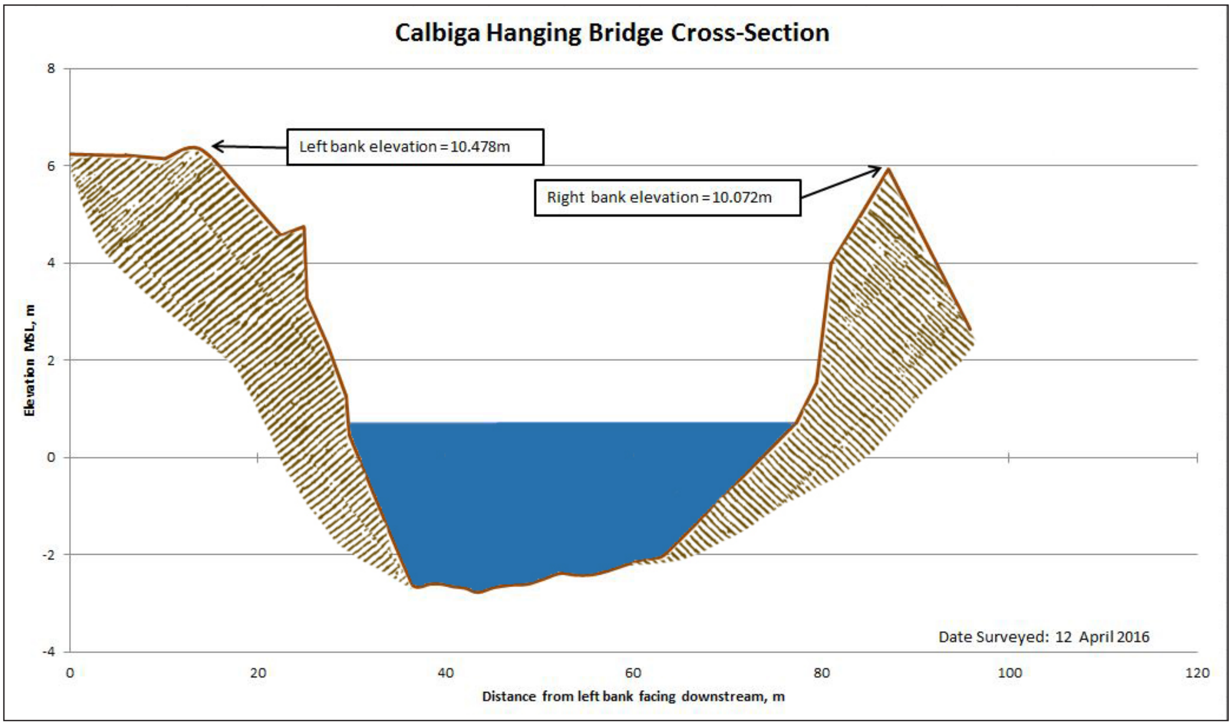



Figure 43. Cross-Section Plot of Calbiga Bridge

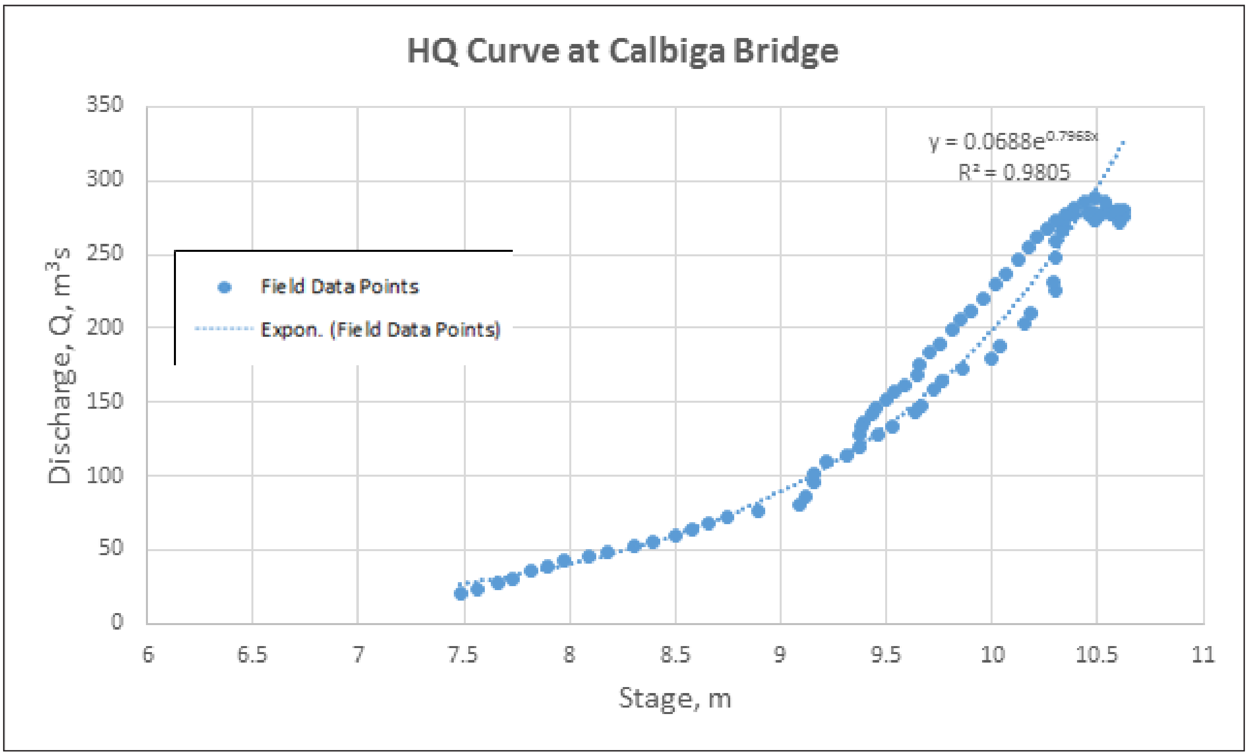



Figure 44. Rating Curve at Calbiga Bridge

This rating curve equation was used to compute the river outflow at Calbiga Bridge for the calibration of the HEC-HMS model shown in Figure 45. Total rain from Calbiga rain gauge is 138 mm. It peaked to 6.6mm on 06 December 2014, 14:30. A summary of the data is seen in Table 26. The lag time between the peak rainfall and discharge is seven hours and thirty minutes.

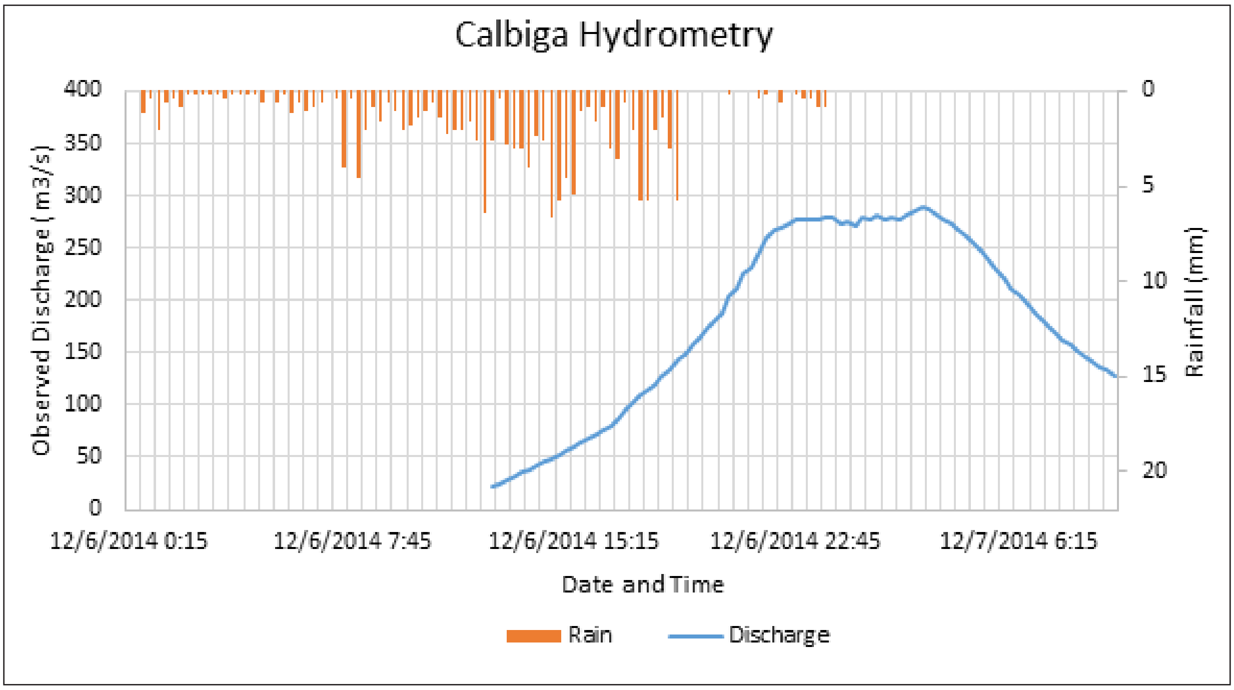



Figure 45. Rainfall and outflow data at Calbiga Bridge used for modeling

## 5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Catbalogan Rain Gauge. The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the value in such a way certain peak value will be attained at a certain time. This station chosen based on its proximity to Catbalogan watershed. The extreme values for this watershed were computed based on a 55-year record.

Table 26. RIDF values for Catbalogan Rain Gauge computed by PAGASA

| COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| T (yrs) | 10 mins | 20 mins | 30 mins | 1 hr | 2 hrs | 3 hrs | 6 hrs | 12 hrs | 24 hrs |
| 2 | 18.5 | 28.1 | 35.6 | 48.1 | 68 | 82.1 | 104.6 | 124.9 | 145 |
| 5 | 25.9 | 38.3 | 63.8 | 63.8 | 90.4 | 108.8 | 137.5 | 165.2 | 190.8 |
| 10 | 30.8 | 45 | 74.2 | 74.2 | 105.3 | 126.5 | 159.3 | 191.9 | 221.2 |
| 15 | 33.5 | 48.8 | 80.1 | 80.1 | 113.7 | 136.5 | 171.5 | 206.9 | 238.4 |
| 20 | 35.5 | 51.5 | 84.2 | 84.2 | 119.6 | 143.5 | 180.1 | 217.5 | 250.4 |
| 25 | 37 | 53.6 | 87.3 | 87.3 | 124.1 | 148.9 | 186.7 | 225.6 | 259.6 |
| 50 | 41.5 | 59.9 | 97.1 | 97.1 | 138.1 | 165.5 | 207.1 | 250.6 | 288.1 |
| 100 | 46.1 | 66.2 | 106.8 | 106.8 | 151.9 | 181.9 | 227.4 | 275.4 | 316.3 |

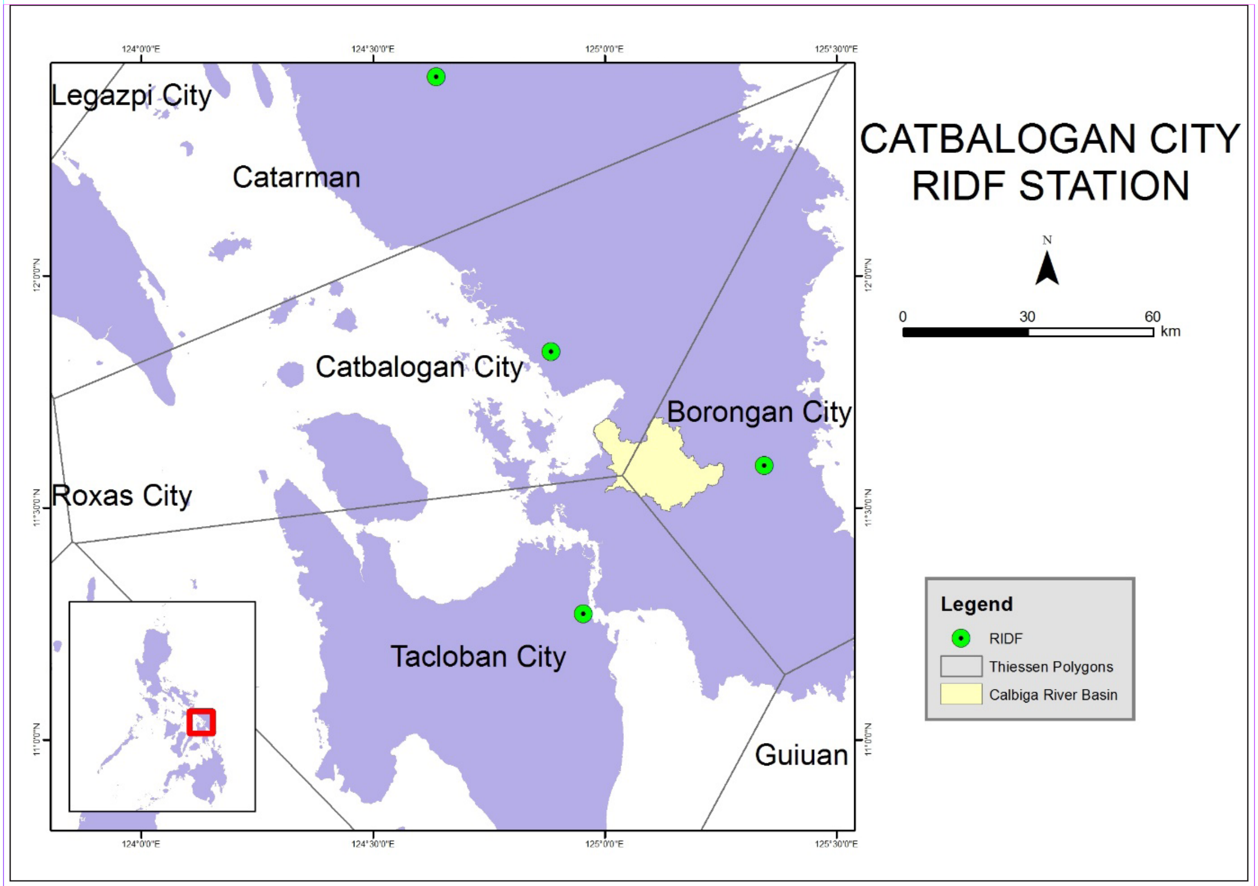



Figure 46. *Location of Catbalogan RIDF station relative to Calbiga River Basin*

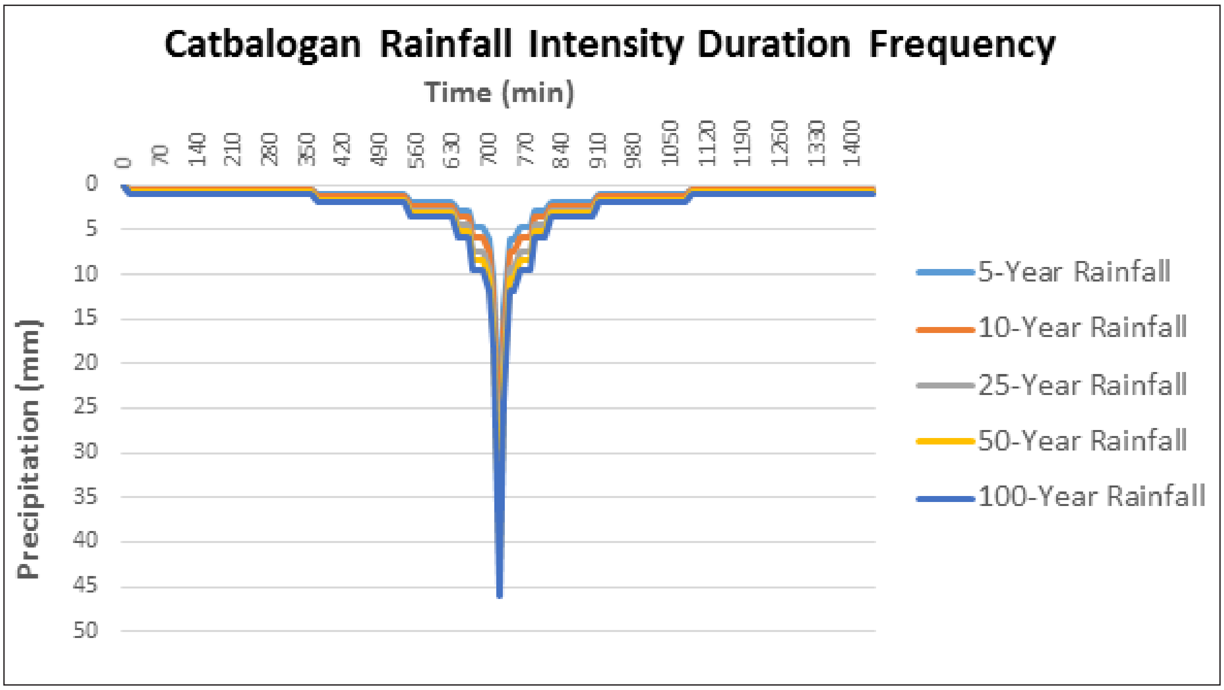



Figure 47. Synthetic storm generated for a 24-hr period rainfall for various return periods

## 5.3 HMS Model

The soil dataset was taken before 2004 from the Bureau of Soils under the Department of Agriculture. The land cover shape file is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Calbiga River Basin are shown in Figure 48 and Figure 49, respectively.

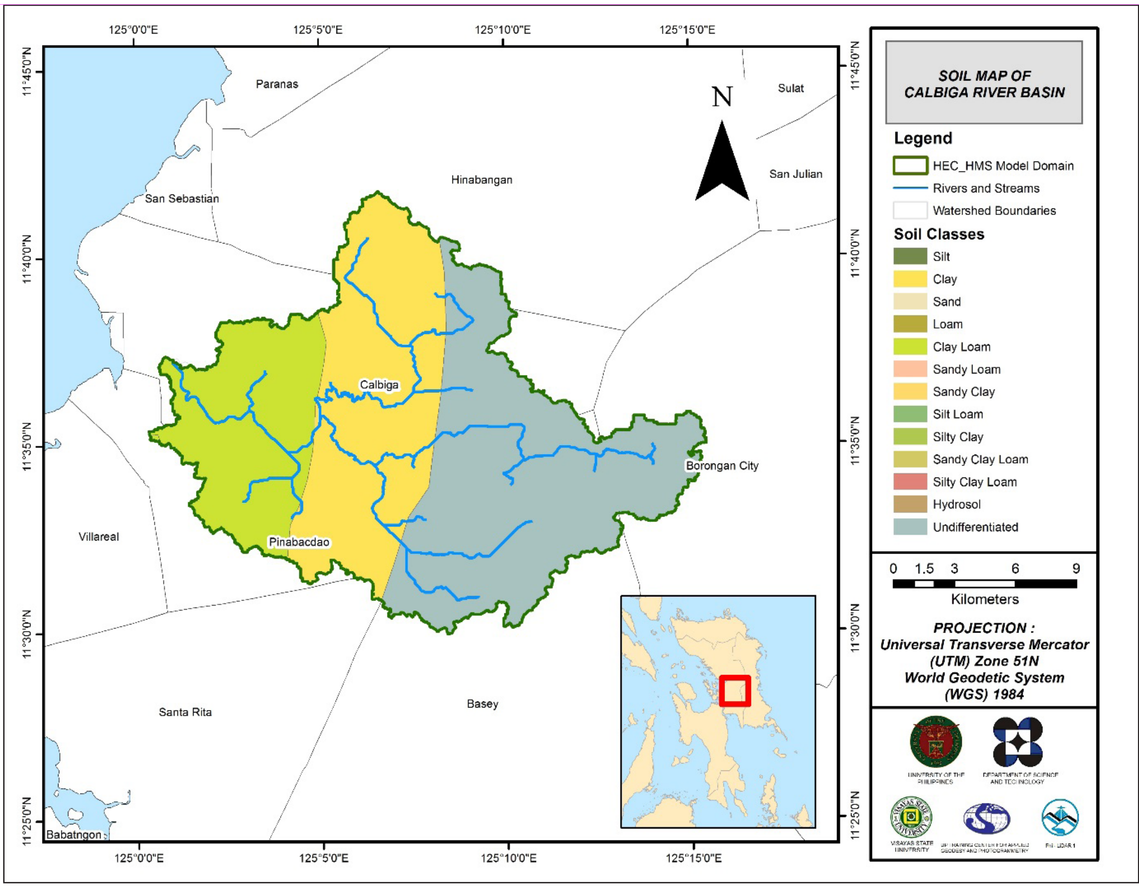



Figure 48. Soil Map of Calbiga River Basin

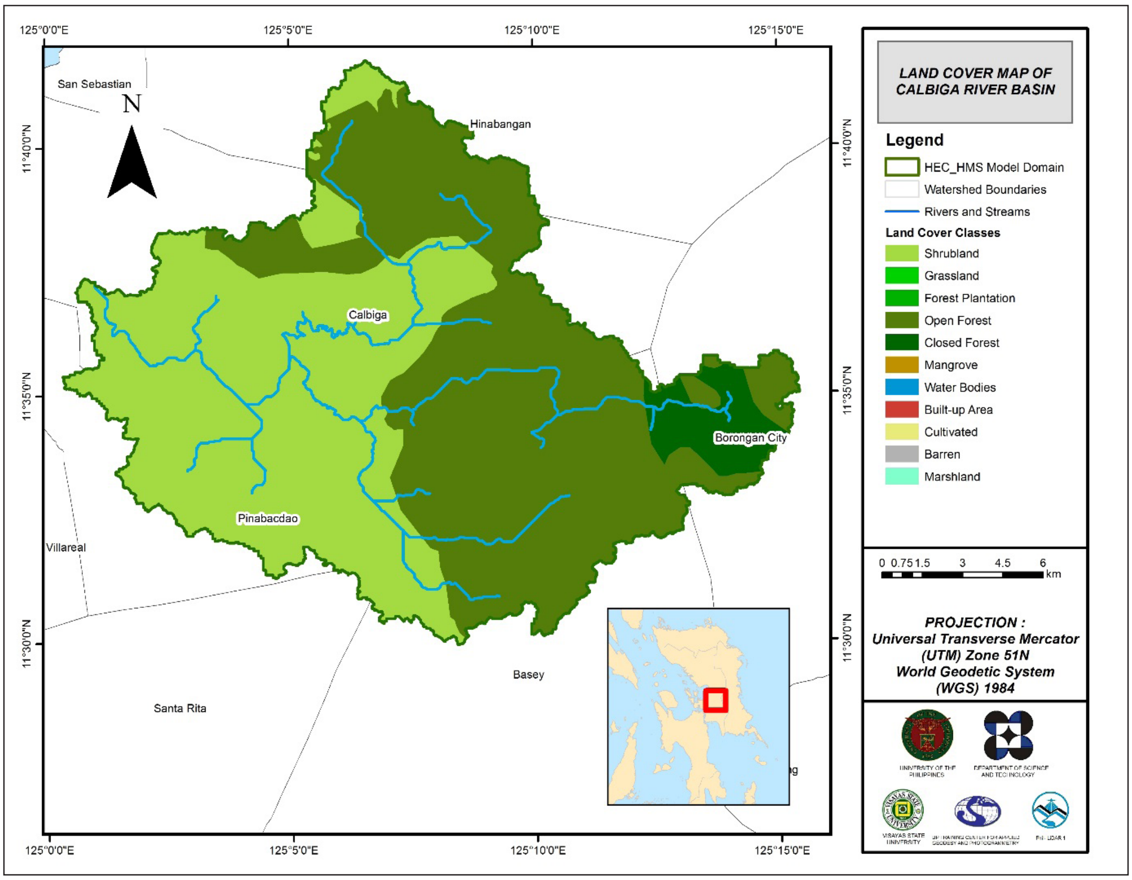



Figure 49. Land Cover Map of Calbiga River Basin

For Calbiga, the soil classes identified were clay, clay loam, and undifferentiated. The land cover types identified were shrubland, open forest, closed forest, and cultivated area.

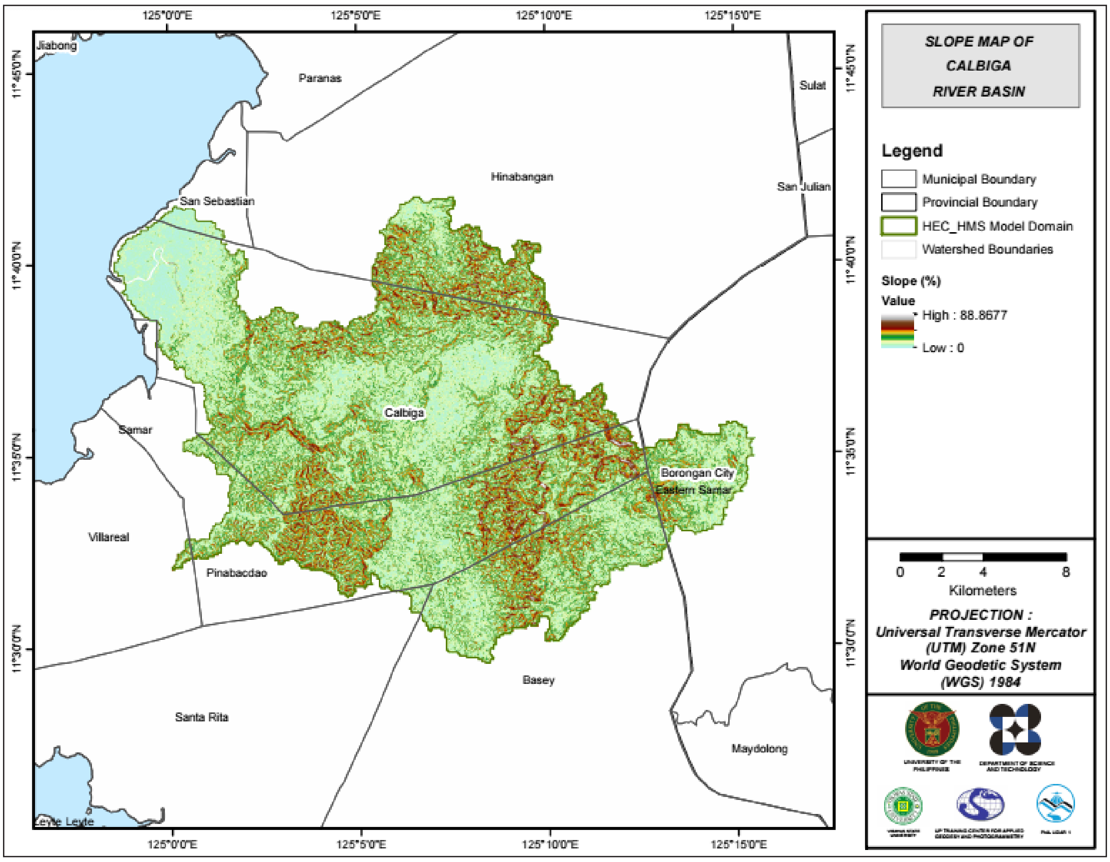



Figure 50. Slope Map of the Calbiga River Basin

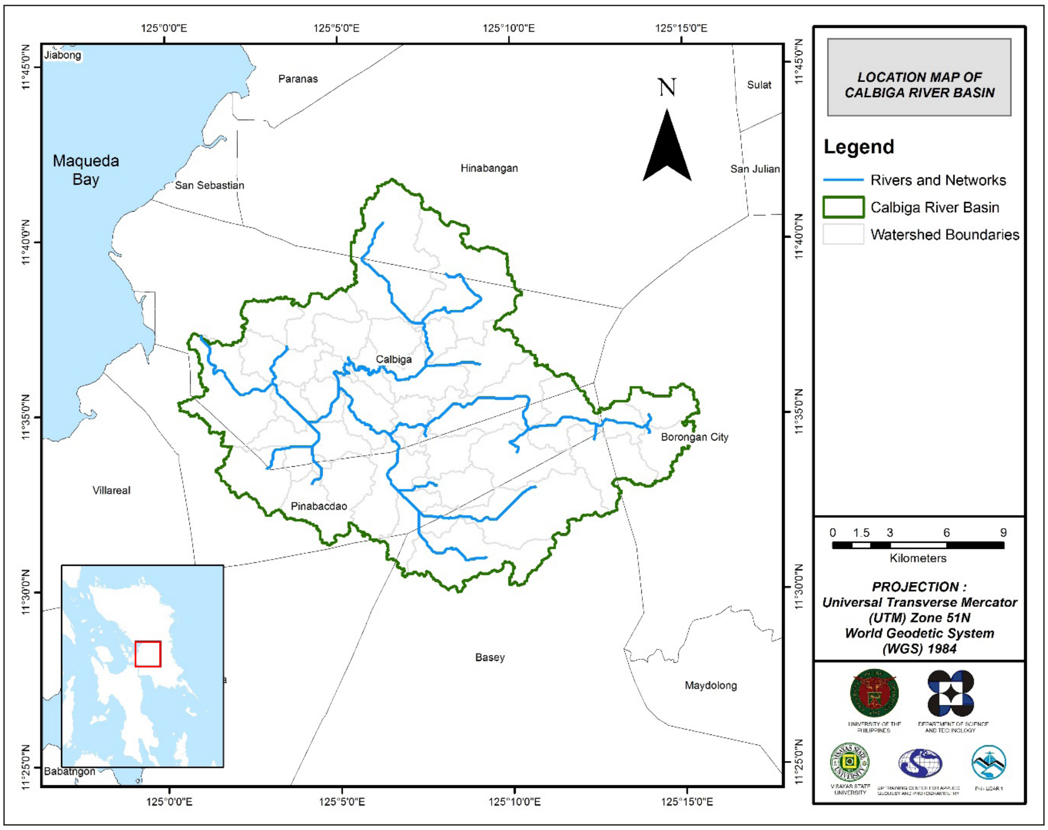



Figure 51. Stream Delineation Map of the Calbiga River Basin

Using the SAR-based DEM, the Calbiga basin was delineated and further subdivided into sub-basins. The model consists of 35 sub basins, 17 reaches, and 35 junctions as shown in Figure 52. The main outlet is at Calbiga Bridge.

