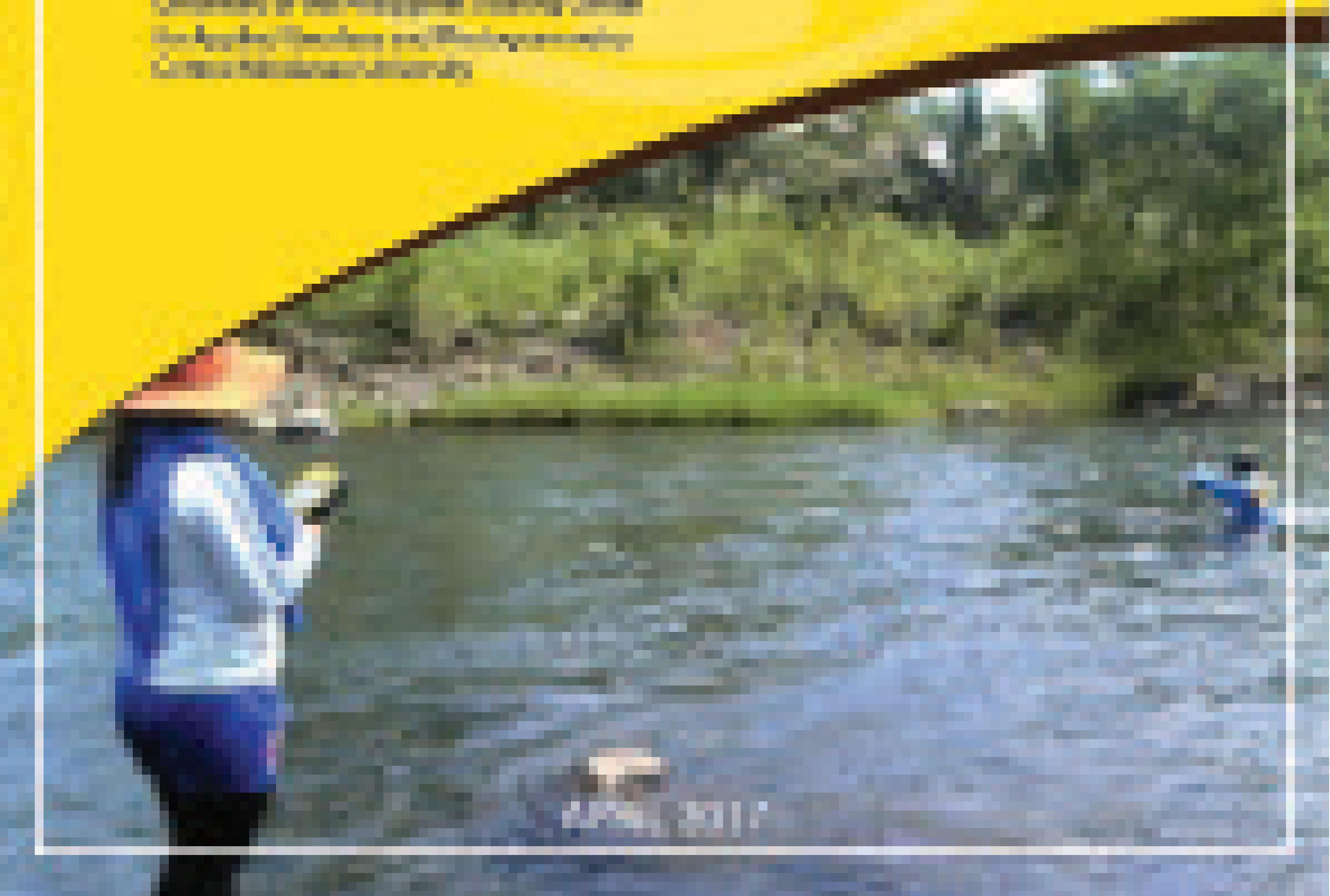
HAZARD MAPPING OF THE PHILIPPINES USING LIDAR (PHIL-LIDAR 1)

LiDAR Surveys and Flood Mapping of Cabulig River

University of the Philippines Training Center for Applied Geodesy and Photogrammetry
Central Mindanao University



APRIL 2017

Published by the UP Training Center for Applied Geodesy and Photogrammetry (TCAGP)
College of Engineering
University of the Philippines – Diliman
Quezon City 1101
PHILIPPINES

This research project is supported by the Department of Science and Technology (DOST) as part of its Grants-in-Aid Program and is to be cited as:

E.C. Paringit, and G. R. Puno, (Eds.). (2017), LiDAR Surveys and Flood Mapping Report of Cabulig River. Quezon City: University of the Philippines Training Center for Applied Geodesy and Photogrammetry, 125 pp.

For questions/queries regarding this report, contact:

Dr. George R. Puno
Project Leader, Phil-LiDAR 1 Program
Central Mindanao University
Maramag, Bukidnon 8714
geopuno@yahoo.com

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

National Library of the Philippines
ISBN: 987-621-430-010-5

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

CHAPTER 1: OVERVIEW OF THE PROGRAM AND CABULIG RIVER

Enrico C. Paringit, Dr. Eng. and Dr. George R. Puno

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.

The program was also 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 titled 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 Central Mindanao University (CMU). CMU 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. The university is located in the Municipality of Maramag in the province of Bukidnon, Philippines.

1.2 Overview of the Cabulig River Basin

Cabulig River is located in the Municipality of Jasaan, Misamis Oriental, Philippines. The river basin has a total area of 23,370 hectares. It is bounded by Balingasag and Claveria in the north; Gingoog and Claveria in the east; Claveria and Villanueva in the south; and Jasaan in the west. Its catchment area is approximately 233.70 km^2. The river drains towards the western direction into Macajalar Bay. Around 78% of Cabulig River basin's area is in the hinterlands of the Municipality of Claveria while only around 6% is within the coastal Municipality of Jasaan. Inhabitants in the basin include the indigenous group Higaonon.

The main stem, Cabulig River, is one of the 13 river systems under the Phil-LiDAR 1 program partner HEI, CMU. Based on the 2010 census, there is an estimated population of 23,366 people distributed among the four (4) municipalities within the river basin. The river is economically important to the area. Jasaan Municipality's coastal barangays such as Bobontugan, Jampas-on, and Lower Jasaan are involved in fishing. The river is also the source of water for agricultural crops and the upper catchment in Claveria. Claveria is extensively hosting pineapple plantations. Additionally, the floodplain of the river basin is only concentrated in the Municipality of Jasaan. Hence, the said municipality is exposed to flood hazard constituted to 42% of the population.

Flooding is the most common disaster experienced by the local communities. Based on the drafted Cabulig Watershed Profile of CMU, the drainage density of the watershed is 0.000147536 m/ha, indicating low density of stream; thus, a slow storm response. When Cabulig River overflows, barangays within the floodplain are directly affected whereas settlements are closer to the river and in a relatively flat surface.

There are several typhoon events that brought damages to livelihood and infrastructures such as:

- Typhoon Undang (December 1972): killed people and animals especially in area near the coast and damaged several properties. It is the biggest flood experienced in the area.
- Typhoon Agaton (January 2014): flooded some houses with 1 m water level rise.
- Typhoon Seniang (December 2014): affected Cabulig Riverbank and flooded some barangays and damaged agriculture and AWLS.

The thick forest of the basin provides basic commodities such as food, water, and medicine to the locals. It caters crop cultivation, as well as support hydroelectric power generation. Sand and gravel extraction along the course of the river also provides income. Along with the continuing exploitation of the resources in the basin is the increasing risk of flood due to the deteriorating river habitats. The continuing increase of typhoon intensity and frequency in the recent years bring clear and present danger to the downstream communities.

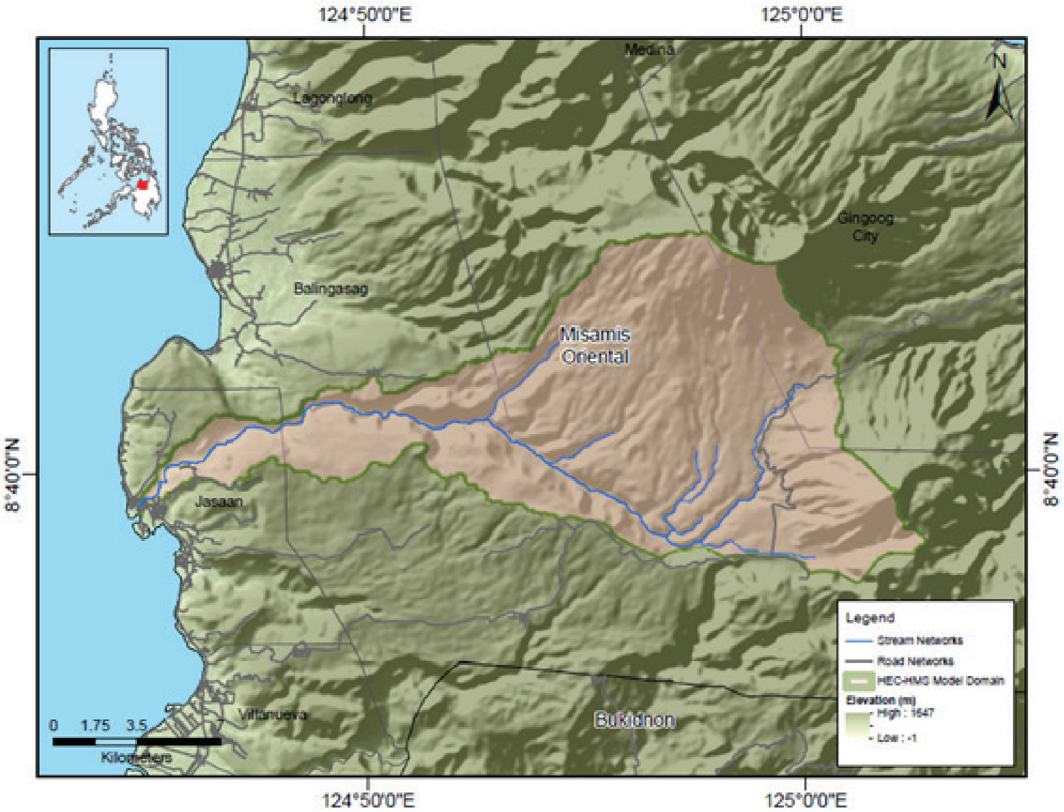


Figure 1. Map of the Cabulig River Basin (in brown)

The Phil-LiDAR 1 Program, an offshoot of the DREAM Program implemented by UP Diliman, includes Cabulig River in the generation of up-to-date, detailed, and high-resolution three-dimensional (3D) flood hazard maps using Light Detection and Ranging (LiDAR) technology. With Central Mindanao University (CMU) as the co-implementer, the flood hazard maps of Cabulig River were generated through flood modeling involving hydrologic and hydraulic model simulations. These were performed using stand alone softwares of Hydrologic Modeling System (HMS) and Hydrologic River Analysis System (RAS) developed by the Hydrologic Engineering Center of the US Army Corps of Engineers. The HMS models the upstream and simulates the complete hydrologic processes of dendritic watershed systems while RAS models the floodplain to perform one-dimensional (1D) unsteady flow river hydraulics calculations.

The basin model was generated using Synthetic Aperture Radar (SAR) 10m Digital Elevation Model (DEM) and digitized river centerline. The model consists of 83 subbasins, 43 reaches, and 43 junctions and was calibrated using an actual data during an Intertropical Convergence Zone (ITCZ) event on September 29-30, 2015. Model performance was revealed to be at satisfactory level based on the statistical tests employed. Using the calibrated model, hypothetical discharge scenarios were simulated using Rainfall Intensity Duration Frequency (RIDF) data of Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) based on a 26-year historical data of Lumbia rain gauge. Flood hydraulic simulation was performed using LiDAR Digital Terrain Model (DTM) consequently showing flood extent and depth information. Flood hazard maps were generated projecting the flood scenarios for the 5, 25, and 100-year return periods.

CHAPTER 2: LIDAR ACQUISITION OF THE CABULIG FLOODPLAIN

Engr. Louie P. Balicanta, Engr. Christopher Cruz, Lovely Gracia Acuña, Engr. Gerome Hipolito, Engr. Renan D. Punto, Ms. Pauline Joanne G. Arceo

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

2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Cabulig Floodplain in Misamis Oriental. These missions were planned for 12 lines and ran for at most four and a half (4.5) hours including take-off, landing, and turning time. The flight planning parameters for the LiDAR system is found in Table 1. The flight plan for Cabulig Floodplain is shown in Figure 2.

Table 1. Flight planning parameters for Pegasus LiDAR system

Block Name	Flying Height (m AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
RX_BLKD	850	30	50	200	30	130	5
RX_BLKE	900	30	50	200	30	130	5

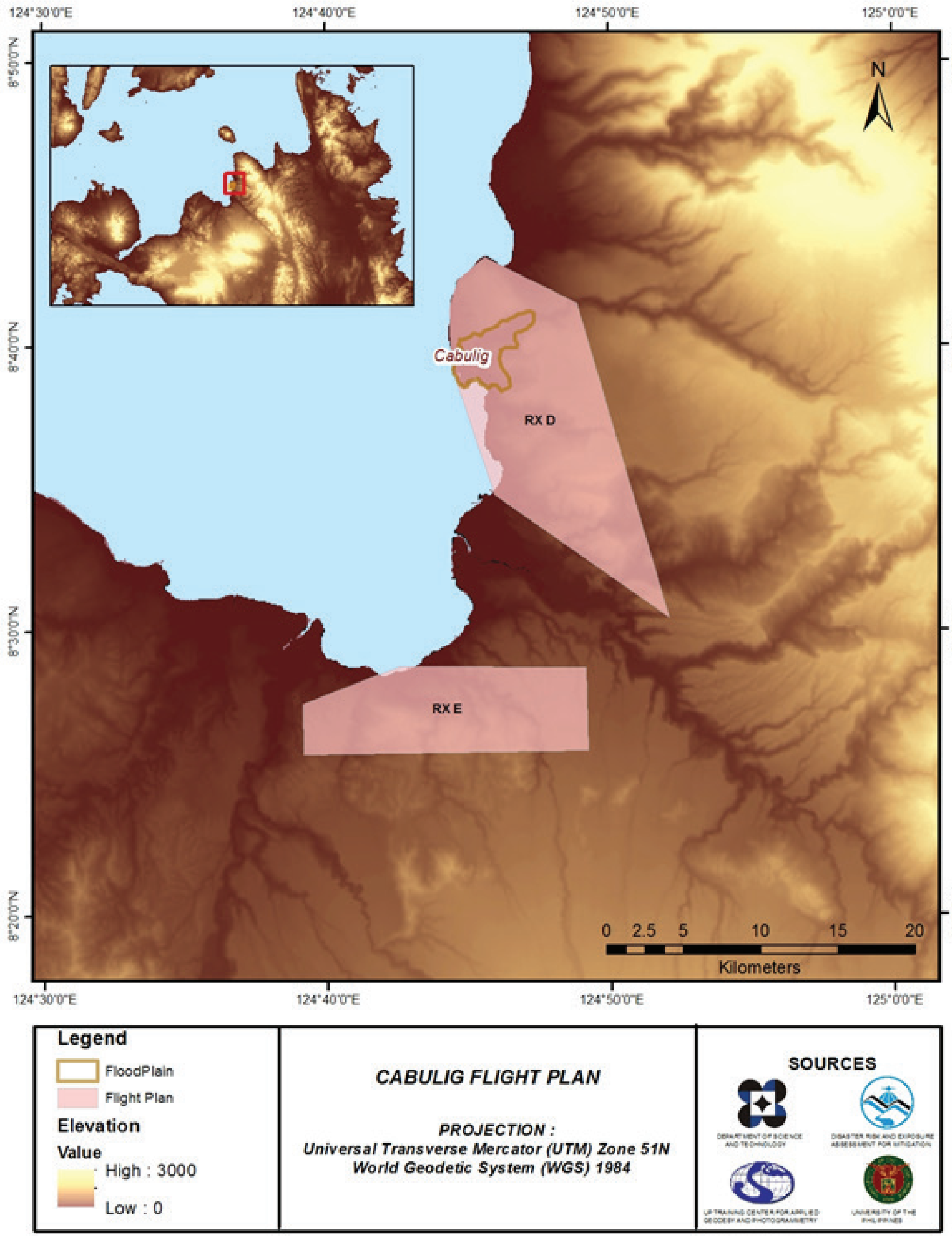


Figure 2. Flight plans used for Cabulig Floodplain

2.2 Ground Base Stations

The project team was able to recover two (2) NAMRIA ground control points: MSE-19 which is of second (2nd) order accuracy and MSE-3241 which is of third (3rd) order accuracy. The certifications for the NAMRIA reference points are found in Annex 2. These points were used as base stations during flight operations for the entire duration of the survey (May 27 – June 16, 2014). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 882 and SPS 852. Flight plans and location of base stations used during the aerial LiDAR acquisition in Cabulig Floodplain are shown in Figure 3. The list of team members is found in Annex 4.

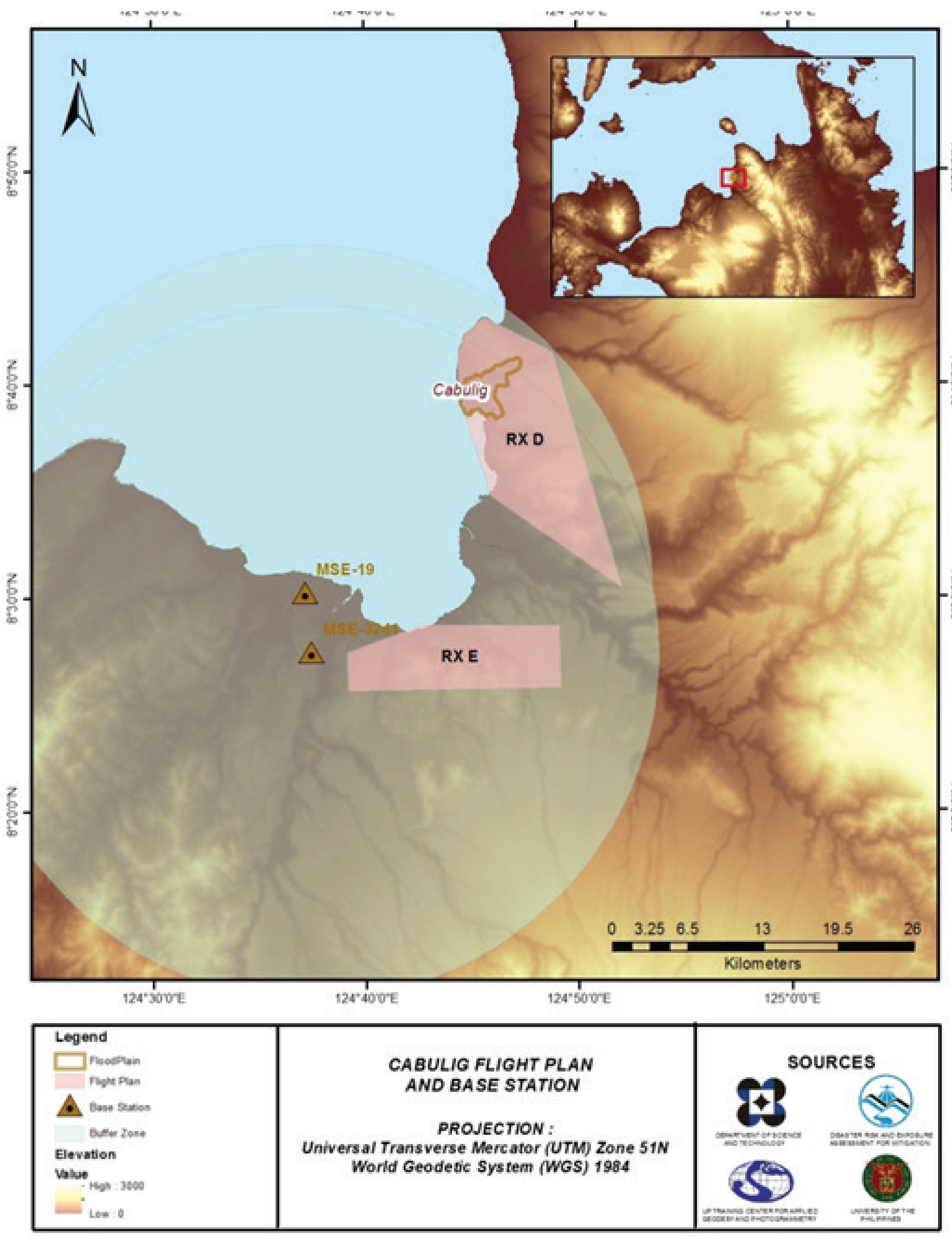


Figure 3. Flight plans and base stations for Cabulig Floodplain

Figure 4 to Figure 5 show the recovered NAMRIA reference points within the area. In addition, Table 2 to Table 3 show the details about the following NAMRIA control stations, while Table 4 shows the list of all ground control points occupied during the acquisition together with the corresponding dates of utilization. The data transfer sheets can be found in Annex 6.

(b)

(a)

Figure 4. GPS set-up over MSE-19 at the center island located at the road intersections going to Cagayan de Oro, Butuan City and Iligan City (a) and NAMRIA reference point MSE-19 (b) as recovered by the field team

Table 2. Details of the recovered NAMRIA horizontal control point MSE-19 used as base station for the LiDAR acquisition

Station Name	**MSE-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	8° 30’ 19.11464” North 124° 37’ 6.46518” East 11.24200 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	457,992.786 meters 940,451.853 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	8° 30’ 15.52234” North 124° 37’ 11.86795” East 78.72200 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	678,151.65 meters 940,474.22 meters

(a)

(b)

Figure 5. GPS set-up over MSE-3241 on a center island near a gasoline station beside SM Cagayan de Oro (a) and NAMRIA reference point MSE-3241 (b) as recovered by the field team

Table 3. Details of the recovered NAMRIA horizontal control point MSE-3241 used as base station for the LiDAR acquisition

Station Name	MSE-3241	
Order of Accuracy	3rd	
Relative Error (horizontal positioning)	1 in 10,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	8° 27' 31.07607" North 124° 37' 23.18891" East 109.46700 meters
Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 5 PRS 92)	Easting Northing	458499.251 meters 935289.375 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	8° 27' 27.49608" North 124° 37' 28.59587" East 177.055 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North	Easting Northing	678684.71 meters 935314.30 meters

Table 4. Ground control points used during LiDAR data acquisition

Date Surveyed	Flight Number	Mission Name	Ground Control Points
May 27,2014	1517P	1RXE147A	MSE-19 & MSE-3241
June 7, 2014	1561P	1RXE158A	MSE-19 & MSE-3241
June 16, 2014	1597P	1BLKRXE167A	MSE-19 & MSE-3241

2.3 Flight Missions

Three (3) missions were conducted to complete the LiDAR data acquisition in Cabulig Floodplain, for a total of twelve hours and four minutes (12+04) of flying time for RP-C9022. All missions were acquired using the Pegasus LiDAR system. Table 5 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 6 presents the actual parameters used during the LiDAR data acquisition.

Table 5. Flight missions for LiDAR data acquisition in Cabulig Floodplain

Date Surveyed	Flight Number	Flight Plan Area (km^2)	Surveyed Area (km^2)	Area Surveyed within the Floodplain (km^2)	Area Surveyed outside the Floodplain (km^2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
May 27, 2014	1517P 147A	256.68	164.99	10.06	154.93	NA	4	23
June 7, 2014	1561P 158A	161.42	193.69	4.25	189.44	NA	3	41
TOTAL		674.78	524.38	15.42	508.96	NA	12	04

Table 6. Details of the recovered NAMRIA horizontal control point ZGS-16 used as base station for the LiDAR data acquisition

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
1517P	900	30	50	200	30	130	5
1561P	1000	30	50	200	30	130	5
1597P	800	30	50	200	30	130	5

2.4 Survey Coverage

Cabulig Floodplain is located in the provinces of Misamis Oriental with majority of the floodplain situated within the municipality of Jasaan. The municipality of Jasaan is fully covered by the survey. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 7. The actual coverage of the LiDAR acquisition for Cabulig Floodplain is presented in Figure 6. The flight status reports are found in Annex 7.

Table 7. List of municipalities and cities surveyed during Cabulig Floodplain LiDAR survey

Province	Municipality/City	Area of Municipality/City (km^2)	Total Area Surveyed (km^2)	Percentage of Area Surveyed
Misamis Oriental	Jasaan	68.33	68.33	100 %
	Villanueva	46.05	38.53	84 %
	Tagoloan	55.72	15.29	28 %
	Cagayan de Oro City	440.17	108.83	25 %
	Balingasag	125.59	22.38	18 %
	Claveria	768.95	44.47	6 %
Bukidnon	Manolo Fortich	350.15	59.80	17 %
	Libona	282.23	26.72	10 %
	Malitbog	359.59	27.29	8 %
TOTAL		2496.78	411.64	33%

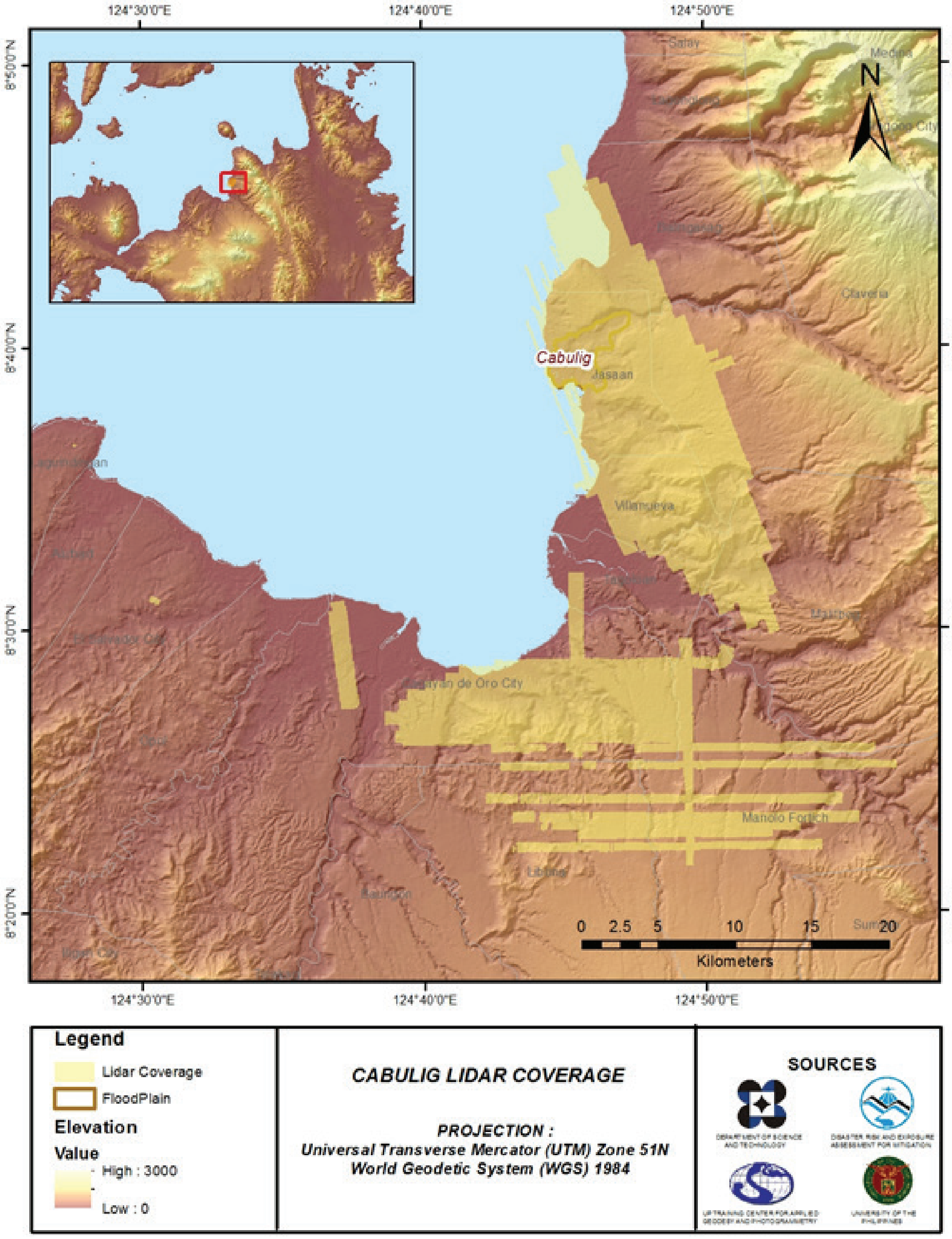


Figure 6. Actual LiDAR survey coverage for Cabulig Floodplain

CHAPTER 3: LIDAR DATA PROCESSING OF THE CABULIG FLOODPLAIN

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

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

3.1 Overview of the LiDAR Data Pre-Processing

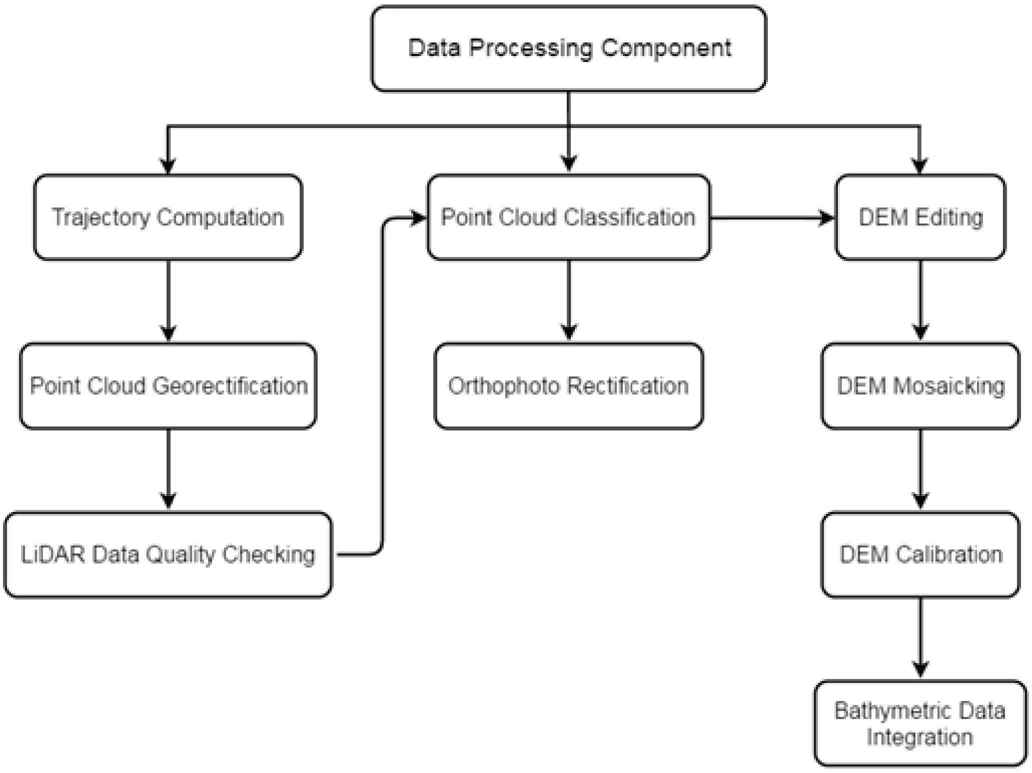


Figure 7. Schematic diagram for Data Pre-Processing Component

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

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

These processes are summarized in the flowchart shown in Figure 7.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Cabulig Floodplain can be found in Annex 5. All missions flown during the first and second survey conducted on May and June 2014 respectively used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) and Pegasus system over Jasaan, Misamis Oriental. The Data Acquisition Component (DAC) transferred a total of 71 Gigabytes of Range data, 659 Megabytes of POS data, and 25.32 Megabytes of GPS base station data to the data server on May 22, 2014 for the first survey and June 28, 2014 for the second survey. The Data Pre-Processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Cabulig was fully transferred on July 28, 2014 as indicated on the data transfer sheets for Cabulig Floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 1561P, one of the Cabulig flights, which is the North, East, and Down position RMSE values are shown in Figure 8. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on June 7, 2014 00:00AM. The y-axis is the RMSE value for that particular position.

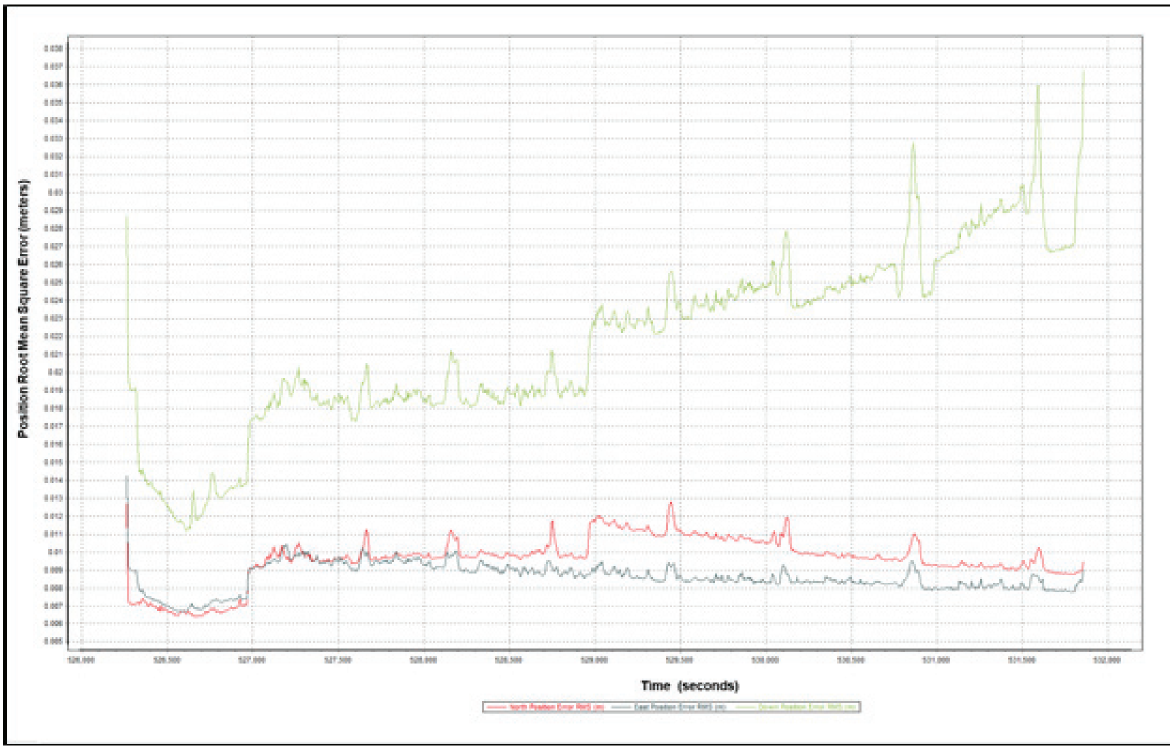


Figure 8. Smoothed Performance Metrics of Cabulig Flight 1561P.

The time of flight was from 526000 seconds to 532000 seconds, which corresponds to morning of June 7, 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 corresponds to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 8 shows that the North position RMSE peaks at 1.30 centimeters, the East position RMSE peaks at 1.10 centimeters, and the Down position RMSE peaks at 3.70 centimeters, which are within the prescribed accuracies described in the methodology.

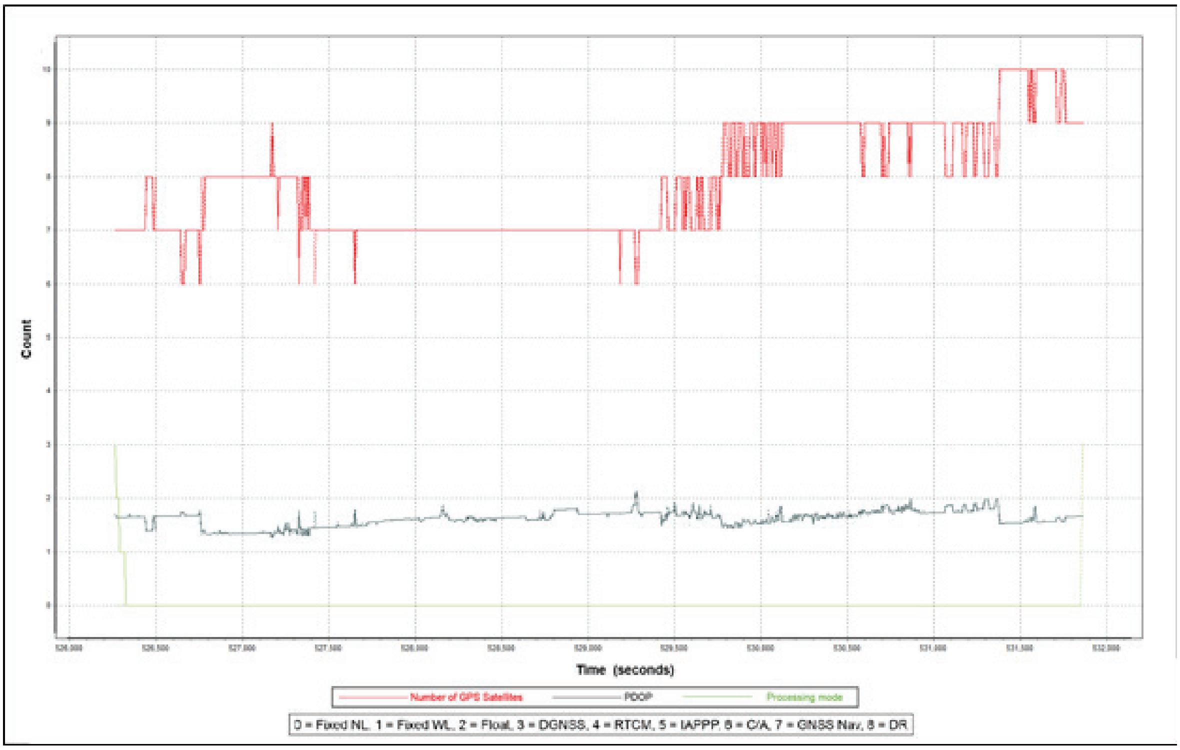


Figure 9. Solution Status Parameters of Cabulig Flight 1561P

The Solution Status parameters of flight 1561P, one of the Cabulig flights, which include the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 9. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Majority of the time, the number of satellites tracked was between 6 and 10. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode stayed at the value of 0 for majority of the survey with some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Cabulig flights is shown in Figure 10.

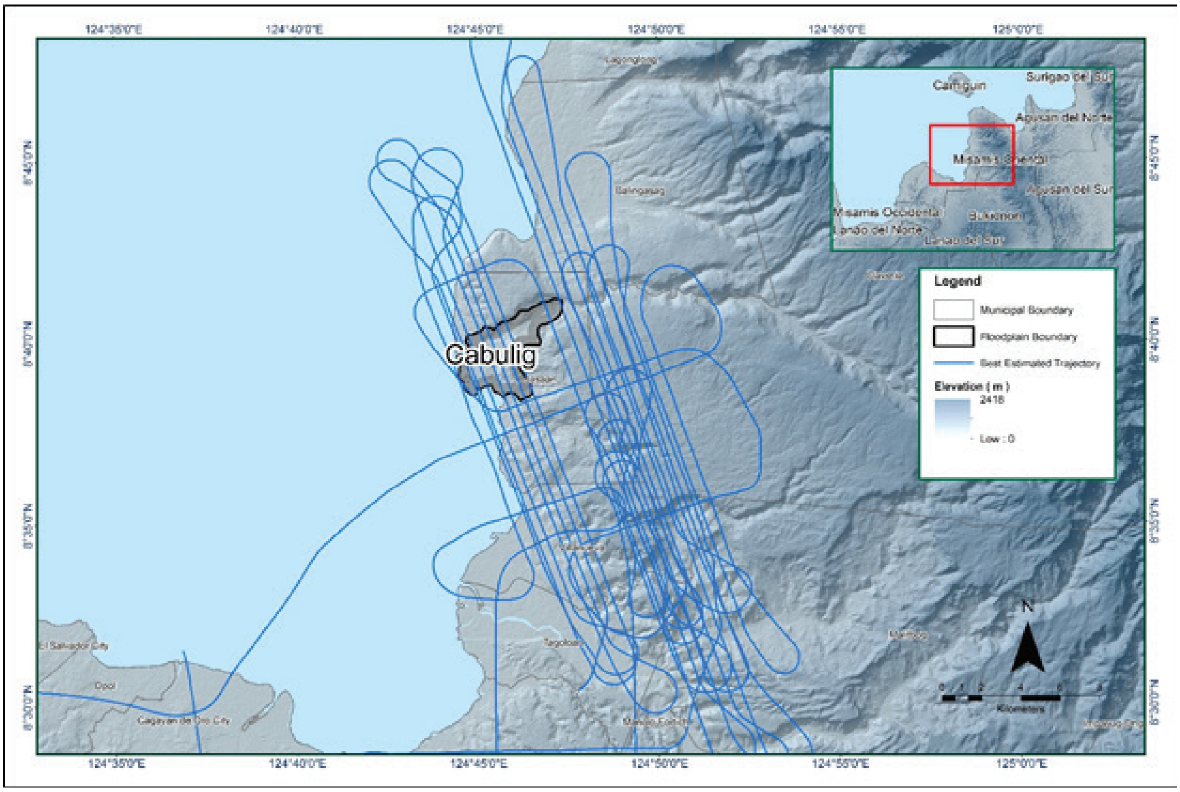


Figure 10. Best estimated trajectory of the LiDAR missions conducted over the Cabulig Floodplain

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 45 flight lines, with each flight line containing two (2) channels, since the Pegasus system contains two (2) channels. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Cabulig Floodplain are given in Table 8.

