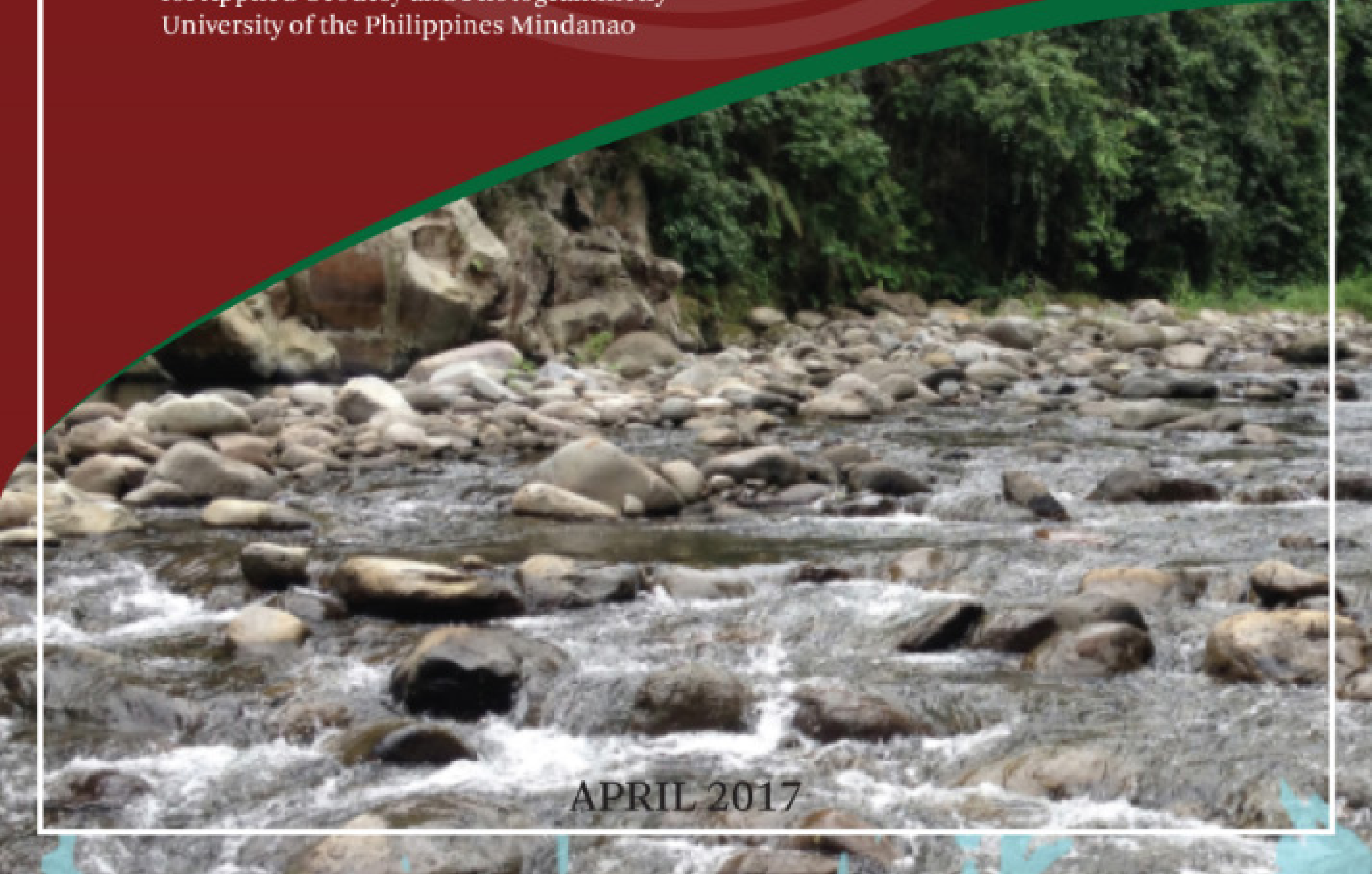
HAZARD MAPPING OF THE PHILIPPINES USING LIDAR (PHIL-LIDAR I)

LiDAR Surveys and Flood Mapping of Sibulan River

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



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 J.E. Acosta, (Eds.). (2017), LiDAR Surveys and Flood Mapping of Sibulan River. Quezon City: University of the Philippines Training Center for Applied Geodesy and Photogrammetry-146 pp.

For questions/queries regarding this report, contact:

Dr. Joseph E. Acosta
Project Leader, Phil-LiDAR 1 Program
University of the Philippines Mindanao
Davao City, Davao del Sur, 8000
E-mail: jacosta_96140@yahoo.com

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

National Library of the Philippines
ISBN: 987-621-430-172-0

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

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

CHAPTER 1: OVERVIEW OF THE PROGRAM AND SIBULAN RIVER

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

1.1 Background of the Phil-LiDAR 1 Program

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

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

The implementing partner university for the Phil-LiDAR 1 Program is the University of the Philippines Mindanao (USC) is in charge of processing LiDAR data and conducting data validation reconnaissance, cross section, bathymetric survey, validation, river flow measurements, flood height and extent data gathering, flood modeling, and flood map generation for the 13 river basins in the Southern Mindanao Region. The university is located in Davao City in the province of Davao del Sur.

1.2 Overview of the Sibulan River Basin

The Sibulan River Basin is located in the Province of Davao del Sur. It covers the Municipality of Santa Cruz and the Cities of Davao and Digos in Davao del Sur and a portion of the Municipality of Makilala in North Cotabato. The basin has a catchment area of 158 km2 with an estimated annual run-off of 316 million cubic meters (MCM) according to DENR-RCBO. The land area of 27,960 hectares represents 6.7% of the total land area of Davao del Sur. Forest land comprises more than 60% of the land area. Sta. Cruz has 18 barangays, with Sibulan occupying the largest land area and Poblacion Zone III, the smallest area.

Its main stem, the Sibulan River (also called Sibulan River or Tagulaya River), is situated between Sibulan Beach and Tagulaya Point. The Sibulan River is bounded by Davao City on the north and Digos City in the south. It is classified, according to its beneficial use, as Class B where waters are protected for primary recreational uses such as swimming, skin diving, water skiing, and secondary recreational uses such as fishing, wildlife, fish consumption, and agriculture (North Carolina Division of Water Resources). Sibulan River is an invaluable resource for the town as it serves as a sustainable water supply for domestic, commercial, and industrial uses (PCW, 2013). Large industrial companies such as Hedcor, invested in creating a hydroelectric plant in the river to provide power to the province of Davao del Sur (Francisco, 2016; Philstar, 2016). The Tudaya Hydropower Plant 2 operates downstream of Sibulan Hydropower Plant B which harnesses the Sibulan River (Hedcor, 2014).

Aboitiz subsidiary Hedcor has trained about 90 farmers in Sta. Cruz, Davao del Sur on abaca farming through experts from the Fiber Industry Development Authority (FIDA). The training is part of Corporate Social Responsibility (CSR) of Hedcor, builder of two hydropower plants in Sibulan, Sta. Cruz (Balanza, 2016).

Regarding recreational uses, Sibulan River is known for its river tubing. Whitewater tubing is a recreational activity where one sits on top of an inner tube and rides the current of the river while trying to avoid large boulders. It is usually enjoyed by adventurers and tourists (Davaotraveler, 2016).

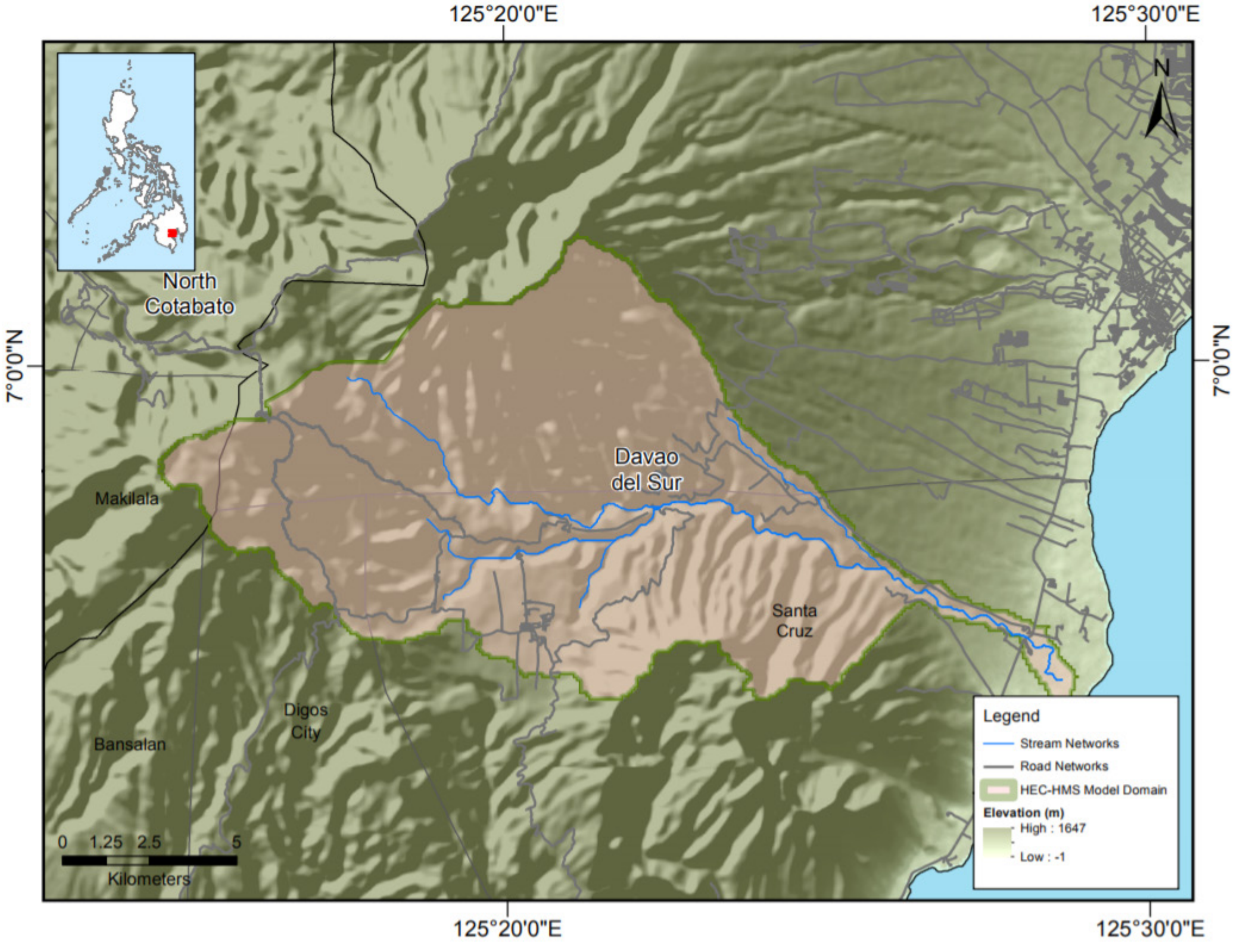


Figure 1. Map of Sibulan River Basin (in brown)

Sibulan watershed is located in the southeastern part of Mindanao. It traverses through Sta. Cruz, Davao del Sur. It covers an area of 167.07 square kilometers and travels for 76.67 kilometers from its source to its mouth in Barangay Astorga, Sta Cruz, Davao del Sur. The Sibulan basin model consisted of 59 sub basins, 29 reaches, and 29 junctions. The basins were identified based on soil and land cover characteristics of the area.

The history of Sibulan River is closely associated with Sta. Cruz Municipality where it is located, in the northern part of Davao del Sur. The municipality of Sta. Cruz takes an active role in the formation of Mindanao's and Philippines' history. The history began to be recorded when the Spanish attempted to settle and Christianize the area but was resisted by the locals. At the time, Davao was inhabited by native Muslim groups and Lumad tribes which include the Tagabawa-Bagobo tribe who later became one of the first Christian converts.

There are a few stories on where the name Sta. Cruz was derived. According to the pioneers, it was when the Spaniards planted a cross under a shelter after failing to convert the settlers. A group of migrants later settled adjacent to the cross which is near the present Municipal Hall. It eventually became to be known as "Sa Cruz" meaning "at the cross". Official records from the Manila Archives indicate that the name was obtained during the Spanish Administration. The story describes the Spanish Governor-General of Mindanao province, Angel Rodriguez, arriving aboard the warship Garduqui and was greeted by both Christian and non-Christian inhabitants bringing embroidered banners with the word "STA. CRUZ". The following day, Rodriguez blessed the town "Sta. Cruz sa Mindanao" and it was called Sta. Cruz ever since.

With its foundation on October 5, 1884, Sta. Cruz is the oldest municipality in the province and the third oldest town in Mindanao. Now it aspires to become a city, given the presence of large industrial companies which invests in the town and its natural resources (Gloria, 1985; Municipality of Sta. Cruz, 2015; Sibulan Trail, 2017).

Figure 2. Sibulan River flood history

A recent flooding event on January 2011 occurred in Darong, Sta. Cruz, Davao del Sur when rampaging waters from Sibulan River overflowed along the highways in Darong (Gallardo, 2011). According to locals, from the year 1971 to 2014, local rainfall and buhawi are the usual cause of flooding near the river. However, PAGASA only noted Low Pressure Area (LPA) events such as the flashflood in 2012.

CHAPTER 2: LIDAR DATA ACQUISITION OF THE SIBULAN FLOODPLAIN

Engr. Louie P. Balicanta, Engr. Christopher Cruz, Lovely Acuna, Engr. Gerome Hipolito, Ms. Pauline Joanne G. Arceo, and Engr. Kenneth A. Quisado.

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 Sibulan floodplain in Davao del Sur. These missions were planned for 14 lines and ran for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameters for the LiDAR system is found in Table 1. Figure 3 shows the flight plan for Sibulan floodplain.

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

Block Name	Flying Height (m AGL)	Overlap (%)	Field of view (ø)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK82A	1000	30	40	100	50	130	5
BLK82B	1000	30	40	100	50	130	5
BLK82C	850/800	30	50	125	40	130	5
BLK82D	1000	30	40	100	50	130	5
BLK82_ voids	1000	35	40	100	40	130	5

[1] The explanation of the parameters used are in the volume "LiDAR Surveys and Flood Mapping in the Philippines: Methods."

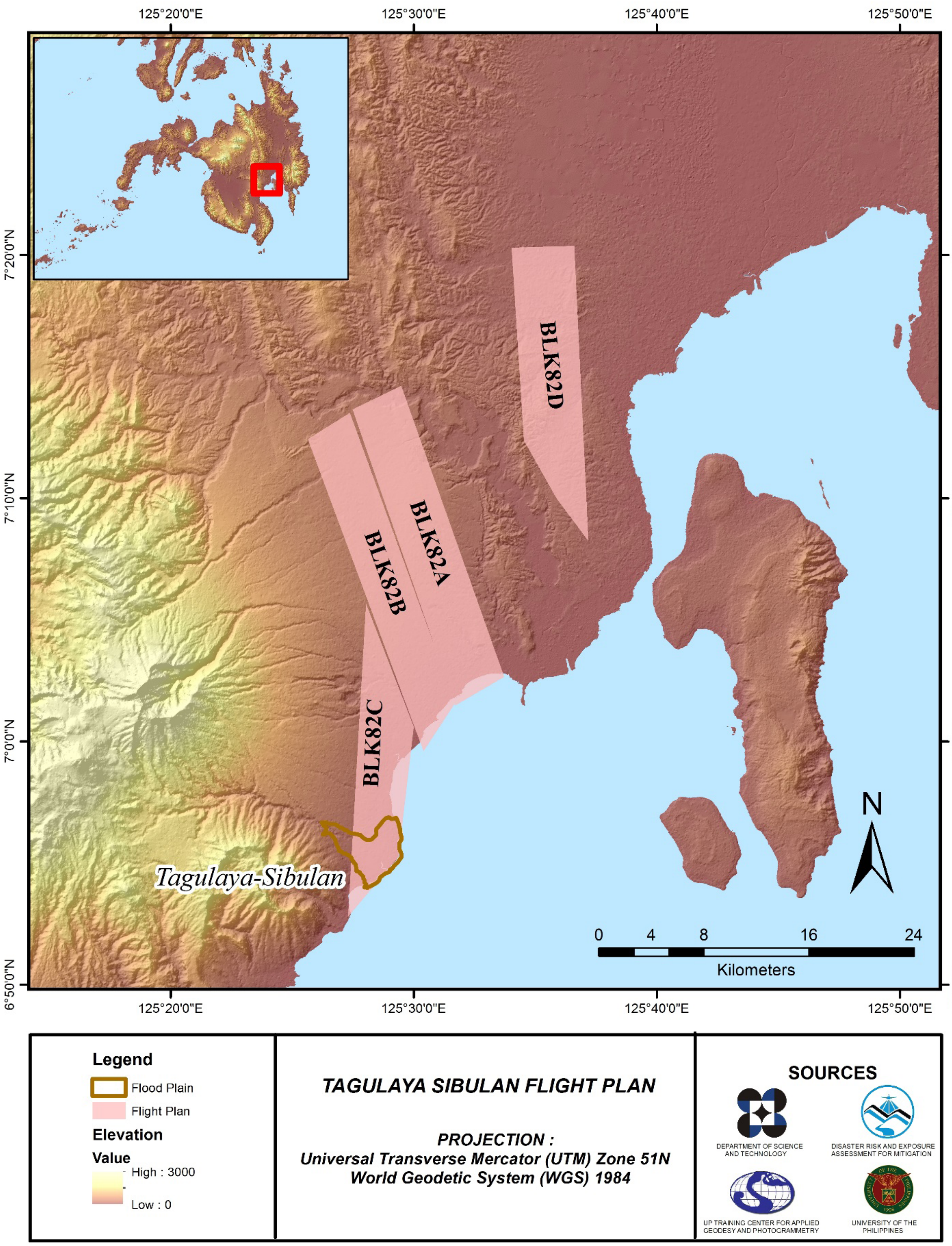
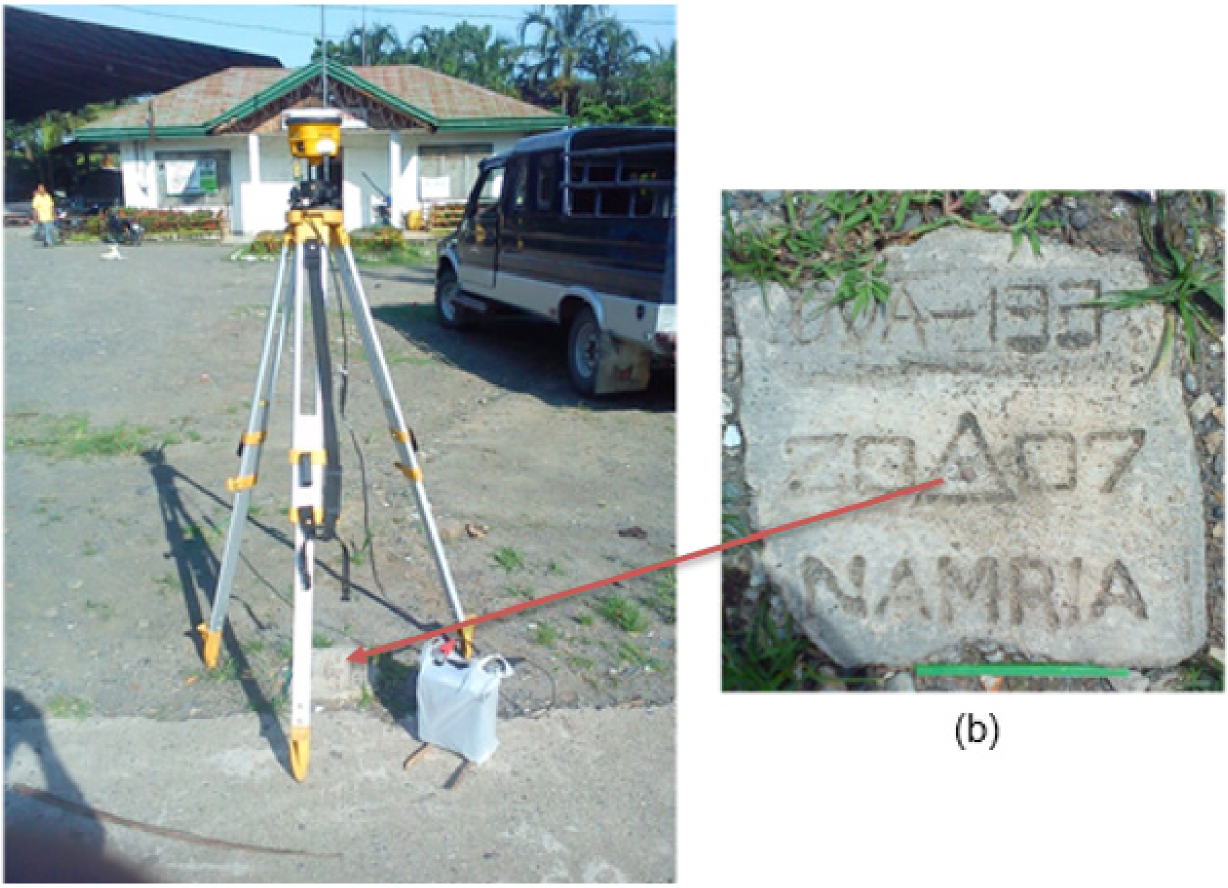


Figure 3. Flight Plan and base station used for the Sibulan Floodplain survey.

2.2 Ground Base Stations

The project team was able to recover three (3) NAMRIA ground control points: DVS-01 and DVA-133 which are of second (2nd) order accuracy, and DVA-3237 which are of fourth (4th) order accuracy. The team also established one (1) ground control point: DVS-01A. Established and 4th order ground control points where then re-processed to obtain coordinates of 2nd order accuracy. The certifications for the NAMRIA reference points are found in Annex B. Baseline processing reports for the re-processed control points are found in Annex C. These were used as base stations during flight operations for the entire duration of the survey (July 18 – August 11, 2014). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 882 and SPS 985. Flight plans and location of base stations used during the aerial LiDAR acquisition in Tagulaya Sibulan floodplain are shown in Figure 3.

Figure 4 to Figure 7 show the recovered NAMRIA reference and established points within the area. In addition, Table 2 to Table 5 show the details about the following NAMRIA control stations and established points while Table 6 shows the list of all ground control points occupied during the acquisition together with the corresponding dates of utilization. The list of team members are found in Annex 4.



(a) (b)

Figure 4. GPS set-up over DVA-133 as located in front of the barangay hall of Manay (a) and NAMRIA reference point DVA-133 (b) as recovered by the field team.

Table 2. Details of the recovered NAMRIA horizontal control point DVA-133 used as base station for the LiDAR acquisition.

Station Name	DVA-133	
Order of Accuracy	2nd	
Relative Error (Horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference 0f 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7°20’57.02014” North 125°35’57.50044” East 23.957 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	566168.597 meters 812626.211 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	7°20’53.82313” North 125°36’2.99870” East 96.163 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	786976.44 meters 813130.63 meters

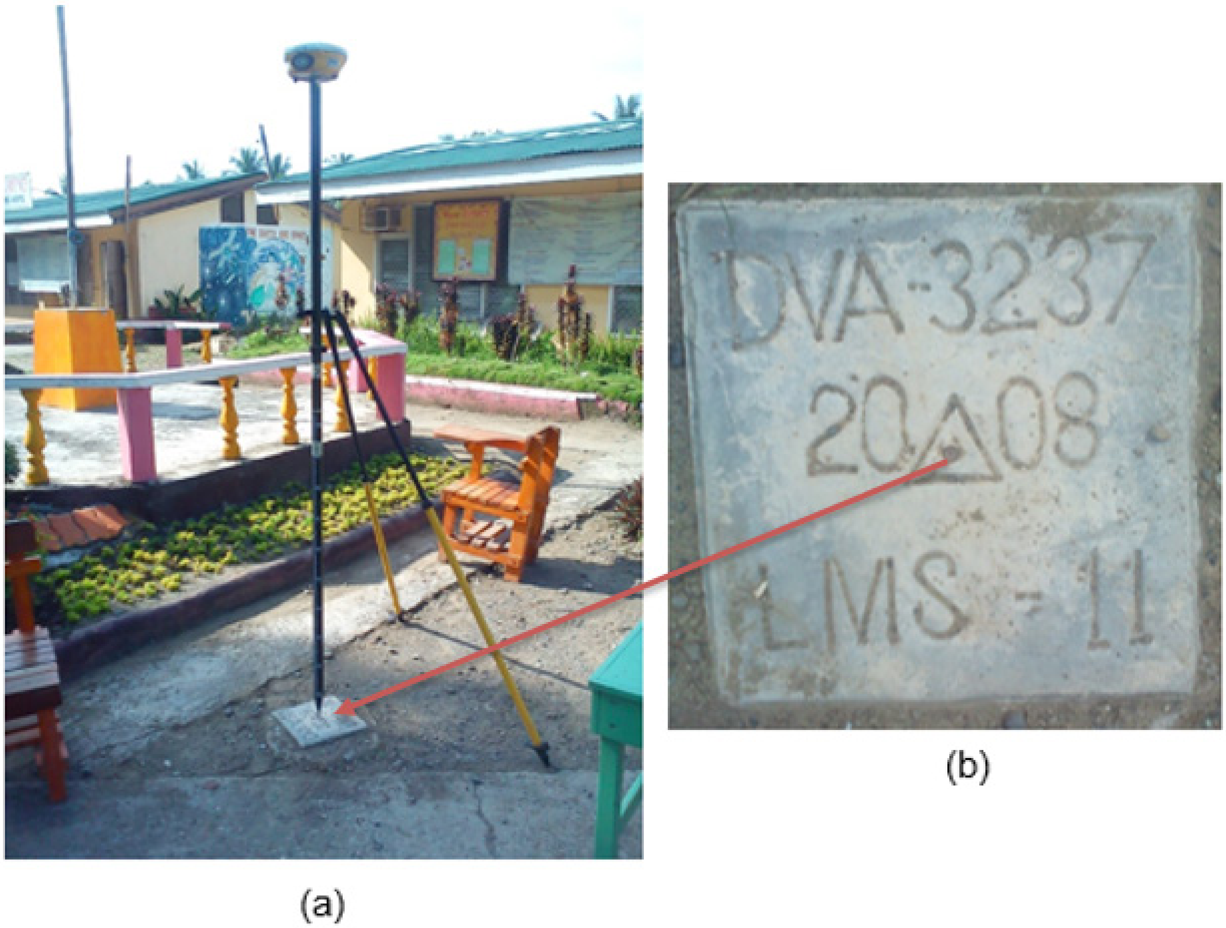


Figure 5. GPS set-up over DVA-3237 located beside the flagpole inside the compound of Nanyo Elementary School (a) and NAMRIA reference point DVA-3237 (b) as recovered by the field team.

Table 3. Details of the recoverd NAMRIA horizontal control point DVA-3237 used as base station for the LiDAR acquisition with re-processed coordinates.

Station Name	DVA-3237	
Order of Accuracy	2nd	
Relative Error (Horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7°19’59.95215” North 125°38’7.26797” East 17.228 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	7°19’56.76267” North 125°38’12.76731” East 89.553 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	790969.206 meters 811399.786 meters

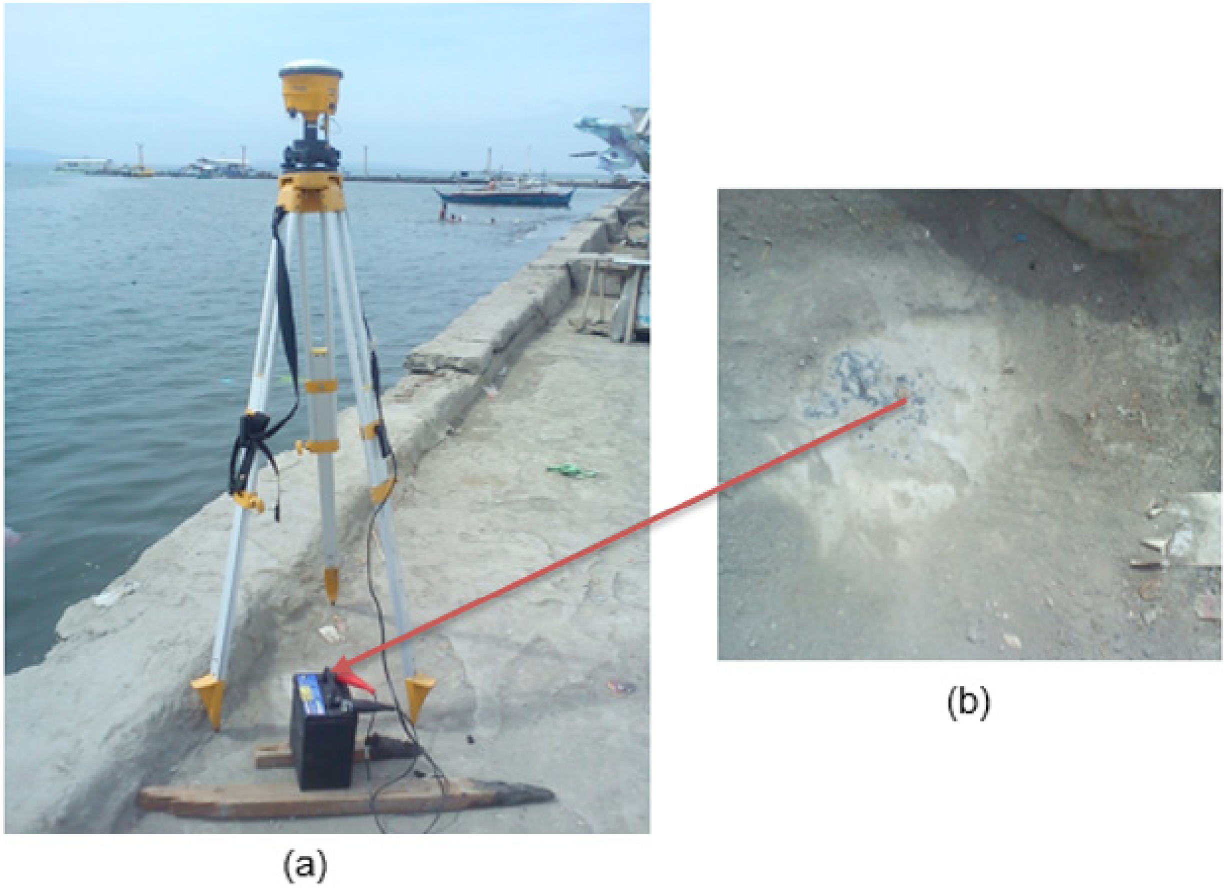


Figure 6. GPS set-up over DVS-01 located at the east side of the pier in Davao City (a) and NAMRIA reference point DVS-01 (b) as recovered by the field team.

Table 4. Details of the recovered NAMRIA horizontal control point DVS-01 used as base station for the LiDAR acquisition.

Station Name	DVS-01	
Order of Accuracy	1st	
Relative Error (horizontal positioning)	1 in 100,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7°4'41.48387" North 125°37'31.24815" East -4.507 meters
Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 5 PRS 92)	Easting Northing	569084.935 meters 782663.345 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	7°4'38.36201" North 125°37'36.77094" East 68.275 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 52N PRS 1992)	Easting Northing	790026.110 meters 783162.170 meters

(a)

(b)

Figure 7. GPS set-up over DVS-01A located at the east side of the pier in Davao City, near DVS-01 (a) and NAMRIA reference point DVS-01A (b) as recovered by the field team.

Table 5. Details of the established horizontal control point DVS-01A used as base station for the LiDAR acquisition.

Station Name	DVS-01A	
Order of Accuracy	1st	
Relative Error (horizontal positioning)	1 in 100,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7°4'41.46785" North 125°37'31.08587" East -4.269 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	7°4'38.34598" North 125°37'36.60866" East 68.513 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 52N PRS 1992)	Easting Northing	790021.135 meters 783161.647 meters

Table 6. Ground control points used during the LiDAR data acquisition.

Date Surveyed	Flight Number	Mission Name	Ground Control Points
July 18, 2014	7378GC	2BLK82A199A	DVS-01 & DVS-01A
July 22, 2014	7386GC	2BLK82CSD203A	DVS-01 & DVS-01A
August 11, 2014	7426GC	2BLK82V223A	DVA-3237 & DVA-133
August 11, 2014	7427GC	2BLK82V223B	DVA-3237 & DVA-133

2.3 Flight Missions

Four (4) missions were conducted to complete the LiDAR data acquisition in Tagulaya Sibulan floodplain, for a total of thirteen hours and forty four minutes (13+44) of flying time for RP-C9322. All missions were acquired using the Gemini LiDAR system. Table 7 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 8 presents the actual parameters used during the LiDAR data acquisition.

Table 7. Flight missions for the LiDAR data acquisition in Sibulan Floodplain.

Date Surveyed	Flight Number	Flight Plan Area (km2)	Surveyed Area (km2)	Area Surveyed within the Floodplain (km2)	Area Surveyed Outside the Floodplain (km2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
July 18, 2014	7378GC	65.694	175.283	4.275	171.008	NA	4	5
July 22, 2014	7386GC	65.694	249.113	11.447	237.666	NA	4	29
August 11, 2014	7426GC	818.466	95.826	0	95.826	NA	2	41
August 11, 2014	7427GC	818.466	47.889	4.890	42.890	NA	2	29
TOTAL		**1768.32**	**526.887**	**20.612**	**547.499**	**NA**	**13**	**44**

Table 8. Actual parameters used during the LiDAR data acquisition of the Sibulan Floodplain.

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (khz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
7378GC	850	30	50	125	40	130	5
7386GC	800	30	50	125	40	130	5
7426GC	1000	35	40	100	50	130	5
7427GC	1000	35	40	100	50	130	5

2.4 Survey Coverage

Sibulan floodplain is located in the province of Davao Del Sur, specifically within the municipality of Santa Cruz. The list of municipalities surveyed, with at least one (1) square kilometer coverage, is shown in Table 9. The actual coverage of the LiDAR acquisition for Sibulan floodplain is presented in Figure 8.

Table 9. List of municipalities and cities surveyed of the Sibulan Floodplain LiDAR acquisition.

Province	Municipality/ City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Davao Oriental	Carmen	58.44	40.23	68.84%
	Catmon	92.99	15.33	16.49%
	Cebu City	290.59	135.38	46.59%
	Compostela	51.55	46.55	90.30%
	Consolacion	32.98	32.96	99.94%
	Danao City	137.12	84.3	61.48%
	Lapu-Lapu City	63.42	3	4.73%
	Liloan	54.98	54.95	99.95%
	Mandaue City	31	30.99	99.97%
	Minglanilla	51.76	5.21	10.07%
	Talisay City	48.61	23.86	49.08%
Total		**913.44**	**472.76**	**51.76%**

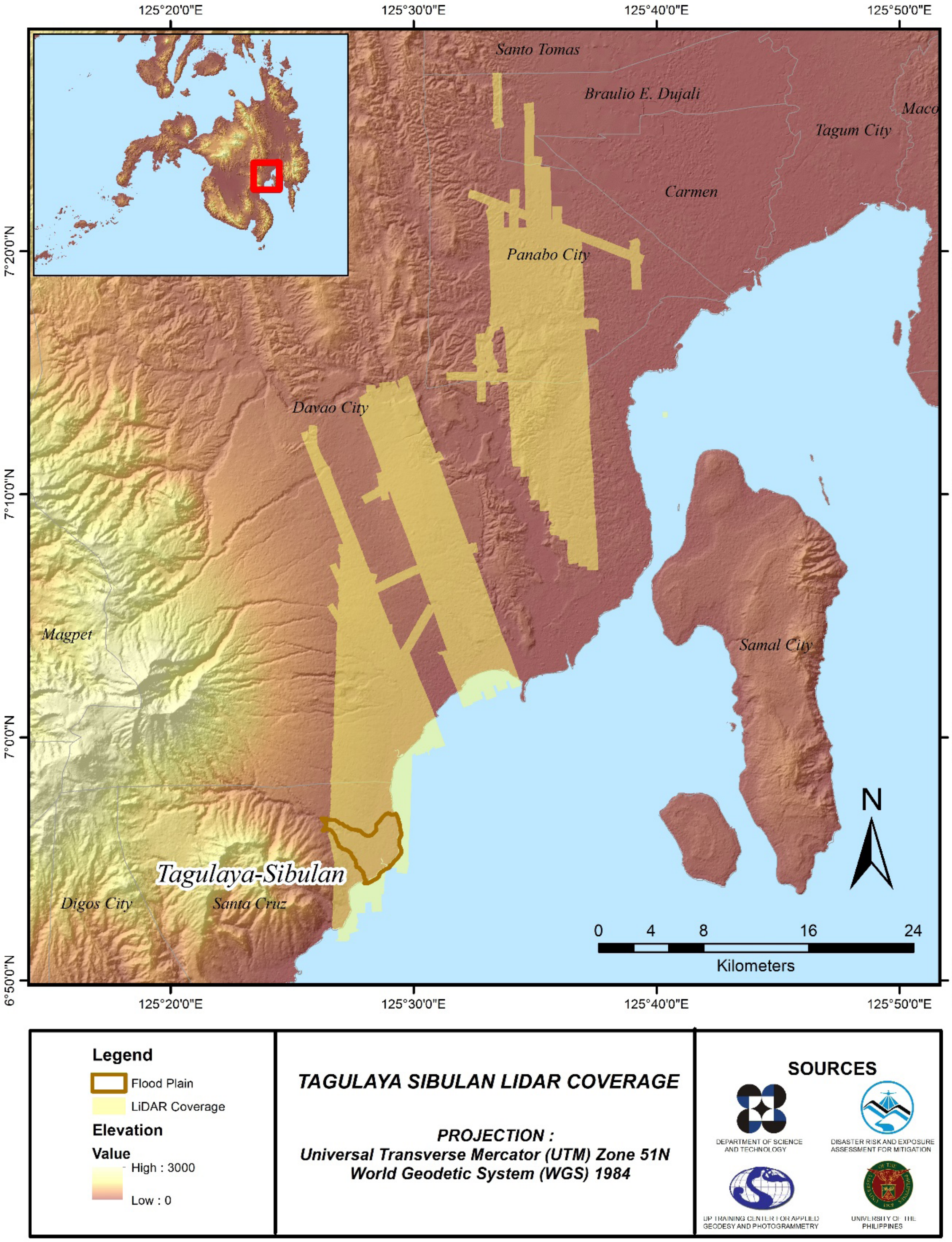


Figure 8. Actual LiDAR survey coverage of the Sibulan Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE SIBULAN FLOODPLAIN

Engr. Ma. Rosario Concepcion O. Ang, Engr. John Louie D. Fabila, Engr. Sarah Jane D. Samalburo, Engr. Harmond F. Santos , Engr. John Dill P. Macapagal , Engr. Ma. Ailyn L. Olanda, Engr. Erica Erin E. Elazegui, Engr. Melissa F. Fernandez , Engr. Ben Joseph J. Harder, and Engr. Karl Adrian P. Vergara

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

3.1 Overview of the LiDAR Data Pre-Processing

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

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

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

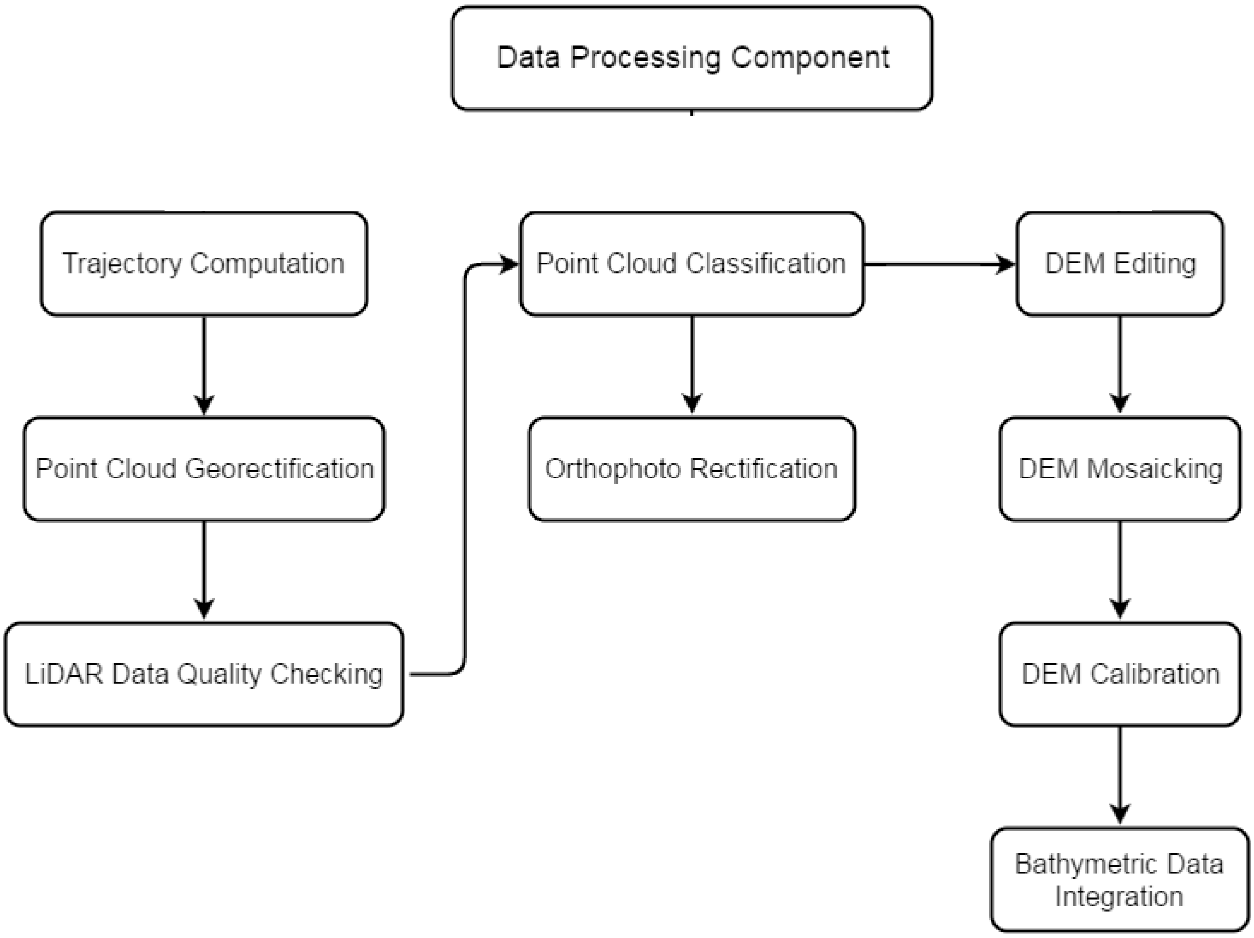


Figure 9. Schematic diagram for Data Pre-Processing Component.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Sibulan floodplain can be found in Annex 5: Data Transfer Sheets. All missions flown during the first survey and second survey conducted on July and August 2014 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Gemini system over Sta. Cruz, Davao del Sur.

The Data Acquisition Component (DAC) transferred a total of 68.56 Gigabytes of Range data, 777 Megabytes of POS data, and 33.06 Megabytes of GPS base station data to the data server on July 18, 2014 for the first survey and August 13, 2014 for the second survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Sibulan was fully transferred on August 29, 2014 as indicated on the Data Transfer Sheets for Sibulan floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metric parameters of the computed trajectory for flight 7378GC, one of the Sibulan flights, which is the North, East, and Down position RMSE values are shown in Figure 10. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on July 18, 2014 00:00 AM. The y-axis is the RMSE value for that particular position.

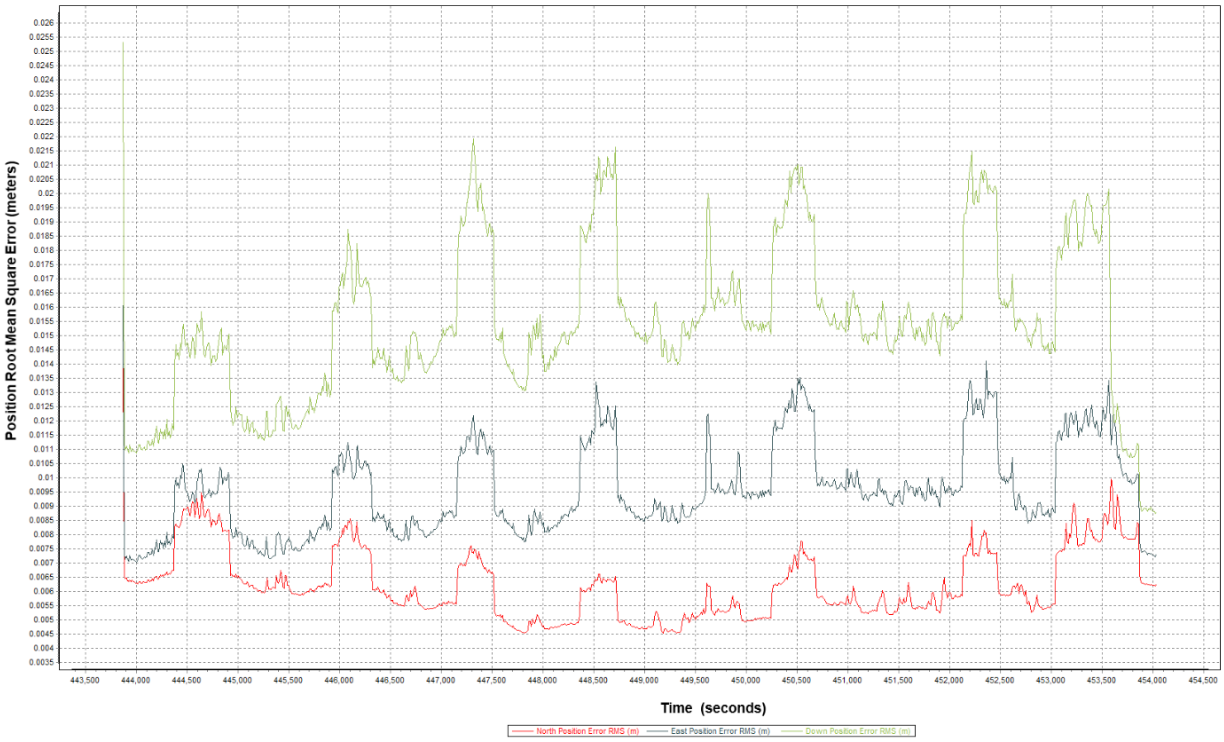


Figure 10. Smoothed Performance Metric Parameters of Sibulan Flight 7378GC

The time of flight was from 443500 seconds to 454000 seconds, which corresponds to morning of July 18, 2014. The initial spike that is seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the POS system starts computing for the position and orientation of the aircraft.

Redundant measurements from the POS system quickly minimized the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values correspond to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 11 shows that the North position RMSE peaks at 1.0 centimeters, the East position RMSE peaks at 1.45 centimeters, and the Down position RMSE peaks at 2.20 centimeters, which are within the prescribed accuracies described in the methodology.