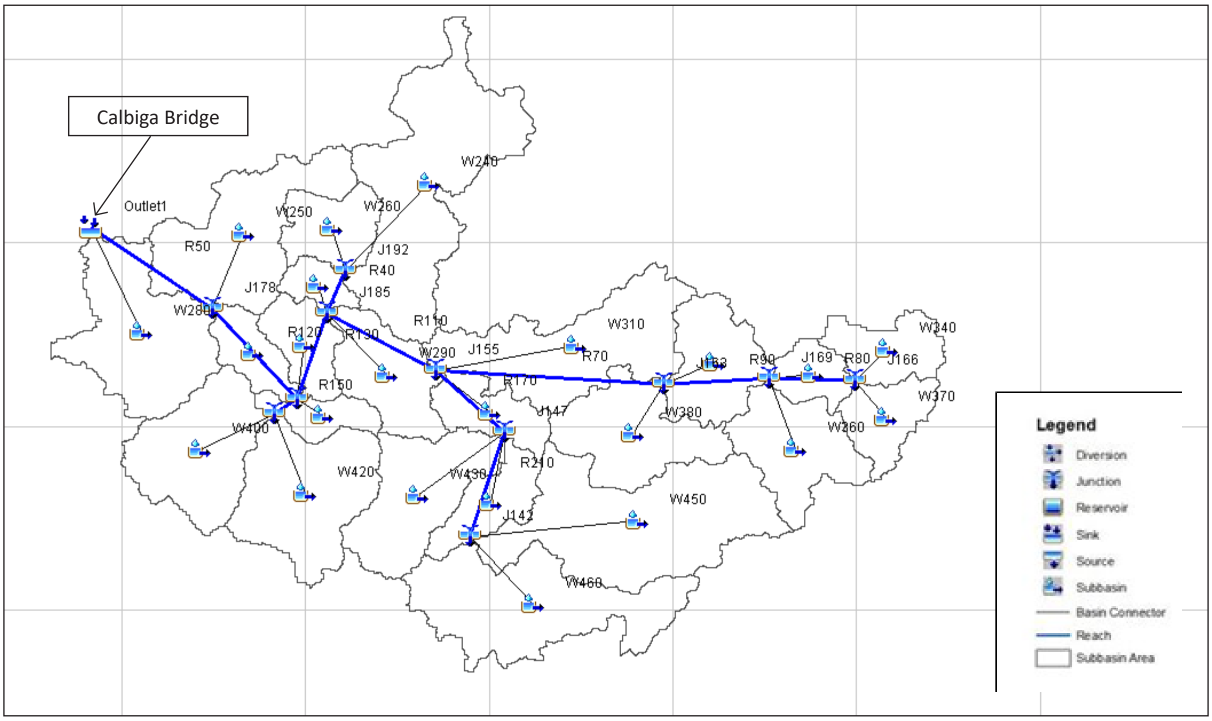



Figure 52. The Calbiga river basin model generated using HEC-HMS

## 5.4 Cross-section Data

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

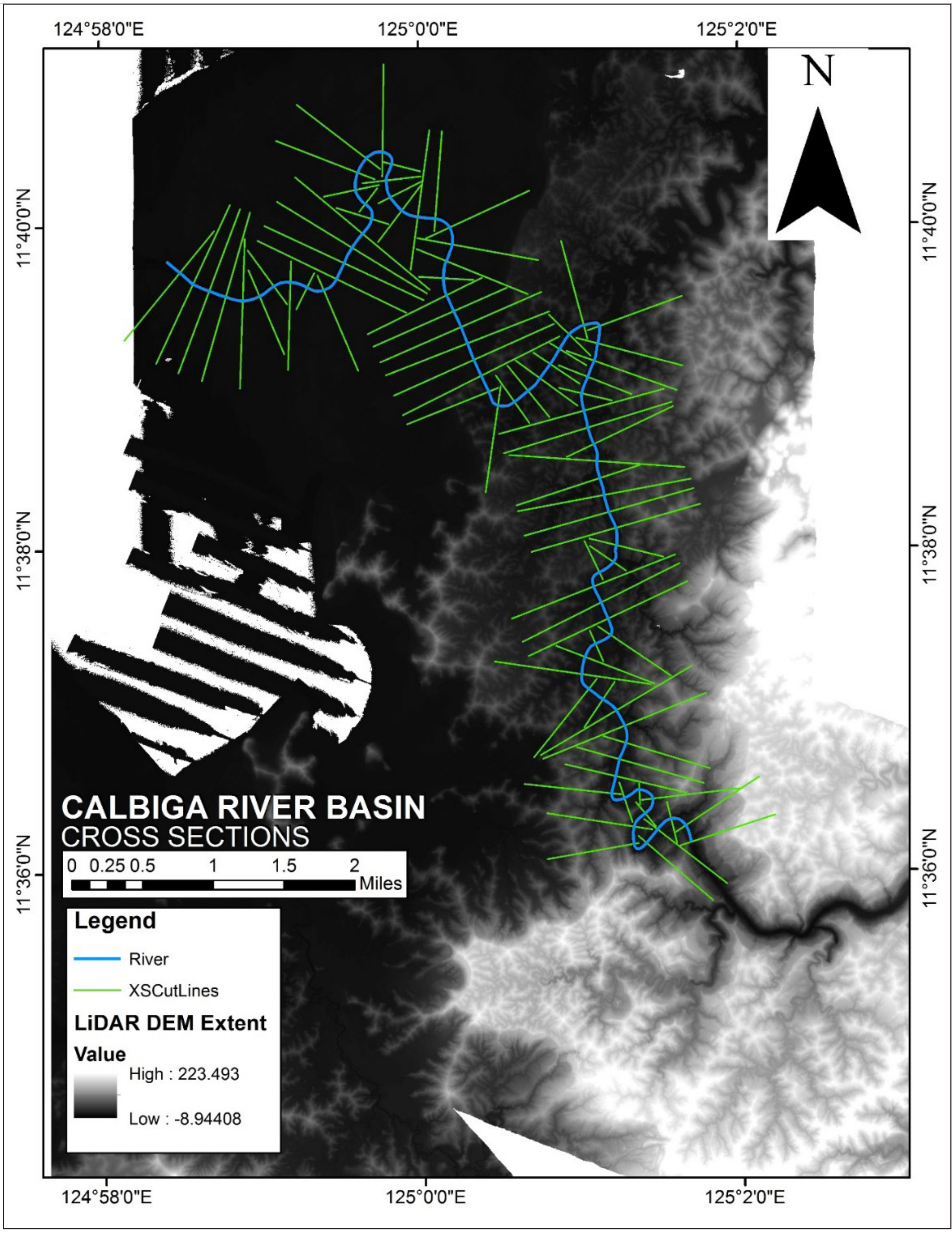



Figure 53. River cross-section of Calbiga River generated through ArcMap HEC GeoRAS tool

## 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 south 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.

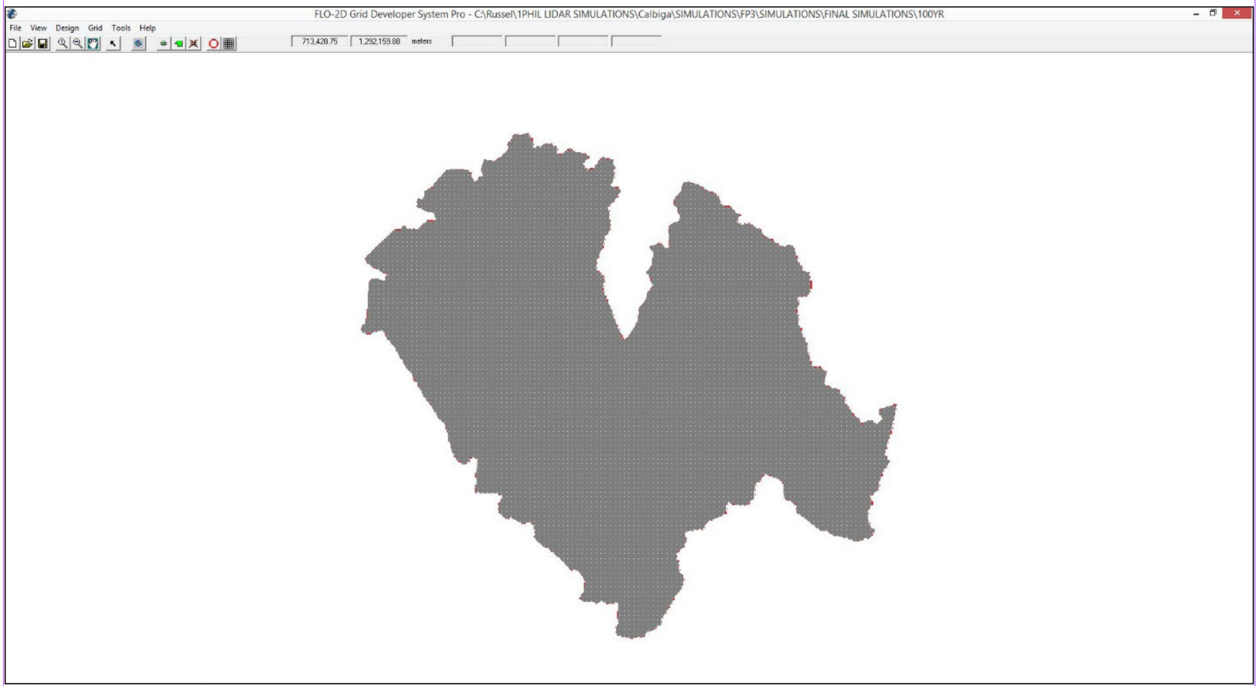


Figure 54. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 46.50610 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 generated hazard maps for Calbiga are in Figure 58, Figure 60, and Figure 62.

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 19 078 000.00 $m^2$. The generated flood depth map for Calbiga are in Figure 59, Figure 61, and Figure 63.

There is a total of 13 468 174.45 $m^3$ of water entering the model. Of this amount, 7 922 604.19 $m^3$ is due to rainfall while 5 545 570.26 $m^3$ is inflow from other areas outside the model. 2 525 722.50 $m^3$ of this water is lost to infiltration and interception, while 3 187 468.59 $m^3$ is stored by the flood plain. The rest, amounting up to 7 754 988.31 $m^3$, is outflow.

## 5.6 Results of HMS Calibration

After calibrating the Calbiga HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 55 shows the comparison between the two discharge data.

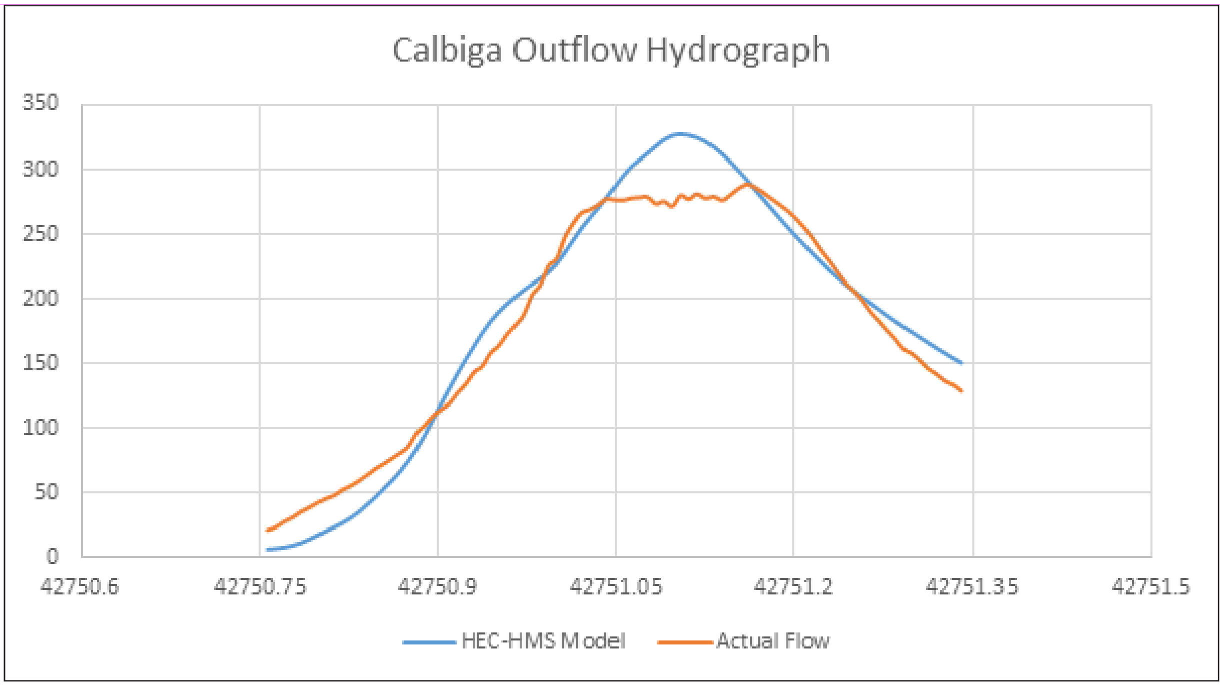



Figure 55. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

Enumerated in Table 27 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 27. Range of Calibrated Values for Calbiga

| Hydrologic Element | Calculation Type | Method | Parameter | Range of Calibrated Values |
|---|---|---|---|---|
| Basin | Loss | SCS Curve number | Initial Abstraction (mm) | 32 - 83 |
| | | | Curve Number | 55 - 75 |
| | Transform | Clark Unit Hydrograph | Time of Concentration (hr) | 0.4 - 3 |
| | | | Storage Coefficient (hr) | 0.2 - 2 |
| | Baseflow | Recession | Recession Constant | 0.01 |
| | | | Ratio to Peak | 1 |
| Reach | Routing | Muskingum-Cunge | Manning's Coefficient | 0.04 |

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 32mm to 83mm means that there is an average amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 55 to 75 for curve number is advisable for Philippine watersheds depending on the soil and land cover of the area (M. Horritt, personal communication, 2012).

Time of concentration and storage coefficient are the travel time and index of temporary storage of runoff in a watershed. The range of calibrated values from 0.4 hours to 3 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant of 0.01 indicates that the basin is likely to quickly go back to its original discharge and instead, will be higher. Ratio to peak of 1 indicates a gentler receding limb of the outflow hydrograph.

Manning's roughness coefficient of 0.04 corresponds to the common roughness of Calbiga watershed, which is determined to be cultivated with mature field crops (Brunner, 2010).

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It computed as 14.8 (m3/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 0.9805.

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 0.94.

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 -2.82.

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 0.25.

Table 28. *Summary of the Efficiency Test of Calbiga HMS Model*

| | |
|---|---|
| **RMSE** | 14.8 |
| **$r^2$** | 0.9805 |
| **NSE** | 0.94 |
| **PBIAS** | -2.82 |
| **RSR** | 0.44 |

## 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 56) shows the Calbiga outflow using the Catbalogan 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.

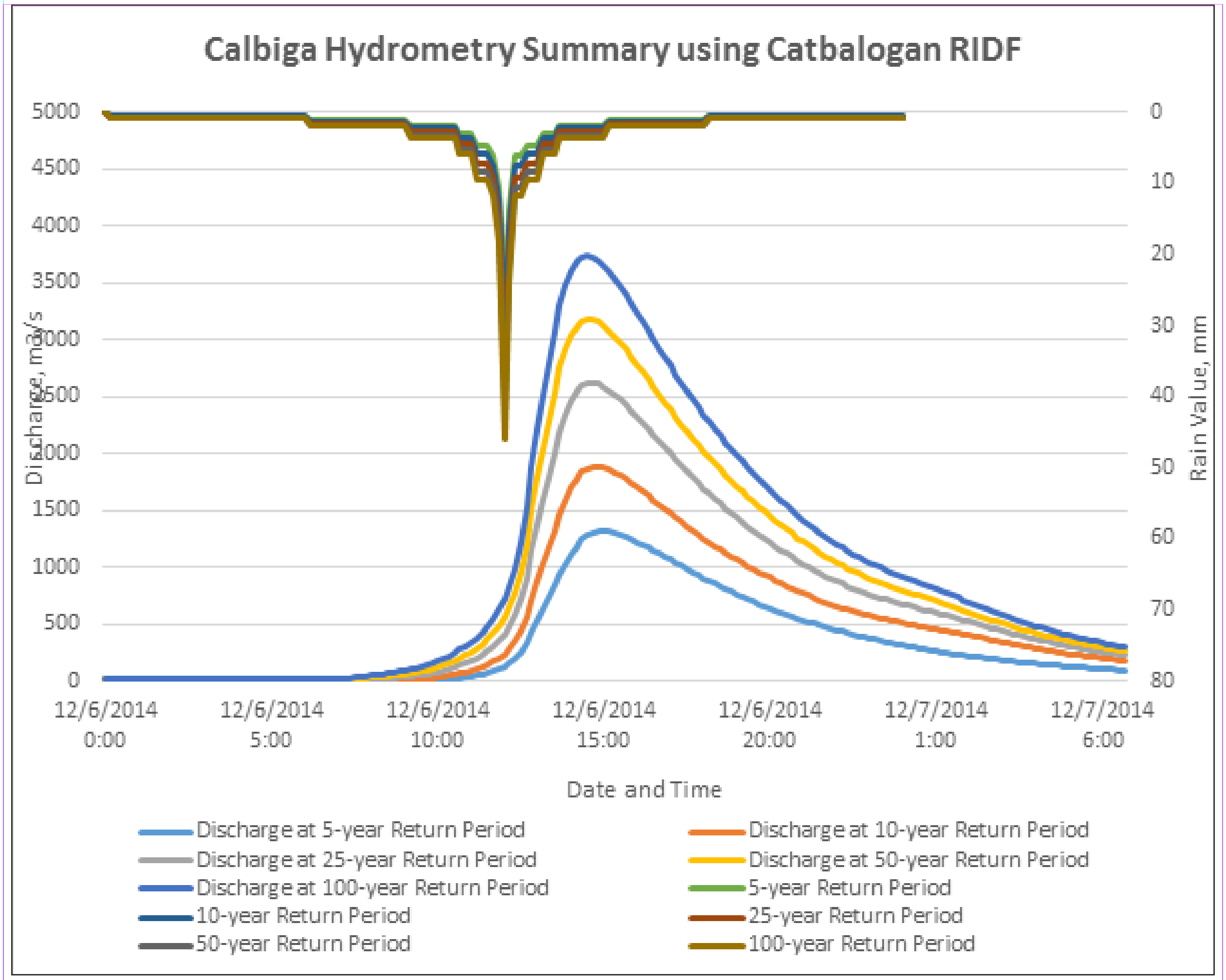



Figure 56. Outflow hydrograph at Calbiga Station generated using Tacloban RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of Calbiga discharge using the Calbiga Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 29.

Table 29. Peak values of the Calbiga HEC-HMS Model outflow using the Tacloban RIDF

| RIDF Period | Total Precipitation (mm) | Peak rainfall (mm) | Peak outflow ($m^3/s$) | Time to Peak |
|---|---|---|---|---|
| 5-Year | 225.3 | 27.2 | 1317.9 | 3 hours |
| 10-Year | 272.1 | 31.8 | 1883.6 | 2 hours, 50 minutes |
| 25-Year | 331.3 | 37.5 | 2621.3 | 2 hours, 40 minutes |
| 50-Year | 375.2 | 41.8 | 3178.4 | 2 hours, 30 minutes |
| 100-Year | 418.8 | 46 | 3733.4 | 2 hours, 30 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, since only the VSU-FMC base flow was calibrated. The sample generated map of Calbiga River using the calibrated HMS base flow is shown in Figure 57.

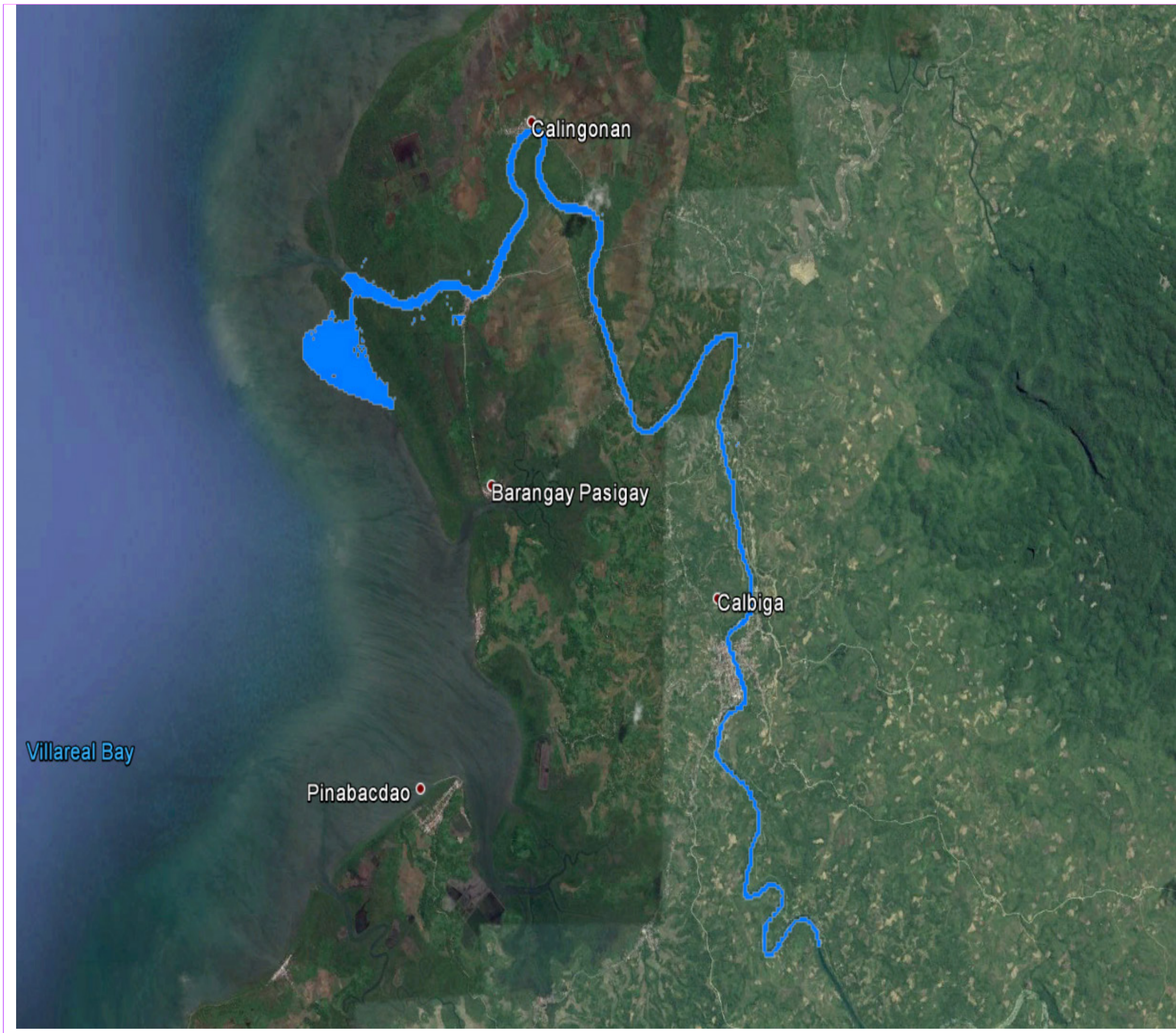



Figure 57. Sample output Calbiga RAS Model

## 5.9 Flood Hazard and Flow Depth Map

The resulting hazard and flow depth maps have a 10m resolution. Figure 58 to Figure 63 shows the 5-, 25-, and 100-year rain return scenarios of the Calbiga floodplain.

The floodplain, with an area of 72.23 sq. km., covers three municipalities namely Calbiga, Pinabacdao, and Villareal. Table shows the percentage of area affected by flooding per municipality.

Table 30. Municipalities affected in Calbiga floodplain

| City / Municipality | Total Area | Area Flooded | % Flooded |
|---|---|---|---|
| Calbiga | 216.76 | 51.50 | 24% |
| Pinabacdao | 118.38 | 18.11 | 15% |
| Villareal | 130.218 | 2.34 | 2% |