Table 8. Self-calibration results values for Cabulig flights

Parameter	Value
Boresight Correction stdev (<0.001 degrees)	0.000179
IMU Attitude Correction Roll and Pitch Corrections stdev (<0.001 degrees)	0.001266
GPS Position Z-correction stdev (<0.01 meters)	0.0058

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

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Cabulig Floodplain is shown in Figure 11. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

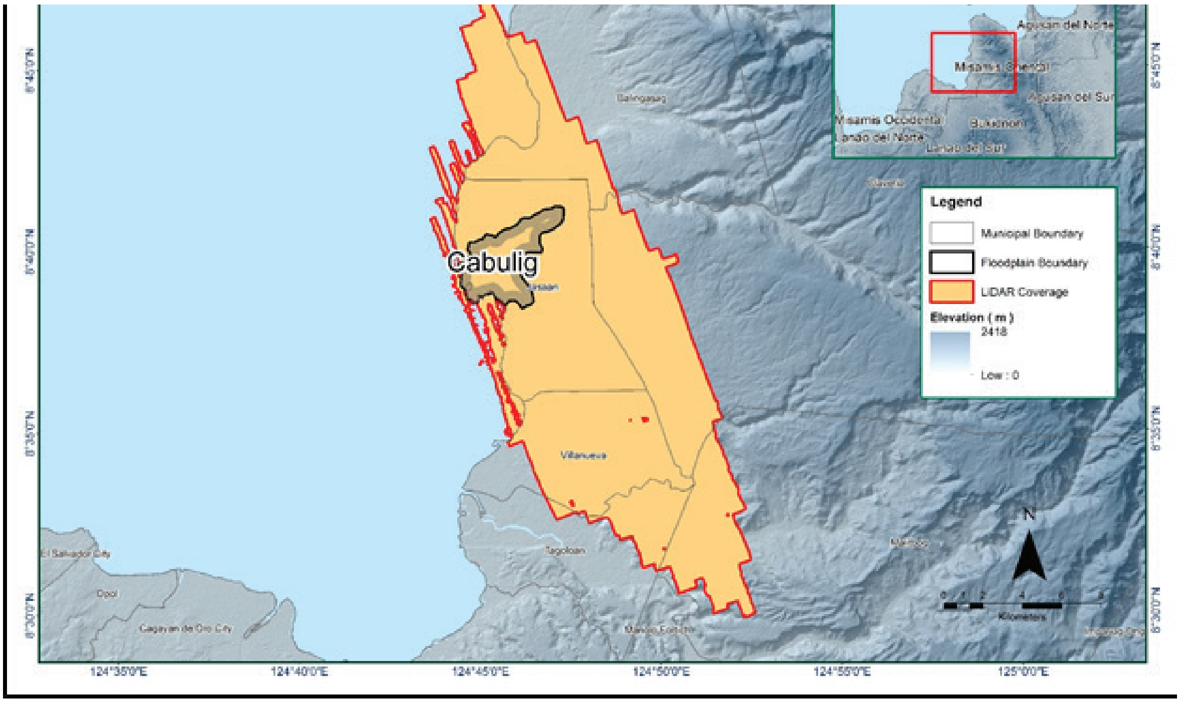


Figure 11. Boundary of the processed LiDAR data over Cabulig Floodplain

The total area covered by the Cabulig missions is 303.10 km^2 that is comprised of three (3) flight acquisitions grouped and merged into two (2) blocks as shown in Table 9.

Table 9. of LiDAR blocks for Cabulig Floodplain

LiDAR Blocks	Flight Numbers	Area (sq km)
NorthernMindanao_RX_D	1517P	241.20
	1561P	
	1597P	
NorthernMindanao_RX_D_additional	1597P	61.90
TOTAL		303.10

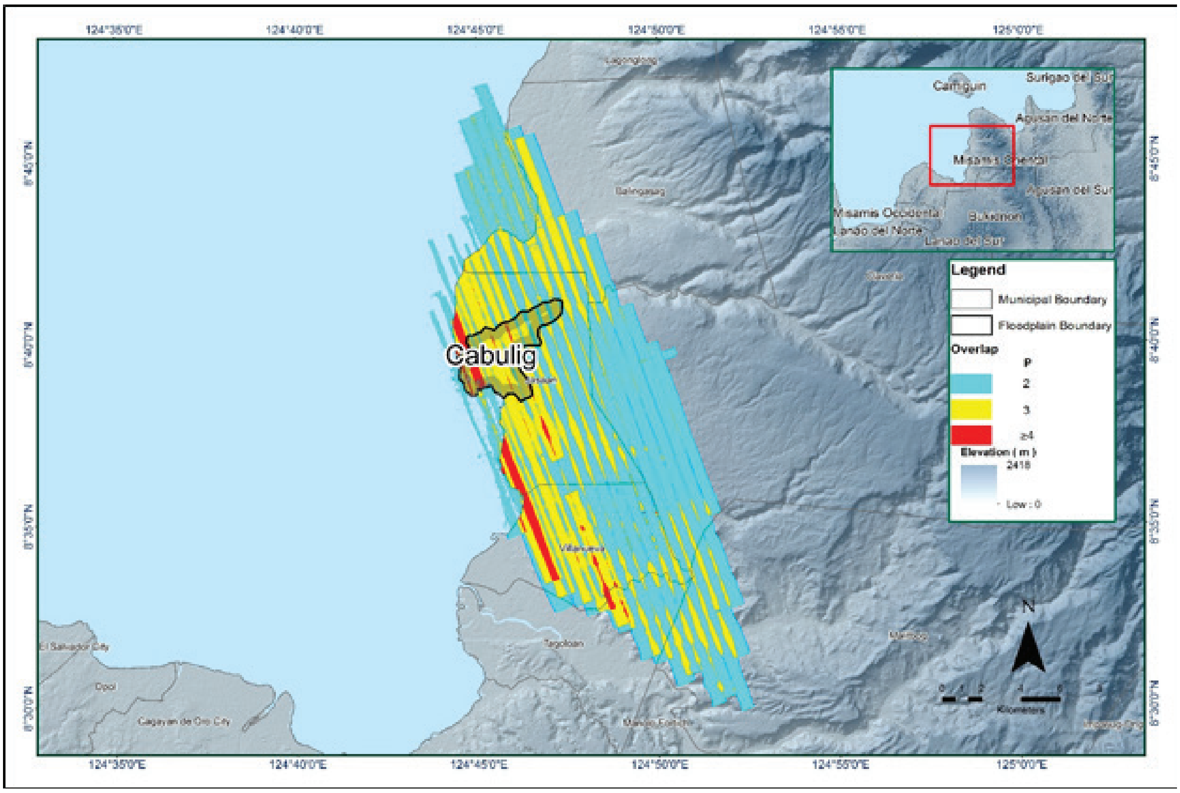


Figure 12. Image of data overlap for Cabulig Floodplain

The overlap statistics per block for the Cabulig Floodplain can be found in Annex 8. One pixel corresponds to 25.0 m^2 on the ground. For this area, the percent overlap computed between flight lines is 33.38%, which passed the 25% requirement.

The density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion, is shown in Figure 13. It was determined that all LiDAR data for Cabulig Floodplain satisfy the point density requirement, and the average density for the entire survey area is 4.28 points per square meter.

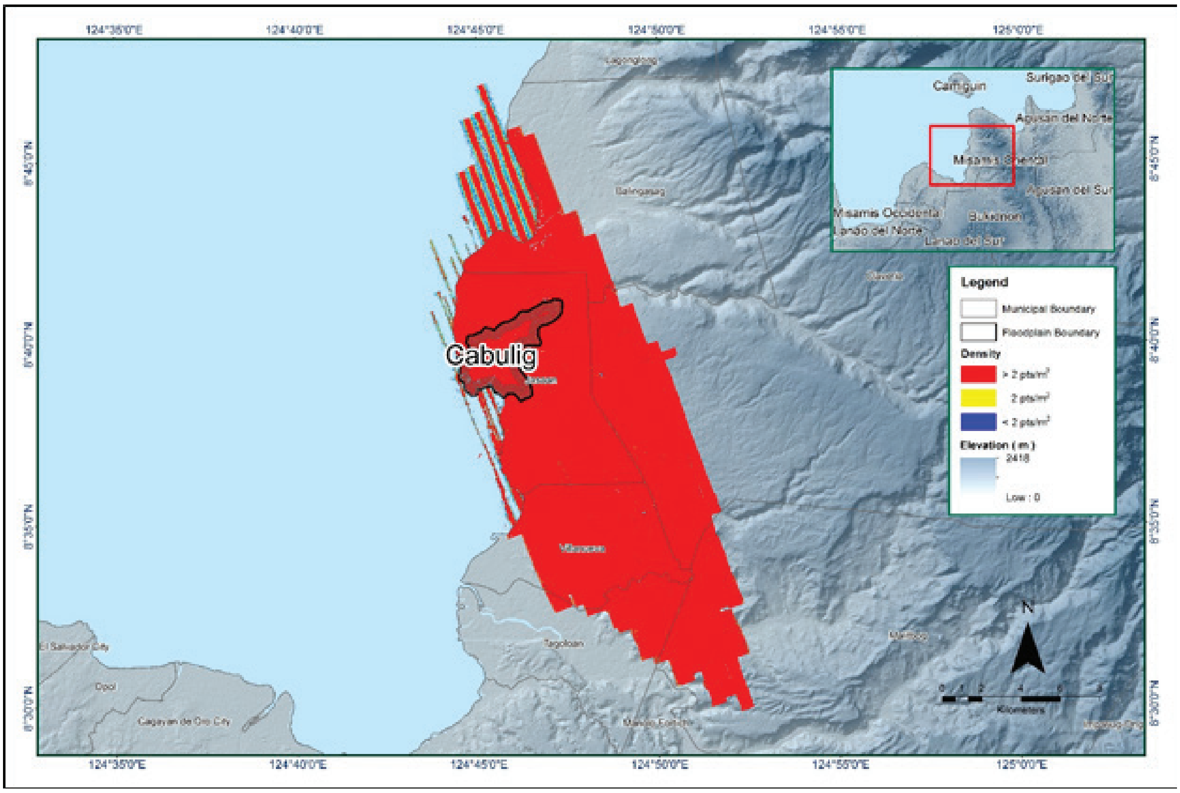


Figure 13. Density map of merged LiDAR data for Cabulig Floodplain

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

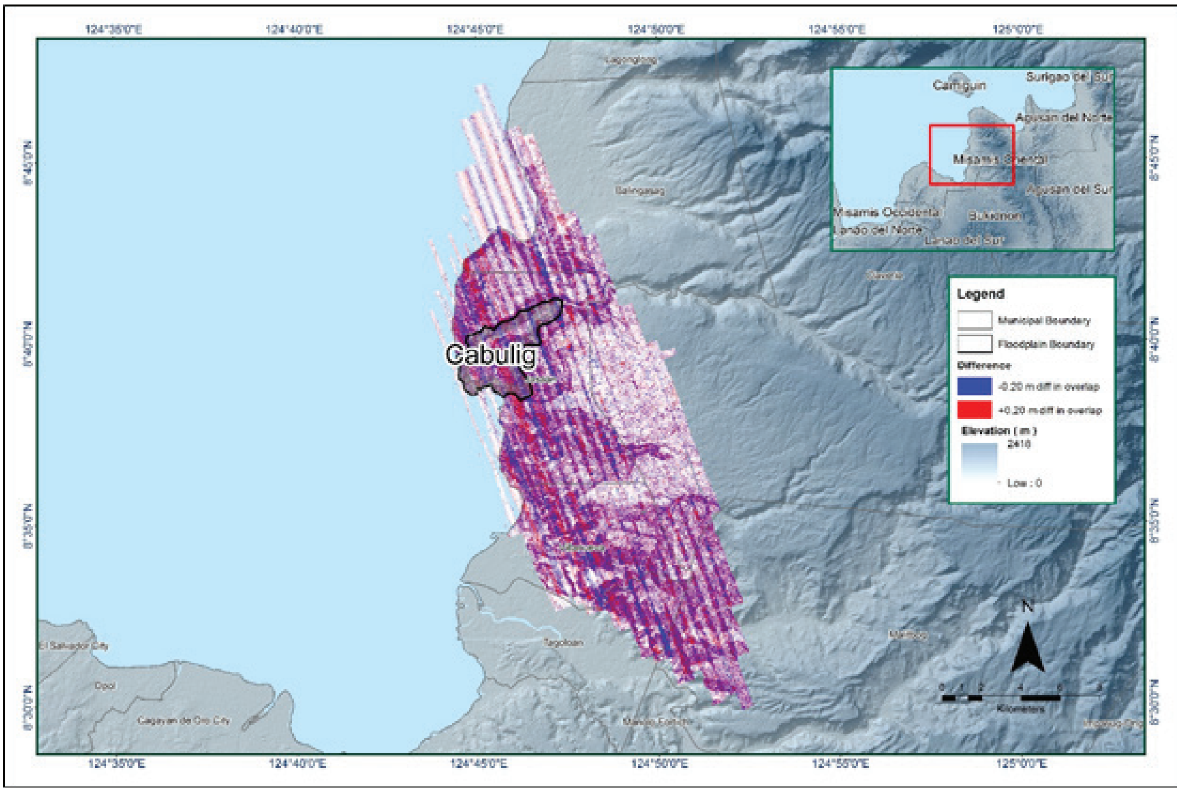


Figure 14. Elevation difference map between flight lines for Cabulig Floodplain

A screen capture of the processed LAS data from a Cabulig flight 1561P loaded in QT Modeler is shown in Figure 15. The upper left image shows the elevations of the points from two (2) overlapping flight strips traversed by the profile, illustrated by a dashed yellow line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

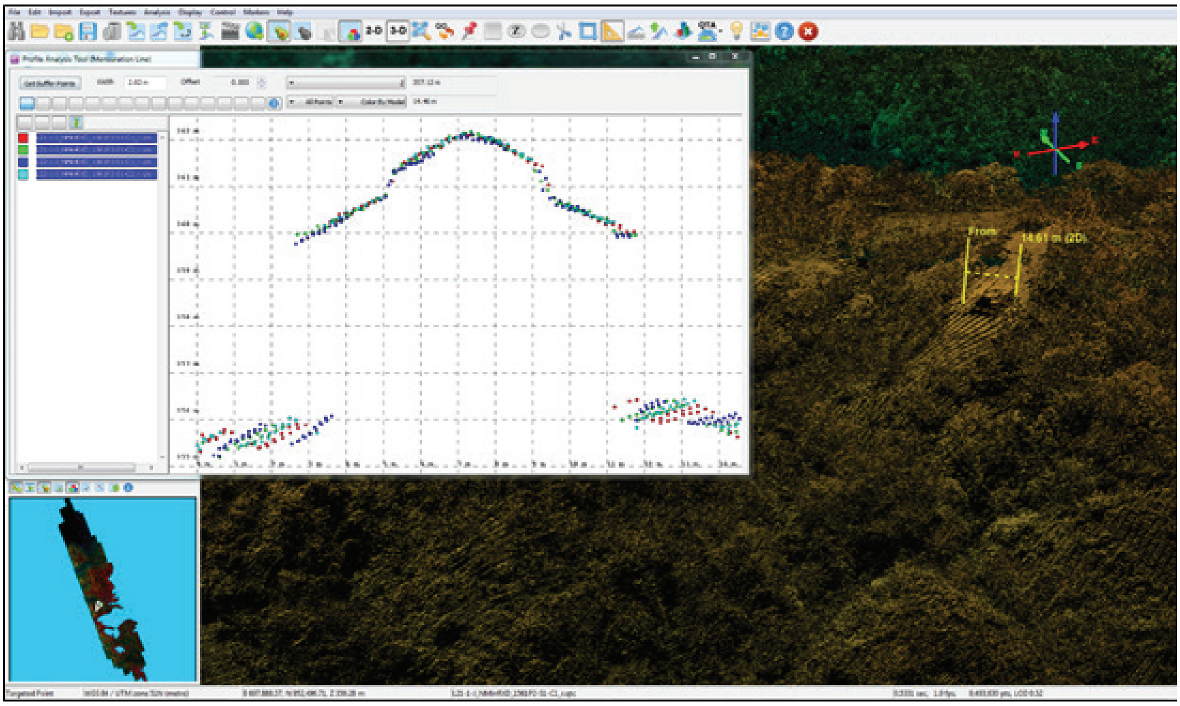


Figure 15. Quality checking for a Cabulig flight 1561P using the Profile Tool of QT Modeler

3.6 LiDAR Point Cloud Classification and Rasterization

Table 10. Cabulig classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	242,066,972
Low Vegetation	274,792,502
Medium Vegetation	473,042,667
High Vegetation	414,982,870
Building	18,900,076

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Cabulig Floodplain is shown in Figure 16. A total of 399 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 10. The point cloud has a maximum and minimum height of 747.65 meters and 66.39 meters, respectively.

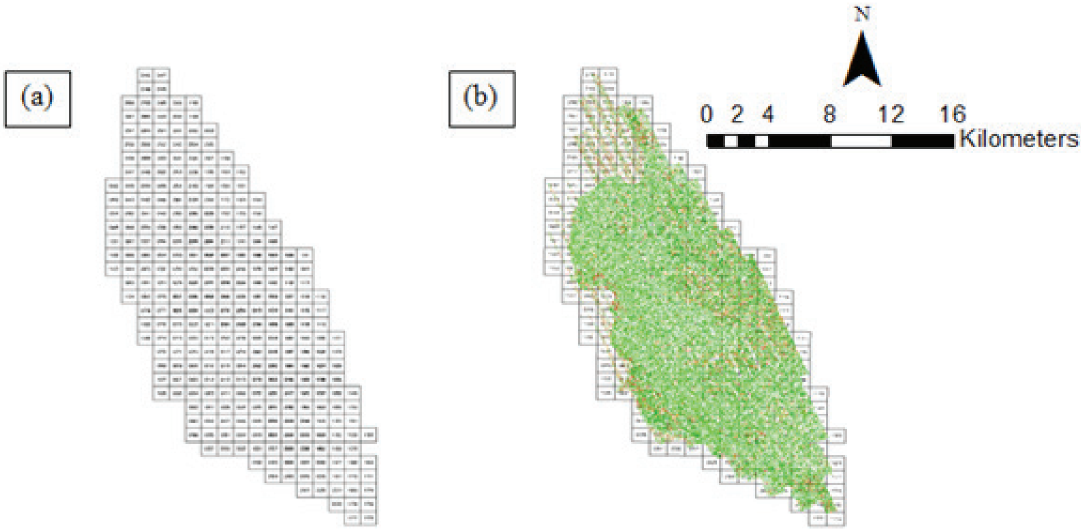


Figure 16. Tiles for Cabulig Floodplain (a) and classification results (b) in TerraScan

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

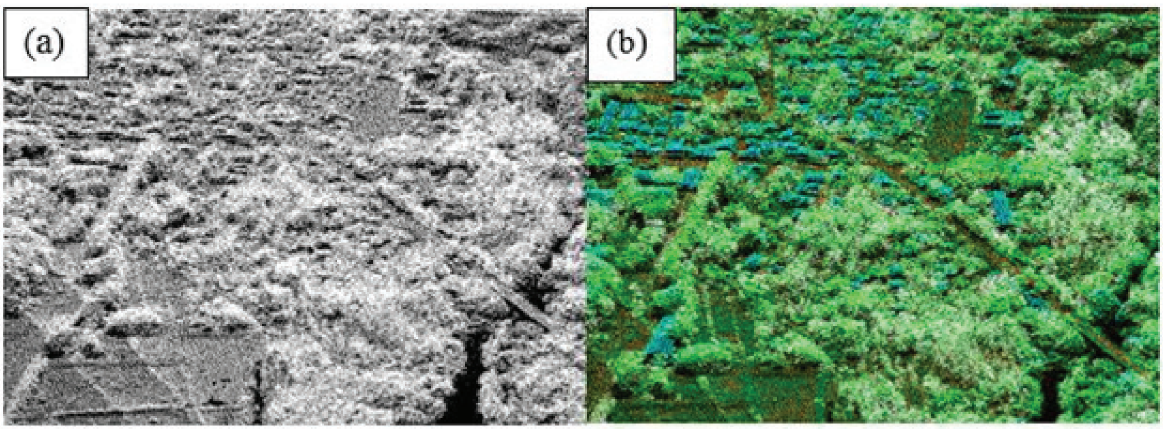


Figure 17. Point cloud before (a) and after (b) classification

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

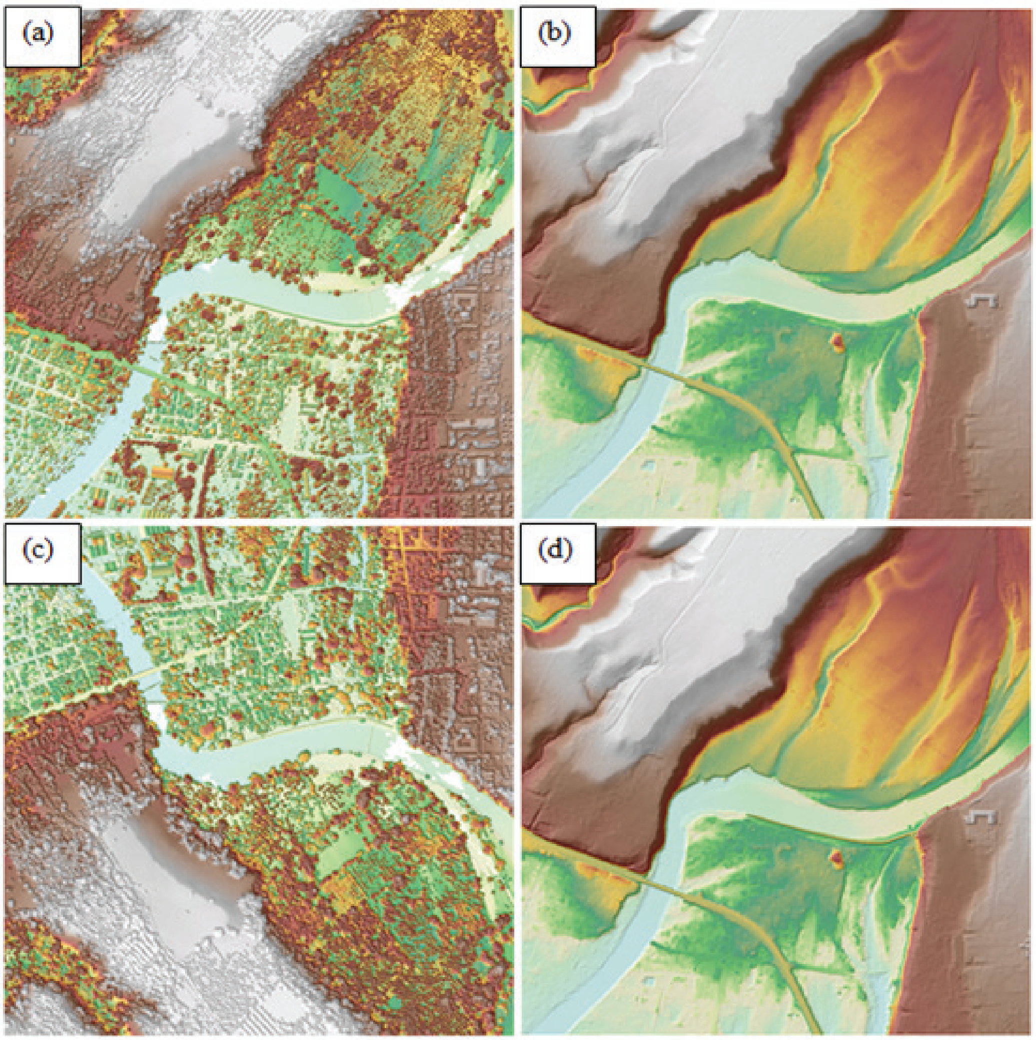


Figure 18. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Cabulig Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

There are no available orthophotographs for Cabulig Floodplain.

3.8 DEM Editing and Hydro-Correction

Two (2) mission blocks were processed for Cabulig Floodplain. These blocks are composed of NorthernMindanao_RX_D block and a supplementary block NorthernMindanao_RX_D_additional with a total area of 303.10 km^2. Table 11 shows the name and corresponding area of each block in square kilometers.

Table 11. LiDAR blocks with its corresponding area

LiDAR Blocks	Area (km^2)
NorthernMindanao_RX_D	241.20
NorthernMindanao_RX_D_additional	61.90
TOTAL	303.10 km^2

Portions of DTM before and after manual editing are shown in Figure 19. The bridge (Figure 19a) was considered to be an impedance to the flow of water along the river and had to be removed (Figure 19b) in order to hydrologically correct the river. This was done through interpolation process wherein a specific polygon determines the upstream and downstream elevation values to generate an interpolated portion of a river and eventually remove the bridge footprint. On the other hand, object retrieval was done in areas such as paddies (Figure 19c) which have been removed during classification process and have to be retrieved to complete the surface (Figure 19d). Portion of hill beside a road network has also (Figure 19e) been misclassified and was needed to be retrieved to retain the correct terrain (Figure 19f). Object retrieval used the secondary DTM (t_layer) to fill in these areas.

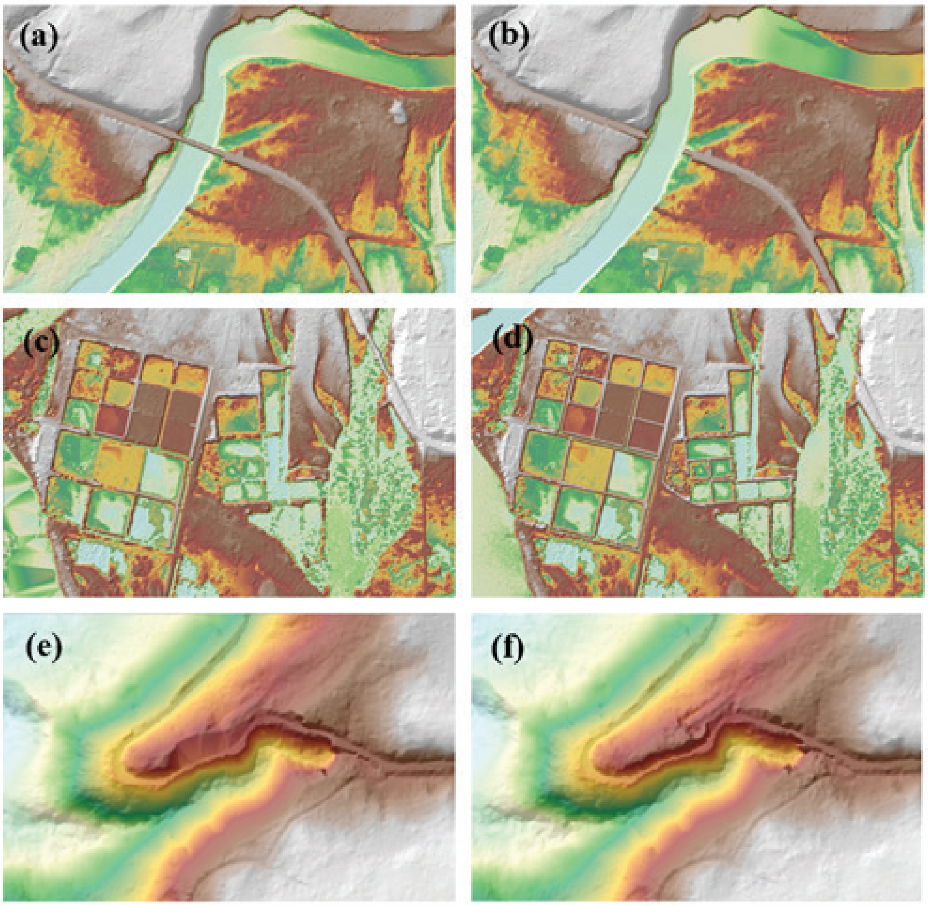


Figure 19. Portions in the DTM of Cabulig Floodplain – Cabulig bridge before (a) and after (b) interpolation; a paddy field before (c) and after (d) data retrieval; and a misclassified hill before (e) and after (f) data retrieval

3.9 Mosaicking of Blocks

The Cabulig Floodplain lies within the NorthernMindanao_RX_D block. Such block was being calibrated when mosaicked to the existing calibrated DEM. Table 12 shows the area of each LiDAR block and the shift values applied to the Cabulig DEM during mosaicking. Furthermore, the mean difference of the calibrated NorthernMindanao_RX_C over the calibrated NorthernMindanao_RX_D resulted in .002 meters.

Mosaicked LiDAR DTM for Cabulig Floodplain is shown in Figure 20. It can be seen that the entire Cabulig Floodplain is 100% covered by LiDAR data.

Table 12. Shift values of each LiDAR Block of Cabulig Floodplain

Mission Blocks	Shift Values (meters)		
	x	y	z
NorthernMindanao_RX_D	1.00	0.00	-0.12
NorthernMindanao_RX_D_additional	0.00	0.00	1.00

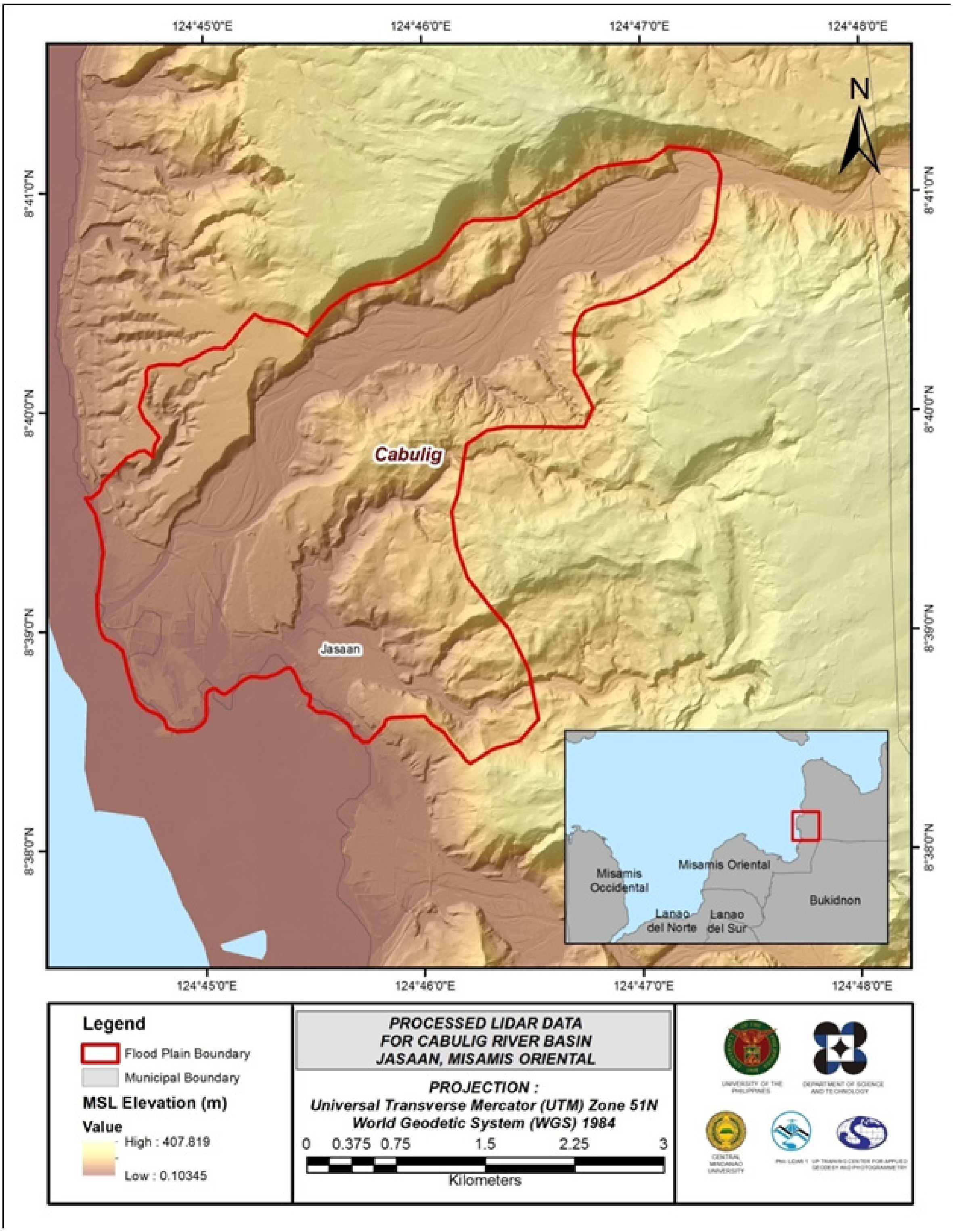


Figure 20. Map of processed LiDAR data for Cabulig Floodplain

3.10 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Cabulig to collect points with which the LiDAR dataset was validated is shown in Figure 21. A total of 1,755 survey points were gathered for the Cabulig Floodplain. However, the point dataset was not used for the calibration of the LiDAR data for Cabulig because during the mosaicking process, each LiDAR block was referred to the calibrated Gingoog DEM. Therefore, the mosaicked DEM of Cabulig can already be considered as a calibrated DEM.

A good correlation between the uncalibrated Gingoog LiDAR DTM and ground survey elevation values is shown in Figure 22. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration points is 0.64 meters with a standard deviation of 0.10 meters. Calibration of Gingoog LiDAR data was done by subtracting the height difference value, 0.64 meters, to Gingoog mosaicked LiDAR data. Table 13 shows the statistical values of the compared elevation values between Gingoog LiDAR data and calibration data. These values were also applicable to the Cabulig DEM.

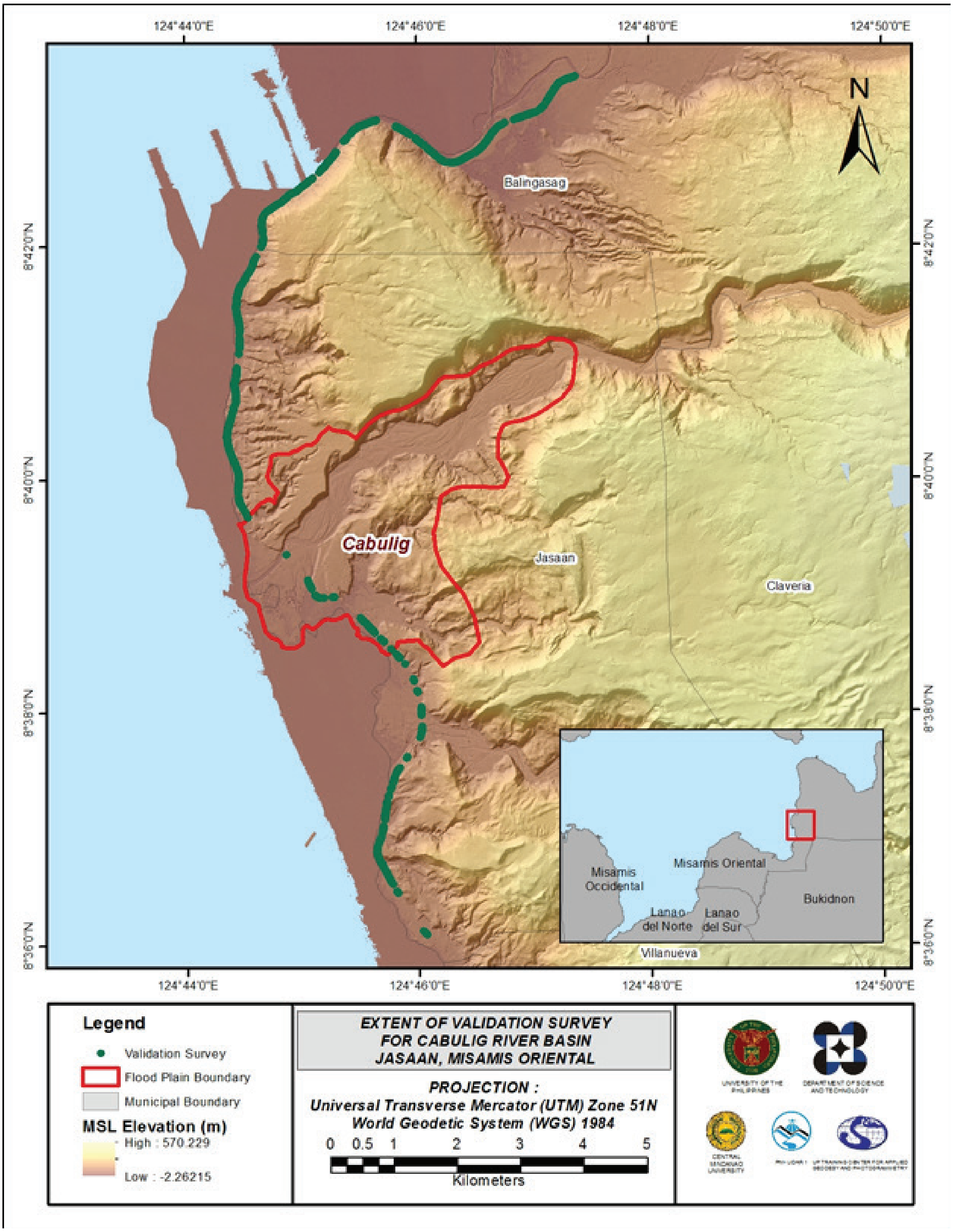


Figure 21. Map of Cabulig Floodplain with validation survey points in green

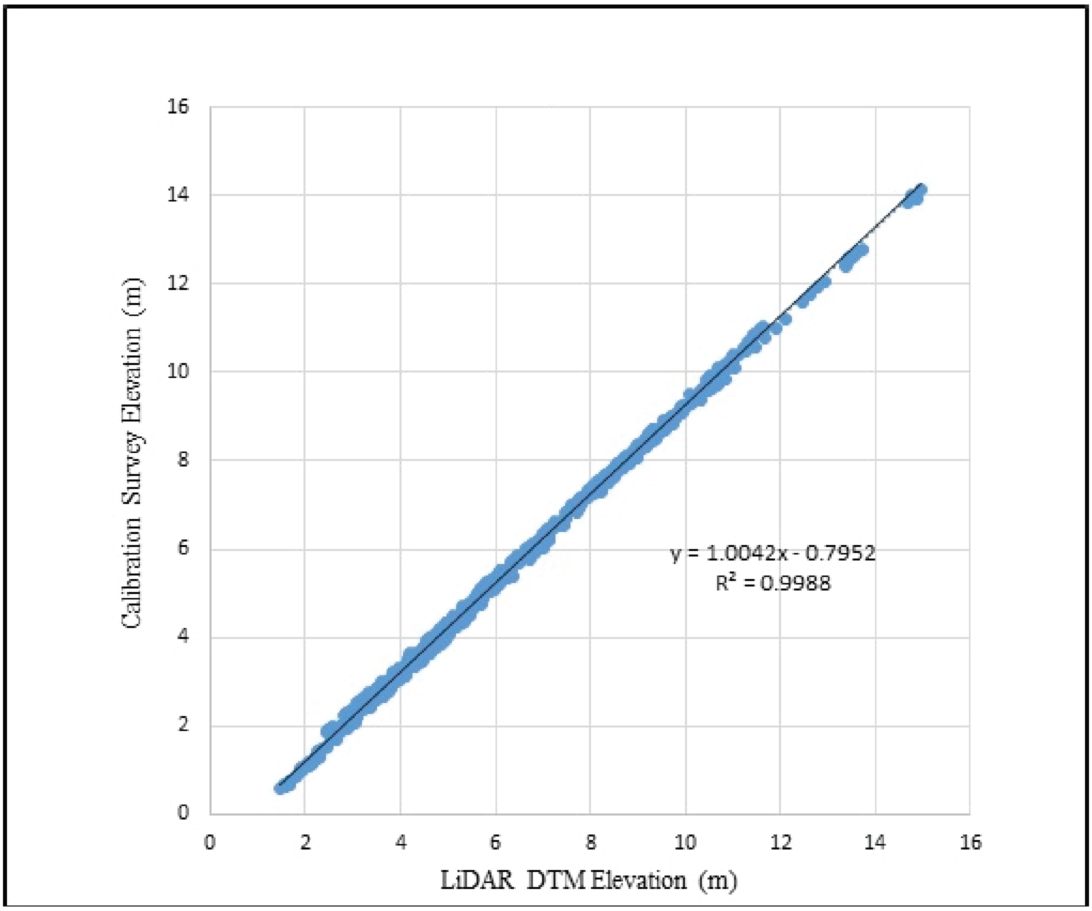


Figure 22. Correlation plot between calibration survey points and LiDAR data

Table 13. Calibration statistical measures

Calibration Statistical Measures	Value (in m)
Height Difference	0.64
Standard Deviation	0.10
Average	-0.64
Minimum	-0.85
Maximum	-0.42

All survey points of the Cabulig Floodplain were used for the validation of calibrated Cabulig DTM. A good correlation between the calibrated mosaicked LiDAR elevation values and the ground survey elevation, which reflects the quality of the LiDAR DTM, is shown in Figure 23. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.13 meters with a standard deviation of 0.13 meters, as shown in Table 14.
`

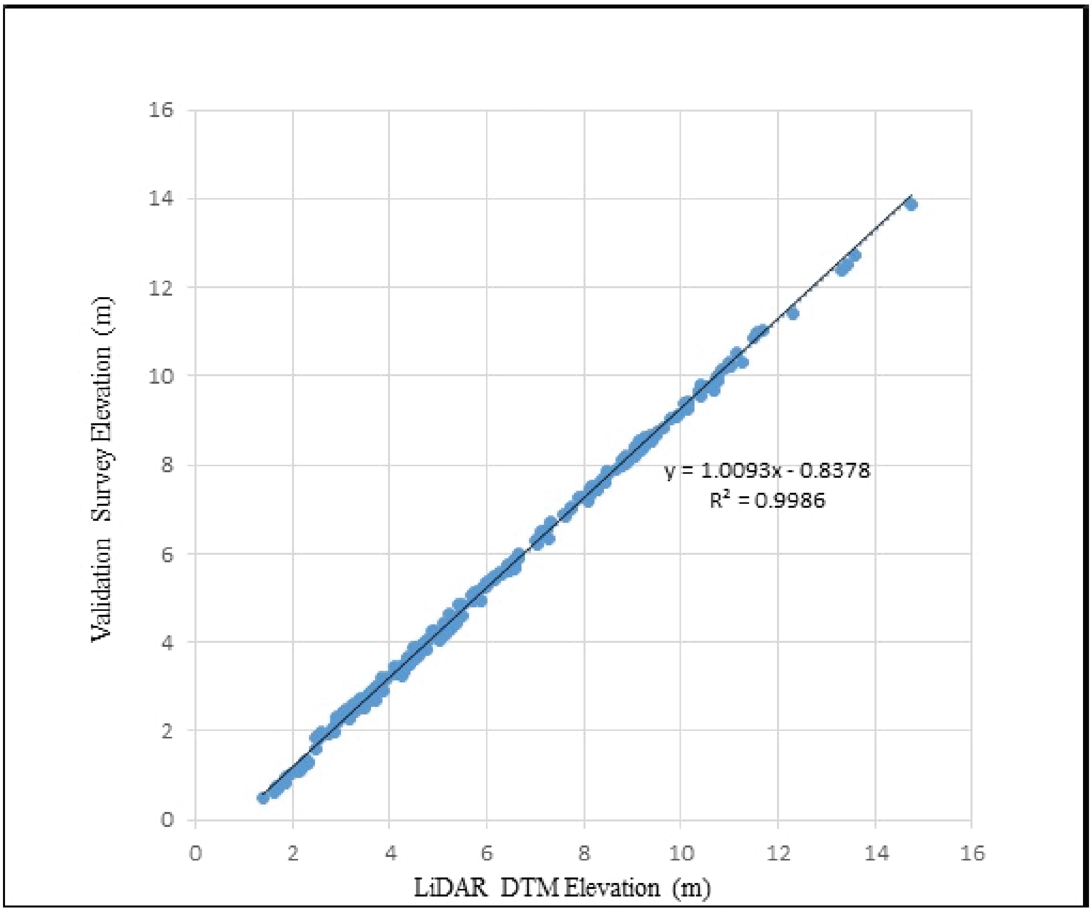


Figure 23. Correlation plot between validation survey points and LiDAR data

Table 14. Validation statistical measures

Validation Statistical Measures	Value (meters)
RMSE	0.13
Standard Deviation	0.13
Average	-0.02
Minimum	-0.42
Maximum	0.47

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, only centerline data was available for Cabulig with 295 bathymetric survey points. The resulting raster surface produced was done by Inverse Distance Weighted (IDW) interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface was represented by the computed RMSE value of 0.24 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Cabulig integrated with the processed LiDAR DEM is shown in Figure 24.

