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

LiDAR Surveys and Flood Mapping of Amro River

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

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LIST OF ACRONYMS AND ABBREVIATIONS

AAC	Asian Aerospace Corporation
Ab	abutment
ALTM	Airborne LiDAR Terrain Mapper
ARG	automatic rain gauge
ATQ	Antique
AWLS	Automated Water Level Sensor
BA	Bridge Approach
BM	benchmark
CAD	Computer-Aided Design
CN	Curve Number
CSRS	Chief Science Research Specialist
DAC	Data Acquisition Component
DEM	Digital Elevation Model
DENR	Department of Environment and Natural Resources
DOST	Department of Science and Technology
DPPC	Data Pre-Processing Component
DREAM	Disaster Risk and Exposure Assessment for Mitigation [Program]
DRRM	Disaster Risk Reduction and Management
DSM	Digital Surface Model
DTM	Digital Terrain Model
DVBC	Data Validation and Bathymetry Component
FMC	Flood Modeling Component
FOV	Field of View
GiA	Grants-in-Aid
GCP	Ground Control Point
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center - River Analysis System
HC	High Chord
IDW	Inverse Distance Weighted [interpolation method]
IMU	Inertial Measurement Unit
ISU	Isabela State University
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
UPC	University of the Philippines Cebu
UP-TCAGP	University of the Philippines – Training Center for Applied Geodesy and Photogrammetry
UTM	Universal Transverse Mercator
WGS	World Geodetic System
ISU	Isabela State University

CHAPTER 1 OVERVIEW OF THE PROGRAM AND AMRO RIVER

1.1 Background of the Phil-LIDAR 1 Program

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

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

The implementing partner university for the Phil-LiDAR 1 Program is the Isabela State University (ISU). ISU is in charge of processing LiDAR data and conducting data validation reconnaissance, cross section, bathymetric survey, validation, river flow measurements, flood height and extent data gathering, flood modeling, and flood map generation for the 22 river basins in the Cagayan Valley Region. The university is located in Echague, Isabela.

1.2. Overview of the Amro River Basin

The Aurora River Basin is located in the East-Central side of Luzon Island (Figure 1). It is bordered on the north by the Provinces of Isabela and Qurino, on the west by Nueva Ecija and Nueva Viscaya, on the south by Bulacan and Quezon, and on the east by the Pacific Ocean. The province's main link to the rest of Luzon is through a narrow mountain gravel road that twists through the Sierra Madre Mountain Range. The road is located between the Municipalities of Baler and Bongabon, Nueva Ecija.

The Province of Aurora covers the eastern portion of the Sierra Madre Mountains, hence it is generally mountainous. There are flat lands unevenly distributed throughout the province. Its coastline spans 332 kilometers in length. The Municipality of Dingalan, in the south, has the most irregular topography.

It belongs to type IV under the coronas climatic classification. Aurora's climate is characterized by rainfall that is evenly distributed throughout the year, since Aurora faces the Pacific Ocean and has no barriers to shield it from typhoons coming from the east. Tropical cyclones are also a seasonal occurrence. The average monthly rainfall is 273.9 millimeters. Rainfall is heaviest during the months of January, February, April, October, and November, while August is the driest month. The province experiences two main wind currents. From November to April, the trade wind generally reaches the province from an easterly direction. The wind then moves in a southwesterly direction for the rest of the year. In Casiguran, the wind comes from the north from October to March and the South from April to September. The average annual wind speed is four knots. The mean monthly temperature of Aurora is 25.3 degrees Celsius. The coldest months are January and February, with a temperature ranging from 19.3 to 20.4 degrees Celsius. The warmest months are from June to July, with temperature from 30 to 33 degrees Celsius.

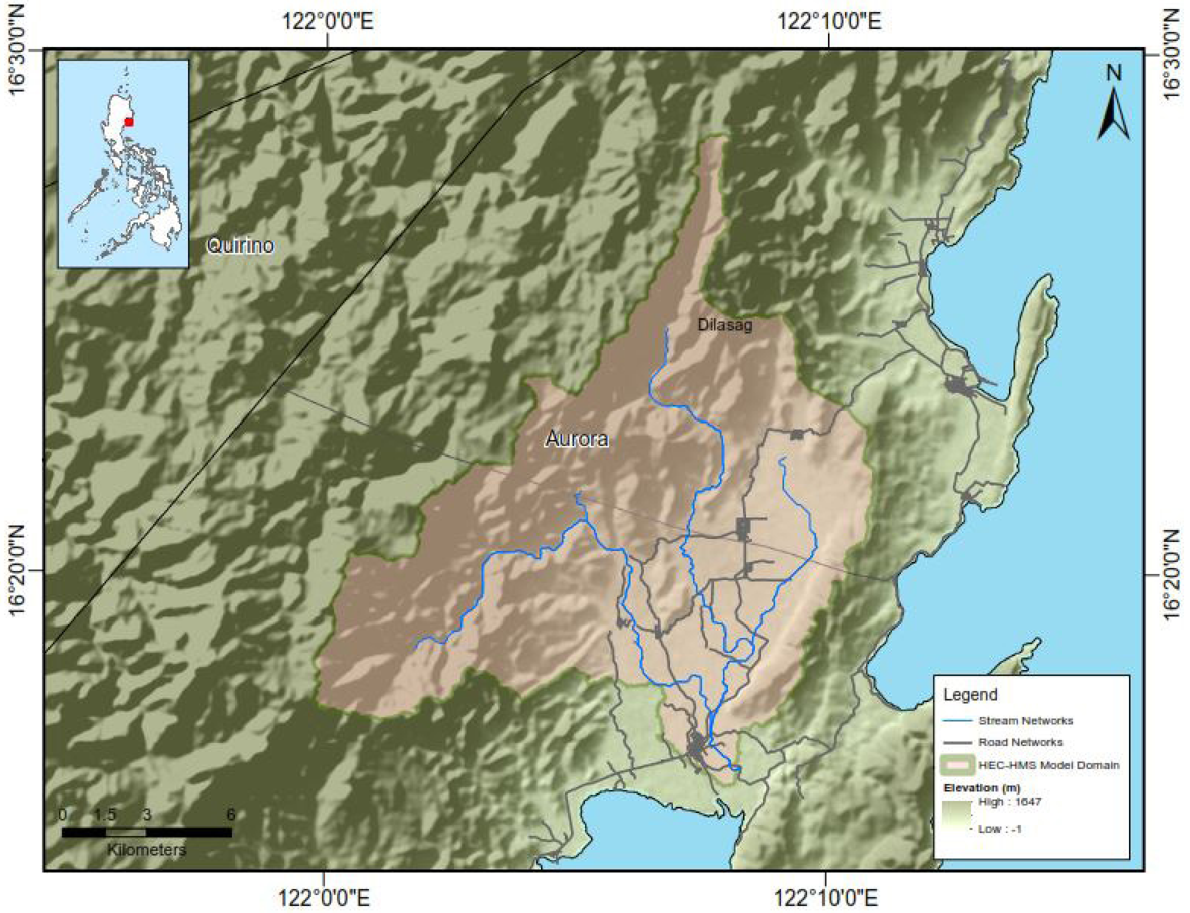


Figure 1. Map of the Amro River Basin (in Brown)

Casiguran is a second class municipality in the northern part of the Province of Aurora, Philippines. It is located at the northern part of Aurora Province, about 121 kms, from Baler, capital town of Aurora Province. It is bounded on the north-east by Dilasag, south-west by Dinalungan, north-west by Quirino and southeast by the Philippine Sea. According to the Philippine Statistics Authority, the municipality has a land area of 715.43 square kilometers (276.23 sq mi) constituting 22.73% of the 3,147.32-square-kilometre-(1,215.19 sq mi) total area of Aurora. The municipality is home to the Amro River Protected Landscape.

The Municipality of Casiguran is politically subdivided into 24 barangays. According to the 2015 census, it has a population of 24,313 people. A total of 12, 159 people are residing along the river, distributed among 16 (sixteen) barangays, namely Barangay 1, 2, 3, 4, 5, 6, 7, 8, Calangcuasan, Calantas, Culat, Esperanza, Lual, Marikit, Tabas and Tinib.

Agriculture is the primary industry in Casiguran. Average gross income for all household amounted to Php 40,000.00 annually base from upland and core farming and non-farming activities.

Casiguran is home to the Aurora Pacific Economic Zone and Freeport Authority or APECO, a special economic zone. Created in 2007 by virtue of Republic Act No. 9490 thru the efforts of Sen. Edgardo Angara and Rep. Juan Edgardo Angara, it is expected be a major transhipment hub going to the pacific region. It aims to boost social, economic and industrial developments in Aurora and nearby provinces by generating jobs for the people, improving the quality of their living conditions, advocating an eco-friendly approach to industrialization and enhancing the potential of the community in productivity

The town was devastated by Super Typhoon Koppu, known as Typhoon Lando on October 18, 2015. Nearly 100% of houses and infrastructure were damaged. At least two people are reported killed and 20 others injured in the town when the typhoon made landfall.

Sources:
http://www.rappler.com/move-ph/issues/disasters/109898-typhoon-lando-damage-casiguran-aurora
http://greedypeg.org/aurora/Amro-River-Protected-Landscape.html
https://www.revolvy.com/topic/Casiguran%2C%20Aurora&uid=1575
https://pediaview.com/openpedia/Amro_River_Protected_Landscape
https://sites.google.com/site/casiguranglobalfamily/home
http://www.aurora.ph/casiguran.html

CHAPTER 2 LIDAR DATA ACQUISITION OF THE AMRO FLOODPLAIN

Engr. Louie P. Balicanta, Engr. Christopher Cruz, Lovely Gracia Acuña, Engr. Gerome Hipolito

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

2.1 Flight Plans

In order to acquire LiDAR data, the Data Acquisition Component (DAC) created flight plans within the delineated priority area of the Amro Floodplain in the Province of Aurora. These missions were planned for seven (7) lines that run for at most three and a half (3.5) hours including take-off, landing and turning time. The flight planning parameters for the LiDAR System is found in Table 1. Figure 2 shows the flight plan for Amro Floodplain.

Table 1. Flight planning parameters for Gemini and Pegasus LiDAR Systems.

Block Name	Flying Height (m AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK 11A	900	30	50	125	40	130	5
BLK 11B	1000	30	50	200	30	130	5
BLK 11C	1000	30	50	200	30	130	5

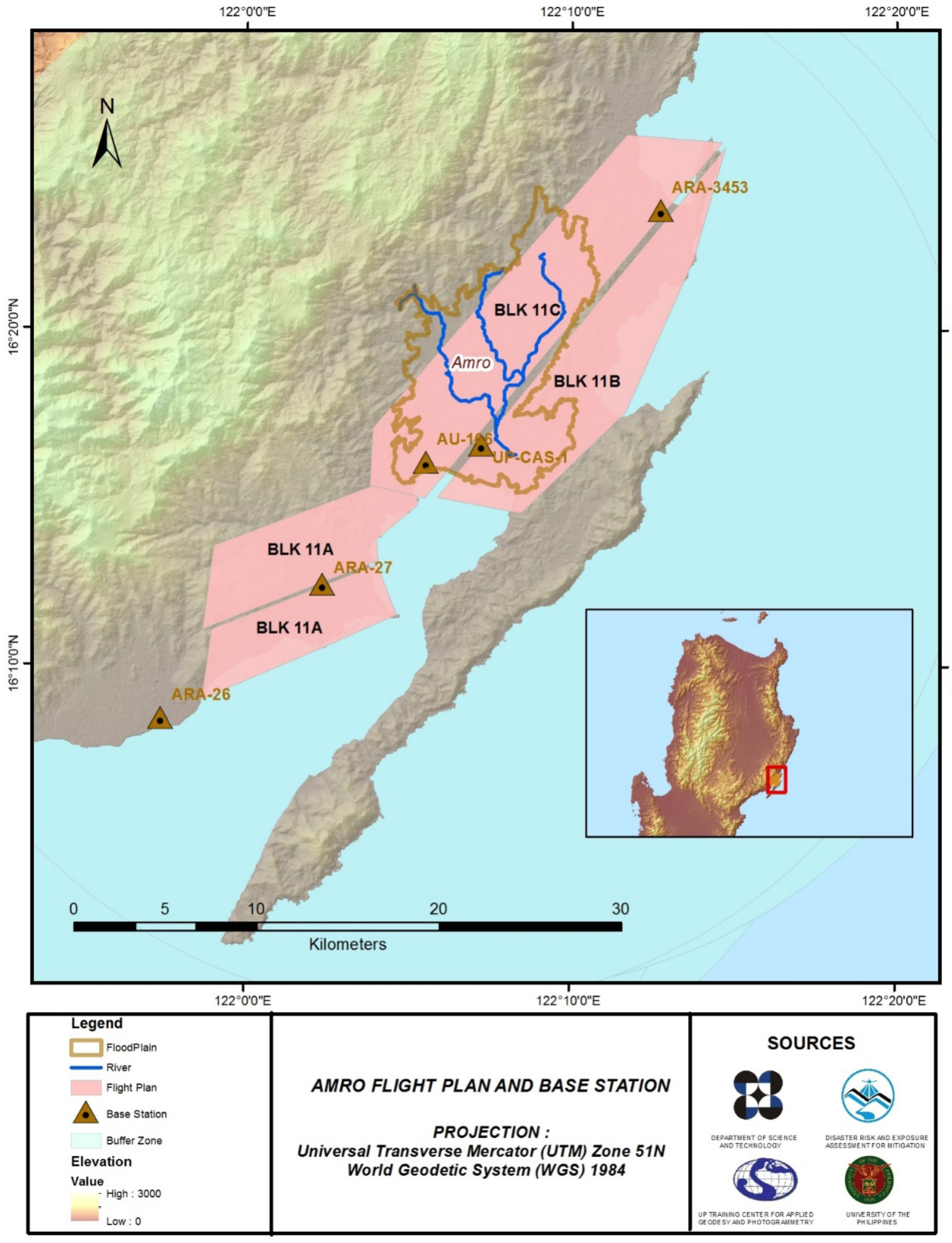


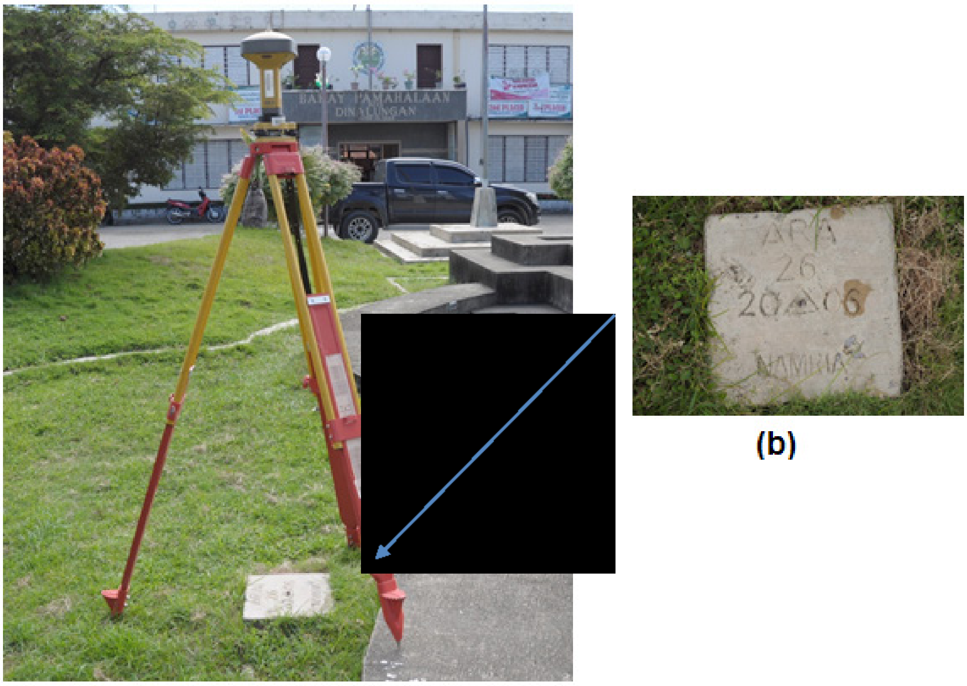
Figure 2. Flight plan and base stations for Amro Floodplain

2.2 Ground Base Station

The Project Team was able to recover four (4) NAMRIA ground control points: ARA-26, ARA-27, which are of second (2nd) order accuracy and ARA-3453 of third (3rd) order, also, AU-166, a benchmark which is of 1st order accuracy. The certifications for the NAMRIA reference points are found inAnnex 2. These were used as base stations during flight operations for the entire duration of the survey (September 10-12, 2015 and March 20-21, 2017). Base stations were observed using dual frequency GPS receivers, TOPCON GR-5 and

TRIMBLE SPS 985. Flight plans and location of base stations used during the aerial LiDAR acquisition in Amro floodplain are shown in Figure 2.

Figures 3 to 7 shows the recovered NAMRIA reference points within the area, in addition Table 2 to Table 6 show the details about the following NAMRIA control stations and established points, Table 7 shows the list of all ground control points occupied during the acquisition together with the dates they are utilized during the survey.



(b)

(a)

Figure 3. a) GPS set-up over ARA-26 as recovered at the Dinalungan Municipal Hall compound in Dinalungan, Aurora.b) NAMRIA reference point ARA-26 as recovered by the field team

Table 2. Details of the recovered NAMRIA horizontal control point ARA-26 used as base station for the LiDAR Acquisition.

Station Name	ARA-26	
Order of Accuracy	2nd Order	
Relative Error (horizontal positioning)	1:50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	16° 8’ 30.72348” 121° 57’ 19.59448” 11.05100 meters
Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 3 PRS 92)	Easting Northing	602193.101 meters 1785380.968 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	16° 8’ 25.02861” North 121° 57’ 24.35223” East 52.36100 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	388,313.59 meters 1,784,802.30 meters

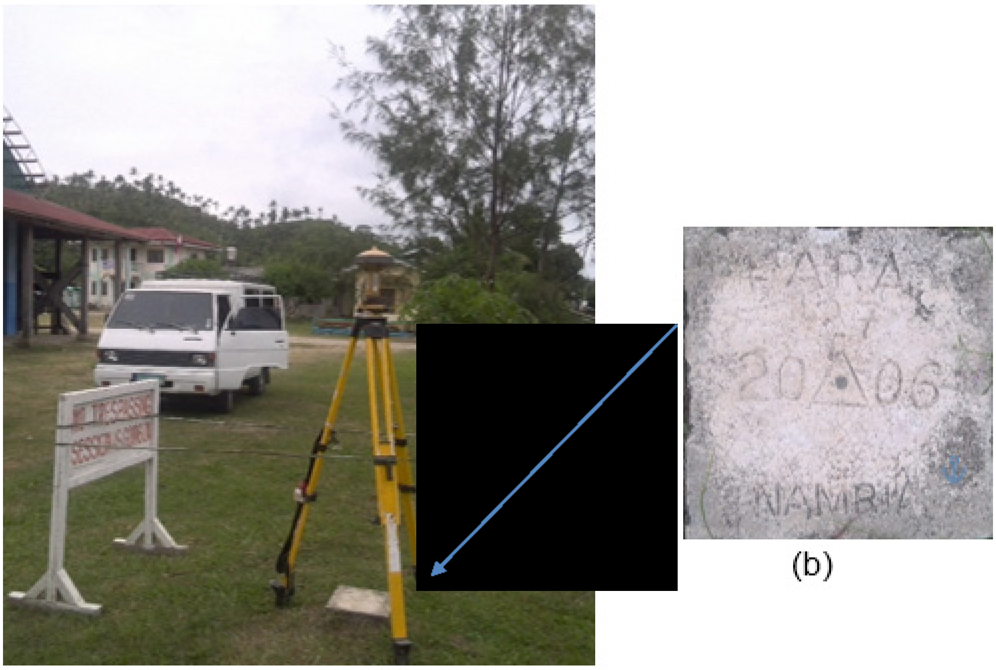


Figure 4. a) GPS set-up over ARA-27 as recovered inside the brgy. hall compound of Brgy. Bianoan, Aurora b) NAMRIA reference point ARA-27 as recovered by the field team

Table 3. Details of the recovered NAMRIA horizontal control point ARA-27 used as base station for the LiDAR Acquisition.

Station Name	ARA-27	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1:50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	16° 12’ 29.85802” North 122° 2’ 17.50426” East 20.69100 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 3 PRS 92)	Easting Northing	611007.921 meters 1792774.804 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	16° 12’ 24.15469” North 122° 2’ 22.25588” East 61.99800 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	397196.8 meters 1792107.52 meters

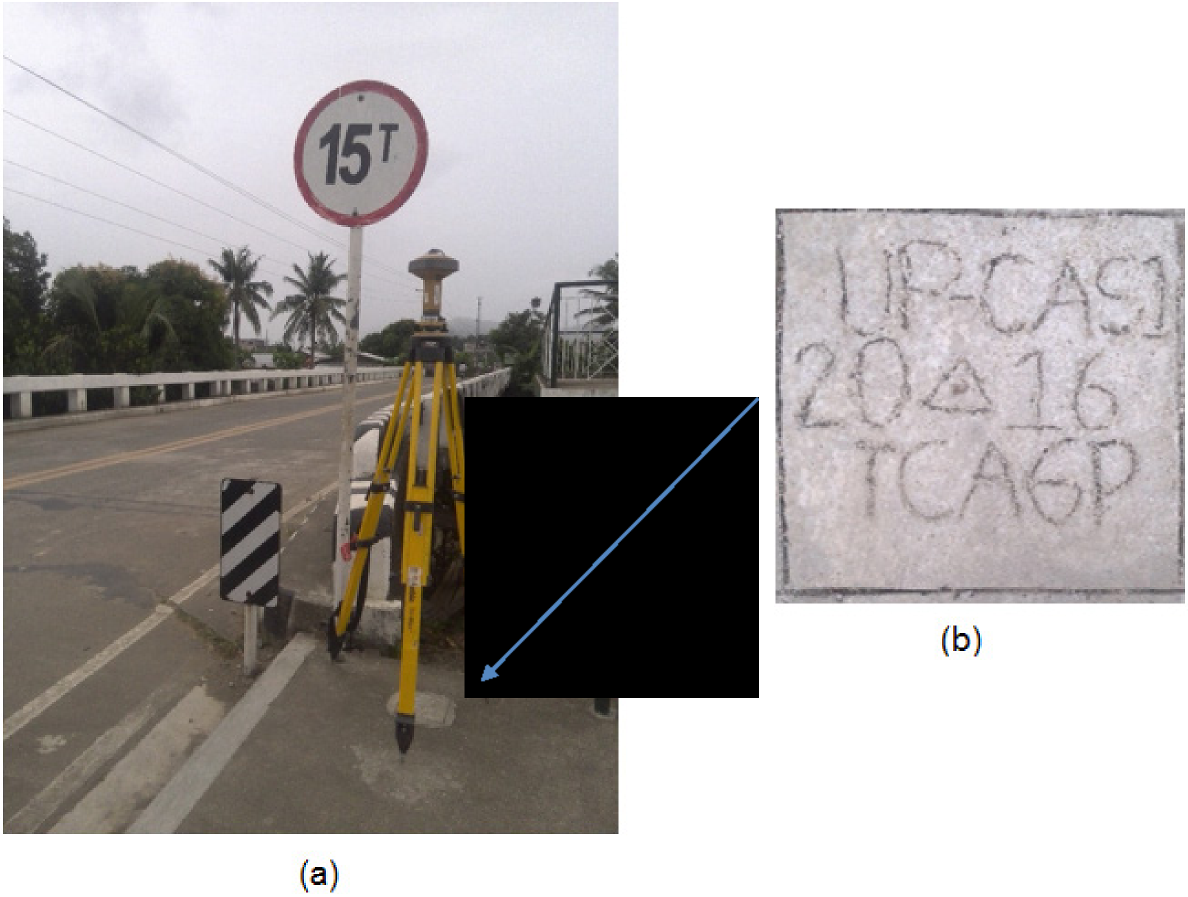


Figure 5. a) GPS set-up over UP-CAS-1 as locatedin a bridge in Aurora b) NAMRIA reference point UP-CAS-1 as recovered by the field team

Table 4. Details of the recovered established horizontal control point UP-CAS-1 used as base station for the LiDAR Acquisition.

Station Name	UP-CAS-1	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1:50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	16°16’ 32.74608” North 122°07’ 14.49861” East 48.834 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 92)	Easting Northing	406048.663 meters 1799641.171 meters

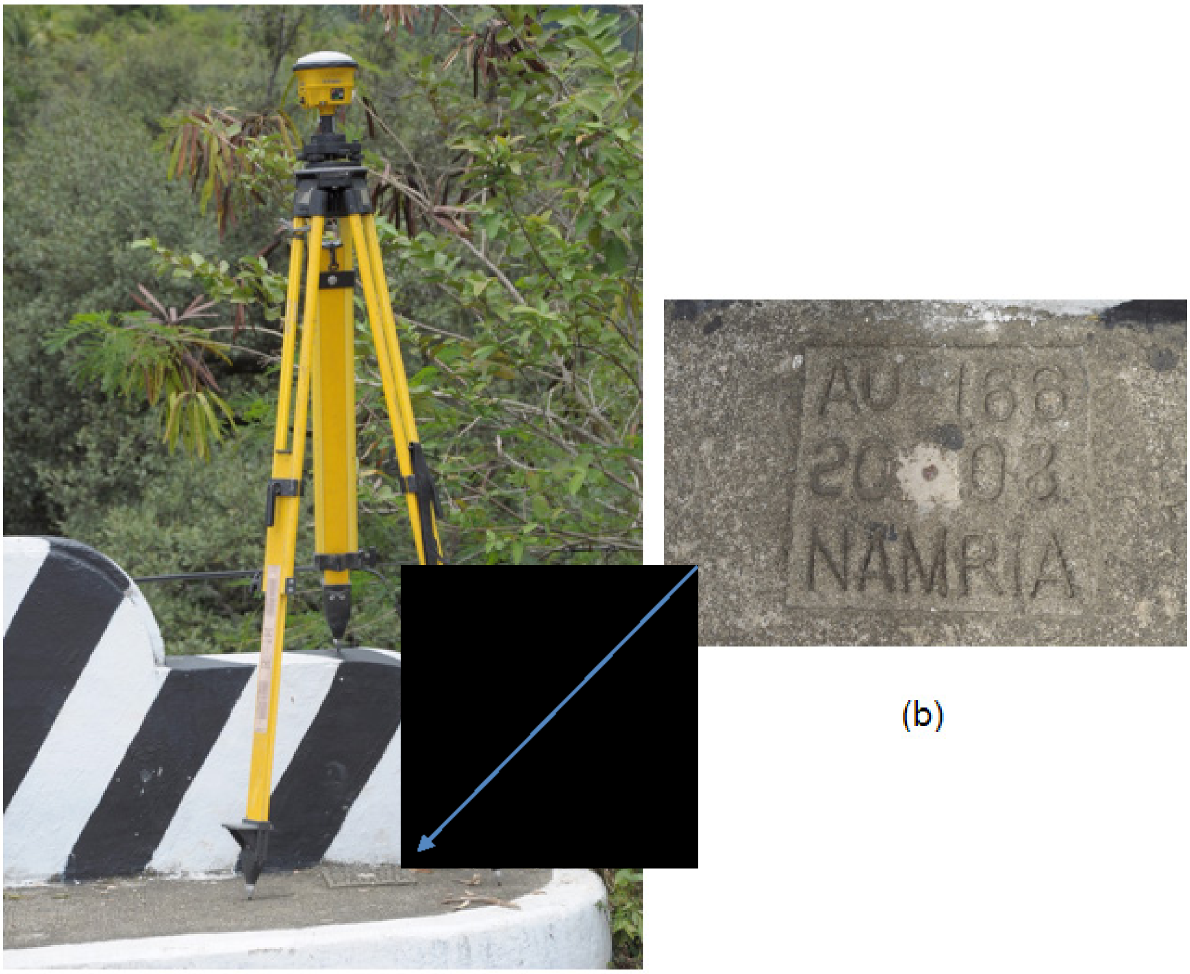
(a)

(b)

Figure 6. a) GPS set-up over ARA-3453 as recovered infront of the covered court of the barangay Ilaya Kabulihan at the left side of the road going to Montero Street b) NAMRIA reference point ARA-3453 as recovered by the field team

Table 5. Details of the recovered NAMRIA horizontal control point ARA-3453 used as base station for the LiDAR Acquisition

Station Name	ARA-3453	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1:50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	16°23’ 38.03287” North
	Longitude	122°12’ 40.04525” East
	Ellipsoidal Height	7.168 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	16°23’ 32.30134” North
	Longitude	122°12’ 44.78014” East
	Ellipsoidal Height	48.323 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 92)	Easting	415760.804 meters
	Northing	1812560.274 meters



(a) (b)

Figure 7. a) GPS set-up over AU-166 as recovered in Brgy. Tinib, Casiguran b) NAMRIA reference point AU-166 as recovered by the field team

Table 6. Details of the recovered NAMRIA benchmark AU-166 used as base station for the LiDAR Acquisition

Station Name	AU-166	
Order of Accuracy	1st	
Relative Error (horizontal positioning)	1:100,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	16° 16′ 02.48145″ North
	Longitude	122° 05′ 32.56842″ East
	Ellipsoidal Height	50.153 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 92)	Easting	402877.618 meters
	Northing	1798790.909 meters

Table 7. Ground control points used during LiDAR data acquisition

Date Surveyed	Flight Number	Mission Name	Ground Control Points
September 10, 2015	2710G	2BLK11A253A	ARA-26 and AU-166
September 12, 2015	2718G	2BLK11A255A	ARA-26 and AU-166
March 20, 2017	23760P	1BLK11B079A	ARA-27 and UP-CAS-1
March 21, 2017	23764P	1BLK11BC080A	ARA-27, ARA-3453 and UP-CAS-1

2.3 Flight Missions

Four (4) missions were conducted to complete the LiDAR data acquisition in Amro Floodplain, for a total of thirteen hours and fifty six minutes (13+56) of flying time for RP-C9122. All missions were acquired using the Gemini and the Pegasus LiDAR Systems. Table 8 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 9 presents the actual parameters used during the LiDAR data acquisition.

Table 8. Flight missions for LiDAR Data Acquisition in Amro Floodplain.

Date Surveyed	Flight Number	Flight Plan Area (km^2)	Surveyed Area (km^2)	Area Surveyed within the Floodplain (km^2)	Area Surveyed Outside the Floodplain (km^2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
September 10, 2015	2710G	41.12	29.28	0.00	103.39	143	2	17
September 12, 2015	2718G	41.12	26.48	0.00	103.39	113	2	59
March 20, 2017	23760P	81.48	22.98	5.12	98.27	0	4	17
March 21, 2017	23764P	190.33	144.62	69.34	34.05	0	4	23
TOTAL		354.05	223.36	74.46	339.1	256	13	56

Table 9. 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)
2710G	900	30	50	125	30	130	5
2718G	900	30	50	125	30	130	5
23760P	1000	30	50	200	40	130	5
23764P	1000	30	50	250	40	130	5

2.4 Survey Coverage

The Amro Floodplain is located in the Province of Aurora with majority of the floodplain situated within the Municipalities of Casiguran and Dilasag. The Municipality of Casiguran is mostly covered by the survey. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 10. The actual coverage of the LiDAR acquisition for Amro Floodplain is presented in Figure 8.

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

Province	Municipality/City	Area of Municipality/ City	Total Area Surveyed	Percentage of Area Surveyed
Aurora	Casiguran	621.74	118.72	19.09%
	Dilasag	398.23	58.00	14.56%
Total		1019.97	176.71	16.83%

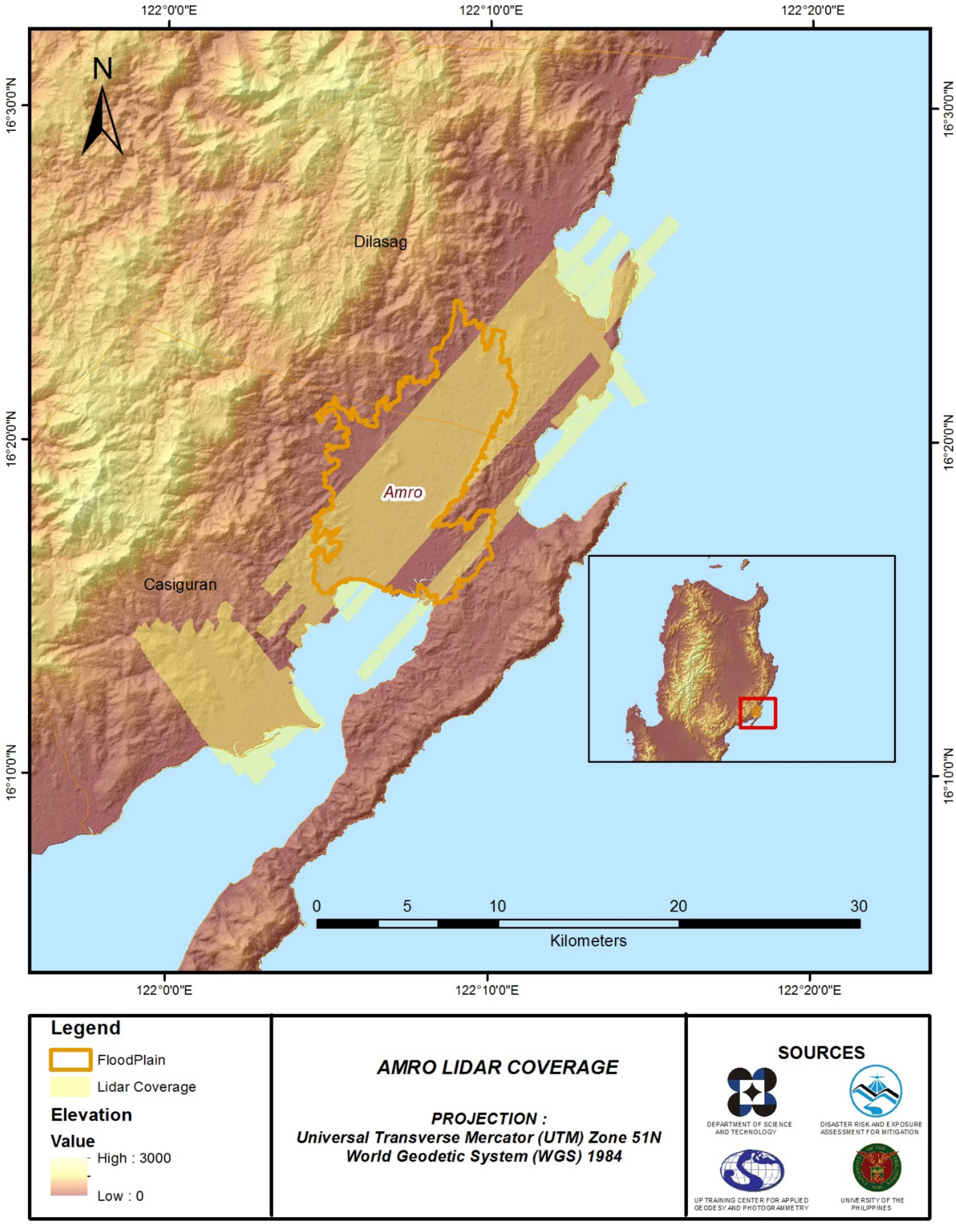


Figure 8. Actual LiDAR survey coverage for Amro Floodplain

CHAPTER 3. LIDAR DATA PROCESSING OF THE AMRO FLOODPLAIN

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

3.1 Overview of the LiDAR Data Pre-Processing

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

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

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

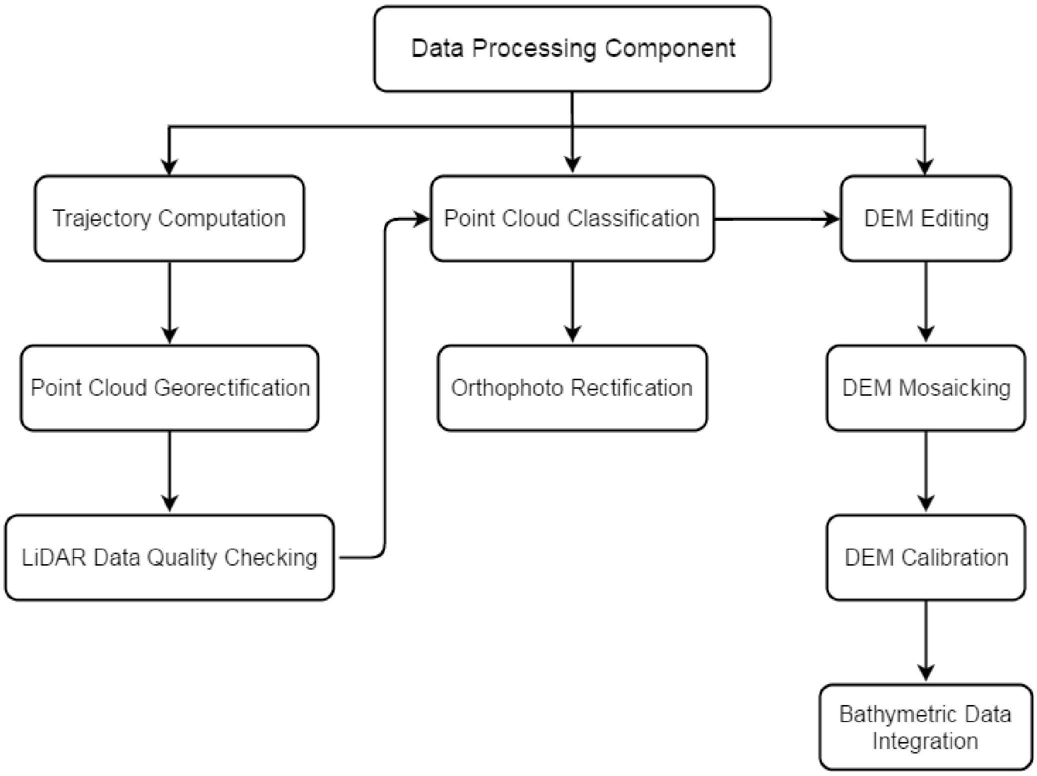

Figure 9. Schematic Diagram for Data Pre-Processing Component

3.2 Transmittal of the Acquired LiDAR Data

Data Transfer Sheets for all the LiDAR missions for Amro Floodplain can be found in Annex 5. Missions flown during the first survey conducted on September 2015 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Gemini System while missions acquired during the second survey on March 2017 were flown using the Pegasus System over Casiguran, Aurora. The Data Acquisition Component (DAC) transferred a total of 26.25 Gigabytes of Range data, 547Megabytes of POS data, 215.30 Megabytes of GPS base station data, and 16.02 Gigabytes of raw image data to the data server on October 5, 2015 for the first survey and March 27, 2017 for the second survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Amro was fully transferred on March 27, 2017 as indicated on the Data Transfer Sheets for Amro Floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metric parameters of the computed trajectory for flight 2710G, one of the Amro flights, which is the North, East, and Down position RMSE values are shown in Figure 10. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on May 11, 2014 00:00AM. The y-axis is the RMSE value for that particular position.

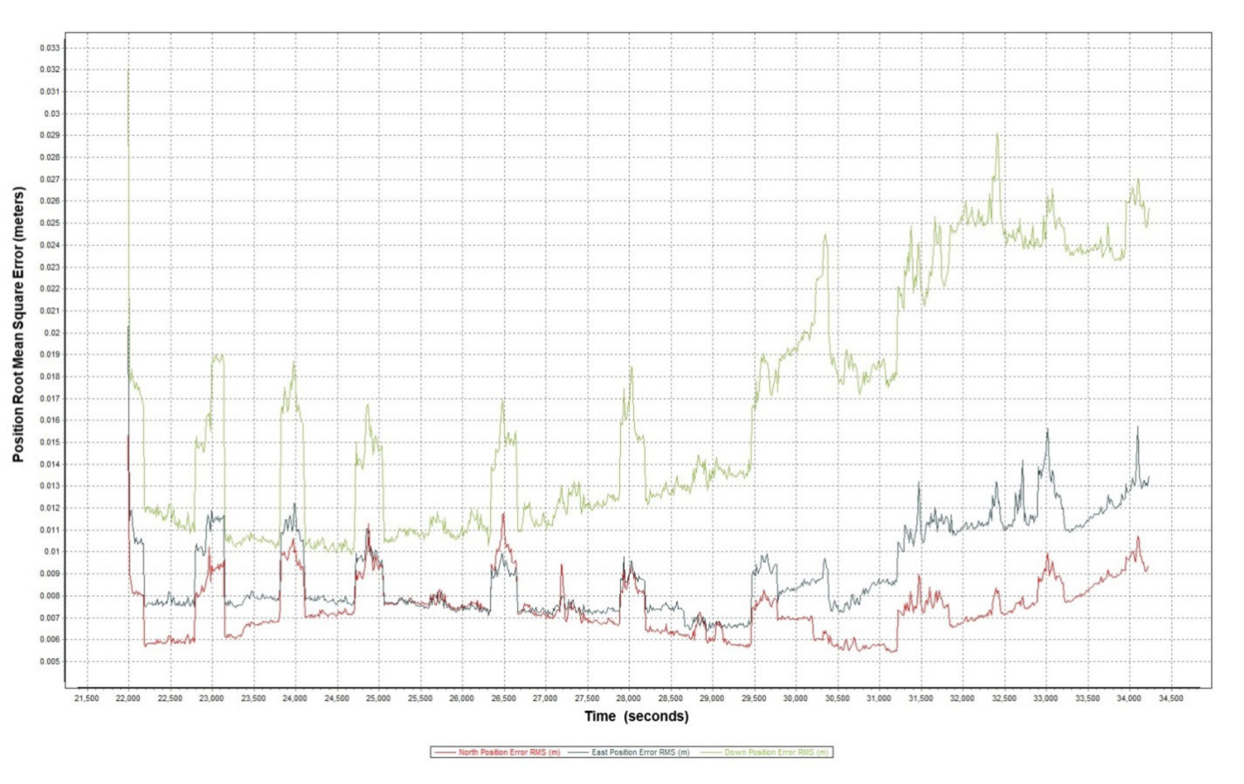

Figure 10. Smoothed Performance Metric Parameters ofAmro Flight 2710G

The time of flight was from 22000 seconds to 34500 seconds, which corresponds to afternoon of May 11, 2014. The initial spike seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and when the POS system started 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 10shows that the North position RMSE peaks at 1.20 centimeters, the East position RMSE peaks at 1. 60 centimeters, and the Down position RMSE peaks at 2.90 centimeters, which are within the prescribed accuracies described in the methodology.

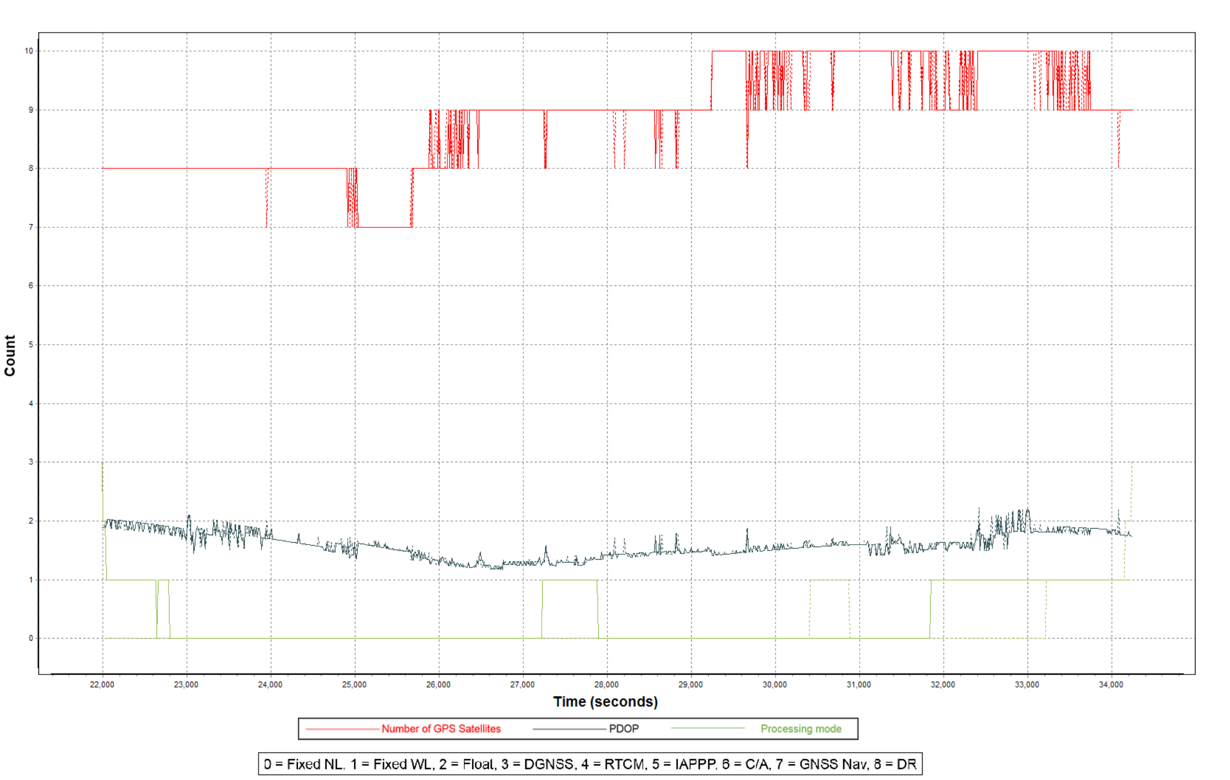

Figure 11. Solution Status Parameters of Amro Flight 2710G

The Solution Status parameters of flight 2710G, one of the Amro flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 11. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Majority of the time, the number of satellites tracked was between 6 and 10. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode stayed at the value of 0 for majority of the survey with some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Amro flights is shown in Figure 12.