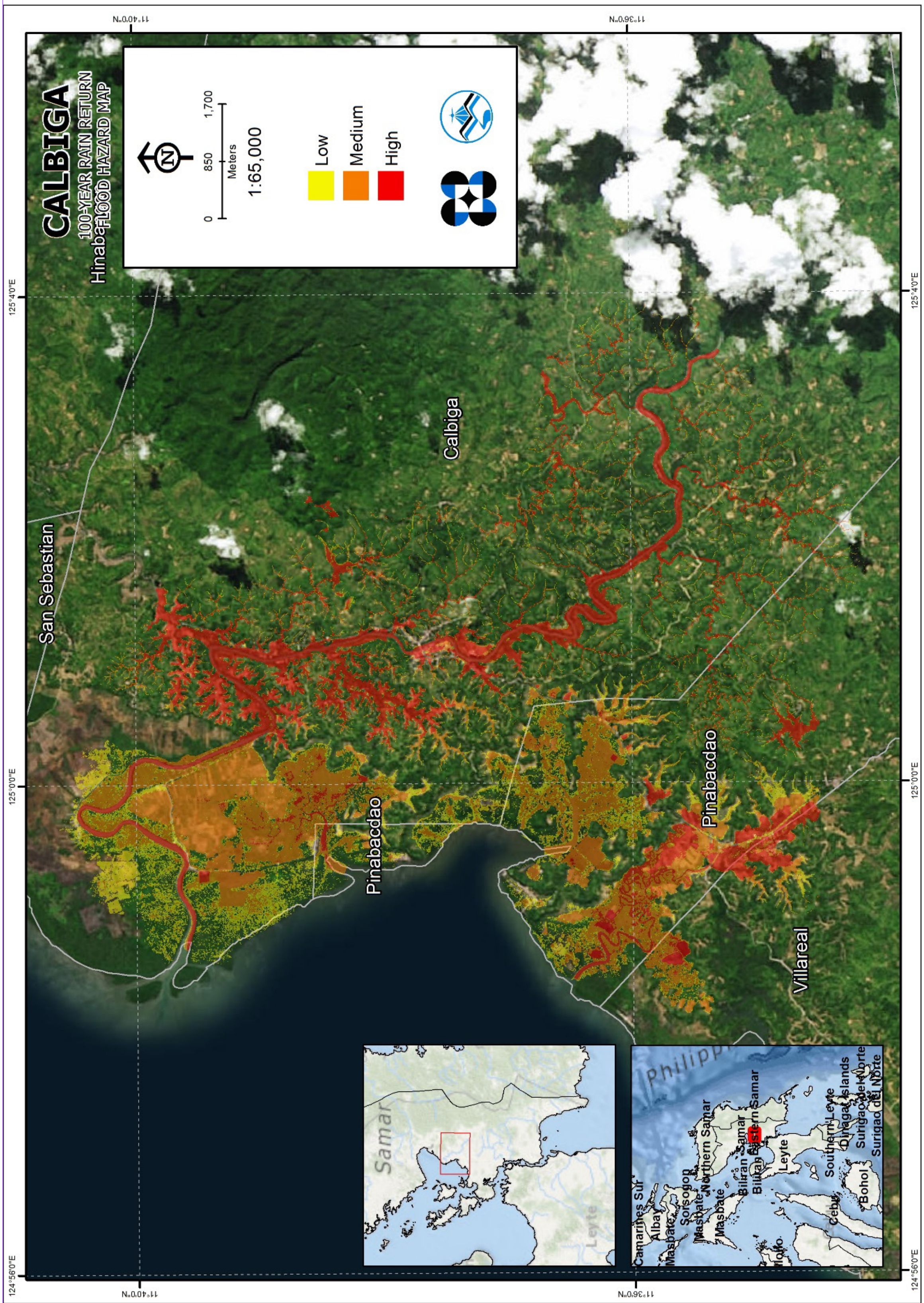



Figure 58. 100-year Flood Hazard Map for Calbiga Floodplain

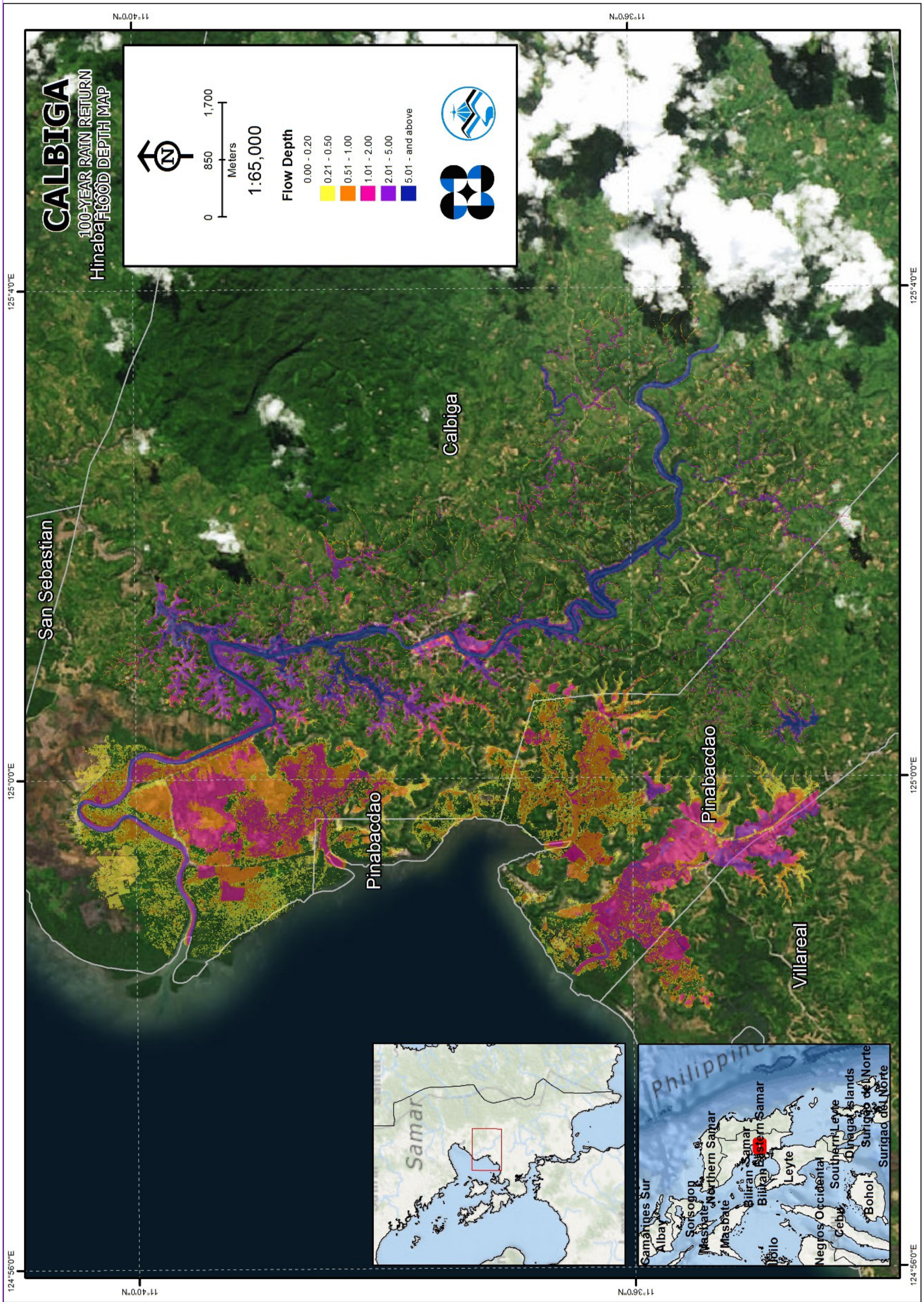



Figure 59. 100-year Flow Depth Map for Calbiga Floodplain

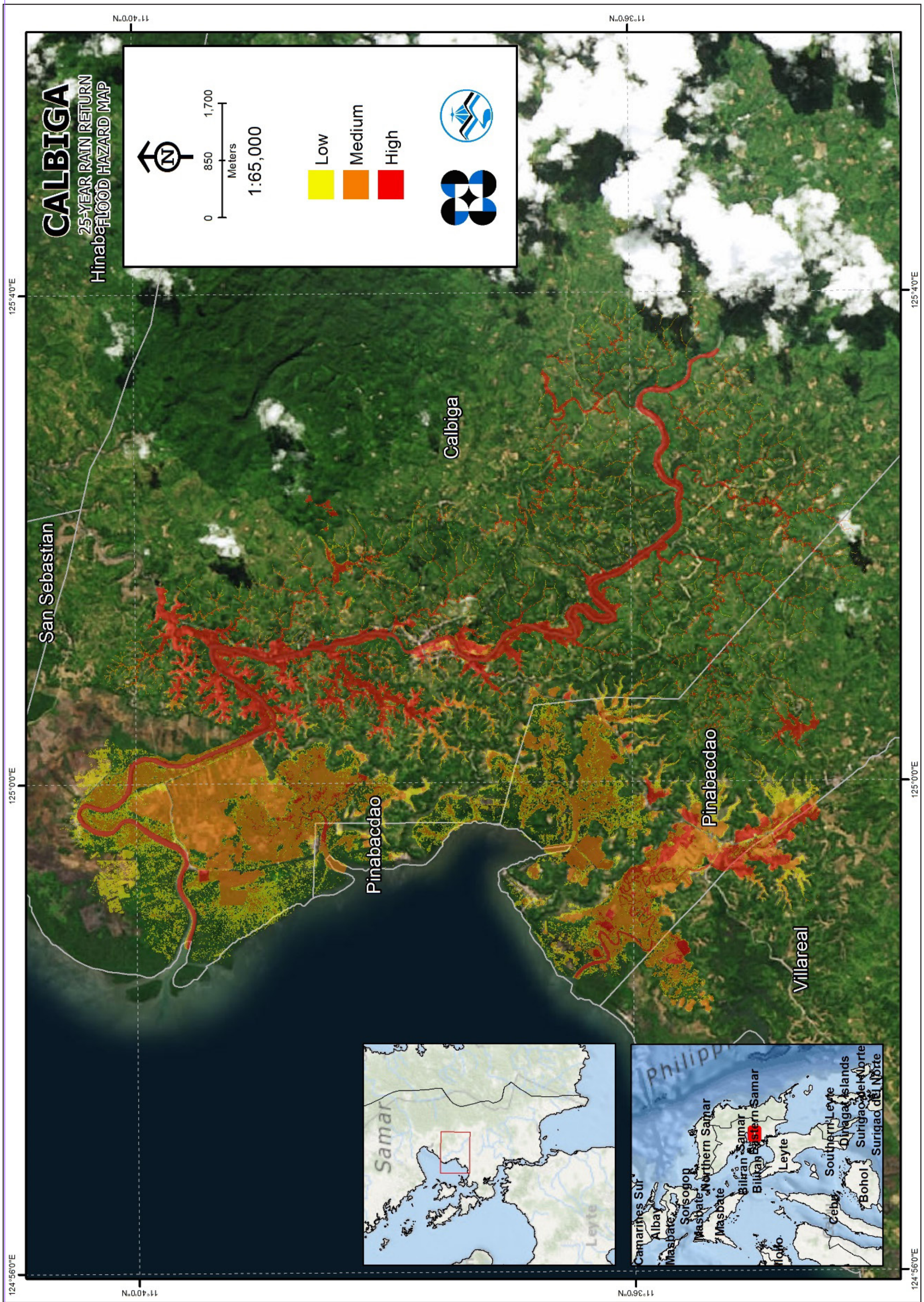



Figure 60. 25-year Flood Hazard Map for Calbiga Floodplain

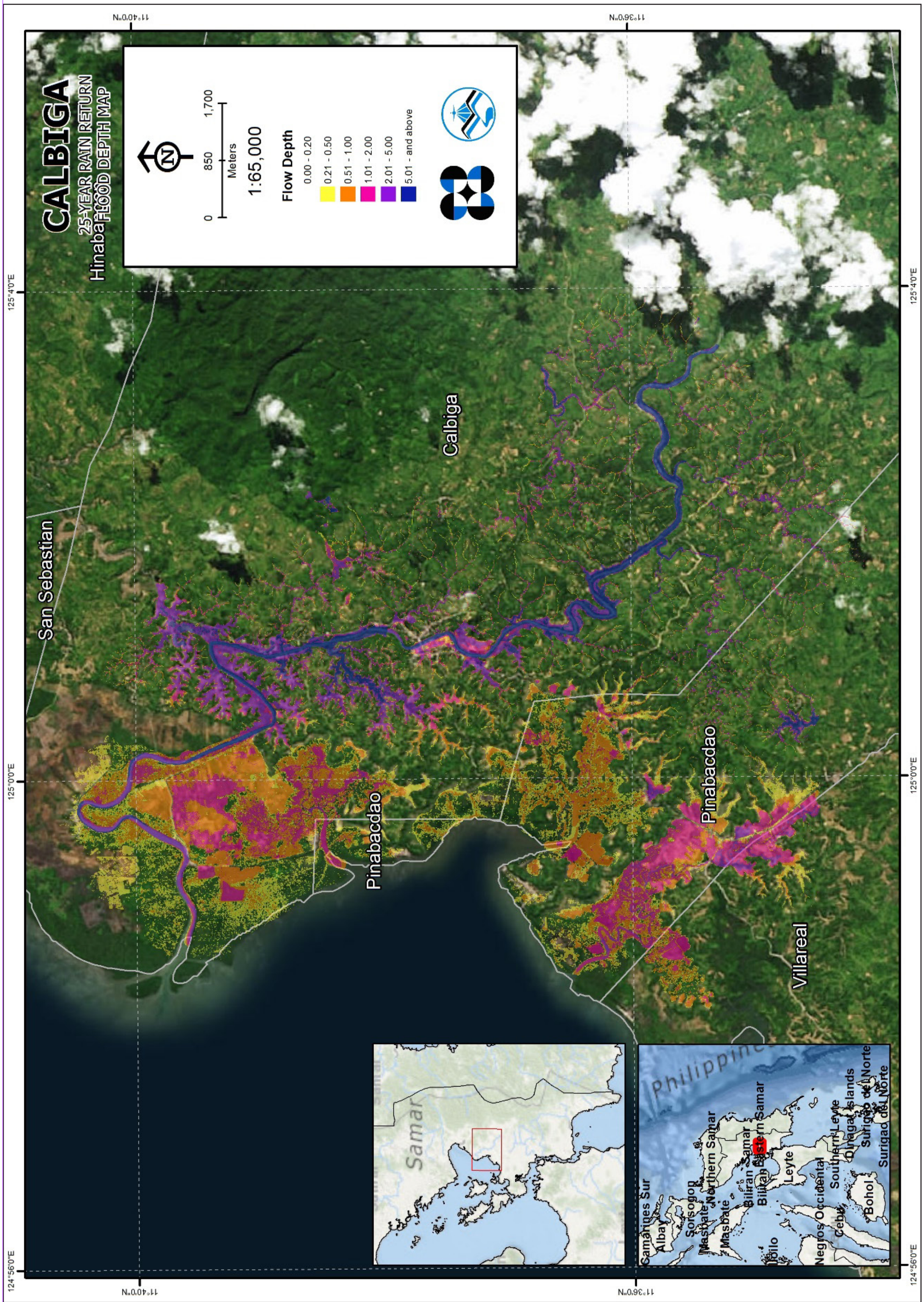



Figure 61. 25-year Flow Depth Map for Calbiga Floodplain

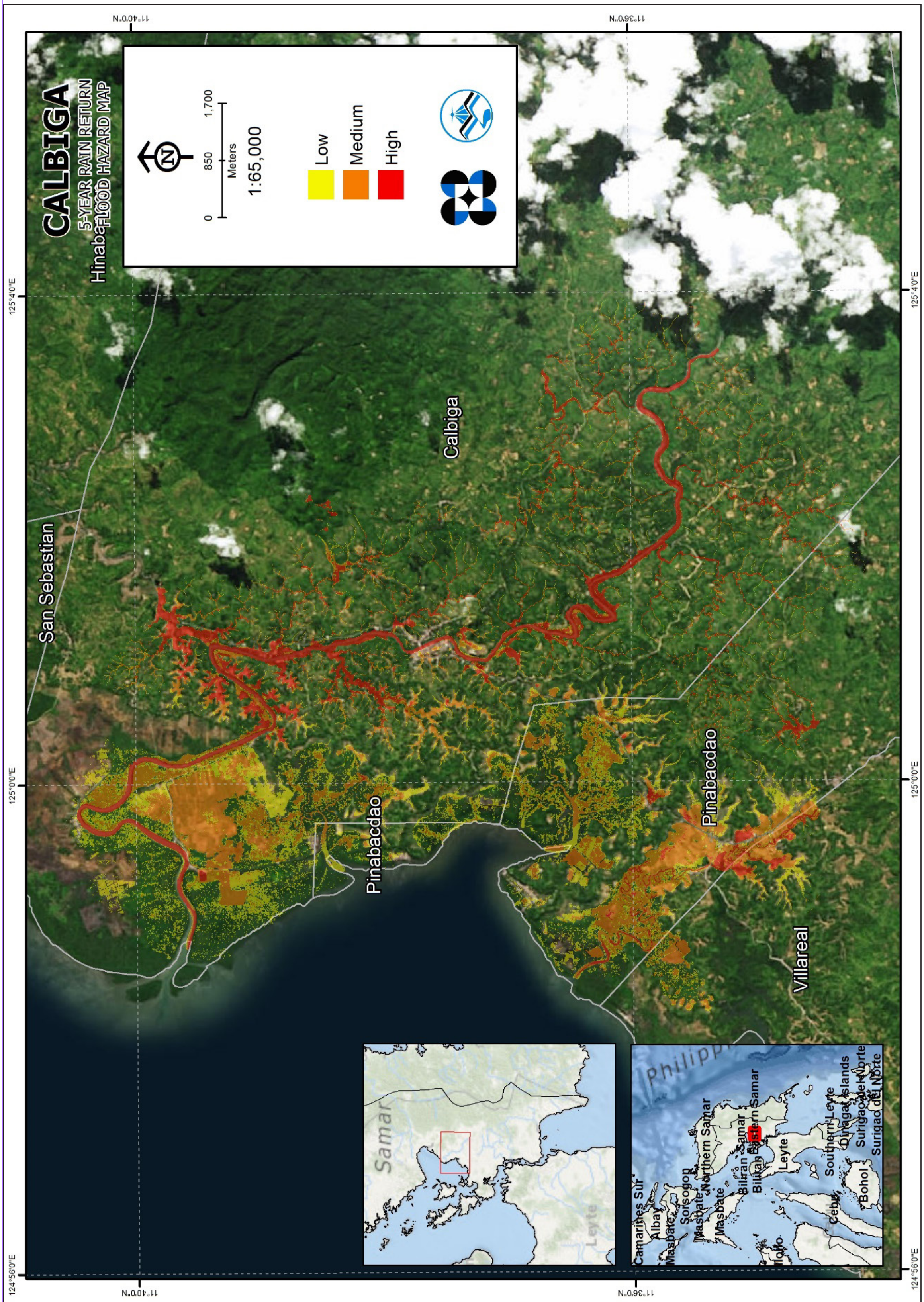



Figure 62. 5-year Flood Hazard Map for Calbiga Floodplain

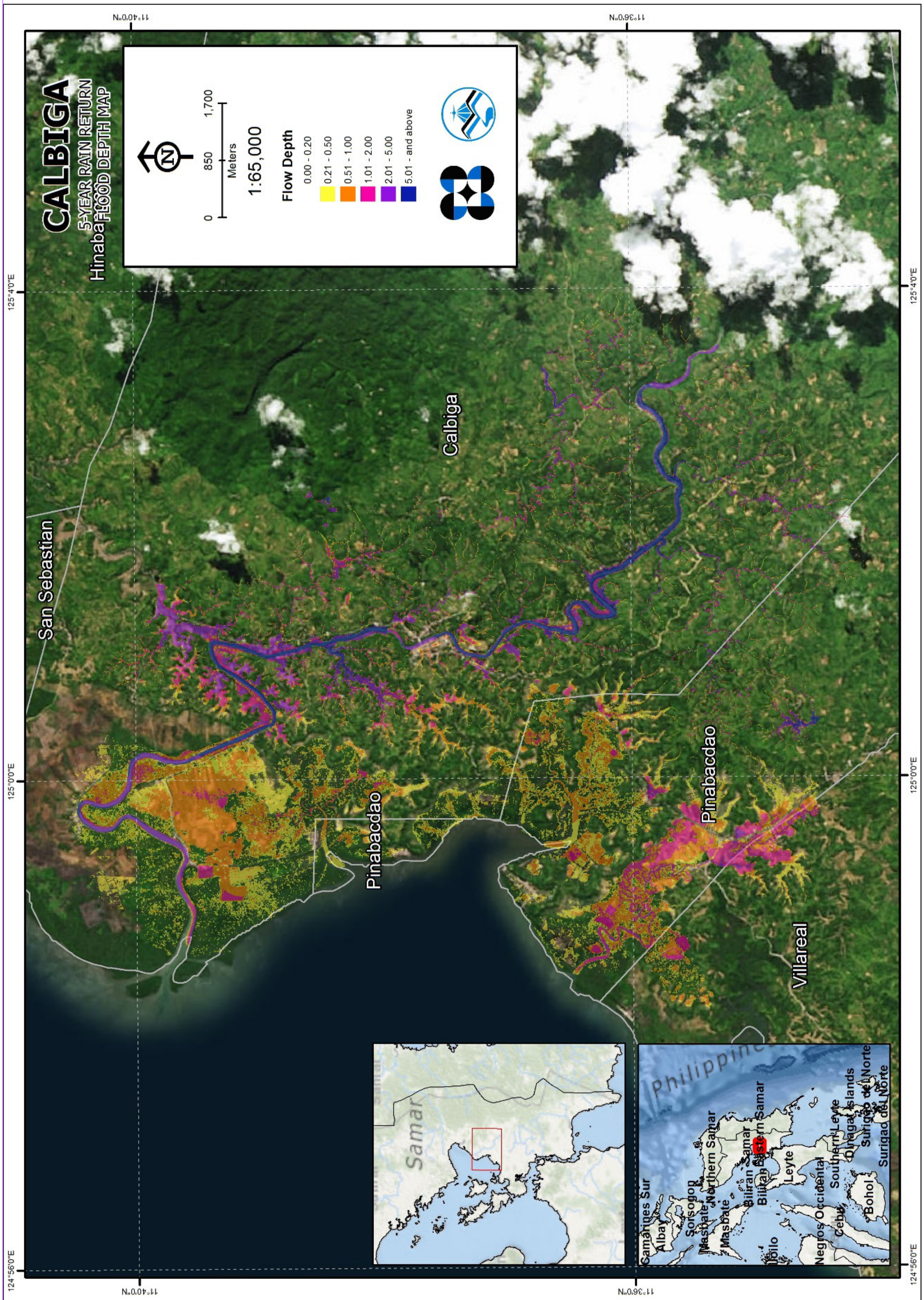



Figure 63. 5-year Flow Depth Map for Calbiga Floodplain

## 5.10 Inventory of Areas Exposed to Flooding

Affected barangays in Calbiga river basin, grouped by municipality, are listed below. For the said basin, 3 municipalities consisting of 48 barangays are expected to experience flooding when subjected to 5-yr rainfall return period.

For the 5-year return period, 18.18% of the municipality of Calbiga with an area of 216.76 sq. km. will experience flood levels of less 0.20 meters. 1.79% of the area will experience flood levels of 0.21 to 0.50 meters while 1.61%, 0.85%, 0.92% and 0.423% 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 31 to Table 33 are the affected areas in square kilometres by flood depth per barangay.

Table 31. Affected Areas in Calbiga, Samar during 5-Year Rainfall Return Period

| CALBIGA BASIN | | Affected Barangays in Calbiga | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Antol | Bacyaran | Brgy. 1 | Brgy. 2 | Brgy. 3 | Brgy. 4 | Brgy. 5 | Brgy. 6 | Brgy. 7 | Barobaybay |
| Affected Area (sq. km.) | 0.03-0.20 | 2.7908213 | 1.13825439 | 0.26193762 | 0.23794348 | 0.26107468 | 0.17333059 | 0.21252069 | 0.14558887 | 0.27919146 | 1.70801230 |
| | 0.21-0.50 | 0.0570599 | 0.08569455 | 0.03284579 | 0.02594705 | 0.01999160 | 0.02965883 | 0.00906824 | 0.05868463 | 0.03389757 | 0.50142301 |
| | 0.51-1.00 | 0.0459258 | 0.09865859 | 0.02687641 | 0.00877866 | 0.01555525 | 0.02394611 | 0.00835519 | 0.04899127 | 0.03847187 | 0.11107735 |
| | 1.01-2.00 | 0.0546320 | 0.03421304 | 0.01109979 | 0.01530952 | 0.01250494 | 0.01922050 | 0.00963662 | 0.00733350 | 0.01392798 | 0.05194043 |
| | 2.01-5.00 | 0.0801209 | 0.00150108 | 0.0001 | 0.00109052 | 0.00659777 | 0.02027363 | 0.00568256 | 0 | 0.00266709 | 0.12236636 |
| | > 5.00 | 0.0014 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.01432102 |

Table 32. Affected Areas in Calbiga, Samar during 5-Year Rainfall Return Period

| CALBIGA BASIN | | Affected Barangays in Calbiga | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Borong | Bulao | Calayaan | Calingonan | Canbagtic | Canticum | Lubang | Macaalan | Malabal | Minata |
| Affected Area (sq. km.) | 0.03-0.20 | 0.9915625 | 3.27181415 | 0.27802603 | 0.21624999 | 3.18425609 | 2.02802170 | 3.37141174 | 3.30114305 | 1.074966473 | 1.066739095 |
| | 0.21-0.50 | 0.02378337 | 0.118714525 | 0.116918457 | 0.037397969 | 0.07432386 | 0.075873664 | 0.078289092 | 0.133577433 | 0.230563582 | 0.027951311 |
| | 0.51-1.00 | 0.02128165 | 0.085335055 | 0.188599511 | 0.000333781 | 0.055839309 | 0.11358695 | 0.063306945 | 0.142991851 | 0.134664202 | 0.034587434 |
| | 1.01-2.00 | 0.01976240 | 0.089017336 | 0.046945804 | 0.000425555 | 0.076526006 | 0.282925705 | 0.085252478 | 0.165873815 | 0.044436827 | 0.04904053 |
| | 2.01-5.00 | 0.00743675 | 0.103220524 | 0.019849102 | 0.002059208 | 0.109841749 | 0.350089461 | 0.128140131 | 0.19500007 | 0.007820082 | 0.043874143 |
| | > 5.00 | 0 | 0.091028808 | 0.023205346 | 0.00247295 | 0.070371992 | 0.114405731 | 0.053964446 | 0.095906645 | 0 | 0.0001 |

Table 33. Affected Areas in Calbiga, Samar during 5-Year Rainfall Return Period

| CALBIGA BASIN | | Affected Barangays in Calbiga | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Otoc | Panayuran | Pasigay | Patong | Polangi | Rawis | San Ignacio | San Mauricio | Timbangan | Tinago |
| Affected Area (sq. km.) | **0.03-0.20** | 2.427766991 | 1.047861123 | 1.100541526 | 0.61551685 | 2.673342168 | 0.650606194 | 0.727814872 | 2.327923242 | 0.823370259 | 1.017837665 |
| | **0.21-0.50** | 0.066389562 | 0.028770767 | 0.604206628 | 0.566701342 | 0.093232291 | 0.144539171 | 0.352127784 | 0.042739334 | 0.029982877 | 0.182437831 |
| | **0.51-1.00** | 0.05572163 | 0.017264694 | 0.235904004 | 1.133201934 | 0.102029251 | 0.156442395 | 0.38494235 | 0.038967475 | 0.042643974 | 0.050285474 |
| | **1.01-2.00** | 0.074656976 | 0.021897703 | 0.064864456 | 0.095382397 | 0.169375557 | 0.128100857 | 0.07270329 | 0.043647076 | 0.082038036 | 0.0006 |
| | **2.01-5.00** | 0.108325254 | 0.011535546 | 0 | 0.031849766 | 0.201815303 | 0.0675956 | 0.108446912 | 0.065389065 | 0.182063679 | 0.0001 |
| | **> 5.00** | 0.104067708 | 0.0001 | 0 | 0 | 0.114430318 | 0.062597416 | 0.027734849 | 0.138345639 | 0 | 0 |

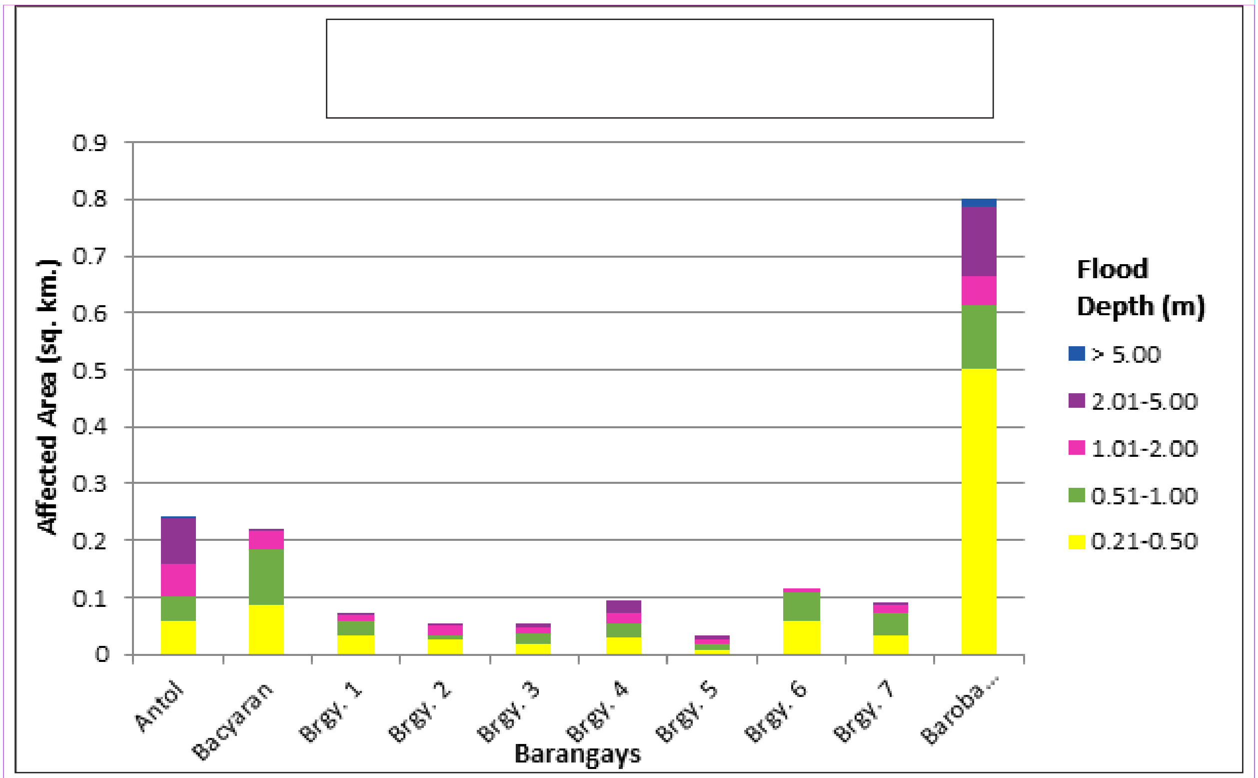



Figure 64. Affected Areas in Calbiga, Samar during 5-Year Rainfall Return Period

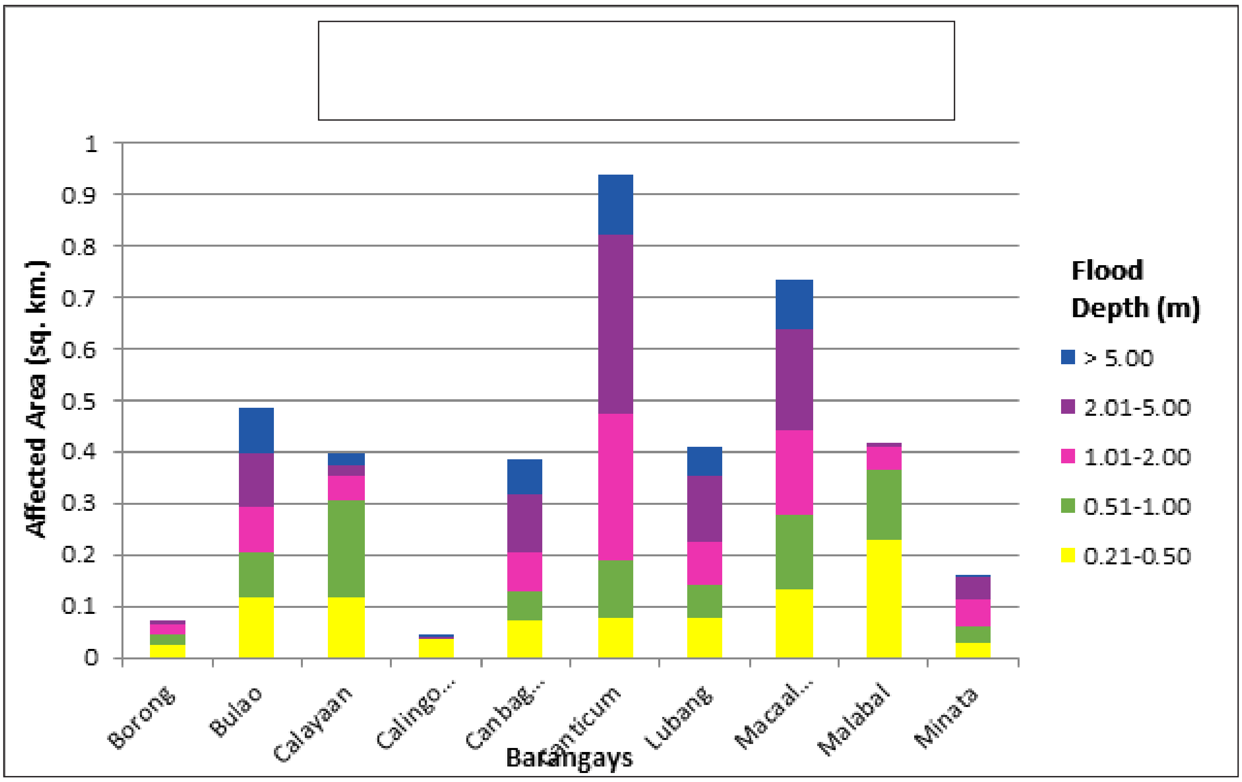



Figure 65. Affected Areas in Calbiga, Samar during 5-Year Rainfall Return Period

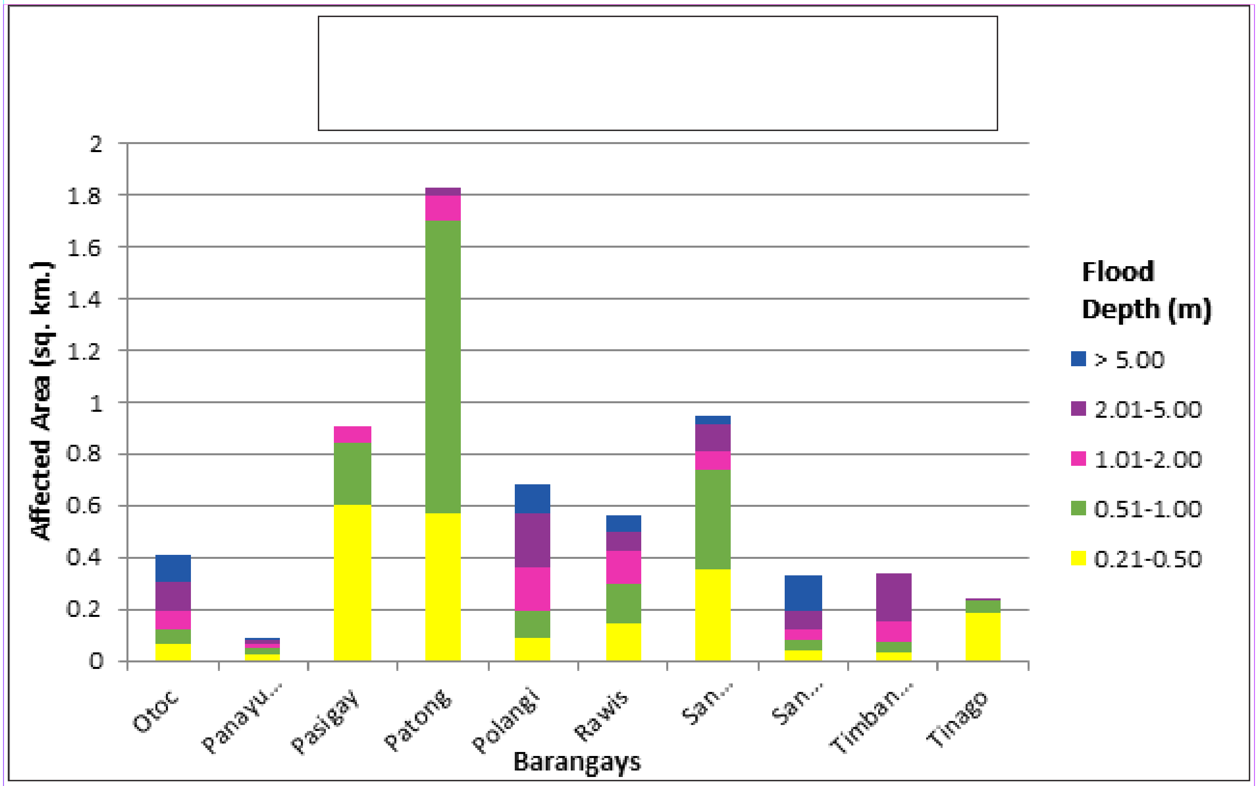



Figure 66. Affected Areas in Calbiga, Samar during 5-Year Rainfall Return Period

For the municipality of Pinabacdao, with an area of 118.38 sq. km., 10.7% will experience flood levels of less 0.20 meters. 1.978% of the area will experience flood levels of 0.21 to 0.50 meters while 1.579%, 0.872%, 0.154% and 0.022% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and above 5 meters, respectively.

Table 34. Affected Areas in Pinabacdao, Samar during 5-Year Rainfall Return Period

| CALBIGA BASIN | | Affected Barangays in Pinabacdao | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Bangon | Barangay I | Barangay II | Botoc | Calampong | Catigawan | Dolores |
| Affected Area (sq. km.) | 0.03-0.20 | 1.339036334 | 0.097629476 | 0.128040147 | 0.82924921 | 1.088534398 | 0.5668208 | 0.479680593 |
| | 0.21-0.50 | 0.407548907 | 0.018317459 | 0.020462153 | 0.265260405 | 0.202143248 | 0.230477891 | 0.061167175 |
| | 0.51-1.00 | 0.45706673 | 0.005098941 | 0.002211983 | 0.188043568 | 0.062675967 | 0.197683467 | 0.10849586 |
| | 1.01-2.00 | 0.265916462 | 0 | 0 | 0.0176 | 0.0013 | 0.025385994 | 0.16331726 |
| | 2.01-5.00 | 0.018770009 | 0 | 0 | 0 | 0 | 0.000926272 | 0.000491876 |
| | > 5.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 35. Affected Areas in Pinabacdao, Samar during 5-Year Rainfall Return Period

| CALBIGA BASIN | | Affected Barangays in Pinabacdao | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Lale | Lawaan | Loctob | Madalunot | Mambog | Nabong | Obayan | San Isidro |
| Affected Area (sq. km.) | 0.03-0.20 | 0.555724933 | 0.92702114 | 2.41456417 | 3.2761933 | 0.200693437 | 0.144175651 | 0.601472205 | 0.014206451 |
| | 0.21-0.50 | 0.134407899 | 0.092796289 | 0.507462406 | 0.080914414 | 0.067282689 | 0.06009538 | 0.192938605 | 0.000501673 |
| | 0.51-1.00 | 0.093812301 | 0.048233669 | 0.236381317 | 0.063864848 | 0.136285058 | 0.159545357 | 0.110499449 | 1.55045E-05 |
| | 1.01-2.00 | 0.084809497 | 0.029887868 | 0.088111552 | 0.072865958 | 0.099462745 | 0.171905477 | 0.01119095 | 0 |
| | 2.01-5.00 | 0.000961821 | 0.019393235 | 0.012479806 | 0.081257603 | 0.010948089 | 0.036665705 | 0 | 0 |
| | > 5.00 | 0 | 0.0004 | 0 | 0.026247126 | 0 | 0 | 0 | 0 |

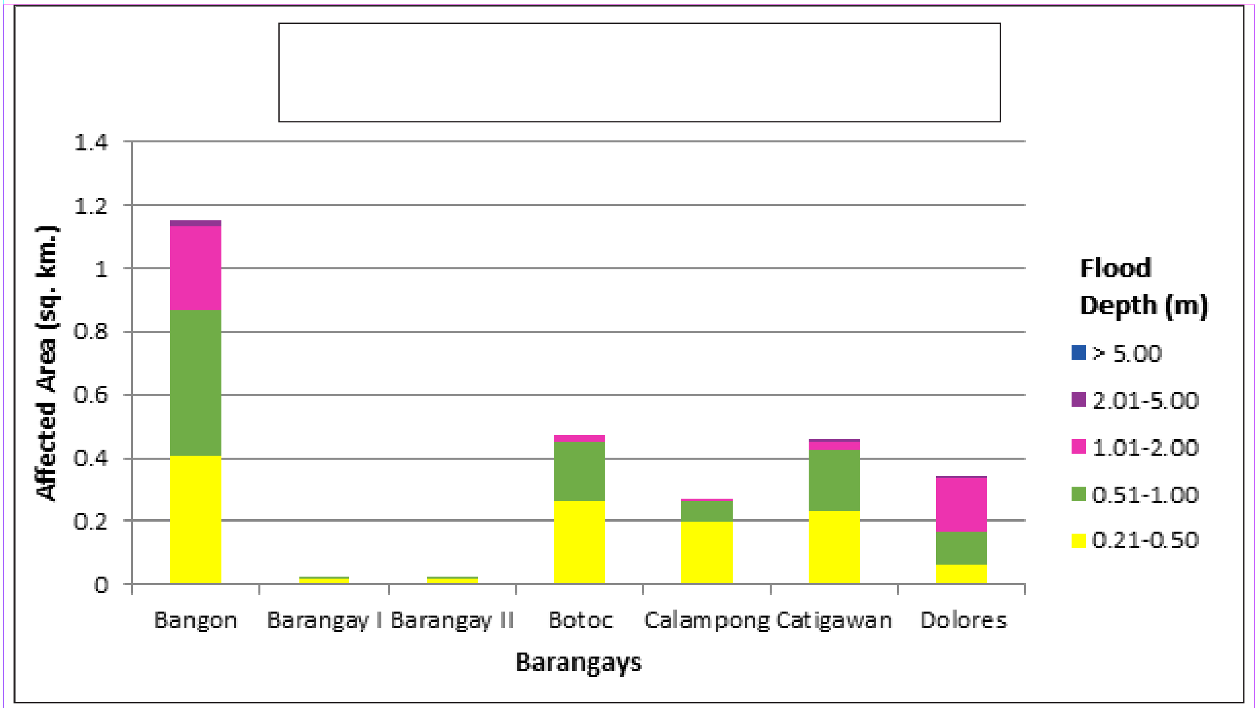



Figure 67. Affected Areas in Pinabacdao, Samar during 5-Year Rainfall Return Period

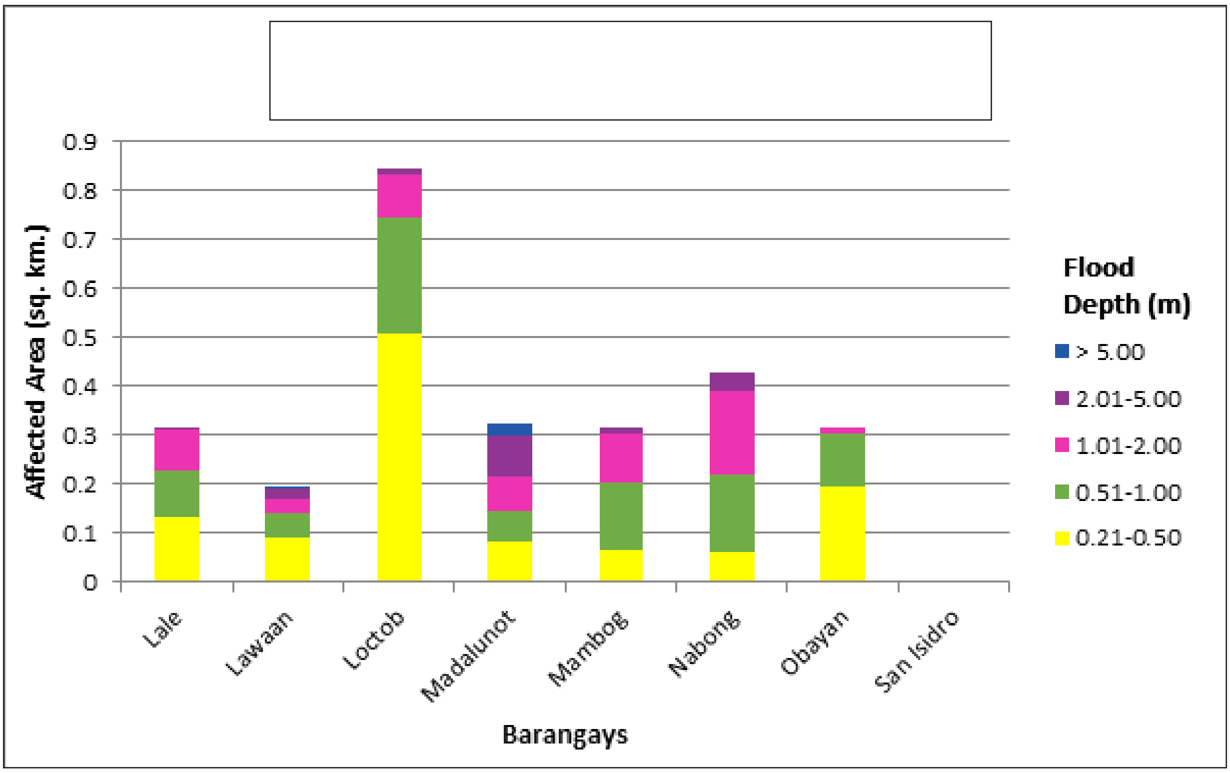



Figure 68. Affected Areas in Pinabacdao, Samar during 5-Year Rainfall Return Period

For the municipality of Villareal, with an area of 130.218 sq. km., 1.15% will experience flood levels of less 0.20 meters. 0.197% of the area will experience flood levels of 0.21 to 0.50 meters while 0.20%, 0.23%, 0.21%, and 0.00015% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters and more than 5 meters, respectively.

Table 36. Affected Areas in Villareal, Samar during 5-Year Rainfall Return Period

| CALBIGA BASIN | | Affected Barangays in Villareal | | |
|---|---|---|---|---|
| | | Malonoy | San Fernando | San Rafael |
| Affected Area (sq. km.) | 0.03-0.20 | 0.364390582 | 0.514468269 | 0.613518068 |
| | 0.21-0.50 | 0.04814328 | 0.069743721 | 0.138841704 |
| | 0.51-1.00 | 0.019286207 | 0.110136002 | 0.132764198 |
| | 1.01-2.00 | 0.018336512 | 0.222497876 | 0.058535344 |
| | 2.01-5.00 | 0.006031989 | 0.021430512 | 0 |
| | > 5.00 | 0.0002 | 0 | 0 |

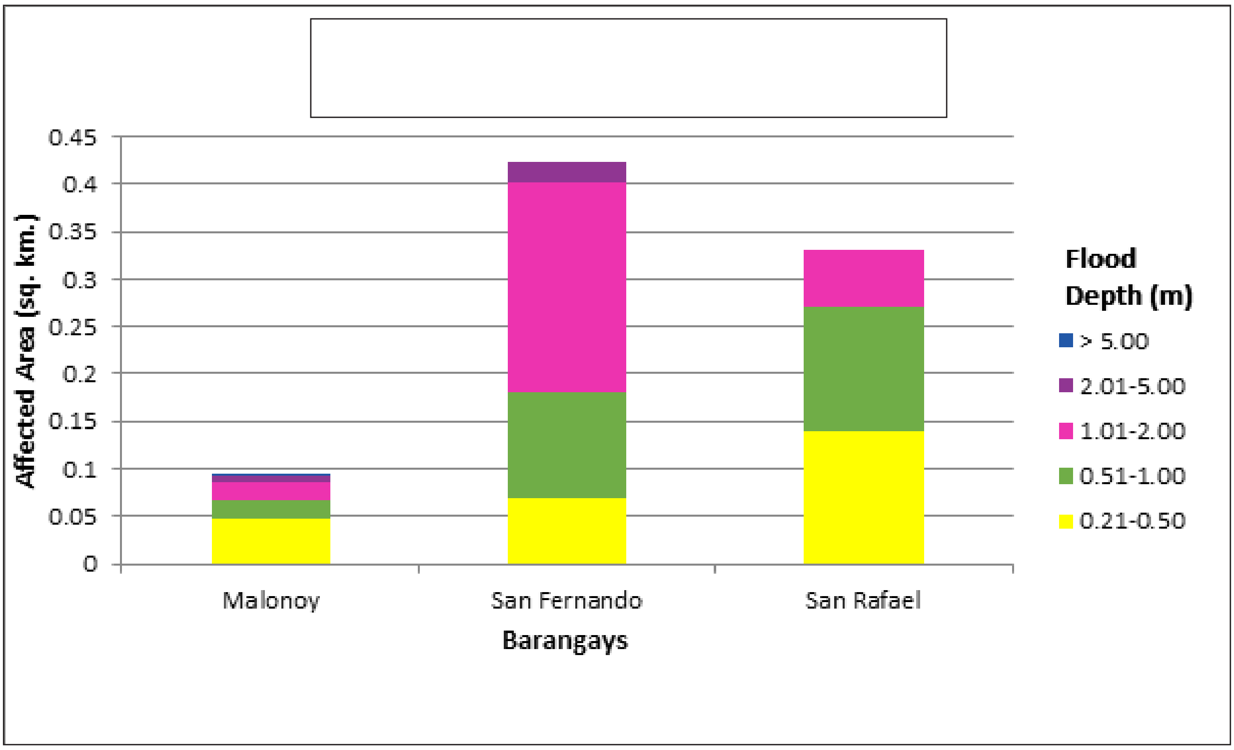



Figure 69. Affected Areas in Villareal, Samar during 5-Year Rainfall Return Period

For the 25-year return period, 16.65% of the municipality of Calbiga with an area of 216.76 sq. km. will experience flood levels of less 0.20 meters. 1.62% of the area will experience flood levels of 0.21 to 0.50 meters while 1.92%, 1.44%, 1.4% and 0.75% 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 to Table 39 are the affected areas in square kilometres by flood depth per barangay.