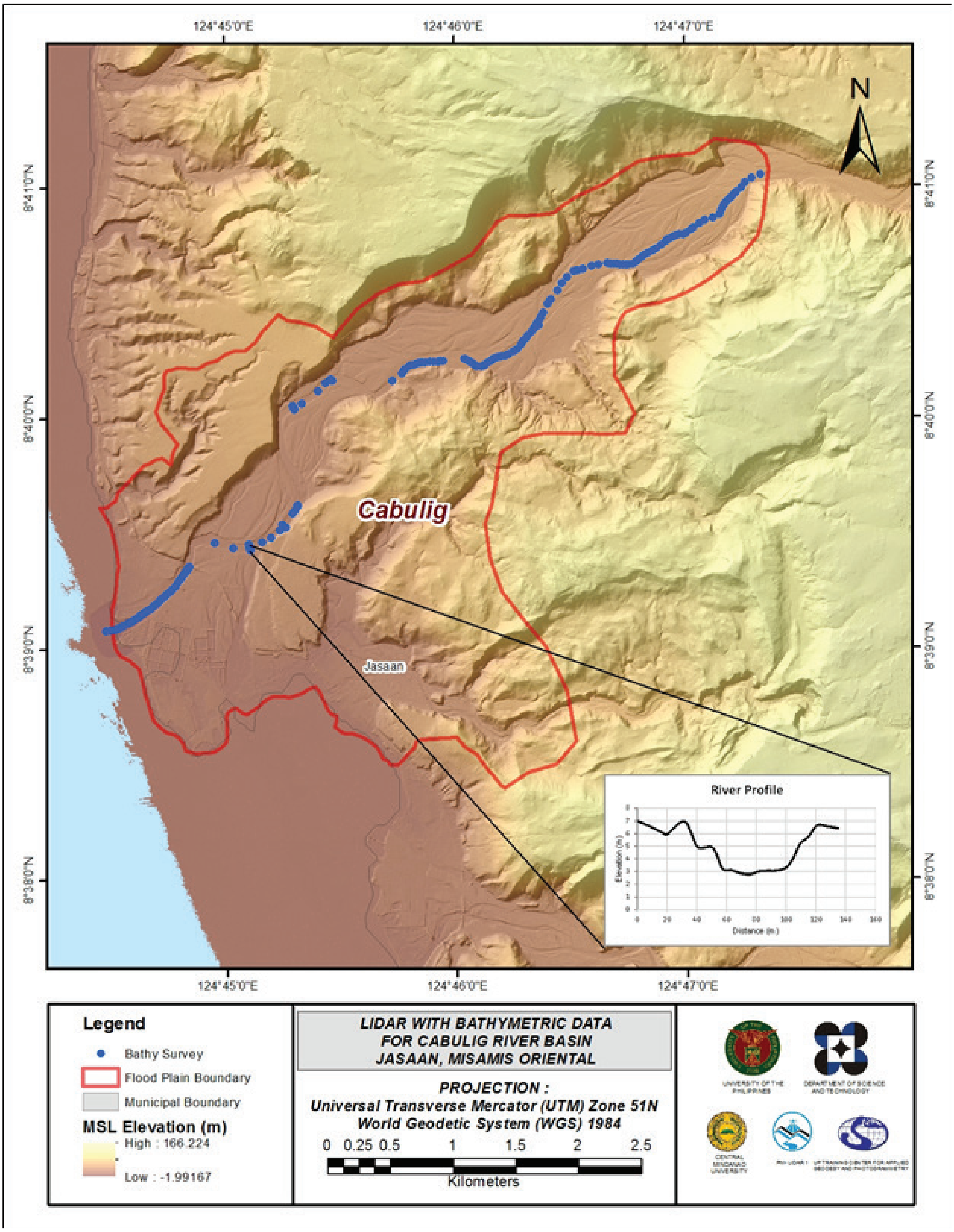


Figure 24. Map of Cabulig Floodplain with bathymetric survey points shown in blue

3.12 Feature Extraction

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

3.12.1 Quality Checking of Digitized Features' Boundary

Cabulig Floodplain, including its 200 m buffer, has a total area of 17.31 km^2. For this area, a total of 5.0 km^2, corresponding to a total of 1395 building features, is considered for QC. Figure 25 shows the QC blocks for Cabulig Floodplain.

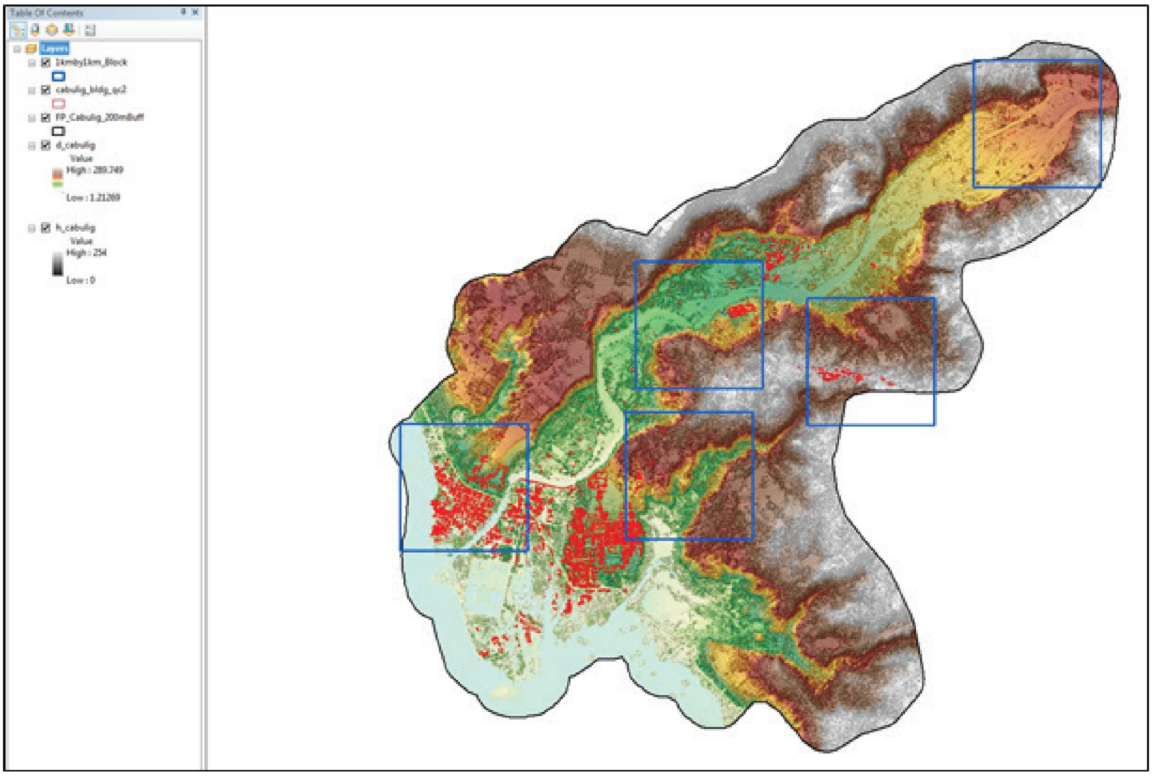


Figure 25. Blocks (in blue) of Cabulig building features subjected to QC

Table 15. . Quality checking ratings for Cabulig building features

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Cabulig	99.93	100.00	99.86	PASSED

3.12.2 Height Extraction

Height extraction was done for 3,484 building features in Cabulig Floodplain. Of these building features, none was filtered out after height extraction, resulting in 3,484 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 14.68 m.

3.12.3 Feature Attribution

Field data collection for the attribution process was done through Geotagging (point to a specific feature and shoot method) using a handheld GPS with a built-in camera. The x, y, z, and the viewing direction of the GPS in 0-359 degrees during the photo capture were the essential information in the process. Using Arcmap's tool "Geotagged Photos to Points," the symbology of the imported point shapefile was set as "Airfield" and the viewing angle was set as "Direction." The "Path" is automatically created in the points' attribute table in which the photo's directory is linked every after the "Identify" button is clicked to a specific point.

Table 16 summarizes the number of building features per type. From the total features identified, approximately 3,211 of it are residential establishments while the commercial establishments are the most common in non-residential features. On the other hand, Table 17 shows the total length of each road type. Table 18 shows the number of major waters extracted.

Table 16. Building features extracted for Cabulig Floodplain

Facility Type	No. of Features
residential	3,211
school	62
market	13
agricultural/agro-Industrial Facilities	0
medical institutions	6
barangay hall	4
military institution	0
sports center/gymnasium/covered court	7
telecommunication facilities	0
transport terminal	0
warehouse	0
power plant/substation	0
NGO/CSO Offices	0
police station	1
water supply/sewerage	0
religious institutions	12
bank	1
factory	0
gas station	2
fire tation	1
other government offices	9
other commercial establishments	154
municipal hall	1
TOTAL	3,484

Table 17. Total length of extracted roads for Cabulig Floodplain

Floodplain	Road Network Length (km)				Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others
Cabulig	16.42	4.34	3.55	0	24.32

Table 18. Number of extracted water bodies for Cabulig Floodplain

Floodplain	Water Body Type					Total
	Rivers/ Streams	Lakes/ Ponds	Sea	Dam	Fish Pen	
Cabulig	3	0	0	0	0	3

A total of three (3) main bridges and a spillway upstream that are part of the river networks were also extracted for the floodplain.

3.12.4 Final Quality Checking of Extracted Features

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

Figure 26 shows the Digital Surface Model (DSM) of Cabulig Floodplain overlaid with its ground features.

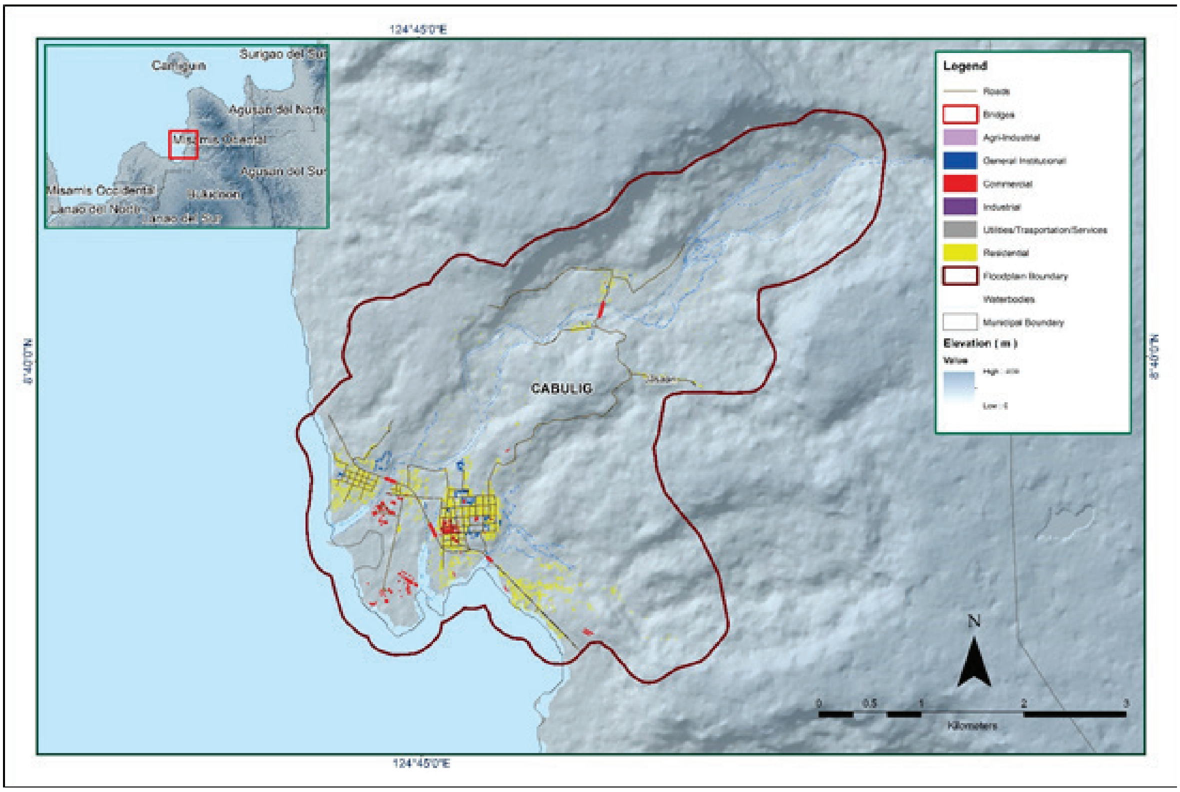


Figure 26. Extracted features for Cabulig Floodplain

CHAPTER 4: LIDAR VALIDATION SURVEY AND MEASUREMENTS OF THE CABULIG RIVER BASIN

Engr. Ma. Rosario Concepcion O. Ang, Engr. John Louie D. Fabila, Engr. Sarah Jane D. Samalburo , Engr. Gladys Mae Apat , Alex John B. Escobido , Engr. Ma. Ailyn L. Olanda, Engr. Justine Y. Francisco, Engr. Vincent Louise DL. Azucena , Engr. Jommer M. Medina, Esmael L. Guardian

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

4.1 Summary of Activities

A ground survey in Cabulig River was conducted by the Data Validation and Bathymetry Component (DVBC) from September 25 to October 09, 2014. The scope of work included a control survey for the establishment of a control point at the approach of the bridge, cross-section and bridge as-built survey, and water level marking of Cabulig Bridge with coordinates Lat 8°39'21.63559"N and Long 124°44'50.14141"E, LiDAR ground validation with an estimated length of 30 km, and manual bathymetric survey of the river starting from the upstream at Brgy. Upper Jasaan down to Brgy. Lower Jasaan with an estimated distance of 7.71 km.

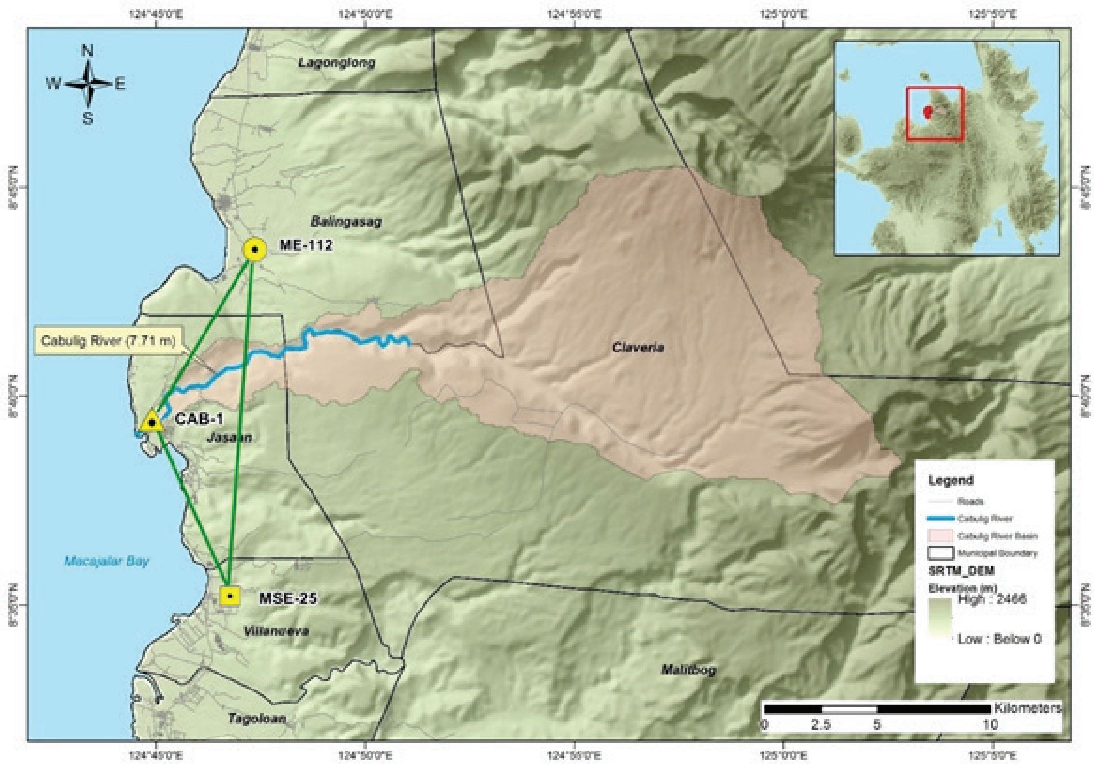


Figure 27. Extent of the bathymetric survey (in blue) and the LiDAR data validation survey (in red) in Cabulig River

4.2 Control Survey

The GNSS network used for Cabulig River Basin is composed of a single loop established on September 29, 2014 occupying the reference points MSE-25, a second order GCP in Brgy. Poblacion 1, Municipality of Villanueva, Misamis Oriental, fixed from previous Phil-LiDAR survey in Misamis Occidental with elevation derived from TGBM.

A control point was established along the approach of bridge, namely: CAB-1, located at Cabulig Bridge in Brgy. Bobontugan, Municipality of Jasaan, Misamis Oriental. A NAMRIA established control point namely ME-112, in Brgy. Talusan, Municipality of Balingasag, Misamis Oriental, was also occupied to use as marker.

The summary of references and control points and its location is summarized in Table 19 while the GNSS network established is illustrated in Figure 28.

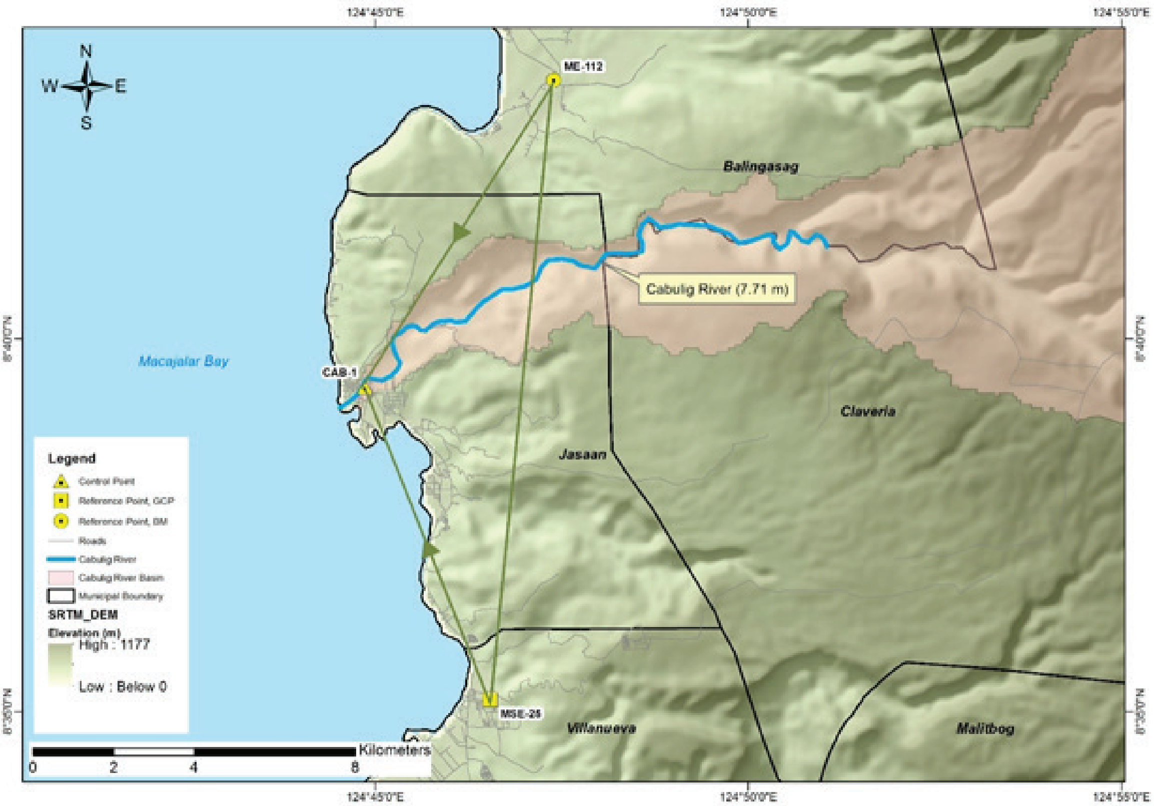


Figure 28. GNSS network of Cabulig River field survey

Table 19. List of reference and control points used in Cabulig River Basin Survey

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoid	Elevation in MSL (m)	Date Established
MSE-25	2nd order, GCP	8°35'09.60584"	124°46'32.43073"	76.139	6.528	2003
ME-112	1st order, BM	-	-	-	-	2007
CAB-1	UP Established	-	-	-	-	2014

Figure 29. GNSS base receiver set-up, Trimble® SPS 852 at MSE-25 in Brgy. Poblacion 1, Municipality of Villanueva, Misamis Oriental

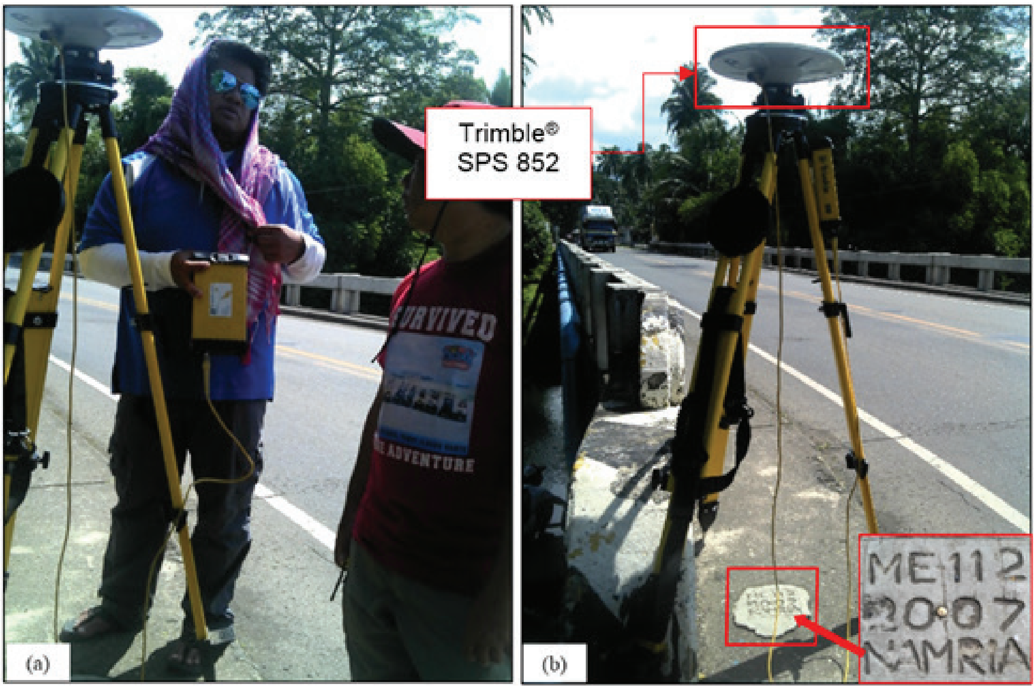


Figure 30. GNSS base receiver set-up, Trimble® SPS 852 at ME-112 at Musi-Musi Bridge in Brgy. Talusan, Municipality of Balingasag, Misamis Oriental

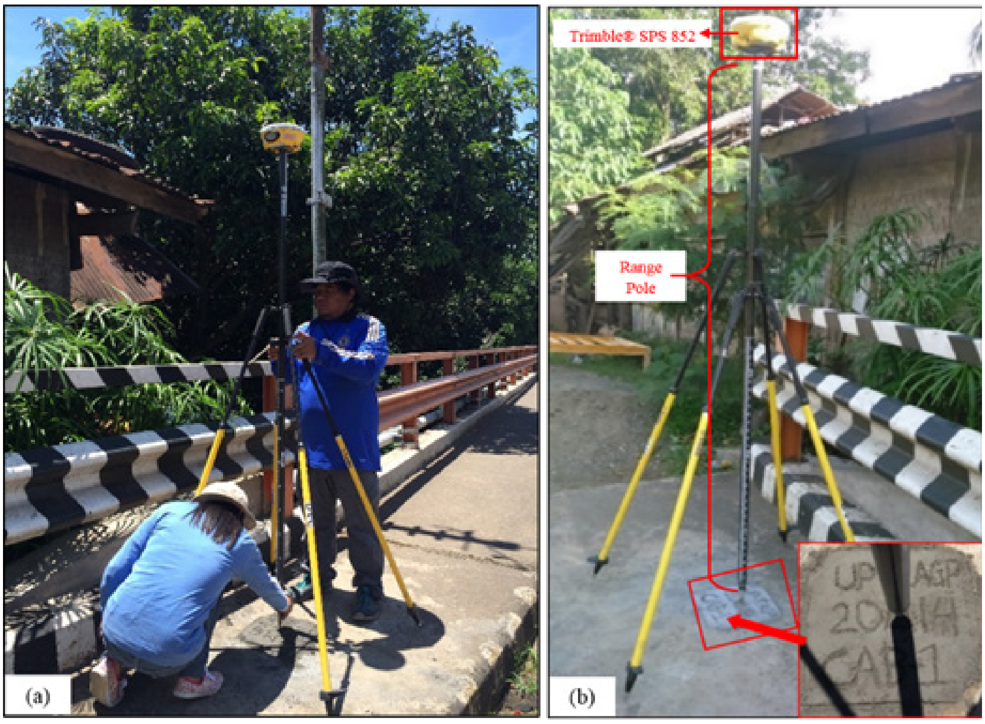


Figure 31. GNSS base occupation, Trimble® SPS 882 at CAB-1 along Iligan-Cagayan de Oro-Butuan Road at the approach of Cabulig Bridge in Brgy. Bobontugan, Municipality of Jasaan, Misamis Oriental

4.3 Baseline Processing

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

Table 20. List of reference and control points used in Cabulig River Basin Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
MSE-25 --- CAB-1	09-29-2014	Fixed	0.003	0.016	338°15'59"	8315.309	0.636
CAB-1 --- ME-112	09-29-2014	Fixed	0.007	0.030	31°26'18"	8885.787	-1.253

As shown in Table 20, a total of three (3) baselines were processed and all of them passed the required accuracy set by the project.

4.4 Network Adjustment

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

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

Where:

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

The three (3) control points, MSE-25, ME-112, and CAB-1, were occupied and observed simultaneously to form a GNSS loop. Coordinates and elevation values of MSE-25 were held fixed during the processing of the control points as presented in Table 21. Through this reference point, the coordinates and elevation of the unknown control points were computed.

Table 21. Control point constraints

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
MSE-25	Grid				Fixed
MSE-25	Global	Fixed	Fixed		
Fixed = 0.000001(Meter)					

The list of adjusted grid coordinates, i.e., Northing, Easting, Elevation, and computed standard errors of the control points in the network, is indicated in Table 22. All fixed control points have no values for grid and elevation errors.

Table 22. Adjusted grid coordinates

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
CAB-1	692303.312	0.006	957244.697	0.005	7.759	0.036	
ME-112	696903.266	0.009	964847.889	0.008	6.695	0.042	
MSE-25	695418.468	?	949534.368	?	6.528	?	LLe

The network is fixed at reference points. The list of adjusted grid coordinates of the network is shown in Table 23. Using the equation ⟦⟦√((x⟧_e)⟧^2+⟦⟦(y⟧_e)⟧^2)<20cm for horizontal and z_e<10 cm for the vertical, below is the computation for accuracy that passed the required precision:

MSE-25
Horizontal accuracy = Fixed
Vertical accuracy = Fixed

ME-112
Horizontal accuracy = $\sqrt{}$ $((0.9)^{2} + (0.8)^{2}$
= $\sqrt{}(0.81 + 0.64)$
= 1.20 cm < 20 cm
Vertical accuracy = 4.2 cm < 10 cm

CAB-1
Horizontal accuracy = $\sqrt{}$ $((0.6)^{2} + (0.5)^{2}$
= $\sqrt{}(0.36 + 0.25)$
= 0.78 cm < 20 cm
Vertical accuracy = 3.6 cm < 10 cm

Following the given formula, the horizontal and vertical accuracy results of the three occupied control points are within the required accuracy of the project.

Table 23. Adjusted grid coordinates

Point ID	Latitude	Longitude	Height	Height Error (Meter)	Constraint
CAB-1	N8°39'21.02516"	E124°44'51.71530"	76.762	0.036	
ME-112	N8°43'27.78957"	E124°47'23.33936"	75.468	0.042	
MSE-25	N8°35'09.60584"	E124°46'32.43073"	76.139	?	LLe

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 23. Based on the result of the computation, the equation was satisfied; hence, the required accuracy for the program was met.

The summary of reference and control points used is indicated in Table 24.

Table 24. Adjusted grid coordinates

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM Zone 51 N		
		Latitude	Longitude	Ellipsoid Height (m)	Northing	Easting	BM Ortho
MSE-25	2nd order, GCP	8°35'09.60584"	124°46'32.43073"	76.139	949534.368	695418.468	6.528
ME-112	1st order, BM	8°43'27.78957"	124°47'23.33936"	75.468	964847.889	696903.266	6.695
CAB-1	UP Established	8°39'21.02516"	124°44'51.71530"	76.762	957244.697	692303.312	7.759

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

Cross-section survey was conducted from October 6 to 8, 2014 along the downstream side of Cabulig Bridge in Brgy. Lower Jasaan, Municipality of Jasaan, Misamis Oriental. A PPK technique was applied using a survey grade GNSS rover receiver, Trimble® SPS 882, to get the cross-section points of the river as shown in Figure 32.

Figure 32. GNSS base occupation, Trimble® SPS 882 at CAB-1 along Iligan-Cagayan de Oro-Butuan Road at the approach of Cabulig Bridge in Brgy. Bobontugan, Municipality of Jasaan, Misamis Oriental

For the bridge as-built survey, the number of piers, span length (distance between piers and distance between piers and abutment), and abutment were determined at the downstream side of the Cabulig Bridge. Its elevation was acquired and referred to MSL.

The resulting cross-sectional line is approximately 341.84 m in Cabulig Bridge with a total of 49 cross-section points gathered using UP-CAB as the GNSS base station. The bridge planimetric map, cross-section diagram, and the bridge as-built form are shown in Figure 33 to Figure 35, respectively.

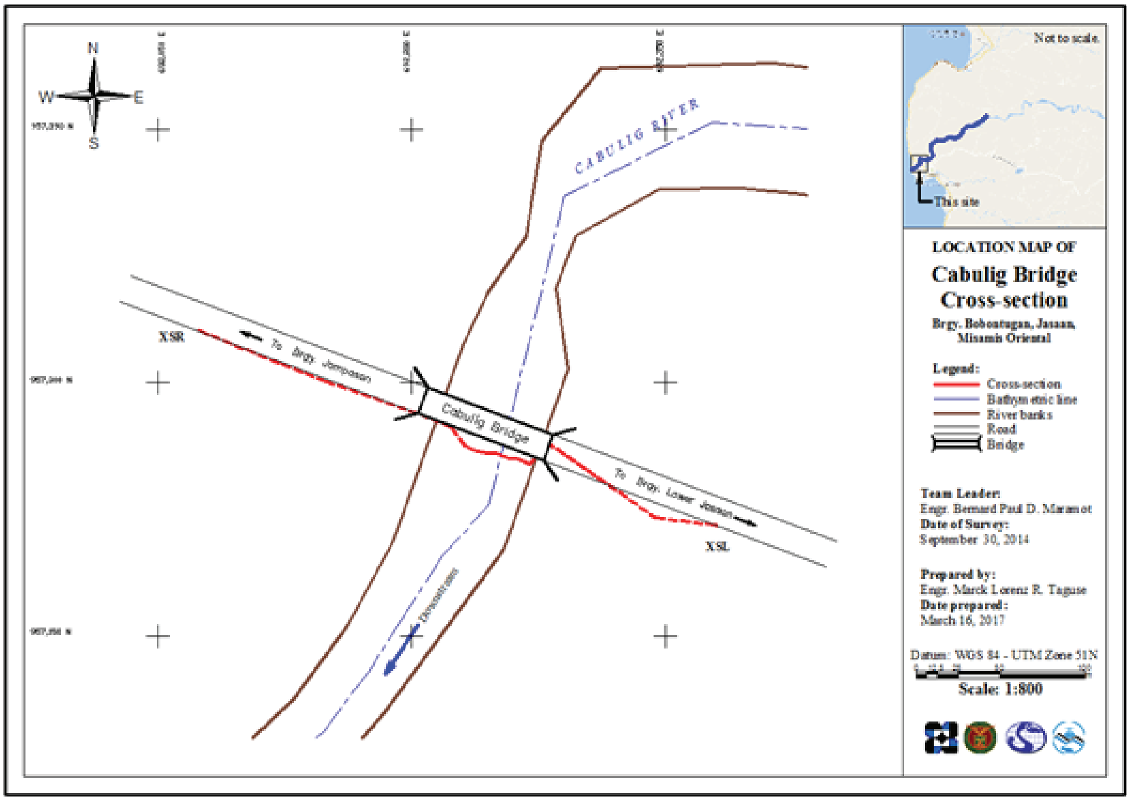


Figure 33. Cabulig bridge cross-section location map

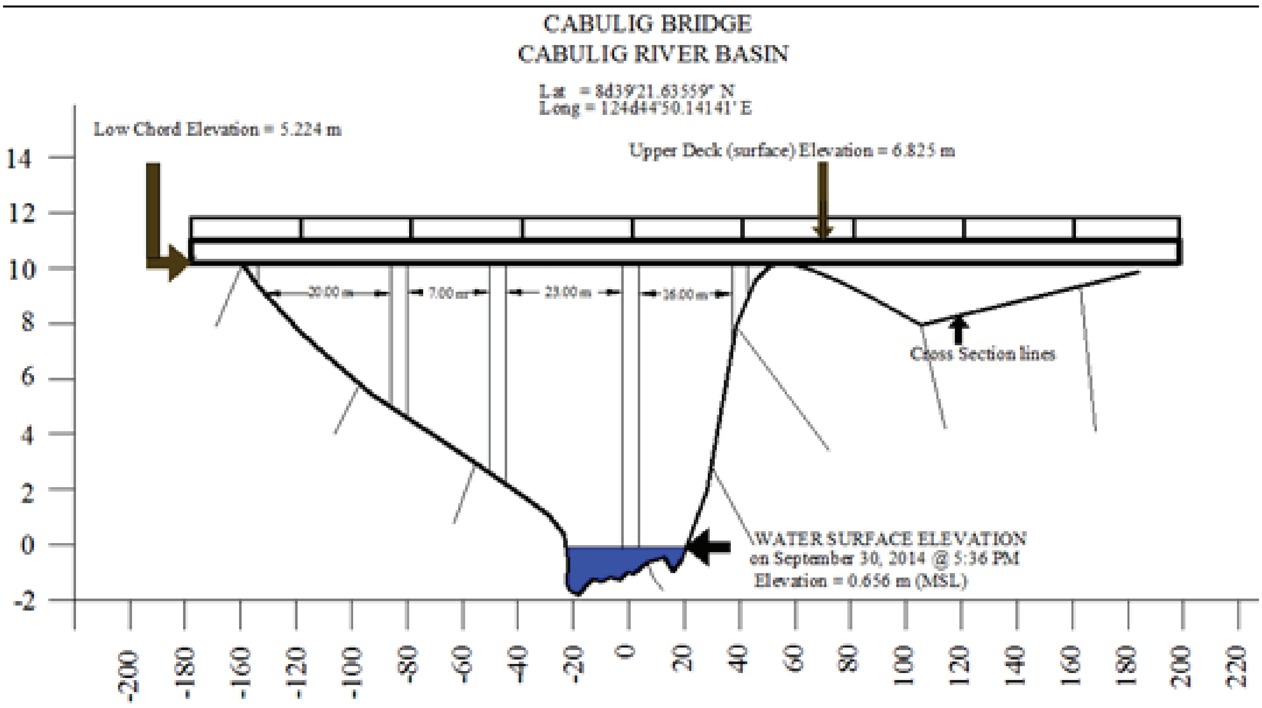
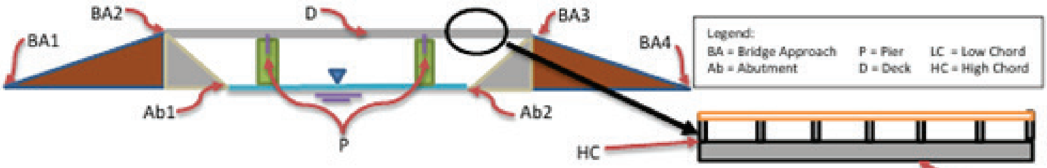


Figure 34. Cross-section diagram of Cabulig Bridge

Bridge Data Form

Bridge Name: CABULIG BRIDGE **Date:** September 30, 2014
River Name: CABULIG RIVER **Time:** 5:36 pm
Location (Brgy, City, Region): Brgy. Lower and Upper Jasaan, Jasaan, Misamis Oriental
Survey Team: DVBC Misamis Oriental Survey Team
Flow condition: low normal high **Weather Condition:** fair rainy
Latitude: 8°39'21.63559" N **Longitude:** 124°44'50.14141" E



Deck (Please start your measurement from the left side of the bank facing downstream)
Elevation 6.825 m (MSL) **Width:** 10.361 meters **Span (BA3-BA2):** 107.938 meters

	Station	High Chord Elevation	Low Chord Elevation
1	Pier 1	6.733	5.224
2			
3			
4			

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

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	0	6.687	BA3	188.497	6.839
BA2	80.556	6.783	BA4	344.2943	6.535

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

	Station (Distance from BA1)	Elevation
Ab1	110.670	1.295
Ab2	166.918	1.783

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

Shape: Cylindrical **Number of Piers:** 7 **Height of column footing:**

	Station (Distance from BA1)	Elevation	Pier Width
Pier 1	83.312	6.685	
Pier 2	103.895	6.731	
Pier 3	110.570	6.821	
Pier 4	133.736	6.424	
Pier 5	144.968	6.667	
Pier 6	170.601	6.334	
Pier 7	186.017	6.843	

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

Figure 35. Cabulig Bridge data form

Figure 36. Water surface elevation marking in Cabulig Bridge

The water surface elevation of Cabulig River at the left and right banks was acquired using a GNSS receiver utilizing a PPK survey method. The water surface elevation data is 0.656 m above MSL during the survey date on October 4, 2014. This was translated onto one of the bridge's pier using a Digital Level and was marked with paint to serve as reference for depth gauge deployment and flow data gathering activities of CMU.

As shown in the series of pictures in Figure 36, the water surface below Cabulig Bridge was determined using a Digital Level: (a) Backsight reading from a known point, (b) Foresight reading with a stadia rod against the wall of the pier, (c) water level marking using red and white paint, and (d) the resulting final MSL elevation mark at Cabulig Bridge pier.

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on September 28, 2014 using a survey grade GNSS rover receiver, Trimble® SPS 882, mounted to a 2 m pole which was attached on the side of a vehicle (see Figure 37). It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The height of instrument was measured from the ground up to the bottom of the notch of the receiver. It is about 2.52 m. The survey was conducted using PPK technique on a continuous topography mode.

Points were gathered along major concrete roads with vehicular speed of 20 to 40 kph, cutting across the flight strips of the DAC. The total distance surveyed is approximately 15 km from Cabulig Bridge going to the Municipality of Balingasag and 15 km from Cabulig Bridge going to the Villanueva Municipal boundary. The control point CAB-1 was occupied as the GNSS base station during the gathering of validation points.

Figure 37. Validation points acquisition survey set-up on a vehicle using a Trimble® SPS 882, mounted on a 2 m pole attached to the side of the vehicle

Figure 38. The LiDAR ground validation survey covering Cabulig River

Figure 38 shows the road validation lines across the Municipalities of Jasaan and Balingasag, Misamis Oriental. There are 1,942 points acquired covering a total length of 30 km.

4.7 River Bathymetric Survey

Bathymetric survey was conducted from September 30 to October 1, 2014 at Cabulig River covering the barangays of Upper and Lower Jasaan in the Municipality of Jasaan. Trimble®. SPS 852 was set up over CAB-1, which served as the GNSS base station for the bathymetric survey of Cabulig River as shown in Figure 39. The bathymetry survey team was divided into two (2) groups; one team was assigned on the upstream at Brgy. Upper Jasaan and the other group was assigned downstream at Brgy. Lower Jasaan.