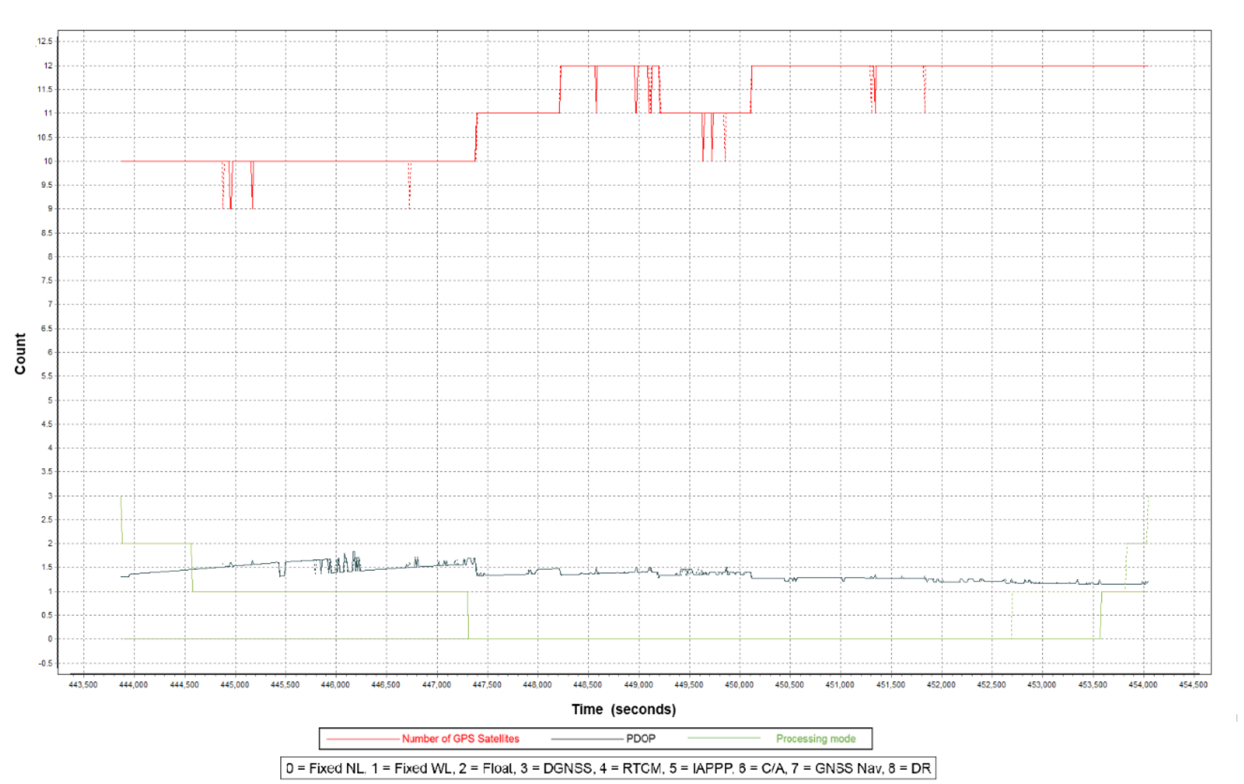


Figure 11. Solution Status Parameters of Sibulan Flight 7378GC.

The Solution Status parameters of flight 7378GC, one of the Sibulan flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure B-3. 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 9 and 12. 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 2 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Sibulan flights is shown in Figure 12.

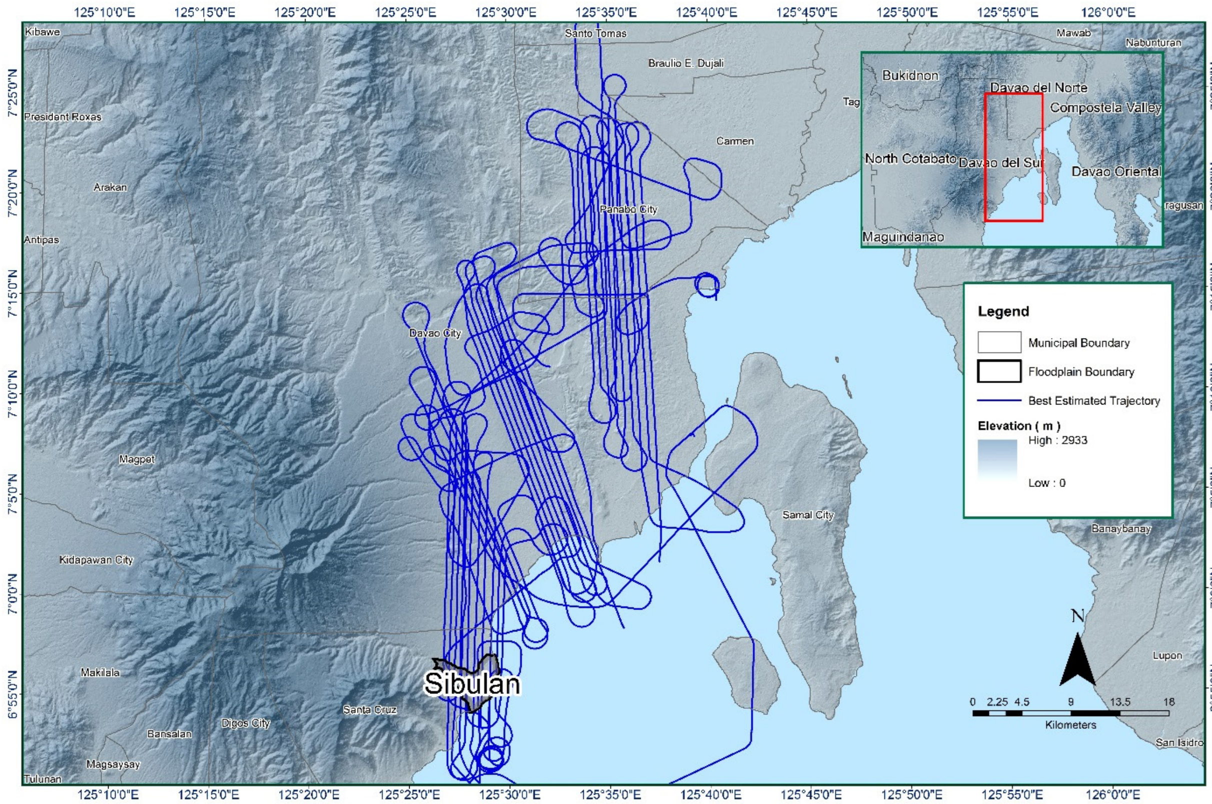


Figure 12. Best Estimated Trajectory of the LiDAR missions conducted over the Sibulan Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 34 flight lines, with each flight line containing one channel, since the Gemini systems contains one channel only. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Sibulan floodplain are given in Table 10.

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

Parameter	Acceptable Value	Computed Value
Boresight Correction stdev	<0.001degrees	0.000930
IMU Attitude Correction Roll and Pitch Correction stdev	<0.001degrees	0.000969
GPS Position Z-correction stdev	<0.01meters	0.0097

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

3.5 LiDAR Data Quality Checking

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

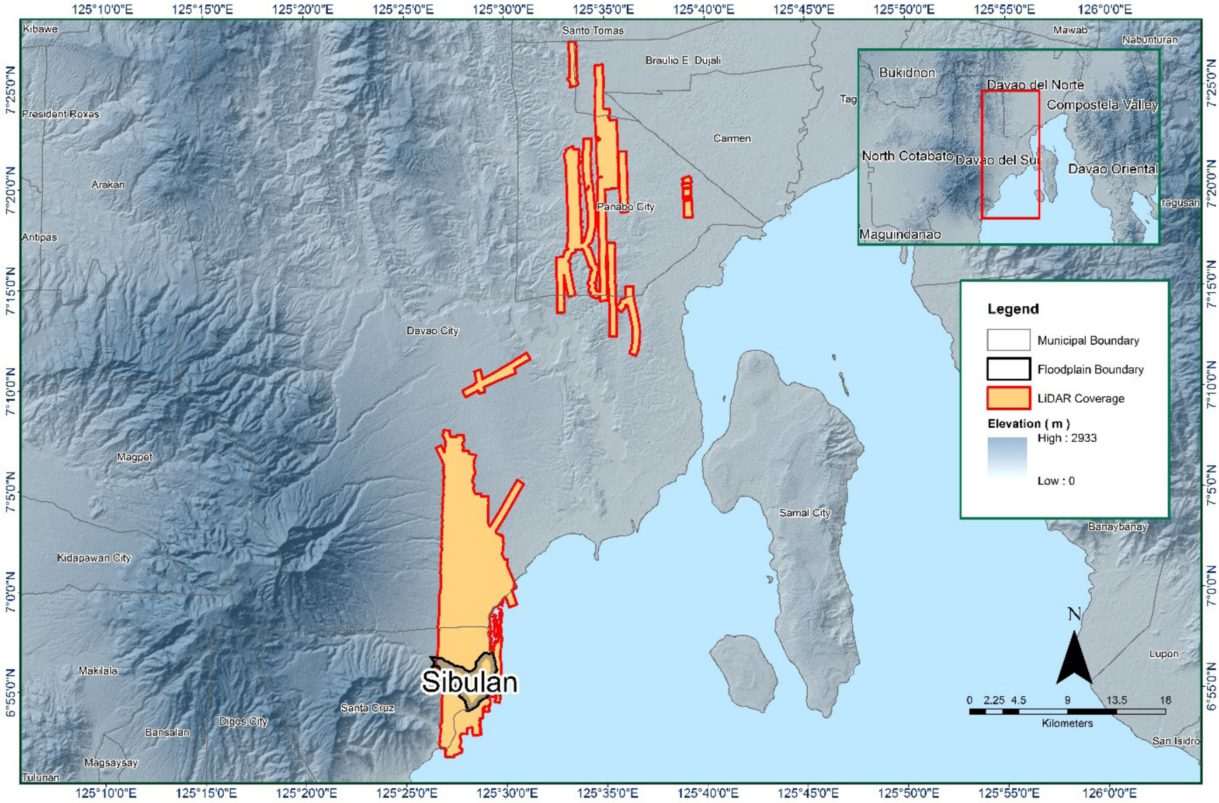


Figure 13. Boundary of the processed LiDAR data over Sibulan Floodplain

The total area covered by the Sibulan missions is 241.16 sq.km that is comprised of four (4) flight acquisitions grouped and merged into two (2) blocks as shown in Table 11.

Table 11. List of LiDAR blocks for Sibulan Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
DavaoDelSur_Blk82C	7378GC	124.17
	7386GC	
DavaoDelSur_Blk82_voids	7427GC	116.99
	7426GC	
TOTAL		**241.16 sq.km.**

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 14. Since the Gemini employs one channel, we would expect an average value of 1 (blue) for areas where there is limited overlap, and a value of 2 (yellow) or more (red) for areas with three or more overlapping flight lines.

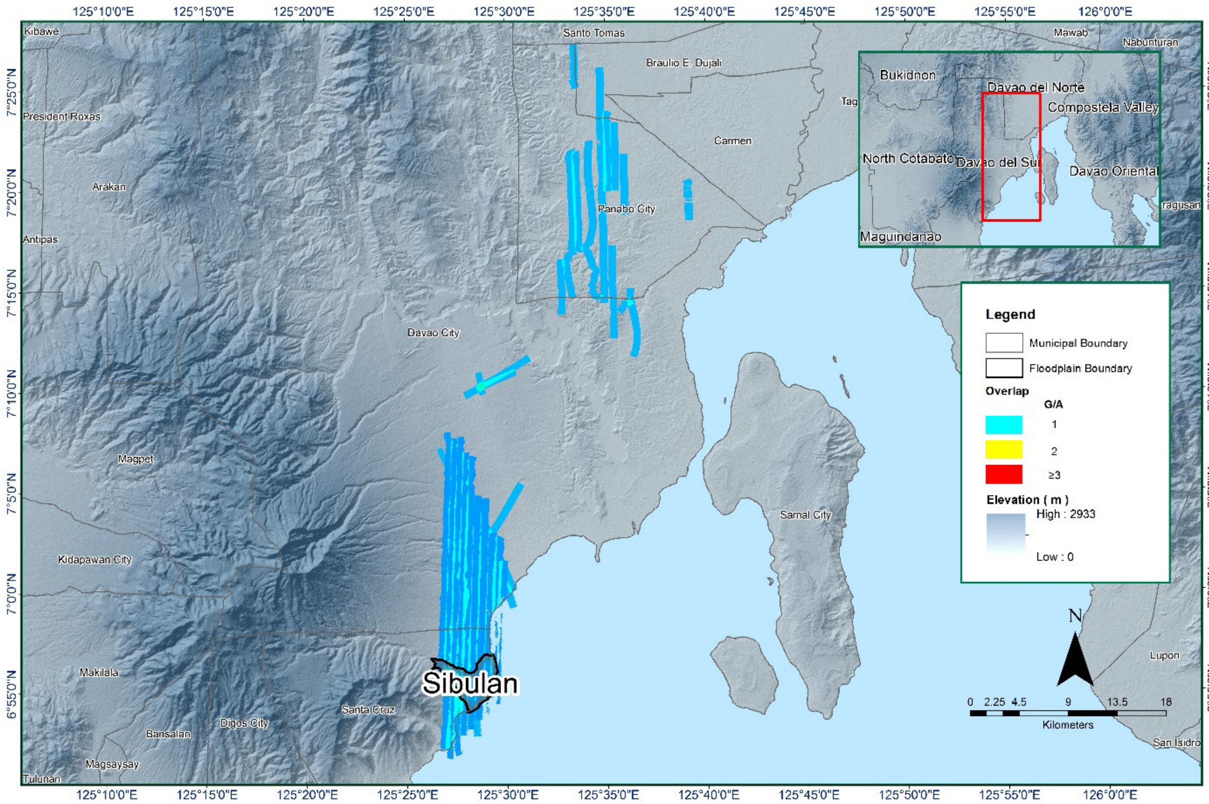


Figure 14. Image of data overlap for Sibulan Floodplain.

The overlap statistics per block for the Sibulan floodplain can be found in Annex B-1. Mission Summary Reports. It should be noted that one pixel corresponds to 25.0 square meters on the ground. For this area, the percent overlap is 10.46%.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 15. It was determined that all LiDAR data for Sibulan floodplain satisfy the point density requirement, and the average density for the entire survey area is 3.14 points per square meter.

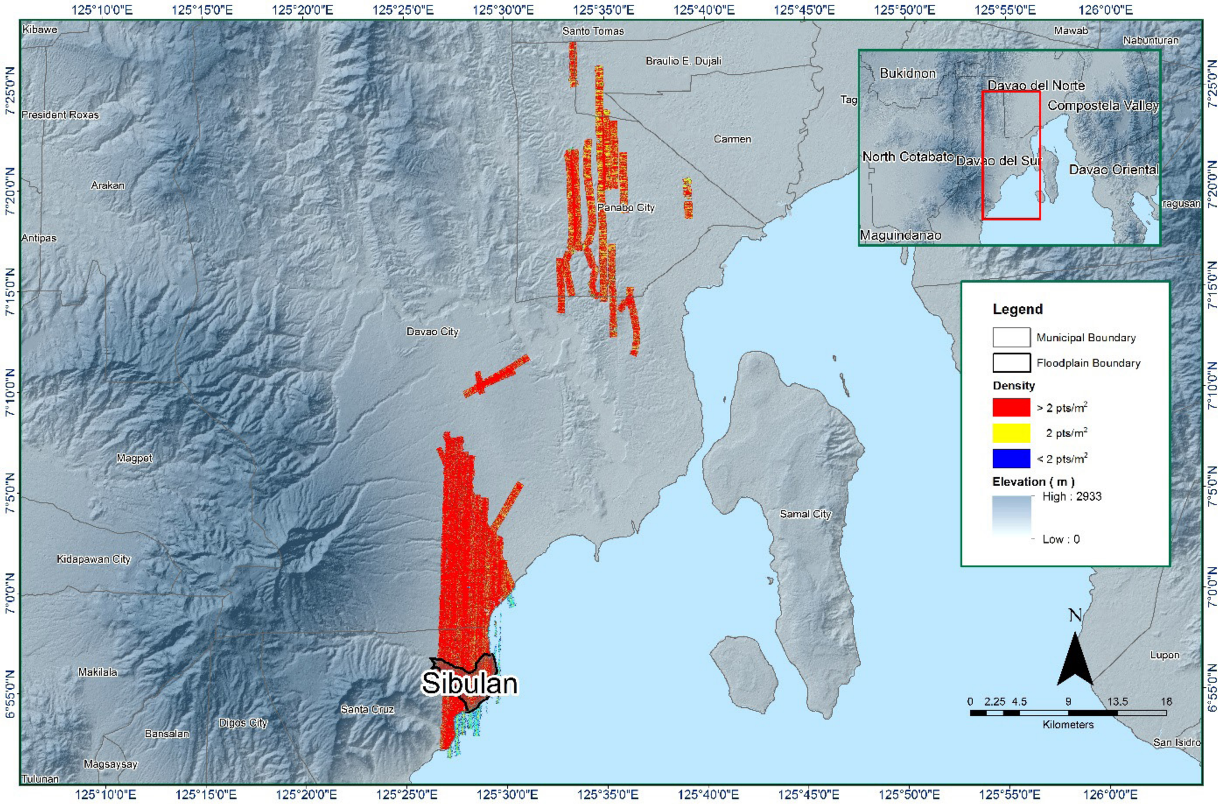


Figure 15. Pulse density map of merged LiDAR data for Sibulan Floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 16. The default color range is from blue to red, where bright blue areas correspond to portions where elevations of a previous flight line, identified by its acquisition time, are higher by more than 0.20m relative to elevations of its adjacent flight line. Bright red areas indicate portions where elevations of a previous flight line are lower by more than 0.20m relative to elevations of its adjacent flight line. Areas with bright red or bright blue need to be investigated further using Quick Terrain Modeler software.

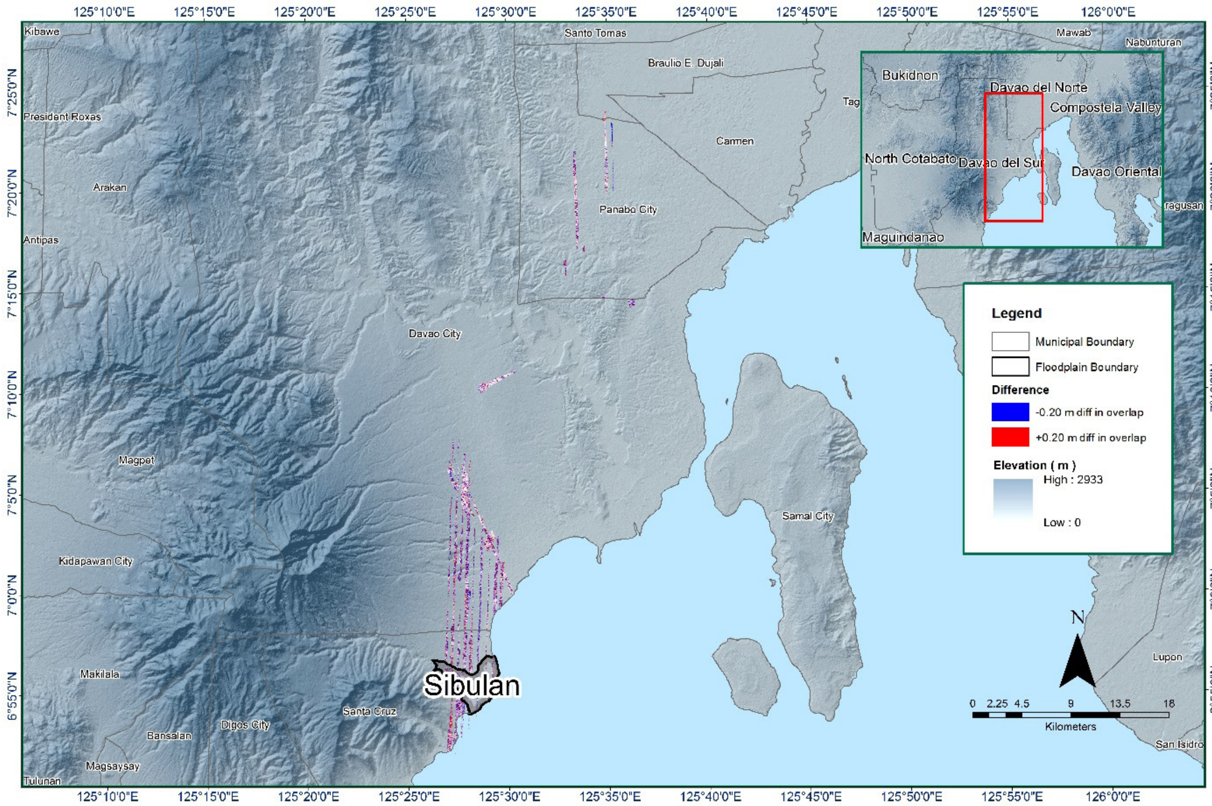


Figure 16. Elevation Difference Map between flight lines for Sibulan Floodplain Survey.

A screen capture of the processed LAS data from a Sibulan flight 7378GC loaded in QT Modeler is shown in Figure 17. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed 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.

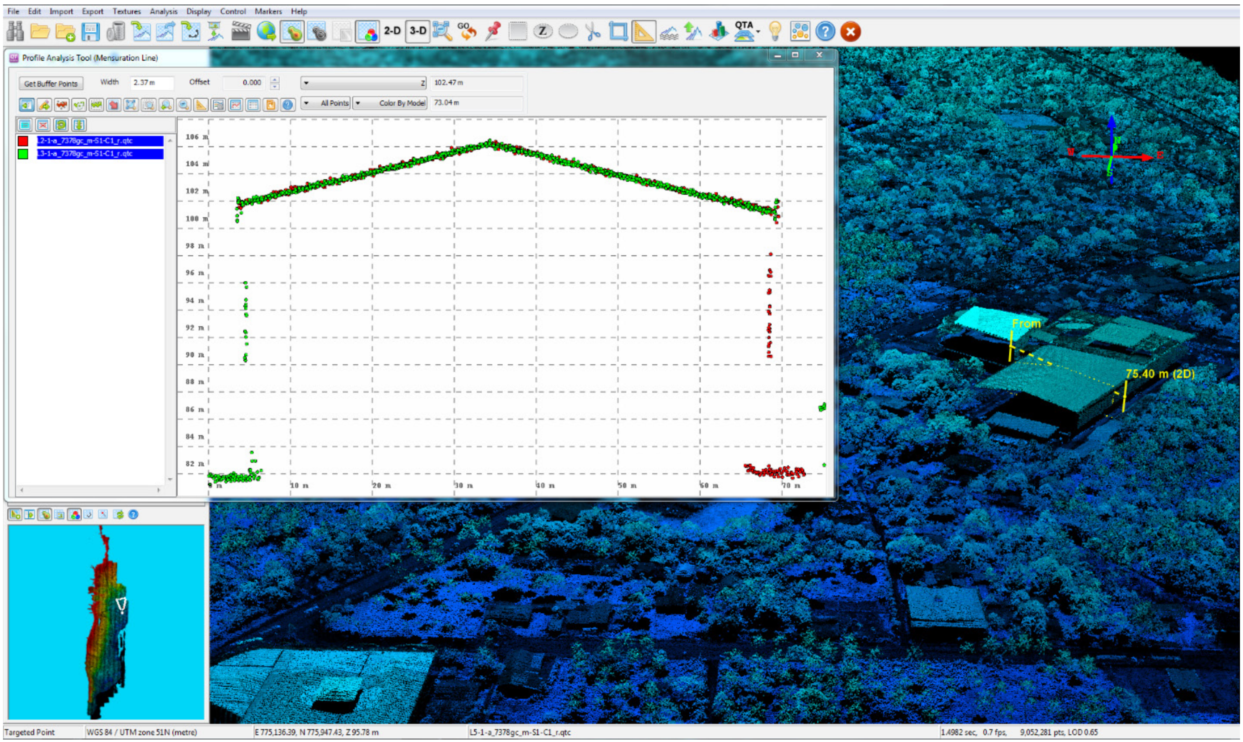


Figure 17. Quality checking for Sibulan Flight 7378GC using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 12. Sibulan classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	73,262,152
Low Vegetation	67,826,647
Medium Vegetation	183,873,811
High Vegetation	381,654,669
Building	6,869,981

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Sibulan floodplain is shown in Figure 18. A total of 437 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 12. The point cloud has a maximum and minimum height of 421.89 meters and 59.35 meters respectively.

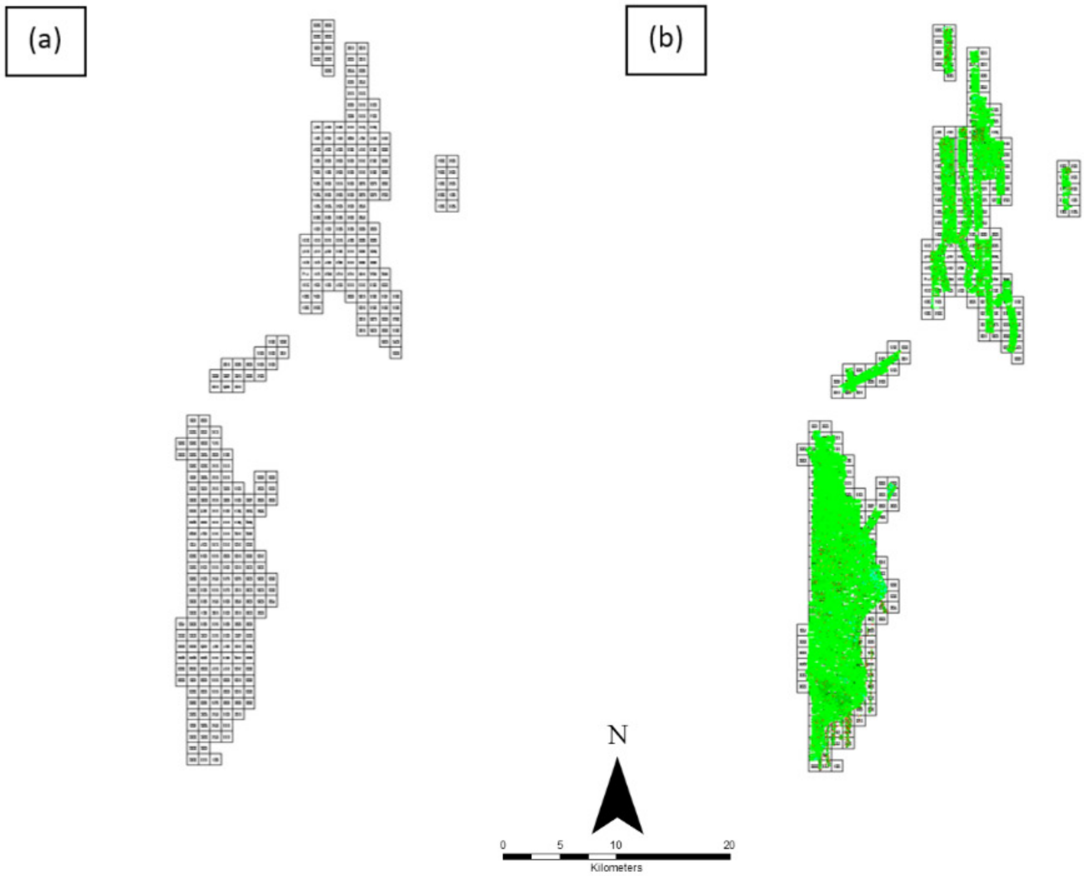


Figure 18. Tiles for Sibulan Floodplain (a) and classification results (b) in TerraScan.

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

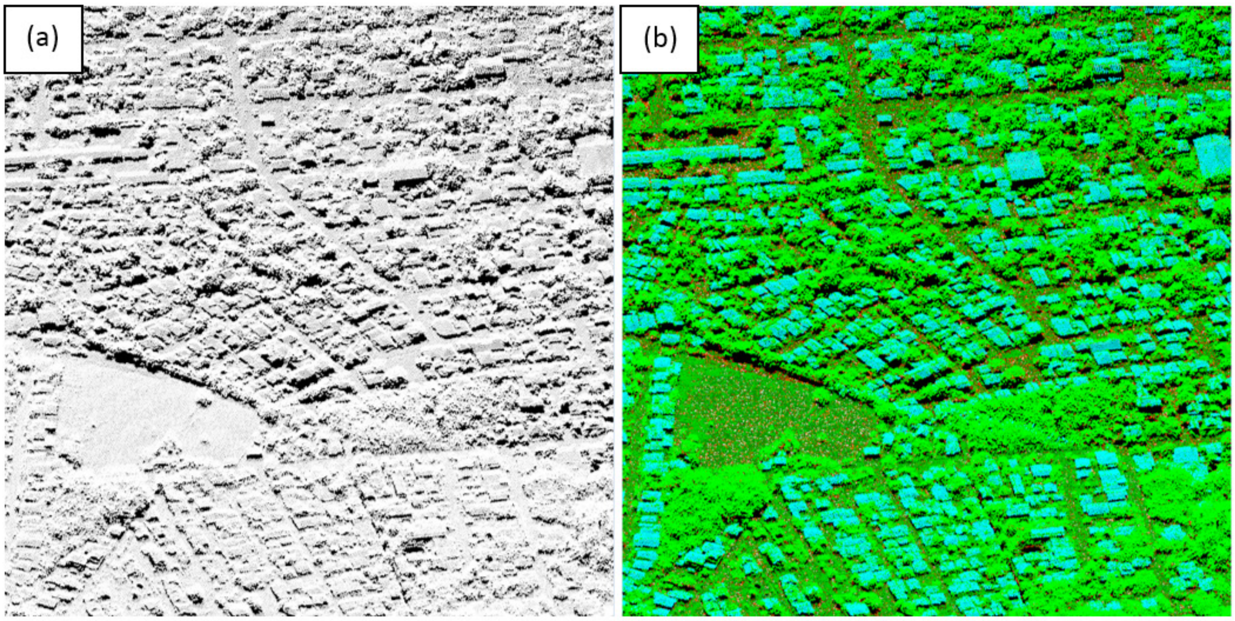


Figure 19. Point cloud before (a) and after (b) classification

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

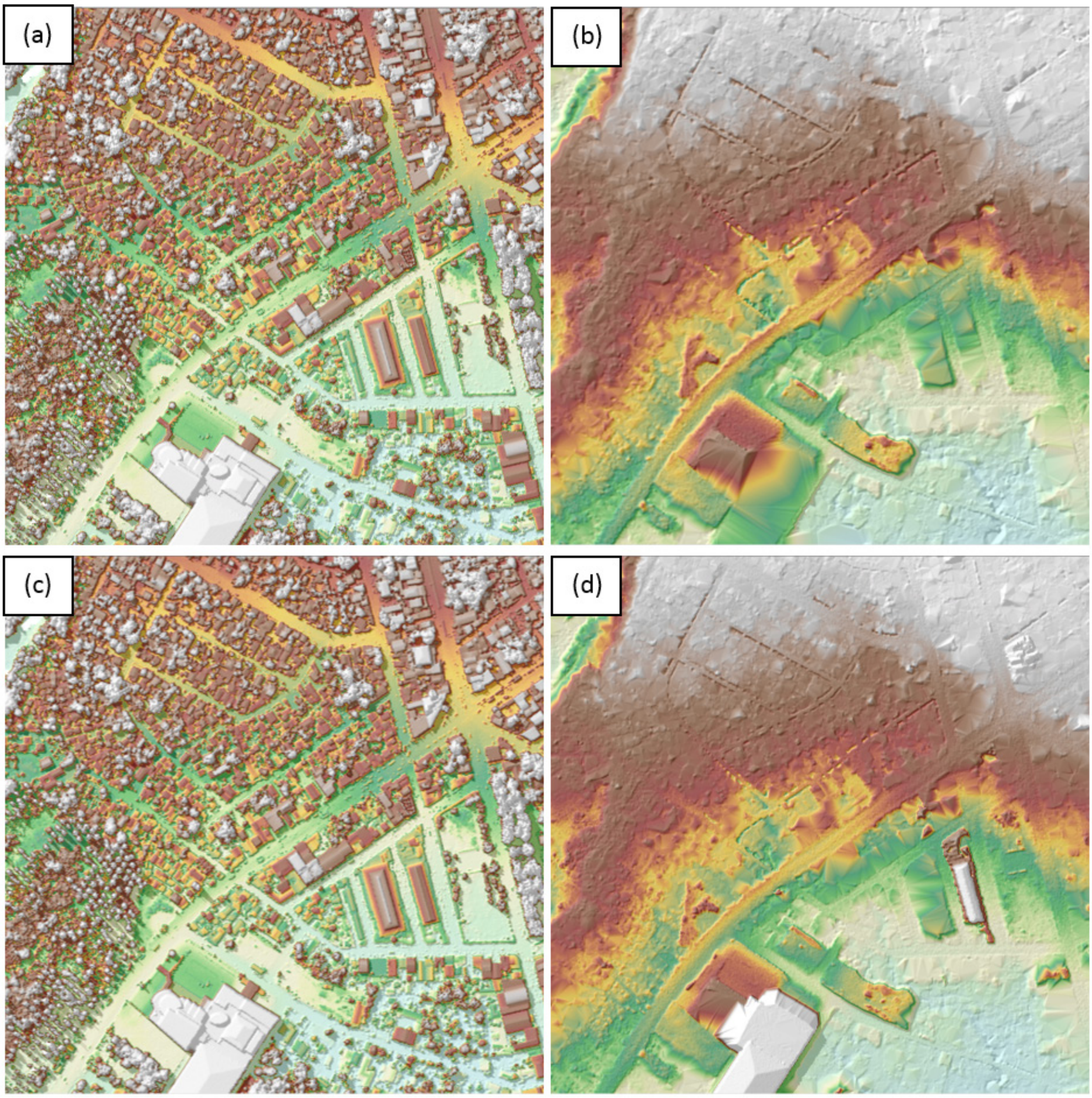


Figure 20. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Sibulan Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

There are no available orthophotographs for the Sibulan floodplain.

3.8 DEM Editing and Hydro-Correction

Two (2) mission blocks were processed for Sibulan flood plain. These blocks are composed of DavaoDelSur blocks with a total area of 241.16 square kilometers. Table 13 shows the name and corresponding area of each block in square kilometers.

Table 13. LiDAR blocks with its corresponding areas.

LiDAR Blocks	Area (sq.km)
DavaoDelSur_Blk82C	124.17
DavaoDelSur_Blk82_voids	116.99
TOTAL	**241.16**

Portions of DTM before and after manual editing are shown in Figure 21. The bridge (Figure 21a) is also considered an impedance to the flow of water along the river and has to be removed (Figure 21b) in order to hydrologically correct the river. Another example is a building that is still present in the DTM after classification (Figure 21c) and has to be removed through manual editing (Figure 21d).

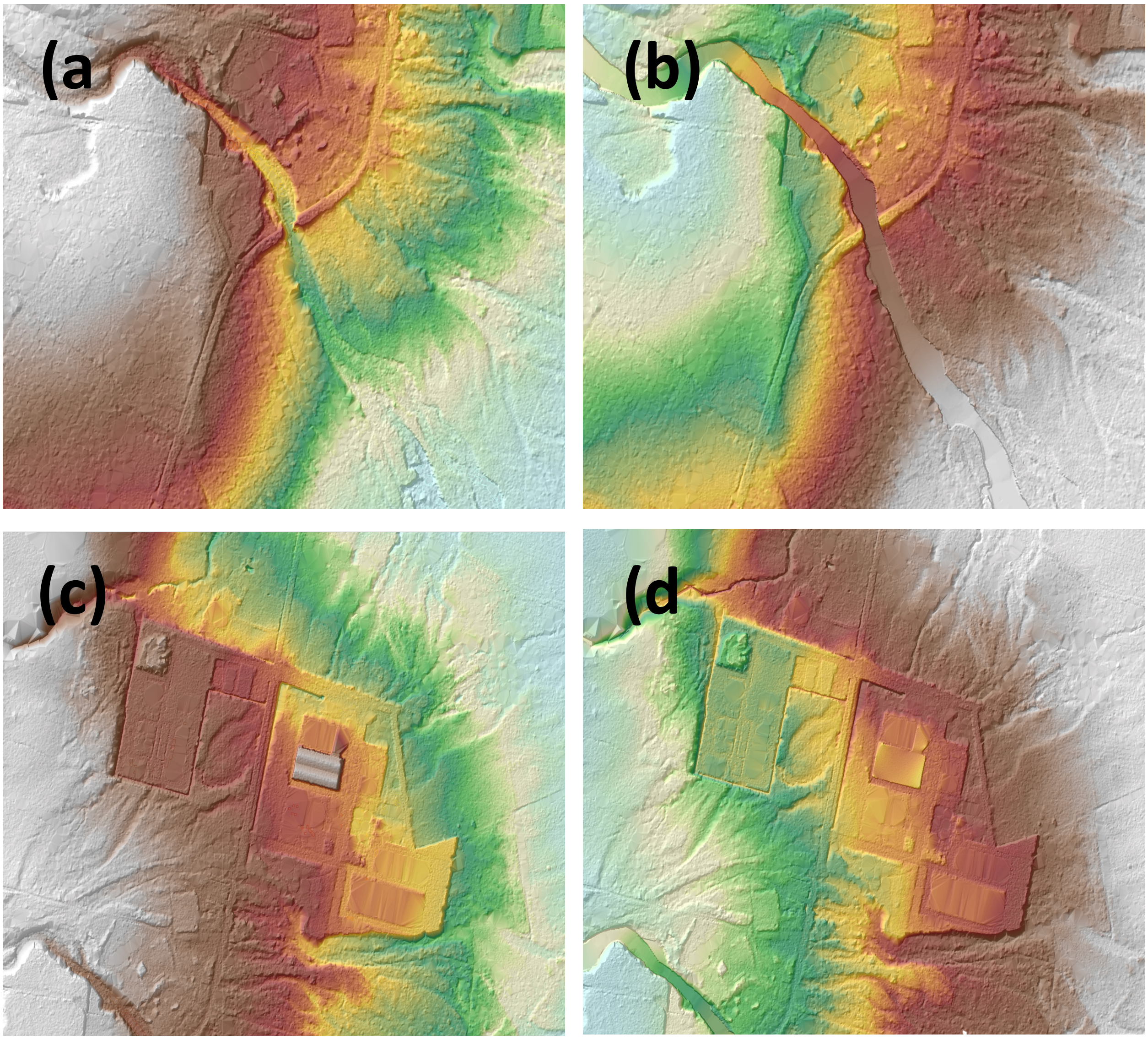


Figure 21. Portions in the DTM of Sibulan floodplain – a bridge before (a) and after (b) manual editing; and a building before (c) and after (d) manual editing

3.9 Mosaicking of Blocks

DavaoDelSur_Blk82A was used as the reference block at the start of mosaicking because it was referred to a base station with an acceptable order of accuracy.

Mosaicked LiDAR DTM for Sibulan floodplain is shown in Figure 22. It can be seen that the entire Sibulan floodplain is 98.33% covered by LiDAR data.

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

Mission Blocks	Shift Values (meters)		
	x	y	z
DavaoDelSur_Blk82C	0.00	0.00	0.00
DavaoDelSur_Blk82_voids	0.50	0.50	0.00

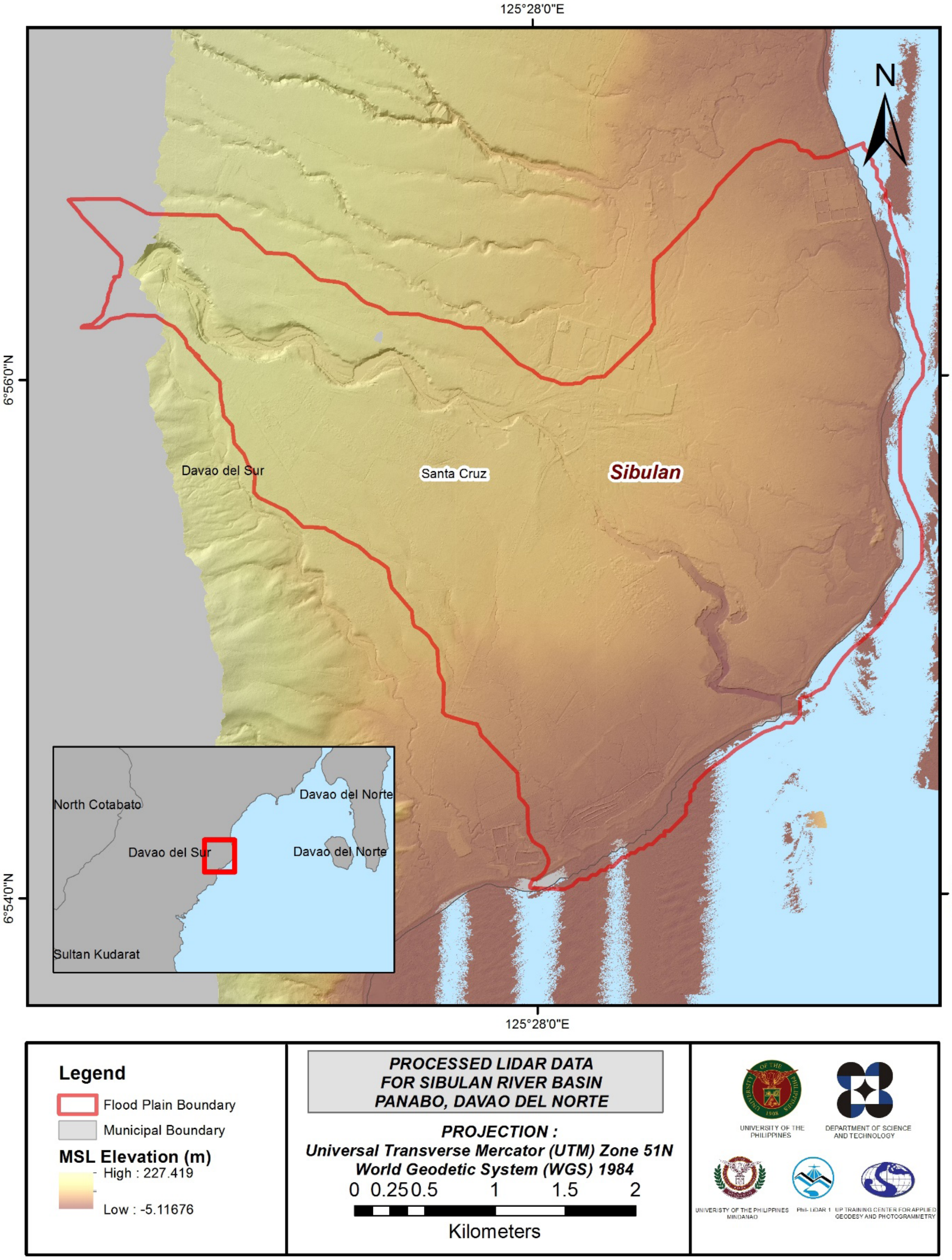


Figure 22. Map of Processed LiDAR Data for Sibulan Floodplain

3.10 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model (DEM)

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Sibulan to collect points with which the LiDAR dataset is validated is shown in Figure 23. A total of 21,221 survey points were used for calibration and validation of Sibulan LiDAR data. Random selection of 80% of the survey points, resulting to 16,977 points, were used for calibration.

The good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values is shown in Figure 24. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration elevation values is 0.58 meters with a standard deviation of 0.12 meters. Calibration of Sibulan LiDAR data was done by adding the height difference value, 0.58 meters, to Sibulan mosaicked LiDAR data. Table 15 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

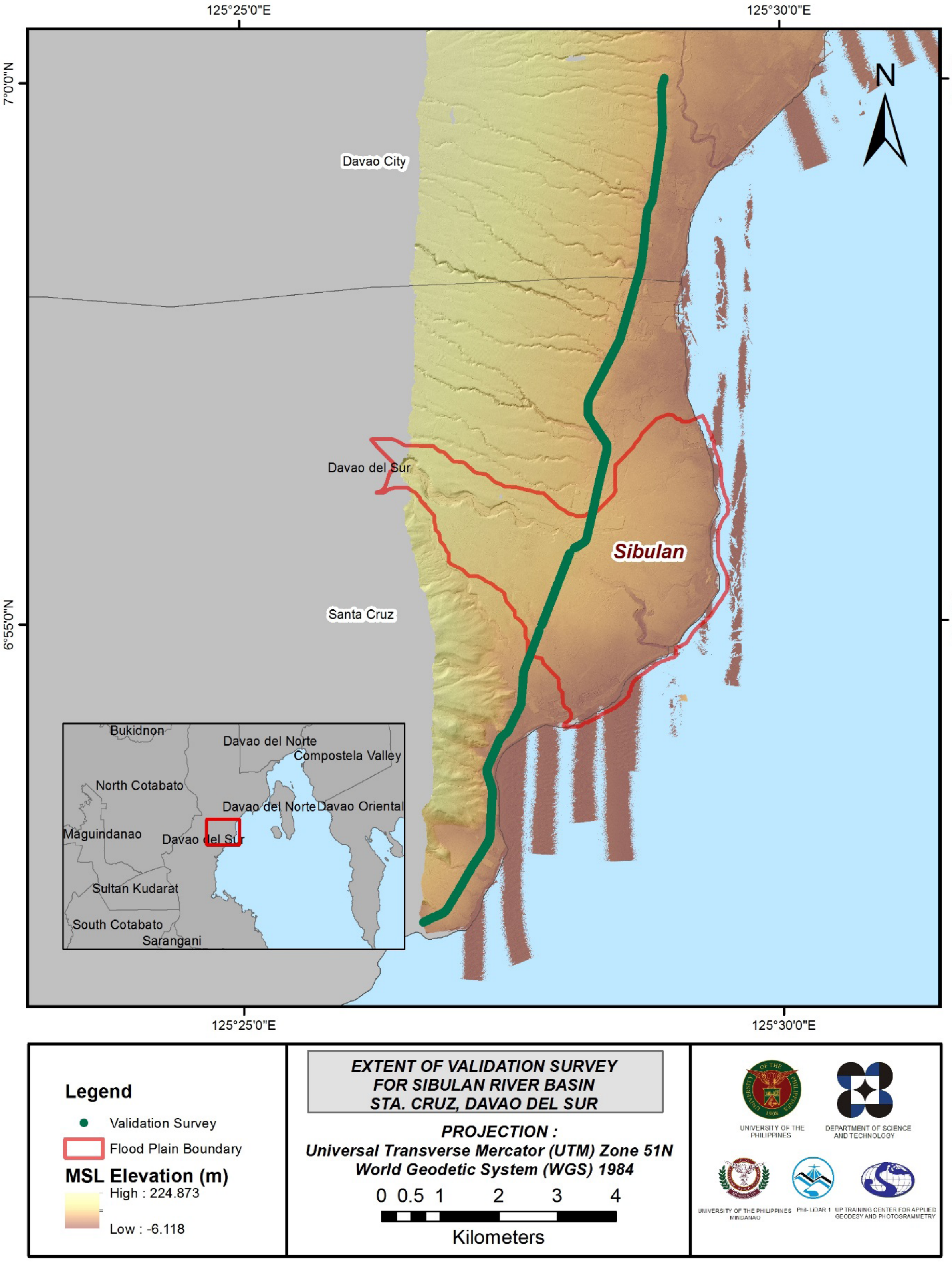


Figure 23. Map of Sibulan Floodplain with validation survey points in green.

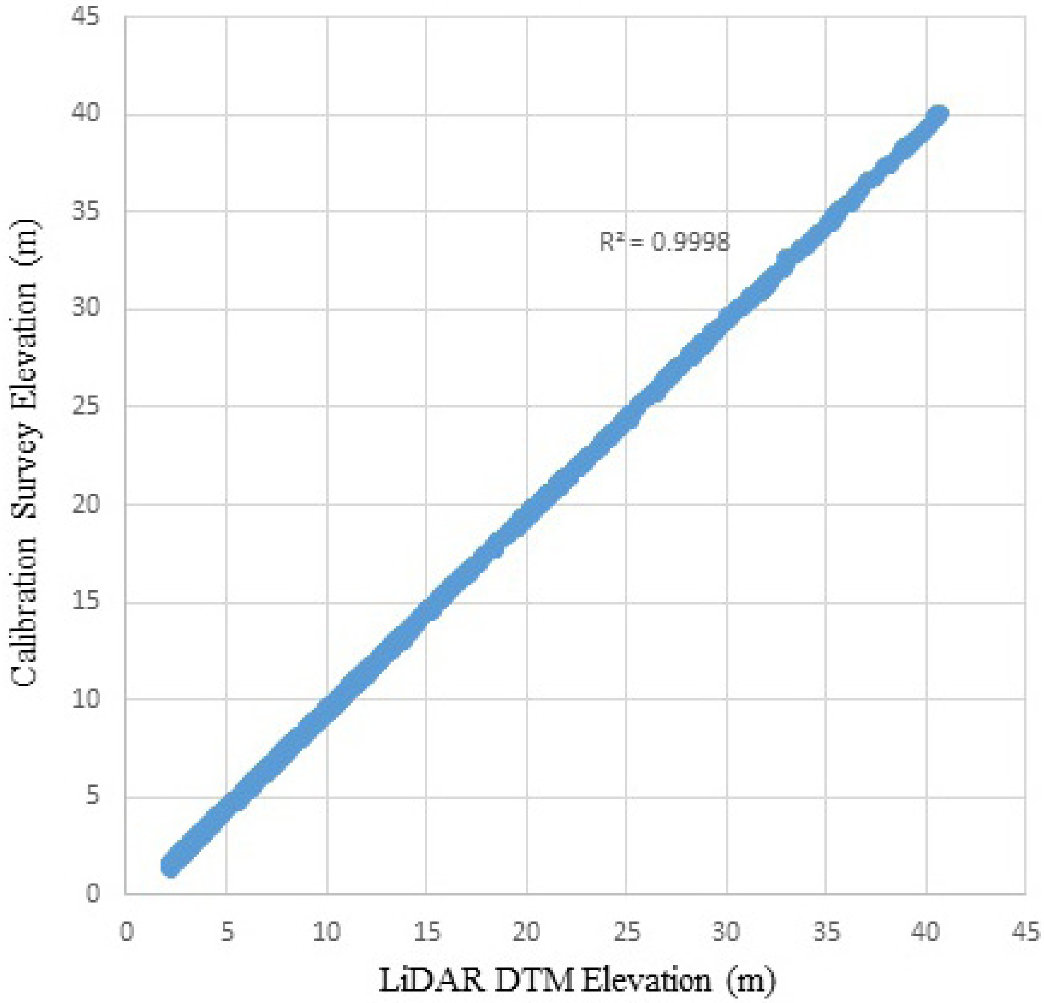


Figure 24. Correlation plot between calibration survey points and LiDAR data.