Table 37. Affected Areas in Calbiga, Samar during 25-Year Rainfall Return Period

| CALBIGA BASIN | | Affected Barangays in Calbiga | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Antol | Bacyaran | Brgy. 1 | Brgy. 2 | Brgy. 3 | Brgy. 4 | Brgy. 5 | Brgy. 6 | Brgy. 7 | Barobaybay |
| Affected Area (sq. km.) | **0.03-0.20** | 2.751371689 | 1.091656901 | 0.241681441 | 0.219099862 | 0.239385212 | 0.140789643 | 0.185536714 | 0.127757738 | 0.250209514 | 1.314214809 |
| | **0.21-0.50** | 0.063998507 | 0.076767766 | 0.030493458 | 0.030047204 | 0.015649951 | 0.027190661 | 0.005688965 | 0.04253411 | 0.029828242 | 0.73572573 |
| | **0.51-1.00** | 0.048713407 | 0.092333596 | 0.018706071 | 0.005900919 | 0.020629361 | 0.027644111 | 0.009427563 | 0.073776006 | 0.045066258 | 0.24642488 |
| | **1.01-2.00** | 0.060129846 | 0.066795881 | 0.010183067 | 0.005302599 | 0.008697363 | 0.015637786 | 0.014769183 | 0.016530434 | 0.025433508 | 0.056731308 |
| | **2.01-5.00** | 0.063304946 | 0.031767529 | 0.031895612 | 0.028718665 | 0.028943679 | 0.04186728 | 0.025598654 | 0 | 0.016390068 | 0.133522756 |
| | **> 5.00** | 0.042441777 | 0 | 0 | 0 | 0.002418698 | 0.01330021 | 0.004242241 | 0 | 0.001228409 | 0.022521027 |

Table 38. Affected Areas in Calbiga, Samar during 25-Year Rainfall Return Period

| CALBIGA BASIN | | Affected Barangays in Calbiga | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Borong | Bulao | Calayaan | Calingonan | Canbagtic | Canticum | Lubang | Macaalan | Malabal | Minata |
| Affected Area (sq. km.) | **0.03-0.20** | 0.976243415 | 3.194612073 | 0.2262326 | 0.180939485 | 3.110521352 | 1.860290259 | 3.305989764 | 2.987446998 | 0.728740795 | 1.03995341 |
| | **0.21-0.50** | 0.030478412 | 0.121838481 | 0.036886563 | 0.072450898 | 0.081109628 | 0.062368205 | 0.088283708 | 0.107836782 | 0.138068689 | 0.026834758 |
| | **0.51-1.00** | 0.022051183 | 0.088586404 | 0.225545945 | 0.000557583 | 0.059320326 | 0.075943112 | 0.069052153 | 0.129208496 | 0.316562045 | 0.033996426 |
| | **1.01-2.00** | 0.022616929 | 0.085669851 | 0.09854314 | 0.000447628 | 0.078438334 | 0.152655056 | 0.087282935 | 0.25413709 | 0.235324179 | 0.052981013 |
| | **2.01-5.00** | 0.012436759 | 0.125751971 | 0.054893291 | 0.001770916 | 0.133126623 | 0.62075344 | 0.113518853 | 0.383435843 | 0.070485071 | 0.066098187 |
| | **> 5.00** | 0 | 0.143771619 | 0.031442718 | 0.00277295 | 0.108642752 | 0.19289314 | 0.116237429 | 0.173527653 | 0.003270386 | 0.002428718 |

Table 39. Affected Areas in Calbiga, Samar during 25-Year Rainfall Return Period

| CALBIGA BASIN | | Affected Barangays in Calbiga | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Otoc | Panayuran | Pasigay | Patong | Polangi | Rawis | San Ignacio | San Mauricio | Timbangan | Tinago |
| Affected Area (sq. km.) | **0.03-0.20** | 2.359125258 | 1.029099845 | 0.771115017 | 0.230096584 | 2.455902907 | 0.530342825 | 0.56341755 | 2.271770175 | 0.760851665 | 0.94568381 |
| | **0.21-0.50** | 0.071013379 | 0.035860989 | 0.578129289 | 0.22403494 | 0.091096565 | 0.043687163 | 0.363434639 | 0.045891758 | 0.029709883 | 0.213956975 |
| | **0.51-1.00** | 0.053143565 | 0.022887891 | 0.452450118 | 1.073203049 | 0.100420876 | 0.215337926 | 0.462031178 | 0.040036466 | 0.034521167 | 0.08979156 |
| | **1.01-2.00** | 0.064168327 | 0.022717031 | 0.203722191 | 0.87450683 | 0.182249763 | 0.149936669 | 0.147109309 | 0.048961392 | 0.068196819 | 0.001928626 |
| | **2.01-5.00** | 0.114883781 | 0.016964077 | 0.0001 | 0.040010888 | 0.278485637 | 0.203317007 | 0.104342532 | 0.066046517 | 0.215471617 | 0.0002 |
| | **> 5.00** | 0.174593811 | 0.0003 | 0 | 0.0008 | 0.246069141 | 0.067260044 | 0.033434849 | 0.184305523 | 0.051347674 | 0 |

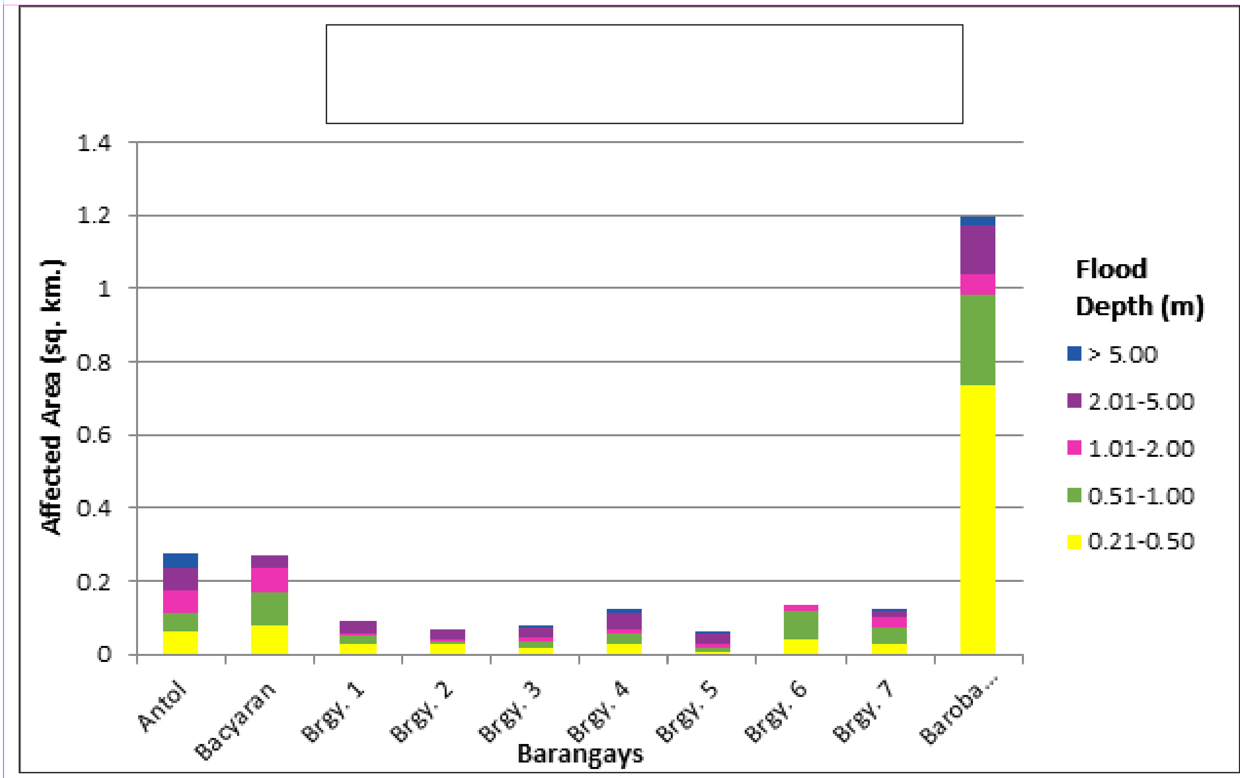



Figure 70. Affected Areas in Calbiga, Samar during 25-Year Rainfall Return Period

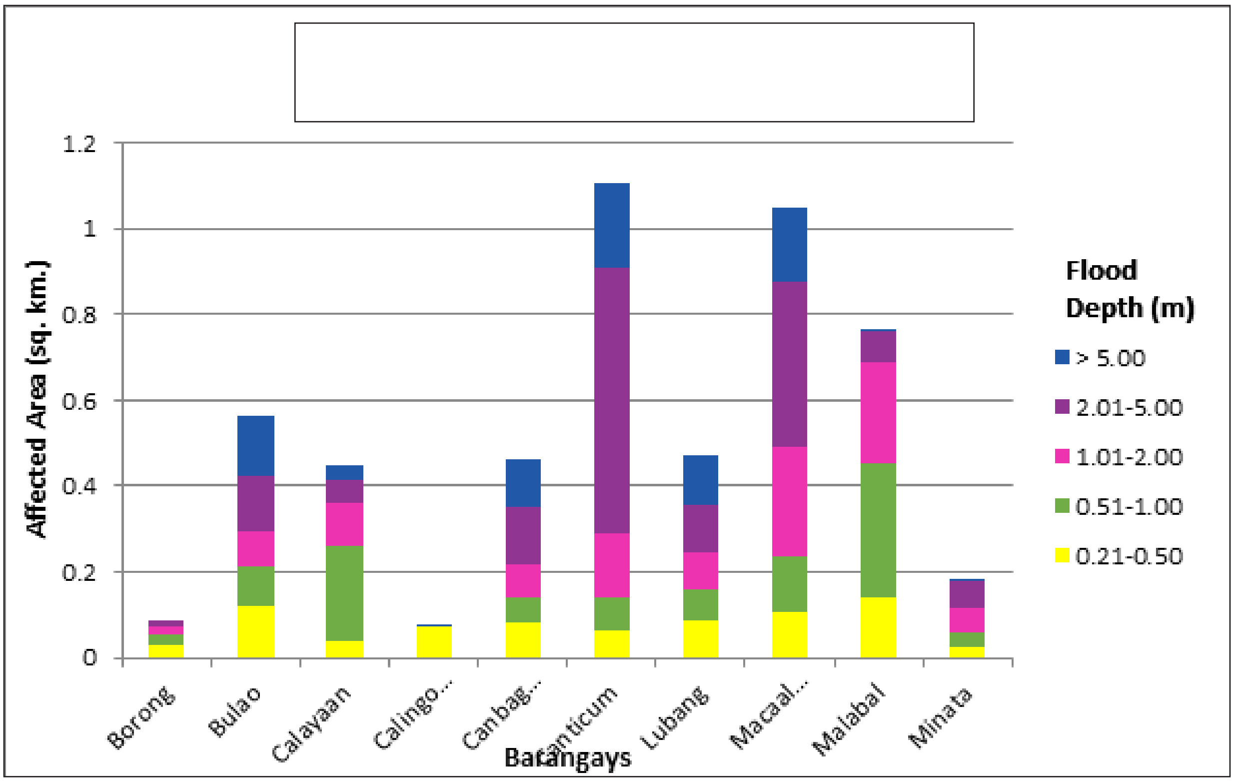



Figure 71. Affected Areas in Calbiga, Samar during 25-Year Rainfall Return Period

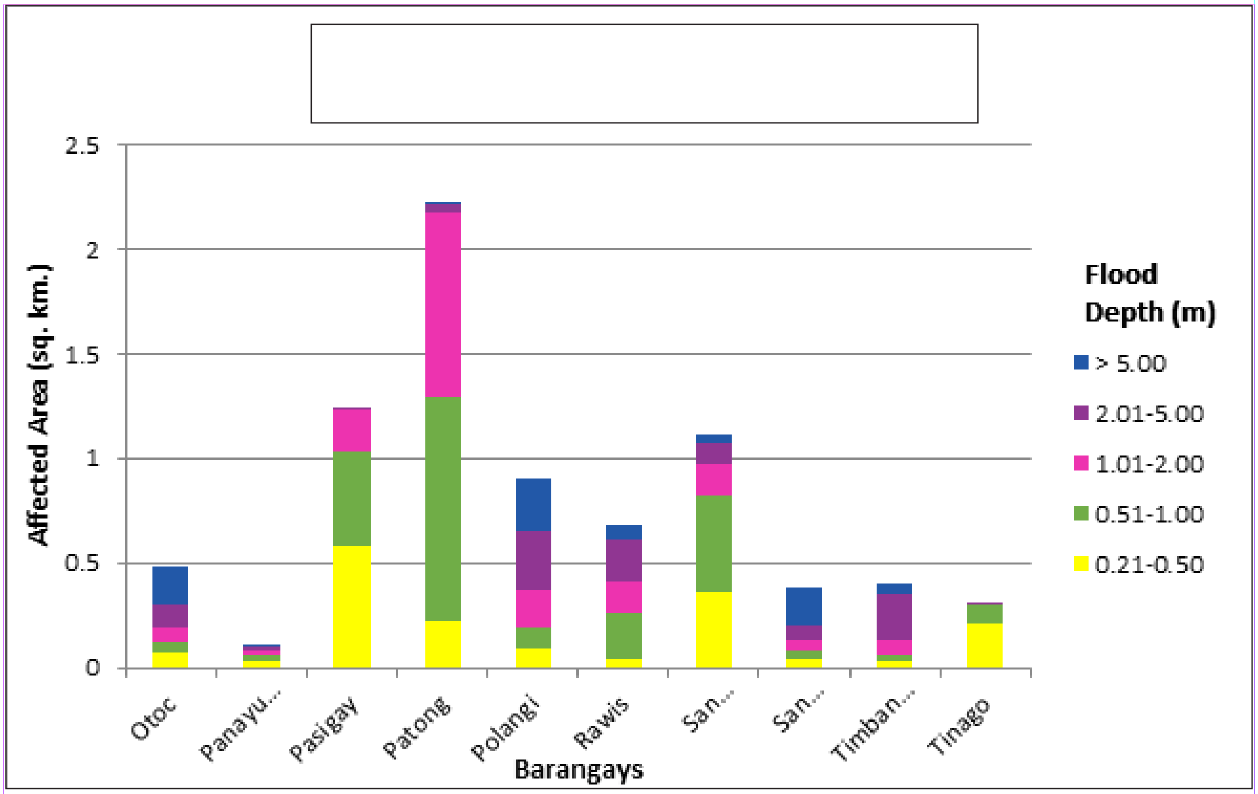



Figure 72. Affected Areas in Calbiga, Samar during 25-Year Rainfall Return Period

For the municipality of Pinabacdao, with an area of 118.38 sq. km., 9.7% will experience flood levels of less 0.20 meters. 1.85% of the area will experience flood levels of 0.21 to 0.50 meters while 1.99%, 1.44%, 0.276% and 0.05% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and above 5 meters, respectively. Listed in Table 40 and Table 41 are the affected areas in square kilometres by flood depth per barangay.

Table 40. Affected Areas in Pinabacdao, Samar during 25-Year Rainfall Return Period

| CALBIGA BASIN | | Affected Barangays in Pinabacdao | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Bangon | Barangay I | Barangay II | Botoc | Calampong | Catigawan | Dolores |
| Affected Area (sq. km.) | **0.03-0.20** | 1.11190971 | 0.091691382 | 0.112411348 | 0.721369872 | 0.969125706 | 0.479445624 | 0.453988204 |
| | **0.21-0.50** | 0.336935741 | 0.022255553 | 0.032328484 | 0.206811306 | 0.238676289 | 0.187459038 | 0.053845022 |
| | **0.51-1.00** | 0.521962954 | 0.007098941 | 0.005974452 | 0.325728502 | 0.098472022 | 0.297227274 | 0.063743083 |
| | **1.01-2.00** | 0.469944903 | 0 | 0 | 0.046243503 | 0.048179597 | 0.055078572 | 0.233641538 |
| | **2.01-5.00** | 0.047585135 | 0 | 0 | 0 | 0.0001 | 0.002083915 | 0.007934918 |
| | **> 5.00** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 41. Affected Areas in Pinabacdao, Samar during 25-Year Rainfall Return Period

| CALBIGA BASIN | | Affected Barangays in Pinabacdao | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Lale | Lawaan | Loctob | Madalunot | Mambog | Nabong | Obayan | San Isidro |
| Affected Area (sq. km.) | **0.03-0.20** | 0.471036642 | 0.896192208 | 2.194771422 | 3.200696176 | 0.169168833 | 0.116957016 | 0.477475572 | 0.013943077 |
| | **0.21-0.50** | 0.148943517 | 0.087575859 | 0.502913264 | 0.083384113 | 0.030800269 | 0.030773787 | 0.222318738 | 0.000726537 |
| | **0.51-1.00** | 0.06802514 | 0.067727526 | 0.403830565 | 0.072334261 | 0.11209928 | 0.129617663 | 0.181443904 | 5.40148E-05 |
| | **1.01-2.00** | 0.166507749 | 0.035519154 | 0.127404193 | 0.080092953 | 0.183215046 | 0.227542021 | 0.034862994 | 0 |
| | **2.01-5.00** | 0.015203403 | 0.029617455 | 0.030279806 | 0.106886516 | 0.019388589 | 0.067497083 | 0 | 0 |
| | **> 5.00** | 0 | 0.0014 | 0 | 0.05794923 | 0 | 0 | 0 | 0 |

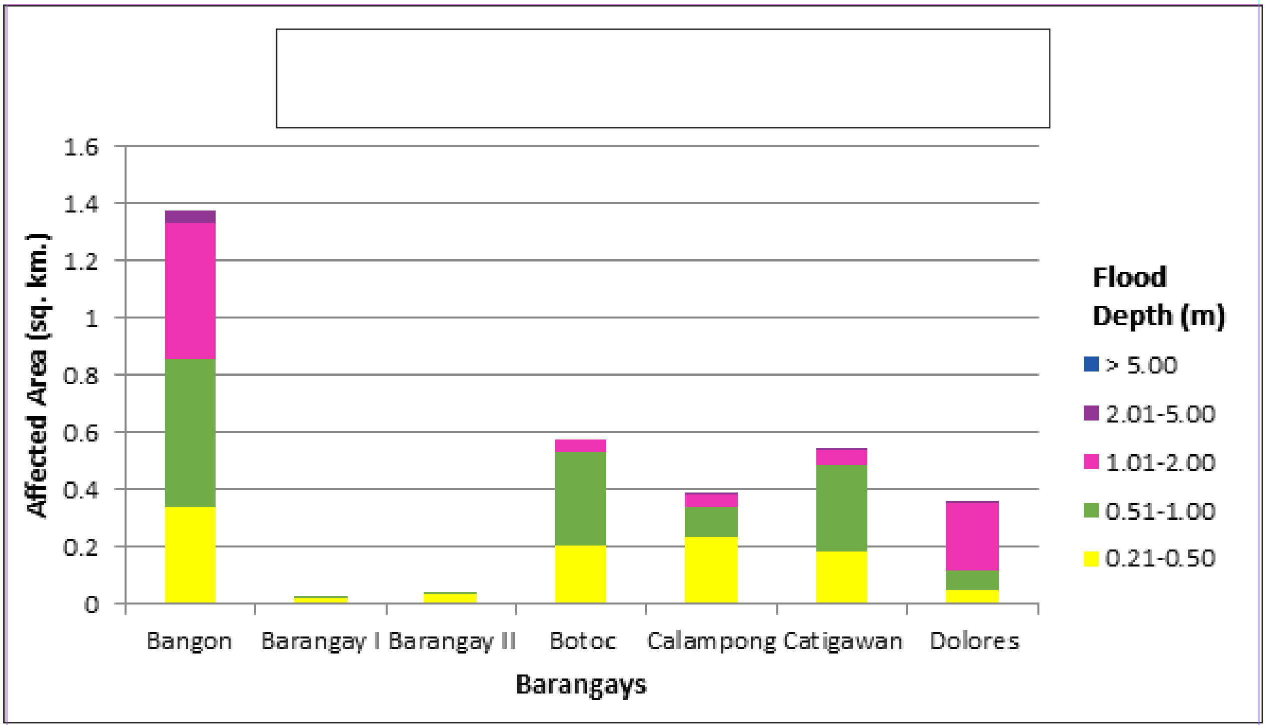



Figure 73. Affected Areas in Pinabacdao, Samar during 25-Year Rainfall Return Period

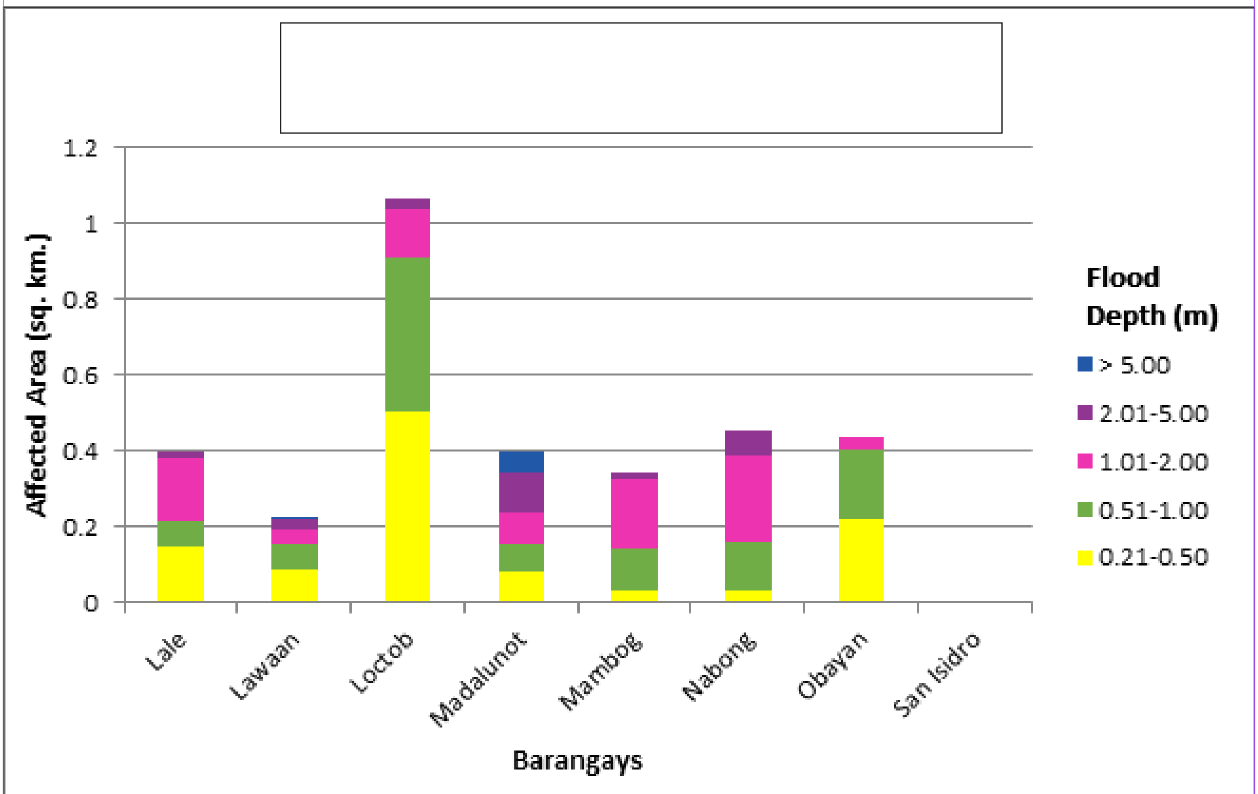



Figure 74. Affected Areas in Pinabacdao, Samar during 25-Year Rainfall Return Period

For the municipality of Villareal, with an area of 130.218 sq. km., 1.02% will experience flood levels of less 0.20 meters. 0.16% of the area will experience flood levels of 0.21 to 0.50 meters while 0.22%, 0.33%, 0.67%, and 0.0003% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters and more than 5 meters, respectively.

Table 42. Affected Areas in Villareal, Samar during 25-Year Rainfall Return Period

| CALBIGA BASIN | | Affected Barangays in Villareal | | |
|---|---|---|---|---|
| | | Malonoy | San Fernando | San Rafael |
| Affected Area (sq. km.) | **0.03-0.20** | 0.352030125 | 0.497998832 | 0.480060388 |
| | **0.21-0.50** | 0.05015897 | 0.046270923 | 0.111015626 |
| | **0.51-1.00** | 0.008937313 | 0.065361266 | 0.207734306 |
| | **1.01-2.00** | 0.029887701 | 0.257028947 | 0.144348995 |
| | **2.01-5.00** | 0.014874461 | 0.071616412 | 0.0005 |
| | **> 5.00** | 0.0005 | 0 | 0 |

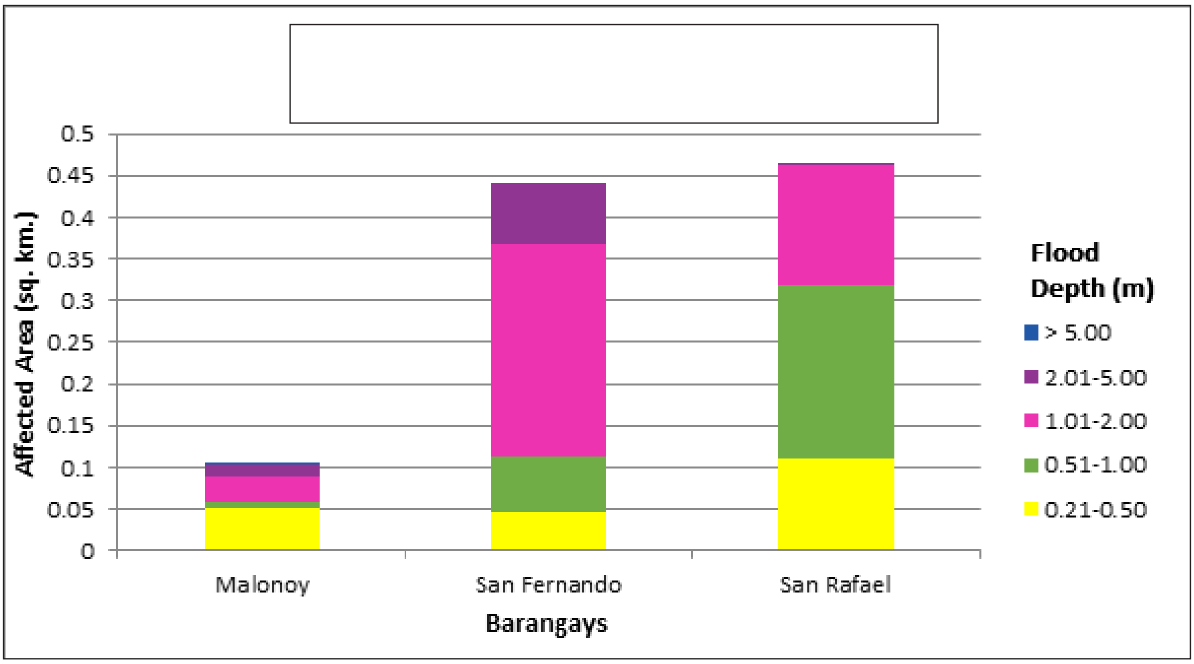



Figure 75. Affected Areas in Villareal, Samar during 25-Year Rainfall Return Period

For the 100-year return period, 13.49% of the municipality of Calbiga with an area of 216.76 sq. km. will experience flood levels of less 0.20 meters. 1.72% of the area will experience flood levels of 0.21 to 0.50 meters while 1.84%, 1.68%, 1.51% and 0.89% 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 43 to Table 45 are the affected areas in square kilometres by flood depth per barangay.

Table 43. Affected Areas in Calbiga, Samar during 100-Year Rainfall Return Period

| CALBIGA BASIN | | Affected Barangays in Calbiga | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Antol | Bacyaran | Brgy. 1 | Brgy. 2 | Brgy. 3 | Brgy. 4 | Brgy. 5 | Brgy. 6 | Brgy. 7 | Barobaybay |
| Affected Area (sq. km.) | 0.03-0.20 | 2.731531681 | 1.06856518 | 0.230223565 | 0.212376619 | 0.231102459 | 0.128925609 | 0.17286287 | 0.11662058 | 0.235805512 | 1.112722794 |
| | 0.21-0.50 | 0.069940328 | 0.072140954 | 0.029926447 | 0.031895499 | 0.012685296 | 0.022362543 | 0.006845863 | 0.037585534 | 0.029586167 | 0.879777557 |
| | 0.51-1.00 | 0.050612604 | 0.087478317 | 0.019973987 | 0.007032659 | 0.023876895 | 0.030415584 | 0.008263086 | 0.079961867 | 0.046875401 | 0.295477571 |
| | 1.01-2.00 | 0.062518343 | 0.073201577 | 0.012450626 | 0.005096116 | 0.009699867 | 0.017710672 | 0.016081422 | 0.026330308 | 0.031356616 | 0.059673074 |
| | 2.01-5.00 | 0.071564959 | 0.058235645 | 0.040186705 | 0.029043074 | 0.028388268 | 0.044521925 | 0.034772662 | 0.0001 | 0.02066283 | 0.138868486 |
| | > 5.00 | 0.043792257 | 0 | 0.000298319 | 0.003625282 | 0.00997148 | 0.022493359 | 0.006437416 | 0 | 0.003869474 | 0.022621027 |

Table 44. Affected Areas in Calbiga, Samar during 100-Year Rainfall Return Period

| CALBIGA BASIN | | Affected Barangays in Calbiga | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Borong | Bulao | Calayaan | Calingonan | Canbagtic | Canticum | Lubang | Macaalan | Malabal | Minata |
| **Affected Area (sq. km.)** | **0.03-0.20** | 0.96640558 | 3.15322766 | 0.212320294 | 0.168278677 | 3.075717012 | 1.808155147 | 3.266605562 | 2.926143735 | 0.674430442 | 1.017303746 |
| | **0.21-0.50** | 0.033716247 | 0.130450411 | 0.030214402 | 0.084557096 | 0.084820737 | 0.0626954 | 0.096485324 | 0.106171782 | 0.117429634 | 0.031398004 |
| | **0.51-1.00** | 0.02412405 | 0.09986468 | 0.19167294 | 0.001112192 | 0.062689717 | 0.079142138 | 0.072177734 | 0.123934364 | 0.281086928 | 0.033498051 |
| | **1.01-2.00** | 0.023944061 | 0.091960676 | 0.137545589 | 0.000447628 | 0.081629643 | 0.141545483 | 0.089544046 | 0.247878094 | 0.319174352 | 0.05066408 |
| | **2.01-5.00** | 0.015636759 | 0.127072862 | 0.069948313 | 0.001870916 | 0.145970176 | 0.611238458 | 0.129891362 | 0.433530597 | 0.087156026 | 0.083399914 |
| | **> 5.00** | 0 | 0.15805411 | 0.031842718 | 0.00267295 | 0.12033173 | 0.262126587 | 0.125660814 | 0.198234291 | 0.01317386 | 0.006028718 |

Table 45. Affected Areas in Calbiga, Samar during 100-Year Rainfall Return Period

| CALBIGA BASIN | | Affected Barangays in Calbiga | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Otoc | Panayuran | Pasigay | Patong | Polangi | Rawis | San Ignacio | San Mauricio | Timbangan | Tinago |
| Affected Area (sq. km.) | **0.03-0.20** | 2.332838072 | 1.018073086 | 0.678585237 | 0.189043313 | 2.346038751 | 0.517917911 | 0.516963077 | 2.24984696 | 0.740365859 | 0.891447529 |
| | **0.21-0.50** | 0.07576766 | 0.039844099 | 0.615368639 | 0.186267178 | 0.097136978 | 0.042830923 | 0.377087974 | 0.048742656 | 0.026343654 | 0.239668981 |
| | **0.51-1.00** | 0.058669454 | 0.025400428 | 0.445737747 | 0.90505189 | 0.104021313 | 0.178810405 | 0.463346392 | 0.042047939 | 0.035158143 | 0.114949309 |
| | **1.01-2.00** | 0.065631617 | 0.024301174 | 0.265724992 | 1.117855767 | 0.175580031 | 0.184666285 | 0.177795234 | 0.052021443 | 0.066218841 | 0.004795152 |
| | **2.01-5.00** | 0.114015591 | 0.020211046 | 0.0001 | 0.043034143 | 0.340576453 | 0.218364386 | 0.104942532 | 0.07214731 | 0.178070686 | 0.0007 |
| | **> 5.00** | 0.190005726 | 0.0004 | 0 | 0.0014 | 0.290871363 | 0.067291724 | 0.033634849 | 0.192205523 | 0.113941642 | 0 |