On September 30, 2014, the bathymetric survey was conducted manually in the upstream shallow portion of the river. The team hired a survey aide to hold a 2 m pole with an attached survey grade GNSS, Trimble® SPS 882 while traversing the river. The next day, October 1, 2014, the team went back to Cabulig River to finish the remaining length of 710 m at Brgy. Lower Jasaan down to the mouth of the river basin.

There are 1,124 bathymetry points gathered within the approximate distance of 7 km bathymetry line length starting from Brgy. San Nicolas with coordinates 8°41’02.93391”N and 124°47’19.74713”E down to Brgy. Lower Jasaan with coordinates 8°39’27.63066”N and 124°44’57.08019”E. Processed data were generated into maps using GIS and its riverbed profile were plotted using CAD (see Figure 40 and Figure 41). An elevation drop of 60.45 m was observed within the approximate distance of 7.71 km.

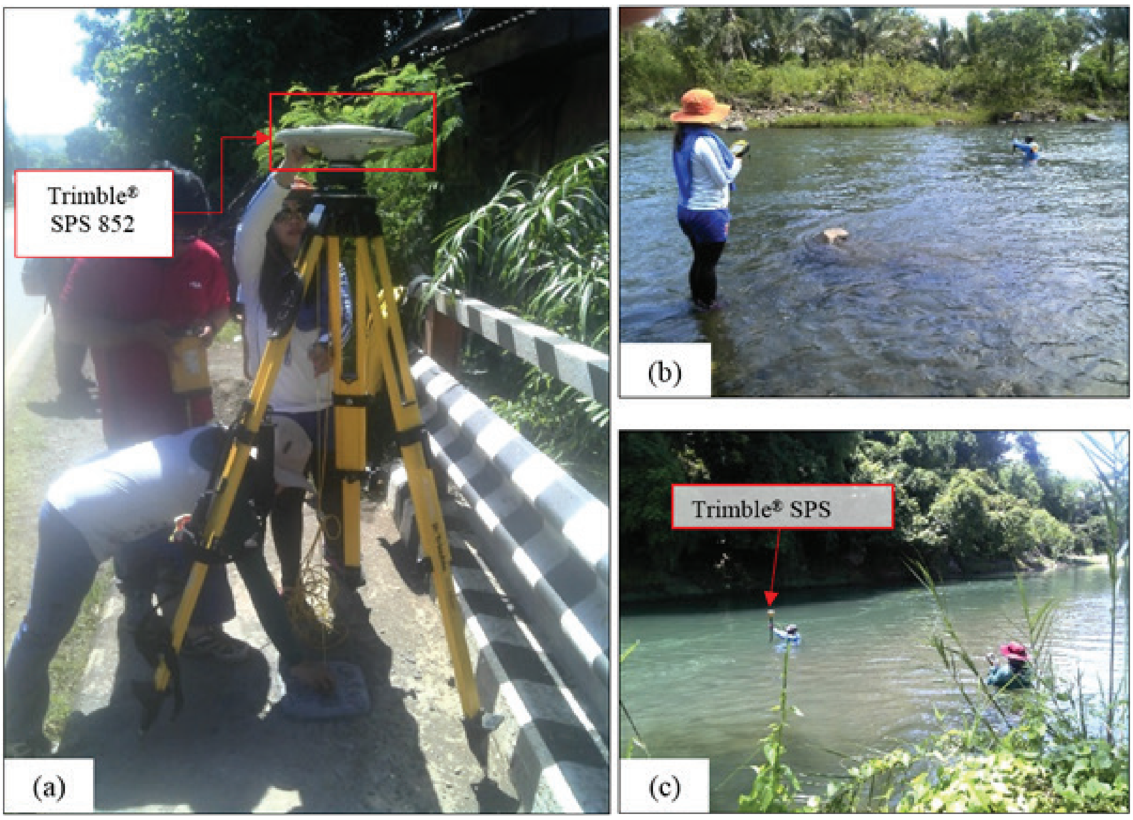


Figure 39. The bathymetric survey team preparation for the conduct of the bathymetric survey: (a) GNSS base station setup over CAB-1 in Cabulig Bridge, (b) gathering of bathymetry data downstream with respect to Cabulig Bridge, and (c) gathering of bathymetry data in the upstream

Figure 40. Map of bathymetry data gathered in Cabulig River

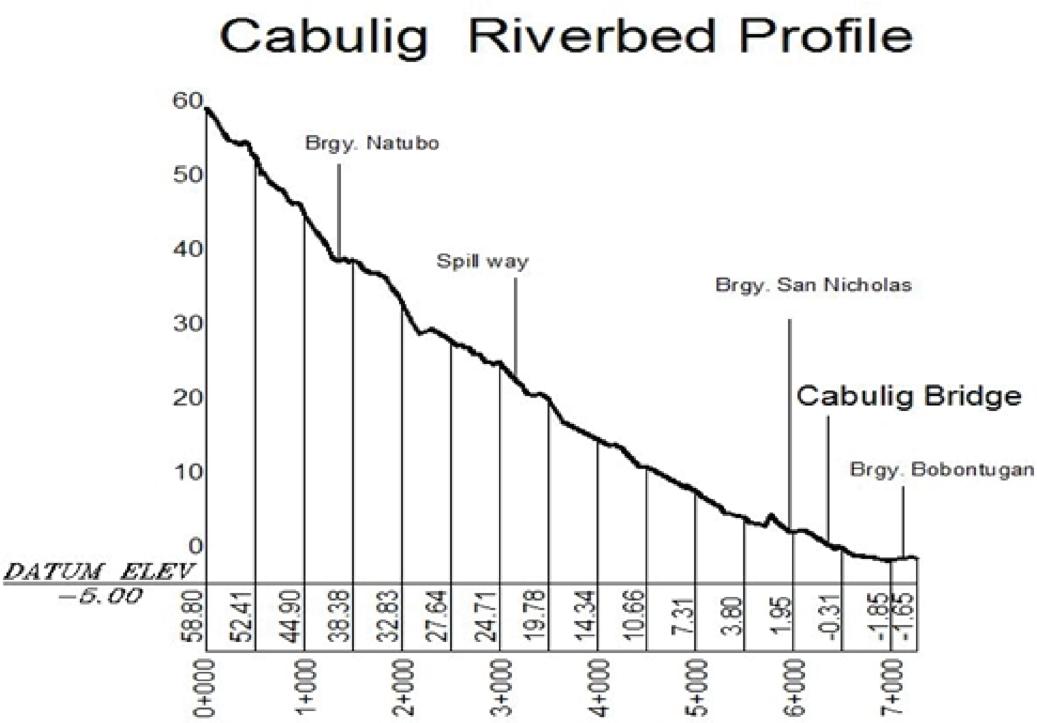


Table 25. Riverbed profile of Cabulig River

CHAPTER 5: FLOOD MODELING AND MAPPING

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

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

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

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

5.1.2 Precipitation

Precipitation data was taken from Automatic Rain Gauge (ARG) installed by the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI) at DA-CES Lanise in Barangay Lanise, Claveria, Misamis Oriental. The Intertropical Convergence Zone (ITCZ) event on September 29–30, 2015 served as input data.

The total precipitation for this event is 21.8 mm which peaked at 11.6 mm on 29 September 2015, 14:00. The lag time between the peak rainfall and discharge is 5 hours and 40 minutes.

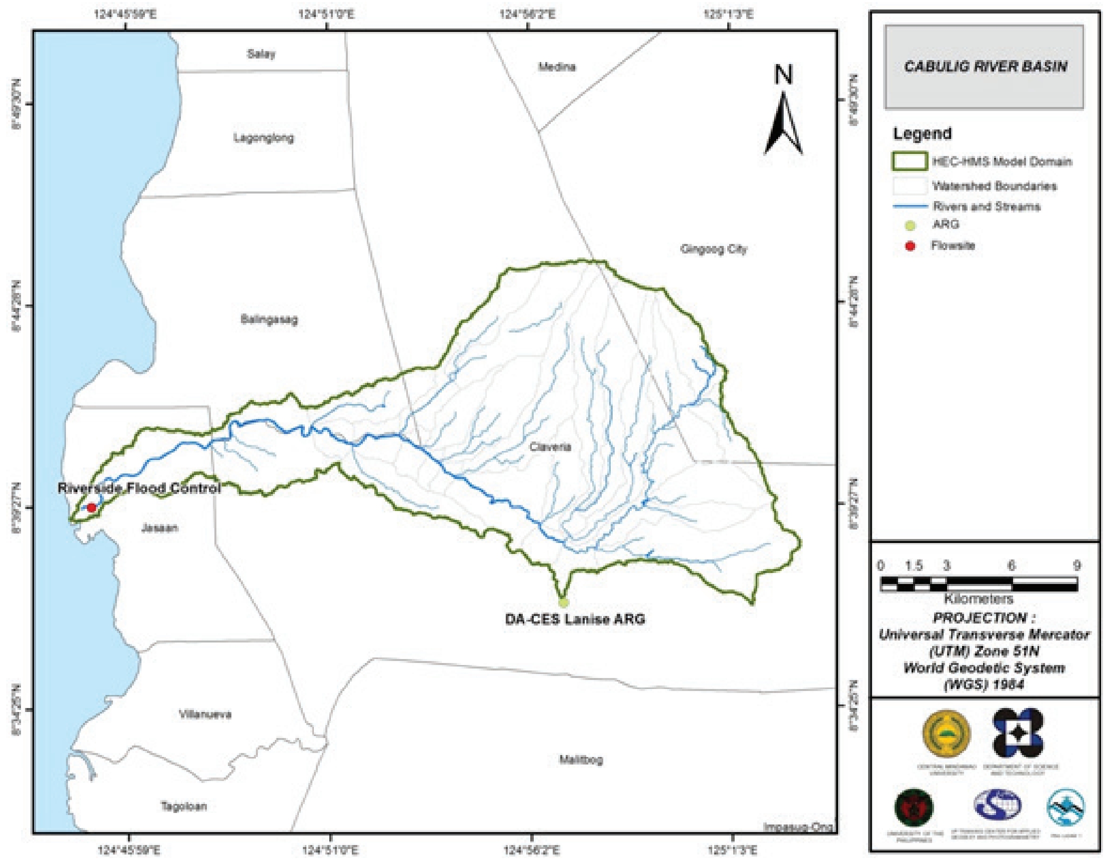


Figure 41. The location map of Cabulig HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

Simultaneous with the rainfall event was the measurement of water level and velocity at the flow site. Flow measurements specifically conducted at the Riverside Flood Control at Barangay Lower Jasaan, Jasaan, Misamis Oriental (8°39'26.43"N, 124°45'8.28"E). These flow data are necessary in the calculation of river discharge. During the event, the peak discharge is 14.1 m^3/s on 29 September 2015 at 19:40. Figure 43 shows river discharge as affected by the rainfall. The ITCZ event resulted in 0.81 meter of water level rise.

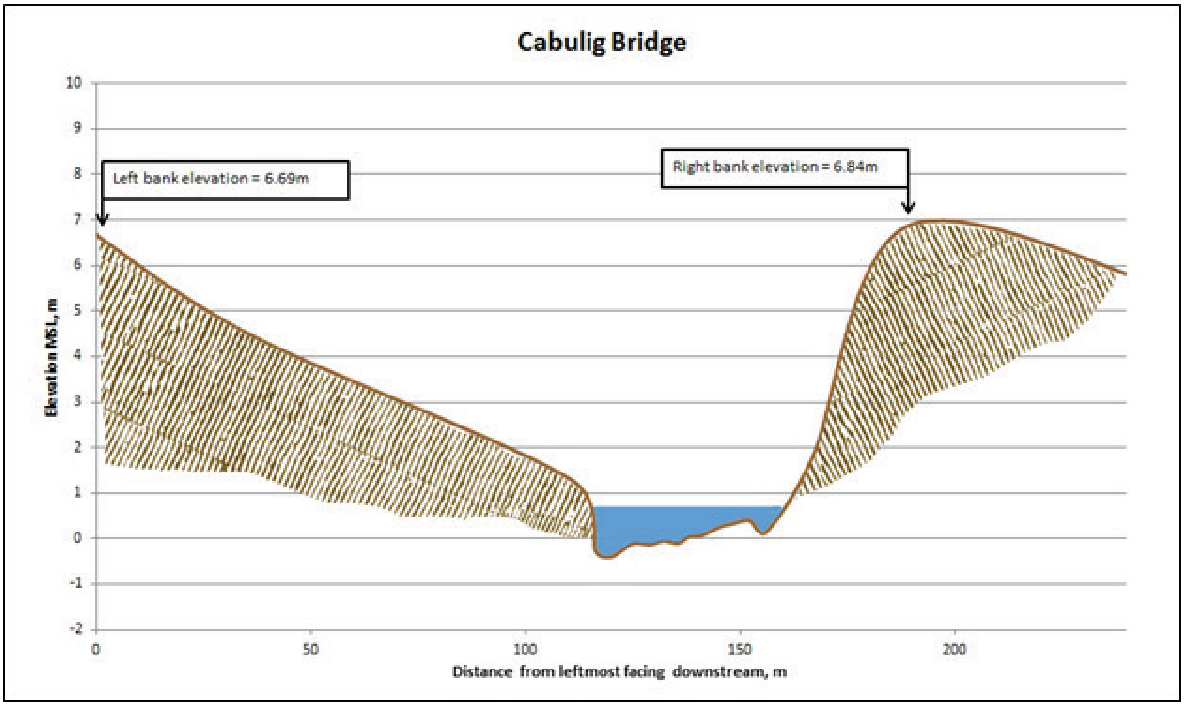


Figure 42. Cross-section plot of Cabulig Bridge

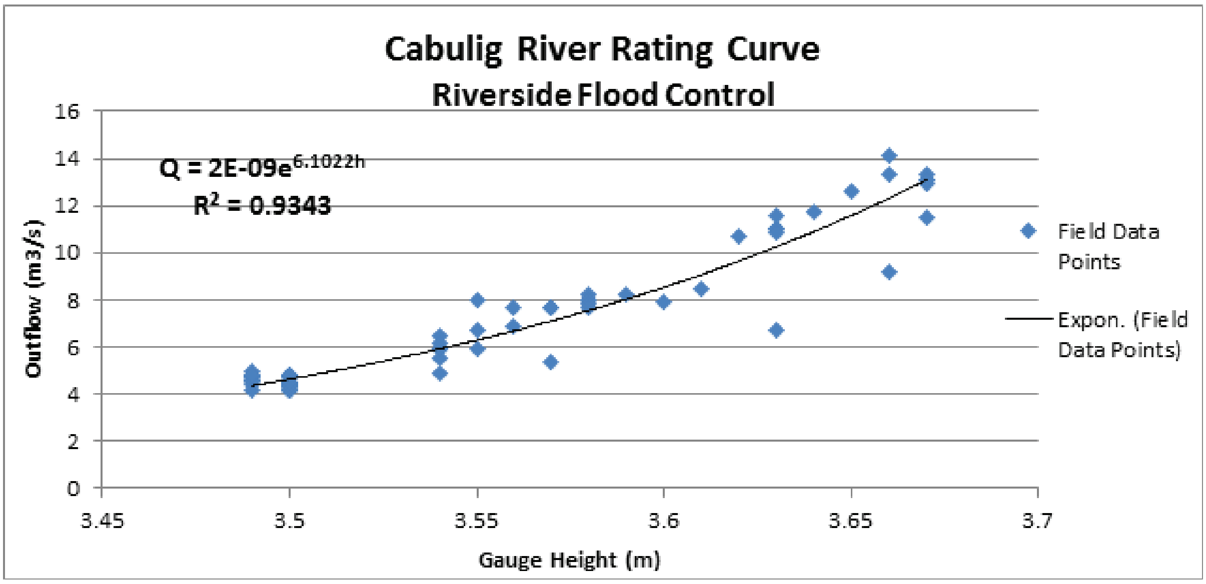


Figure 43. HQ curve of HEC-HMS model

The river outflow data were then used to generate rating curve. The curve gives the relationship between the observed water level and river outflow at the flow site location. It is expressed in the form of the following equation: Q=anh

where, Q : discharge (m^3/s),
h : gauge height (reading from riverside staff gauge), and
a and n : constants.

The rating curve for the data collected at the Cabulig flow site is expressed as Q = 2E-9e6.1022h as shown in Figure 44. This equation is helpful in calculating discharge using water level data.

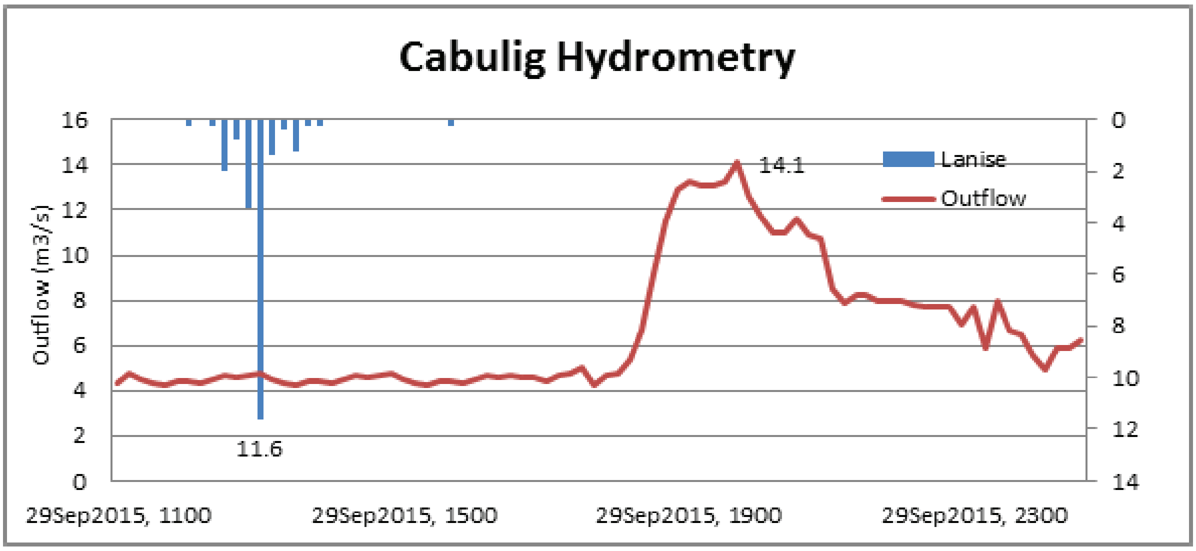


Figure 44. Rainfall and outflow data at Cabulig used for modeling

5.2 RIDF Station

The Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed for Rainfall Intensity Duration Frequency (RIDF) values for the Lumbia Rain Gauge. The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the values in such a way a certain peak value will be attained at a certain time. This station is chosen based on its proximity to the Cabulig watershed. The extreme values for this watershed were computed based on a 26-year record.

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

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	10 mins	20 mins	30 mins	1 hr	2 hrs	3 hrs	6 hrs	12 hrs	24 hrs
2	22.3	32.5	42	56.6	68.1	74.1	82.1	85.1	88.8
5	27.1	39.9	52.7	74	91.5	96.5	104.8	110.4	129.2
10	30.2	44.9	59.8	85.4	107.1	111.4	119.9	127.1	156
15	32	47.6	63.8	91.9	115.8	119.7	128.4	136.5	171.1
20	33.3	49.6	66.6	96.4	122	125.6	134.4	143.1	181.6
25	34.2	51.1	68.7	99.9	126.7	130.1	139	148.2	189.8
50	37.2	55.7	75.4	110.7	141.3	144	153.1	163.9	214.8
100	40.2	60.3	82	121.3	155.7	157.8	167.2	179.4	239.7

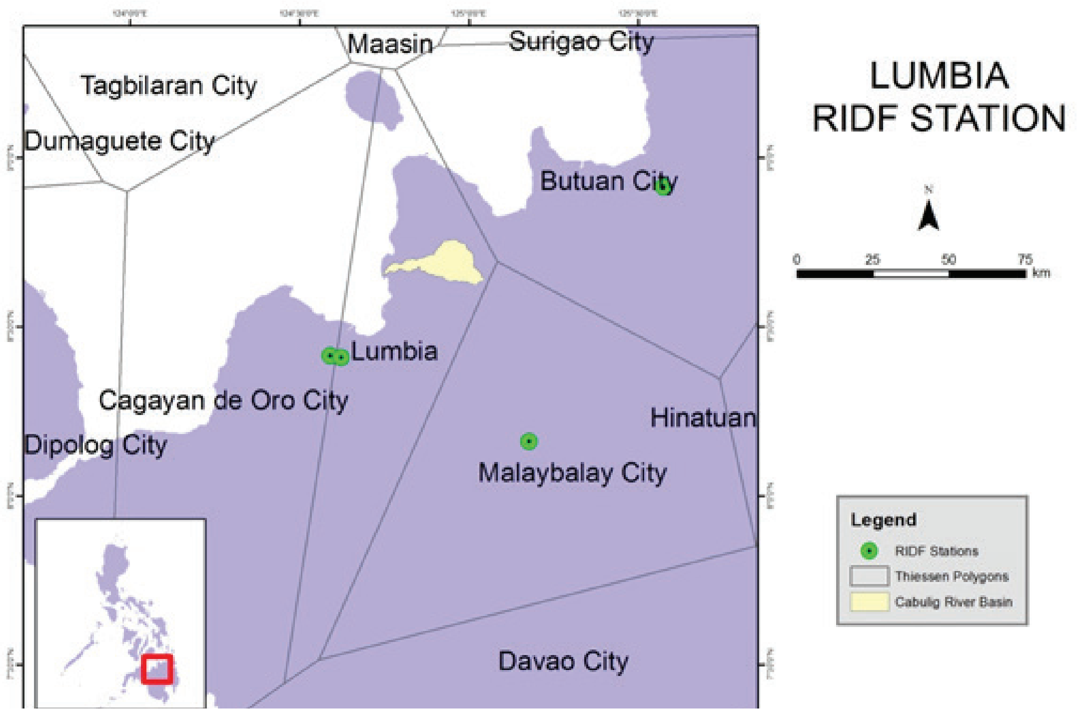


Figure 45. Location of Lumbia RIDF Station relative to Cabulig River Basin

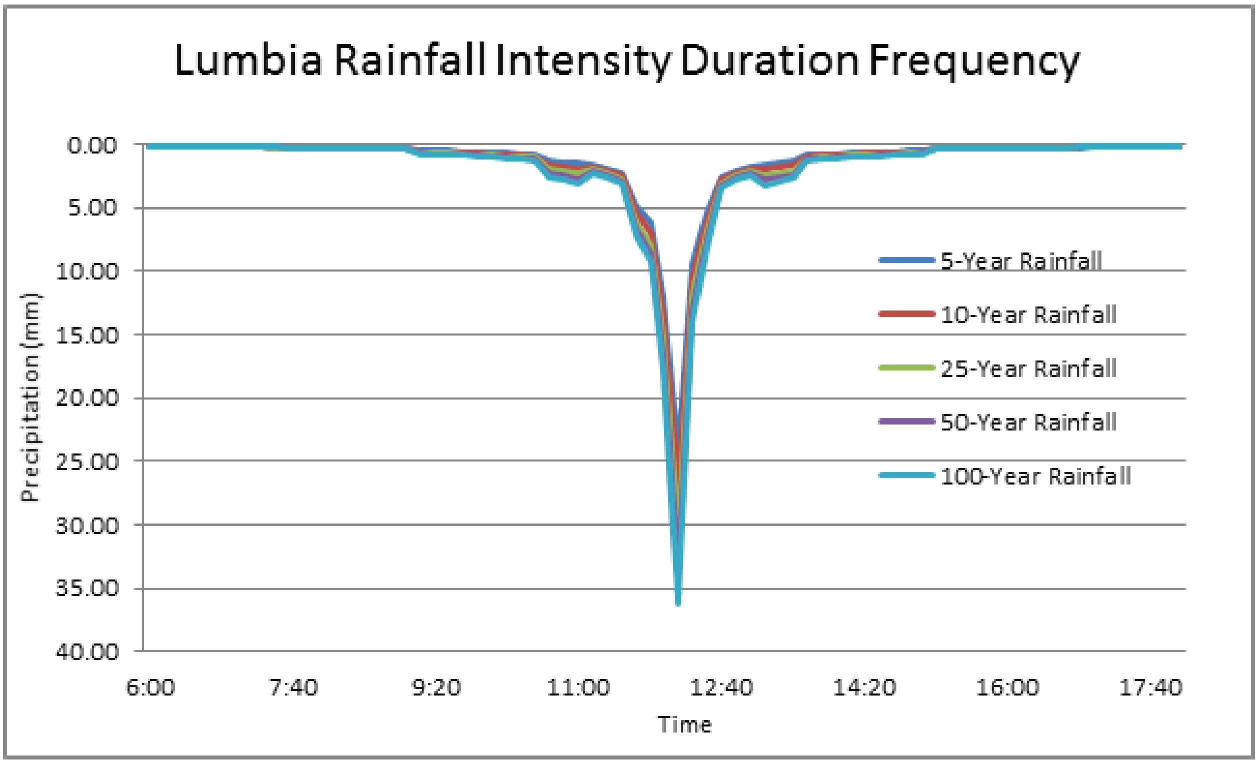


Figure 46. Location of Lumbia RIDF Station relative to Cabulig River Basin

5.3 HMS Model

The soil dataset was generated by and taken from the Bureau of Soils and Water Management (BSWM) under the Department of Agriculture (DA). The land cover shape file is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Cabulig River Basin are shown in Figure 47 and Figure 48, respectively.

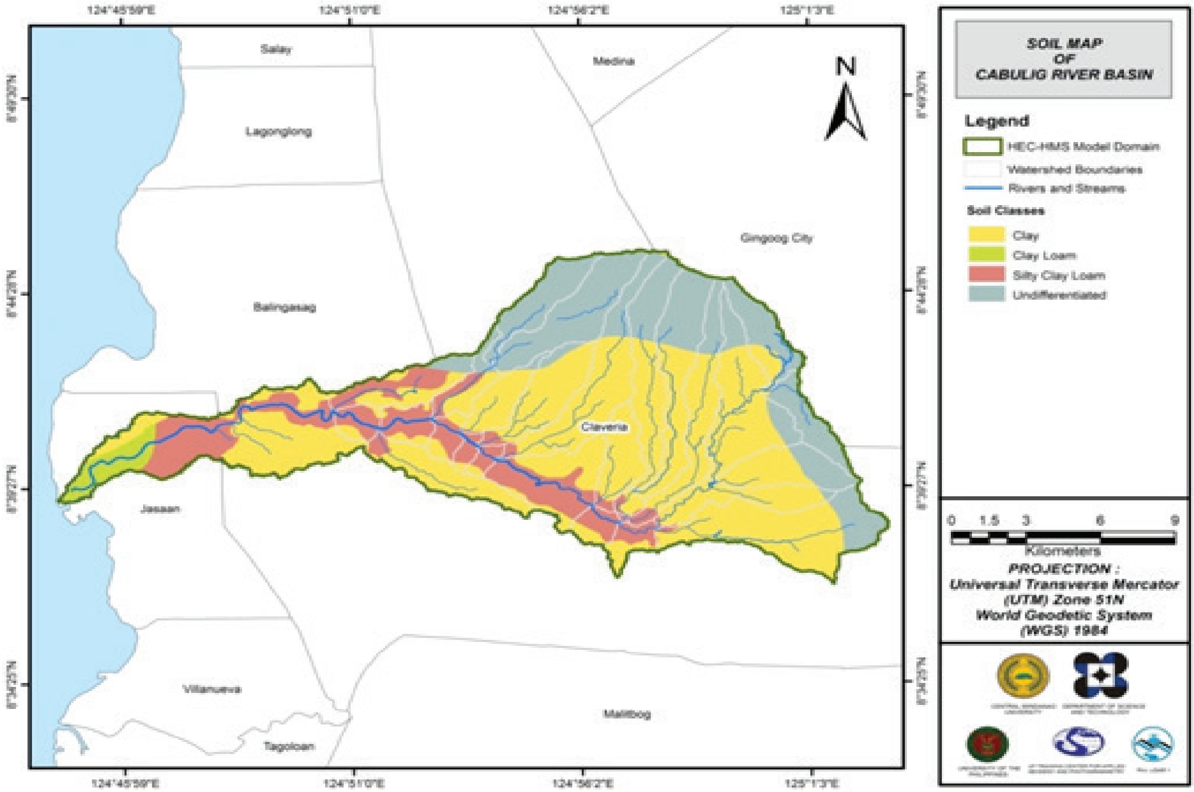


Figure 47. Soil map of the Cabulig River Basin

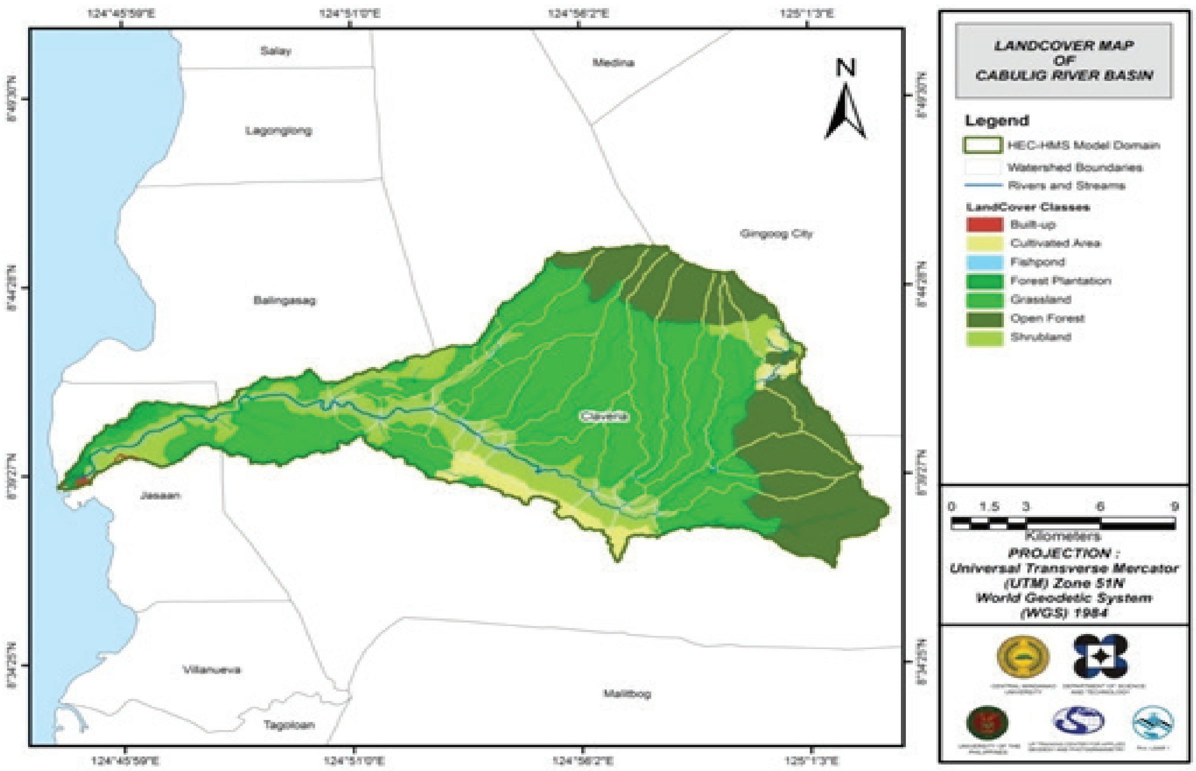


Figure 48. Land cover map of the Cabulig River Basin (Source: NAMRIA)

For Cabulig, four (4) soil classes were identified. These are clay loam, clay, silty clay loam, and undifferentiated soil. Moreover, seven land cover classes were identified. These include built-up, cultivated area, fishpond, forest plantation, grassland, open forest, and shrubland.

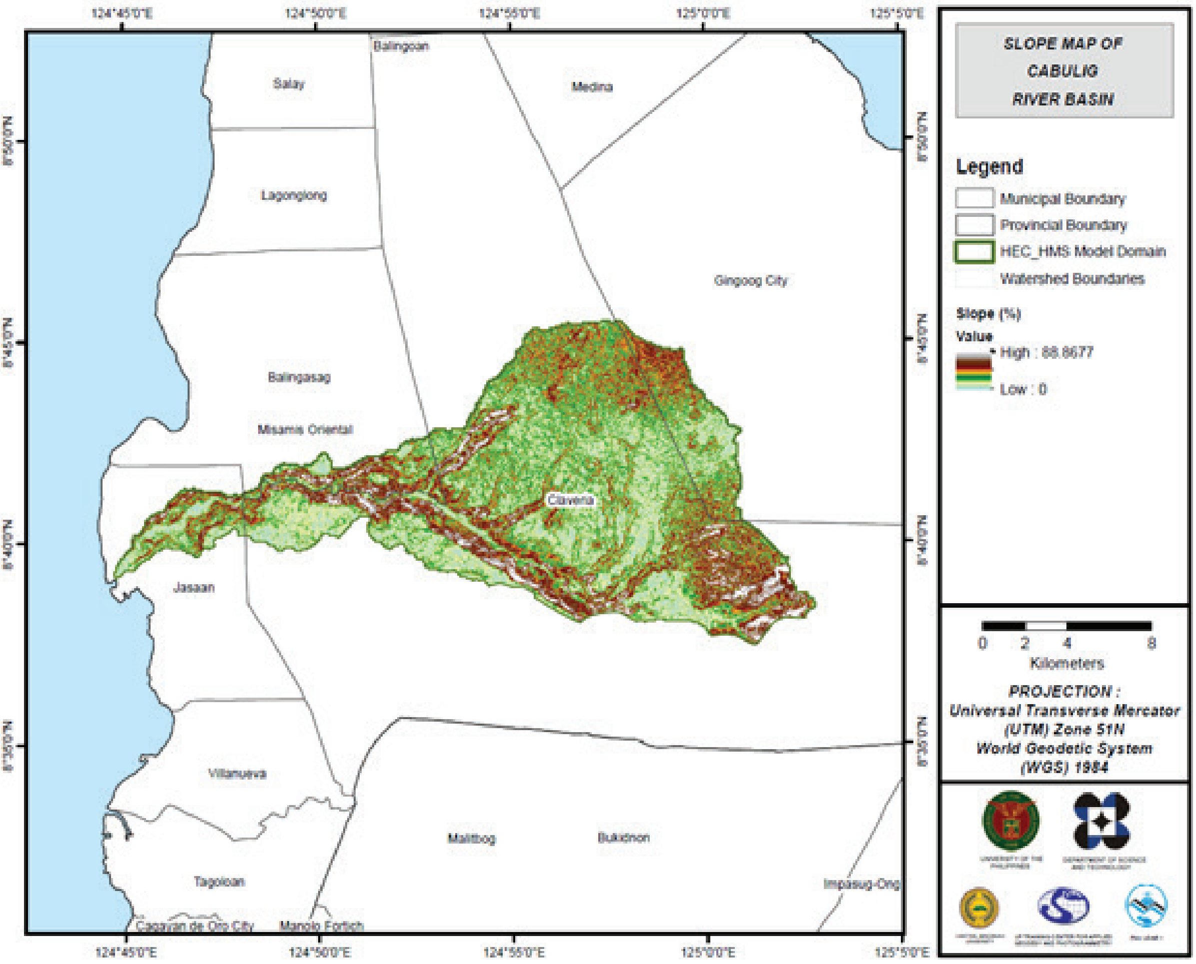


Figure 49. Slope map of Cabulig River Basin

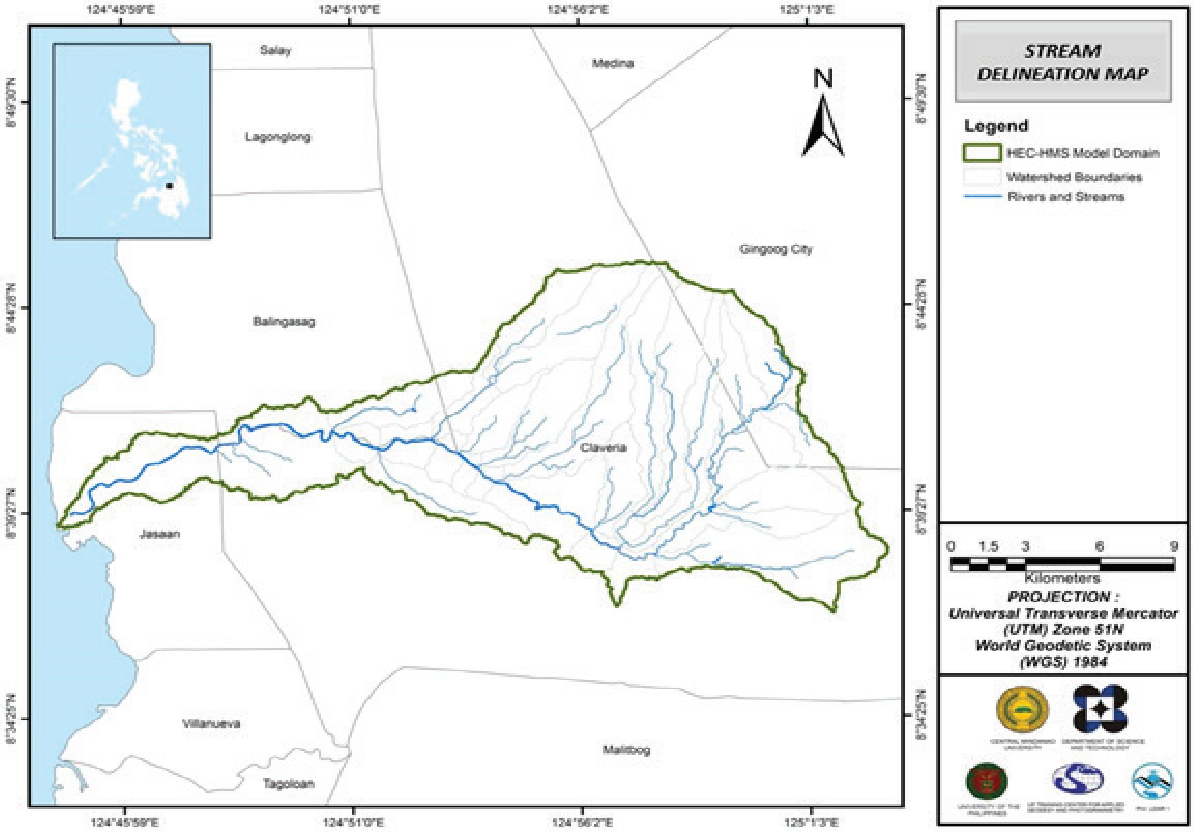


Figure 50. Stream delineation map of Cabulig River Basin

Using the SAR-based DEM, the Cabulig basin was delineated and further subdivided into subbasins. The Cabulig basin model consists of 83 subbasins, 43 reaches, and 43 junctions. The main outlet located at the estuary of Barangay Lower Jasaan is illustrated in Figure 51. Finally, it was calibrated using precipitation data from DOST rain gauge and discharge data gathered at the Riverside Flood Control, Lower Jasaan using mechanical flow meter and staff gauge on September 29–30, 2015 (Intertropical Convergence Zone).