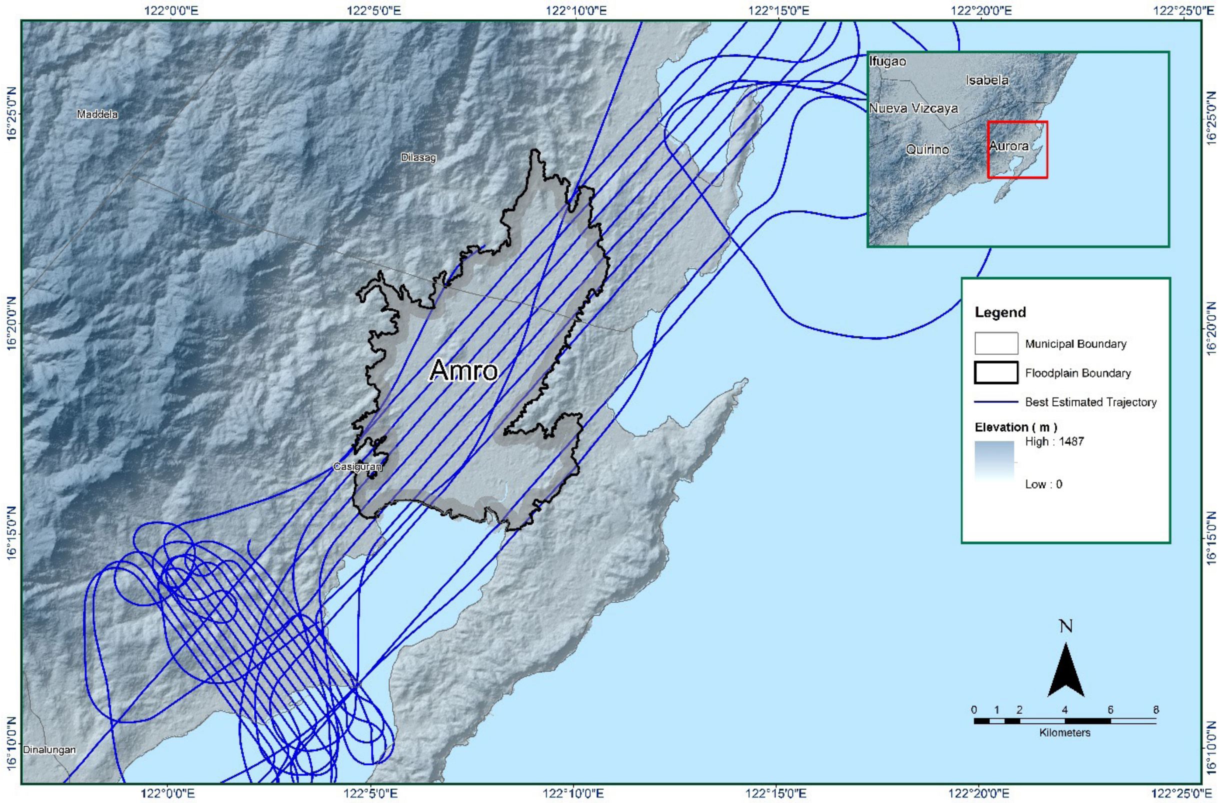

Figure 12. Best Estimated Trajectory for Amro Floodplain

3.4 LiDAR Point Cloud Computation

The produced LAS data contain twenty four (24) flight lines, with each flight line containing one channel for the Gemini block since the Gemini System contains only one channel and two channels for the Pegasus blocks since the Pegasus System contains two channels. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Amro Floodplain are given in Table 11.

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

Parameter	Computed Value	Acceptable Value
Boresight Correction stdev	(<0.001degrees)	0.000498
IMU Attitude Correction Roll and Pitch Corrections stdev	(<0.001degrees)	0.000997
GPS Position Z-correction stdev	(<0.01meters)	0.0088

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

3.5 LiDAR Data Quality Checking

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

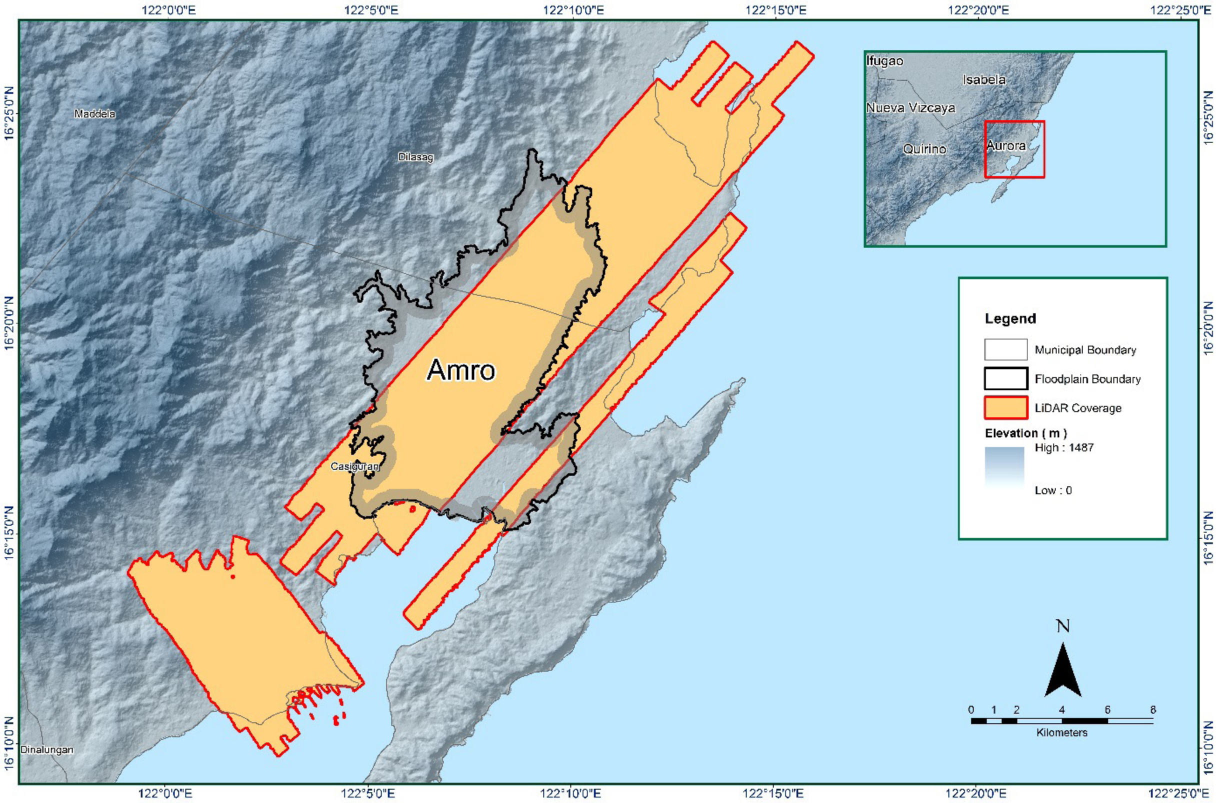

Figure 13. Boundary of the processed LiDAR data over Amro Floodplain

The total area covered by the Amro missions is 209.22 sq.km that is comprised of four (4) flight acquisitions grouped and merged into three (3) blocks as shown in Table 12.

Table 12. List of LiDAR blocks for Amro Floodplain

LiDAR Blocks	Flight Numbers	Area (sq. km)
Palanan_Blk11A	2710G 2718G	46.52
Cauayan_reflights_Blk11A	23760P	22.43
Cauayan_reflights_Blk11B	23764P	140.27
	TOTAL	**209.22 sq.km**

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 14. Since the Gemini System employs one channel, we 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. While for the Pegasus system which employs two channels, we would expect an average value of 2 (blue) for areas where there is limited overlap and a value of 3 (yellow) or more (red) for areas with three or more overlapping flight lines.

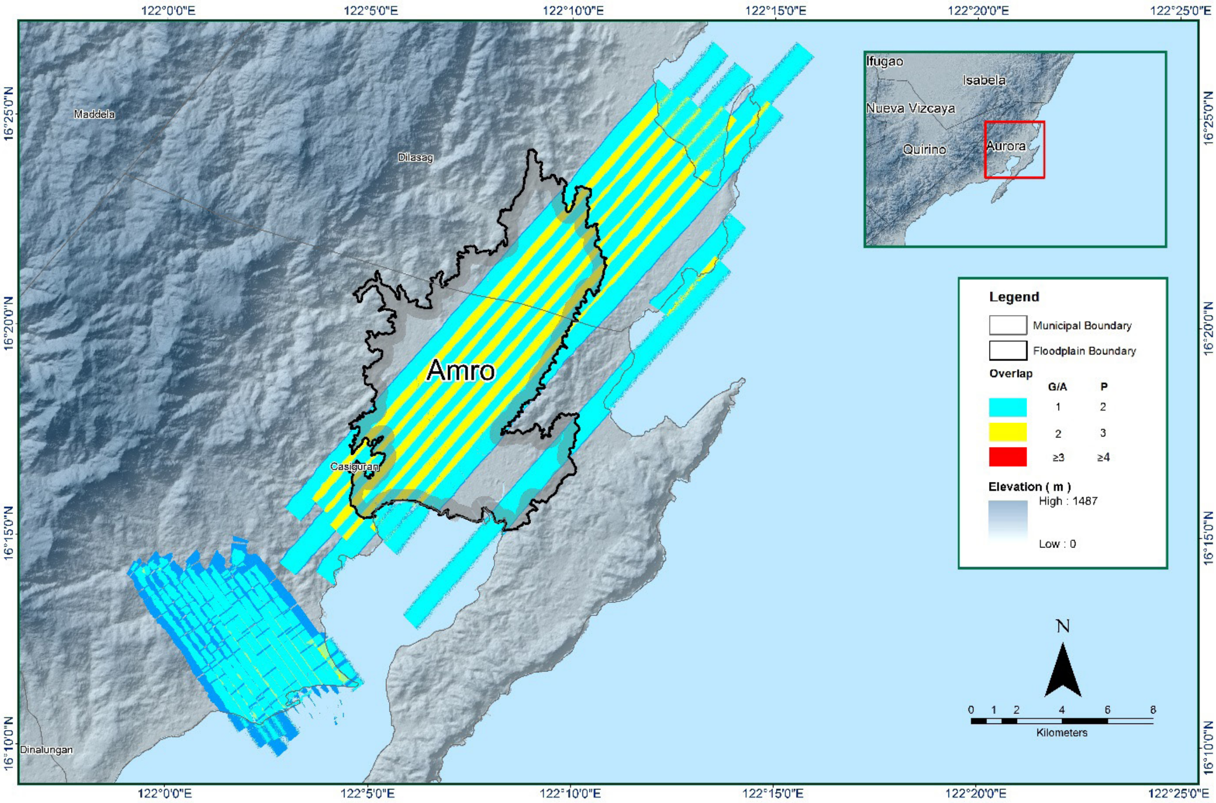

Figure 14. Image of data overlap for Amro Floodplain

The overlap statistics per block for the Amro Floodplain can be found in Annex 8. One pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 33.31% and 71.09% respectively, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 15. It was determined that all LiDAR data for Amro Floodplain met the point density requirement, and the average density for the entire survey area is 3.19 points per square meter.

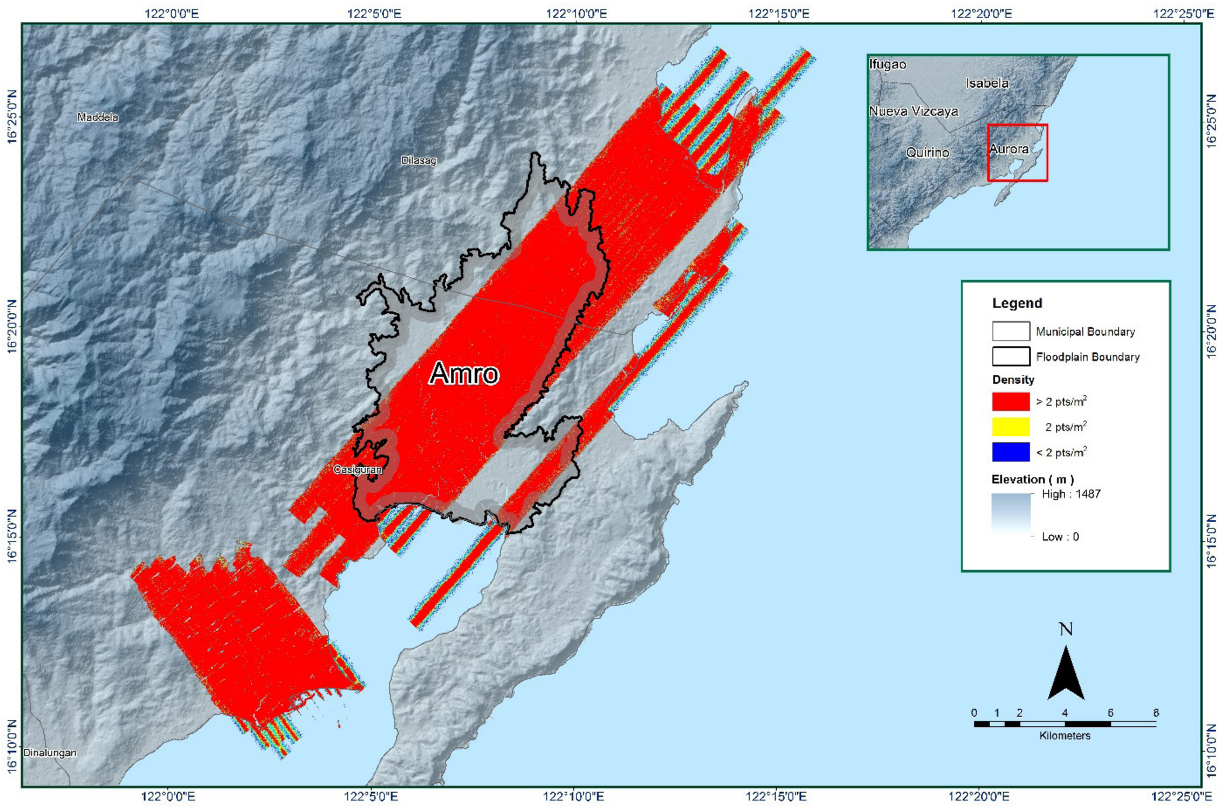

Figure 15. Pulse density map of merged LiDAR data for Amro Floodplain

The elevation difference between overlaps of adjacent flight lines is shown in Figure 16. The default color range is from blue to red, where bright blue areas correspond to portions where elevations of a previous flight line, identified by its acquisition time, are higher by more than 0.20m 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.

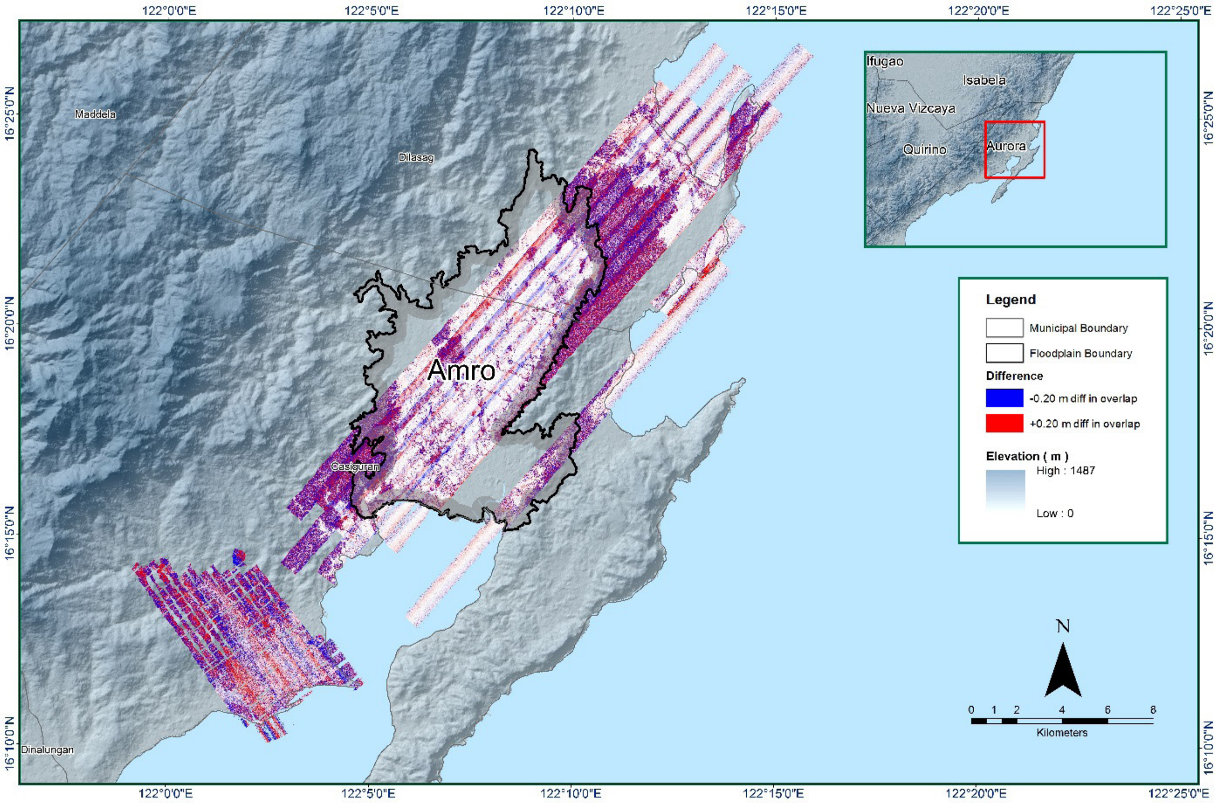

Figure 16. Elevation difference map between flight lines for Amro Floodplain

A screen capture of the processed LAS data from anAmro flight 2710G loaded in QT Modeler is shown in Figure 17. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed 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.

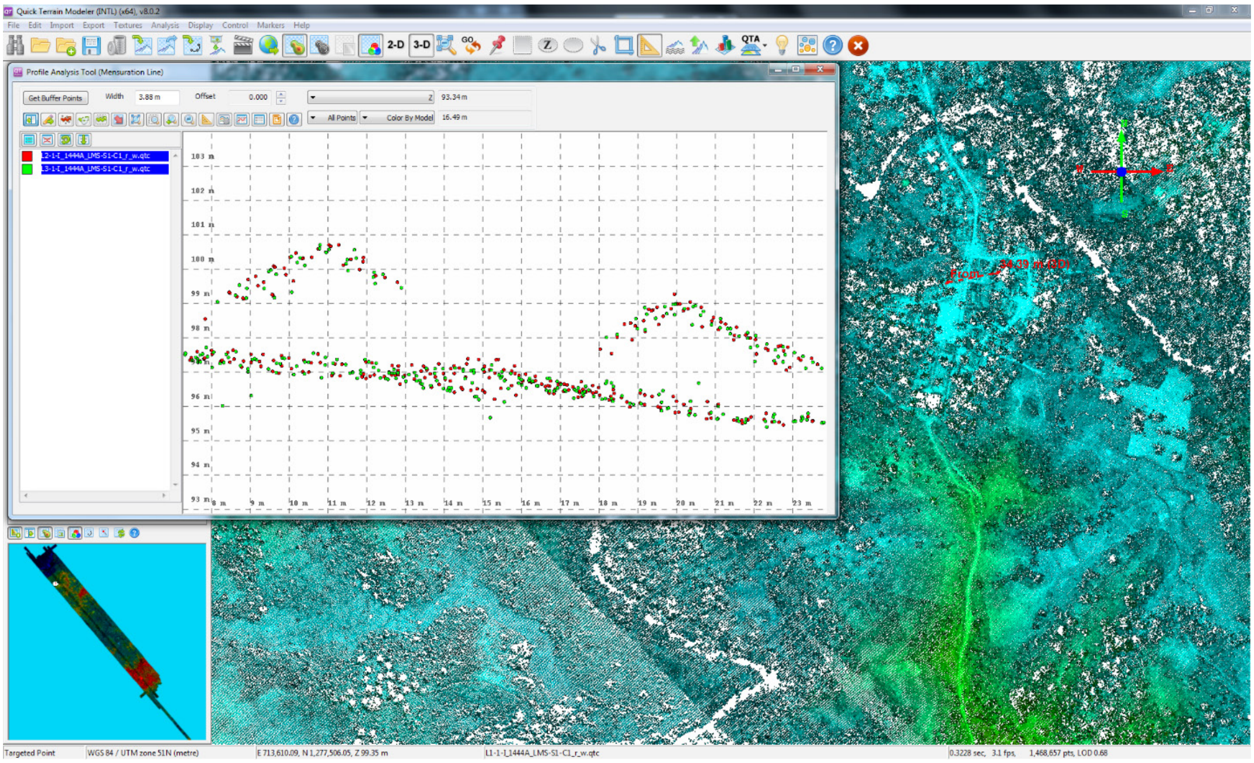

Figure 17. Quality checking for a Amro flight 2710G using the Profile Tool of QT Modeler

3.6 LiDAR Point Cloud Classification and Rasterization

Table 13. Amro classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	220,426,775
Low Vegetation	102,731,198
Medium Vegetation	234,491,880
High Vegetation	394,871,763
Building	6,460,260

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Amro Floodplain is shown in Figure 18. A total of 331 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 13. The point cloud has a maximum and minimum height of 451.11 meters and 39.63 meters respectively.

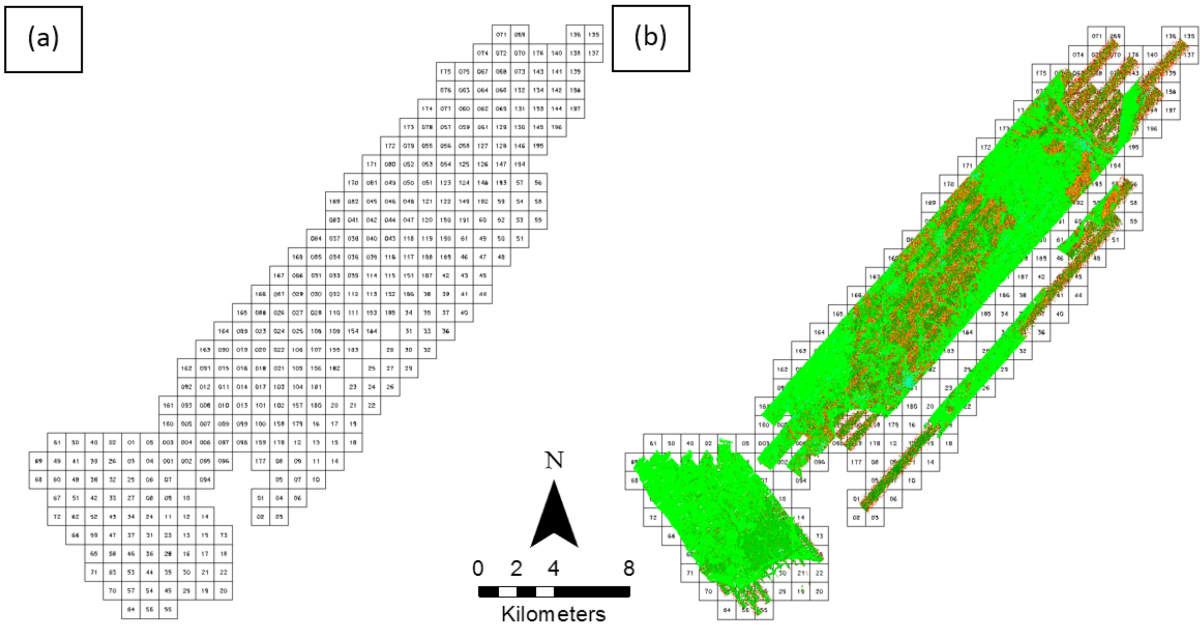

Figure 18. Tiles for Amro Floodplain (a) and classification results (b) in TerraScan

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

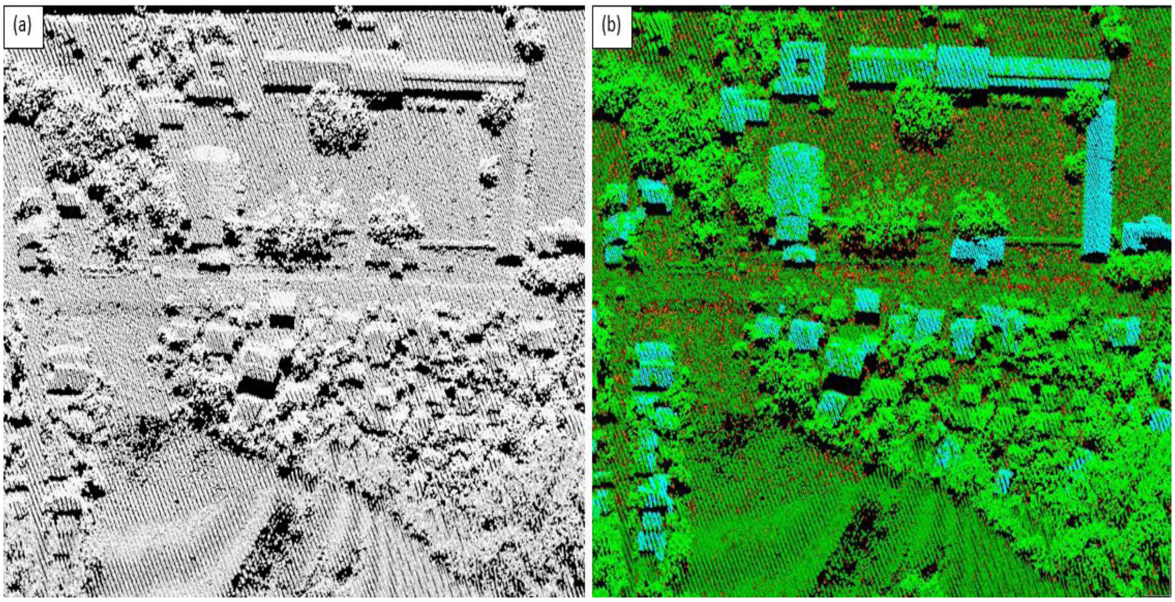

Figure 19. Point cloud before (a) and after (b) classification

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

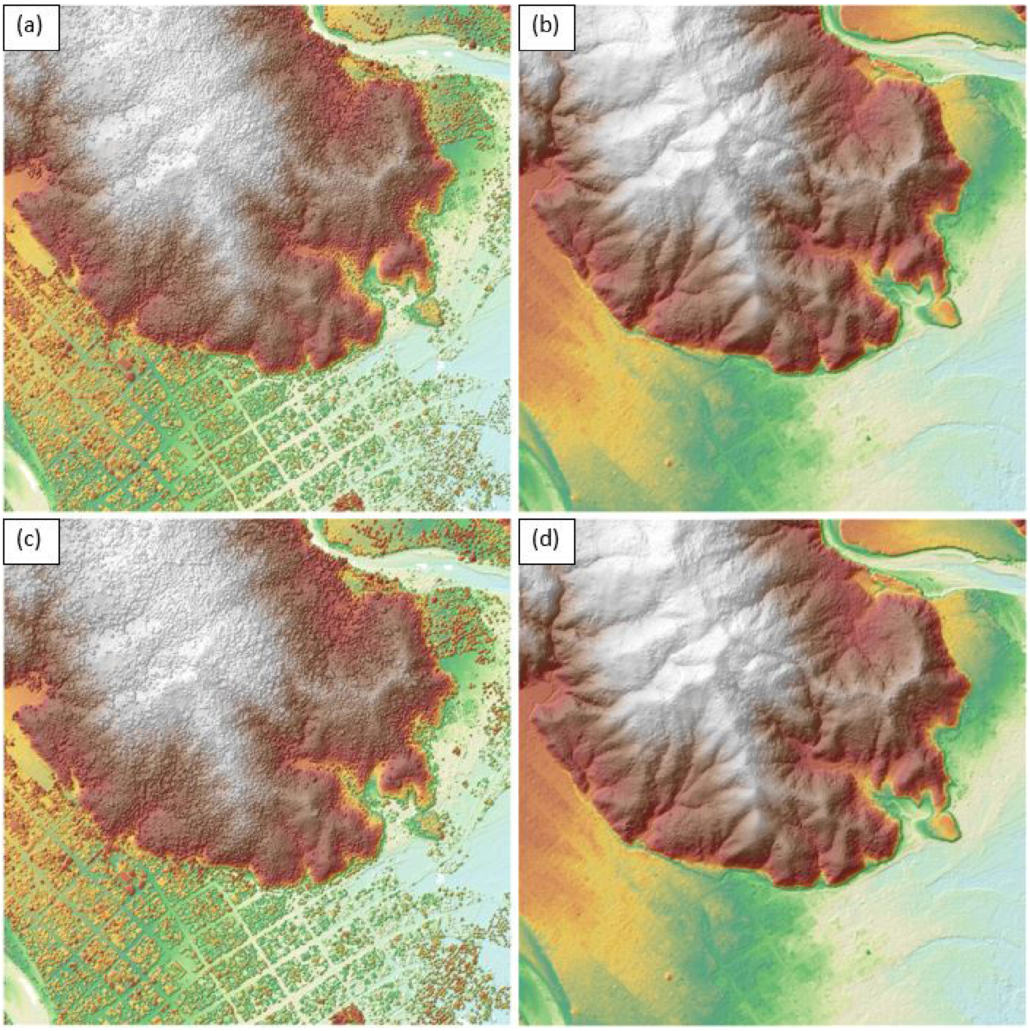

Figure 20. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Amro Floodplain

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 71 1km by 1km tiles area covered by Amro Floodplain is shown in Figure 21. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Amro Floodplain has a total of 49.34 sq.km orthophotograph coverage comprised of 254 images. However, the block does not have a complete set of orthophotographs and no orthophotographs cover the area of the Amro Floodplain. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 22.

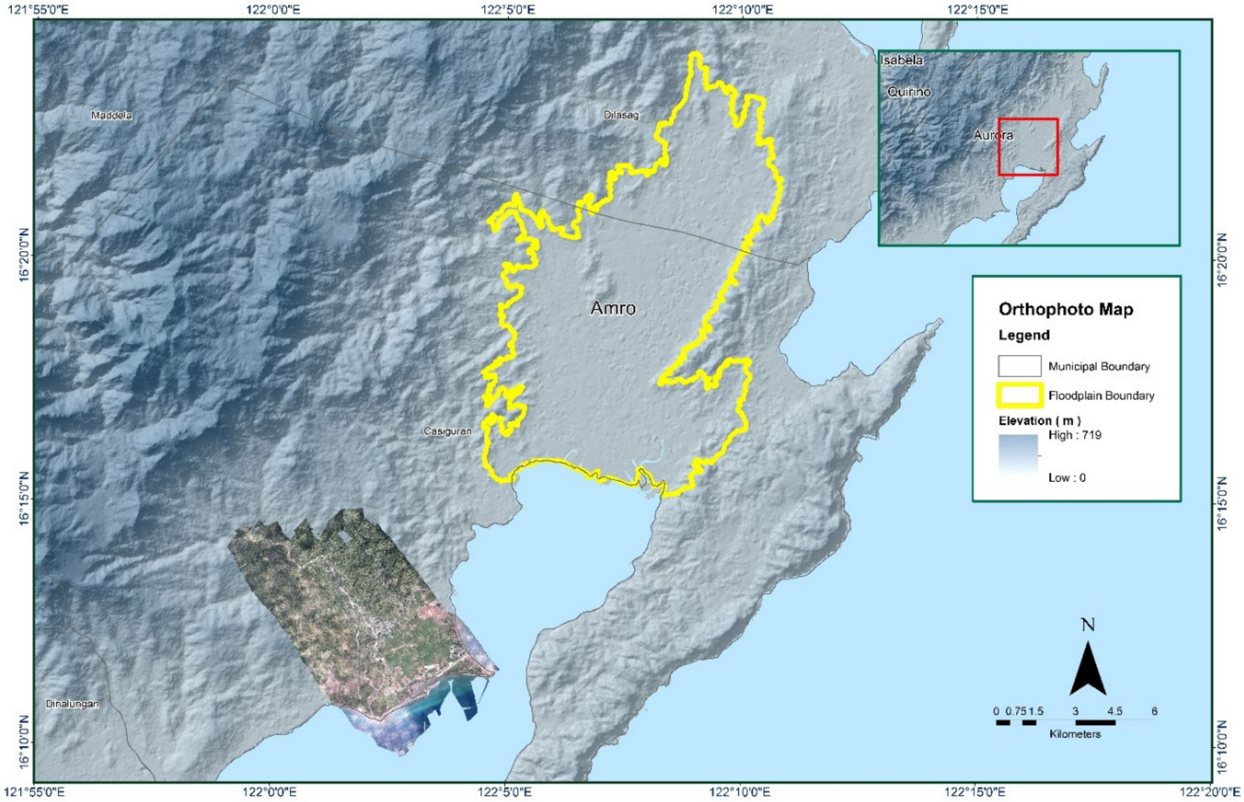

Figure 21. Available orthophotographs near Amro Floodplain

Figure 22. Sample orthophotograph tiles near Amro Floodplain

3.8 DEM Editing and Hydro-Correction

Three (3) mission blocks were processed for Amro Floodplain. These blocks are comprised of SamarLeyte and Leyte blocks with a total area of 209.22 square kilometers. Table 14 shows the name and corresponding area of each block in square kilometers.

Table 14. LiDAR blocks with its corresponding area

LiDAR Blocks	Area (sq.km)
Palanan_Blk11A	46.52
Cauayan_reflights_Blk11A	22.43
Cauayan_reflights_Blk11B	140.27
TOTAL	**209.22 sq.km**

Portions of DTM before and after manual editing are shown in Figure 23. A bridge (Figure 23a) has been misclassified and removed during classification process and has to be interpolated to complete the surface (23b) to allow the correct flow of water. Another example is an interpolated ridge (Figure 23c) has to be retrieved using object retrieval to achieve the actual surface (Figure 23d).An interpolated irrigation (Figure 23e) was retrieved (Figure 23f) in order to hydrologically correct the irrigation system. Another example is a building that is still present in the DTM after classification (Figure 23g) and has to be removed through manual editing (Figure 23h).

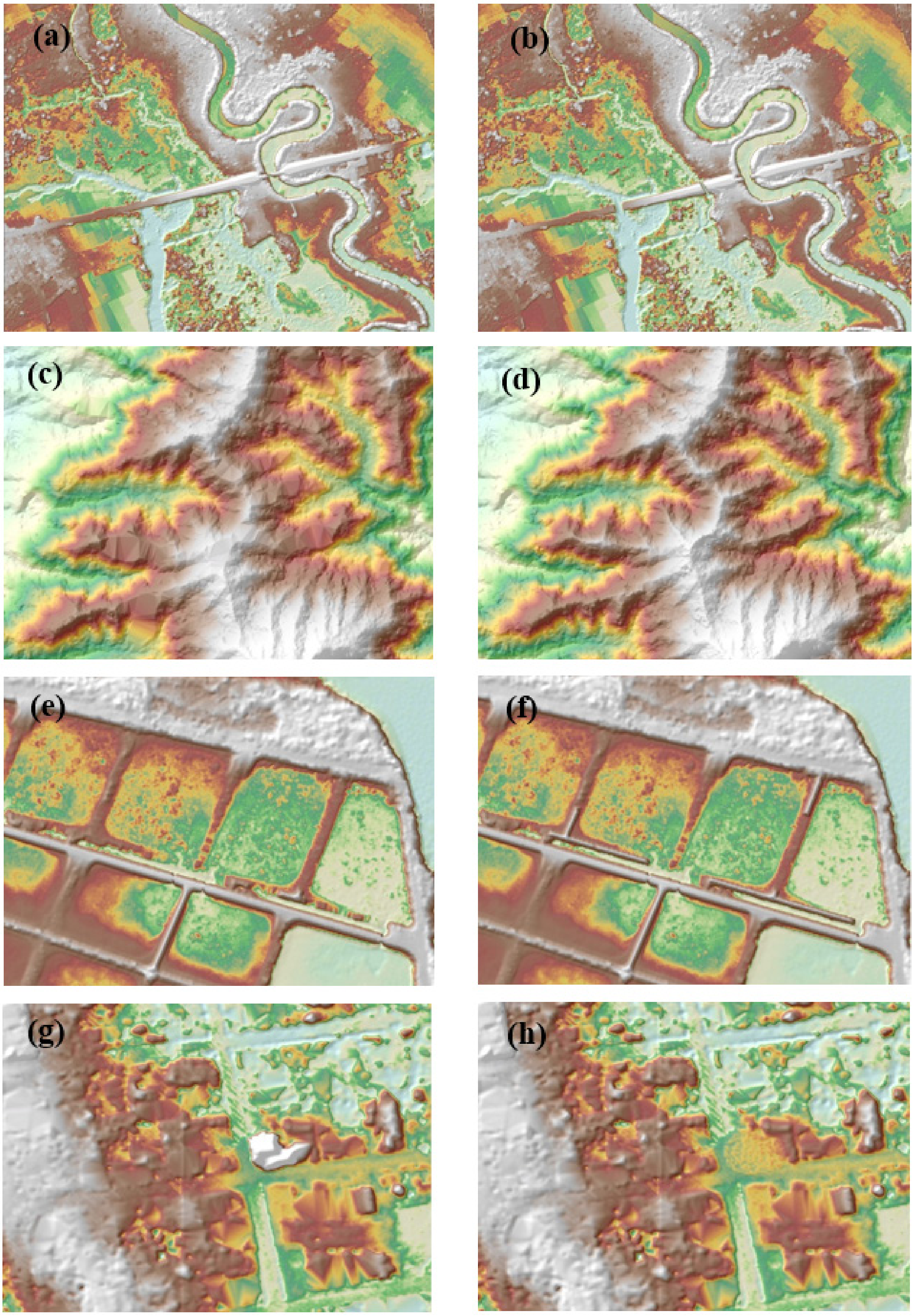

Figure 23. Portions in the DTM of Amro Floodplain – a bridge before (a) and after (b) manual editing; irrigation before (c) and after (d); interpolated ridge before (e) and after (f) object retrieval; and a building before (g) and after (h) manual editing

3.9 Mosaicking of Blocks

The Cauayan_reflight_Blk11B was used as the reference during mosaicking. Table 15 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Amro floodplain is shown in Figure 24. It can be seen that the entire Amro Floodplain is 61.00% covered by LiDAR datawhile portions with no LiDAR data were patched with the available IFSAR data.

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

Mission Blocks	**Shift Values (meters)**		
	x	**y**	**z**
Palanan_Blk11A	0.00	0.00	0.00
Cauayan_reflights_Blk11A	0.00	0.00	-1.00
Cauayan_reflights_Blk11B	0.00	0.00	3.50

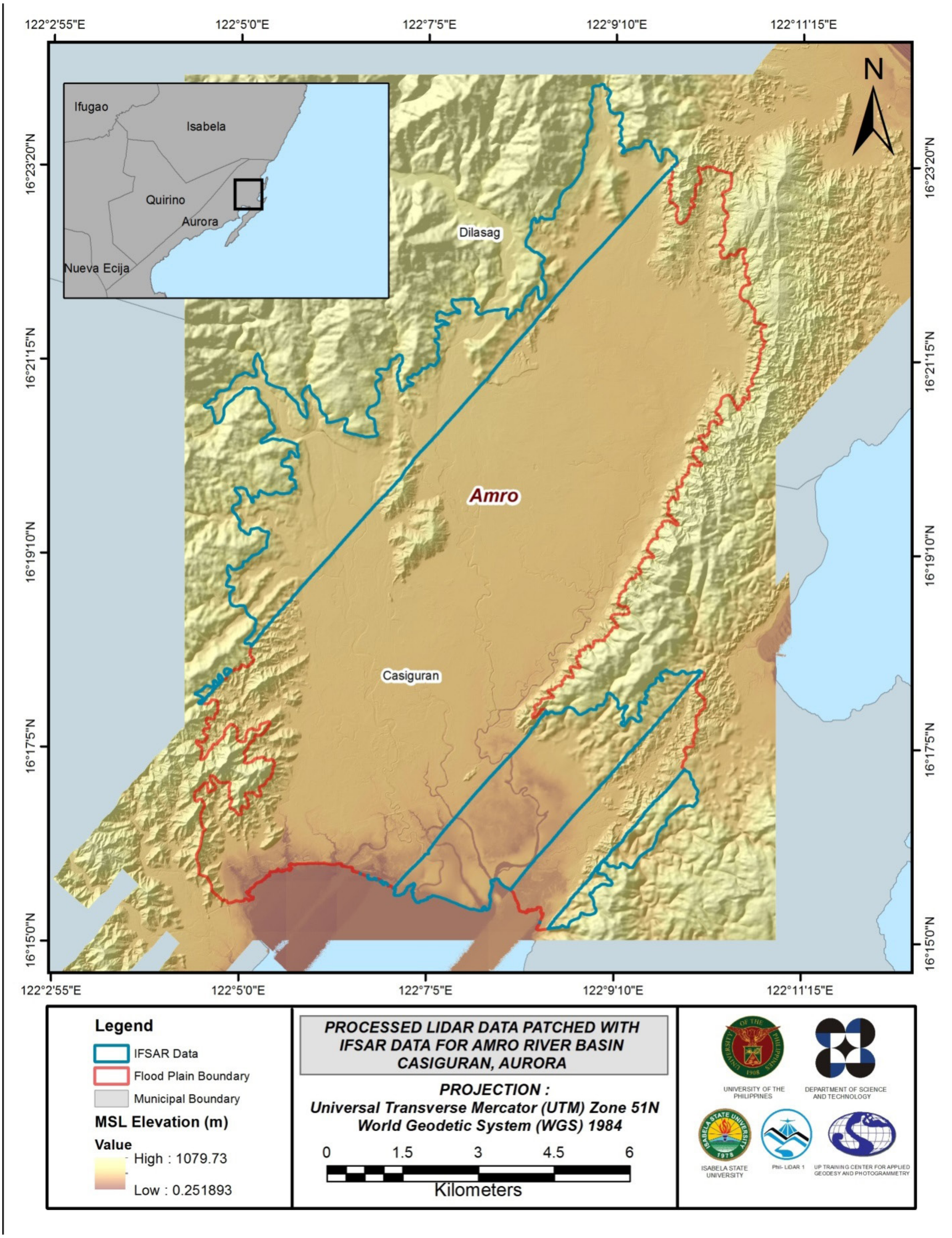

Figure 24. Map of Processed LiDAR Data for Amro Floodplain

3.10 Calibration and Validation of Mosaicked LiDAR DEM

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Amro to collect points with which the LiDAR dataset is validated is shown in Figure 25. A total of 1,683 survey points were gathered for the floodplain of Amro in Casiguran, Aurora. These points were used for calibration and validation of Amro LiDAR with IFSAR data.

A good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values is shown in Figure 26. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration elevation values is 0.75 meters with a standard deviation of 0.18 meters. Calibration of Amro IFSAR data was done by adding the height difference value, 0.75 meters, to Amro IFSAR data. Table 16 shows the statistical values of the compared elevation values between IFSAR data and calibration data.

