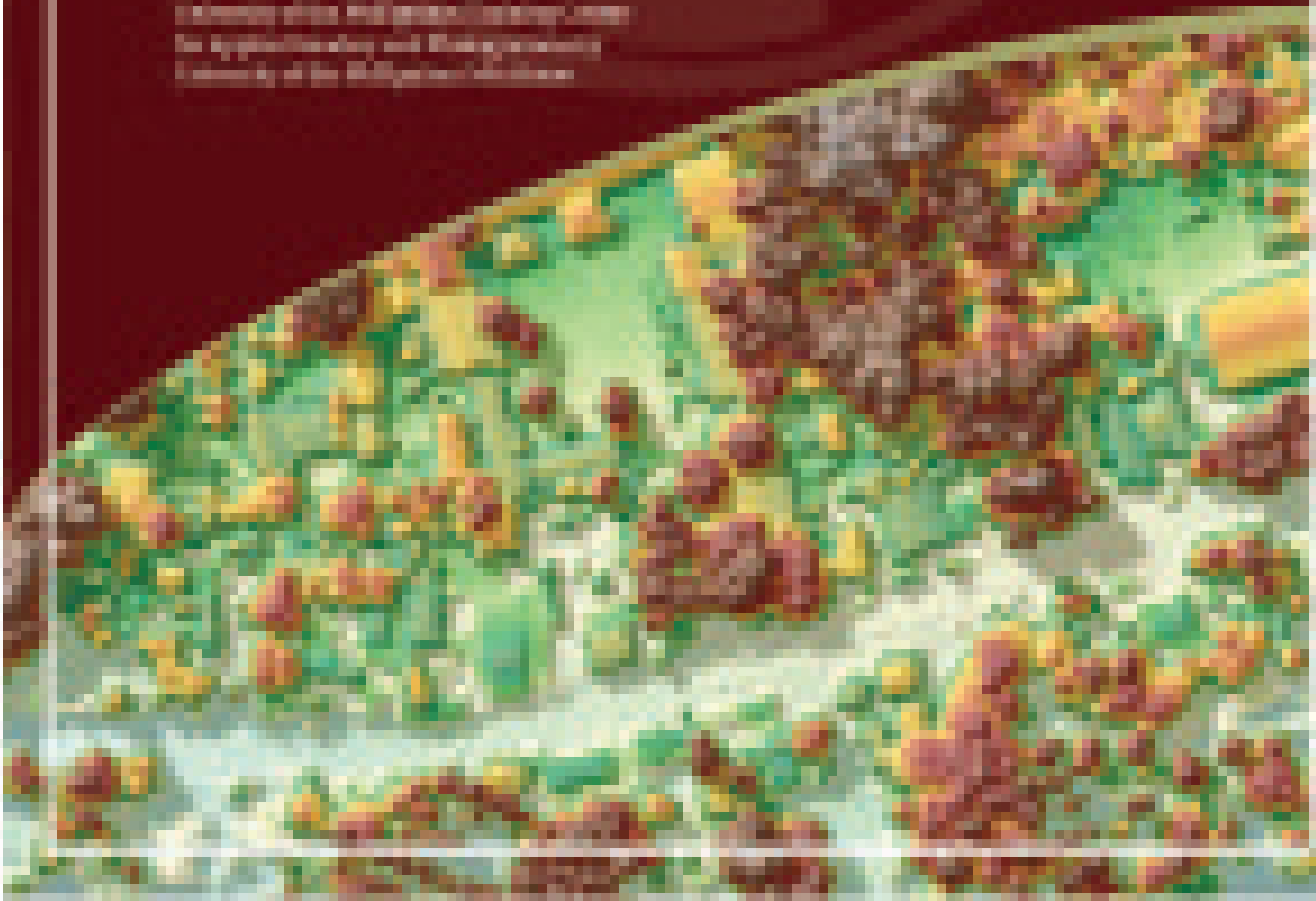
HAZARD MAPPING OF THE PHILIPPINES USING LIDAR (PHIL-LIDAR 1)

LiDAR Surveys and Flood Mapping of Casauman River



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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
kts	knots
LAS	LiDAR Data Exchange File format
LC	Low Chord
LGU	local government unit
LiDAR	Light Detection and Ranging
LMS	LiDAR Mapping Suite
m AGL	meters Above Ground Level
MCM	
MMS	Mobile Mapping Suite
MSL	mean sea level
NSTC	Northern Subtropical Convergence
PAF	Philippine Air Force
PAGASA	Philippine Atmospheric Geophysical and Astronomical Services Administration
PDOP	Positional Dilution of Precision
PPK	Post-Processed Kinematic [technique]
PRF	Pulse Repetition Frequency
PTM	Philippine Transverse Mercator
QC	Quality Check
QT	Quick Terrain [Modeler]
RA	Research Associate
RCBO	River Basin Control Office
RIDF	Rainfall-Intensity-Duration-Frequency
RMSE	Root Mean Square Error
SAR	Synthetic Aperture Radar
SCS	Soil Conservation Service
SRTM	Shuttle Radar Topography Mission
SRS	Science Research Specialist
SSG	Special Service Group
TBC	Thermal Barrier Coatings
UPMin	University of the Philippines Mindanao
UP-TCAGP	University of the Philippines – Training Center for Applied Geodesy and Photogrammetry
UTM	Universal Transverse Mercator
WGS	World Geodetic System

CHAPTER 1: OVERVIEW OF THE PROGRAM AND CASAUMAN RIVER

Enrico C. Paringit, Dr. Eng., and Dr. Joseph E. Acosta

1.1 Background of the Phil-LiDAR 1 Program

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

Also, the program was aimed at producing an up-to-date and detailed national elevation dataset suitable for 1:5,000 scale mapping, with 50 cm and 20 cm horizontal and vertical accuracies, respectively. These accuracies were achieved through the use of the state-of-the-art Light Detection and Ranging (LiDAR) airborne technology procured by the project through DOST. The methods applied in this report are thoroughly described in a separate publication entitled "FLOOD MAPPING OF RIVERS IN THE PHILIPPINES USING AIRBORNE LiDAR: METHODS (Paringit, et. al. 2017) available separately.

The implementing partner university for the Phil-LiDAR 1 Program is the University of the Philippines Mindanao (UPMin). UPMin 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 13 river basins in the Davao Region. The university is located in Davao City in the province of Davao del Sur, Philippines.

1.2 Overview of the CASAUMAN River Basin

The Casauman River is located in the Municipality of Manay in Davao Oriental, on the south-eastern side of Mindanao. It traverses through this municipality with its outlet situated at Manay Bay facing the Pacific Ocean. Manay is a municipality in Davao Oriental and is bounded by the municipality of Caraga on the north, Lupon and Maragusan towns on the west, the municipality of Tarragona on the south, and the Pacific Ocean on the east (Bugayong et.al., 2016). Casauman watershed has a rugged topography consisting of rolling hills, mountains, and valleys. It has 55 subbasins, 27 junctions, and 27 reaches.

Manay was originally a barrio of the town of Caraga, in the northeastern side of Casauman River. In 1897, the barrio of Manay was created into a municipality by virtue of the Administrative Code of the Department of Mindanao and Sulu (Lancion et.al, 1995). The name of the municipality came from the word Manay which is a local word used to address an older sister with due respect. It is said that in the year 1860, three sisters went to the river to wash their clothes and take a bath. Noticing a galleon carrying Spanish soldiers, the sisters ran leaving behind the youngest shouting "Manay! Manay!" calling out to her sisters, thus the name of the municipality. Mandayas and Mansakas were pioneer settlers in Manay. These ethnic groups lived along the river and mountain tops and was ruled by a Bagani. Jesuit missionaries established a settlement of the Mandayas near the sources of the Casauman River and successfully converted them into Christianity (Caraga Antigua, 1885; Official Website of Manay, 2017).

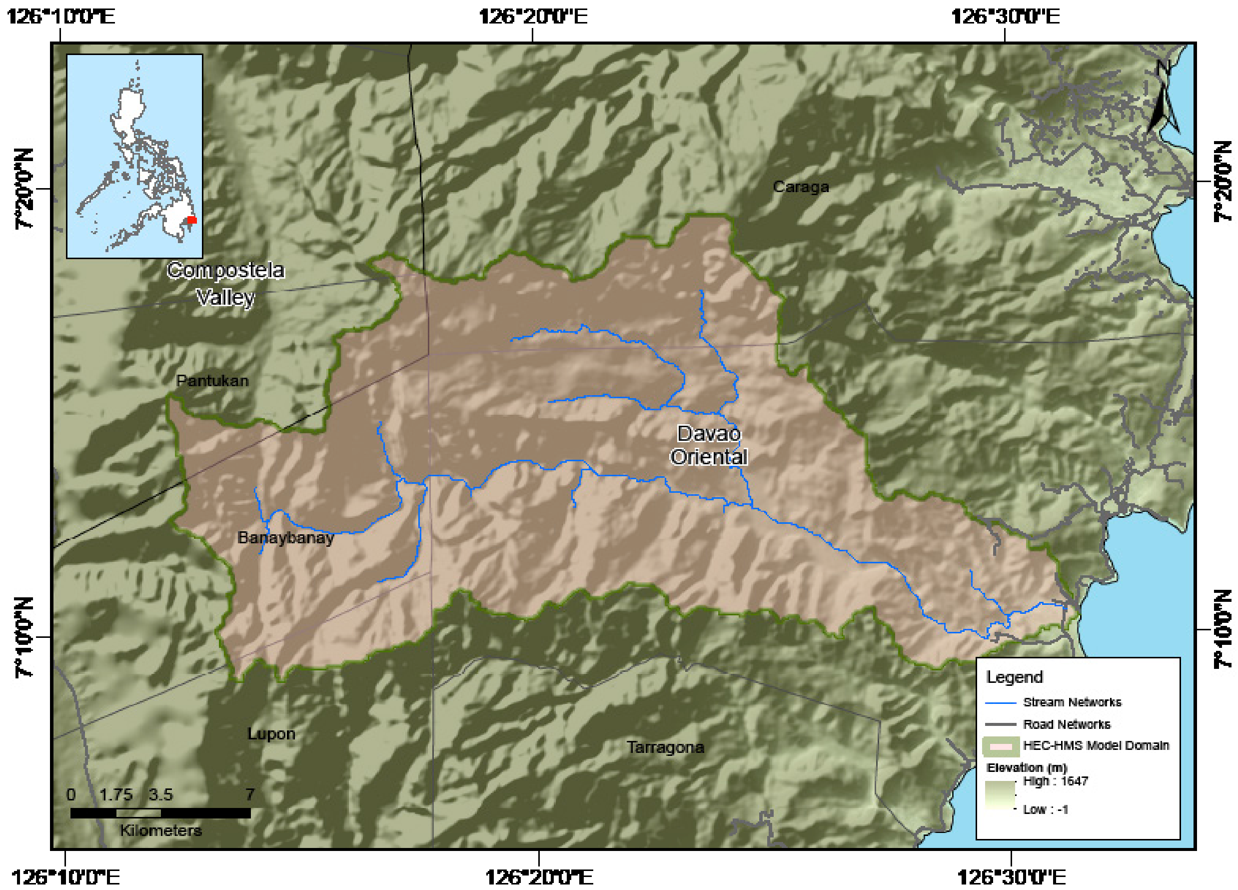


Figure 1. Map of Casauman River Basin (in brown).

Visitas de Caraga in 1873 was the name of the Spanish Mission on the eastern side of Mindanao that aimed to convert local tribes to Christianity. Worth mentioning included Manay, Manreza, Zaragosa, Capasnan, and Casauman (Official Website of Manay, 2017). Lake Diomaboc is a small upland lake located at the foot of Mt. Kampalili in Sitio Matabang, Brgy. Taocanga, Manay and is considered to be the largest lake in Davao Oriental with approximately 13 hectares in area. It is home to different species of flora and fauna including the newest described species of Rafflesia which was recently discovered. The indigenous community of Taocanga works hand in hand with the Local Government Unit of Manay and Non-Government Philippine Eagle Foundation in the protection and preservation (Balete, 2010; Official Website of Manay, 2017).

Casauman River is one of the two (2) major rivers that drain the Coal Project of the Titan Mining and Energy Corporation (TMEC) in Davao Oriental. It is located north of the said project area, originating from Mount Kampalili and flows towards the Philippine Sea (COAL Asia Holdings and Payawal, 2012).

There are four (4) flood prone barangays namely Holy Cross, Zaragosa, Old Macopa, and Del Pilar that were confirmed as flood prone areas by the LGU officials and barangay officials present during the courtesy call held at Municipal Mayor's Residence last February 25, 2015.

According to locals, from the year 2012 to 2015, local rainfall and upstream rainfall are the usual cause of flooding near the river. However, PAGASA only noted typhoon events such as Pablo in 2012, Agaton and Amang in 2014. Although floods occur every year, it is mostly only along the river banks and does not swell up for long. Based from the UP Mindanao DVC reconnaissance survey, all nearby residences along the Casauman River in the downstream area experienced floods.

CHAPTER 2: LIDAR ACQUISITION IN CASAUMAN FLOODPLAIN

Engr. Louie P. Balicanta, Engr. Christopher Cruz, Lovely Gracia Acuña, Engr. Gerome Hipolito, Ms. Julie Pearl S. Mars, and Ms. Kristine Joy P. Andaya

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

2.1 Flight Plans

To initiate the LiDAR acquisition survey of the Casauman floodplain, the Data Acquisition Component (DAC) created flight plans within the delineated priority area for Casauman Floodplain in Davao Oriental. These flight missions were planned for 15 lines and ran for at most four and a half hours (4.5) including take-off, landing and turning time. The flight planning parameters for the LiDAR system are outlined in Table 1. Figure 2 shows the flight plan for Casauman floodplain survey.

Table 1. Flight planning parameters for the Gemini LiDAR system.

Block Name	Flying Height (AGL)	Overlap (%)	Field of View	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency	Average Speed	Average Turn Time (minutes)
BLK80A	1000	30	40	100	50	130	5
BLK80B	1000	30	40	100	50	130	5
BLK83A	1000	40	40	100	50	130	5
BLK84B	1000	40	40	100	50	130	5
BLK85C	1000	40	40	100	50	130	5
BLK86B	1000	30	40	100	50	130	5
BLK86C	850	30	40	125	50	130	5

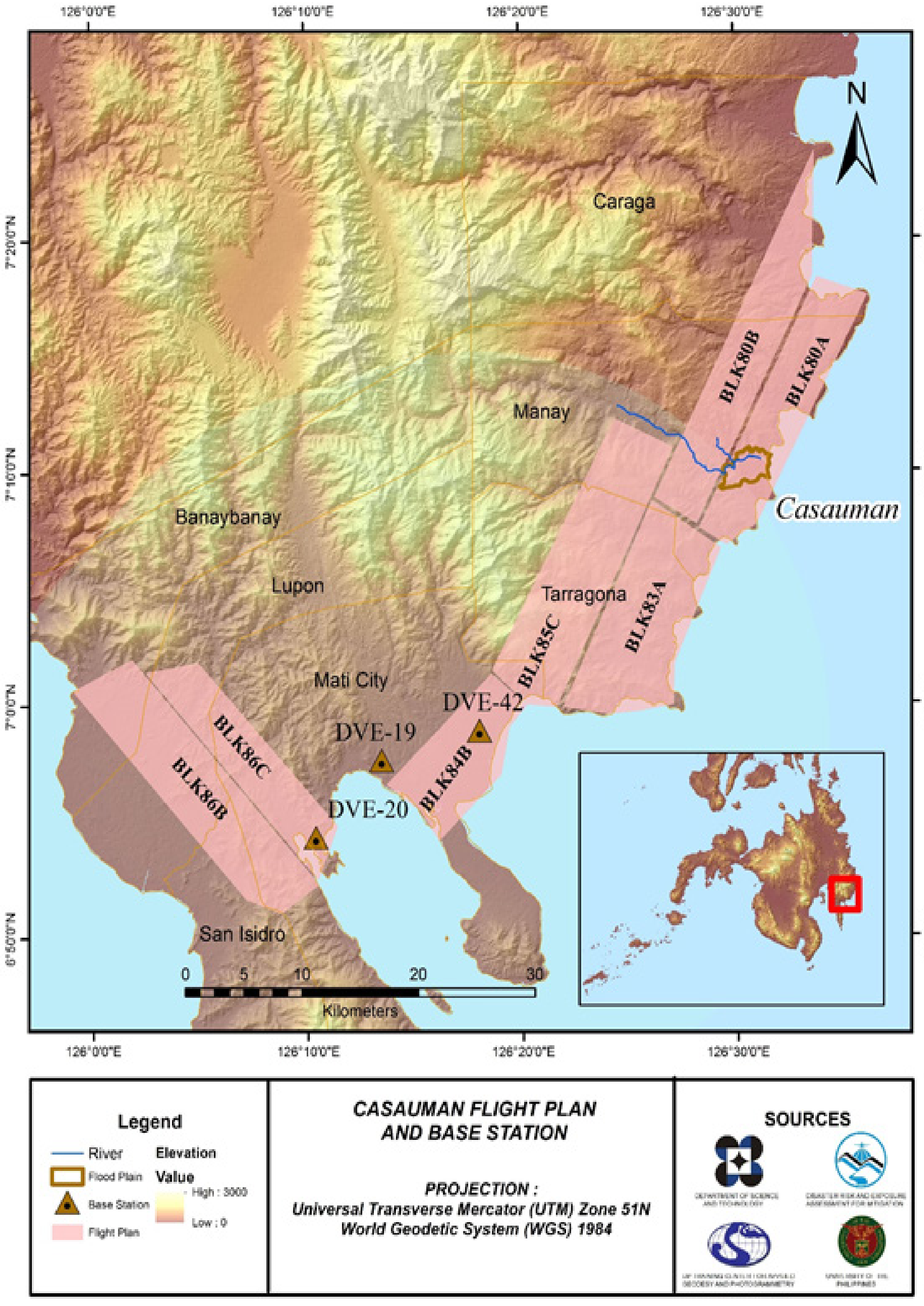


Figure 2. Flight plans and base stations used for Casauman floodplain using Gemini LiDAR system.

2.2 Ground Base Stations

The project team was able to recover four (4) NAMRIA horizontal ground control points: DVE-42 which is of second (2^{nd}) order accuracy, DVE-19 and DVE-20 which are both of third (3^{rd}) order accuracy, and DVE-3088 which is of fourth (4^{th}) order accuracy. The project team also re-processed ground control points: DVE-19, DVE-20, and DVE-3088 to obtain coordinates of second (2^{nd}) order accuracy.

The certifications for the base stations are found in Annex 2 while the baseline processing reports for the established control points are found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey from June 19 to 23, 2014. Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 852 and SPS 985. Flight plans and location of base stations used during the aerial LiDAR acquisition in Casauman floodplain are shown in Figure 2.

The succeeding sections depict the sets of reference points, control stations and established points, and the ground control points for the entire Casauman Floodplain LiDAR Survey. Figure 3 to Figure 6 show the recovered NAMRIA reference points within the area of the floodplain, while Table 2 to Table 5 show the details about the following NAMRIA control stations and established points. Table 6, on the other hand, shows the list of all ground control points occupied during the acquisition together with the corresponding dates of utilization.

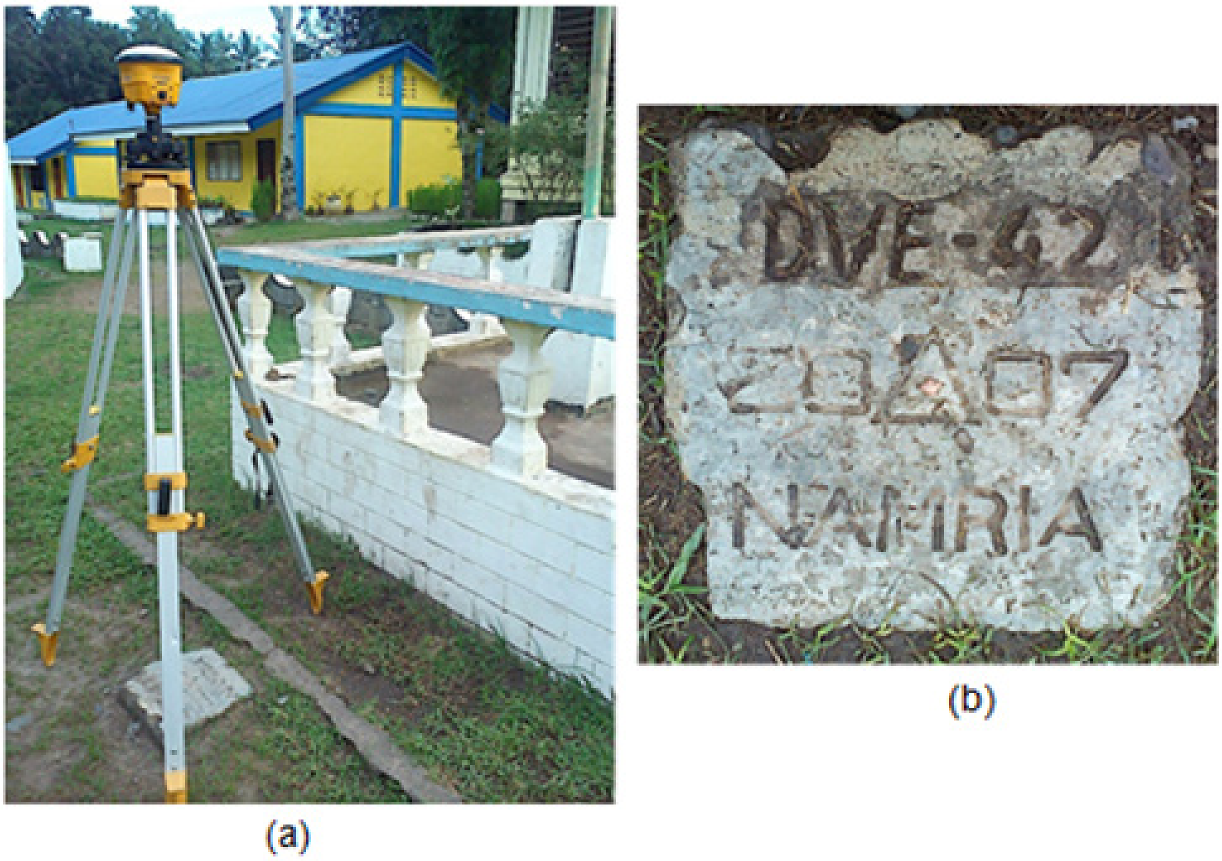


Figure 3. GPS set-up over DVE-42 located inside the premises of Don Enrique Elementary School, in front of the flagpole (a) and NAMRIA reference point DVE-42 (b) as recovered by the field team.

Table 2. Details of the recovered NAMRIA horizontal control point DVE-42 used as base station for the LiDAR acquisition.

Station Name	**DVE-42**	
Order of Accuracy	**2nd**	
Relative Error (horizontal positioning)	**1 in 50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	6°58’54.82726” North 126°17’56.05259” East 6.395 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	643534.636 meters 772166.69 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	6°58’51.79295” North 126°18’1.57690” East 81.025 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1992)	Easting Northing	201538.20 meters 772554.34 meters

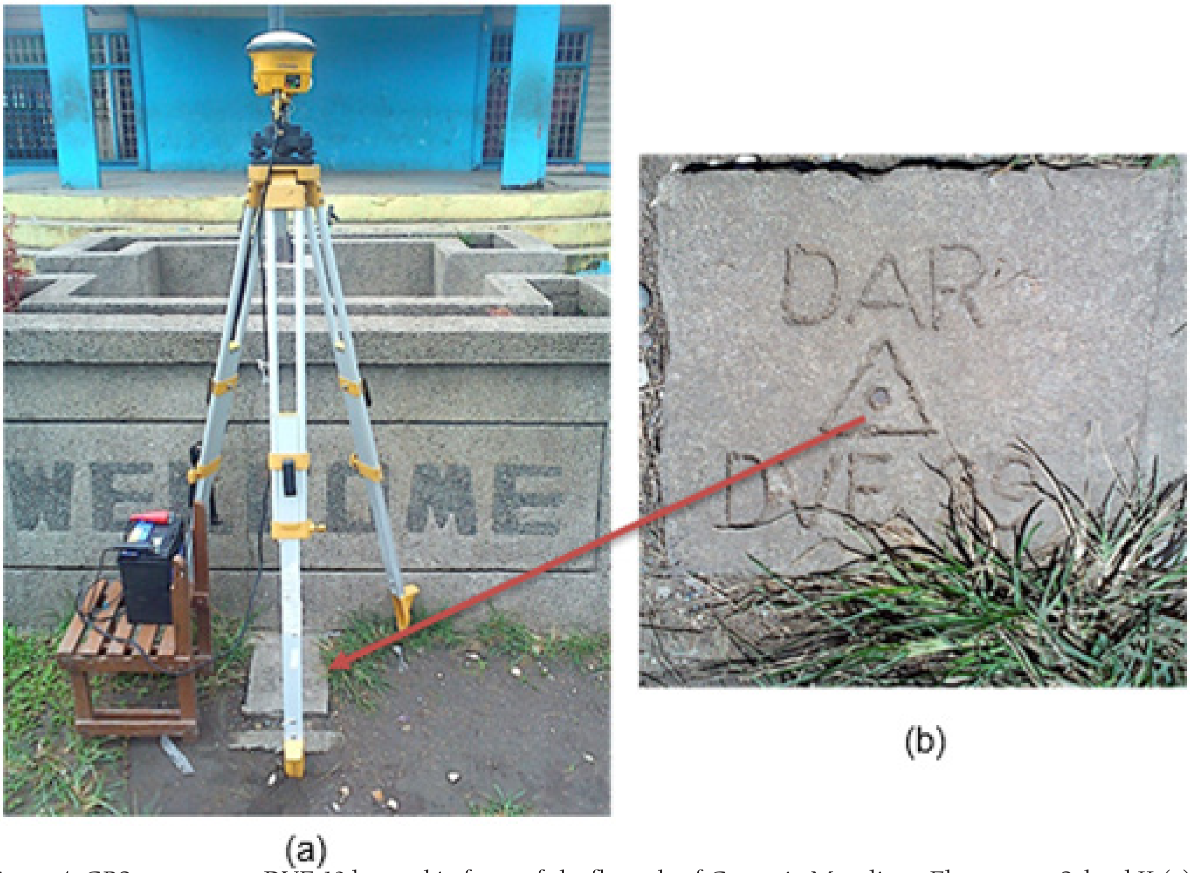
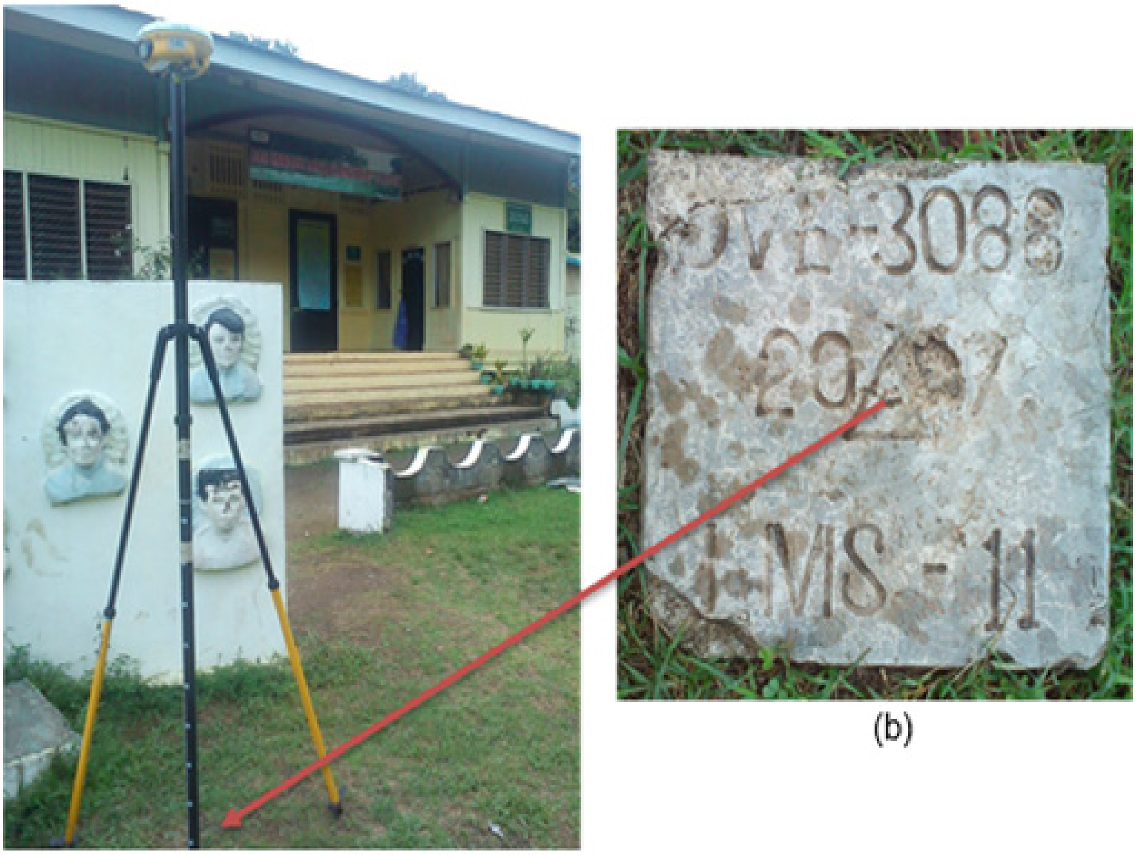


Figure 4. GPS set-up over DVE-19 located in front of the flagpole of Gregorio Moralizon Elementary School II (a) and NAMRIA reference point DVE-19 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point DVE-19 used as base station for the LiDAR acquisition with re-processed coordinates.

Station Name	DVE-19	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7°12’55.40701” North 126°32’20.36757” East -5.263 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	7°12’52.33155” North 126°32’25.86780” East 69.522 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRD 1992)	Easting Northing	228220.964 meters 798242.634 meters



(a) (b)

Figure 5. GPS set-up over DVE-3088 located inside Don Enrique Lopez Elementary School (a) and NAMRIA reference point DVE-3088 (b) as recovered by the field team.

Table 4. Details of the recovered NAMRIA horizontal control point DVE-3088 used as base station for the LiDAR acquisition with re-processed coordinates.

Station Name	**DVE-3088**	
Order of Accuracy	**2nd**	
Relative Error (horizontal positioning)	**1 in 50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	6°58'54.59451" North 126°17'56.18350"East 6.363 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	6°58'51.56021" North 126°18'1.70781" East 80.992 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRD 1992)	Easting Northing	201542.167 meters 772547.163 meters

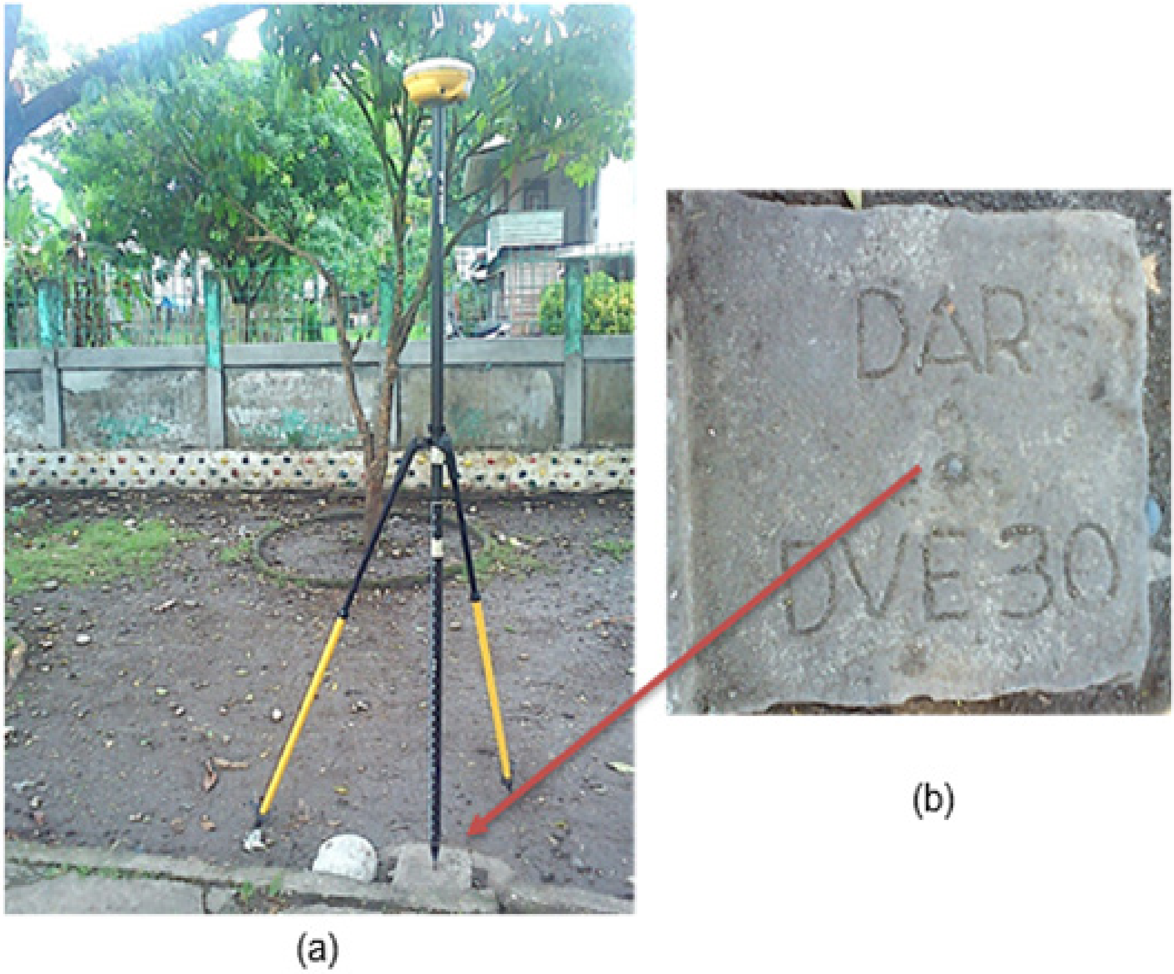


Figure 6. GPS set-up over DVE-20 located inside the premises of Gregorio Moralizon Elementary School I, at the corner side of the basketball court 3 meters from the gate of the school (a) and NAMRIA reference point DVE-20 (b) as recovered by the field team.

Table 5. Details of the recovered NAMRIA horizontal control point DVE-20 used as base station for the LiDAR acquisition with re-processed coordinates.

Station Name	**DVE-20**	
Order of Accuracy	**2nd**	
Relative Error (horizontal positioning)	**1 in 50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7°12’51.11197” North 126°32’20.35543” East -6.215 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	7°12’48.03684” North 126°32’25.85577” East 68.572 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRD 1992)	Easting Northing	228219.879 meters 798110.635 meters

Table 6. Details of the established point ZN- 11 used as base station for the LiDAR Acquisition.

Date Surveyed	Flight Number	Mission Name	Ground Control Points
June 19, 2014	7320GC	2BLK83A84B170A	DVE-42 & DVE-3088
June 20, 2014	7322GC	2BLK84AS&86B171A	DVE-42 & DVE-3088
June 20, 2014	7323GC	2BLK86C&83A171B	DVE-42 & DVE-3088
June 23, 2014	7328GC	2BLK80ABS174A	DVE-19 & DVE-20

2.3 Flight Missions

A total of four (4) missions were conducted to complete the LiDAR data acquisition in Casauman floodplain, for a total of sixteen and thirty minutes (16+30) of flying time for RP-C9322 (See Annex 6). All missions were acquired using Gemini system. As shown below, the total area of actual coverage per mission and the corresponding flying hours are depicted in Table 7, while the actual parameters used during the LiDAR data acquisition are presented in Table 8.

Table 8. Details of the established point ZN- 53 used as base station for the LiDAR Acquisition.

Date Surveyed	Flight Number	Flight Plan Area (km²)	Surveyed Area (km²)	Area Surveyed within the Floodplain	Area Surveyed Outside the	No. of Images (frames)	Flying Hours	
							hr	min
June 19, 2014	7320GC	190.72	121.57	0	121.57	NA	3	47
June 20, 2014	7322GC	251.73	209.19	0.16	209.03	NA	4	11
June 20, 2014	7323GC	199.62	214.08	0.44	213.64	NA	4	9
June 23, 2014	7328GC	211.43	244.67	8.47	236.20	NA	4	23
TOTAL		853.5	789.51	9.07	780.44	NA	16	30

Table 7. Actual parameters used during LiDAR data acquisition.

Flight Number	Flying Height (AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (minutes)
7320GC	1100	40	40	100	50	130	5
7322GC	1100	30	40	100	50	130	5
7323GC	1100	30	40	100	50	130	5
7328GC	1100	30	40	100	50	130	5

2.4 Survey Coverage

This certain LiDAR acquisition survey covered the Casauman floodplain (See Annex 7). It is located in the province of Davao Oriental with majority of the floodplain situated within the municipality of Manay. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 9. Figure 7, on the other hand, shows the actual coverage of the LiDAR acquisition for the Casauman floodplain.

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

Province	Municipality/City	Area of Municipality/City (km^2)	Total Area Surveyed (km^2)	Percentage of Area Surveyed
Davao Oriental	Manay	430.89	172.67	40.07%
	Tarragona	277.9	100.71	36.24%
	Lupon	356.28	84.18	23.63%
	Mati	797.38	127.6	16.00%
	San Isidro	224.84	24.05	10.70%
	Banaybanay	385.28	34.94	9.07%
	Caraga	569.48	36.17	6.35%
TOTAL		**3,042.05**	**580.32**	**19.08%**

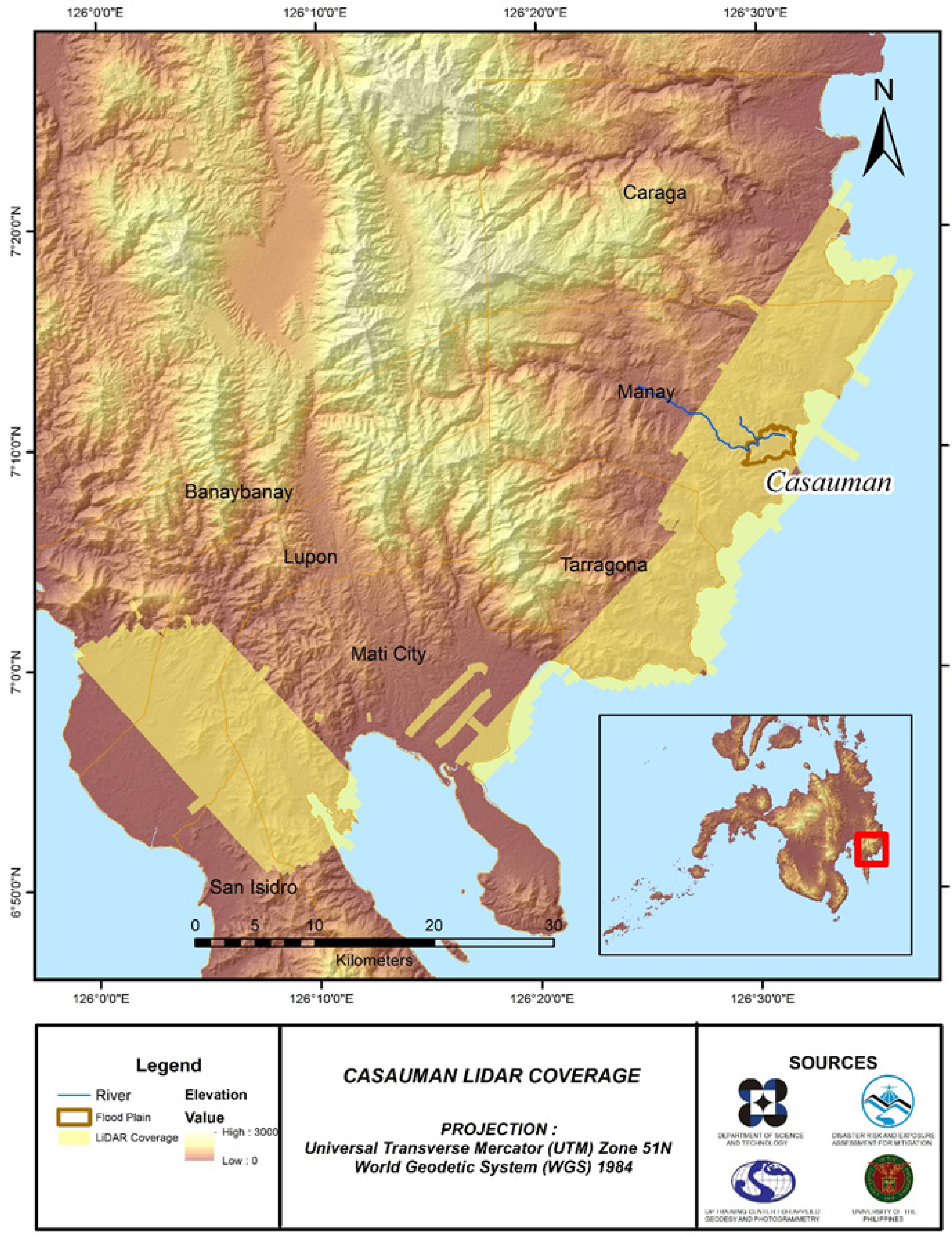


Figure 7. Actual LiDAR survey coverage for Casauman floodplain.

CHAPTER 3: LIDAR DATA PROCESSING FOR CASAUMAN FLOODPLAIN

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

3.1 Overview of LiDAR Data Pre-Processing

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

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

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

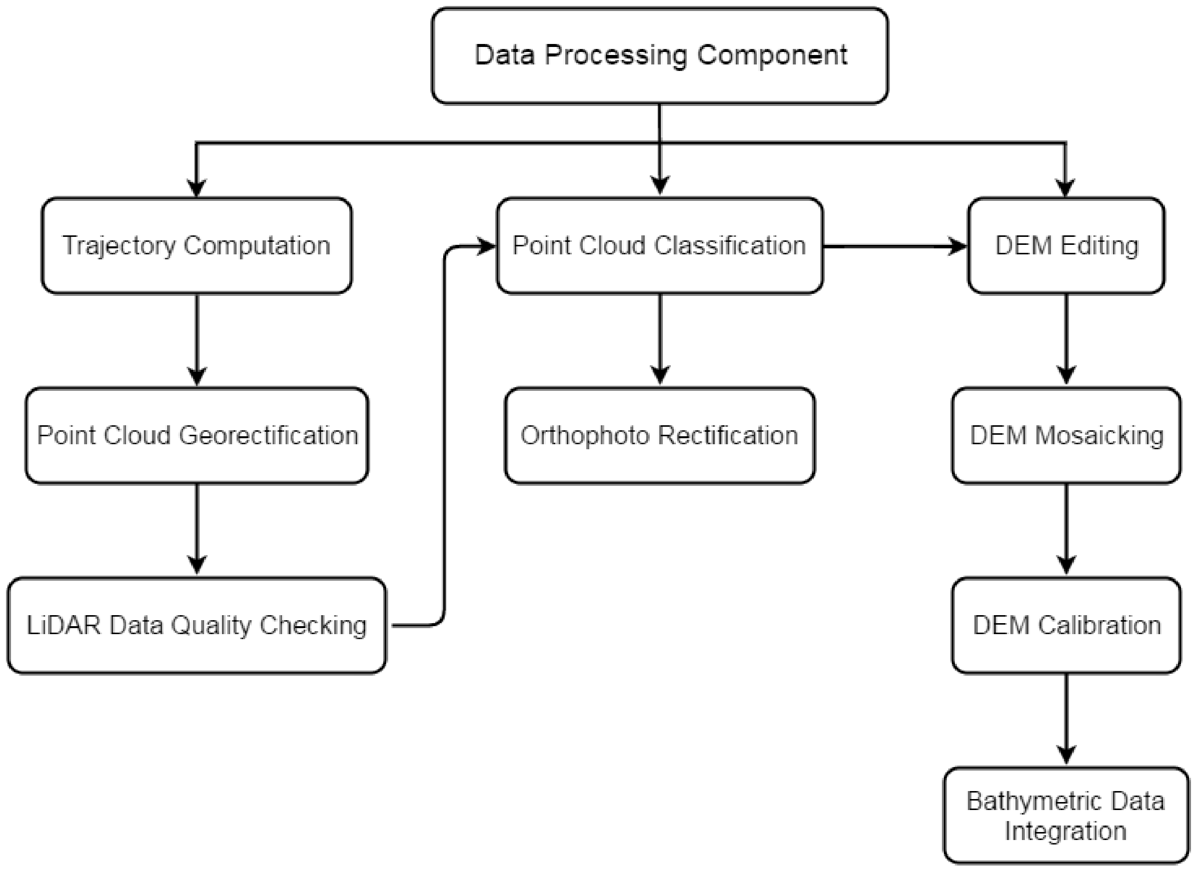

Figure 8. Schematic diagram for the data pre-processing.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions of the Casauman Floodplain can be found in Annex 5. The missions flown during the conduct of the first survey in June 2014 utilized the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Gemini system over Manay, Davao oriental.