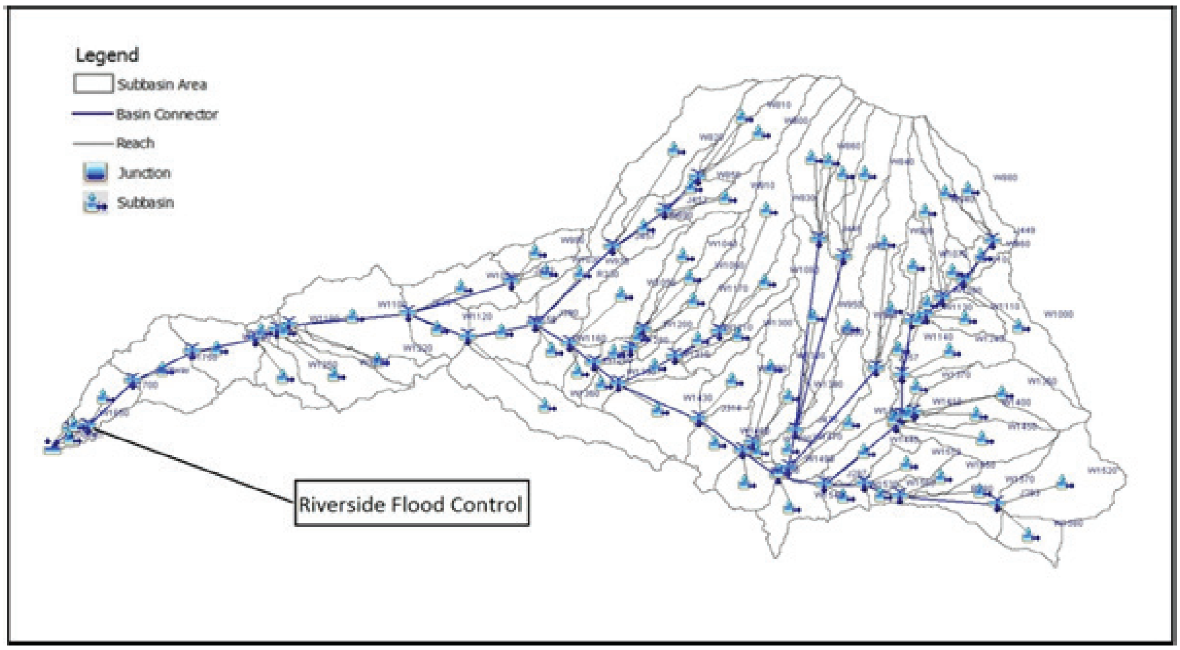


Figure 51. The Cabulig River basin model generated using HEC-HMS

5.4 Cross-section Data

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

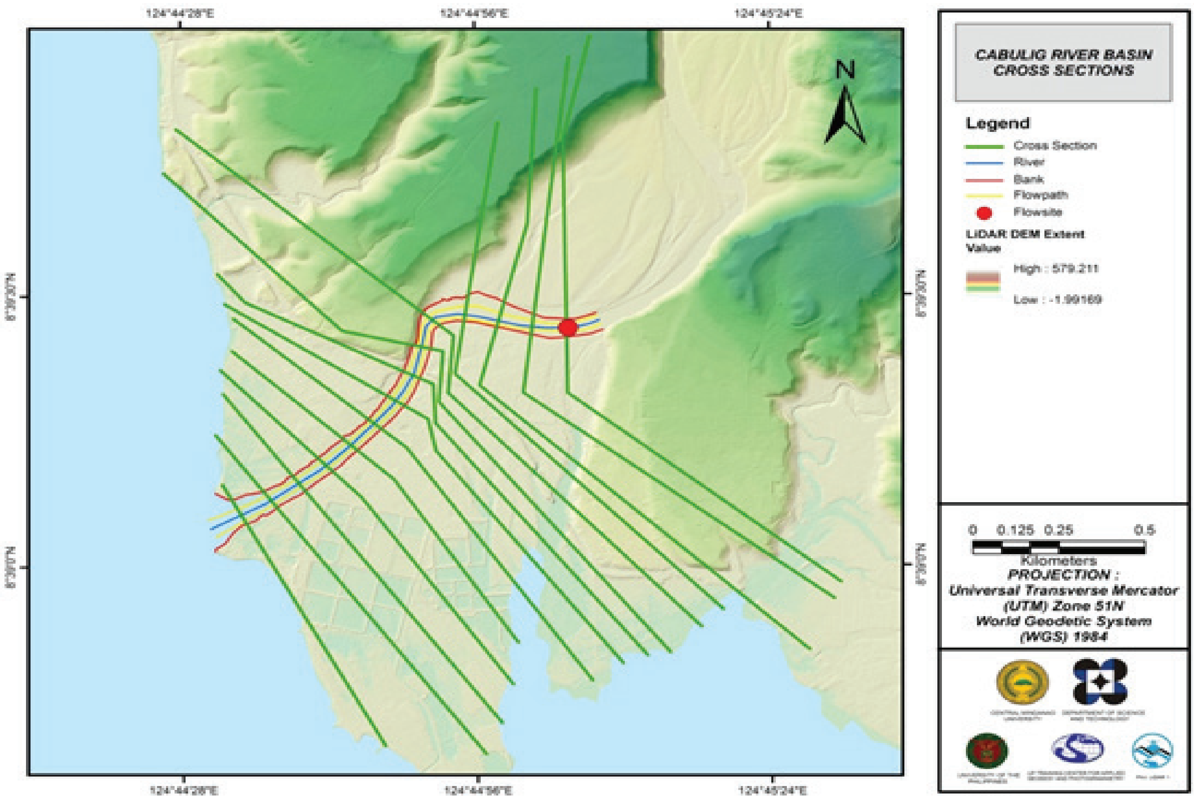


Figure 52. River cross-section of Cabulig River generated through Arcmap HEC GeoRAS tool

5.5 Flo-2D Model

The automated modelling process allows for the creation of a model with boundaries that are almost exactly coincidental with that of the catchment area. As such, they have approximately the same land area and location. The entire area was divided into square grid elements, 10 meter by 10 meter in size. Each element was 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 were arranged spatially to form the model, allowing the software to simulate the flow of water across the grid elements and in eight directions (north, south, east, west, northeast, northwest, southeast, southwest).

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

Figure 53. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation was then run through FLO-2D GDS Pro. This particular model had a computer run time of 39.55225 hours. After the simulation, FLO-2D Mapper Pro was 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 created the following food hazard map. Most of the default values given by FLO-2D Mapper Pro were used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) was set at 0.2 m while the minimum vh [Product of maximum velocity (v) times maximum depth (h)] was set at 0 m^2/s.

The creation of a flood hazard map from the model also automatically created a flow depth map depicting the maximum amount of inundation for every grid element. The legend used by default in FLO-2D Mapper was not a good representation of the range of flood inundation values, so a different legend was used for the layout. In this particular model, the inundated parts cover a maximum land area of 39 385 900.00 m^2.

There is a total of 18,419,757.72 m^3 of water entering the model. Of this amount, 10,725,727.85 m^3 is due to rainfall while 7,694,029.87 m^3 is inflow from other areas outside the model. 3,960,626.75 m^3 of this water is lost to infiltration and interception, while 12,447 417.07 m^3 is stored by the floodplain. The rest, amounting up to 2,011,714.06 m^3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Cabulig HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 54 shows the comparison between the two (2) discharge data.

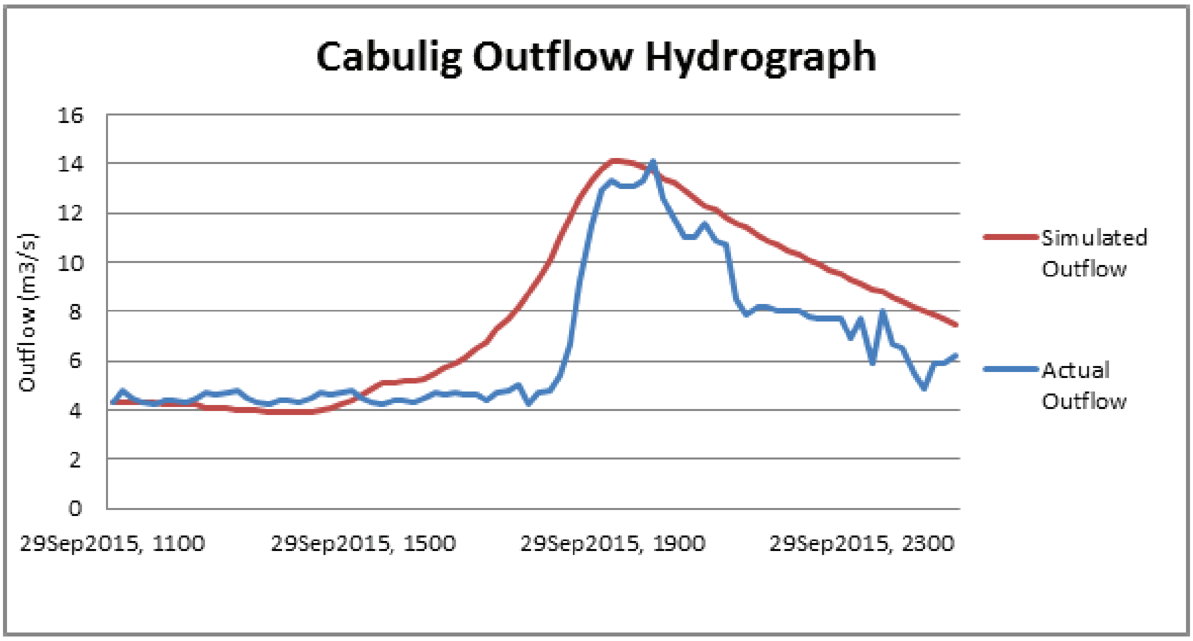


Figure 54. Outflow hydrograph of Cabulig produced by the HEC-HMS model compared with observed outflow

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

Table 27. Range of calibrated values for Cabulig River Basin

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	50	2.54 - 10.48
				53.4 - 83.68
	Transform	Clark Unit Hydrograph	50	0.01667
				0.11 - 2.01
	Baseflow	Recession	50	0.5
				0.01
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.001 - 0.003

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 2.54 mm to 10.48 mm means that there is minimal amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 53.4 to 83.68 for curve number is advisable for Philippine watersheds depending on the soil and land cover of the area. For Cabulig, the basin mostly consists of grassland and the soil consists of clay and undifferentiated soil.

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 0.01667 hours to 2.01 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant of 0.5 indicates that the basin is unlikely to quickly go back to its original discharge and instead, will be higher. Ratio to peak of 0.01 indicates a steeper receding limb of the outflow hydrograph.

Manning's roughness coefficient of 0.001–0.003 is less than the usual Manning's n value for Philippine rivers.

Table 28. Range of calibrated values for Cabulig River Basin

Accuracy Measure	Value
RMSE	7.00
r^2	0.986
NSE	0.52
PBIAS	19.32
RSR	0.70

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 2.00 (m^3/s).

The Pearson correlation coefficient (r^2) assesses the strength of the linear relationship between the observations and the model. A value 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 0.986.

The Nash-Sutcliffe (E) method is also used to assess the predictive power of the model. Here, the optimal value is 1. The model attained an efficiency coefficient of 0.52.

A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate bias towards over-prediction. Again, the optimal value is 0. In the model, the PBIAS is 19.32.

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 0.70.

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 (Figures 55) shows the Cabulig outflow using the Lumbia Rainfall Intensity-Duration-Frequency curves (RIDF) in five (5) different return periods: 5-year, 10-year, 25-year, 50-year, and 100-year return periods based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

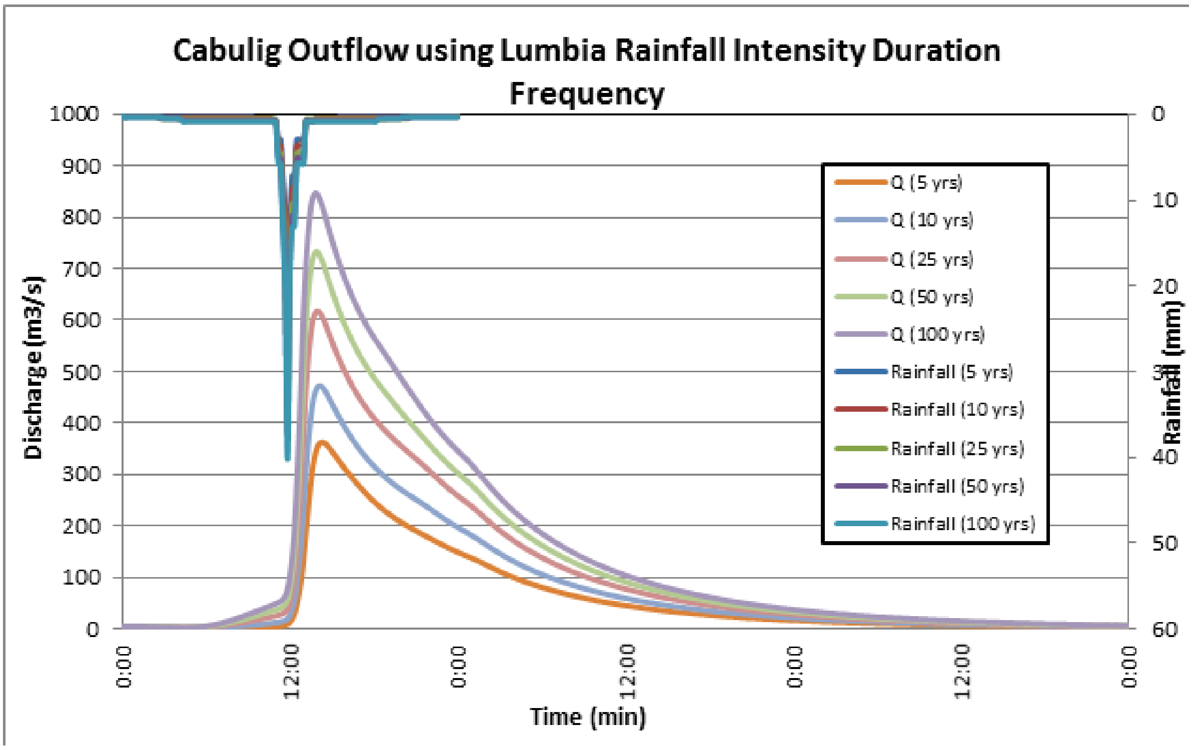


Figure 55. Outflow hydrograph at Cabulig Station generated using Lumbia RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of Cabulig discharge using the Lumbia RIDF in five (5) different return periods is shown in Table 29.

Table 29. Peak values of the Cabulig HECHMS Model outflow using the Lumbia RIDF

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m^3/s)	Time to Peak
5-Year	129.2	27.1	347.2	2 hours and 30 minutes
10-Year	156	30.2	478.8	2 hours and 20 minutes
25-Year	189.8	34.2	621.9	2 hours and 10 minutes
50-Year	214.8	37.2	729.7	2 hours
100-Year	239.7	40.2	839.9	2 hours

5.7.2 Discharge Data Using Dr. Horritts's Recommended Hydrologic Method

The river discharge for the river entering the floodplain is shown in Figure 14 and the peak values are summarized in Table 30.

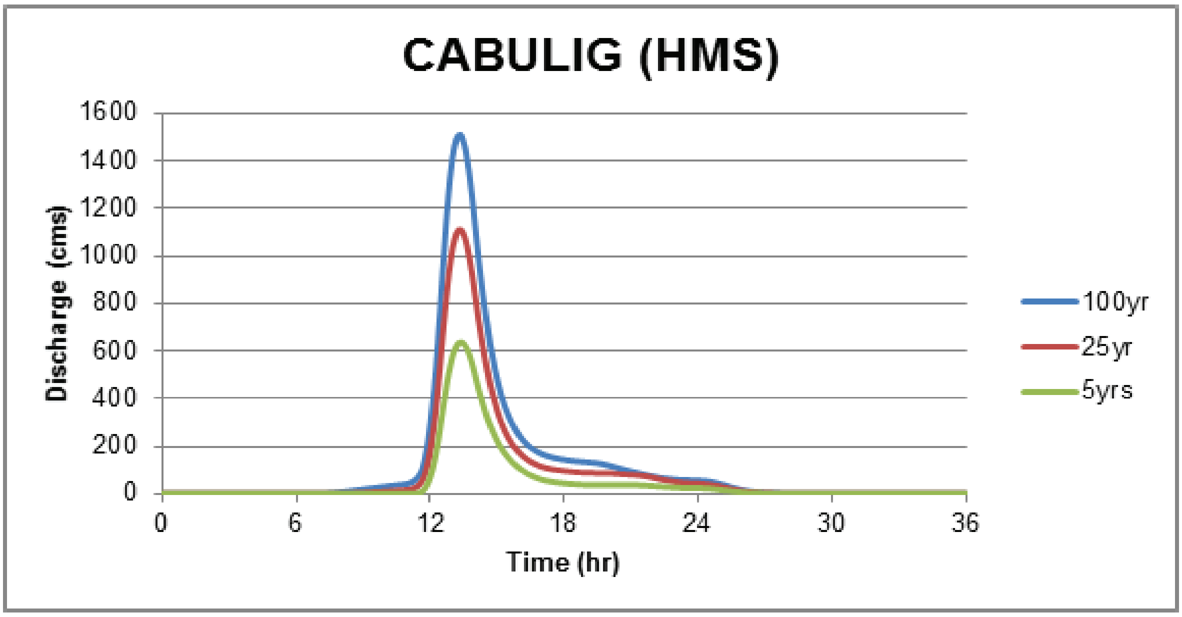


Figure 56. Cabulig River generated discharge using 5-, 25-, and 100-year Lumbia RIDF in HEC-HMS

Table 30. Summary of Cabulig River (1) discharge generated in HEC-HMS

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	**1509.0**	**13 hours, 20 minutes**
25-Year	1110.2	13 hours, 20 minutes
5-Year	636.9	13 hours, 20 minutes

The comparison of the discharge results using Dr. Horritt's recommended hydrological method against the bankful and specific discharge estimates is shown in Table 31.

Table 31. Validation of river discharge estimatesHMS

Discharge Point	QMED(SCS), cms	QBANKFUL, cms	QMED(SPEC), cms	VALIDATION	
				Bankful Discharge	Specific Discharge
Cabulig (1)	422.664	475.770	327.735	Pass	Pass

The value from the HEC-HMS river discharge estimate was able to satisfy the condition for validation using the bankful and specific discharge methods. The calculated value is based on theory but is supported using other discharge computation methods so it was good to use flood modeling. However, this will need further investigation for the purpose of validation. It is therefore recommended to obtain actual values of the river discharges for higher-accuracy modeling.

5.8 River Analysis Model Simulation

The HEC-RAS flood model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model was used in determining the flooded areas within the model. The simulated model is an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. For this publication, only a sample output map river is to be shown. The sample generated map of Cabulig River using the calibrated HMS base flow is shown in Figure 57.

Figure 57. Sample output of Cabulig RAS Model

5.9 Flow Depth and Flood Hazard

The resulting flow depth and flood hazard maps have a 10m resolution. Figure 58 to Figure 63 show the 100, 25, and 5-year rain return scenarios of the Cabulig Floodplain. The floodplain, with an area of 38.03 km^2, covers two (2) municipalities, namely Claveria and Jasaan. Table 32 shows the percentage of area affected by flooding per municipality.

Table 32. Municipalities affected in Cabulig Floodplain

Municipality	Total Area	Area Flooded	% Flooded
Claveria	622.22	9.96	1.60%
Jasaan	64.84	28.02	43.21%

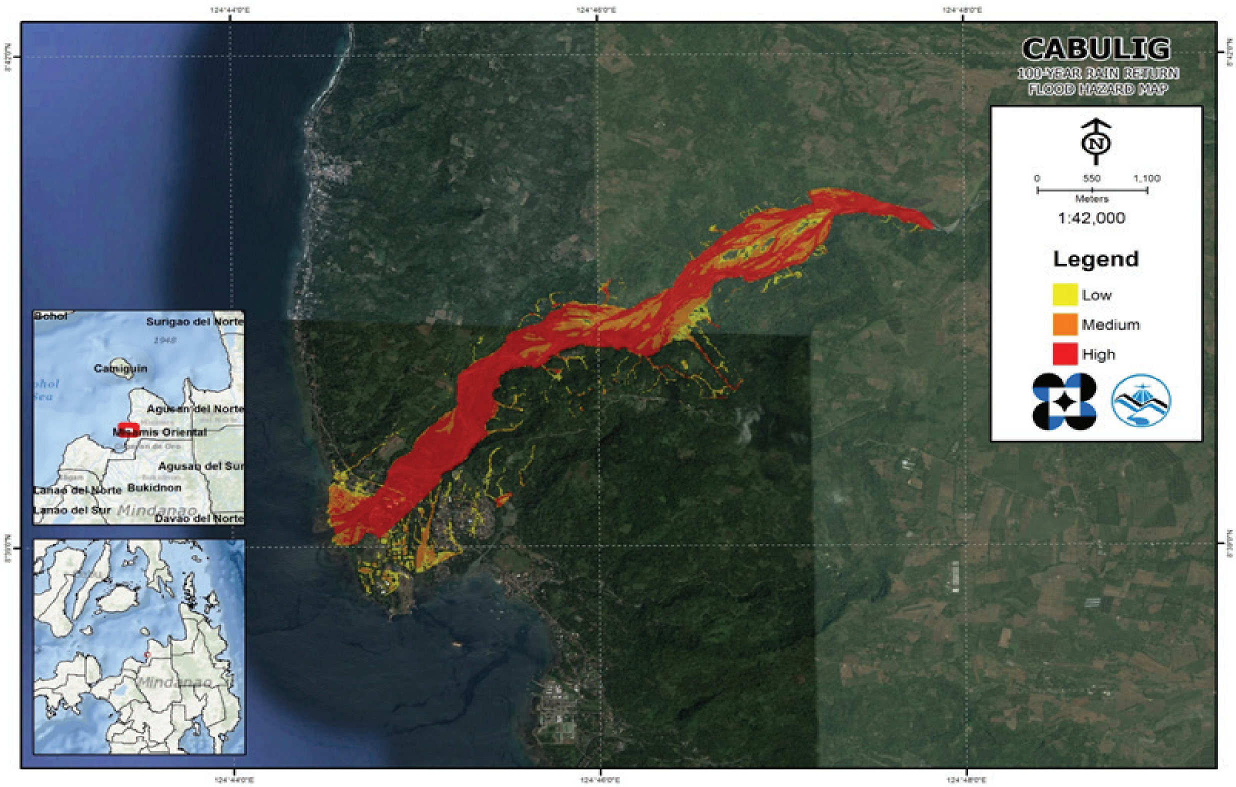


Figure 58. 100-year flood hazard map for Cabulig Floodplain

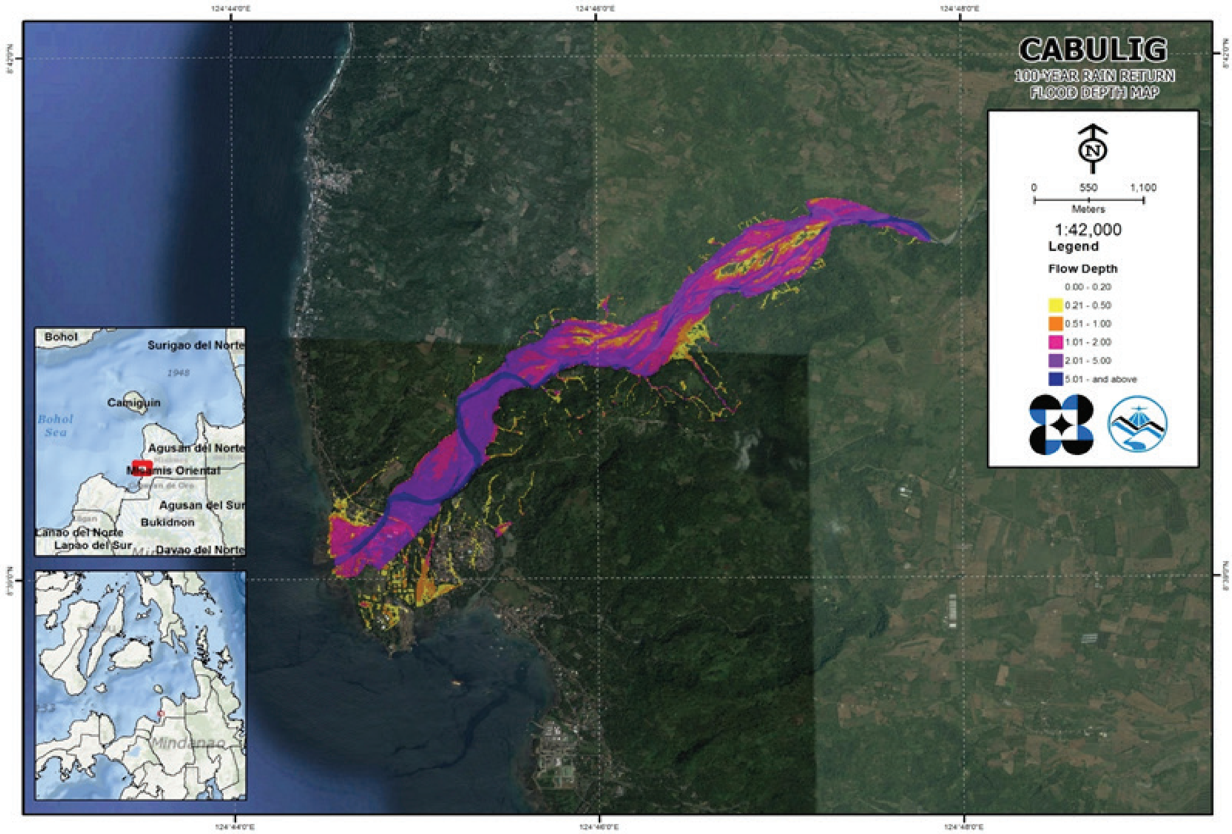


Figure 59. 100-year flow depth map for Cabulig Floodplain

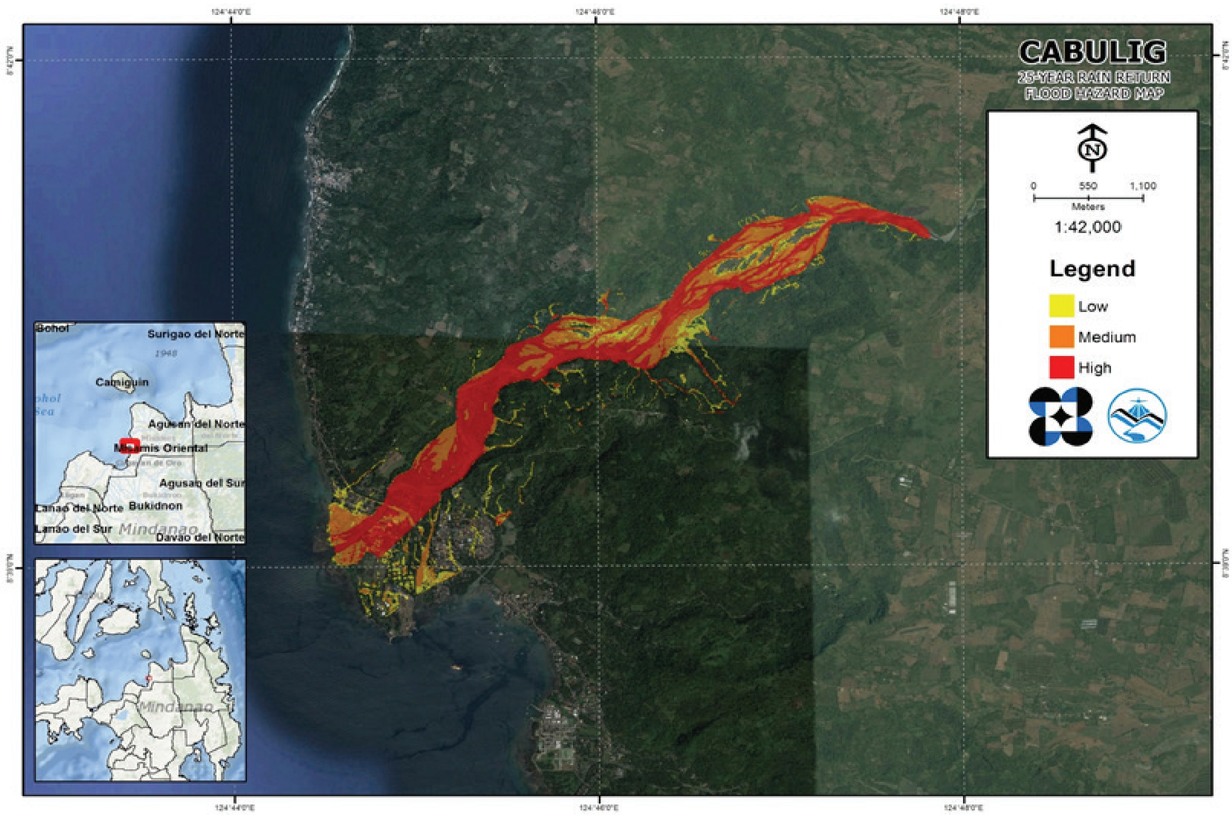


Figure 60. 25-year flood hazard map for Cabulig Floodplain

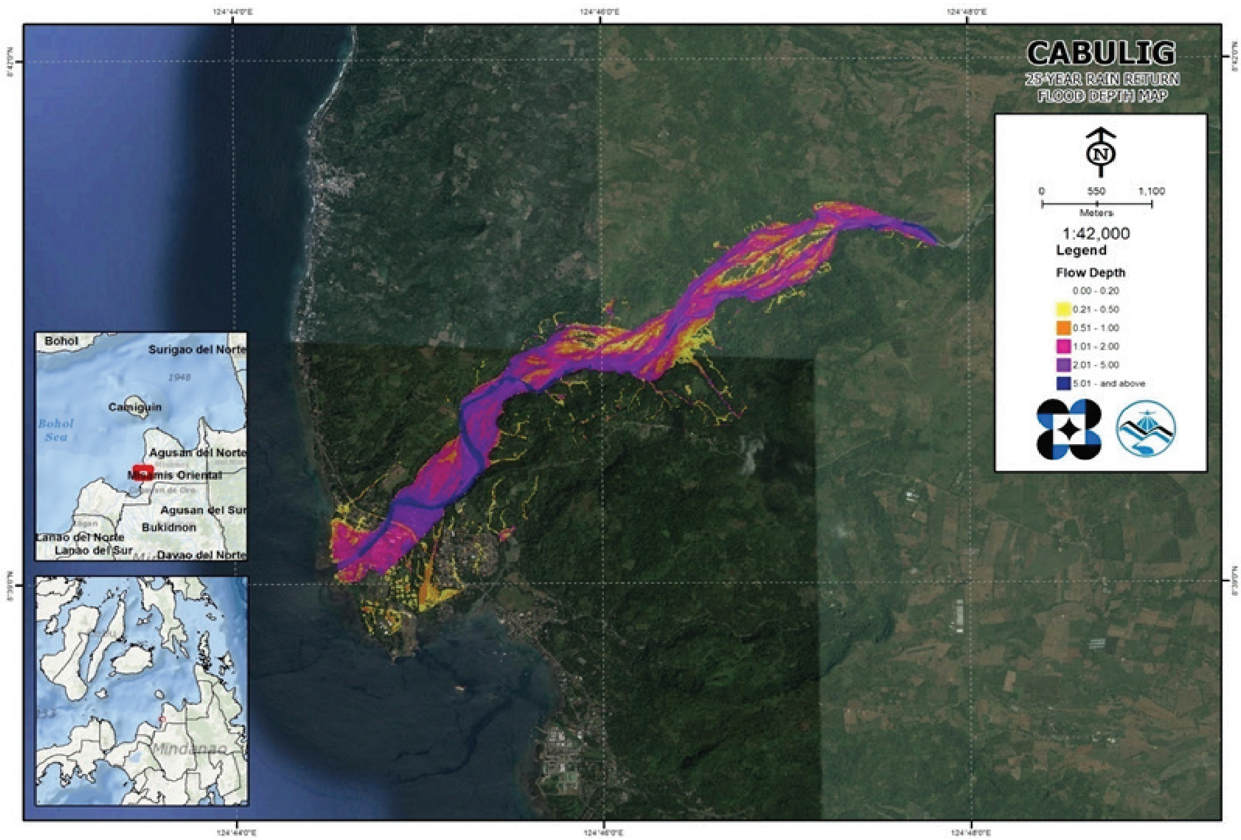


Figure 61. 25-year flow depth map for Cabulig Floodplain

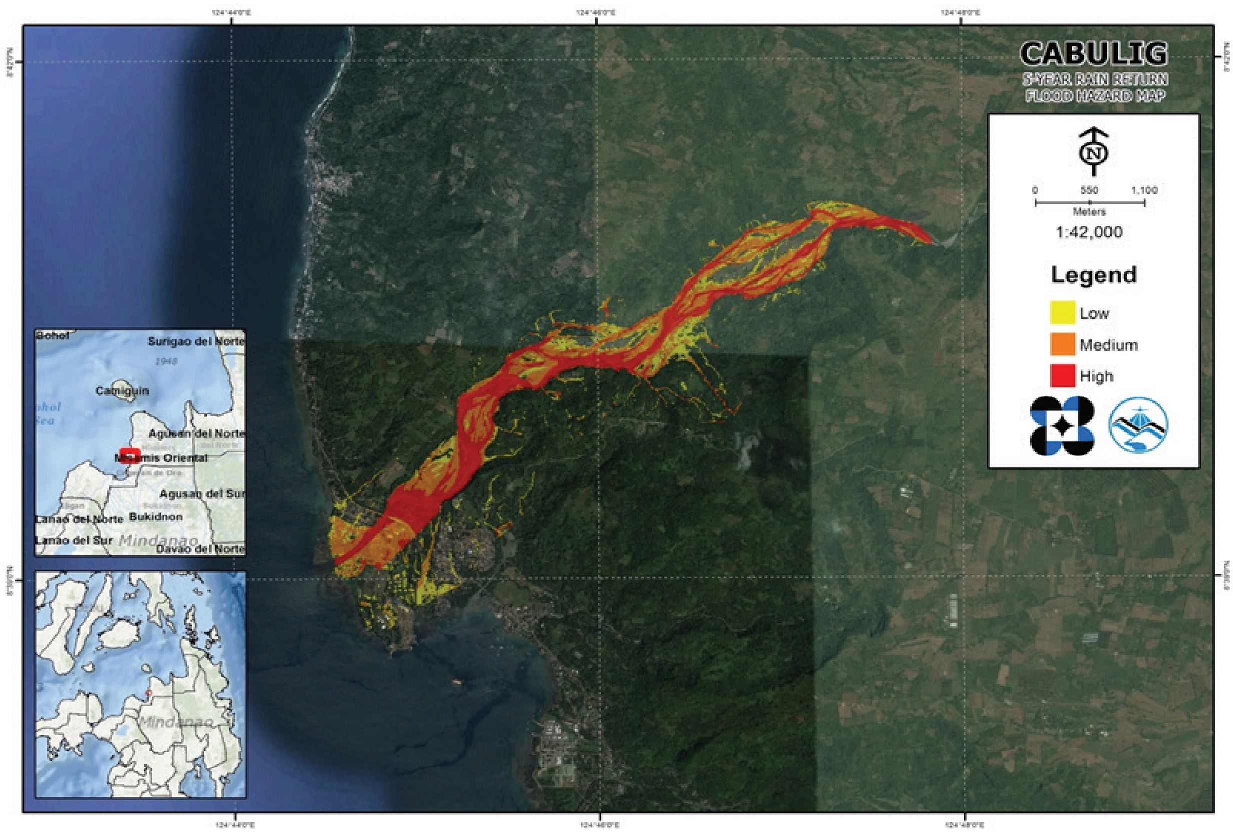


Figure 62. 5-year flood hazard map for Cabulig Floodplain

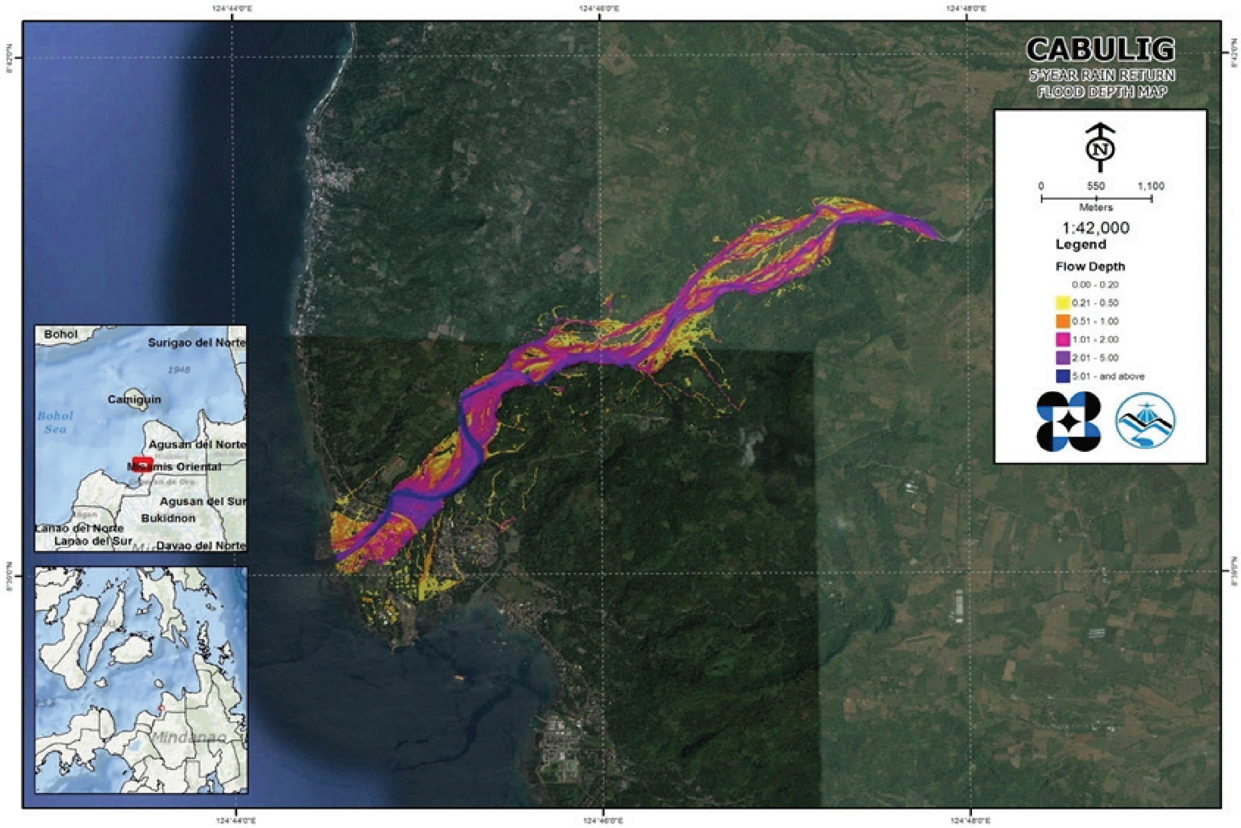


Figure 63. 5-year flood depth map for Cabulig Floodplain

5.10 Inventory of Areas Exposed to Flooding

Affected barangays in Cabulig River basin are listed below. For the said basin, only one (1) municipality consisting of six (6) barangays is expected to experience flooding when subjected to 5-year rainfall return period.

For the 5-year return period, 6.78% of the municipality of Jasaan with an area of 68.327103 km^2 will experience flood levels of less than 0.20 meters; 0.94% of the area will experience flood levels of 0.21 to 0.50 meters; while 1.06%, 1.29%, 1.10%, and 0.21% 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 the table are the affected areas in square kilometers by flood depth per barangay.

Table 33. Affected areas in Jasaan, Misamis Oriental during a 5-year rainfall return period

Affected Area (in sq.km.) by flood depth (in m.)	Affected Barangays in Jasaan (sq. km.)					
	Bobontugan	Jampason	Lower Jasaan	Natubo	San Nicolas	Upper Jasaan
0.03-0.20	0.36	0.102	0.54	0.84	2.48	0.30
0.21-0.50	0.057	0.00078	0.11	0.12	0.34	0.015
0.51-1.00	0.103	0.00048	0.077	0.095	0.44	0.0038
1.01-2.00	0.089	0.000092	0.073	0.12	0.59	0.0034
2.01-5.00	0.093	0	0.052	0.075	0.53	0.00074
> 5.00	0.048	0	0.0003	0.000099	0.092	0

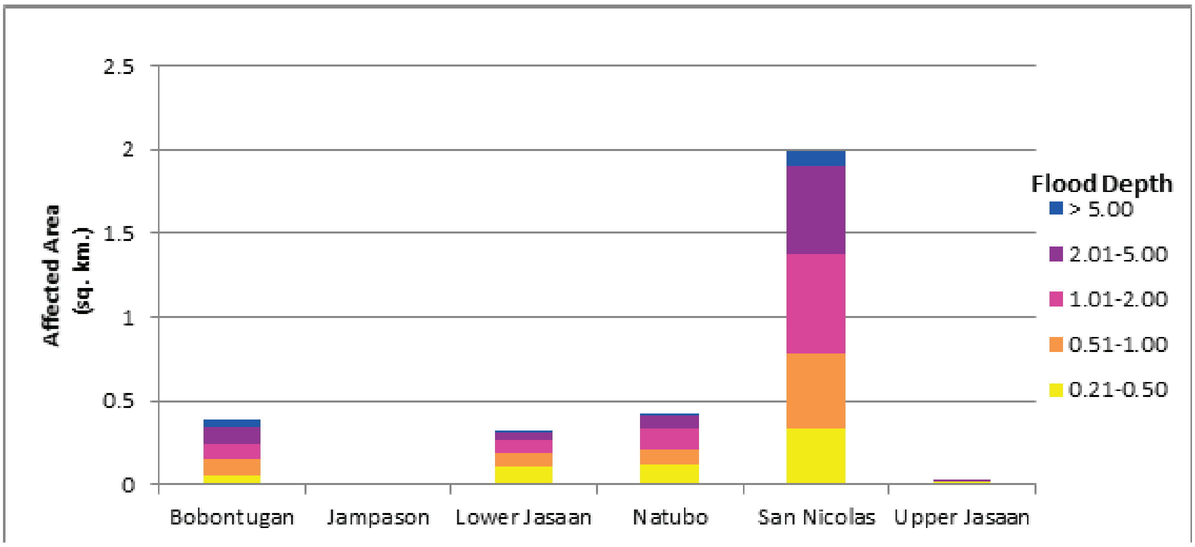


Figure 64. Affected areas in Jasaan, Misamis Oriental during a 5-year rainfall return period

For the 25-year return period, 6.14% of the municipality of Jasaan with an area of 68.327103 km^2 will experience flood levels of less than 0.20 meters; 0.69% of the area will experience flood levels of 0.21 to 0.50; meters while 0.85%, 1.67%, 1.71%, and 0.30% 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 the table are the affected areas in square kilometers by flood depth per barangay.

Table 34. Affected areas in Jasaan, Misamis Oriental during a 25-year rainfall return period

Affected Area (in sq.km.) by flood depth (in m.)	Affected Barangays in Jasaan (sq. km.)					
	Bobontugan	Jampason	Lower Jasaan	Natubo	San Nicolas	Upper Jasaan
0.03-0.20	0.32	0.101	0.49	0.79	2.201	0.28
0.21-0.50	0.039	0.0012	0.12	0.105	0.19	0.024
0.51-1.00	0.044	0.00095	0.0805	0.105	0.34	0.0059
1.01-2.00	0.15	0.000092	0.097	0.14	0.75	0.0039
2.01-5.00	0.14	0	0.073	0.11	0.85	0.00208
> 5.00	0.057	0	0.0006	0.0011	0.15	0

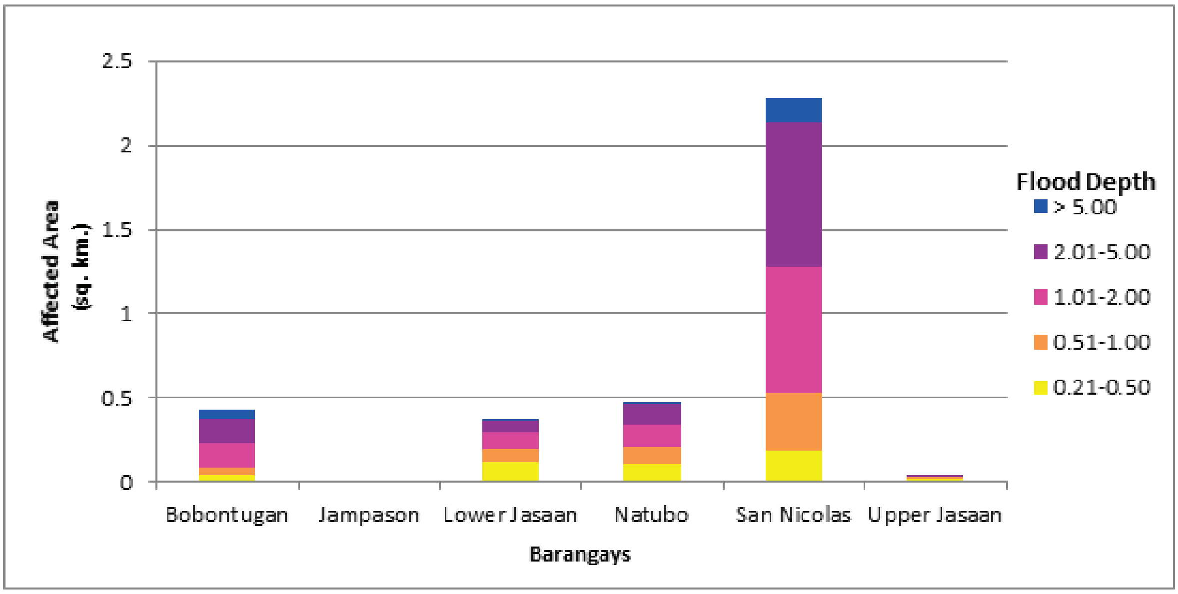


Figure 65. Affected areas in Jasaan, Misamis Oriental during a 25-year rainfall return period

For the 100-year return period, 5.88% of the municipality of Jasaan with an area of 68.327103 km^2 will experience flood levels of less than 0.20 meters; 0.62% of the area will experience flood levels of 0.21 to 0.50 meters; while 0.60%, 1.58%, 2.29%, and 0.40% 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 the table are the affected areas in square kilometers by flood depth per barangay.