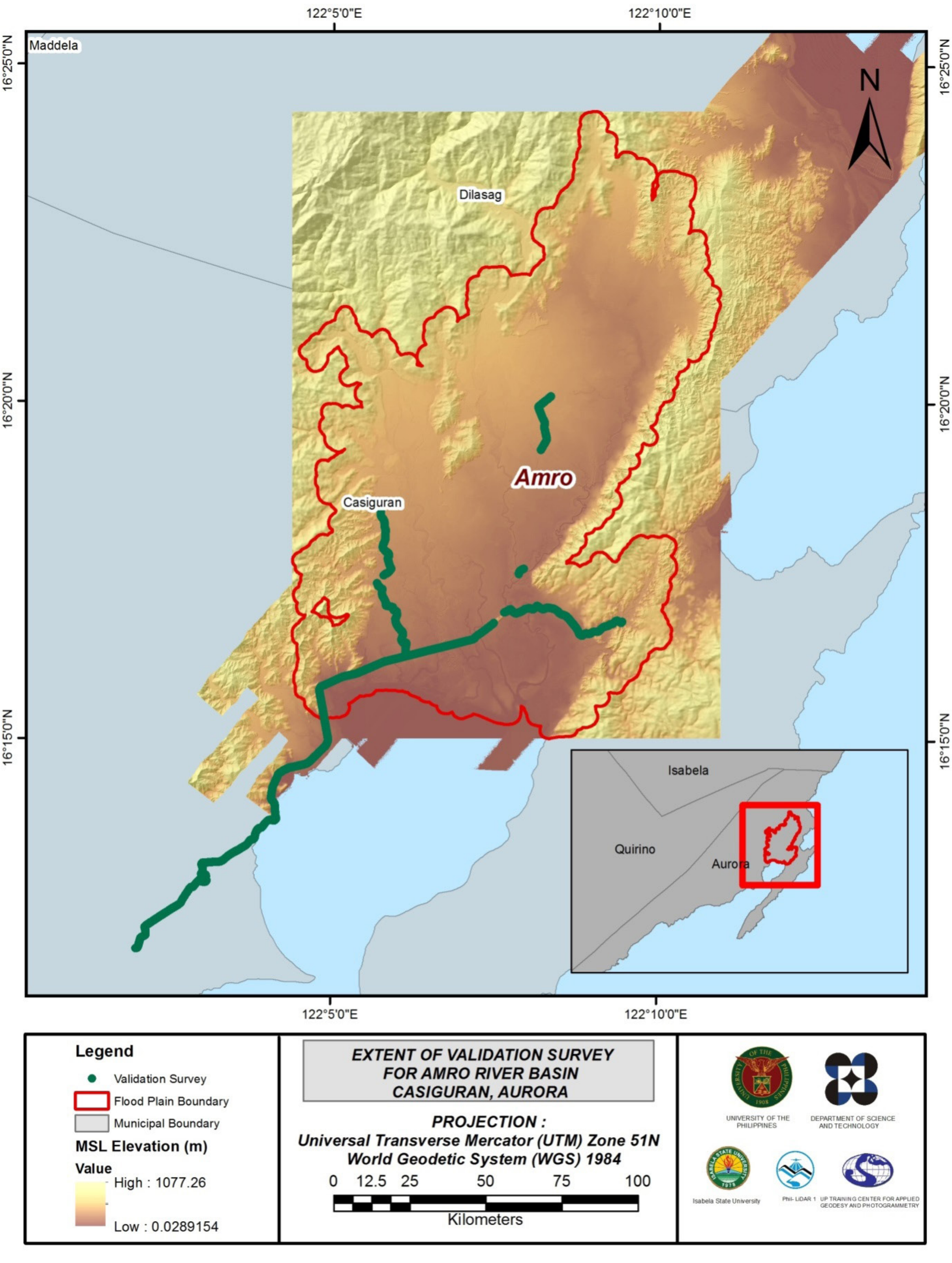

Figure 25. Map of Amro Floodplain with validation survey points in green

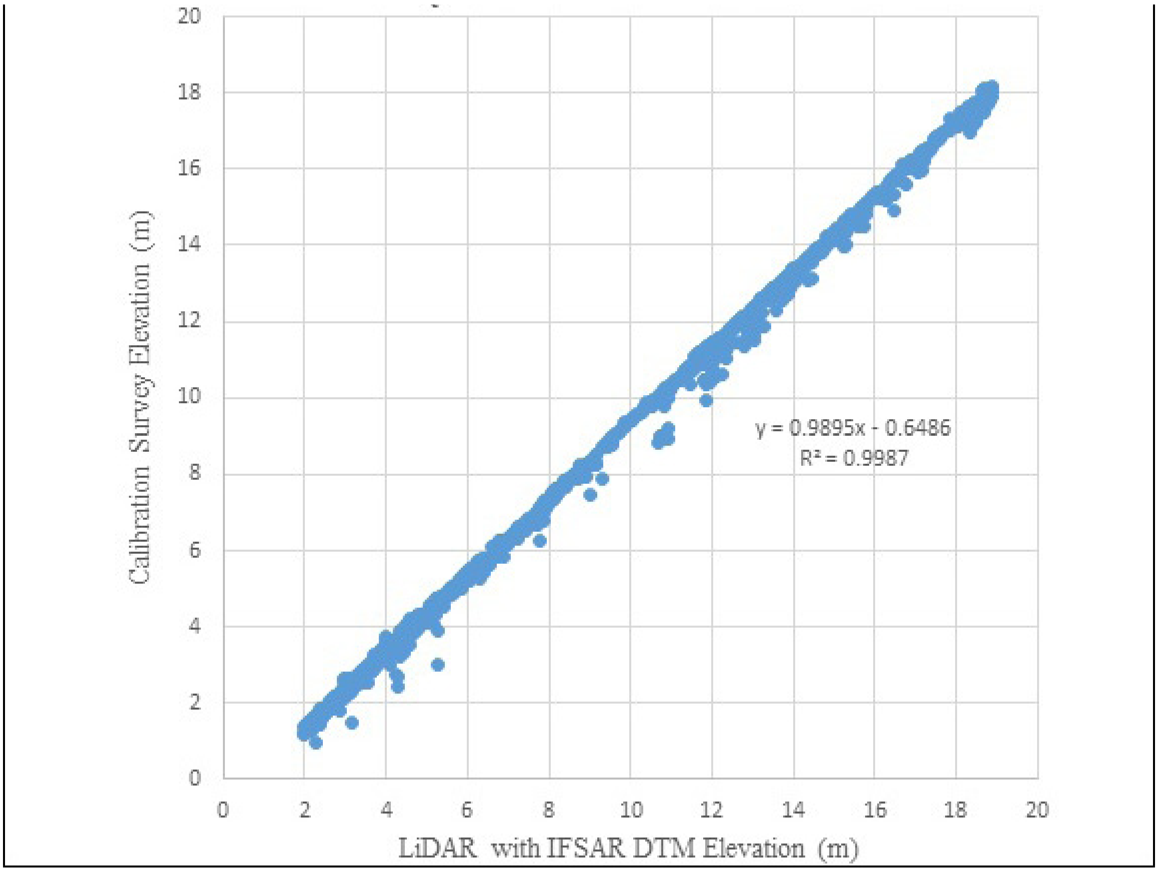

Figure 26. Correlation plot between calibration survey points and LiDAR data

Table 16. Calibration Statistical Measures

Calibration Statistical Measures	Value (meters)
Height Difference	0.75
Standard Deviation	0.18
Average	0.73
Minimum	0.26
Maximum	2.26

A total of 2,100 survey points lie within Amro floodplain and were used for the validation of the calibrated Amro DTM. A good correlation between the calibrated mosaicked LiDAR elevation values and the ground survey elevation, which reflects the quality of the LiDAR DTM is shown in Figure 27. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.17 meters with a standard deviation of 0.17 meters, as shown in Table 17.

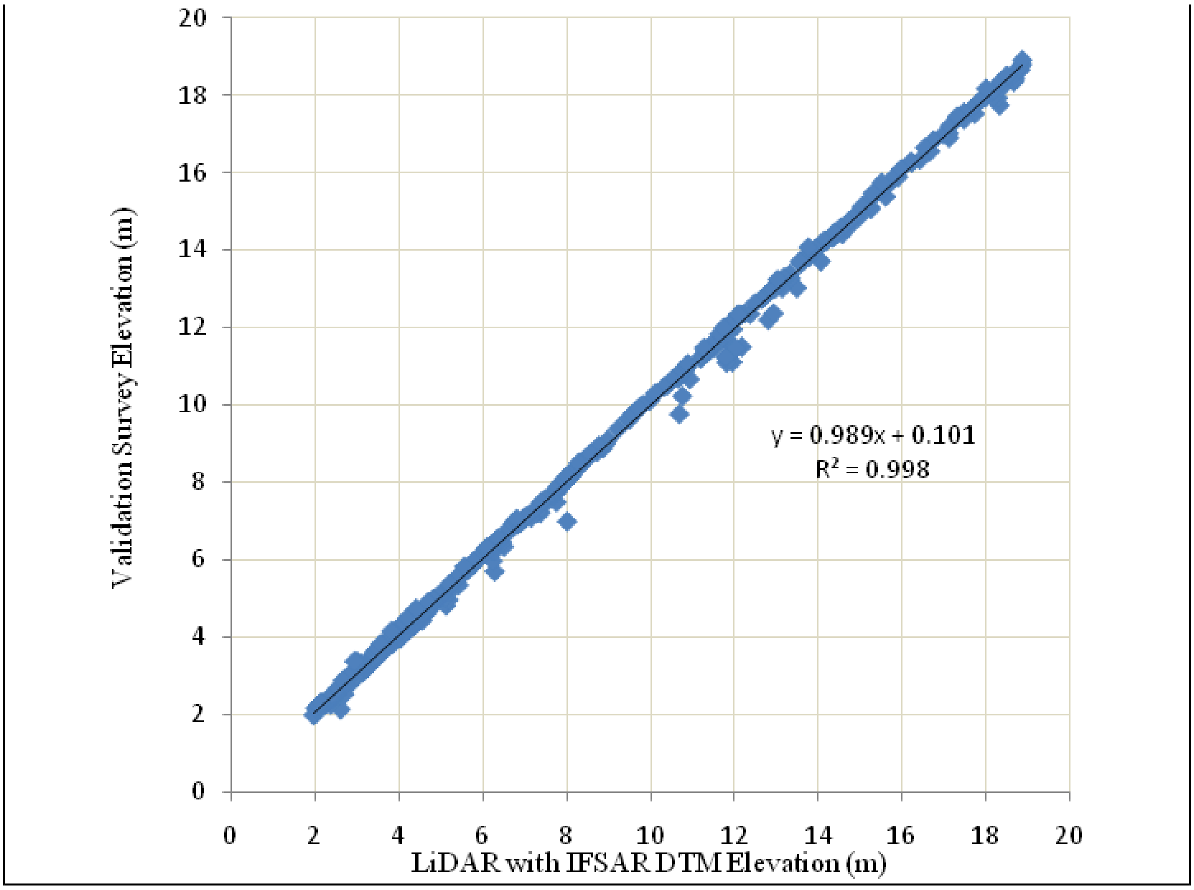

Figure 27. Correlation plot between validation survey points and LiDAR data

Table 17. Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.17
Standard Deviation	0.17
Average	-0.02
Minimum	-0.42
Maximum	1.04

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, zigzag and centerline data were available for Amro with 947 bathymetric survey points. The resulting raster surface produced was done by Inverse Distance Weighted (IDW) interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.07 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Amro integrated with the processed LiDAR DEM is shown in Figure 28.

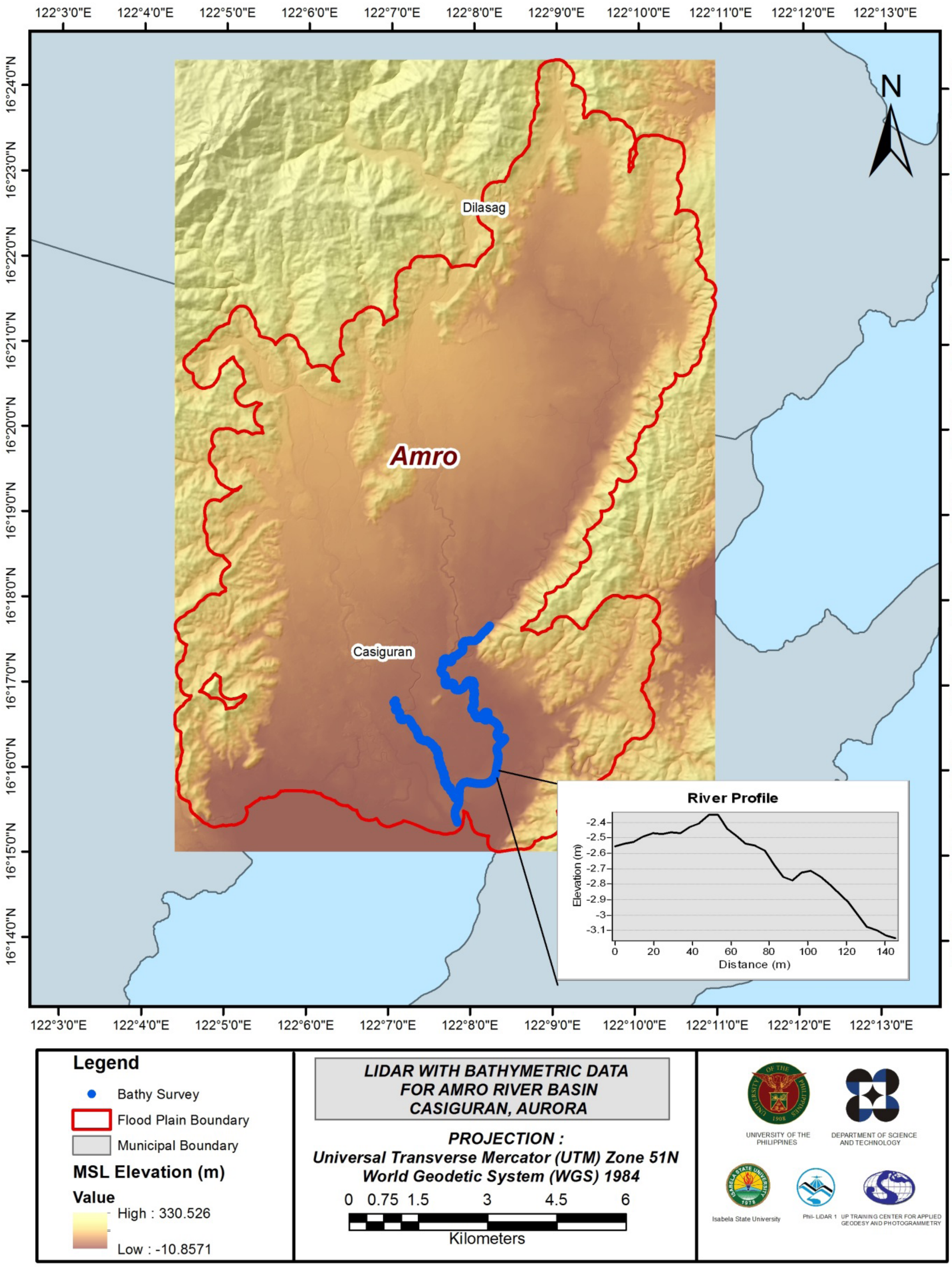

Figure 28. Map of Amro Floodplain with bathymetric survey points shown in blue

3.12 Feature Extraction

The features salient in flood hazard exposure analysis include buildings, road networks, bridges and water bodies within the floodplain area with 200 m buffer zone. Mosaicked LiDAR DEM with 1 m resolution was used to delineate footprints of building features, consist of residential buildings, government offices, medical facilities, religious institutions, and commercial establishments, among others. Road networks, comprised 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

The Amro Floodplain, including its 200 m buffer, has a total area of 120.99 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 547 building features, are considered for QC. Figure 29 shows the QC blocks for Amro Floodplain.

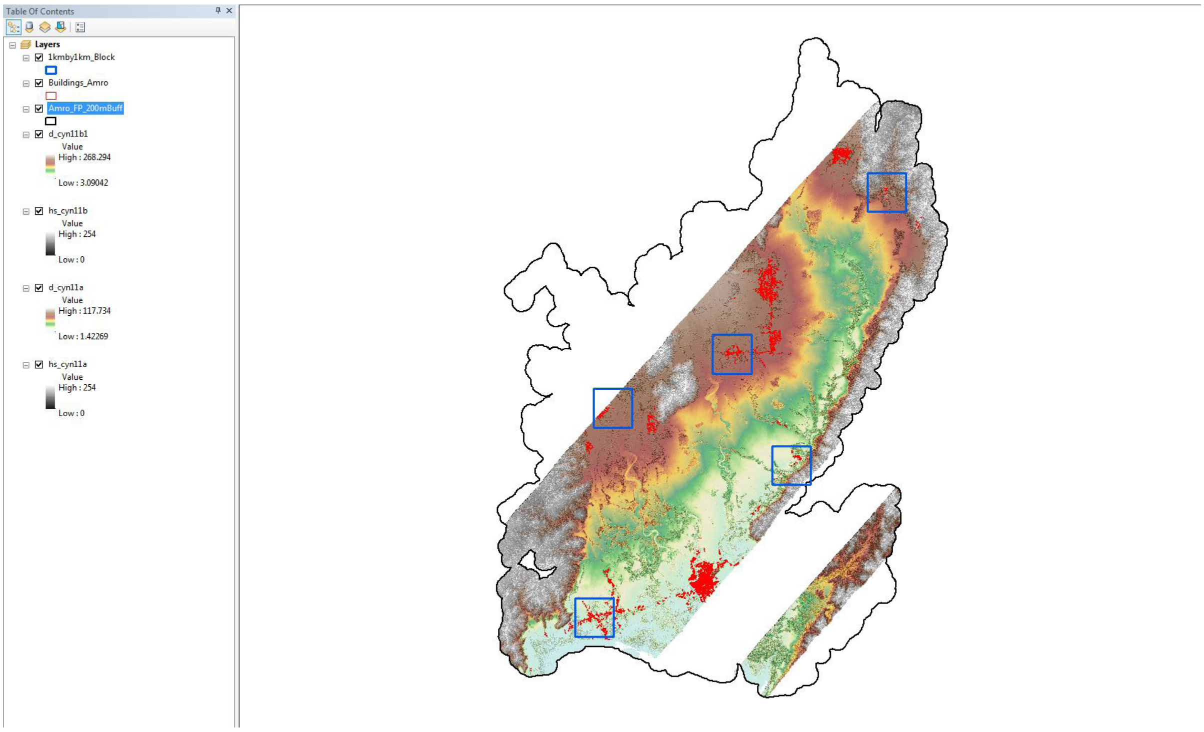

Figure 29. QC blocks for Amro building features

Quality checking of Amro building features resulted in the ratings shown in Table 18.

Table 18. Quality Checking Ratings for Amro Building Features.

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Amro	99.64	100.00	98.54	PASSED

3.12.2 Height Extraction

Height extraction was done for 4,063 building features in Amro Floodplain. Of these building features, 467 were filtered out after height extraction, resulting to 3,596 buildings with height attributes. The lowest building height is at 2.00m, while the highest building is at 4.97 m.

3.12.3 Feature Attribution

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

Table 19 summarizes the number of building features per type. On the other hand, Table 20 shows the total length of each road type, while Table 21 shows the number of water features extracted per type.

Table 19. Building Features Extracted for Amro Floodplain

Facility Type	No. of Features
Residential	3285
School	92
Market	0
Agricultural/Agro-Industrial Facilities	4
Medical Institutions	10
Barangay Hall	16
Military Institution	0
Sports Center/Gymnasium/Covered Court	2
Telecommunication Facilities	2
Transport Terminal	0
Warehouse	3
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	1
Water Supply/Sewerage	1
Religious Institutions	11
Bank	2
Factory	0
Gas Station	0
Fire Station	0
Other Government Offices	26
Other Commercial Establishments	141
Total	**3,596**

Table 20. Total Length of Extracted Roads for Amro Floodplain

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Amro	51.41	9.81	28.3	5.48	0	**95**

Table 21. Number of Extracted Water Bodies for Amro Floodplain

Floodplain	**Water Body Type**					**Total**
	Rivers/ Streams	Lakes/ Ponds	Sea	Dam	Fish Pen	
Amro	27	0	0	0	30	**57**

A total of 19 bridges and culverts over small channels that are part of the river network were also extracted for the floodplain.

3.12.4 Final Quality Checking of Extracted Features

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

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

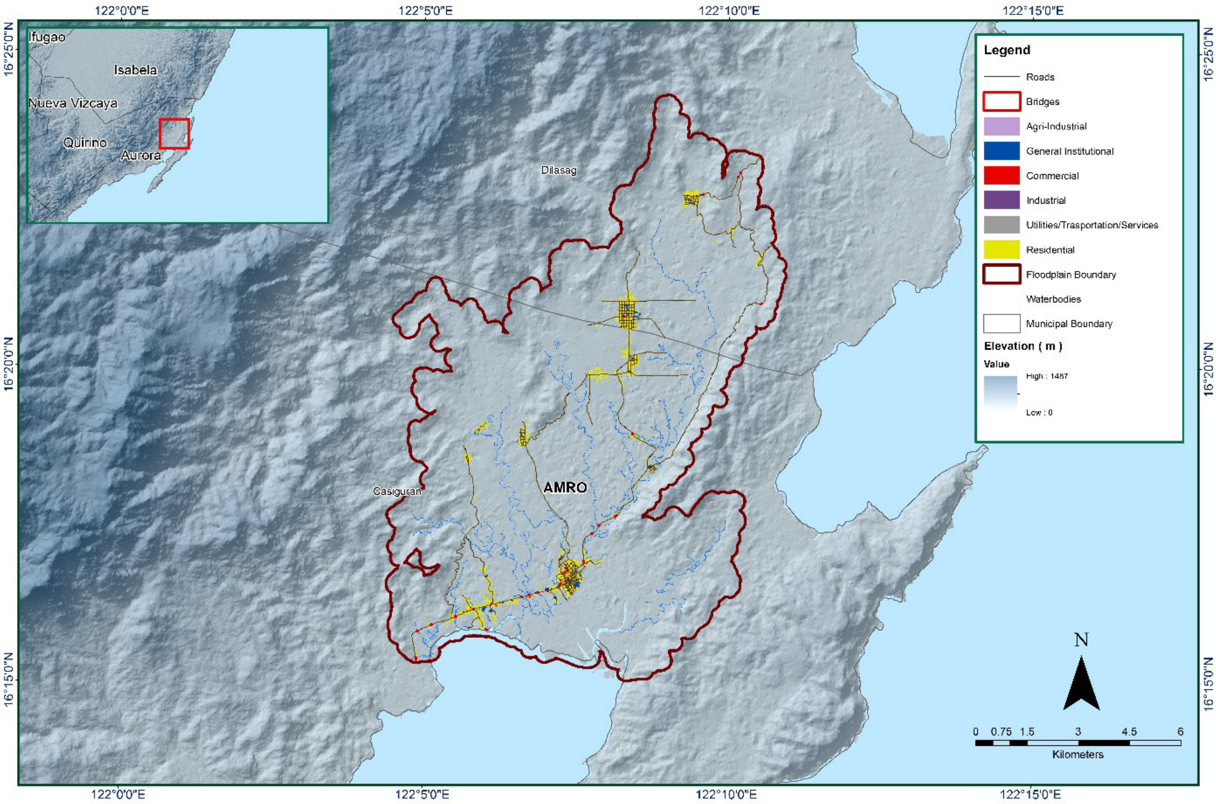

Figure 30. Extracted features for Amro Floodplain

CHAPTER 4 LIDAR VALIDATION SURVEY AND MEASUREMENT OF THE AMRO RIVER BASIN

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

4.1 Summary of Activities

DVBC conducted a field survey in Casalugan and Casiguran River on November 30 – December 14, 2016 with the following scope of work: reconnaissance; control survey; cross-section and as-built survey at Casiguran Bridge in Brgy. 8, Casiguran, Aurora and Casalugan Bridge in Barangay Culat, Casiguran, Aurora; validation points acquisition of about 25 km in the municipality of Casiguran, Aurora; and bathymetric survey from its upstream in Brgy. Culat to the mouth of the river located in Brgy. Lual with an approximate length of 7.631 km for Casalugan River and 2.929 km for Casiguran River using Ohmex™ single beam echo sounder and Trimble ® SPS 882 GNSS PPK survey technique.

4.2 Control Survey

The GNSS network used for Amro River Basin is composed of three (3) loopsestablished on December 9 and 13, 2016, occupying the reference points: ARA-27, a 2nd order NAMRIA GCP in Brgy. Calabgan, Municipality of Casiguran, Aurora; QRN-40, a 2nd order NAMRIA GCP in Brgy. Sangbay, Municipality of Nagtipunan, Quirino; and,AU-166, a 1st order BM located at the approach of Disulon Bridge in Brgy. Tinib, Municipality of Casiguran, Aurora.

The Control points were established namely UP-CAS-1 located at the approach of Casiguran Bridge in Barangay 8, Municipality of Casiguran, Aurora; and, UP-CAS-2 located at the approach of Casalugan Bridge in Brgy. Culat, Municipality of Casiguran, Aurora. These established points were also occupied to use as markers for the survey.

The summary of reference and control points and its location is summarized in Table 22 while the GNSS network established is illustrated in Figure 31.

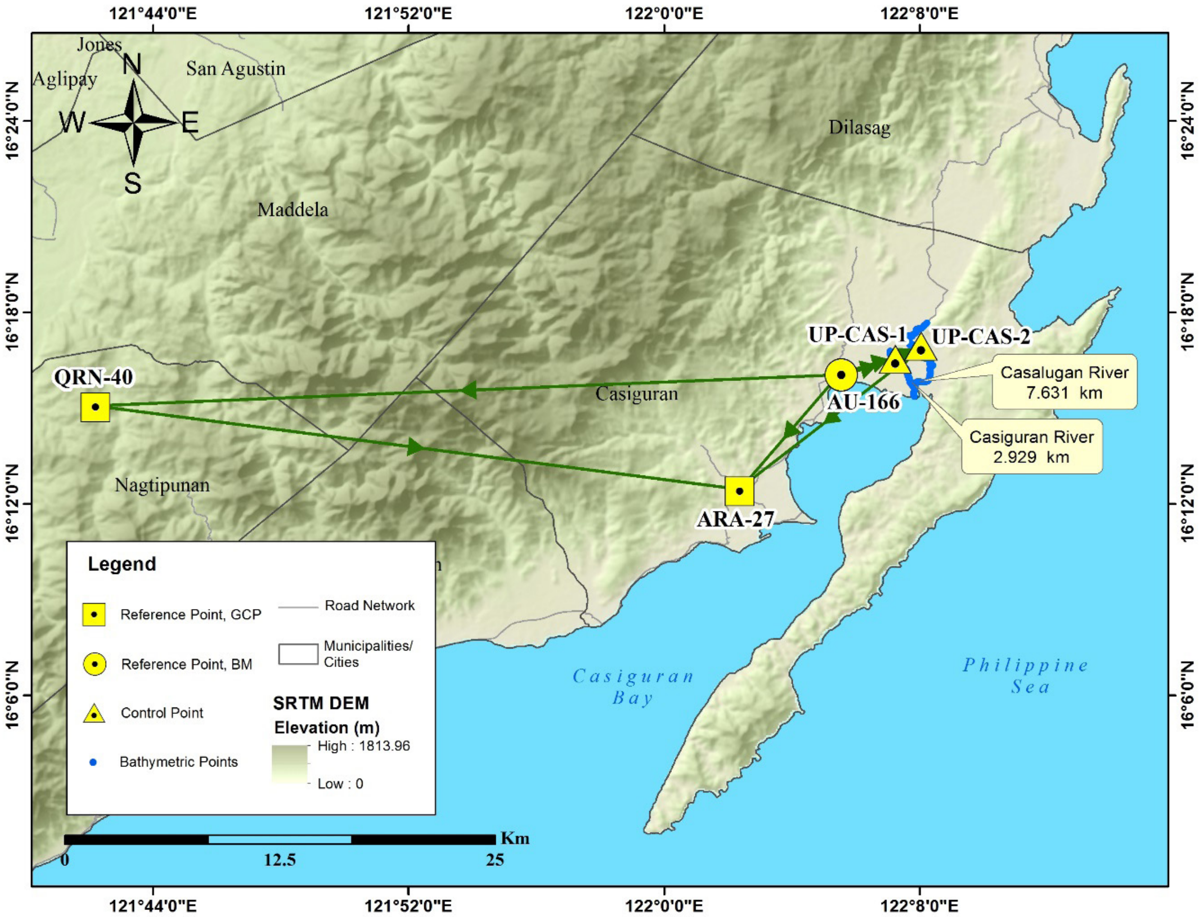


Figure 31. Amro River Basin Control Survey Extent

Table 22.List of Reference and Control Points occupied for Amro River Survey

(Source: NAMRIA; UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (m)	MSL Elevation (m)	Date of Estab-lishment
Control Survey on December 13, 2016						
ARA-27	2nd Order, GCP	16°12’24.15469”	122°02’22.25588”	59.173	-	12-9-16
QRN-40	2nd Order, GCP	16°15’02.32851”	121°42’11.92719”	498.995	453.98	12-9-16
AU-166	1st Order, BM	-	-	47.590	4.61	-
UP-CAS-1	UP estab-lished	-	-	47.752	-	12-13-16
UP-CAS-2	UP estab-lished	-	-	47.632	-	12-13-16

The GNSS set-ups on recovered reference points and established control points in Casiguran and Casalugan Rivers are shown in Figures 32 to 37.

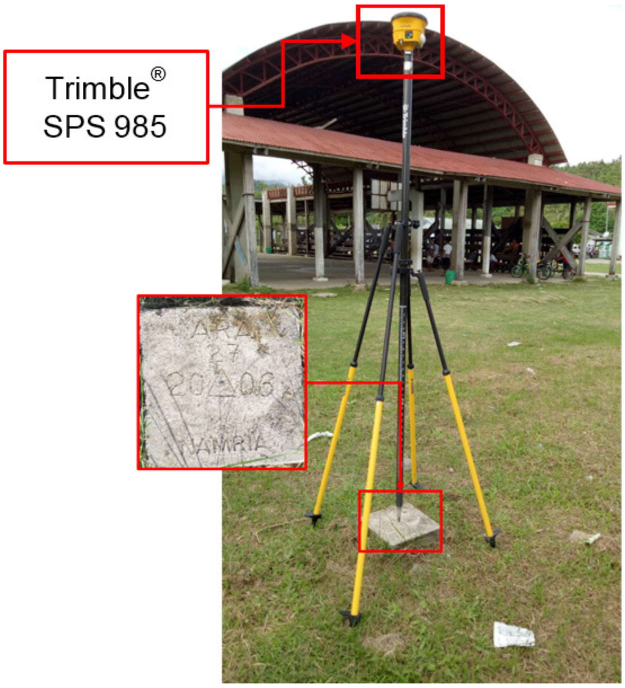


Figure 32.GNSS receiver setup, Trimble® SPS 985, at ARA-27, locatedwithin the grounds of Binaoan Barangay Hall in Brgy. Binaoan, Municipality of Casiguran, Aurora

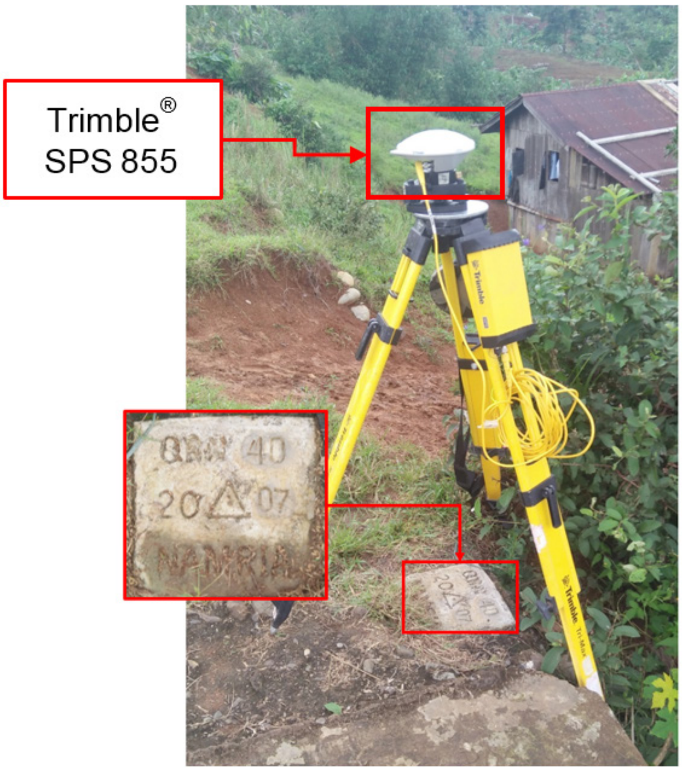


Figure 33. GNSS base set up, Trimble® SPS 855, at QRN-40, locatedin Brgy. Sangbay, Municipality of Nagtipunan, Quirino

Figure 34. GNSS receiver setup, Trimble® SPS 985 at AU-166, located at the approach of Disulon Bridge in Brgy. Tinib, Municipality of Casiguran, Aurora

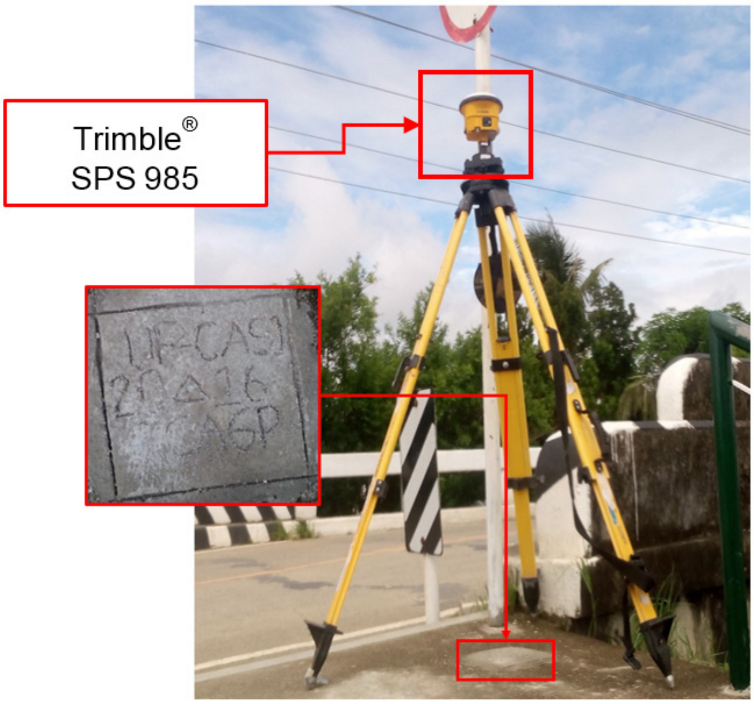


Figure 35. GNSS receiver setup, Trimble® SPS 985, at UP-CAS-1, locatedat the approach of Casiguran Bridge in Barangay 8, Municipality of Casiguran, Aurora

Figure 36. GNSS receiver setup, Trimble® SPS 882, at UP-CAS-2, located at the approach of Casalugan Bridge in Brgy. Culat, Municipality of Casiguran, Aurora

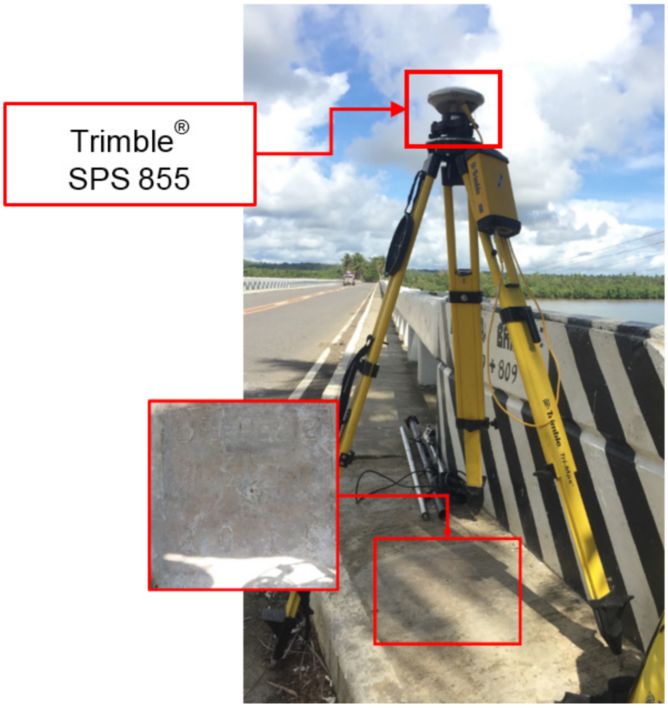


Figure 37. GNSS receiver setup, Trimble® SPS 855, at UP-ULO-2, located at the approach of Casalugan Bridge in Brgy. Culat, Municipality of Casiguran, Aurora

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 Amro River Basin is summarized in Table 23 generated by TBC software.

Table 23. Baseline Processing Summary Report for Amro River Survey

Obser-vation	Date of Obser-vation	Solution Type	H.Prec. (Meter)	V.Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	Height (Meter)
AU-166 --- QRN-40 (B10)	12-9-16	Fixed	0.003	0.014	267°30’37”	41629.652	451.360
AU-166 --- ARA-27 (B7)	12-9-16	Fixed	0.003	0.013	220°06’31”	8773.847	11.543
AU-166 --- ARA-27 (B11)	12-9-16	Fixed	0.003	0.013	220°06’31”	8773.865	11.577
AU-166 --- UP-CAS-2 (B8)	12-13-16	Fixed	0.002	0.010	69°17’17”	4765.078	0.016
AU-166 --- UP-CAS-2 (B15)	12-13-16	Fixed	0.003	0.014	69°17’17”	4765.078	0.052
AU-166 --- UP-CAS-1 (B13)	12-13-16	Fixed	0.003	0.012	73°00’31”	3166.392	0.185
QRN-40 --- ARA-27 (B12)	12-9-16	Fixed	0.003	0.013	97°39’31”	36270.685	-439.791
UP-CAS-2 --- ARA-27 (B9)	12-13-16	Fixed	0.003	0.014	230°18’10”	13141.223	11.533
UP-CAS-1 --- UP-CAS-2 (B14)	12-13-16	Fixed	0.002	0.004	62°00’08”	1618.457	-0.117

As shown Table23 a total of nine (9) baselines were processed withcoordinate and elevation values of ARA-27, QRN-40, and AU-166 held fixed. All of them passed the required accuracy.

4.4 Network Adjustment

After the baseline processing procedure, network adjustment was performed using TBC. Looking at the Adjusted Grid Coordinates table of the TBC generated Network Adjustment Report, it was 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 Tables 24 to 27 for complete details.

The two (2) control points, UP-CAS-1 and UP-CAS-2 were occupied and observed simultaneously to form a GNSS loop. Coordinates of ARA-27 and QRN-40; elevation value of AU-166 and QRN-40; and fixed values of ARA-27, QRN-40, and AU-166 were held fixed during the processing of the control points as presented in Table 24. Through these reference 22points, the coordinates and elevation of the unknown control points will be computed.

Table 24. Control Point Constraints

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
ARA-27	Global	Fixed	Fixed		
AU-166	Grid				Fixed
QRN-40	Grid				Fixed
QRN-40	Global	Fixed	Fixed		
Fixed = 0.000001 (Meter)					

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 25. All fixed control points have no values for grid and elevation errors.

Table 25. Adjusted Grid Coordinates

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
ARA-27	397338.487	?	1792040.846	?	16.010	0.037	LL
QRN-40	361429.660	?	1797099.703	?	453.980	?	LLe
AU-166	403018.907	0.008	1798724.684	0.007	4.610	?	e
UP-CAS-1	406050.312	0.010	1799636.404	0.010	5.138	0.036	
UP-CAS-2	407482.188	0.009	1800389.860	0.009	5.171	0.034	

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

a. **ARA-27**

horizontal accuracy = Fixed

vertical accuracy = 3.7< 10 cm

b. **QRN-40**

horizontal accuracy = Fixed

vertical accuracy = Fixed

c. **AU-166**

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

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

= 1.06< 20 cm

vertical accuracy = Fixed

d. **UP-CAS-1**

horizontal accuracy = $\sqrt{((1.0)^2 + (1.0)^2}$

= $\sqrt{(1 + 1)}$

= 1.41< 20 cm

vertical accuracy = 3.6 < 10 cm

e. **UP-CAS-2**

horizontal accuracy = $\sqrt{((0.9)^2 + (0.9)^2}$

= $\sqrt{(0.81 + 0.81)}$

= 1.27< 20 cm

vertical accuracy = 3.4 < 10 cm

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

Table 26. Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Ellipsoid Height (Meter)	Height Error (Meter)	Constraint
ARA-27	N16°12’24.15469”	E122°02’22.25588”	59.173	0.037	LL
AU-166	N16°16’02.49218”	E122°05’32.56323”	47.590	?	e
QRN-40	N16°15’02.32851”	E121°42’11.92719”	498.995	?	LLe
UP-CAS-1	N16°16’32.59118”	E122°07’14.55483”	47.752	0.036	
UP-CAS-2	N16°16’57.30823”	E122°08’02.68747”	47.632	0.034	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 26. 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 27.

Table 27. Reference and control points used and its location (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellip-soidal Height (m)	Northing	Easting	BM Ortho (m)
ARA-27	2nd Order, GCP	16°12’24.15469”	122°02’22.25588”	59.173	1792040.846	397338.487	16.01
QRN-40	2nd Order, GCP	16°15’02.32851”	121°42’11.92719”	498.995	1797099.703	361429.660	453.98
AU-166	1st Order, BM	16°16’02.49218”	122°05’32.56323”	47.590	1798724.684	403018.907	4.61
UP-CAS-1	UP estab-lished	16°16’32.59118”	122°07’14.55483”	47.752	1799636.404	406050.312	5.138
UP-CAS-2	UP estab-lished	16°16’57.30823”	122°08’02.68747”	47.632	1800389.860	407482.188	5.171

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

Cross-section and as-built surveys were conducted on December 11, 2016 at the downstream side of Casiguran bridge in Barangay 8, Municipality of Casiguran, Aurora; and, on the same day, at the down-stream side of Casalugan Bridge in Brgy. Culat, Municipality of Casiguran, Aurora as shown in Figure 38. A survey grade GNSS receiver Trimble® SPS 985 in PPK survey technique was utilized for this survey as shown in Figure 39 and Figure 40.

Figure 38. Casalugan Bridge facing upstream

Figure 39. As-built survey of Casiguran Bridge

Figure 40. As-built survey of Casalugan Bridge

The cross-sectional line of Casiguran Bridge is about 64.452 m with thirty seven (37) cross-sectional points, using the control point UP-CAS-2; while, the cross-sectional line of Casalugan Bridge is about 65.129 m with twenty seven (27) cross-sectional points, using the control point UP-CAS-2 as GNSS base stations. The cross-section diagrams, location map, and the bridge data forms are shown in Figures 41 to 46, respectively.