Table 15. Calibration Statistical Measures

Calibration Statistical Measures	Value (meters)
Height Difference	0.58
Standard Deviation	0.12
Average	0.57
Minimum	0.32
Maximum	0.82

The remaining 20% of the total survey points, resulting to 4,244 points, were used for the validation of calibrated Sibulan 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 25. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.18 meters with a standard deviation of 0.18 meters, as shown in Figure 16.

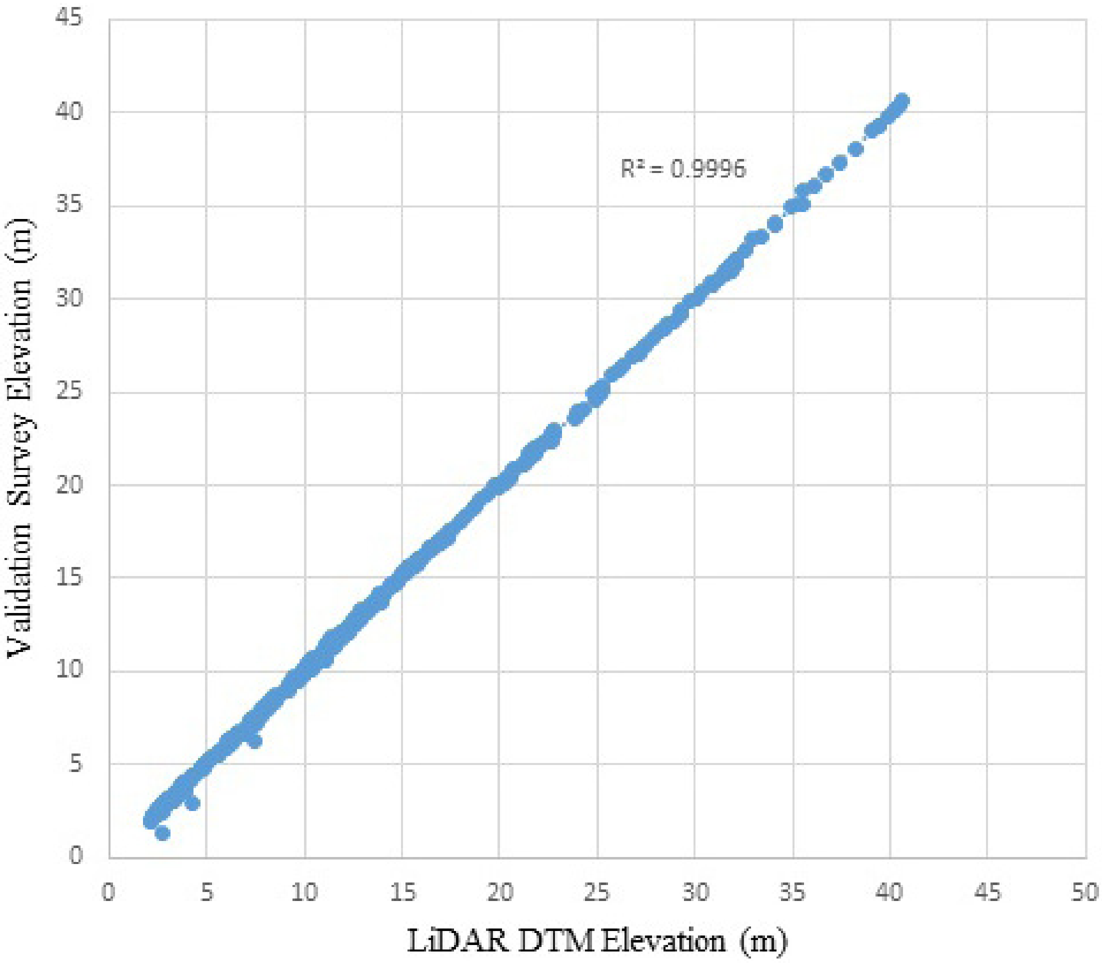


Figure 25. Correlation plot between validation survey points and LiDAR data.

Table 16. Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.18
Standard Deviation	0.18
Average	-0.02
Minimum	-0.39
Maximum	0.34

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, only centerline and cross-section data was available for Sibulan with 1,625 bathymetric survey points. The resulting raster surface produced was done by Inverse Distance Weighted (IDW) interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.25 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Sibulan integrated with the processed LiDAR DEM is shown in Figure 26.

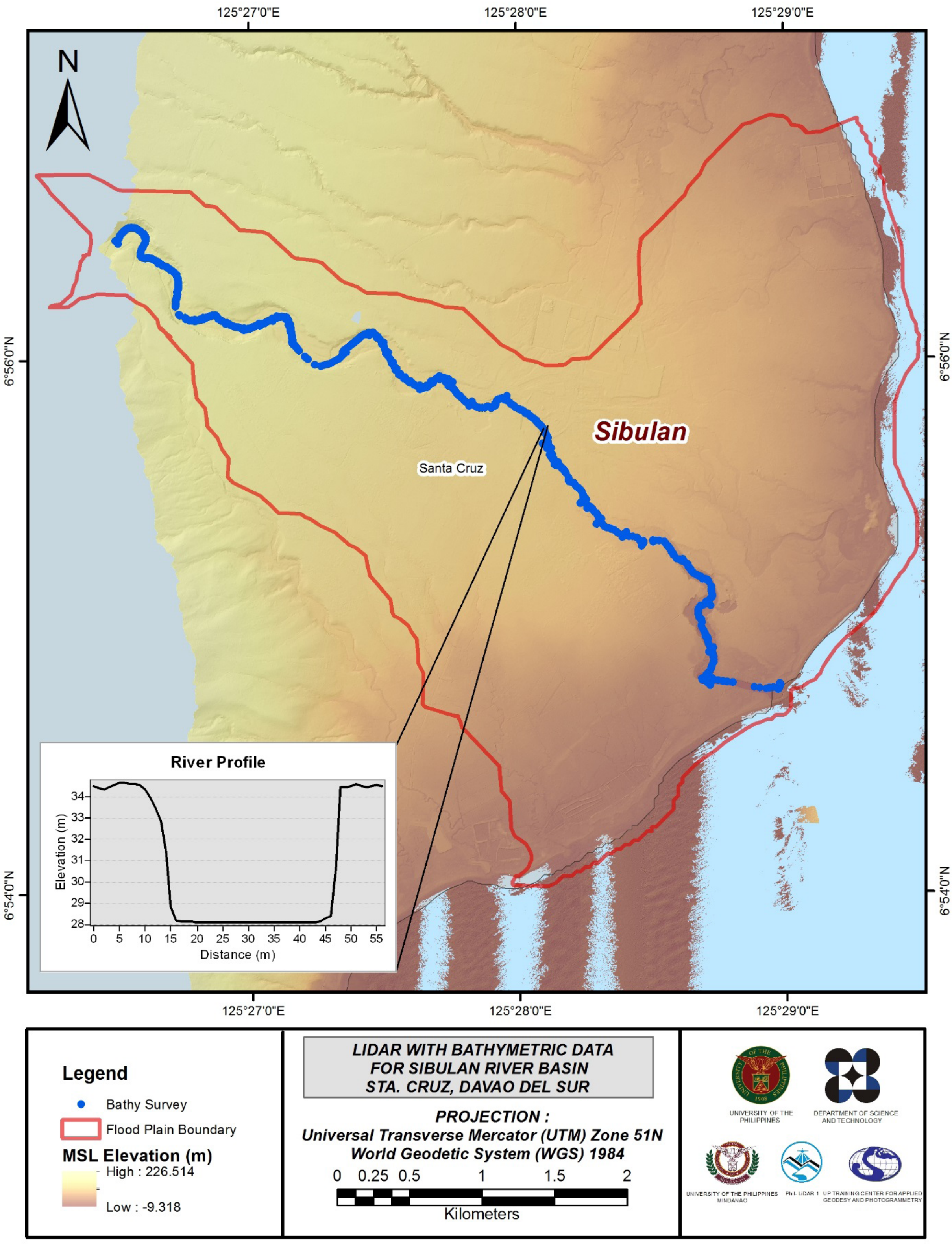


Figure 26. Map of Sibulan Floodplain with bathymetric survey points shown in blue.

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

Sibulan floodplain, including its 200 m buffer, has a total area of 19.93 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 363 building features, are considered for QC. Figure 27 shows the QC blocks for Sibulan floodplain.

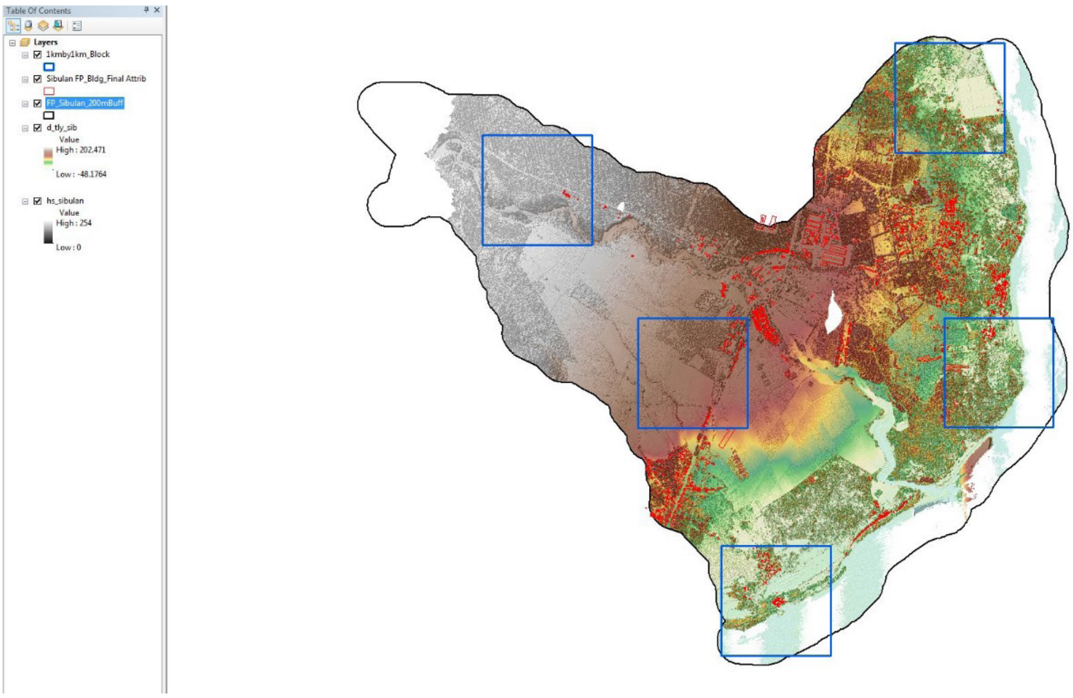


Figure 27. Blocks (in blue) of Sibulan building features that were subjected to QC

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

Table 17. Quality Checking Ratings for Sibulan Building Features

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Sibulan	93.86	97.81	83.60	PASSED

3.12.2 Height Extraction

Height extraction was done for 2,175 building features in Sibulan floodplain. Of these building features, 50 was filtered out after height extraction, resulting to 2,125 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 11.46 m.

3.12.3 Feature Attribution

Field validation for Sibulan floodplain has already been completed last November, 2015. However, in November of the same year, there were changes in the Feature Extraction Manual given by UP Diliman Data Pre-Processing Component, which then prompted for the conduct of the another field work on August 15-16, 2016 for the digitized features in the additional area scope.

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

Barangay Health Workers (BHWs) were requested and hired to guide the University of the Philippines Mindanao Phil-LiDAR1 field enumerators during validation. The local hires deployed by the barangay captains were given a brief orientation by the field enumerators before the actual field work. The team surveyed the two (2) barangays covered by the floodplain namely Barangays Darong and Astorga, Sta. Cruz Municipality.

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

Table 18. Building Features Extracted for Sibulan Floodplain.

Facility Type	No. of Features
Residential	1,899
School	33
Market	2
Agricultural/Agro-Industrial Facilities	65
Medical Institutions	3
Barangay Hall	1
Military Institution	2
Sports Center/Gymnasium/Covered Court	3
Telecommunication Facilities	1
Transport Terminal	0
Warehouse	7
Power Plant/Substation	3
NGO/CSO Offices	2
Police Station	0
Water Supply/Sewerage	2
Religious Institutions	16
Bank	0
Factory	51
Gas Station	3
Fire Station	0
Other Government Offices	0
Other Commercial Establishments	32
Total	**2,125**

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

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Sibulan	21.74	2.01	0	7.57	0	31.32

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

Floodplain	Water Body Type					Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Sibulan	1	0	0	0	21	22

One (1) bridge was 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 28 shows the Digital Surface Model (DSM) of Sibulan floodplain overlaid with its ground features.

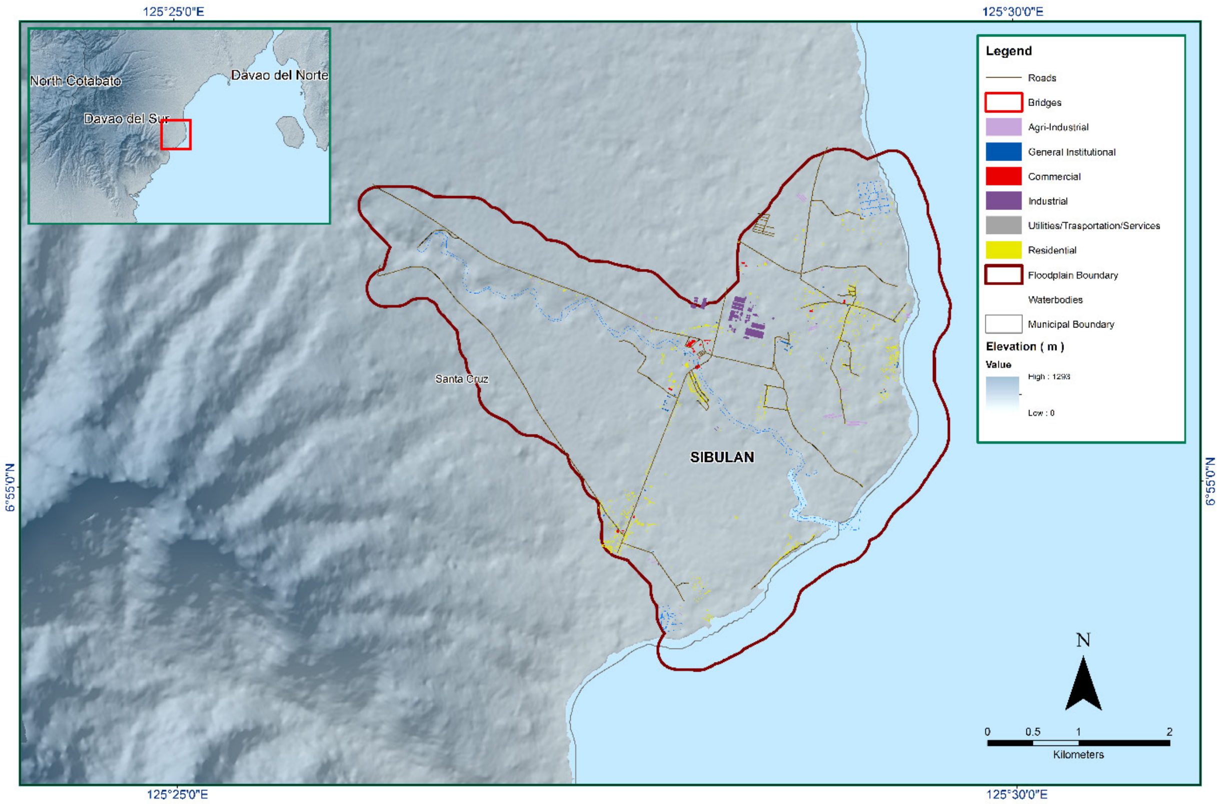


Figure 28. Extracted features for Sibulan Floodplain.

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

Engr. Louie P. Balicanta, Engr. Joemarie Caballero, Patrizcia Mae. P. dela Cruz, Engr. Dexter T. Lozano

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

The Data Validation and Bathymetry Component (DVBC) conducted a field survey in Sibulan River from June 28 to July 12, 2015 was conducted with the following scope of work: reconnaissance survey to assess the actual condition of the river and recovery of existing control points; courtesy call with UP Mindanao and LGUs of Davao del Sur; control survey for the establishment of a control; cross-section, bridge-as-built and water level marking in Cebulan Bridge in Brgy. Astorga, Municipality of Sta. Cruz, Davao Del Sur; validation points acquisition along concrete roads with estimated distance of 19.9 km; and bathymetric survey of Sibulan River with an approximate length of 6.9 km. The entire survey extent is illustrated in Figure 29.

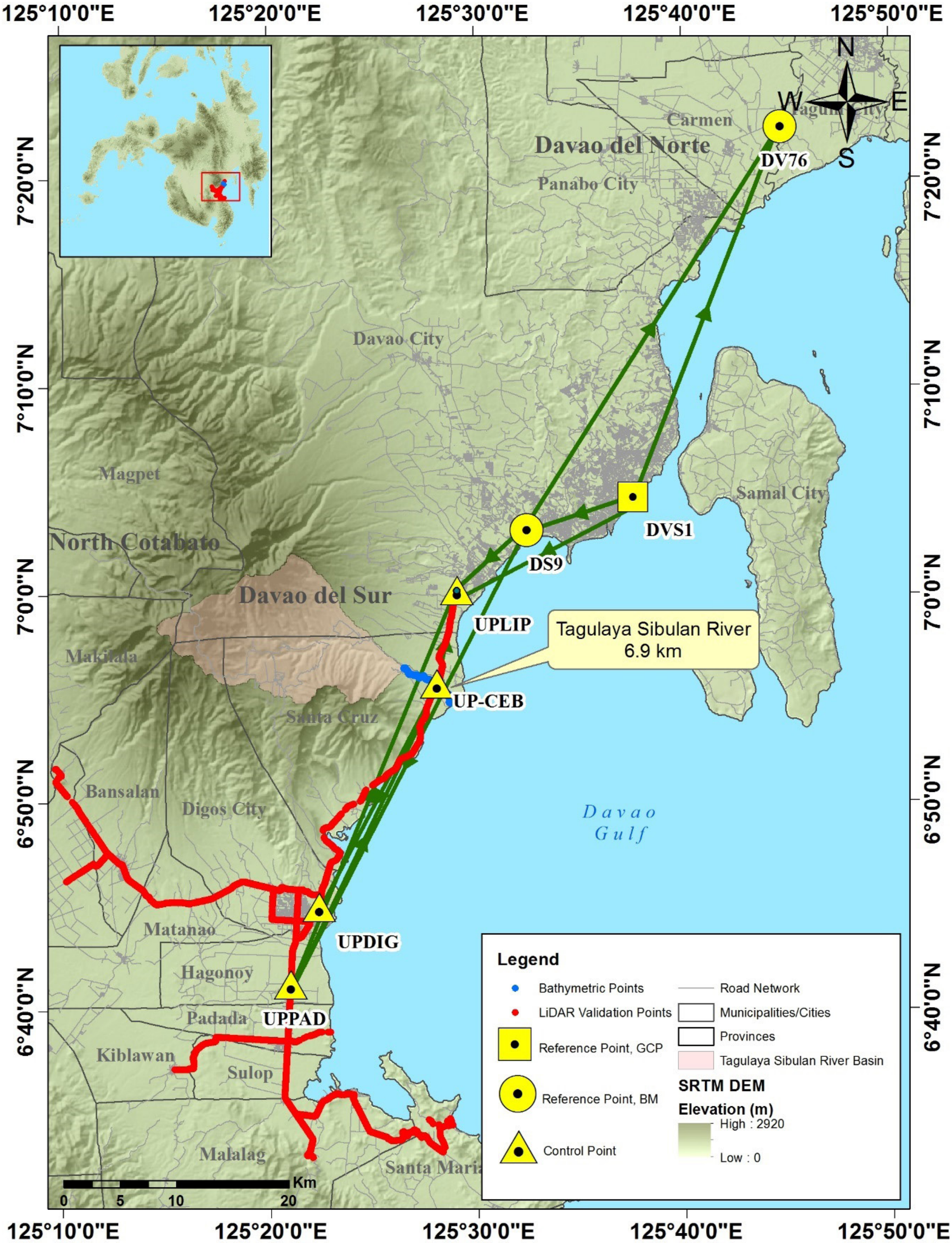


Figure 29. Extent of the bathymetric survey (in blue line) in Sibulan River and the LiDAR data validation survey (in red).

4.2 Control Survey

The GNSS network used in Tagulaya-Sibulan River survey was composed of six (6) loops established on July 4 and 5, 2015 with the following reference points: DVS-1, a first order GCP in Brgy. Leon Garcia Sr, Davao City, Davao Del Sur; and DV-76, a first order benchmark located Brgy. Guadalupe, Municipality of Carmen, Davao Del Norte.

Five (5) control points were established along approach of bridges namely: UP-CEB at Cebulan Bridge in Brgy. Darong, Municipality of Sta. Cruz Davao Del Sur; UP-DIG in Digos Bridge in Brgy. Aplaya, Digos City, Davao Del Sur; UP-LIP2 at Lipadas Bridge approach in Brgy. Lizada, Davao City, Daao Del Sur; and UP-PAD at Padada Bridge, in Brgy. Guihing, Muncipality of Hagonoy, Davao Del Sur. A NAMRIA established control point namely DS-9, located in Brgy. Talomo, Davao City, was also occupied to use as marker during the survey.

The summary of reference and control points and its location is summarized in Table 21, and the GNSS network established is illustrated in Figure 30.

Table 21. List of Reference and Control Points occupied for Sibulan River Survey

(Source: NAMRIA; UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (Meter)	Elevation in MSL (Meter)	Date Established
DVS-1	1st order GCP	7°04'38.36201"	125°37'36.77094"	68.5	-	2013
DV-76	1st order BM	-	-	76.155	8.359	2007
DS-9	Used as Marker	-	-	-	-	2007
UP-CEB	UP Established	-	-	-	-	7-5-2015
UP-DIG	UP Established	-	-	-	-	7-5-2015
UP-LIP2	UP Established	-	-	-	-	7-4-2015
UP-PAD	UP Established	-	-	-	-	7-5-2015

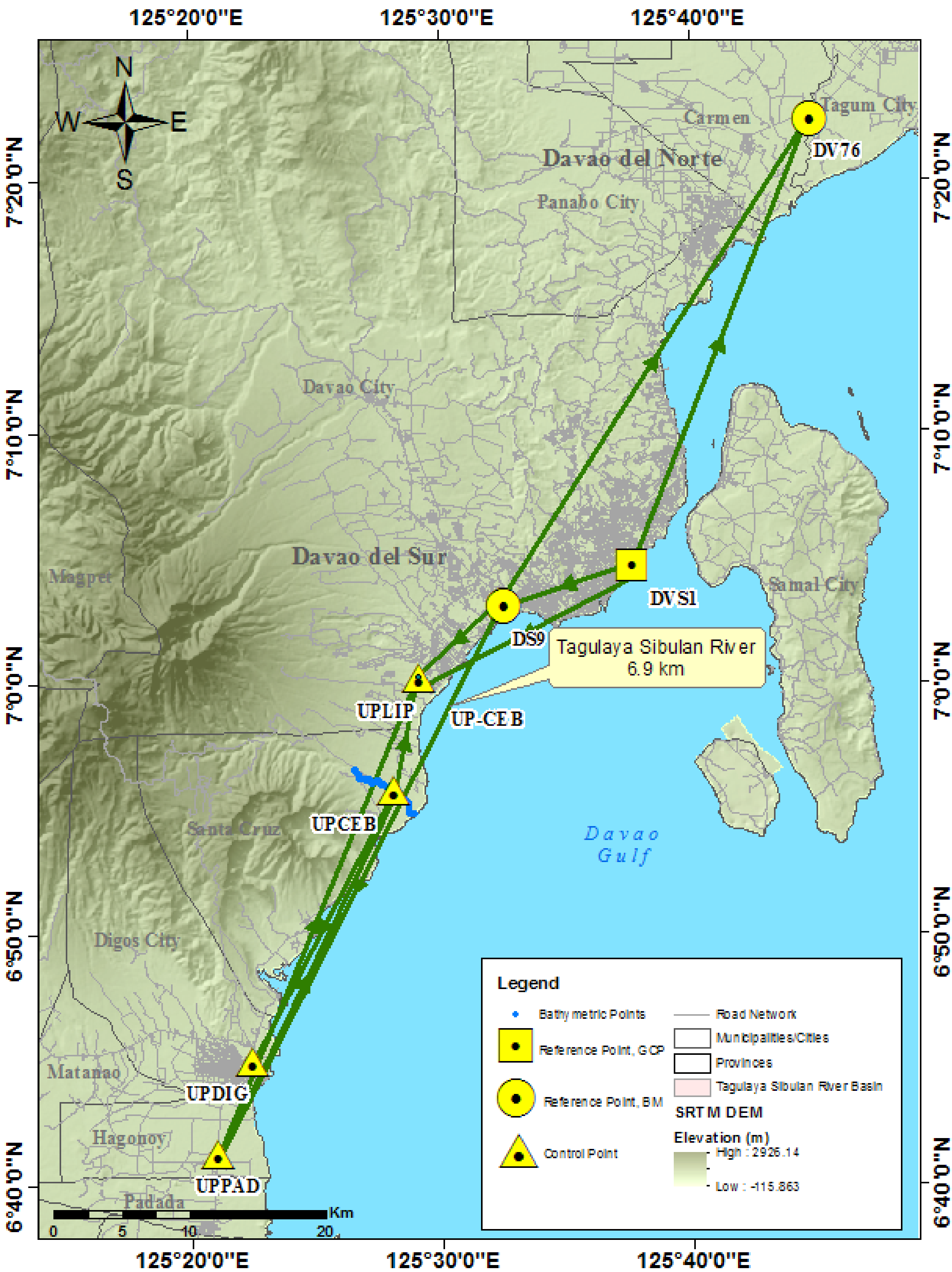


Figure 30. The GNSS Network established in the Sibulan River Survey.

The GNSS set up for control points used are shown in Figure 31 to Figure 37 respectively.

Figure 31. GNSS base receiver setup, Trimble® SPS 852 at DVS-1 at the east side of Pier, in Brgy. Leon Garcia Sr., Davao City, Davao Del Sur

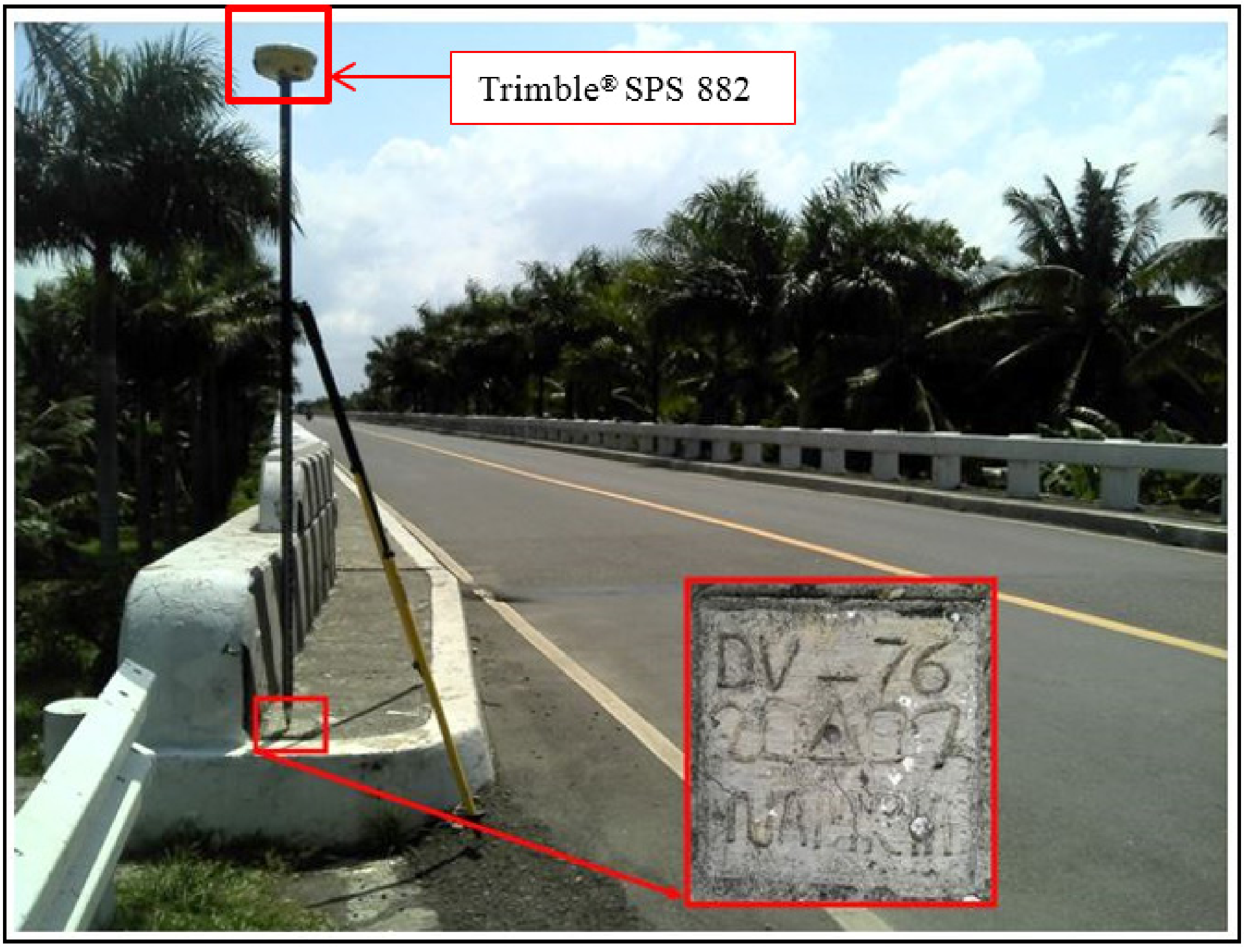


Figure 32. GNSS base receiver setup, Trimble® SPS 882 at DV-76 at the Gov. Miranda Bridge Approach, Brgy. Guadalupe, Municipality of Carmen, Davao Del Norte

Figure 33. GNSS base receiver setup, Trimble® SPS 882 at DS-09 located at stair of Nograles Park along Mac Arthur Highway, in Brgy. Talomo, Davao City, Davao Del Sur

Figure 34. GNSS base receiver setup, Trimble® SPS 852 at UP-CEB on the right approach of Cebulan Bridge in Brgy Darong, Municipality of Santa Cruz, Davao Del Sur

Figure 35. GNSS base receiver setup, Trimble® SPS 882 at UP-DIG, right approach of Digos Bridge in Brgy. Aplaya, Digos City, Davao Del Sur

Figure 36. GNSS base receiver setup, Trimble® SPS 852 at UP-LIP2, on the right approach of Lipadas Bridge along National Highway in Brgy. Lizada, Toril District, Davao Del Sur

Figure 37. GNSS base receiver setup, Trimble® SPS 882 at UP-PAD, Padada Bridge, Brgy. Guihing, Municipality of Hagonoy, Davao del Sur

4.3 Baseline Processing

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

Table 22. Baseline Processing Summary Report for Sibulan River Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
UPPAD --- UPCEB	7-4-2015	Fixed	0.005	0.024	26°11'09"	29668.539	20.427
DVS1 --- DS9	6-30-2015	Fixed	0.004	0.013	252°53'03"	9875.482	3.720
DVS1 --- UPLIP2	7-4-2015	Fixed	0.003	0.016	242°19'23"	17735.680	10.641
UPLIP2 --- UPPAD	7-4-2015	Fixed	0.004	0.017	203°09'13"	37929.527	4.455
UPLIP2 --- UPCEB	7-4-2015	Fixed	0.004	0.024	192°23'44"	8451.500	24.864
UPPAD --- UPTOL	7-4-2015	Fixed	0.003	0.014	240°13'14"	2487.973	1.230
DVS1 --- DS9	6-30-2015	Fixed	0.006	0.033	252°53'03"	9875.477	3.723
DS9 --- UPLIP2	6-30-2015	Fixed	0.006	0.042	229°36'22"	8229.009	6.907
UPLIP2 --- DS9	6-30-2015	Fixed	0.006	0.035	229°36'23"	8228.967	6.965
DS9 --- UPPAD	6-30-2015	Fixed	0.011	0.036	207°47'10"	45445.416	11.450
DS9 --- UPCEB	7-5-2015	Fixed	0.011	0.046	210°44'50"	15809.215	31.878
DS9 --- DV76	6-30-2015	Fixed	0.005	0.049	32°23'13"	42306.620	3.850
DVS1 --- DV76	7-5-2015	Fixed	0.003	0.015	21°57'24"	35381.584	7.644
UPLIP2 --- DV76	7-5-2015	Fixed	0.006	0.021	35°09'36"	50225.907	-2.996
DS9 --- UPDIG	6-30-2015	Fixed	0.006	0.039	209°08'05"	38212.638	8.511
UPLIP2 --- UPDI	7-5-2015	Fixed	0.003	0.017	203°44'17"	30638.805	1.495
UPDIG --- UPPAD	7-5-2015	Fixed	0.004	0.017	200°41'13"	7298.998	2.930
UPDIG --- UPCEB	7-5-2015	Fixed	0.004	0.025	27°58'39"	22414.077	23.379

As shown in Table 22, a total of 18 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 C-of the TBC generated Network Adjustment Report, it is observed that the square root of the sum of the squares of x and y must be less than 20 cm and z less than 10 cm or in equation form:

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

Where:

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

for each control point. See the Network Adjustment Report shown in Table 23 to Table 25 for the complete details.

The seven (7) control points, DVS-1, DV-76, DS-9, UP-CEB, UP-DIG, UP-LIP2 and UP-PAD were occupied and observed simultaneously to form GNSS LOOP. Coordinates of DVS-1 and elevation value of DV-76 were held fixed during the processing of the control points as presented in Table 23. Through these reference points, the coordinates and elevation of the unknown control points will be computed.

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

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
DVS-1	Global	Fixed	Fixed		
DVS-76	Grid				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 24. The fixed control point DV-76 and DVS-1, has no values for standard elevation and coordinates error, respectively.

Table 24. Adjusted grid coordinates for the control points used in the Sibulan River Floodplain survey.

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
DS9	780765.613	0.009	780155.271	0.007	3.801	0.079	
DV76	803241.598	0.008	816030.498	0.008	8.359	?	e
DVS1	790192.921	?	783116.705	?	0.771	0.064	LL
UPCEB	772752.259	0.012	766517.370	0.011	34.883	0.097	
UPDIG	762330.012	0.011	746661.467	0.009	10.556	0.090	
UPLIP2	774523.929	0.008	774785.649	0.007	10.067	0.072	
UPPAD	759783.560	0.011	739817.613	0.010	13.208	0.089	

The networks are fixed at reference points DVS-1 and DV-76. With the mentioned equation,

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

a. DVS-1

horizontal accuracy	=	Fixed
vertical accuracy	=	6.4cm < 10 cm

b. DV-76

horizontal accuracy	=	√((0.8)² + (0.8)²
	=	√(0.64 + 0.64)
	=	1.13 cm < 20 cm
vertical accuracy	=	Fixed

c. DS-09

horizontal accuracy	=	√((0.9)² + (0.7)²
	=	√(0.81 + 0.49)
	=	1.14 cm < 20 cm
vertical accuracy	=	7.9 cm < 10 cm

d. UP-CEB

horizontal accuracy	=	√((1.2)² + (1.1)²
	=	√(1.44 + 1.21)
	=	2.69 cm < 20 cm
vertical accuracy	=	1.63 cm < 10 cm

e. UP-DIG

horizontal accuracy	=	√((1.1)² + (0.9)²
	=	√(1.21 + 0.81)
	=	1.42 cm < 20 cm
vertical accuracy	=	9.0 cm < 10 cm

f. UP-LIP2

horizontal accuracy	=	√((0.8)² + (0.7)²
	=	√(0.64+ 0.49
	=	1.06 cm < 20 cm
vertical accuracy	=	7.2 cm< 10 cm

g. UP-PAD

horizontal accuracy	=	√((1.1)² + (1.0)²
	=	√(1.21 + 1.0)
	=	1.49 cm < 20 cm
vertical accuracy	=	8.9 cm < 10 cm

Following the given formula, the horizontal and vertical accuracy result of the seven (7) occupied control points are within the required accuracy of the program.

Table 25. Adjusted geodetic coordinates for control points used in the Sibulan River Floodplain validation.

Point ID	Latitude	Longitude	Ellipsoid	Height	Constraint
DS9	N7°03'03.72282"	E125°32'29.23786"	72.195	0.079	
DV76	N7°22'26.51286"	E125°44'48.14120"	76.155	?	e
DVS1	N7°04'38.36201"	E125°37'36.77094"	68.500	0.064	LL
UPCEB	N6°55'41.41306"	E125°28'05.94638"	104.051	0.097	
UPDIG	N6°44'57.07991"	E125°22'23.41362"	80.677	0.090	
UPLIP	N7°00'10.77316"	E125°29'05.16478"	78.215	0.089	
UPLIP2	N7°00'10.11838"	E125°29'05.04512"	79.165	0.072	
UPPAD	N6°41'14.79422"	E125°20'59.46050"	83.620	0.089	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 25. Based on the result of the computation, the accuracy condition is satisfied; hence, the required accuracy for the program was met.

The summary of reference control points used is indicated in Table 26.

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

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
DVS-1	1st Order GCP	7°04'38.36201"	125°37'36.77094"	68.5	783116.705	790192.921	0.771
DV-76	1st Order M	7°22'26.51286"	125°44'48.14120"	76.155	816030.498	803241.598	8.359
DS-9	Used as Marker	7°03'03.72282"	125°32'29.23786"	72.195	780155.271	780765.613	3.801
UP-CEB	UP Established	6°55'41.41306"	125°28'05.94638"	104.051	766517.37	772752.259	34.883
UP-DIG	UP Established	6°44'57.07991"	125°22'23.41362"	80.677	746661.467	762330.012	10.556
UP-LIP2	UP Established	7°00'10.11838"	125°29'05.04512"	79.165	774785.649	774523.929	10.067
UP-PAD	UP Established	6°41'14.79422"	125°20'59.46050"	83.62	739817.613	759783.56	13.208

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

Cross-section and as-built survey was conducted on June 30, 2015 at the downstream, side of Cebulan Bridge in Brgy. Astorga, Municipality of Sta. Cruz, Davao Del Sur. A GNSS receiver Trimble® SPS 882 in PPK survey technique was implemented as shown in Figure 38.

Figure 38. Cross-section and bridge as-built survey at the downstream side of Cebulan Bridge, Brgy. Astorga, Santa Cruz, Davao del Sur

The survey gathered thirty-one (31) points with an estimated length of 70 m from left to right banks using UP-CEB as the GNSS base station. The summary of gathered cross-section illustrated in a location map, cross-section diagram, and as-built data form of Cebulan Bridge are shown in Figure 39 to Figure 41, respectively.

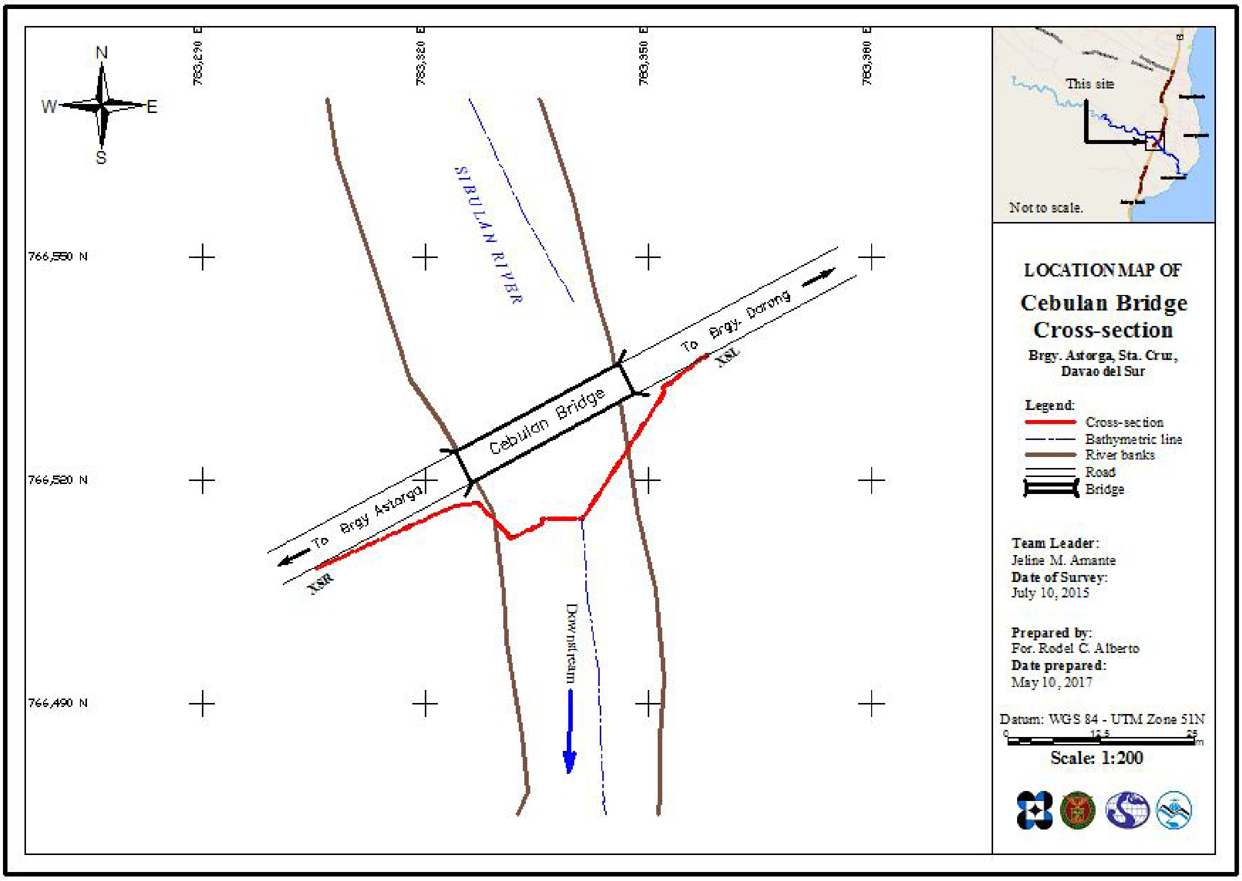


Figure 39. Location map of Cebulan Bridge cross-section survey

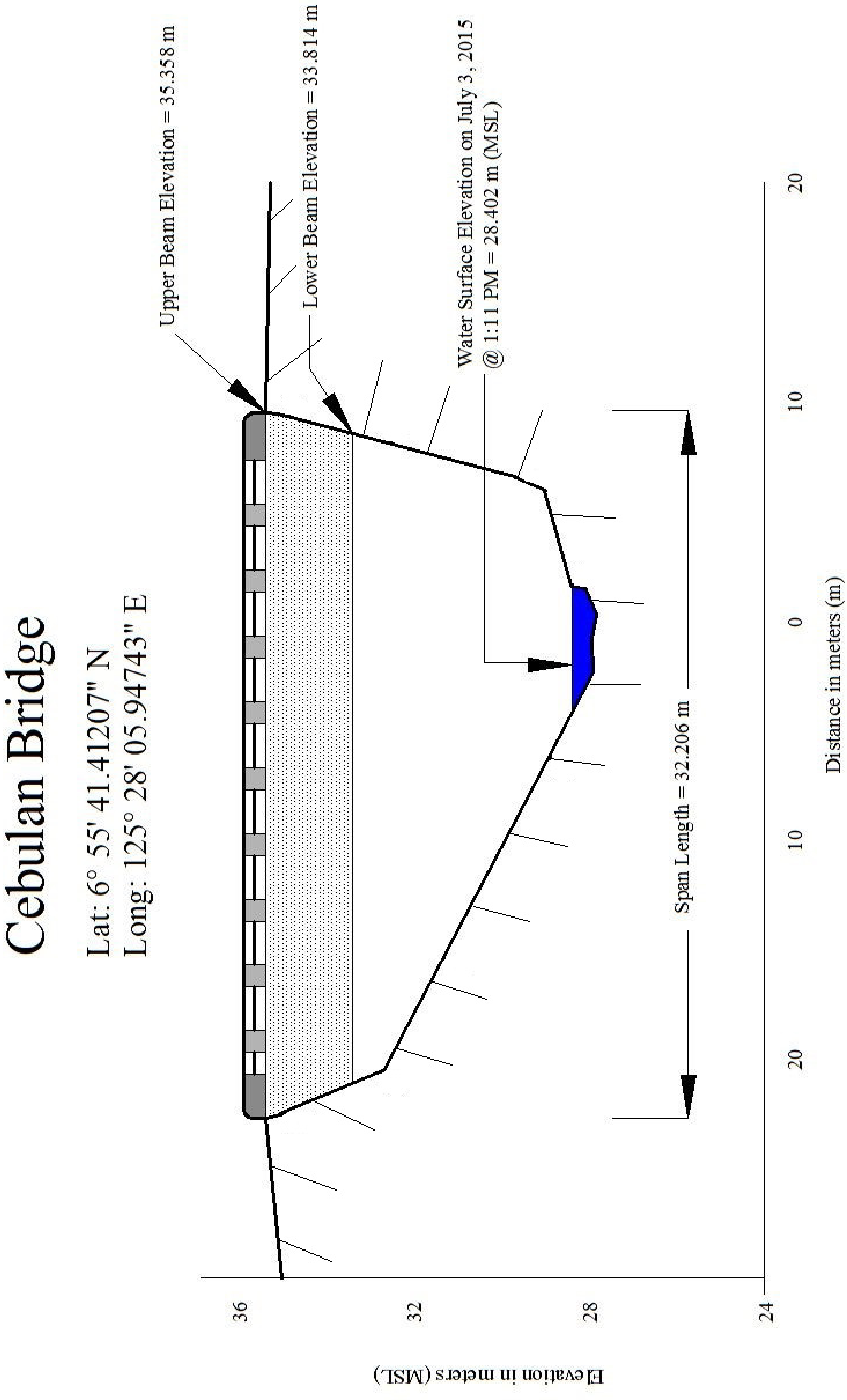


Figure 40. Cebulan Bridge cross-section diagram

Bridge Data Form

Bridge Name: CEBULAN BRIDGE Date: July 10, 2015

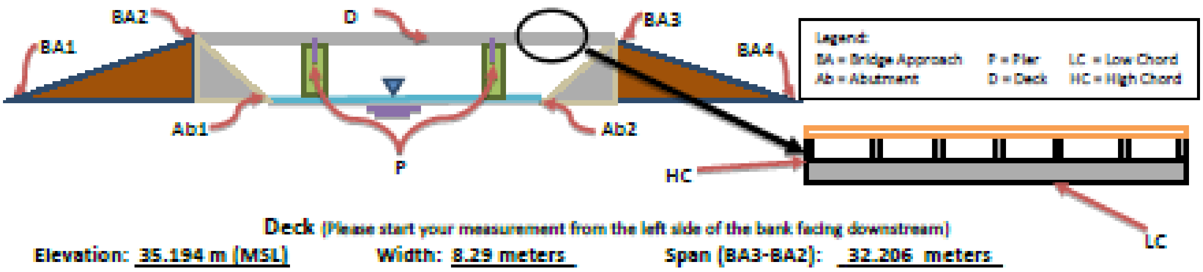
River Name: TAGULAYA-SIBULAN RIVER Time: 12:46 pm

Location (Brgy, City, Region): Brgy. Astorga, Sta. Cruz, Davao del Sur

Survey Team: DVBC/DVC Davao del Sur Survey Team

Flow condition: low normal high Weather Condition: fair rainy

Latitude: 6°55'41.41207"N Longitude: 125°28'05.94743" E



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

Elevation: 35.194 m (MSL) Width: 8.29 meters Span (BA3-BA2): 32.206 meters

	Station	High Chord Elevation	Low Chord Elevation
1	-	35.358 m	33.814 m
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	35.028	BA3	39.481	35.368
BA2	7.274	35.388	BA4	63.184	34.78

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

	Station (Distance from BA1)	Elevation
Ab1	-	-
Ab2	-	-

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

Shape: N/A Number of Piers: 0 Height of column footing: ______

	Station (Distance from BA1)	Elevation	Pier Width
Pier 1	No pier	-	-
Pier 2	No pier	-	-
Pier 3	-	-	-
Pier 4	-	--	-

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

Figure 41. As-built survey of Sibulan Bridge

Water surface elevation in MSL of Cebulan Bridge was determined using Trimble® SPS 882 in PPK mode survey on July 3, 2015 at 1:11 PM. This was translated onto marking the bridge's pier using a digital level. The marked pier, see Figure 42, shall serve as reference for flow data gathering and depth gauge deployment by the accompanying HEI, UP Mindanao, who is responsible for Sibulan River.