Table 35. Affected areas in Jasaan, Misamis Oriental during 100-year rainfall return period

Affected Area (in sq.km.) by flood depth (in m.)	Affected Barangays in Jasaan (sq.km.)					
	Bobontugan	Jampason	Lower Jasaan	Natubo	San Nicolas	Upper Jasaan
0.03-0.20	0.303	0.1006	0.47	0.77	2.1009	0.28
0.21-0.50	0.045	0.0014	0.12	0.0902	0.14	0.030
0.51-1.00	0.033	0.0012	0.086	0.084	0.20	0.0073
1.01-2.00	0.14	0.00049	0.067	0.16	0.71	0.0047
2.01-5.00	0.17	0	0.12	0.14	1.12	0.0026
> 5.00	0.062	0	0.0022	0.0034	0.203	0

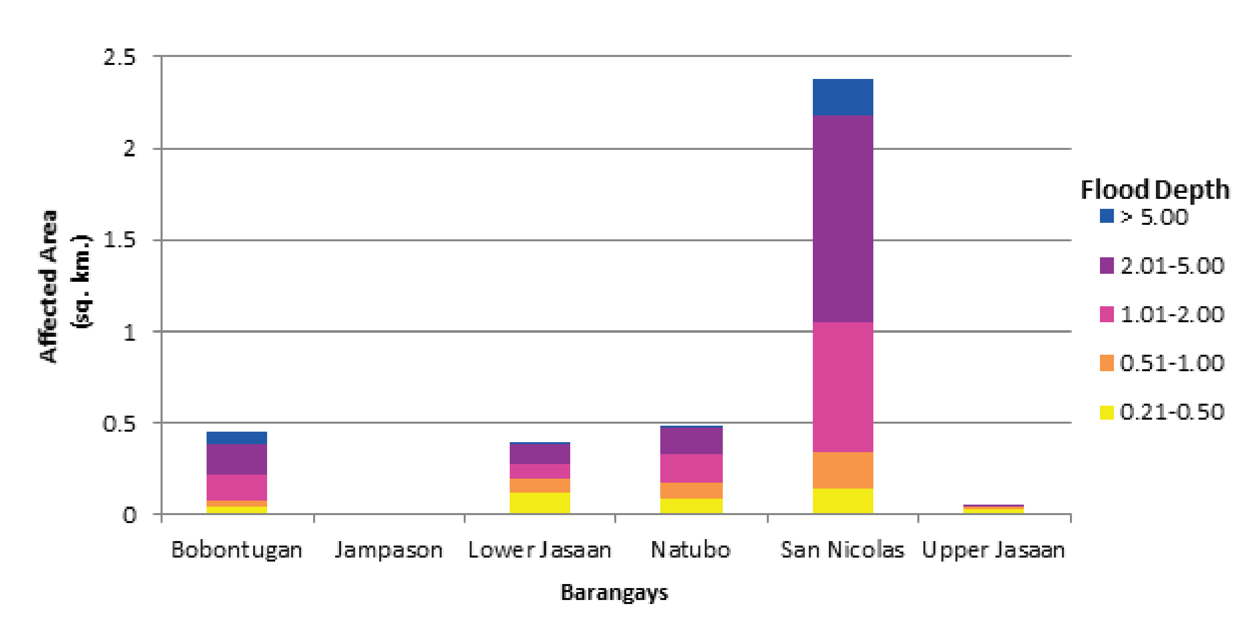


Figure 66. Affected areas in Jasaan, Misamis Oriental during 100-year rainfall return period

Among the barangays in the municipality of Cabulig, San Nicolas is projected to have the highest percentage of area that will experience flood levels at 6.56%. Meanwhile, Natubo posted the 2nd highest percentage of area that may be affected by flood depths at 1.83%.

Moreover, the generated flood hazard maps for the Alubijid 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 36. Area covered by each warning level with respect to the rainfall scenario

Warning Level	Area Covered in sq km		
	5 year	25 year	100 year
Low	0.65	0.48	0.43
Medium	1.24	1.17	0.905
High	1.28	1.96	2.44
Total	3.17	3.61	3.78

Of the 11 identified educational institutions in Cabulig Floodplain, three (3) schools were assessed to be exposed to low-level flooding in a 5-year scenario while one (1) school was assessed to be exposed to medium-level flooding in the same scenario. In the 25-year scenario, three (3) schools were assessed to be exposed to low-level flooding while one (1) school was assessed to be exposed to medium-level flooding. In the 100-year scenario, two (2) schools were assessed for low-level flooding and one (1) school for medium-level flooding. In the same scenario, one (1) school was assessed to be exposed to high-level flooding. The school exposed to high-level flooding is located in Barangay Lower Jasaan, Jasaan. The complete details are found in Annex 12.

5.11 Flood Validation

In order to check and validate the extent of flooding in different river systems, validation survey work must be performed. Field personnel gathered secondary data regarding flood occurrence in the area within the major river systems of the Philippines.

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

The validation personnel then went to specified points identified in the river basin and gathered data regarding the actual flood level in each location. Data gathering was done by obtaining maps or situation reports about past flooding events from the local DRRM office or interviewing residents who have knowledge or have experienced flooding in a particular area within the river basin.

After which, the actual field data were compared to the simulated data to assess the accuracy of the flood depth maps produced and to improve on what is needed.

The flood validation consists of 256 points randomly selected all over the Cabulig Floodplain. It has an RMSE value of 1.16.

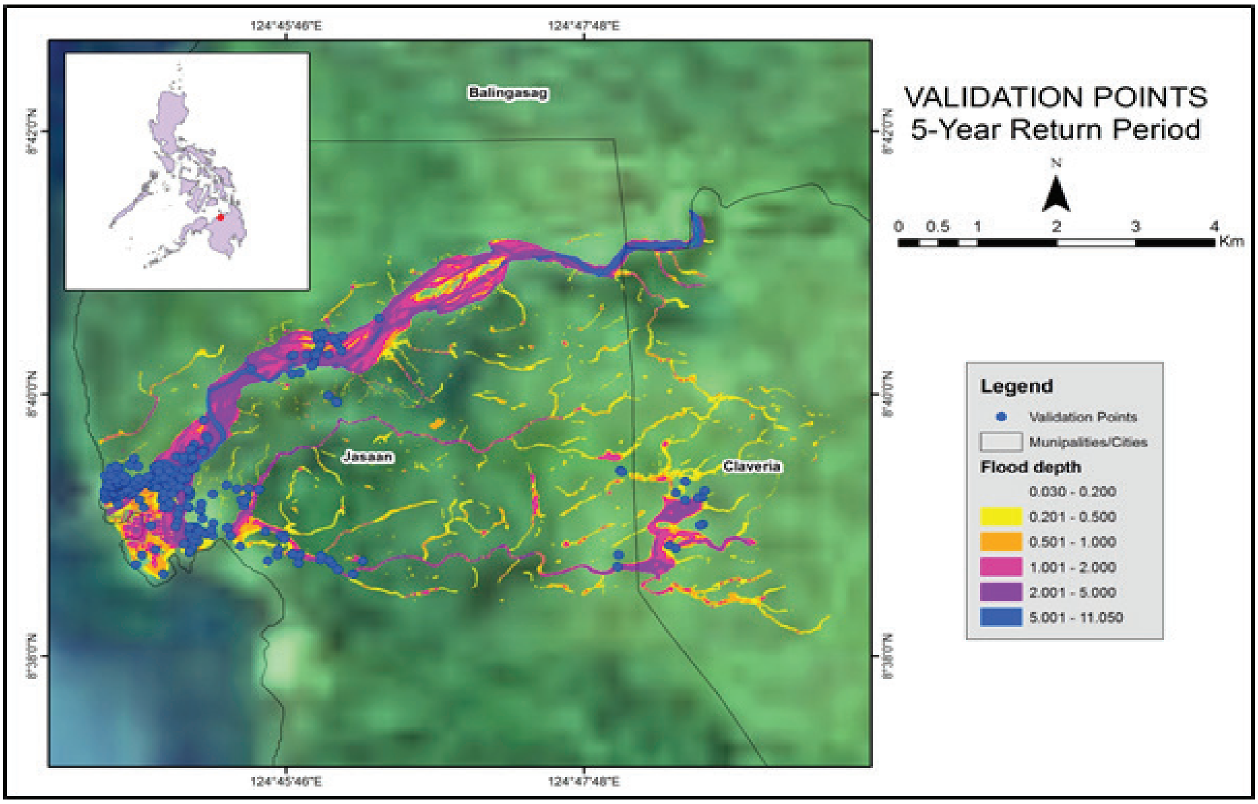


Figure 67. Cabulig flood validation points

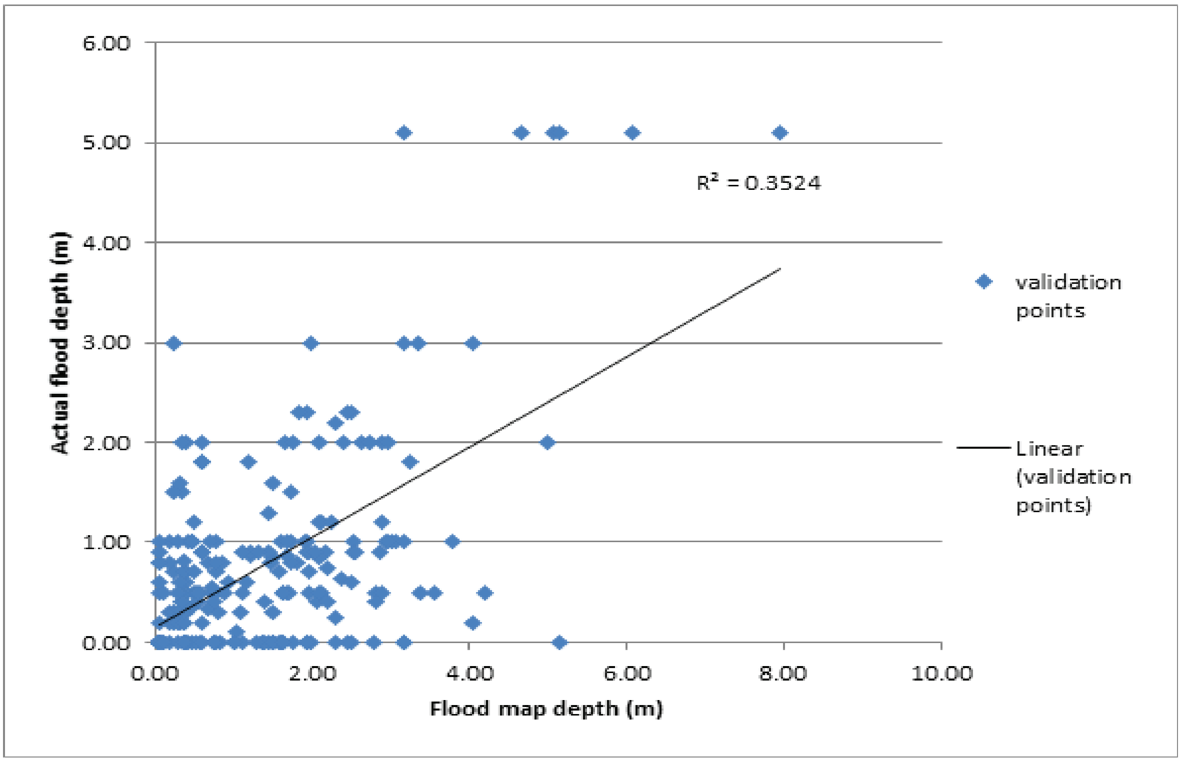


Figure 68. Flood map depth vs. actual flood depth

Table 37. Actual flood depth vs. simulated flood depth in Cabulig

Actual Flood Depth (m)	Modeled Flood Depth (m)						
	0-0.20	0.21-0.50	0.51-1.00	1.01-2.00	2.01-5.00	> 5.00	Total
0-0.20	45	13	10	19	7	1	95
0.21-0.50	3	19	10	9	11	0	52
0.51-1.00	7	13	10	20	16	0	66
1.01-2.00	0	6	3	6	12	0	27
2.01-5.00	0	1	0	3	6	0	10
> 5.00	0	0	0	0	2	4	6
Total	55	52	33	57	54	5	256

The overall accuracy generated by the flood model is estimated at 35.16%, with 90 points correctly matching the actual flood depths. In addition, there were 79 points estimated one level above and below the correct flood depths while there were 48 points and 39 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 128 points were overestimated while a total of 38 points were underestimated in the modeled flood depths of Cabulig.

Table 38. Summary of accuracy assessment in Cabulig

	No. of Points	%
Correct	90	35.16
Overestimated	128	50.00
Underestimated	38	14.84
Total	256	100.00

REFERENCES

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

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

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

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

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

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

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

ANNEXES

Annex 1. OPTECH Technical Specification of the Pegasus Sensor

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

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

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

MSE-19

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: **MISAMIS ORIENTAL**	
	Station Name: **MSE-19**	
Island: **MINDANAO**	Order: **2nd**	Barangay: **BULUA**
Municipality: **CAGAYAN DE ORO**		
	PRS92 Coordinates	
Latitude: **8° 30' 19.11464"**	Longitude: **124° 37' 6.46518"**	Ellipsoidal Hgt: **11.24200 m.**
	WGS84 Coordinates	
Latitude: **8° 30' 15.52234"**	Longitude: **124° 37' 11.86795"**	Ellipsoidal Hgt: **78.72200 m.**
	PTM Coordinates	
Northing: **940451.853 m.**	Easting: **457992.786 m.**	Zone: **5**
	UTM Coordinates	
Northing: **940,474.22**	Easting: **678,151.65**	Zone: **51**

Location Description

MSE-19
The station is located at the intersection of roads going to Cagayan de Oro City, Butuan City and Iligan City. It is situated on the center island between two triangular islands, about 14.5 m E of Bulua marker, about 21m W of black-tiled peace marker, about 10m S of road centerline, and about 3.5m S of the N end of the arc-shaped curb of the island. Statio mark is the head of a 4" copper nail set on the center of a 30cm. x 30 cm. x 60cm. concrete monument protruding by about 12cm. above the ground, with inscriptions, MSE-19, 2003 NAMRIA.

Requesting Party:	**Engr. Cruz**
Pupose:	**Reference**
OR Number:	**8796376 A**
T.N.:	**2014-1437**

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

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

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

2. MSE-3241

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

April 18, 2013

CERTIFICATION

To whom it may concern:

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

Province: **MISAMIS ORIENTAL**
Station Name: **MSE-3241**
Order: **3rd**

Island: **MINDANAO**
Municipality: **CAGAYAN DE ORO CITY (CAPITAL)**
Barangay: **BARANGAY 10 (POB.)**

PRS92 Coordinates

Latitude: **8° 27' 31.07607"**	Longitude: **124° 37' 23.18891"**	Ellipsoidal Hgt: **109.46700 m.**

WGS84 Coordinates

Latitude: **8° 27' 27.49608"**	Longitude: **124° 37' 28.59687"**	Ellipsoidal Hgt: **177.05500 m.**

PTM Coordinates

Northing: **935289.375 m.**	Easting: **458499.251 m.**	Zone: **5**

UTM Coordinates

Northing: **935,314.30**	Easting: **678,684.71**	Zone: **51**

Location Description

MSE-3241
Is located at the center island along Macapagal Rd., Brgy. 10 (Pob.), Cagayan de Oro City. It is situated between Sungcle Bldg. and Super Mart Mall, about 20 m. facing the mall entrance. Mark is the head of a 4 in. copper nail embedded on a 25 cm. x 25 cm. concrete block, with inscriptions "MSE-3241 2007 NAMRIA".

Requesting Party: **UP DREAM/ Melchor Nery**
Pupose: **Reference**
OR Number: **3943540 B**
T.N.: **2013-0311**

RUEL DM. BELEN, MNSA
Director, Mapping and Geodesy Department

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

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

There are no baseline processing reports available for the Cabulig river basin.

Annex 4. The LiDAR Survey Team Composition

Data Acquisition Component Sub -Team	Designation	Name	Agency / Affiliation
Phil-LiDAR 1	Program Leader	Enrico C. Paringit, Dr. Eng.	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	Engr. Czar Jakiri Sarmiento	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	Engr. Christopher Cruz	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	Lovely Gracia Acuña	UP-TCAGP
		Lovelyn Asuncion	UP-TCAGP
FIELD TEAM			
LiDAR Operation	Senior Science Research Specialist (SSRS)	Jasmine Alviar	UP-TCAGP
	Research Associate (RA)	Grace Sinadjan	UP-TCAGP
		Engr. Iro Niel Roxas	UP-TCAGP
Ground Survey, Data Download and Transfer		Lance Kerwin Cinco	UP-TCAGP
LiDAR Operation	Airborne Security	Ssg. Lee Jay Punzalan	PHILIPPINE AIR FORCE (PAF)
	Pilot	Capt. Jeffrey Jeremy Alajar	ASIAN AEROSPACE CORPORATION (AAC)
		Capt. Cesar Alfonso III	AAC

Annex 5. Data Transfer Sheet for Cabulig Floodplain

DATA TRANSFER SHEET
06/10/2014(Northern Mindanao) Outgoing

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	
5/22/2014	1497P	1BLK87B142A	PEGASUS	1.8	1342	8.61	201	31.8	221	19.1	NA	5.19	1KB	1KB	49	NA	Z:\Airborne_Raw\1497P
5/23/2014	1501P	1BLK87C143A	PEGASUS	3	1221	14.1	271	77.3	539	29.5	NA	7.61	1KB	1KB	59/58	NA	Z:\Airborne_Raw\1501P
5/24/2014	1505P	1BLK87BC144A	PEGASUS	2.25	759	10	212	46.7	340	21.8	NA	7.68	1KB	1KB	97	NA	Z:\Airborne_Raw\1505P
5/25/2014	1509P	1RDXE145A	PEGASUS	2.4	338	11.2	254	NA 31.6 [illegible]	[illegible] NA	26.2	NA	4.96	1KB	1KB	50/43	NA	Z:\Airborne_Raw\1509P
5/27/2014	1517P	1RXE147A	PEGASUS	2.74	1497	12	235	NA	NA	27.7	NA	9.7	1KB	1KB	78/72	NA	Z:\Airborne_Raw\1517P
5/28/2014	1521P	1RXC148A	PEGASUS	2.39	490	12	252	NA	NA	28	NA	5.54	1KB	1KB	52	NA	Z:\Airborne_Raw\1521P

Received from

Name C. Joaquin
Position
Signature

Received by

Name JOIDA PRIETO
Position SSRS
Signature
6/10/2014

DATA TRANSFER SHEET
06/20/2014(Northern Mindanao)

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	
29-May-14	1525P	1RXB149A	PEGASUS	1.6	457	9.27	265	na	na	26.5	NA	9.83	1KB	1KB	40	NA	Z:\Airborne_Raw\1525P
31-May-14	1533P	1BLK67151A	PEGASUS	3.32	270	14.4	224	43.2	428	33.3	NA	8.87	1KB	1KB	47/38	NA	Z:\Airborne_Raw\1533P
2-Jun-14	1541P	1BLK71B153A	PEGASUS	4	242	0	285	19.7	139	39	674MB	12.6	1KB	1KB	47/45/40/34	NA	Z:\Airborne_Raw\1541P
3-Jun-14	1545P	1BLK71C154A	PEGASUS	4.13	2259	13	253	69.7	533	40.1	272MB	9.95	1KB	1KB	141	NA	Z:\Airborne_Raw\1545P
4-Jun-14	1549P	1BLK71D155A	PEGASUS	3.48	150	14.3	264	NA	NA	34.6	NA	11.2	1KB	1KB	54/50/45	NA	Z:\Airborne_Raw\1549P
7-Jun-14	1561P	1RXE158A	PEGASUS	NA	44	NA	187	NA	NA	22	NA	8.1	1KB	1KB	71	NA	Z:\Airborne_Raw\1561P
8-Jun-14	1565P	1BLK71B159A	PEGASUS	NA	16	5.35	168	22.1	163	13.3	NA	7.75	1KB	1KB	36	NA	Z:\Airborne_Raw\1565P

Received from

Name C. JOAQUIN
Position RA
Signature

Received by

Name JOIDA F. PRIETO
Position SSRS
Signature

6/23/2014

DATA TRANSFER SHEET
07/28/2014(Northern Mindanao - ready)

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	
6/8/2014	1565P	1BLK71B159A	Pegasus	NA	16	6.93	168	NA	NA	13.3	NA	7.75	1KB	1KB	36	NA	Z:\Airborne_Raw
6/9/2014	1569P	1BLKRXE160A	Pegasus	4.16	832	16.5	290	8.86	62	38.5	NA	10	1KB	1KB	85	NA	Z:\Airborne_Raw
6/16/2014	1597P	1BLKRXE167A	Pegasus	2.18	332	10.5	237	NA	NA	21.3	NA	7.52	1KB	1KB	68	NA	Z:\Airborne_Raw
6/19/2014	1609P	1RXS170A	Pegasus	2.16	526	11.2	259	45.3	309	22.1	NA	7.07	1KB	1KB	77/76	NA	Z:\Airborne_Raw
6/20/2014	1613P	1BLK71G171A	Pegasus	3.44	177	13.7	258	67.3	437	33.2	NA	5.92	1KB	1KB	46	NA	Z:\Airborne_Raw
6/23/2014	1625P	1BLK67BC174A	Pegasus	3.09	1112	11.7	212	60.3	415	29.4	86.6	4.97	1KB	1KB	52/56	NA	Z:\Airborne_Raw
6/24/2014	1629P	1BLKRXES175A	Pegasus	2.79	370	10.7	187	36.3	268	26.1	NA	4.45	1KB	1KB	73	NA	Z:\Airborne_Raw
6/27/2014	1641P	1BLK68A178A	Pegasus	2.94	1995	12.6	268	57.4	398	28.9	57.2	7.7	1KB	1KB	65/65/60/58	NA	Z:\Airborne_Raw
6/27/2014	1643P	1BLK67ABS178B	Pegasus	532	95	4.33	119	NA	NA	5.65	NA	7.7	1KB	1KB	48	NA	Z:\Airborne_Raw
6/28/2014	1645P	1BLK71C179A	Pegasus	2.84	NA	11.4	242	51.8	375	27.4	NA	6.25	1KB	1KB	59/68	NA	Z:\Airborne_Raw

Received from

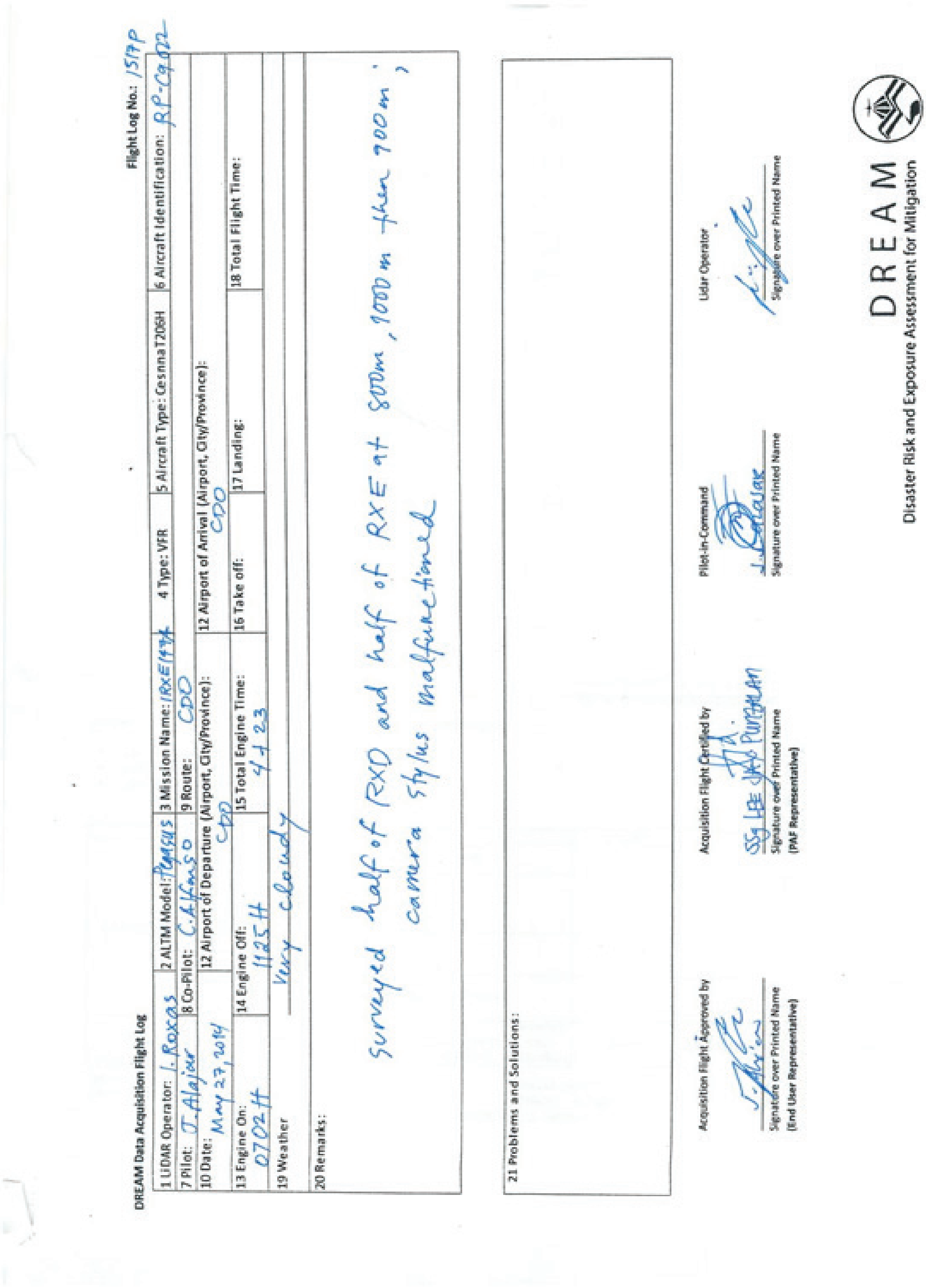
Name TIN ANDAYA
Position RA
Signature

Received by

Name IDINA BRETO'
Position SSRS
Signature 7/28/14

Annex 6. Flight Logs for the Flight Missions

1. Flight Log for 1517P Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 1517P

1 LiDAR Operator: I. Roxas	2 ALTM Model: Pegasus	3 Mission Name: 1RXE147A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RP-C9022
7 Pilot: J. Alajar	8 Co-Pilot: C. Alfonso	9 Route: CDO			
10 Date: May 27, 2014	12 Airport of Departure (Airport, City/Province): CDO		12 Airport of Arrival (Airport, City/Province): CDO		
13 Engine On: 0702H	14 Engine Off: 1125H	15 Total Engine Time: 4+23	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: Very cloudy					

20 Remarks:

surveyed half of RXD and half of RXE at 800m, 1000m then 900m; camera stylus malfunctioned

21 Problems and Solutions:

Acquisition Flight Approved by
J. Alajar
Signature over Printed Name
(End User Representative)

Acquisition Flight Certified by
SSg Lee Jay Punzalan
Signature over Printed Name
(PAF Representative)

Pilot-in-Command
J. Salazar
Signature over Printed Name

Lidar Operator
Signature over Printed Name

DREAM
Disaster Risk and Exposure Assessment for Mitigation

2. Flight Log for 1561P Mission

DREAM Data Acquisition Flight Log

Flight Log No.: 1561P

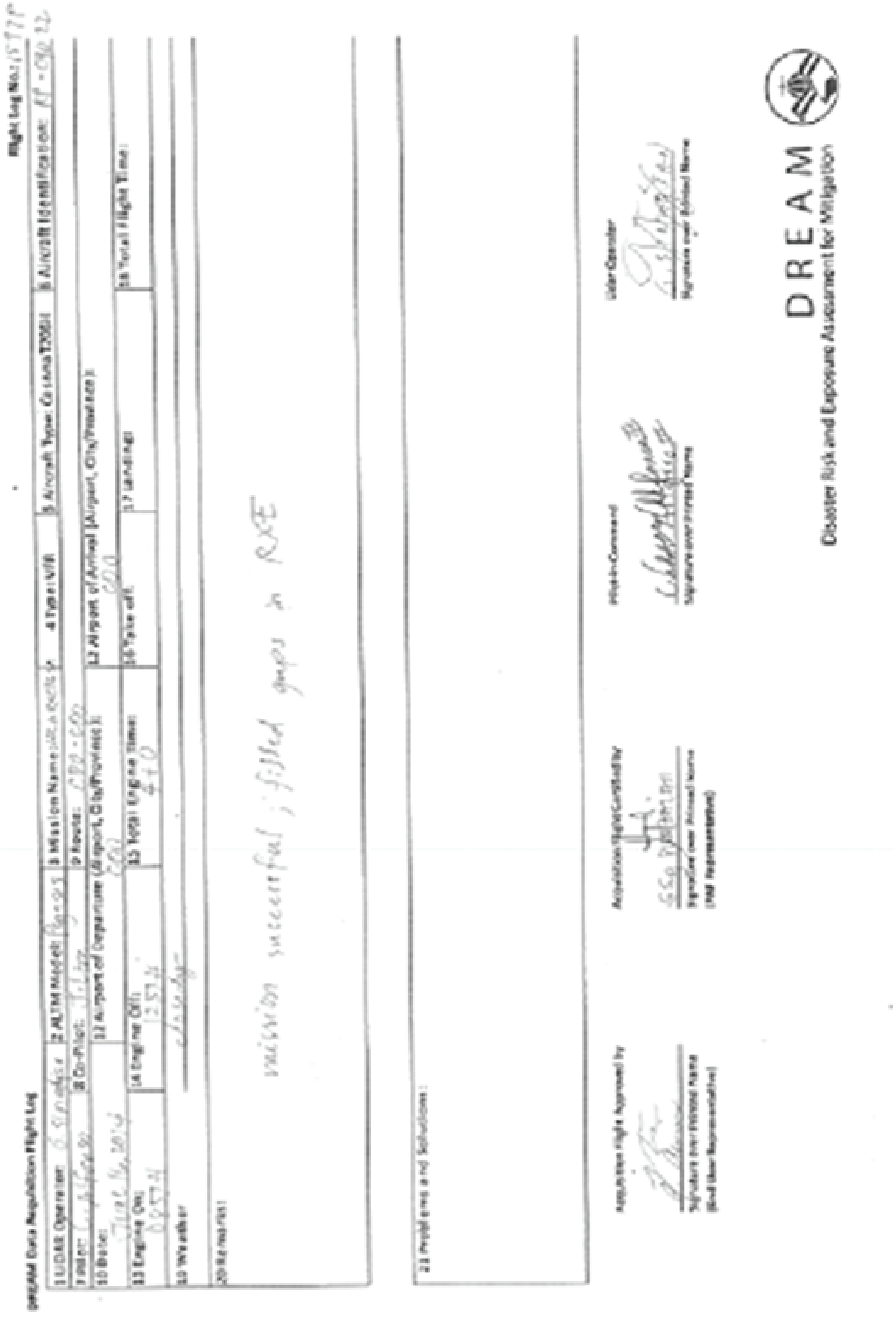
1 LIDAR Operator: G. Sinadjan	2 ALTM Model: Pegasus	3 Mission Name: 1BLK72XBS158A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso	8 Co-Pilot: J. Lim	9 Route: CPO - CPO			
10 Date: June 7, 2014	12 Airport of Departure (Airport, City/Province): CPO		12 Airport of Arrival (Airport, City/Province): CPO		
13 Engine On: 0919H	14 Engine Off: 1300H	15 Total Engine Time: 3+41	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: partly cloudy					
20 Remarks:					

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
J. Alviar	SSG Punzalan	C. Alfonso III	G. Sinadjan
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

DREAM
Disaster Risk and Exposure Assessment for Mitigation

3. Flight Log for 1597P Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 1597P

1 LiDAR Operator: G. Sinadjan	2 ALTM Model: Pegasus	3 Mission Name: [illegible]	4 Type: VFR	5 Aircraft Type: Cessna T206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso	8 Co-Pilot: [illegible]	9 Route: CDO - CDO			
10 Date: June 16, 2014	12 Airport of Departure (Airport, City/Province): CDO		12 Airport of Arrival (Airport, City/Province): CDO		
13 Engine On: 0857H	14 Engine Off: 1257H	15 Total Engine Time: 4+00	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: cloudy					

20 Remarks:

mission successful; filled gaps in RXE

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 — Signature over Printed Name

Lidar Operator — Signature over Printed Name

DREAM

Disaster Risk and Exposure Assessment for Mitigation

Annex 7. Flight Status Reports

NORTHERN MINDANAO
(May 27 - June 16, 2014)

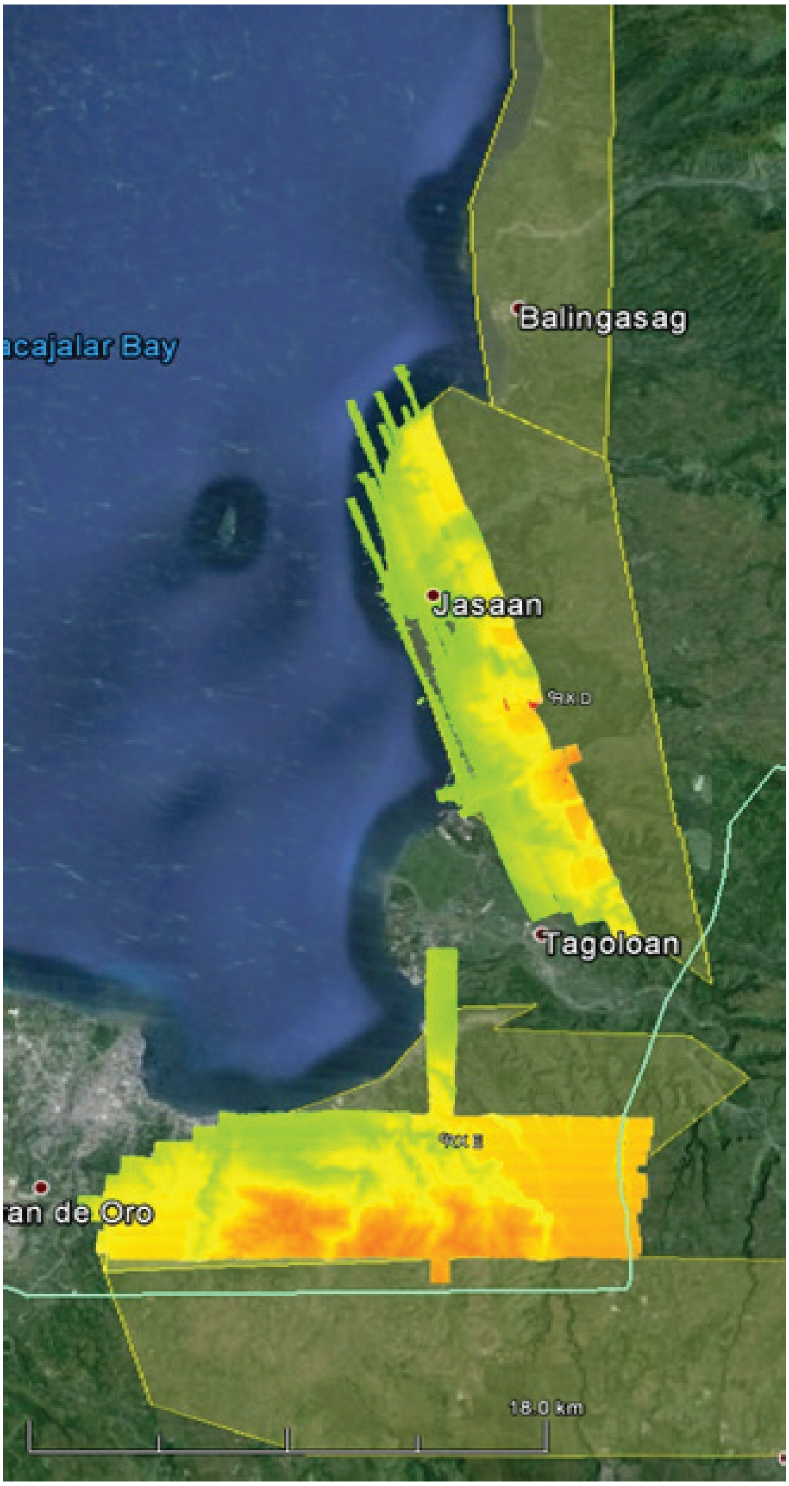
FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
1517P	RX BLKD,E	1RXE147A	I. Roxas	May 27, 2014	Surveyed half of RX D and half of RX E at 800m, 1000m then 900m; cam stylus malfunctioned
1561P	RX BLKD	1RXE158A	G.Sinadjan	June 7, 2014	Mission successful; gaps due to high terrain
1597P	RX BLKD,E	1BLKRXE167A	G.Sinadjan	June 16, 2014	Mission successful; filled gaps in RX E

LAS BOUNDARIES PER FLIGHT

Flight No. :	1517P
Area:	RX D, RX E
Mission Name:	1RXE147A

Parameters:

Altitude:	900m;
Scan Frequency:	30Hz;
Scan Angle:	25deg;
Overlap:	30%

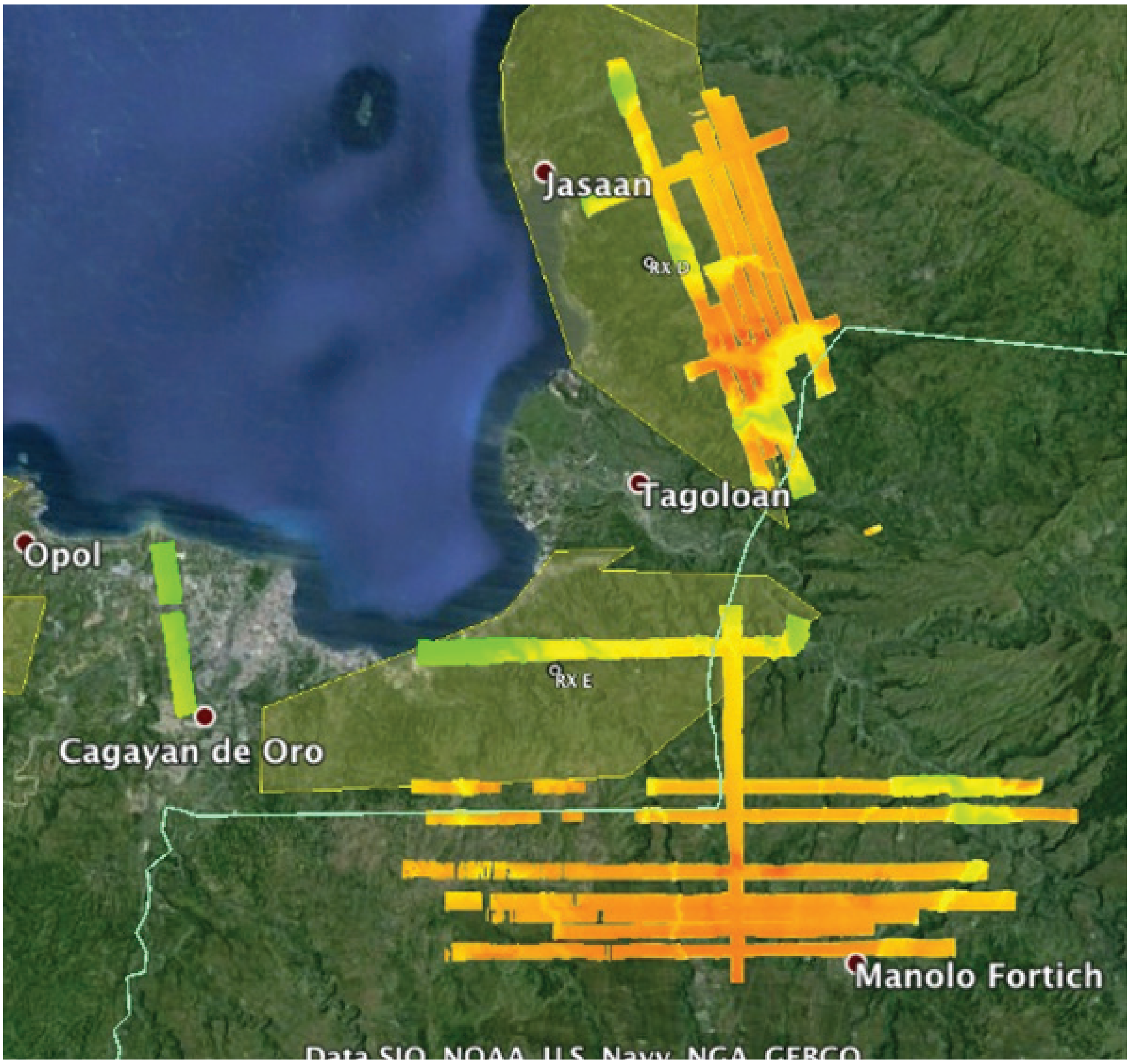


Flight No. :	1561P
Area:	RX D
Mission Name:	1RXE158A
Parameters:	
Altitude:	1000 m;
Scan Frequency:	30Hz;
Scan Angle:	25deg;
Overlap:	30%