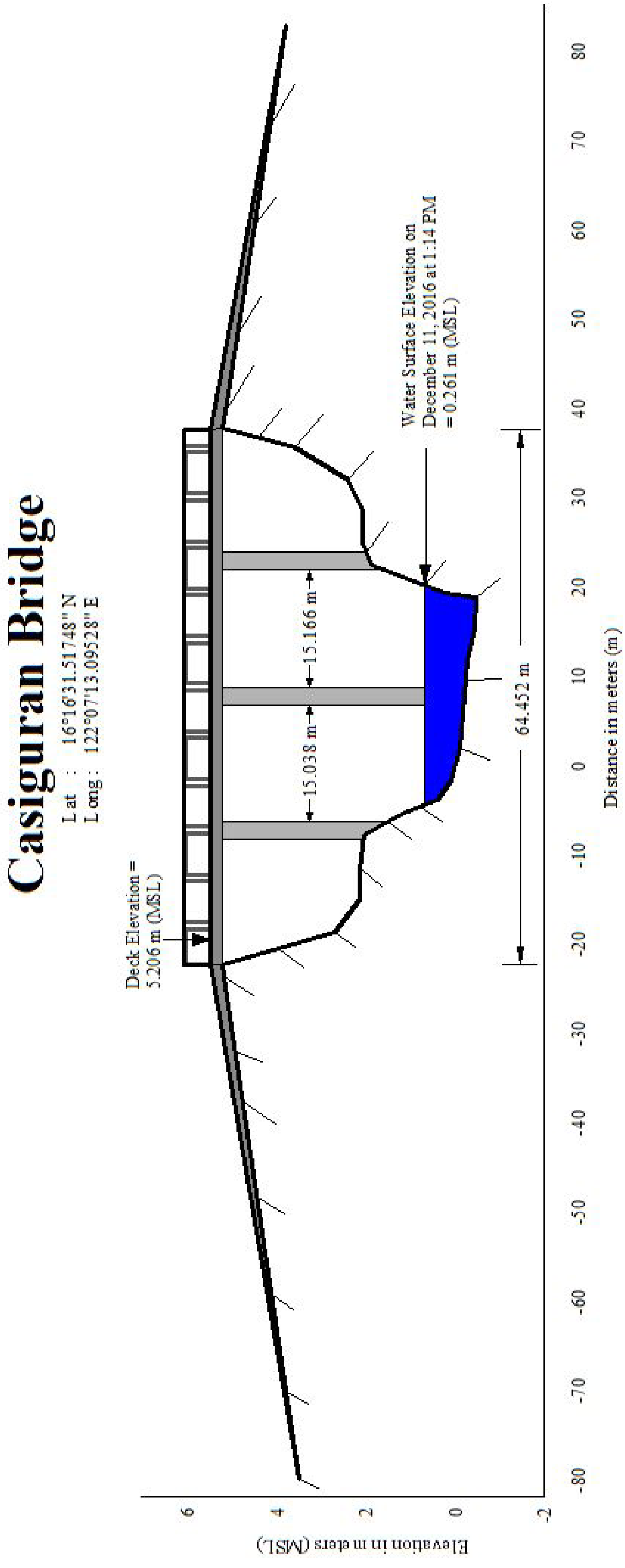


Figure 41. Casiguran Bridge cross-section diagram

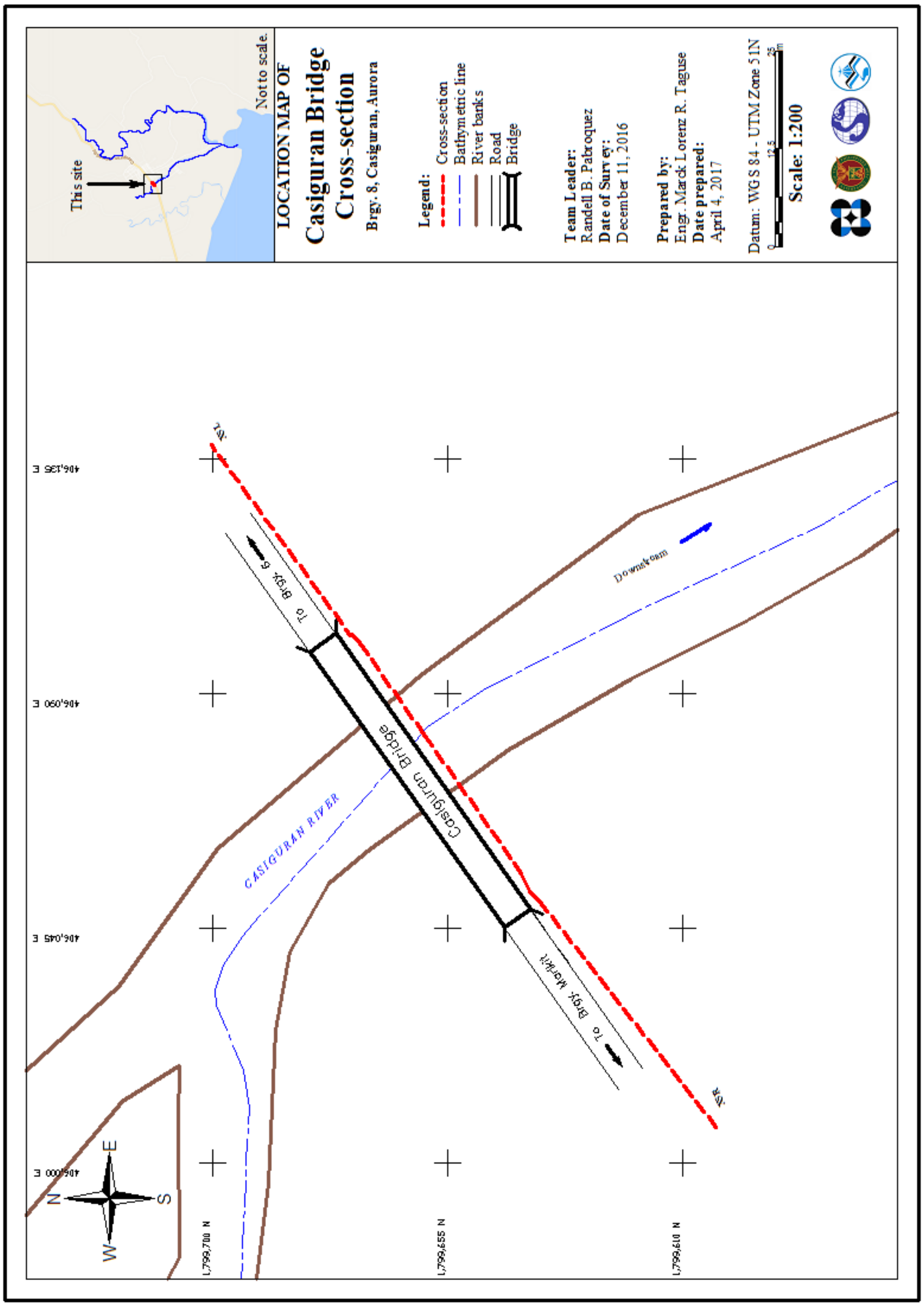


Figure 42. Location Map of Casiguran Bridge Cross-Section Survey

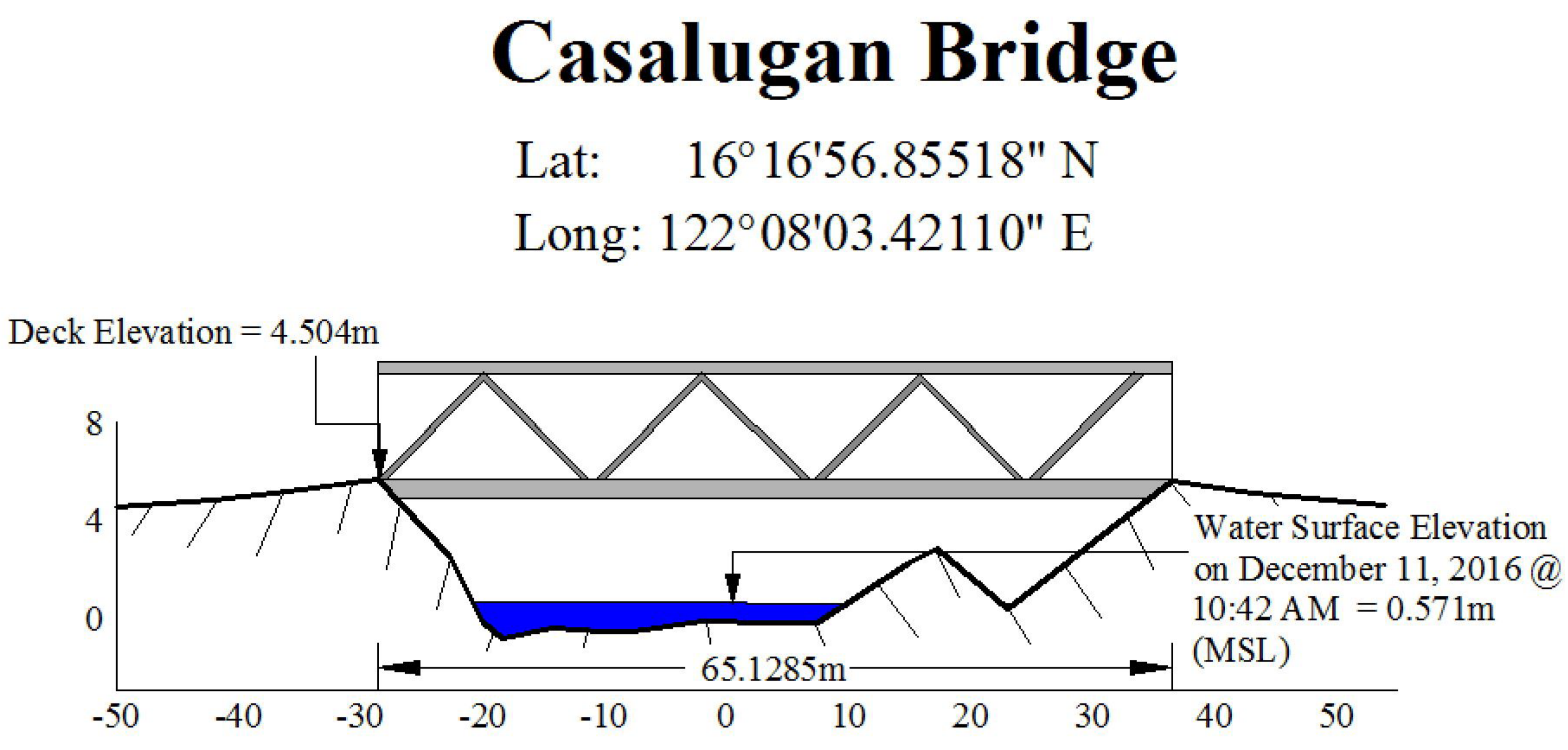


Figure 43. Casalugan Bridge cross-section diagram

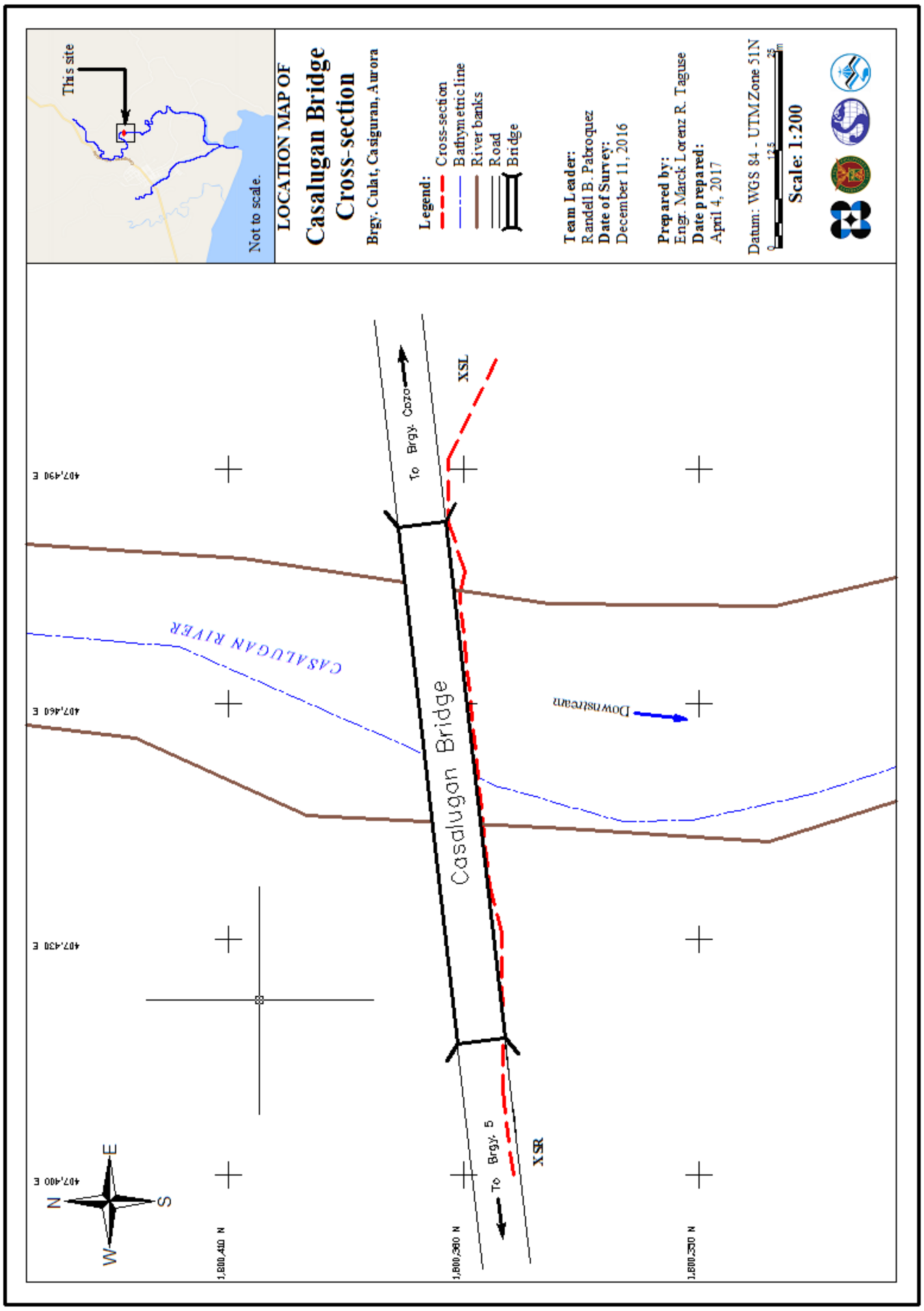
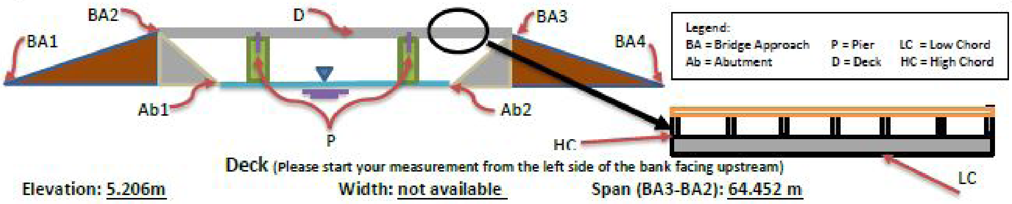


Figure 44. Casalugan River planimetric map

Bridge Data Form

Bridge Name: Casiguran Bridge	Date: December 11, 2016
River Name: Amro-Casiguran River	Time: 01:14 PM
Location (Brgy, City,Region): Brgy. 8, Casiguran, Aurora	
Survey Team: Randell Pabroquez, Janina Jupiter	
Flow condition: average	Weather Condition: fair
Latitude: 16°16'31.51748"N	Longitude: 122°07'13.09528"E



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

Elevation: 5.206m   Width: not available   Span (BA3-BA2): 64.452 m

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

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

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	0	3.460 m	BA3	119.528 m	5.117 m
BA2	55.076 m	5.113 m	BA4	162.801 m	3.754 m

Abutment: Is the abutment sloping? ; If yes, fill in the following information:

	Station (Distance from BA1)	Elevation
NA	Not Available	Not Available

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

Shape: round   Number of Piers: 3   Height of column footing: Not available

	Station (Distance from BA1)	Elevation	Pier Diameter
Pier 1	72.585 m	5.210 m	
Pier 2	87.623 m	5.203 m	
Pier 3	102.788 m	5.137 m	

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

DREAM
Disaster Risk and Exposure Assessment for Mitigation

Figure 45. Bridge as-built form of Casiguran Bridge

Bridge Data Form

Bridge Name: Casalugan Bridge — Date: December 11, 2016

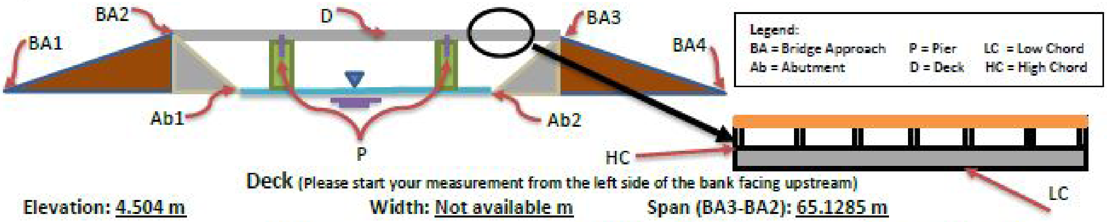
River Name: Casalugan River — Time: 10:42 AM

Location (Brgy, City,Region): Brgy. Culat, Municipality of Casiguran, Aurora

Survey Team: Randell Pabroquez, Janina Jupiter

Flow condition: normal — Weather Condition: fair

Latitude: 16°16'56.85518" N — Longitude: 122°08'03.42110" E



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

Elevation: 4.504 m — Width: Not available m — Span (BA3-BA2): 65.1285 m

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

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

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	0	4.504 m	BA3	86.510 m	5.553 m
BA2	21.421 m	5.618 m	BA4	93.161 m	5.082 m

Abutment: Is the abutment sloping? Yes; If yes, fill in the following information:

	Station (Distance from BA1)	Elevation
Ab1	24.465	4.095
Ab2	24.807	3.357
Ab3	82.529	3.989
Ab4	82.646	1.048

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

Shape: N/A — Number of Piers: N/A — Height of column footing: N/A

	Station (Distance from BA1)	Elevation	Pier Diameter
Pier 1	Not available	Not available	Not available

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

DREAM
Disaster Risk and Exposure Assessment for Mitigation

Figure 46. Bridge as-built form of Casalugan Bridge

Water surface elevation of Casiguran River was determined by a survey grade GNSS receiver Trimble® SPS 985 in PPK survey technique on December 11, 2016 at 1:14 PM at Casiguran Bridge with a value of 0.261 m in MSL as shown in Figure 41. This was translated into marking on the bridge's deck as shown in Figure 47; furthermore, the water surface elevation of Casalugan River was determined by a survey grade GNSS receiver Trimble® SPS 985 in PPK survey technique on December 11, 2016 at 10:42 AM at Casalugan Bridge with a value of 0.571 m in MSL as shown in Figure 43. This was translated into marking on the bridge's deck as shown in Figure 48. The marking will serve as reference for flow data gathering and depth gauge deployment of the partner HEI responsible for Casiguran and Casalugan Rivers, the Isabela State University.

Figure 47. Water-level markings onCasiguran Bridge

Figure 48. Water-level markings on Casalugan Bridge

4.6 Validation Points Acquisition Survey

The Validation Points Acquisition survey was conducted on December 11, 2016 using a survey-grade GNSS Rover receiver, Trimble® SPS 985, mounted in frontof a vehicle as shown in Figure 49. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The antenna heightwas 1.945m and measured from the ground up to the bottom of notch of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with UP-CAS-2 occupied as the GNSS base station in the conduct of the survey.

Figure 49. Validation Points Acquisition survey set up along Amro River Basin

The survey started in Barangay Culat, Municipality of Casiguran going southwest along national highway covering fourteen (14)barangays in the Municipality of Casiguran which ended in Brgy. Calabgan, Municipality of Casiguran, Aurora. A total of 4,599 points with approximate length of 25 km using UP-CAS-2 as GNSS base station for the entire extent validation points acquisition survey as illustrated in the map in Figure 50.

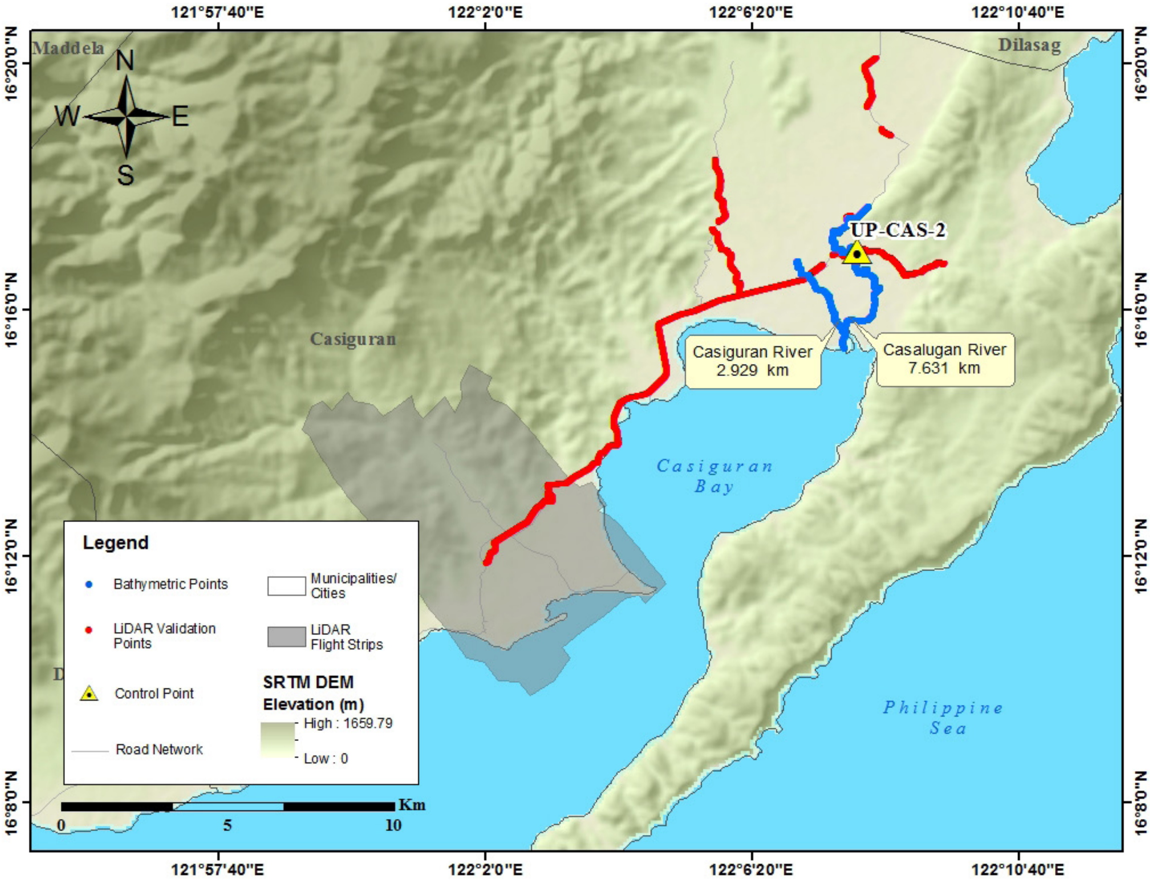


Figure 50. Validation Point Acquisition survey of Amro River Basin

4.7 River Bathymetric Survey

Bathymetric survey for both Casiguran and Casalugan Rivers were executed on December 10, 2016 using Trimble® SPS 882 in GNSS PPK survey technique in continuous topo mode as illustrated in Figure 51. The bathymetric survey for Casiguran River started in Brgy, Culat, Municipality of Casiguran with coordinates 16°17'40.52002"N, 122°08'13.44121"E, traversed down the river by boat and ended at the mouth of the river in Brgy. Lual, Municipality of Casiguran, Aurora with coordinates 16°15'21.94062"N, 122°07'50.49745"E; meanwhile, the bathymetric survey for Casalugan River started in Barangay 1, Municipality of Casiguran with coordinates 16°16'47.69829"N, 122°07'04.90660"E, traversed down the river by boat as well, and ended at the mouth of the river in the same Barangay as Casiguran River. The control UP-CAS-2was used as GNSS base stations all throughout the entire survey.

Figure 51. Bathymetric survey using a Trimble® SPS 882 in GNSS PPK survey technique in Casiguran and Casalugan Rivers

The bathymetric survey for Casiguran River gathered a total of 3,211 points covering 2.929 km of the river traversing Barangay 1, Municipality of Casiguran, Aurora downstream to Brgy. Lual in the same Municipality; while, Casalugan River gathered a total of 7,716 points covering 7.631 km of the river traversing Brgy. Culat, Municipality of Casiguran, Aurora downstream to Brgy. Lual in the same Municipality.

A CAD drawing was also produced to illustrate the riverbed profile of Casiguran and Casalugan Rivers. As shown in Figures 53 and 54, the highest and lowest elevation has a 3.407-m difference for Casiguran River, and a 6.365-m difference for Casalugan River. The highest elevation observed was –0.19 m below MSL located at the upstream part of Casiguran river; while the lowest was –3.597 m below MSL located in the upstream portion. For Casalugan River, the highest elevation observed was –1.203 m below MSL located at the upstream part of the river; while the lowest was –7.883 m below MSL located in the downstream portion. A length of approximately 3 km in the upstream portion was not surveyed due to lack of communities present in the concerned area.

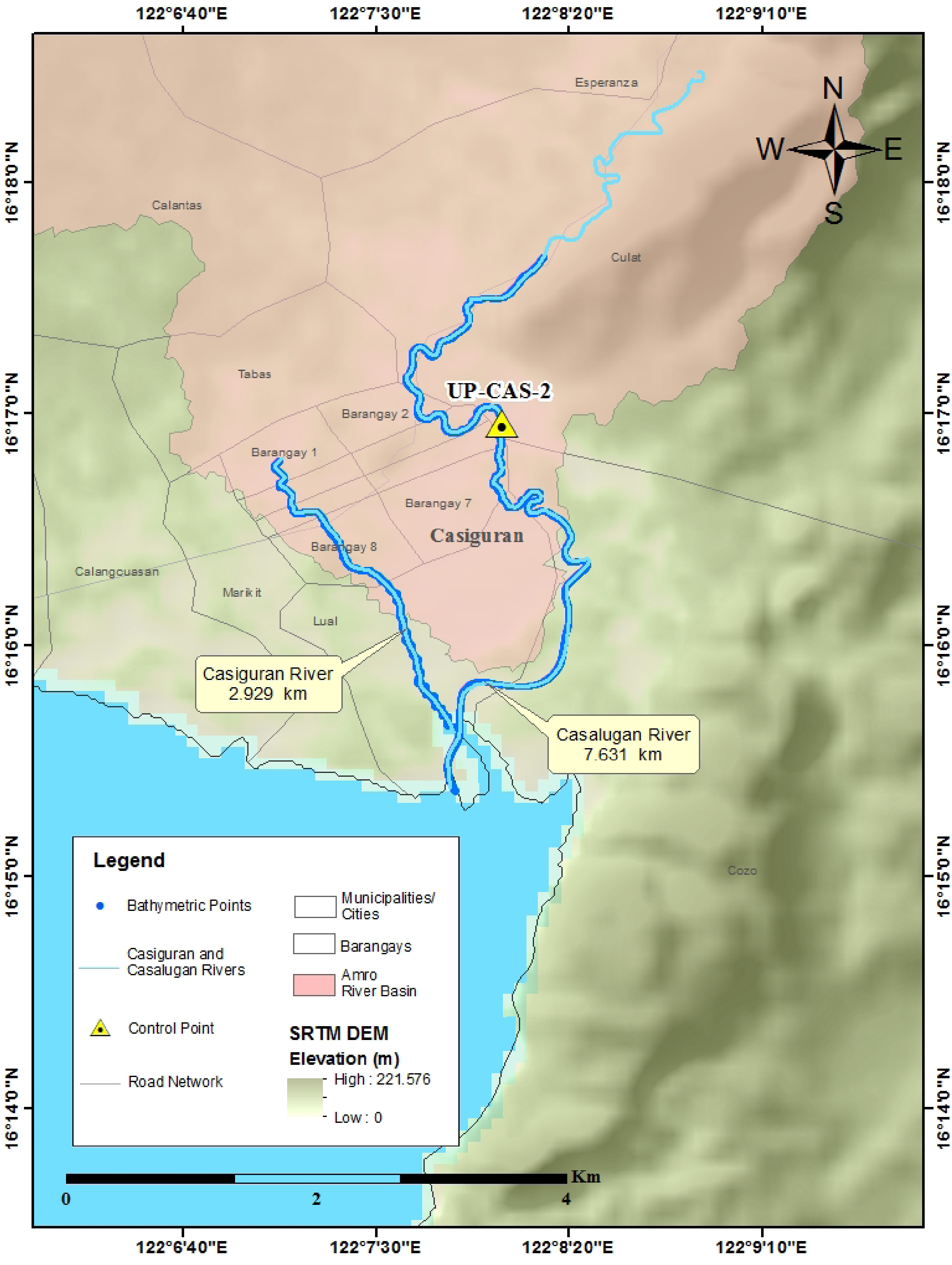


Figure 52. Bathymetric survey of Casiguran and Casalugan Rivers

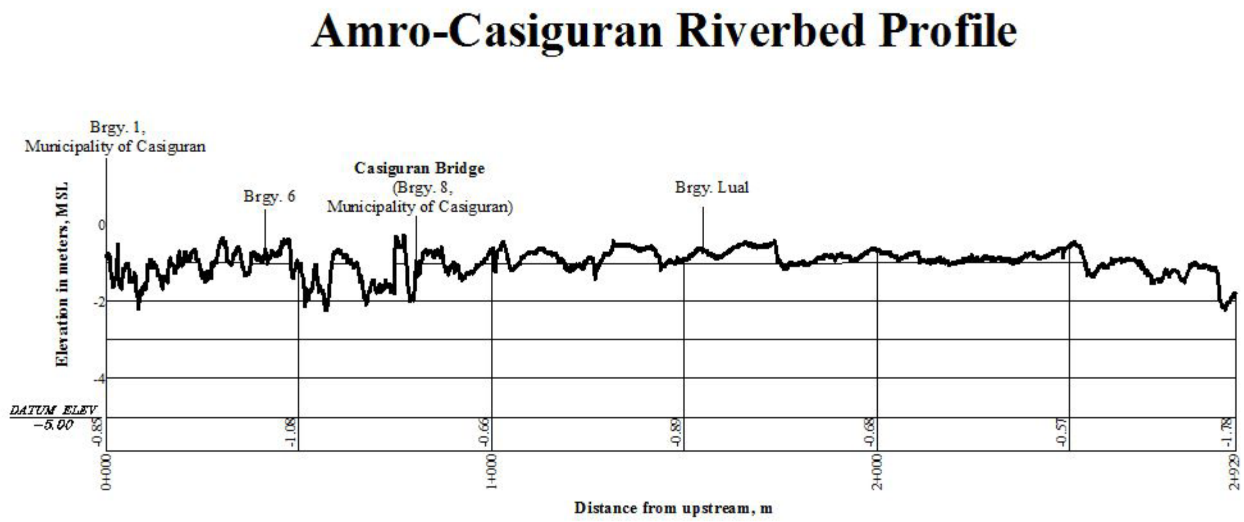


Figure 53. Casiguran Riverbed Profile

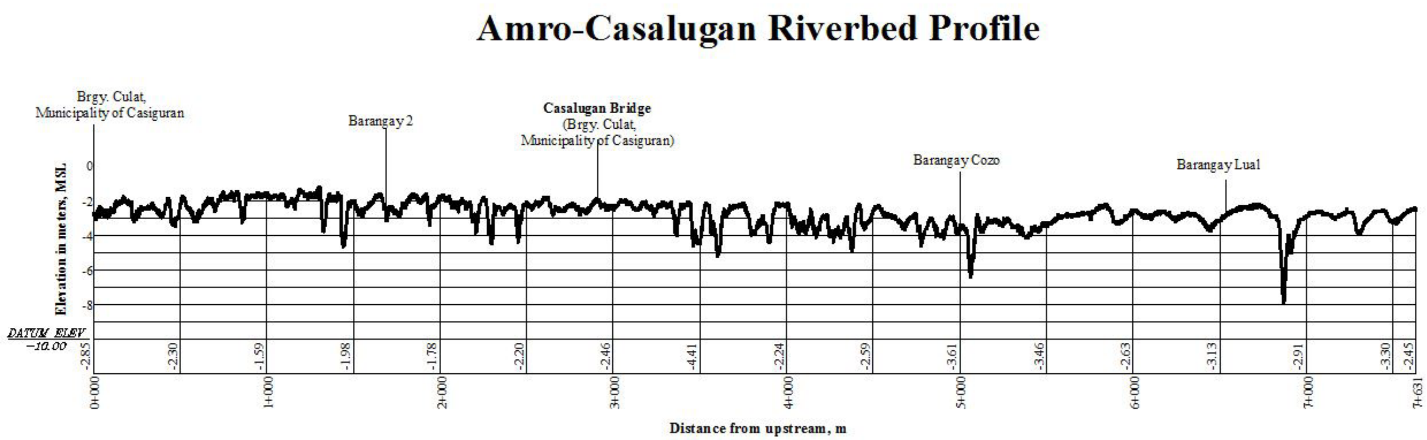


Figure 54. Casalugan Riverbed Profile

CHAPTER 5 FLOOD MODELING AND MAPPING

Dr. Alfredo Mahar Lagmay, Christopher Uichanco, Sylvia Sueno, Marc Moises, Hale Ines, Miguel del Rosario, Kenneth Punay, Neil Tingin, Mariel Monteclaro

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

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

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

5.1.2 Precipitation

Aurora, including the Amro River Basin, experienced long and heavy rain during the month of February 2017. The hydrologic data collection covered the period 7:00 P.M. on 01 February 2017 until 5:20 P.M. on 03 February 2017. Hydrologic data include the river velocity, water depth and rain collected from data logging sensors (mechanical velocity meter, depth gauge and rain gauges) in specific time period. Precipitation data was taken from the Portable Rain Gauge installed by ISU Phil – LiDAR1 since there is no Automatic Rain Gauge within the river basin. The location of the rain gauge is seen in Figure 65.

Total rain from the Portable Rain Gauge is 145.2 mm. It peaked to 5.2 mm. on 1 February 2017 7:30 P.M. The lag time between the peak rainfall and discharge is 1 day, 6 hours and 10 minutes. The location of rain gauge within the Amro River Basin is shown Figure 55.

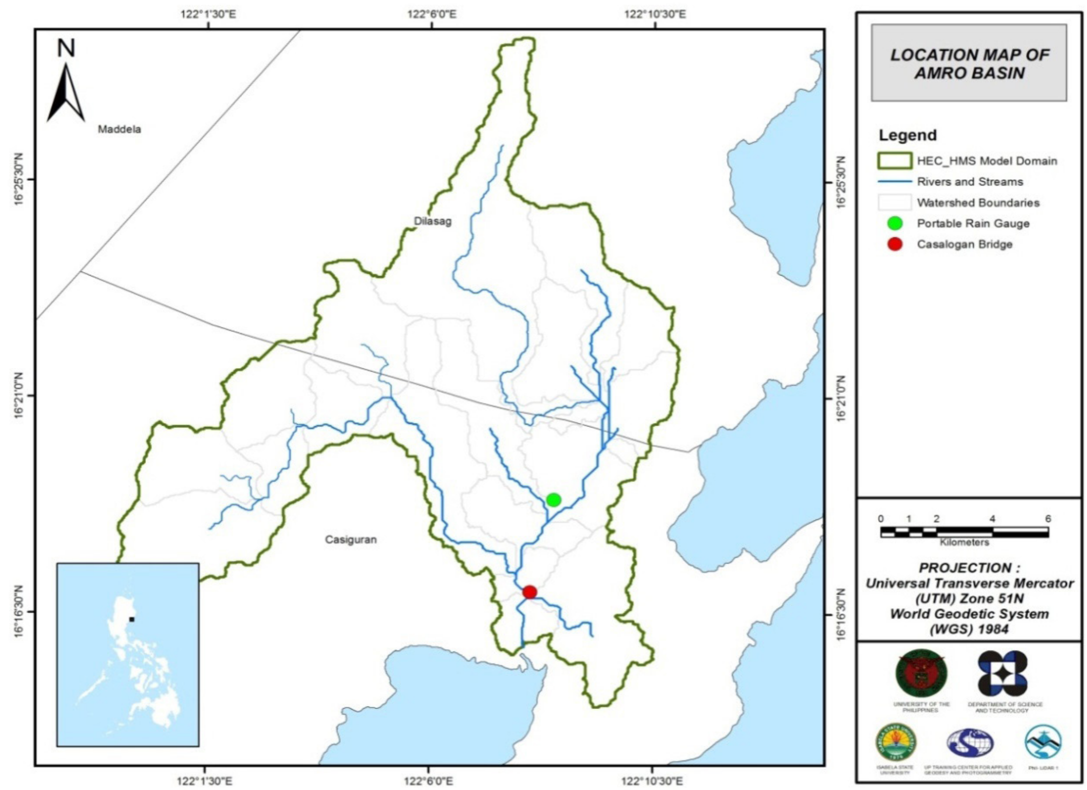


Figure 55. The location map of Alubijid HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

Monsoon rain that occurred on 01 – 03 February 2017 contributed to a 3.31 meter water level rise with peak discharge of 284.7 m^3/s recorded at 2:50 AM on 03 February 2017 with accumulated rainfall 145.2 mm. These hydrologic data is the actual event of Amro River and inputted to hydrologic modeling. Hydrologic measurements were taken from Casalogan Bridge, Casiguran, Aurora.

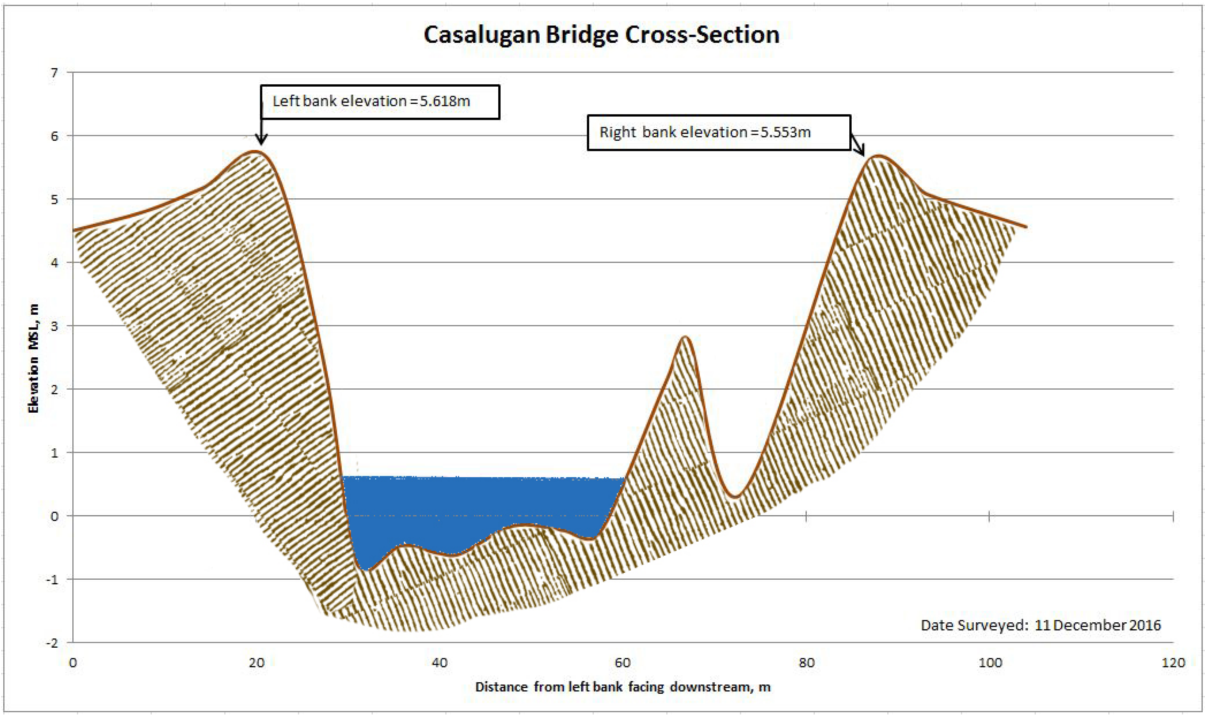


Figure 56. Cross-Section Plot of Casalugan Bridge

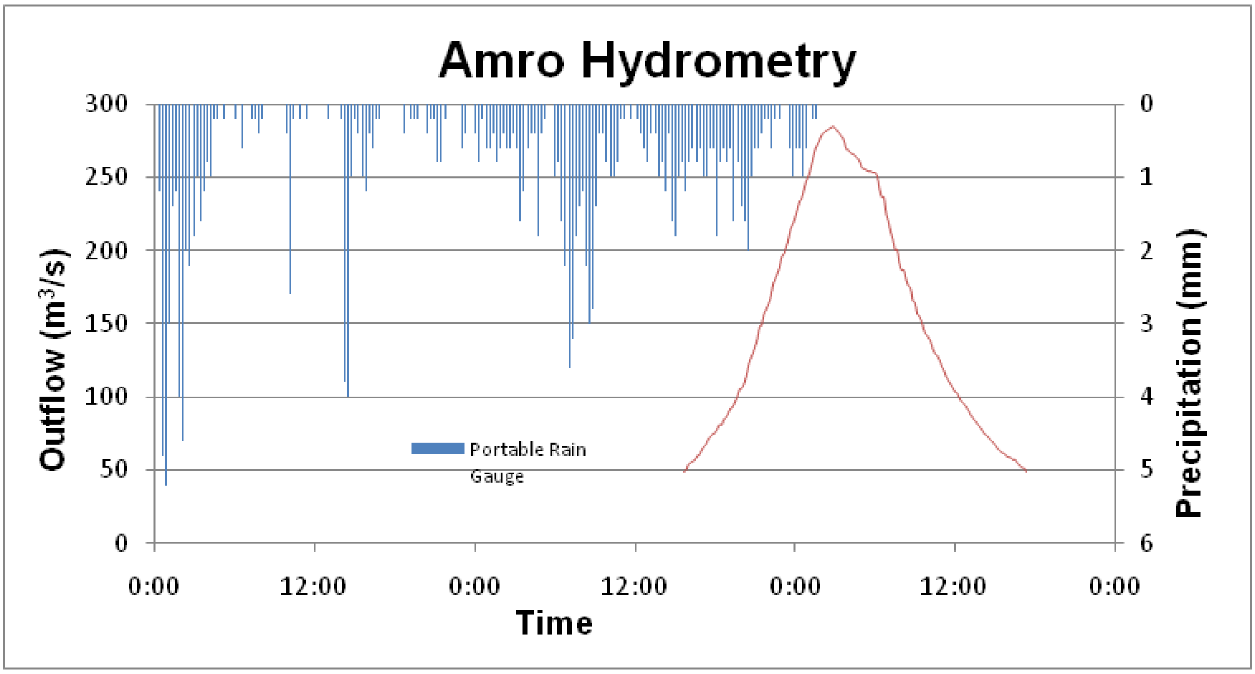


Figure 57. Rainfall and outflow data used for modeling

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

$$Q=a^{nh}$$

where, Q : Discharge (m^3/s),

h : Gauge height (reading from Alubijid Bridge depth gauge sensor), and

a and n : Constants.

The Amro River Rating Curve measured at Casalogan Bridge is expressed as $Q = 0.0032e^{3.4429x}$ (Figure 58).

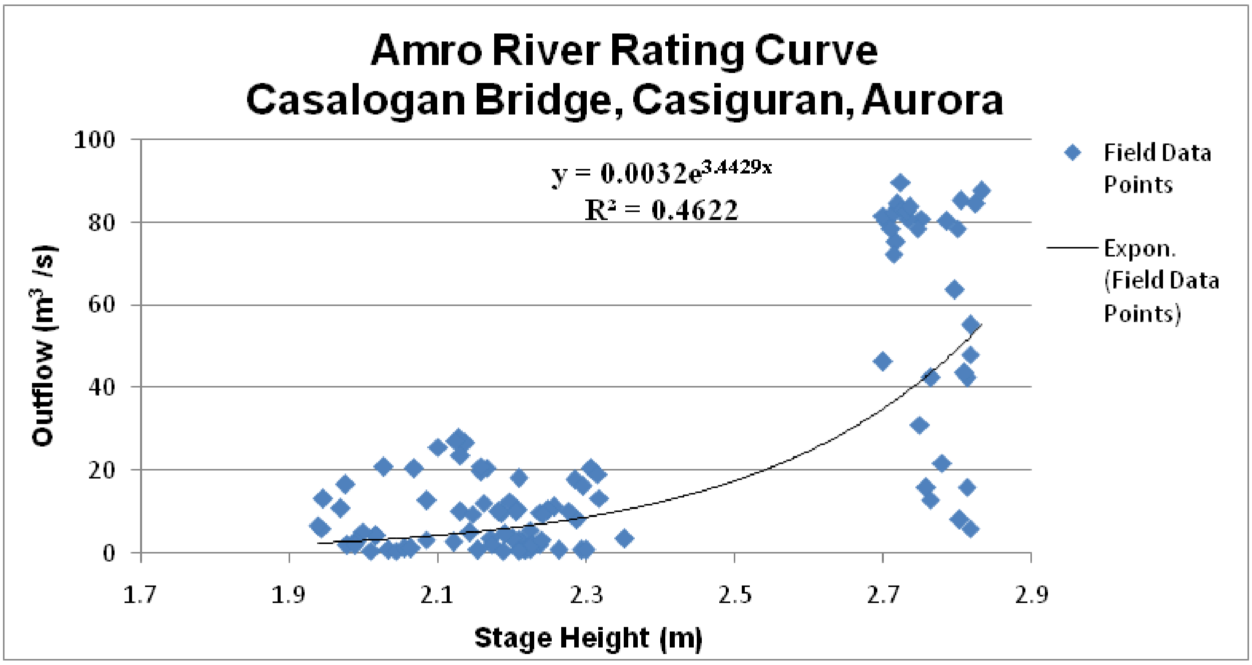


Figure 58. HQ Curve of HEC-HMS model

5.2 RIDF Station

The Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed for Rainfall Intensity Duration Frequency (RIDF) values for the Casiguran Rain Gauge. The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the values in such a way a certain peak value will be attained at a certain time. This station is chosen based on its proximity to the Amro watershed. The extreme values for this watershed were computed based on a 28-year record.