The Data Acquisition Component (DAC) transferred a total of 83.6 Gigabytes of Range data, 949 Megabytes of POS data, 19.15 Megabytes of GPS base station data, and 91.3 Gigabytes of raw image data to the data server on June 23, 2014 which was verified for accuracy and completeness by the DPPC. The whole dataset for the Casauman Floodplain was fully transferred on July 2, 2014, as indicated on the Data Transfer Sheets for the Casauman floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metric parameters of the computed trajectory for Flight 7320G, one of the Casauman flights, which is the North, East, and Down position RMSE values are shown in Figure 9. The x-axis corresponds to the time of the flight, which was measured by the number of seconds from the midnight of the start of the GPS week, which fell on the date and time of June 19, 2014, 00:00 AM. The y-axis, on the other hand, represents the RMSE value for that particular position.

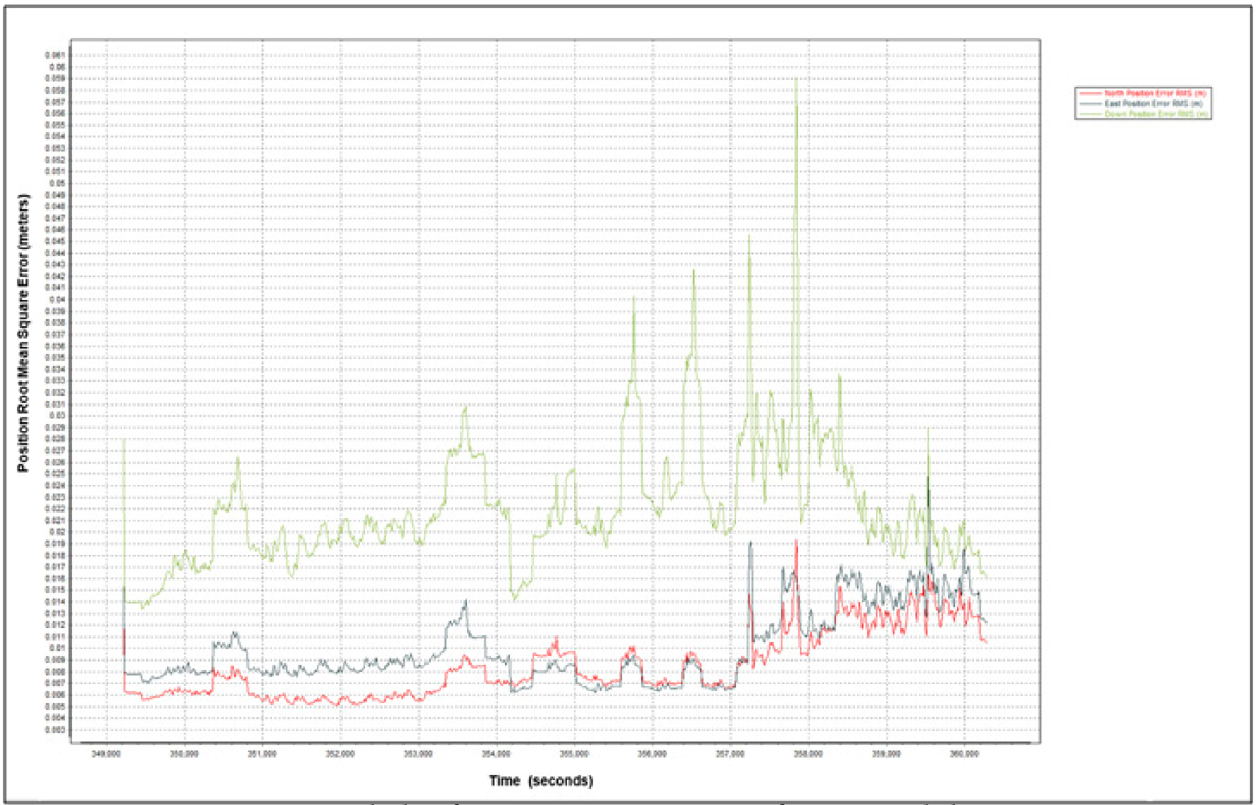

Figure 9. Smoothed Performance Metric Parameters of Casauman Flight 7320G.

The time of flight was from 349200 seconds to 360200 seconds, which corresponds to morning of June 19, 2014. The initial spike that is seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the POS system starts computing for the position and orientation of the aircraft.

Redundant measurements from the POS system quickly minimized the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values correspond to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 10 shows that the North position RMSE peaks at 1.90 centimeters, the East position RMSE peaks at 2.50 centimeters, and the Down position RMSE peaks at 5.90 centimeters, which are within the prescribed accuracies described in the methodology.

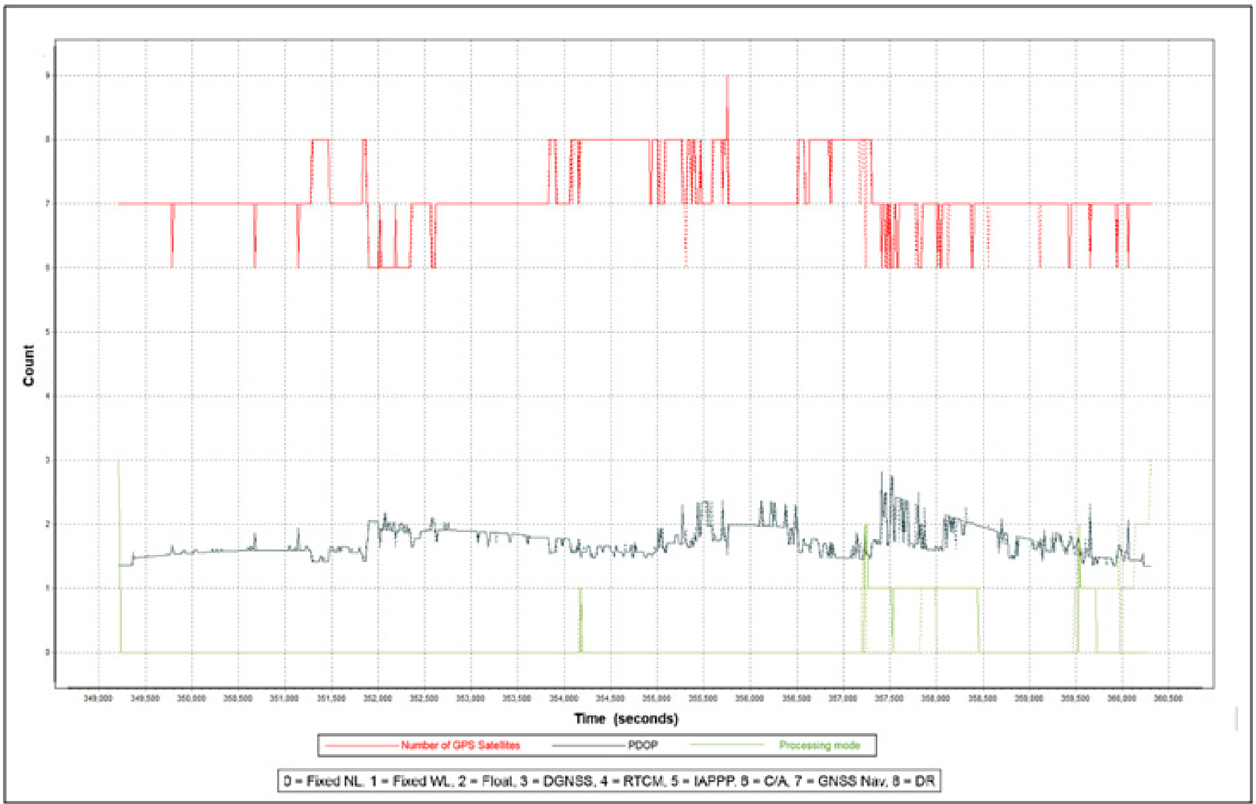

Figure 10. 10. Solution Status Parameters of Casauman Flight 7320G.

The Solution Status parameters, which indicate the number of GPS satellites; Positional Dilution of Precision (PDOP); and the GPS processing mode used for Casauman Flight 7320G are shown in Figure 10. For the Solution Status parameters, the figure above signifies that the number of satellites utilized and tracked during the acquisition were between 6 and 9, not going lower than 6. Similarly, the PDOP value did not go above the value of 3, which indicates optimal GPS geometry. The processing mode also stayed at the value of 0 for the majority of the survey stayed at the value of 0 for majority of the survey with some peaks up to 2 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane Mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for the POSPAC MMS. Fundamentally, 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 Casauman flights is shown in Figure 11.

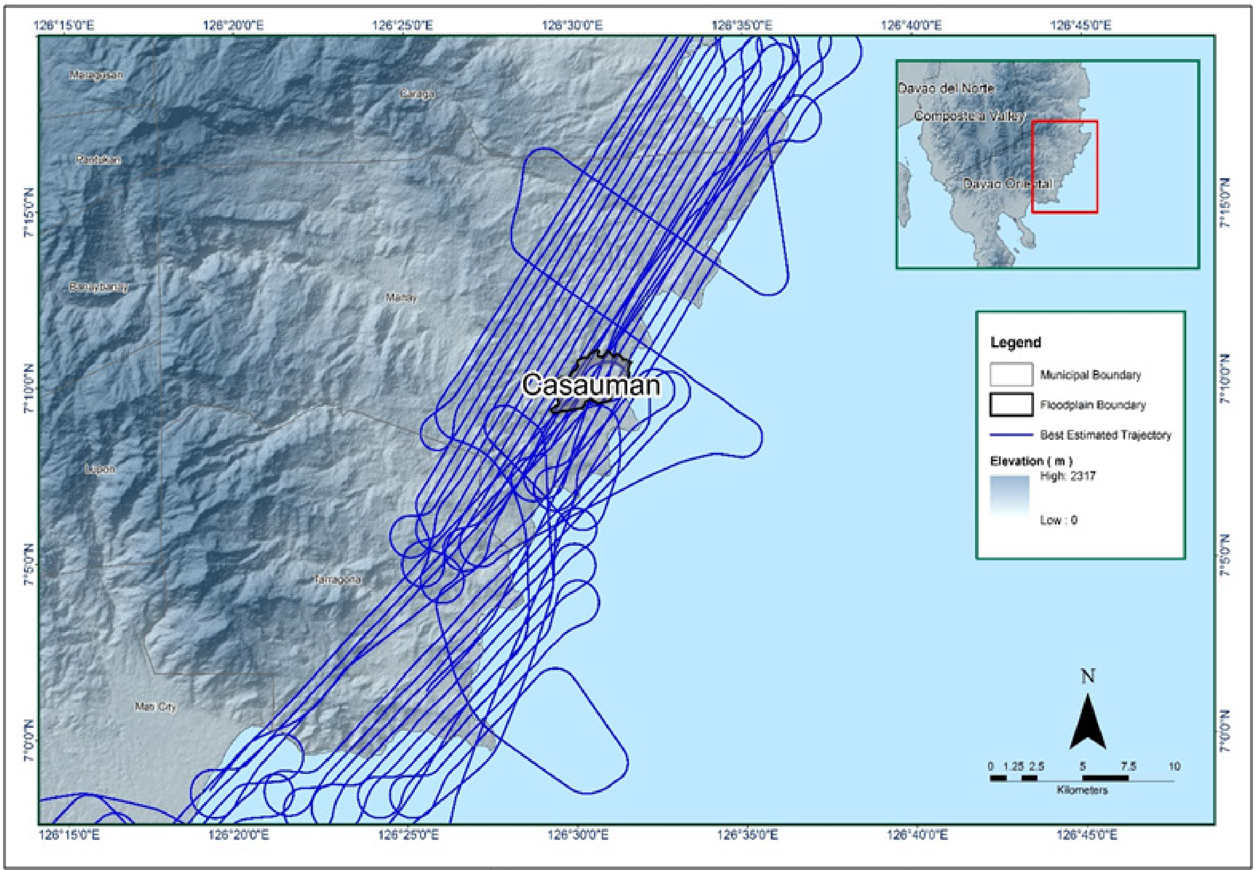

Figure 11. Best Estimated Trajectory of the LiDAR missions conducted over the Casauman Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS contains 30 flight lines, with each flight line contains one (1) channel, since the Gemini system contains only one (1) channel. The summary of the self-calibration results obtained from LiDAR processing in the LiDAR Mapping Suite (LMS) software for all flights over the Casauman Floodplain are given in Table 16.

Table 10. Self-calibration Results values for Casauman flights.

Parameter	Acceptable Value	Value
Boresight Correction (stdev)	<0.001degrees	0.000272
IMU Attitude Correction Roll and Pitch Corrections (stdev)	<0.001degrees	0.000959
GPS Position Z-correction (stdev)	<0.01meters	0.0099

The optimum accuracy values for all Casauman flights were also calculated, which are based on the computed standard deviations of the corrections of the orientation parameters. The standard deviation values for individual blocks are presented in the Mission Summary Reports (Annex 8).

3.5 LiDAR Data Quality Checking

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

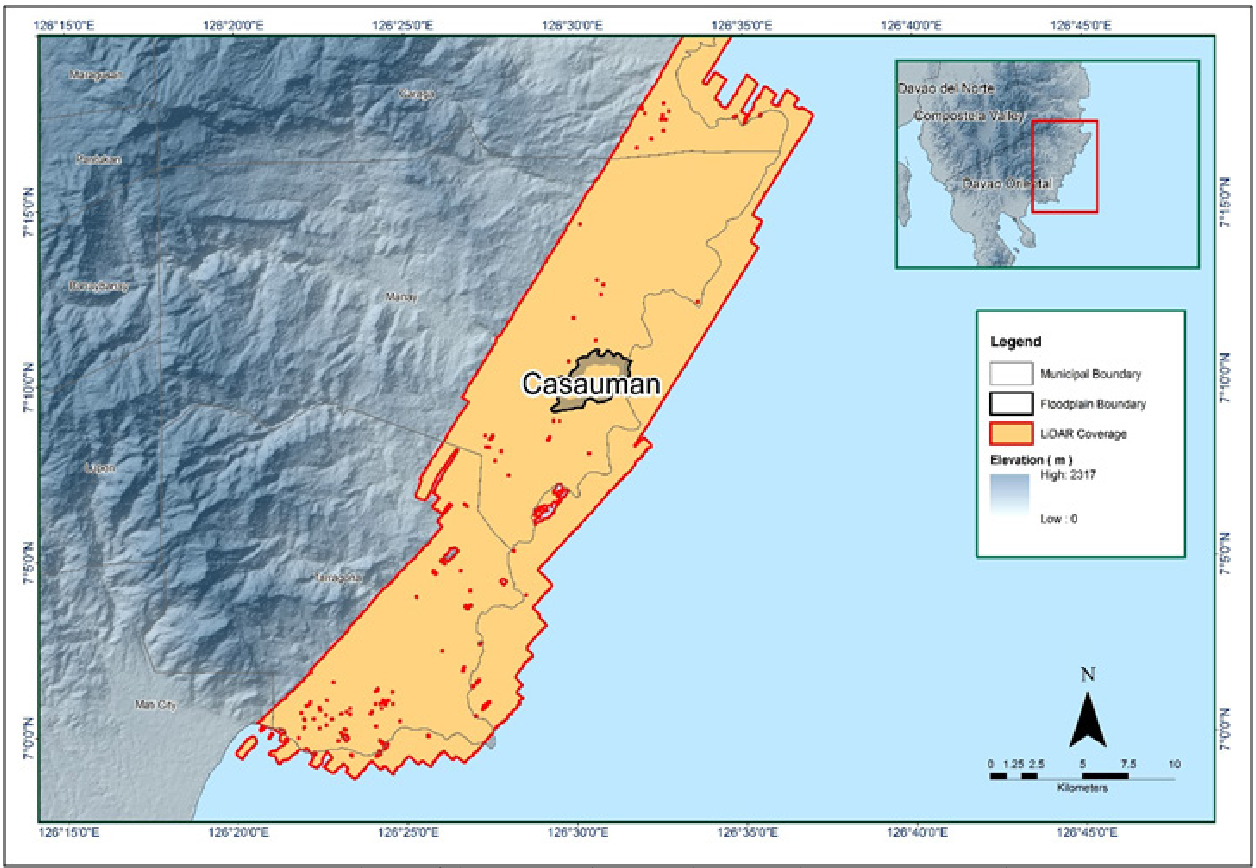

Figure 12. Boundaries of the processed LiDAR data over the Casauman Floodplain.

A total area of 303.7 km^2 were covered by the Casauman flight missions as a result of four (4) flight acquisitions, which were grouped and merged into two (2) blocks accordingly, as portrayed in Table 11.

Table 11. List of LiDAR blocks for the Casauman floodplain.

LiDAR Blocks	Flight Numbers	Area (km²)
Davao_Oriental_Blk80A_ supplement	7328GC	138.39
Davao_Oriental_Blk83A	7320G	165.31
	7322G	
	7323G	
TOTAL		**303.7 km²**

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 13. Since the Gemini system employs one (1) channel, we would expect an average value of 1 (blue) for areas where there is limited overlap, and a value of 2 (yellow) or more (red) for areas with three or more overlapping flight lines.

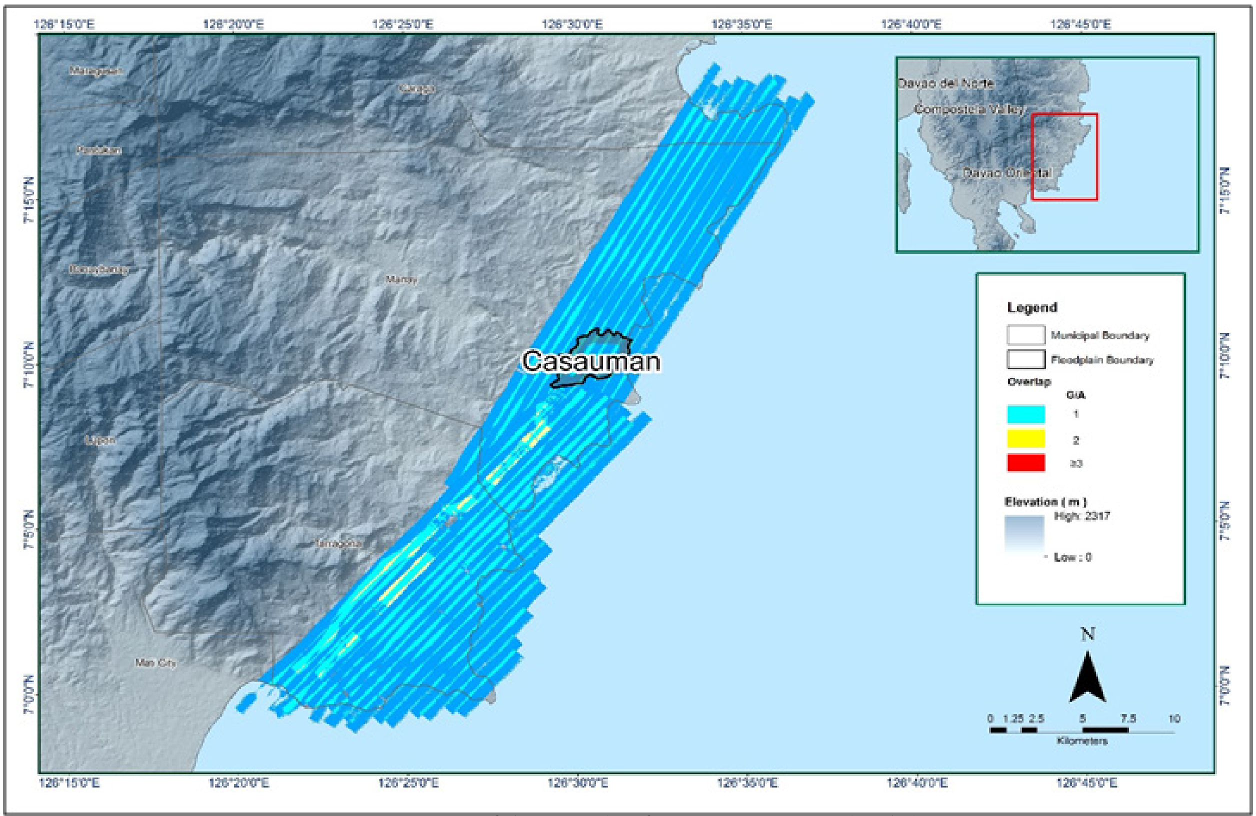

Figure 13. Image of data overlap for CASAUMAN Floodplain.

The overlap statistics per block for the Casauman floodplain can be found in the Mission Summary Reports (Annex 8). One pixel corresponds to 25.0 square meters on the ground. For this area, the percent overlap is 31.39%,, 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 two (2) points per square meter criterion is shown in Figure 14. As seen in the figure below, it was determined that all LiDAR data for the Casauman Floodplain Survey satisfy the point density requirement, as the average density for the entire survey area is 2.90 points per square meter.

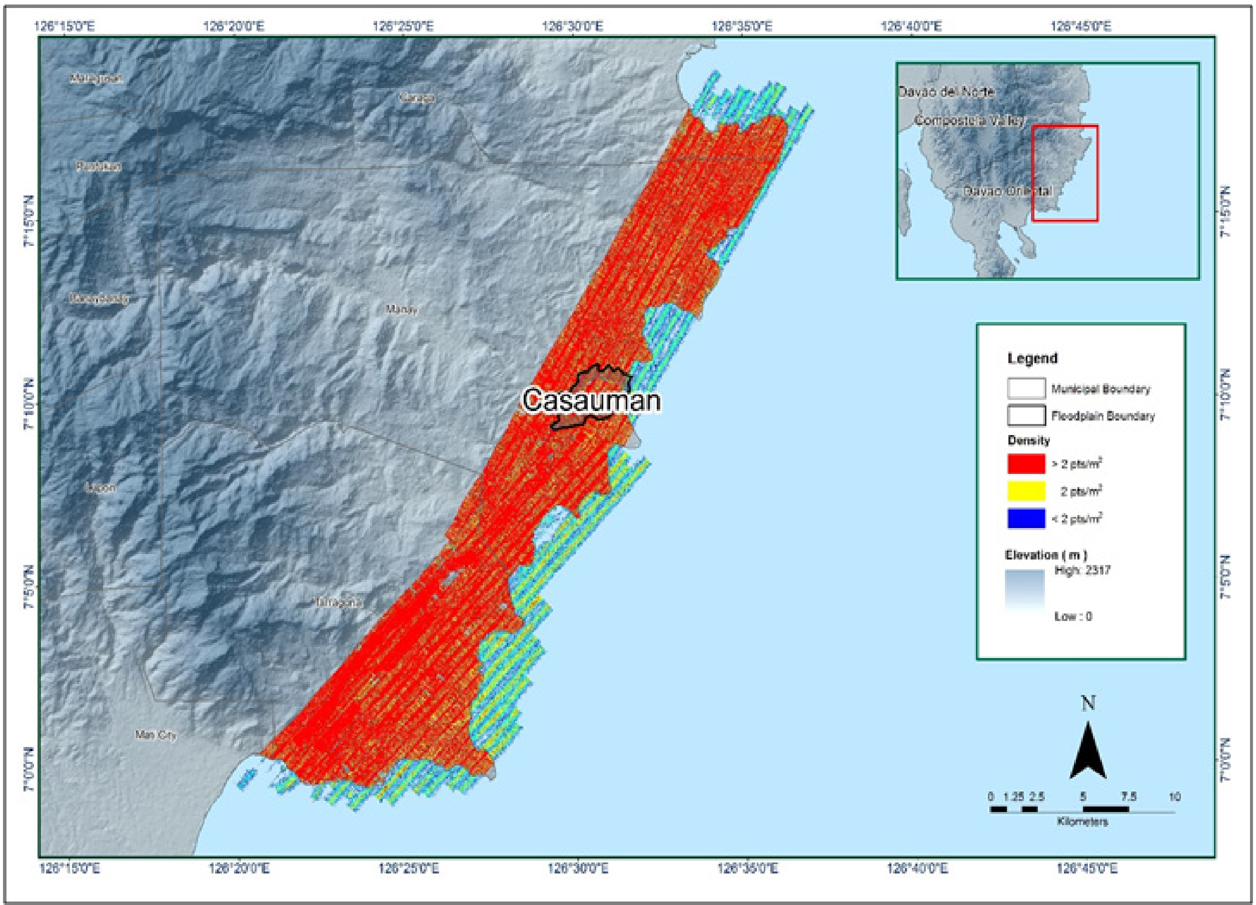

Figure 14. Pulse density map of the merged LiDAR data for Casauman floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 15. The default color range is blue to red, where bright blue areas correspond to portions where elevations of a previous flight line are higher by more than 0.20 m, as identified by its acquisition time; which is relative to the elevations of its adjacent flight line. Similarly, bright red areas indicate portions where elevations of a previous flight line are lower by more than 0.20 m, relative to the elevations of its adjacent flight line. Areas highlighted in bright red or bright blue necessitate further investigation using the Quick Terrain Modeler software.

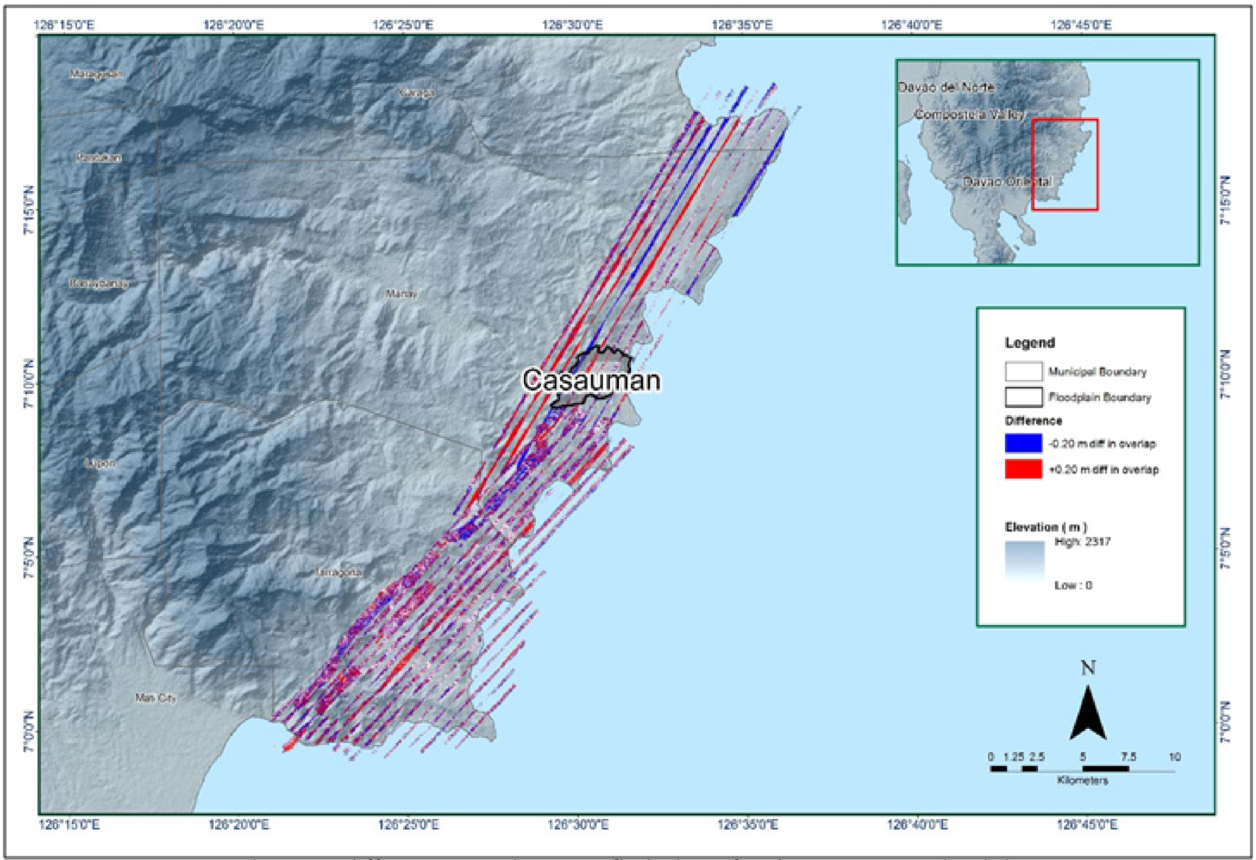

Figure 15. Elevation difference Map between flight lines for the Casauman Floodplain Survey.

A screen-capture of the processed LAS data from Casauman flight 7320G loaded in QT Modeler is shown in Figure 16. The upper left image shows the elevations of the points from two (2) 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 generated satisfactory results. No reprocessing was done for this LiDAR dataset.

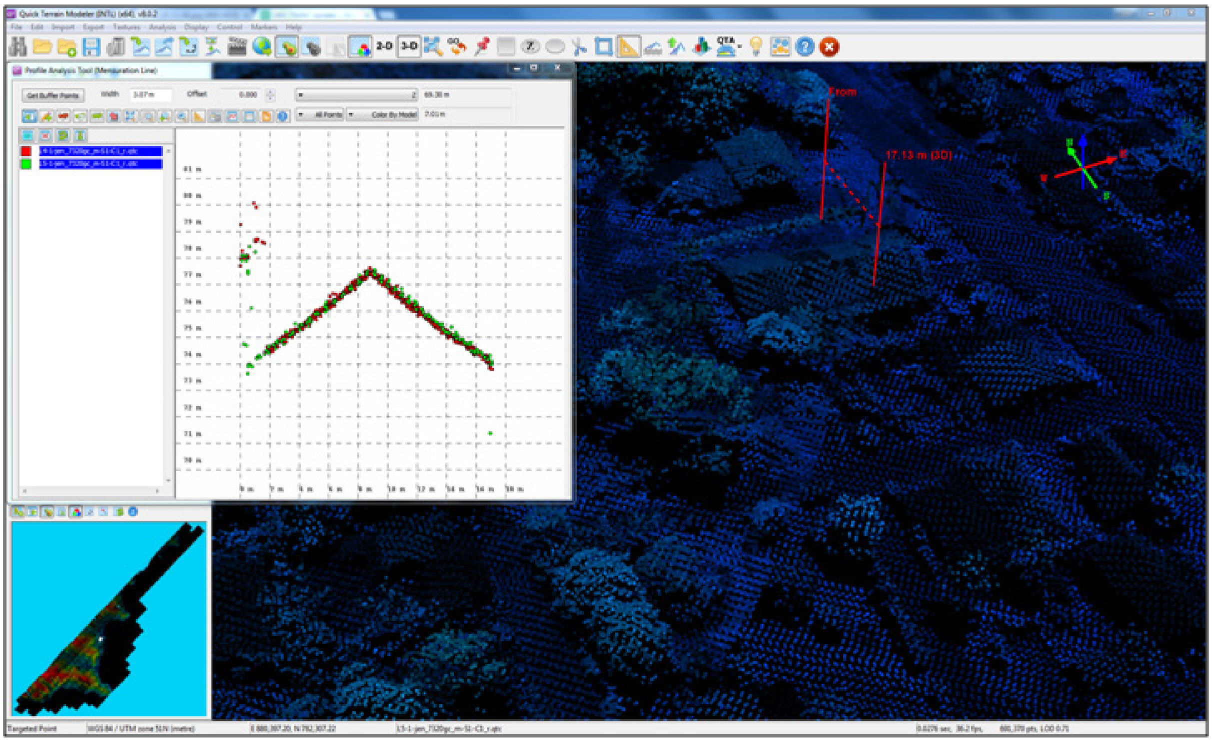

Figure 16. Quality checking for Casauman flight 7320G using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 12. Casauman classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	101,682,388
Low Vegetation	52,961,367
Medium Vegetation	155,919,856
High Vegetation	435,625,423
Building	2,667,706

The tile system that TerraScan employed for the LiDAR data as well as the final classification image for a block of the Casauman Floodplain is shown in Figure 17. A total of 411 tiles with 1 km. X 1 km. (one kilometer by one kilometer) size were produced. Correspondingly, Table 12 summarizes the number of points classified to the pertinent categories. The point cloud has a maximum and minimum height of 648.03 meters and 55.88 meters respectively.

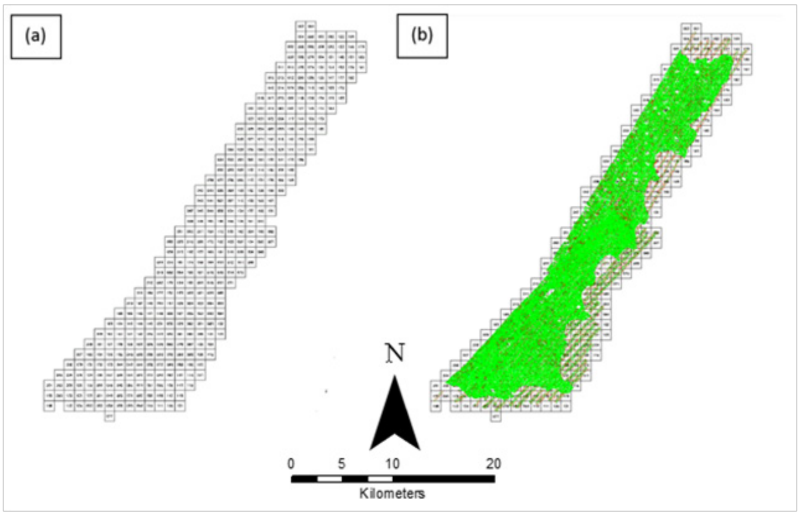

Figure 17. Tiles for Casauman floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 21. The ground points are in orange, the vegetation is in different shades of green, and the buildings are in cyan. It can be seen that residential structures adjacent or even below canopy are classified correctly, due to the density of the LiDAR data.

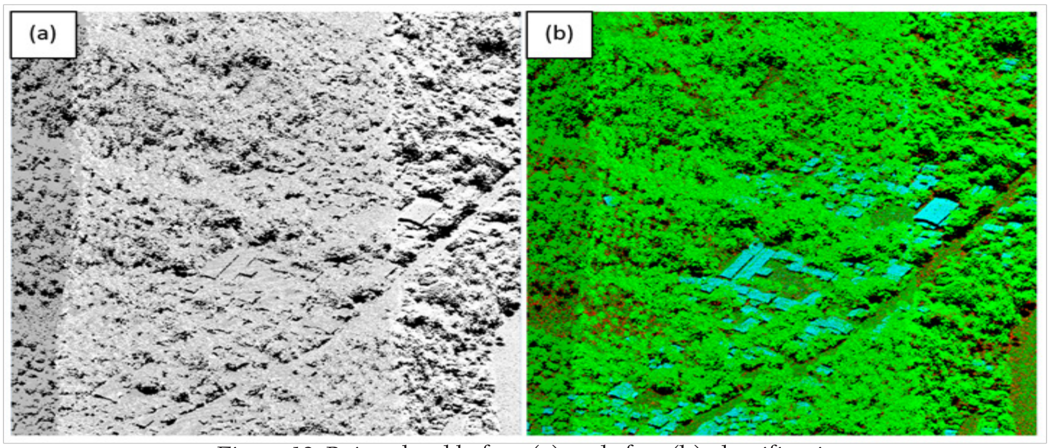

Figure 18. Point cloud before (a) and after (b) classification.

The production of the last return (V_ASCII) and secondary (T_ ASCII) DTM as well as the first (S_ ASCII) and last (D_ ASCII) return DSM of the area in top view display are show in Figure 19. It shows that DTMs are the representation of the bare earth, while on the DSMs, all features are present, such as buildings and vegetation.

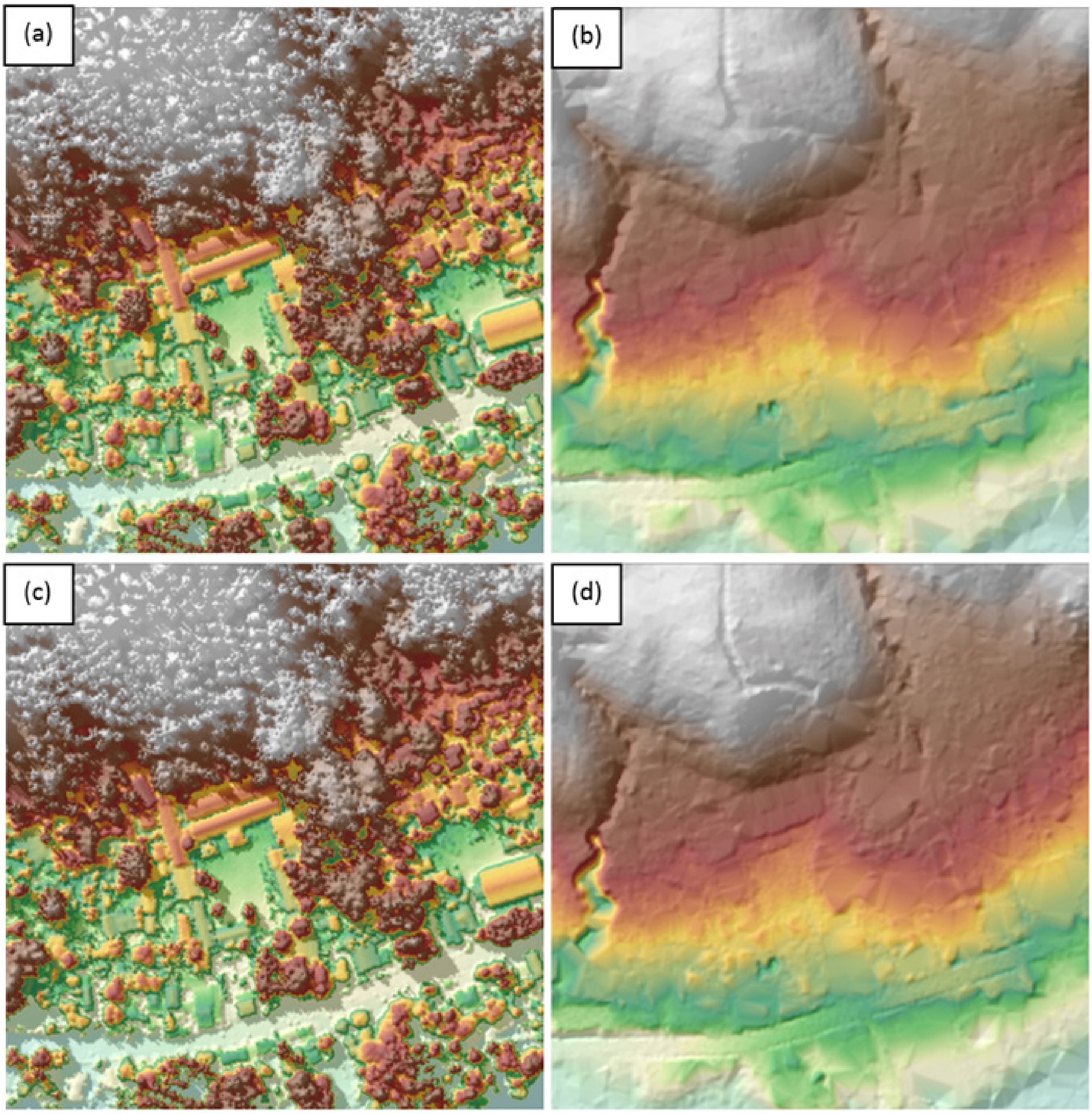

Figure 19. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Casauman floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

There are no available orthophotographs for the Casauman floodplain

3.8 DEM Editing and Hydro-Correction

Two (2) mission blocks were processed for the Casauman Floodplain Survey. These blocks are composed of Davao_Oriental blocks with a total area of 303.70 km^2. Table 13 shows the name and corresponding area of each block in square kilometers.

Table 13. LiDAR blocks with its corresponding areas.

LiDAR Blocks	Area (km^2)
Davao_Oriental_Blk83A	165.31
Davao_Oriental_Blk80A_supplement	138.39
TOTAL	**303.70 km^2**

Figure 20 shows portions of a DTM before and after manual editing. As evident in the figure, the bridge (Figure 20a) has obstructed the flow of water along the river. To correct the river hydrologically, the bridge was removed through manual editing (Figure 20b).

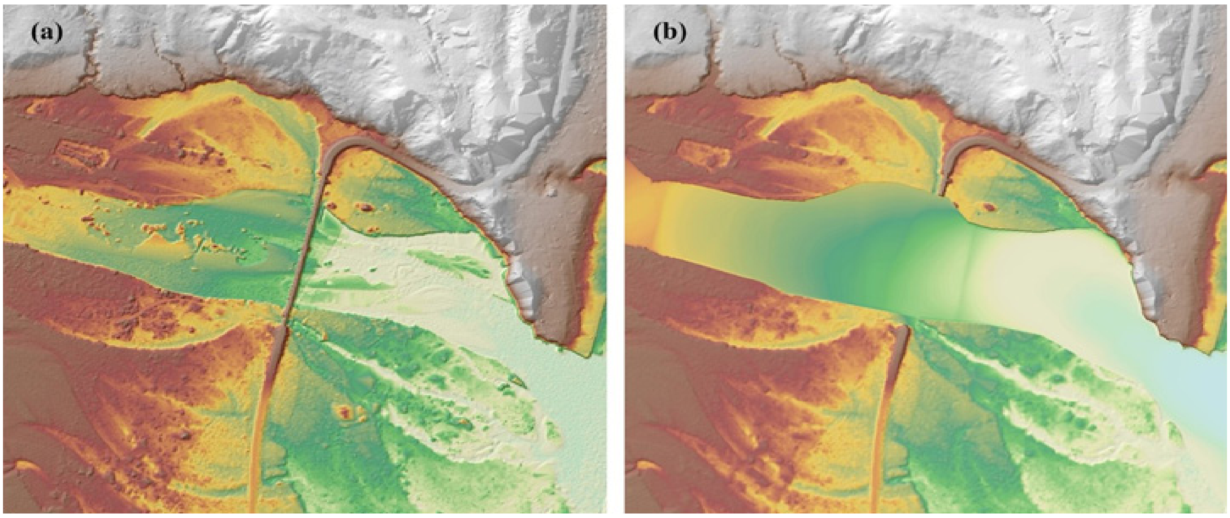

Figure 20. Portions in the DTM of the Casauman Floodplain – a bridge before (a) and after (b) manual editing.

3.9 Mosaicking of Blocks

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

Mosaicked LiDAR DTM for Casauman Floodplain is shown in Figure 21. It can be seen that the entire Casauman floodplain is 99.90% covered by LiDAR data.