LAS

Flight No. :	1597P
Area:	RX D, RX E
Mission Name:	1BLKRXE167A
Parameters:	
Altitude:	800m
Scan Frequency:	30Hz
Scan Angle:	25 deg
Overlap:	30%

LAS



Annex 8. Mission Summary Reports

Flight Area	Northern Mindanao
Mission Name	RX_D
Inclusive Flights	1561P
Range data size	22 GB
Base data size	
POS	187 MB
Image	n/a
Transfer date	June 23, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.3
RMSE for East Position (<4.0 cm)	1.05
RMSE for Down Position (<8.0 cm)	3.2
Boresight correction stdev (<0.001deg)	0.000179
IMU attitude correction stdev (<0.001deg)	0.001266
GPS position stdev (<0.01m)	0.0058
Minimum % overlap (>25)	33.38%
Ave point cloud density per sq.m. (>2.0)	3.85
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	297
Maximum Height	747.65 m
Minimum Height	66.39
Classification (# of points)	
Ground	242,066,972
Low vegetation	216,117,519
Medium vegetation	359,141,389
High vegetation	333,494,074
Buildings	15,951,611
Orthophoto	
Processed by	Engr. Jommer Medina, Engr. Kenneth Solidum, Aljon Rie Araneta, and Engr. Gladys Mae Apat

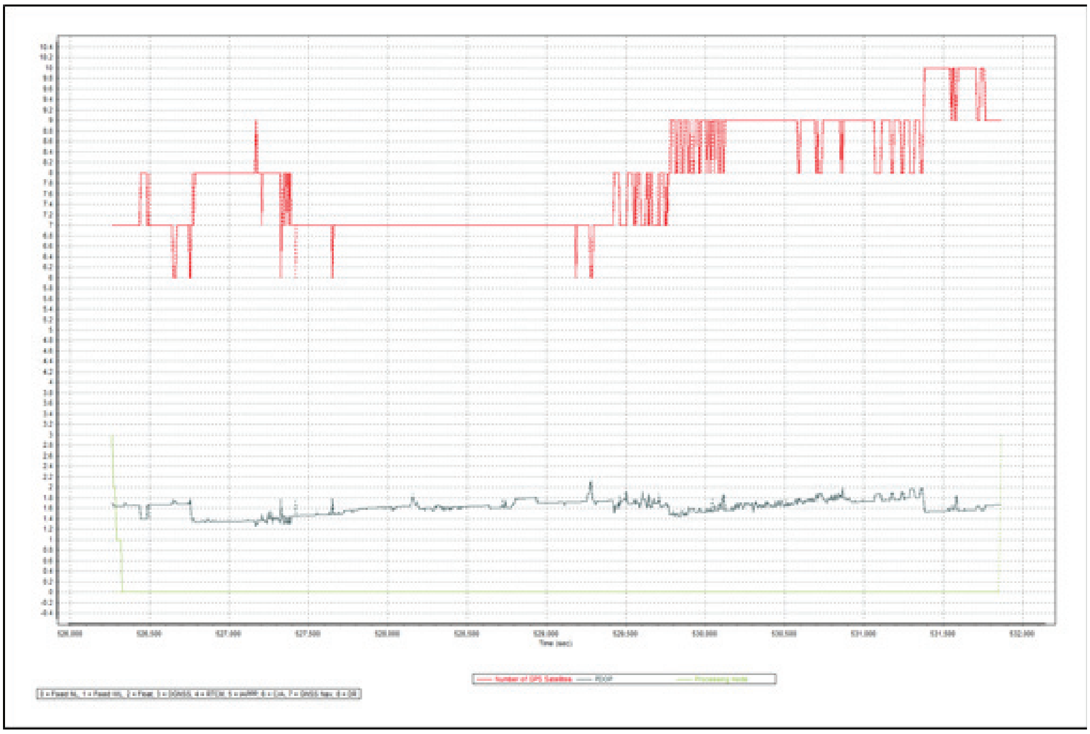


Figure A-8.1. Solution Status

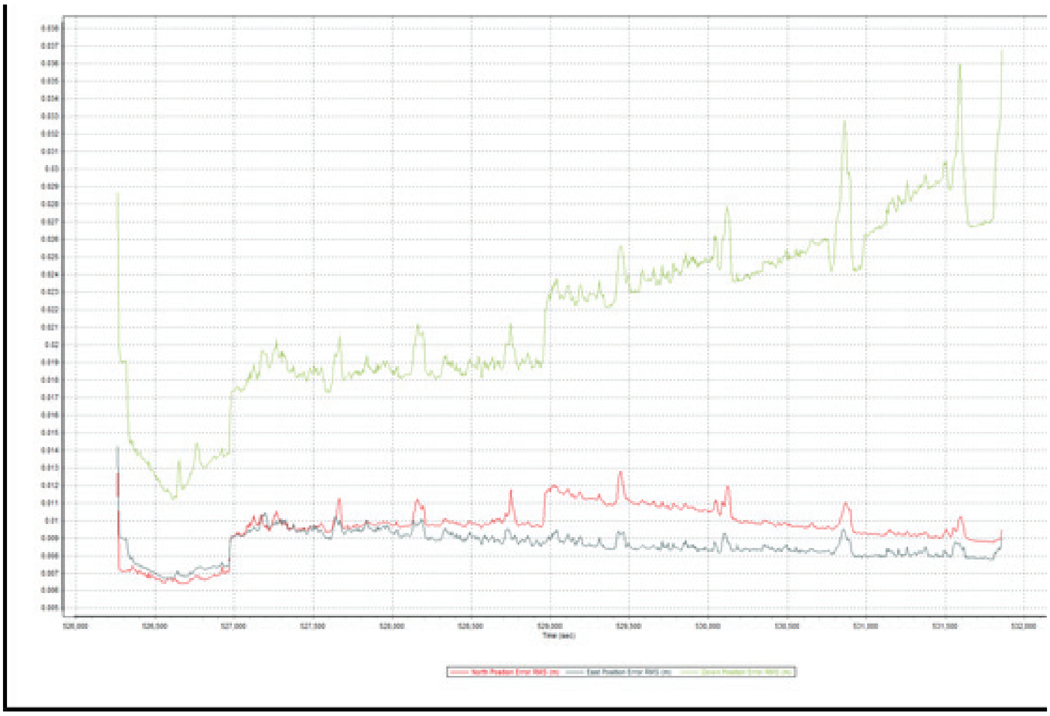


Figure A-8.2. Smoothed Performance Metric Parameters

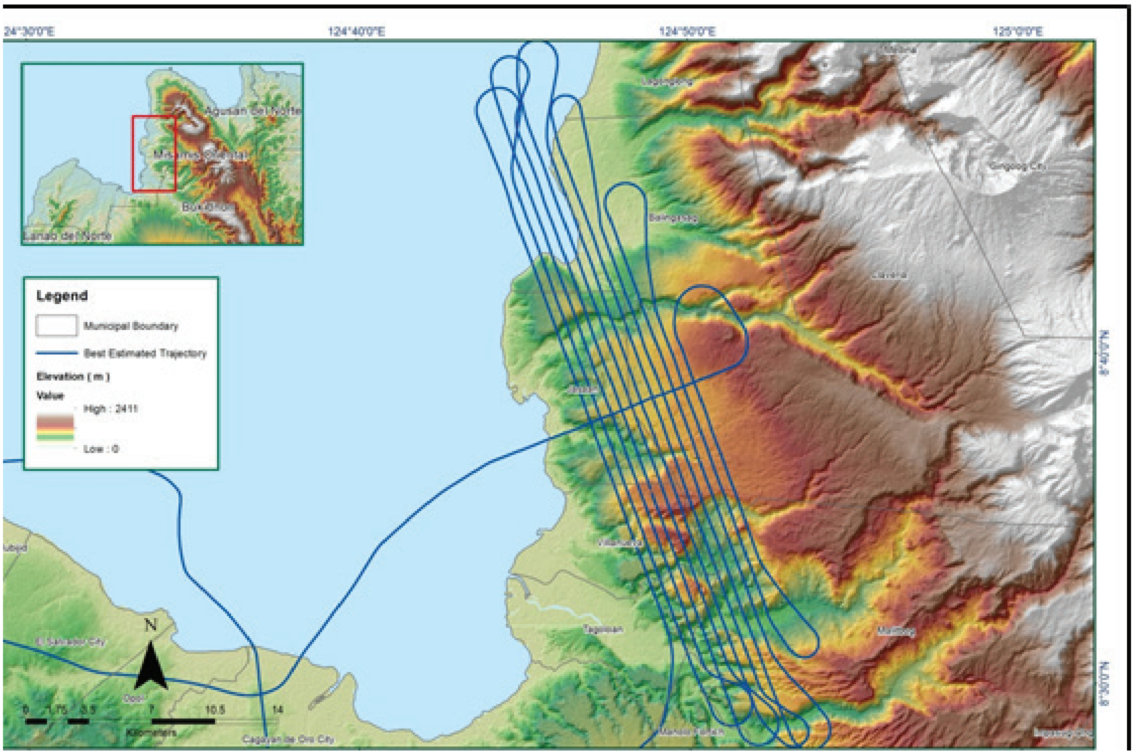


Figure A-8.3. Best Estimated Trajectory

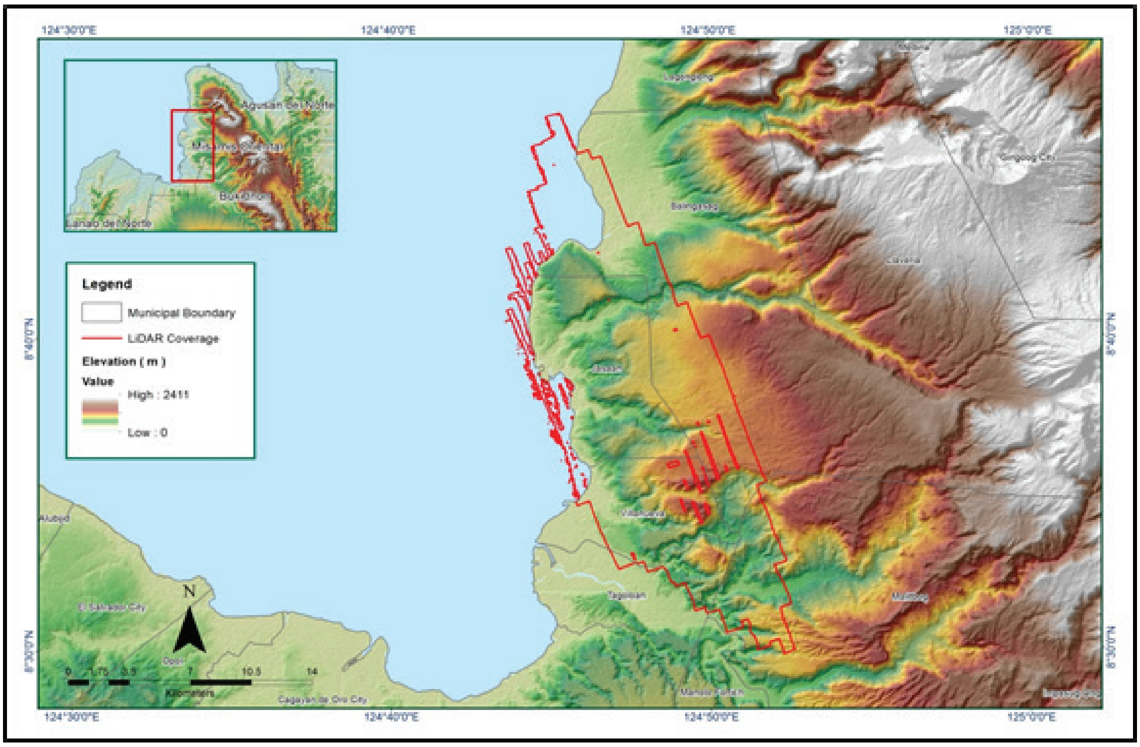


Figure A-8.4. Coverage of LiDAR data

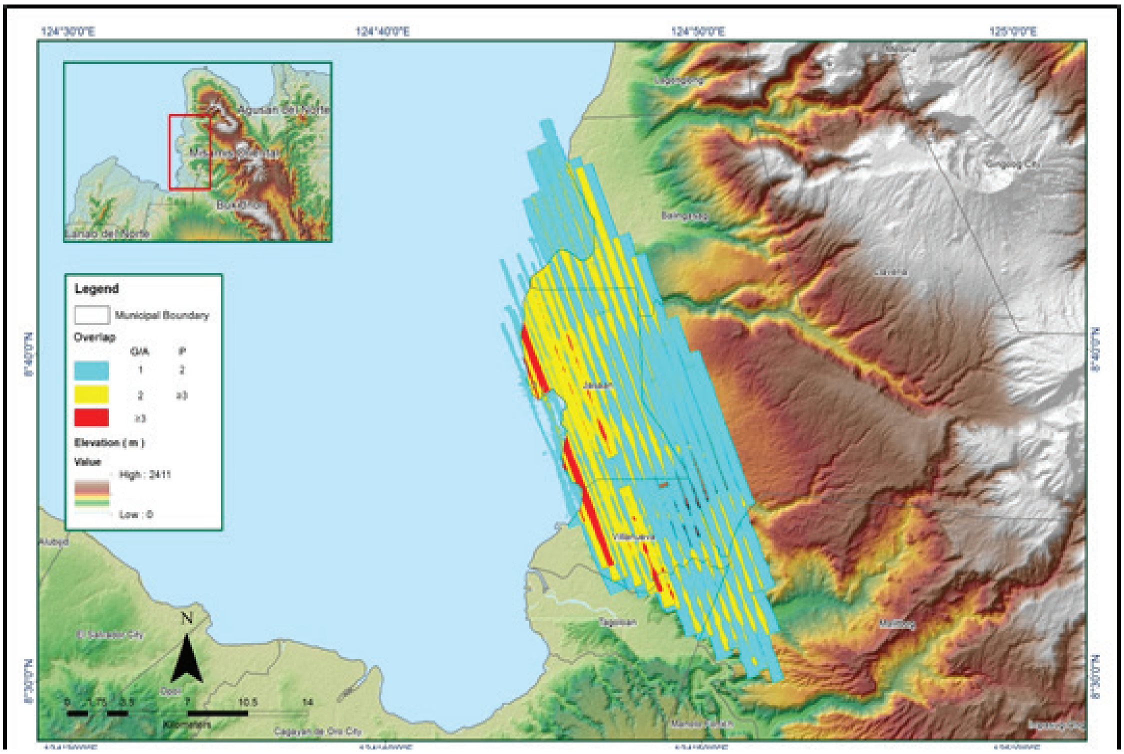


Figure A-8.5. Image of data overlap

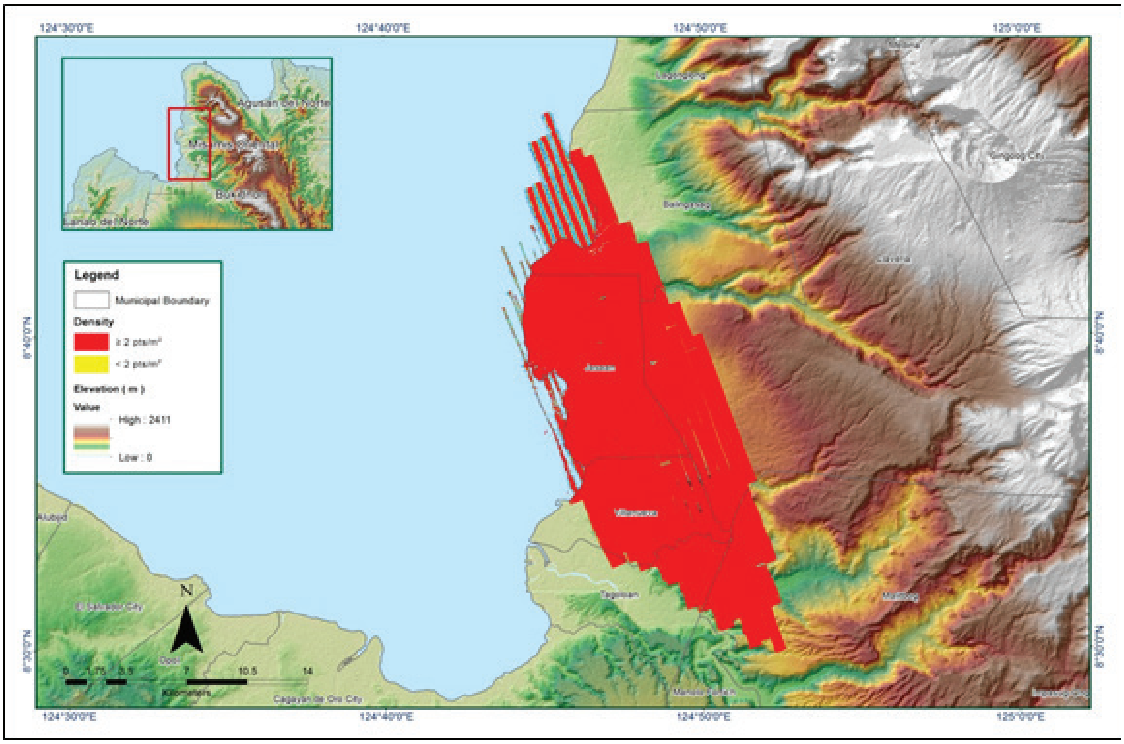


Figure A-8.6. Density map of merged LiDAR data

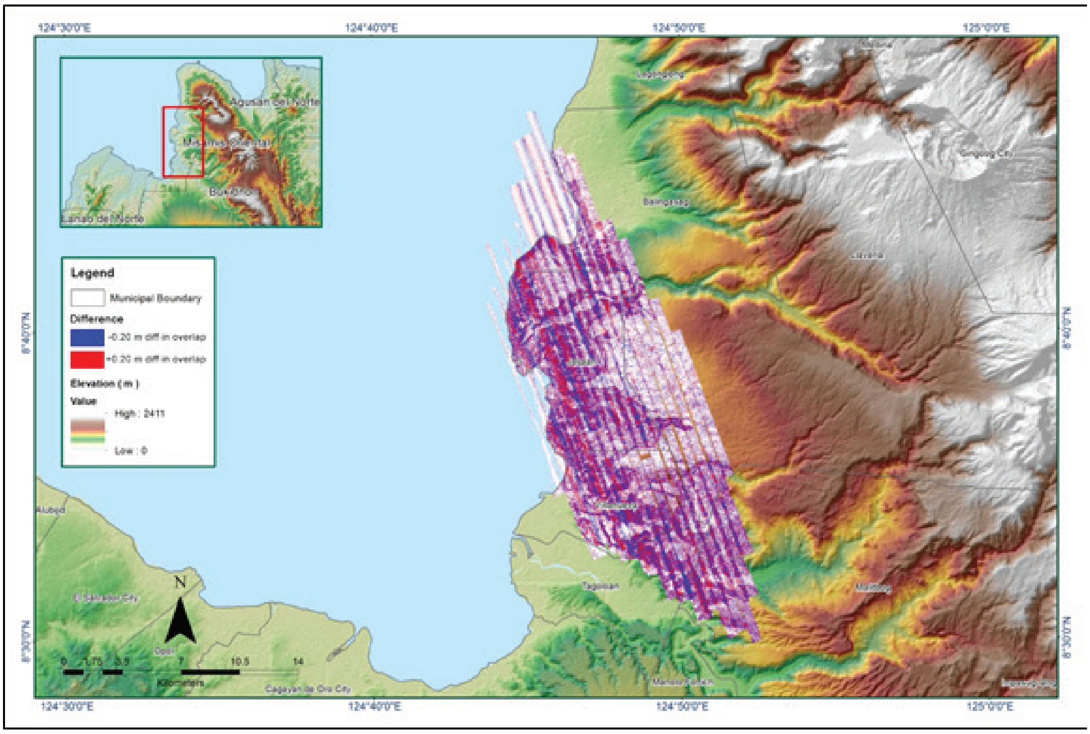


Figure A-8.7. Elevation difference between flight lines

Flight Area	Northern Mindanao
Mission Name	RX_D_additional
Inclusive Flights	1597P
Range data size	21.3 GB
Base data size	7.52 MB
POS	237 MB
Image	n/a
Transfer date	August 1, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	1.7

RMSE for North Position (<4.0 cm)	1.7
RMSE for East Position (<4.0 cm)	1.3
RMSE for Down Position (<8.0 cm)	4.4
Boresight correction stdev (<0.001deg)	0.00340
IMU attitude correction stdev (<0.001deg)	0.004112
GPS position stdev (<0.01m)	0.0130
Minimum % overlap (>25)	2.14%
Ave point cloud density per sq.m. (>2.0)	4.71
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	102
Maximum Height	107.46 m
Minimum Height	746.85
Classification (# of points)	
Ground	59,413,187
Low vegetation	58,674,983
Medium vegetation	113,901,278
High vegetation	81,488,796
Building	2,948,465
Orthophoto	
Processed by	Engr. Kenneth Solidum, Engr. Melanie Hingpit, Engr. Roa Shelmar Redo

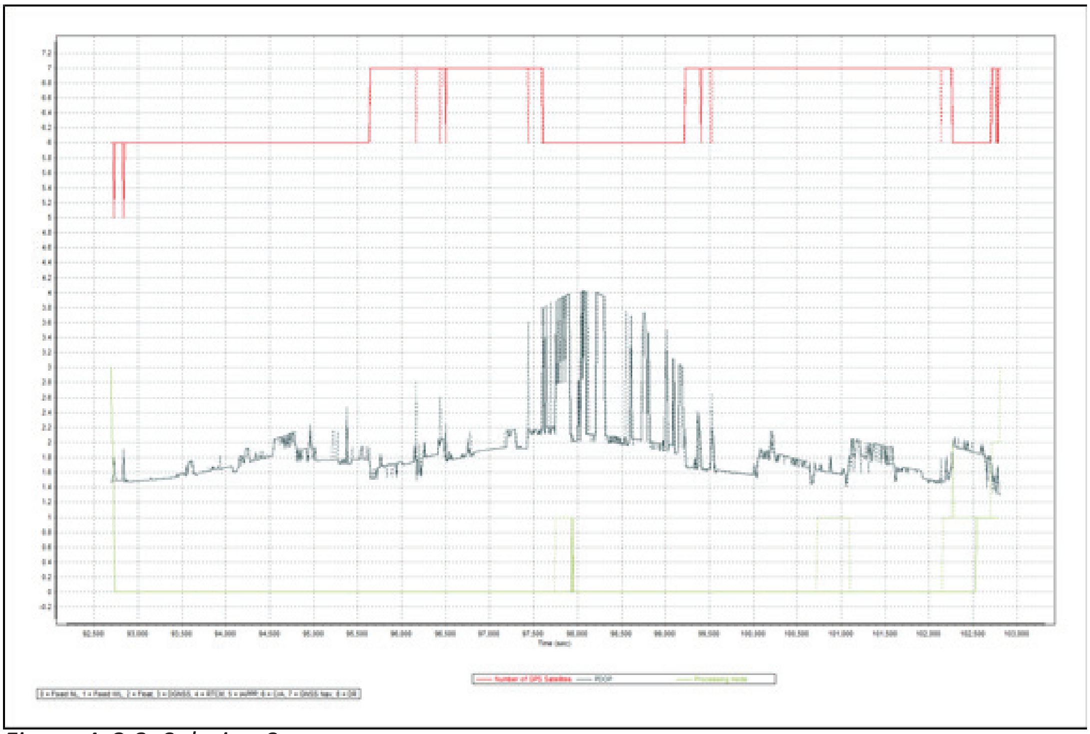


Figure A-8.8. Solution Status

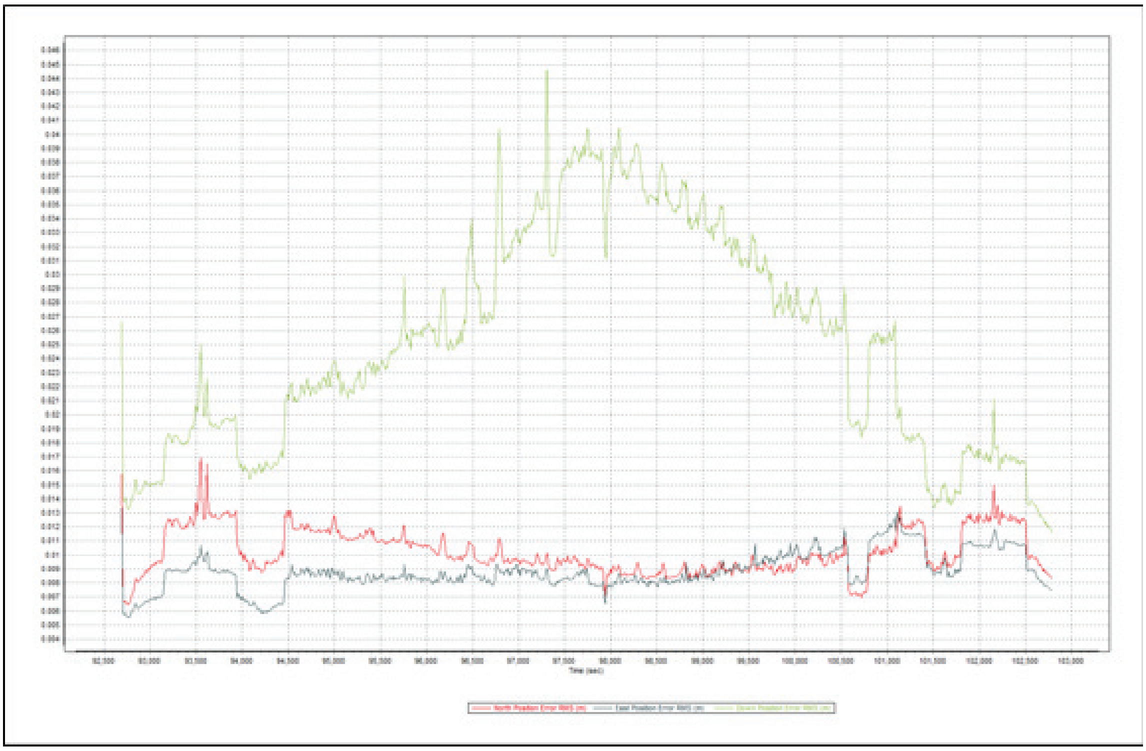


Figure A-8.9. Smoothed Performance Metric Parameters

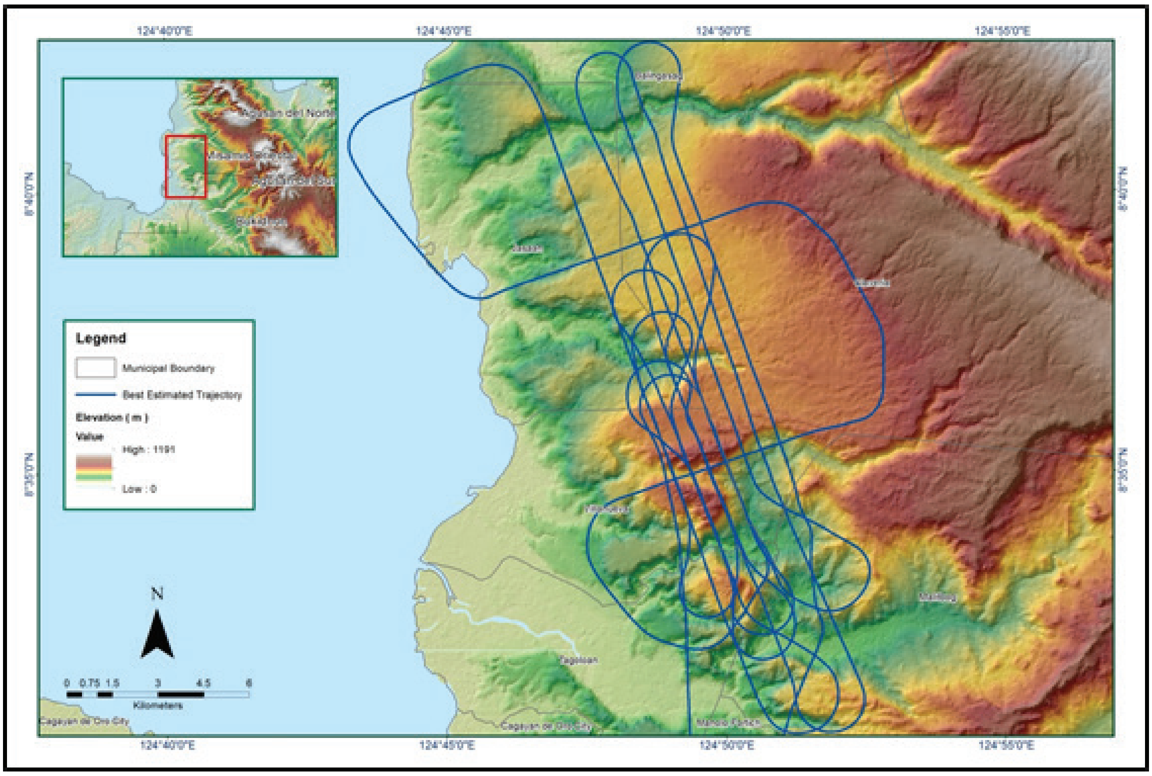


Figure A-8.10. Best Estimated Trajectory

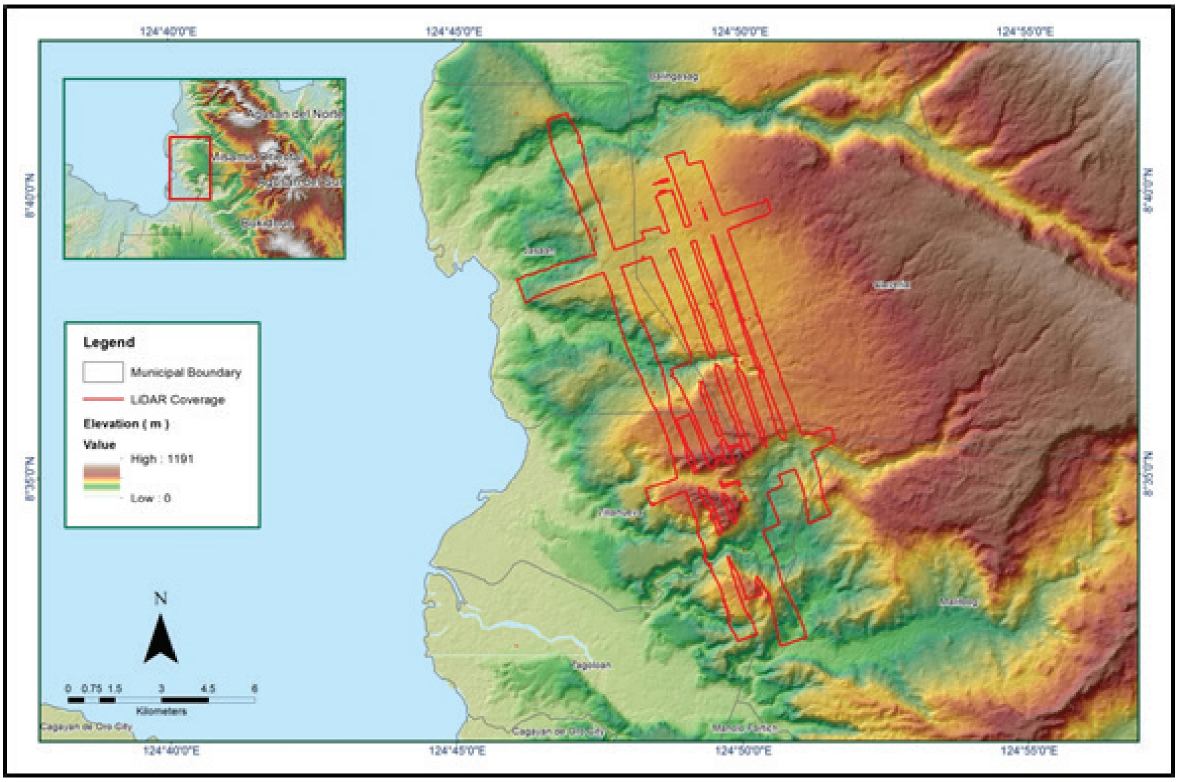


Figure A-8.11. Coverage of LiDAR data

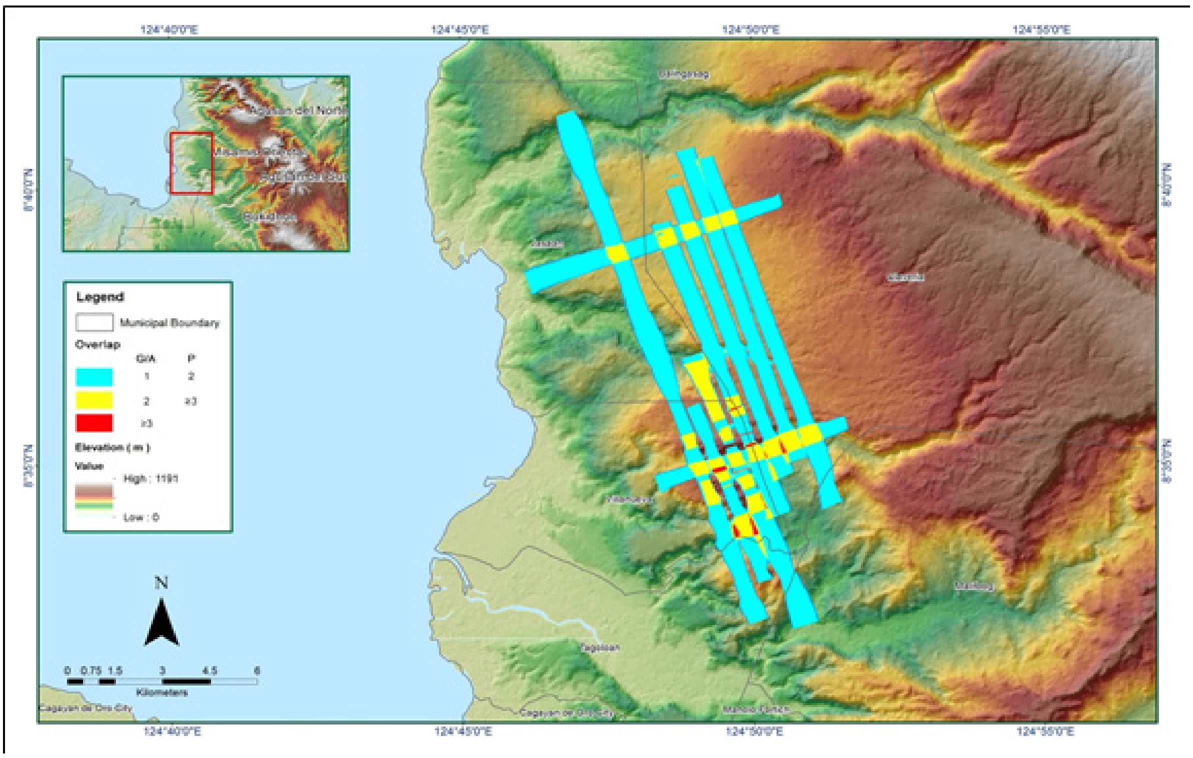


Figure A-8.11. Coverage of LiDAR data

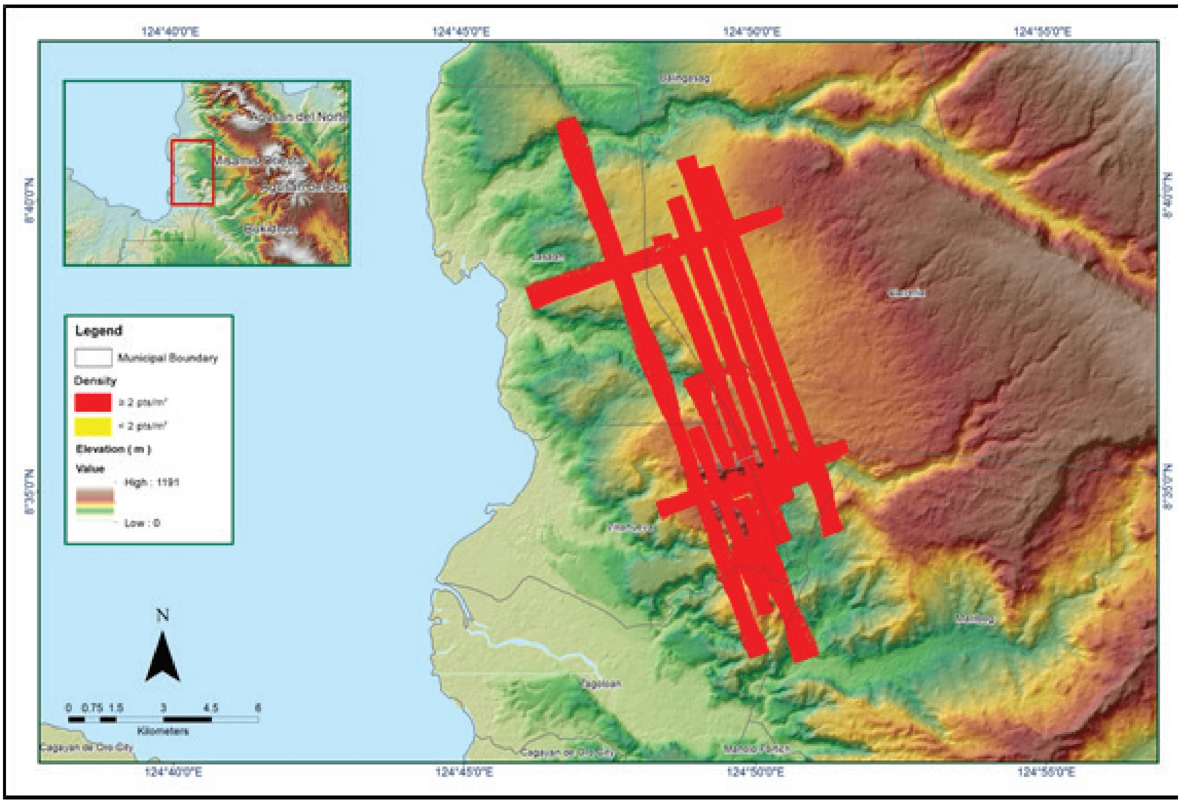


Figure A-8.13. Density map of merged LiDAR data

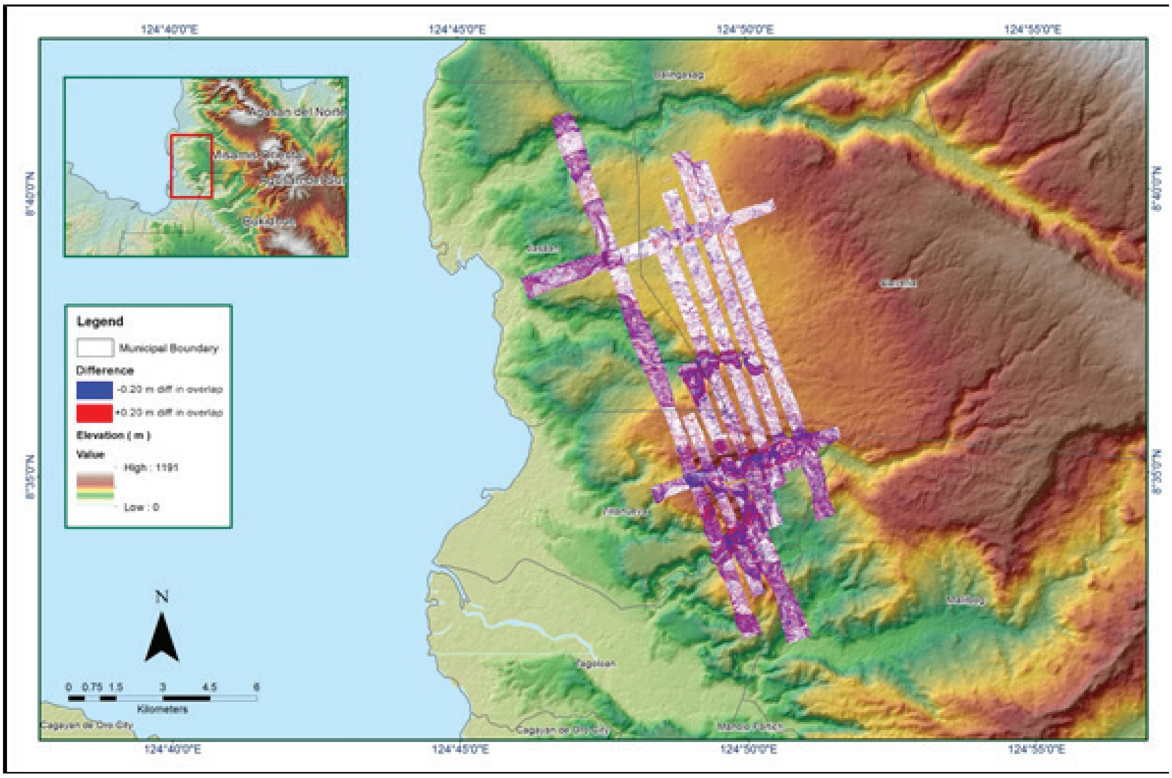


Figure A-8.14. Elevation difference between flight lines

Annex 9. Cabulig 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	8.0066	65.893	0	0.01667	18.25445	Discharge	0.092568	0.00001	Ratio to Peak	0.00001
W1010	4.0796	81.065	0	0.01667	6.7325	Discharge	0.026808	0.00001	Ratio to Peak	0.00001
W1020	4.5706	78.78	0	0.01667	11.22655	Discharge	0.074983	0.00001	Ratio to Peak	0.00001
W1030	5.5893	74.439	0	0.01667	11.21225	Discharge	0.030952	0.00001	Ratio to Peak	0.00001
W1040	5.2585	75.793	0	0.01667	12.9519	Discharge	0.052021	0.00001	Ratio to Peak	0.00001
W1050	4.4122	79.502	0	0.01667	11.9091	Discharge	0.092119	0.00001	Ratio to Peak	0.00001
W1060	4.057	81.02	0	0.01667	10.74255	Discharge	0.048503	0.00001	Ratio to Peak	0.00001
W1070	4.3249	79.906	0	0.01667	9.35435	Discharge	0.0375	0.00001	Ratio to Peak	0.00001
W1080	4.057	81.02	0	0.01667	9.85925	Discharge	0.040936	0.00001	Ratio to Peak	0.00001
W1090	4.057	81.02	0	0.01667	3.96667	Discharge	0.008769	0.00001	Ratio to Peak	0.00001
W1100	4.4926	79.134	0	0.01667	19.86045	Discharge	0.15369	0.00001	Ratio to Peak	0.00001
W1110	5.7977	73.612	0	0.01667	8.3561	Discharge	0.035483	0.00001	Ratio to Peak	0.00001
W1120	4.9503	77.101	0	0.01667	8.30715	Discharge	0.049204	0.00001	Ratio to Peak	0.00001
W1130	4.057	81.02	0	0.01667	3.96667	Discharge	0.002973	0.00001	Ratio to Peak	0.00001
W1140	4.057	81.02	0	0.01667	8.48205	Discharge	0.015432	0.00001	Ratio to Peak	0.00001
W1150	4.8232	77.655	0	0.01667	8.16525	Discharge	0.067398	0.00001	Ratio to Peak	0.00001
W1160	4.7183	78.118	0	0.01667	7.2418	Discharge	0.047718	0.00001	Ratio to Peak	0.00001
W1170	4.057	81.02	0	0.01667	12.425	Discharge	0.050579	0.00001	Ratio to Peak	0.00001
W1180	4.3963	79.575	0	0.01667	3.96667	Discharge	0.006242	0.00001	Ratio to Peak	0.00001
W1190	4.5513	78.867	0	0.01667	3.96667	Discharge	0.011603	0.00001	Ratio to Peak	0.00001
W1200	4.057	81.02	0	0.01667	3.96667	Discharge	0.006502	0.00001	Ratio to Peak	0.00001
W1210	4.057	81.02	0	0.01667	4.52205	Discharge	0.027855	0.00001	Ratio to Peak	0.00001