Table 28. RIDF values for Cagayan de Oro 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	21.2	31.9	40.6	59.4	82.3	98.7	122.7	151.4	179
5	27	39.3	50.3	76.1	116.1	139.9	167.1	201.7	245.6
10	30.9	44.2	56.8	87.2	138.5	167.2	196.4	235	289.8
15	33	46.9	60.4	93.5	151.1	182.6	213	253.8	314.7
20	34.6	48.8	62.9	97.8	159.9	193.4	224.6	266.9	332.1
25	35.7	50.3	64.9	101.2	166.7	201.7	233.5	277	345.5
50	39.3	54.9	70.9	111.6	187.7	227.3	261	308.2	386.9
100	42.9	59.4	76.9	121.9	208.5	252.7	288.4	339.2	427.9

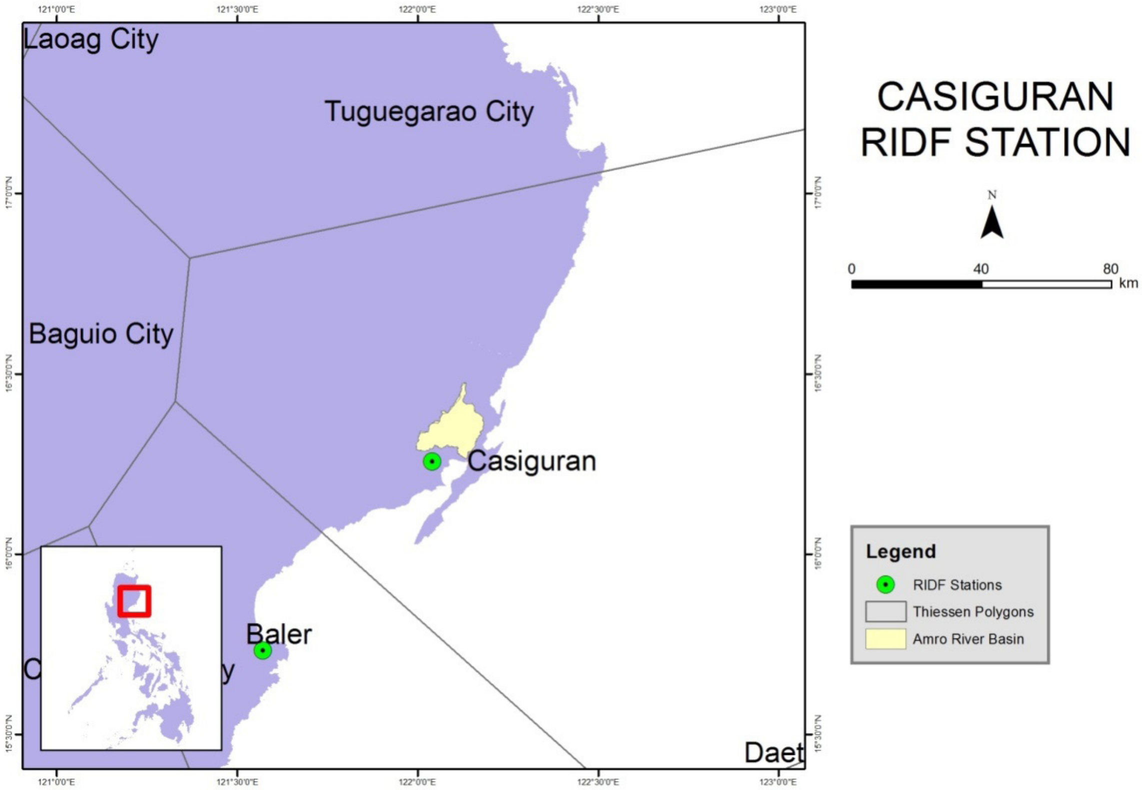


Figure 59. Location of Casiguran RIDF Station relative to Amro River Basin

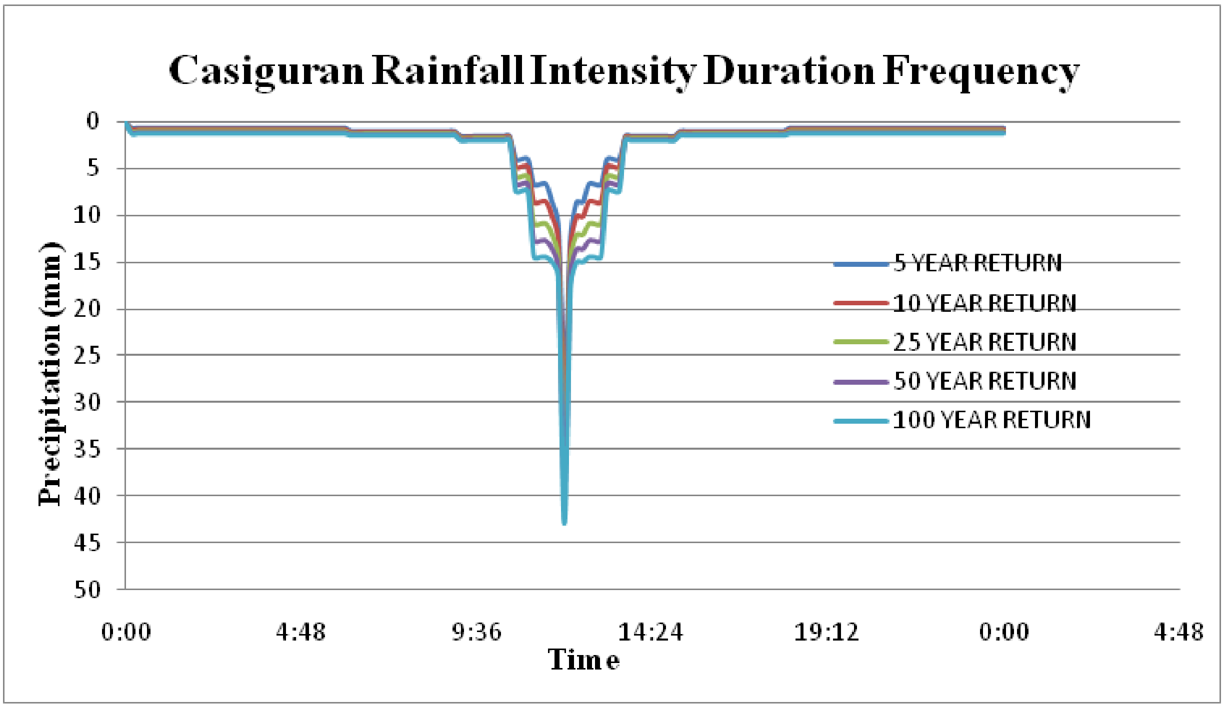


Figure 60. Synthetic storm generated for a 24-hr period rainfall for various return periods

5.3 HMS Model

The soil dataset, taken in 2004, was sourced out from the Bureau of Soils under the Department of Agriculture. The land cover data, on the other hand, was taken from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Amro River Basin are shown in Figures 61 and 62, respectively.

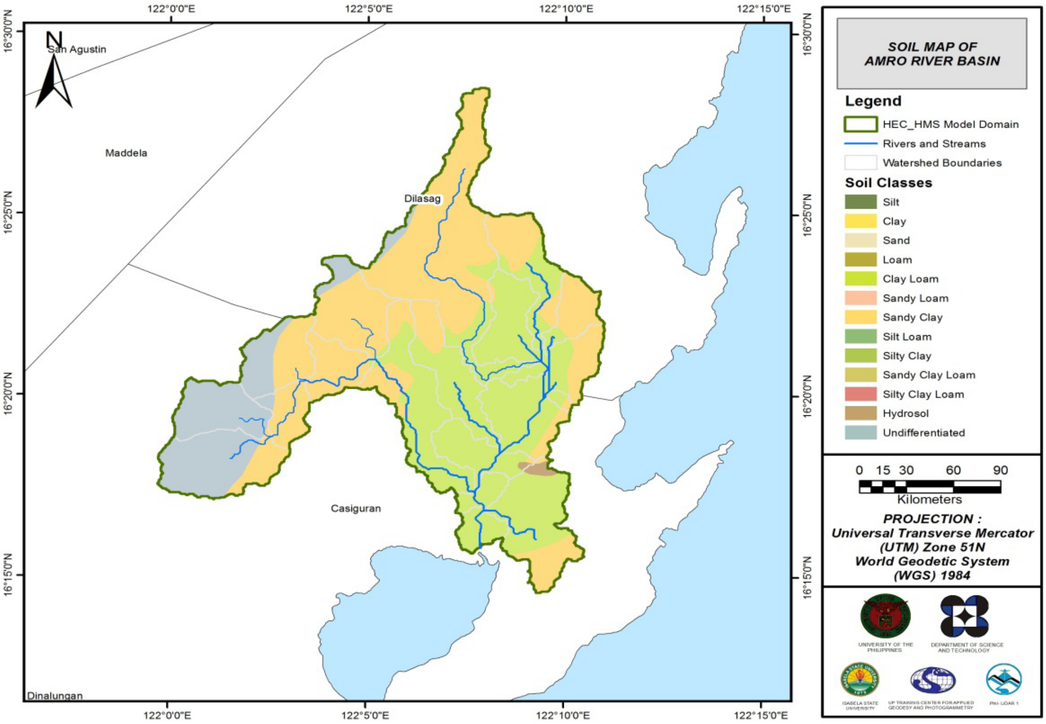


Figure 61. The soil map of the Amro River Basin

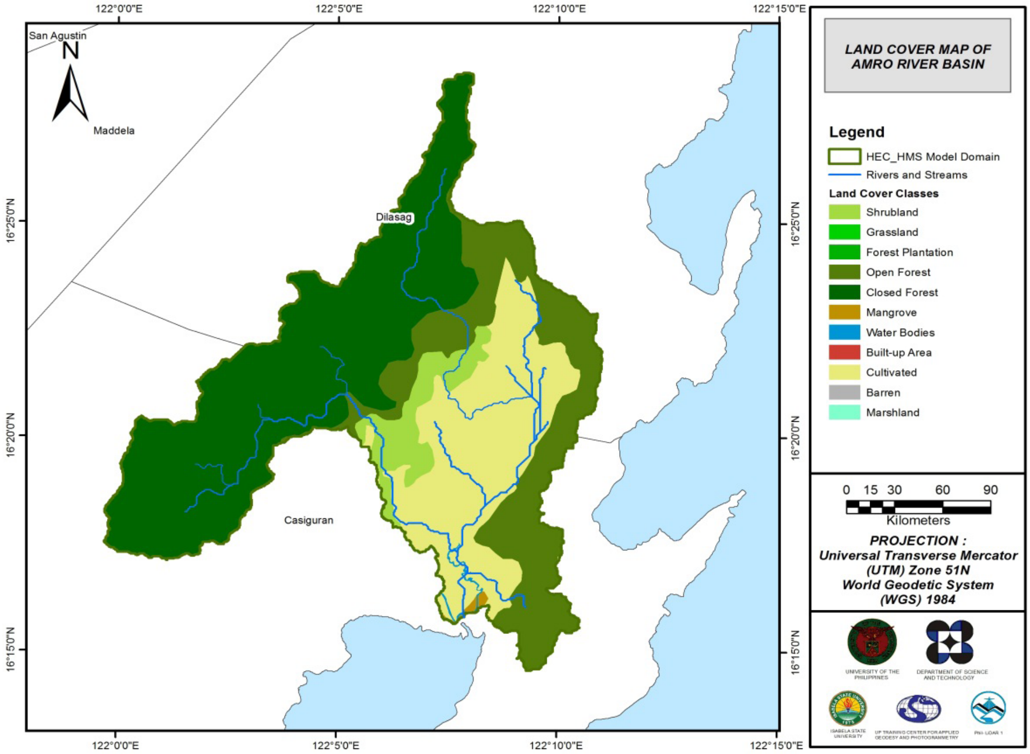


Figure 62. The land cover map of the Amro River Basin

For Amro, three soil classes were identified. These are clay loam, clay, and undifferentiated soil. Moreover, four land cover classes were identified. These are shrubland, cultivated, open and closed forest.

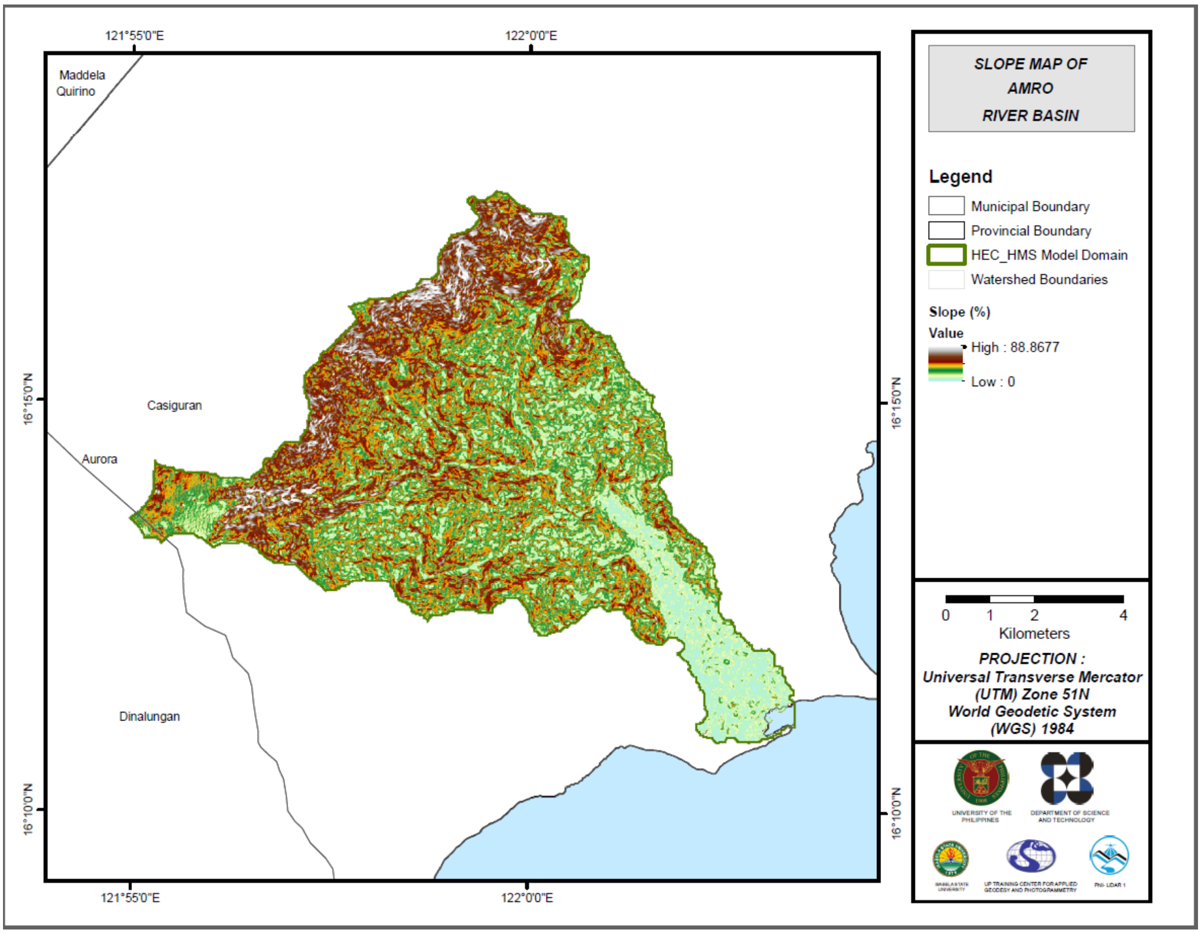


Figure 63. Slope map of the Amro River Basin

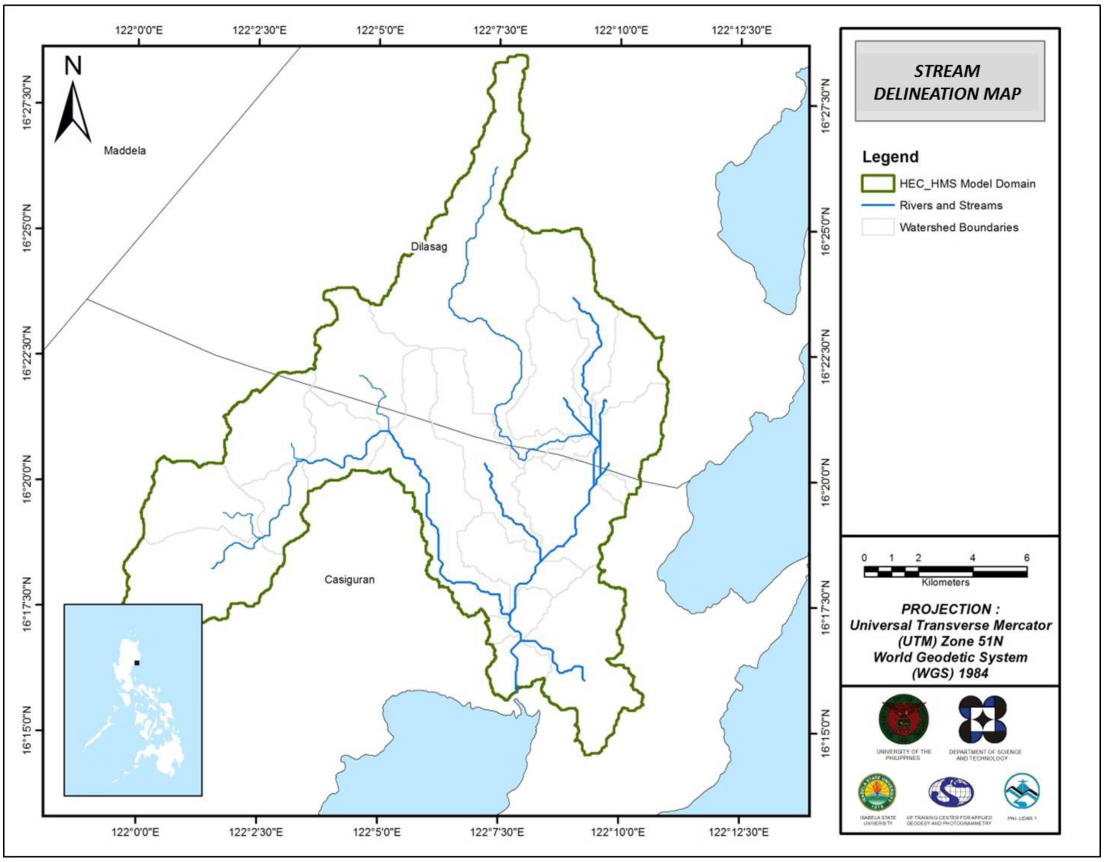


Figure 64. Stream delineation map of Amro River Basin

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

Using the SAR-based DEM, the Amro basin was delineated and further subdivided into subbasins.The Amro basin model consists of 20 subbasins, 9 reaches, and 9 junctions. The main outlet is Outlet 1. This basin model is illustrated in Figure 65. The basins were identified based on soil and land cover characteristics of the area. Precipitation from the 01-03 February 2017 (Monsoon Rain) was taken from portable rain gauge. Finally, it was calibrated using data from the Casalogan Bridge depth gauge sensor.

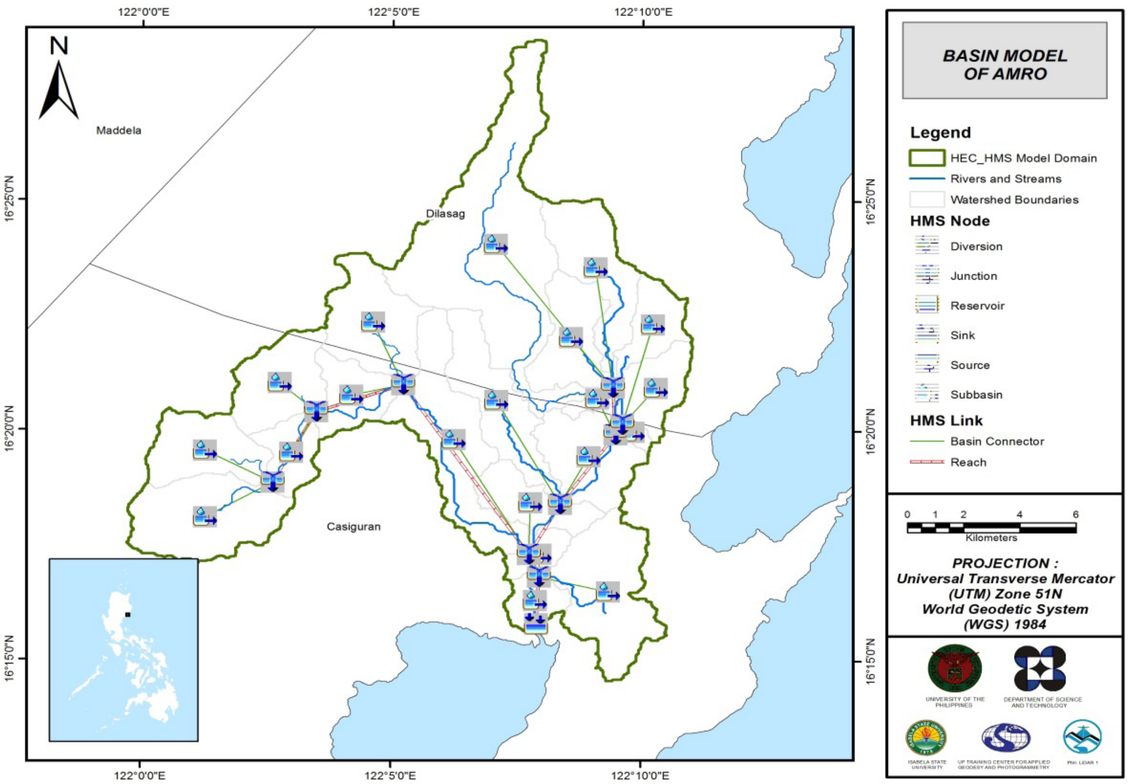


Figure 65. HEC-HMS generated Alubijid River Basin Model

5.4 Cross-section Data

The 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.

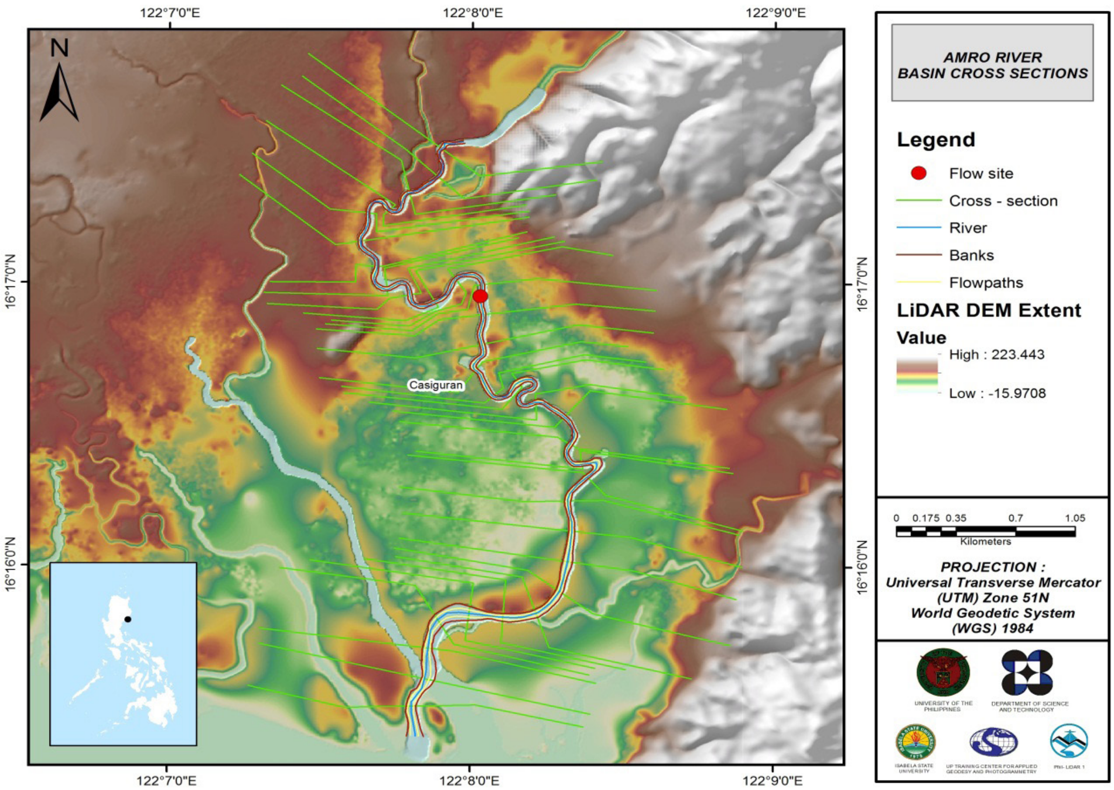


Figure 66. Alubijid River Cross-section generated using HEC GeoRAS tool

5.5 Flo 2D Model

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

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

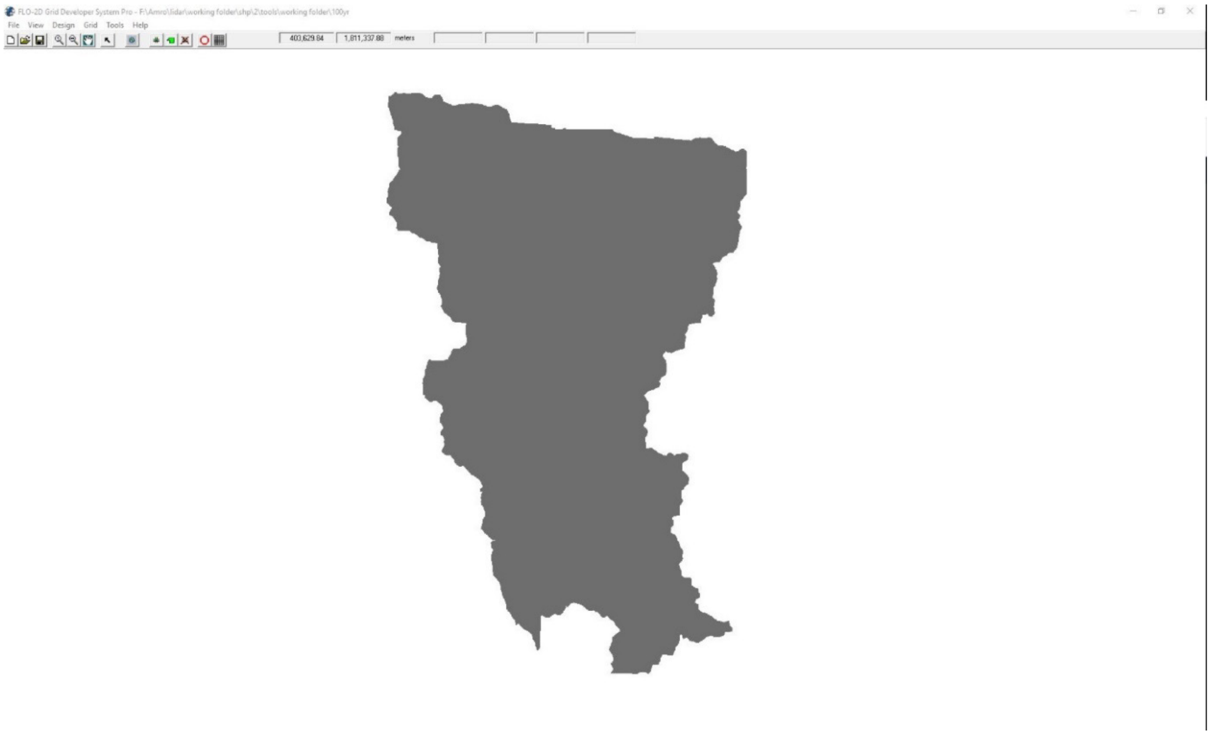


Figure 67. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 116.75024hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m^2/s.

The creation of a flood hazard map from the model also automatically creates a flow depth map depicting the maximum amount of inundation for every grid element. The legend used by default in Flo-2D Mapper is not a good representation of the range of flood inundation values, so a different legend is used for the layout. In this particular model, the inundated parts cover a maximum land area of 75431424.00 m^2.

There is a total of 49571647.96 m^3 of water entering the model. Of this amount, 32520401.89 m^3 is due to rainfall while 17051246.08 m^3 is inflow from other areas outside the model. 11018022.00 m^3 of this water is lost to infiltration and interception, while 20342779.30 m^3 is stored by the flood plain. The rest, amounting up to 18210828.22 m^3,is outflow.

5.6 Results of HMS Calibration

After calibrating the Amo HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 68 shows the comparison between the two discharge data.

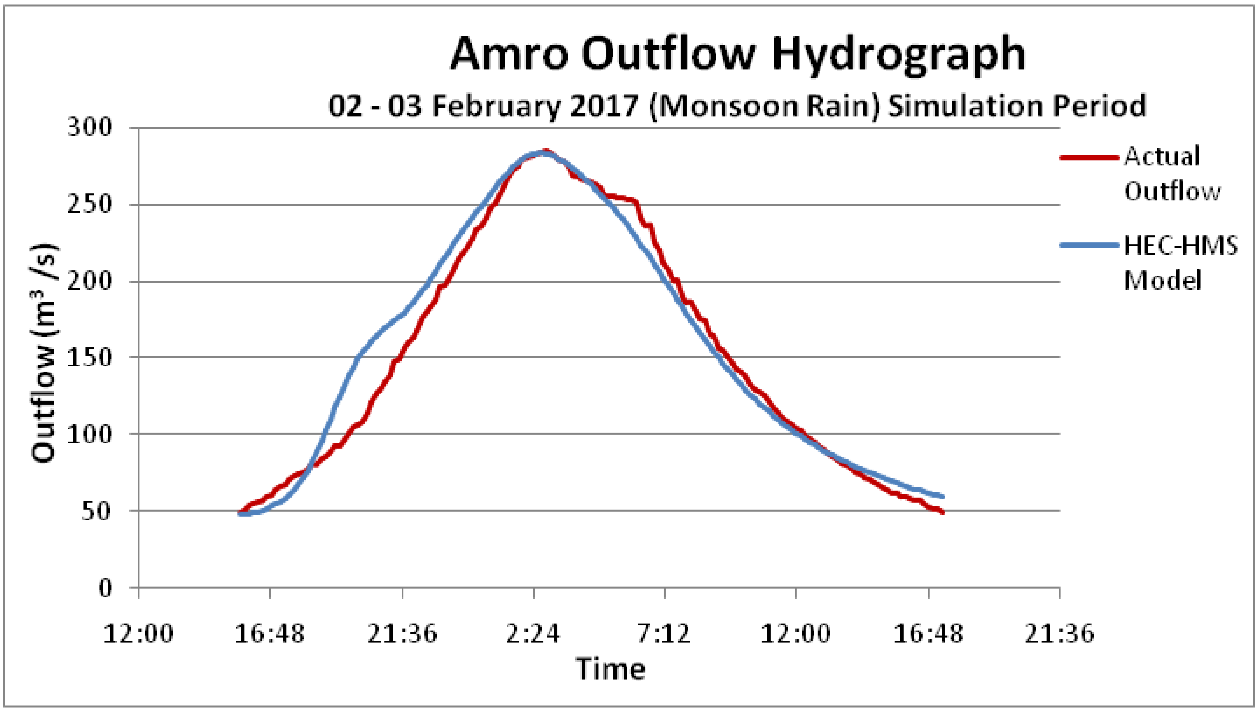


Figure 68.Outflow Hydrograph of Amro produced by the HEC-HMS model compared with observed outflow

Enumerated in Table 29 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 29. Range of Calibrated Values for Amro

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	1 – 12
			Curve Number	99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.9 – 10.9
			Storage Coefficient (hr)	0.5 – 6.23
	Baseflow	Recession	Recession Constant	0.8
			Ratio to Peak	0.03
Reach	Routing	Muskingum-Cunge	Manning’s Coefficient	0.05

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 1mm to 12mm means that there is minimal amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. A curve number is greater than the advisable range for Philippine watersheds (70-80) depending on the soil and land cover of the area. For Amro, the basin mostly consists of forest (closed and open), and cultivated land and the soil consists of clay loam and sandy clay.

Time of concentration and storage coefficient are the travel time and index of temporary storage of runoff in a watershed. The range of calibrated values from 0.5 hours to 10.9 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant of 0.8 indicates that the basin is unlikely to quickly go back to its original discharge and instead, will be higher. Ratio to peak of 0.03 indicates a steeper receding limb of the outflow hydrograph.

Manning's roughness coefficient of 0.05 corresponds to the common roughness of Philippine watersheds.

Table 30. Summary of the Efficiency Test of Amro HMS Model

r^2	0.9665
NSE	0.96
PBIAS	-2.42
RSR	0.19

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 14.8 (m^3/s).

The Pearson correlation coefficient (r2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.9665.

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 0.96.

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 -2.42.

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 0.19.

5.7 Calculated Outflow hydrographys and discharge values for different Rainfall Return Periods

5.7.1 Hydrograph using the Rainfall Runoff Model

The summary graph (Figure 69) shows the Amro River outflow using the Casiguran 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.

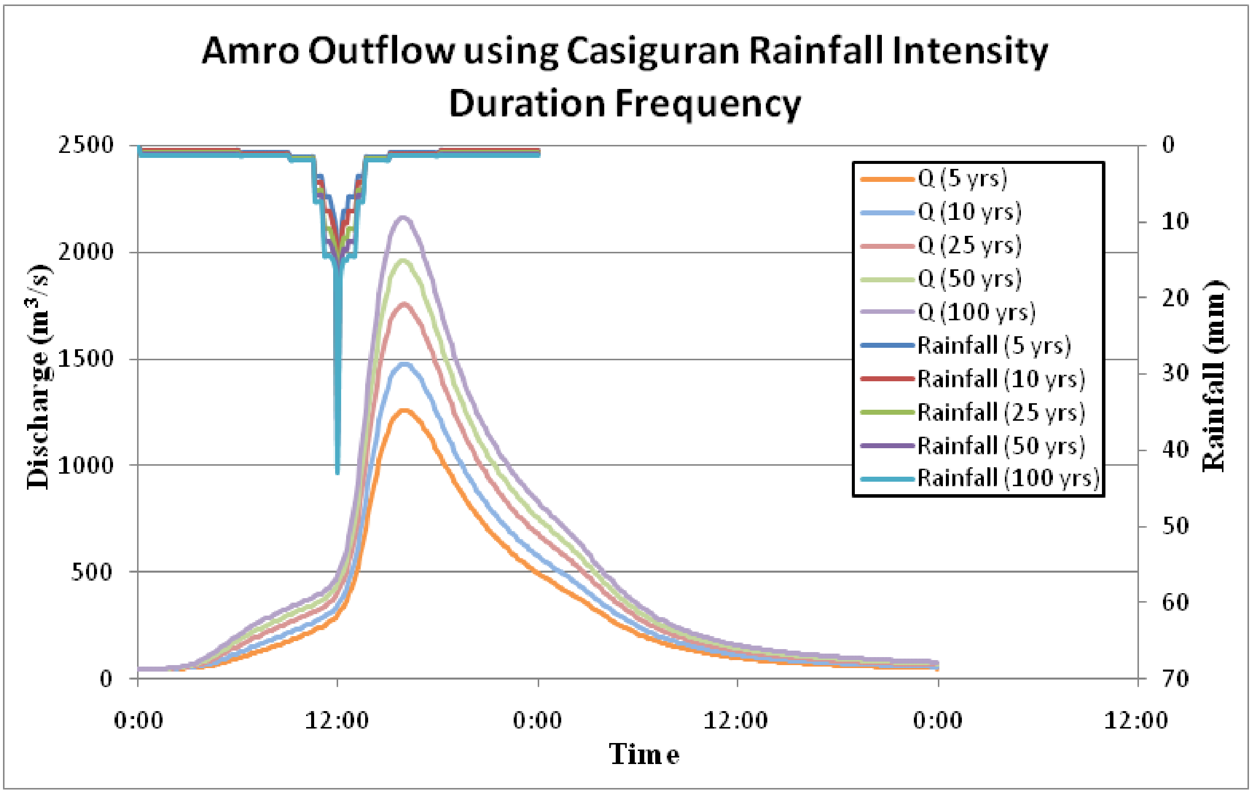


Figure 69. Outflow hydrograph at Amro Station generated using Casiguran RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of the Amro discharge using the Casiguran Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 31.

Table 31. Peak values of Amro HEC-HMS Model outflow using the Casiguran RIDF

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m^3s)	Time to Peak
5-Year	245.6	27	1259.1	4 hours
10-Year	289.8	30.9	1477.1	4 hours
25-Year	345.5	35.7	1754.6	4 hours
50-Year	386.9	39.3	1958	3 hours, 50 minutes
100-Year	427.9	42.9	2162.1	3 hours, 50 minutes

5.8 River Analysis (RAS) Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. For this publication, only a sample output map river was to be shown. The sample generated map of Amro River using the calibrated HMS is shown in Figure 70.

Figure 70. Sample output of Amro RAS Model

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. Figure 71 to Figure 76 shows the 5-, 25-, and 100-year rain return scenarios of the Amro floodplain. The floodplain, with an area of 157.76 sq. km., covers two municipalites namely Casiguran and Dilasag. Table shows the percentage of area affected by flooding per municipality.

Table 32. Municipalities affected in Amro Floodplain

Municipality	Total Area	Area Flooded	% Flooded
Casiguran	419.89	55.13	13.13%
Dilasag	495.20	102.60	20.72%