Table 14. Shift values of each LiDAR block of Casauman Floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
Davao_Oriental_Blk83A	1.40	1.70	-2.72
Davao_Oriental_Blk80A_ supplement	-11.00	1.00	4.42

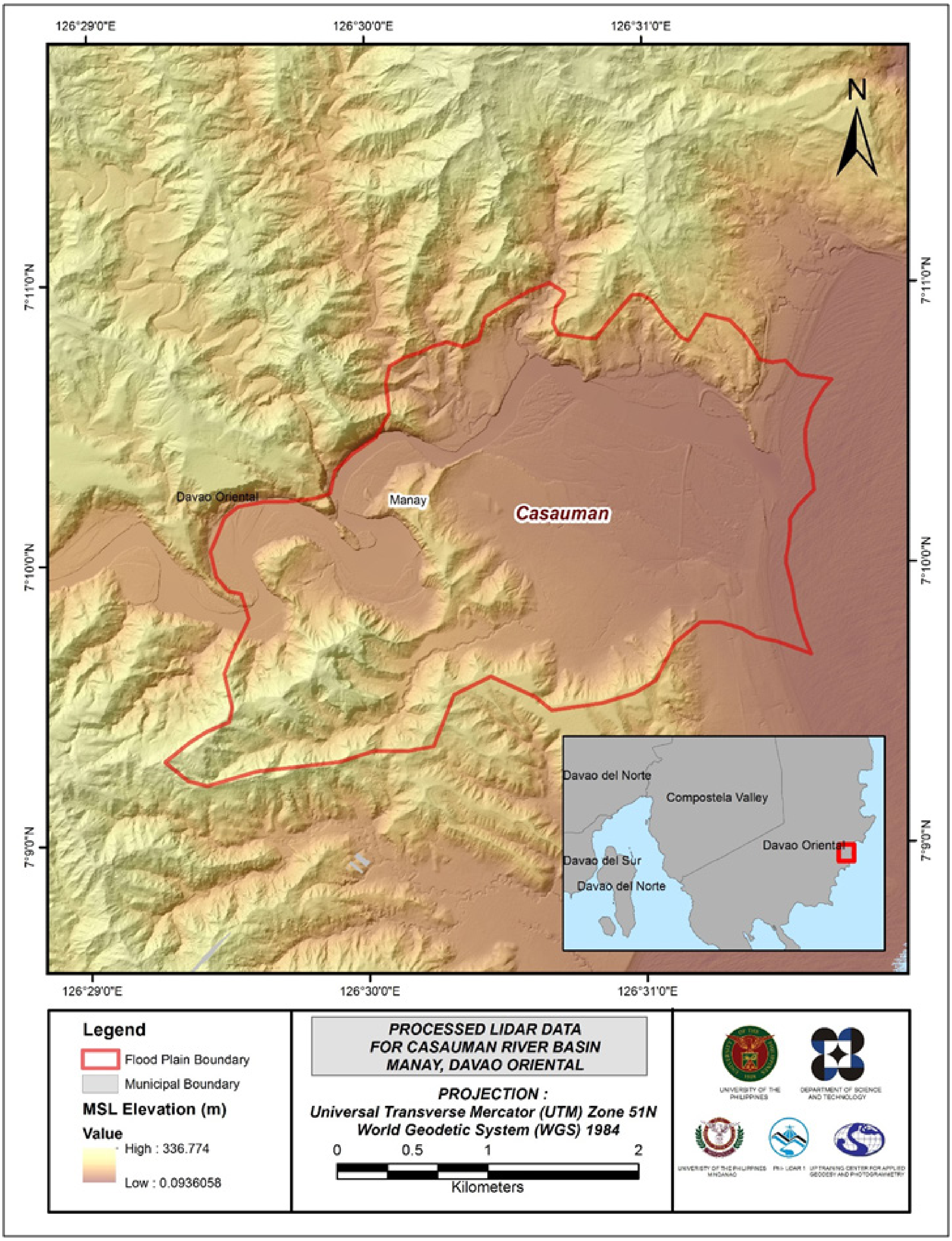

Figure 21. Map of processed LiDAR data for the Casauman Floodplain.

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 Casauman to collect points with which the LiDAR dataset is validated is shown in Figure 22, with the validation survey points highlighted in green. A total of 7,104 survey points were gathered for the Casauman Floodplain. Random selection of 80% of the survey points, resulting to 5,683 points, was used for calibration.

A good correlation between the uncalibrated mosaicked LiDAR DTM and the ground survey elevation values is shown in Figure 23. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of the data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration points is 1.81 meters, with a standard deviation of 0.20 meters. The calibration of the Casauman LiDAR data was accomplished by adding the height difference value of 1.81 meters to the Casauman mosaicked LiDAR data. Table 15 shows the statistical values of the compared elevation values between the Casauman LiDAR data and the calibration data.

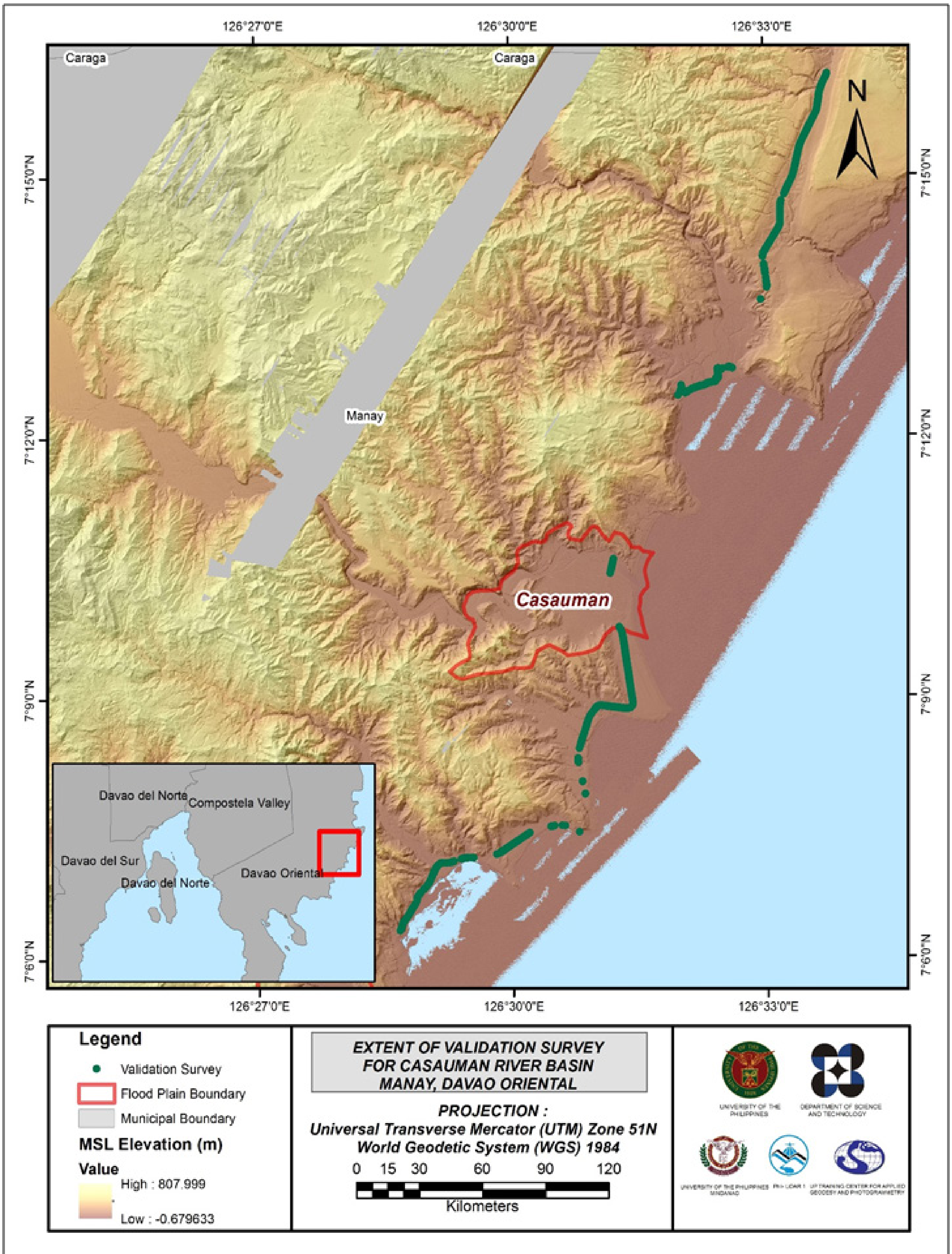

Figure 22. Map of Casauman Floodplain with validation survey points in green.

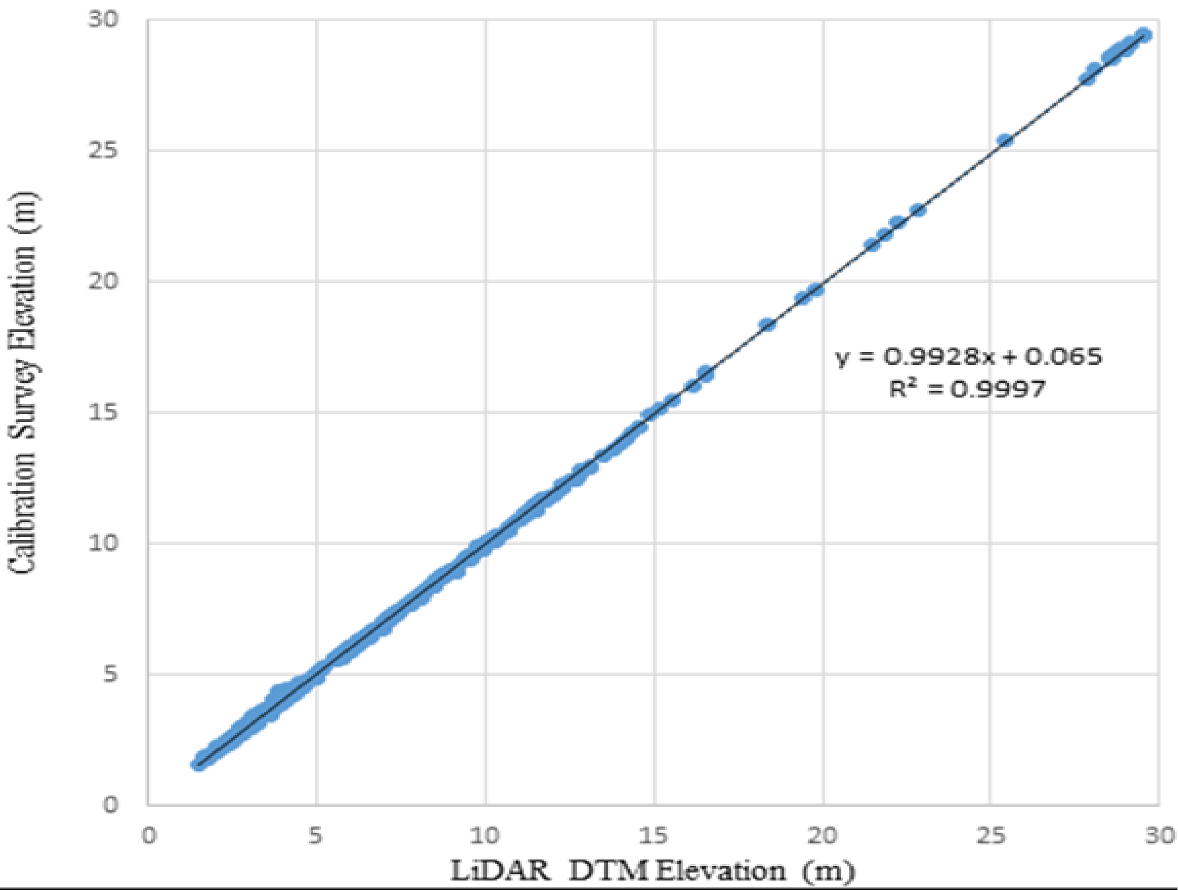

Figure 23. Correlation plot between calibration survey points and LiDAR data.

Table 15. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	1.81
Standard Deviation	0.20
Average	1.80
Minimum	1.41
Maximum	2.20

A total of 1,421 survey points lie within the Casauman Floodplain; all of which were used to validate the calibrated Casauman DTM. A good correlation between the calibrated mosaicked LiDAR elevation and the ground survey elevation values, which point toward the quality of the LiDAR DTM is shown in Figure 24. The computed RMSE value between the calibrated LiDAR DTM and the validation elevation values is at 0.20 meters with a standard deviation of 0.20 meters, as shown in Table 16.

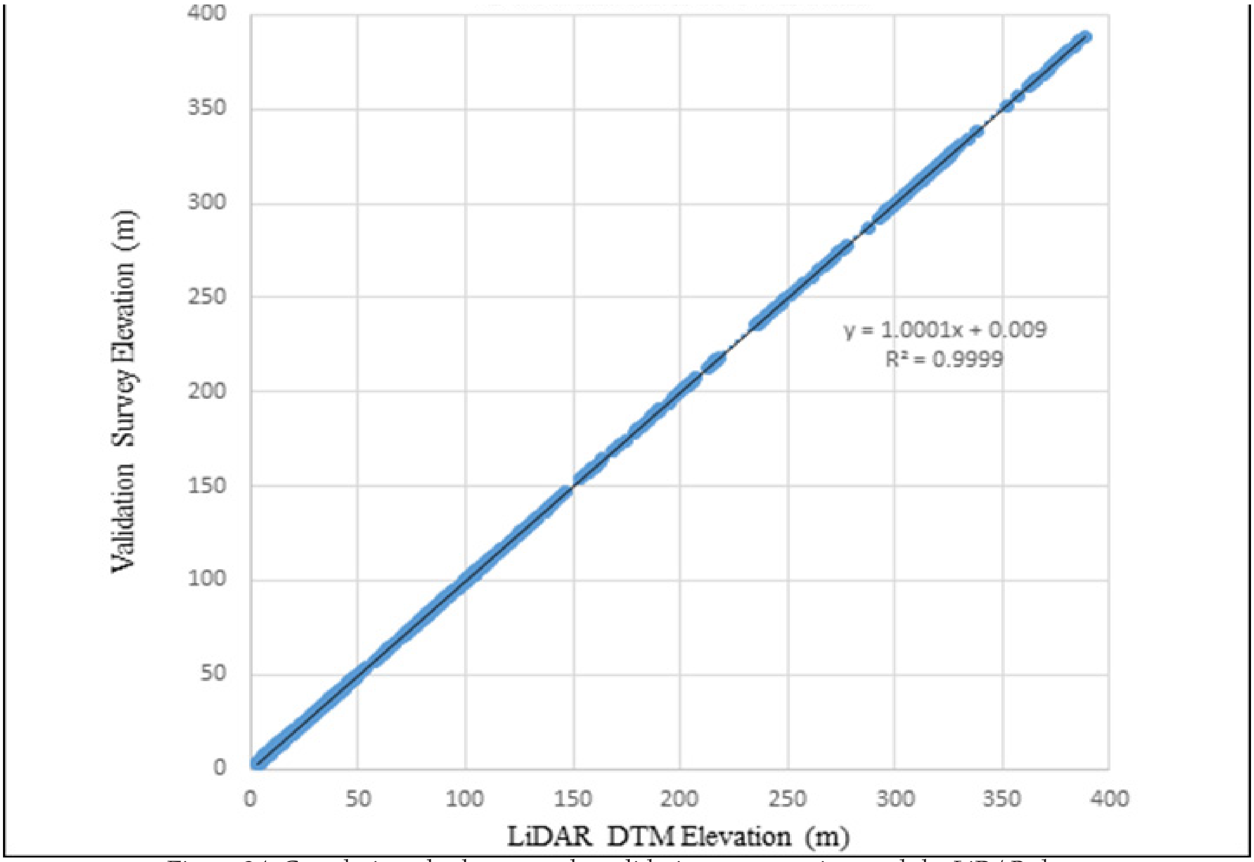

Figure 24. Correlation plot between the validation survey points and the LiDAR data.

Table 16. Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.20
Standard Deviation	0.20
Average	-0.01
Minimum	-0.41
Maximum	0.38

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and zigzag data were available for CASAUMAN with 15,917 bathymetric survey points. The resulting raster surface produced was done by Kernel interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.48 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Casauman integrated with the processed LiDAR DEM is shown in Figure 30.

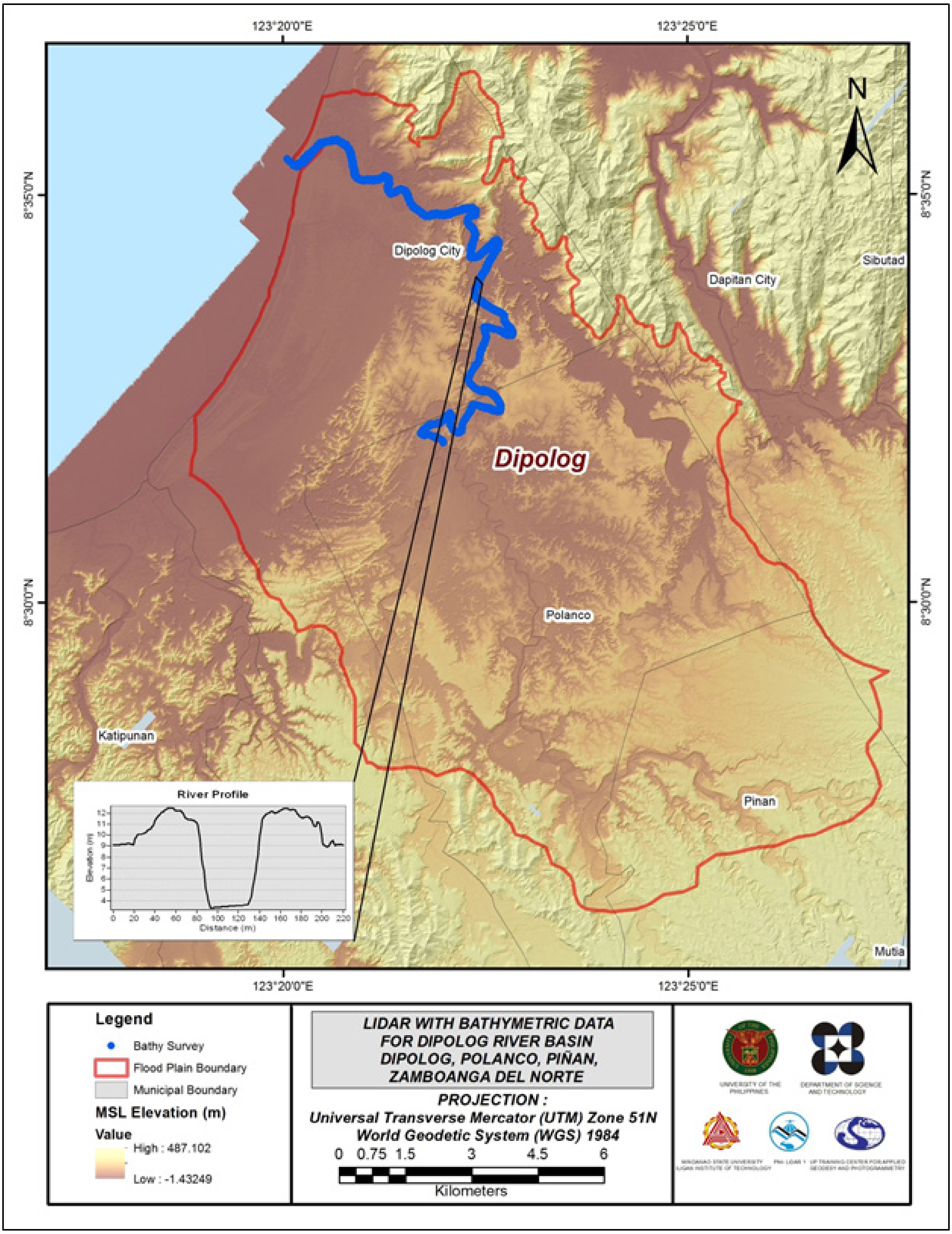

Figure 25. Map of CASAUMAN Floodplain with bathymetric survey points shown in blue.

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 a 200-meter buffer zone. Mosaicked LiDAR DEMs with a 1-m resolution were used to delineate footprints of building features, which comprised of residential buildings, government offices, medical facilities, religious institutions, and commercial establishments, among others. Road networks comprise of main thoroughfares such as highways and municipal and barangay roads essential for the routing of disaster response efforts. These features are represented by network of road centerlines.

3.12.1 Quality Checking of Digitized Features' Boundary

Casauman Floodplain, including its 200-m buffer, has a total area of 11.50 km^2. For this area, a total of 3.0 km^2, corresponding to a total of 47 building features, were considered for QC. Figure 26 shows the QC blocks for the Casauman Floodplain.

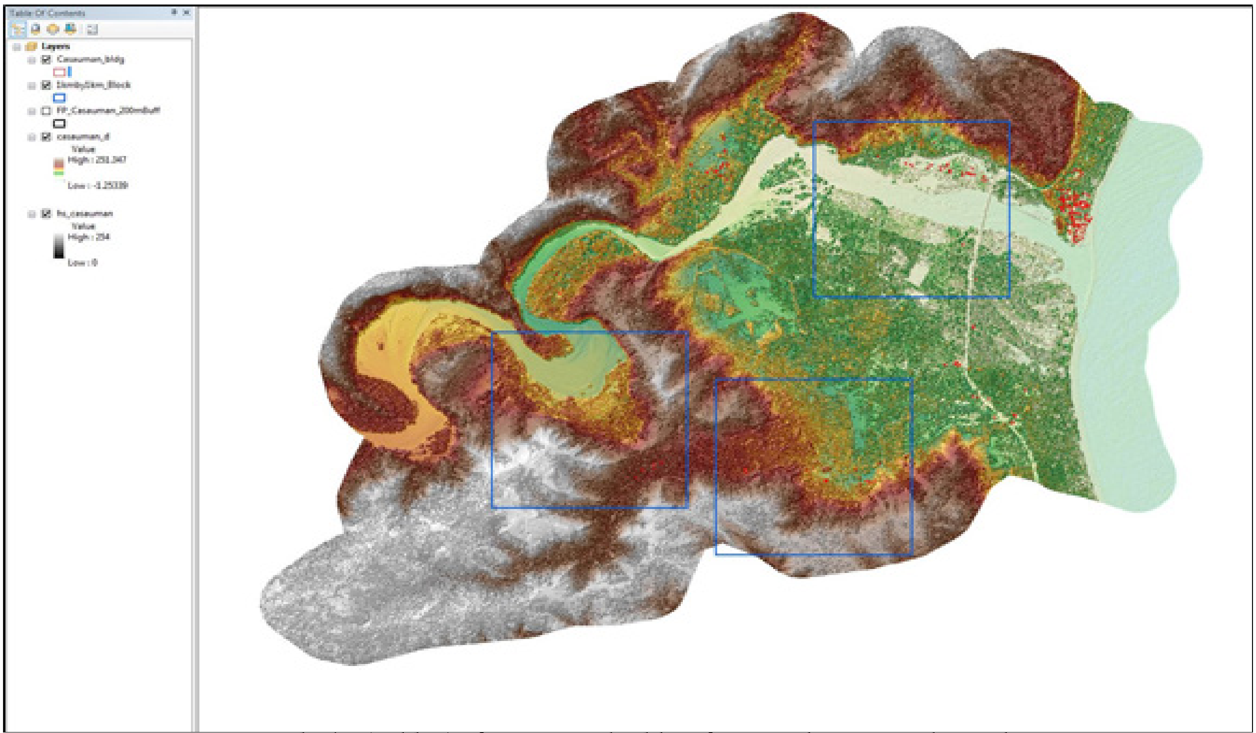

Figure 26. Blocks (in blue) of Casauman building features that were subjected to QC.

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

Table 17. Details of the quality checking ratings for the building features extracted for the Casauman River Basin

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Casauman	100.00	100.00	96.77	PASSED

3.12.2 Height Extraction

Height extraction was done for 367 building features in Casauman Floodplain. Of these building features, 183 was filtered out after height extraction, resulting to 184 buildings with height attributes. The lowest building height is at 2.01 meters, while the highest building is at 14.30 meters.

3.12.3 Feature Attribution

Before the actual field validation, courtesy calls were conducted to seek permission and assistance from the Local Government Units (LGUs) of each barangay. This was done to ensure the safety and security in the area for the field validation process to go smoothly. Verification of barangay boundaries was also done to finalize the distribution of features for each barangay.

The courtesy calls and project presentations were done on May 27, 2016. Barangay Health Workers (BHWs) were requested and hired to guide the University of the Philippines Mindanao Phil-LiDAR 1 field enumerators during validation. The field work activity was conducted on June 14, 2016. The local hires deployed by the barangay captains were given a brief orientation by the field enumerators before the actual field work. The team surveyed the two (2) barangays covered by the floodplain namely Holy Cross and Zaragosa, Manay Municipality.

Manay Municipality LGUs' representative highlighted during the courtesy call that aside from the Casauman River, Manay and Mahan-og rivers surround the central areas of their municipality. These rivers were said to be contributing to the flooding too. There have been boundary conflicts between Manay Municipality and Tarragona Municipality. Nonetheless, the field work continued and was able to finish according to schedule.

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

Table 18. Building features extracted for Casauman Floodplain.

Facility Type	No. of Features
Residential	162
School	4
Prominent Stores	0
Agricultural/Agro-Industrial Facilities	10
Medical Institutions	0
Barangay Hall	1
Military Institution	0
Sports Center/Gymnasium/Covered Court	0
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	1
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	0
Water Supply/Sewerage	0
Religious Institutions	4
Bank	0
Factory	0
Gas Station	0
Fire Station	0
Other Government Offices	0
Other Commercial Establishments	2
Total	**184**

Table 19. Total length of extracted roads for Casauman Floodplain.

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Casauman	6,865.03	0	0	2,773.81	0.00	**9,638.84**

Table 20. Number of extracted water bodies for Casauman Floodplain.

Floodplain	Water Body Type					Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Casauman	1	0	0	0	0	**1**

A total of 67 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 given the complete required attributes. Respectively, all these output features comprise the flood hazard exposure database for the floodplain. The final quality checking completes the feature extraction phase of the project.

Figure 27 shows the completed Digital Surface Model (DSM) of the Casauman floodplain overlaid with its ground features.

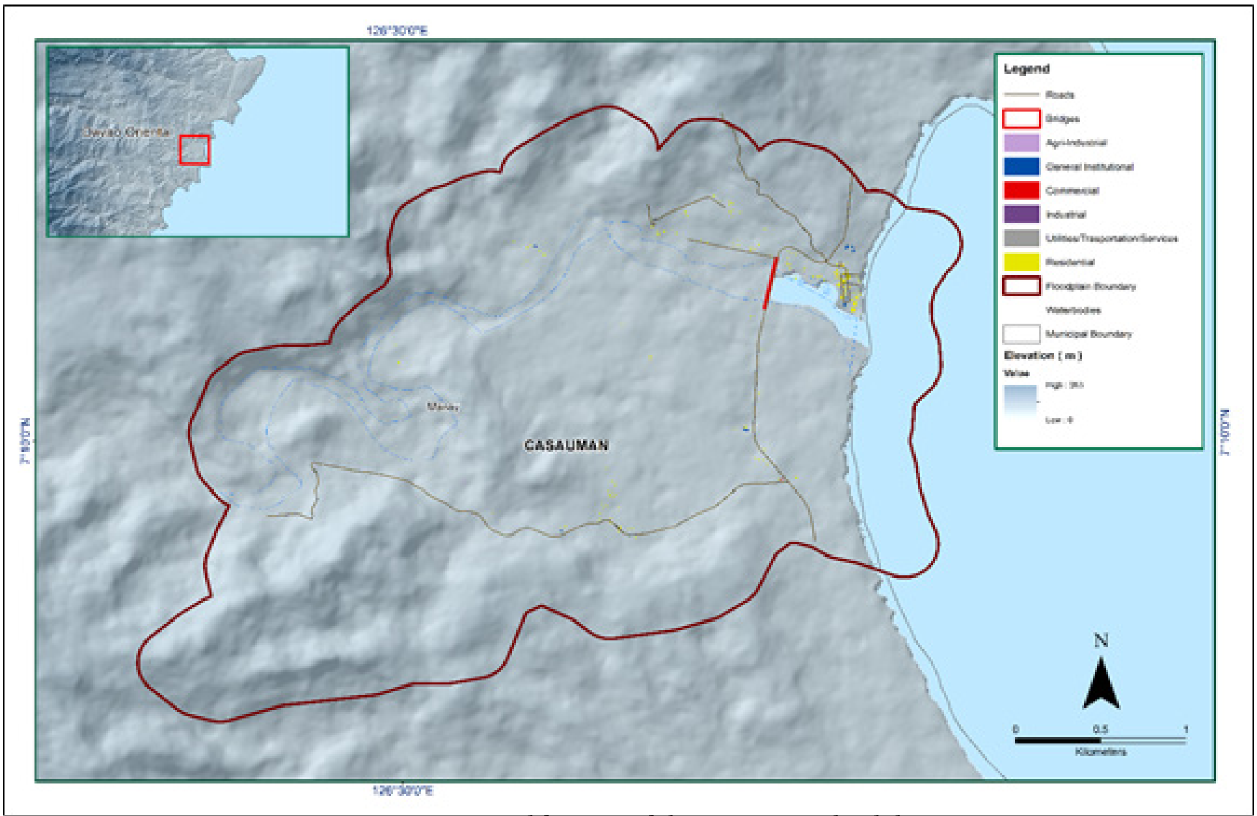

Figure 27. Extracted features of the Casauman Floodplain.

CHAPTER 4: DATA VALIDATION SURVEY AND MEASUREMENTS IN THE CASAUMAN RIVER BASIN

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

4.1 Summary of Activities

The AB Surveying and Development (ABSD) conducted a field survey in Casauman River on February 25, 2016, March 11-14, 2016, and March 20, 2016 with the following scope: reconnaissance; control survey; cross-section and as-built survey at Casauman Bridge in Brgy. Zaragosa, Manay, Davao Oriental; and bathymetric survey from its upstream in Brgy. Del Pilar to the mouth of the river located in Brgy. Holy Cross, Manay, with an approximate length of 10.5 km using a Horizon® Total Station. Random checking points for the contractor's cross-section and bathymetry data were gathered by DVBC on May 10-24, 2016 using a survey grade GNSS receiver Trimble® SPS 985 GNSS PPK survey technique. In addition to this, validation points acquisition survey was conducted covering the Casauman River Basin area. The entire survey extent is illustrated in Figure 28.

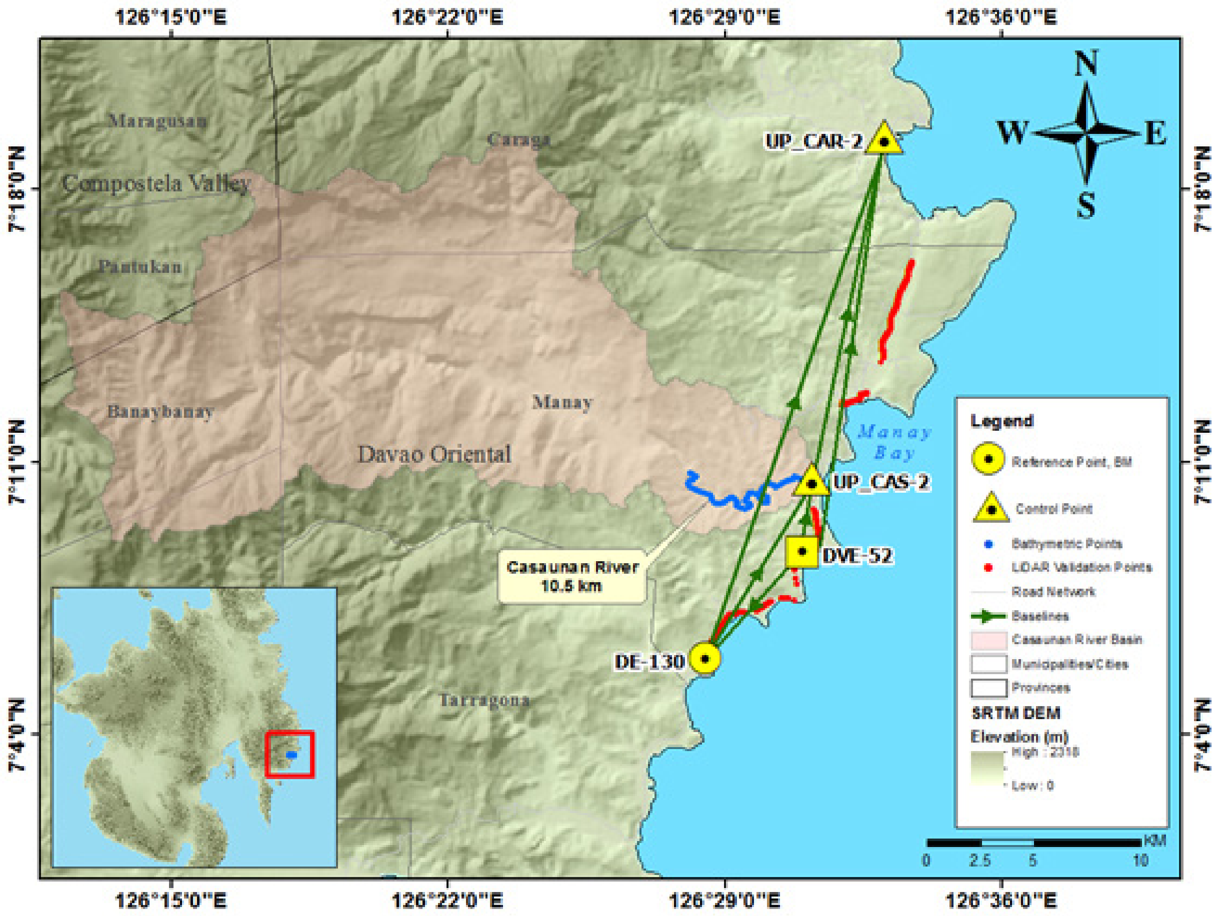


Figure 28. Casauman River Survey Extent

4.2 Control Survey

The GNSS network used for Casauman River survey is composed of four (4) loops established on May 21, 2016 occupying the following reference points: DVE-52 a second-order GCP, in Brgy. Holy Cross, Manay, Davao Oriental and DE-130, a first-order BM, in Brgy. San Ignacio, Manay, Davao Oriental.

Two (2) control points established in the area by ABSD were also occupied: UP_CAR-2 beside the railings near Caraga Bridge in Brgy. Poblacion, Caraga, Province of Davao Oriental and UP_CAS-2 located beside the railings near Casauman Bridge in Brgy. Zaragosa, Manay, Davao Oriental.

Table 21 depicts the summary of reference and control points utilized, with their corresponding locations, while Figure 29 shows the GNSS network established in the Casauman River Survey.

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

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

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (meter)	Elevation in MSL (meter)	Date Established
DVE-52	2nd order, GCP	7°08'41.11589"N	126°30'57.88590"E	83.666	19.242	2007
DE-130	1st order, BM	7°05'57.25021"N	126°28'30.44531"E	101.499	36.988	2009
UP_CAR-2	Established	7°19'20.88068"N	126°33'02.08750"E	72.980	7.391	3-11-16
UP_CAS-2	Established	7°10'34.98817"N	126°31'12.23401"E	74.558	9.812	3-11-16

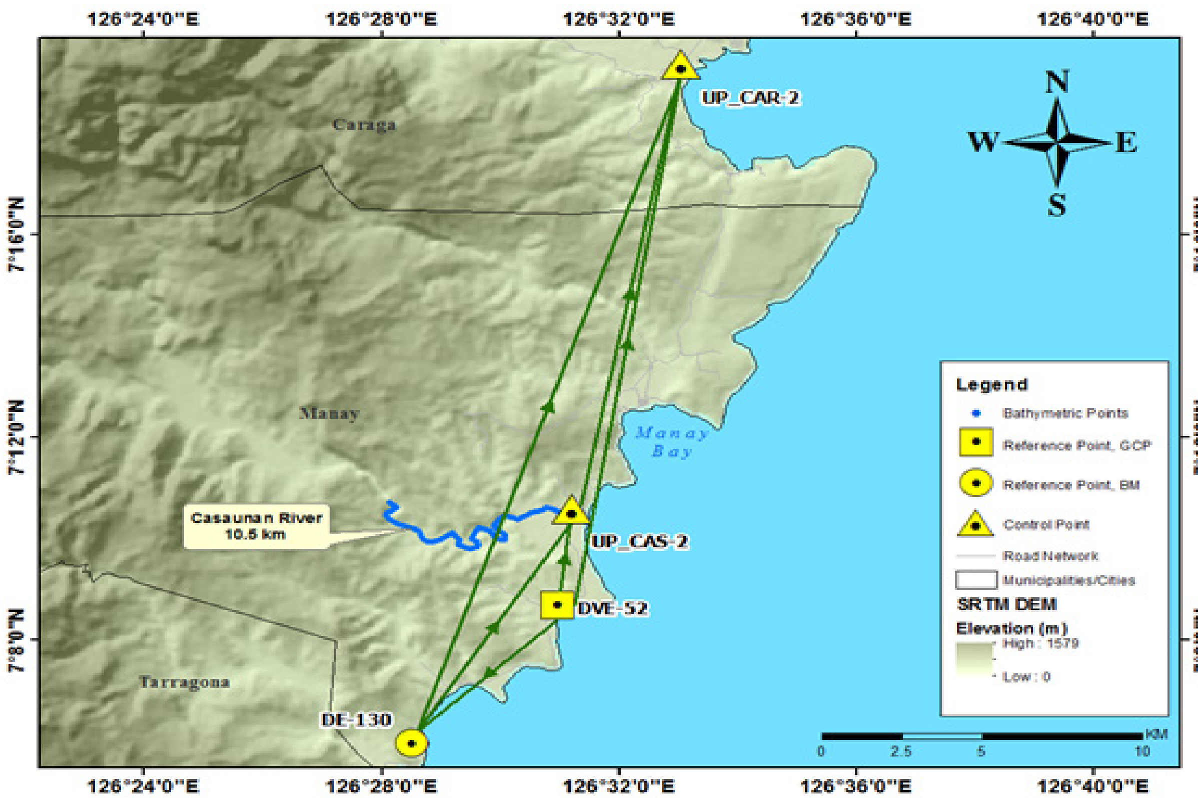


Figure 29. GNSS Network of CASAUMAN Field Survey

Figure 30 to Figure 33 depict the setup of the GNSS on recovered reference points and established control points in the Casauman River.

Figure 30. GNSS base set up, Trimble® SPS 852, at DVE-52, located on top of a water reservoir inside the grounds of the barangay of Brgy. Holy Cross in Manay, Davao Oriental

Figure 31. GNSS receiver set up, Trimble® SPS 985, at DE-130, located on top of a culvert at the side of the road in Brgy. San Ignacio, Municipality of Manay, Province of Davao Oriental

Figure 32. GNSS receiver set up, Trimble® SPS 852, at UP_CAR-2, located at the side of the railing near Caraga Bridge in Brgy. Poblacion, Caraga, Davao Oriental

Figure 33. GNSS receiver set up, Trimble® SPS 985, at UP_CAS-2, located beside the railings near Casauman Bridge in Brgy. Zaragosa, Manay, Davao Oriental

4.3 Baseline Processing

The 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 cases where one or more baselines did not meet all of these criteria, masking was performed. Masking is the removal or covering of portions of the baseline data using the same processing software. The data is then repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, a resurvey is initiated. Table 22 presents the baseline processing results of control points in the Casauman River Basin, as generated by the TBC software.

Table 22. The Baseline processing report for the Casauman River GNSS static observation survey.

Observation	Date of Observation	Solution Type	H. Prec. (meter)	V. Prec. (meter)	Geodetic Az.	Ellipsoid Dist. (meter)	ΔHeight (meter)
DVE-52 --- UP_CAR-2	5-21-2016	Fixed	0.007	0.017	10°58'11"	20019.494	-10.696
DE-130 – UP_CAR-2	5-21-2016	Fixed	0.020	0.037	18°38'54"	26056.144	-28.533
DE-130 --- UP_CAS-2	5-21-2016	Fixed	0.019	0.048	30°11'24"	9871.200	-26.967
UP_CAS-2 ---UP_CAR-2	5-21-2016	Fixed	0.008	0.032	11°46'50"	16503.147	-1.535
DVE-52 --- DE-130	5-21-2016	Fixed	0.011	0.031	221°57'01"	6768.248	17.831
DVE-52 --- UP_CAS-2	5-21-2016	Fixed	0.004	0.014	7°10'21"	3525.735	-9.099

As shown in Table 22, a total of three (3) baselines were processed with the coordinates of DVE-52, and the elevation value of reference points DE-130 held fixed; it is apparent that all baselines passed the required accuracy.

4.4 Network Adjustment

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

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

where:

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

For complete details, see the Network Adjustment Report shown in Table 23 to Table 25.

The four (4) control points, DVE-52, DE-130, UP-CAR-2, and UP_CAR-2 were occupied and observed simultaneously to form a GNSS loop. The coordinate values of DVE-52 and elevation of DE-130 were held fixed during the processing of the control points as presented in Table 23. Through this reference point, the coordinates and ellipsoidal height of the unknown control points will be computed.

Table 23. Constraints applied to the adjustment of the control points.

Point ID	Type	East σ (meter)	North σ (meter)	Height σ (meter)	Elevation σ (meter)
DE-130	Grid				Fixed
DVE-52	Global	Fixed	Fixed		
Fixed = 0.000001 (meter)					

Likewise, the list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 24.

Table 24. Adjusted grid coordinates for the control points used in the Casauman River flood plain survey.

Point ID	Easting	Easting Error (meter)	Northing (meter)	Northing Error (meter)	Elevation (meter)	Elevation Error (meter)	Constraint
DE-130	785478.959	0.007	221096.035	0.015	36.988	?	e
DVE-52	790491.017	?	225649.982	?	19.242	0.046	LL
UP_CAR-2	810133.793	0.004	229568.764	0.009	7.391	0.048	
UP_CAS-2	793988.582	0.004	226109.356	0.006	9.812	0.049	

The results of the computation for accuracy are as follows:

a. **DE-130v**

horizontal accuracy = $\sqrt{(0.7)^2 + (1.5)^2}$
= $\sqrt{0.49 + 2.25}$
= 2.74 < 20 cm

vertical accuracy = Fixed

b. **DVE-52**

horizontal accuracy = Fixed
vertical accuracy = 4.6 < 10 cm

c. **UP_CAR-2**

horizontal accuracy = $\sqrt{(0.4)^2 + (0.9)^2}$
= $\sqrt{0.16 + 0.81}$
= 0.97 < 20 cm

vertical accuracy = 4.8 < 10 cm

d. **UP_CAS-2**

horizontal accuracy = $\sqrt{(0.4)^2 + (0.6)^2}$
= $\sqrt{0.16 + 0.36}$
= 0.52 < 20 cm

vertical accuracy = 4.9 < 10 cm

Following the given formula, the horizontal and vertical accuracy result of the four (4) occupied control points are within the required precision.

Table 25. Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (meter)	Height Error (meter)	Constraint
DVE-52	N7°05'57.25021"	E126°28'30.44531"	101.499	?	e
DE-130	N7°08'41.11589"	E126°30'57.88590"	83.666	0.046	LL
UP_CAR-2	N7°19'20.88068"	E126°33'02.08750"	72.980	0.048	
UP_CAS-2	N7°10'34.98817"	E126°31'12.23401"	74.558	0.049	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 25. Based on the results of the computation, the accuracy conditions are satisfied; hence, the required accuracy for the program was met. The computed coordinates of the reference and control points utilized in the Casauman River GNSS Static Survey are seen in Table 26.

Table 26. The reference and control points utilized in the Casauman River Static Survey, with their corresponding locations (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing	Easting	MSL Elevation (m)
DVE-52	2nd order, GCP	7°08'41.11589"N	126°30'57.88590"E	83.666	790491.017	225649.982	19.242
DE-130	1st order, BM	7°05'57.25021"N	126°28'30.44531"E	101.499	785478.959	221096.035	36.988
UP_CAR-2	Established	7°19'20.88068"N	126°33'02.08750"E	72.980	810133.793	229568.764	7.391
UP_CAS-2	Established	7°10'34.98817"N	126°31'12.23401"E	74.558	793988.582	226109.356	9.812

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

The bridge cross-section and as-built surveys were conducted on March 20, 2016 at the downstream side of Casauman Bridge in Brgy. Zaragosa, Manay. Horizon® Total Station was utilized for this survey, (Figure 34 and Figure 35).

Figure 34. Cross-section Survey at Polanco Bridge in Brgy. Obay, Polanco, Zamboanga del Norte

Figure 35. As-built survey conducted at Casauman Bridge.

The length of the cross-sectional line surveyed at Casauman Bridge is about 455 meters (Figure 36) with two hundred and fifteen (215) points acquired using the control points UP_CAS-1 and UP_CAS-2 as the GNSS base stations. The location map, cross-section diagram and the accomplished bridge data from are shown in Figure 36, 37 and 38. Gathering of random points for the checking of ABSD's bridge cross-section and bridge points data was performed by DVBC on May 14, 2016 using a survey grade GNSS Rover receiver attached to a 2-m pole, as seen in Figure 39.