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
W1220	4.0983	80.976	0	0.01667	12.8133	Discharge	0.038825	0.00001	Ratio to Peak	0.00001
W1240	4.7334	78.051	0	0.01667	10.10125	Discharge	0.072131	0.00001	Ratio to Peak	0.00001
W1250	4.5205	79.006	0	0.01667	10.3856	Discharge	0.041794	0.00001	Ratio to Peak	0.00001
W1260	4.9131	77.262	0	0.01667	5.46585	Discharge	0.025793	0.00001	Ratio to Peak	0.00001
W1270	4.1234	80.856	0	0.01667	14.42755	Discharge	0.073918	0.00001	Ratio to Peak	0.00001
W1280	4.6318	78.504	0	0.01667	3.96667	Discharge	0.014616	0.00001	Ratio to Peak	0.00001
W1290	4.057	81.02	0	0.01667	11.52905	Discharge	0.031833	0.00001	Ratio to Peak	0.00001
W1300	4.057	81.02	0	0.01667	10.78545	Discharge	0.040612	0.00001	Ratio to Peak	0.00001
W1310	4.4076	79.523	0	0.01667	6.4993	Discharge	0.028046	0.00001	Ratio to Peak	0.00001
W1320	4.0989	80.973	0	0.01667	11.34315	Discharge	0.066561	0.00001	Ratio to Peak	0.00001
W1260	4.9131	77.262	0	0.01667	5.46585	Discharge	0.025793	0.00001	Ratio to Peak	0.00001
W1270	4.1234	80.856	0	0.01667	14.42755	Discharge	0.073918	0.00001	Ratio to Peak	0.00001
W1280	4.6318	78.504	0	0.01667	3.96667	Discharge	0.014616	0.00001	Ratio to Peak	0.00001
W1290	4.057	81.02	0	0.01667	11.52905	Discharge	0.031833	0.00001	Ratio to Peak	0.00001
W1300	4.057	81.02	0	0.01667	10.78545	Discharge	0.040612	0.00001	Ratio to Peak	0.00001
W1310	4.4076	79.523	0	0.01667	6.4993	Discharge	0.028046	0.00001	Ratio to Peak	0.00001
W1320	4.0989	80.973	0	0.01667	11.34315	Discharge	0.066561	0.00001	Ratio to Peak	0.00001

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
W1330	4.6864	78.26	0	0.01667	4.6942	Discharge	0.024749	0.00001	Ratio to Peak	0.00001
W1340	4.1886	80.546	0	0.01667	14.7999	Discharge	0.065346	0.00001	Ratio to Peak	0.00001
W1350	6.27	71.806	0	0.01667	13.476754	Discharge	0.10426	0.00001	Ratio to Peak	0.00001
W1360	3.4554	84.178	0	0.01667	16.76725	Discharge	0.1477	0.00001	Ratio to Peak	0.00001
W1370	4.0406	81.253	0	0.01667	5.9493	Discharge	0.023938	0.00001	Ratio to Peak	0.00001
W1380	4.1017	80.959	0	0.01667	9.09475	Discharge	0.053092	0.00001	Ratio to Peak	0.00001
W1390	4.1042	80.948	0	0.01667	10.665	Discharge	0.041317	0.00001	Ratio to Peak	0.00001
W1400	4.3221	79.919	0	0.01667	7.035	Discharge	0.042667	0.00001	Ratio to Peak	0.00001
W1410	4.057	81.02	0	0.01667	3.96667	Discharge	0.003164	0.00001	Ratio to Peak	0.00001
W1420	4.057	81.02	0	0.01667	3.96667	Discharge	0.002691	0.00001	Ratio to Peak	0.00001
W1430	4.6466	78.438	0	0.01667	12.10875	Discharge	0.10213	0.00001	Ratio to Peak	0.00001
W1440	4.1763	80.604	0	0.01667	12.6615	Discharge	0.05414	0.00001	Ratio to Peak	0.00001
W1450	4.1687	80.641	0	0.01667	7.9392	Discharge	0.074913	0.00001	Ratio to Peak	0.00001
W1460	4.4836	79.175	0	0.01667	8.6168	Discharge	0.064813	0.00001	Ratio to Peak	0.00001
W1470	4.3749	79.674	0	0.01667	4.341045	Discharge	0.021678	0.00001	Ratio to Peak	0.00001
W1480	4.9761	76.99	0	0.01667	3.96667	Discharge	0.007402	0.00001	Ratio to Peak	0.00001
W1490	5.157	76.02	0	0.01667	3.96667	Discharge	0.002314	0.00001	Ratio to Peak	0.00001
W1500	4.0893	81.019	0	0.01667	5.99165	Discharge	0.048499	0.00001	Ratio to Peak	0.00001

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
W1510	4.057	81.02	0	0.01667	7.9964	Discharge	0.045607	0.00001	Ratio to Peak	0.00001
W1520	6.4628	71.095	0	0.01667	9.28835	Discharge	0.13411	0.00001	Ratio to Peak	0.00001
W1530	4.6147	78.581	0	0.01667	4.36893	Discharge	0.022684	0.00001	Ratio to Peak	0.00001
W1540	3.9958	81.469	0	0.01667	6.2265	Discharge	0.055222	0.00001	Ratio to Peak	0.00001
W1550	4.0217	81.344	0	0.01667	5.6688	Discharge	0.032403	0.00001	Ratio to Peak	0.00001
W1560	4.057	81.02	0	0.01667	4.27653	Discharge	0.010539	0.00001	Ratio to Peak	0.00001
W1570	3.9852	81.521	0	0.01667	9.09585	Discharge	0.077126	0.00001	Ratio to Peak	0.00001
W1580	3.857	82.02	0	0.01667	3.96667	Discharge	0.038919	0.00001	Ratio to Peak	0.00001
W1600	2.5123	89.384	0	0.01667	6.42615	Discharge	0.009675	0.00001	Ratio to Peak	0.00001
W1650	3.107	86.02	0	0.01667	3.97414	Discharge	0.004394	0.00001	Ratio to Peak	0.00001
W1700	4.5667	78.797	0	0.01667	9.94285	Discharge	0.047176	0.00001	Ratio to Peak	0.00001
W1750	5.3545	75.395	0	0.01667	10.11665	Discharge	0.10208	0.00001	Ratio to Peak	0.00001
W1760	4.6744	78.313	0	0.01667	9.5419	Discharge	0.078946	0.00001	Ratio to Peak	0.00001
W800	9.1848	62.427	0	0.01667	17.0538	Discharge	0.076015	0.00001	Ratio to Peak	0.00001
W810	9.2964	62.119	0	0.01667	12.99315	Discharge	0.034093	0.00001	Ratio to Peak	0.00001

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
W820	9.5397	61.457	0	0.01667	21.42245	Discharge	0.13	0.00001	Ratio to Peak	0.00001
W830	5.89	73.252	0	0.01667	20.68435	Discharge	0.13619	0.00001	Ratio to Peak	0.00001
W840	8.2125	65.258	0	0.01667	12.7209	Discharge	0.071207	0.00001	Ratio to Peak	0.00001
W850	9.657	61.02	0	0.01667	9.00235	Discharge	0.034106	0.00001	Ratio to Peak	0.00001
W860	8.3466	64.852	0	0.01667	14.9572	Discharge	0.067988	0.00001	Ratio to Peak	0.00001
W870	7.7916	66.569	0	0.01667	13.855	Discharge	0.052003	0.00001	Ratio to Peak	0.00001
W880	9.0546	62.791	0	0.01667	14.89175	Discharge	0.054752	0.00001	Ratio to Peak	0.00001
W890	10.4527	59.101	0	0.01667	10.6507	Discharge	0.045878	0.00001	Ratio to Peak	0.00001
W900	5.9663	72.957	0	0.01667	18.7731	Discharge	0.10125	0.00001	Ratio to Peak	0.00001
W910	9.4849	61.605	0	0.01667	14.29225	Discharge	0.034091	0.00001	Ratio to Peak	0.00001
W920	7.851	66.381	0	0.01667	12.3502	Discharge	0.047021	0.00001	Ratio to Peak	0.00001
W930	8.2041	65.284	0	0.01667	12.6659	Discharge	0.028447	0.00001	Ratio to Peak	0.00001
W940	7.1777	68.583	0	0.01667	14.5623	Discharge	0.054174	0.00001	Ratio to Peak	0.00001
W950	4.057	81.02	0	0.01667	17.91345	Discharge	0.12121	0.00001	Ratio to Peak	0.00001
W960	4.9754	76.993	0	0.01667	9.75035	Discharge	0.019103	0.00001	Ratio to Peak	0.00001
W970	5.7072	73.969	0	0.01667	14.30765	Discharge	0.075675	0.00001	Ratio to Peak	0.00001
W980	4.4592	79.286	0	0.01667	20.79985	Discharge	0.1173	0.00001	Ratio to Peak	0.00001
W990	7.9192	66.166	0	0.01667	11.05	Discharge	0.041847	0.00001	Ratio to Peak	0.00001

Annex 10. Cabulig 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	2265.7	0.14653	0.015	Trapezoid	60	1
R130	Automatic Fixed Interval	1853.1	0.032004	0.015	Trapezoid	60	1
R1630	Automatic Fixed Interval	659.12	0.0004	0.015	Trapezoid	60	1
R1680	Automatic Fixed Interval	2810.2	0.0087413	0.015	Trapezoid	60	1
R170	Automatic Fixed Interval	1330.7	0.0406729	0.015	Trapezoid	60	1
R1730	Automatic Fixed Interval	2445.3	0.0082458	0.015	Trapezoid	60	1
R1780	Automatic Fixed Interval	2595.6	0.0100872	0.015	Trapezoid	60	1
R180	Automatic Fixed Interval	4059.5	0.0527176	0.015	Trapezoid	60	1
R190	Automatic Fixed Interval	1109.5	0.0579811	0.015	Trapezoid	60	1
R220	Automatic Fixed Interval	596.42	0.0541487	0.015	Trapezoid	60	1
R230	Automatic Fixed Interval	3848	0.0584263	0.015	Trapezoid	60	1
R240	Automatic Fixed Interval	6298.9	0.011985	0.015	Trapezoid	60	1
R270	Automatic Fixed Interval	582.22	0.0314673	0.015	Trapezoid	60	1
R30	Automatic Fixed Interval	1684.5	0.18826	0.015	Trapezoid	60	1
R310	Automatic Fixed Interval	2902.2	0.0153409	0.015	Trapezoid	60	1
R320	Automatic Fixed Interval	830.56	0.0170386	0.015	Trapezoid	60	1
R330	Automatic Fixed Interval	2735.5	0.0139185	0.015	Trapezoid	60	1
R340	Automatic Fixed Interval	1697.3	0.0202277	0.015	Trapezoid	60	1
R360	Automatic Fixed Interval	772.45	0.13148	0.015	Trapezoid	60	1
R400	Automatic Fixed Interval	1829.6	0.1173	0.015	Trapezoid	60	1

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R410	Automatic Fixed Interval	1396	0.0085707	0.015	Trapezoid	60	1
R420	Automatic Fixed Interval	1374	0.11611	0.015	Trapezoid	60	1
R480	Automatic Fixed Interval	2664.3	0.0414665	0.015	Trapezoid	60	1
R490	Automatic Fixed Interval	1406.1	0.0210972	0.015	Trapezoid	60	1
R500	Automatic Fixed Interval	2273.3	0.0766931	0.015	Trapezoid	60	1
R520	Automatic Fixed Interval	1869	0.0509273	0.015	Trapezoid	60	1
R530	Automatic Fixed Interval	451.65	0.11	0.015	Trapezoid	60	1
R550	Automatic Fixed Interval	4099.8	0.0144893	0.015	Trapezoid	60	1
R570	Automatic Fixed Interval	490.1	0.0086312	0.015	Trapezoid	60	1
R590	Automatic Fixed Interval	7598.6	0.0638639	0.015	Trapezoid	60	1
R600	Automatic Fixed Interval	7422	0.055656	0.015	Trapezoid	60	1
R630	Automatic Fixed Interval	822.51	0.0004	0.015	Trapezoid	60	1
R650	Automatic Fixed Interval	2533.3	0.0164463	0.015	Trapezoid	60	1
R660	Automatic Fixed Interval	464.85	0.10673	0.015	Trapezoid	60	1
R670	Automatic Fixed Interval	1784.9	0.0913081	0.015	Trapezoid	60	1
R680	Automatic Fixed Interval	5810.8	0.0639837	0.015	Trapezoid	60	1
R690	Automatic Fixed Interval	2001.1	0.0200018	0.015	Trapezoid	60	1
R700	Automatic Fixed Interval	444.76	0.0974876	0.015	Trapezoid	60	1
R720	Automatic Fixed Interval	4120	0.0430977	0.015	Trapezoid	60	1
R730	Automatic Fixed Interval	1512.9	0.10753	0.015	Trapezoid	60	1
R740	Automatic Fixed Interval	2367.2	0.0529475	0.015	Trapezoid	60	1
R760	Automatic Fixed Interval	1336.3	0.0642163	0.015	Trapezoid	60	1
R780	Automatic Fixed Interval	3541.2	0.0449421	0.015	Trapezoid	60	1

Annex 11. Cabulig Flood Validation Points

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
1	8.65267800061	124.74364000100	0.78	1.00	0.22	Seniang/29Dec2014	5YR
2	8.65395599984	124.74431400000	0.07	0.50	0.43	Seniang/29Dec2014	5YR
3	8.65409799965	124.74451700100	0.50	0.50	0.00	Seniang/29Dec2014	5YR
4	8.65466499995	124.74856000000	0.58	0.50	-0.08	Seniang/29Dec2014	5YR
5	8.65495200009	124.74284600000	0.59	1.80	1.21	Seniang/29Dec2014	5YR
6	8.65516800006	124.74486800000	0.06	0.80	0.74	Seniang/29Dec2014	5YR
7	8.65521299981	124.75023200100	2.63	2.00	-0.63	Seniang/29Dec2014	5YR
8	8.65540300025	124.74334000100	0.53	0.50	-0.03	Seniang/29Dec2014	5YR
9	8.65575299969	124.75031800000	2.08	2.00	-0.08	Seniang/29Dec2014	5YR
10	8.65576000022	124.74365700100	0.06	0.00	-0.06	Seniang/29Dec2014	5YR
11	8.65607300016	124.74763900100	3.80	1.00	-2.80	Seniang/29Dec2014	5YR
12	8.65631800019	124.75094200100	3.38	0.50	-2.88	Seniang/29Dec2014	5YR
13	8.65648400030	124.74887800000	3.18	0.00	-3.18	Seniang/29Dec2014	5YR
14	8.65659100025	124.75164400000	2.95	1.00	-1.95	Seniang/29Dec2014	5YR
15	8.65707899955	124.74856400000	2.79	0.00	-2.79	Seniang/29Dec2014	5YR
16	8.65733699977	124.75237100000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
17	8.67069799996	124.76598400100	5.00	2.00	-3.00	Seniang/29Dec2014	5YR
18	8.67428800052	124.76640000100	2.81	0.50	-2.31	Seniang/29Dec2014	5YR
19	8.67625300047	124.77336100100	1.11	0.00	-1.11	Seniang/29Dec2014	5YR
20	8.64903600044	124.75172700000	1.99	3.00	1.01	Seniang/29Dec2014	5YR
21	8.64911600001	124.75331800000	1.81	0.80	-1.01	Seniang/29Dec2014	5YR
22	8.64939499965	124.75273800000	1.50	0.30	-1.20	Seniang/29Dec2014	5YR

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
23	8.64975899996	124.75256700000	0.07	0.60	0.53	Seniang/29Dec2014	5YR
24	8.64975999932	124.75196900100	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
25	8.64978799970	124.75206700100	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
26	8.65027399984	124.75447700000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
27	8.65081299945	124.75328800100	0.34	0.40	0.06	Seniang/29Dec2014	5YR
28	8.65187299999	124.75303900100	0.20	0.00	-0.20	Seniang/29Dec2014	5YR
29	8.65192300043	124.75293600000	0.24	0.20	-0.04	Seniang/29Dec2014	5YR
30	8.65209800049	124.74939100100	0.83	0.00	-0.83	Seniang/29Dec2014	5YR
31	8.65218399987	124.75173000000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
32	8.65235100059	124.75166900100	0.05	0.00	-0.05	Seniang/29Dec2014	5YR
33	8.65271999998	124.75314600000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
34	8.65319099955	124.74862200000	1.91	1.00	-0.91	Seniang/29Dec2014	5YR
35	8.65331799966	124.74225900000	0.40	0.60	0.20	Seniang/29Dec2014	5YR
36	8.65338999954	124.74314300000	0.47	1.00	0.53	Seniang/29Dec2014	5YR
37	8.65362199972	124.74338300100	0.23	0.70	0.47	Seniang/29Dec2014	5YR
38	8.65365100028	124.74254800000	0.79	0.70	-0.09	Seniang/29Dec2014	5YR
39	8.65366099980	124.75178200100	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
40	8.65370199959	124.74388200000	0.35	1.50	1.15	Seniang/29Dec2014	5YR
41	8.65370399986	124.74338900100	0.24	3.00	2.76	Seniang/29Dec2014	5YR
42	8.65373699978	124.74876800100	0.86	0.80	-0.06	Seniang/29Dec2014	5YR
43	8.65379300030	124.74217200000	0.24	0.30	0.06	Seniang/29Dec2014	5YR
44	8.65383100041	124.74316200000	0.50	1.20	0.70	Seniang/29Dec2014	5YR
45	8.65383099992	124.74508800000	1.73	1.50	-0.23	Seniang/29Dec2014	5YR
46	8.65386600050	124.75183200100	0.07	0.00	-0.07	Seniang/29Dec2014	5YR

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
47	8.65392200029	124.75443400000	0.05	0.00	-0.05	Seniang/29Dec2014	5YR
48	8.65395899950	124.74319700000	0.40	2.00	1.60	Seniang/29Dec2014	5YR
49	8.65396199983	124.74520200100	1.93	2.30	0.37	Seniang/29Dec2014	5YR
50	8.65407900010	124.74222200000	0.40	0.70	0.30	Seniang/29Dec2014	5YR
51	8.65411499971	124.74969100000	0.40	0.50	0.10	Seniang/29Dec2014	5YR
52	8.65412699980	124.74300500000	0.40	0.50	0.10	Seniang/29Dec2014	5YR
53	8.65413700037	124.74962700100	0.40	0.30	-0.10	Seniang/29Dec2014	5YR
54	8.65414299986	124.74316100000	0.35	2.00	1.65	Seniang/29Dec2014	5YR
55	8.65414500019	124.75185900000	1.50	0.00	-1.50	Seniang/29Dec2014	5YR
56	8.65417399948	124.74535000000	1.84	2.30	0.46	Seniang/29Dec2014	5YR
57	8.65428400002	124.74452400000	0.36	0.20	-0.16	Seniang/29Dec2014	5YR
58	8.65429799997	124.74216000100	0.19	1.00	0.81	Seniang/29Dec2014	5YR
59	8.65438600020	124.75171000000	4.20	0.50	-3.70	Seniang/29Dec2014	5YR
60	8.65443300052	124.74394500100	0.34	0.50	0.16	Seniang/29Dec2014	5YR
61	8.65451199991	124.75014000000	2.90	0.50	-2.40	Seniang/29Dec2014	5YR
62	8.65451400036	124.75167300100	4.04	0.20	-3.84	Seniang/29Dec2014	5YR
63	8.65451799940	124.74495200000	0.71	1.00	0.29	Seniang/29Dec2014	5YR
64	8.65452300022	124.75014200000	2.90	2.00	-0.90	Seniang/29Dec2014	5YR
65	8.65457599956	124.74469200100	0.43	1.00	0.57	Seniang/29Dec2014	5YR
66	8.65467299926	124.74863800000	0.37	0.50	0.13	Seniang/29Dec2014	5YR
67	8.65469499930	124.74238600100	0.74	0.50	-0.24	Seniang/29Dec2014	5YR
68	8.65473299985	124.74319000000	0.36	0.70	0.34	Seniang/29Dec2014	5YR
69	8.65476799994	124.74353900000	0.19	0.30	0.11	Seniang/29Dec2014	5YR
70	8.65482399989	124.74756800000	0.59	0.90	0.31	Seniang/29Dec2014	5YR

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
71	8.65483399960	124.74359800100	0.19	0.80	0.61	Seniang/29Dec2014	5YR
72	8.65486600070	124.74256800100	0.24	1.50	1.26	Seniang/29Dec2014	5YR
73	8.65488500024	124.74359900100	0.36	0.70	0.34	Seniang/29Dec2014	5YR
74	8.65490900008	124.74286800000	0.59	1.80	1.21	Seniang/29Dec2014	5YR
75	8.65491099934	124.74603700000	2.50	2.30	-0.20	Seniang/29Dec2014	5YR
76	8.65502000057	124.74584600100	0.61	2.00	1.39	Seniang/29Dec2014	5YR
77	8.65508100021	124.74398400000	0.46	1.00	0.54	Seniang/29Dec2014	5YR
78	8.65509200021	124.74369200000	0.49	0.70	0.21	Seniang/29Dec2014	5YR
79	8.65511700011	124.75600900000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
80	8.65513099955	124.74725099900	1.44	1.30	-0.14	Seniang/29Dec2014	5YR
81	8.65514499998	124.74243100100	0.37	0.50	0.13	Seniang/29Dec2014	5YR
82	8.65516199985	124.74628000000	2.45	2.30	-0.15	Seniang/29Dec2014	5YR
83	8.65519300001	124.74371000000	0.28	1.00	0.72	Seniang/29Dec2014	5YR
84	8.65523200009	124.74726500100	1.65	2.00	0.35	Seniang/29Dec2014	5YR
85	8.65525200019	124.74795300000	1.19	1.80	0.61	Seniang/29Dec2014	5YR
86	8.65526899996	124.74412100100	0.06	1.00	0.94	Seniang/29Dec2014	5YR
87	8.65529499996	124.74853300000	0.69	0.80	0.11	Seniang/29Dec2014	5YR
88	8.65529899947	124.74375500100	0.28	0.30	0.02	Seniang/29Dec2014	5YR
89	8.65533799971	124.74501500100	0.07	0.80	0.73	Seniang/29Dec2014	5YR
90	8.65542399963	124.74750300100	2.29	2.20	-0.09	Seniang/29Dec2014	5YR
91	8.65546799986	124.74439900100	0.32	0.20	-0.12	Seniang/29Dec2014	5YR
92	8.65552800063	124.74563800000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
93	8.65554700074	124.74789200100	1.76	2.00	0.24	Seniang/29Dec2014	5YR
94	8.65555699951	124.74443100000	0.32	0.50	0.18	Seniang/29Dec2014	5YR

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
95	8.65557400014	124.74829700100	0.33	0.50	0.17	Seniang/29Dec2014	5YR
96	8.65564099991	124.74655900100	3.18	3.00	-0.18	Seniang/29Dec2014	5YR
97	8.65571500000	124.74796500100	0.33	1.60	1.27	Seniang/29Dec2014	5YR
98	8.65571899993	124.74266300100	0.47	1.00	0.53	Seniang/29Dec2014	5YR
99	8.65572300067	124.74886800100	2.39	2.00	-0.39	Seniang/29Dec2014	5YR
100	8.65574599993	124.74773900000	0.81	0.30	-0.51	Seniang/29Dec2014	5YR
101	8.65581800041	124.74342600000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
102	8.65584399927	124.75136000100	4.05	3.00	-1.05	Seniang/29Dec2014	5YR
103	8.65593099990	124.74834300000	3.26	1.80	-1.46	Seniang/29Dec2014	5YR
104	8.65594999995	124.74603900100	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
105	8.65597499997	124.74462700000	0.24	0.30	0.06	Seniang/29Dec2014	5YR
106	8.65602799978	124.75146000100	3.34	3.00	-0.34	Seniang/29Dec2014	5YR
107	8.65609799945	124.74727900000	7.95	5.10	-2.85	Seniang/29Dec2014	5YR
108	8.65615999987	124.74710300100	6.08	5.10	-0.98	Seniang/29Dec2014	5YR
109	8.65625100002	124.74222400000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
110	8.65631399931	124.74283100100	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
111	8.65632700012	124.74425300000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
112	8.65646500075	124.75013600000	1.67	0.50	-1.17	Seniang/29Dec2014	5YR
113	8.65688100013	124.75120300000	3.01	1.00	-2.01	Seniang/29Dec2014	5YR
114	8.65693200033	124.74347400000	0.20	0.20	0.00	Seniang/29Dec2014	5YR
115	8.65699700008	124.75197900000	3.06	1.00	-2.06	Seniang/29Dec2014	5YR
116	8.65704000014	124.75005800100	2.96	1.00	-1.96	Seniang/29Dec2014	5YR
117	8.65717999998	124.74279200000	0.38	0.30	-0.08	Seniang/29Dec2014	5YR
118	8.65730400081	124.74382100000	0.07	0.20	0.13	Seniang/29Dec2014	5YR
119	8.65733100026	124.74925200000	3.17	5.10	1.93	Seniang/29Dec2014	5YR
120	8.65737599976	124.74781900000	4.66	5.10	0.44	Seniang/29Dec2014	5YR

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
121	8.65746299944	124.74346400000	0.28	0.20	-0.08	Seniang/29Dec2014	5YR
122	8.65749200012	124.74595200100	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
123	8.65750600016	124.74798900100	5.07	5.10	0.03	Seniang/29Dec2014	5YR
124	8.65759399998	124.74832600000	5.15	5.10	-0.05	Seniang/29Dec2014	5YR
125	8.65764899995	124.74503400000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
126	8.65824499946	124.75166300000	3.17	1.00	-2.17	Seniang/29Dec2014	5YR
127	8.65853300024	124.74546200100	0.05	0.00	-0.05	Seniang/29Dec2014	5YR
128	8.65867564484	124.75033207400	1.96	0.50	-1.46	Seniang/29Dec2014	5YR
129	8.65882300050	124.75162800000	1.64	0.50	-1.14	Seniang/29Dec2014	5YR
130	8.65958200035	124.75221200000	1.60	1.00	-0.60	Seniang/29Dec2014	5YR
131	8.66563899978	124.76857200100	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
132	8.66648700047	124.76763800000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
133	8.66924599954	124.76349700000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
134	8.66937799931	124.76446600100	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
135	8.67165199984	124.76509900000	2.06	0.40	-1.66	Seniang/29Dec2014	5YR
136	8.67187300067	124.76605700000	1.73	1.00	-0.73	Seniang/29Dec2014	5YR
137	8.67187699978	124.76607200000	1.73	0.80	-0.93	Seniang/29Dec2014	5YR
138	8.67215099997	124.76645500000	1.95	1.00	-0.95	Seniang/29Dec2014	5YR
139	8.67294599944	124.76862200100	0.78	0.00	-0.78	Seniang/29Dec2014	5YR
140	8.67320600028	124.76670300000	0.79	0.80	0.01	Seniang/29Dec2014	5YR
141	8.67353199965	124.76839000100	1.69	1.00	-0.69	Seniang/29Dec2014	5YR
142	8.67370500044	124.76629800000	1.57	0.70	-0.87	Seniang/29Dec2014	5YR
143	8.67374699990	124.76821300100	1.10	0.30	-0.80	Seniang/29Dec2014	5YR
144	8.67388600000	124.76722400000	1.16	0.60	-0.56	Seniang/29Dec2014	5YR
145	8.67391199999	124.76665500000	1.93	0.90	-1.03	Seniang/29Dec2014	5YR
146	8.67411299992	124.76634800100	2.54	1.00	-1.54	Seniang/29Dec2014	5YR
147	8.67442200001	124.76699000000	0.37	0.20	-0.17	Seniang/29Dec2014	5YR

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
148	8.67443200000	124.76700000000	0.37	0.30	-0.07	Seniang/29Dec2014	5YR
149	8.67287000000	124.76670000000	1.11	0.50	-0.61	Seniang/29Dec2014	5YR
150	8.67401000000	124.76920000000	1.39	0.40	-0.99	Seniang/29Dec2014	5YR
151	8.67217600000	124.76910000000	1.96	0.90	-1.06	Seniang/29Dec2014	5YR
152	8.67167800000	124.76760000000	2.11	0.50	-1.61	Seniang/29Dec2014	5YR
153	8.67161500000	124.76620000000	2.96	2.00	-0.96	Seniang/29Dec2014	5YR
154	8.66985200000	124.75880000000	2.82	0.40	-2.42	Seniang/29Dec2014	5YR
155	8.67147200000	124.76340000000	2.17	0.90	-1.27	Seniang/29Dec2014	5YR
156	8.67162500000	124.76370000000	2.09	0.85	-1.24	Seniang/29Dec2014	5YR
157	8.67054700000	124.76590000000	5.15	0.00	-5.15	Seniang/29Dec2014	5YR
158	8.67025000000	124.76570000000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
159	8.64545900000	124.77150000000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
160	8.64375700000	124.77040000000	1.67	0.87	-0.80	Seniang/29Dec2014	5YR
161	8.64438300000	124.76870000000	0.36	0.00	-0.36	Seniang/29Dec2014	5YR
162	8.64514500000	124.76800000000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
163	8.64556000000	124.76770000000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
164	8.64559300000	124.76670000000	1.58	0.00	-1.58	Seniang/29Dec2014	5YR
165	8.64609900000	124.76680000000	0.47	0.35	-0.12	Seniang/29Dec2014	5YR
166	8.64631400000	124.76440000000	2.05	0.90	-1.15	Seniang/29Dec2014	5YR
167	8.64612700000	124.76410000000	2.38	0.64	-1.74	Seniang/29Dec2014	5YR
168	8.64636100000	124.76350000000	1.96	0.70	-1.26	Seniang/29Dec2014	5YR
169	8.64622700000	124.76180000000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
170	8.64518100000	124.76420000000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
171	8.64923000000	124.76040000000	0.54	0.40	-0.14	Seniang/29Dec2014	5YR
172	8.64878000000	124.76260000000	2.50	0.60	-1.90	Seniang/29Dec2014	5YR
173	8.64864300000	124.76220000000	2.50	0.00	-2.50	Seniang/29Dec2014	5YR
174	8.64823700000	124.76260000000	1.21	0.87	-0.34	Seniang/29Dec2014	5YR

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
175	8.64696100000	124.76190000000	0.32	0.31	-0.01	Seniang/29Dec2014	5YR
176	8.64544500000	124.76070000000	0.05	0.00	-0.05	Seniang/29Dec2014	5YR
177	8.64732100000	124.75760000000	0.37	0.81	0.44	Seniang/29Dec2014	5YR
178	8.64863400000	124.75650000000	0.69	0.34	-0.35	Seniang/29Dec2014	5YR
179	8.64965300000	124.75610000000	0.05	0.00	-0.05	Seniang/29Dec2014	5YR
180	8.65474400000	124.75850000000	1.60	0.00	-1.60	Seniang/29Dec2014	5YR
181	8.65455200000	124.75970000000	2.45	0.00	-2.45	Seniang/29Dec2014	5YR
182	8.65350400000	124.75830000000	0.57	0.00	-0.57	Seniang/29Dec2014	5YR
183	8.65322000000	124.75770000000	0.36	0.00	-0.36	Seniang/29Dec2014	5YR
184	8.65249900000	124.75800000000	0.34	0.41	0.07	Seniang/29Dec2014	5YR
185	8.65462400000	124.75720000000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
186	8.65299900000	124.75810000000	0.75	0.00	-0.75	Seniang/29Dec2014	5YR
187	8.66332100000	124.75340000000	1.04	0.10	-0.94	Seniang/29Dec2014	5YR
188	8.66135800000	124.75370000000	1.50	0.85	-0.65	Seniang/29Dec2014	5YR
189	8.66093100000	124.75390000000	2.20	0.75	-1.45	Seniang/29Dec2014	5YR
190	8.65974200000	124.75350000000	1.62	0.00	-1.62	Seniang/29Dec2014	5YR
191	8.65942700000	124.75340000000	1.99	0.00	-1.99	Seniang/29Dec2014	5YR
192	8.65928100000	124.75330000000	1.70	0.50	-1.20	Seniang/29Dec2014	5YR
193	8.66026700000	124.75230000000	1.38	0.00	-1.38	Seniang/29Dec2014	5YR
194	8.65978900000	124.75210000000	1.46	0.00	-1.46	Seniang/29Dec2014	5YR
195	8.65967400000	124.75190000000	1.51	0.00	-1.51	Seniang/29Dec2014	5YR
196	8.65838000000	124.75130000000	1.45	0.90	-0.55	Seniang/29Dec2014	5YR
197	8.65818500000	124.75110000000	1.49	1.60	0.11	Seniang/29Dec2014	5YR
198	8.65866500000	124.75120000000	1.48	0.80	-0.68	Seniang/29Dec2014	5YR
199	8.65849300000	124.75210000000	2.20	0.40	-1.80	Seniang/29Dec2014	5YR
200	8.65861600000	124.75220000000	1.95	0.00	-1.95	Seniang/29Dec2014	5YR
201	8.65696500000	124.80080000000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
202	8.65677400000	124.80100000000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
203	8.65556700000	124.80820000000	0.40	0.00	-0.40	Seniang/29Dec2014	5YR
204	8.65432900000	124.81040000000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
205	8.65349400000	124.81010000000	0.78	0.50	-0.28	Seniang/29Dec2014	5YR
206	8.65348800000	124.80960000000	1.21	0.90	-0.31	Seniang/29Dec2014	5YR
207	8.65314600000	124.80820000000	0.07	0.90	0.83	Seniang/29Dec2014	5YR
208	8.65012700000	124.81020000000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
209	8.64998100000	124.80990000000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
210	8.64739900000	124.80640000000	1.31	0.90	-0.41	Seniang/29Dec2014	5YR
211	8.64708600000	124.80710000000	1.38	0.00	-1.38	Seniang/29Dec2014	5YR
212	8.65408100000	124.80710000000	0.43	0.00	-0.43	Seniang/29Dec2014	5YR
213	8.64468400000	124.80050000000	3.17	0.00	-3.17	Seniang/29Dec2014	5YR
214	8.64622500000	124.80060000000	0.07	0.00	-0.07	Seniang/29Dec2014	5YR
215	8.65325300000	124.74610000000	0.60	0.20	-0.40	Seniang/29Dec2014	5YR
216	8.65225200000	124.74660000000	0.59	0.90	0.31	Seniang/29Dec2014	5YR
217	8.64995000000	124.74740000000	1.39	0.00	-1.39	Seniang/29Dec2014	5YR
218	8.64500900000	124.74570000000	0.11	0.00	-0.11	Seniang/29Dec2014	5YR
219	8.64617700000	124.74640000000	0.48	0.00	-0.48	Seniang/29Dec2014	5YR
220	8.64690600000	124.74790000000	1.00	0.00	-1.00	Seniang/29Dec2014	5YR
221	8.64380800000	124.74880000000	0.53	0.00	-0.53	Seniang/29Dec2014	5YR
222	8.65477600000	124.74810000000	0.75	0.40	-0.35	Seniang/29Dec2014	5YR
223	8.65624000000	124.75070000000	1.95	0.00	-1.95	Seniang/29Dec2014	5YR
224	8.65345900000	124.74900000000	0.60	0.00	-0.60	Seniang/29Dec2014	5YR
225	8.65221800000	124.74890000000	2.29	0.25	-2.04	Seniang/29Dec2014	5YR
226	8.65413200000	124.74890000000	0.94	0.60	-0.34	Seniang/29Dec2014	5YR
227	8.65392800000	124.74980000000	0.29	0.00	-0.29	Seniang/29Dec2014	5YR
228	8.65274600000	124.74960000000	0.40	0.00	-0.40	Seniang/29Dec2014	5YR

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
229	8.65209000000	124.75060000000	1.12	0.90	-0.22	Seniang/29Dec2014	5YR
230	8.65135600000	124.75050000000	2.87	0.90	-1.97	Seniang/29Dec2014	5YR
231	8.65042400000	124.75040000000	2.54	0.90	-1.64	Seniang/29Dec2014	5YR
232	8.64982300000	124.75020000000	2.56	0.90	-1.66	Seniang/29Dec2014	5YR
233	8.64978200000	124.75180000000	0.74	0.55	-0.19	Seniang/29Dec2014	5YR
234	8.64868400000	124.75190000000	1.77	0.00	-1.77	Seniang/29Dec2014	5YR
235	8.64762400000	124.75180000000	1.00	0.00	-1.00	Seniang/29Dec2014	5YR
236	8.64764400000	124.75120000000	1.61	0.00	-1.61	Seniang/29Dec2014	5YR
237	8.64714100000	124.75220000000	0.75	0.00	-0.75	Seniang/29Dec2014	5YR
238	8.64655100000	124.75180000000	0.33	0.60	0.27	Seniang/29Dec2014	5YR
239	8.64664700000	124.75180000000	0.37	0.00	-0.37	Seniang/29Dec2014	5YR
240	8.64796400000	124.75280000000	0.88	0.50	-0.38	Seniang/29Dec2014	5YR
241	8.64814400000	124.75230000000	1.29	0.00	-1.29	Seniang/29Dec2014	5YR
242	8.64925800000	124.75270000000	1.64	0.50	-1.14	Seniang/29Dec2014	5YR
243	8.64881900000	124.75260000000	1.50	0.00	-1.50	Seniang/29Dec2014	5YR
244	8.64926700000	124.75290000000	1.64	0.00	-1.64	Seniang/29Dec2014	5YR
245	8.64881300000	124.75370000000	0.55	0.50	-0.05	Seniang/29Dec2014	5YR
246	8.64870700000	124.75440000000	0.11	0.50	0.39	Seniang/29Dec2014	5YR
247	8.64939100000	124.75430000000	0.12	0.00	-0.12	Seniang/29Dec2014	5YR
248	8.65502600000	124.74930000000	0.28	0.50	0.22	Seniang/29Dec2014	5YR
249	8.65550600000	124.74980000000	2.09	0.50	-1.59	Seniang/29Dec2014	5YR
250	8.65598700000	124.74950000000	2.13	1.20	-0.93	Seniang/29Dec2014	5YR
251	8.65662900000	124.74980000000	2.08	1.20	-0.88	Seniang/29Dec2014	5YR
252	8.65689300000	124.74950000000	2.24	1.20	-1.04	Seniang/29Dec2014	5YR
253	8.65606800000	124.74890000000	2.90	1.20	-1.70	Seniang/29Dec2014	5YR
254	8.65685200000	124.74830000000	2.73	2.00	-0.73	Seniang/29Dec2014	5YR
255	8.65591700000	124.75090000000	3.56	0.50	-3.06	Seniang/29Dec2014	5YR
256	8.65491000000	124.75070000000	2.29	0.00	-2.29	Seniang/29Dec2014	5YR

Annex 12. Educational Institutions Affected by Flooding in Cabulig Floodplain

Misamis Oriental				
Jasaan				
Building Name	**Barangay**	**Rainfall Scenario**		
		5-year	**25-year**	**100-year**
Bubontugan National High School	Bobontugan			
Brgy Nahalinan Day Care Center	Lower Jasaan	Medium	Medium	High
DMMA Jasaan	Lower Jasaan			
School	Lower Jasaan	Low	Low	Medium
High School	San Nicolas			
San Nicolas Elem School	San Nicolas			
Colegio de Sto. Nino de Jasaan	Upper Jasaan			
High School	Upper Jasaan	Low	Low	Low
Jasaan Central School	Upper Jasaan			
Jasaan Parish School	Upper Jasaan	Low	Low	Low
St. Mary's Academy	Upper Jasaan			

Annex 13. Health Institutions Affected by Flooding in Cabulig Floodplain

Misamis Oriental				
Jasaan				
Building Name	**Barangay**	**Rainfall Scenario**		
		5-year	**25-year**	**100-year**
Jasaan Municipal Hospital	Lower Jasaan			
St. Therese Medical Clinic	Lower Jasaan			
Health Center	San Nicolas	Low	Medium	Medium
Jasaan Municipal Hospital	Upper Jasaan			