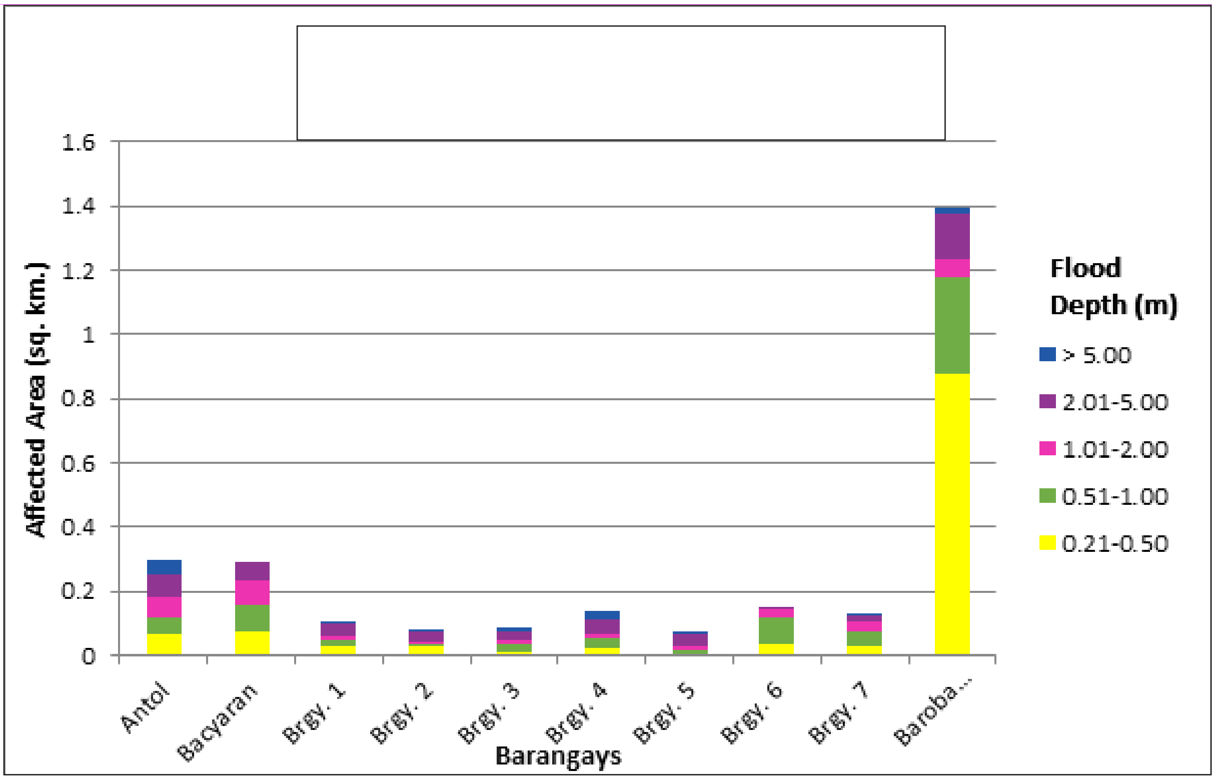



Figure 76. Affected Areas in Calbiga, Samar during 100-Year Rainfall Return Period

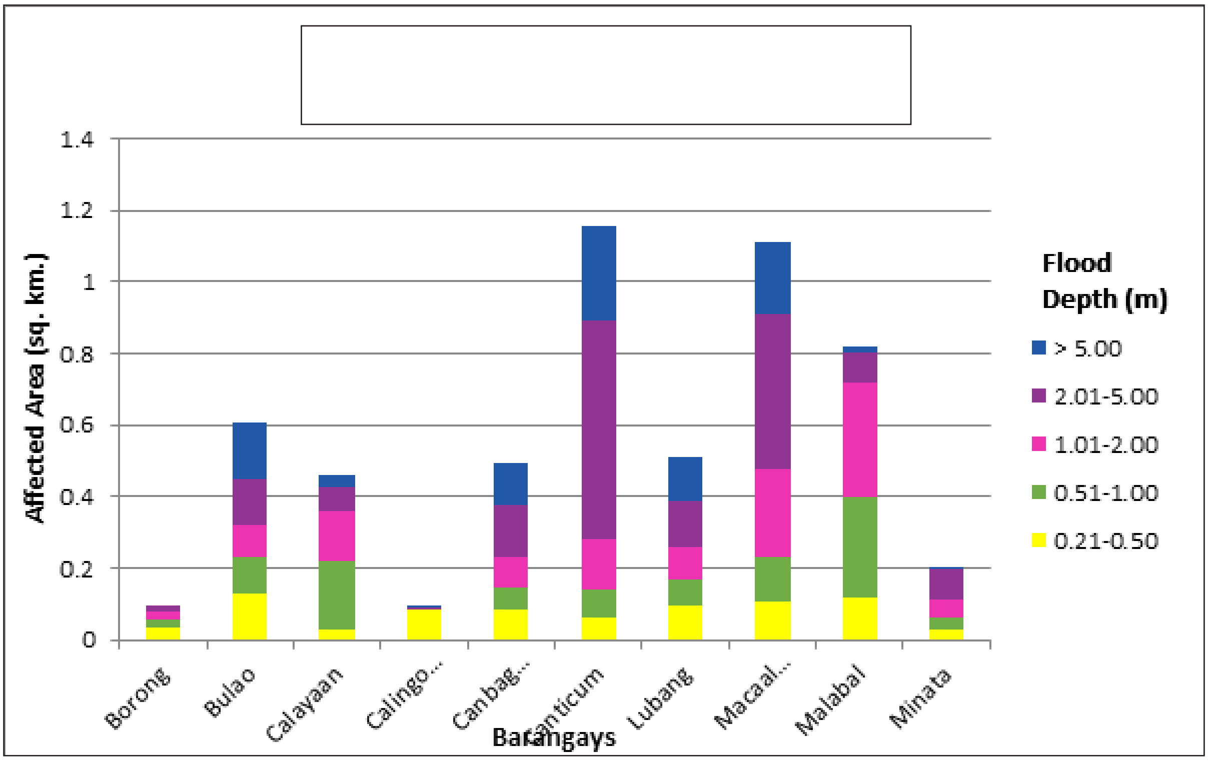



Figure 77. Affected Areas in Calbiga, Samar during 100-Year Rainfall Return Period

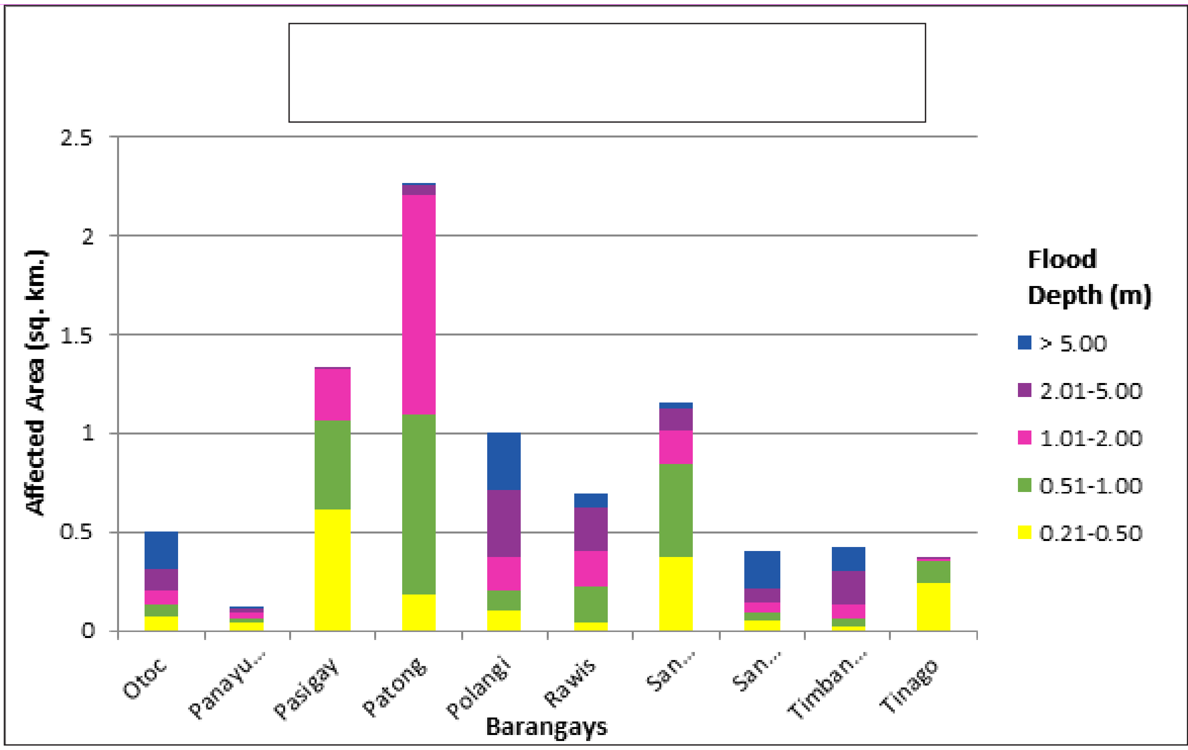



Figure 78. Affected Areas in Calbiga, Samar during 100-Year Rainfall Return Period

For the municipality of Pinabacdao, with an area of 118.38 sq. km., 9.13% will experience flood levels of less 0.20 meters. 1.73% of the area will experience flood levels of 0.21 to 0.50 meters while 2.13%, 1.8%, 0.43% and 0.08% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and above 5 meters, respectively. Listed in Table 46 and Table 47 are the affected areas in square kilometres by flood depth per barangay.

Table 46. Affected Areas in Pinabacdao, Samar during 100-Year Rainfall Return Period

| CALBIGA BASIN | | Affected Barangays in Pinabacdao | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Bangon | Barangay I | Barangay II | Botoc | Calampong | Catigawan | Dolores |
| Affected Area (sq. km.) | 0.03-0.20 | 0.972027865 | 0.086405124 | 0.095164231 | 0.663288018 | 0.895260627 | 0.431806932 | 0.440461092 |
| | 0.21-0.50 | 0.289284842 | 0.024741811 | 0.045496297 | 0.191429947 | 0.270999688 | 0.159710403 | 0.049917321 |
| | 0.51-1.00 | 0.513424342 | 0.009898941 | 0.010053756 | 0.363338463 | 0.128388378 | 0.326459416 | 0.058966873 |
| | 1.01-2.00 | 0.62873871 | 0 | 0 | 0.082096755 | 0.058424904 | 0.100986313 | 0.235344809 |
| | 2.01-5.00 | 0.084862684 | 0 | 0 | 0 | 0.00147994 | 0.002331359 | 0.028462669 |
| | > 5.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 47. Affected Areas in Pinabacdao, Samar during 100-Year Rainfall Return Period

| CALBIGA BASIN | | Affected Barangays in Pinabacdao | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Lale | Lawaan | Loctob | Madalunot | Mambog | Nabong | Obayan | San Isidro |
| Affected Area (sq. km.) | 0.03-0.20 | 0.429349244 | 0.876170866 | 2.085266247 | 3.148443248 | 0.158687176 | 0.103984655 | 0.404966281 | 0.013901178 |
| | 0.21-0.50 | 0.117552896 | 0.076476765 | 0.46549873 | 0.087069607 | 0.020183102 | 0.024393613 | 0.22853977 | 0.000558694 |
| | 0.51-1.00 | 0.076316425 | 0.088145673 | 0.493627199 | 0.076671008 | 0.074102166 | 0.078020076 | 0.227192576 | 0.000263756 |
| | 1.01-2.00 | 0.187200832 | 0.041068068 | 0.167374712 | 0.083813025 | 0.22511854 | 0.265145118 | 0.055402581 | 0 |
| | 2.01-5.00 | 0.059297054 | 0.034070828 | 0.047532363 | 0.117431579 | 0.036581033 | 0.100644108 | 0 | 0 |
| | > 5.00 | 0 | 0.0025 | 0 | 0.088014783 | 0 | 0.0002 | 0 | 0 |

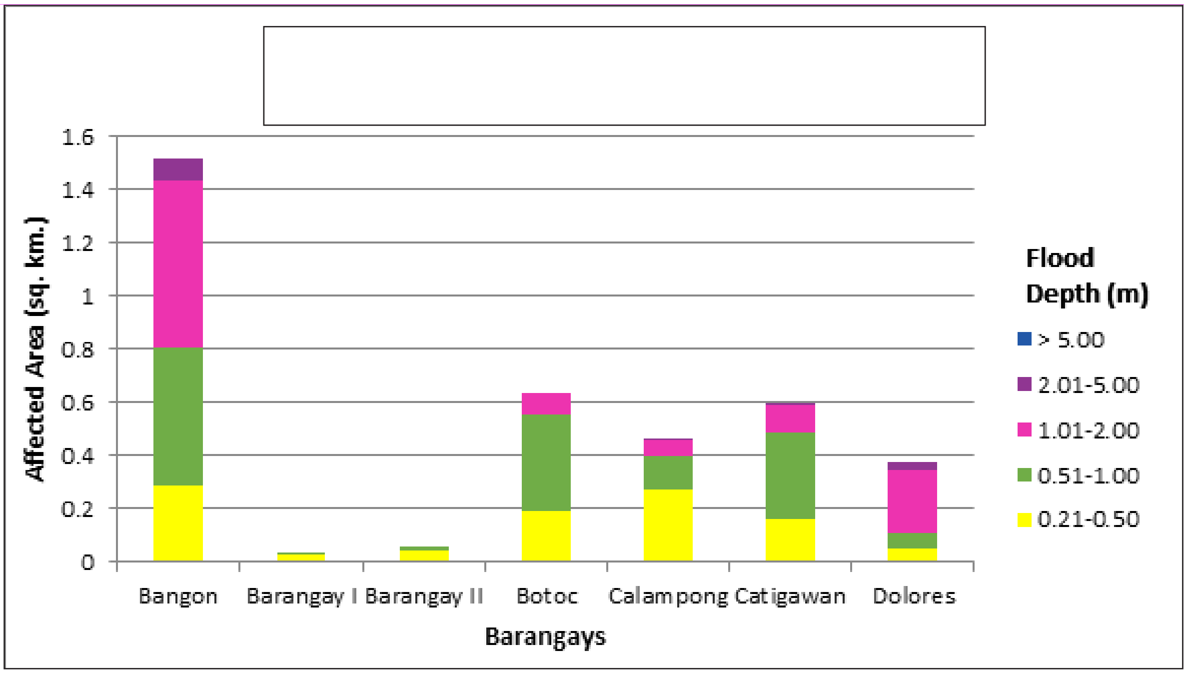



Figure 79. Affected Areas in Pinabacdao, Samar during 100-Year Rainfall Return Period

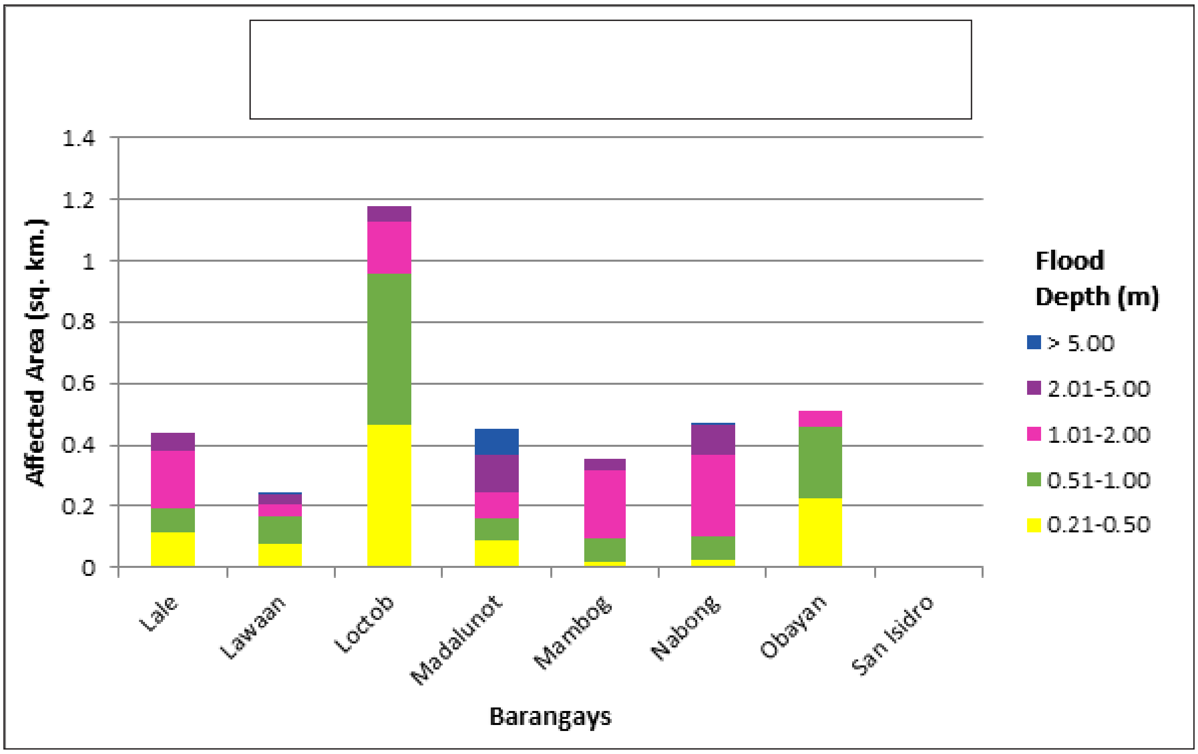



Figure 80. Affected Areas in Pinabacdao, Samar during 100-Year Rainfall Return Period

For the municipality of Villareal, with an area of 130.218 sq. km., 0.97% will experience flood levels of less 0.20 meters. 0.13% of the area will experience flood levels of 0.21 to 0.50 meters while 0.22%, 0.35%, 0.12%, and 0.0006% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters and more than 5 meters, respectively.

Table 48. Affected Areas in Villareal, Samar during 100-Year Rainfall Return Period

| CALBIGA BASIN | | Affected Barangays in Villareal | | |
|---|---|---|---|---|
| | | Malonoy | San Fernando | San Rafael |
| Affected Area (sq. km.) | **0.03-0.20** | 0.345977397 | 0.486581546 | 0.427623578 |
| | **0.21-0.50** | 0.046324377 | 0.034545638 | 0.085039795 |
| | **0.51-1.00** | 0.015854252 | 0.061954527 | 0.211331281 |
| | **1.01-2.00** | 0.023580495 | 0.229951638 | 0.209359822 |
| | **2.01-5.00** | 0.023952049 | 0.125143031 | 0.010304839 |
| | **> 5.00** | 0.0007 | 0.0001 | 0 |

Figure 81. Affected Areas in Villareal, Samar during 100-Year Rainfall Return Period

Among the barangays in the municipality of Calbiga, Macaalan is projected to have the highest percentage of area that will experience flood levels at 1.86%. Meanwhile, Canticum posted the second highest percentage of area that may be affected by flood depths at 1.74%.

Among the barangays in the municipality of Pinabacdao, Madalunot is projected to have the highest percentage of area that will experience flood levels at 3.04%. Meanwhile, Loctob posted the second highest percentage of area that may be affected by flood depths at 2.75%.

Among the barangays in the city of Villareal, San Rafael is projected to have the highest percentage of area that will experience flood levels of at 0.725%. Meanwhile, San Fernando posted the second highest percentage of area that may be affected by flood depths of at 0.720%.

The generated flood hazard maps for the Calbiga 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 49. 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 | 6.64 | 6.05 | 6.04 |
| Medium | 7.80 | 10.44 | 11.08 |
| High | 4.34 | 6.96 | 8.16 |
| Total | 18.78 | 23.45 | 25.28 |

Of the 24 identified Education Institutions in Calbiga Flood plain, 3 schools were assessed to be exposed to the Low level flooding during a 5 year scenario while 2 were assessed to be exposed to Medium and 1 to High level flooding in the same scenario. In the 25 year scenario, 3 schools were assessed to be exposed to the Low level flooding while 5 schools were assessed to be exposed to Medium and 2 to High level flooding. For the 100 year scenario, 3 schools were assessed for Low level flooding and 3 schools for Medium level flooding. In the same scenario, 4 schools were assessed to be exposed to High level flooding. See Annex 12 for a detailed enumeration of schools inside Calbiga floodplain.

Of the 6 identified Medical Institutions in Calbiga Flood plain, 1 was assessed to be exposed to the Medium level flooding during a 5 year scenario. In the 25 year and 100 year scenario, 1 was assessed to be exposed to the Low level flooding while 5 were assessed to be exposed to Medium level flooding. See Annex 13 for a detailed enumeration of medical institutions inside Calbiga floodplain.

## 5.11 Flood Validation

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

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

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

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

The flood validation consists of 196 points randomly selected all over the Calbiga flood plain. It has an RMSE value of 0.83.

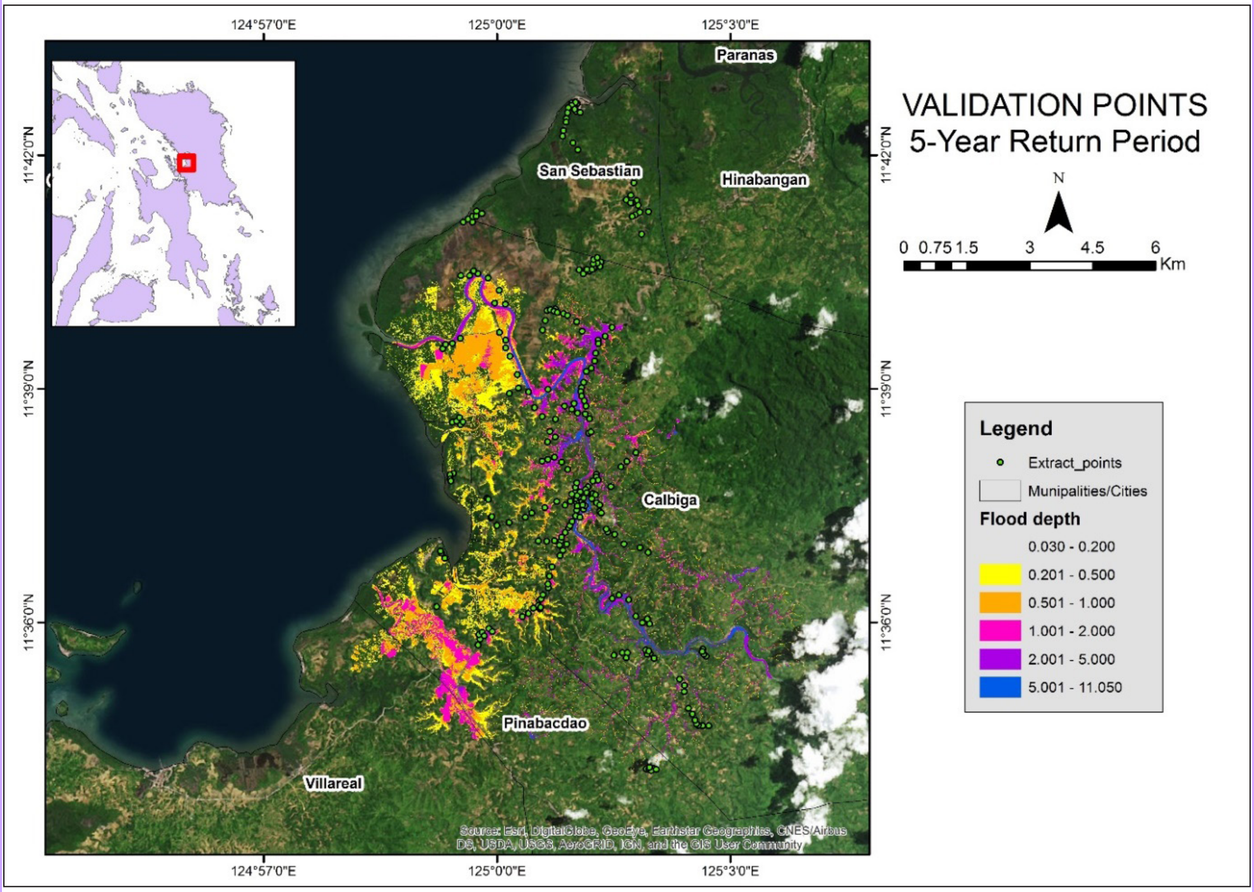



Figure 82. Validation points for 100-year Flood Depth Map of Calbiga Floodplain

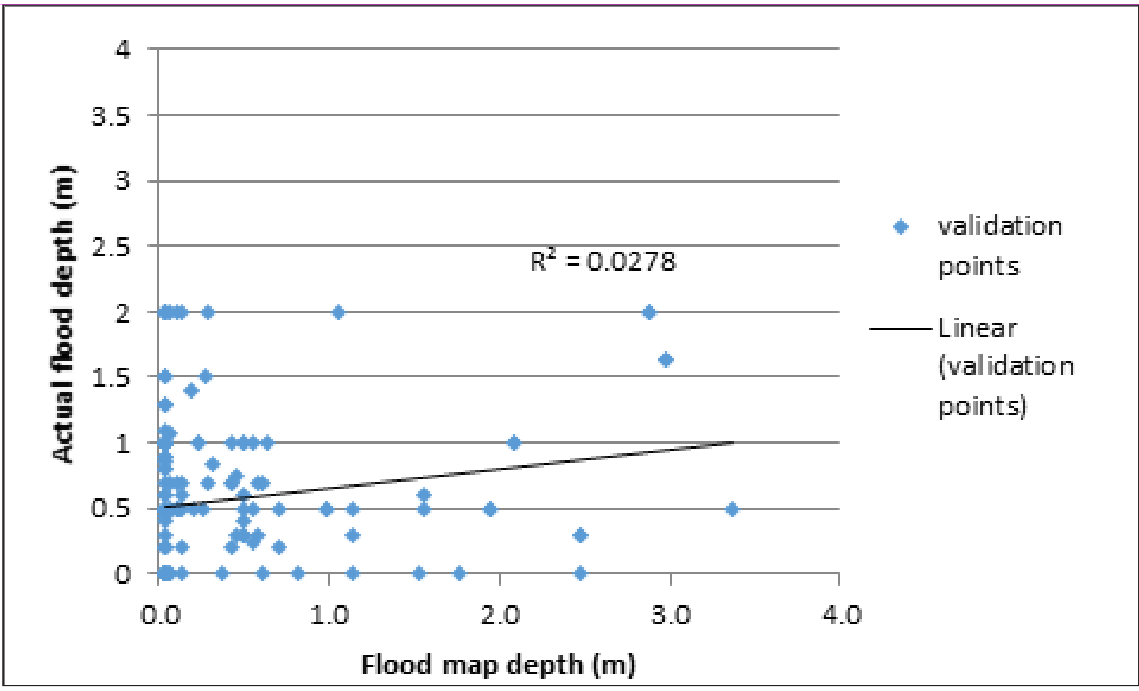



Figure 83. Flood map depth vs actual flood depth

Table 50. Actual Flood Depth vs Simulated Flood Depth in Calbiga

| CALBIGA BASIN | | Modeled Flood Depth (m) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0-0.20 | 0.21-0.50 | 0.51-1.00 | 1.01-2.00 | 2.01-5.00 | > 5.00 | Total |
| Actual Flood Depth (m) | 0-0.20 | 64 | 2 | 3 | 3 | 1 | 0 | 73 |
| | 0.21-0.50 | 29 | 7 | 6 | 5 | 3 | 0 | 50 |
| | 0.51-1.00 | 31 | 11 | 4 | 1 | 2 | 0 | 49 |
| | 1.01-2.00 | 17 | 2 | 0 | 1 | 4 | 0 | 24 |
| | 2.01-5.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | > 5.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Total | 141 | 22 | 13 | 10 | 10 | 0 | 196 |

The overall accuracy generated by the flood model is estimated at 38.78%, with 76 points correctly matching the actual flood depths. In addition, there were 53 points estimated one level above and below the correct flood depths while there were 43 points and 24 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 30 points were overestimated while a total of 90 points were underestimated in the modelled flood depths of Calbiga.

Table 51. Summary of Accuracy Assessment in Calbiga

| | No. of Points | % |
|---|---|---|
| Correct | 76 | **38.78** |
| Overestimated | 30 | 15.31 |
| Underestimated | 90 | 45.92 |
| Total | 196 | 100 |

# REFERENCES

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

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

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

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

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

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

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

# ANNEXES

## ANNEX 1. OPTECH TECHNICAL SPECIFICATION OF THE GEMINI SENSOR

**GEMINI**

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

# ANNEX 2. NAMRIA CERTIFICATES OF REFERENCE POINTS USED

SMR-53

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

April 23, 2014

## CERTIFICATION

To whom it may concern:

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

Province: **SAMAR (WESTERN SAMAR)**
Station Name: **SMR-53**
Order: **2nd**

Island: **VISAYAS**
Municipality: **SANTA RITA**
Barangay: **SAN ISIDRO**

*PRS92 Coordinates*

Latitude: **11° 30' 17.85657"** Longitude: **125° 1' 29.83739"** Ellipsoidal Hgt: **26.13400 m.**

*WGS84 Coordinates*

Latitude: **11° 30' 13.52495"** Longitude: **125° 1' 34.96980"** Ellipsoidal Hgt: **87.78700 m.**

*PTM Coordinates*

Northing: **1272180.079 m.** Easting: **502722.403 m.** Zone: **5**

*UTM Coordinates*

Northing: **1,272,513.40** Easting: **720,874.14** Zone: **51**

Location Description

SMR-53
From Tacloban City Proper, travel about 45 km. north going to Brgy. San.Isidro. The NAMRIA monument was located about 15 m. west inside the San Isidro Elementary School, and almost near at the school building and flag pole about 5 m. north. Mark is the head of a 4" copper nail flushed in a cement block embedded in the ground with inscriptions "SMR-53; 2007; NAMRIA."

Requesting Party: **Engr. Christopher Cruz/ UP-DREAM**
Pupose: **Reference**
OR Number: **8796021 A**
T.N.: **2014-920**

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

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

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

SM-271

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

January 27, 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: **SAMAR (WESTERN SAMAR)**
Station Name: **SM-271**

| | | |
|---|---|---|
| Island: **VISAYAS** | Municipality: **PINABACDAO** | Barangay: **LAYGAYON** |
| Elevation: **80.1571 +/- 0.05 m.** | Order: **1st Order** | Datum: **Mean Sea Level** |
| Latitude: | Longitude: | |

Location Description

SM-271 is in the Province of Western Samar, town of Pinabakdaw, Brgy. Laygayon along right side of the National highway. It is located beside km post 864 and about 5.00m E from the centerline of the national highway. Station mark is the head of 4" copper nail centered on a 0.30m x 0.30m concrete block and mark with "SM-271,2007,NAMRIA."

| | |
|---|---|
| Requesting Party: | **UP DREAM** |
| Purpose: | **Reference** |
| OR Number: | **8089687 I** |
| T.N.: | **2016-0241** |

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

9 9 0 1 2 7 2 0 1 6 1 5 1 2 2 0

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

# ANNEX 3. BASELINE PROCESSING REPORTS OF REFERENCE POINTS USED

Processing Summary

| Observation | From | To | Solution Type | H. Prec. (Meter) | V. Prec. (Meter) | Geodetic Az. | Ellipsoid Dist. (Meter) | ΔHeight (Meter) |
|---|---|---|---|---|---|---|---|---|
| SMR-53 --- LYT-104 (B1) | SMR-53 | LYT-104 | Fixed | 0.008 | 0.017 | 200°40'31" | 42653.401 | 7.525 |
| SMR-53 --- LYT-104 (B2) | SMR-53 | LYT-104 | Fixed | 0.004 | 0.016 | 200°40'31" | 42653.384 | 7.601 |

Acceptance Summary

| Processed | Passed | Flag | Fail |
|---|---|---|---|
| 2 | 2 | 0 | 0 |

Vector Components (Mark to Mark)

| From: | SMR-53 | | | | |
|---|---|---|---|---|---|
| Grid | | Local | | Global | |
| Easting | 720874.133 m | Latitude | N11°30'17.85656" | Latitude | N11°30'13.52495" |
| Northing | 1272513.396 m | Longitude | E125°01'29.83738" | Longitude | E125°01'34.96980" |
| Elevation | 24.750 m | Height | 26.134 m | Height | 87.787 m |

| To: | LYT-104 | | | | |
|---|---|---|---|---|---|
| Grid | | Local | | Global | |
| Easting | 706089.510 m | Latitude | N11°08'38.92234" | Latitude | N11°08'34.67033" |
| Northing | 1232496.838 m | Longitude | E124°53'13.52786" | Longitude | E124°53'18.69323" |
| Elevation | 32.311 m | Height | 33.659 m | Height | 95.861 m |

| Vector | | | | | |
|---|---|---|---|---|---|
| ΔEasting | -14784.623 m | NS Fwd Azimuth | 200°40'31" | ΔX | 7839.600 m |
| ΔNorthing | -40016.558 m | Ellipsoid Dist. | 42653.401 m | ΔY | 15051.644 m |
| ΔElevation | 7.561 m | ΔHeight | 7.525 m | ΔZ | -39131.928 m |

Standard Errors

| Vector errors: | | | | | |
|---|---|---|---|---|---|
| σ ΔEasting | 0.003 m | σ NS fwd Azimuth | 0°00'00" | σ ΔX | 0.006 m |
| σ ΔNorthing | 0.002 m | σ Ellipsoid Dist. | 0.002 m | σ ΔY | 0.007 m |
| σ ΔElevation | 0.009 m | σ ΔHeight | 0.009 m | σ ΔZ | 0.002 m |

LYT-104

## Processing Summary

| Observation | From | To | Solution Type | H. Prec. (Meter) | V. Prec. (Meter) | Geodetic Az. | Ellipsoid Dist. (Meter) | ΔHeight (Meter) |
|---|---|---|---|---|---|---|---|---|
| SM-271 --- SMR-53 (B2) | SMR-53 | SM-271 | Fixed | 0.004 | 0.018 | 5°23'32" | 2272.463 | 55.956 |
| SM-271 --- SMR-53 (B1) | SMR-53 | SM-271 | Fixed | 0.004 | 0.014 | 5°23'31" | 2272.470 | 55.944 |

## Acceptance Summary

| Processed | Passed | Flag | Fail |
|---|---|---|---|
| 2 | 2 | 0 | 0 |

Vector Components (Mark to Mark)

| From: | SMR-53 | | | | |
|---|---|---|---|---|---|
| Grid | | Local | | Global | |
| Easting | 720874.133 m | Latitude | N11°30'17.85656" | Latitude | N11°30'13.52495" |
| Northing | 1272513.396 m | Longitude | E125°01'29.83738" | Longitude | E125°01'34.96980" |
| Elevation | 24.750 m | Height | 26.134 m | Height | 87.787 m |

| To: | SM-271 | | | | |
|---|---|---|---|---|---|
| Grid | | Local | | Global | |
| Easting | 721071.745 m | Latitude | N11°31'31.48932" | Latitude | N11°31'27.15275" |
| Northing | 1274777.717 m | Longitude | E125°01'36.88440" | Longitude | E125°01'42.01496" |
| Elevation | 80.707 m | Height | 82.090 m | Height | 143.697 m |

| Vector | | | | | |
|---|---|---|---|---|---|
| ΔEasting | 197.612 m | NS Fwd Azimuth | 5°23'32" | ΔX | 52.927 m |
| ΔNorthing | 2264.321 m | Ellipsoid Dist. | 2272.463 m | ΔY | -447.483 m |
| ΔElevation | 55.957 m | ΔHeight | 55.956 m | ΔZ | 2228.061 m |