Figure 42. Water level markings on Cebulan Bridge

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted from July 8 to 11, 2015 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted on a range pole which was attached on the left side of the vehicle as shown in Figure 43. It was secured with a cable tie to ensure that it was horizontally and vertically balanced. The antenna height was measured and recorded to be 2.463 m from the ground up to the bottom of notch of the GNSS Rover receiver.

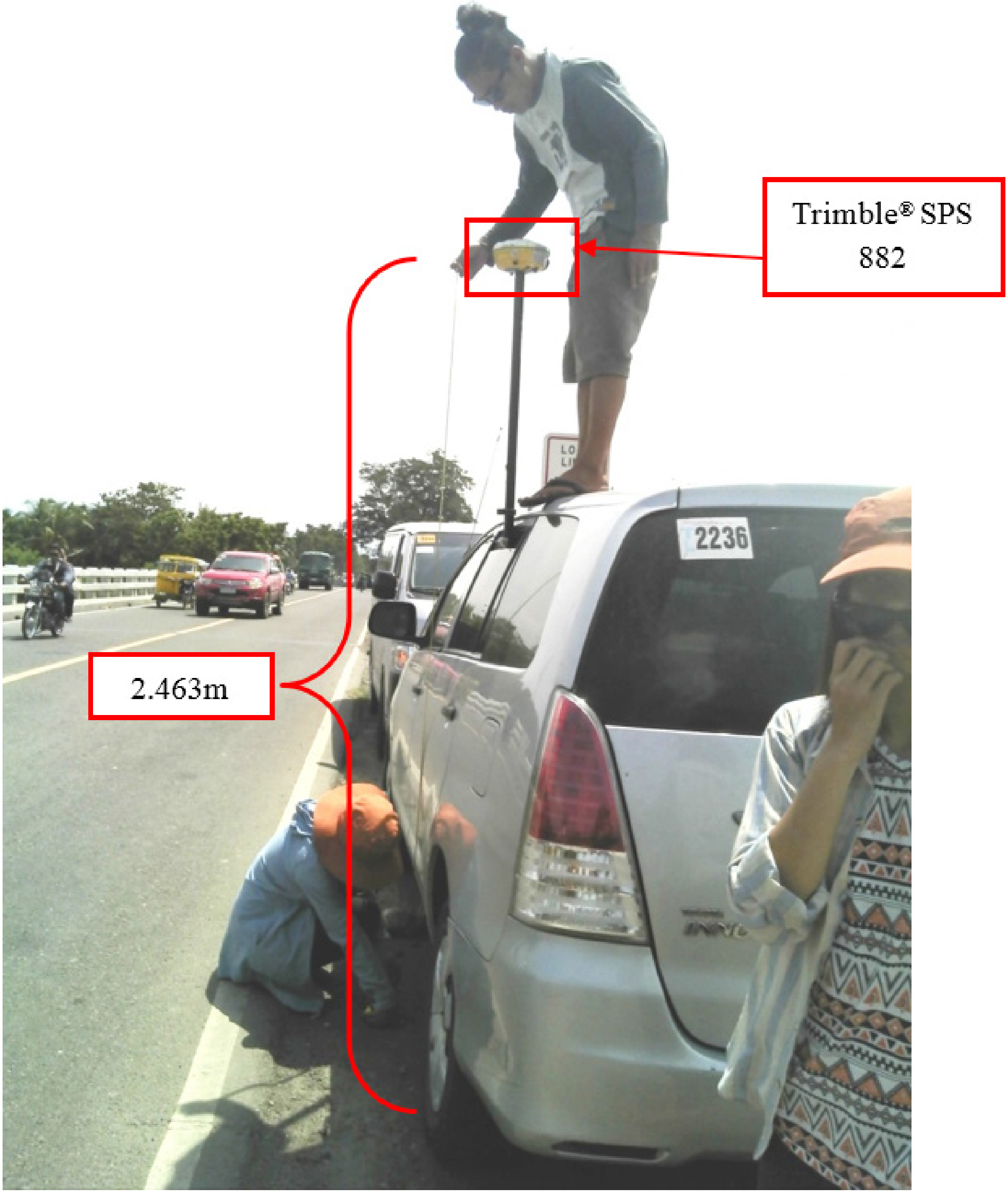


Figure 43. Validation points acquisition survey set-up on a vehicle for Davao del Sur

The survey was conducted using PPK technique on a continuous topography mode, which covered the major roads from the Municipality of Santa Cruz to Davao City, as illustrated in Figure 44. The survey gathered a total of 2,927 validation points covering an approximate distance of 19.9 km using the control point UP-CEB as the GNSS base station.

Figure 44. Validation point acquisition survey of Sibulan River Basin

4.7 River Bathymetric Survey

Bathymetric survey was conducted on July 3 and 10, 2015 using a survey grade GNSS Rover receiver Trimble® SPS 882 in PPK survey technique as shown in Figure 45 at Sibulan River. The survey started in the upstream part of the river in Brgy. Darong, Municipality of Sta. Cruz with coordinates 6°56’26.30791” 125°26’30.17498”, traversed down by foot and ended at the mputh of the river in Brgy. Astorga, also in Municipality of Sta. Cruz with coordinates 6°54’46.86679”N 125°28’58.33546”E. The control point UP-CEB was used as GNSS base station for the survey.

Figure 45. Bathymetric survey in Sibulan River

The bathymetric line has an estimated length of 6.9 km with a total of 1,579 bathymetric points gathered covering barangay boundaries of Brgy. Darong and Brgy. Astorga in Santa Cruz as shown in Figure 46. A CAD drawing was also produced to illustrate the riverbed profile of Sibulan river. As shown in Figure 47, an elevation drop of 129.25 m was observed within the distance of approximately 6.9 km from upstream. The highest elevation observed was 126.71 m in MSL located in the upstream, while the lowest elevation observed was -2.91 m below MSL located in the mouth of the river.

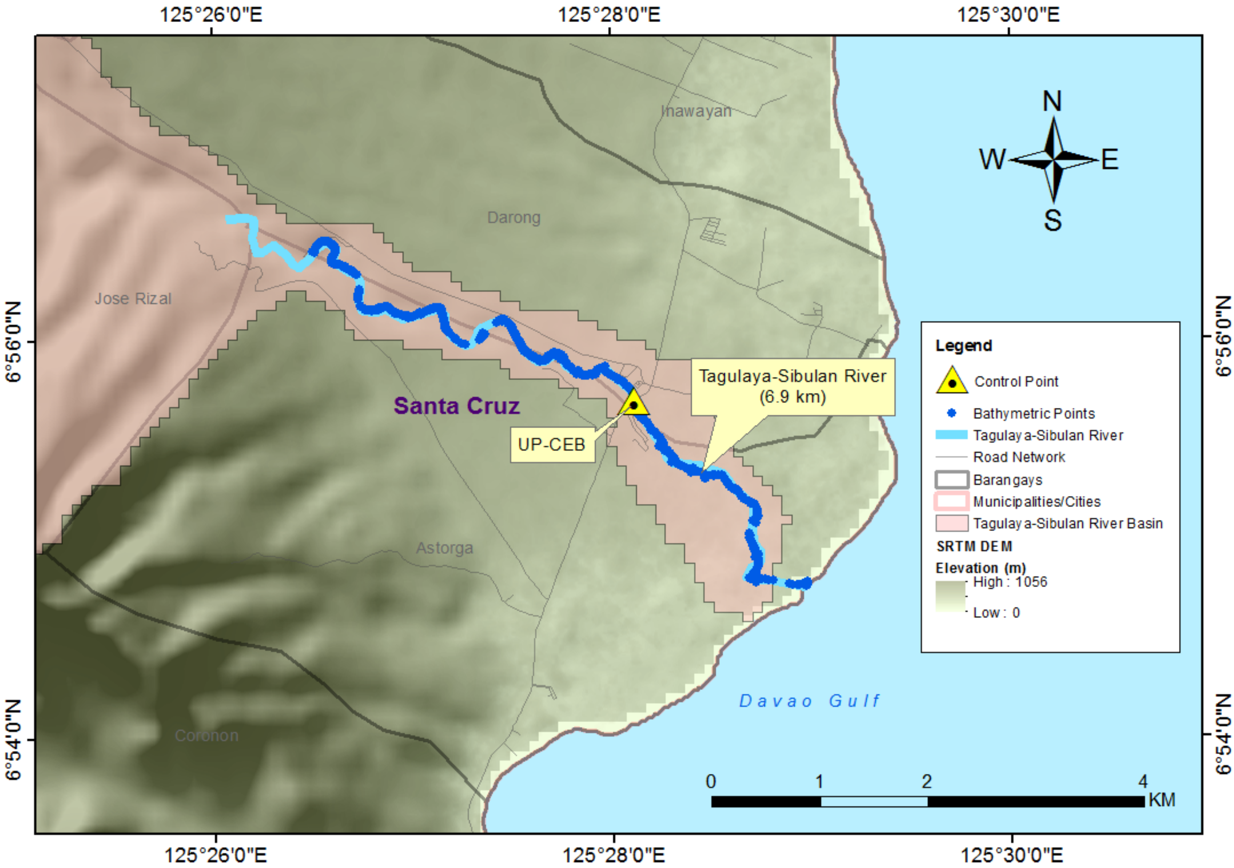


Figure 46. Extent of the Sibulan River Bathymetry Survey

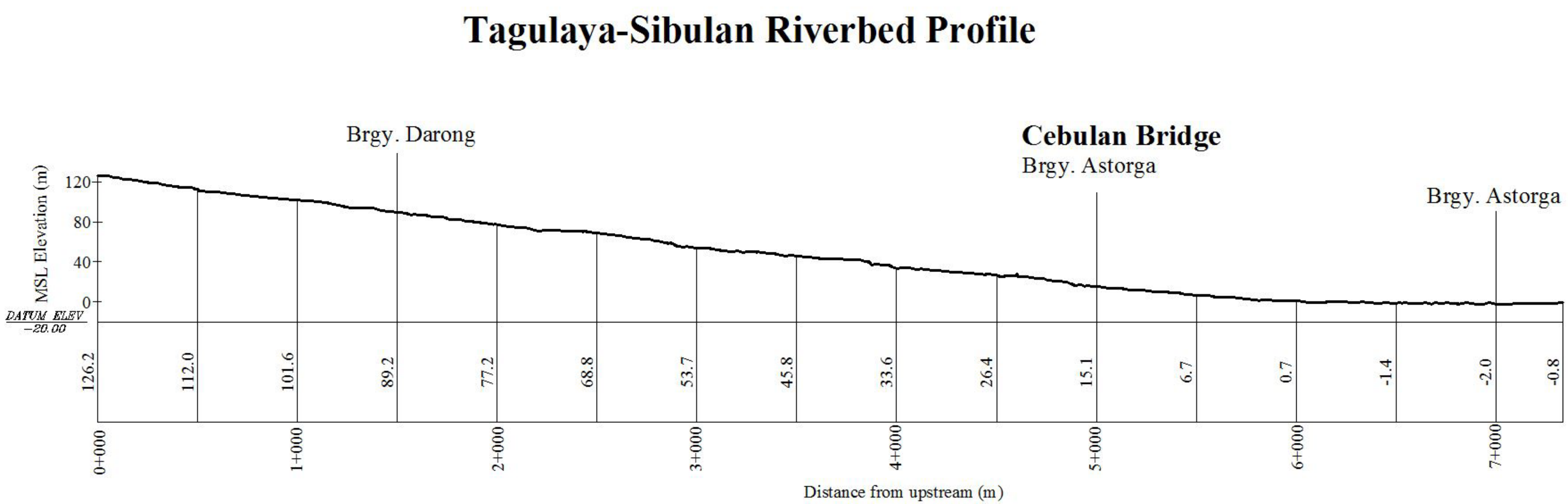


Figure 47. Sibulan riverbed profile.

CHAPTER 5: FLOOD MODELING AND MAPPING

Alfredo Mahar Francisco A. Lagmay, Enrico C. Paringit, Dr. Eng., Christopher Noel L. Uichanco, Sylvia Sueno, Marc Moises, Hale Ines, Miguel del Rosario, Kenneth Punay, Neil R. Tingin, Narvin Clyd Tan, and Hannah Aventurado

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

All data that affect the hydrologic cycle of the Sibulan 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 Silaga River Basin were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from the rain gauge installed by the University of the Philippines Mindanao Phil-LiDAR 1. This rain gauge is located in Barangay Sibulan, Sta. Cruz, Davao del Sur with the following coordinates: 6° 57’ 55.55”N, 125° 23’ 49.09”E (Figure 48). The precipitation data collection started from June 3, 2016 at 12:30 AM to June 4, 2016 at 8:40 AM with a 10-minute recording interval.

The total precipitation for this event in the installed rain gauge was 31.6 mm. It has a peak rainfall of 5.2 mm. on June 3, 2016 at 2:50 AM. The lag time between the peak rainfall and discharge is 3 hours and 40 minutes.

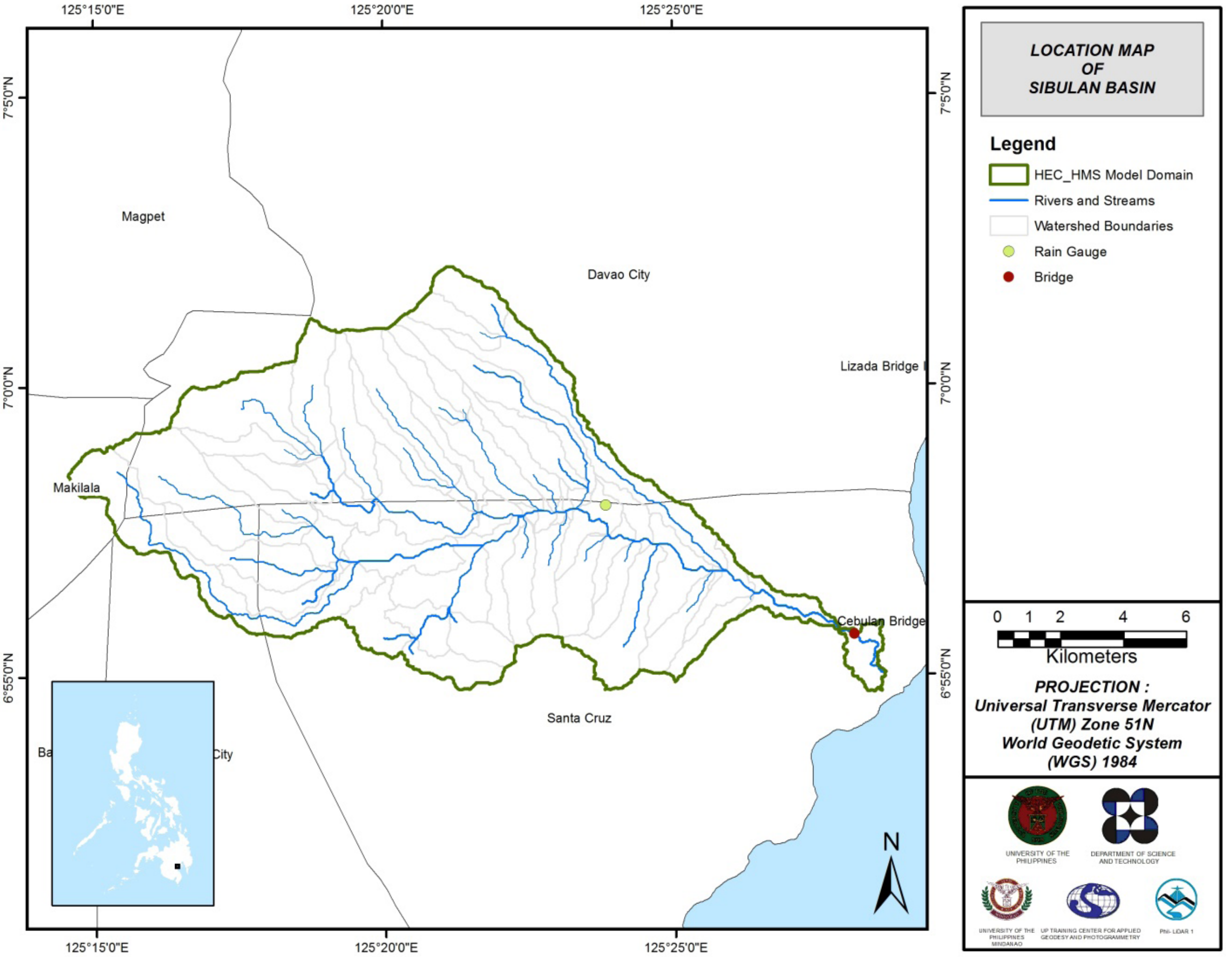


Figure 48. Location map of the Sibulan HEC-HMS model used for calibration.

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Cebulan Bridge, Barangay Astorga, Sta. Cruz, Davao del Sur (6° 54' 48.92", 126° 2' 47.33"). It gives the relationship between the observed water level at the Cebulan Bridge and outflow of the watershed at this location.

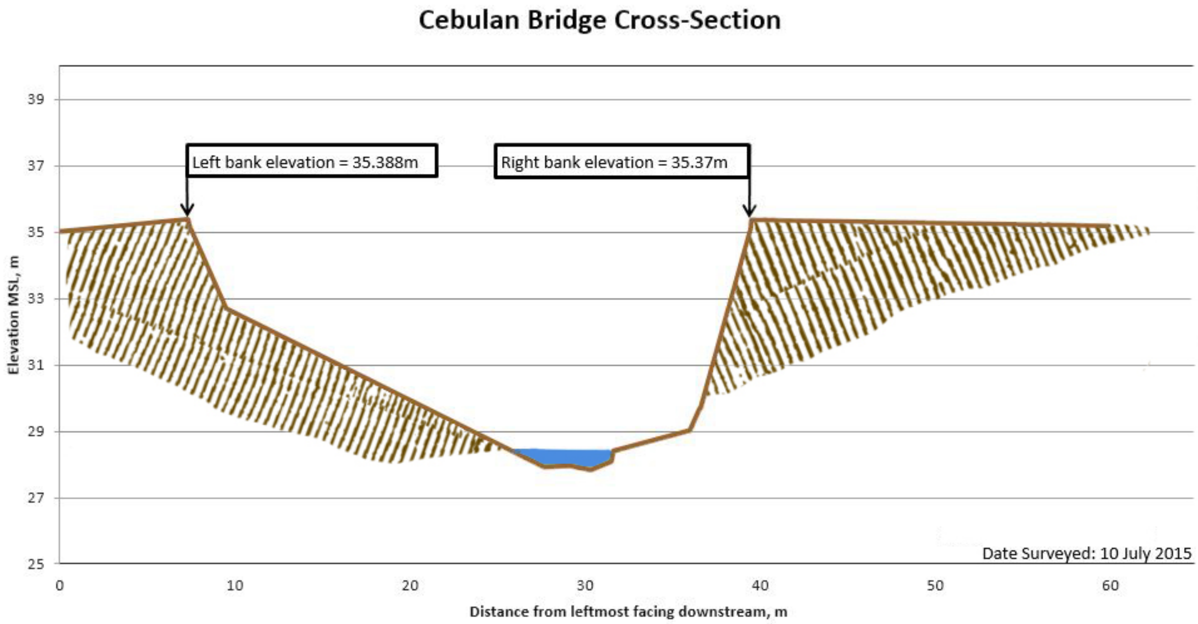


Figure 49. Cross-section plot of Cebulan Bridge

For Cebulan Bridge, the rating curve is expressed as Q = 1.6227E-37e3.0504x as shown in Figure 50.

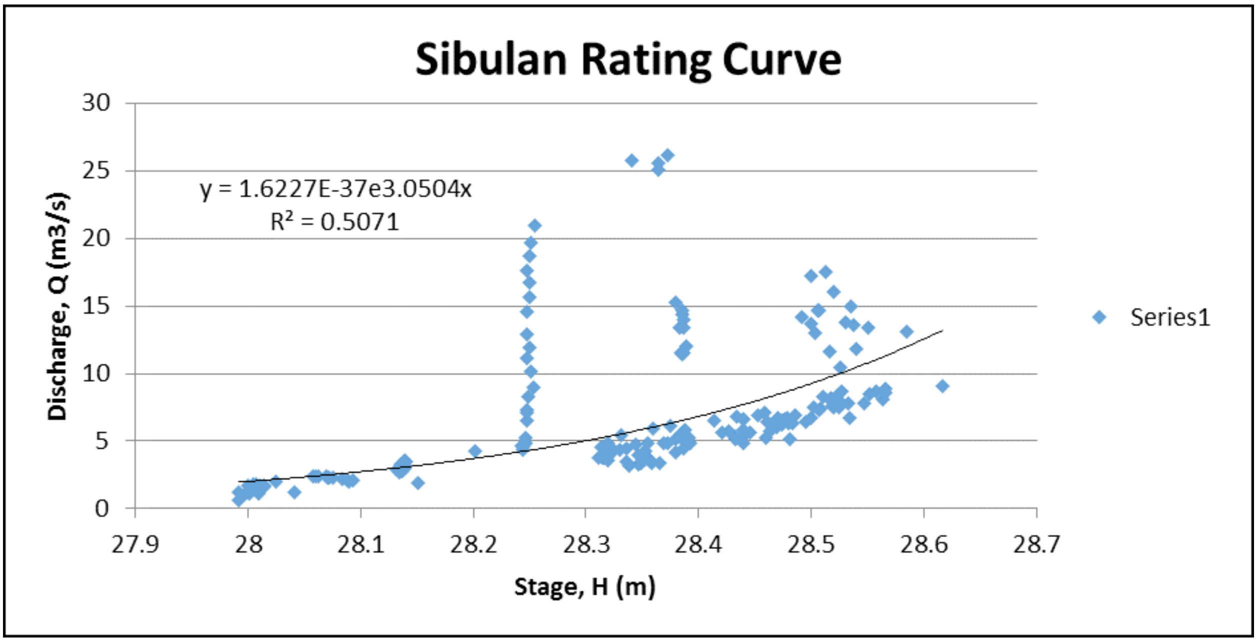


Figure 50. Rating curve at Cebulan Bridge, Sta. Cruz, Davao del Sur

The rating curve equation was used to compute for the river outflow at Cebulan Bridge for the calibration of the HEC-HMS model for Sibulan, as shown in Figure 51. The total rainfall for this event is 31.6 mm and the peak discharge is 26.1 m3/s at 6:30 AM of June 3, 2016.

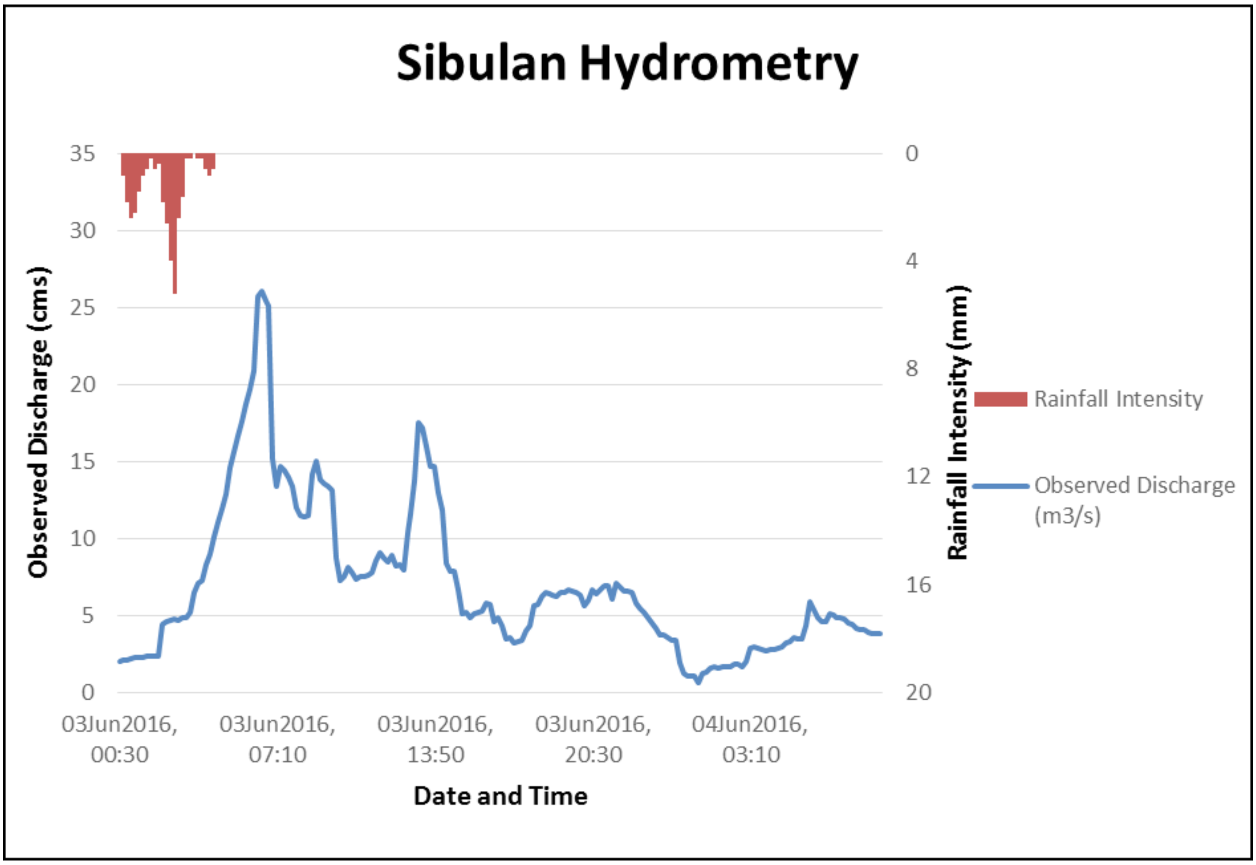


Figure 51. Rainfall and outflow data at Cebulan Bridge used for modeling

5.2 RIDF Station

The Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed for Rainfall Intensity Duration Frequency (RIDF) values for the Davao 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 Sibulan watershed. The extreme values for this watershed were computed based on a 59-year record.

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

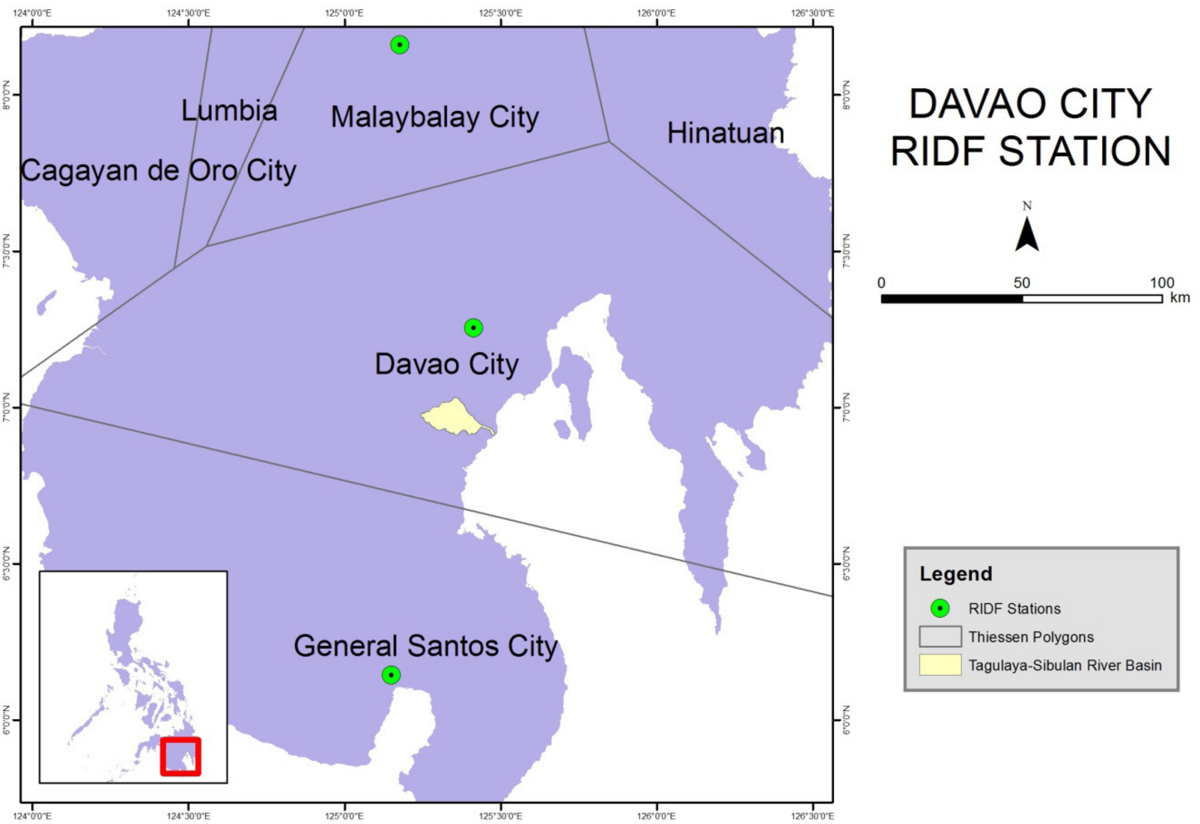


Figure 52. Location of Davao RIDF Station relative to Sibulan River Basin

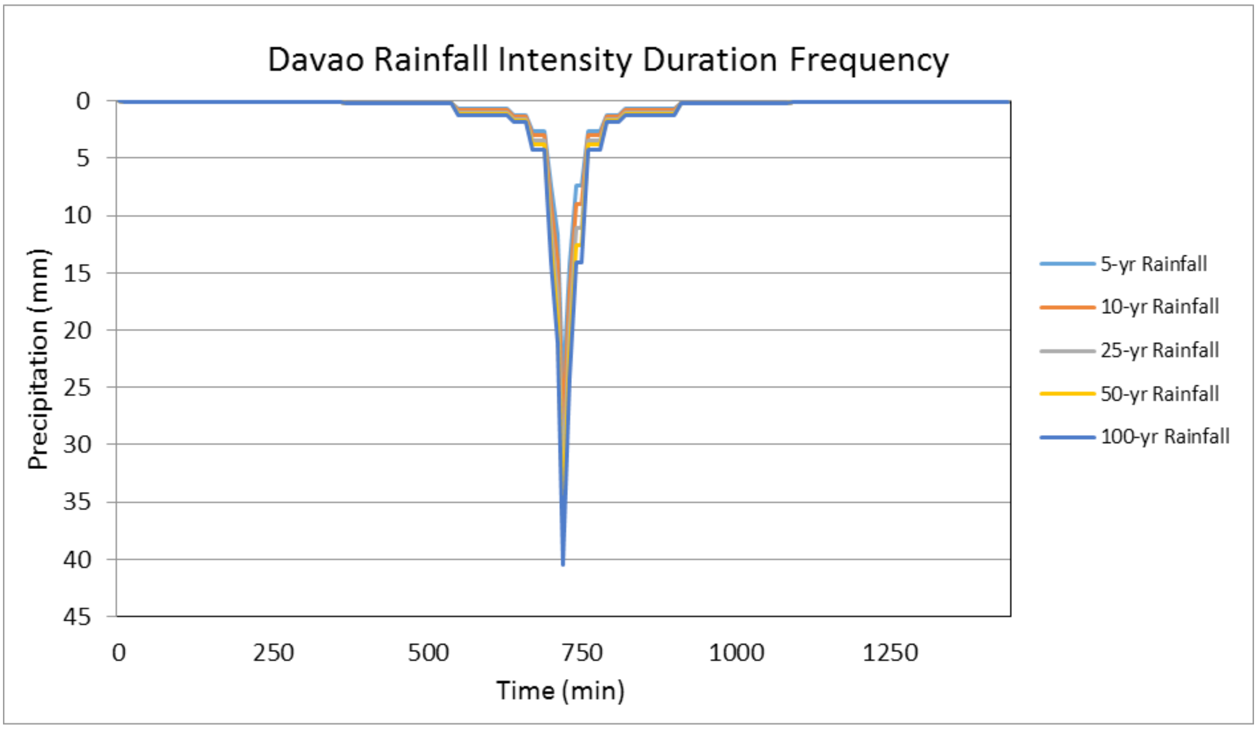


Figure 53. Synthetic storm generated for a 24-hr period rainfall for various return periods.

5.3 HMS Model

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

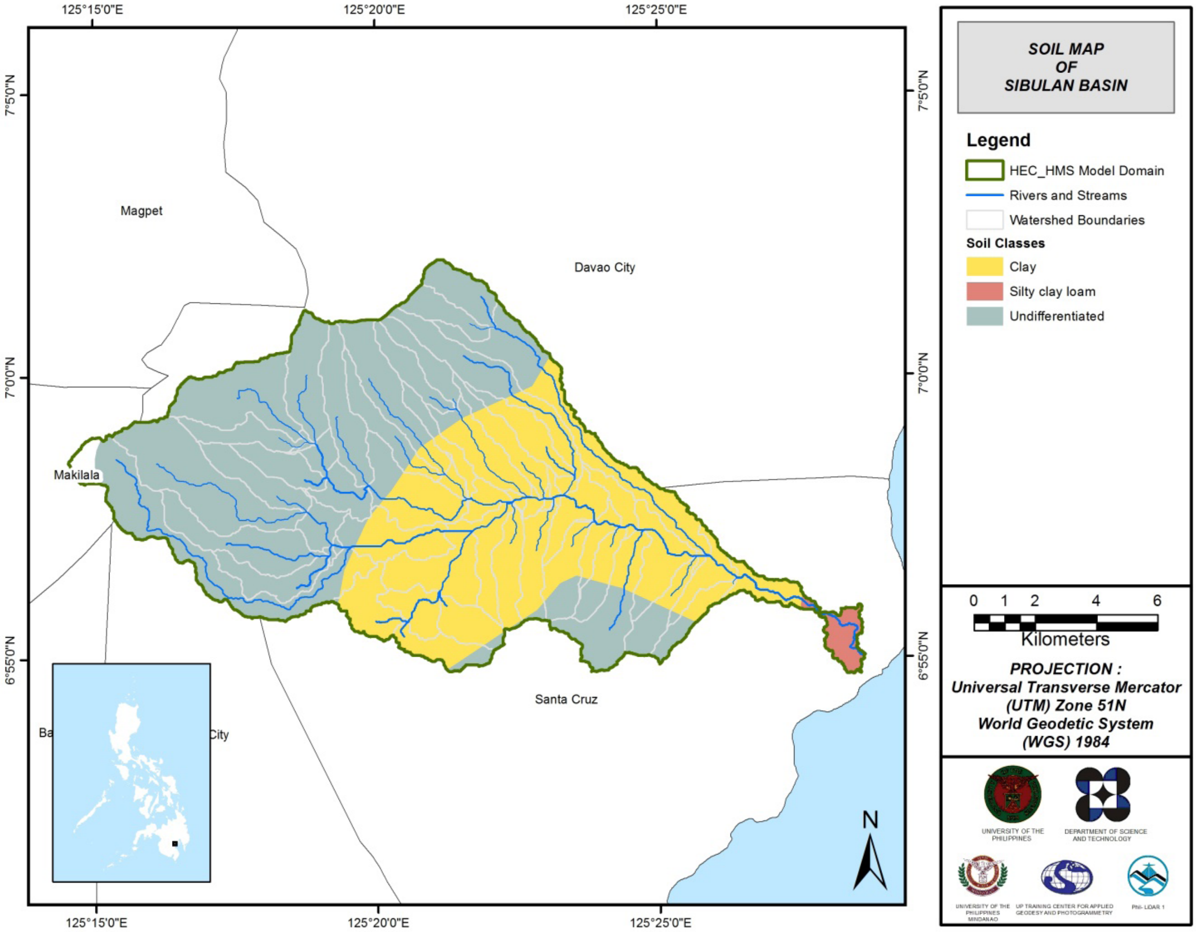


Figure 54. Soil Map of Sibulan River Basin used for the estimation of the CN parameter.

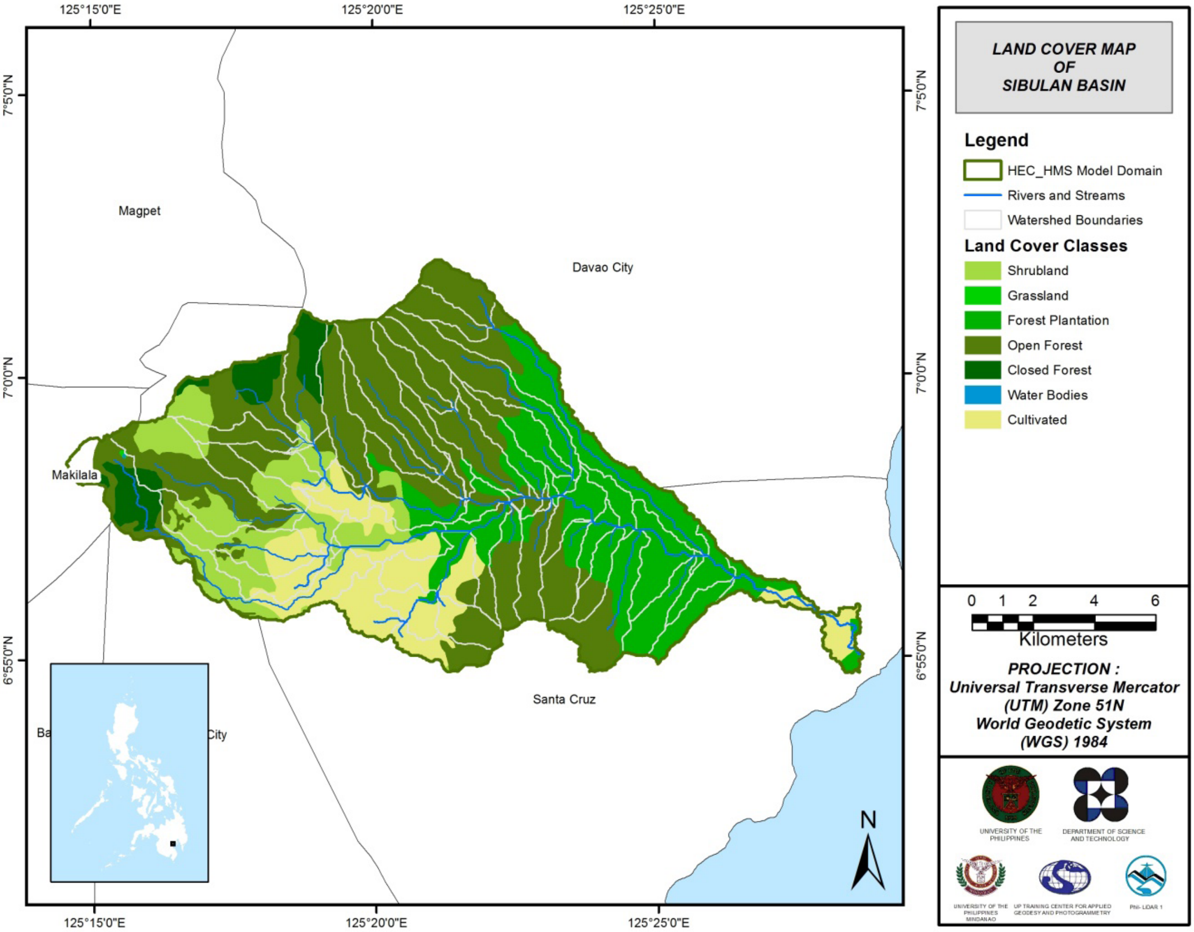


Figure 55. Land Cover Map of Sibulan River Basin used for the estimation of the Curve Number (CN) and the watershed lag parameters of the rainfall-runoff model.

For Sibulan, four (4) soil classes were identified. These are clay, silty clay loam and undifferentiated land. Moreover, six (6) land cover classes were identified. These are shrublands, grasslands, forest plantations, open and closed forests, and cultivated areas.

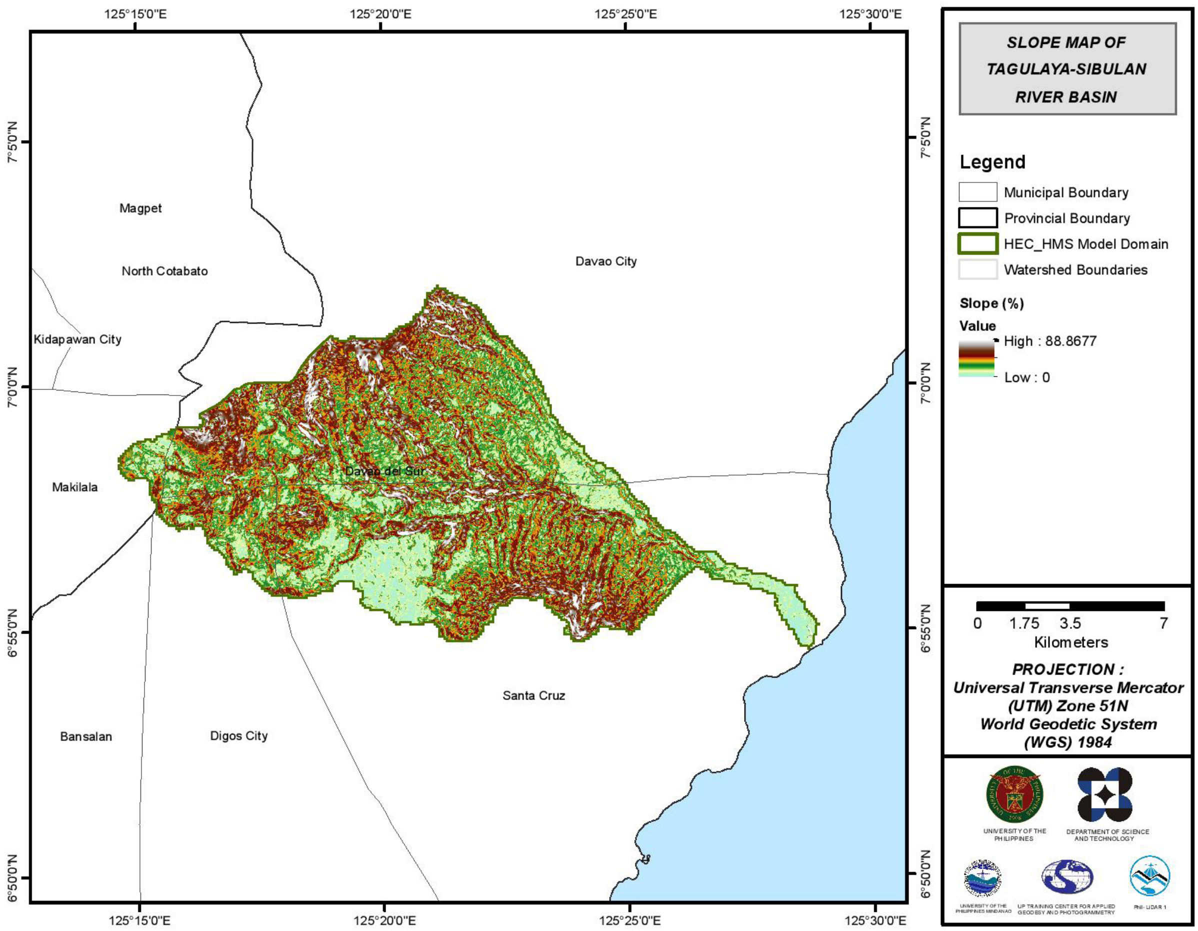


Figure 56. Slope Map of Sibulan River Basin

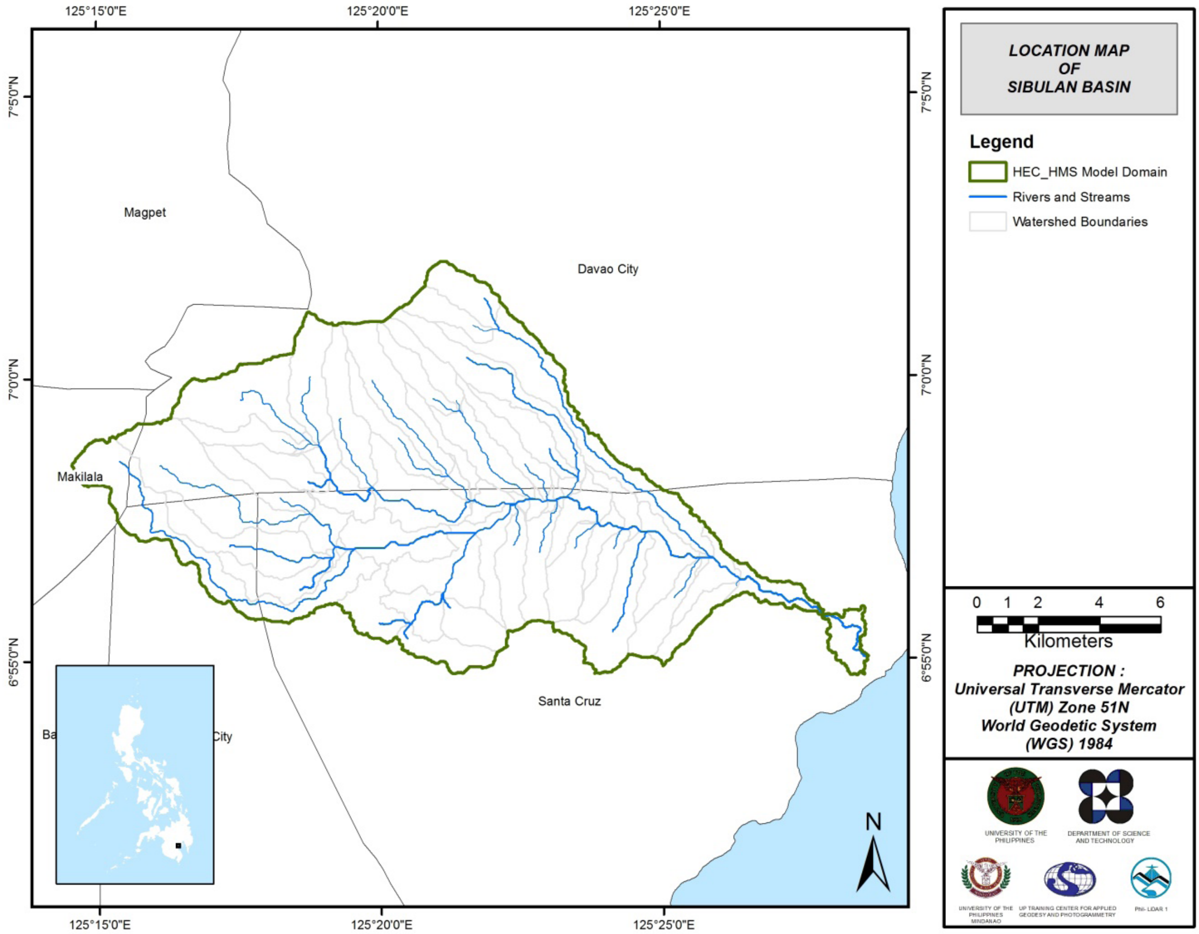


Figure 57. Stream Delineation Map of Sibulan River Basin

Using the SAR-based DEM, the Sibulan basin was delineated and further subdivided into subbasins. The Sibulan basin model consists of 59 sub basins, 29 reaches, and 29 junctions as shown in Figure 58. The main outlet is at Cebulan Bridge.