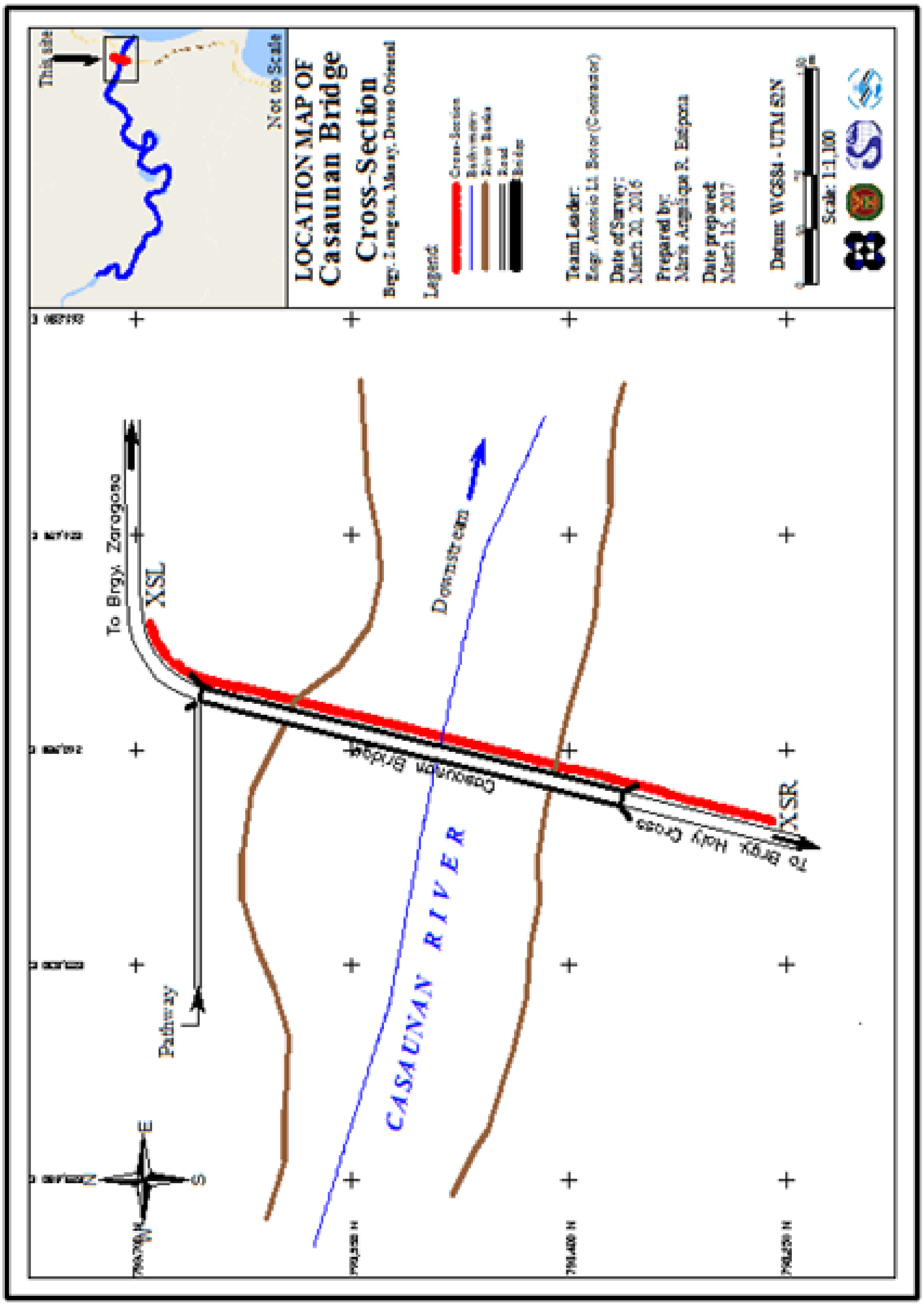


Figure 36. Location map of the Casauman Bridge Cross Section

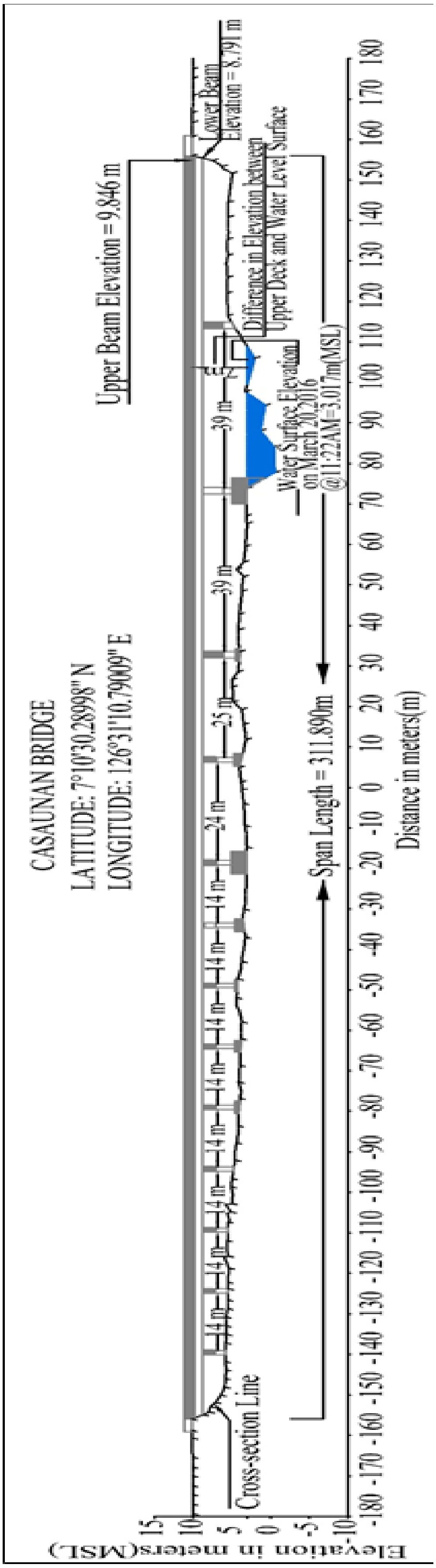


Figure 37. The Casauman cross-section diagram.

Bridge Data Form

Bridge Name: CASAUMAN BRIDGE

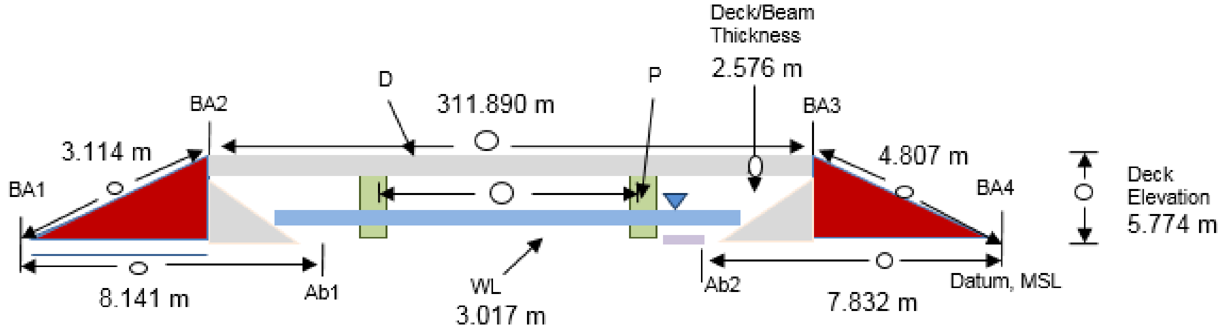
River Name: CASAUMAN RIVER
Location: (Brgy, City, Region): Brgy. Zaragosa, Manay, Davao Oriental

Survey Team: Jayson Illustre, Ryan Antonio
Date and Time: March 20, 2016, 11:22 AM

Flow Condition: low normal high

Weather Condition: fair rainy

Cross-sectional View (not to scale)



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

Line Segment	Measurement (m)	Remarks
1. BA1-BA2	3.114 m	
2. BA2-BA3	311.890 m	
3. BA3-BA4	4.807 m	
4. BA1-Ab1	8.141 m	
5. Ab2-BA4	7.832 m	
6. Deck/beam thickness	2.576 m	
7. Deck elevation	5.774 m	

Note: Observer should be facing downstream

Figure 38. Casauman Bridge Data Sheet.

Figure 39. Gathering of random cross-section points along the downstream side of Casauman River.

Linear square correlation (R^2) and RMSE analysis were performed on the two (2) datasets. The linear square coefficient range is determined to ensure that the submitted data of the contractor is within the accuracy standard of the project which is ±20 cm and ±10 cm for horizontal and vertical, respectively. The R^2 value must be within 0.85 to 1. An R^2 approaching 1 signifies a strong correlation between the vertical (elevation values) of the two datasets. A computed R^2 value of 1.00 was obtained by comparing the data of the contractor and DVBC; signifying a strong correlation between the two (2) datasets.

In addition to linear square correlation, Root Mean Square (RMSE) analysis is also performed in order to assess the difference in elevation between the DVBC checking points and the contractor's. The RMSE value should only have a maximum radial distance of 5 m and the difference in elevation within the radius of 5 meters should not be beyond 0.50 m. For the bridge cross-section data, a computed value of 0.178 was acquired. The computed R^2 and RMSE values are within the accuracy requirement of the program.

The water surface elevation of Casauman River was determined by a Horizon® Total Station on March 20, 2016 at 11:22 AM at Casauman Bridge area with a value of 3.017 m in MSL as shown in Figure 37. This was translated into marking on the bridge's pier as shown in Figure 40. The marking will serve as reference for flow data gathering and depth gauge deployment of the partner SUC responsible for Casauman River, UP MIndanao.

Figure 40. Water-level markings on Casauman Bridge.

4.6 Validation Points Acquisition Survey

The validation points acquisition survey was conducted from June 13 to 14, 2016 using a survey GNSS rover receiver South® S86T mounted on a range pole, which was attached in front of the vehicle as shown in Figure 42. It was secured with a bipod and ropes to ensure that it was horizontally and vertically balanced. The antenna height was 2.950 m and measured from the ground up to the bottom of the quick release of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with T-1 occupied as the GNSS base station in the conduct of the survey.

Figure 41. GNSS Receiver South® S86T installed on a vehicle for Ground Validation Survey.

The survey acquired 6,426 ground validation points with an approximate length of 44.768 km, covered the major roads of CASAUMAN-Polanco-Oroquieta, CASAUMAN Zamboanga Highway and CASAUMAN Punta Dansullan-Serio Osmeña as shown in the map in Figure 44. The control point UP-POL was used as the GNSS base station all throughout the survey.

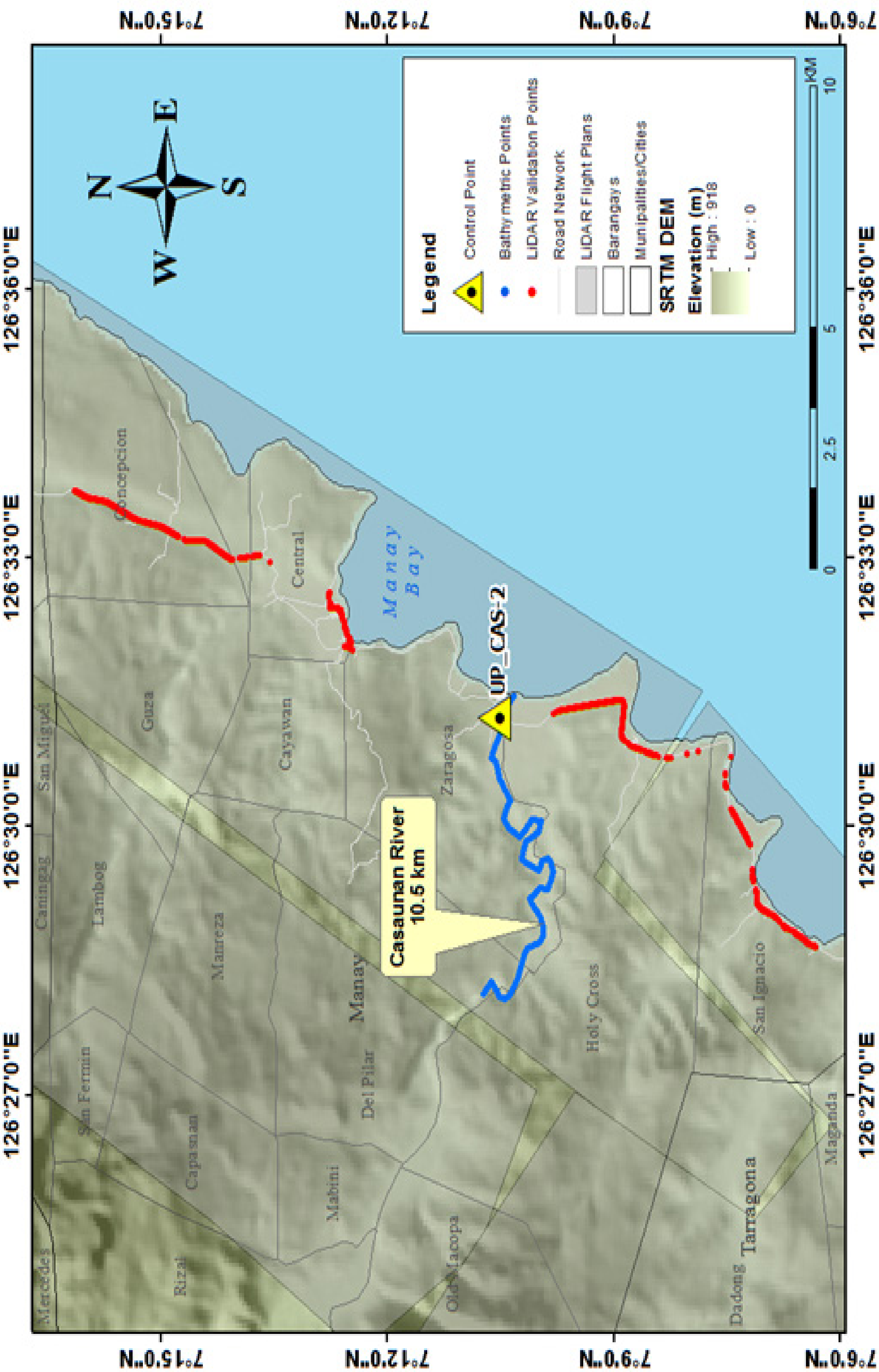


Figure 42. The extent of the LiDAR ground validation survey (in red) for Casauman River Basin.

4.7 River Bathymetric Survey

A manual bathymetric survey was performed on March 11-14, 2016 using a Horizon® Total Station as shown in Figure 44.

Figure 43. Set up of the bathymetric survey of ABSD at Casauman River using Horizon® Total Stationsurvey

The survey started in Brgy. Del Pilar, Manay, Davao Oriental with coordinates 7° 10' 47.24829"N, 126° 28' 3.75996"E and ended at the mouth of the river in Brgy. Holy Cross, Manay, Davao Oriental with coordinates 7° 10' 15.02560"N, 126° 31' 28.24140"E. The control points UP_CAS-1 and UP_CAS-2 served as the GNSS base stations all throughout the bathymetric survey.

Gathering of random points for the checking of ABSD's bathymetric data was performed by DVBC on May 14, 2016 using a GNSS Rover receiver, Trimble® SPS 985 attached to a 2-m pole, see Figure 44. A map showing the DVBC bathymetric checking points is shown in Figure 46.

Figure 44. Gathering of random bathymetric points along Casauman River

Overall, the bathymetric survey for Casauman River gathered a total of 5,057 points covering 10.5 km of the river traversing barangays Del Pilar, Zaragosa, and Holy Cross in the Municipality of Manay. The extent of the bathymetric survey for the Casauman River is shown in Figure 45. To further illustrate this, a CAD drawing of the riverbed profile of the Casauman River was produced. As seen in Figure 47, the highest and lowest elevation has a 66-m difference. The highest elevation observed was 64.406 m above MSL located in Brgy. Del Pilar, Manay while the lowest was -1.446 m below MSL located in Brgy. Holy Cross, Manay.

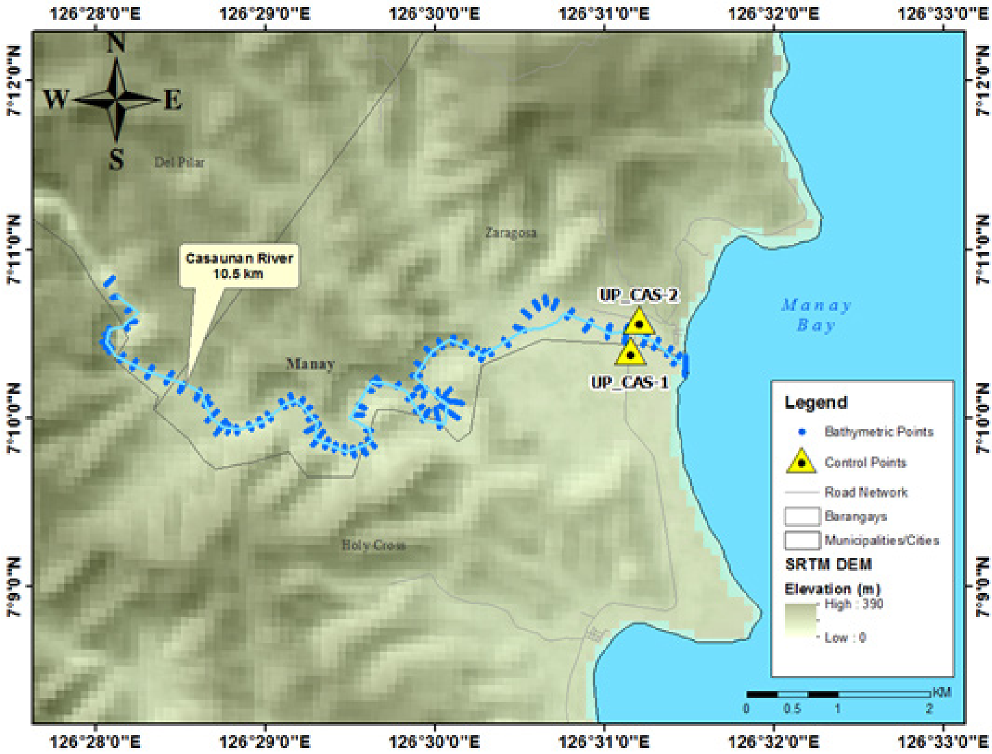


Figure 45. The extent of the Casauman River Bathymetry Survey.

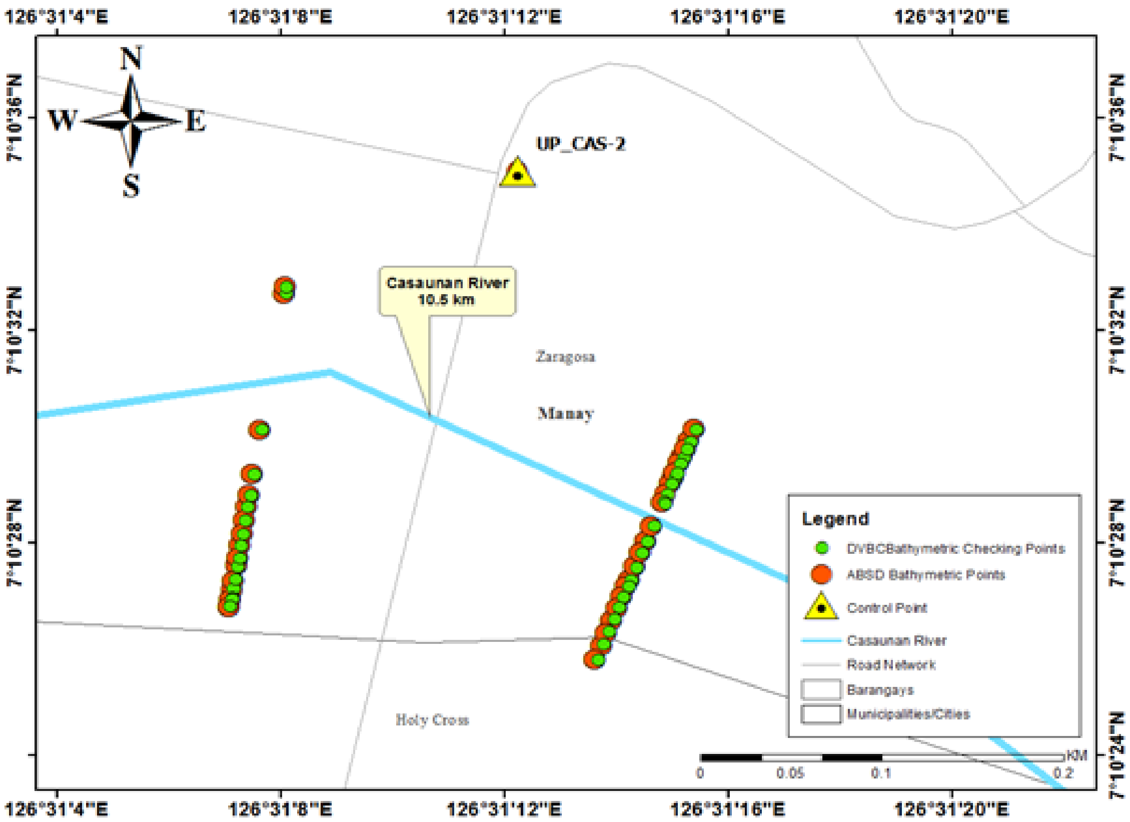


Figure 46. Quality checking points gathered by DVBC along Casauman River.

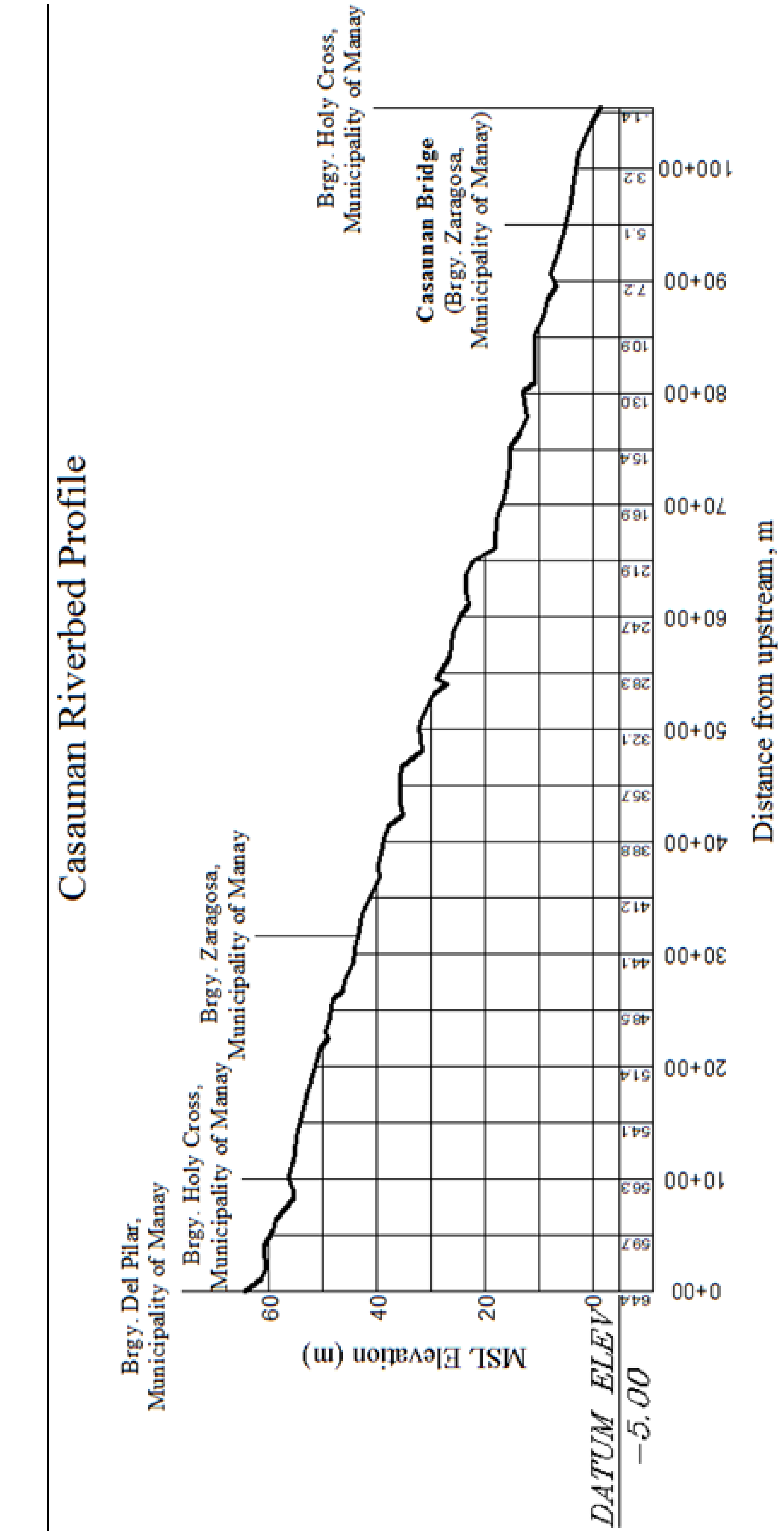


Figure 47. The Casauman Riverbed Profile.

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, Narvin Clyd Tan, Hannah Aventurado

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

5.1 Data used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

All components and data, such as rainfall, water level, and flow in a certain period of time, which may affect the hydrologic cycle of the Casauman River Basin were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from an automatic rain gauge (ARG) installed by the University of the Philippines Mindanao Phil-LiDAR 1 team. The ARG was installed at Barangay Rizal, Manay, Davao Oriental with the following coordinates: 7° 14’ 46” N, 126° 25’ 17.29” as illustrated in Figure 48. The precipitation data collection started from December 16, 2015 at 2:50 PM to December 17, 2015 at 12:00 NN on the same day with a 10-minute recording interval.

The total precipitation for this event in the installed rain gauge was 22.8 mm. It has a peak rainfall of 10.8 mm. on December 16, 2015 at 3:20 PM. The lag time between the peak rainfall and discharge is 7 hours.

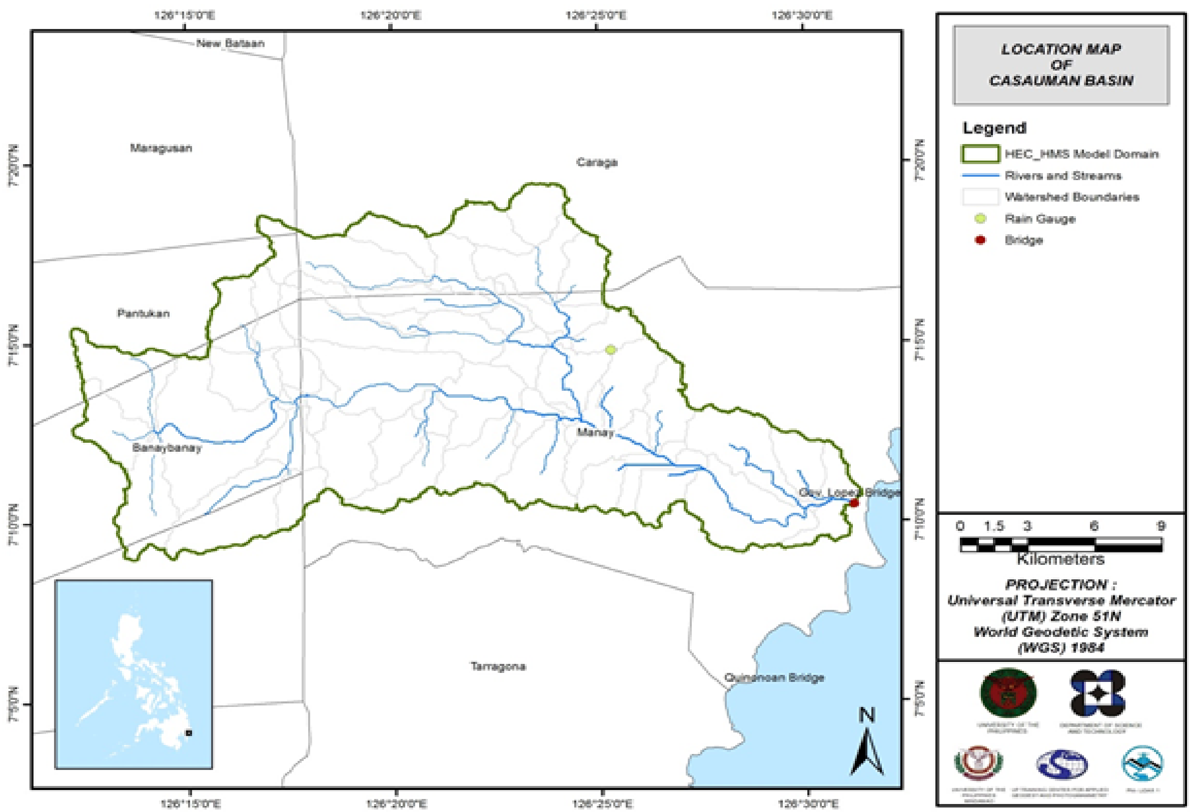


Figure 48. The location map of CASAUMAN HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Governor Lopez Bridge, Barangay Zaragosa, Manay, Davao Oriental (7° 10' 27.26" N, 126° 31' 10.31" E) to establish the relationship between the observed water levels (H) at Governor Lopez Bridge and outflow (Q) of the watershed at this location.

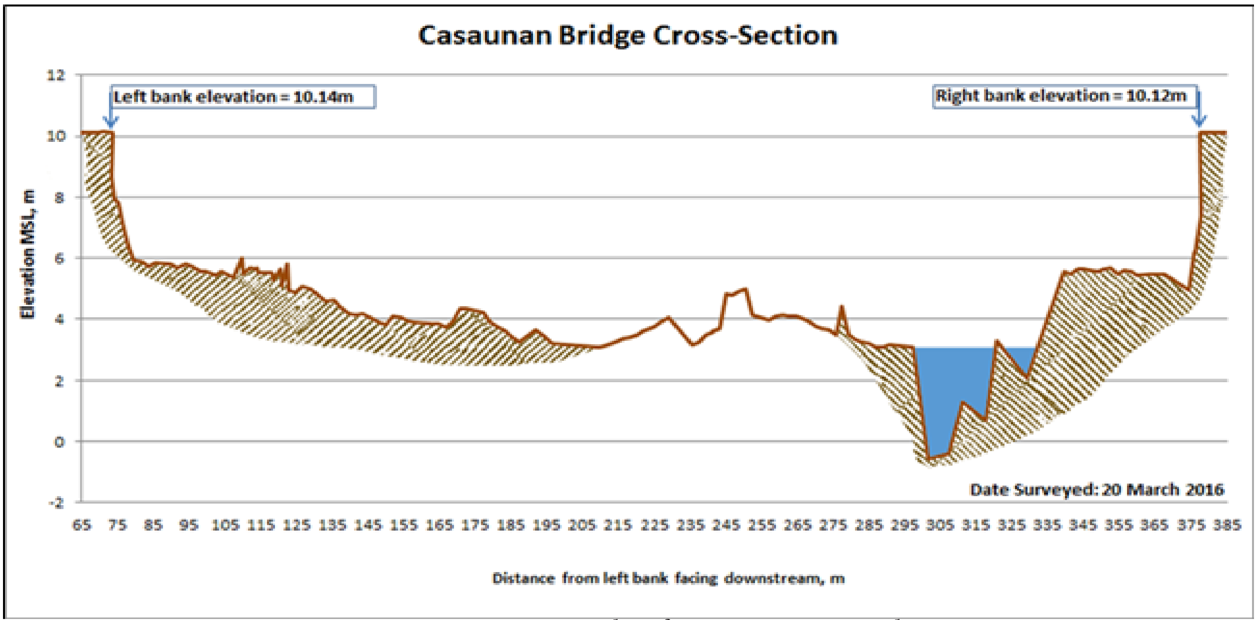


Figure 49. Cross-Section Plot of Governor Lopez Bridge.

For Governor Lopez Bridge, the rating curve is expressed as Q = 2.0767E-10e7.9878x as shown in Figure 50.

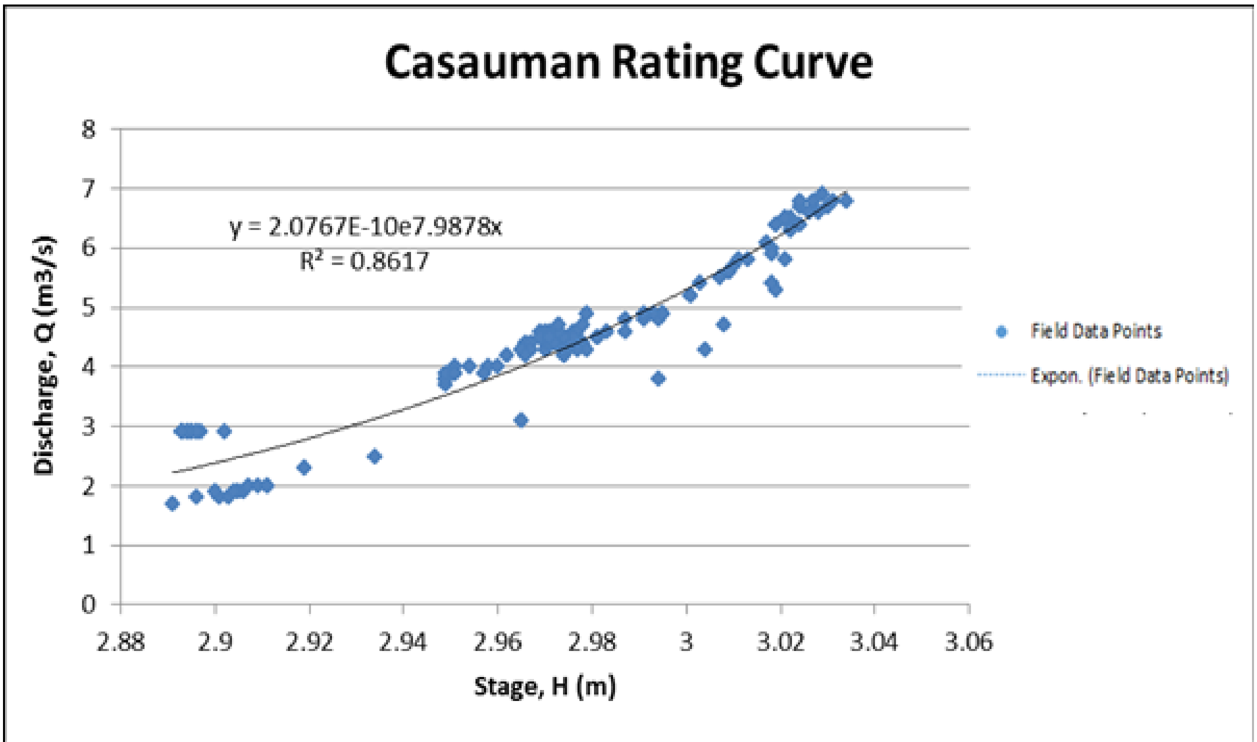


Figure 50. Rating Curve at Polanco Bridge

This rating curve equation was used to compute the river outflow at Governor Lopez Bridge for the calibration of the HEC-HMS model for Casauman shown in Figure 48. The total rainfall for this event is 22.8 mm and the peak discharge is 6.9 m^3/s at 10:20 PM of December 16, 2015.

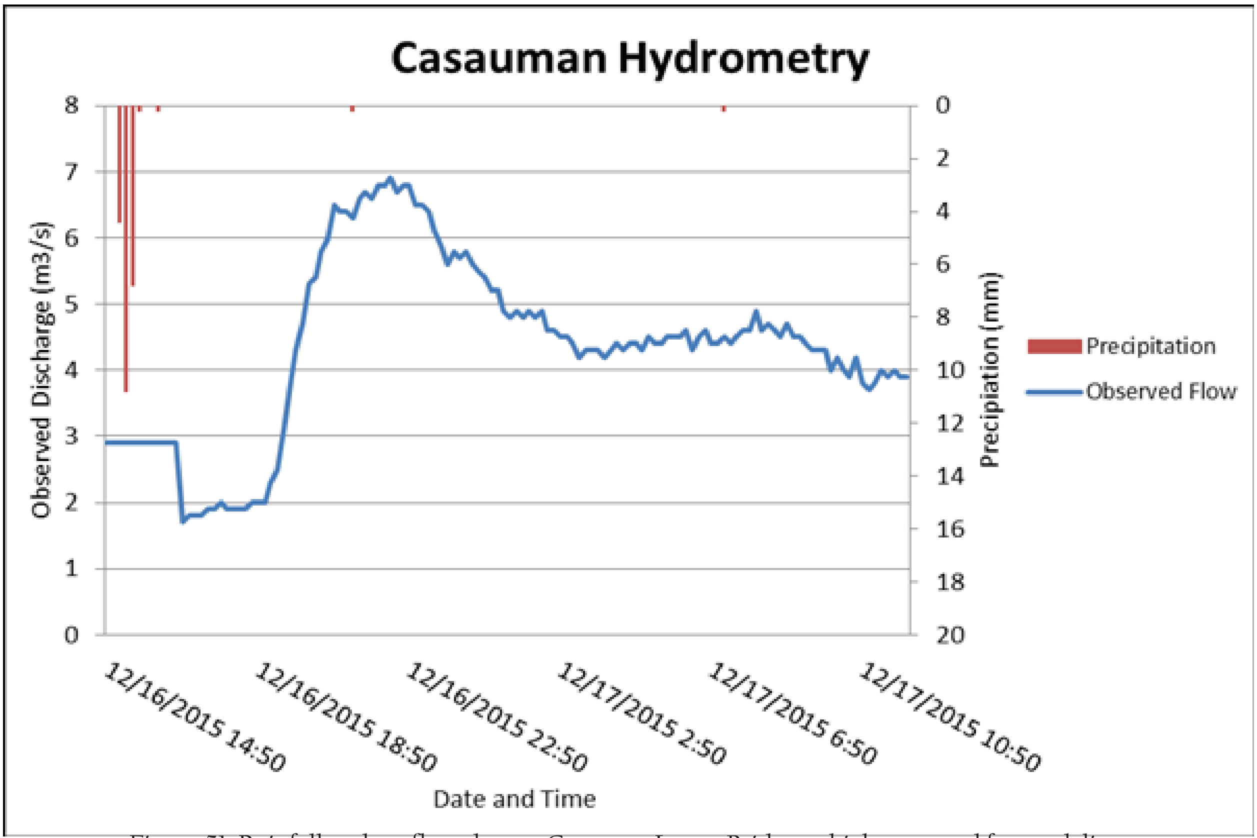


Figure 51. Rainfall and outflow data at Governor Lopez Bridge, which was used for modeling.

5.2 RIDF Station

PAGASA computed the Rainfall Intensity Duration Frequency (RIDF) values for the Davao Rain Gauge (Table 27). The RIDF rainfall amount for 24 hours was converted into a synthetic storm by interpolating and re-arranging the values in such a way that certain peak values will be attained at a certain time (Figure 53). This station was selected based on its proximity to the Casauman watershed. The extreme values for this watershed were computed based on a 59-year record.

Table 27. RIDF values for the Casauman River Basin based on average RIDF data of Davao station, as 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	19.5	30	38.2	53.2	65.2	71.6	80.3	85.8	91.4
5	25.1	39.3	51	73.2	88.8	96.4	108.7	114.9	121.1
10	28.8	45.4	59.4	86.5	104.5	112.8	127.5	134.1	140.7
15	30.9	48.9	64.2	94	113.3	122.1	138.1	145	151.8
20	32.4	51.3	67.6	99.3	119.5	128.6	145.5	152.6	159.5
25	33.5	53.2	70.1	103.3	124.2	133.6	151.2	158.5	165.5
50	37	59	78.1	115.8	138.9	149	168.8	176.5	183.9
100	40.5	64.7	85.9	128.1	153.5	164.2	186.3	194.4	202.1

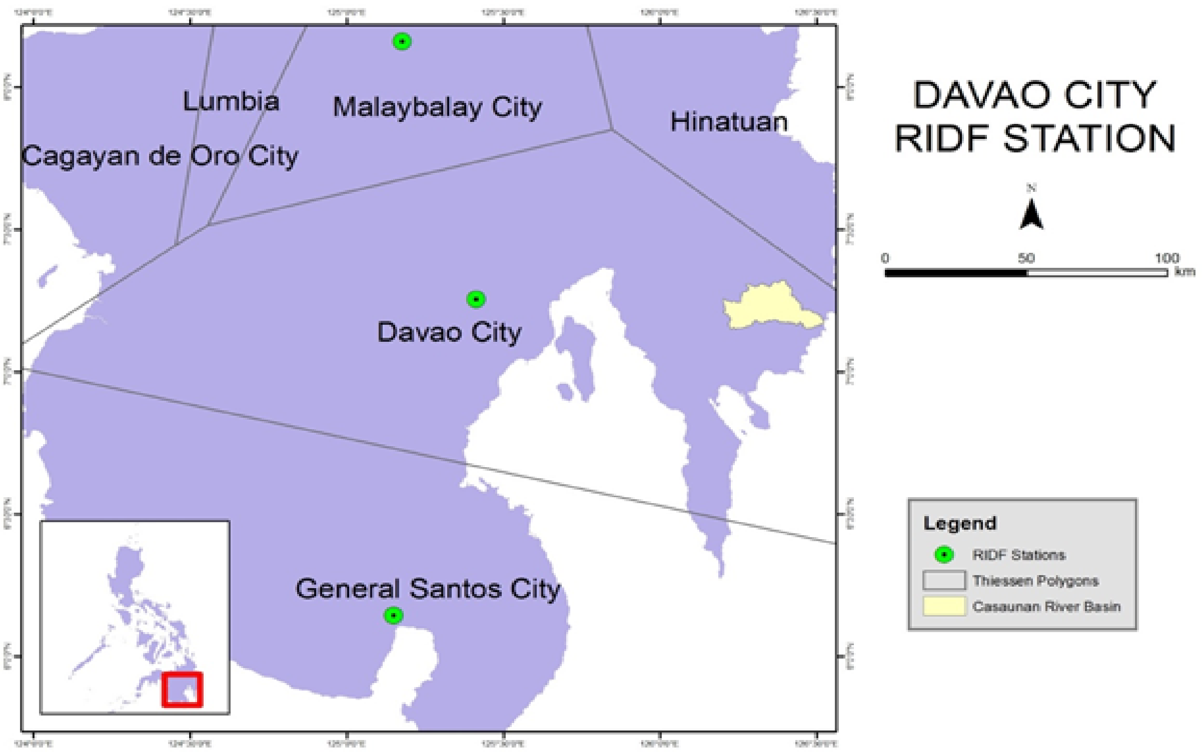


Figure 52. The location of the Davao RIDF station relative to the Casauman River Basin.