Standard Errors

| Vector errors: | | | | | |
|---|---|---|---|---|---|
| σ ΔEasting | 0.002 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 | 0.008 m |
| σ ΔElevation | 0.009 m | σ ΔHeight | 0.009 m | σ ΔZ | 0.002 m |

Aposteriori Covariance Matrix (Meter²)

| | X | Y | Z |
|---|---|---|---|
| X | 0.0000261223 | | |
| Y | -0.0000356331 | 0.0000567847 | |
| Z | -0.0000091774 | 0.0000140863 | 0.0000048698 |

SM-271

Vector Components (Mark to Mark)

| From: | SMR-53 | | | | |
|---|---|---|---|---|---|
| Grid | | Local | | Global | |
| Easting | 720874.133 m | Latitude | N11°30'17.85656" | Latitude | N11°30'13.52495" |
| Northing | 1272513.396 m | Longitude | E125°01'29.83738" | Longitude | E125°01'34.96980" |
| Elevation | 24.750 m | Height | 26.134 m | Height | 87.787 m |

| To: | SM-271 | | | | |
|---|---|---|---|---|---|
| Grid | | Local | | Global | |
| Easting | 721071.738 m | Latitude | N11°31'31.48956" | Latitude | N11°31'27.15300" |
| Northing | 1274777.724 m | Longitude | E125°01'36.88417" | Longitude | E125°01'42.01474" |
| Elevation | 80.695 m | Height | 82.078 m | Height | 143.685 m |

| Vector | | | | | |
|---|---|---|---|---|---|
| ΔEasting | 197.605 m | NS Fwd Azimuth | 5°23'31" | ΔX | 52.941 m |
| ΔNorthing | 2264.328 m | Ellipsoid Dist. | 2272.470 m | ΔY | -447.490 m |
| ΔElevation | 55.945 m | ΔHeight | 55.944 m | ΔZ | 2228.066 m |

Standard Errors

| Vector errors: | | | | | |
|---|---|---|---|---|---|
| σ ΔEasting | 0.001 m | σ NS fwd Azimuth | 0°00'00" | σ ΔX | 0.004 m |
| σ ΔNorthing | 0.001 m | σ Ellipsoid Dist. | 0.001 m | σ ΔY | 0.006 m |
| σ ΔElevation | 0.007 m | σ ΔHeight | 0.007 m | σ ΔZ | 0.002 m |

Aposteriori Covariance Matrix (Meter²)

| | X | Y | Z |
|---|---|---|---|
| X | 0.0000168455 | | |
| Y | -0.0000221649 | 0.0000355369 | |
| Z | -0.0000052344 | 0.0000087190 | 0.0000031341 |

# ANNEX 4. THE SURVEY TEAM

| Data Acquisition Component Sub-Team | Designation | Name | Agency/ Affiliation |
|---|---|---|---|
| PHIL-LIDAR 1 | Program Leader | ENRICO C. PARINGIT, D.ENG | UP-TCAGP |
| Data Acquisition Component Leader | Component Project Leader - I | ENGR. CZAR JAKIRI SARMIENTO | UP-TCAGP |
| | Component Project Leader – I | ENGR. LOUIE BALICANTA | UP-TCAGP |
| Survey Supervisor | Chief Science Research Specialist (CSRS) | ENGR. CHRISTOPHER CRUZ | UP-TCAGP |
| | Supervising Science Research Specialist (Supervising SRS) | LOVELY GRACIA ACUñA | UP-TCAGP |
| | | LOVELYN ASUNCION | UP-TCAGP |
| **FIELD TEAM** | | | |
| LiDAR Operation, Data Download and Transfer | Senior Science Research Specialist (SSRS) | PAULINE JOANNE ARCEO | UP-TCAGP |
| | Research Associate (RA) | ENGR. GRACE SINADJAN | UP-TCAGP |
| | RA | JONATHAN ALMALVEZ | UP-TCAGP |
| | RA | JERIEL PAUL ALAMBAN | UP-TCAGP |
| LiDAR Operation | Airborne Security | SSG RAYMUND DOMINE | PHILIPPINE AIR FORCE (PAF) |
| | Pilot | CAPT. ALBERT LIM | ASIAN AEROSPACE CORPORATION (AAC) |
| | | CAPT. RANDY LAGCO | AAC |

# ANNEX 5. DATA TRANSFER SHEET FOR CALBIGA FLOODPLAIN

3727G, 3729G

DATA TRANSFER SHEET
CATARMAN 5/24/2016

| DATE | FLIGHT NO. | MISSION NAME | SENSOR | RAW LAS | | LOGS | 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 | |
| April 11, 2016 | 8431AC | 3BLK33D102A | AQUA/CASI | NA | 297 | 710 | 237 | NA | NA | 12.5 | NA | 118 | 1KB | 1KB | 9 | NA | Z:\DAC\RAW DATA |
| April 12, 2016 | 8433AC | 3BLK33KSJ103A | AQUA/CASI | NA | 367 | 707 | 245 | 44.9 | NA | 13.8 | NA | 127 | 1KB | NA | 46 | NA | Z:\DAC\RAW DATA |
| April 13, 2016 | 8435AC | 3BLK33IK104A | AQUA/CASI | NA | 302 | 706 | 240 | NA | NA | 12.3 | NA | 159 | 1KB | 1KB | 13 | NA | Z:\DAC\RAW DATA |
| April 14, 2016 | 8437AC | 3BLK33ISA105A | AQUA/CASI | NA | 643 | 793 | 268 | 64.7 | 177 | 14.5 | 239 | 175 | 1KB | 1KB | 13 | NA | Z:\DAC\RAW DATA |
| April 14, 2016 | 8438AC | 3BLK33AS105B | AQUA/CASI | NA | 90 | 222 | 83.7 | 15.8 | NA | 3.11 | 46.7 | 175 | 1KB | 1KB | 11 | NA | Z:\DAC\RAW DATA |
| April 16, 2016 | 8441AC | 3BLK33N107A | AQUA/CASI | NA | 301 | 702 | 246 | 64.7 | 267 | 12.8 | 221 | 91.8 | 1KB | 1KB | 8 | 301 | Z:\DAC\RAW DATA |
| April 16, 2016 | 8442AC | 3BLK33MNS107B | AQUA/CASI | NA | 411 | 259 | 122 | 15.8 | 74.1 | 5.04 | 83.9 | 91.8 | 1KB | 1KB | 8 | 301 | Z:\DAC\RAW DATA |
| April 17, 2016 | 8443AC | 3BLK33MS108A | AQUA/CASI | NA | 251 | 629 | 249 | 43.8 | 803 | 10.7 | 187 | 89.9 | 1KB | 1KB | 8 | 301 | Z:\DAC\RAW DATA |

**Received from**

Name: R. Punto
Position: RA
Signature:

**Received by**

Name: AC Bongat
Position: SSRS
Signature: 6/4/2016

# ANNEX 6. FLIGHT LOGS

Flight Log for 3727G Mission

**PHIL-LIDAR 1 Data Acquisition Flight Log**

Flight Log No.: 3727

| | | | | | |
|---|---|---|---|---|---|
| 1 LiDAR Operator: J. Almalvez | 2 ALTM Model: Gemini | 3 Mission Name: 2BLK34028B | 4 Type: VFR | 5 Aircraft Type: CesnnaT206H | 6 Aircraft Identification: RPC-9022 |
| 7 Pilot: A. Lim | 8 Co-Pilot: R. Cagiro | 9 Route: TACLOBAN LOCAL | | | |
| 10 Date: 1-29-16 | 12 Airport of Departure (Airport, City/Province): TACLOBAN | | 12 Airport of Arrival (Airport, City/Province): TACLOBAN | | |
| 13 Engine On: 14:12 | 14 Engine Off: 18:17 | 15 Total Engine Time: 4:05 | 16 Take off: 14:17 | 17 Landing: 18:12 | 18 Total Flight Time: 03:55 |
| 19 Weather: cloudy | | | | | |

**20 Flight Classification**

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

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

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

**21 Remarks**

Successful Flight.
Completed BLK 34I & 34J

**22 Problems and Solutions**

- o Weather Problem
- o System Problem
- o Aircraft Problem
- o Pilot Problem
- o Others: ____________

| Acquisition Flight Approved by | Acquisition Flight Certified by | Pilot-in-Command | LiDAR Operator | Aircraft Mechanic/ LiDAR Technician |
|---|---|---|---|---|
| P. Arroyo | SSg Raymund Dominic | A. Lim | J. Almalvez | [signature] |
| 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 |

Flight Log for 3729G Mission

**PHIL-LiDAR 1 Data Acquisition Flight Log**

Flight Log No.: 3729

| | | | | | |
|---|---|---|---|---|---|
| 1 LiDAR Operator: P. Arceo | 2 ALTM Model: Gemini | 3 Mission Name: 2BLK34030A | 4 Type: VFR | 5 Aircraft Type: Cesnna T206H | 6 Aircraft Identification: RPC-9022 |
| 7 Pilot: A. Lim | 8 Co-Pilot: R. Lagco | 9 Route: Tacloban Local | | | |
| 10 Date: 1-30-16 | 12 Airport of Departure (Airport, City/Province): Tacloban | | 12 Airport of Arrival (Airport, City/Province): Tacloban | | |
| 13 Engine On: 8:29 | 14 Engine Off: 12:40 | 15 Total Engine Time: 4+11 | 16 Take off: 8:34 | 17 Landing: 12:35 | 18 Total Flight Time: 4+01 |
| 19 Weather: Cloudy | | | | | |

**20 Flight Classification**

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

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

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

**21 Remarks**

Successful Flight.

**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 |
|---|---|---|---|---|
| P. Arceo | SSg Bungmunot Y Domini | A. Lim | P. Arceo | |
| 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 |

# ANNEX 7. FLIGHT STATUS

FLIGHT STATUS REPORT

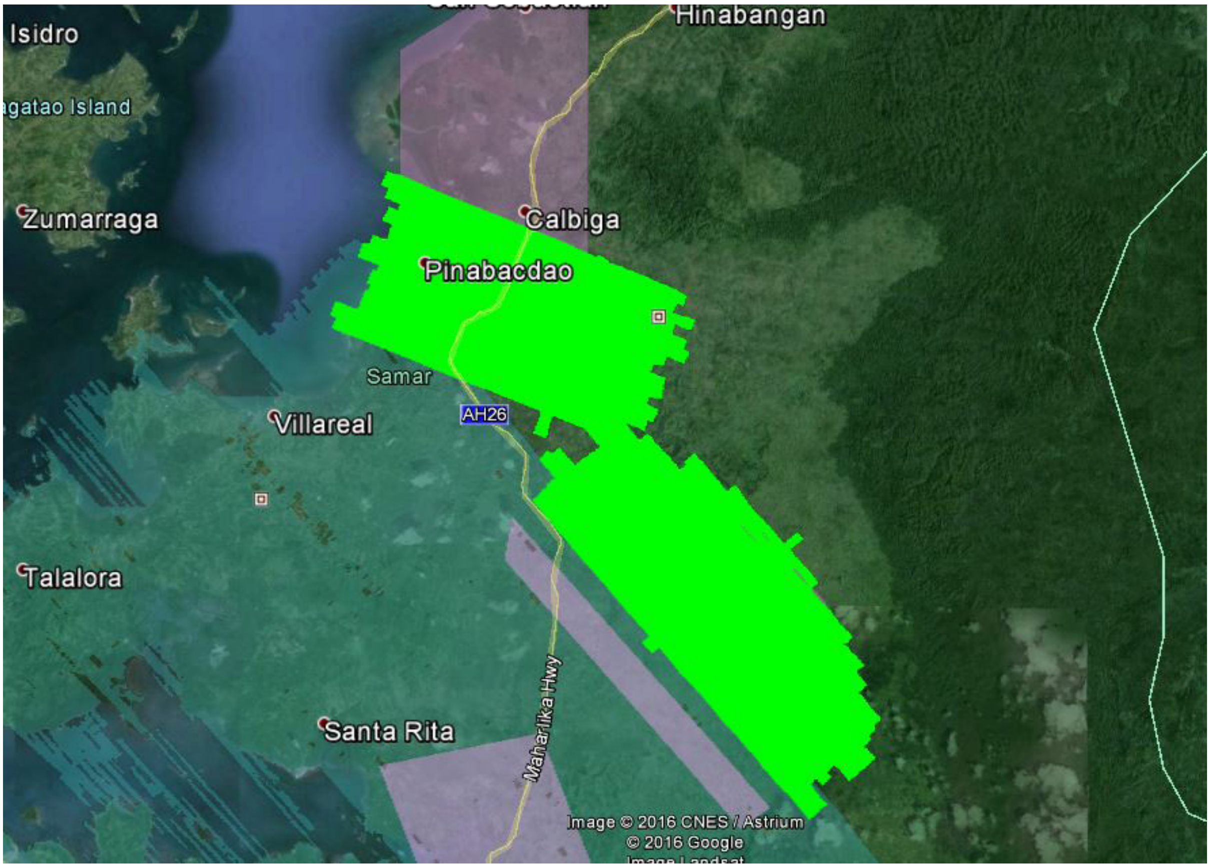
**Tacloban / Samar**

January 29 to 30, 2016

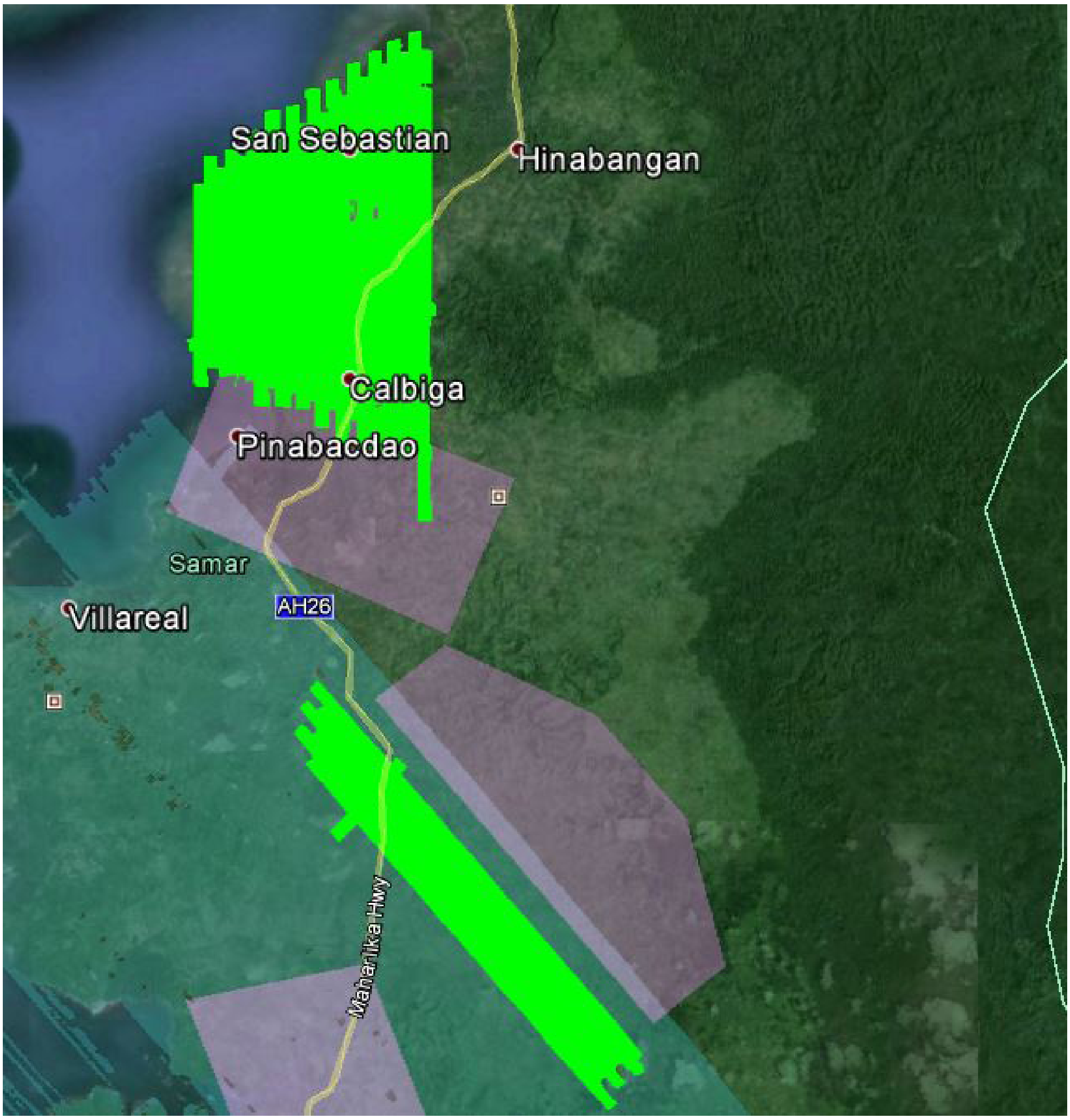
| FLIGHT NO | AREA | MISSION | OPERATOR | DATE FLOWN | REMARKS |
|---|---|---|---|---|---|
| 3727G | BLK34I<br>BLK34J | 2BLK34IJ029B | J. ALMALVEZ | January 29, 2016 | Completed BLK34I and surveyed 15 lines at BLK34J. |
| 3729G | BLK34H<br>BLK34J | 2BLK34HJ030A | P. ARCEO | January 30, 2016 | Completed BLK34H and BLK34J. |

**SWATH PER FLIGHT MISSION**

FLIGHT NO.: 3727G
AREA: Samar
MISSION NAME: 2BLK34IJ029B
ALT: 800m SCAN FREQ: 40Hz
SCAN ANGLE: 25 deg SURVEYED AREA: 144.55 sq.km.



| | |
|---|---|
| FLIGHT NO.: | 3729G |
| AREA: | Samar |
| MISSION NAME: | 2BLK34HJ030A |
| ALT: 650m | SCAN FREQ: 50Hz |
| SCAN ANGLE: 20deg | SURVEYED AREA: 105.73 km$^2$ |



# ANNEX 8. MISSION SUMMARY REPORTS

| Flight Area | Leyte |
|---|---|
| Mission Name | Blk33H_Supplement |
| Inclusive Flights | 3727G |
| Range data size | 22.8 |
| POS data size | 243 |
| Base data size | 4.2 |
| Image | n/a |
| Transfer date | February 26, 2016 |
| | |
| Solution Status | |
| Number of Satellites (>6) | Yes |
| PDOP (<3) | Yes |
| Baseline Length (<30km) | Yes |
| Processing Mode (<=1) | Yes |
| | |
| Smoothed Performance Metrics (in cm) | |
| RMSE for North Position (<4.0 cm) | 0.8 |
| RMSE for East Position (<4.0 cm) | 1.1 |
| RMSE for Down Position (<8.0 cm) | 2.3 |
| | |
| Boresight correction stdev (<0.001deg) | 0.001045 |
| IMU attitude correction stdev (<0.001deg) | 0.000441 |
| GPS position stdev (<0.01m) | 0.0251 |
| | |
| Minimum % overlap (>25) | 28.06 |
| Ave point cloud density per sq.m. (>2.0) | 4.38 |
| Elevation difference between strips (<0.20 m) | Yes |
| | |
| Number of 1km x 1km blocks | 95 |
| Maximum Height | 282.08 m |
| Minimum Height | 40.33 m |
| | |
| Classification (# of points) | |
| Ground | 60,241,285 |
| Low vegetation | 19,719,082 |
| Medium vegetation | 66,617,944 |
| High vegetation | 7,923,473 |
| Building | 0 |
| | |
| Orthophoto | No |
| Processed by | Engr. Analyn Naldo, Engr. Harmond Santos, Engr. Melissa Fernandez |