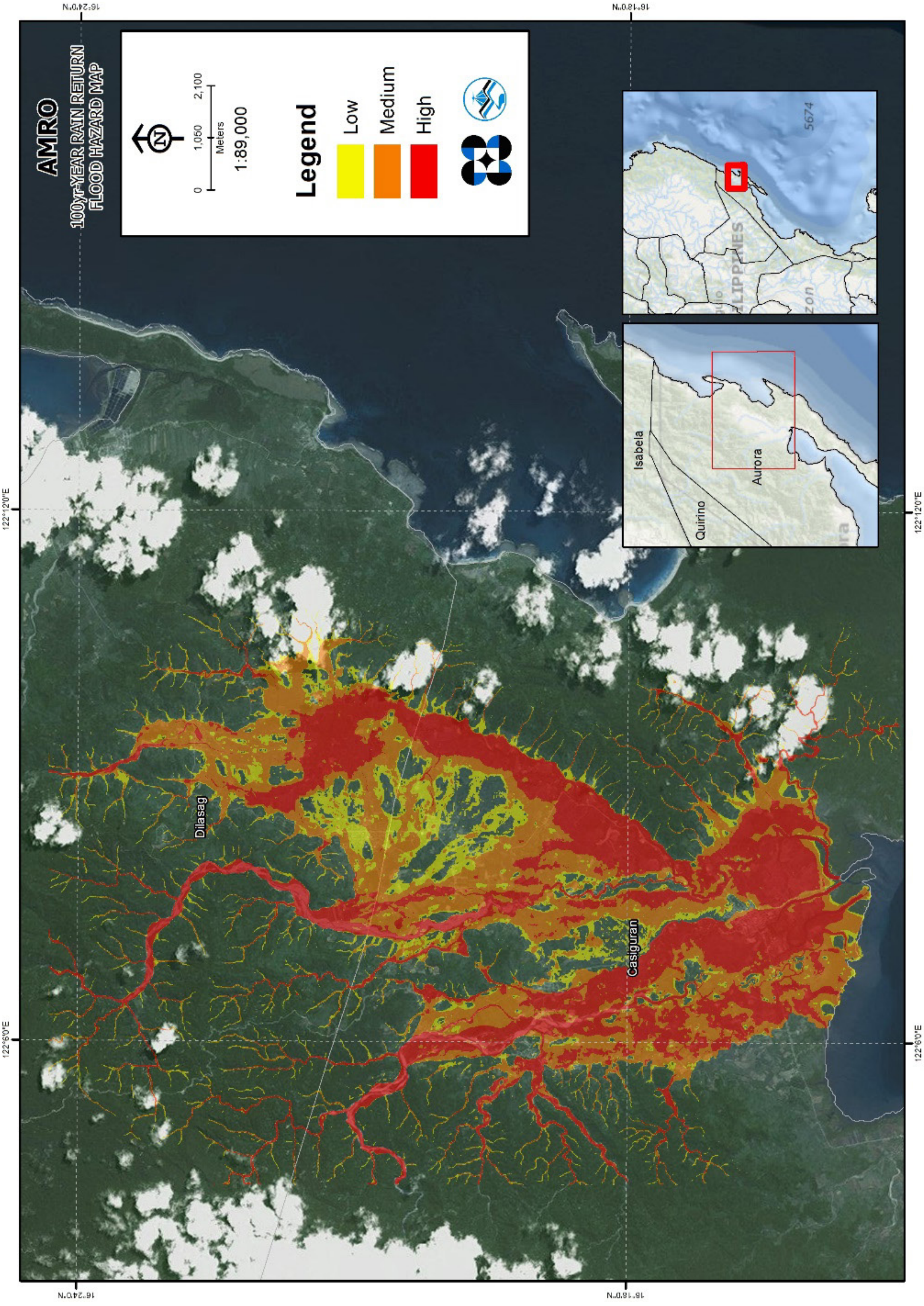


Figure 71. 100-year Flood Hazard Map for Amro Floodplain

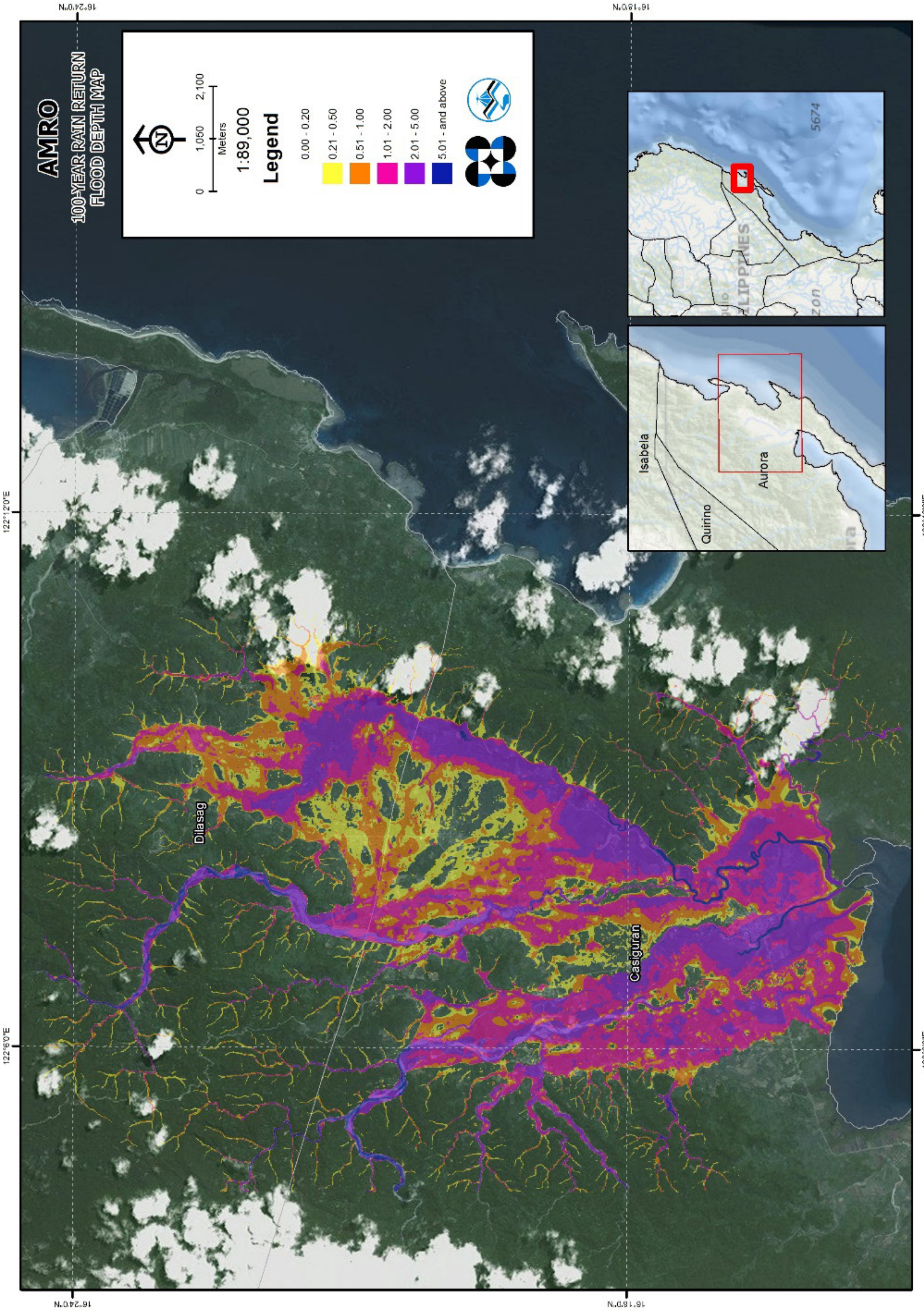


Figure 72. 100-year Flow Depth Map for Amro Floodplain

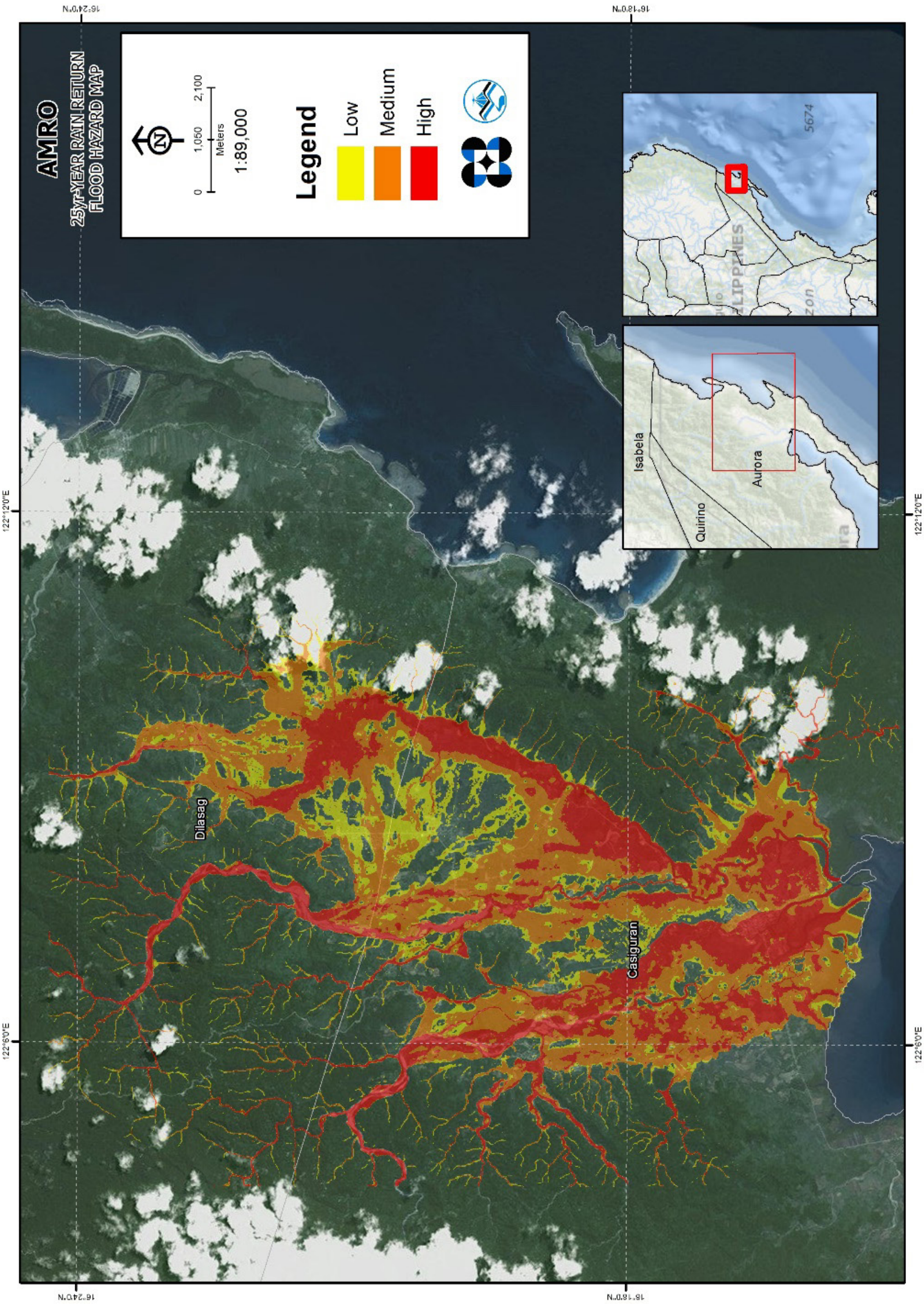


Figure 73. 25-year Flood Hazard Map for Amro Floodplain

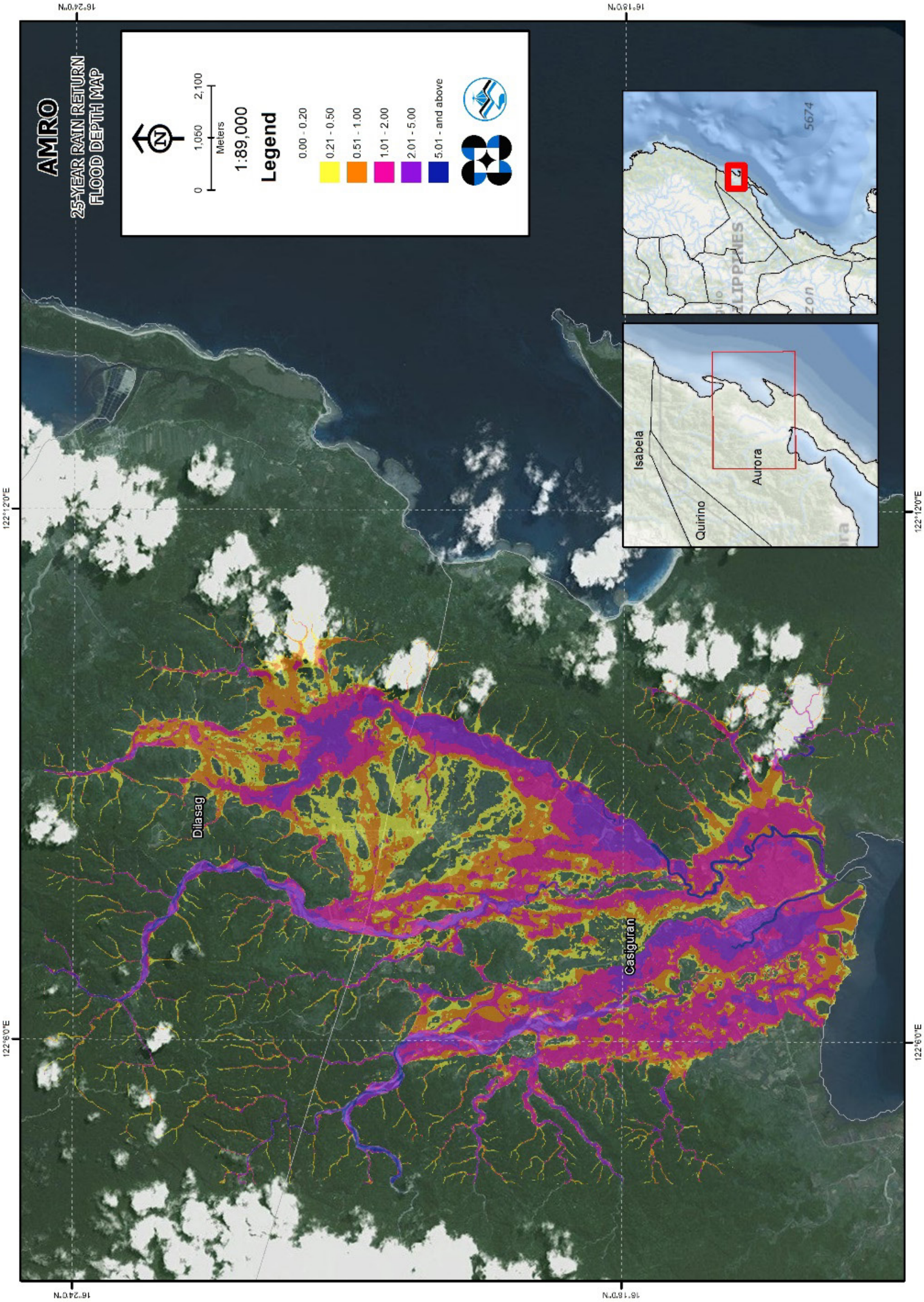


Figure 74. 25-year Flow Depth Map for Amro Floodplain

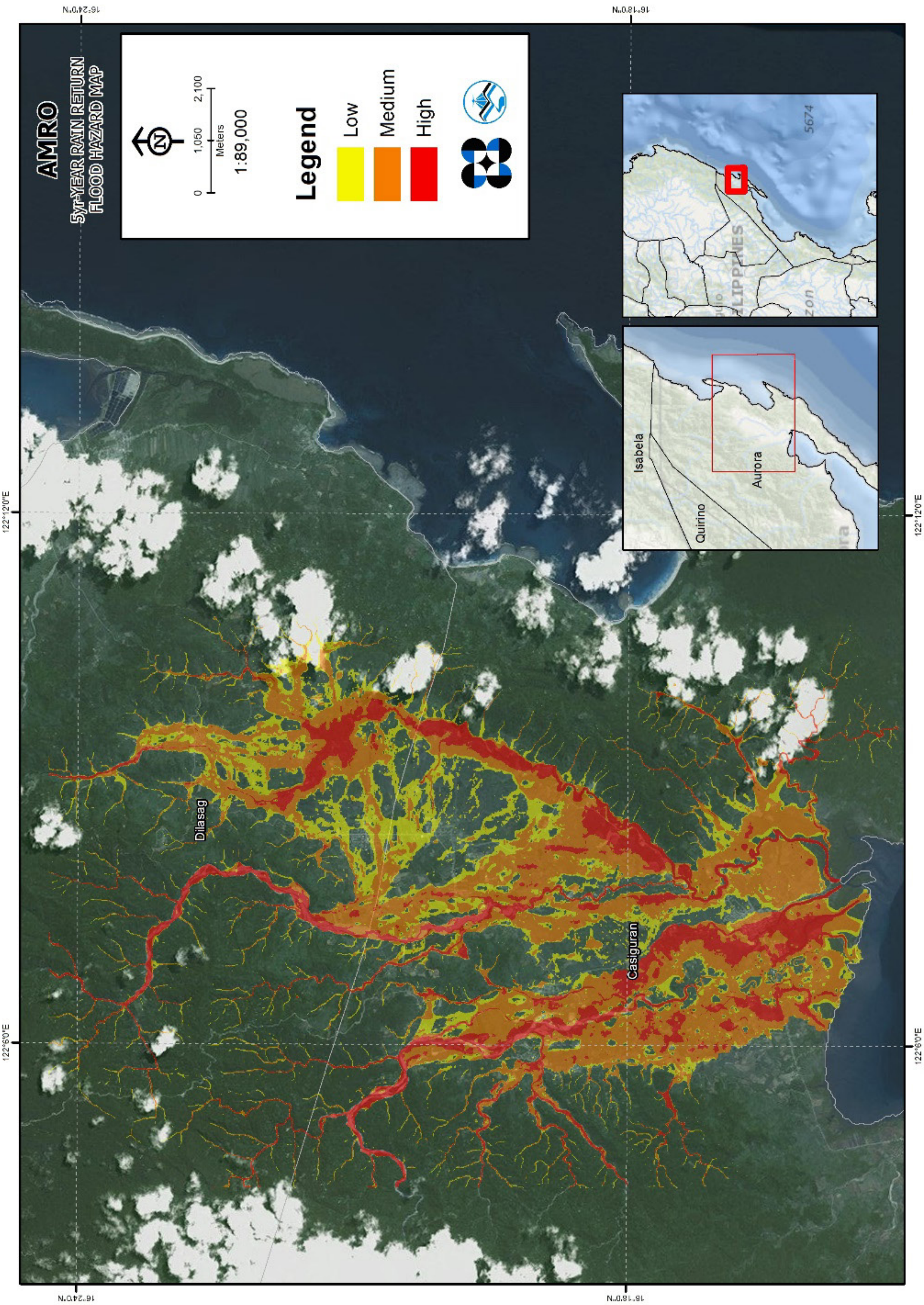


Figure 75. 5-year Flood Hazard Map for Amro Floodplain

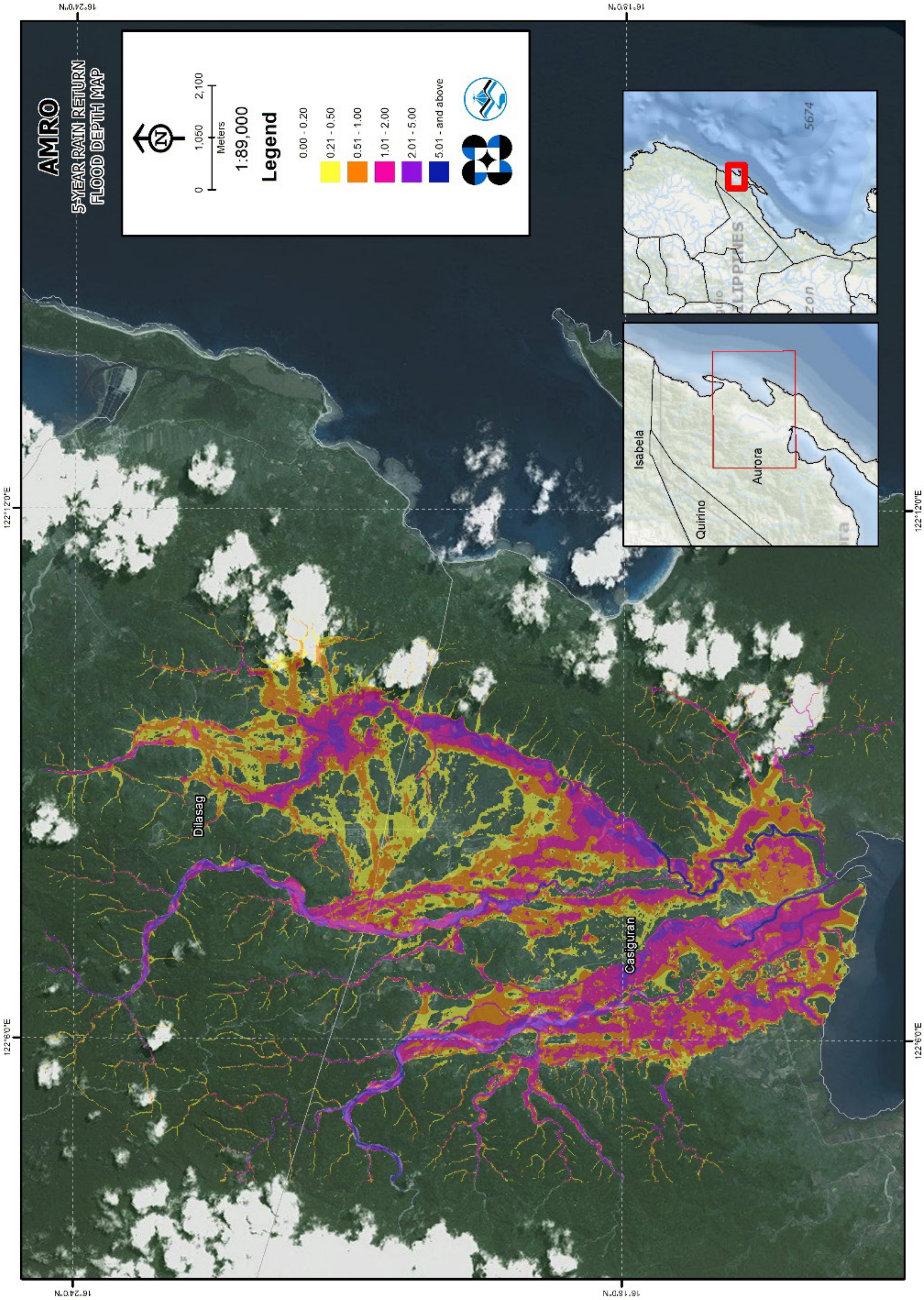


Figure 76. 5-year Flood Depth Map for Amro Floodplain

5.10 Inventory of Areas Exposed to Flooding of Affected Areas

Affected barangays in Amro River Basin, grouped by municipality, are listed below. For the said basin, two (2) municipalities consisting of 22 barangays are expected to experience flooding when subjected to 5-yr rainfall return period.

For the 5-year return period, 16.09% of the municipality of Dilasag with an area of 398.2279 sq. km. will experience flood levels of less 0.20 meters. 2.43% of the area will experience flood levels of 0.21 to 0.50 meters while 2.28%, 1.64%, 0.56%, and 0.03% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, and more than 2 meters, respectively. Listed in Table 33 are the affected areas in square kilometres by flood depth per barangay.

Table 33. Affected Areas in Dilasag, Aurora during 5-Year Rainfall Return Period

AMRO BASIN		Affected Barangays in Dilasag				
		Dimaseset	Esperanza	Lawang	Manggitahan	Ura
Affected Area (sq. km.)	**0.03-0.20**	2.31498	12.28076	23.65523	4.92861	20.91464
	0.21-0.50	0.10525	4.29055	4.4402	0.14631	0.70205
	0.51-1.00	0.03563	4.64751	3.80997	0.07379	0.49837
	1.01-2.00	0.03937	3.37687	2.19947	0.04683	0.86069
	2.01-5.00	0.01854	0.85688	0.60364	0.07358	0.69188
	> 5.00	0.0005	0.02032	0	0.02128	0.05802

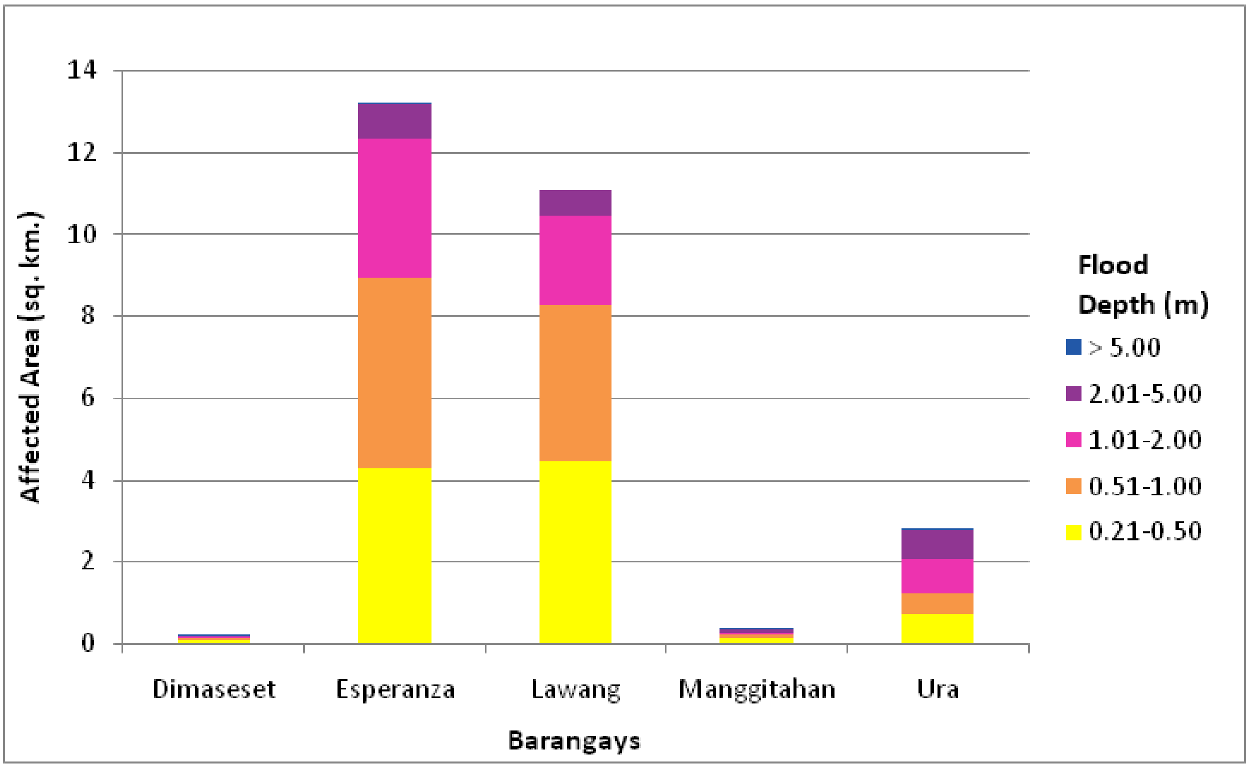


Figure 77. Affected Areas in Dilasag, Aurora during 5-Year Rainfall Return Period

For the Municipality of Casiguran, with an area of 709.041 sq. km., 7.28% will experience flood levels of less 0.20 meters. 1.22% of the area will experience flood levels of 0.21 to 0.50 meters while 1.76%, 1.90%, 0.65%, and 0.07% of the area will experience flood depths of 0.51 to 1 meter, and 1.01 to 2 meters, and more than 2 meters, respectively.

Table 34. Affected Areas in Casiguran, Aurora during 5-Year Rainfall Return Period

AMRO BASIN		Affected Barangays in Casiguran								
		Barangay 1	Barangay 2	Barangay 3	Barangay 4	Barangay 5	Barangay 6	Barangay 7	Barangay 8	Calangcuasan
Affected Area (sq. km.)	**0.03-0.20**	0	0.13289	0.11201	0.00144	0.07206	0.00213	0.08412	0.04246	0.27188
	0.21-0.50	0.00783	0.07046	0.02982	0.00767	0.04486	0.00899	0.09125	0.03198	0.36122
	0.51-1.00	0.04012	0.04011	0.0271	0.03269	0.06257	0.0202	0.27895	0.08781	1.1835
	1.01-2.00	0.27718	0.04601	0.01491	0.0947	0.00572	0.06839	0.06406	0.28762	1.28039
	2.01-5.00	0.06423	0.01793	0.00823	0.03665	0.00273	0.04856	0.01074	0.05786	0.1889
	> 5.00	0.00859	0.01997	0.02529	0.00792	0.00471	0.01084	0.01902	0.03276	0

Table 35. Affected Areas in Casiguran, Aurora during 5-Year Rainfall Return Period

AMRO BASIN		Affected Barangays in Casiguran							
		Calantas	Cozo	Culat	Esperanza	Lual	Marikit	Tabas	Tinib
Affected Area (sq. km.)	**0.03-0.20**	16.29569	5.88795	12.90413	12.28076	0.46283	0.35927	0.48129	2.25118
	0.21-0.50	1.21161	0.48012	1.30784	4.29055	0.14064	0.23059	0.21851	0.13695
	0.51-1.00	2.18029	0.89863	1.29609	4.64751	0.7577	0.39428	0.40946	0.13226
	1.01-2.00	3.39764	0.64352	1.8872	3.37687	0.88531	0.44279	0.65672	0.06223
	2.01-5.00	1.43572	0.1858	1.26223	0.85688	0.21412	0.04527	0.12184	0.03327
	> 5.00	0.13048	0.09645	0.10615	0.02032	0.01742	0	0	0

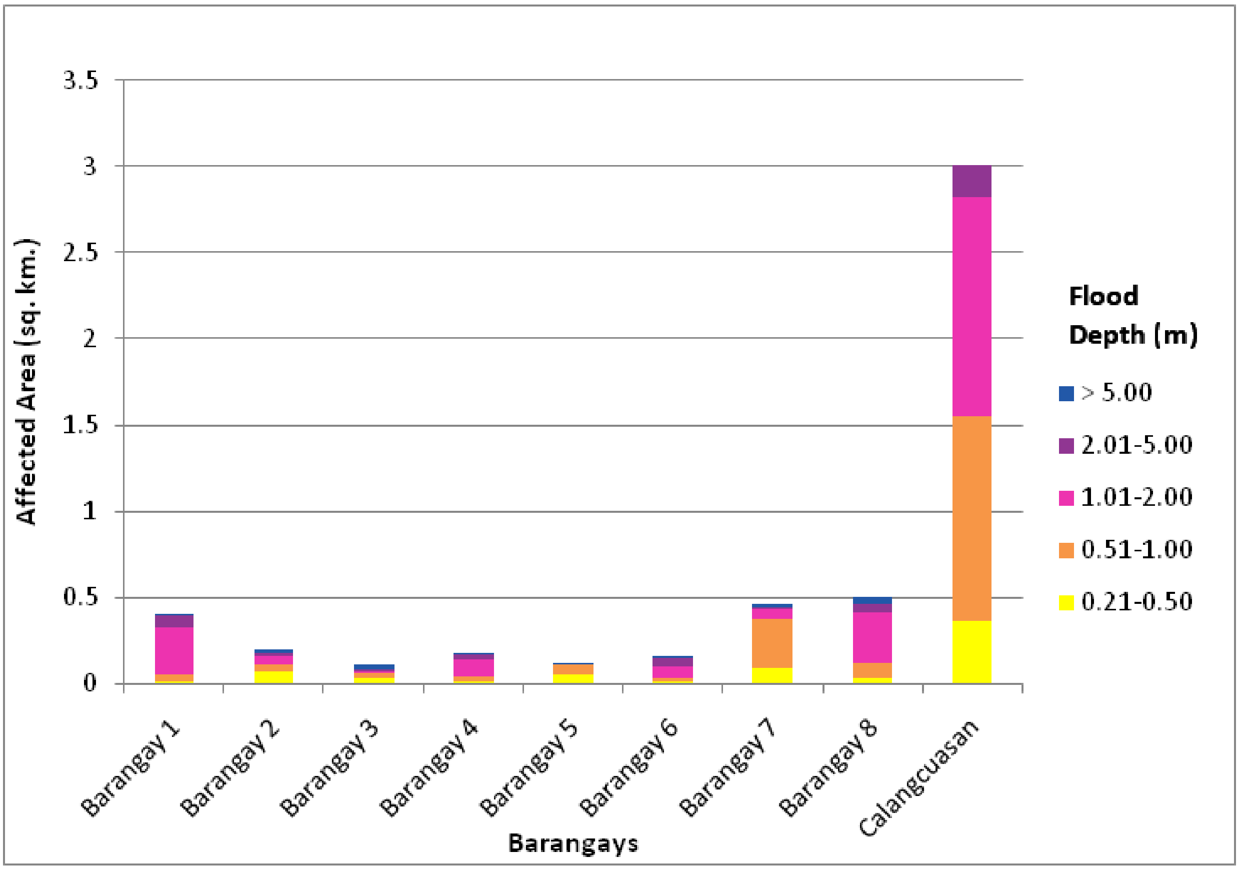


Figure 78. Affected Areas in Casiguran, Aurora during 5-Year Rainfall Return Period

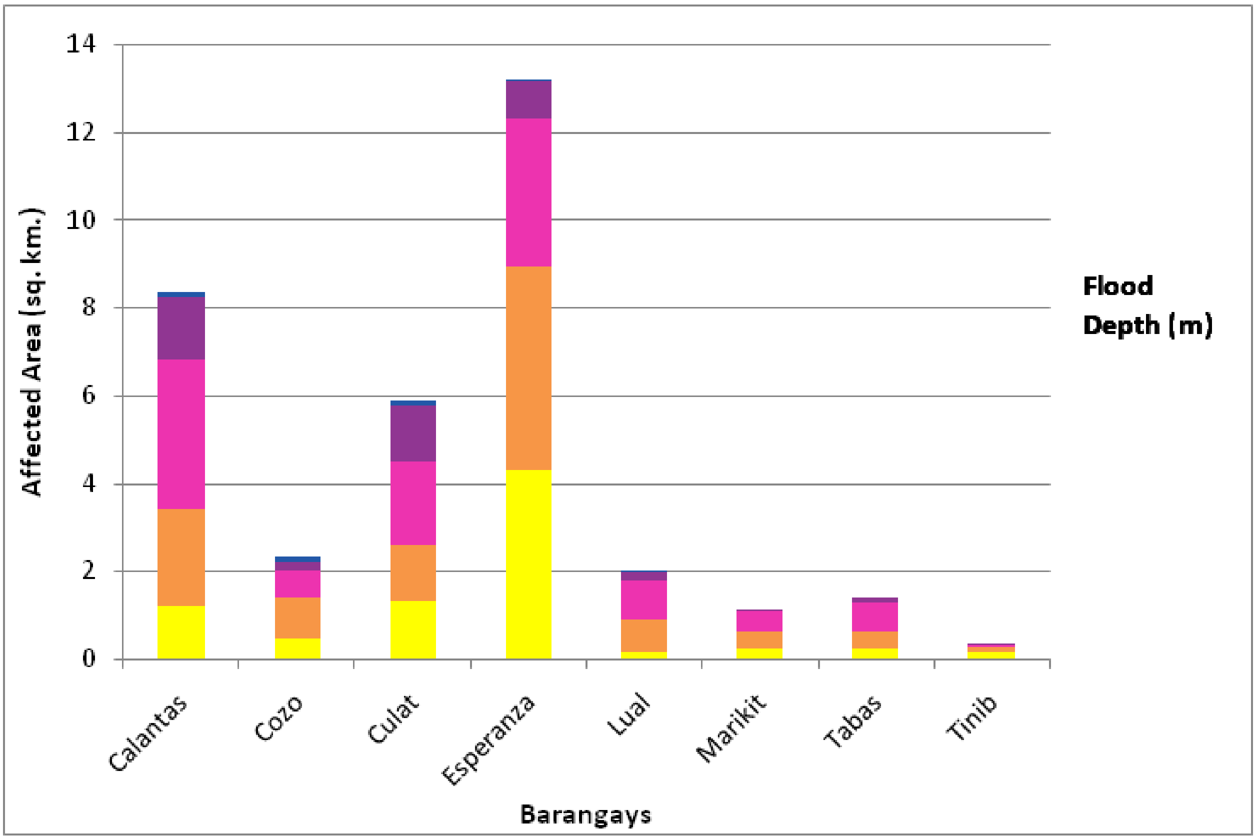


Figure 79. Affected Areas in Casiguran, Aurora during 5-Year Rainfall Return Period

For the 25-year return period, 15.02% of the Municipality of Dilasag with an area of 398.2279 sq. km. will experience flood levels of less 0.20 meters. 2.28% of the area will experience flood levels of 0.21 to 0.50 meters while 2.48%, 2.16%, 1.04%, and 0.02% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, and more than 2 meters, respectively. Listed in Table 36 are the affected areas in square kilometres by flood depth per barangay.

Table 36. Affected Areas in Dilasag, Aurora during 25-Year Rainfall Return Period

AMRO BASIN		Affected Barangays in Dilasag				
		Dimaseset	Esperanza	Lawang	Manggitahan	Ura
Affected Area (sq. km.)	**0.03-0.20**	2.26991	10.16309	21.9144	4.85514	20.59788
	0.21-0.50	0.12699	4.04464	3.92686	0.17681	0.78485
	0.51-1.00	0.04404	4.7684	4.55022	0.08536	0.42548
	1.01-2.00	0.03944	4.84454	2.88139	0.05534	0.78003
	2.01-5.00	0.03318	1.63537	1.43854	0.07908	0.98618
	> 5.00	0.0007	0.02446	0	0.03867	0

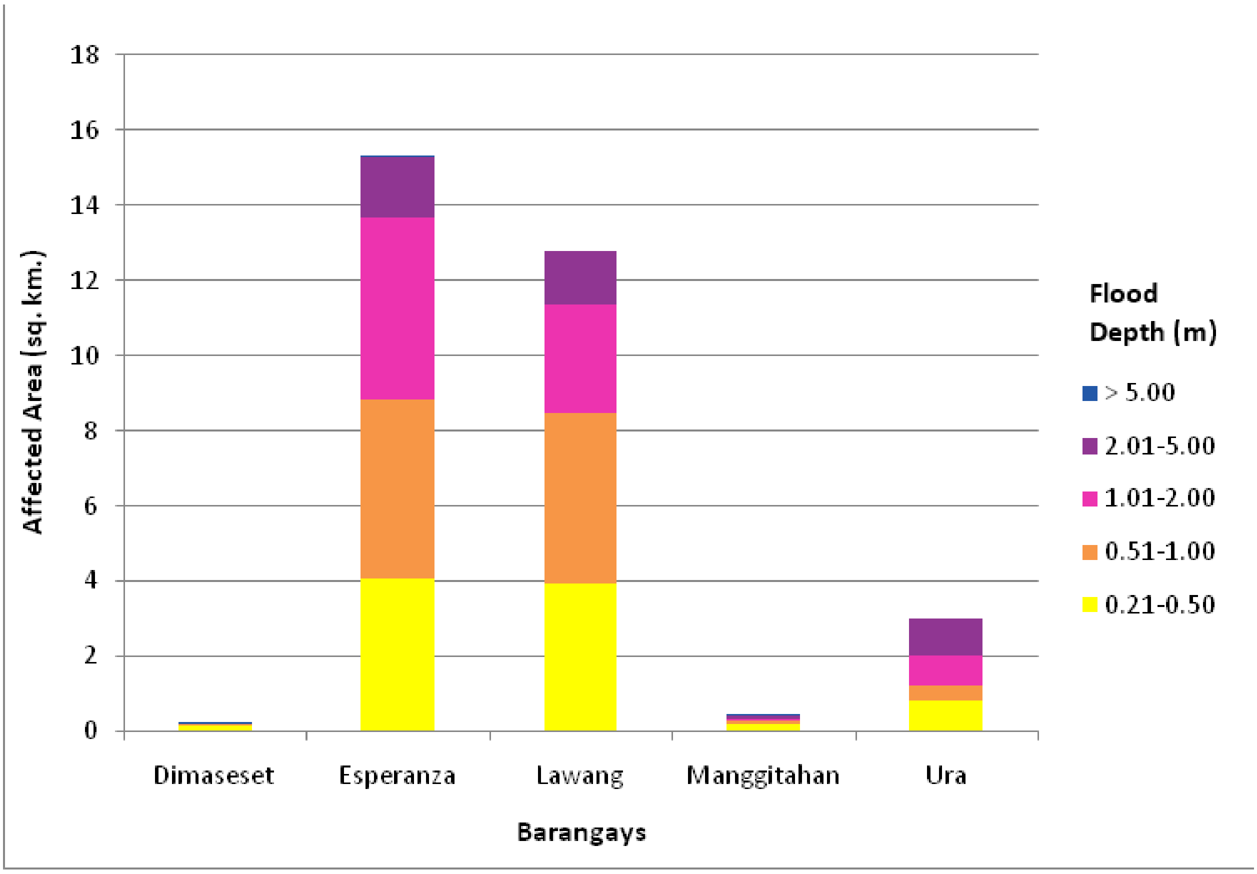


Figure 80. Affected Areas in Dilasag, Aurora during 25-Year Rainfall Return Period

For the Municipality of Casiguran, with an area of 709.041 sq. km., 6.65% will experience flood levels of less 0.20 meters. 1.05% of the area will experience flood levels of 0.21 to 0.50 meters while 1.43%, 2.44%, 1.22%, and 0.1% of the area will experience flood depths of 0.51 to 1 meter, and 1.01 to 2 meters, and more than 2 meters, respectively.

Table 37. Affected Areas in Casiguran, Aurora during 25-Year Rainfall Return Period

AMRO BASIN		Affected Barangays in Casiguran								
		Barangay 1	Barangay 2	Barangay 3	Barangay 4	Barangay 5	Barangay 6	Barangay 7	Barangay 8	Calangcuasan
Affected Area (sq. km.)	**0.03-0.20**	0	0.09913	0.08164	0.00002	0.03946	0.00008	0.02668	0.00612	0.12296
	0.21-0.50	0	0.04859	0.02297	0.00048	0.01445	0.00042	0.01775	0.01003	0.20597
	0.51-1.00	0.00687	0.07055	0.05217	0.00485	0.06741	0.00243	0.04968	0.02099	0.7998
	1.01-2.00	0.15694	0.06252	0.02783	0.09018	0.06437	0.04757	0.41476	0.20528	1.76604
	2.01-5.00	0.22485	0.02618	0.00852	0.07683	0.00338	0.09639	0.01997	0.25986	0.39112
	> 5.00	0.00929	0.02137	0.02579	0.0087	0.00495	0.01221	0.0204	0.03823	0

Table 38. Affected Areas in Casiguran, Aurora during 25-Year Rainfall Return Period

AMRO BASIN		Affected Barangays in Casiguran							
		Calantas	Cozo	Culat	Esperanza	Lual	Marikit	Tabas	Tinib
Affected Area (sq. km.)	**0.03-0.20**	15.70053	5.56226	12.29859	10.16309	0.32722	0.21522	0.32497	2.20201
	0.21-0.50	1.08171	0.36449	1.07311	4.04464	0.08572	0.15066	0.18568	0.11104
	0.51-1.00	1.52272	0.62056	1.14647	4.7684	0.15641	0.35262	0.34971	0.15541
	1.01-2.00	3.97395	1.13371	1.89711	4.84454	1.31084	0.53276	0.66456	0.09477
	2.01-5.00	2.13589	0.37337	2.22921	1.63537	0.56887	0.22094	0.36251	0.05135
	> 5.00	0.23663	0.13807	0.11915	0.02446	0.03234	0	0.0005	0.00131

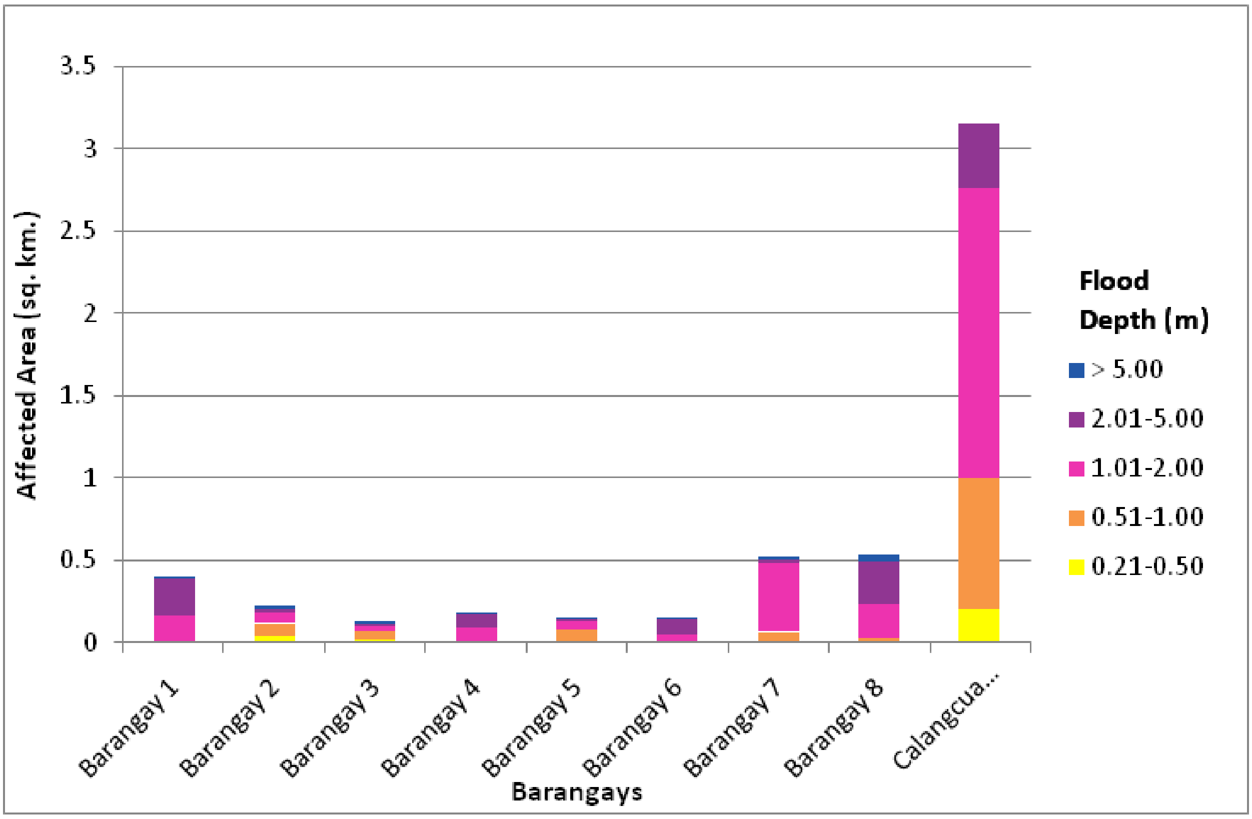


Figure 81. Affected Areas in Casiguran, Aurora during 25-Year Rainfall Return Period

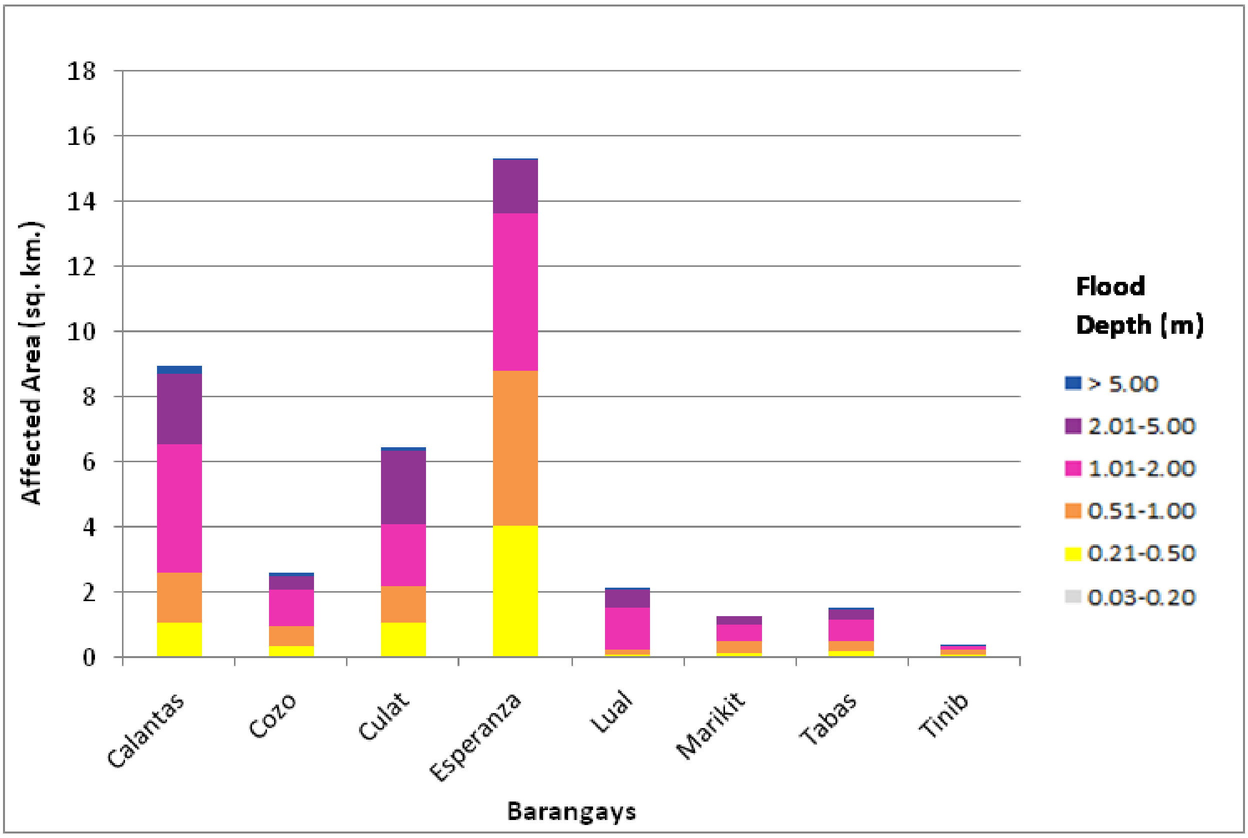


Figure 82. Affected Areas in Santa Rita, Samar during 25-Year Rainfall Return Period

For the 100-year return period, 14.37% of the municipality of Dilasag with an area of 398.2279 sq. km. will experience flood levels of less 0.20 meters. 2.11% of the area will experience flood levels of 0.21 to 0.50

meters while 2.46%, 2.42%, 1.58%, and 0.097% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, and more than 2 meters, respectively. Listed in Table 39 are the affected areas in square kilometres by flood depth per barangay.

Table 39. Affected Areas in Dilasag, Aurora during 100-Year Rainfall Return Period

AMRO BASIN		Affected Barangays in Dilasag				
		Dimaseset	**Esperanza**	**Lawang**	**Manggitahan**	**Ura**
Affected Area (sq. km.)	**0.03-0.20**	2.24175	8.82354	20.99043	4.79135	20.37589
	0.21-0.50	0.13685	3.78931	3.41939	0.20596	0.84286
	0.51-1.00	0.05143	4.52003	4.7142	0.09158	0.4231
	1.01-2.00	0.03936	5.51877	3.35232	0.05953	0.67587
	2.01-5.00	0.04218	2.80165	2.23348	0.08692	1.11312
	> 5.00	0.0027	0.03079	0.00297	0.05507	0.29542

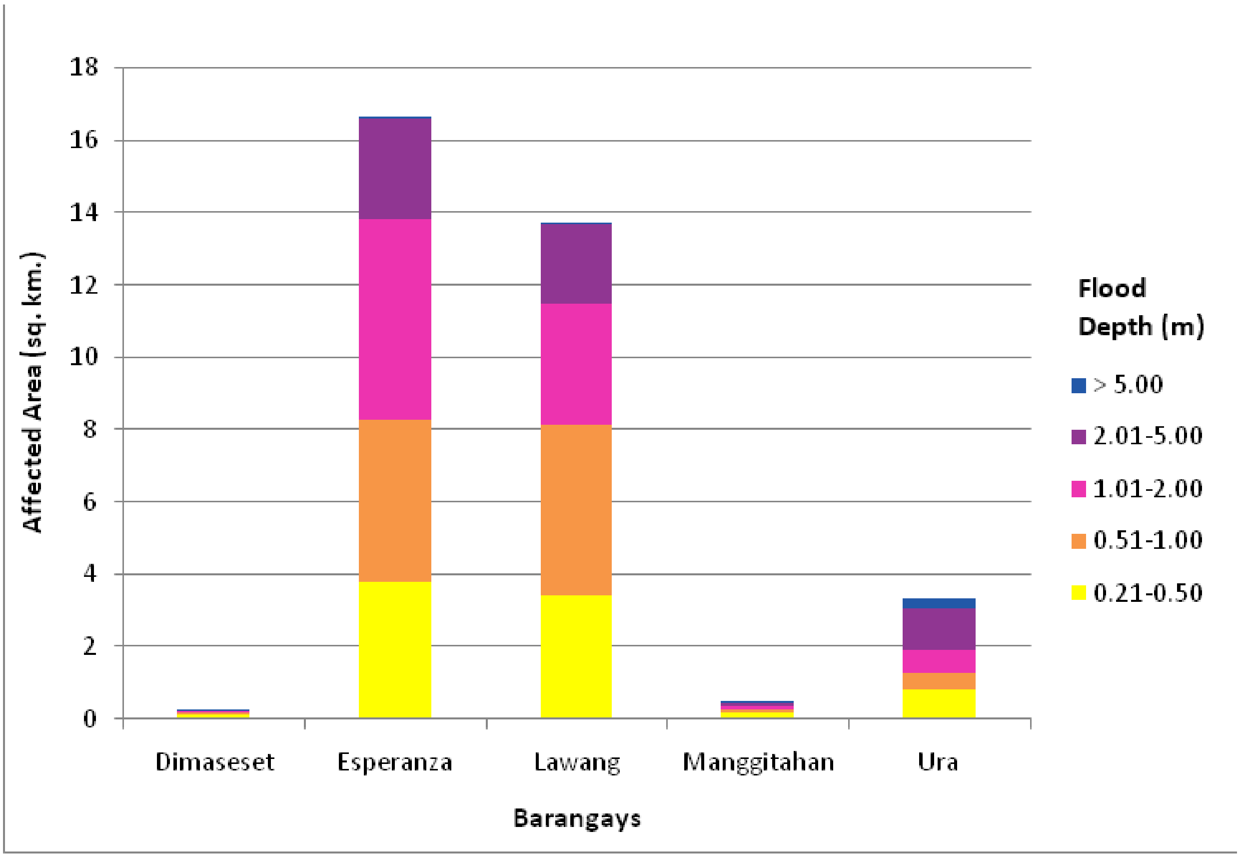


Figure 7. Affected Areas in Dilasag, Aurora during 100-Year Rainfall Return Period

For the municipality of Casiguran, with an area of 709.041 sq. km., 6.65% will experience flood levels of less 0.20 meters. 1.05% of the area will experience flood levels of 0.21 to 0.50 meters while 1.43%, 2.44%, 1.22%, and 0.1% of the area will experience flood depths of 0.51 to 1 meter, and 1.01 to 2 meters, and more than 2 meters, respectively.