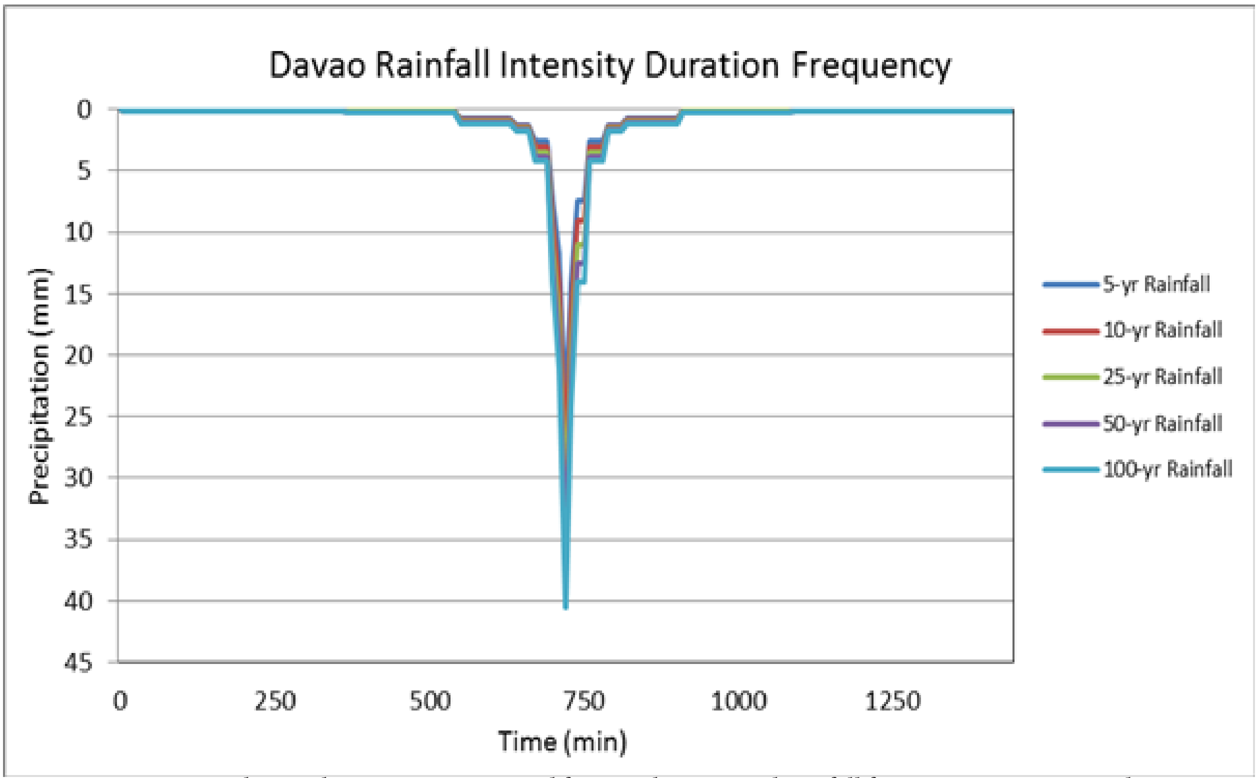


Figure 53. The synthetic storm generated for a 24-hour period rainfall for various return periods

5.3 HMS Model

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

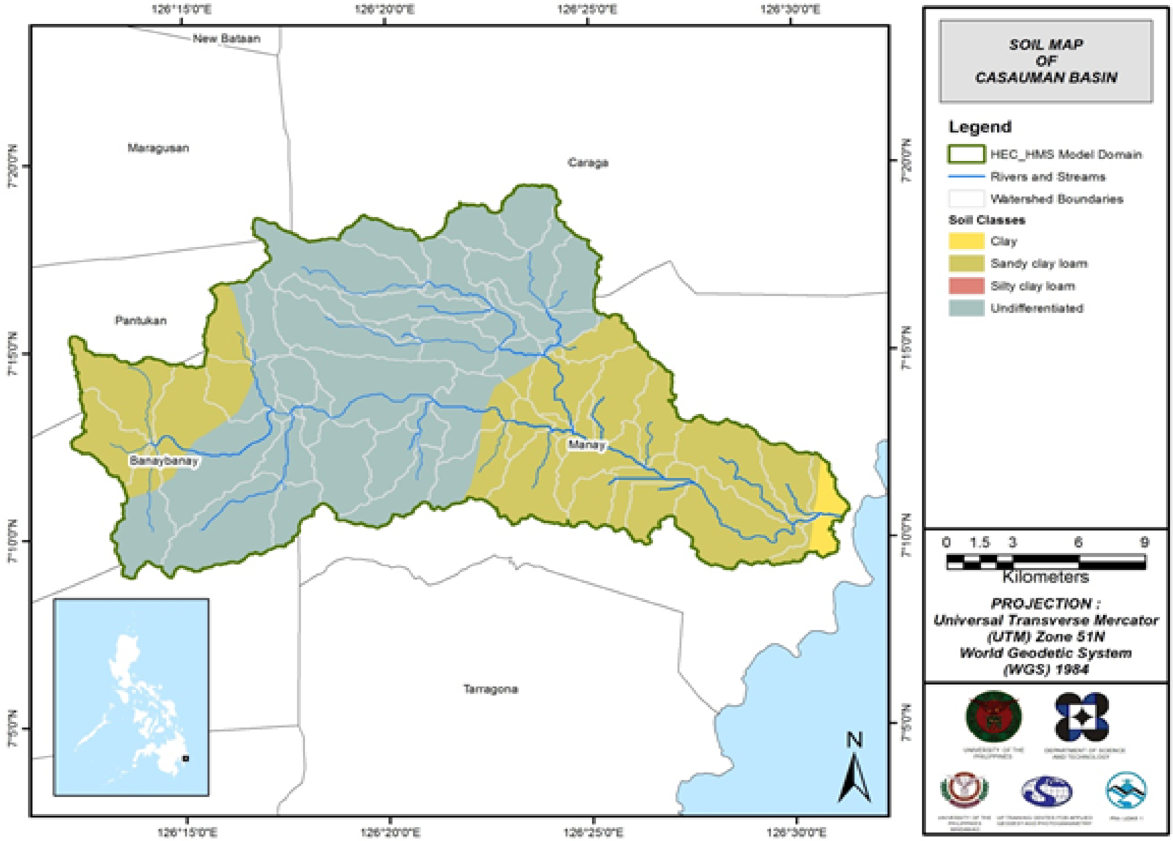


Figure 54. Soil Map of Casauman River Basin.

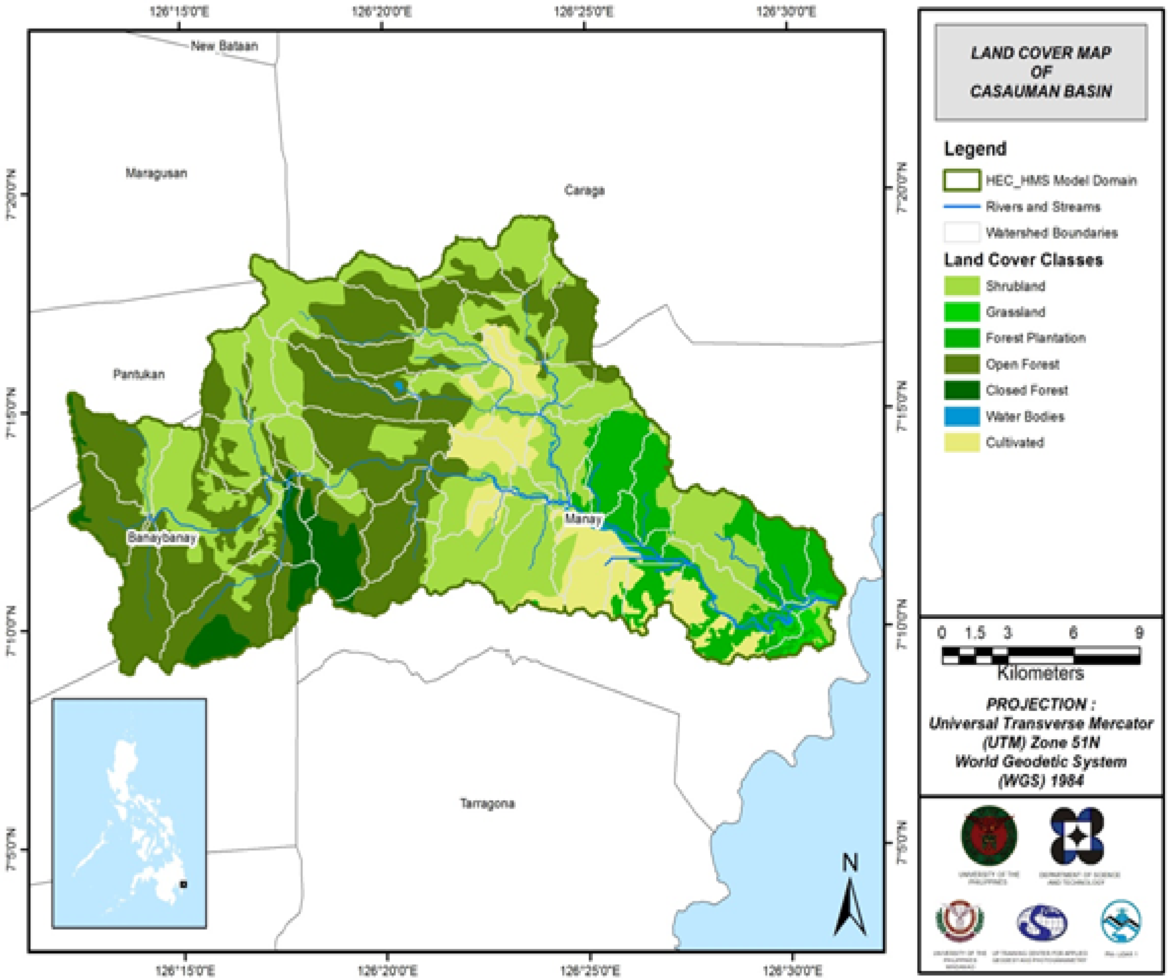


Figure 55. Land Cover Map of Casauman River Basin.

For Casauman, four soil classes were identified. These are clay, sandy clay loam, silty clay loam and undifferentiated land. Moreover, seven (7) land cover classes were identified. These are shrublands, grasslands, forest plantations, open forests, closed forests, water bodies, and cultivated areas.

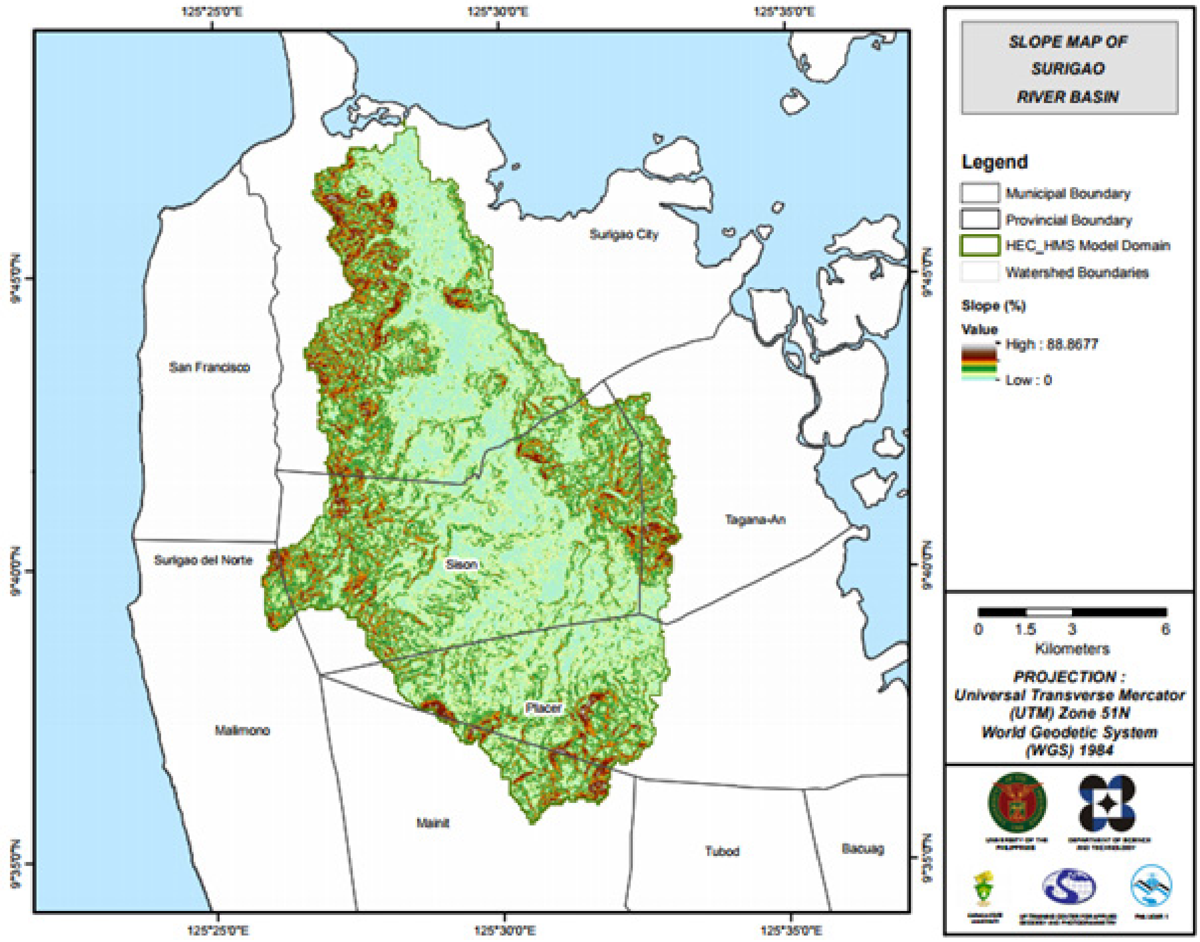


Figure 56. Slope Map of the Casauman River Basin.

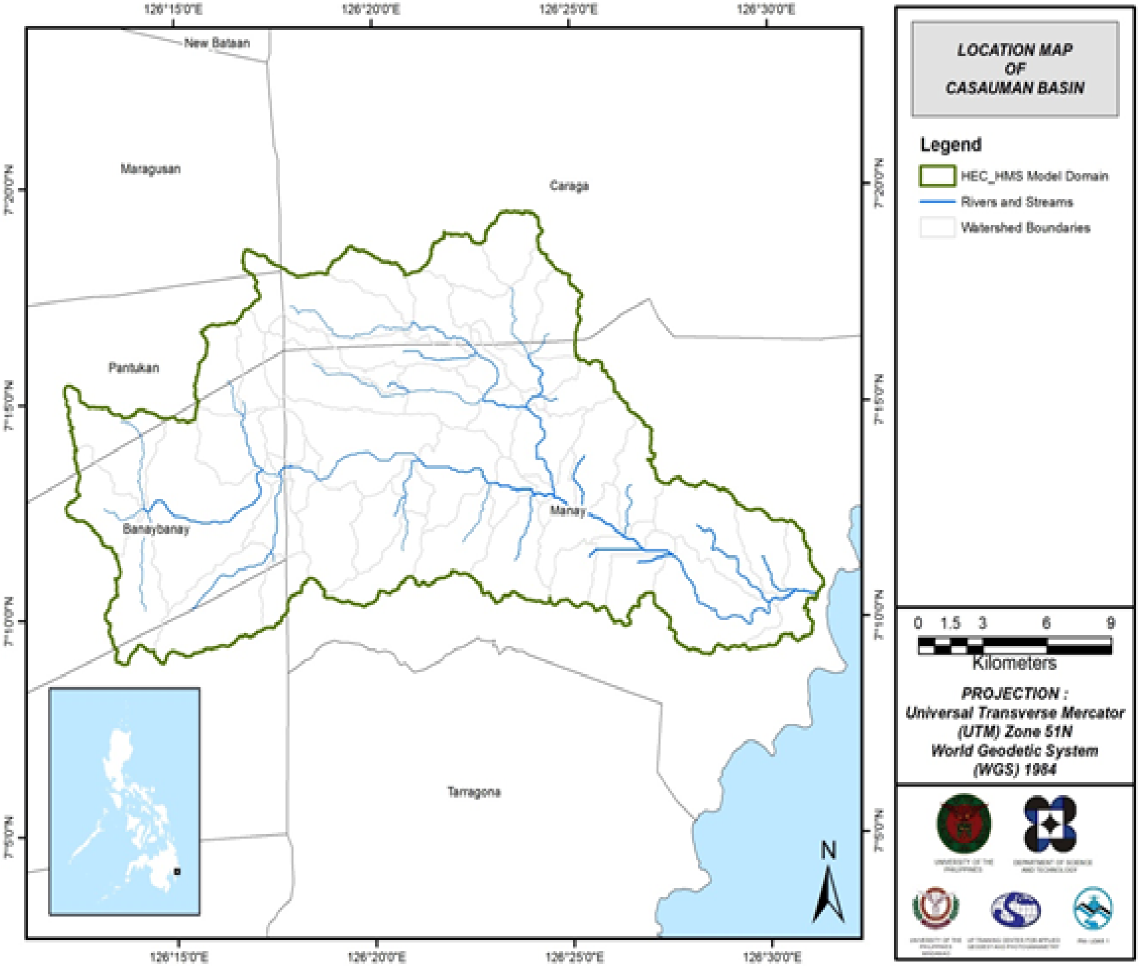


Figure 57. Stream Delineation Map of Casauman River Basin

Using the SAR-based DEM, the Casauman Basin was delineated and further subdivided into subbasins. The model consists of 55 sub basins, 27 reaches, and 27 junctions as shown in Figure 58. The main outlet is at Governor Lopez Bridge.

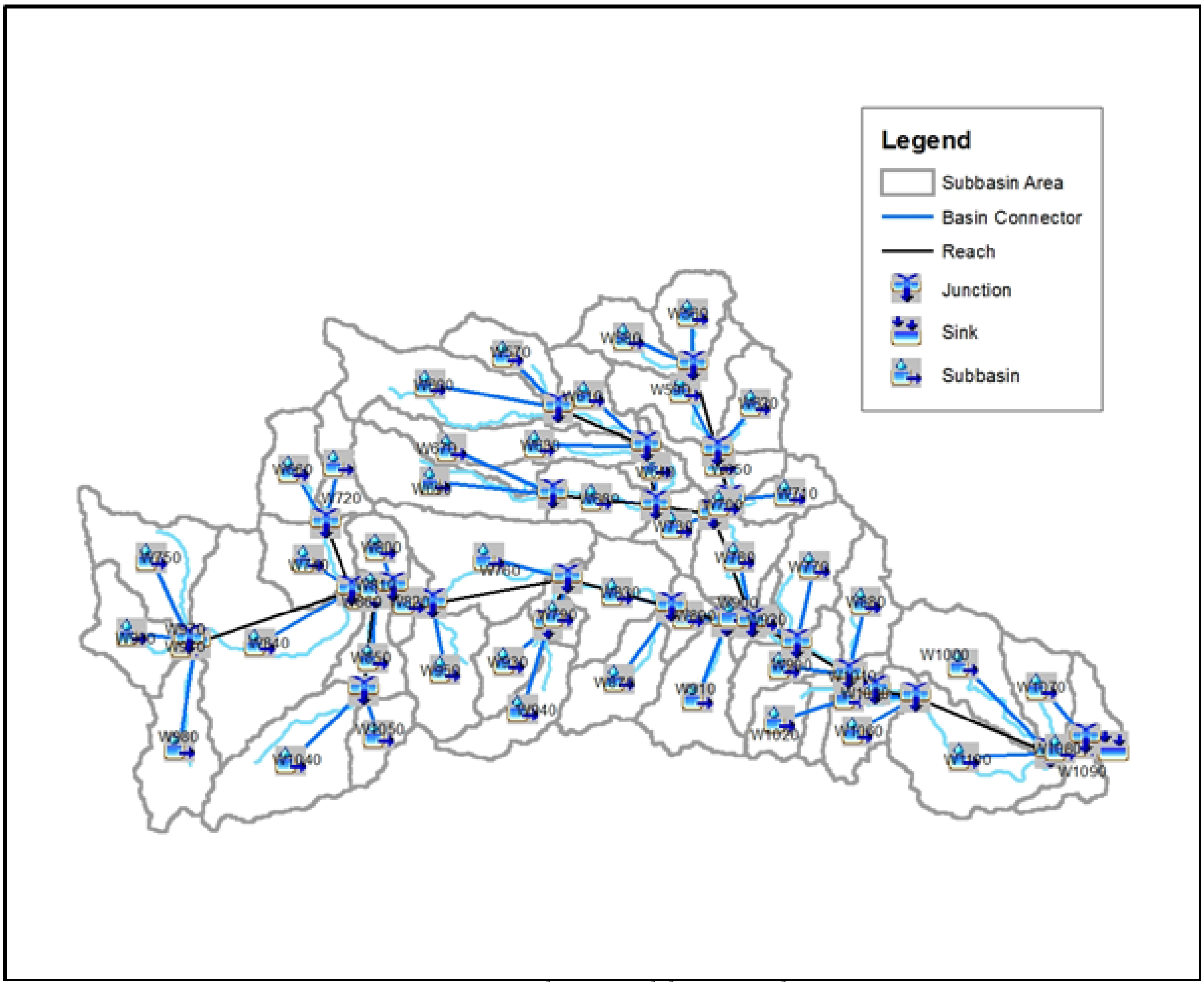


Figure 58. Casauman river basin model generated in HEC-HMS.

5.4 Cross-section Data

The riverbed cross-sections of the watershed were necessary in the HEC-RAS model setup. The cross-section data for the HEC-RAS model was derived from the LiDAR DEM data, which was defined using the Arc GeoRAS tool and was post-processed in ArcGIS (Figure 59).

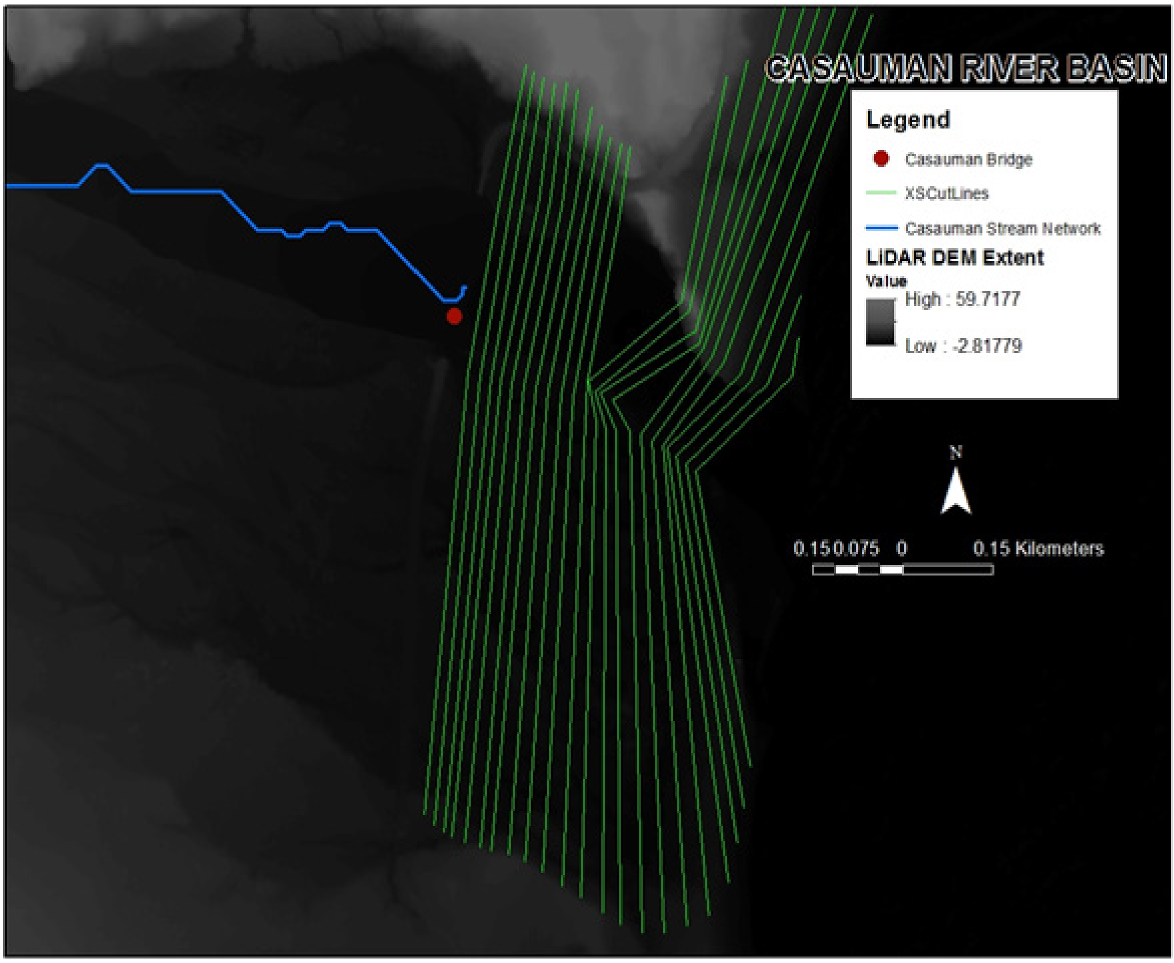


Figure 59. River cross-section of the Casauman River through the ArcMap HEC GeoRas tool.

5.5 Flo 2D Model

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

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

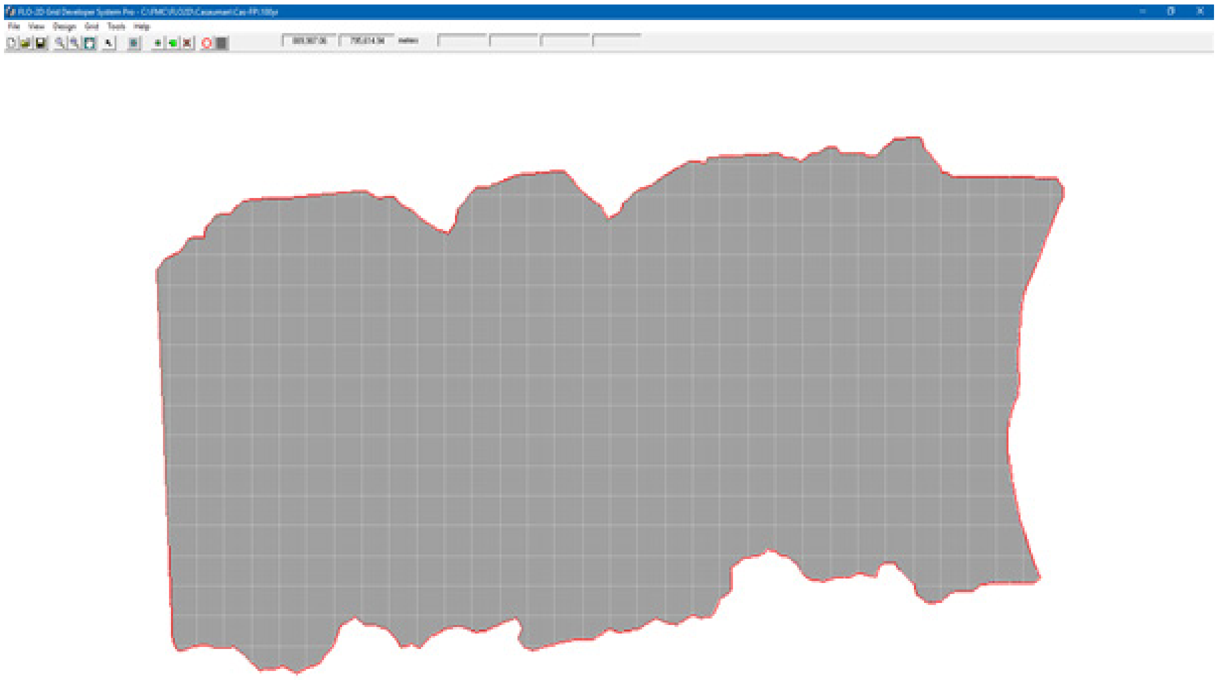


Figure 60. A screenshot of the river sub-catchment with the computational area to be modeled in FLO-2D Grid Developer S ystem Pro (FLO-2D GDS Pro).

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 53.15430 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh [Product of maximum velocity (v) times maximum depth (h)] is set at 0 m^2/s. The generated hazard maps for Casauman are in Figure 64, 66, and 68.

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 20 409 100.00 m^2. The generated flood depth maps for Casauman are in Figure 65, 67, and 69.

There is a total of 142 591 389.45 m^3 of water entering the model. Of this amount, 8 999 786.63 m^3 is due to rainfall while 133 591 602.81 m^3 is inflow from other areas outside the model. 2 344 289.25 m^3 of this water is lost to infiltration and interception, while 1 180 884.23 m^3 is stored by the flood plain. The rest, amounting up to 139 066 229.25 m^3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Casauman HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 61 shows the comparison between the two (2) discharge data.

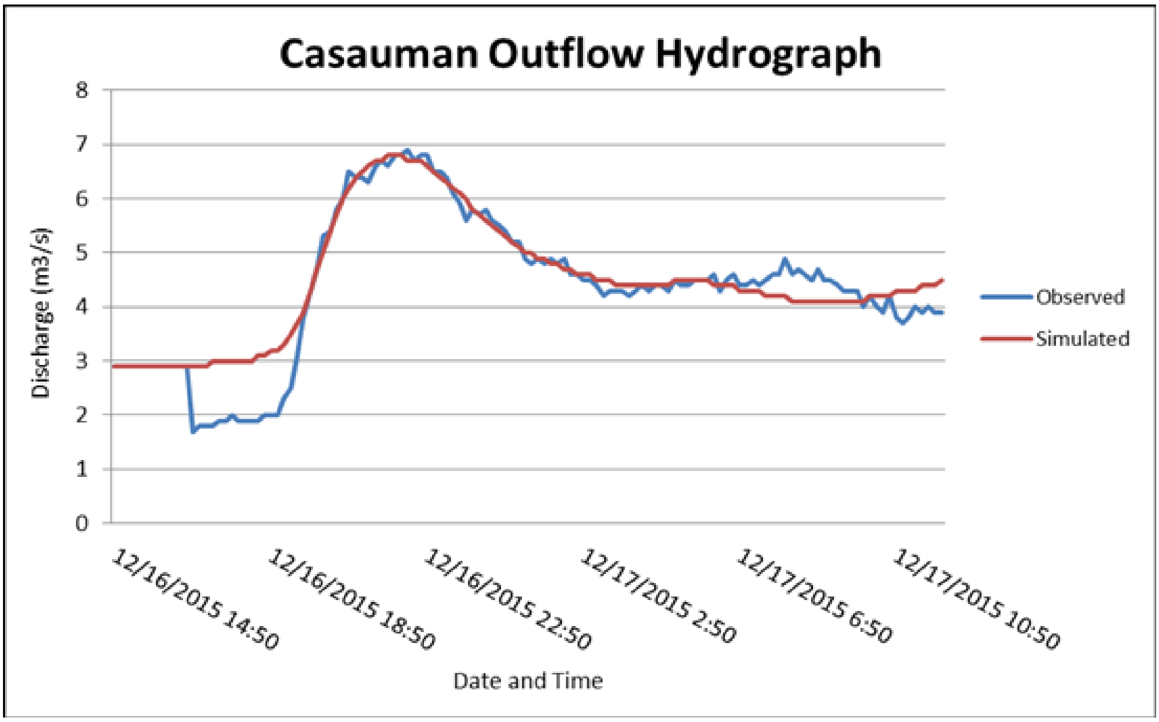


Figure 61. Outflow Hydrograph of Casauman produced by the HEC-HMS model compared with observed outflow.

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

Table 28. Range of calibrated values for the Casauman River Basin.

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve Number	Initial Abstraction (mm)	4.6 – 24.88
			Curve Number	49.23 – 83.985
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.0167 – 28.97
			Storage Coefficient (hr)	0.56 – 38.578
	Baseflow	Recession	Recession Constant	0.004 – 0.03
			Ratio to Peak	0.0645 – 0.5
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.01 – 0.0188

Initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as initial abstraction decreases. The range of values from 4.6 mm to 24.88 mm means that there is a small initial fraction of the storm depth after which runoff begins, increasing the river outflow.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 65 to 90 for curve number is advisable for Philippine watersheds depending on the soil and land cover of the area (M. Horritt, personal communication, 2012). For Casauman, the basin consists mainly of shrublands and open forests and the soil consists of mostly undifferentiated land and sandy clay loam.

Time of concentration and storage coefficient are the travel time and index of temporary storage of runoff in a watershed. The range of calibrated values from 0.0167 hours to 38.578 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 values within the range of 0.004 to 0.03 indicate that the basin is likely to quickly go back to its original discharge. Ratio to peak within the range of 0.0645 to 0.5 indicate a steeper receding limb of the outflow hydrograph.

Manning's roughness coefficient of 0.025 corresponds to the common roughness in the Philippine watersheds. Casauman river basin reaches Manning's coefficients range from 0.01 – 0.0188, showing that there is variety in surface roughness all over the catchment (Brunner, 2010).

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

Accuracy measure	Value
RMSE	0.5
r^2	0.912
NSE	0.89
PBIAS	-3.01
RSR	0.34

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two (2) measurements. It was computed as 0.5 m^3/s.

The Pearson correlation coefficient (r^2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.912.

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 0.89.

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 -3.01.

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 0.34.

5.7 Calculated outflow hydrographs and discharge values for different rainfall return periods

5.7.1 Hydrograph using the Rainfall Runoff Model

The summary graph (Figure 62) shows the Casauman outflow using the Davao Rainfall Intensity-Duration-Frequency curves (RIDF) in five (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 (PAGASA) data. The simulation results reveal increasing outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

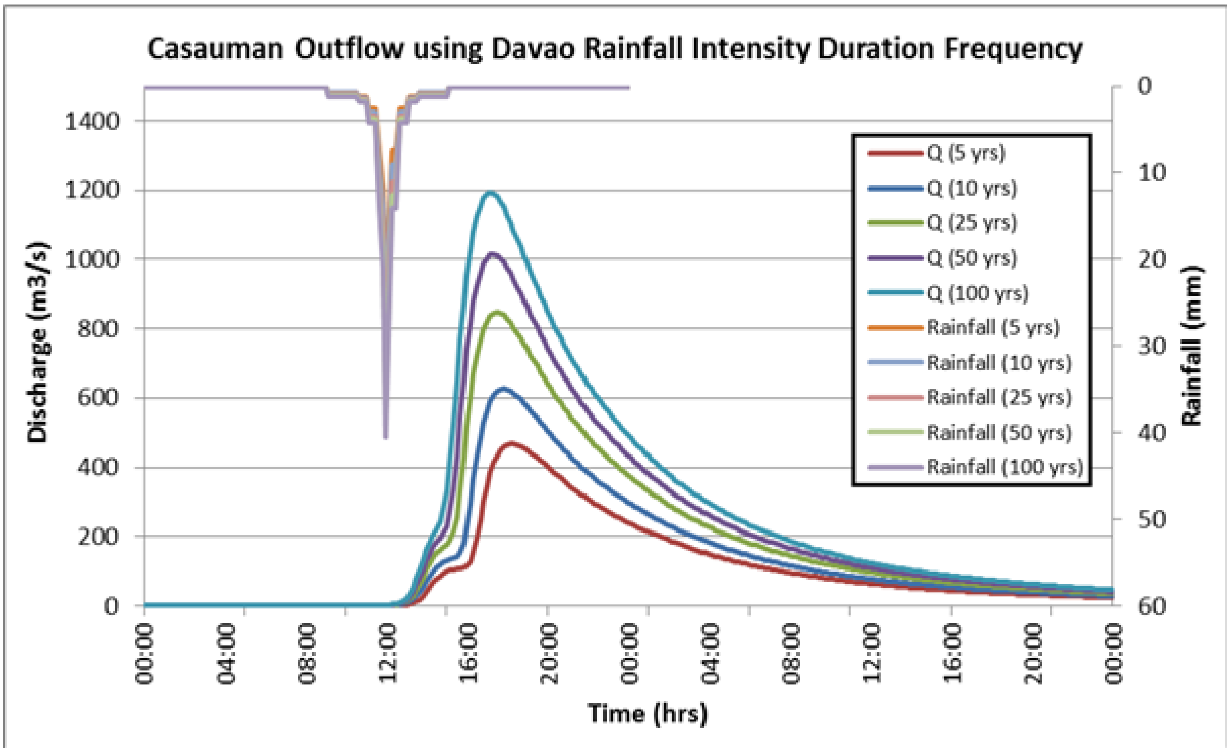


Figure 62. The Outflow hydrograph at the Casauman Station, generated using the Davao RIDF simulated in HEC-HMS.

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of the Casauman discharge using the Davao Rainfall Intensity-Duration-Frequency curves (RIDF) in five (5) different return periods is shown in Table 30.

Table 30. The peak values of the Casauman HEC-HMS Model outflow at Anomar Bridge using the Casauman RIDF.

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m^3/s)	Time to Peak
5-Year	121.1	25.1	468.6	6 hours, 10 minutes
10-Year	140.7	28.8	627	5 hours, 50 minutes
25-Year	165.5	33.5	847	5 hours, 30 minutes
50-Year	183.9	37	1015.2	5 hours, 20 minutes
100-Year	202.1	40.5	1192.7	5 hours, 10 minutes

5.8 River Analysis Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. Figure 63 shows a generated sample map of the Casauman River using the calibrated HMS base flow.

Figure 63. Sample output map of the Casauman RAS Model.

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10 m resolution. Figure 64 to Figure 69 shows the 5-, 25-, and 100-year rain return scenarios of the Casauman Floodplain. The floodplain, with an area of 172.14 km^2, covers four (4) municipalites namely Placer, Sison, Casauman City and Tagana-an. Table 31 shows the percentage of area affected by flooding per municipality.

Table 31. Municipalities affected in Casauman floodplain.

Municipality	Total Area	Area Flooded	% Flooded
Davao Oriental	Manay	430.894	20.2609

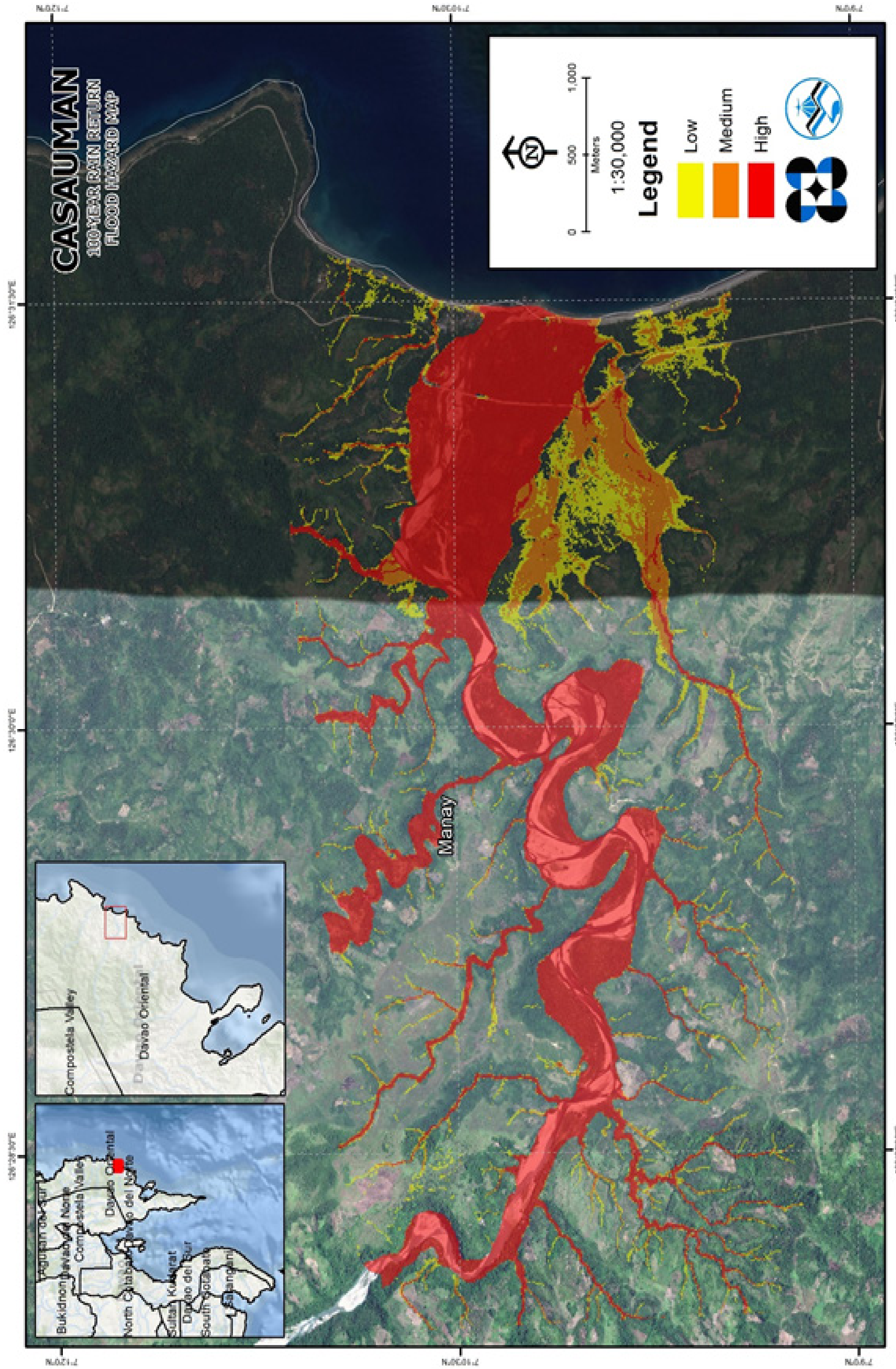


Figure 64. A 100-year Flood Hazard Map for Casauman Floodplain overlaid on Google Earth imagery.

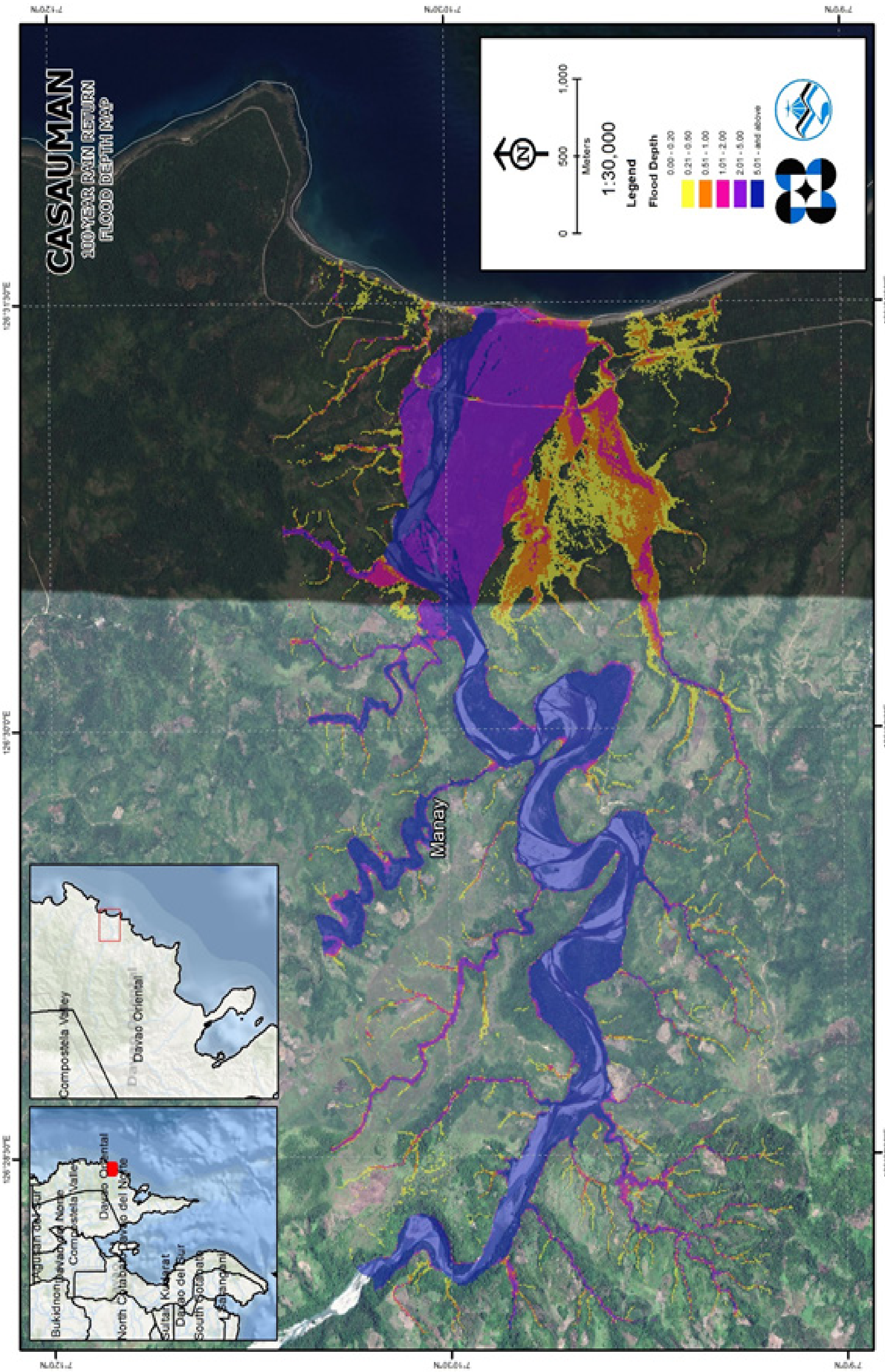


Figure 65. A 100-year Flow Depth Map for Casauman Floodplain overlaid on Google Earth imagery.