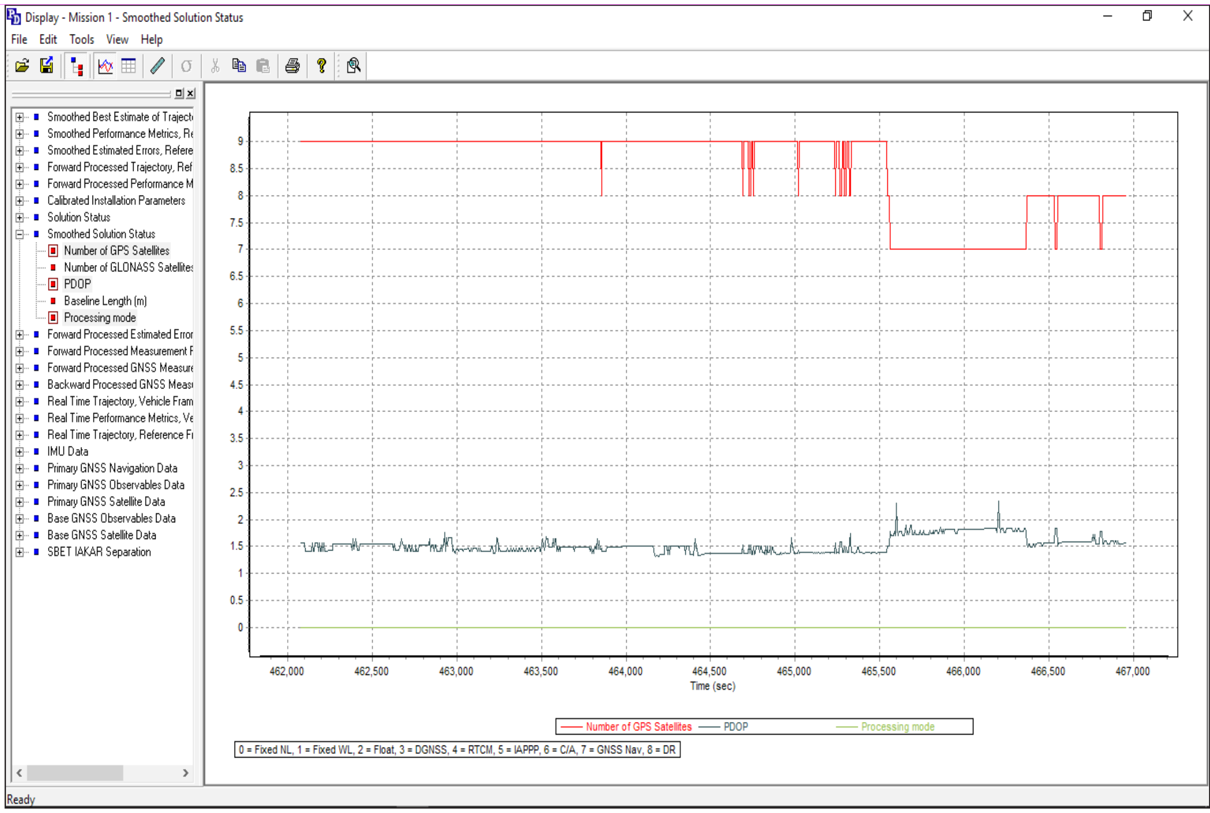



Figure 1.1.1. Solution Status

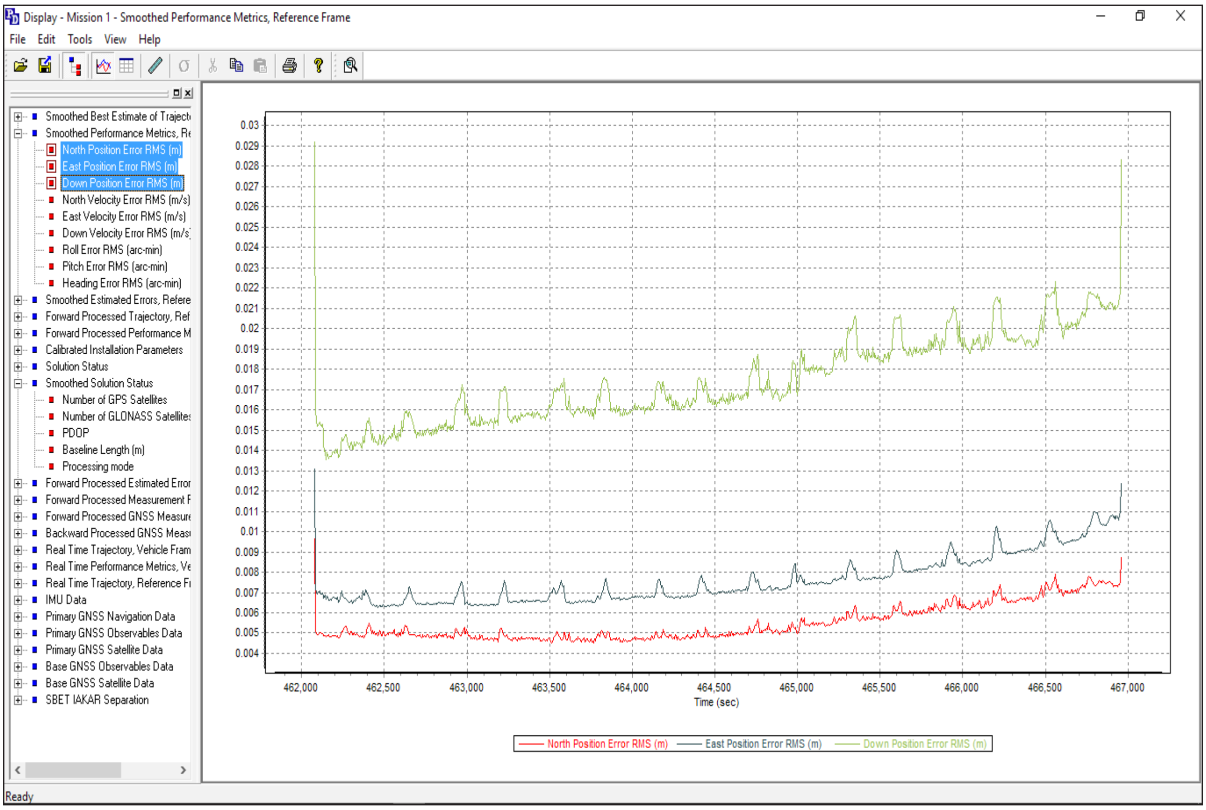



Figure 1.1.2. Smoothed Performance Metric Parameters

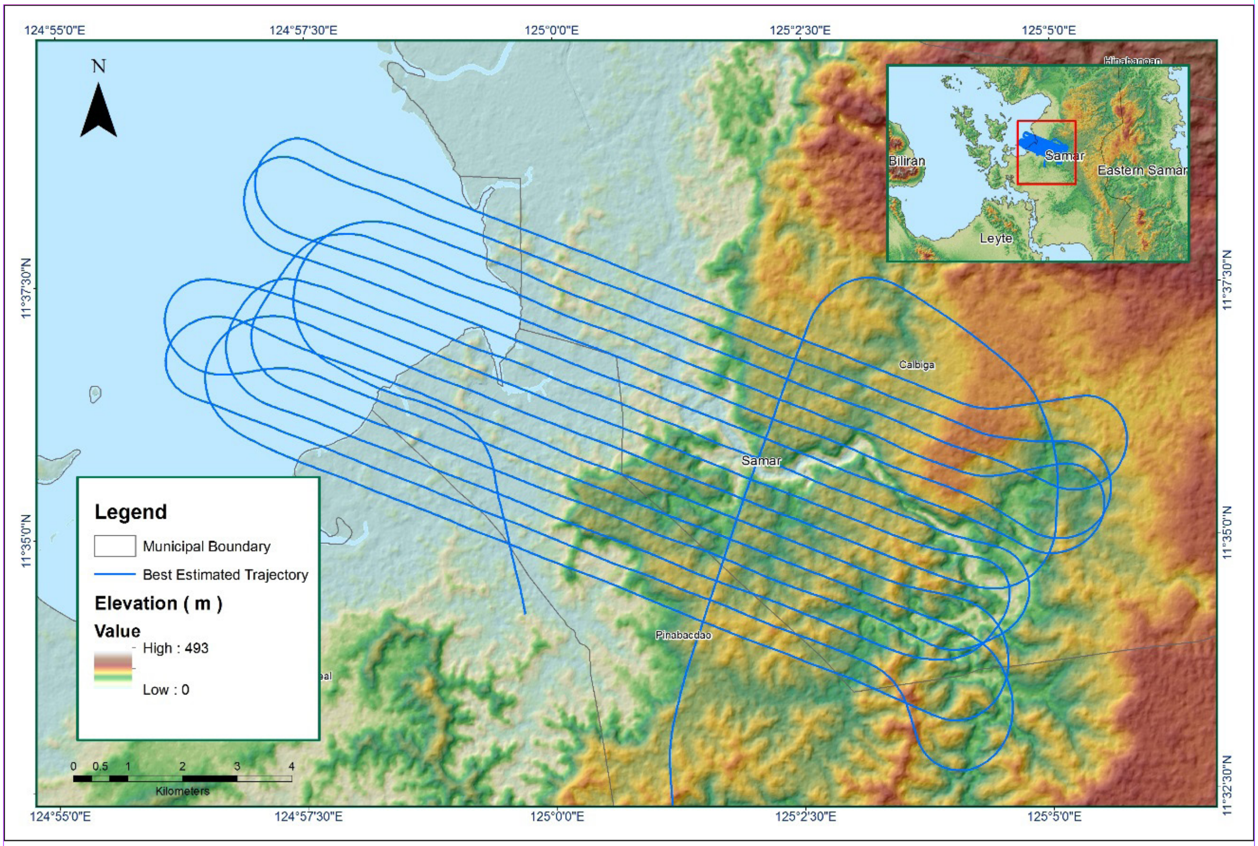



Figure 1.1.3. Best Estimated Trajectory

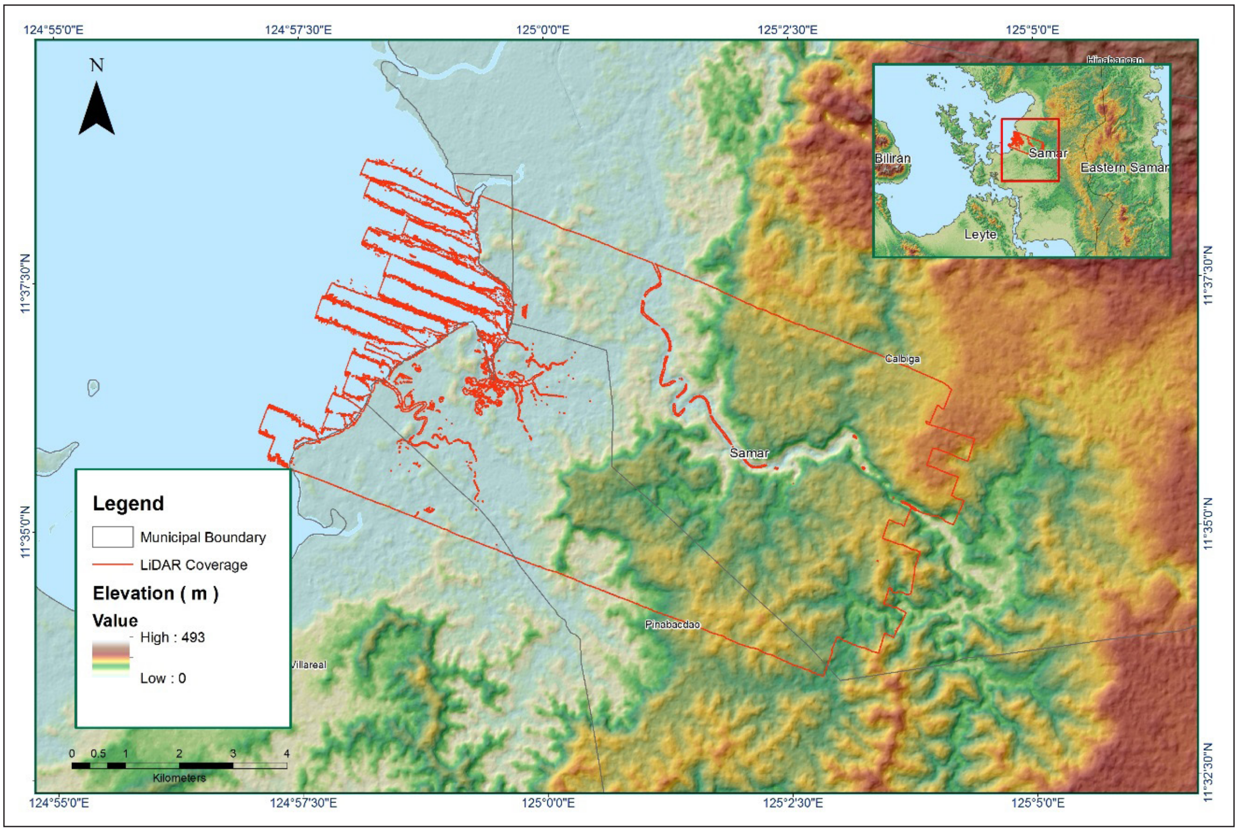



Figure 1.1.4. Coverage of LiDAR Data

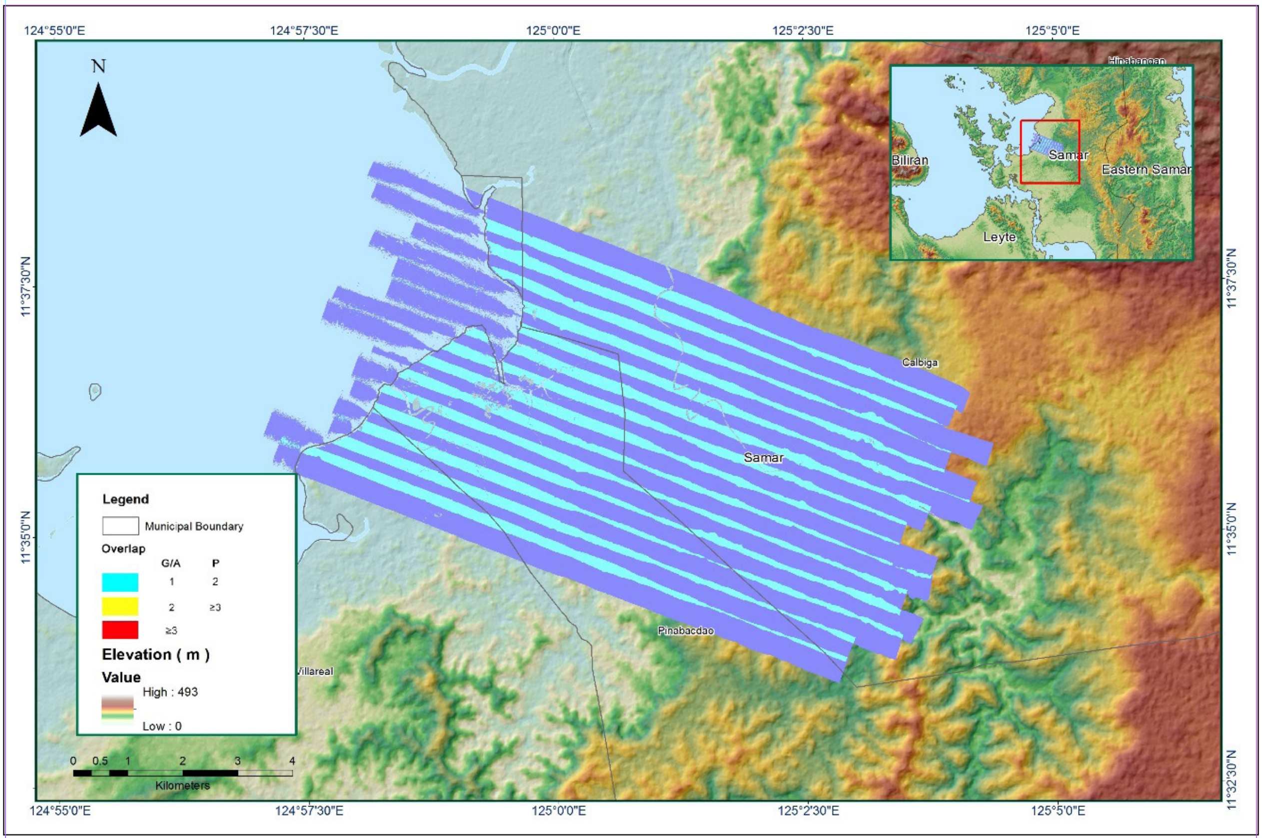



Figure 1.1.5. Image of data overlap

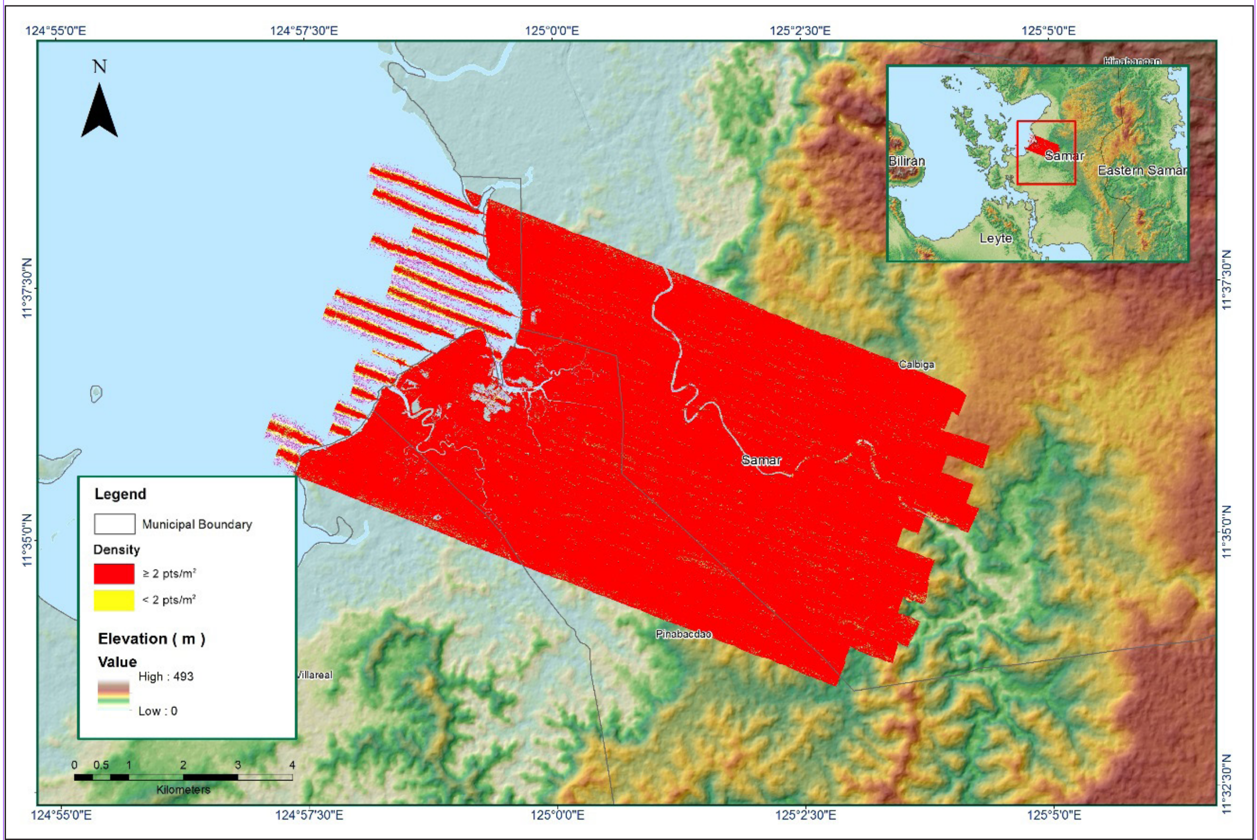



Figure 1.1.6. Density map of merged LiDAR data

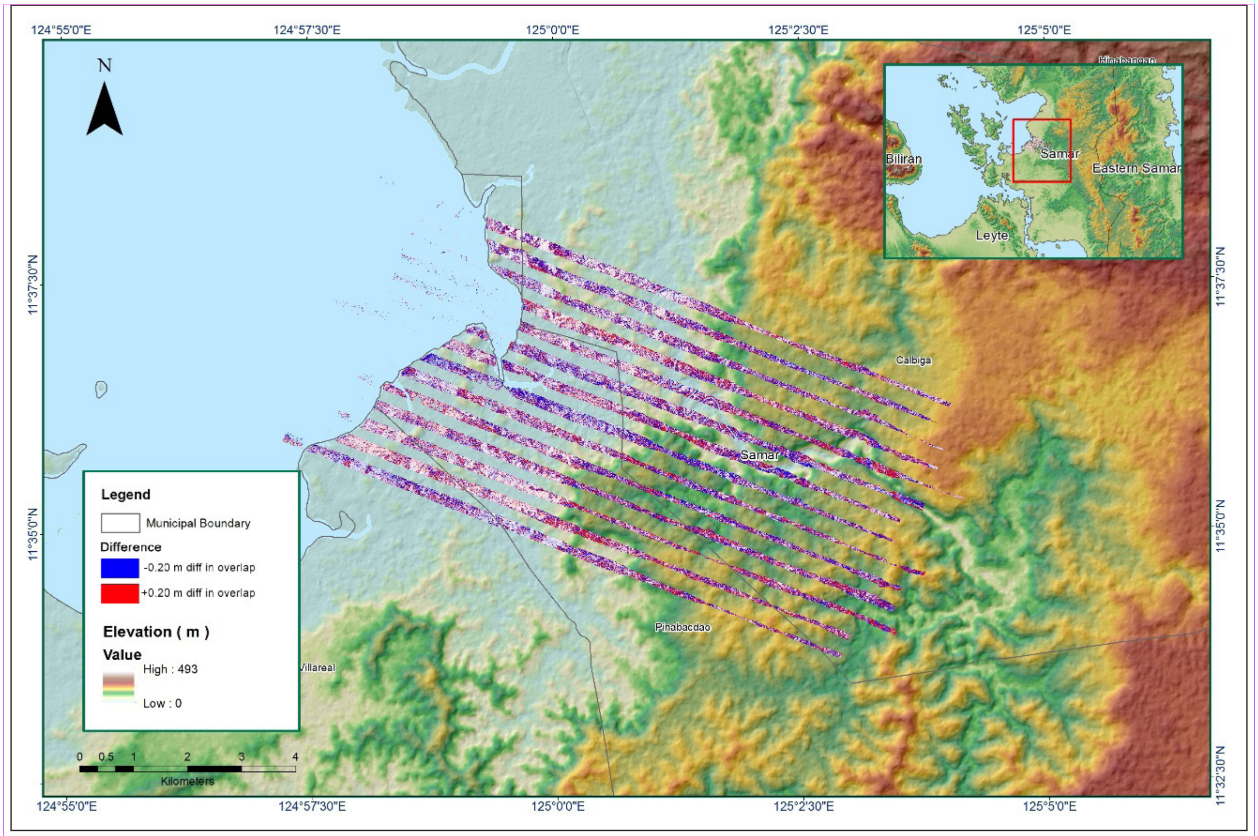



Figure 1.1.7. Elevation difference between flight lines

| Flight Area | Leyte |
|---|---|
| Mission Name | Blk33I |
| Inclusive Flights | 3729G |
| Range data size | 20.3 |
| POS data size | 243 |
| Base data size | 608 |
| Image | n/a |
| Transfer date | February 26, 2016 |
| | |
| Solution Status | |
| Number of Satellites (>6) | Yes |
| PDOP (<3) | No |
| Baseline Length (<30km) | No |
| Processing Mode (<=1) | Yes |
| | |
| Smoothed Performance Metrics (in cm) | |
| RMSE for North Position (<4.0 cm) | 2.1 |
| RMSE for East Position (<4.0 cm) | 2.0 |
| RMSE for Down Position (<8.0 cm) | 4.1 |
| | |
| Boresight correction stdev (<0.001deg) | N/A |
| IMU attitude correction stdev (<0.001deg) | N/A |
| GPS position stdev (<0.01m) | N/A |

| | |
|---|---|
| Minimum % overlap (>25) | 36.04 |
| Ave point cloud density per sq.m. (>2.0) | 5.31 |
| Elevation difference between strips (<0.20 m) | Yes |
| | |
| Number of 1km x 1km blocks | 108 |
| Maximum Height | 298.19 m |
| Minimum Height | 59.64 m |
| | |
| Classification (# of points) | |
| Ground | 43970465 |
| Low vegetation | 45085297 |
| Medium vegetation | 162080919 |
| High vegetation | 125702925 |
| Building | 1307188 |
| | |
| Orthophoto | No |
| Processed by | Engr. Kenneth Solidum, Engr. Velina Angela Bemida, Maria Tamsyn Malabanan |

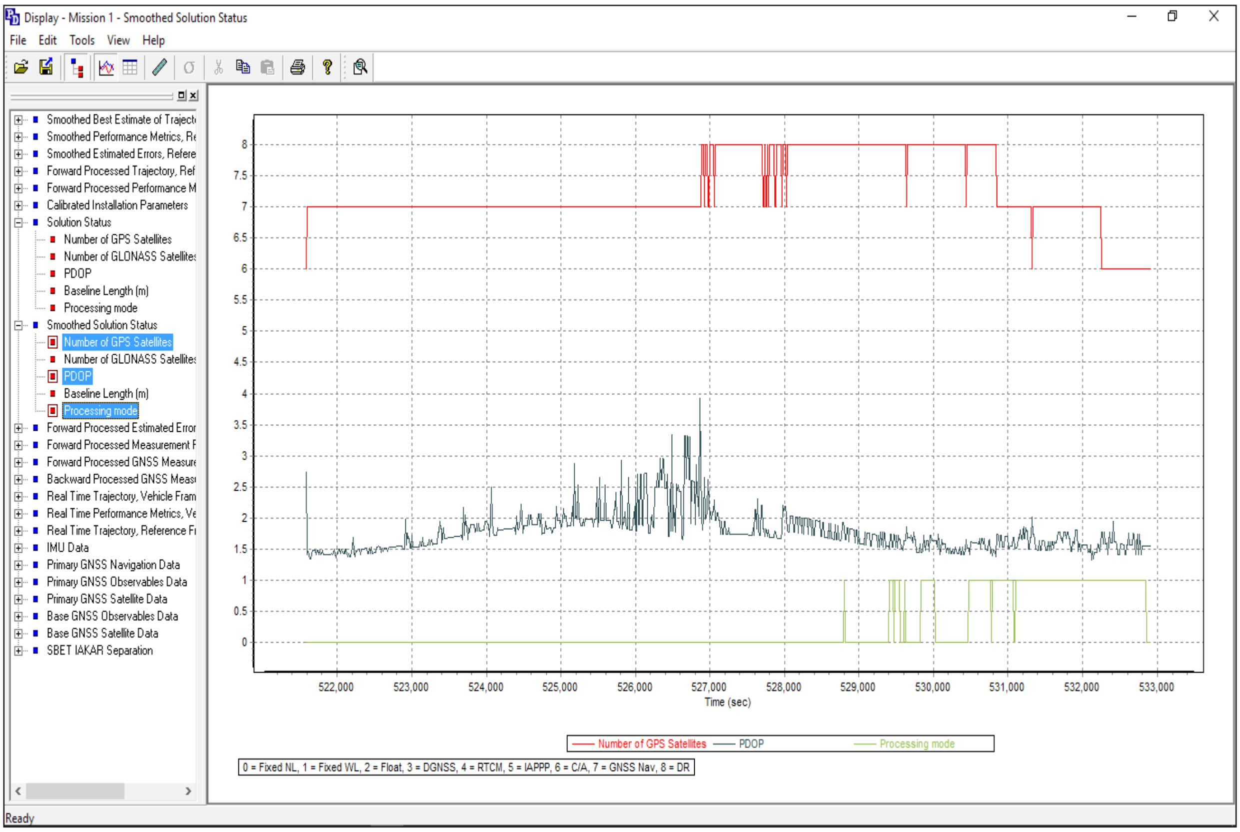



Figure 1.2.1. Solution Status

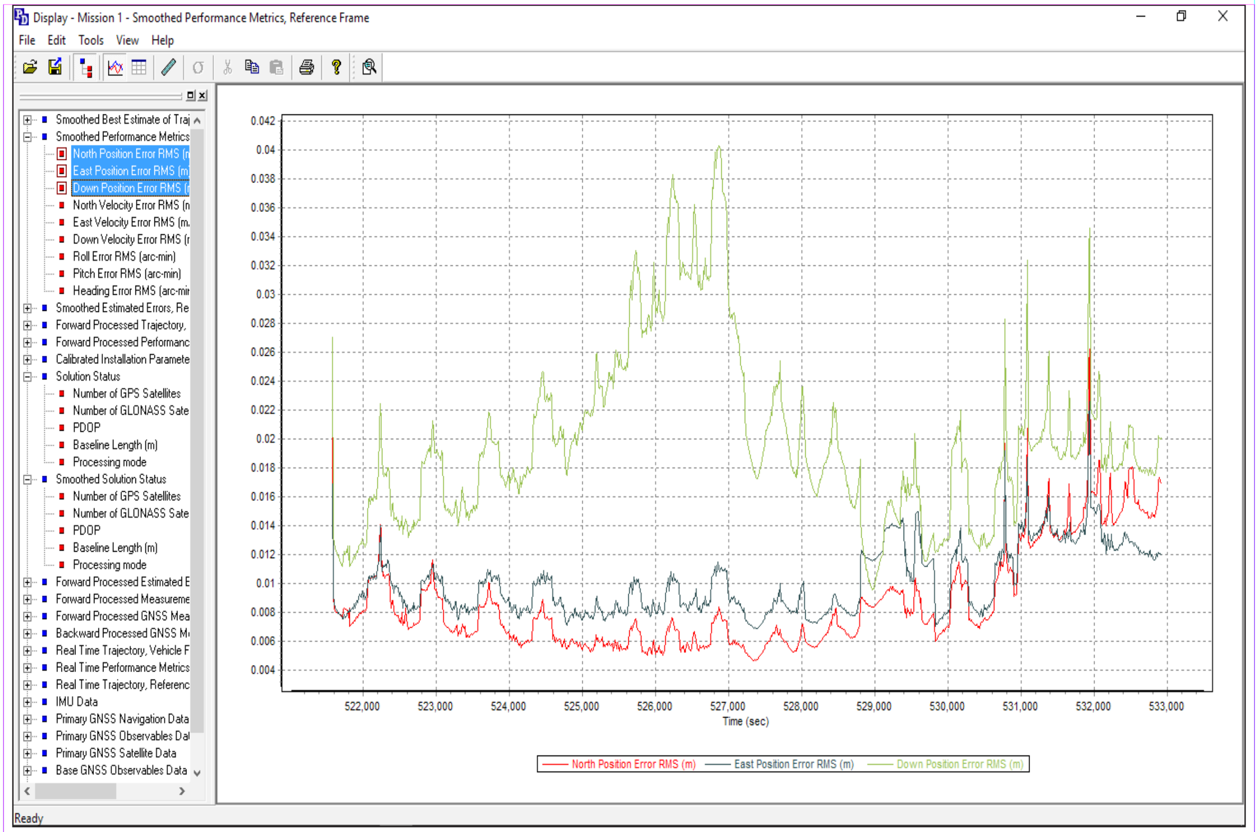



Figure 1.2.2. Smoothed Performance Metric Parameters

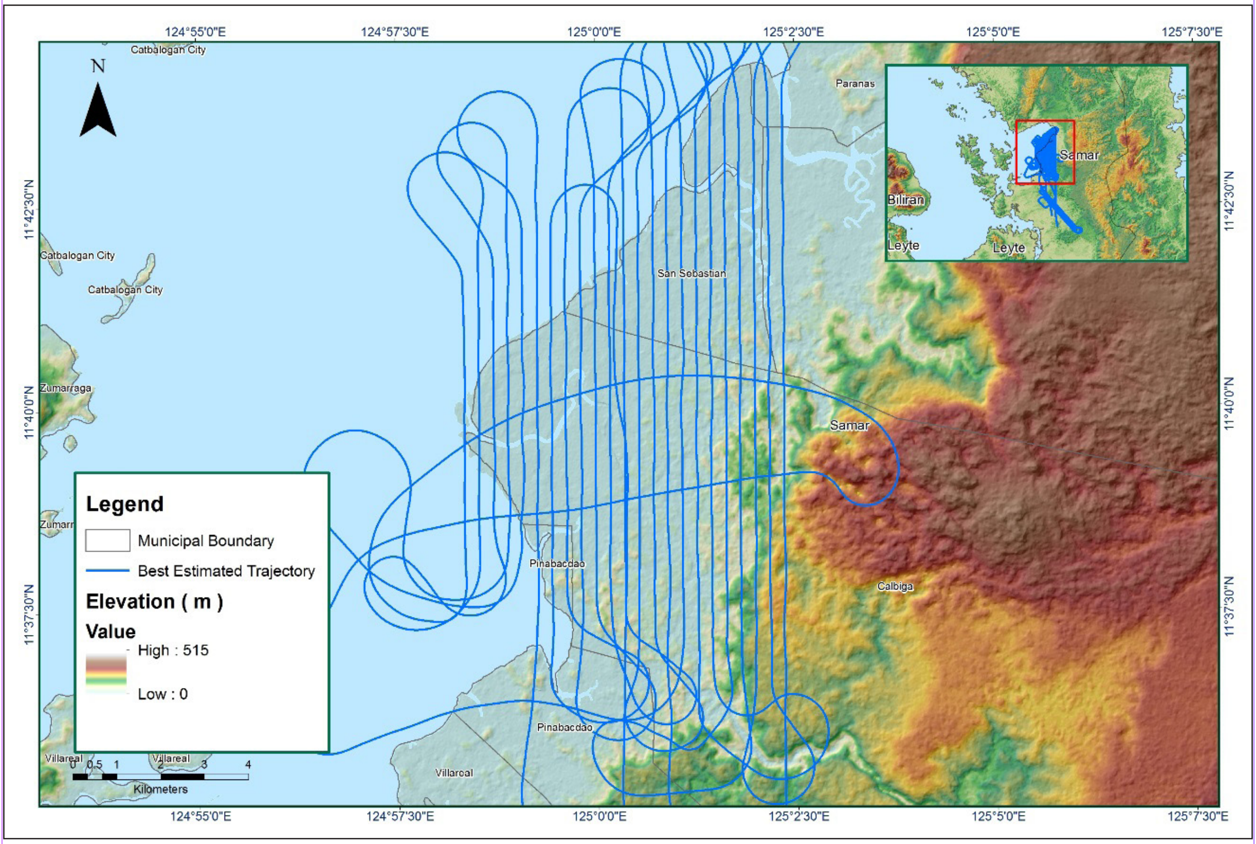



Figure 1.2.3. Best Estimated Trajectory

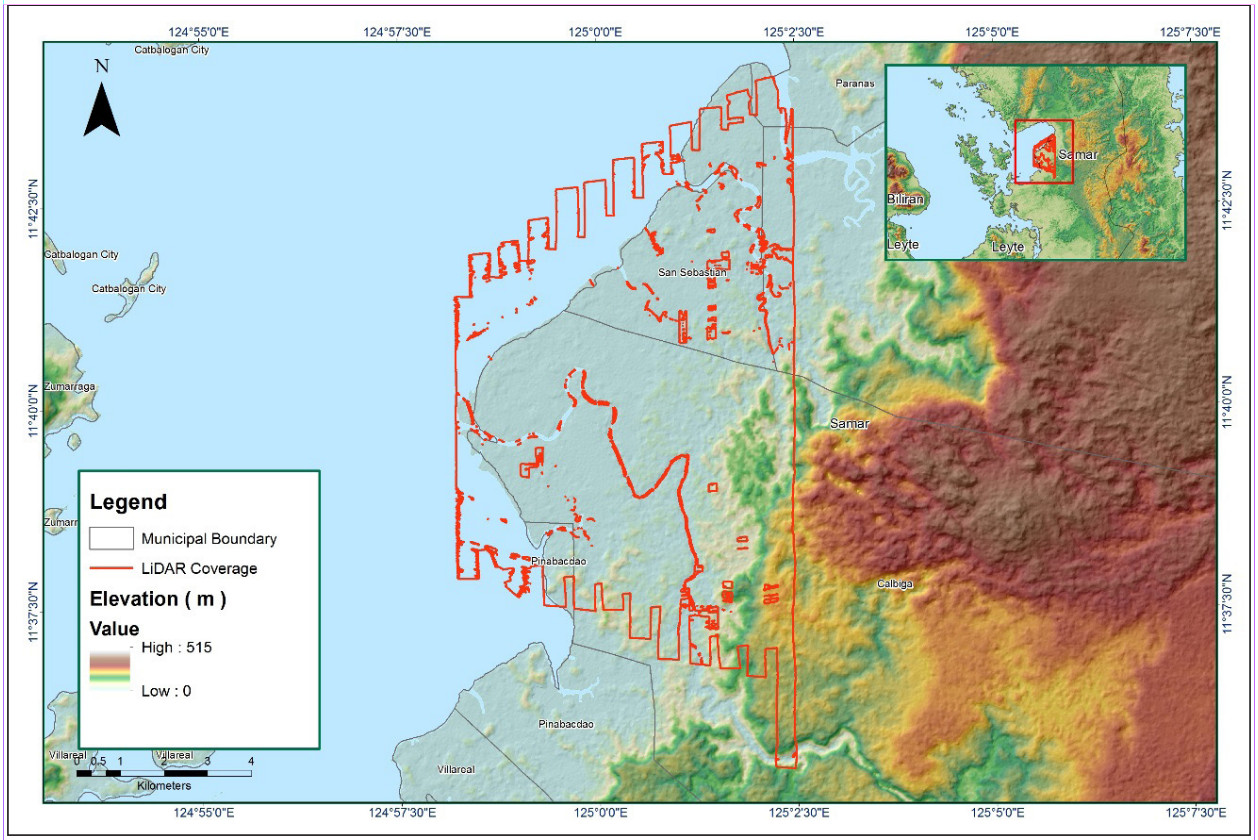



Figure 1.2.4. Coverage of LiDAR Data

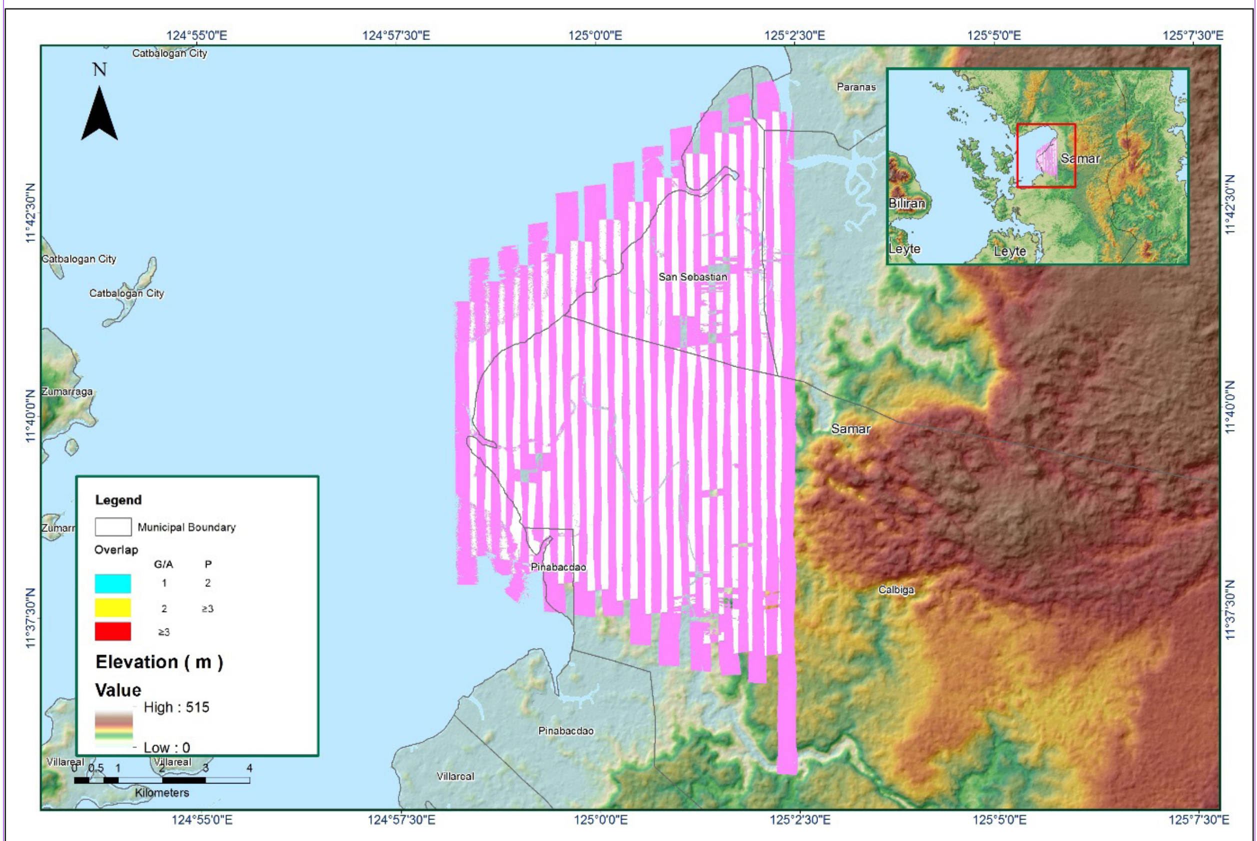



Figure 1.2.5. Image of data overlap

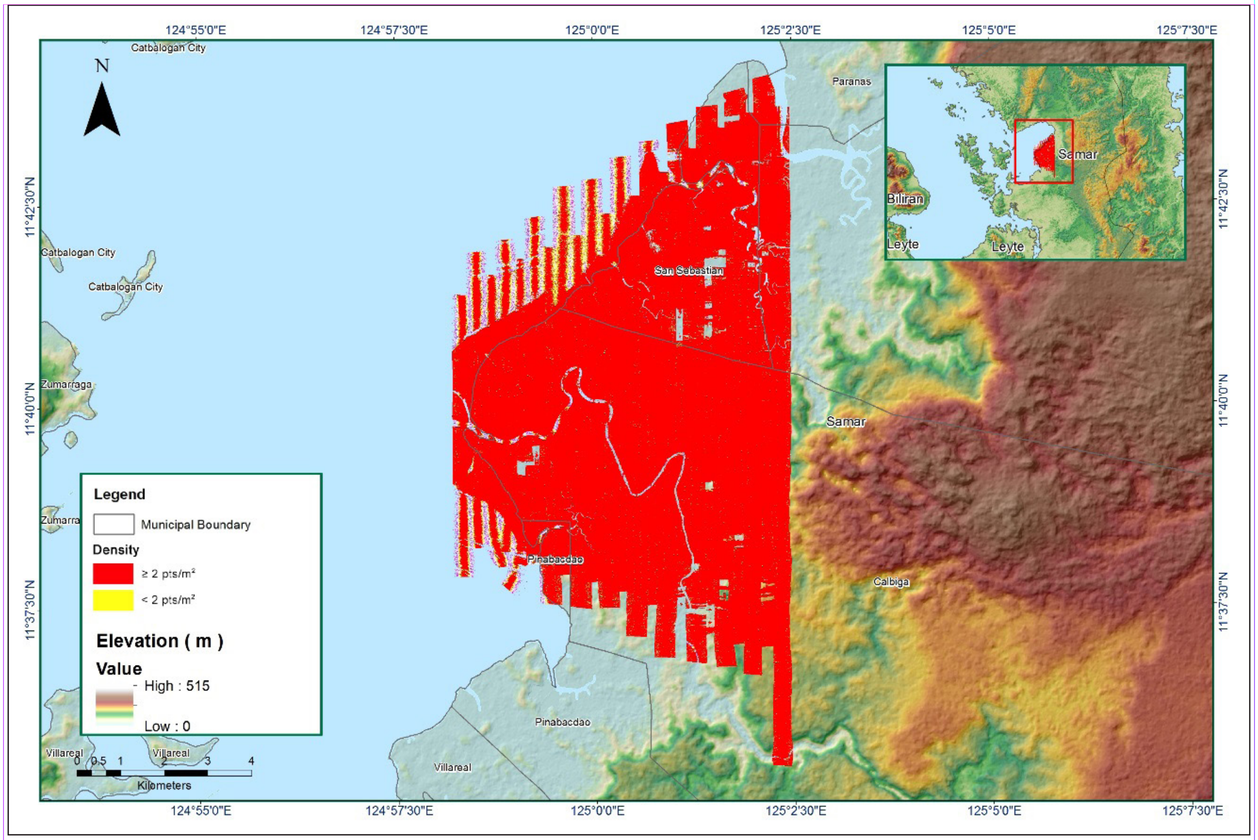



Figure 1.2.6. Density map of merged LiDAR data

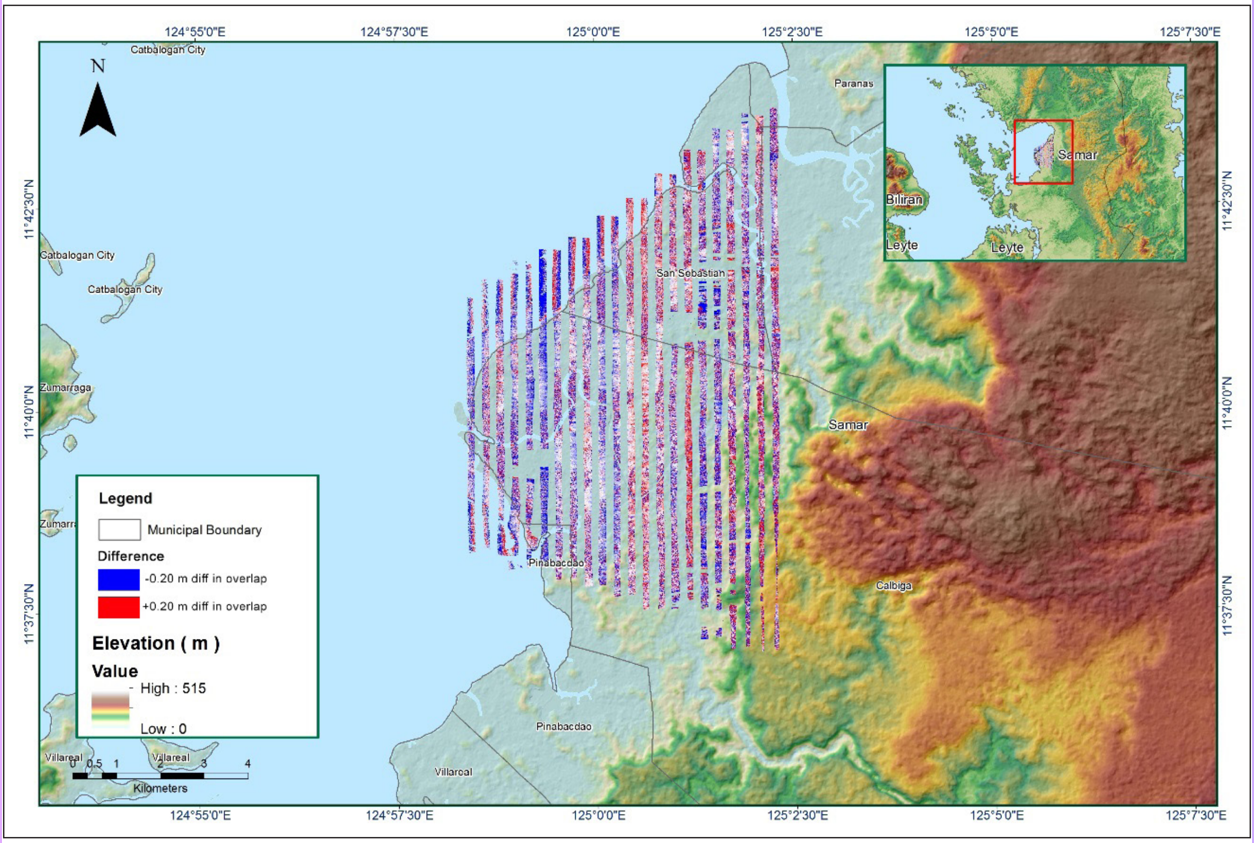



Figure 1.2.7. Elevation difference between flight lines

# ANNEX 9. CALBIGA 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 |
| W240 | 32.09544 | 75.48354 | 0 | 2.026444 | 0.9153 | Discharge | 2.1268 | 0.01 | Ratio to Peak | 1 |
| W250 | 35.060064 | 73.86291 | 0 | 0.844536 | 0.450342 | Discharge | 1.3532 | 0.01 | Ratio to Peak | 1 |
| W260 | 32.948916 | 75.01032 | 0 | 0.481936 | 0.286074 | Discharge | 0.51934 | 0.01 | Ratio to Peak | 1 |
| W270 | 38.10456 | 72.27 | 0 | 0.549332 | 0.60834 | Discharge | 0.22103 | 0.01 | Ratio to Peak | 1 |
| W280 | 38.10456 | 72.27 | 0 | 1.776096 | 2.1312 | Discharge | 1.4039 | 0.01 | Ratio to Peak | 1 |
| W290 | 38.10456 | 72.27 | 0 | 1.23228 | 1.5837 | Discharge | 0.75844 | 0.01 | Ratio to Peak | 1 |
| W300 | 38.10456 | 72.27 | 0 | 0.717836 | 1.49148 | Discharge | 0.44477 | 0.01 | Ratio to Peak | 1 |
| W310 | 59.515716 | 62.75016 | 0 | 1.488144 | 0.236592 | Discharge | 1.5004 | 0.01 | Ratio to Peak | 1 |
| W320 | 38.10456 | 72.27 | 0 | 0.851872 | 0.2223 | Discharge | 0.37031 | 0.01 | Ratio to Peak | 1 |
| W330 | 68.89116 | 59.32773 | 0 | 0.661136 | 0.356934 | Discharge | 0.77634 | 0.01 | Ratio to Peak | 1 |
| W340 | 74.632428 | 57.4101 | 0 | 1.0633 | 0.476376 | Discharge | 0.50328 | 0.01 | Ratio to Peak | 1 |
| W350 | 79.177176 | 55.97757 | 0 | 0.704816 | 1.48668 | Discharge | 0.31626 | 0.01 | Ratio to Peak | 1 |
| W360 | 73.409544 | 57.80808 | 0 | 1.171912 | 0.95712 | Discharge | 0.878 | 0.01 | Ratio to Peak | 1 |
| W370 | 81.399864 | 55.30338 | 0 | 1.010492 | 0.330426 | Discharge | 0.47857 | 0.01 | Ratio to Peak | 1 |
| W380 | 68.682276 | 59.4 | 0 | 1.520204 | 0.88404 | Discharge | 1.0032 | 0.01 | Ratio to Peak | 1 |
| W390 | 38.10456 | 72.27 | 0 | 0.368564 | 1.4322 | Discharge | 0.29657 | 0.01 | Ratio to Peak | 1 |
| W400 | 38.10456 | 72.27 | 0 | 1.982148 | 0.52452 | Discharge | 1.1215 | 0.01 | Ratio to Peak | 1 |
| W410 | 43.374864 | 69.66828 | 0 | 0.550648 | 0.75108 | Discharge | 0.45789 | 0.01 | Ratio to Peak | 1 |
| W420 | 38.10456 | 72.27 | 0 | 1.596084 | 2.37582 | Discharge | 1.2949 | 0.01 | Ratio to Peak | 1 |
| W430 | 38.868648 | 71.87994 | 0 | 2.82492 | 0.5658 | Discharge | 1.0496 | 0.01 | Ratio to Peak | 1 |
| W440 | 69.988308 | 58.95153 | 0 | 1.774192 | 0.56784 | Discharge | 0.48245 | 0.01 | Ratio to Peak | 1 |
| W450 | 69.726696 | 59.04063 | 0 | 2.099076 | 0.72588 | Discharge | 2.0696 | 0.01 | Ratio to Peak | 1 |
| W460 | 82.754568 | 54.90045 | 0 | 2.658208 | 0.461034 | Discharge | 1.6146 | 0.01 | Ratio to Peak | 1 |