Table 40. Affected Areas in Casiguran, Aurora during 100-Year Rainfall Return Period

AMRO BASIN		Affected Barangays in Casiguran								
		Barangay 1	Barangay 2	Barangay 3	Barangay 4	Barangay 5	Barangay 6	Barangay 7	Barangay 8	Calangcuasan
Affected Area (sq. km.)	**0.03-0.20**	0	0.07503	0.06601	0	0.03138	0	0.01513	0.00124	0.07847
	0.21-0.50	0	0.04235	0.01835	0	0.00572	0	0.00733	0.00285	0.11514
	0.51-1.00	0	0.05845	0.02705	0.00123	0.01651	0.00054	0.02195	0.01307	0.52854
	1.01-2.00	0.06343	0.08639	0.06738	0.04371	0.12125	0.02295	0.26837	0.12085	1.97882
	2.01-5.00	0.32367	0.04143	0.01373	0.12281	0.01403	0.12191	0.21456	0.36034	0.58491
	> 5.00	0.01085	0.02468	0.02689	0.01331	0.00555	0.0137	0.0219	0.04163	0

Table 41. Affected Areas in Casiguran, Aurora during 100-Year Rainfall Return Period

AMRO BASIN		Affected Barangays in Casiguran							
		Calantas	Cozo	Culat	Esperanza	Lual	Marikit	Tabas	Tinib
Affected Area (sq. km.)	**0.03-0.20**	15.36681	5.39621	11.98193	8.82354	0.29615	0.15352	0.22705	2.17441
	0.21-0.50	1.03507	0.33391	0.95511	3.78931	0.07081	0.1156	0.16323	0.10241
	0.51-1.00	1.2254	0.48604	1.02434	4.52003	0.12823	0.31407	0.29807	0.14781
	1.01-2.00	3.88183	1.14019	1.71479	5.51877	0.72217	0.56264	0.63581	0.12454
	2.01-5.00	2.81758	0.67108	2.92531	2.80165	1.22501	0.32637	0.56013	0.06332
	> 5.00	0.32473	0.16504	0.16216	0.03079	0.03667	0	0.00363	0.00341

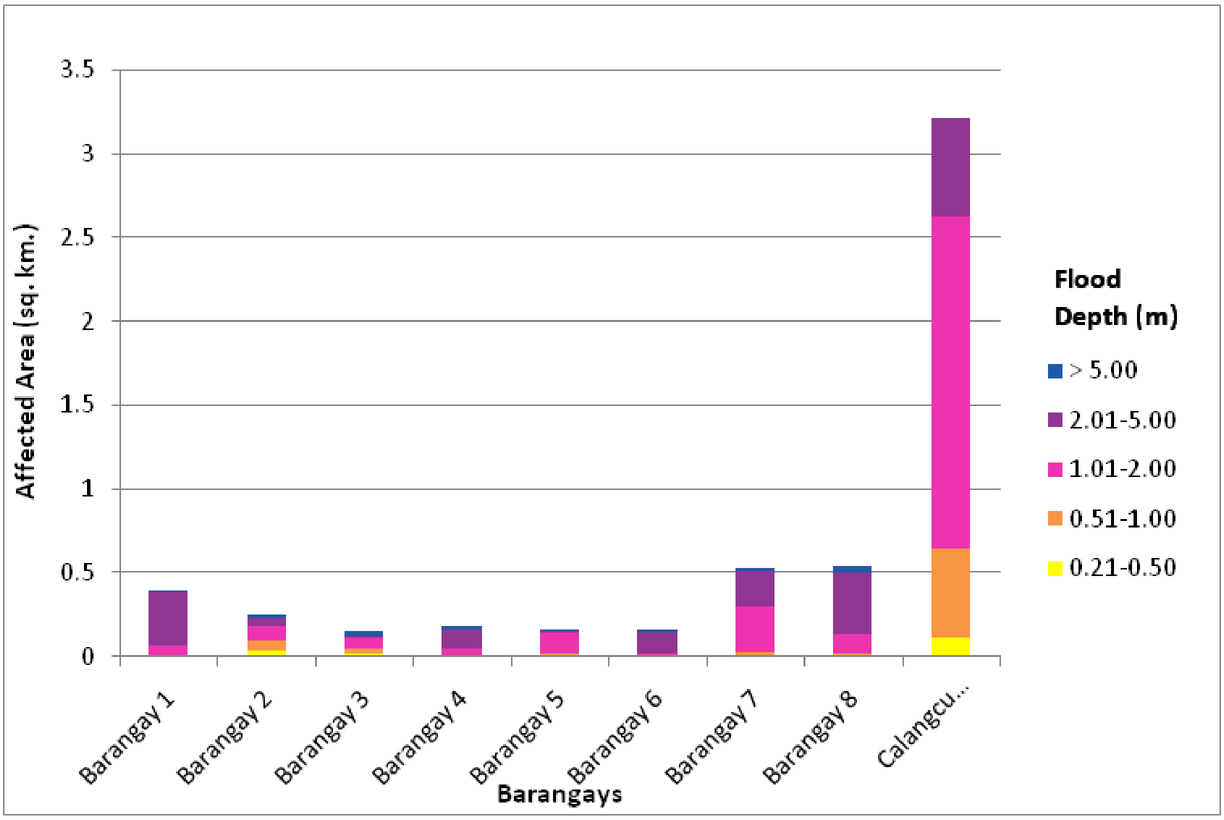


Figure 83. Affected Areas in Casiguran, Aurora during 100-Year Rainfall Return Period

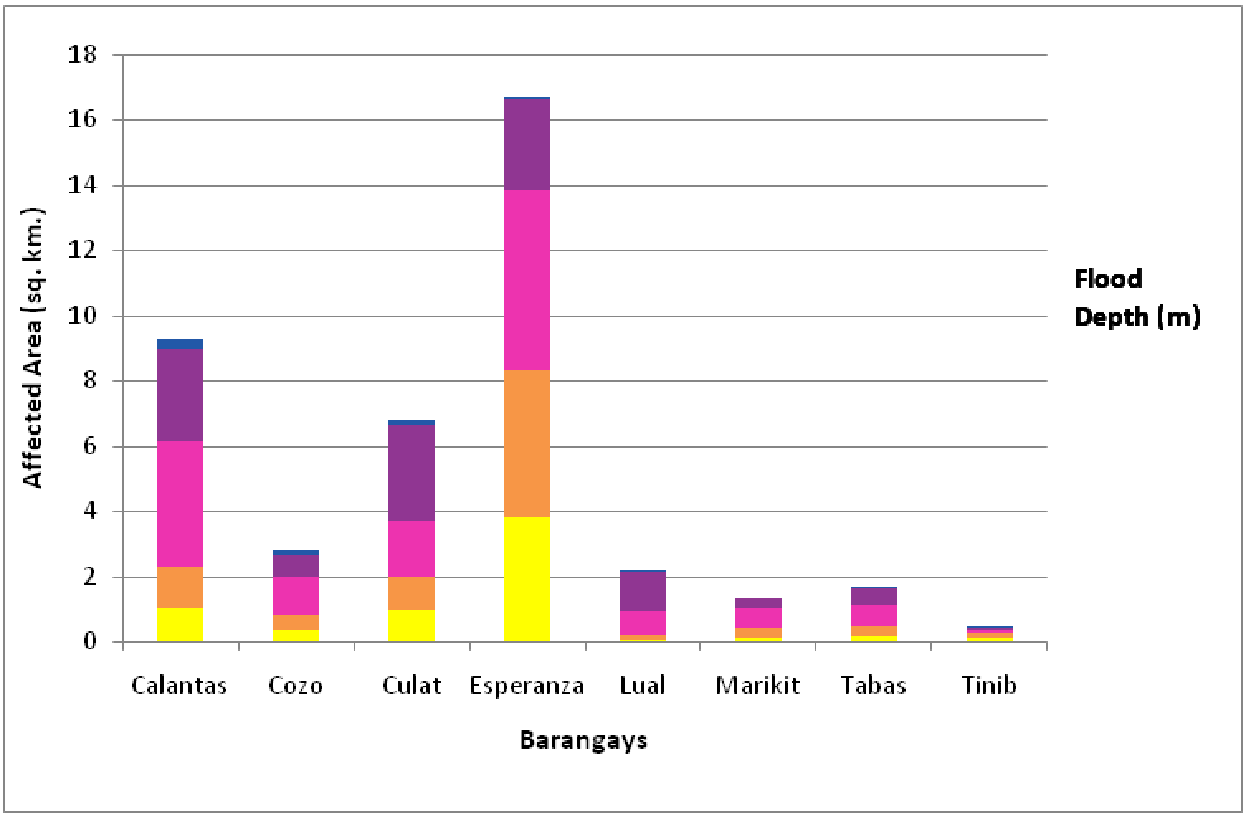


Figure 84. Affected Areas in Casiguran, Aurora during 100-Year Rainfall Return Period

Among the barangays in the Municipality of Dilasag, Lawang is projected to have the highest percentage of area that will experience flood levels at 8.72%. Meanwhile, Esperanza posted the second highest percentage of area that may be affected by flood depths at 6.40%.

Among the barangays in the municipality of Casiguran, Culat is projected to have the highest percentage of area that will experience flood levels at 3.59%. Meanwhile, Calantas posted the second highest percentage of area that may be affected by flood depths at 3.48%.

Moreover, the generated flood hazard maps for the Amro 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 42. 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	14.0397	12.3222	11.165
Medium	27.5326	26.877701	25.230499
High	13.2071	22.184799	28.661699

Of the twenty four (24)) identified Education Institute in Silaga Flood plain, 3 schools were assessed to be exposed to the Low level flooding during a 5 year scenario while 3 schools were assessed to be exposed to medium level flooding in the same scenario. In the 25 year scenario, 3 schools were assessed to be exposed to the Low level flooding while 4 schools were assessed to be exposed to medium level flooding. For the 100 year scenario, 1 school was assessed for Low level flooding and 4 schools for Medium level flooding. In the same scenario, 2 schools were assessed to be exposed to High level flooding. Both schools are located in Barangay Parasanon, Pinabacdao.

Two (2) Medical Institutions were identified in Silaga Floodplain, only 1 was assessed to be exposed to Medium level flooding in the three different scenarios in Barangay Tominamos, Santa Rita.

5.11 Flood Validation

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

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

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

After which, the actual data from the field were compared to the simulated data to assess the accuracy of the Flood Depth Maps produced and to improve on what is needed.

The flood validation was consisted of 202 points randomly selected all over the Alubijid Floodplain. It has an RMSE value of 1.33.

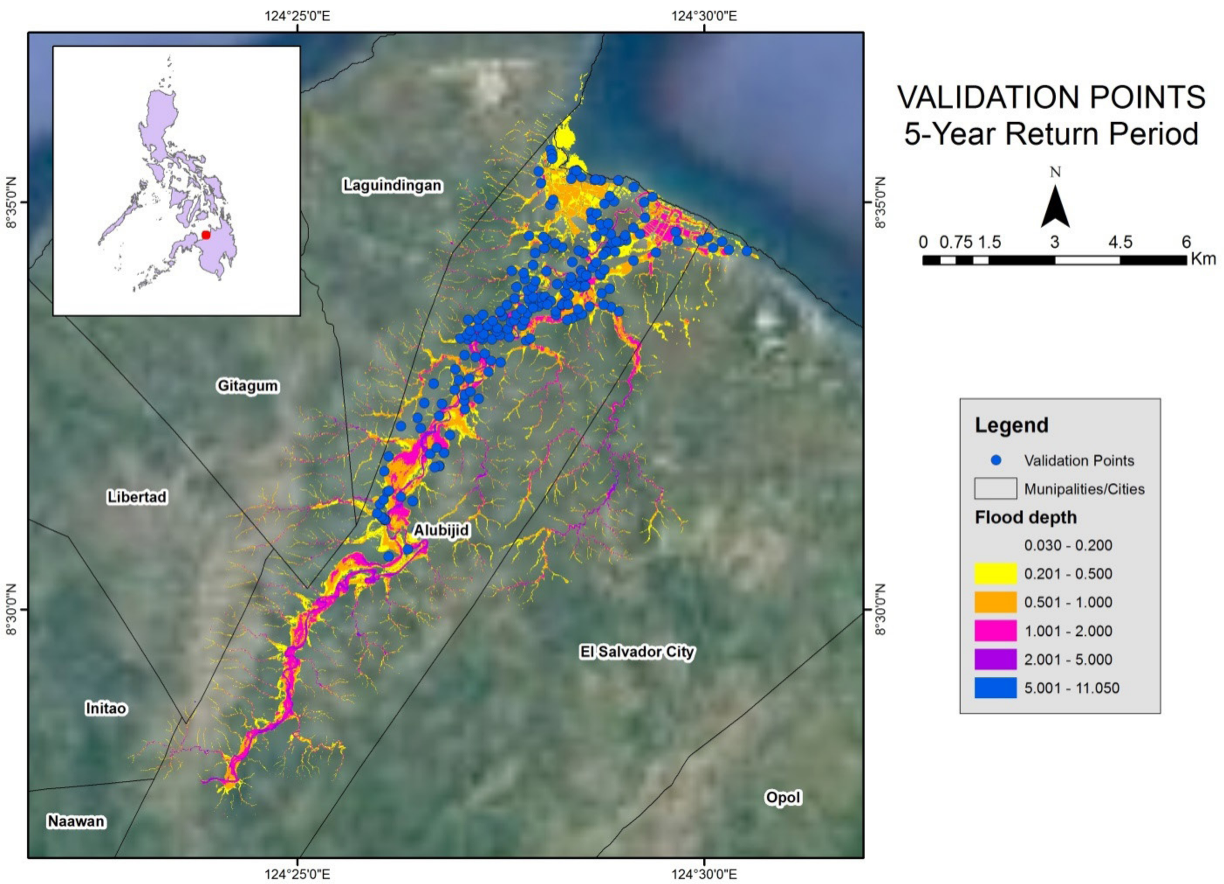


Figure 85. Alubijid Flood Validation Points

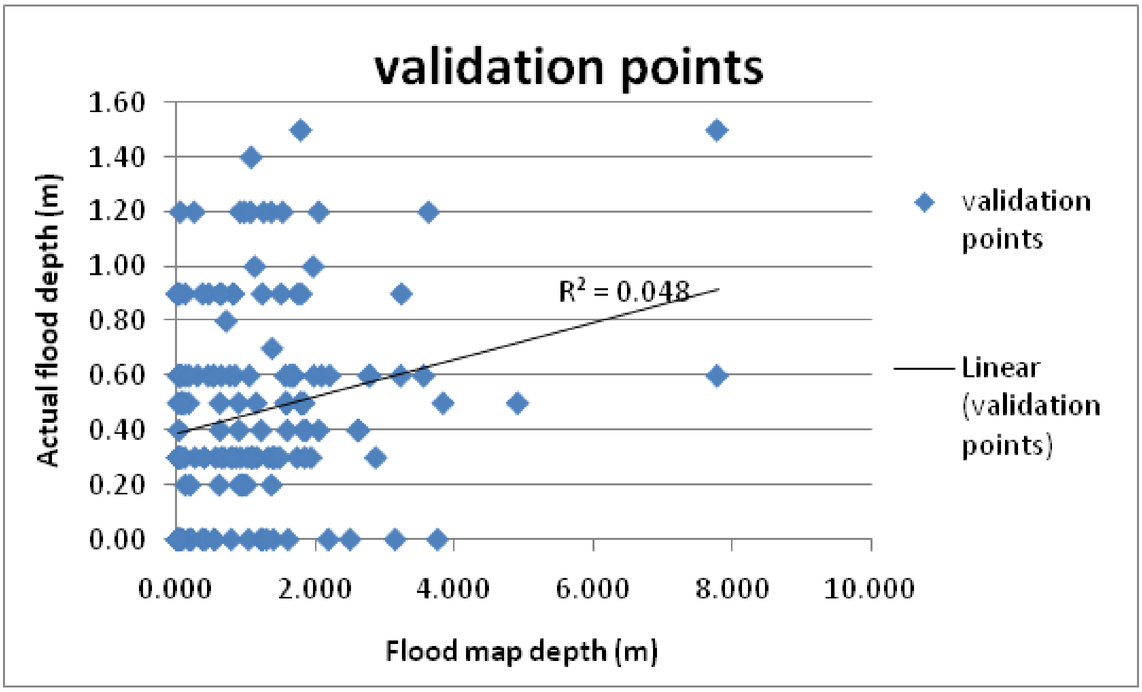


Figure 86. Flood map depth vs actual flood depth

Table 43. Actual flood vs simulated flood depth at differnent levels in the Silaga River Basin.

	SILAGA 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	17	6	8	9	4	0	44
	0.21-0.50	17	3	11	28	6	0	65
	0.51-1.00	14	4	12	14	7	1	52
	1.01-2.00	1	1	2	6	2	1	13
	2.01-5.00	0	0	0	0	0	0	0
	> 5.00	0	0	0	0	0	0	0
	Total	49	14	33	57	19	2	174

On the whole, the overall accuracy generated by the flood model is estimated at 21.84%, with 38 points correctly matching the actual flood depths. In addition, there were 56 points estimated one level above and below the correct flood depths, while there were 59 points and 21 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 97 points were overestimated, while a total of 39 points were underestimated in the modeled flood depths of Amro. Table 43 depicts the summary of the Accuracy Assessment in the Amro River Basin Survey.

Table 44. The summary of the Accuracy Assessment in the Silaga River Basin Survey

	No. of Points	%
Correct	38	**21.84**
Overestimated	97	**55.75**
Underestimated	39	**22.41**
Total	174	**100.00**

REFERENCES

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

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

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

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

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

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

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

ANNEXES

ANNEX 1. Technical Specifications of the Lidar Sensors Used In The Amro Floodplain Survey

Annex 1.A GEMINI SENSOR

Parameter	Specification
Operational envelope (1,2,3,4)	150-4000 m AGL, nominal
Laser wavelength	1064 nm
Horizontal accuracy (2)	1/5,500 x altitude, (m AGL)
Elevation accuracy (2)	<5-35 cm, 1 σ
Effective laser repetition rate	Programmable, 33-167 kHz
Position and orientation system	POS AV™ AP50 (OEM); 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 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 1.b PEGASUS SENSOR

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

ANNEX 2. NAMRIA Certificates of Reference Points Used in the LiDAR Survey

Annex 2.a ARA-26

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

September 21, 2015

CERTIFICATION

To whom it may concern:

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

	Province: **AURORA**	
	Station Name: **ARA-26**	
	Order: **2nd**	
Island: **LUZON**	Barangay: **POBLACION**	
Municipality: **DINALUNGAN**	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **16° 8' 30.72348"**	Longitude: **121° 57' 19.59448"**	Ellipsoidal Hgt: **11.05100 m.**
	WGS84 Coordinates	
Latitude: **16° 8' 25.02861"**	Longitude: **121° 57' 24.35223"**	Ellipsoidal Hgt: **52.36100 m.**
	PTM / PRS92 Coordinates	
Northing: **1785380.968 m.**	Easting: **602193.101 m.**	Zone: **3**
	UTM / PRS92 Coordinates	
Northing: **1,784,802.30**	Easting: **388,313.59**	Zone: **51**

Location Description

ARA-26
Is located at the Dinalungan Municipal Hall compound, between the mun. hall/bldg. and M. L. Quezon St. It is situated 20 m. W of the said hall, 10 m. NW of the flagpole and 1 m. N of the concrete pavement fronting the flagpole. Mark is the head of a 4 in. copper nail centered and embedded in a 30 cm. x 30 cm. concrete block flushed on the ground, with inscriptions "ARA-26 2006 NAMRIA".

Requesting Party: **UP-DREAM**
Purpose: **Reference**
OR Number: **8087355 I**
T.N.: **2015-2815**

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

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

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Annex 2.b ARA-27

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

October 12, 2015

CERTIFICATION

To whom it may concern:

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

	Province: **AURORA**	
	Station Name: **ARA-27**	
	Order: **2nd**	
Island: **LUZON**	Barangay: **BIANOAN**	
Municipality: **CASIGURAN**	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **16° 12' 29.85802"**	Longitude: **122° 2' 17.50426"**	Ellipsoidal Hgt: **20.69100 m.**
	WGS84 Coordinates	
Latitude: **16° 12' 24.15469"**	Longitude: **122° 2' 22.25588"**	Ellipsoidal Hgt: **61.99800 m.**
	PTM / PRS92 Coordinates	
Northing: **1792774.804 m.**	Easting: **611007.921 m.**	Zone: **3**
	UTM / PRS92 Coordinates	
Northing: **1,792,107.52**	Easting: **397,196.80**	Zone: **51**

Location Description

ARA-27
From Casiguran, travel S going to Brgy. Bianoan. Station is located inside the brgy. hall compound, about 9 m. NW of the mun. road centerline. It is also about 2.5 m. NW of these fence, about 12 m. SE of the S corner post of the multi-purpose hall and about 70 m. S of the brgy. hall. Mark is the head of a 4 in. copper nail centered and embedded in a 30 cm. x 30 cm. concrete block protruding 20 cm. above the ground, with inscriptions "ARA-27 2006 NAMRIA".

Requesting Party:	**Christopher Cruz / UP-DREAM**
Purpose:	**Reference**
OR Number:	**8088300 I**
T.N.:	**2015-3191**

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

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

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Annex 2.c AU-166

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

December 02, 2015

CERTIFICATION

To whom it may concern:

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

Province: **AURORA**
Station Name: **AU-166**

Island: **Luzon**	Municipality: **CASIGURAN**	Barangay: **TINIB**
Elevation: **4.6098 +/- 0.03 m.**	Order: **1st Order**	Datum: **Mean Sea Level**
Latitude:	Longitude:	

Location Description

AU-166

STATION MARK: The station marked by 4" copper nail set on top of a cement putty with an inscription placed around the mark as shown: AU-166, 2008 , NAMRIA.

ACCESS: The station BM AU-164 is in the Province of Aurora, Municipality of Casiguran, Brgy. of Tinib and along the left side of the road leading to Casiguran Town Proper and about 89.4m northwest of KM. post 348. Station is located on top northeast end of the footwall of Disulon Bridge about 48.5m East of the wooden electric post and about 4.4 m south from the center of the road.

Requesting Party:	**UP DREAM**
Purpose:	**Reference**
OR Number:	**8088735 I**
T.N.:	**2015-3965**

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

9 9 1 2 0 2 2 0 1 5 1 0 5 8 2 7

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

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

Annex 3.a AU-166

Project information		Coordinate System	
Name:	C:\Users\Windows User\Documents \Business Center - HCE\ara-26 to au-166.vce	Name:	UTM
		Datum:	PRS 92
Size:	162 KB	Zone:	51 North (123E)
Modified:	10/14/2015 6:29:11 PM (UTC:8)	Geoid:	EGMPH
Time zone:	China Standard Time	Vertical datum:	
Reference number:			
Description:			

Baseline Processing Report

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
ARA-26 --- AU-166 (B1)	ARA-26	AU-166	Fixed	0.054	0.095	45°51'47"	20199.216	-2.147

Acceptance Summary

Processed	Passed	Flag	Fail
1	1	0	0

ARA-26 - AU-166 (10:42:03 AM-1:52:36 PM) (S1)

Baseline observation:	ARA-26 --- AU-166 (B1)
Processed:	10/14/2015 6:34:09 PM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.054 m
Vertical precision:	0.095 m
RMS:	0.003 m
Maximum PDOP:	2.894
Ephemeris used:	Broadcast
Antenna model:	Trimble Relative
Processing start time:	9/12/2015 10:42:03 AM (Local: UTC+8hr)
Processing stop time:	9/12/2015 1:52:36 PM (Local: UTC+8hr)
Processing duration:	03:10:33
Processing interval:	1 second

1

Vector Components (Mark to Mark)

From:	ARA-26				
Grid		Local		Global	
Easting	388313.591 m	Latitude	N16°08'30.72348"	Latitude	N16°08'25.02861"
Northing	1784802.296 m	Longitude	E121°57'19.59448"	Longitude	E121°57'24.35223"
Elevation	8.948 m	Height	11.051 m	Height	52.361 m

To:	AU-166				
Grid		Local		Global	
Easting	402877.618 m	Latitude	N16°16'08.19430"	Latitude	N16°16'02.48145"
Northing	1798790.909 m	Longitude	E122°05'27.82224"	Longitude	E122°05'32.56842"
Elevation	7.173 m	Height	8.904 m	Height	50.153 m

Vector					
ΔEasting	14564.026 m	NS Fwd Azimuth	45°51'47"	ΔX	-10212.143 m
ΔNorthing	13988.613 m	Ellipsoid Dist.	20199.216 m	ΔY	-11018.203 m
ΔElevation	-1.775 m	ΔHeight	-2.147 m	ΔZ	13502.584 m

Standard Errors

Vector errors:					
σ ΔEasting	0.021 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.037 m
σ ΔNorthing	0.010 m	σ Ellipsoid Dist.	0.020 m	σ ΔY	0.033 m
σ ΔElevation	0.048 m	σ ΔHeight	0.048 m	σ ΔZ	0.021 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0013524839		
Y	-0.0009281985	0.0011010523	
Z	-0.0006829894	0.0005906398	0.0004458778

2

Annex 3.b ARA-3453

Vector Components (Mark to Mark)

From:	ARA-27				
Grid		Local		Global	
Easting	397196.803 m	Latitude	N16°12'29.85802"	Latitude	N16°12'24.15469"
Northing	1792107.515 m	Longitude	E122°02'17.50426"	Longitude	E122°02'22.25588"
Elevation	18.835 m	Height	20.691 m	Height	61.998 m

To:	ARA-3453				
Grid		Local		Global	
Easting	415760.804 m	Latitude	N16°23'38.03287"	Latitude	N16°23'32.30134"
Northing	1812560.274 m	Longitude	E122°12'40.04525"	Longitude	E122°12'44.78014"
Elevation	6.257 m	Height	7.168 m	Height	48.323 m

Vector					
ΔEasting	18564.000 m	NS Fwd Azimuth	41°57'31"	ΔX	-12578.907 m
ΔNorthing	20452.759 m	Ellipsoid Dist.	27629.376 m	ΔY	-14720.714 m
ΔElevation	-12.578 m	ΔHeight	-13.523 m	ΔZ	19709.257 m

Standard Errors

Vector errors:					
σ ΔEasting	0.004 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.013 m
σ ΔNorthing	0.004 m	σ Ellipsoid Dist.	0.004 m	σ ΔY	0.023 m
σ ΔElevation	0.027 m	σ ΔHeight	0.027 m	σ ΔZ	0.009 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0001781672		
Y	-0.0002874431	0.0005190766	
Z	-0.0001064173	0.0001901997	0.0000848166

Annex 3.c UP-CAS-1

Vector Components (Mark to Mark)

From:	AU-166				
Grid		Local		Global	
Easting	403017.282 m	Latitude	N16°16'02.65112"	Latitude	N16°16'02.65112"
Northing	1798729.576 m	Longitude	E122°05'32.50776"	Longitude	E122°05'32.50776"
Elevation	5.669 m	Height	48.649 m	Height	48.649 m

To:	UP-CAS-1				
Grid		Local		Global	
Easting	406048.663 m	Latitude	N16°16'32.74608"	Latitude	N16°16'32.74608"
Northing	1799641.171 m	Longitude	E122°07'14.49861"	Longitude	E122°07'14.49861"
Elevation	6.220 m	Height	48.834 m	Height	48.834 m

Vector					
ΔEasting	3031.381 m	NS Fwd Azimuth	73°00'31"	ΔX	-2427.451 m
ΔNorthing	911.595 m	Ellipsoid Dist.	3166.392 m	ΔY	-1828.920 m
ΔElevation	0.551 m	ΔHeight	0.185 m	ΔZ	888.101 m

ANNEX 4. The LIDAR Survey Team Composition

Data Acquisition Component Sub -Team	Designation	Name	Agency / Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	ENGR. CZAR JAKIRI SARMIENTO	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUÑA	UP-TCAGP
		ENGR. GEROME HIPOLITO	UP-TCAGP
FIELD TEAM			
LiDAR Operation	Senior Science Research Specialist (SSRS)	JASMINE ALVIAR	UP-TCAGP
	Research Associate (RA)	SANDRA POBLETE	UP-TCAGP
	RA	JONALYN GONZALES	UP-TCAGP
	RA	JERIEL PAUL ALAMBAN	UP-TCAGP
	RA	KENNETH QUISADO	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	ENGR. BRYLLE ADAM DE CASTRO	UP-TCAGP
	RA	ENGR. FRANK NICOLAS ILEJAY	UP-TCAGP
LiDAR Operation	Airborne Security	SSG JOHN ERIC CACANINDIN	PHILIPPINE AIR FORCE (PAF)
		SSG CHARISMA NAVARRO	PAF
	Pilot	CAPT. KHALIL CHI	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. ALBERT LIM	AAC
		CAPT. JUANITO NASTOR	AAC
		CAPT. DEXTER CABUDOL	AAC

ANNEX 5. Data Transfer Sheet for Amro Floodplain

Annex 5.a

DATA TRANSFER SHEET
palanan 9/22/15

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
4-Sep-15	2686	2BLK9C247A	gemini	na	354	516	230	13.6	16/105/7	19.6	na	77.7	1KB	1KB	3	na	Z:\DAC\RAW DATA
5-Sep-15	2690	2BLK9A248A	gemini	na	265	443	172	9.31	1/178/1	13.4	na	78.7	1KB	1KB	3/3	na	Z:\DAC\RAW DATA
6-Sep-15	2696	2CGYRH249B	gemini	na	63	133	49.8	na	na	7.85	na	13.7	1KB	1KB	23	na	Z:\DAC\RAW DATA
7-Sep-15	2700	2CGYRH250A	gemini	na	237	426	149	23.7	166/1	12.5	na	25.4	1KB	1KB	23	na	Z:\DAC\RAW DATA
8-Sep-15	2702	2BLK9AB251A	gemini	na	69	754	212	45.1	308	22.9	na	85.5	1KB	1KB	3/4/4	na	Z:\DAC\RAW DATA
9-Sep-15	2706	2BLK9B252A	gemini	na	184	299	122	14.6	[illegible]/99	9.51	na	70.5	1KB	1KB	4	na	Z:\DAC\RAW DATA
10-Sep-15	2710	2BLK11A253A	gemini	na	104	198	129	9	73	5.84	na	39.2	1KB	1KB	3	na	Z:\DAC\RAW DATA
12-Sep-15	2718	2BLK11A255A	gemini	na	88	177	136	7.02	58	5.02	na	44.3	1KB	1KB	3	na	Z:\DAC\RAW DATA
14-Sep-15	2726	2CGYRABE257A	gemini	na	321	543	171	2.25/25.3	20/201	19.5	na	80.3	1KB	1KB	22	na	Z:\DAC\RAW DATA
14-Sep-15	2728	2CGYRG257B	gemini	na	323	534	108	21.3	57/5/100/33	14.1	na	80.6	1KB	1KB	22	na	Z:\DAC\RAW DATA
15-Sep-15	2730	2BLK9CGYRFG258A	gemini	na	307/46	564	211	31.2	1/243	14.4	na	81.6	1KB	1KB	22/2	na	Z:\DAC\RAW DATA
15-Sep-15	2732	2CGYRC258B	gemini	na	534	504	104	138	17.2	10	na	80.3	1KB	1KB	23	na	Z:\DAC\RAW DATA

Received from

Name C Joaquin
Position RA
Signature

Received by

Name AC Bongat
Position SSRS
Signature 10/5/15

DATA TRANSFER SHEET
CAUAYAN-AURORA 3/27/2017

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	
March 20, 2017	23760P	1BLK11B079A	PEGASUS	138	422	5.43	108	NA	NA	2.39	NA	52.8	1KB	1KB	86	NA	Z:\DAC\RAWDATA\23760P
March 21, 2017	23764P	1BLK11C080A	PEGASUS	1.29	1103KB	7.19	174	NA	NA	`13GB	NA	79	1KB	1KB	144	NA	Z:\DAC\RAWDATA\23764P

Received from

Name R. Punzo
Position RA
Signature [signature]

Received by

Name AC Bongat
Position SSRS
Signature [signature] 3/27/17

ANNEX 6. Flight logs for the AmroFlight Missions

Annex 6.a Flight Log for 2710G Mission

PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 2710

1 LIDAR Operator: J. Gonzales	2 ALTM Model: Gemini	3 Mission Name: 2BLK11A253A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9122
7 Pilot: A. Lim	8 Co-Pilot: D. Alburo	9 Route: Casiguran, Aurora			
10 Date: 9/10/2015	12 Airport of Departure (Airport, City/Province): Cauayan City, Isabela		12 Airport of Arrival (Airport, City/Province): Cauayan City, Isabela		
13 Engine On: 0825H	14 Engine Off: 1042H	15 Total Engine Time: 2:17	16 Take off: 0830H	17 Landing: 1037H	18 Total Flight Time: 2:07
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; surveyed BLK11A

22 Problems and Solutions
- ☑ 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
Genaro Hipolito	Charisma M. Navarro	A. Lim	Jonathan S. Gonzales	G. Antonio
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

Annex 6.b Flight Log for 2718G Mission

PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 2718

1 LIDAR Operator: JP Alamban	2 ALTM Model: Gemini	3 Mission Name: 2BLK11A255A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9122
7 Pilot: A. Lim	8 Co-Pilot: D. Cabrales	9 Route: Cauayan			
10 Date: 9/12/2015	12 Airport of Departure (Airport, City/Province): Cauayan City, Isabela		12 Airport of Arrival (Airport, City/Province): Cauayan City, Isabela		
13 Engine On: 0930H	14 Engine Off: 1229H	15 Total Engine Time: 2:59	16 Take off: 0935H	17 Landing: 1224H	18 Total Flight Time: 2:54
19 Weather					

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 BLK11A

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
E. Hidalgo	Charisma M. Navarro	A. Lim	JP Alamban	G. Antonio
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

Annex 6.c Flight Log for 23760P Mission

PHIL-LiDAR 1 Data Acquisition Flight Log

Flight Log No.: 23760

1 LiDAR Operator: K. Quisado	2 ALTM Model: Peg	3 Mission Name: 1BLK11S078A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP-C9122
7 Pilot: K. Chi	8 Co-Pilot: J. Mastor	9 Route: Cauayan - Cauayan			
10 Date: March 20, 2014	12 Airport of Departure (Airport, City/Province): Cauayan		12 Airport of Arrival (Airport, City/Province): Cauayan		
13 Engine On: 0830	14 Engine Off: 1053	15 Total Engine Time: 2+23	16 Take off: 0835	17 Landing: 1048	18 Total Flight Time: 2+13
19 Weather	partly cloudy to heavy build up				

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

1 line only, heavy build up

22 Problems and Solutions

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	LiDAR Operator	Aircraft Mechanic/ LiDAR Technician
J. Alfiera	JEC Orgonindar	KHALIL S. CHI	Kenneth Quisado	
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 6.d Flight Log for 23764P Mission

PHIL-LiDAR 1 Data Acquisition Flight Log

Flight Log No.: 23764

1 LiDAR Operator: K Quisado	2 ALTM Model: Pegasus	3 Mission Name:	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RP-C9122
7 Pilot: K Chi	8 Co-Pilot: J Nastor	9 Route: Cavayan - Cavayan			
10 Date: March 21, 2017	12 Airport of Departure (Airport, City/Province): Cavayan		12 Airport of Arrival (Airport, City/Province): Cavayan		
13 Engine On: 0755	14 Engine Off: 1100	15 Total Engine Time: 3+05	16 Take off: 0800	17 Landing: 1055	18 Total Flight Time: 2+55
19 Weather	partly cloudy to heavy buildup				

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

7 lines only, cloud build up

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
[signature]	JEC CHANNDN	KHALIL S. CHI	Kenneth Quisado	[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

ANNEX 7. Flight Status Reports

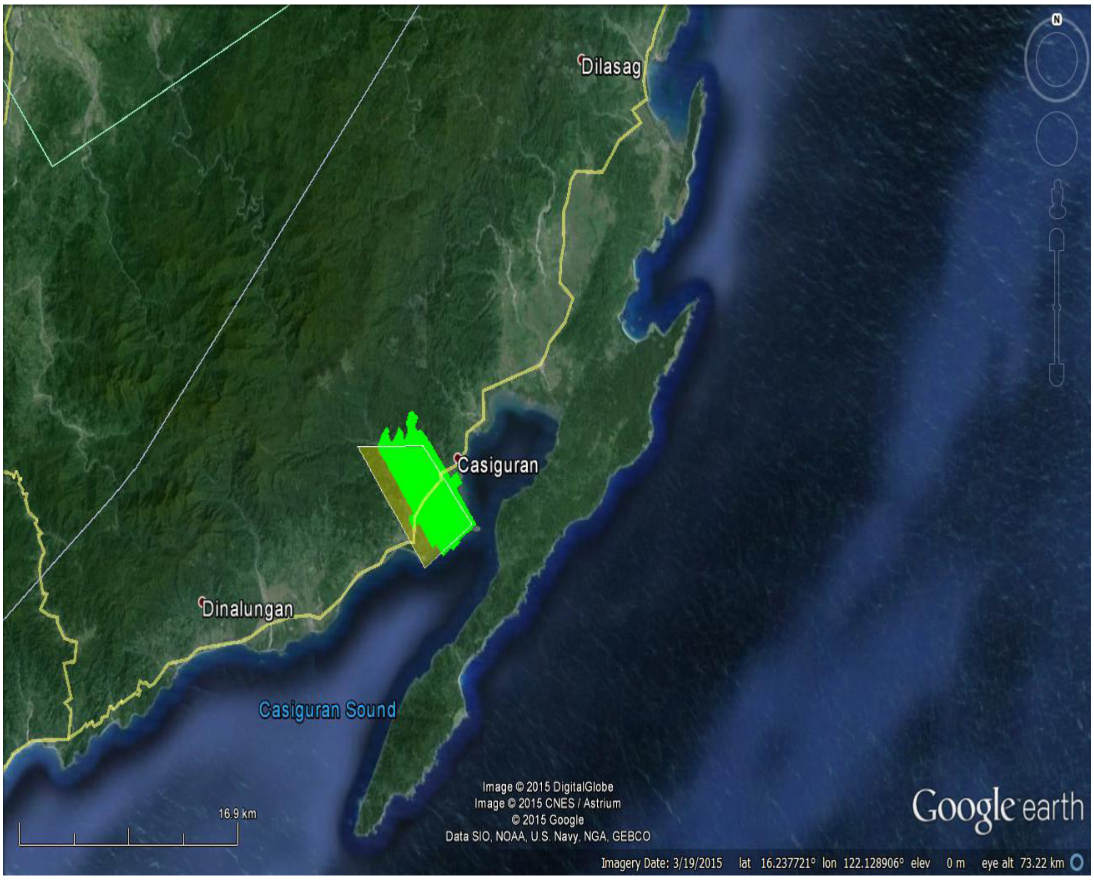
FLIGHT STATUS REPORT
AURORA
September 10-12, 2015 and March 20-21, 2017

FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
2710G	BLK 11A	2BLK11A253A	J. GONZALES	10-Sep-15	Successful; Start survey of BLK11A
2718G	BLK 11A	2BLK11A255A	J. ALAMBAN	12-Sep-15	Successful; Completed BLK11A
23760P	BLK11B	1BLK11B079A	K QUSIADO	20-March-17	Mission cut short due to heavy build up
23764P	BLK 11BC	1BLK11BC080A	K QUSIADO	21-March-17	Surveyed Amro floodplain at 1000m

LAS/SWATH BOUNDARIES PER MISSION FLIGHT

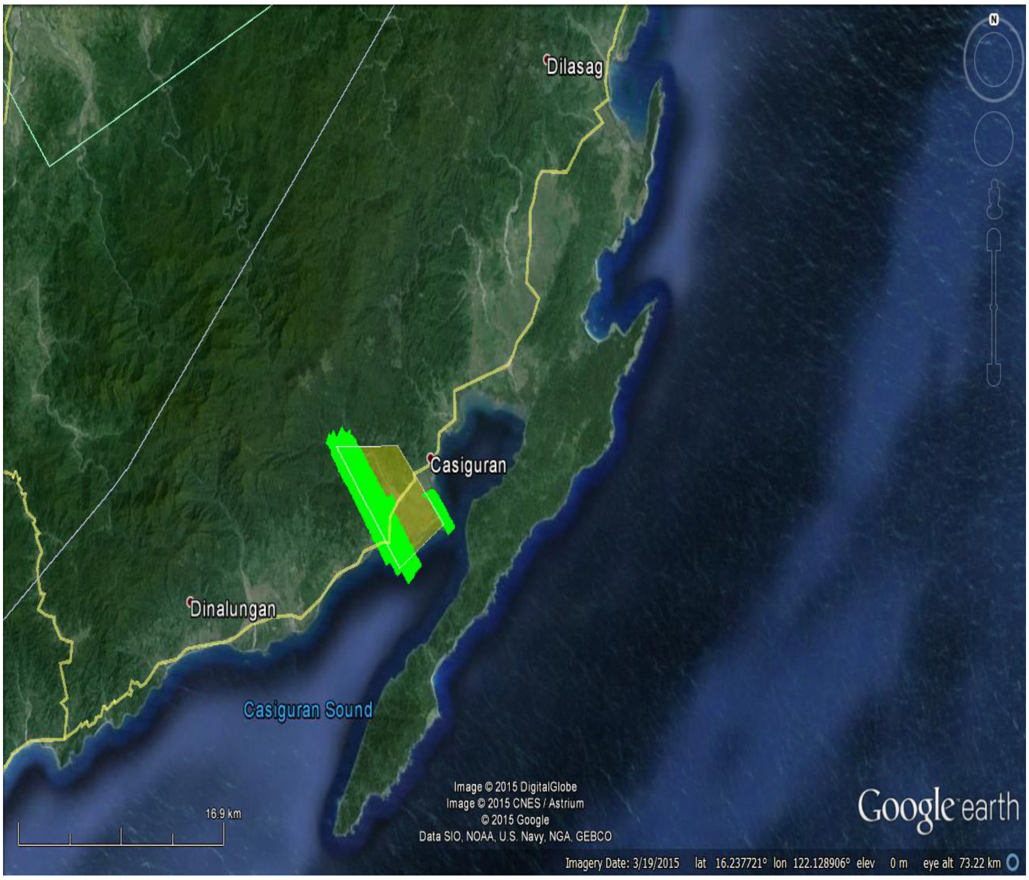
Flight No. : 2710
Area: BLK 11A
Mission Name: 2BLK11A253A
Parameters: Altitude: 900; Scan Frequency: 40; Scan Angle: 25;
Total Area Surveyed: 29.28 sq km

LAS/SWATH



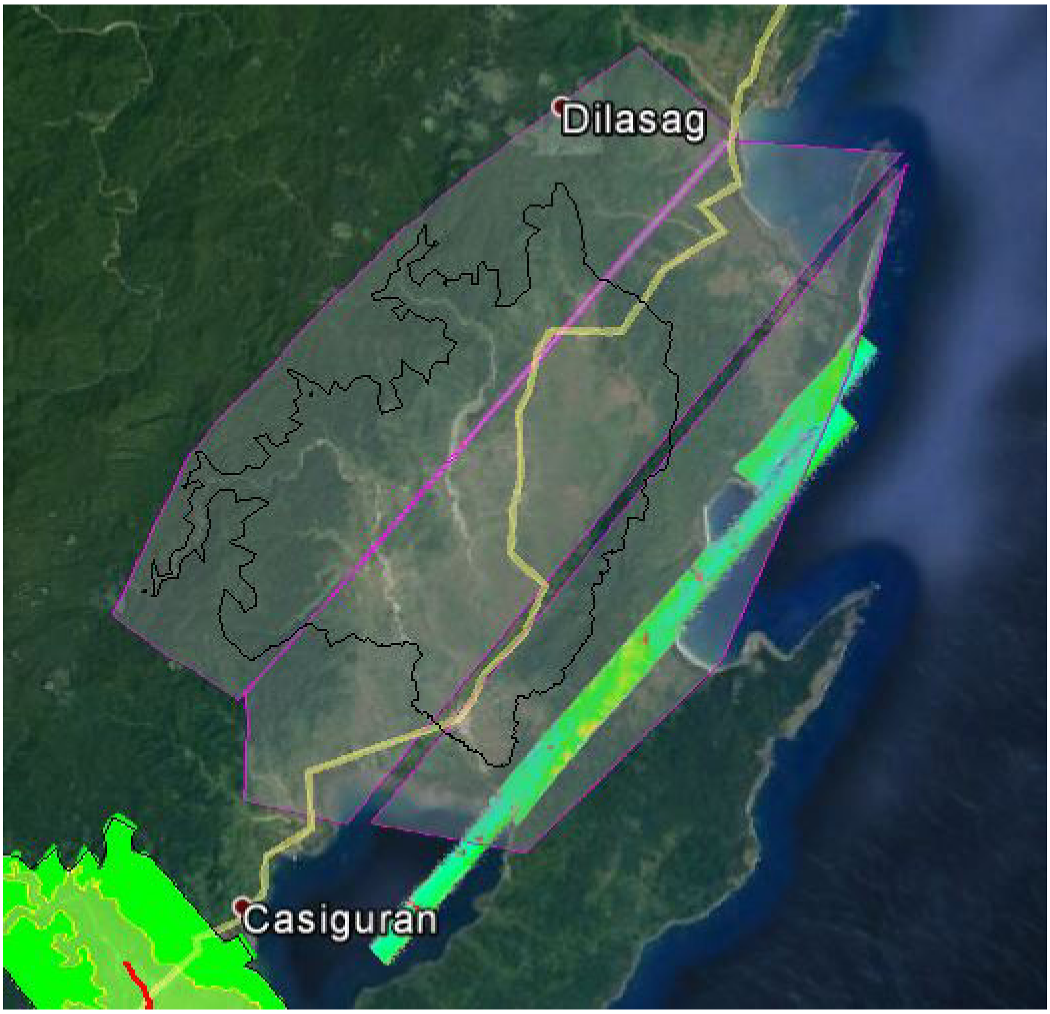
Flight No. : 2718G
Area: BLK 11A
Mission Name: 2BLK11A255A
Parameters: Altitude: 900; Scan Frequency: 40; Scan Angle: 25;
Total Area Surveyed: 26.47 sq km