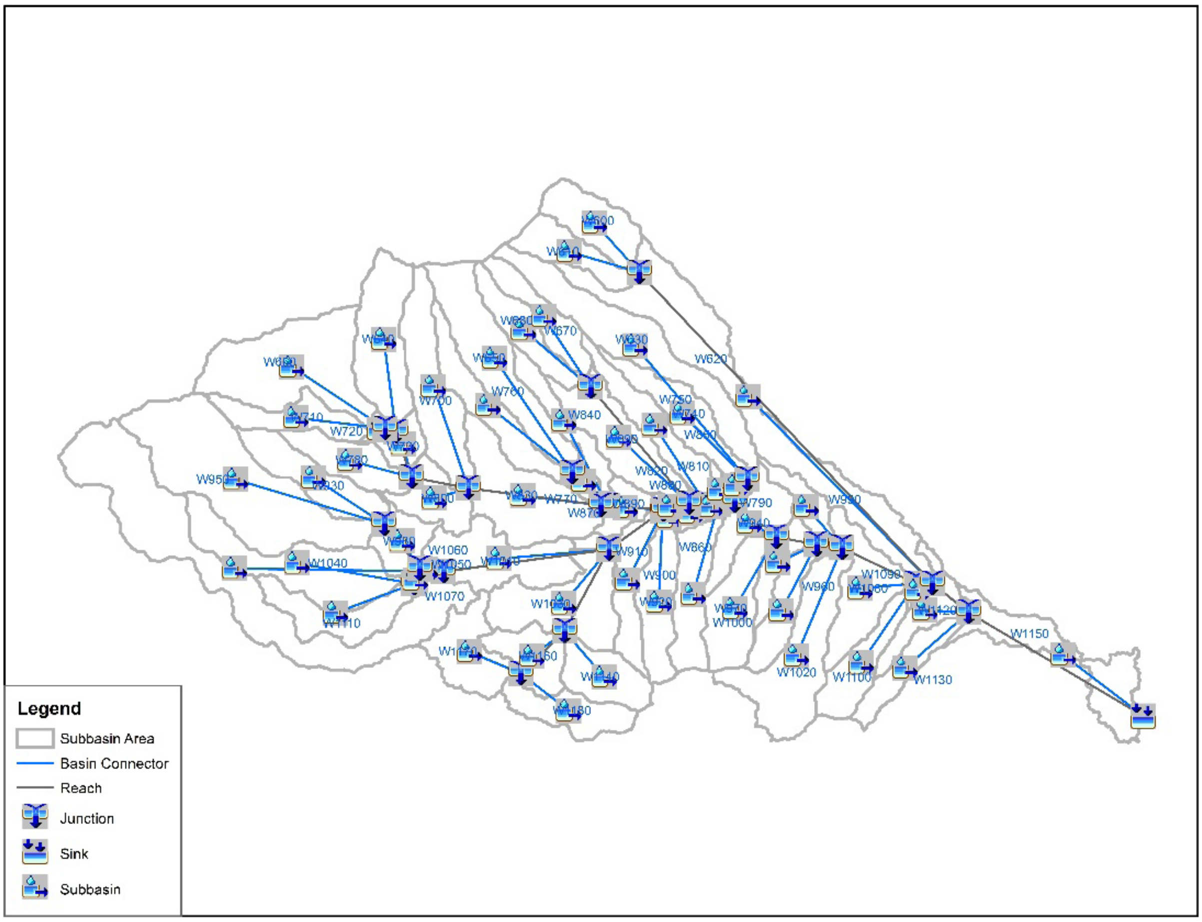


Figure 58. Sibulan River Basin model generated in HEC-HMS

5.4 Cross-section Data

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

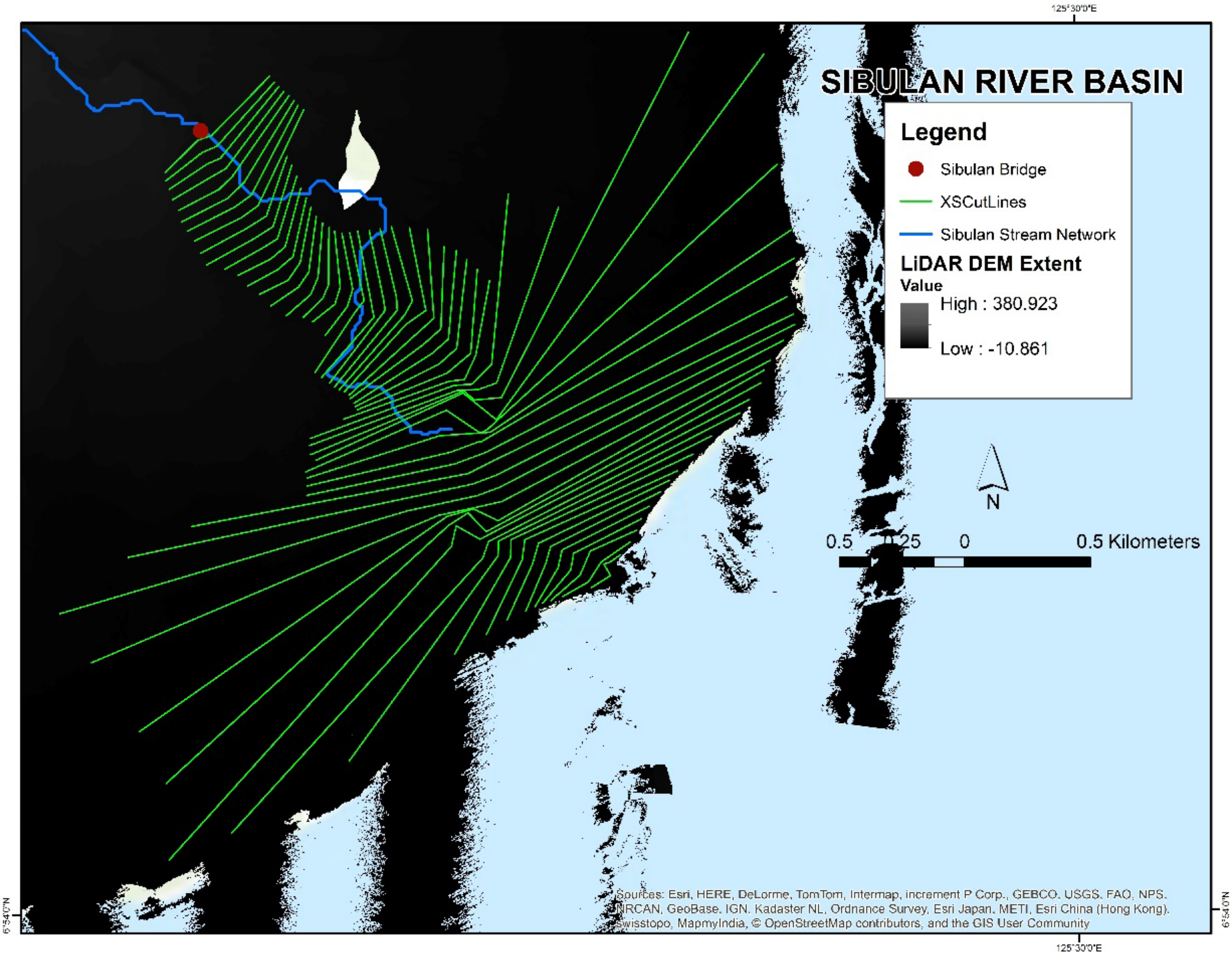


Figure 59. River cross-section of Sibulan River generated through Arcmap HEC GeoRAS tool

5.5 Flo 2D Model

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

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

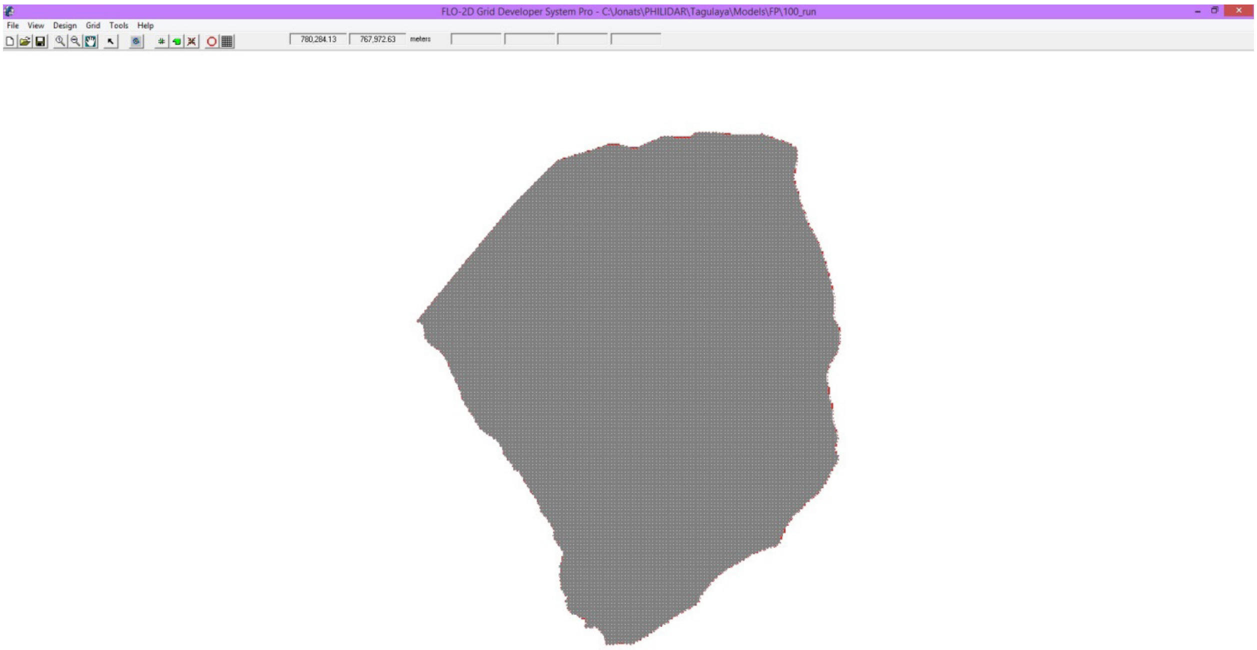


Figure 60. Screenshot of the river sub-catchment with the computational area to be modeled in FLO-2D Grid Developer System Pro (FLO-2D GDS Pro)

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 11.10498hours. After the simulation, FLO-2D Mapper Pro is used to transform the simula-tion results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maxi-mum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maxi-mum depth (h)) is set at 0 m2/s. The generated hazard maps for Sibulan are in Figures 65, Figure 67, and Figure 69.

The creation of a flood hazard map from the model also automatically creates a flow depth map depicting the maximum amount of inundation for every grid element. The legend used by default in Flo-2D Mapper is not a good representation of the range of flood inundation values, so a differ-ent legend is used for the layout. In this particular model, the inundated parts cover a maximum land area of 22092700.00 m2. The generated flood depth maps for Sibulan are in Figure 66, Fig-ure 68, and Figure 70.

There is a total of 50534401.14 m3 of water entering the model. Of this amount, 4448768.20 m3 is due to rainfall while 46085632.94 m3 is inflow from other areas outside the model. 2078150.38 m3 of this water is lost to infiltration and interception, while 1037607.79 m3 is stored by the flood plain. The rest, amounting up to 43004179.46 m3, is outflow.

5.6 Results of HMS Calibration

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

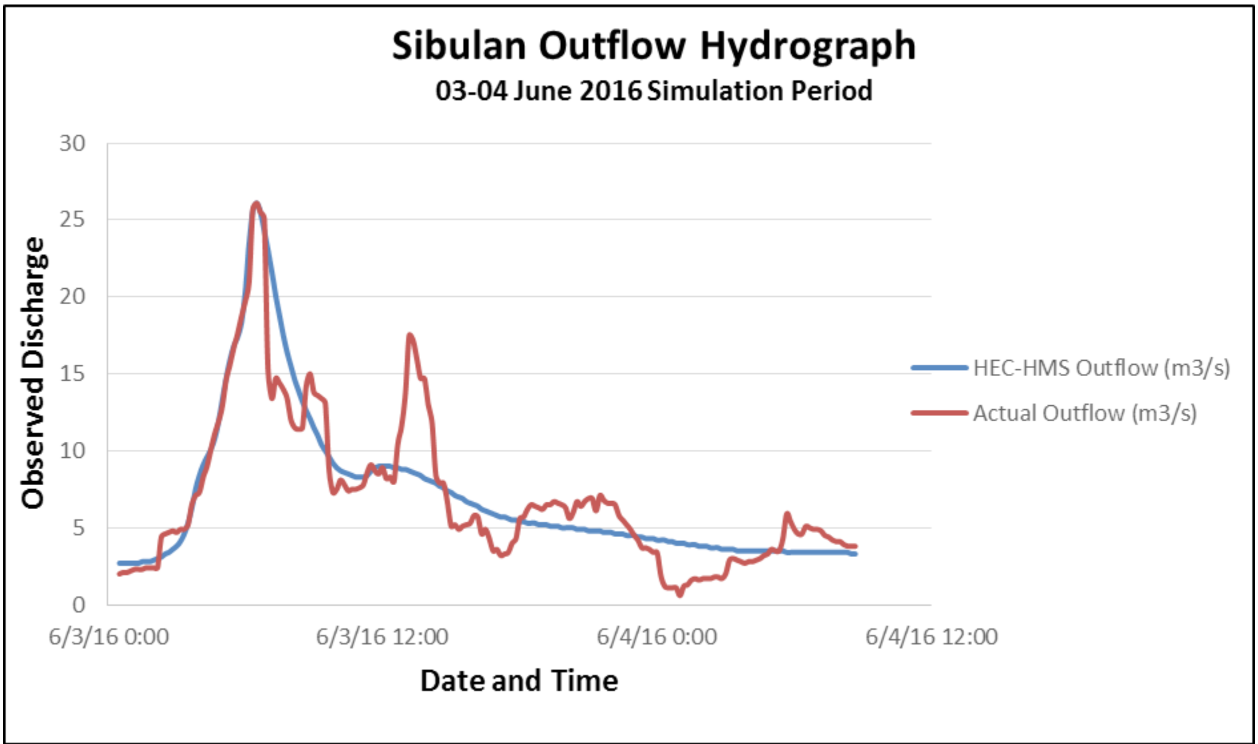


Figure 61. Outflow hydrograph of Sibulan produced by the HEC-HMS model compared with observed outflow

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

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

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	0.0075 – 17.845
			Curve Number	35.392 – 99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.34 – 26.47
			Storage Coefficient (hr)	0.0167 – 4.326
	Baseflow	Recession	Recession Constant	1E-5 – 1.43E-3
			Ratio to Peak	0.0015 – 0.498
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.0944

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 0.0075 mm to 17.845 mm means that there is a small initial fraction of the storm depth after which runoff begins, increasing the river outflow.

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

Time of concentration and storage coefficient are the travel time and index of temporary storage of runoff in a watershed. The range of calibrated values from 0.0167 hours to 26.47 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant values within the range of 1E-5 to 1.43E-3 indicate that the basin is highly likely to quickly go back to its original discharge. Values of ratio to peak within the range of 0.0015 to 0.498 indicate a steeper receding limb of the outflow hydrograph.

Manning's roughness coefficients correspond to the common roughness of Philippine watersheds. Sibulan river basin reaches' Manning's coefficient is 0.0944, showing that the catchment is mostly filled with trees and plantations (Brunner, 2010).

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

Accuracy measure	Value
RMSE	2.2
r2	0.818
NSE	0.81
PBIAS	-0.65
RSR	0.43

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 2.2 m3/s.

The Pearson correlation coefficient (r2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.818.

The Nash-Sutcliffe (E) method was also used to assess the predictive power of the model. Here the optimal value is 1. The model attained an efficiency coefficient of 0.81.

A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate bias towards over-prediction. Again, the optimal value is 0. In the model, the PBIAS is -0.65.

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 0.43.

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

5.7.1 Hydrograph using the Rainfall Runoff Model

The summary graph (Figure 64) shows the Sibulan outflow using the Davao Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

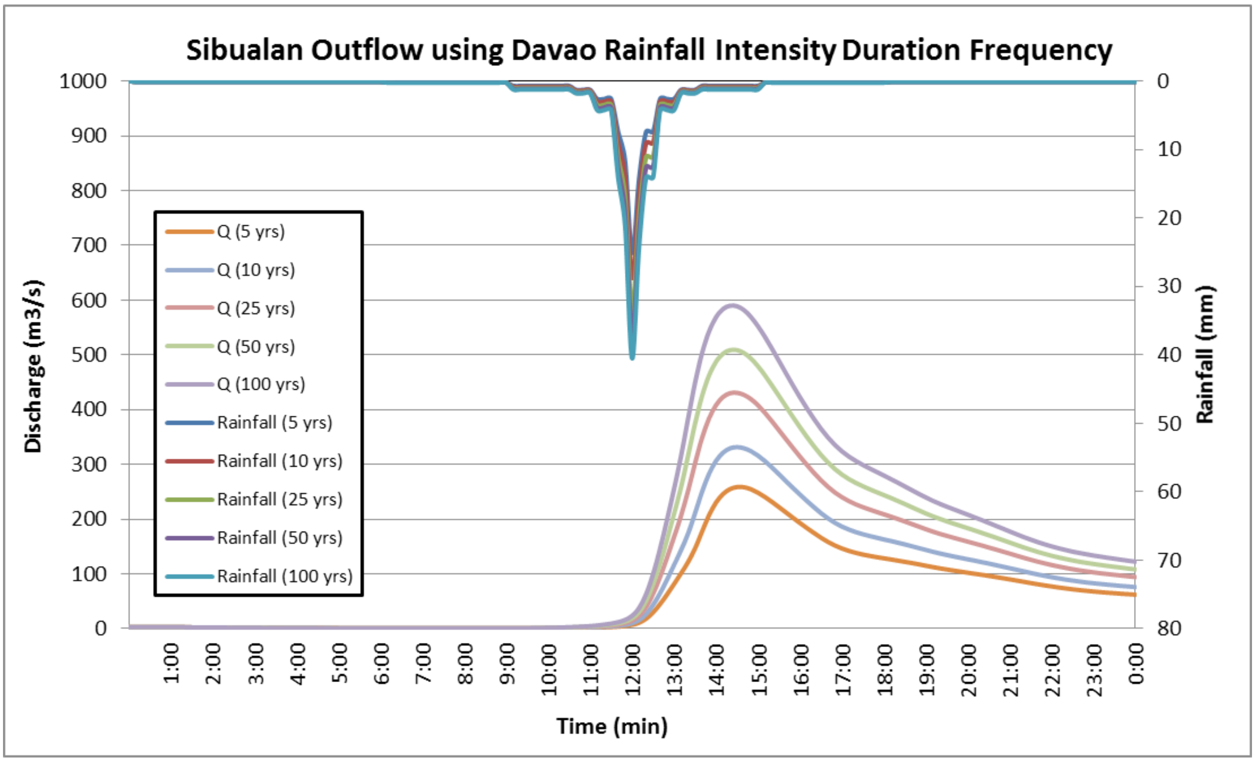


Figure 62. Outflow hydrograph at Sibulan Station generated using the Davao RIDF simulated in HEC-HMS.

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

Table 30. Peak values of the Sibulan HEC-HMS Model outflow using the Davao RIDF 24-hour values.

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	121.1	25.1	258.7	2 hours, 30 minutes
10-Year	140.7	28.8	331.6	2 hours, 30 minutes
25-Year	165.5	33.5	430.8	2 hours, 30 minutes
50-Year	183.9	37	508.8	2 hours, 30 minutes
100-Year	202.1	40.5	589.9	2 hours, 20 minutes

5.7.2 Discharge data using Dr. Horritt's recommended hydrologic method

The river discharges for the three rivers entering the floodplain are shown in Figure 63 to Figure 65 and the peak values are summarized in Table 31 to Table 32.

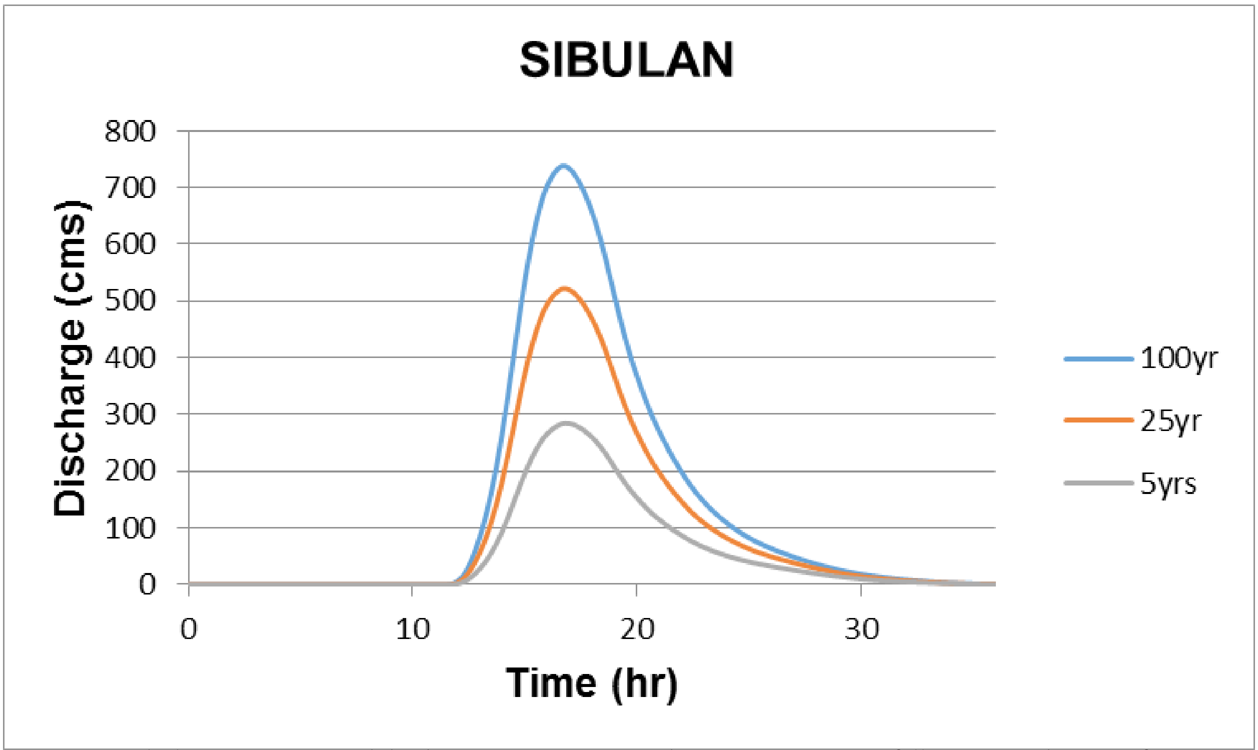


Figure 63. Sibulan river generated discharge using 5-, 25-, and 100-year Davao rainfall intensity-duration-frequency (RIDF) in HEC-HMS

Table 31. Summary of Sibulan river discharge generated in HEC-HMS

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	738.0	16 hours, 50 minutes
25-Year	522.2	16 hours, 50 minutes
5-Year	284.7	16 hours, 50 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 32.

Table 32. Validation of river discharge estimates

Discharge Point	QMED(SCS), cms	QBANKFUL, cms	QMED(SPEC), Subcms	Validation	
				Bankful Discharge	Specific Discharge
Sibulan	250.536	442.617	445.284	Pass	Pass

Discharge values from the HEC-HMS river discharge estimates were able to satisfy the conditions for validation using the bankful and specific discharge methods. The calculated values are based on theory but are supported using other discharge computation methods so they were good to use for flood modeling. However, these values 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 (RAS) Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. For this publication, only a sample output map river was to be shown. The sample generated map of Sibulan River using the calibrated HMS base flow is shown in Figure 64.

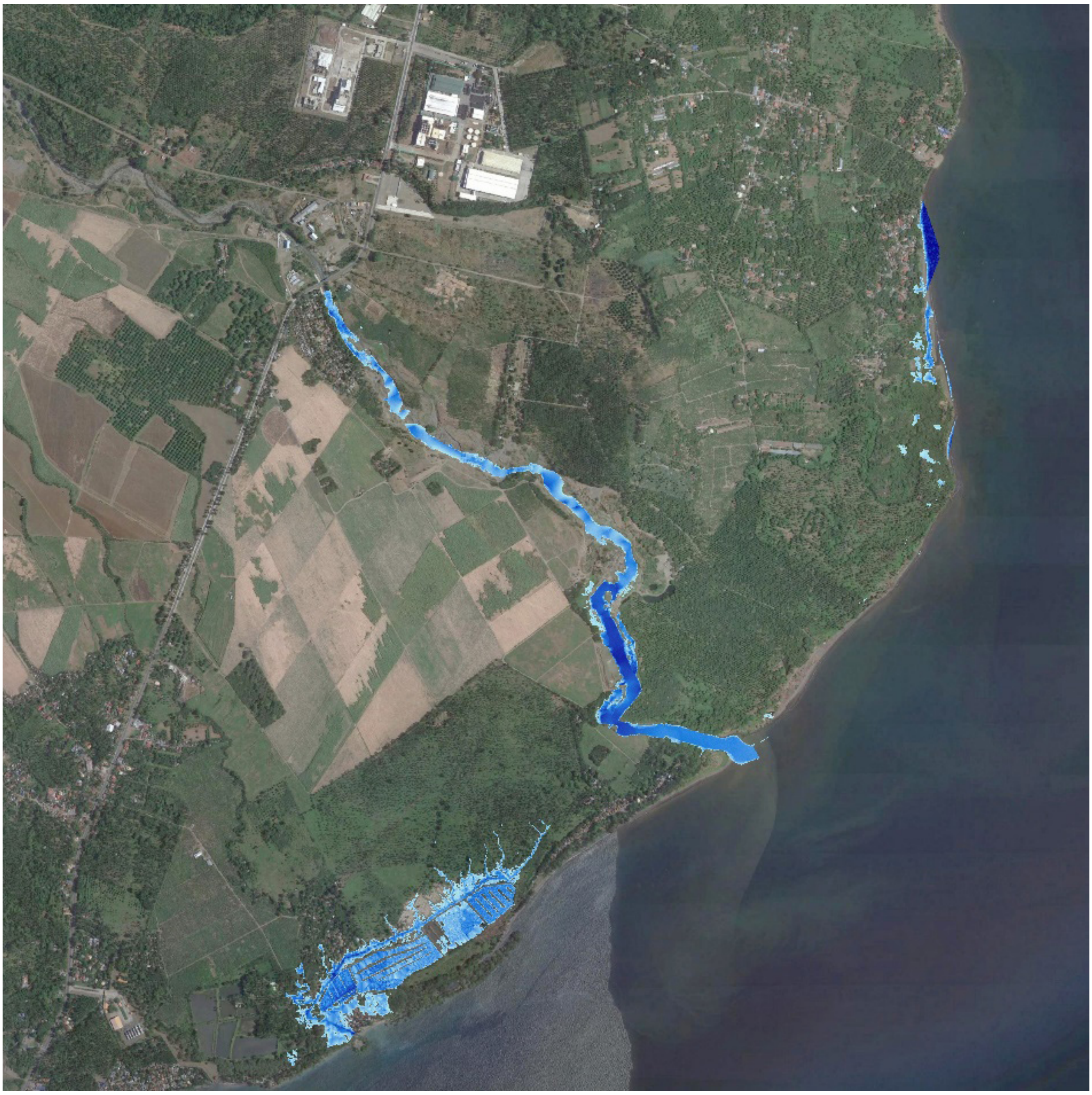


Figure 64. Sample output map of Sibulan RAS Model

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. The 5-, 25-, and 100-year rain return scenarios of the Sibulan floodplain are shown in Figure 65 to Figure 70. The floodplain, with an area of 22.09 sq. km., covers only one municipality. Table 33 shows the percentage of area affected by flooding per municipality.

Table 33. Municipality affected in Sibulan Floodplain

Province	Municipality	Total Area	Area Flooded	% Flooded
Davao del Sur	Santa Cruz	267.54	22.06	8.25%

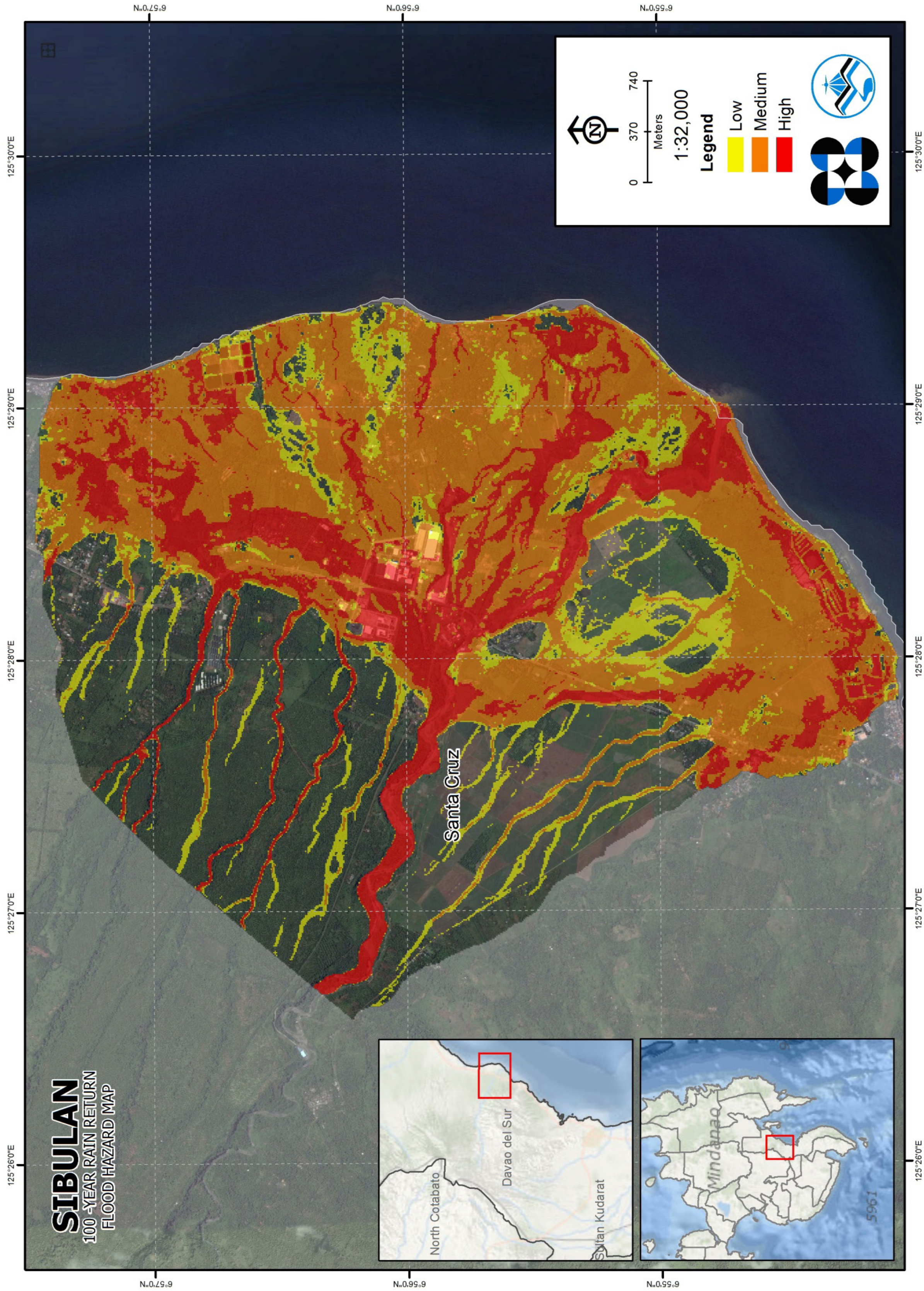


Figure 65. 100-year Flood Hazard Map for Sibulan Floodplain overlaid on Google Earth imagery

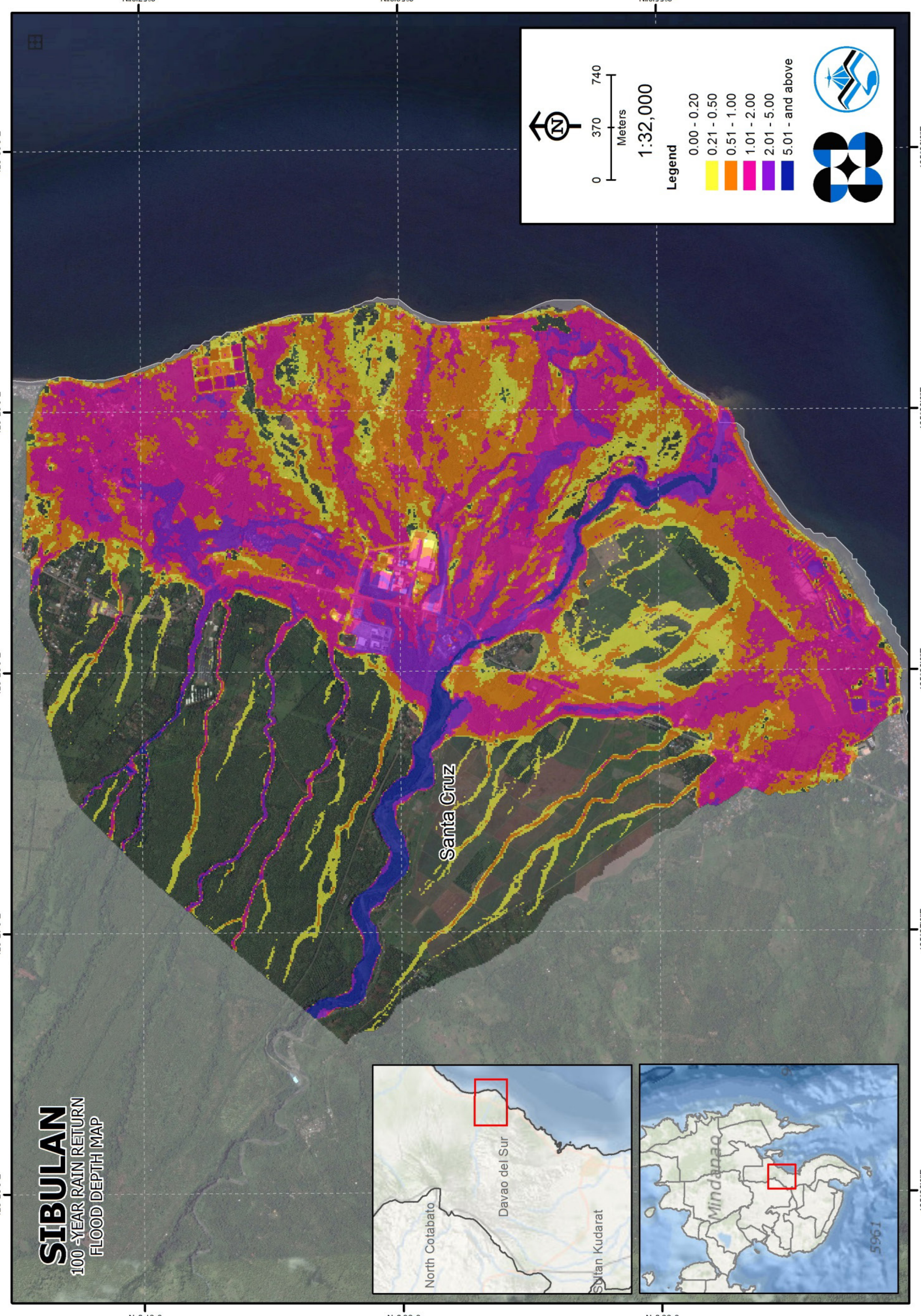


Figure 66. 100-year Flow Depth Map for Sibulan Floodplain overlaid on Google Earth imagery

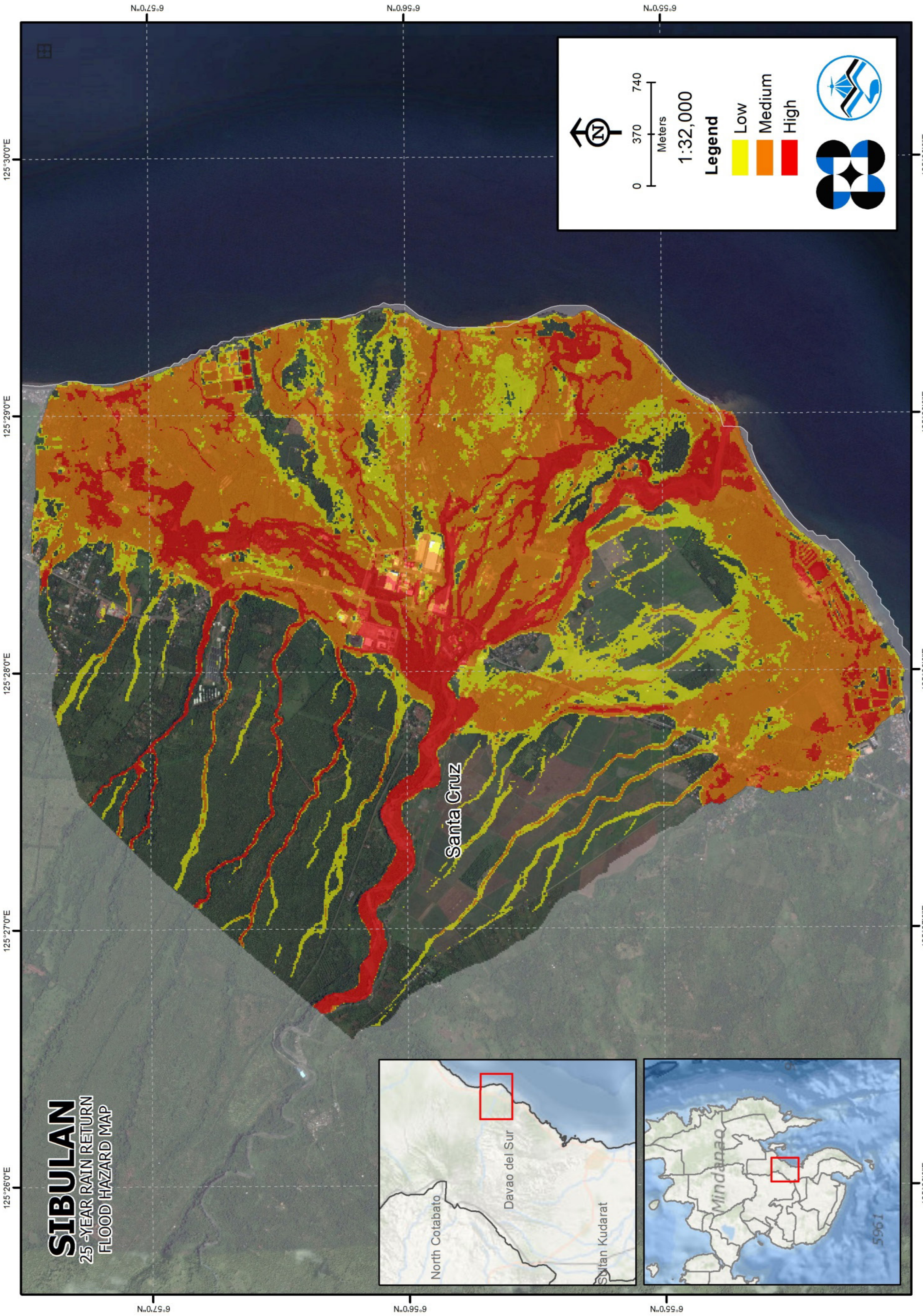


Figure 67. 25-year Flood Hazard Map for Sibulan Floodplain overlaid on Google Earth imagery

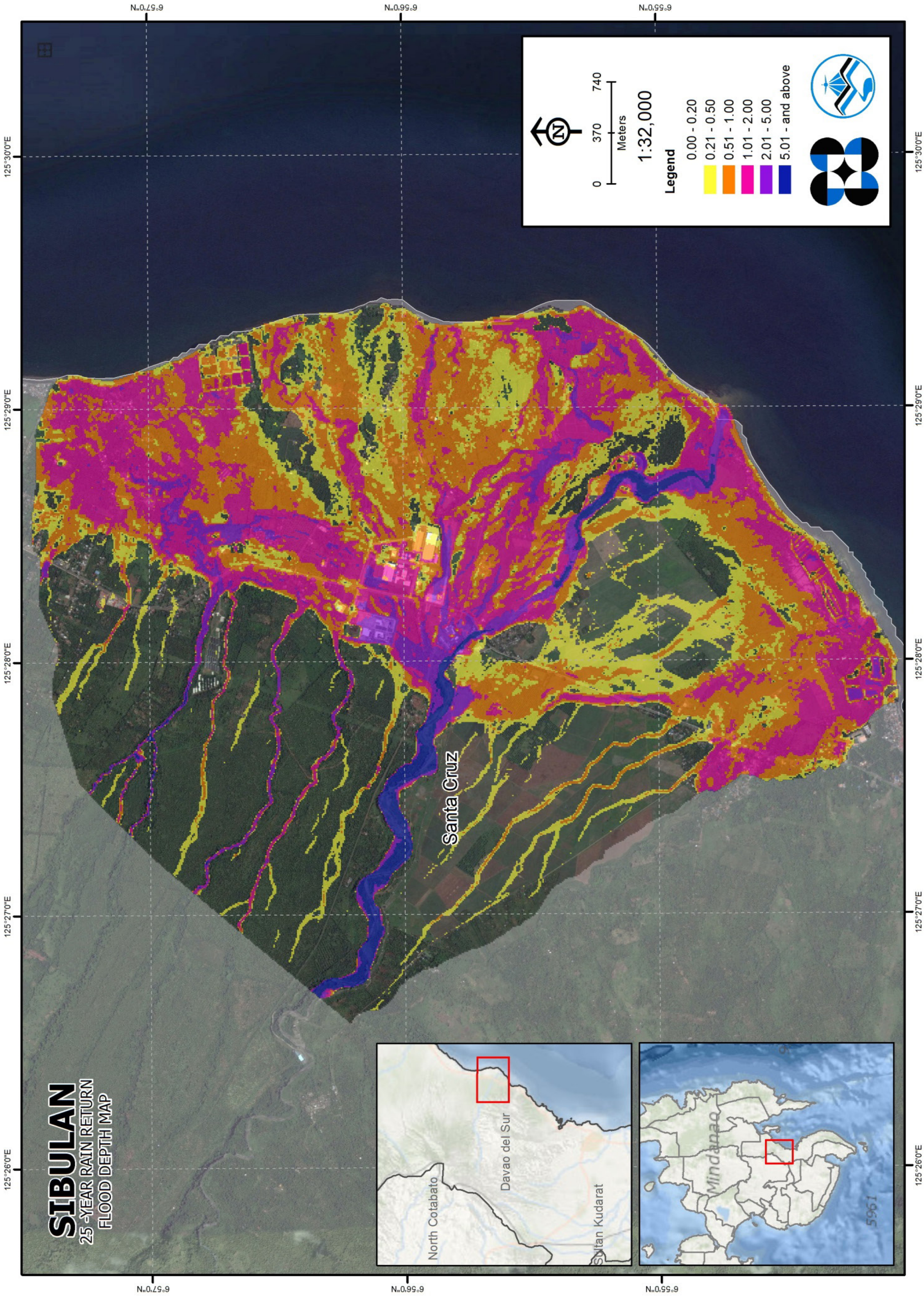


Figure 68. 25-year Flow Depth Map for Sibulan Floodplain overlaid on Google Earth imagery

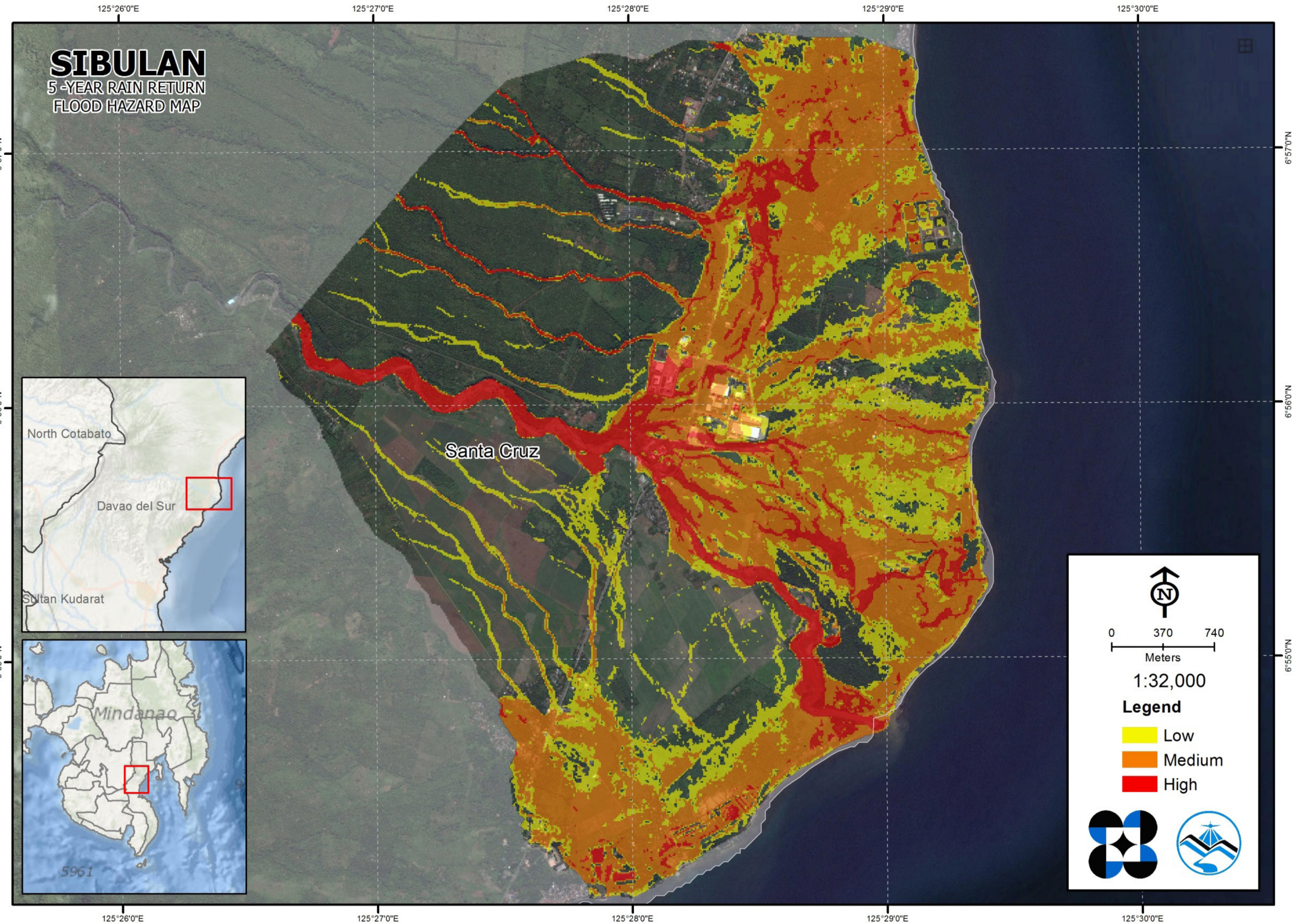


Figure 69. 5-year Flood Hazard Map for Sibulan Floodplain overlaid on Google Earth imagery

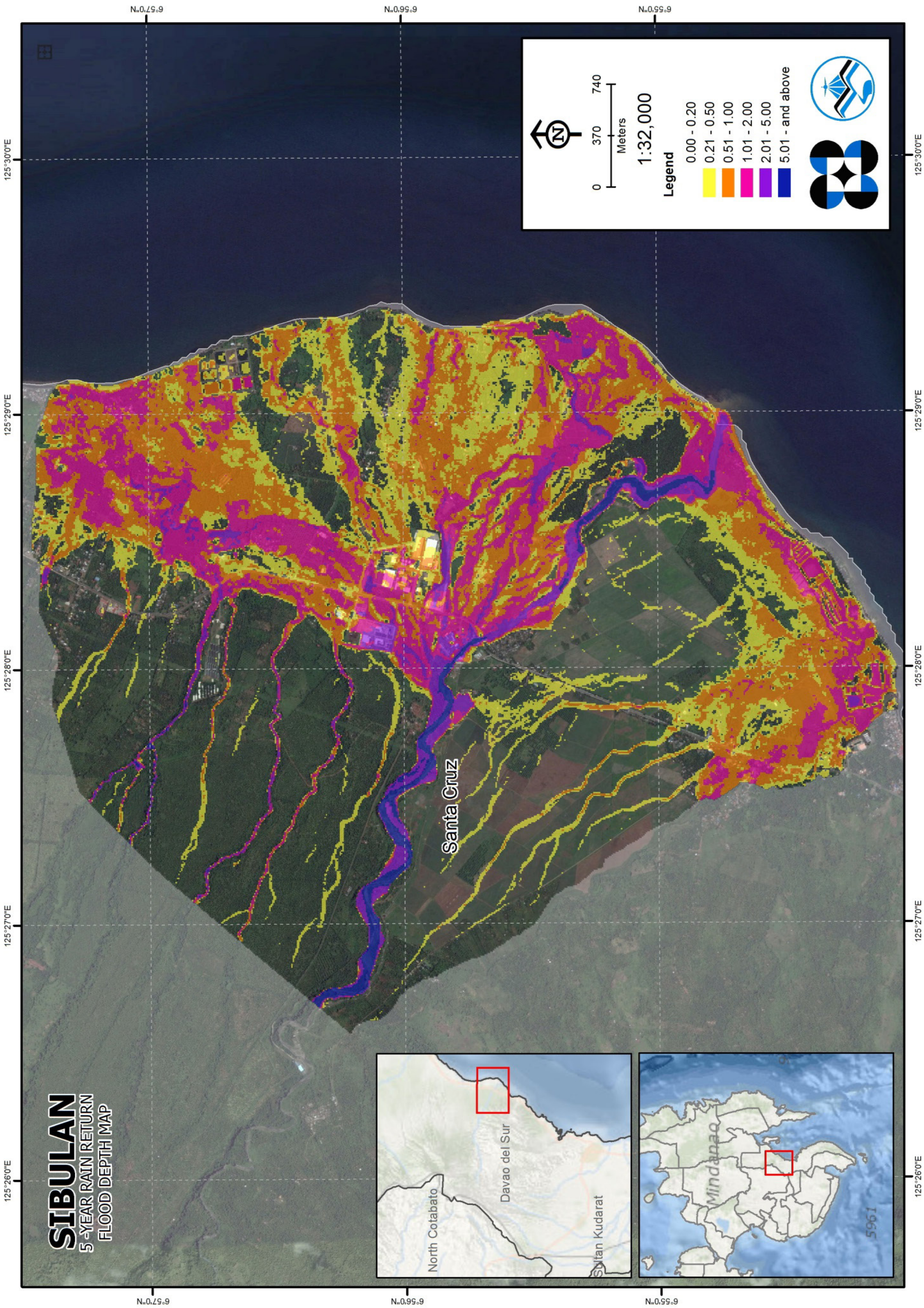


Figure 70. 5-year Flood Depth Map for Sibulan Floodplain overlaid on Google Earth imagery

5.10 Inventory of Areas Exposed to Flooding

Affected barangays in Sibulan river basin, grouped by municipality, are listed below. For the said basin, only one municipality consisting of three barangays is expected to experience flooding when subjected to 5-yr rainfall return period.