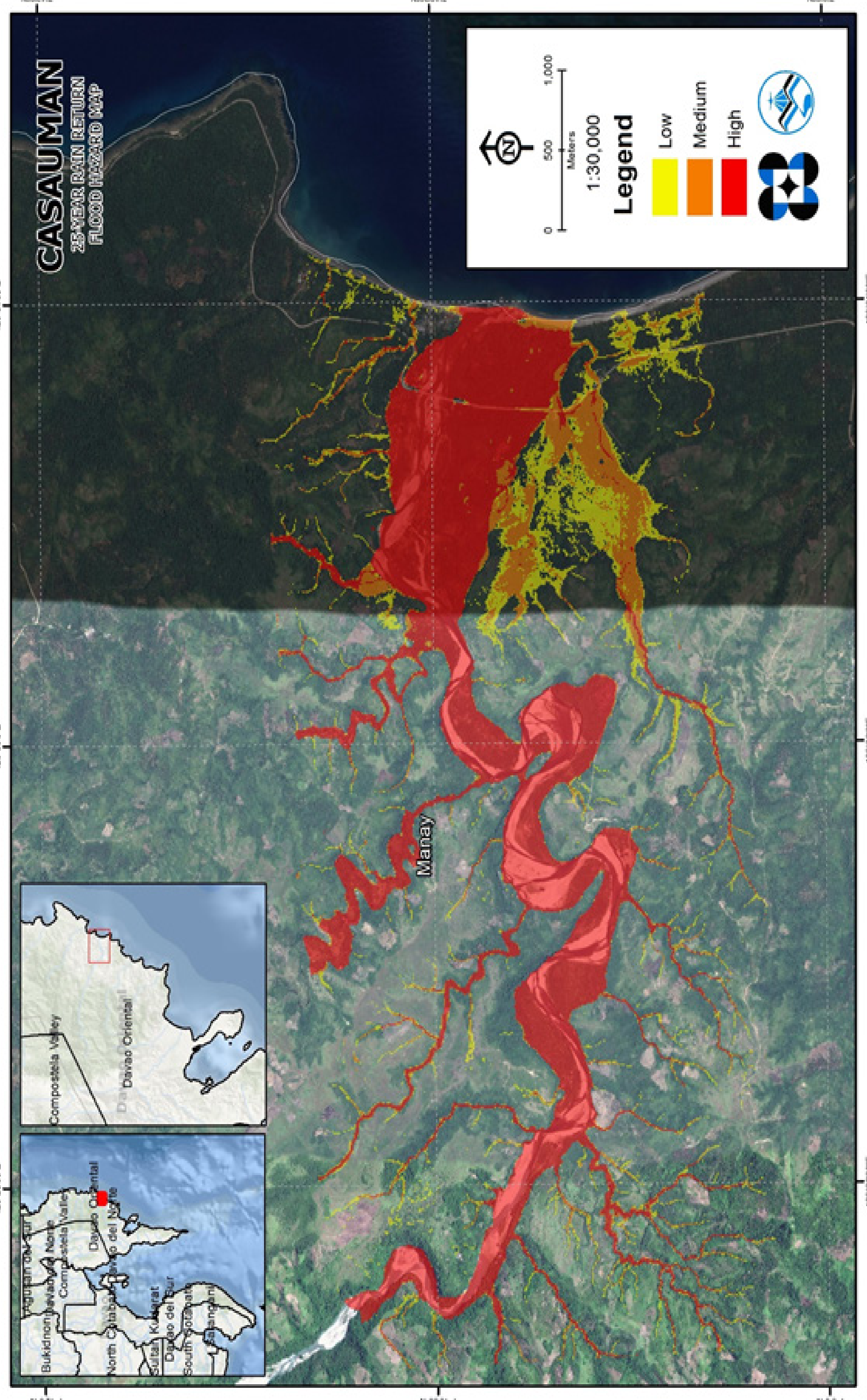


Figure 66. A 25-year Flood Hazard Map for Casauman Floodplain overlaid on Google Earth imagery.

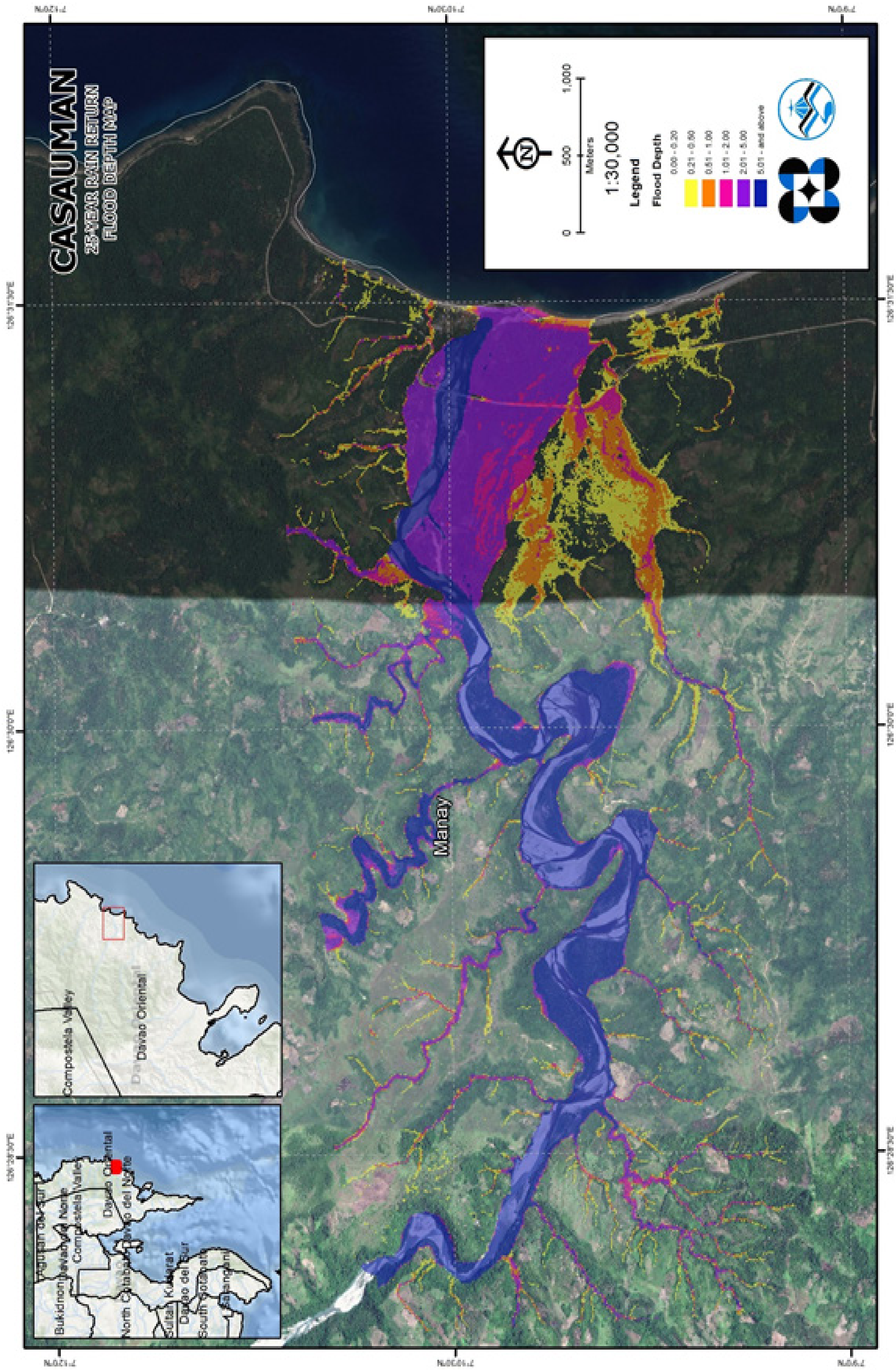


Figure 67. A 25-year Flow Depth Map for Casauman Floodplain overlaid on Google Earth imagery.

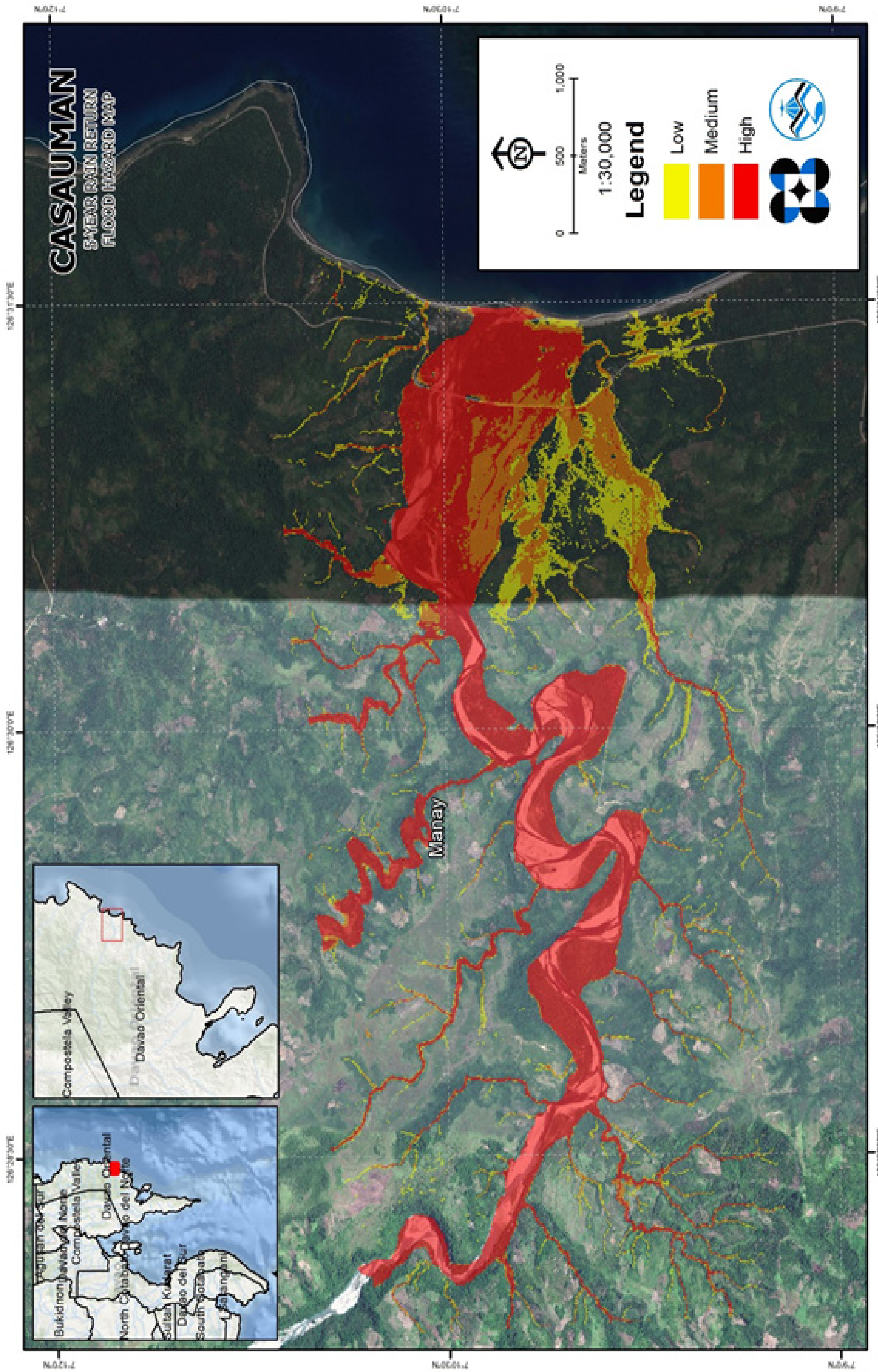


Figure 68. A 5-year Flood Hazard Map for Casauman Floodplain overlaid on Google Earth imagery.

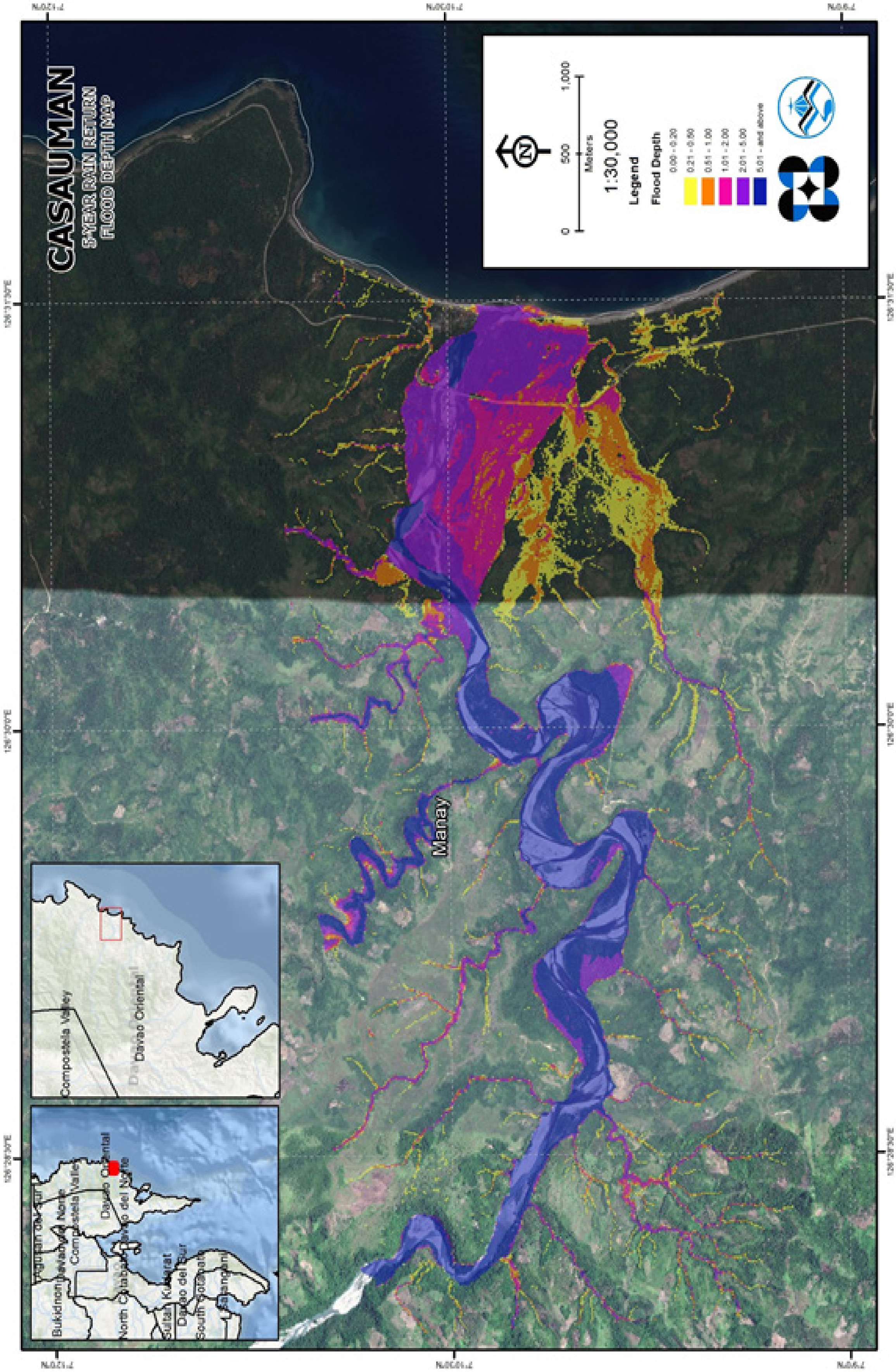


Figure 69. A 5-year Flood Depth Map for Casauman Floodplain overlaid on Google Earth imagery

5.10 Inventory of Areas Exposed to Flooding

Listed below are the affected barangays in the Casauman River Basin, grouped accordingly by municipality. For the said basin, only one municipality is expected to experience flooding when subjected to 5-yr rainfall return period.

For the 5-year return period, 3.39% of the municipality of Manay with an area of 430.894 km^2. will experience flood levels of less 0.20 meters. 0.23% of the area will experience flood levels of 0.21 to 0.50 meters while 0.15%, 0.19%, 0.31%, and 0.45% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 32 are the affected areas in Manay in square kilometers by flood depth per barangay. Annex 12 shows the educational institutions exposed to flooding.

Table 32. Affected Areas in Manay, Davao Oriental during 5-Year Rainfall Return Period.

Affected area (sq.km) by flood depth (in m.)	Areas of affected Barangays in Placer (in km^2)		
	Del Pilar	Holy Cross	Zaragosa
0.03-0.20	1.23	7.07	6.32
0.21-0.50	0.034	0.74	0.2
0.51-1.00	0.013	0.47	0.15
1.01-2.00	0.016	0.58	0.21
2.01-5.00	0.022	0.49	0.81
> 5.00	0.19	0.18	1.54

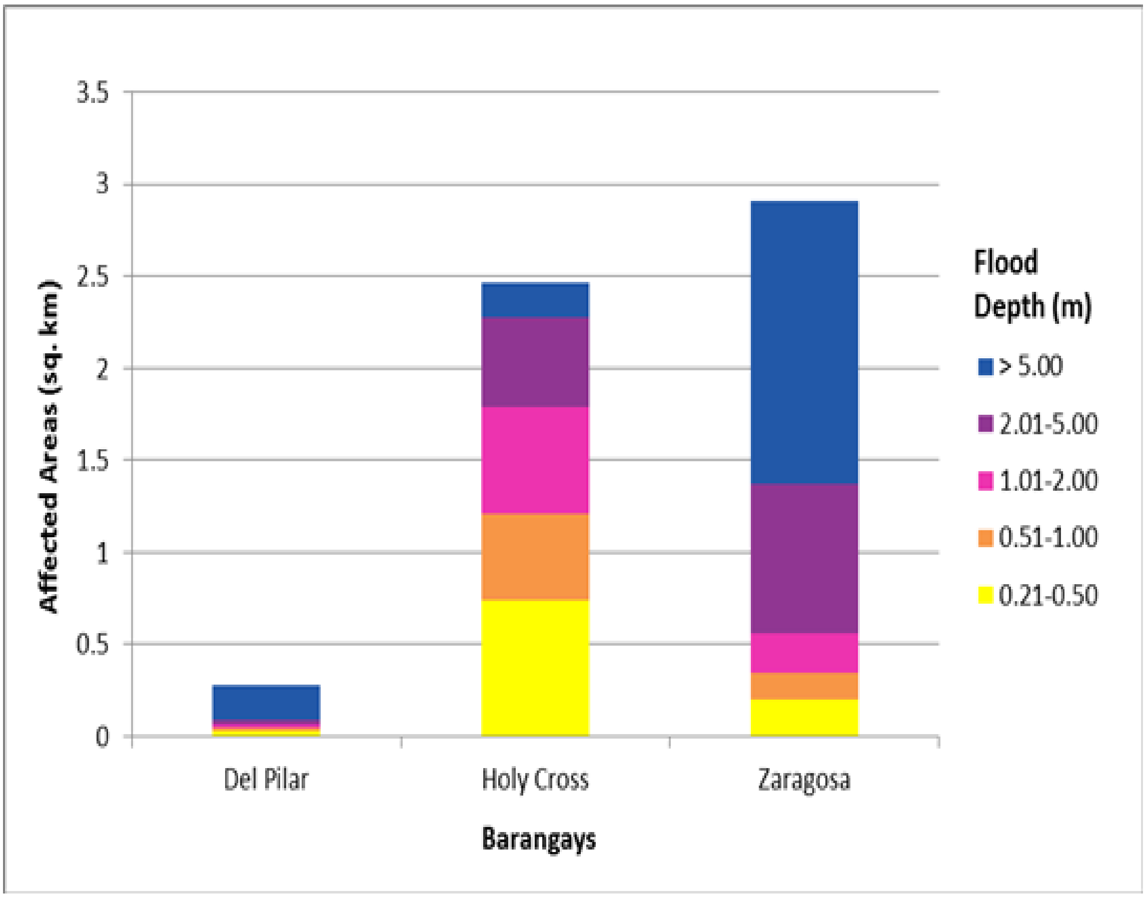


Figure 70. Affected Areas in Manay, Davao Oriental during 5-Year Rainfall Return Period.

Table 33. Affected Areas in Manay, Davao Oriental during 5-Year Rainfall Return Period.

Affected area (sq.km.) by flood depth (in m.)	Areas of affected Barangays in Placer (in km²)		
	Del Pilar	Holy Cross	Zaragosa
0.03-0.20	1.2	6.77	6.13
0.21-0.50	0.044	0.77	0.24
0.51-1.00	0.015	0.53	0.15
1.01-2.00	0.018	0.37	0.16
2.01-5.00	0.025	0.84	0.66
> 5.00	0.21	0.25	1.9

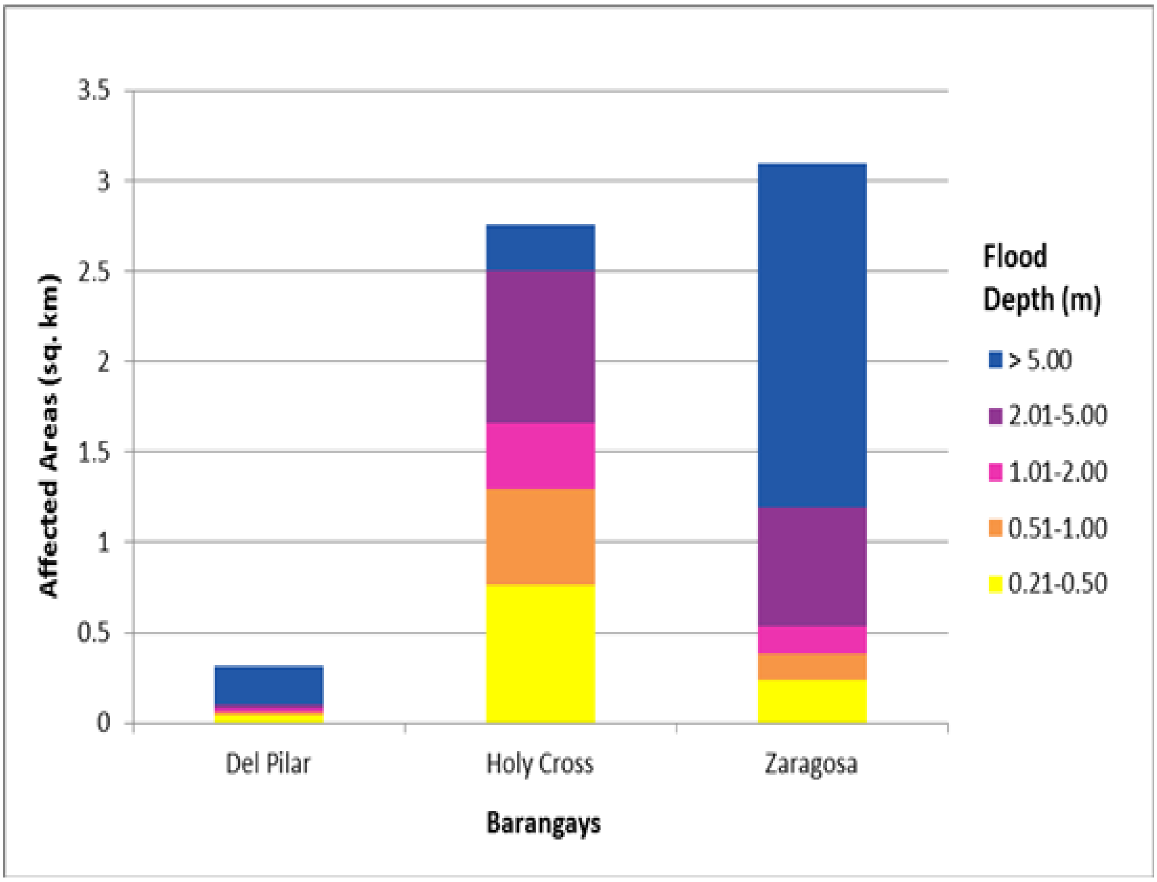


Figure 71. Affected Areas in Manay, Davao Oriental during 25-Year Rainfall Return Period.

Table 34. Affected Areas in Manay, Davao Oriental during 100-Year Rainfall Return Period.

Affected area (sq.km.) by flood depth (in m.)	Areas of affected Barangays in Placer (in km²)		
	Del Pilar	Holy Cross	Zaragosa
0.03-0.20	1.17	6.57	5.97
0.21-0.50	0.052	0.78	0.27
0.51-1.00	0.019	0.57	0.14
1.01-2.00	0.017	0.32	0.16
2.01-5.00	0.029	0.99	0.6
> 5.00	0.23	0.29	2.09

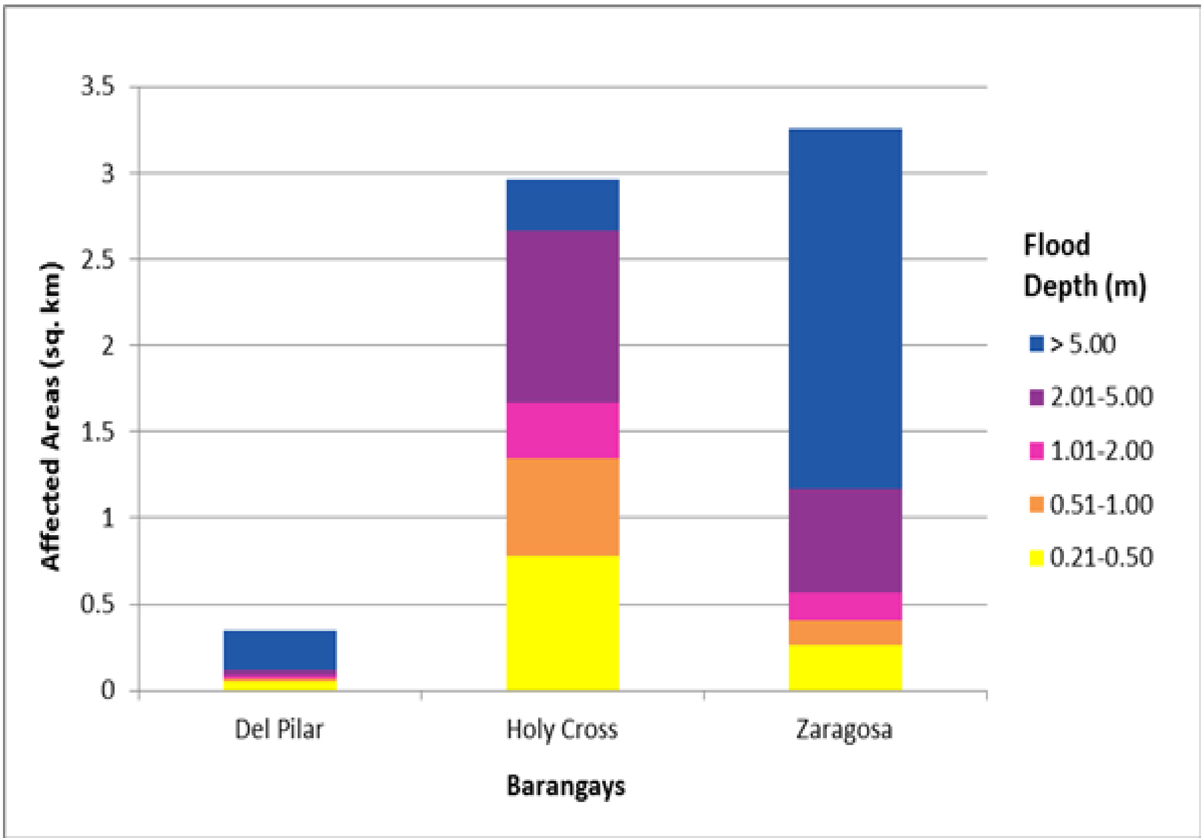


Figure 72. Affected Areas in Manay, Davao Oriental during 100-Year Rainfall Return Period

Among the barangays in the municipality of Manay in Davao Oriental, Holy Cross is projected to have the highest percentage of area that will experience flood levels at 2.21%. Meanwhile, Zaragosa posted the second highest percentage of area that may be affected by flood depths at 2.14%.

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

Table 35. Area covered by each warning level with respect to the rainfall scenarios

Warning Level	Area Covered in km^2		
	5 year	25 year	100 year
Low	0.965	1.042	1.085
Medium	1.032	0.916	0.996
High	3.716	4.277	4.549

Of the two (2) identified Education Institute in Casauman Flood plain, only one school was discovered exposed to Low-level flooding for the 25- and 100-year scenarios. This is the Francisco Lahora Elementary School in Brgy. Zaragosa. No medical institutions were identified in the Casauman Floodplain.

5.11 Flood Validation

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

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

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

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 the results of the flood map. The points in the flood map versus its corresponding validation depths are shown in Figure 73.

The flood validation consists of 180 points randomly selected all over the Casauman flood plain Comparing it with the flood depth map of the nearest storm event, the map has an RMSE value of 0.68 m. Table 36 shows a contingency matrix of the comparison. The validation points are found in Annex 11.

The validation data were obtained on November 22-25, 2016 / December 13-14, 2016.

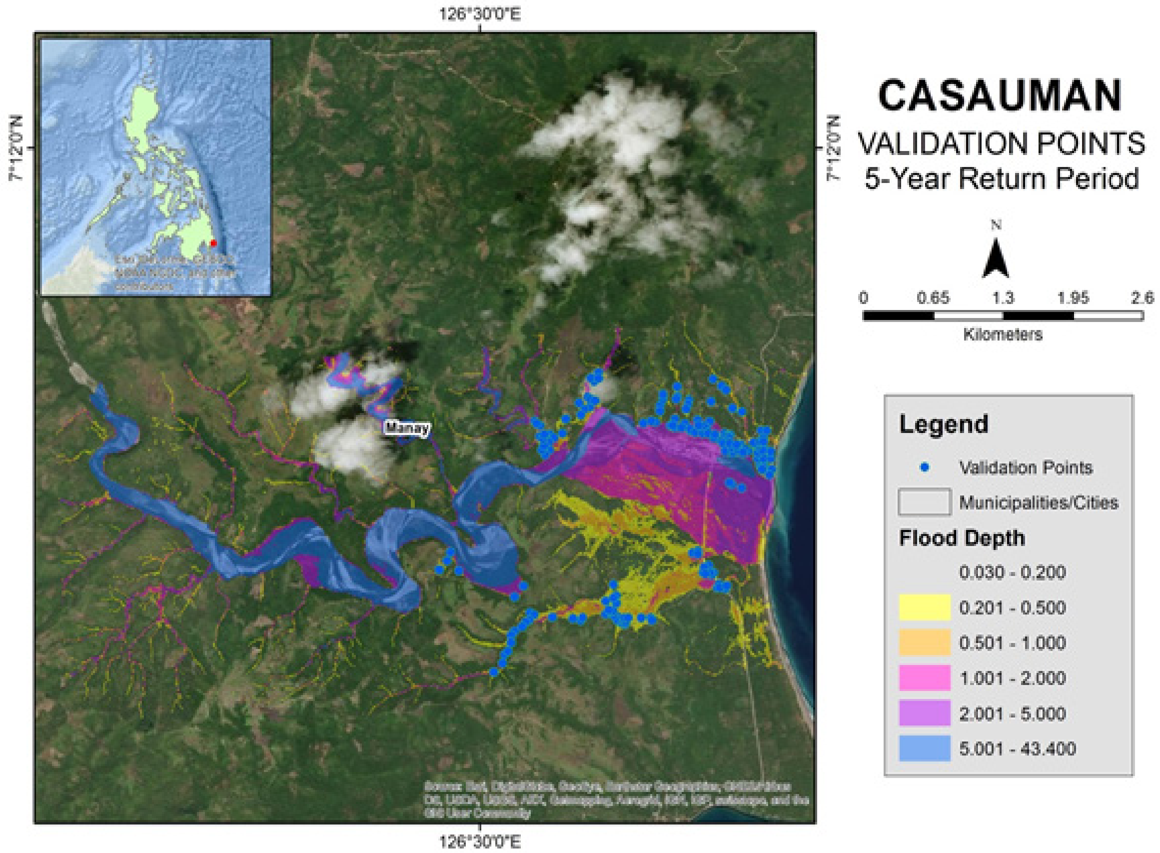


Figure 73. Validation Points for a 5-year Flood Depth Map of the Casauman Floodplain.

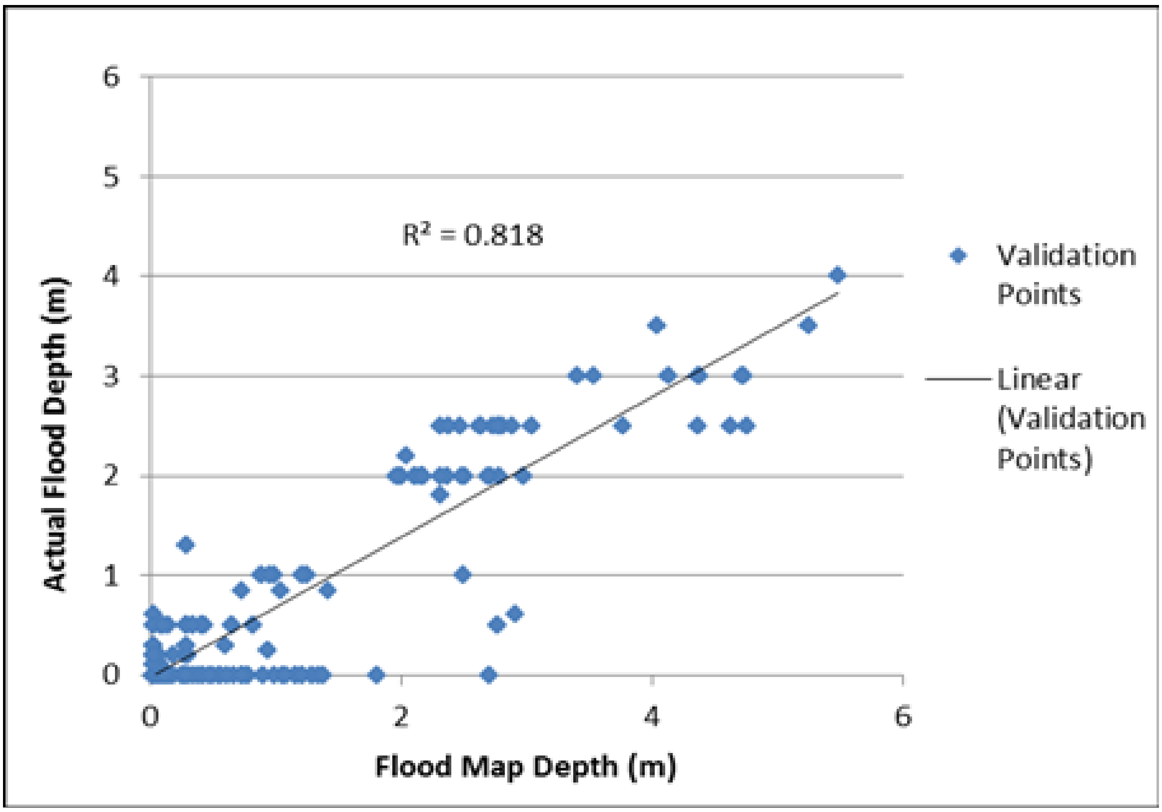


Figure 74. Flood Map depth versus Actual Flood Depth

Table 36. Actual Flood Depth versus Simulated Flood Depth at different levels in the Casauman River Basin.

CASAUMAN 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	65	16	11	10	1	0	103
	0.21-0.50	6	10	4	0	1	0	21
	0.51-1.00	1	0	4	4	2	0	11
	1.01-2.00	0	1	0	3	15	0	19
	2.01-5.00	0	0	0	0	24	2	26
	> 5.00	0	0	0	0	0	0	0
	Total	72	27	19	17	43	2	180

On the whole, the overall accuracy generated by the flood model is estimated at 58.89%, with 106 points correctly matching the actual flood depths. In addition, there were 47 points estimated one level above and below the correct flood depths while there were 15 points and 12 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 66 points were overestimated while a total of eight (8) points were underestimated in the modelled flood depths of Casauman. Table 37 depicts the summary of the Accuracy Assessment in the Casauman River Basin Flood Depth Map.

Table 37. Summary of the Accuracy Assessment in the Casauman River Basin Survey.

	No. of Points	%
Correct	106	58.89
Overestimated	66	36.67
Underestimated	8	4.44
Total	180	100

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

1. GEMINI SENSOR

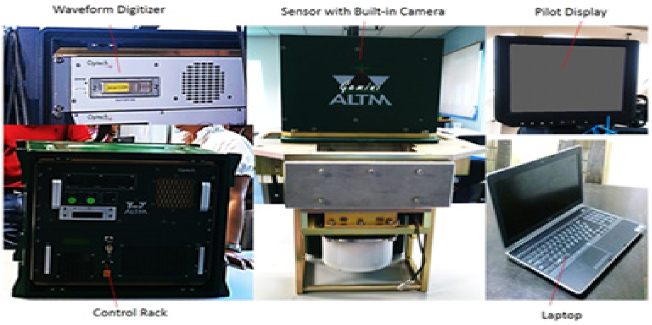

Figure A-1.2. Gemini Sensor

Table A-1.1. Parameters and Specifications of 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
	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 2. NAMRIA Certificate of Reference Points Used in the LiDAR Survey

1. DVE-42

Figure A-2.1. DVE-42

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

June 24, 2014

CERTIFICATION

To whom it may concern:

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

Province: **DAVAO ORIENTAL**
Station Name: **DVE-42**
Order: **2nd**

Island: **MINDANAO**
Municipality: **MATI (CAPITAL)**
Barangay: **DON ENRIQUE LOPEZ**

PRS92 Coordinates

Latitude:	**6° 58' 54.82726"**	Longitude:	**126° 17' 56.05259"**	Ellipsoidal Hgt:	**6.39500 m.**

WGS84 Coordinates

Latitude:	**6° 58' 51.79295"**	Longitude:	**126° 18' 1.57690"**	Ellipsoidal Hgt:	**81.02500 m.**

PTM Coordinates

Northing:	**772166.69 m.**	Easting:	**643534.636 m.**	Zone:	**5**

UTM Coordinates

Northing:	**772,554.34**	Easting:	**201,538.20**	Zone:	**52**

Location Description

DVE-42
"DVE-42" is in Barangay Don Enrique Lopez, Mati City, Davao Oriental. From Mati Proper, travel south for about 12 km. then turn left and continue travel for about 2.3 km. towards the Don Enrique Elem. School. Station is located at the Don Enrique Elem. School, 5 cm "SW" of the flagpole. Mark is the head of 4" copper nail embedded in a .30x0.30x1.0 m. concrete monument with inscription "DVE-42 2007 NAMRIA".