LAS/SWATH



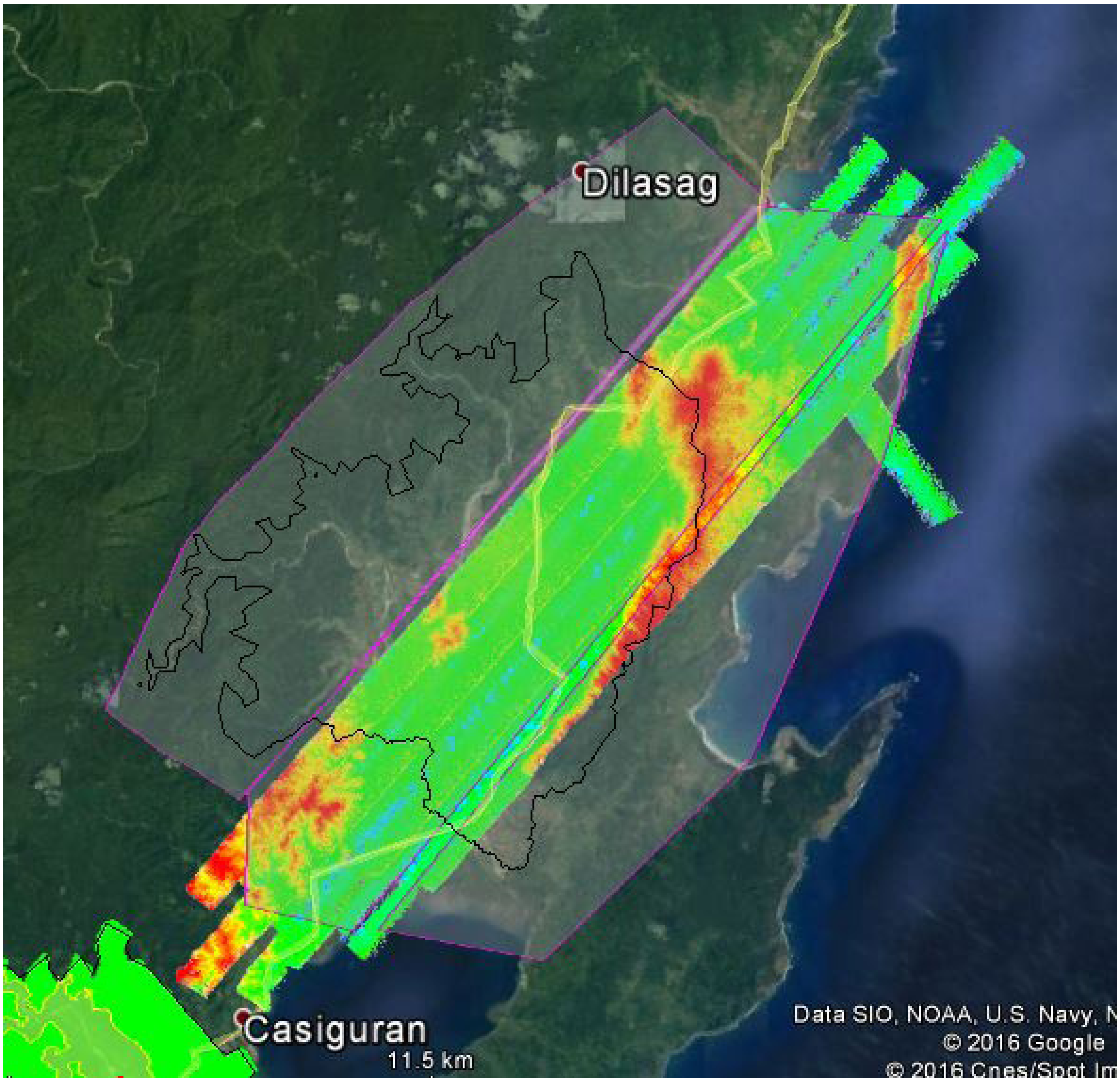
Flight No. :	23760P		
Area:	BLK 11B		
Mission Name:	1BLK11B079A		
Parameters:	FOV 50	SIDELAP 30	FLYING HT. 1000M

LAS/SWATH



Flight No. :	23764P		
Area:	BLK 11BC		
Mission Name:	1BLK11BC080A		
Parameters:	FOV 50	SIDELAP 30	FLYING HT. 1000M

LAS/SWATH



ANNEX 8. Mission Summary Reports

Flight Area	Palanan
Mission Name	Blk11A
Inclusive Flights	2710G, 2718G
Range data size	10.86 GB
POS	265 MB
Image	16.02 GB
Transfer date	10/5/15
Solution Status	
Number of Satellites (>6)	No
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	No
Smoothed Performance Metrics(in cm)	
RMSE for North Position (<4.0 cm)	1.1
RMSE for East Position (<4.0 cm)	1.2
RMSE for Down Position (<8.0 cm)	1.8
Boresight correction stdev (<0.001deg)	0.000020
IMU attitude correction stdev (<0.001deg)	0.000785
GPS position stdev (<0.01m)	0.0247
Minimum % overlap (>25)	71.09%
Ave point cloud density per sq.m. (>2.0)	5.43
Elevation difference between strips (<0.20m)	Yes
Number of 1km x 1km blocks	72
Maximum Height	453.24 m
Minimum Height	38.44 m
Classification (# of points)	
Ground	16,648,598
Low vegetation	11,700,361
Medium vegetation	97,740,576
High vegetation	119,230,524
Building	33,157
Orthophoto	Yes
Processed by	Engr. Analyn Naldo, Engr. Melanie Hingpit, Engr. Mark Sueden Lyle Magtalas

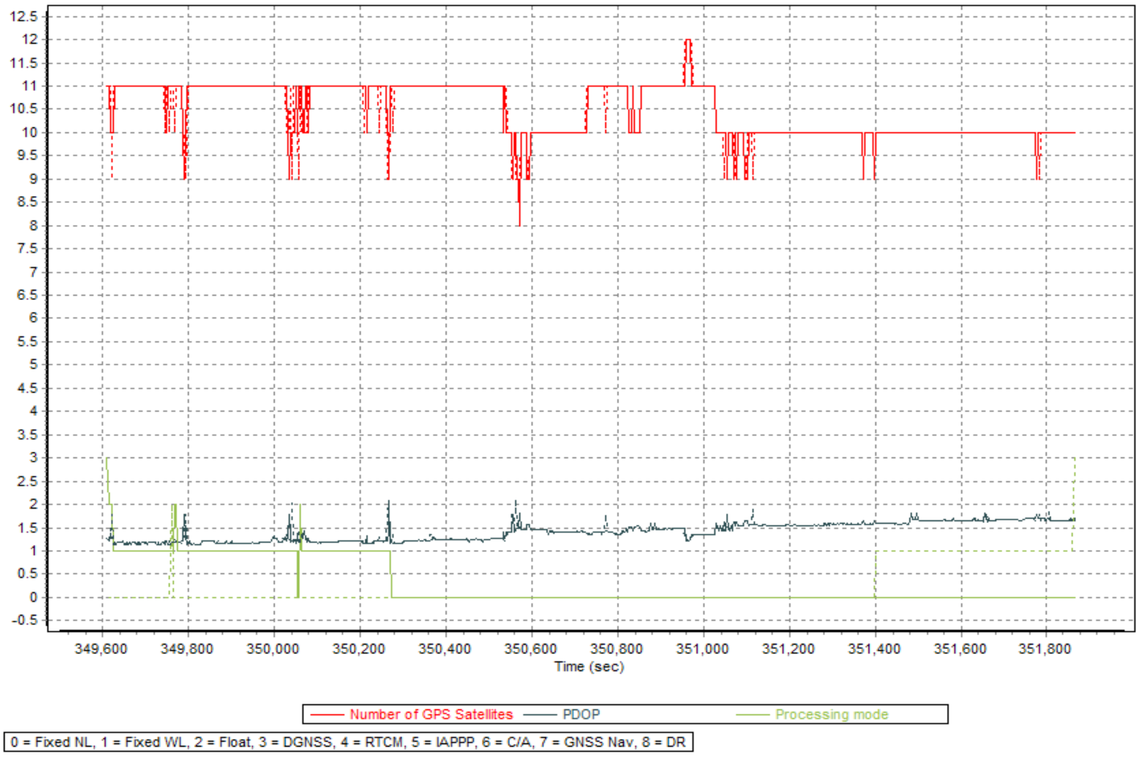


Figure 1.1.1Solution Status

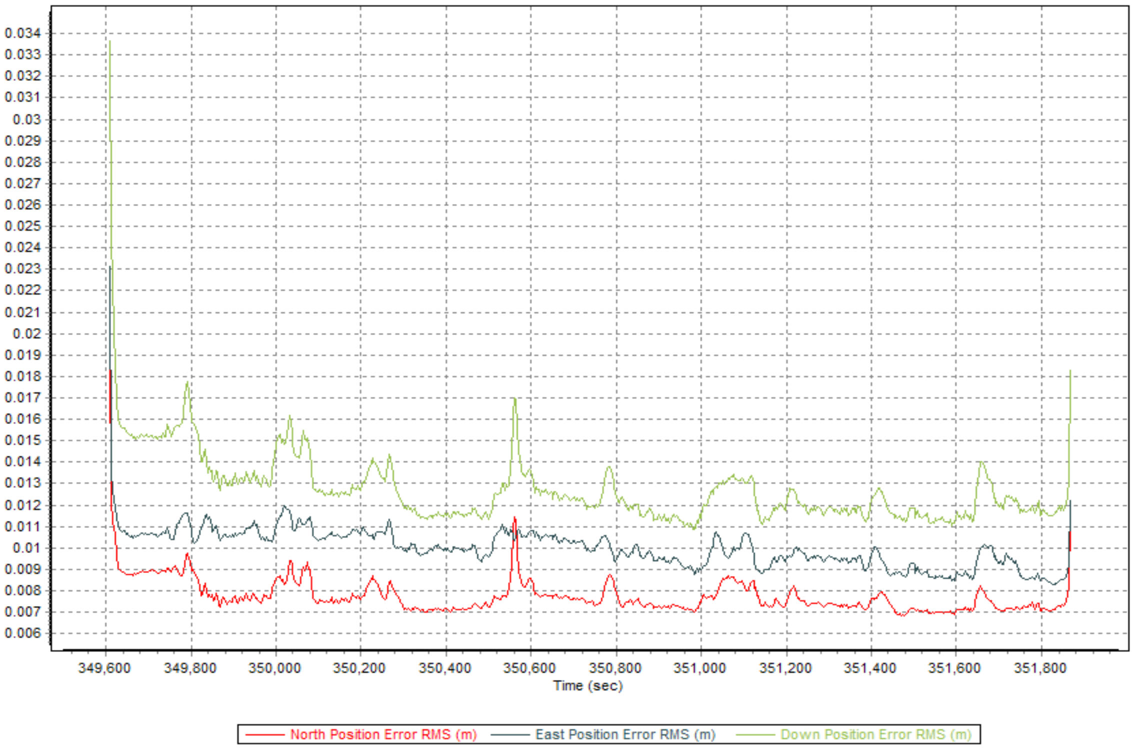


Figure 1.1.2.Smoothed Performance Metric Parameters

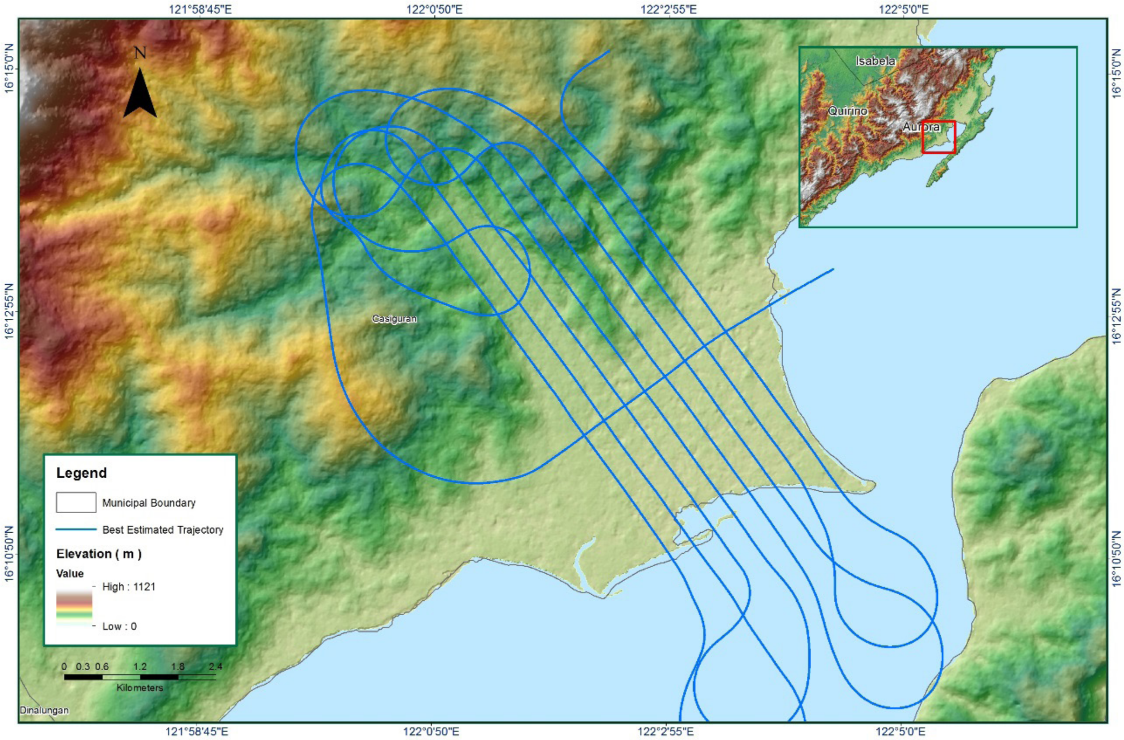


Figure 1.1.3.Best Estimated Trajectory

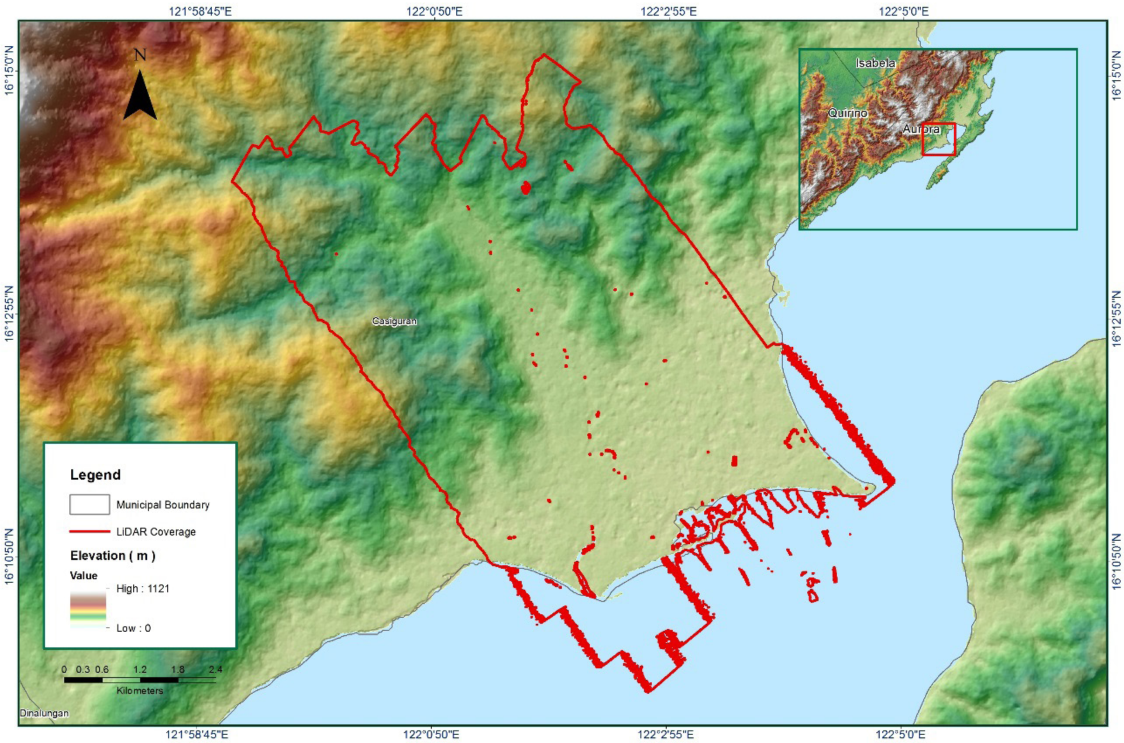


Figure 1.1.4.Coverage of LiDAR data

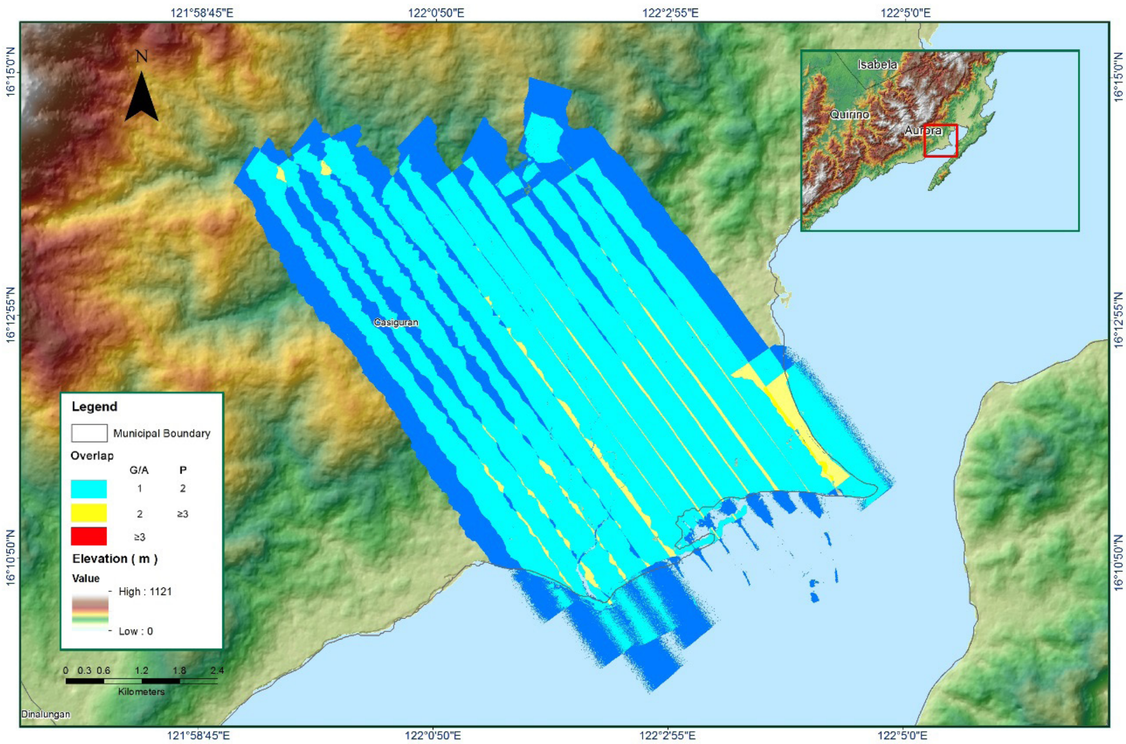


Figure 1.1.5.Image of data overlap

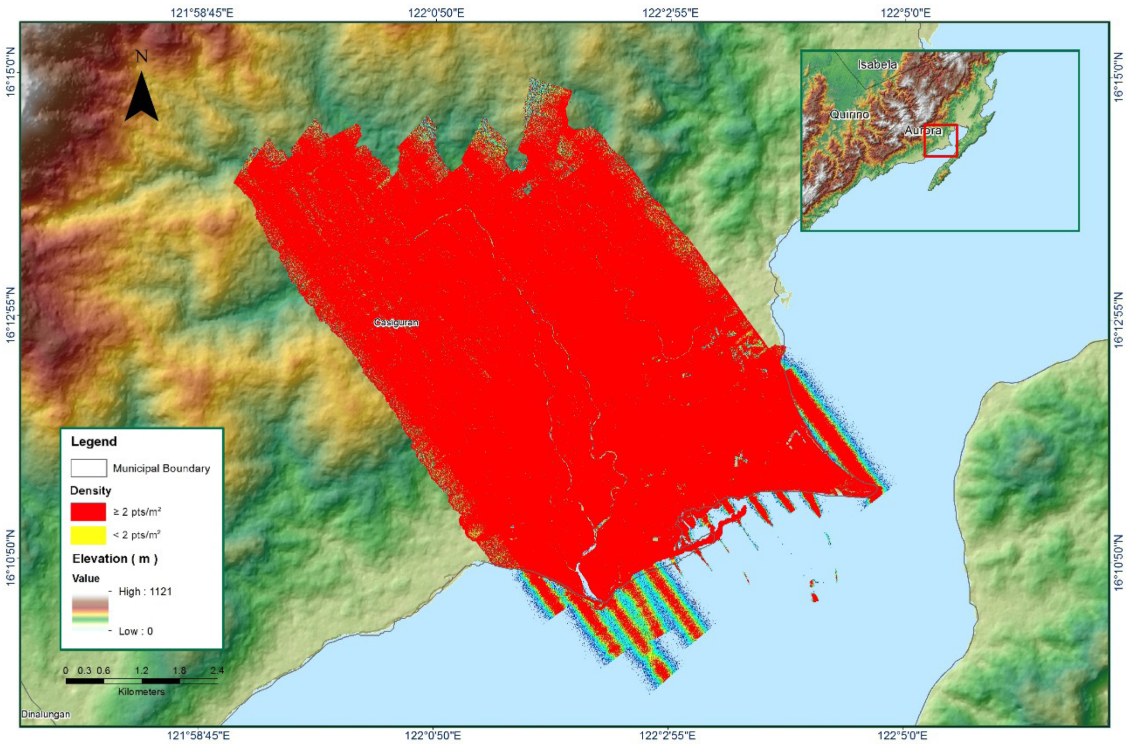


Figure 1.1.6.Density map of merged LiDAR data

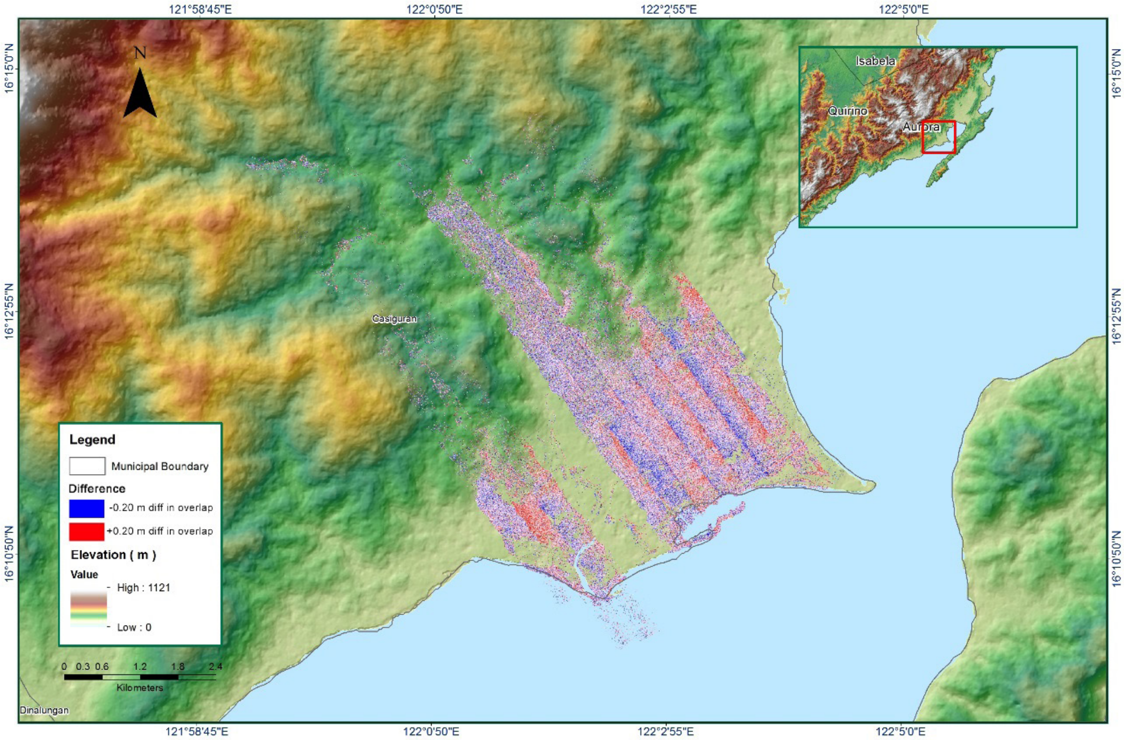


Figure 1.1.7.Elevation difference between flight lines

ANNEX 9. AmroModel 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
W210	4.5211	99	0	10.909	6.2315	Discharge	9.3961	0.8	Ratio to Peak	0.03
W220	3.2037	99	0	4.5336	2.5896	Discharge	2.7512	0.8	Ratio to Peak	0.03
W230	5.4476	99	0	3.7781	2.1581	Discharge	2.9348	0.8	Ratio to Peak	0.03
W240	3.0645	99	0	2.8239	1.613	Discharge	2.2163	0.8	Ratio to Peak	0.03
W250	3.4074	99	0	5.2061	2.9737	Discharge	1.3403	0.8	Ratio to Peak	0.03
W260	4.5522	99	0	2.6778	1.5295	Discharge	1.5579	0.8	Ratio to Peak	0.03
W270	1.8836	99	0	5.848	3.3404	Discharge	0.36766	0.8	Ratio to Peak	0.03
W280	7.6773	99	0	3.0206	1.7254	Discharge	2.4086	0.8	Ratio to Peak	0.03
W290	5.1661	99	0	2.5431	1.4526	Discharge	1.2424	0.8	Ratio to Peak	0.03
W300	3.3552	99	0	4.978	2.8434	Discharge	2.7551	0.8	Ratio to Peak	0.03
W310	2.8155	99	0	2.928	1.6724	Discharge	1.5196	0.8	Ratio to Peak	0.03
W320	2.8059	99	0	0.90967	0.5196	Discharge	0.24116	0.8	Ratio to Peak	0.03
W330	2.2625	99	0	9.4383	5.3912	Discharge	2.6422	0.8	Ratio to Peak	0.03
W340	12.321	99	0	4.1756	2.3851	Discharge	2.3338	0.8	Ratio to Peak	0.03
W350	10.084	99	0	5.5319	3.1598	Discharge	3.6600	0.8	Ratio to Peak	0.03
W360	2.5452	99	0	6.0379	3.4488	Discharge	1.6864	0.8	Ratio to Peak	0.03
W370	4.0226	99	0	6.4497	3.6841	Discharge	4.2889	0.8	Ratio to Peak	0.03
W380	2.0512	99	0	2.3682	1.3527	Discharge	0.64459	0.8	Ratio to Peak	0.03
W390	1.6699	99	0	5.35	3.0559	Discharge	0.83748	0.8	Ratio to Peak	0.03
W400	3.6246	99	0	5.0485	2.8837	Discharge	3.8518	0.8	Ratio to Peak	0.03

ANNEX10. Amro Model Reach Parameters

Reach Number	MuskingumCunge Channel Routing						
	Time Step Method	Length (m)	Slope	Man-ning's n	Shape	Width	Side Slope
R100	Automatic Fixed Interval	489.36	0.002044	0.05	Trapezoid	31.26	0.1185
R120	Automatic Fixed Interval	3962.1	0.025997	0.05	Trapezoid	31.26	0.1185
R140	Automatic Fixed Interval	3863	0.001	0.05	Trapezoid	31.26	0.1185
R160	Automatic Fixed Interval	10139	0.006608	0.05	Trapezoid	31.26	0.1185
R170	Automatic Fixed Interval	2627.7	0.001	0.05	Trapezoid	31.26	0.1185
R180	Automatic Fixed Interval	1193.8	0.001	0.05	Trapezoid	31.26	0.1185
R200	Automatic Fixed Interval	2179.2	0.001	0.05	Trapezoid	31.26	0.1185
R60	Automatic Fixed Interval	4406	0.024058	0.05	Trapezoid	31.26	0.1185
R90	Automatic Fixed Interval	2101	0.001	0.05	Trapezoid	31.26	0.1185

ANNEX 11. AmroField Validation Points

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Lat	Long					
1	16.26423	122.12931	0.130	0.50	0.37	TS Lando/ October 2015	5 Yr
2	16.26498	122.12902	0.640	0.40	-0.24	TS Lando/ October 2015	5 Yr
3	16.26717	122.13837	0.270	1.20	0.93	TS Harurot/ July 2003	5 Yr
4	16.26902	122.12363	1.660	0.60	-1.06	TS Yolanda/ November 2013	5 Yr
5	16.26916	122.12707	0.800	0.00	-0.80		5 Yr
6	16.26938	122.12756	0.430	0.00	-0.43		5 Yr
7	16.26962	122.12361	1.580	0.60	-0.98	TS Harurot/ July 2003	5 Yr
8	16.27002	122.12455	0.920	0.20	-0.72	TS Harurot/ July 2003	5 Yr
9	16.27003	122.12353	1.600	0.50	-1.10	TS Harurot/ July 2003	5 Yr
10	16.27022	122.12228	2.060	0.40	-1.66	TS Harurot/ July 2003	5 Yr
11	16.27023	122.12232	2.060	1.20	-0.86	TS Onyok/December 2015	5 Yr
12	16.27040	122.13120	0.910	0.40	-0.51	TS Lando/ October 2015	5 Yr
13	16.27105	122.11987	1.380	0.20	-1.18	TS Harurot/ July 2003	5 Yr
14	16.27106	122.12271	1.880	0.40	-1.48	TS Harurot/ July 2003	5 Yr
15	16.27106	122.11988	1.380	1.20	-0.18	2003 heavy rain	5 Yr
16	16.27106	122.12468	1.390	0.70	-0.69	TS Harurot/ July 2003	5 Yr
17	16.27131	122.10526	1.420	0.30	-1.12	TS Lando/ October 2015	5 Yr
18	16.27138	122.12329	1.800	0.50	-1.30	TS Lando/ October 2015	5 Yr
19	16.27139	122.12329	1.800	0.50	-1.30	TS Harurot/ July 2003	5 Yr
20	16.27139	122.12329	1.800	1.50	-0.30	TS Harurot/ July 2003	5 Yr
21	16.27152	122.12311	1.840	0.50	-1.34	TS Lando/ October 2015	5 Yr
22	16.27187	122.13643	0.930	1.20	0.27	TS Harurot/ July 2003	5 Yr
23	16.27204	122.10815	0.280	0.30	0.02	TS Lando/ October 2015	5 Yr
24	16.27264	122.11973	0.990	1.20	0.21	TS Harurot/ July 2003	5 Yr
25	16.27269	122.12538	0.070	1.20	1.13	TS Lando/ October 2015	5 Yr
26	16.27269	122.12538	1.540	1.20	-0.34	TS Lando/ October 2015	5 Yr
27	16.27308	122.11244	0.830	0.90	0.07	TS Lando/ October 2015	5 Yr
28	16.27333	122.11922	0.970	0.20	-0.77	TS Harurot/ July 2003	5 Yr
29	16.27334	122.11921	1.020	0.20	-0.82	TS Harurot/ July 2003	5 Yr
30	16.27389	122.12529	1.240	0.00	-1.24		5 Yr
31	16.27401	122.12125	1.590	0.50	-1.09	TS Lando/ October 2015	5 Yr
32	16.27428	122.12462	1.330	0.30	-1.03	TS Lando/ October 2015	5 Yr
33	16.27477	122.12437	1.400	0.30	-1.10	TS Lando/ October 2015	5 Yr
34	16.27477	122.11538	0.870	0.30	-0.57	TS Harurot/ July 2003	5 Yr
35	16.27483	122.12198	4.920	0.50	-4.42	TS Lando/ October 2015	5 Yr
36	16.27484	122.11533	0.790	0.30	-0.49	TS Harurot/ July 2003	5 Yr
37	16.27488	122.11969	1.270	1.20	-0.07	TS Lando/ October 2015	5 Yr
38	16.27504	122.12034	1.230	0.00	-1.23		5 Yr
39	16.27546	122.12027	1.160	0.50	-0.66	TS Lando/ October 2015	5 Yr
40	16.27606	122.12111	3.770	0.00	-3.77		5 Yr
41	16.27649	122.12333	1.460	0.30	-1.16	TS Harurot/ July 2003	5 Yr

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Lat	Long					
42	16.27700	122.16833	0.190	0.00	-0.19		5 Yr
43	16.27711	122.12330	1.410	0.00	-1.41		5 Yr
44	16.27730	122.12011	2.640	0.40	-2.24	TS Lando/ October 2015	5 Yr
45	16.27753	122.12406	0.780	0.60	-0.18	TS Lando/ October 2015	5 Yr
46	16.27771	122.12145	2.620	0.40	-2.22	TS Lando/ October 2015	5 Yr
47	16.27777	122.12147	3.250	0.90	-2.35	TS Harurot/ July 2003	5 Yr
48	16.27791	122.12463	0.320	0.60	0.28	TS Lando/ October 2015	5 Yr
49	16.27809	122.12105	1.810	0.90	-0.91	TS Harurot/ July 2003	5 Yr
50	16.27818	122.12410	0.470	0.60	0.13	TS Harurot/ July 2003	5 Yr
51	16.27821	122.12221	2.880	0.30	-2.58	TS Lando/ October 2015	5 Yr
52	16.27830	122.12510	0.070	0.60	0.53	TS Lando/ October 2015	5 Yr
53	16.27844	122.12022	0.830	0.90	0.07	TS Harurot/ July 2003	5 Yr
54	16.27847	122.11395	0.100	0.50	0.40	TS Harurot/ July 2003	5 Yr
55	16.27852	122.11391	0.100	0.50	0.40	TS Harurot/ July 2003	5 Yr
56	16.27859	122.12112	1.750	0.30	-1.45	TS Lando/ October 2015	5 Yr
57	16.27863	122.12151	2.200	0.00	-2.20		5 Yr
58	16.27882	122.12124	1.760	0.90	-0.86	TS Harurot/ July 2003	5 Yr
59	16.27883	122.12291	1.410	0.30	-1.11	TS Lando/ October 2015	5 Yr
60	16.27887	122.12498	0.040	0.60	0.56	TS Harurot/ July 2003	5 Yr
61	16.27887	122.12498	0.050	0.60	0.55	TS Harurot/ July 2003	5 Yr
62	16.27905	122.12209	3.850	0.50	-3.35	TS Lando/ October 2015	5 Yr
63	16.27920	122.12106	1.250	0.90	-0.35	TS Harurot/ July 2003	5 Yr
64	16.27927	122.12106	1.250	0.00	-1.25		5 Yr
65	16.27942	122.12265	1.230	0.40	-0.83	TS Lando/ October 2015	5 Yr
66	16.27955	122.12294	0.910	0.50	-0.41	TS Harurot/ July 2003	5 Yr
67	16.28002	122.12560	0.030	0.00	-0.03		5 Yr
68	16.28023	122.12395	0.060	0.30	0.24	TS Harurot/ July 2003	5 Yr
69	16.28027	122.12267	0.660	0.90	0.24	TS Lando/ October 2015	5 Yr
70	16.28027	122.12390	0.060	0.30	0.24	TS Lando/ October 2015	5 Yr
71	16.28028	122.12269	0.660	0.90	0.24	TS Harurot/ July 2003	5 Yr
72	16.28050	122.12590	0.030	0.30	0.27	TS Lando/ October 2015	5 Yr
73	16.28051	122.12274	0.640	0.90	0.26	TS Lando/ October 2015	5 Yr
74	16.28053	122.12274	0.640	0.50	-0.14	TS Lando/ October 2015	5 Yr
75	16.28070	122.12746	0.030	0.00	-0.03		5 Yr
76	16.28095	122.12074	1.400	0.30	-1.10	TS Harurot/ July 2003	5 Yr
77	16.28099	122.12536	0.130	0.30	0.17	TS Lando/ October 2015	5 Yr
78	16.28100	122.12325	0.070	0.30	0.23	TS Lando/ October 2015	5 Yr
79	16.28121	122.12421	0.050	0.30	0.25	TS Harurot/ July 2003	5 Yr
80	16.28122	122.14185	0.150	0.60	0.45	TS Labuyo/ September 2005	5 Yr
81	16.28140	122.12381	0.040	0.50	0.46	TS Harurot/ July 2003	5 Yr
82	16.28144	122.14157	0.230	0.00	-0.23	TS Harurot/ July 2003	5 Yr
83	16.28163	122.12274	0.420	0.30	-0.12	TS Lando/ October 2015	5 Yr

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Lat	Long					
84	16.28184	122.12448	0.060	0.60	0.54	TS Labuyo/ September 2005	5 Yr
85	16.28204	122.12239	0.580	0.30	-0.28	TS Lando/ October 2015	5 Yr
86	16.28208	122.13248	0.190	0.50	0.31	TS Lando/ October 2015	5 Yr
87	16.28218	122.12735	0.070	0.60	0.53	TS Harurot/ July 2003	5 Yr
88	16.28233	122.12731	0.220	0.00	-0.22		5 Yr
89	16.28237	122.13294	0.090	0.60	0.51	TS Lando/ October 2015	5 Yr
90	16.28241	122.12359	0.040	0.30	0.26	TS Lando/ October 2015	5 Yr
91	16.28242	122.12081	1.180	0.30	-0.88	TS Lando/ October 2015	5 Yr
92	16.28244	122.12091	1.140	1.00	-0.14	TS Lando/ October 2015	5 Yr
93	16.28249	122.09917	1.050	0.00	-1.05		5 Yr
94	16.28268	122.12105	1.130	0.30	-0.83	TS Harurot/ July 2003	5 Yr
95	16.28329	122.13593	0.730	0.80	0.07	TS Lando/ October 2015	5 Yr
96	16.28333	122.12731	0.200	0.60	0.40	TS Harurot/ July 2003	5 Yr
97	16.28355	122.12182	1.840	0.50	-1.34	TS Lando/ October 2015	5 Yr
98	16.28357	122.12185	1.840	0.40	-1.44	TS Harurot/ July 2003	5 Yr
99	16.28493	122.12353	0.030	0.90	0.87	TS Labuyo/ September 2005	5 Yr
100	16.28493	122.12353	0.480	0.90	0.42	TS Labuyo/ September 2005	5 Yr
101	16.28496	122.12204	1.500	0.30	-1.20	TS Harurot/ July 2003	5 Yr
102	16.28497	122.12712	0.860	0.60	-0.26	TS Harurot/ July 2003	5 Yr
103	16.28719	122.09626	0.030	0.00	-0.03		5 Yr
104	16.28726	122.12114	1.950	0.30	-1.65	TS Harurot/ July 2003	5 Yr
105	16.28737	122.12735	1.060	0.60	-0.46	TS Harurot/ July 2003	5 Yr
106	16.28835	122.12761	1.090	1.40	0.31	TS Lando/ October 2015	5 Yr
107	16.28842	122.12764	1.090	0.30	-0.79	TS Lando/ October 2015	5 Yr
108	16.28934	122.12950	1.980	1.00	-0.98	TS Lando/ October 2015	5 Yr
109	16.28958	122.11680	0.940	0.30	-0.64	TS Harurot/ July 2003	5 Yr
110	16.28998	122.11881	1.100	0.30	-0.80	TS Harurot/ July 2003	5 Yr
111	16.29085	122.13111	0.660	0.60	-0.06	TS Harurot/ July 2003	5 Yr
112	16.29235	122.13256	0.550	0.60	0.05	TS Harurot/ July 2003	5 Yr
113	16.29249	122.13290	0.550	0.60	0.05	TS Harurot/ July 2003	5 Yr
114	16.29318	122.13425	1.520	0.90	-0.62	TS Harurot/ July 2003	5 Yr
115	16.29337	122.13469	2.100	0.60	-1.50	TS Harurot/ July 2003	5 Yr
116	16.29355	122.12042	3.640	1.20	-2.44	TS Karen/ October 2016	5 Yr
117	16.29389	122.13581	3.570	0.60	-2.97	TS Harurot/ July 2003	5 Yr
118	16.29394	122.13586	2.800	0.60	-2.20	TS Lando/ October 2015	5 Yr
119	16.29430	122.13646	7.790	1.50	-6.29	TS Harurot/ July 2003	5 Yr
120	16.29434	122.13649	7.790	0.60	-7.19	TS Harurot/ July 2003	5 Yr
121	16.29521	122.13701	3.240	0.60	-2.64	TS Harurot/ July 2003	5 Yr
122	16.29704	122.09664	0.390	0.00	-0.39		5 Yr
123	16.29705	122.09664	0.390	0.00	-0.39		5 Yr

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Lat	Long					
124	16.29742	122.13931	2.220	0.60	-1.62	TS Harurot/ July 2003	5 Yr
125	16.29783	122.13997	1.990	0.60	-1.39	TS Harurot/ July 2003	5 Yr
126	16.29892	122.14094	1.710	0.60	-1.11	TS Harurot/ July 2003	5 Yr
127	16.30076	122.14058	1.690	0.60	-1.09	TS Harurot/ July 2003	5 Yr
128	16.30177	122.14077	3.160	0.00	-3.16		5 Yr
129	16.30180	122.14079	2.780	0.60	-2.18	TS Harurot/ July 2003	5 Yr
130	16.30492	122.09621	0.030	0.00	-0.03		5 Yr
131	16.30535	122.14378	1.860	0.30	-1.56	TS Harurot/ July 2003	5 Yr
132	16.30685	122.14462	1.640	0.60	-1.04	TS Harurot/ July 2003	5 Yr
133	16.30693	122.14456	1.610	0.40	-1.21	TS Harurot/ July 2003	5 Yr
134	16.30719	122.14458	1.620	0.00	-1.62		5 Yr
135	16.30731	122.14457	1.590	0.50	-1.09	TS Harurot/ July 2003	5 Yr
136	16.30874	122.09569	0.030	0.00	-0.03		5 Yr
137	16.30936	122.14502	1.080	1.20	0.12	TS Lando/ October 2015	5 Yr
138	16.30939	122.14495	1.030	0.30	-0.73	TS Lando/ October 2015	5 Yr
139	16.31016	122.14575	1.090	0.30	-0.79	TS Harurot/ July 2003	5 Yr
140	16.31103	122.14652	0.700	0.30	-0.40	TS Harurot/ July 2003	5 Yr
141	16.31112	122.14661	0.660	0.30	-0.36	TS Harurot/ July 2003	5 Yr
142	16.31131	122.14676	0.640	0.90	0.26	TS Harurot/ July 2003	5 Yr
143	16.31171	122.14715	0.820	0.30	-0.52	TS Harurot/ July 2003	5 Yr
144	16.31237	122.14640	0.970	0.20	-0.77	TS Harurot/ July 2003	5 Yr
145	16.31261	122.11054	0.080	0.50	0.42	TS Harurot/ July 2003	5 Yr
146	16.31266	122.11108	0.080	0.50	0.42	TS Harurot/ July 2003	5 Yr
147	16.31310	122.14491	0.040	0.30	0.26	TS Harurot/ July 2003	5 Yr
148	16.31325	122.11180	0.140	0.90	0.76	TS Harurot/ July 2003	5 Yr
149	16.31337	122.14426	0.090	0.30	0.21	TS Harurot/ July 2003	5 Yr
150	16.31365	122.14388	0.140	0.20	0.06	TS Harurot/ July 2003	5 Yr
151	16.31410	122.11000	0.060	0.90	0.84	TS Harurot/ July 2003	5 Yr
152	16.31465	122.14169	0.560	0.00	-0.56		5 Yr
153	16.31468	122.14181	0.560	0.00	-0.56		5 Yr
154	16.31480	122.11263	0.030	0.00	-0.03		5 Yr
155	16.31492	122.11117	0.030	0.90	0.87	TS Harurot/ July 2003	5 Yr
156	16.31587	122.09823	0.050	0.00	-0.05		5 Yr
157	16.31611	122.10982	0.030	0.90	0.87	TS Harurot/ July 2003	5 Yr
158	16.31611	122.10982	0.390	0.90	0.51	TS Harurot/ July 2003	5 Yr
159	16.31629	122.09765	0.090	0.00	-0.09		5 Yr
160	16.31629	122.09766	0.090	0.00	-0.09		5 Yr
161	16.31662	122.11062	0.050	0.90	0.85	TS Harurot/ July 2003	5 Yr
162	16.31800	122.10208	2.510	0.00	-2.51		5 Yr
163	16.31925	122.09756	0.060	0.00	-0.06		5 Yr
164	16.32083	122.12152	0.060	0.00	-0.06		5 Yr
165	16.32086	122.12159	0.060	0.00	-0.06		5 Yr
166	16.32272	122.12187	0.030	0.00	-0.03		5 Yr

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Lat	Long					
167	16.32372	122.12231	0.060	0.00	-0.06		5 Yr
168	16.32652	122.12315	1.310	0.00	-1.31		5 Yr
169	16.32721	122.12472	0.030	0.00	-0.03		5 Yr
170	16.33109	122.12778	0.630	0.20	-0.43	TS Harurot/ July 2003	5 Yr
171	16.33131	122.12919	0.960	0.20	-0.76	TS Harurot/ July 2003	5 Yr
172	16.33137	122.13076	0.410	0.30	-0.11	TS Harurot/ July 2003	5 Yr
173	16.33152	122.13406	0.050	0.40	0.35	TS Harurot/ July 2003	5 Yr
174	16.33164	122.12734	0.210	0.20	-0.01	TS Harurot/ July 2003	5 Yr

ANNEX 12. Educational Institutions Affected by Flooding in Amro Floodplain

ANNEX 13. Health Institutions Affected by Flooding in Amro Floodplain