For the 5-year return period, 6.21% of the municipality of Santa Cruz with an area of 267.54 sq. km. will experience flood levels of less than 0.20 meters. 1.04% of the area will experience flood levels of 0.21 to 0.50 meters while 0.60%, 0.25%, 0.13%, and 0.02% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 34 and shown in Figure 71 are the affected areas in square kilometres by flood depth per barangay.

Table 34. Affected areas in Santa Cruz, Davao del Sur during a 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Santa Cruz (in sq. km.)		
	Astorga	Darong	Inawayan
0.03-0.20	7.05	7.71	1.86
0.21-0.50	1.41	0.75	0.61
0.51-1.00	0.71	0.31	0.58
1.01-2.00	0.26	0.17	0.25
2.01-5.00	0.22	0.13	0.0078
> 5.00	0.034	0.018	0

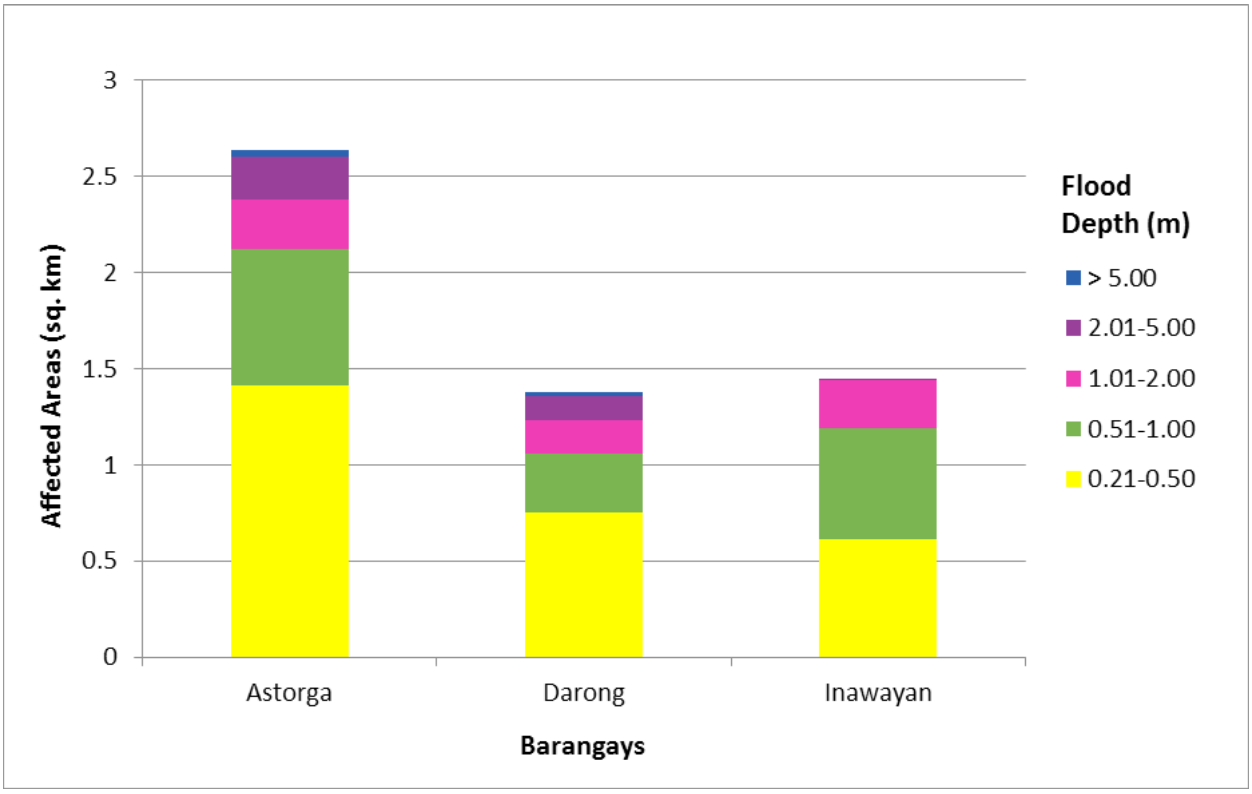


Figure 71. Affected Areas in Santa Cruz, Davao del Sur during 5-Year Rainfall Return Period

For the 25-year return period, 5.14% of the municipality of Santa Cruz with an area of 267.54 sq. km. will experience flood levels of less than 0.20 meters. 1.38% of the area will experience flood levels of 0.21 to 0.50 meters while 0.97%, 0.52%, 0.17%, and 0.05% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 35 and shown in Figure 72 are the affected areas in square kilometres by flood depth per barangay.

Table 35. Affected areas in Santa Cruz, Davao del Sur during a 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Santa Cruz (in sq. km.)		
	Astorga	Darong	Inawayan
0.03-0.20	6.03	6.14	1.59
0.21-0.50	1.67	1.45	0.58
0.51-1.00	1.12	0.81	0.66
1.01-2.00	0.52	0.43	0.45
2.01-5.00	0.23	0.2	0.026
> 5.00	0.099	0.046	0

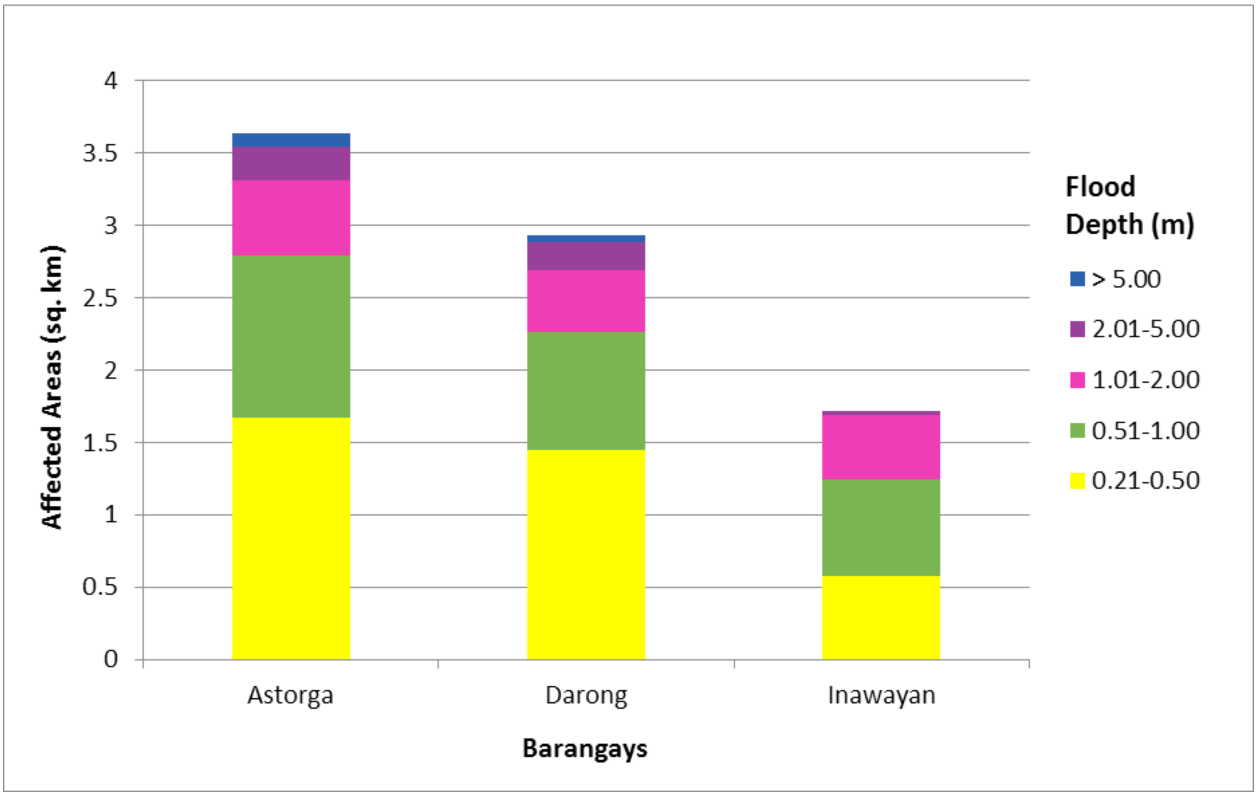


Figure 72. Affected Areas in Santa Cruz, Davao del Sur during 25-Year Rainfall Return Period

For the 100-year return period, 4.64% of the municipality of Santa Cruz with an area of 267.54 sq. km. will experience flood levels of less than 0.20 meters. 1.45% of the area will experience flood levels of 0.21 to 0.50 meters while 1.18%, 0.69%, 0.21%, and 0.07% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 36 and shown in Figure 73 are the affected areas in square kilometres by flood depth per barangay.

Table 36. Affected areas in Santa Cruz, Davao del Sur during a 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Santa Cruz (in sq. km.)		
	Astorga	Darong	Inawayan
0.03-0.20	5.55	5.45	1.41
0.21-0.50	1.77	1.57	0.55
0.51-1.00	1.33	1.13	0.7
1.01-2.00	0.65	0.6	0.59
2.01-5.00	0.24	0.27	0.062
> 5.00	0.13	0.067	0

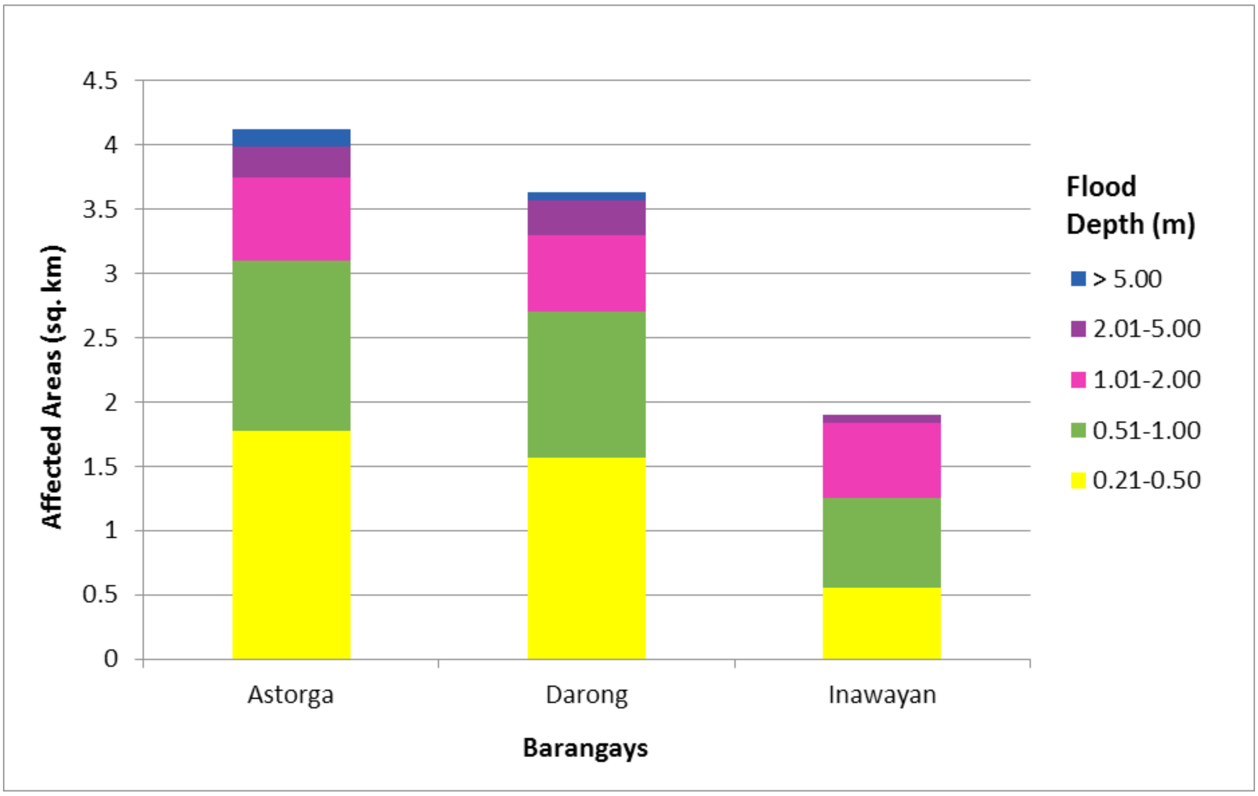


Figure 73. Affected Areas in Santa Cruz, Davao del Sur during 100-Year Rainfall Return Period

Among the barangays in the municipality of Santa Cruz in Davao del Sur, Astorga is projected to have the highest percentage of area that will experience flood levels at 3.62%. Meanwhile, Darong posted the second highest percentage of area that may be affected by flood depths at 3.40%.

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

Table 37. Areas covered by each warning level with respect to the rainfall scenarios

Warning Level	Area Covered in sq. km.		
	5 year	25 year	100 year
Low	2.86	3.78	3.97
Medium	2.14	3.63	4.47
High	0.62	1.08	1.42
TOTAL	**5.62**	**8.49**	**9.85**

Of the 28 identified educational institutions in the Sibulan floodplain, one school was assessed to be prone to flooding as they are exposed to the Medium level flooding for the 5-year return period and High level flooding in the other two rainfall scenarios. This is the Darong Elementary School in Brgy. Darong. The educational institutions exposed to flooding are shown in Annex 12.

Three medical institutions were identified in the Sibulan floodplain. San Miguel Beer Community Clinic in Brgy. Darong was found to be relatively prone to flooding, having Low level flooding in the 25-year return period and Medium level flooding in the 100-year rainfall scenario. The medical institutions exposed to flooding are shown in Annex 13.

5.11 Flood Validation

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

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

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

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

The flood validation survey was conducted on March 14-21, 2016 and May 5-6, 2016. The flood validation consists of 180 points randomly selected all over the Sibulan flood plain. It has an RMSE value of 0.69.

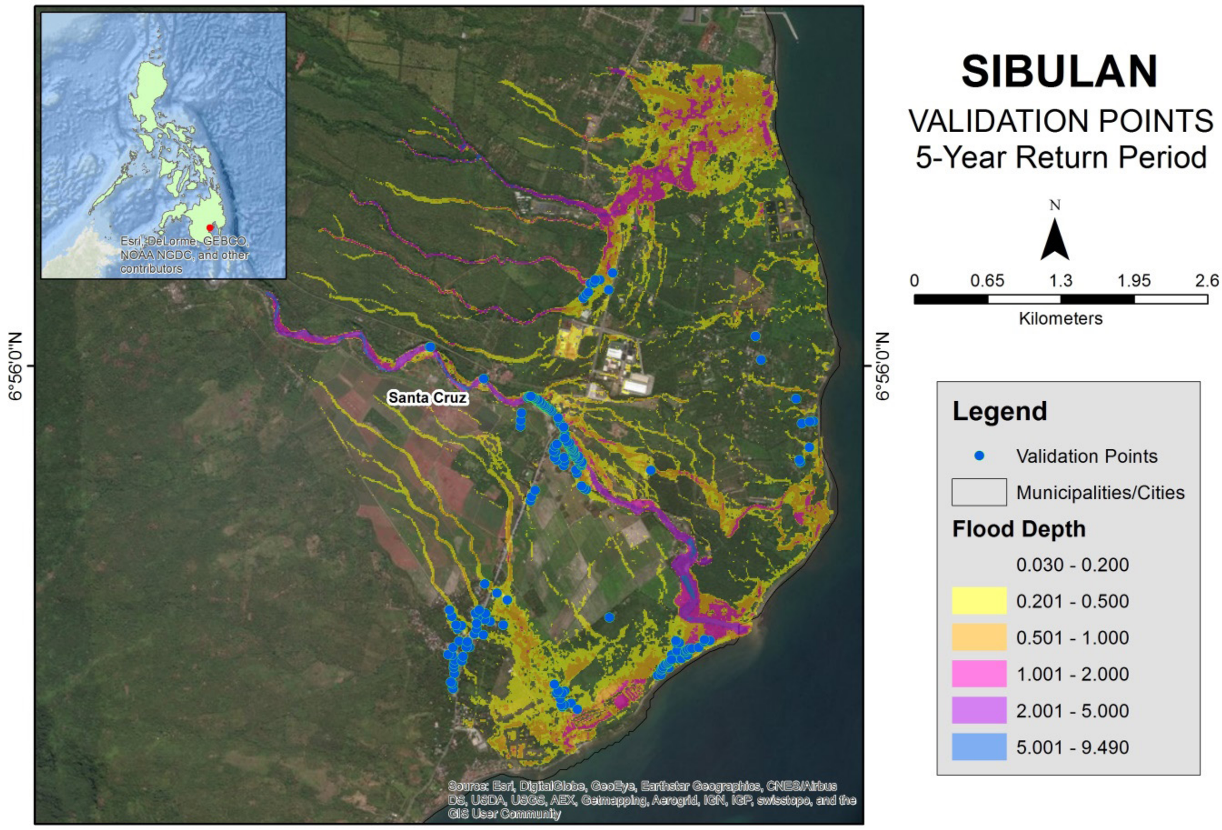


Figure 74. Sibulan Flood Validation Points

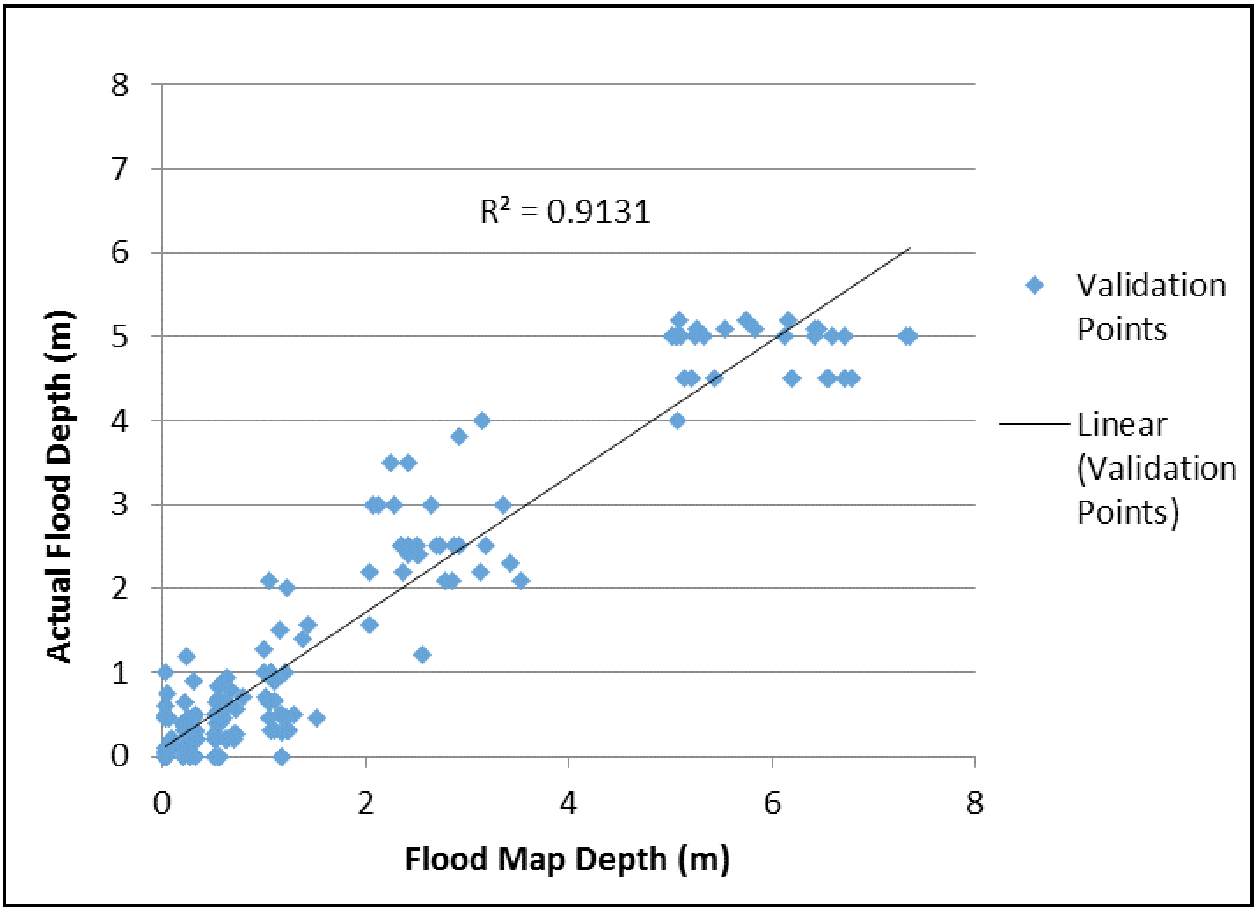


Figure 75. Flood map depth vs. actual flood depth

Table 38. Actual flood vs simulated flood depth at different levels in the Sibulan River Basin.

Actual Flood Depth (m)	Modeled Flood Depth (m)						
	0-0.20	0.21-0.50	0.51-1.00	1.01-2.00	2.01-5.00	> 5.00	Total
0-0.20	22	9	9	2	0	0	42
0.21-0.50	5	18	9	11	0	0	43
0.51-1.00	3	2	12	11	0	0	28
1.01-2.00	0	1	0	5	2	0	8
2.01-5.00	0	0	0	1	28	22	51
> 5.00	0	0	0	0	0	8	8
Total	30	30	30	30	30	30	180

The overall accuracy generated by the flood model is estimated at 51.67%, with 93 points correctly matching the actual flood depths. In addition, there were 61 points estimated one level above and below the correct flood depths while there were 24 points and 2 points estimated two levels above and below, and three or more levels above and below the correct flood depth. A total of 75 points were overestimated while a total of 12 points were underestimated in the modelled flood depths of Sibulan. The summary of the accuracy assessment is presented in Table 39.

Table 39. Summary of the Accuracy Assessment in the Sibulan River Basin Survey

	No. of Points	**%**
Correct	93	51.67
Overestimated	75	41.67
Underestimated	12	6.67
Total	180	100

REFERENCES

Ang M.C., 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.C., Lagmay, A.F., 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.J.S., Paringit E.C., et al. 2014. DREAM Data Aquisition Component Manual. Quezon City, Philippines: UP Training Center for Applied Geodesy and Photogrammetry

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

ANNEXES

Annex 1. Optech Technical Specification of the Gemini Sensor

Table A-1.1. Parameters and Specification of the Gemini Sensor

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

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

Annex 2. NAMRIA Certification of Reference Points Used in the LIDAR Survey

1. DVS-01

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

April 26, 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: DAVAO DEL SUR
Station Name: DVS-1
Order: 1st

Island: MINDANAO Municipality: DAVAO CITY		Barangay: TOWN PROPER
	PRS92 Coordinates	
Latitude: 7° 4' 41.48387"	Longitude: 125° 37' 31.24815"	Ellipsoidal Hgt: -4.50700 m.
	WGS84 Coordinates	
Latitude: 7° 4' 38.36201"	Longitude: 125° 37' 36.77094"	Ellipsoidal Hgt: 68.27510 m.
	PTM Coordinates	
Northing: 782663.345 m.	Easting: 569084.935 m.	Zone: 5
	UTM Coordinates	
Northing: 783,162.17	Easting: 790,026.11	Zone: 51

Location Description

DVS-1
From Davao City hall travel southeast along San Pedro street for 400 meters. Upon reaching the "T" intersection of San Pedro street and Quezon boulevard travel for 2.1 kms. up to the cross intersection of roads at Monteverde street, Leon Garcia street and Quezon boulevard. From this intersection turn right to Sta. Ana pier. The station is located on the east side of the new pier; 94 meters Northeast of coast guard house and north of the old pier. Station mark is 0.15 m x 0.01 m in diameter brass rod with cross cut on top, set in a drill hole, centered in a 30 cm x 30 cm cement patty on top of concrete pavement of wharf. Inscribed on top with the station name. All reference marks are 0.15 m x 0.01 m in diameter brass rods with cross cut on top, set in drill holes, centered in cement patty on concrete pavement of wharf. Inscribed on top with the reference mark numbers and arrow pointing to the station.

Requesting Party: UP-TCAGP
Pupose: Reference
OR Number: 3943584 B
T.N.: 2013-0366

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

9904262013163513

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

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

Figure A-2.1. DVS-01

2. DVA-3237

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

July 25, 2014

CERTIFICATION

To whom it may concern:

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

Province: **DAVAO DEL NORTE**
Station Name: **DVA-3237**
Order: **4th**

Island: **MINDANAO**
Municipality: **CITY OF PANABO**
Barangay: **NANYO**
MSL Elevation:

PRS92 Coordinates

Latitude:	**7° 19' 59.93670"**	Longitude:	**125° 38' 7.27962"**	Ellipsoidal Hgt:	**16.91200 m.**

WGS84 Coordinates

Latitude:	**7° 19' 56.74722"**	Longitude:	**125° 38' 12.77896"**	Ellipsoidal Hgt:	**89.23800 m.**

PTM / PRS92 Coordinates

Northing:	**810878.179 m.**	Easting:	**570151.447 m.**	Zone:	**5**

UTM / PRS92 Coordinates

Northing:	**811,399.31**	Easting:	**790,969.56**	Zone:	**51**

Location Description

DVA-3237

The station is located beside the flagpole inside the compound of Nanyo Elementary School.

Marked is the head of a 4" copper nail embedded and centered on a 0.25cm. x 0.25cm. x 1.00m. concrete monument with inscriptions "DVA-3237; 2008; LMS XI."

Requesting Party: **UP-TCAGP / Engr. Christopher Cruz**
Pupose: **Reference**
OR Number: **8799582 A**
T.N.: **2014-1737**

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

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

CIP/4701/12/09/814

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.2. DVA-3237

3. DVA-133

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

July 25, 2014

CERTIFICATION

To whom it may concern:

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

Province: **DAVAO DEL NORTE**
Station Name: **DVA-133**
Order: **2nd**

Island: **MINDANAO**
Municipality: **CITY OF PANABO**
Barangay: **MANAY**
MSL Elevation:

PRS92 Coordinates

Latitude:	7° 20' 57.02014"	Longitude:	125° 35' 57.50044"	Ellipsoidal Hgt:	23.95700 m.

WGS84 Coordinates

Latitude:	7° 20' 53.82313"	Longitude:	125° 36' 2.99870"	Ellipsoidal Hgt:	96.16300 m.

PTM / PRS92 Coordinates

Northing:	812626.211 m.	Easting:	566168.597 m.	Zone:	5

UTM / PRS92 Coordinates

Northing:	813,130.63	Easting:	786,976.44	Zone:	51

Location Description

DVA-133
"DVA-133" is in Barangay Manay, Municipality of Panabo. To reach the station travel for about 9 kms. from the intersection of National Highway and barangay road turn right going to Barangay Manay. Station is located infront of the Barangay Hall 15 m. from the flagpole and "NW" of volleyball court. Mark is the head of 4" copper nail embedded in a 30 x 30 cm. concrete monument with the inscription "DVA-133 2007 NAMRIA".

Requesting Party: **UP-TCAGP / Engr. Christopher Cruz**
Pupose: **Reference**
OR Number: **8799582 A**
T.N.: **2014-1736**

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

9 9 0 7 2 5 2 0 1 4 1 3 2 0 4 6

CIP/4701/12/09/814

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.3. DVA-133

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

1. DVS-01A

Table A-3.1. DVS-01A

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
DVS-01 --- DVS-01A (B1)	DVS-01	DVS-01A	Fixed	0.001	0.001	264°18'19"	5.002	-0.009
DVS-01 --- DVS-01A (B2)	DVS-01	DVS-01A	Fixed	0.001	0.001	264°19'14"	4.993	-0.006
DVS-01 --- DVS-01A (B3)	DVS-01	DVS-01A	Fixed	0.001	0.001	264°19'50"	4.999	0.844

Acceptance Summary

Processed	Passed	Flag	Fail
3	3	0	0

Vector Components (Mark to Mark)

From:	DVS-01				
Grid		Local		Global	
Easting	790026.116 m	Latitude	N7°04'41.48388"	Latitude	N7°04'38.36201"
Northing	783162.167 m	Longitude	E125°37'31.24815"	Longitude	E125°37'36.77094"
Elevation	0.546 m	Height	-4.507 m	Height	68.275 m

To:	DVS-01A				
Grid		Local		Global	
Easting	790021.138 m	Latitude	N7°04'41.46772"	Latitude	N7°04'38.34585"
Northing	783161.643 m	Longitude	E125°37'31.08595"	Longitude	E125°37'36.60874"
Elevation	0.537 m	Height	-4.516 m	Height	68.266 m

Vector					
ΔEasting	-4.978 m	NS Fwd Azimuth	264°18'19"	ΔX	4.016 m
ΔNorthing	-0.525 m	Ellipsoid Dist.	5.002 m	ΔY	2.942 m
ΔElevation	-0.009 m	ΔHeight	-0.009 m	ΔZ	-0.494 m

Standard Errors

Vector errors:					
σ ΔEasting	0.000 m	σ NS fwd Azimuth	0°00'08"	σ ΔX	0.000 m
σ ΔNorthing	0.000 m	σ Ellipsoid Dist.	0.000 m	σ ΔY	0.000 m
σ ΔElevation	0.000 m	σ ΔHeight	0.000 m	σ ΔZ	0.000 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000001708		
Y	-0.0000000623	0.0000001761	
Z	-0.0000000132	0.0000000282	0.0000000414

2. DVA-3237

Table A-3.2. DVA-3237

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
DVA-133 --- DVA-3237 (B1)	DVA-133	DVA-3237	Fixed	0.004	0.014	113°46'08"	4349.013	-6.729

Acceptance Summary

Processed	Passed	Flag	Fail
1	1	0	0

Vector Components (Mark to Mark)

From:	DVA-133				
Grid		Local		Global	
Easting	786976.453 m	Latitude	N7°20'57.02014"	Latitude	N7°20'53.82313"
Northing	813130.631 m	Longitude	E125°35'57.50044"	Longitude	E125°36'02.99870"
Elevation	27.682 m	Height	23.957 m	Height	96.163 m

To:	DVA-3237				
Grid		Local		Global	
Easting	790969.206 m	Latitude	N7°19'59.95215"	Latitude	N7°19'56.76267"
Northing	811399.786 m	Longitude	E125°38'07.26797"	Longitude	E125°38'12.76731"
Elevation	21.363 m	Height	17.228 m	Height	89.553 m

Vector					
ΔEasting	3992.752 m	NS Fwd Azimuth	113°46'08"	ΔX	-3362.078 m
ΔNorthing	-1730.845 m	Ellipsoid Dist.	4349.013 m	ΔY	-2141.245 m
ΔElevation	-6.319 m	ΔHeight	-6.729 m	ΔZ	-1739.408 m

Standard Errors

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

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000160458		
Y	-0.0000220689	0.0000368585	
Z	-0.0000043801	0.0000072587	0.0000024695

Annex 4. The LIDAR Survey Team Composition

Table A-4.1. The LiDAR Survey Team Composition

Data Acquisition Component Sub-Team	Designation	Name	Agency/ Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, 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)	JULIE PEARL MARS	UP-TCAGP
	Research Associate (RA)	FOR. MA. VERLINA TONGA	UP-TCAGP
	RA	ENGR. LARAH KRISELLE PARAGAS	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	JERIEL PAUL ALAMBAN, GEOL.	UP-TCAGP
LiDAR Operation	Airborne Security	TSG. MIKE DIAPANA	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. JOHN BRYAN DONGUINES	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. NEIL ACHILLES AGA-WIN	AAC

Annex 5. Data Transfer Sheet for Sibulan Floodplain

DATA TRANSFER SHEET
07/08/2014(Davao Oriental - 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	
7/18/2014	7378GC	2BLK82A199A	Gemini	NA	242	493	243	NA	NA	24.1	NA	8.53	1KB	1KB	7/7	16	Z:\DAC\RAW_DATA
7/22/2014	7386GC	2BLK82CSD203A	Gemini	NA	141/159	637	267	NA	NA	29.2	NA	8.87	1KB	1KB	3/3	NA	Z:\DAC\RAW_DATA
7/23/2014	7388GC	2BLK82AB204A	Gemini	NA	89	488	228	NA	NA	21.4	NA	8.69	1KB	1KB	4/3	10	Z:\DAC\RAW_DATA
7/24/2014	7390GC	2BLK82FH205A	Gemini	NA	93	591	241	NA	NA	29	NA	17.6	1KB	1KB	2/4	NA	Z:\DAC\RAW_DATA
7/27/2014	7396GC	2BLK82GSH208A	Gemini	NA	280	769	214	NA	NA	27.1	NA	5.65	1KB	1KB	4/4	NA	Z:\DAC\RAW_DATA
7/29/2014	7401GC	2BLK82EFGHS210B	Gemini	NA	83	339	104	NA	NA	8.25	NA	7.1	1KB	1KB	12/12/12	NA	Z:\DAC\RAW_DATA

Received from

Name TIN ANDAYA
Position RA
Signature

Received by

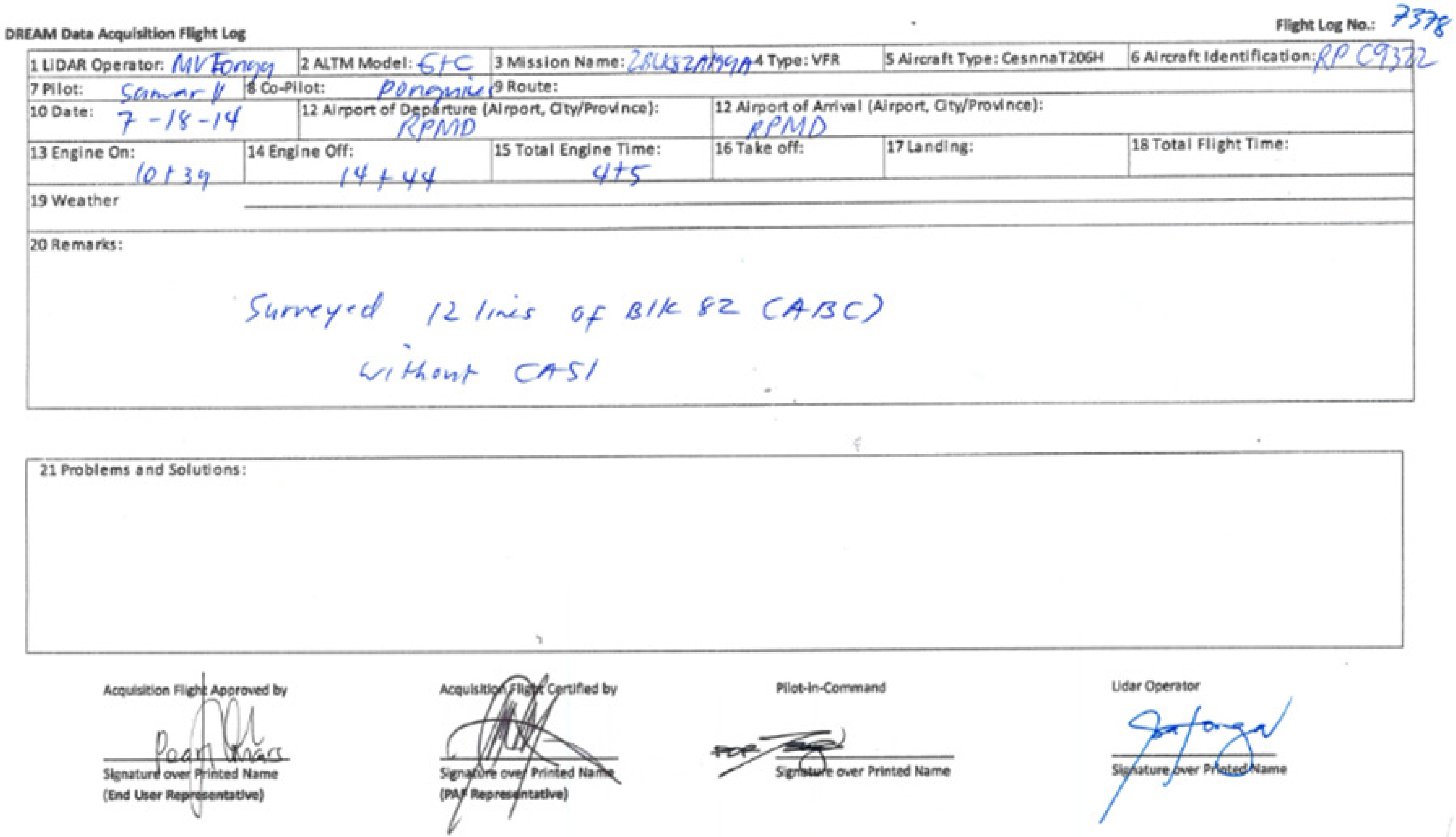
Name JOIDA F. PRIETO
Position SSRS
Signature

8/7/2014

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

Annex 6. Flight Logs for the Flight Missions

1. Flight Log for Mission 7378GC



DREAM Data Acquisition Flight Log

Flight Log No.: 7378

1 LiDAR Operator: MV Fonga	2 ALTM Model: GHC	3 Mission Name: 2BLK82A199A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RP C9322
7 Pilot: Samar K	8 Co-Pilot: Ponognic	9 Route:			
10 Date: 7-18-14	12 Airport of Departure (Airport, City/Province): RPMD		12 Airport of Arrival (Airport, City/Province): RPMD		
13 Engine On: 10+39	14 Engine Off: 14+44	15 Total Engine Time: 4+5	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather					
20 Remarks: Surveyed 12 lines of Blk 82 (ABC) without CASI					

21 Problems and Solutions:

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

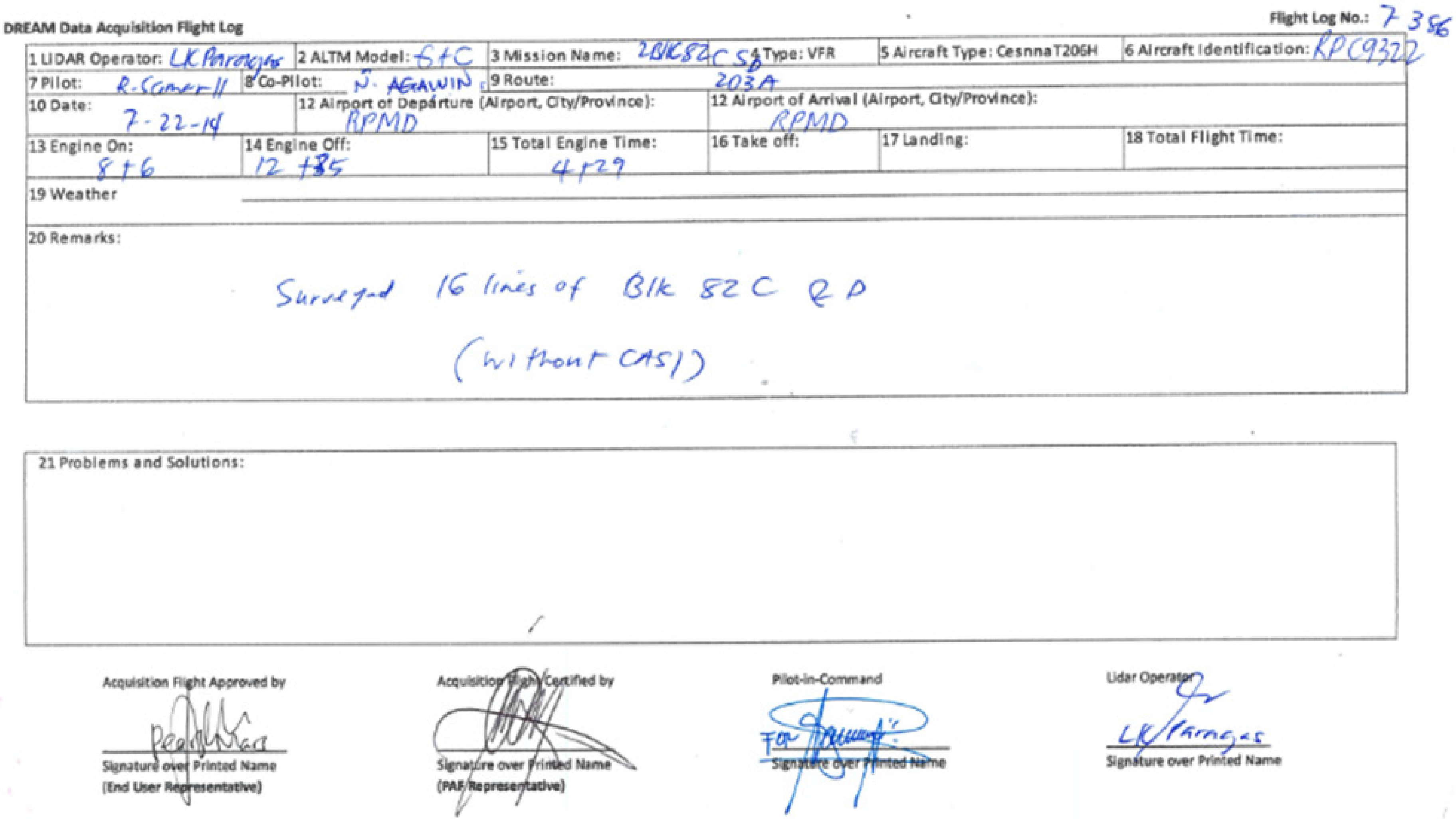
Acquisition Flight Certified by
Signature over Printed Name
(PAF Representative)

Pilot-in-Command
Signature over Printed Name

Lidar Operator
Signature over Printed Name

Figure A-6.1. Flight Log for Mission 7378GC

2. Flight Log for 7386GC Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 7356

1 LIDAR Operator: LK Paragas	2 ALTM Model: G+C	3 Mission Name: 2BLK82C SB	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RPC9322
7 Pilot: R. Samer II	8 Co-Pilot: N. AGAWIN	9 Route: 203A			
10 Date: 7-22-14	12 Airport of Departure (Airport, City/Province): RPMD		12 Airport of Arrival (Airport, City/Province): RPMD		
13 Engine On: 8+6	14 Engine Off: 12+35	15 Total Engine Time: 4+29	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather					

20 Remarks:

Surveyed 16 lines of Blk 82C & D

(without CASI)

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
For
Signature over Printed Name

Lidar Operator
LK Paragas
Signature over Printed Name

Figure A-6.2. Flight Log for Mission 7386GC

3. Flight Log for 7426GC Mission

DREAM Data Acquisition Flight Log

Flight Log No.: 7362

1 LiDAR Operator: LK Paragas	2 ALTM Model: GEM+CAS	3 Mission Name: 2BLK85CSHIA	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9322
7 Pilot: X. SAMAR	8 Co-Pilot: B. Donguines	9 Route: MATI			
10 Date: July 10, 2014	12 Airport of Departure (Airport, City/Province): MATI		12 Airport of Arrival (Airport, City/Province):		
13 Engine On: 7:37	14 Engine Off: 10:48	15 Total Engine Time: 3+11	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather Fair					
20 Remarks: Completed BLK84C (without CASI)					

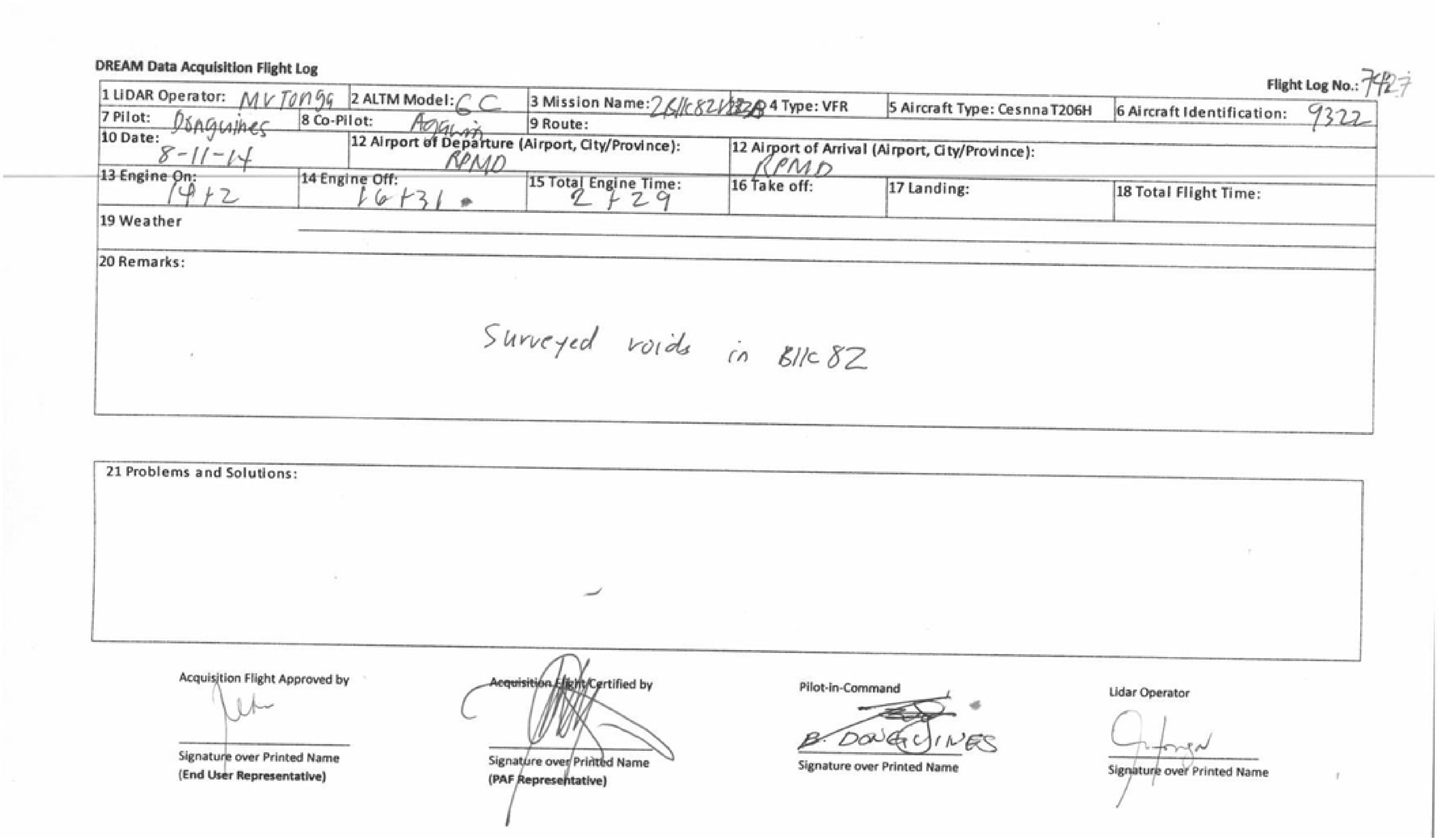
21 Problems and Solutions:

/

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

Figure A-6.3. Flight Log for Mission 7426GC

4. Flight Log for 7427GC Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 7427

1 LiDAR Operator: MV Tongga	2 ALTM Model: GC	3 Mission Name: 2BlK82V223B	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9322
7 Pilot: Donguines	8 Co-Pilot: Aquino	9 Route:			
10 Date: 8-11-14	12 Airport of Departure (Airport, City/Province): RPMD		12 Airport of Arrival (Airport, City/Province): RPMD		
13 Engine On: 1412	14 Engine Off: 1631	15 Total Engine Time: 2+29	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather					
20 Remarks: Surveyed voids in Blk 82					
21 Problems and Solutions:					

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

Figure A-6.4. Flight Log for Mission 7427GC

Annex 7. Flight Status Reports

DAVAO DEL SUR
July 16 - August 13, 2014

Table A-7.1. Flight Status Report

FLIGHT NO.	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
7378GC	BLK82C	2BLK82A199A	MVE TONGA	July 18, 2014	Flown BLK82ABC and surveyed 12 lines with-out CASI @ 850 AGL
7386GC	BLK82C	2BLK82CSD203A	LK PARAGAS	July 22, 2014	Completed BLK82C (9 lines) and surveyed BLK82C (7 lines) without CASI @ 800 AGL
7426GC	BLK82	2BLK82V223A	LK PARAGAS	Aug 11, 2014	14 lines that filled up BLK 82 voids
7427GC	BLK82	2BLK82V223B	MVE TONGA	Aug 11, 2014	Filled up voids in BLK 82@1000m

LAS BOUNDARIES PER FLIGHT

Flight No. :	7378GC	
Area:	BLK82C	
Mission name:	2BLK82A199A	
Parameters:	Altitude: 850 m;	Scan Frequency: 40 Hz;
Scan Angle: 25 deg;	Overlap: 30 %	
Area covered:	175.283 sq. km.	