Requesting Party:	**Engr. Cruz**
Pupose:	**Reference**
OR Number:	**8796376 A**
T.N.:	**2014-1446**

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

9 9 0 6 2 4 2 0 1 4 1 1 1 8 4 2

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 Surveyed

1. DVE-3088

Table A-3.1. DVE-3088

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
DVE-3088 --- DVE-42 (B1)	DVE-42	DVE-3088	Fixed	0.001	0.002	160°37'05"	8.200	-0.026
DVE-3088 --- DVE-42 (B2)	DVE-42	DVE-3088	Fixed	0.001	0.002	160°36'35"	8.199	-0.029
DVE-42 --- DVE-3088 (B3)	DVE-42	DVE-3088	Fixed	0.001	0.002	160°36'48"	8.202	-0.036
DVE-3088 --- DVE-42 (B4)	DVE-42	DVE-3088	Fixed	0.001	0.002	160°40'50"	8.200	-0.031
DVE-3088 --- DVE-42 (B5)	DVE-42	DVE-3088	Fixed	0.001	0.001	160°40'52"	8.202	-0.036
DVE-42 --- DVE-3088 (B6)	DVE-42	DVE-3088	Fixed	0.001	0.001	160°40'53"	8.203	-0.034

Vector Components (Mark to Mark)

From:	DVE-42				
Grid		Local		Global	
Easting	201638.187 m	Latitude	N6°58'54.82727"	Latitude	N6°58'51.79296"
Northing	772654.341 m	Longitude	E126°17'56.05259"	Longitude	E126°18'01.67690"
Elevation	15.607 m	Height	6.396 m	Height	81.026 m

To:	DVE-3088				
Grid		Local		Global	
Easting	201642.172 m	Latitude	N6°58'54.59466"	Latitude	N6°58'51.56037"
Northing	772647.168 m	Longitude	E126°17'56.18366"	Longitude	E126°18'01.70797"
Elevation	15.582 m	Height	6.370 m	Height	80.999 m

Vector					
ΔEasting	3.986 m	NS Fwd Azimuth	160°37'05"	ΔX	-3.741 m
ΔNorthing	-7.173 m	Ellipsoid Dist.	8.200 m	ΔY	-1.703 m
ΔElevation	-0.026 m	ΔHeight	-0.026 m	ΔZ	-7.095 m

Standard Errors

Vector errors:					
σ ΔEasting	0.001 m	σ NS fwd Azimuth	0°00'12"	σ ΔX	0.001 m
σ ΔNorthing	0.000 m	σ Ellipsoid Dist.	0.000 m	σ ΔY	0.001 m
σ ΔElevation	0.001 m	σ ΔHeight	0.001 m	σ ΔZ	0.000 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000004144		
Y	-0.0000001656	0.0000005443	
Z	-0.0000000528	0.0000000816	0.0000000908

2. DVE-19

Table A-3.2. DVE-19

Vector Components (Mark to Mark)

From:	SRS-51				
Grid		Local		Global	
Easting	186815.622 m	Latitude	N8°59'14.14996"	Latitude	N8°59'10.56678"
Northing	994598.260 m	Longitude	E126°09'06.83416"	Longitude	E126°09'12.17833"
Elevation	5.763 m	Height	3.970 m	Height	74.223 m

To:	DVE-19				
Grid		Local		Global	
Easting	228220.944 m	Latitude	N7°12'55.40692"	Latitude	N7°12'52.33147"
Northing	798242.632 m	Longitude	E126°32'20.36690"	Longitude	E126°32'25.86714"
Elevation	4.520 m	Height	-5.421 m	Height	69.364 m

Vector					
ΔEasting	41405.322 m	NS Fwd Azimuth	167°41'20"	ΔX	-50724.032 m
ΔNorthing	-196355.628 m	Ellipsoid Dist.	200641.192 m	ΔY	-3051.661 m
ΔElevation	-1.243 m	ΔHeight	-9.391 m	ΔZ	-193987.320 m

Standard Errors

Vector errors:					
σ ΔEasting	0.015 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.018 m
σ ΔNorthing	0.007 m	σ Ellipsoid Dist.	0.009 m	σ ΔY	0.024 m
σ ΔElevation	0.027 m	σ ΔHeight	0.027 m	σ ΔZ	0.008 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0003330378		
Y	-0.0002190878	0.0005839047	
Z	-0.0000099289	0.0000986309	0.0000610561

Occupations

	From	To
Point ID:	SRS-51	DVE-19
Data file:	C:\Users\Windows User\Documents \Business Center - HCE\DVE-19 DVE-201\SRS51 (Modular) 7-8-14 [1.629m].T02	C:\Users\Windows User\Documents \Business Center - HCE\DVE-19 DVE-201\DVE-19 07-08-2014.T02
Receiver type:	SPS852	SPS985
Receiver serial number:	5203K81512	5246F15419
Antenna type:	Zephyr Geodetic 2	SPS985 Internal
Antenna serial number:	--------	--------
Antenna height (measured):	1.629 m	1.481 m
Antenna method:	Bottom of notch	Bottom of antenna mount

3. ZN-74

Table A-3.3. DVE-20

Vector Components (Mark to Mark)

From:	DVE-20				
Grid		Local		Global	
Easting	228219.879 m	Latitude	N7°12'51.11197"	Latitude	N7°12'48.03684"
Northing	798110.635 m	Longitude	E126°32'20.35543"	Longitude	E126°32'25.85577"
Elevation	3.741 m	Height	-6.215 m	Height	68.572 m

To:	DVE-19				
Grid		Local		Global	
Easting	228220.734 m	Latitude	N7°12'55.40683"	Latitude	N7°12'52.33137"
Northing	798242.630 m	Longitude	E126°32'20.36008"	Longitude	E126°32'25.86031"
Elevation	4.340 m	Height	-5.601 m	Height	69.184 m

Vector					
ΔEasting	0.855 m	NS Fwd Azimuth	0°03'43"	ΔX	9.390 m
ΔNorthing	131.995 m	Ellipsoid Dist.	131.930 m	ΔY	-12.906 m
ΔElevation	0.599 m	ΔHeight	0.614 m	ΔZ	130.962 m

Standard Errors

Vector errors:					
σ ΔEasting	0.008 m	σ NS fwd Azimuth	0°00'12"	σ ΔX	0.011 m
σ ΔNorthing	0.006 m	σ Ellipsoid Dist.	0.006 m	σ ΔY	0.012 m
σ ΔElevation	0.015 m	σ ΔHeight	0.015 m	σ ΔZ	0.006 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0001243942		
Y	-0.0000742449	0.0001516896	
Z	-0.0000004838	0.0000124527	0.0000328557

Occupations

	From	To
Point ID:	DVE-20	DVE-19
Data file:	C:\Users\Windows User\Documents \Business Center - HCE\DVE-19 DVE-201\DVE-20 07-08-2014.T02	C:\Users\Windows User\Documents \Business Center - HCE\DVE-19 DVE-201\DVE-19 07-08-2014.T02
Receiver type:	SPS882	SPS985
Receiver serial number:	5152479948	5245F15419
Antenna type:	R8 GNSS/SPS88x Internal	SPS985 Internal
Antenna serial number:	--------	--------
Antenna height (measured):	2.000 m	1.481 m
Antenna method:	Bottom of antenna mount	Bottom of antenna mount

Annex 4. The Survey Team

Table A-4.1. 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. LOVELYN ASUNCION	UP-TCAGP
FIELD TEAM			
LiDAR Operation	Senior Science Research Specialist (SSRS)	JULIE PEARL MARS	UP-TCAGP
	Research Associate (RA)	FOR. MA. VERLINA TONGA	UP-TCAGP
	RA	ENGR. LARAH KRISELLE PARAGAS	UP-TCAGP
Ground Survey, Data Download & Transfer	RA	ENGR. KENNETH QUISADO	UP-TCAGP
LiDAR Operation	Airborne Security	TSG. MIKE DIAPANA	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. RAUL CZ SAMAR II	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. BRYAN JOHN DONGUINES	AAC

Annex 5. Data Transfer Sheet for Casauman Floodplain

DATA TRANSFER SHEET
06/28/2014(DAVAO ORIENTAL - [illegible])

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	
6/18/2014	7318GC*	2BLK34A169A	GEMINI	NA	217	6.21	217	17.3	106KB	17.8	NA	4.66	1KB	2KB	3	9	Z:\Airborne_Raw\7318GC
6/19/2014	7320G	2BLK33AB43170A	GEMINI	NA	116/38	330	224	na	na	13.3	NA	3.62	1KB	1KB	4	NA	Z:\Airborne_Raw\7320GC
6/20/2014	7322G	2BLK34AS68171A	GEMINI	NA	405	524	242	na	na	25	NA	4.66	1KB	1KB	6	9	Z:\Airborne_Raw\7322GC
6/20/2014	7323G	2BLK36C33A171B	GEMINI	NA	393/191	509	244	na	na	20.4	NA	5.26	1KB	1KB	4	na	Z:\Airborne_Raw\7323GC
6/22/2014	7326G	2BLK8OB173A	GEMINI	NA	335	533	252	na	na	23.4	NA	7	1KB	1KB	4	9	Z:\Airborne_Raw\7326G
6/23/2014	7328GC*	2BLK30A8174A	GEMINI	NA	na	582	230	913	177kb	20.9	NA	5.81	1KB	1KB	8	na	Z:\Airborne_Raw\7328GC

Received from

Name C. Joaquin
Position
Signature

Received by

Name Lida F. Prieto
Position
Signature 07/02/2014

*PRIORITY FLIGHTS WITH CASI DATA

Figure A-5.1. Transfer Sheet for Casauman Floodplain - A

Annex 6. Flight Logs

1. Flight Log for 7320GC Mission

DREAM Data Acquisition Flight Log — Flight Log No.: 7320

1 LiDAR Operator: LK Paragas	2 ALTM Model: Gem+CAS	3 Mission Name: 2BLK83A84B	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RP-C9322
7 Pilot: R. Samaniego	8 Co-Pilot: B. Donguines	9 Route: 170A			
10 Date: 6-19-14	12 Airport of Departure (Airport, City/Province): RPMQ		12 Airport of Arrival (Airport, City/Province): RPMQ		
13 Engine On: 8+45	14 Engine Off: 12+42	15 Total Engine Time: 3+47	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather					

20 Remarks:

Surveyed 9 lines in Blk 83A & 6 lines in Blk 84B

Conducted CASI test

21 Problems and Solutions:

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

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

Pilot-in-Command — R. SAMANIEGO — Signature over Printed Name

Lidar Operator — LK Paragas — Signature over Printed Name

Figure A-6.1. Flight Log for Mission 7320GC

2. Flight Log for 7322GC Mission

DREAM Data Acquisition Flight Log

Flight Log No.: 7322

1 LiDAR Operator: MV Tonga	2 ALTM Model: Gen ?CASI	3 Mission Name: 2BLK83AS	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RP-C9322
7 Pilot: R. Samar II	8 Co-Pilot: B. Donguines	9 Route: 866179A			
10 Date: 6-20-14	12 Airport of Departure (Airport, City/Province): RPMQ	12 Airport of Arrival (Airport, City/Province): RPMQ			
13 Engine On: 6+48	14 Engine Off: 10+59	15 Total Engine Time: 4+11	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather					

20 Remarks:

Surveyed 3 lines in Blk 83A & completed Blk 86B (without CASI)

21 Problems and Solutions:

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

Figure A-6.2. Flight Log for Mission 7322GC

3. Flight Log for 7323GC Mission

DREAM Data Acquisition Flight Log

Flight Log No.: 7323

1 LiDAR Operator: LK Paragas	2 ALTM Model: Gemini	3 Mission Name: 1BLK96 S83A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RP-C9322
7 Pilot: R. Samson II	8 Co-Pilot: B. Dongamos	9 Route: 171B			
10 Date: 6-20-14	12 Airport of Departure (Airport, City/Province): RPMQ		12 Airport of Arrival (Airport, City/Province): RPMQ		
13 Engine On: 1334	14 Engine Off: 1723	15 Total Engine Time: 4+9	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather					
20 Remarks: Completed 83A & 86E (without CASI)					

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
[signature]	[signature]	R. Santos	LK Paragas
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

Figure A-6.3. Flight Log for Mission 7323GC

Flight Log for 2125P Missionv

DREAM Data Acquisition Flight Log

Flight Log No.: 7328

1 LiDAR Operator: LK Paragas	2 ALTM Model: Gemini/CASI	3 Mission Name: 2BLKABS174A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP-C9322
7 Pilot: R. Samarli	8 Co-Pilot: B. Dirquines	9 Route:			
10 Date: 6-23-14	12 Airport of Departure (Airport, City/Province): RPMQ		12 Airport of Arrival (Airport, City/Province): RPMQ		
13 Engine On: 817	14 Engine Off: 1240	15 Total Engine Time: 4+23	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather					
20 Remarks: Completed Block 80A and Block 80B (with CASI)					

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	R. SAMARLI Signature over Printed Name	LK Paragas Signature over Printed Name

Figure A-6.4. Flight Log for Mission 7328GC

Annex 7. Flight Status Report

Casauman Mission
June 16 to July 16, 2014

Table A-7.1. Flight Status Report

FLIGHT NO.	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
7320GC	BLK84B	2BLK83A84B170A	LK PARAGAS	June 19, 2014	Started with 86B. Moved to 84B due to high terrain (6 lines). Moved to 83A due to clouds (9 lines). *CASI testing at the end of the mission flight
7322G	BLK83A, BLK86B	2BLK84AS&86B171A	MV TONGA	June 20, 2014	BLK 83A (3 lines). Moved to 86B (13 lines)
7323G	BLK86C, BLK83A	2BLK86C&83A171B	LK PARAGAS	June 20, 2014	BLK84A (3 lines) changed area due to rain. BLK86C (10 lines). Cloudy/rainy moved to BLK83A (7 lines)
7328*	BLK80A, BLK80B	2BLK80ABS174A	LK PARAGAS	June 23, 2014	With CASI (19 lines)

SWATH PER FLIGHT MISSION

Flight No. : 7320GC
Area: BLK83A, BLK84B
Mission name: 2BLK83A84B170A
Parameters:
Altitude: 1100 m;
Scan Frequency: 50 Hz;
Scan Angle: 20 deg;
Overlap: 40 %
Area covered: 121.57 km2

Figure A-7.1. Swath for Flight No. 7320GC

Flight No. : 7322GC
Area: BLK83A, BLK86B
Mission name: 2BLK84AS86B171A
Parameters:
Altitude: 1100 m;
Scan Frequency: 50 Hz;
Scan Angle: 20 deg;
Overlap: 30 %
Area covered: 209.19 km2

Figure A-7.2. Swath for Flight No. 7323GC

Flight No. :	7323GC
Area:	BLK86C, BLK83A
Mission name:	2BLK86C83A171B
Parameters:	
Altitude: 1100 m;	
Scan Frequency: 50 Hz;	
Scan Angle: 20 deg;	
Overlap: 30 %	
Area covered:	214.08 km2

Figure A-7.3. Swath for Flight No. 7323GC

Flight No. :	7328GC
Area:	BLK80A, BLK80B
Mission name:	2BLK80AB174A
Parameters:	
Altitude: 1100 m;	
Scan Frequency: 50 Hz;	
Scan Angle: 20 deg;	
Overlap: 30 %	
Area covered:	244.67 km2

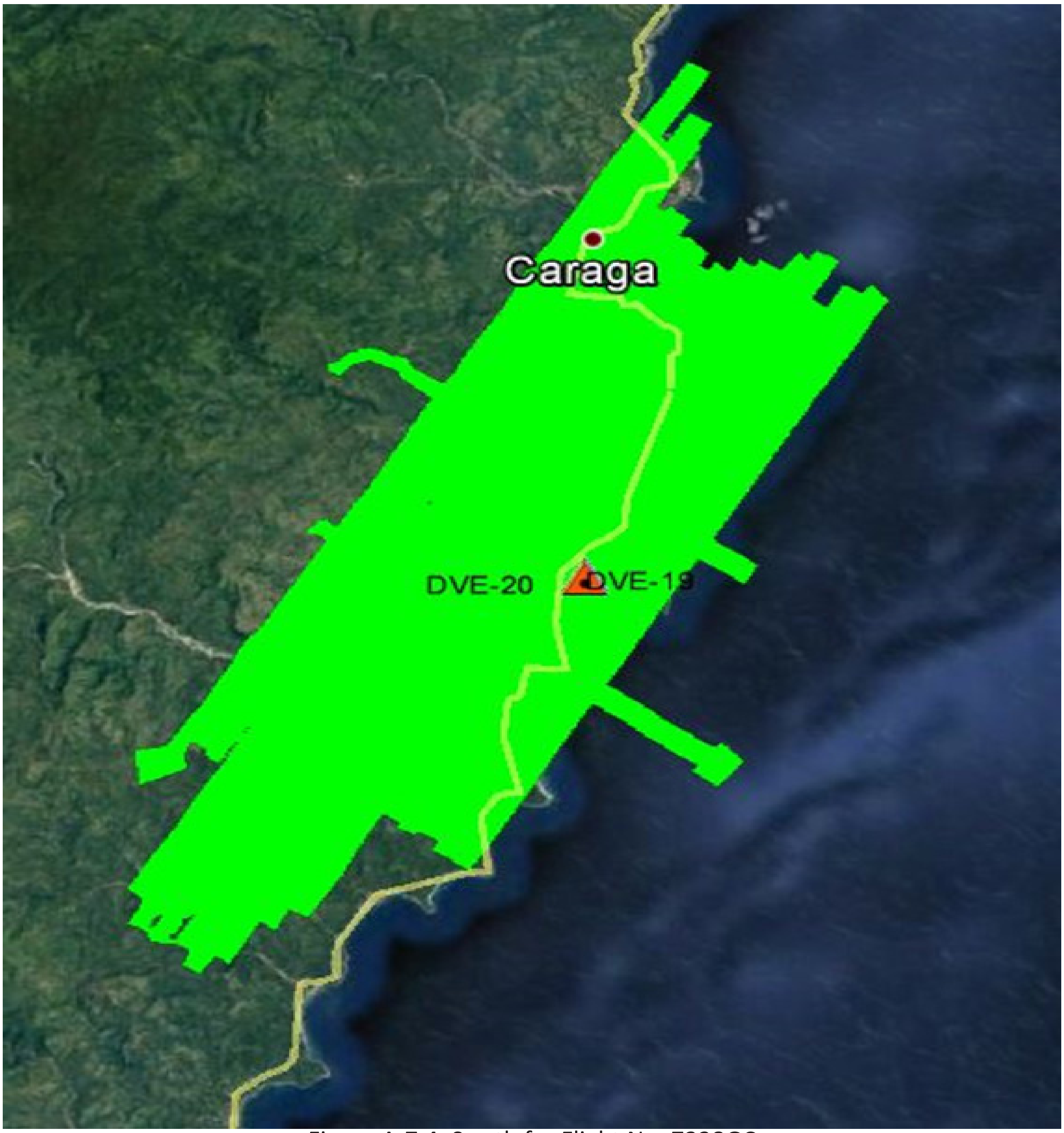

Figure A-7.4. Swath for Flight No. 7328GC

Annex 8. Mission Summary Report

Table A-8.1. Mission Summary Report for Mission Blk83A

Flight Area	Davao Oriental
Mission Name	Blk83A
Inclusive Flights	7320G,7322G,7323G
Range data size	56.7 GB
POS	711 MB
Image	na
Transfer date	July 2, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.9
RMSE for East Position (<4.0 cm)	2.85
RMSE for Down Position (<8.0 cm)	5.9
Boresight correction stdev (<0.001deg)	0.000272
IMU attitude correction stdev (<0.001deg)	0.014248
GPS position stdev (<0.01m)	0.0169
Minimum % overlap (>25)	31.39
Ave point cloud density per sq.m. (>2.0)	2.88
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	217
Maximum Height	1099.91 m
Minimum Height	61.78 m
Classification (# of points)	
Ground	48,414,685
Low vegetationv	30,977,716
Medium vegetation	85,948,712
High vegetation	242,710,117
Building	1,534,395
Orthophoto	No
Processed by	Engr. Jennifer Saguran, Engr. Harmond Santos, Engr. Gladys Apat

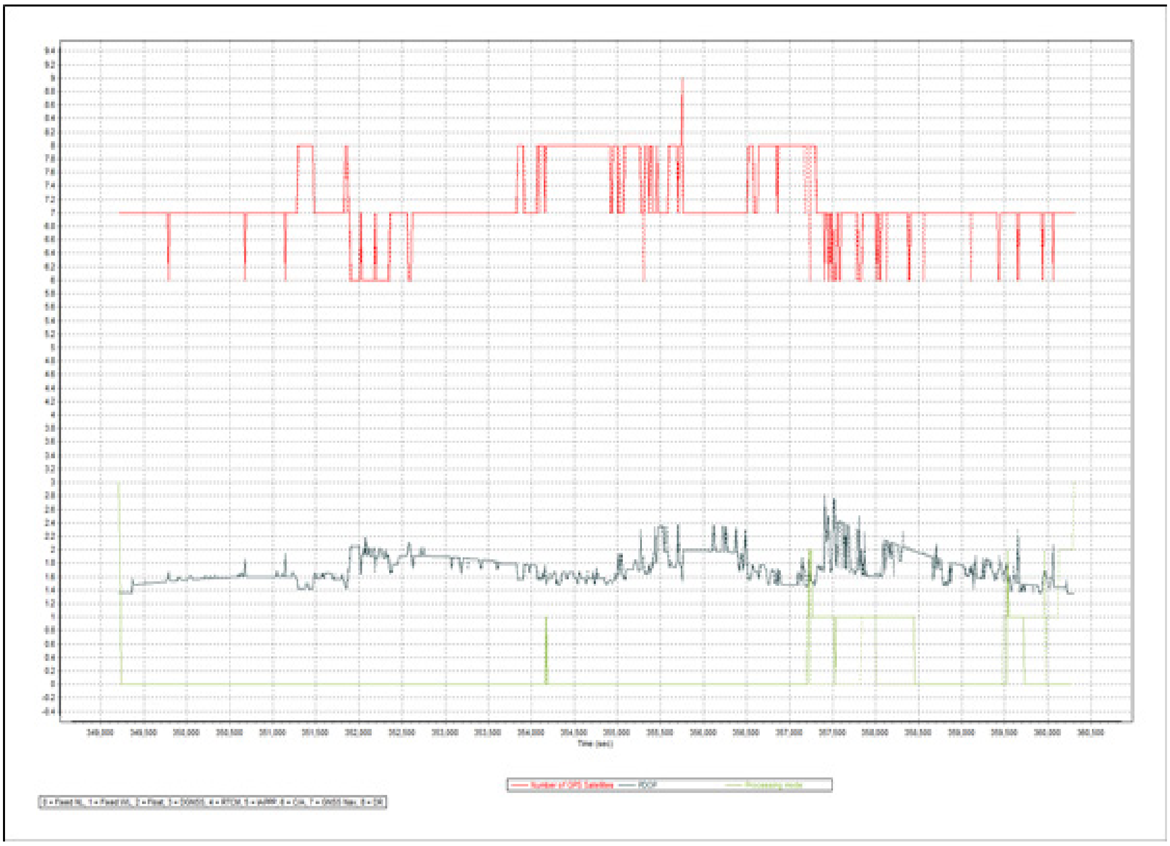

Figure A-8.1 Solution Status

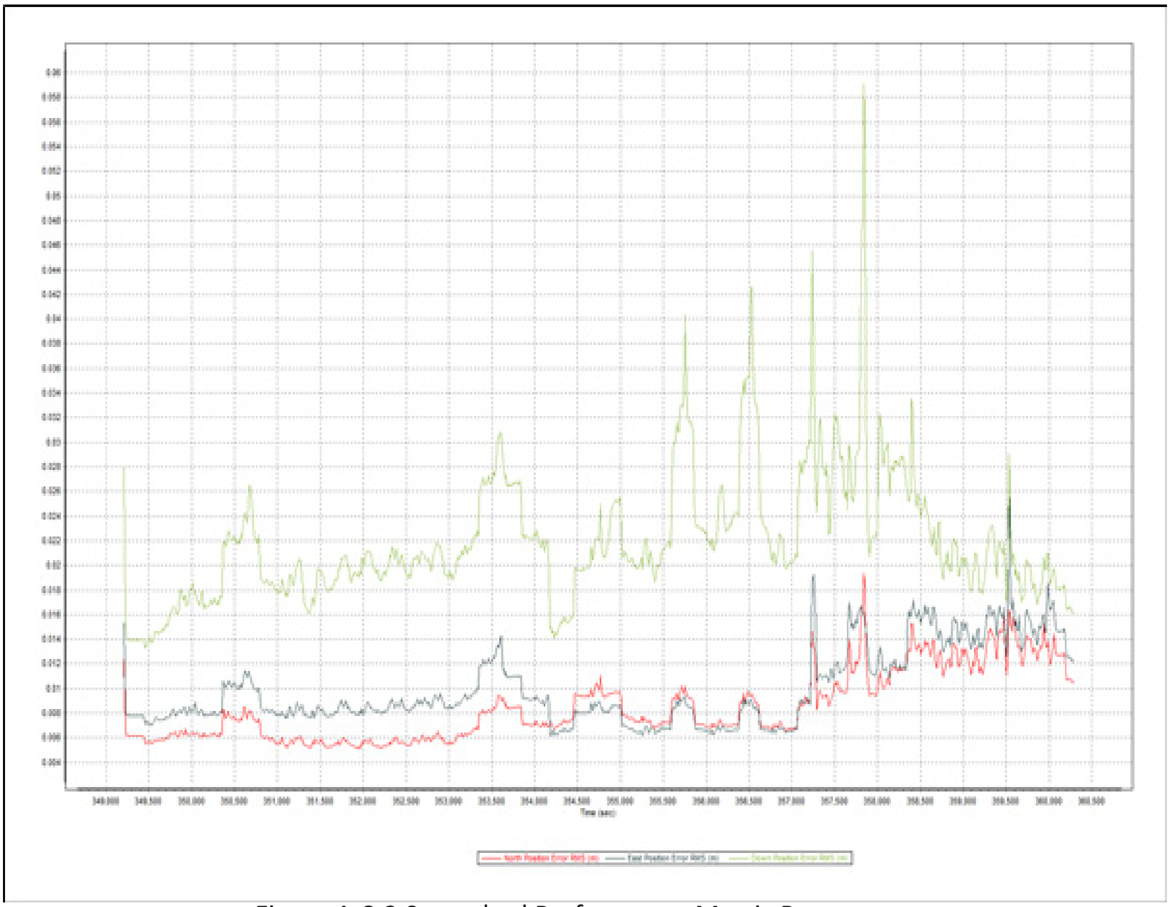

Figure A-8.2 Smoothed Performance Metric Parameters

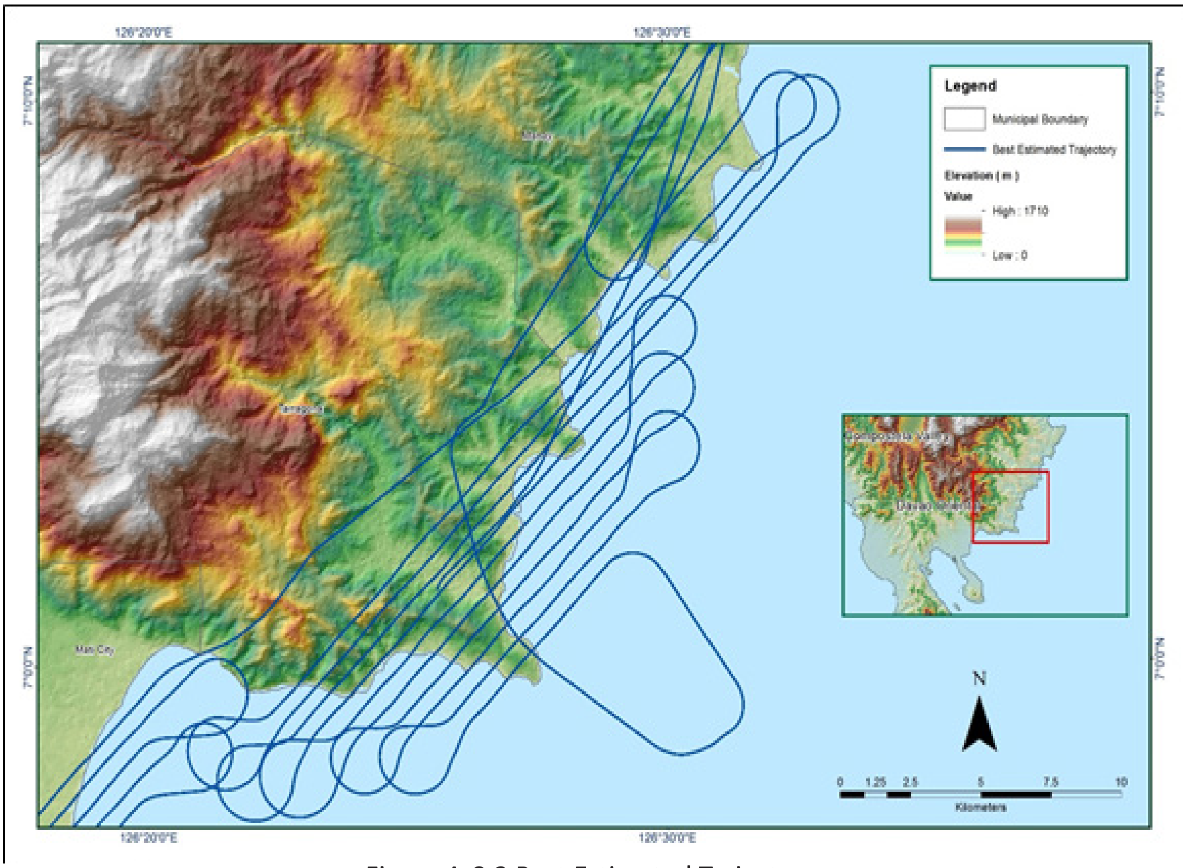

Figure A-8.3 Best Estimated Trajectory

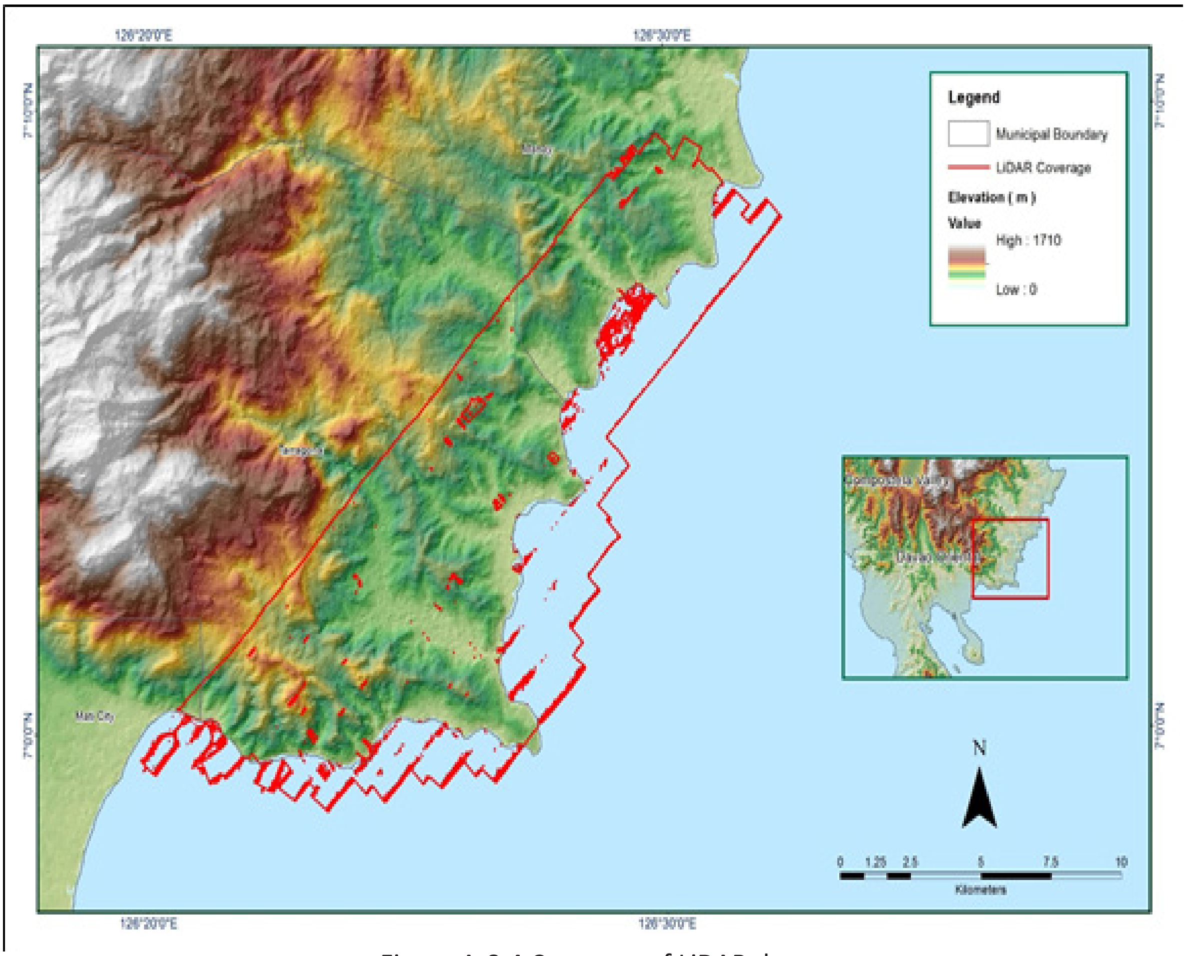

Figure A-8.4 Coverage of LiDAR data

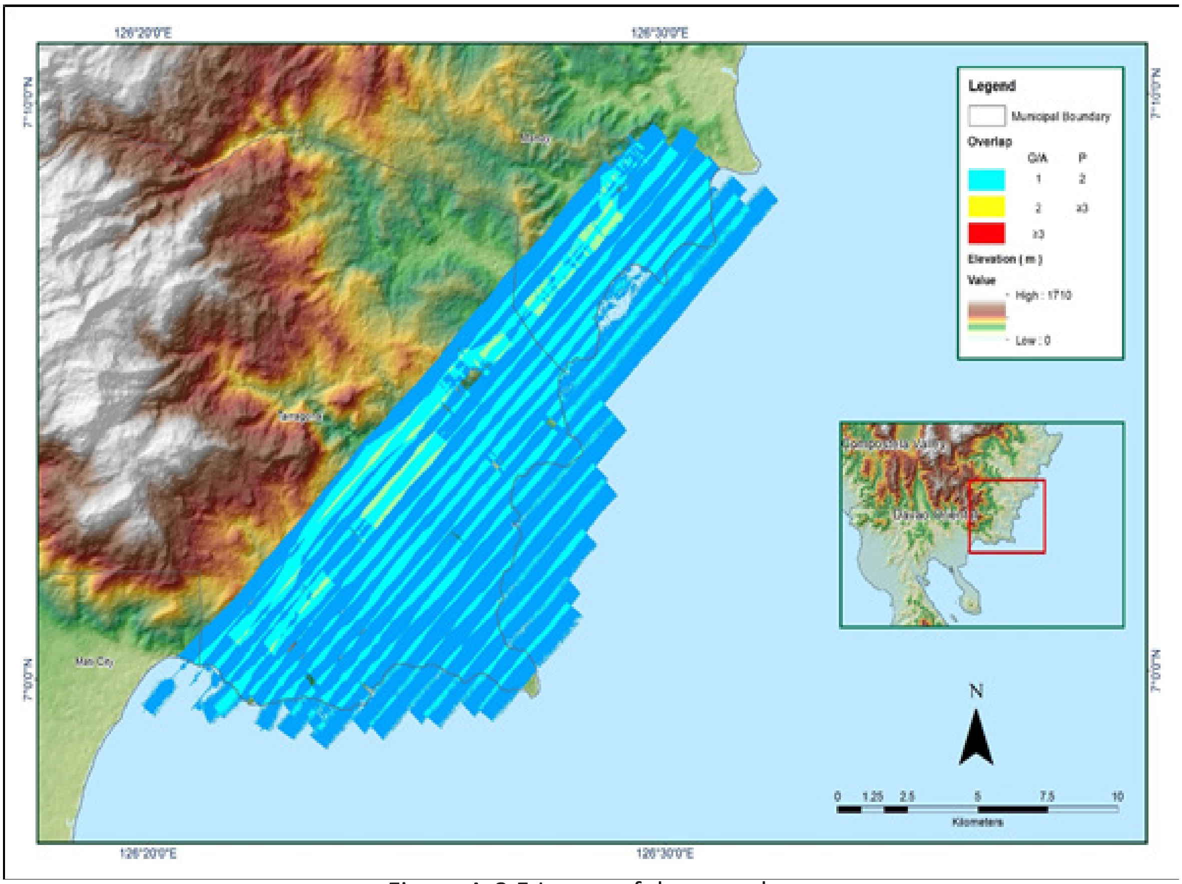

Figure A-8.5 Image of data overlap

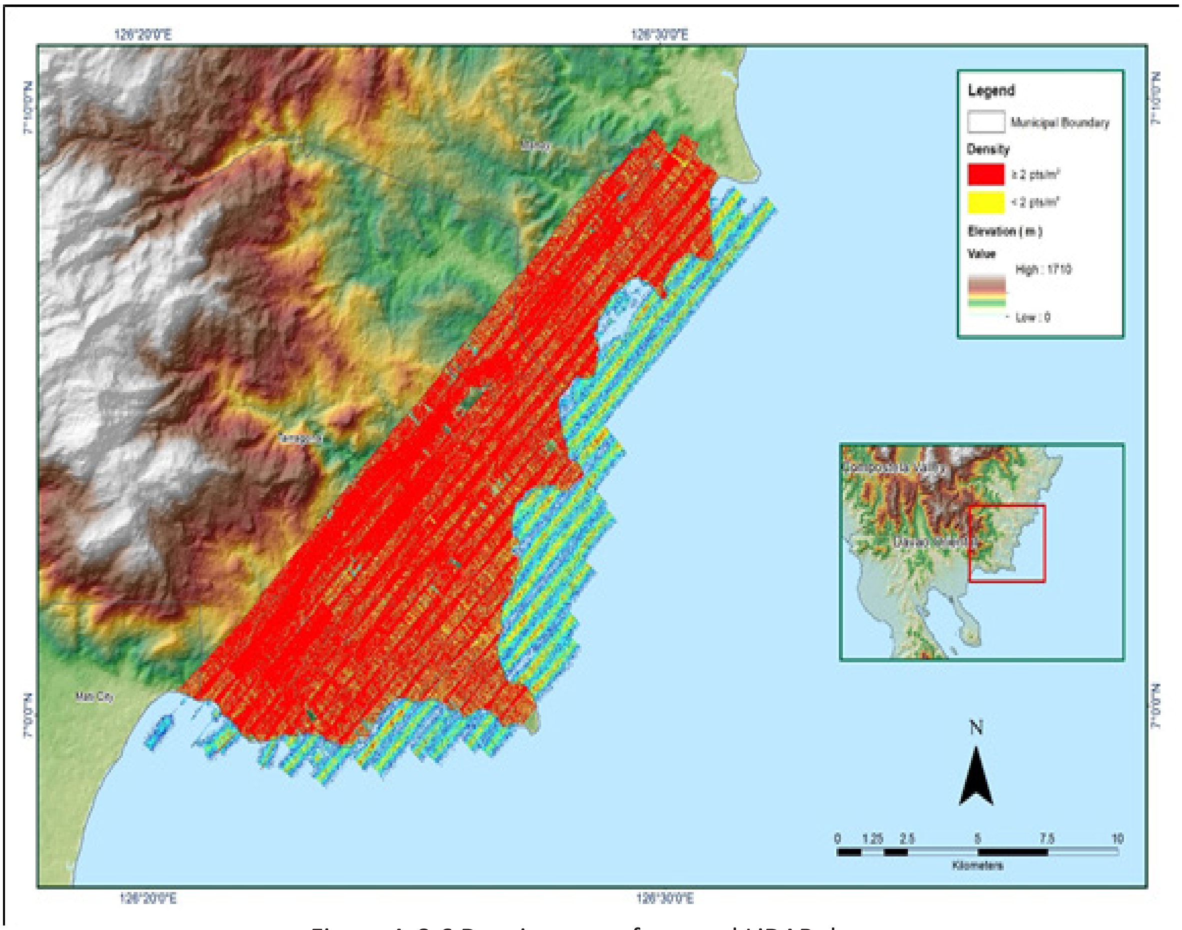

Figure A-8.6 Density map of merged LiDAR data

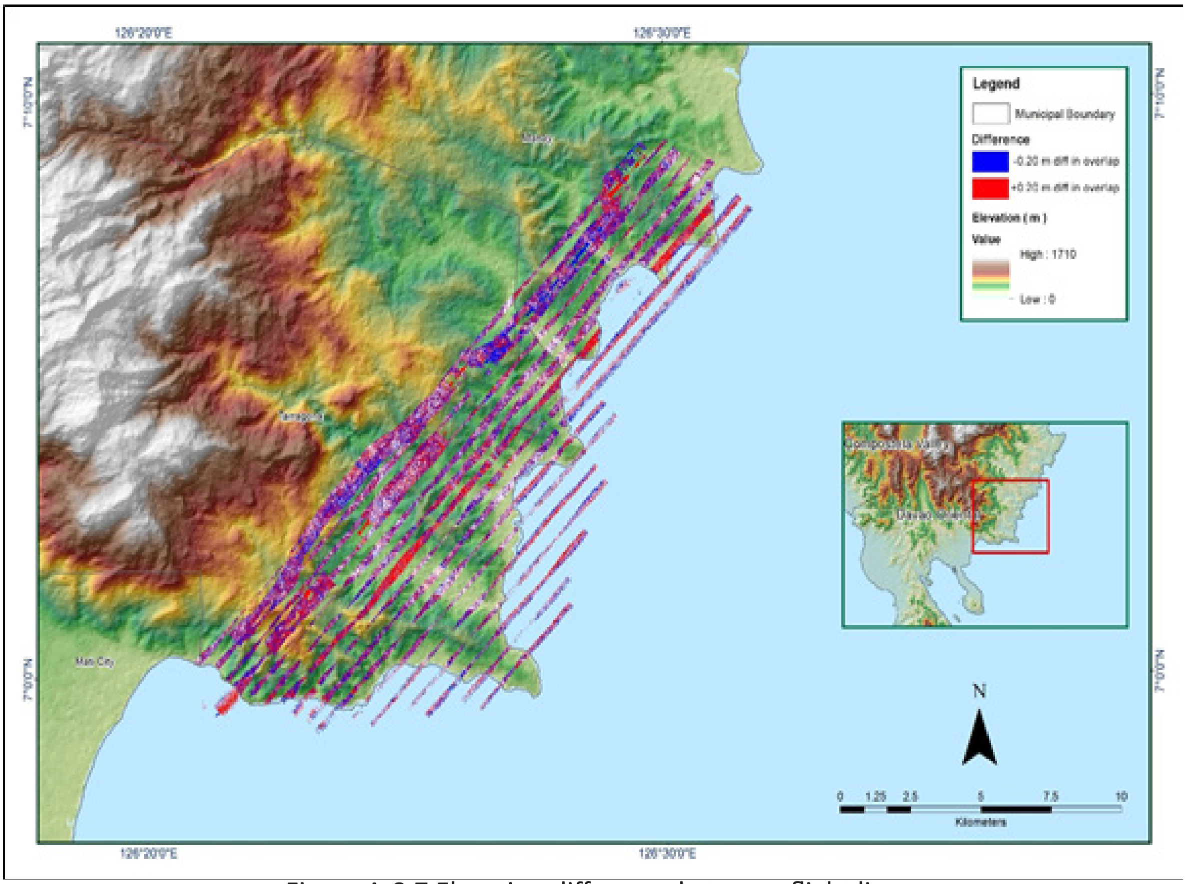

Figure A-8.7 Elevation difference between flight lines

Table A-8.2. Mission Summary Report for Mission Blk80A_supplement

Flight Area	Davao Oriental
Mission Name	DavaoOriental_Blk80A_supplement
Inclusive Flights	7328GC
Range data size	26.9 GB
POS data size	239 MB
Base data size	5.61 MB
Image	n/a
Transfer date	July 2, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	No
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	4.9
RMSE for East Position (<4.0 cm)	5.6
RMSE for Down Position (<8.0 cm)	30.7
Boresight correction stdev (<0.001deg)	0.000359
IMU attitude correction stdev (<0.001deg)	0.091610
GPS position stdev (<0.01m)	0.0023
Minimum % overlap (>25)	18.37%
Ave point cloud density per sq.m. (>2.0)	2.96
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	194
Maximum Height	450.04 m
Minimum Height	55.88 m
Classification (# of points)	
Ground	53,267,703
Low vegetation	21,983,651
Medium vegetation	69,971,144
High vegetation	192,915,306
Building	1,133,311
Orthophoto	No
Processed by	Engr. Angelo Carlo Bongat, Engr. Harmond Santos, Engr. Gladys Mae Apat