# ANNEX 10. CALBIGA MODEL REACH PARAMETERS

| Reach Number | Muskingum Cunge Channel Routing | | | | | | |
|---|---|---|---|---|---|---|---|
| | Time Step Method | Length (m) | Slope | Manning's n | Shape | Width | Side Slope |
| R40 | Automatic Fixed Interval | 3054.9 | 0.025522 | 0.04 | Trapezoid | 19.962 | 1 |
| R50 | Automatic Fixed Interval | 7616 | 0.00654 | 0.04 | Trapezoid | 38.914 | 1 |
| R70 | Automatic Fixed Interval | 9202.5 | 0.009089 | 0.04 | Trapezoid | 15.41 | 1 |
| R80 | Automatic Fixed Interval | 3580.1 | 0.020666 | 0.04 | Trapezoid | 19.848 | 1 |
| R90 | Automatic Fixed Interval | 3806.9 | 2.50E-05 | 0.04 | Trapezoid | 15.41 | 1 |
| R110 | Automatic Fixed Interval | 8201.1 | 0.015502 | 0.04 | Trapezoid | 24.442 | 1 |
| R120 | Automatic Fixed Interval | 4831.7 | 0.004468 | 0.04 | Trapezoid | 47.156 | 1 |
| R130 | Automatic Fixed Interval | 4631.7 | 0.006094 | 0.04 | Trapezoid | 39.244 | 1 |
| R150 | Automatic Fixed Interval | 1915.7 | 0.001316 | 0.04 | Trapezoid | 19.548 | 1 |
| R170 | Automatic Fixed Interval | 3537.6 | 0.008901 | 0.04 | Trapezoid | 15.41 | 1 |
| R210 | Automatic Fixed Interval | 4685.7 | 8.44E-05 | 0.04 | Trapezoid | 16.794 | 1 |

# ANNEX 11. CALBIGA FIELD VALIDATION

| Point No | Validation Coordinates | | Actual Flood Depth | Flood Depth based on Model | Error | Event/Date | Return Period of Event |
|---|---|---|---|---|---|---|---|
| | Latitude | Longitude | | | | | |
| 1 | 11.71112931 | 125.0171814 | 0 | 0.029999999 | -0.03 | | |
| 2 | 11.62072554 | 124.9999257 | 0 | 0.029999999 | -0.03 | | |
| 3 | 11.62261558 | 124.9988406 | 0.5 | 0.029999999 | 0.47 | Ruby/December 6, 2014 | 5-yr |
| 4 | 11.62634435 | 124.9981132 | 0.5 | 0.029999999 | 0.47 | Ruby/December 6, 2014 | 5-yr |
| 5 | 11.61652227 | 125.0133951 | 0 | 0.029999999 | -0.03 | | |
| 6 | 11.61748677 | 125.0122657 | 0.5 | 0.029999999 | 0.47 | Yolanda/November 8, 2013 | 2-yr |
| 7 | 11.61748677 | 125.0122657 | 0.5 | 0.029999999 | 0.47 | Ruby/December 6, 2014 | 5-yr |
| 8 | 11.61733372 | 125.0106071 | 0.5 | 0.029999999 | 0.47 | Ruby/December 6, 2014 | 5-yr |
| 9 | 11.61539641 | 125.0140871 | 0 | 0.029999999 | -0.03 | | |
| 10 | 11.61424046 | 125.0134861 | 0 | 0.029999999 | -0.03 | | |
| 11 | 11.61189152 | 125.0117535 | 0 | 0.07 | -0.07 | | |
| 12 | 11.60988682 | 125.011257 | 1.07 | 0.059999999 | 1.01 | Ruby/December 6, 2014 | 5-yr |
| 13 | 11.60735674 | 125.0109723 | 0.5 | 0.029999999 | 0.47 | Ruby/December 6, 2014 | 5-yr |
| 14 | 11.60586183 | 125.0098533 | 0 | 0.050000001 | -0.05 | | |
| 15 | 11.60468149 | 125.0090117 | 0.5 | 0.209999993 | 0.29 | Ruby/December 6, 2014 | 5-yr |
| 16 | 11.60299136 | 125.0077691 | 0.5 | 0.029999999 | 0.47 | Ruby/December 6, 2014 | 5-yr |
| 17 | 11.60120937 | 125.0054576 | 0.5 | 0.029999999 | 0.47 | Ruby/December 6, 2014 | 5-yr |
| 18 | 11.603604 | 125.0088357 | 0.5 | 0.709999979 | -0.21 | Ruby/December 6, 2014 | 5-yr |
| 19 | 11.60284971 | 125.0091925 | 0.5 | 0.25999999 | 0.24 | Ruby/December 6, 2014 | 5-yr |
| 20 | 11.60185855 | 125.0066702 | 0.5 | 0.029999999 | 0.47 | Ruby/December 6, 2014 | 5-yr |
| 21 | 11.60818948 | 125.0109252 | 0 | 0.029999999 | -0.03 | | |
| 22 | 11.61819823 | 125.0138473 | 0 | 0.029999999 | -0.03 | | |
| 23 | 11.61921705 | 125.0146422 | 2 | 0.129999995 | 1.87 | Ruby/December 6, 2014 | 5-yr |
| 24 | 11.62019094 | 125.0153277 | 1.63 | 2.970000029 | -1.34 | Ruby/December 6, 2014 | 5-yr |
| 25 | 11.62019094 | 125.0153277 | 1.63 | 2.970000029 | -1.34 | Yolanda/November 8, 2013 | 2-yr |
| 26 | 11.62157957 | 125.0160888 | 0.9 | 0.029999999 | 0.87 | Ruby/December 6, 2014 | 5-yr |
| 27 | 11.62069822 | 125.0155971 | 1 | 0.629999995 | 0.37 | Ruby/December 6, 2014 | 5-yr |
| 28 | 11.62280057 | 125.0168352 | 1.5 | 0.029999999 | 1.47 | Ruby/December 6, 2014 | 5-yr |
| 29 | 11.62492521 | 125.0188537 | 0 | 0.029999999 | -0.03 | | |
| 30 | 11.62421082 | 125.0185353 | 0 | 0.029999999 | -0.03 | | |
| 31 | 11.62583331 | 125.0182388 | 1.4 | 0.189999998 | 1.21 | Ruby/December 6, 2014 | 5-yr |
| 32 | 11.62661894 | 125.0185734 | 1.3 | 0.029999999 | 1.27 | Ruby/December 6, 2014 | 5-yr |
| 33 | 11.62399214 | 125.017093 | 0 | 0.029999999 | -0.03 | | |
| 34 | 11.62491524 | 125.0172208 | 0 | 0.029999999 | -0.03 | | |
| 35 | 11.62571152 | 125.0169999 | 0.5 | 0.119999997 | 0.38 | Ruby/December 6, 2014 | 5-yr |
| 36 | 11.60578916 | 125.0261315 | 0 | 0.029999999 | -0.03 | | |
| 37 | 11.116969 | 125.007715 | 0.9 | 0.029999999 | 0.87 | Yolanda/November 8, 2013 | 2-yr |
| 38 | 11.116969 | 125.007715 | 0.85 | 0.029999999 | 0.82 | Ruby/December 6, 2014 | 5-yr |
| 39 | 11.6012926 | 125.0297818 | 0 | 0.029999999 | -0.03 | | |
| 40 | 11.71117583 | 125.0159731 | 0 | 0.029999999 | -0.03 | | |

| Point No | Validation Coordinates | | Actual Flood Depth | Flood Depth based on Model | Error | Event/Date | Return Period of Event |
|---|---|---|---|---|---|---|---|
| | Latitude | Longitude | | | | | |
| 41 | 11.59967372 | 125.0326899 | 0 | 0.029999999 | -0.03 | | |
| 42 | 11.59369751 | 125.0439533 | 0 | 0.029999999 | -0.03 | | |
| 43 | 11.59423814 | 125.0440991 | 0 | 0.029999999 | -0.03 | | |
| 44 | 11.59316358 | 125.0443358 | 0 | 0.029999999 | -0.03 | | |
| 45 | 11.5927263 | 125.044754 | 0 | 0.029999999 | -0.03 | | |
| 46 | 11.59290374 | 125.0250575 | 0 | 0.029999999 | -0.03 | | |
| 47 | 11.59349819 | 125.0268462 | 0 | 0.029999999 | -0.03 | | |
| 48 | 11.59345737 | 125.0279058 | 0 | 0.029999999 | -0.03 | | |
| 49 | 11.59239002 | 125.0277252 | 0 | 0.029999999 | -0.03 | | |
| 50 | 11.59405106 | 125.0318709 | 0 | 0.029999999 | -0.03 | | |
| 51 | 11.59382475 | 125.0324778 | 0 | 0.029999999 | -0.03 | | |
| 52 | 11.59330666 | 125.0327987 | 0 | 0.029999999 | -0.03 | | |
| 53 | 11.61424046 | 125.0134861 | 0 | 0.029999999 | -0.03 | | |
| 54 | 11.62586499 | 125.0127931 | 0.8 | 0.029999999 | 0.77 | Ruby/December 6, 2014 | 5-yr |
| 55 | 11.6250522 | 125.0145497 | 0 | 0.029999999 | -0.03 | | |
| 56 | 11.62690611 | 125.0174603 | 1 | 0.029999999 | 0.97 | Ruby/December 6, 2014 | 5-yr |
| 57 | 11.62712496 | 125.0171328 | 1 | 0.029999999 | 0.97 | Ruby/December 6, 2014 | 5-yr |
| 58 | 11.62799818 | 125.0168312 | 2 | 1.049999952 | 0.95 | Seniang/December 30, 2014 | 2-yr |
| 59 | 11.62747549 | 125.0160161 | 2 | 0.029999999 | 1.97 | Ruby/December 6, 2014 | 5-yr |
| 60 | 11.62747549 | 125.0160161 | 2 | 0.029999999 | 1.97 | Seniang/December 30, 2014 | 2-yr |
| 61 | 11.6264995 | 125.0169597 | 1 | 0.029999999 | 0.97 | Ruby/December 6, 2014 | 5-yr |
| 62 | 11.6264995 | 125.0169597 | 1 | 0.029999999 | 0.97 | Seniang/December 30, 2014 | 2-yr |
| 63 | 11.62790875 | 125.0178336 | 2 | 0.029999999 | 1.97 | Ruby/December 6, 2014 | 5-yr |
| 64 | 11.62790875 | 125.0178336 | 2 | 0.029999999 | 1.97 | Seniang/December 30, 2014 | 2-yr |
| 65 | 11.6234313 | 125.00746 | 1 | 0.029999999 | 0.97 | Ruby/December 6, 2014 | 5-yr |
| 66 | 11.6234313 | 125.00746 | 1 | 0.029999999 | 0.97 | Seniang/December 30, 2014 | 2-yr |
| 67 | 11.62984145 | 125.0171098 | 1 | 0.230000004 | 0.77 | Ruby/December 6, 2014 | 5-yr |
| 68 | 11.62984145 | 125.0171098 | 1 | 0.230000004 | 0.77 | Seniang/December 30, 2014 | 2-yr |
| 69 | 11.62774555 | 125.0191774 | 0 | 0.029999999 | -0.03 | | |
| 70 | 11.62734901 | 125.0201695 | 0 | 0.029999999 | -0.03 | | |
| 71 | 11.62648248 | 125.0202832 | 0 | 0.029999999 | -0.03 | | |
| 72 | 11.62727826 | 125.0210567 | 0 | 0.029999999 | -0.03 | | |
| 73 | 11.63024244 | 125.0205204 | 1 | 0.029999999 | 0.97 | Ruby/December 6, 2014 | 5-yr |
| 74 | | | 0.5 | 0.029999999 | 0.47 | Yolanda/November 8, 2013 | 2-yr |
| 75 | 11.63114048 | 125.0212423 | 1.5 | 0.029999999 | 1.47 | Ruby/December 6, 2014 | 5-yr |
| 76 | | | 1 | 0.029999999 | 0.97 | Yolanda/November 8, 2013 | 2-yr |
| 77 | 11.63331089 | 125.0265771 | 0 | 0.029999999 | -0.03 | | |
| 78 | 11.63440146 | 125.0278245 | 0 | 0.029999999 | -0.03 | | |

| Point No | Validation Coordinates | | Actual Flood Depth | Flood Depth based on Model | Error | Event/Date | Return Period of Event |
|---|---|---|---|---|---|---|---|
| | Latitude | Longitude | | | | | |
| 79 | 11.63629753 | 125.0297554 | 0 | 0.029999999 | -0.03 | | |
| 80 | 11.64563832 | 125.0159867 | 2 | 0.029999999 | 1.97 | Ruby/December 6, 2014 | 5-yr |
| 81 | 11.64563832 | 125.0159867 | 2 | 0.029999999 | 1.97 | Seniang/December 30, 2014 | 2-yr |
| 82 | 11.64479887 | 125.0172572 | 2 | 2.880000114 | -0.88 | Ruby/December 6, 2014 | 5-yr |
| 83 | 11.64479887 | 125.0172572 | 2 | 2.880000114 | -0.88 | Seniang/December 30, 2014 | 2-yr |
| 84 | 11.64630149 | 125.019012 | 0 | 0.370000005 | -0.37 | | |
| 85 | 11.64744755 | 125.0186936 | 0 | 0.610000014 | -0.61 | | |
| 86 | 11.64842564 | 125.0181084 | 0 | 2.470000029 | -2.47 | | |
| 87 | 11.64937086 | 125.0179556 | 0 | 1.129999995 | -1.13 | | |
| 88 | 11.64355047 | 125.0198087 | 0 | 0.039999999 | -0.04 | | |
| 89 | 11.64461598 | 125.0189183 | 0 | 0.059999999 | -0.06 | | |
| 90 | 11.64050289 | 125.0196728 | 0 | 0.029999999 | -0.03 | | |
| 91 | 11.6407577 | 125.0200903 | 0 | 0.029999999 | -0.03 | | |
| 92 | 11.65305681 | 125.0043266 | 2 | 0.289999992 | 1.71 | Ruby/December 6, 2014 | 5-yr |
| 93 | 11.65305681 | 125.0043266 | 0.7 | 0.289999992 | 0.41 | Seniang/December 30, 2014 | 2-yr |
| 94 | 11.65013471 | 125.004576 | 1 | 0.029999999 | 0.97 | Ruby/December 6, 2014 | 5-yr |
| 95 | 11.65013471 | 125.004576 | 1 | 0.029999999 | 0.97 | Seniang/December 30, 2014 | 2-yr |
| 96 | 11.64898261 | 125.0026102 | 1 | 0.029999999 | 0.97 | Ruby/December 6, 2014 | 5-yr |
| 97 | 11.64898261 | 125.0026102 | 1 | 0.029999999 | 0.97 | Seniang/December 30, 2014 | 2-yr |
| 98 | 11.64932359 | 125.006731 | 1 | 0.029999999 | 0.97 | Ruby/December 6, 2014 | 5-yr |
| 99 | 11.64932359 | 125.006731 | 1 | 0.029999999 | 0.97 | Seniang/December 30, 2014 | 2-yr |
| 100 | 11.66314744 | 125.0246079 | 0 | 1.529999971 | -1.53 | | |
| 101 | 11.66127652 | 125.0231643 | 0 | 0.029999999 | -0.03 | | |
| 102 | 11.66041595 | 125.0216672 | 0 | 0.029999999 | -0.03 | | |
| 103 | 11.65965412 | 125.0216807 | 0 | 0.039999999 | -0.04 | | |
| 104 | 11.65759971 | 125.0211113 | 0 | 0.029999999 | -0.03 | | |
| 105 | 11.65595007 | 125.0208854 | 0 | 1.769999981 | -1.77 | | |
| 106 | 11.65441518 | 125.0202436 | 0 | 0.810000002 | -0.81 | | |
| 107 | 11.64988794 | 125.0109283 | 0.5 | 0.99000001 | -0.49 | Ruby/December 6, 2014 | 5-yr |
| 108 | 11.64988794 | 125.0109283 | 0.5 | 0.99000001 | -0.49 | Seniang/December 30, 2014 | 2-yr |
| 109 | 11.65700435 | 125.0027292 | 0.75 | 0.460000008 | 0.29 | Ruby/December 6, 2014 | 5-yr |
| 110 | 11.65700435 | 125.0027292 | 0.3 | 0.460000008 | -0.16 | Seniang/December 30, 2014 | 2-yr |
| 111 | 11.65877184 | 125.0018484 | 0.7 | 0.579999983 | 0.12 | Ruby/December 6, 2014 | 5-yr |
| 112 | 11.65877184 | 125.0018484 | 0.3 | 0.579999983 | -0.28 | Seniang/December 30, 2014 | 2-yr |
| 113 | 11.6604224 | 125.0018579 | 0.5 | 0.49000001 | 0.01 | Ruby/December 6, 2014 | 5-yr |
| 114 | 11.6604224 | 125.0018579 | 0.3 | 0.49000001 | -0.19 | Seniang/December 30, 2014 | 2-yr |

| Point No | Validation Coordinates | | Actual Flood Depth | Flood Depth based on Model | Error | Event/Date | Return Period of Event |
|---|---|---|---|---|---|---|---|
| | Latitude | Longitude | | | | | |
| 115 | 11.66209434 | 125.000506 | 0.5 | 0.029999999 | 0.47 | Ruby/December 6, 2014 | 5-yr |
| 116 | 11.66209434 | 125.000506 | 0.3 | 0.029999999 | 0.27 | Seniang/December 30, 2014 | 2-yr |
| 117 | 11.64228757 | 124.992195 | 1.3 | 0.029999999 | 1.27 | Ruby/December 6, 2014 | 5-yr |
| 118 | 11.64295091 | 124.9926823 | 1.5 | 0.270000011 | 1.23 | Ruby/December 6, 2014 | 5-yr |
| 119 | 11.64382355 | 124.9919634 | 1 | 0.029999999 | 0.97 | Ruby/December 6, 2014 | 5-yr |
| 120 | 11.66836878 | 124.9994977 | 1 | 0.550000012 | 0.45 | Ruby/December 6, 2014 | 5-yr |
| 121 | 11.66809679 | 125.0017849 | 1 | 0.419999987 | 0.58 | Ruby/December 6, 2014 | 5-yr |
| 122 | 11.67108661 | 125.0004511 | 1 | 0.5 | 0.50 | Ruby/December 6, 2014 | 5-yr |
| 123 | 11.67108661 | 125.0004511 | 1 | 0.5 | 0.50 | Yolanda/November 8, 2013 | 2-yr |
| 124 | 11.63965398 | 125.0124476 | 0.5 | 0.029999999 | 0.47 | Ruby/December 6, 2014 | 5-yr |
| 125 | 11.63965398 | 125.0124476 | 0.5 | 0.029999999 | 0.47 | Yolanda/November 8, 2013 | 2-yr |
| 126 | 11.64085804 | 125.0113111 | 0.5 | 1.950000048 | -1.45 | Ruby/December 6, 2014 | 5-yr |
| 127 | 11.64085804 | 125.0113111 | 0.5 | 1.950000048 | -1.45 | Yolanda/November 8, 2013 | 2-yr |
| 128 | 11.63446943 | 125.0096638 | 0.5 | 0.029999999 | 0.47 | Ruby/December 6, 2014 | 5-yr |
| 129 | 11.63536504 | 125.0122699 | 0.5 | 3.369999886 | -2.87 | Ruby/December 6, 2014 | 5-yr |
| 130 | 11.63428805 | 125.0138068 | 0.5 | 0.029999999 | 0.47 | Ruby/December 6, 2014 | 5-yr |
| 131 | 11.63271803 | 125.015135 | 0.5 | 0.100000001 | 0.40 | Ruby/December 6, 2014 | 5-yr |
| 132 | 11.61670248 | 125.0149417 | 0 | 0.029999999 | -0.03 | | |
| 133 | 11.61189152 | 125.0117535 | 0 | 0.029999999 | -0.03 | | |
| 134 | 11.62590304 | 125.0156947 | 0.8 | 0.029999999 | 0.77 | Ruby/December 6, 2014 | 5-yr |
| 135 | 11.62840731 | 125.0189923 | 0 | 0.029999999 | -0.03 | | |
| 136 | 11.62900569 | 125.0194986 | 0 | 0.029999999 | -0.03 | | |
| 137 | 11.63041452 | 125.0216723 | 0.84 | 0.319999993 | 0.52 | Low Pressure 1/January 9, 2017 | 2-yr |
| 138 | 11.63169988 | 125.0212768 | 0 | 0.140000001 | -0.14 | | |
| 139 | 11.62904047 | 125.0243757 | 1 | 0.029999999 | 0.97 | Yolanda/November 8, 2013 | 2-yr |
| 140 | 11.64687557 | 125.016536 | 1 | 2.089999914 | -1.09 | Ruby/December 6, 2014 | 5-yr |
| 141 | 11.64687557 | 125.016536 | 1 | 2.089999914 | -1.09 | Yolanda/November 8, 2013 | 2-yr |
| 142 | 11.68753216 | 124.9967658 | 0 | Not Covered on Map | | | |
| 143 | 11.64280264 | 124.9904234 | 1 | 0.029999999 | 0.97 | Low Pressure 1/January 9, 2017 | 2-yr |
| 144 | 11.64309592 | 124.9913297 | 0.45 | 0.029999999 | 0.42 | Yolanda/November 8, 2013 | 2-yr |
| 145 | 11.63867145 | 125.0107892 | 0.5 | 0.029999999 | 0.47 | Ruby/December 6, 2014 | 5-yr |
| 146 | 11.70910483 | 125.0150735 | 0.7 | 0.610000014 | 0.09 | Ruby/December 6, 2014 | 5-yr |
| 147 | 11.67422983 | 124.9922681 | 0.6 | 0.140000001 | 0.46 | Yolanda/November 8, 2013 | 2-yr |
| 148 | 11.67422983 | 124.9922681 | 0.5 | 0.140000001 | 0.36 | Ruby/December 6, 2014 | 5-yr |
| 149 | 11.67422983 | 124.9922681 | 0.2 | 0.140000001 | 0.06 | Low Pressure 1/January 9, 2017 | 2-yr |

| Point No | Validation Coordinates | | Actual Flood Depth | Flood Depth based on Model | Error | Event/Date | Return Period of Event |
|---|---|---|---|---|---|---|---|
| | Latitude | Longitude | | | | | |
| 150 | 11.67422983 | 124.9922681 | 0.7 | 0.140000001 | 0.56 | Seniang/December 30, 2014 | 2-yr |
| 151 | 11.67424425 | 124.9941514 | 0.5 | 0.109999999 | 0.39 | Yolanda/November 8, 2013 | 2-yr |
| 152 | 11.67424425 | 124.9941514 | 0.5 | 0.109999999 | 0.39 | Ruby/December 6, 2014 | 5-yr |
| 153 | 11.67424425 | 124.9941514 | 2 | 0.109999999 | 1.89 | Low Pressure 1/January 9, 2017 | 2-yr |
| 154 | 11.67424425 | 124.9941514 | 0.7 | 0.109999999 | 0.59 | Seniang/December 30, 2014 | 2-yr |
| 155 | 11.67524471 | 124.9949575 | 0.5 | 0.029999999 | 0.47 | Yolanda/November 8, 2013 | 2-yr |
| 156 | 11.67524471 | 124.9949575 | 0.5 | 0.029999999 | 0.47 | Ruby/December 6, 2014 | 5-yr |
| 157 | 11.67524471 | 124.9949575 | 2 | 0.029999999 | 1.97 | Low Pressure 1/January 9, 2017 | 2-yr |
| 158 | 11.67524471 | 124.9949575 | 0.7 | 0.029999999 | 0.67 | Seniang/December 30, 2014 | 2-yr |
| 159 | 11.6747138 | 124.9958821 | 0.5 | 0.059999999 | 0.44 | Yolanda/November 8, 2013 | 2-yr |
| 160 | 11.6747138 | 124.9958821 | 0.5 | 0.059999999 | 0.44 | Ruby/December 6, 2014 | 5-yr |
| 161 | 11.6747138 | 124.9958821 | 2 | 0.059999999 | 1.94 | Low Pressure 1/January 9, 2017 | 2-yr |
| 162 | 11.6747138 | 124.9958821 | 0.7 | 0.059999999 | 0.64 | Seniang/December 30, 2014 | 2-yr |
| 163 | 11.67369967 | 124.9980885 | 1.1 | 0.029999999 | 1.07 | Ruby/December 6, 2014 | 5-yr |
| 164 | 11.67369967 | 124.9980885 | 0.6 | 0.029999999 | 0.57 | Yolanda/November 8, 2013 | 2-yr |
| 165 | 11.67369967 | 124.9980885 | 0.4 | 0.029999999 | 0.37 | Low Pressure 1/January 9, 2017 | 2-yr |
| 166 | 11.67369967 | 124.9980885 | 1 | 0.029999999 | 0.97 | Seniang/December 30, 2014 | 2-yr |
| 168 | 11.67108661 | 125.0004511 | 0.6 | 0.5 | 0.10 | Ruby/December 6, 2014 | 5-yr |
| 169 | 11.67108661 | 125.0004511 | 0.3 | 0.5 | -0.20 | Yolanda/November 8, 2013 | 2-yr |
| 170 | 11.67108661 | 125.0004511 | 0.4 | 0.5 | -0.10 | Low Pressure 1/January 9, 2017 | 2-yr |
| 171 | 11.66836878 | 124.9994977 | 0.5 | 0.550000012 | -0.05 | Ruby/December 6, 2014 | 5-yr |
| 172 | 11.66836878 | 124.9994977 | 0.25 | 0.550000012 | -0.30 | Low Pressure 1/January 9, 2017 | 2-yr |
| 173 | 11.66809679 | 125.0017849 | 0.7 | 0.419999987 | 0.28 | Yolanda/November 8, 2013 | 2-yr |
| 174 | 11.66809679 | 125.0017849 | 0.7 | 0.419999987 | 0.28 | Ruby/December 6, 2014 | 5-yr |
| 175 | 11.66809679 | 125.0017849 | 0.2 | 0.419999987 | -0.22 | Low Pressure 1/January 9, 2017 | 2-yr |
| 176 | 11.6663505 | 125.0129201 | 0.2 | 0.699999988 | -0.50 | Ruby/December 6, 2014 | 5-yr |
| 177 | 11.66611749 | 125.0142074 | 0.2 | 0.029999999 | 0.17 | Ruby/December 6, 2014 | 5-yr |
| 178 | 11.66571164 | 125.0150924 | 0.2 | 0.029999999 | 0.17 | Ruby/December 6, 2014 | 5-yr |
| 179 | 11.66432443 | 125.0170636 | 0.2 | 0.029999999 | 0.17 | Ruby/December 6, 2014 | 5-yr |
| 180 | 11.66232593 | 125.0182364 | 0.2 | 0.029999999 | 0.17 | Ruby/December 6, 2014 | 5-yr |

| Point No | Validation Coordinates | | Actual Flood Depth | Flood Depth based on Model | Error | Event/Date | Return Period of Event |
|---|---|---|---|---|---|---|---|
| | Latitude | Longitude | | | | | |
| 181 | 11.65373884 | 125.0191398 | 0.5 | 0.029999999 | 0.47 | Seniang/December 30, 2014 | 2-yr |
| 182 | 11.65373884 | 125.0191398 | 0.6 | 0.029999999 | 0.57 | Low Pressure 1/January 9, 2017 | 2-yr |
| 183 | 11.65138814 | 125.0185651 | 0.5 | 1.559999943 | -1.06 | Seniang/December 30, 2014 | 2-yr |
| 184 | 11.65138814 | 125.0185651 | 0.6 | 1.559999943 | -0.96 | Low Pressure 1/January 9, 2017 | 2-yr |
| 185 | 11.65023898 | 125.0180543 | 0.3 | 2.480000019 | -2.18 | Seniang/December 30, 2014 | 2-yr |
| 186 | 11.65023898 | 125.0180543 | 0.3 | 2.480000019 | -2.18 | Low Pressure 1/January 9, 2017 | 2-yr |
| 187 | 11.64937086 | 125.0179556 | 0.3 | 1.129999995 | -0.83 | Seniang/December 30, 2014 | 2-yr |
| 188 | 11.64937086 | 125.0179556 | 0.5 | 1.129999995 | -0.63 | Low Pressure 1/January 9, 2017 | 2-yr |
| 189 | 11.59312025 | 125.032153 | 0 | 0.029999999 | -0.03 | | |
| 190 | 11.59229974 | 125.0336166 | 0 | 0.029999999 | -0.03 | | |
| 191 | 11.60487302 | 125.0282003 | 0 | 0.029999999 | -0.03 | | |
| 192 | 11.60505708 | 125.024669 | 0 | 0.029999999 | -0.03 | | |
| 193 | 11.59988645 | 125.0311425 | 0 | 0.029999999 | -0.03 | | |
| 194 | 11.600728 | 125.0322046 | 0 | 0.029999999 | -0.03 | | |
| 195 | 11.64932359 | 125.006731 | 0 | 0.029999999 | -0.03 | | |
| 196 | 11.64898261 | 125.0026102 | 0 | 0.029999999 | -0.03 | | |
| 197 | 11.64596253 | 125.0080134 | 0 | 0.029999999 | -0.03 | | |

## ANNEX 12. EDUCATIONAL INSTITUTIONS AFFECTED IN CALBIGA FLOOD PLAIN

| SAMAR | | | | |
|---|---|---|---|---|
| CALBIGA | | | | |
| Building Name | Barangay | Rainfall Scenario | | |
| | | 5-year | 25-year | 100-year |
| Tinago Elementary School | Bacyaran | | | |
| Malabal Elementary School | Barangay 5 | Medium | High | High |
| Bacyaran Elementary School | Bulao | | | |
| Day Care Center | Calingonan | Low | Low | Low |
| Bulao Elementary School | Canbagtic | | | |
| Canticum Elementary School | Canticum | High | High | High |
| Rawis Elementary School | Canticum | | | |
| Bacyaran Elementary School | Macaalan | | | |
| Calbiga Central Elementary School | Macaalan | | | |
| Calbiga National High School | Macaalan | | Medium | High |
| Day Care Center | Macaalan | | Medium | Medium |
| Pasigay Day Care Center | Pasigay | Low | Low | Low |
| Pasigay Elementary School | Pasigay | Low | Medium | Medium |
| Malabal Day Care Center | Polangi | | | |
| Malabal Elementary School | Polangi | | Medium | High |
| Patong Elementary School | Rawis | | | |
| Calingonan Elementary School | San Ignacio | | | |
| San Mauricio Elementary School | San Mauricio | | | |
| Day Care Center | Tinago | | | |

| SAMAR | | | | |
|---|---|---|---|---|
| PINABACDAO | | | | |
| Building Name | Barangay | Rainfall Scenario | | |
| | | 5-year | 25-year | 100-year |
| Pinabacdao National High School | Bangon | | | |
| Pinabacdao Central Elementary School | Botoc | | | |
| Pasigay Elementary School | Calampong | | Low | Low |
| Obayan Elementary School | Catigawan | Medium | Medium | Medium |
| Botoc Elementary School | Loctob | | | |

# ANNEX 13. MEDICAL INSTITUTIONS AFFECTED IN CALBIGA FLOOD PLAIN

| SAMAR | | | | |
|---|---|---|---|---|
| CALBIGA | | | | |
| Building Name | Barangay | Rainfall Scenario | | |
| | | 5-year | 25-year | 100-year |
| Brgy. Health Center | Calayaan | Medium | Medium | Medium |
| Birthing Clinic | Macaalan | | Medium | Medium |
| Clinic | Macaalan | | Medium | Medium |
| Rural Health Unit | Macaalan | | Medium | Medium |
| TB-DOTS Center | Macaalan | | Medium | Medium |
| Brgy. Health Center | San Ignacio | | Low | Low |