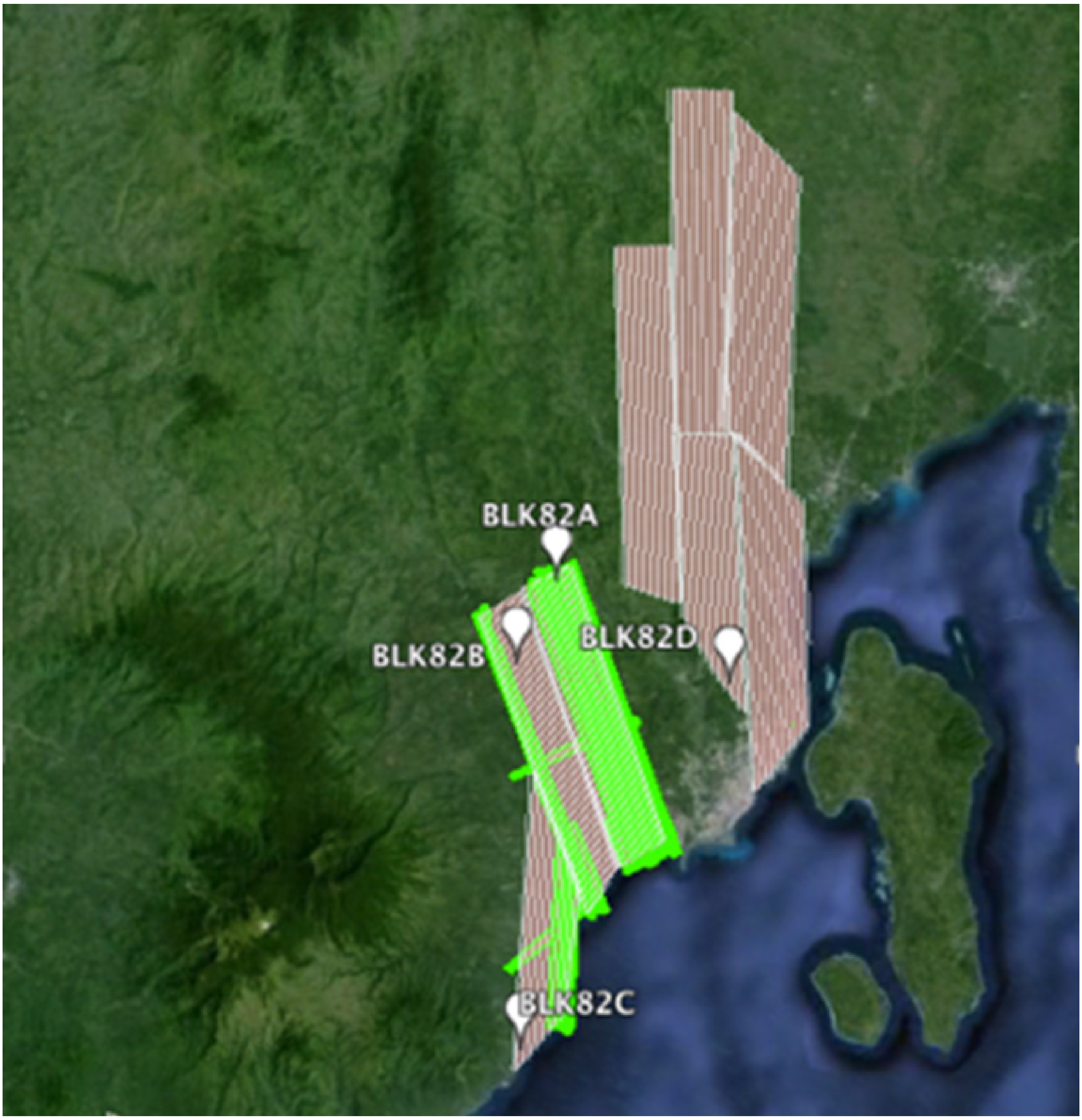


Figure A-7.1. Swath for Flight No. 7378GC

Flight No. :	7386GC	
Area:	BLK82C	
Mission name:	2BLK82CSD203A	
Parameters:	Altitude: 800 m;	Scan Frequency: 40 Hz;
Scan Angle: 25 deg;	Overlap: 35 %	
Area covered:	249.113 sq. km.	

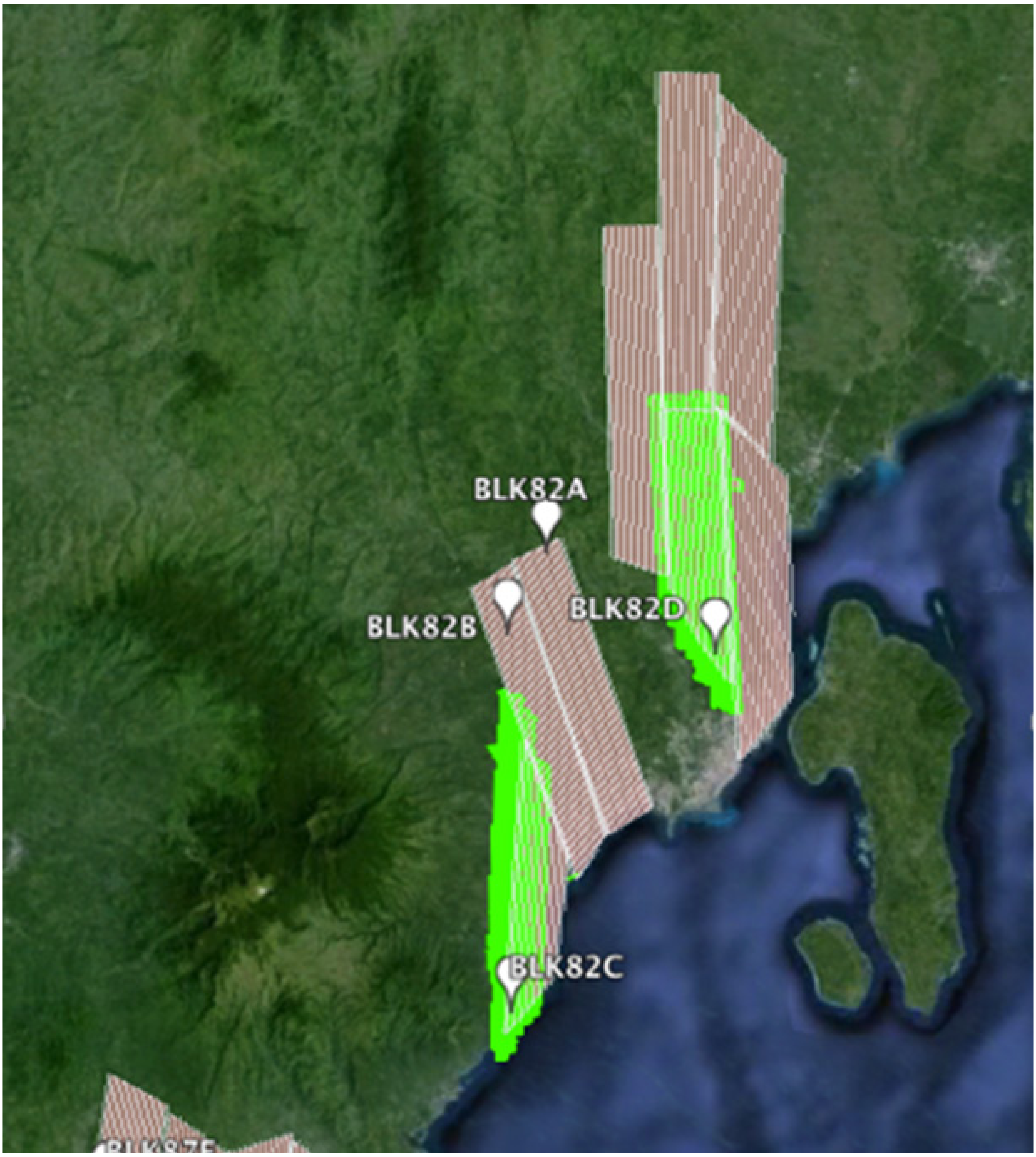


Figure A-7.2. Swath for Flight No. 7386GC

Flight No. :	7426GC	
Area:	BLK82_voids	
Mission name:	2BLK82V223A	
Parameters:	Altitude: 1000 m;	Scan Frequency: 50 Hz;
Scan Angle: 20 deg;	Overlap: 35 %	
Area covered:	95.826 sq. km.	

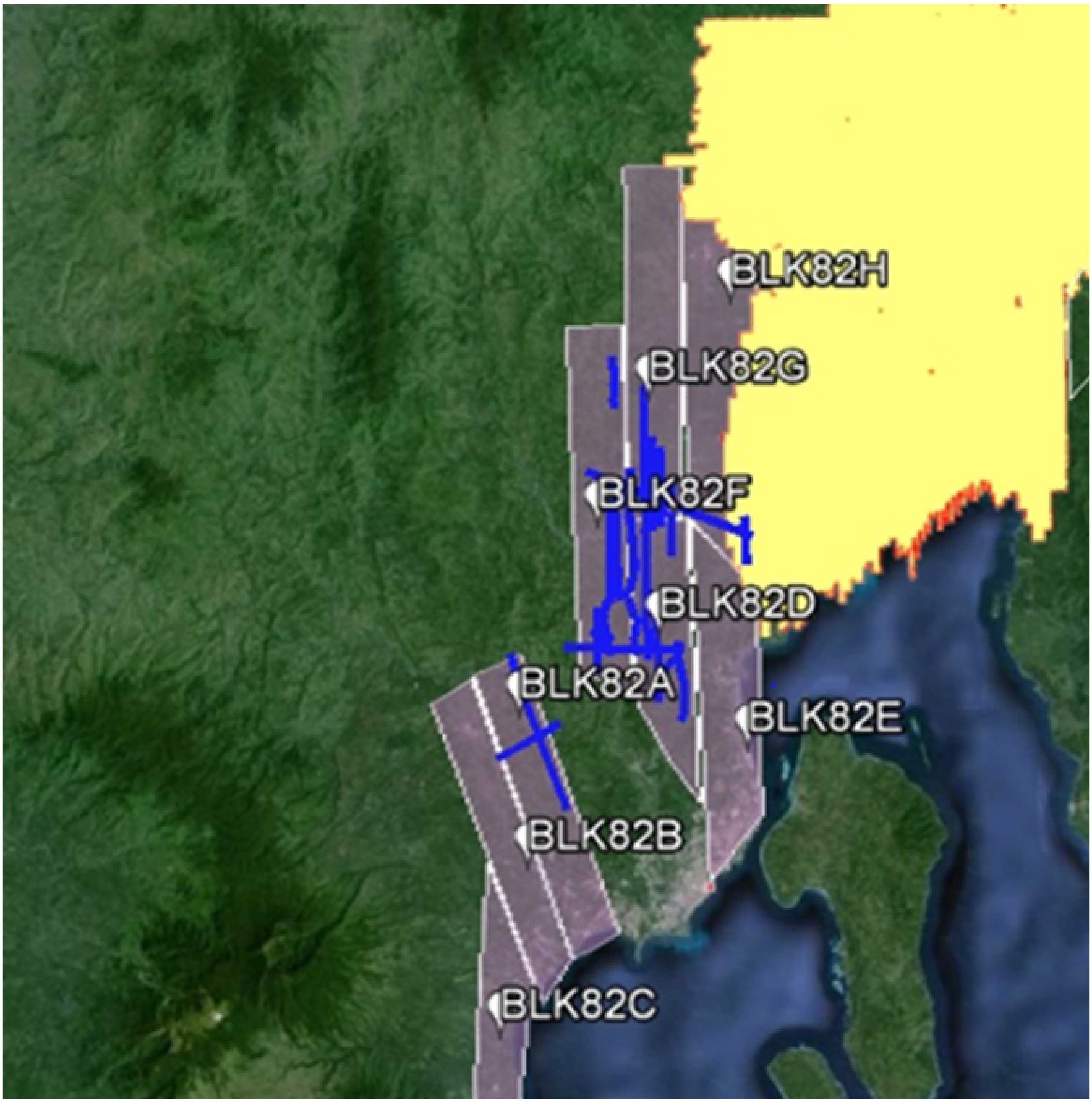


Figure A-7.3. Swath for Flight No. 7426GC

Flight No. :	7427GC	
Area:	BLK82B_voids	
Mission name:	2BLK82V223B	
Parameters:	Altitude: 1000 m;	Scan Frequency: 50 Hz;
Scan Angle: 20 deg;	Overlap: 35 %	
Area covered:	47.889 sq. km.	

Figure A-7.4. Swath for Flight No. 7427GC

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Blk82C

Flight Area	Davao Del Sur
Mission Name	Blk82C
Inclusive Flights	7378G,7386G
Range data size	77.5 GB
POS	510 MB
Base data size	17.4 MB
Image	NA
Transfer date	August 7, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.12
RMSE for East Position (<4.0 cm)	1.26
RMSE for Down Position (<8.0 cm)	3.1
Boresight correction stdev (<0.001deg)	0.000930
IMU attitude correction stdev (<0.001deg)	0.061913
GPS position stdev (<0.01m)	0.0120
Minimum % overlap (>25)	21.43%
Ave point cloud density per sq.m. (>2.0)	3.49
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	165
Maximum Height	415.85 m
Minimum Height	59.35 m
Classification (# of points)	
Ground	32,667,342
Low vegetation	33,428,343
Medium vegetation	125,375,546
High vegetation	215,082,432
Building	2,016,848
Orthophoto	No
Processed by	Engr. Carlyn Ann Ibañez, Engr. Christy Lubiano, Engr. Jeffrey Delica

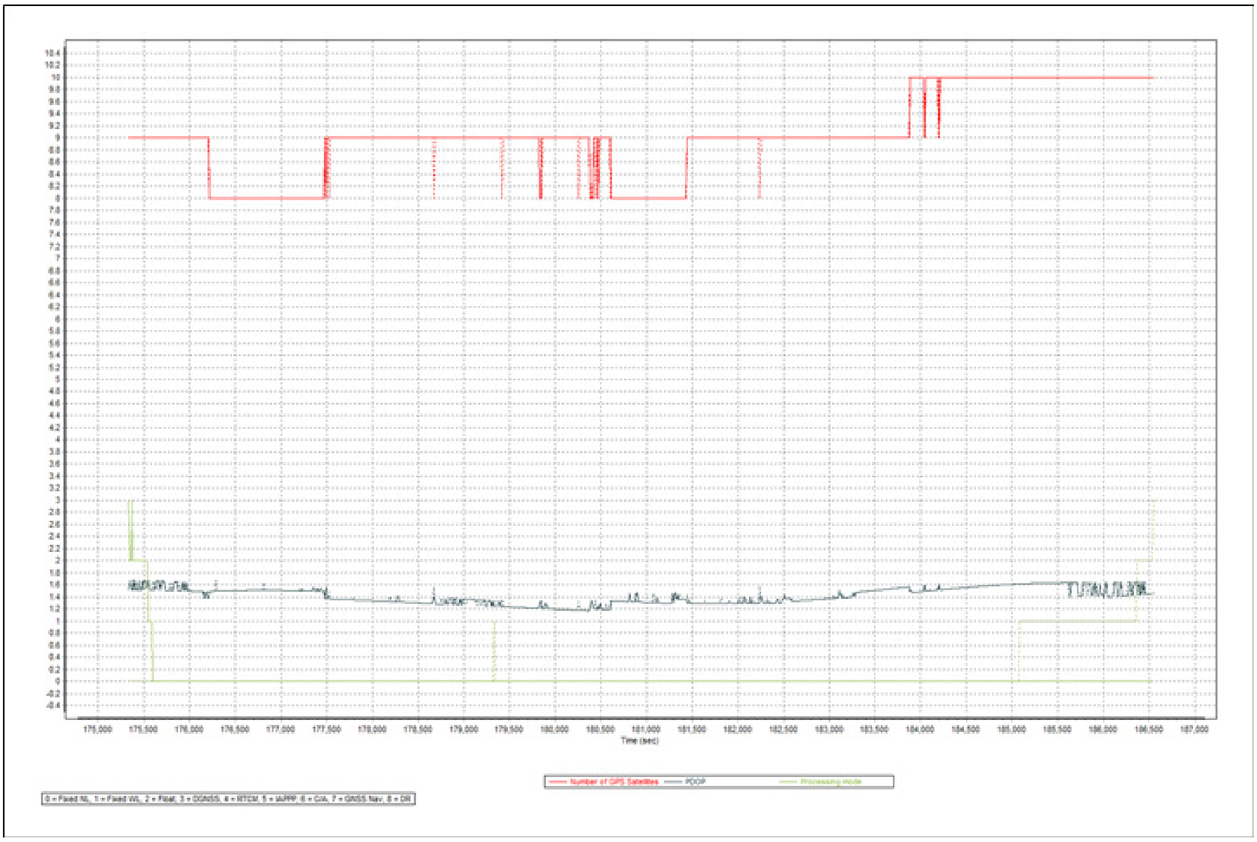


Figure A-8.1. Solution Status

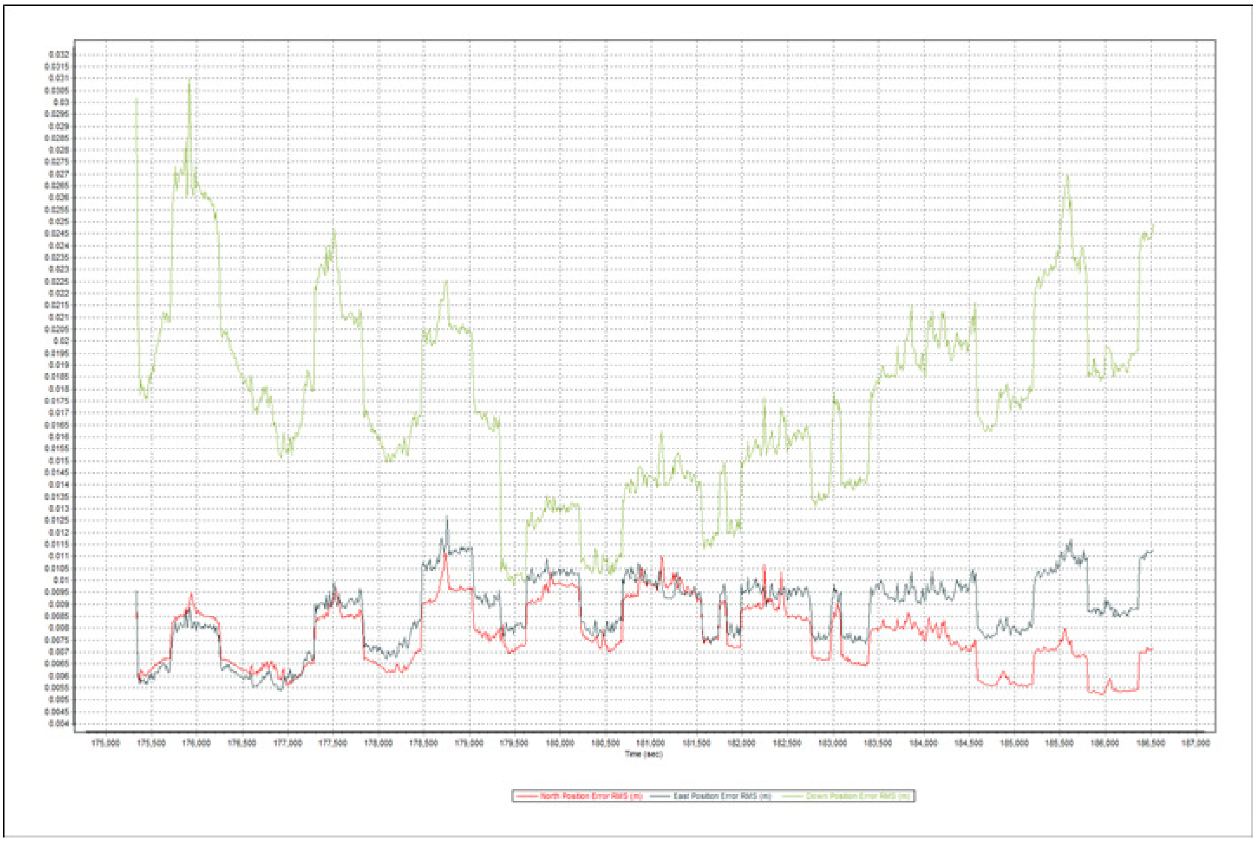


Figure A-8.2. Smoothed Performance Metrics Parameters

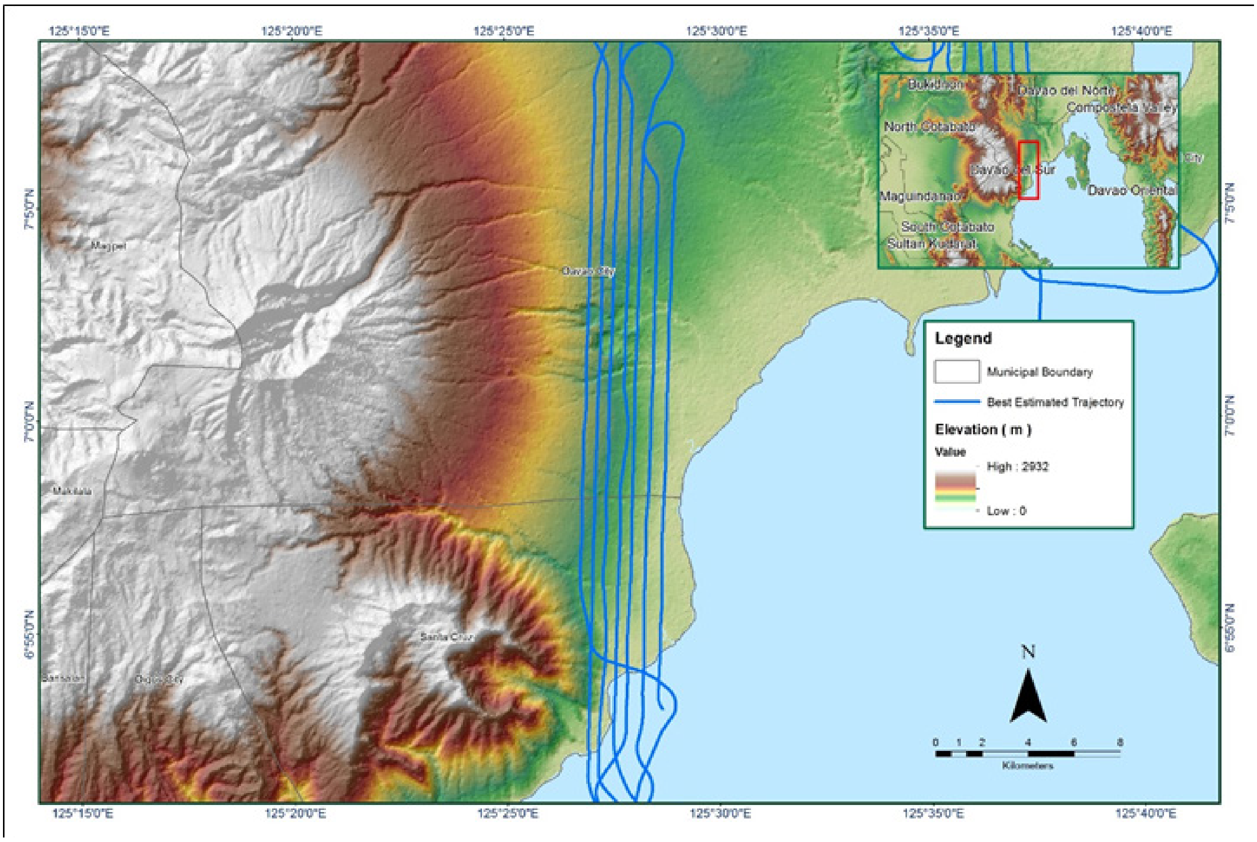


Figure A-8.3. Best Estimated Trajectory

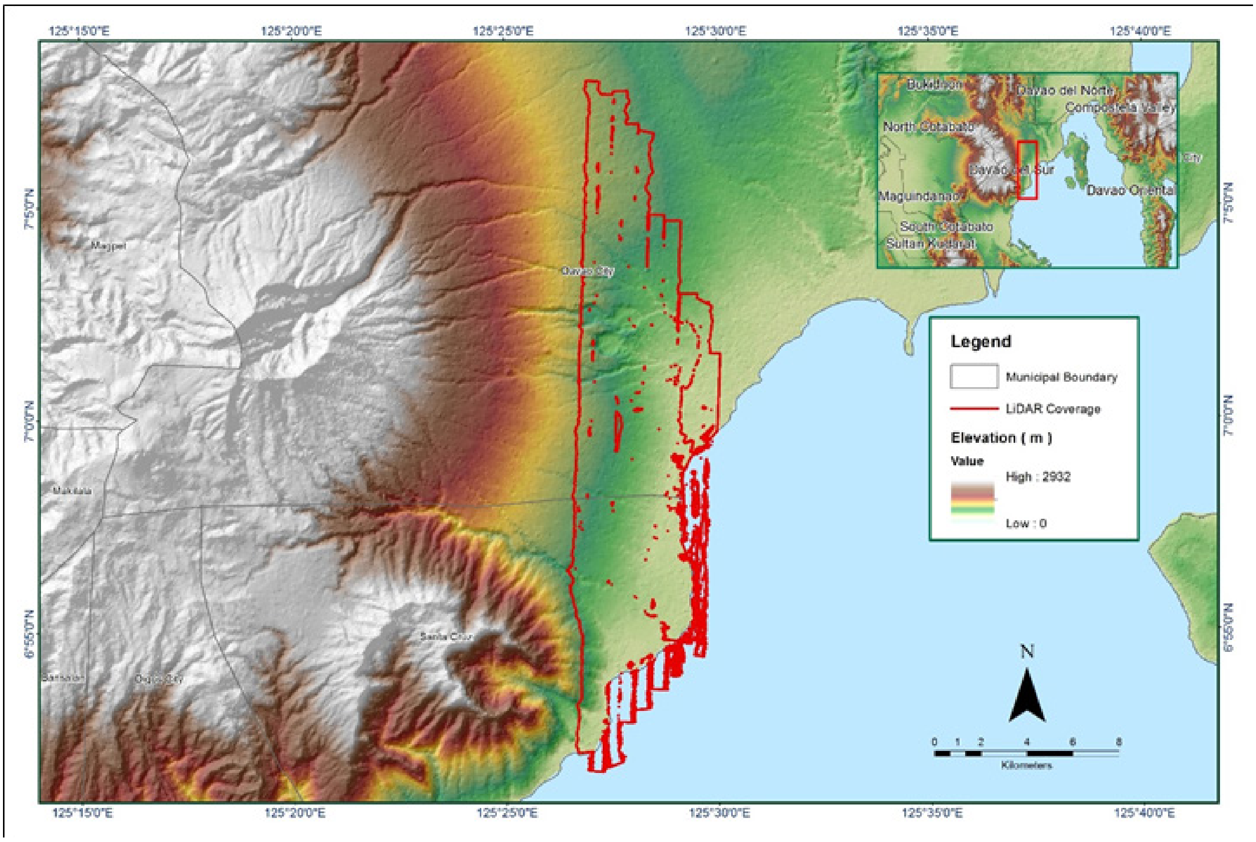


Figure A-8.4. Coverage of LiDAR data

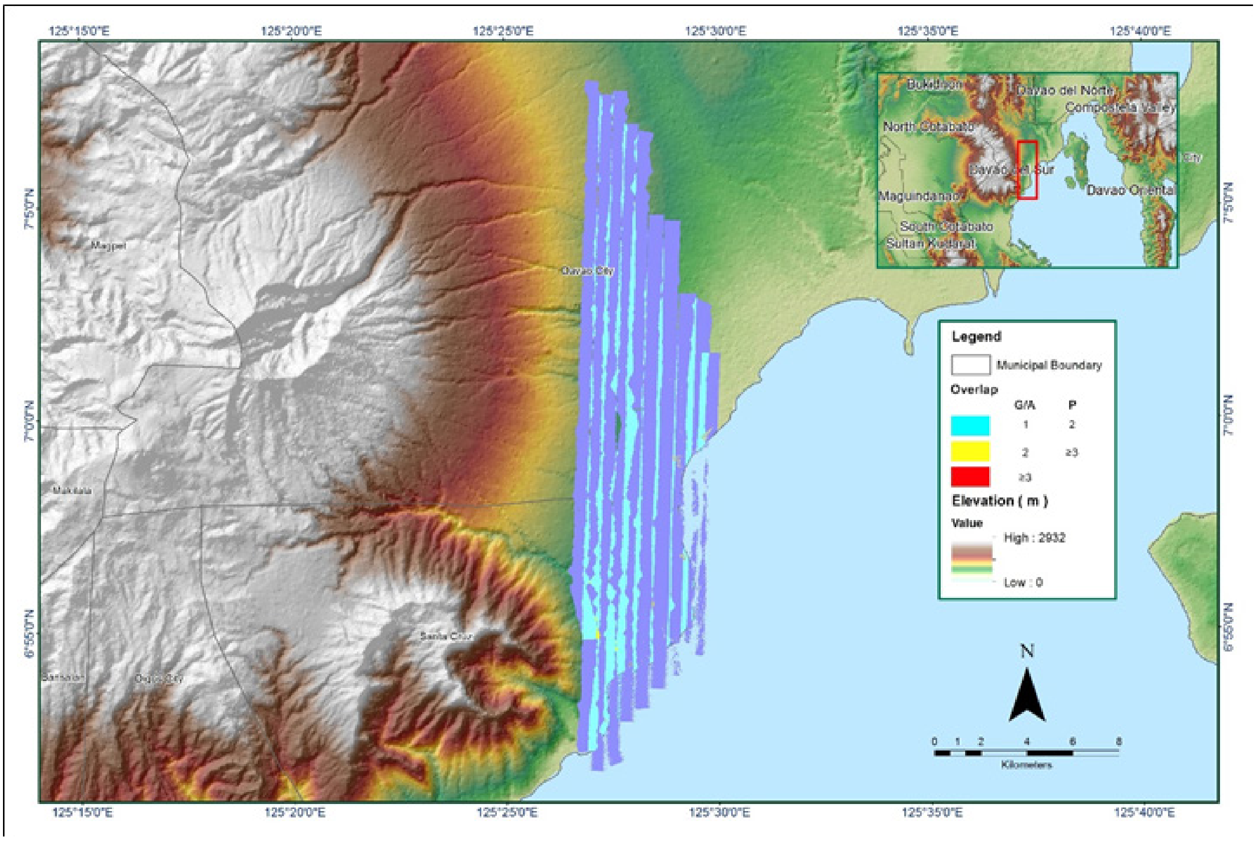


Figure A-8.5. Image of Data Overlap

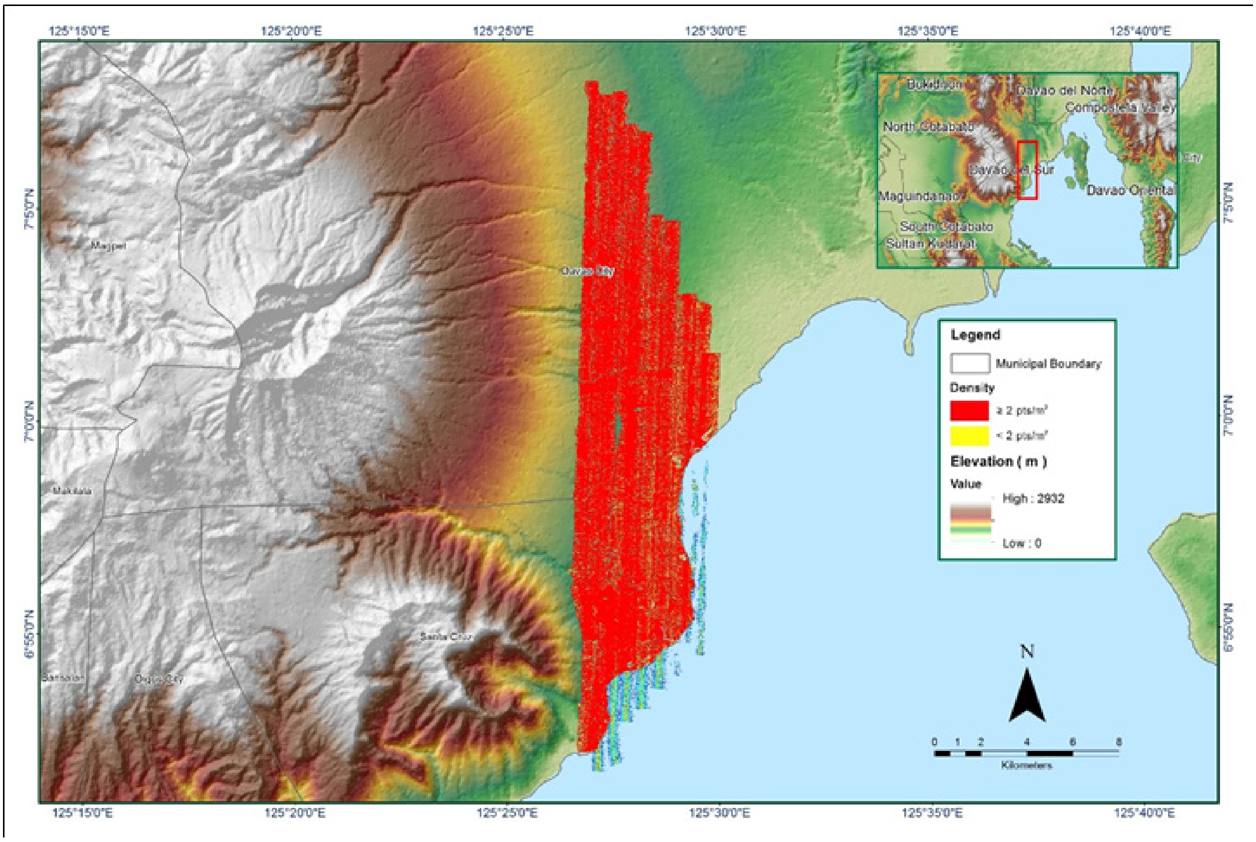


Figure A-8.6. Density map of merged LiDAR data

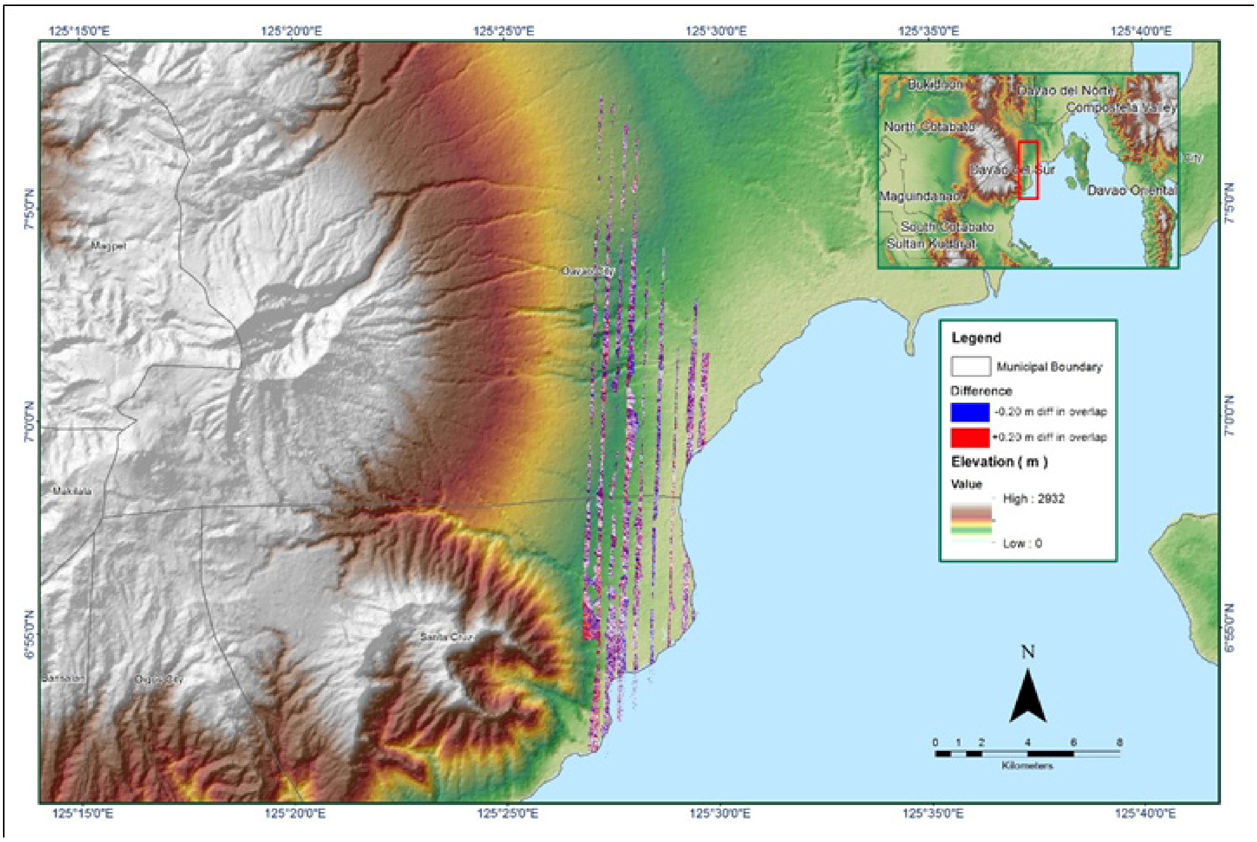


Figure A-8.7. Elevation difference between flight lines

Table A-8.2. Mission Summary Report for Mission Blk82 Voids

Flight Area	Davao Del Sur
Mission Name	Blk82 Voids
Inclusive Flights	7427G,7426G
Range data size	15.26 GB
POS	267 MB
Base data size	15.66 MB
Image	NA
Transfer date	August 29, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	2.5
RMSE for East Position (<4.0 cm)	3.1
RMSE for Down Position (<8.0 cm)	7.4
Boresight correction stdev (<0.001deg)	0.001127
IMU attitude correction stdev (<0.001deg)	0.016683
GPS position stdev (<0.01m)	0.0248
Minimum % overlap (>25)	10.46%
Ave point cloud density per sq.m. (>2.0)	2.79
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	272
Maximum Height	421.89 m
Minimum Height	67.51 m
Classification (# of points)	
Ground	40,594,810
Low vegetation	34,398,304
Medium vegetation	58,498,265
High vegetation	166,572,237
Building	4,853,133
Orthophoto	No
Processed by	Engr. Analyn Naldo, Engr. Edgardo Gubatanga, Jr., Ailyn Biñas