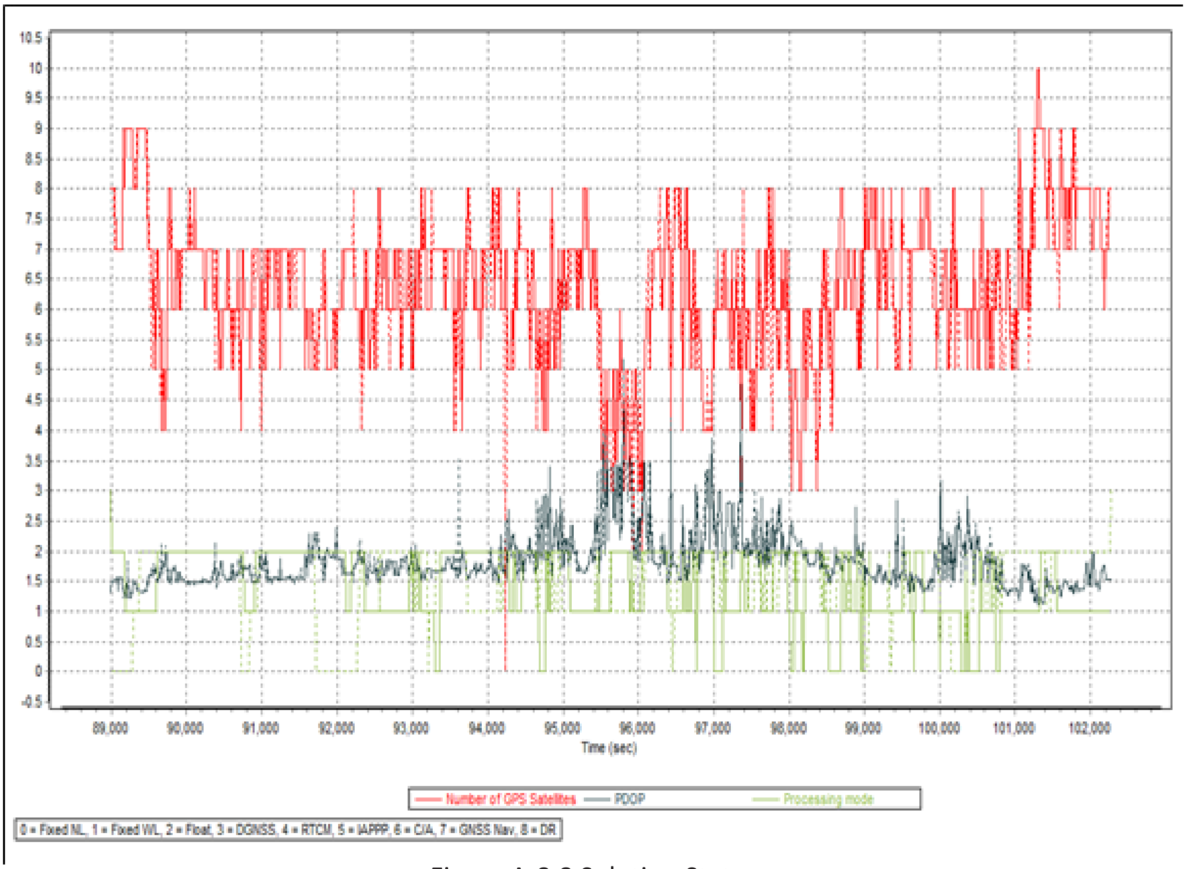

Figure A-8.8 Solution Status

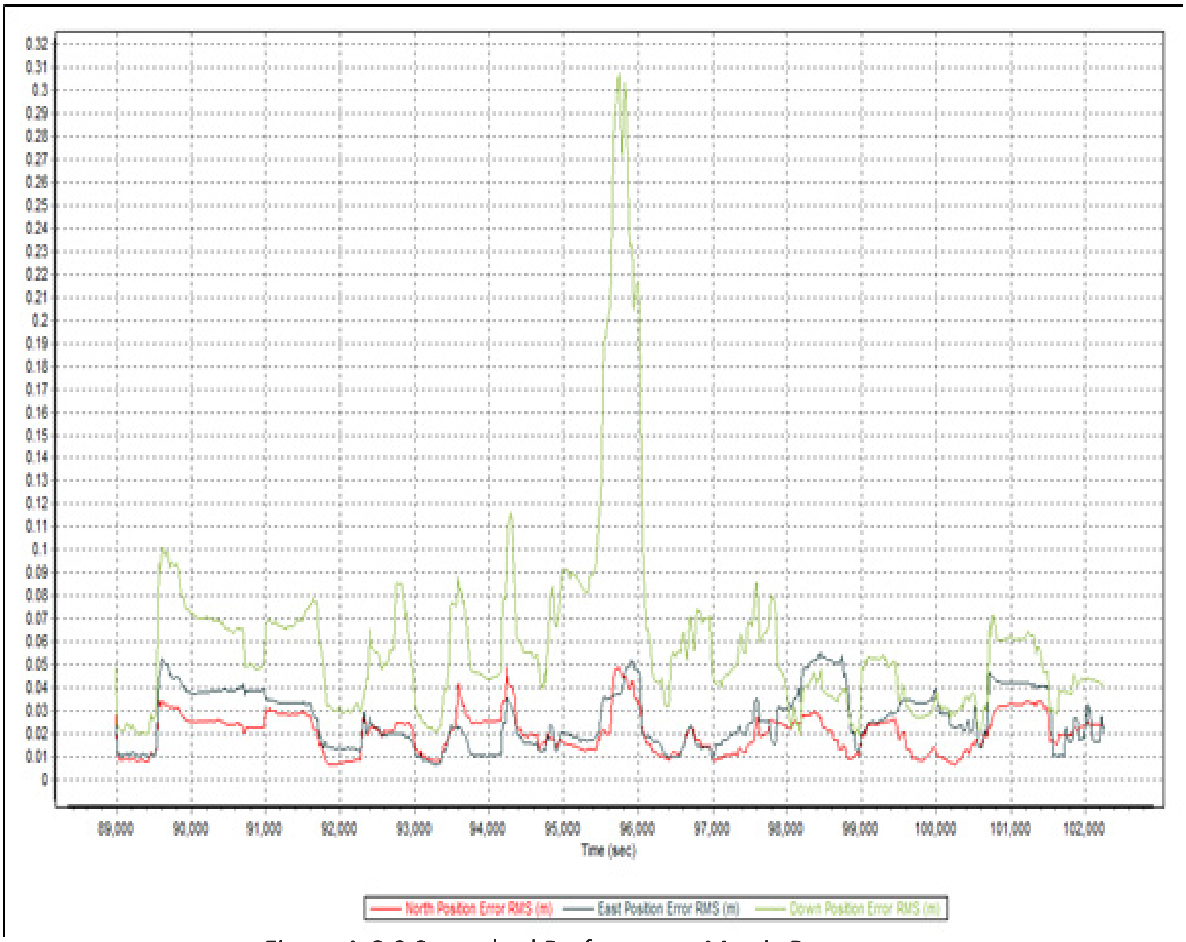

Figure A-8.9 Smoothed Performance Metric Parameters

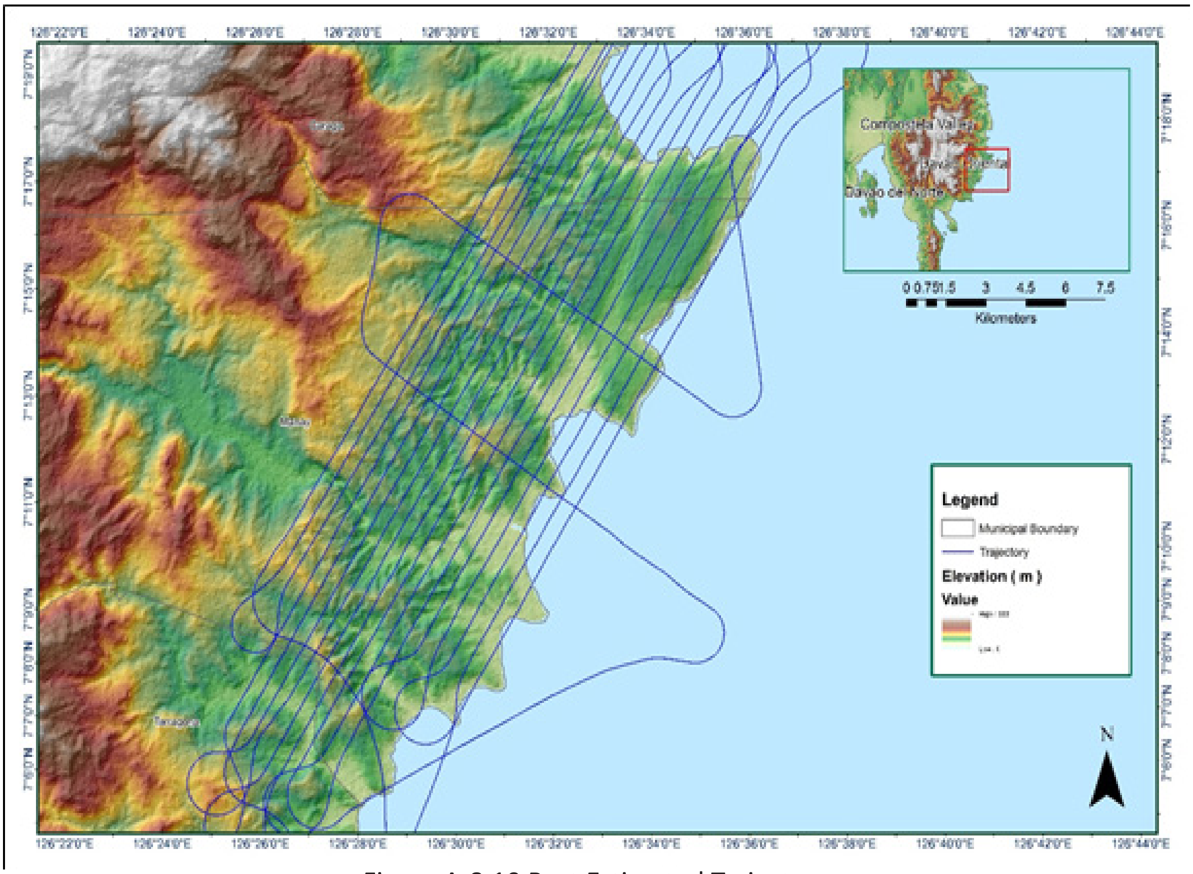

Figure A-8.10 Best Estimated Trajectory

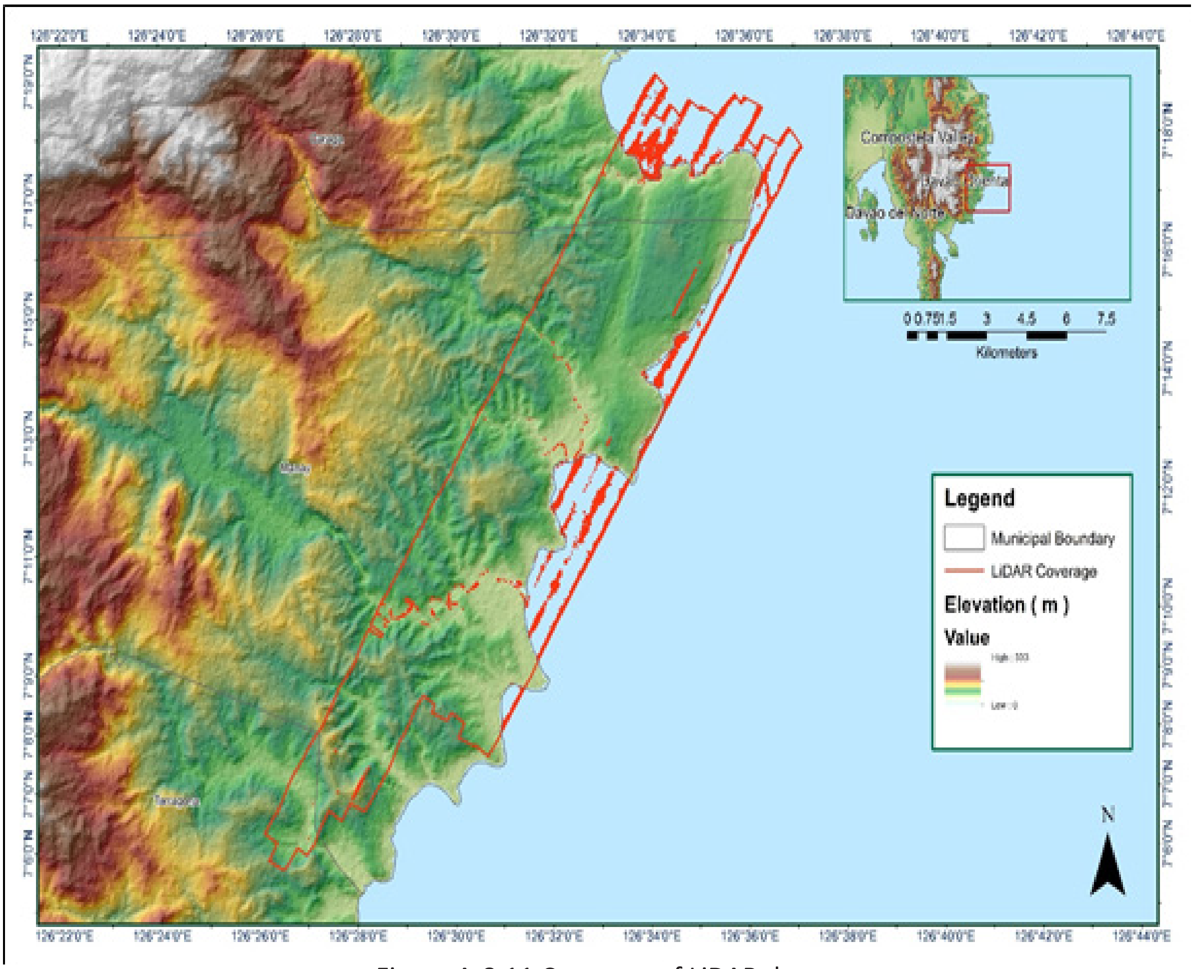

Figure A-8.11 Coverage of LiDAR data

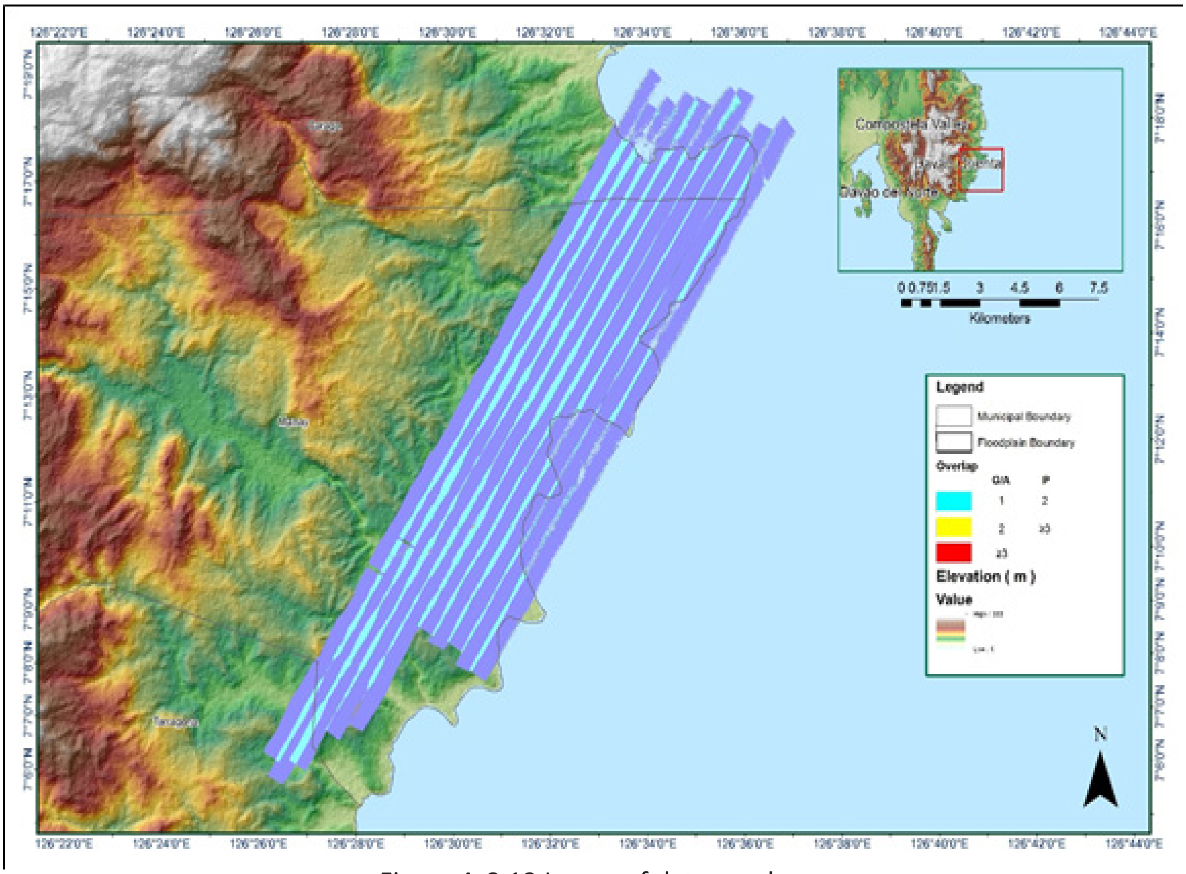

Figure A-8.12 Image of data overlap

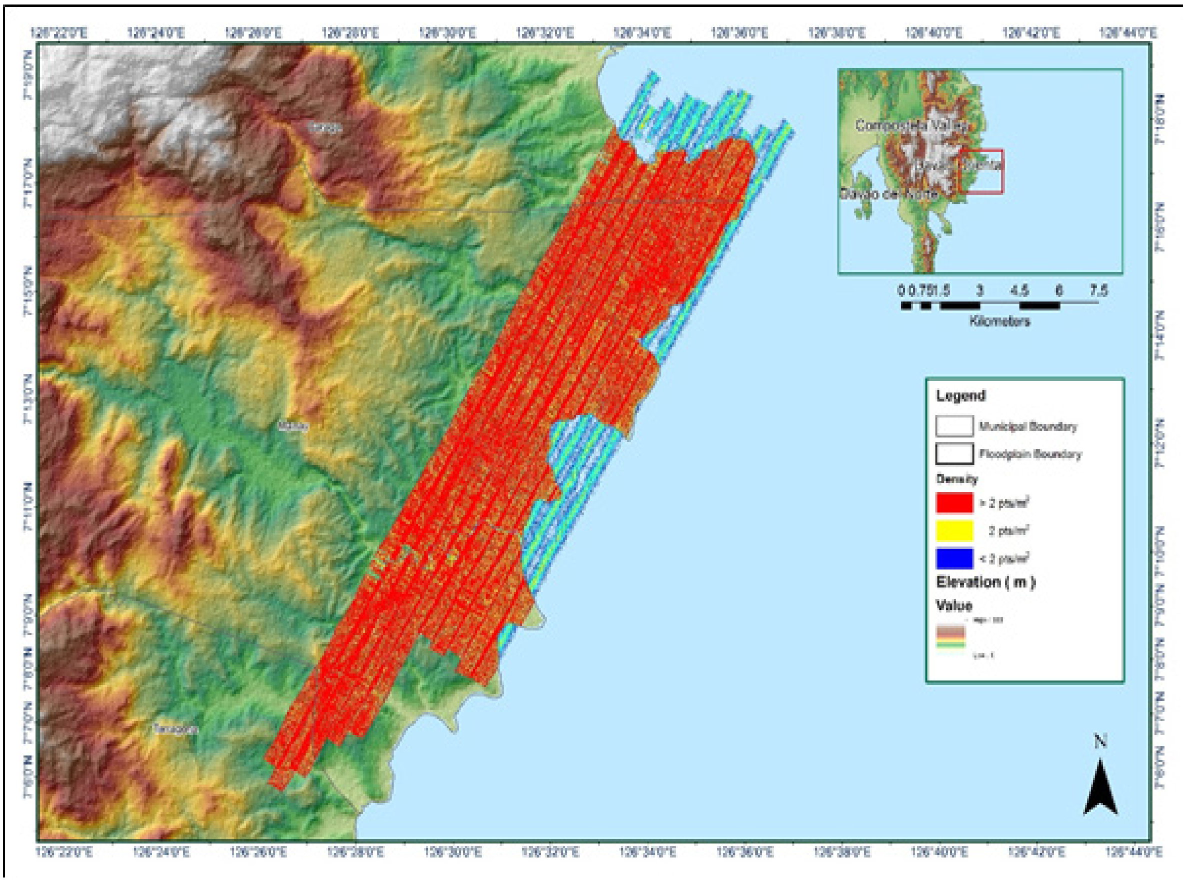

Figure A-8.13 Density map of merged LiDAR data

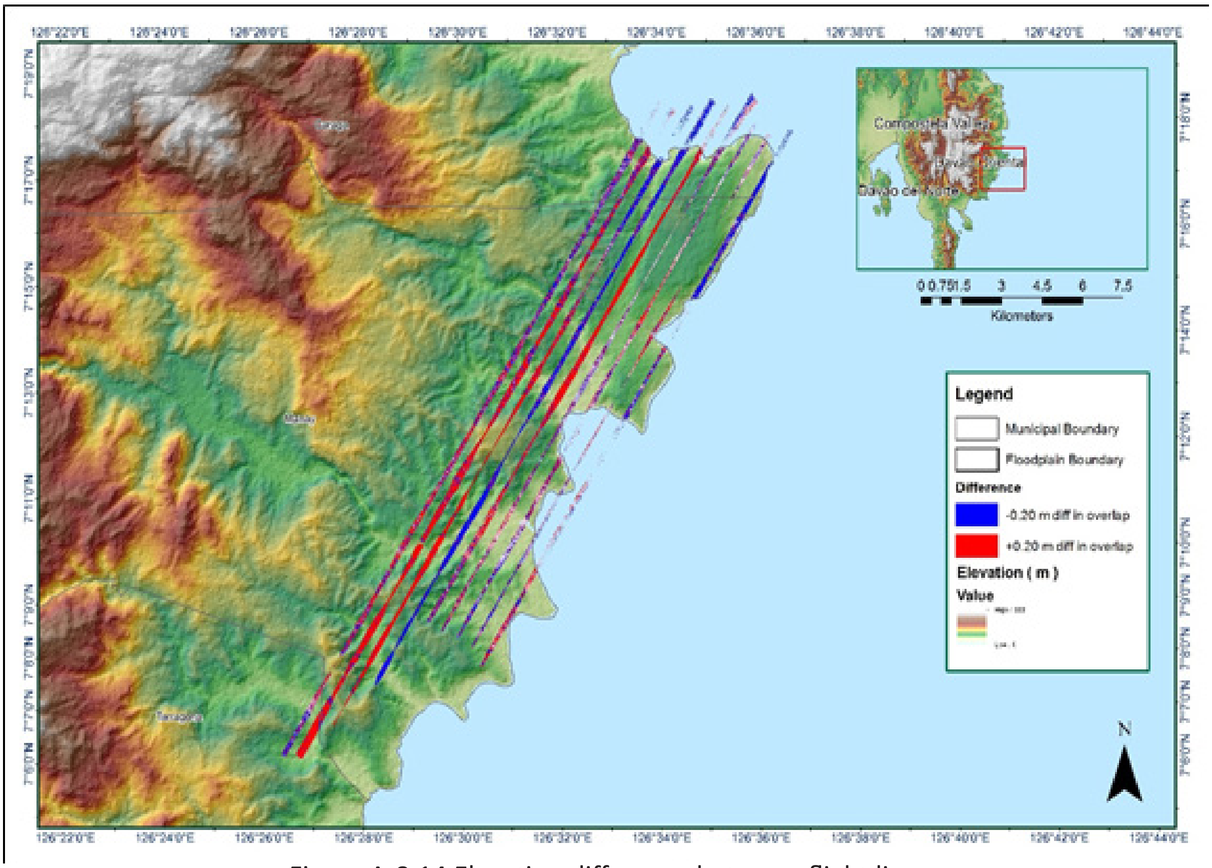

Figure A-8.14 Elevation difference between flight lines

Annex 9. Casauman Model Basin Parameters

Table A-9.1. Casauman Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
W1000	11.7249	67.299	0	2.2244	0.83999	Discharge	0.095227	0.041743	Ratio to Peak	0.46731
W1010	5.6981	80.897	0	38.956	15.888	Discharge	0.014453	0.019639	Ratio to Peak	0.5
W1020	4.601325	83.985	0	2.1546	8.4718	Discharge	0.034045	0.019639	Ratio to Peak	0.33333
W1030	5.89741	80.36	0	26.93	24.901	Discharge	0.02722	0.01964	Ratio to Peak	0.5
W1040	17.717	57.662	0	7.719	3.1532	Discharge	0.11543	0.01173	Ratio to Peak	0.4025
W1050	17.23015	58.341	0	2.3116	1.4164	Discharge	0.03593	0.007743	Ratio to Peak	0.4706
W1060	5.89475	80.367	0	24.189	21.42	Discharge	0.039513	0.013362	Ratio to Peak	0.5
W1070	7.33723	76.683	0	5.4063	4.5929	Discharge	0.047639	0.019637	Ratio to Peak	0.32743
W1080	6.09862	79.825	0	6.2565	5.8144	Discharge	0.003666	0.0293	Ratio to Peak	0.84908
W1090	6.364145	79.13	0	9.1678	10.904	Discharge	0.051311	0.00391	Ratio to Peak	0.5
W1100	7.137825	77.172	0	4.8407	1.6123	Discharge	0.122508	0.06223	Ratio to Peak	0.46652
W560	24.8824	49.232	0	2.6768	1.6402	Discharge	0.045508	0.005736	Ratio to Peak	0.5
W570	21.30565	53.108	0	3.2288	1.9784	Discharge	0.043957	0.008432	Ratio to Peak	0.5
W580	22.32	51.948	0	3.4396	2.1076	Discharge	0.045273	0.005736	Ratio to Peak	0.5
W590	20.27585	54.34	0	3.8348	2.3498	Discharge	0.073964	0.005736	Ratio to Peak	0.33333
W600	21.06245	53.394	0	6.2263	3.8151	Discharge	0.11832	0.012394	Ratio to Peak	0.5
W610	20.3376	54.264	0	3.8399	2.3529	Discharge	0.046594	0.003902	Ratio to Peak	0.5
W620	18.677	56.369	0	2.5876	1.5855	Discharge	0.050389	0.003902	Ratio to Peak	0.27118
W630	18.99335	55.956	0	5.3065	3.2516	Discharge	0.055501	0.003902	Ratio to Peak	0.5
W640	14.5749	62.343	0	0.84549	1.9425	Discharge	0.024372	0.008432	Ratio to Peak	0.19685
W650	14.6813	62.172	0	3.5926	3.7858	Discharge	0.042791	0.003902	Ratio to Peak	0.3013
W660	13.0397	64.919	0	1000	1.525	Discharge	0.052463	0.003902	Ratio to Peak	0.5

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
W670	17.4724	58.001	0	4.8134	2.9494	Discharge	0.038478	0.003902	Ratio to Peak	0.5
W680	18.12505	57.105	0	2.4997	2.2975	Discharge	0.05551	0.003902	Ratio to Peak	0.21778
W690	18.77295	56.243	0	4.8793	2.9898	Discharge	0.08509	0.005736	Ratio to Peak	0.5
W700	16.215	59.809	0	4.3771	2.6741	Discharge	0.005009	0.003902	Ratio to Peak	0.33333
W710	12.2721	66.287	0	4.7313	2.2016	Discharge	0.035001	0.003902	Ratio to Peak	0.22855
W720	23.96375	50.173	0	2.9793	1.8256	Discharge	0.038638	0.005268	Ratio to Peak	0.5
W730	12.55995	65.768	0	8.0175	2.9501	Discharge	0.033335	0.005814	Ratio to Peak	0.5
W740	15.21045	61.336	0	3.7956	1.4906	Discharge	0.061914	0.008604	Ratio to Peak	0.28812
W750	9.5361	71.674	0	0.016667	19.468	Discharge	0.08748	0.007901	Ratio to Peak	0.5
W760	18.26945	56.911	0	4.9656	3.5375	Discharge	0.13319	0.008604	Ratio to Peak	0.33333
W770	8.06911	74.94	0	9.718	29.134	Discharge	0.06703	0.0192	Ratio to Peak	0.5
W780	10.5621	69.555	0	17.993	7.0085	Discharge	0.059417	0.00866	Ratio to Peak	0.5
W790	16.6535	59.166	0	3.6376	2.2278	Discharge	2.05E-02	0.003902	Ratio to Peak	0.22222
W800	23.5087	50.652	0	2.125	1.3021	Discharge	2.93E-02	0.005736	Ratio to Peak	0.5
W810	16.8169	58.93	0	0.9164	0.56152	Discharge	0.004949	0.003902	Ratio to Peak	0.18078
W820	20.52	54.042	0	1.6875	1.034	Discharge	0.019053	0.003902	Ratio to Peak	0.20087
W830	13.3703	64.346	0	28.972	12.221	Discharge	0.080075	0.003902	Ratio to Peak	0.5
W840	16.09015	59.995	0	0.016667	3.8694	Discharge	0.19609	0.019472	Ratio to Peak	0.32503
W850	20.25305	54.368	0	3.1374	1.9224	Discharge	0.039932	0.005268	Ratio to Peak	0.33333
W860	20.61	53.934	0	1.1186	0.68544	Discharge	0.00423	0.007743	Ratio to Peak	0.4172
W870	14.68035	62.174	0	10.46	4.4403	Discharge	0.066978	0.003902	Ratio to Peak	0.5
W880	7.860775	75.428	0	14.011	12.909	Discharge	0.053136	0.01964	Ratio to Peak	0.5
W890	9.331375	72.113	0	4.3056	9.7343	Discharge	0.024778	0.0124	Ratio to Peak	0.5
W900	11.30595	68.095	0	10.529	6.448	Discharge	0.006291	0.0127	Ratio to Peak	0.5

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
W910	12.36425	66.12	0	11.594	7.2712	Discharge	0.077206	0.00845	Ratio to Peak	0.5
W920	10.148003	70.395	0	17.736	10.772	Discharge	0.019348	0.0196	Ratio to Peak	0.5
W930	16.12055	59.95	0	3.8114	1.5648	Discharge	0.043665	0.005809	Ratio to Peak	0.21778
W940	16.66015	59.157	0	4.0375	2.4739	Discharge	0.053055	0.005853	Ratio to Peak	0.32013
W950	19.63555	55.135	0	3.9533	2.4224	Discharge	0.077187	0.005853	Ratio to Peak	0.32667
W960	9.25034	72.288	0	3.9233	1.6608	Discharge	0.060725	0.008735	Ratio to Peak	0.33551
W970	10.46995	69.74	0	0.65046	0.70058	Discharge	0.001489	0.016732	Ratio to Peak	0.064529
W980	14.17495	62.994	0	0.016667	4.0129	Discharge	0.082768	0.011852	Ratio to Peak	0.4975
W990	7.32982	76.701	0	18.987	38.578	Discharge	0.053061	0.030031	Ratio to Peak	0.5

Annex 10. Casauman Model Reach Parameters

Table A-10.1. Casauman Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R100	Automatic Fixed Interval	2342.5	0.029586	0.010002	Trapezoid	304.105	1
R120	Automatic Fixed Interval	3013.6	0.057361	0.018379	Trapezoid	304.105	1
R140	Automatic Fixed Interval	4069.1	0.089612	0.016299	Trapezoid	304.105	1
R150	Automatic Fixed Interval	2240.2	0.034512	0.014495	Trapezoid	304.105	1
R160	Automatic Fixed Interval	814.97	0.030726	0.014351	Trapezoid	304.105	1
R200	Automatic Fixed Interval	2913.5	0.055854	0.017974	Trapezoid	304.105	1
R210	Automatic Fixed Interval	689.41	0.027418	0.015967	Trapezoid	304.105	1
R220	Automatic Fixed Interval	1116.7	0.086169	0.017209	Trapezoid	304.105	1
R230	Automatic Fixed Interval	1617.1	0.042071	0.016039	Trapezoid	304.105	1
R240	Automatic Fixed Interval	5697	0.040859	0.018826	Trapezoid	304.105	1
R250	Automatic Fixed Interval	4302.5	0.031517	0.017965	Trapezoid	304.105	1
R260	Automatic Fixed Interval	2195.4	0.011871	0.018351	Trapezoid	304.105	1
R270	Automatic Fixed Interval	5028.3	0.018743	0.015816	Trapezoid	304.105	1
R280	Automatic Fixed Interval	1064.3	0.007262	0.018144	Trapezoid	304.105	1
R290	Automatic Fixed Interval	2219.9	0.065614	0.016609	Trapezoid	304.105	1
R310	Automatic Fixed Interval	271.42	0.029378	0.014571	Trapezoid	304.105	1
R320	Automatic Fixed Interval	1847.5	0.007328	0.014571	Trapezoid	304.105	1
R360	Automatic Fixed Interval	7850.5	0.026068	0.014816	Trapezoid	304.105	1
R380	Automatic Fixed Interval	2190.8	0.004321	0.014816	Trapezoid	304.105	1
R410	Automatic Fixed Interval	1133.7	0.00126	0.015153	Trapezoid	304.105	1
R420	Automatic Fixed Interval	3670.7	0.058359	0.014984	Trapezoid	304.105	1
R440	Automatic Fixed Interval	1483.6	0.005416	0.016633	Trapezoid	304.105	1
R50	Automatic Fixed Interval	3889.9	0.079334	0.012387	Trapezoid	304.105	1

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R50	Automatic Fixed Interval	3889.9	0.079334	0.012387	Trapezoid	304.105	1
R500	Automatic Fixed Interval	1134.1	0.001	0.109	Trapezoid	304.105	1
R520	Automatic Fixed Interval	1492.7	0.005926	0.11	Trapezoid	304.105	1
R550	Automatic Fixed Interval	7605.4	0.013164	0.11	Trapezoid	304.105	1
R60	Automatic Fixed Interval	3696.1	0.090728	0.009519	Trapezoid	304.105	1

Annex 11. Casauman Field Validation

Table A-11.1. Casauman Field Validation Points

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
1	7.164184	126.51983	0.03	0	0.0009		5-Year
2	7.164454	126.52001	0.03	0	0.0009		5-Year
3	7.165996	126.51912	0.07	0	0.0049		5-Year
4	7.164088	126.52055	0.06	0	0.0036		5-Year
5	7.16536	126.51957	0.03	0.3	0.0729	Intense local rainfall/ 1980's	5-Year
6	7.164182	126.5201	0.06	0	0.0036		5-Year
7	7.165181	126.51939	0.59	0.3	0.0841	Upstream rainfall/ November 2013	5-Year
8	7.165363	126.51921	0.93	0.25	0.4624	Upstream rainfall/ July 2010	5-Year
9	7.167176	126.51823	0.55	0	0.3025		5-Year
10	7.165367	126.51866	0.72	0.85	0.0169	Upstream rainfall/ July 2010	5-Year
11	7.166999	126.51777	0.78	0	0.6084		5-Year
12	7.164359	126.52065	0.06	0	0.0036		5-Year
13	7.165818	126.51876	1.42	0.85	0.3249	Upstream rainfall/ July 2010	5-Year
14	7.166905	126.51822	1.15	0	1.3225		5-Year
15	7.165275	126.51884	1.04	0.85	0.0361	Upstream rainfall/ July 2010	5-Year
16	7.172572	126.52107	4.13	3	1.2769		5-Year
17	7.172295	126.52188	4.37	3	1.8769		5-Year
18	7.172754	126.52089	3.4	3	0.16		5-Year
19	7.179029	126.51506	0.11	0	0.0121		5-Year
20	7.179462	126.51751	0.07	0	0.0049		5-Year
21	7.179568	126.51534	0.08	0	0.0064		5-Year
22	7.17974	126.51651	0.06	0	0.0036		5-Year
23	7.179101	126.51741	0.56	0	0.3136		5-Year
24	7.178741	126.51723	0.28	1.3	1.0404	Intense local rainfall/ January 2013	5-Year
25	7.17993	126.51534	0.26	0	0.0676		5-Year
26	7.178577	126.51506	0.03	0	0.0009		5-Year
27	7.177595	126.5137	0.03	0.3	0.0729	Yolanda/ November 2013	5-Year
28	7.177677	126.51469	0.09	0	0.0081		5-Year
29	7.177568	126.51713	2.91	0.6	5.3361	Pablo/ December 2012	5-Year
30	7.17777	126.51433	0.05	0	0.0025		5-Year
31	7.17739	126.50501	2.76	0.5	5.1076		5-Year
32	7.176744	126.50691	0.04	0	0.0016		5-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
33	7.178893	126.50918	0.77	0	0.5929		5-Year
34	7.179261	126.50828	0.08	0	0.0064		5-Year
35	7.175398	126.50581	0.29	0	0.0841		5-Year
36	7.178716	126.50873	0.73	0	0.5329		5-Year
37	7.177915	126.50719	1.15	0	1.3225	Buhawi/ Year 1995	5-Year
38	7.178267	126.50846	0.1	0	0.01		5-Year
39	7.179707	126.50901	1.25	1	0.0625		5-Year
40	7.176662	126.50582	0.06	0	0.0036		5-Year
41	7.17956	126.51642	1.05	0	1.1025		5-Year
42	7.176388	126.50618	1.21	0	1.4641		5-Year
43	7.17603	126.50573	2.1	2	0.01		5-Year
44	7.177936	126.51632	0.08	0.1	0.0004	Upstream rainfall/ December 25, 2013	5-Year
45	7.177213	126.51631	2.04	2.2	0.0256	Pablo/ December 2012	5-Year
46	7.180553	126.51652	0.37	0	0.1369		5-Year
47	7.177209	126.51686	2.31	1.8	0.2601	Pablo/ December 2012	5-Year
48	7.177397	126.51595	2.73	2.5	0.0529	Upstream rainfall/ December 25, 2013	5-Year
						December 25, 2013	
50	7.175039	126.50545	3.53	3	0.2809		5-Year
51	7.177755	126.50457	3.04	2.5	0.2916		5-Year
52	7.180967	126.50956	1.21	1	0.0441		5-Year
53	7.18124	126.50929	2.17	2	0.0289		5-Year
54	7.175402	126.50518	4.72	3	2.9584		5-Year
56	7.176487	126.50501	1.28	0	1.6384		5-Year
57	7.176305	126.50528	2.7	0	7.29		5-Year
58	7.177573	126.50474	4.36	2.5	3.4596		5-Year
59	7.176665	126.50537	4.75	2.5	5.0625		5-Year
60	7.179525	126.50928	5.48	4	2.1904		5-Year
61	7.181687	126.50993	2.8	2.5	0.09		5-Year
62	7.179432	126.50964	0.98	1	0.0004		5-Year
63	7.181235	126.50993	0.03	0.6	0.3249		5-Year
64	7.161472	126.50842	0.08	0.1	0.0004		5-Year
65	7.16181	126.51149	0.27	0.2	0.0049	Intense local rainfall	5-Year
66	7.161998	126.5105	0.03	0	0.0009		5-Year
67	7.161698	126.5143	0.12	0	0.0144		5-Year
68	7.161447	126.51176	0.3	0.2	0.01	Pablo/ 2012	5-Year
69	7.161173	126.51212	0.28	0.5	0.0484	Pablo/ 2012	5-Year
70	7.161357	126.51167	0.41	0.5	0.0081	Pablo/ 2012	5-Year
71	7.162137	126.50417	0.26	0	0.0676		5-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
72	7.161539	126.51149	0.08	0.5	0.1764		5-Year
73	7.161517	126.51439	0.3	0	0.09		5-Year
74	7.161265	126.51194	0.43	0.5	0.0049	Pablo/ December 2012	5-Year
75	7.161954	126.50453	0.18	0	0.0324		5-Year
76	7.161658	126.50779	0.66	0	0.4356		5-Year
77	7.161445	126.51203	0.28	0.5	0.0484	Pablo/ December 2012	5-Year
78	7.161705	126.51348	0.72	0	0.5184		5-Year
79	7.161903	126.51113	0.03	0.2	0.0289	Intense local rainfall	5-Year
80	7.162175	126.51096	0.82	0.5	0.1024	Rainfall	5-Year
81	7.161742	126.5086	0.34	0	0.1156		5-Year
82	7.161506	126.50408	0.03	0.5	0.2209		5-Year
83	7.161353	126.51221	0.4	0.5	0.01	Pablo/ 2012	5-Year
84	7.163526	126.51142	0.41	0	0.1681		5-Year
85	7.164431	126.51115	0.41	0	0.1681		5-Year
86	7.161715	126.51213	0.34	0.5	0.0256	Pablo/ 2012	5-Year
87	7.162894	126.51141	0.14	0	0.0196		5-Year
88	7.163082	126.51051	0.49	0	0.2401		5-Year
89	7.163348	126.51115	0.46	0	0.2116		5-Year
90	7.161713	126.5124	0.29	0.5	0.0441	Pablo/ 2012	5-Year
91	7.162264	126.51114	0.88	1	0.0144	Rainfall	5-Year
92	7.164308	126.50365	0.29	0	0.0841		5-Year
93	7.166343	126.49725	0.15	0	0.0225		5-Year
94	7.161761	126.50607	0.61	0	0.3721		5-Year
95	7.162357	126.51078	0.99	0	0.9801		5-Year
96	7.167063	126.49752	0.03	0	0.0009		5-Year
97	7.165626	126.49661	0.03	0	0.0009		5-Year
98	7.165523	126.49823	0.05	0	0.0025		5-Year
99	7.163411	126.50292	0.89	0	0.7921		5-Year
100	7.160612	126.5029	2.47	2.5	0.0009		5-Year
101	7.157284	126.50115	0.14	0.5	0.1296		5-Year
102	7.161327	126.50381	3.77	2.5	1.6129		5-Year
103	7.160253	126.50262	4.04	3.5	0.2916		5-Year
104	7.160968	126.50353	4.71	3	2.9241		5-Year
105	7.159711	126.50262	0.05	0.2	0.0225		5-Year
106	7.158722	126.50207	5.25	3.5	3.0625		5-Year
107	7.158001	126.50188	0.65	0.5	0.0225		5-Year
108	7.158991	126.50234	2.97	2	0.9409		5-Year
109	7.173996	126.52379	0.03	0	0.0009		5-Year
110	7.174358	126.52371	0.04	0	0.0016		5-Year
111	7.17445	126.52343	0.03	0	0.0009		5-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
113	7.174179	126.52343	0.03	0	0.0009		5-Year
114	7.174088	126.52352	0.03	0	0.0009		5-Year
115	7.173996	126.5237	0.03	0	0.0009		5-Year
116	7.173817	126.52361	0.03	0	0.0009		5-Year
117	7.174722	126.52326	0.07	0	0.0049		5-Year
118	7.17673	126.52047	0.73	0	0.5329		5-Year
119	7.176191	126.5201	1.21	0	1.4641		5-Year
120	7.17499	126.52362	0.03	0	0.0009		5-Year
121	7.175078	126.52389	0.08	0	0.0064		5-Year
122	7.175713	126.52354	0.06	0	0.0036		5-Year
123	7.176636	126.52092	0.03	0	0.0009		5-Year
124	7.174808	126.5238	0.04	0	0.0016		5-Year
125	7.174897	126.52407	0.05	0	0.0025		5-Year
126	7.175354	126.52326	0.06	0	0.0036		5-Year
127	7.175349	126.52389	0.05	0	0.0025		5-Year
128	7.176977	126.52354	0.05	0	0.0025		5-Year
129	7.174719	126.52371	0.05	0	0.0025		5-Year
130	7.175174	126.52326	0.05	0	0.0025		5-Year
131	7.175351	126.52362	0.05	0	0.0025		5-Year
132	7.175716	126.52317	0.06	0	0.0036		5-Year
133	7.174714	126.52434	0.07	0	0.0049		5-Year
134	7.175897	126.52308	0.08	0	0.0064		5-Year
135	7.176974	126.524	0.1	0.5	0.16		5-Year
136	7.175817	126.52182	0.11	0	0.0121		5-Year
137	7.175256	126.52435	0.06	0.2	0.0196	Pablo/ December 2012	5-Year
138	7.175989	126.5229	0.26	0	0.0676		5-Year
139	7.176075	126.52345	0.18	0.2	0.0004		5-Year
140	7.17527	126.52245	0.04	0.2	0.0256		5-Year
141	7.175645	126.52073	0.95	1	0.0025	Upstream rainfall/ 2010	5-Year
142	7.179357	126.51931	0.28	0.3	0.0004		5-Year
143	7.17381	126.52442	0.34	0.5	0.0256		5-Year
144	7.178802	126.52112	0.28	0.3	0.0004		5-Year
145	7.175646	126.52055	0.03	0.1	0.0049	Upstream rainfall/ 2010	5-Year
146	7.176344	126.52372	0.04	0.1	0.0036		5-Year
147	7.181162	126.51951	0.03	0.1	0.0049		5-Year
148	7.17336	126.52424	0.24	0	0.0576		5-Year
149	7.177733	126.51921	0.04	0.2	0.0256	Pablo/ December 2012	5-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
150	7.177831	126.51822	0.06	0.2	0.0196	Pablo/ December 2012	5-Year
151	7.176073	126.52372	0.03	0.2	0.0289		5-Year
152	7.176547	126.52074	1.34	0	1.7956		5-Year
153	7.176458	126.52056	1.38	0	1.9044		5-Year
154	7.180614	126.52023	0.29	0	0.0841		5-Year
155	7.180251	126.52059	1.08	0	1.1664		5-Year
156	7.176366	126.52083	1.8	0	3.24		5-Year
157	7.178525	126.52193	0.12	0	0.0144		5-Year
158	7.175826	126.52055	1.98	2	0.0004	Upstream rainfall/ 2010	5-Year
159	7.176097	126.52065	2.16	2	0.0256	Upstream rainfall/ 2010	5-Year
160	7.175283	126.52082	2	2	0	Upstream rainfall/ 2010	5-Year
161	7.175918	126.52037	1.96	2	0.0016	Upstream rainfall/ 2010	5-Year
162	7.176933	126.51758	2.12	2	0.0144	Pablo/ December 2012	5-Year
163	7.17546	126.52127	2.63	2.5	0.0169	Upstream rainfall/ 2010	5-Year
164	7.175285	126.52055	2.17	2	0.0289	Upstream rainfall/ 2010	5-Year
165	7.175453	126.52218	0.03	0.2	0.0289	Upstream rainfall/ 1991	5-Year
166	7.177113	126.51758	2.17	2	0.0289	Pablo/ December 2012	5-Year
167	7.17519	126.52118	2.36	2	0.1296	Upstream rainfall/ 1991	5-Year
168	7.176376	126.51956	2.78	2.5	0.0784	Yolanda/ 2013	5-Year
169	7.175551	126.52109	2.31	2.5	0.0361		5-Year
170	7.176839	126.51803	2.5	2	0.25	Pablo/ December 2012	5-Year
171	7.177193	126.51894	2.31	2	0.0961	Upstream rainfall/ 2010	5-Year
172	7.176744	126.51866	2.37	2.5	0.0169	Upstream rainfall/ 2010	5-Year
173	7.177376	126.51867	2.48	2	0.2304	Pablo/ December 2012	5-Year
174	7.177379	126.5183	2.49	1	2.2201	Pablo/ December 2012	5-Year
175	7.175367	126.52163	2.76	2.5	0.0676	Upstream rainfall	5-Year
176	7.175914	126.52091	2.78	2	0.6084		5-Year
177	7.17582	126.52146	2.71	2	0.5041	Upstream rainfall	5-Year
178	7.17674	126.51911	2.88	2.5	0.1444	Pablo/ December 2012	5-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
179	7.176646	126.51965	2.69	2	0.4761	Yolanda/ 2013	5-Year
180	7.175183	126.52199	4.62	2.5	4.4944		5-Year

RMSE 0.683308

Annex 12. Educational Institutions Affected in Casauman Flood Plain

Table A-12.1. Educational Institutions in Manay, Davao Oriental affected by flooding in Casauman Flood Plain

Davao Oriental				
Manay				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Zaragosa	FRANCISCO LAHORA ELEMENTARY SCHOOL		Low	Low
Zaragosa	ZARAGOSA DAY CARE CENTER			

Annex 13. Medical Institutions Affected in Casauman Flood Plain

This river basin has no medical institutions affected.