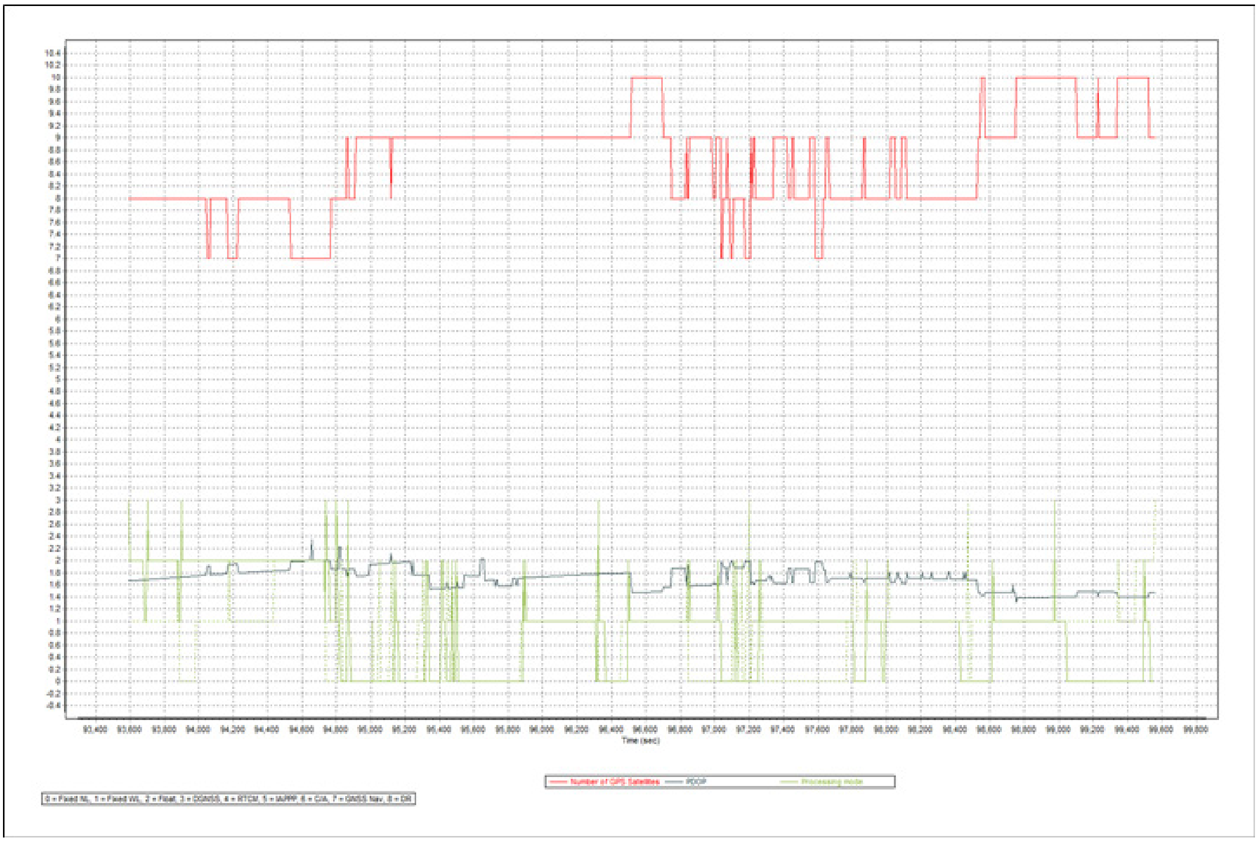


Figure A-8.8. Solution Status

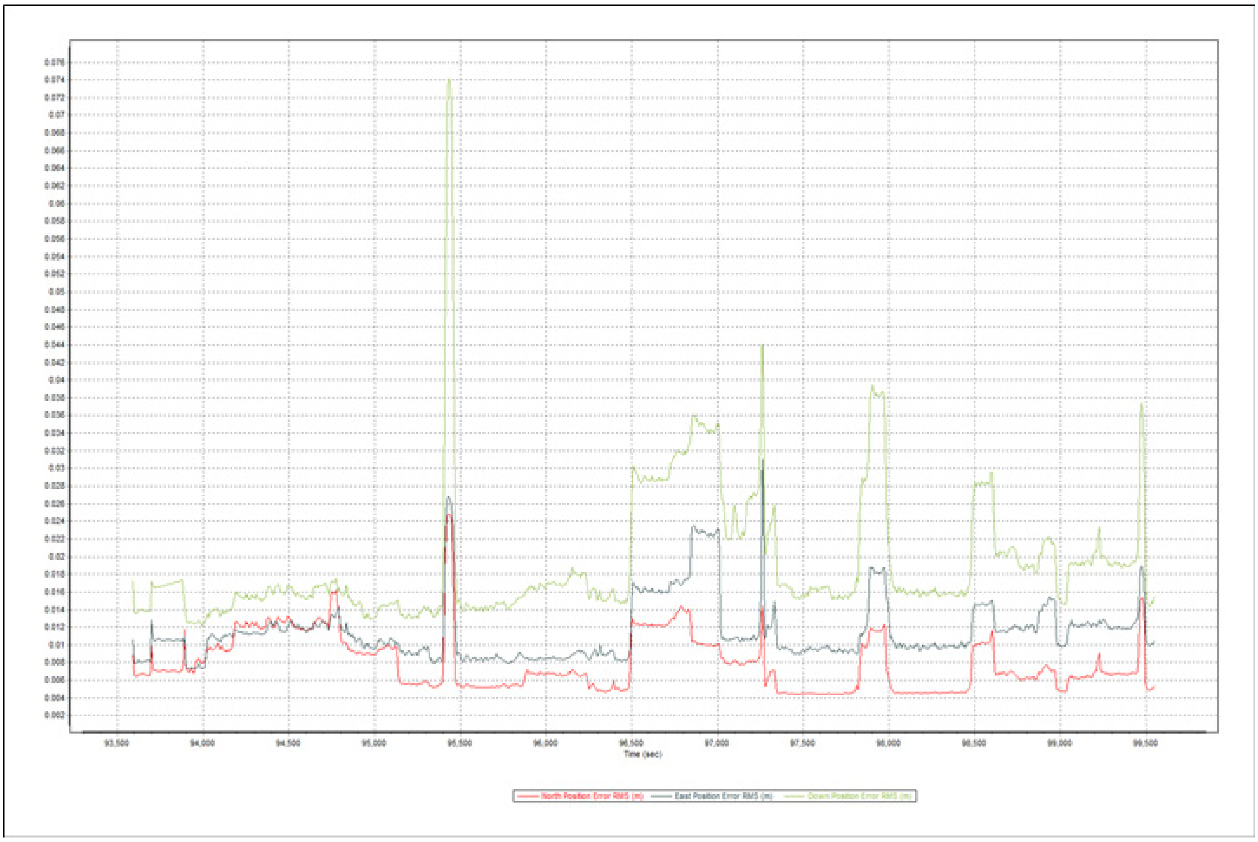


Figure A-8.9. Smoothed Performance Metrics Parameters

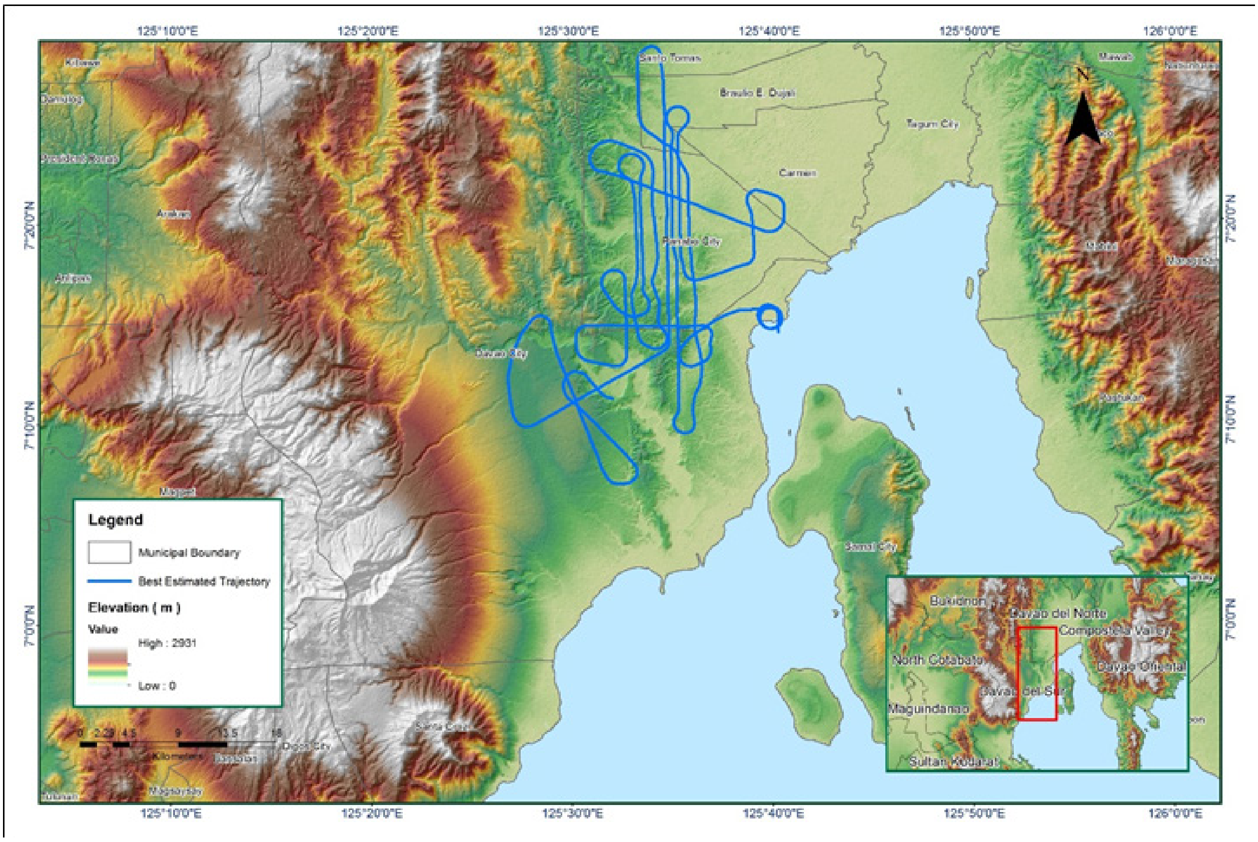


Figure A-8.10. Best Estimated Trajectory

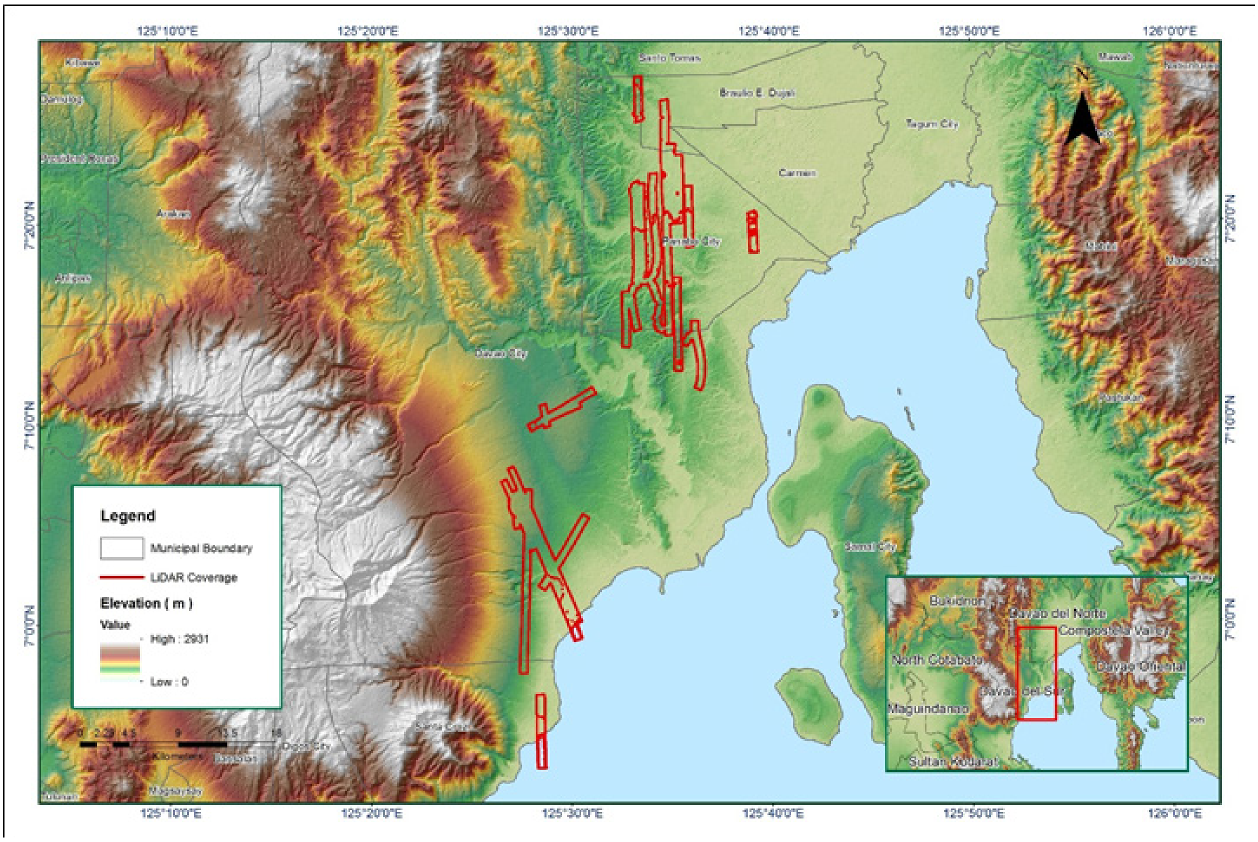


Figure A-8.11. Coverage of LiDAR data

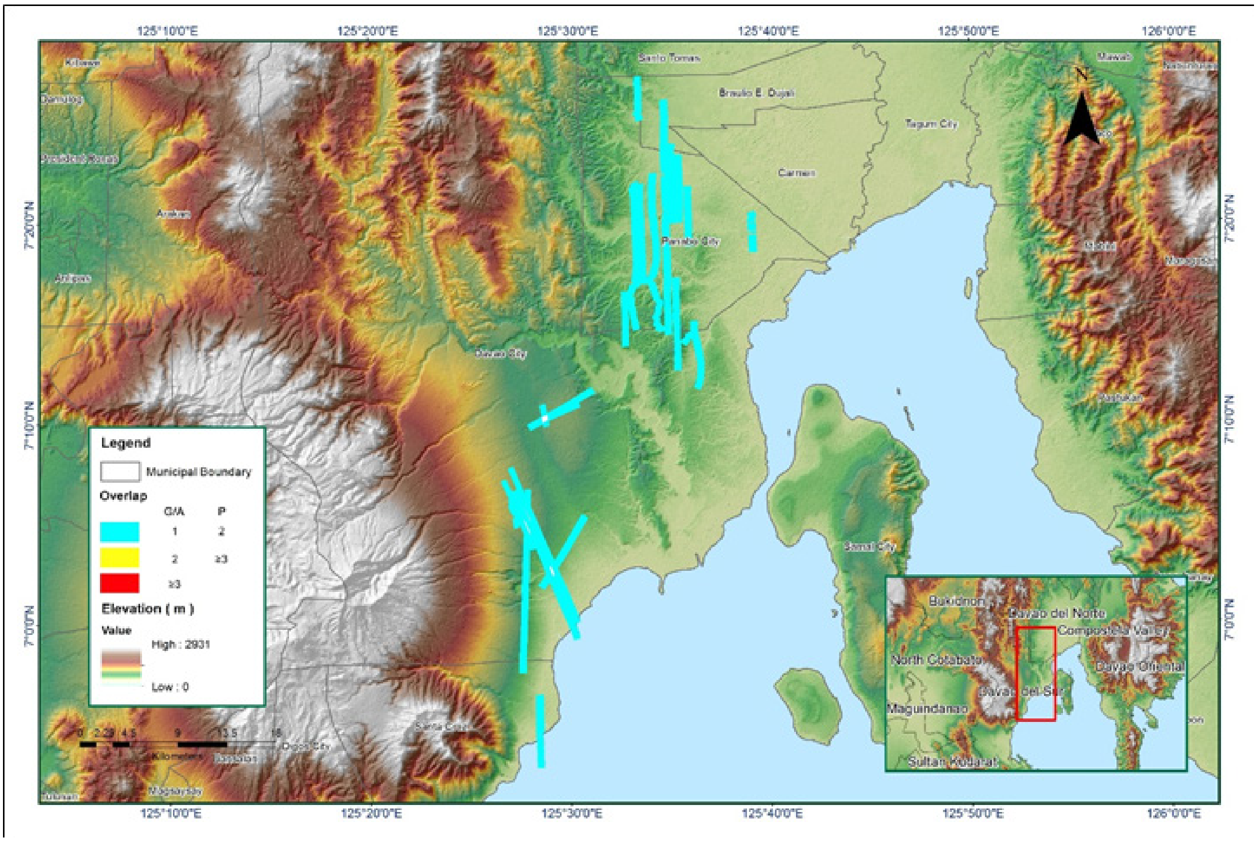


Figure A-8.12. Image of Data Overlap

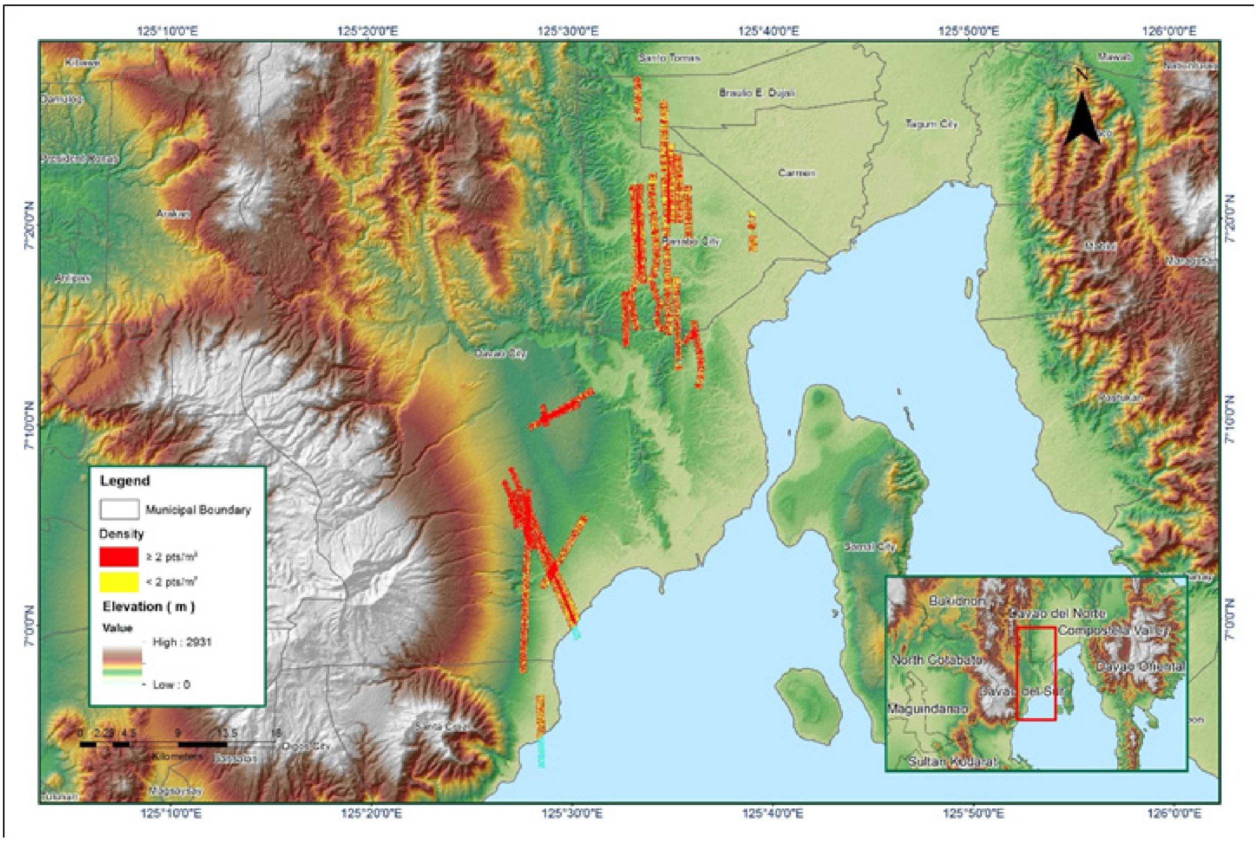


Figure A-8.13. Density map of merged LiDAR data

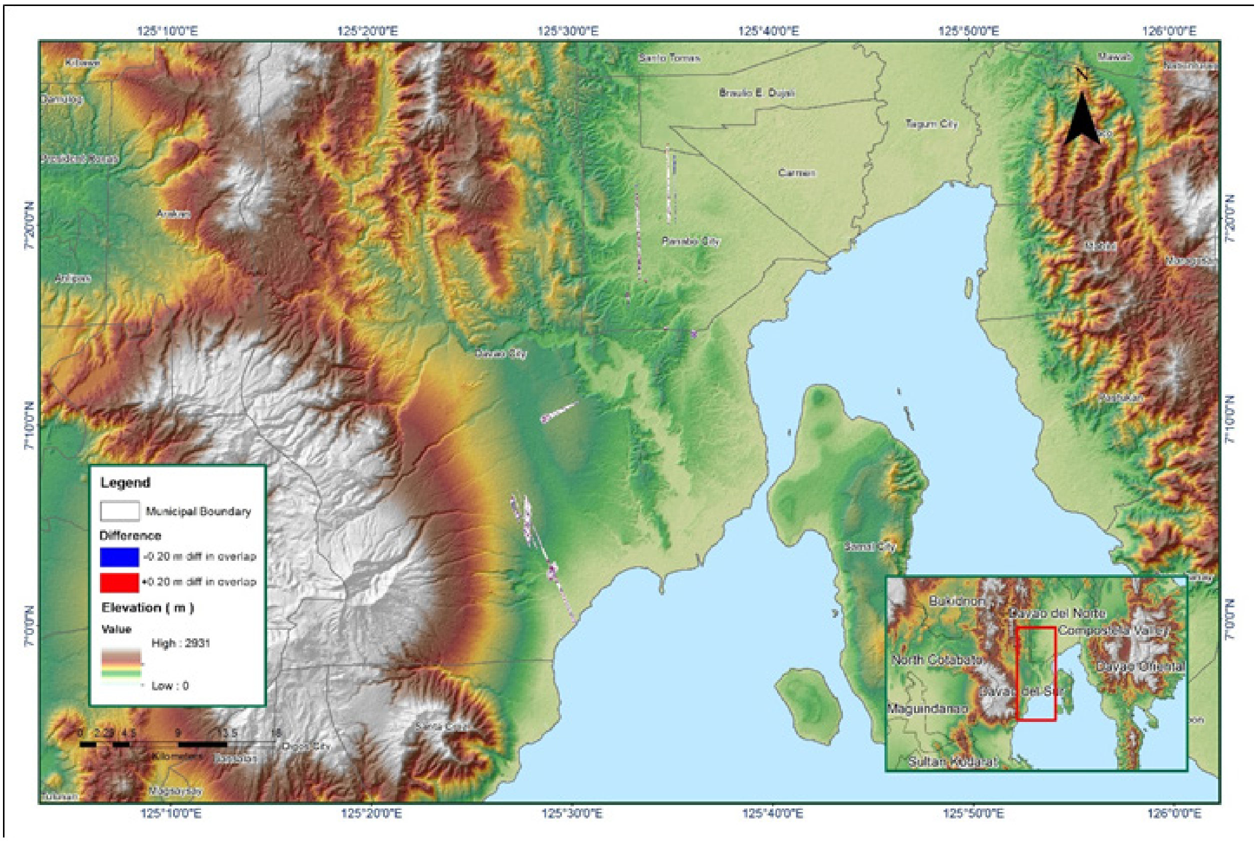


Figure A-8.14. Elevation difference between flight lines

Annex 9. Sibulan Model Basin Parameters

Table A-9.1. Sibulan 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	1.9901	60.663	0	2.6333	0.38003	Discharge	0.033187	5.26E-05	Ratio to Peak	0.11617
W1010	1.5333	35.392	0	1.6848	3.5623	Discharge	0.066695	7.46E-05	Ratio to Peak	0.06037
W1020	6.095	36.582	0	4.4927	0.18539	Discharge	0.088817	5.53E-05	Ratio to Peak	0.038855
W1030	1.2047	70.611	0	2.0906	0.84902	Discharge	0.073045	5.38E-05	Ratio to Peak	0.006977
W1040	9.4668	81.544	0	6.3859	2.634	Discharge	0.085903	0.000412	Ratio to Peak	0.20009
W1050	4.8901	99	0	0.34159	0.084763	Discharge	0.002314	4.88E-05	Ratio to Peak	0.001511
W1060	7.8707	99	0	3.8678	0.060467	Discharge	0.002119	5.43E-05	Ratio to Peak	0.039051
W1070	2.8226	86.498	0	46.754	7.4289	Discharge	0.18729	4.14E-05	Ratio to Peak	0.45
W1080	6.9096	36.354	0	1.7493	0.33252	Discharge	0.058539	1.00E-05	Ratio to Peak	0.47736
W1090	0.0075196	81.353	0	1.3389	0.057169	Discharge	0.002373	3.67E-05	Ratio to Peak	0.13871
W1100	1.8377	39.859	0	4.1466	0.28046	Discharge	0.040211	5.53E-05	Ratio to Peak	0.061463
W1110	16.418	63.35	0	9.4294	2.1247	Discharge	0.043695	0.000187	Ratio to Peak	0.20353
W1120	0.98155	65.209	0	1.011	0.016667	Discharge	0.03229	3.58E-05	Ratio to Peak	0.1315
W1130	2.1273	65.679	0	3.2079	0.11932	Discharge	0.030163	5.53E-05	Ratio to Peak	0.027799
W1140	0.80081	59.36	0	1.9443	0.35024	Discharge	0.038792	1.66E-05	Ratio to Peak	0.002277
W1150	0.5639	75.199	0	4.4904	0.18743	Discharge	0.065965	8.13E-05	Ratio to Peak	0.051513
W1160	0.98556	78.831	0	3.4359	0.45939	Discharge	0.035065	8.09E-05	Ratio to Peak	0.002253
W1170	2.3504	81.981	0	15.705	3.6174	Discharge	0.047158	0.001427	Ratio to Peak	0.10311
W1180	8.0973	89.812	0	1.4926	0.10939	Discharge	0.038756	0.000179	Ratio to Peak	0.007647
W600	11.58	42.312	0	5.4821	0.26159	Discharge	0.043666	0.000232	Ratio to Peak	0.49831
W610	3.6091	53.012	0	4.4189	1.5053	Discharge	0.034328	0.000281	Ratio to Peak	0.37316
W620	5.8376	47.897	0	42.031	1.9504	Discharge	0.15492	5.48E-05	Ratio to Peak	0.20099
W630	5.4508	79.411	0	20.771	0.91627	Discharge	0.09376	1.00E-05	Ratio to Peak	0.023445

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	THreschold Type	Ratio to Peak
W640	7.9102	82.136	0	26.077	2.7973	Discharge	0.070083	1.45E-05	Ratio to Peak	0.03604
W650	3.9638	52.886	0	10.189	2.0919	Discharge	0.083615	0.000114	Ratio to Peak	0.26371
W660	10.523	67.254	0	7.1634	0.96155	Discharge	0.1124	0.000882	Ratio to Peak	0.20533
W670	41.874	52.572	0	4.8826	0.75015	Discharge	0.033782	1.48E-05	Ratio to Peak	0.058266
W680	17.845	46.626	0	5.1105	0.28955	Discharge	0.034984	1.00E-05	Ratio to Peak	0.023361
W690	2.2114	46.741	0	5.5744	0.31993	Discharge	0.062815	3.67E-05	Ratio to Peak	0.026403
W700	29.976	52.96	0	26.468	1.9254	Discharge	0.070065	1.00E-05	Ratio to Peak	0.11685
W710	4.4664	43.298	0	19.376	2.3135	Discharge	0.037626	6.47E-05	Ratio to Peak	0.057009
W720	3.9328	64.113	0	1.5667	0.11705	Discharge	0.002836	8.23E-05	Ratio to Peak	0.021477
W730	4.4134	99	0	15.303	2.7885	Discharge	0.017493	1.06E-05	Ratio to Peak	0.039701
W740	3.5813	46.719	0	2.7675	0.16976	Discharge	0.044099	6.48E-05	Ratio to Peak	0.005463
W750	3.3936	46.641	0	3.3403	0.38241	Discharge	4.23E-02	3.27E-05	Ratio to Peak	0.14347
W760	7.22	40.801	0	6.9925	1.3977	Discharge	4.64E-02	0.000116	Ratio to Peak	0.14549
W770	3.6703	81.083	0	2.3006	0.16177	Discharge	0.009532	7.18E-05	Ratio to Peak	0.040875
W780	6.8812	35.779	0	16.192	3.543	Discharge	0.037846	2.83E-05	Ratio to Peak	0.040118
W790	4.0863	76.775	0	1.1031	0.016667	Discharge	0.005999	5.29E-05	Ratio to Peak	0.005203
W800	4.3213	37.338	0	2.9085	0.52456	Discharge	0.034026	0.000123	Ratio to Peak	0.026711
W810	2.6154	59.278	0	3.0785	0.082867	Discharge	0.004763	3.56E-05	Ratio to Peak	0.007129
W820	2.3379	70.568	0	2.9257	0.065772	Discharge	0.00416	2.42E-05	Ratio to Peak	0.095105
W830	3.4788	39.035	0	16.524	2.7946	Discharge	0.083939	2.11E-05	Ratio to Peak	0.001518
W840	1.8135	43.062	0	12.329	0.54743	Discharge	0.027303	0.00025	Ratio to Peak	0.060992
W850	2.6432	66.177	0	1.2239	0.06624	Discharge	0.00293	3.64E-05	Ratio to Peak	0.034806
W860	0.62725	40.032	0	3.1816	0.19059	Discharge	0.04613	5.42E-05	Ratio to Peak	0.2604
W870	11.862	98.701	0	2.4792	0.05918	Discharge	0.000693	1.00E-05	Ratio to Peak	0.091436

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	THreschold Type	Ratio to Peak
W880	3.9328	66.624	0	0.88634	0.0692	Discharge	0.006515	0.00012	Ratio to Peak	0.034616
W890	2.8233	53.358	0	2.8664	0.25759	Discharge	0.019216	3.60E-05	Ratio to Peak	0.011349
W900	7.3632	99	0	0.63507	0.0491	Discharge	0.000415	0.000124	Ratio to Peak	0.07698
W910	1.5798	44.985	0	8.5141	0.54686	Discharge	0.043676	8.22E-05	Ratio to Peak	0.037827
W920	1.1581	67.271	0	3.1788	0.28567	Discharge	0.046421	5.32E-05	Ratio to Peak	0.092767
W930	4.0806	83.415	0	7.5836	1.1799	Discharge	0.047997	0.000558	Ratio to Peak	0.06307
W940	2.4585	44.614	0	3.2656	0.34463	Discharge	0.04017	3.65E-05	Ratio to Peak	0.18614
W950	6.1037	96.694	0	41.784	4.3261	Discharge	0.15864	0.000266	Ratio to Peak	0.30147
W960	3.1078	81.153	0	1.5885	0.12002	Discharge	0.023172	5.53E-05	Ratio to Peak	0.003503
W970	1.8472	69.662	0	6.3778	0.12614	Discharge	0.049605	5.48E-05	Ratio to Peak	0.017975
W980	4.5348	58.304	0	2.745	0.064854	Discharge	0.027109	0.00042	Ratio to Peak	0.040654
W990	1.8473	71.152	0	3.7223	0.41035	Discharge	0.022189	0.000123	Ratio to Peak	0.20244

Annex 10. Sibulan Model Reach Parameters

Table A-10.1. Sibulan Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R110	Automatic Fixed Interval	1265.7	0.062769	0.0944	Trapezoid	32.3	1
R160	Automatic Fixed Interval	699.12	0.15578	0.0944	Trapezoid	32.3	1
R170	Automatic Fixed Interval	4131.4	0.14387	0.0944	Trapezoid	32.3	1
R180	Automatic Fixed Interval	434.85	0.058182	0.0944	Trapezoid	32.3	1
R200	Automatic Fixed Interval	1169.5	0.16478	0.0944	Trapezoid	32.3	1
R220	Automatic Fixed Interval	302.43	0.028449	0.0944	Trapezoid	32.3	1
R230	Automatic Fixed Interval	168.28	0.10251	0.0944	Trapezoid	32.3	1
R240	Automatic Fixed Interval	2167.9	0.056853	0.0944	Trapezoid	32.3	1
R250	Automatic Fixed Interval	477.99	0.086756	0.0944	Trapezoid	32.3	1
R260	Automatic Fixed Interval	682.13	0.042405	0.0944	Trapezoid	32.3	1
R270	Automatic Fixed Interval	28.284	0.020649	0.0944	Trapezoid	32.3	1
R280	Automatic Fixed Interval	1510.8	0.080006	0.0944	Trapezoid	32.3	1
R300	Automatic Fixed Interval	4297.6	0.09763	0.0944	Trapezoid	32.3	1
R310	Automatic Fixed Interval	1718.8	0.038732	0.0944	Trapezoid	32.3	1
R330	Automatic Fixed Interval	1140.8	0.026355	0.0944	Trapezoid	32.3	1
R340	Automatic Fixed Interval	735.27	0.042501	0.0944	Trapezoid	32.3	1
R350	Automatic Fixed Interval	1829.9	0.12474	0.0944	Trapezoid	32.3	1
R370	Automatic Fixed Interval	1689.9	0.073954	0.0944	Trapezoid	32.3	1
R400	Automatic Fixed Interval	598.99	0.05254	0.0944	Trapezoid	32.3	1
R410	Automatic Fixed Interval	4345.5	0.058553	0.0944	Trapezoid	32.3	1
R430	Automatic Fixed Interval	400	0.050226	0.0944	Trapezoid	32.3	1
R440	Automatic Fixed Interval	11872	0.077059	0.0944	Trapezoid	32.3	1

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R450	Automatic Fixed Interval	472.13	0.08886	0.0944	Trapezoid	32.3	1
R460	Automatic Fixed Interval	2417.2	0.038203	0.0944	Trapezoid	32.3	1
R480	Automatic Fixed Interval	1241	0.035227	0.0944	Trapezoid	32.3	1
R510	Automatic Fixed Interval	2462.5	0.087598	0.0944	Trapezoid	32.3	1
R550	Automatic Fixed Interval	1925.1	0.05498	0.0944	Trapezoid	32.3	1
R590	Automatic Fixed Interval	6604.7	0.14196	0.0944	Trapezoid	32.3	1
R60	Automatic Fixed Interval	297.28	0.19936	0.0944	Trapezoid	32.3	1

Annex 11. Sibulan Field Validation Points

Table A-11.1. Sibulan Field Validation Points

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
1	6.9074	125.46846	0.04	0.1	0.0036	Intense local rainfall/ 2013	5-Year
2	6.907588	125.45955	0.11	0.2	0.0081	Intense local rainfall/ 2014	5-Year
3	6.907987	125.45953	0.09	0.2	0.0121	Intense local rainfall/ 2014	5-Year
4	6.913268	125.47202	0.03	0	0.0009	0	5-Year
5	6.906415	125.469	0.25	0.45	0.04	Intense local rainfall/ January 2011	5-Year
6	6.909259	125.47679	0.32	0.5	0.0324	Intense local rainfall/ 1990	5-Year
7	6.90595	125.46946	0.59	0.45	0.0196	Intense local rainfall/ January 2011	5-Year
8	6.906131	125.46828	0.73	0.55	0.0324	Intense local rainfall/ January 2011	5-Year
9	6.906293	125.46843	0.67	0.79	0.0144	Intense local rainfall/ 2013	5-Year
10	6.906311	125.46818	0.66	0.63	0.0009	Intense local rainfall/ October 2014	5-Year
11	6.906788	125.46811	0.61	0.9	0.0841	Intense local rainfall/ 2013	5-Year
12	6.907213	125.46827	0.55	0.68	0.0169	Intense local rainfall/ 2015	5-Year
13	6.907233	125.46782	0.64	0.65	0.0001	Intense local rainfall/ 2014	5-Year
14	6.907407	125.46792	0.6	0.65	0.0025	Intense local rainfall/ 2015	5-Year
15	6.907938	125.46765	0.52	0.5	0.0004	Intense local rainfall/ August 2012	5-Year
16	6.908634	125.47588	0.61	0.45	0.0256	Tetang/ 1970's	5-Year
17	6.908713	125.47616	0.53	0.2	0.1089	Intense local rainfall/ 2011	5-Year
18	6.90996	125.47752	0.72	0.26	0.2116	Buhawi/ January 2011	5-Year
19	6.909983	125.47779	0.51	0.26	0.0625	Buhawi/ January 2011	5-Year
20	6.910242	125.47824	0.7	0.26	0.1936	Buhawi/ January 2011	5-Year
21	6.910263	125.47699	0.57	0	0.3249	0	5-Year

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
22	6.910515	125.47797	0.8	0.7	0.01	Intense local rainfall/ 2010	5-Year
23	6.910615	125.47743	0.71	0.2	0.2601	Buhawi/ December 8, 1961	5-Year
24	6.911246	125.47735	0.51	0.2	0.0961	Buhawi/ December 8, 1961	5-Year
25	6.911245	125.47761	0.64	0.2	0.1936	Buhawi/ December 8, 1961	5-Year
26	6.911413	125.47735	0.62	0.2	0.1764	Buhawi/ December 8, 1961	5-Year
27	6.909069	125.47616	1.07	1	0.0049	Intense local rainfall/ 2011	5-Year
28	6.909162	125.47625	1.21	1	0.0441	Intense local rainfall/ 2011	5-Year
29	6.909341	125.47633	1.01	1	0.0001	Intense local rainfall/ 2011	5-Year
30	6.909521	125.47661	1.18	0.5	0.4624	Intense local rainfall/ 1990's	5-Year
31	6.909532	125.47652	1.15	0.5	0.4225	Intense local rainfall/ 1990's	5-Year
32	6.909619	125.4767	1.1	0.9	0.04	Tetang/ 1970's	5-Year
33	6.909703	125.47679	1.1	0.9	0.04	Tetang/ 1970's	5-Year
34	6.909816	125.47688	1.17	0	1.3689	0	5-Year
35	6.909889	125.47699	1.18	0	1.3924	0	5-Year
36	6.910501	125.47806	1.02	0.7	0.1024	Intense local rainfall/ 2010	5-Year
37	6.910596	125.47826	1.07	0.3	0.5929	Tetang/ 2013	5-Year
38	6.910692	125.47826	1.22	0.3	0.8464	Tetang/ 2013	5-Year
39	6.910773	125.47842	1.25	0.3	0.9025	Intense local rainfall/ 1994	5-Year
40	6.910785	125.47863	1.1	0.3	0.64	Intense local rainfall/ 1990's	5-Year
41	6.910863	125.47915	1.05	0.65	0.16	Intense local rainfall	5-Year
42	6.911328	125.47961	1.04	0.67	0.1369	Intense local rainfall	5-Year
43	6.911404	125.47987	1.05	0.67	0.1444	Intense local rainfall	5-Year
44	6.911418	125.48006	1.1	0.67	0.1849	Intense local rainfall	5-Year
45	6.911503	125.47962	1.3	0.5	0.64	Intense local rainfall/ 2010	5-Year
46	6.908775	125.45967	0.03	0.04	0.0001	Intense local rainfall/ 2014	5-Year

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
47	6.909283	125.4596	0.05	0.04	0.0001	Intense local rainfall/ 2014	5-Year
48	6.909546	125.45962	0.04	0.48	0.1936	Intense local rainfall/ 2013	5-Year
49	6.909878	125.45971	0.03	0.5	0.2209	Buhawi/ 2013	5-Year
50	6.910272	125.45946	0.05	0.75	0.49	Opening of dam/ 2011	5-Year
51	6.910313	125.45916	0.03	0.45	0.1764	Intense local rainfall/ 2011	5-Year
52	6.910881	125.45955	0.03	0.05	0.0004	Buhawi/ 2013	5-Year
53	6.910888	125.46086	0.03	0	0.0009	0	5-Year
54	6.911394	125.46004	0.06	0.45	0.1521	Intense local rainfall/ 2011-2012	5-Year
55	6.92537	125.46837	0.05	0.05	0	Buhawi/ 2013	5-Year
56	6.92568	125.46846	0.09	0.15	0.0036	Buhawi/ 2013	5-Year
57	6.925799	125.46786	0.04	0	0.0016	0	5-Year
58	6.92603	125.46842	0.03	0	0.0009	0	5-Year
59	6.908091	125.45938	0.23	0.31	0.0064	Buhawi/ 2013	5-Year
60	6.909788	125.46025	0.32	0.28	0.0016	Upstream rainfall/ 1995	5-Year
61	6.910156	125.46034	0.26	0.28	0.0004	Upstream rainfall/ 1995	5-Year
62	6.910901	125.46061	0.33	0.3	0.0009	Intense local rainfall/ 2011	5-Year
63	6.911325	125.4607	0.29	0.3	0.0001	Intense local rainfall/ 2011	5-Year
64	6.911952	125.46125	0.25	0.28	0.0009	Buhawi/ 2014	5-Year
65	6.912341	125.45991	0.31	0.46	0.0225	Intense local rainfall/ 2012	5-Year
66	6.912345	125.46144	0.27	0.28	0.0001	Buhawi/ 2014	5-Year
67	6.912602	125.46025	0.22	0.64	0.1764	Intense local rainfall/ 2012	5-Year
68	6.912676	125.45979	0.24	1.19	0.9025	Buhawi/ January 2012	5-Year
69	6.912666	125.46358	0.23	0.34	0.0121	Buhawi/ 2004/2013	5-Year
70	6.91294	125.46251	0.34	0.2	0.0196	Buhawi/ 2013	5-Year
71	6.913088	125.46208	0.29	0.2	0.0081	Buhawi/ 2013	5-Year
72	6.91332	125.46153	0.31	0.25	0.0036	Buhawi/ 2012	5-Year
73	6.913335	125.45945	0.21	0.38	0.0289	Intense local rainfall/ May 2015	5-Year
74	6.913581	125.46216	0.32	0.2	0.0144	Buhawi/ 2013	5-Year
75	6.913592	125.46134	0.26	0.25	0.0001	Buhawi/ 2012	5-Year

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
76	6.913867	125.45926	0.31	0.9	0.3481	Yolanda/ 2013	5-Year
77	6.913862	125.46162	0.28	0	0.0784	0	5-Year
78	6.914664	125.46388	0.29	0.04	0.0625	Intense local rainfall/ 1990's	5-Year
79	6.915937	125.46209	0.25	0.45	0.04	Buhawi/ 2014	5-Year
80	6.922552	125.46574	0.27	0.2	0.0049	Upstream rainfall/ 2007	5-Year
81	6.922899	125.46582	0.21	0	0.0441	0	5-Year
82	6.923418	125.46611	0.32	0	0.1024	0	5-Year
83	6.911869	125.46199	0.55	0.64	0.0081	Buhawi/ 2005	5-Year
84	6.912771	125.46144	0.53	0.64	0.0121	Buhawi/ 2005	5-Year
85	6.915191	125.46306	0.51	0	0.2601	0	5-Year
86	6.923477	125.47018	0.55	0	0.3025	0	5-Year
87	6.923574	125.46999	0.51	0	0.2601	0	5-Year
88	6.923755	125.46981	0.57	0.5	0.0049	Heavy rainfall	5-Year
89	6.924754	125.46945	0.56	0.83	0.0729	Buhawi/ 2013	5-Year
90	6.925024	125.46937	0.64	0.94	0.09	Buhawi/ 2013	5-Year
91	6.926029	125.46764	0.03	0	0.0009	0	5-Year
92	6.926455	125.46774	0.03	0	0.0009	0	5-Year
93	6.926552	125.46756	0.03	0	0.0009	0	5-Year
94	6.926922	125.46767	0.03	0	0.0009	0	5-Year
95	6.927094	125.46785	0.03	0	0.0009	0	5-Year
96	6.928516	125.46494	0.03	0	0.0009	0	5-Year
97	6.928992	125.46498	0.03	0	0.0009	0	5-Year
98	6.929566	125.46503	0.03	0	0.0009	0	5-Year
99	6.927558	125.46838	1.05	2.1	1.1025	Heavy rainfall/ January 17, 2011	5-Year
100	6.927643	125.46847	2.85	2.1	0.5625	Heavy rainfall/ January 17, 2011	5-Year
101	6.927751	125.46847	2.04	2.2	0.0256	Heavy rainfall/ 2011	5-Year
102	6.927832	125.46849	2.37	2.2	0.0289	Heavy rainfall/ 2011	5-Year
103	6.928727	125.46811	3.35	3	0.1225	Upstream rainfall/ 2013	5-Year
104	6.929085	125.46796	3.15	4	0.7225	Upstream rainfall/ 2013	5-Year
105	6.929997	125.46695	2.93	3.8	0.7569	Upstream rainfall/ 2013	5-Year
106	6.928374	125.46839	5.07	5	0.0049	Upstream rainfall/ 2013	5-Year

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
107	6.928465	125.46839	5.02	5	0.0004	Upstream rainfall/ 2013	5-Year
108	6.92919	125.46794	5.07	4	1.1449	Upstream rainfall/ 2013	5-Year
109	6.929721	125.46742	5.21	4.5	0.5041	Upstream rainfall/ 2013	5-Year
110	6.929822	125.46731	5.14	4.5	0.4096	Upstream rainfall/ 2013	5-Year
111	6.929913	125.46722	5.44	4.5	0.8836	Upstream rainfall/ 2013	5-Year
112	6.930003	125.46705	6.2	4.5	2.89	Upstream rainfall/ 2013	5-Year
113	6.930086	125.46694	6.72	4.5	4.9284	Upstream rainfall/ 2013	5-Year
114	6.930174	125.46687	6.56	4.5	4.2436	Upstream rainfall/ 2013	5-Year
115	6.930183	125.46668	7.33	5	5.4289	Upstream rainfall/ 2013	5-Year
116	6.930184	125.46677	7.36	5	5.5696	Upstream rainfall/ 2013	5-Year
117	6.93027	125.46661	6.78	4.5	5.1984	Upstream rainfall/ 2013	5-Year
118	6.930279	125.46669	6.55	4.5	4.2025	Upstream rainfall/ 2013	5-Year
119	6.930364	125.4665	6.71	5	2.9241	Upstream rainfall/ 2013	5-Year
120	6.930459	125.4664	6.59	5	2.5281	Upstream rainfall/ 2013	5-Year
121	6.930465	125.4665	6.42	5	2.0164	Upstream rainfall/ 2013	5-Year
122	6.930552	125.46622	6.43	5.1	1.7689	Heavy rainfall/ January 17, 2011	5-Year
123	6.930559	125.46631	6.46	5.1	1.8496	Heavy rainfall/ January 17, 2011	5-Year
124	6.930638	125.46615	6.17	5.2	0.9409	Heavy rainfall/ January 17, 2011	5-Year
125	6.930642	125.46631	6.13	5	1.2769	Heavy rainfall/ January 17, 2011	5-Year
126	6.930724	125.46605	5.83	5.1	0.5329	Heavy rainfall/ January 17, 2011	5-Year
127	6.930816	125.4655	5.74	5.2	0.2916	Heavy rainfall/ January 17, 2011	5-Year

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
128	6.930825	125.46596	5.27	5.1	0.0289	Heavy rainfall/ January 17, 2011	5-Year
129	6.930833	125.46588	5.09	5.2	0.0121	Heavy rainfall/ January 17, 2011	5-Year
130	6.930906	125.4656	5.53	5.1	0.1849	Heavy rainfall/ January 17, 2011	5-Year
131	6.930911	125.46567	5.33	5	0.1089	Heavy rainfall/ January 17, 2011	5-Year
132	6.930911	125.46578	5.1	5	0.01	Heavy rainfall/ January 17, 2011	5-Year
133	6.932293	125.462	5.25	5	0.0625	Heavy rainfall/ January 17, 2011	5-Year
134	6.934841	125.45766	5.02	5	0.0004	Heavy rainfall/ January 17, 2011	5-Year
135	6.934843	125.45776	5.05	5	0.0025	Heavy rainfall/ January 17, 2011	5-Year
136	6.928729	125.48739	0.03	0.6	0.3249	Heavy rainfall/ January 17, 2011	5-Year
137	6.928899	125.48829	0.03	1	0.9409	Heavy rainfall/ January 17, 2011	5-Year
138	6.930718	125.48694	0.03	0.46	0.1849	Buhawi/ January 2013	5-Year
139	6.933804	125.48416	0.08	0.1	0.0004	Buhawi/ January 2013	5-Year
140	6.935682	125.4837	0.04	0.1	0.0036	Buhawi/ January 2013	5-Year
141	6.925645	125.48729	0.21	0.1	0.0121	Buhawi/ January 2013	5-Year
142	6.925836	125.48718	0.28	0.4	0.0144	Buhawi/ 2013	5-Year
143	6.926821	125.488	0.21	0.4	0.0361	Intense local rainfall/ January 2013	5-Year
144	6.928893	125.48802	0.22	0.3	0.0064	Buhawi/ January 2013	5-Year
145	6.939396	125.47199	0.53	0.4	0.0169	Intense local rainfall/ 1990's	5-Year
146	6.940726	125.47228	0.57	0.4	0.0289	Intense local rainfall/ 2012	5-Year

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
147	6.924999	125.47535	1.07	1	0.0049	Buhawi/ January 17, 2013	5-Year
148	6.926284	125.4691	1.22	2	0.6084	Buhawi/ January 17, 2013	5-Year
149	6.926821	125.46884	1.43	1.56	0.0169	Buhawi/ January 2013	5-Year
150	6.938755	125.46997	1.18	0.28	0.81	Upstream rainfall/ January 2013	5-Year
151	6.939029	125.47017	1.15	1.5	0.1225	0	5-Year
152	6.939211	125.47035	1.01	1.28	0.0729	Intense local rainfall/ August 2012	5-Year
153	6.939919	125.47053	1.53	0.45	1.1664	Buhawi/ August 30, 2014	5-Year
154	6.93993	125.4708	1.06	0.45	0.3721	Buhawi/ August 30, 2014	5-Year
155	6.940197	125.47126	1.23	0.45	0.6084	Buhawi/ January 2013	5-Year
156	6.940202	125.4709	1.38	1.4	0.0004	Buhawi/ 2004	5-Year
157	6.925383	125.46982	2.36	2.5	0.0196	Upstream rainfall/ January 2013	5-Year
158	6.925465	125.46982	2.42	2.4	0.0004	Upstream rainfall/ January 2013	5-Year
159	6.925565	125.46982	2.51	2.4	0.0121	Upstream rainfall/ January 2013	5-Year
160	6.925645	125.46965	2.07	3	0.8649	Heavy rainfall/ January 6, 2013	5-Year
161	6.925663	125.46983	2.52	2.4	0.0144	Upstream rainfall/ January 2013	5-Year
162	6.925839	125.46955	2.64	3	0.1296	Heavy rainfall/ January 6, 2013	5-Year
163	6.925923	125.46947	2.56	1.2	1.8496	Pablo/ January 6, 2013	5-Year
164	6.926101	125.46928	2.12	3	0.7744	Heavy rainfall/ January 6, 2013	5-Year
165	6.926104	125.46956	2.43	3.5	1.1449	Heavy rainfall/ January 6, 2013	5-Year
166	6.926193	125.46928	2.24	3.5	1.5876	Heavy rainfall/ January 6, 2013	5-Year
167	6.926283	125.4692	2.28	3	0.5184	Heavy rainfall/ January 6, 2013	5-Year

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
168	6.926384	125.46919	2.36	2.5	0.0196	Heavy rainfall/ January 17, 2011	5-Year
169	6.926476	125.46911	2.51	2.5	1E-04	Heavy rainfall/ January 17, 2011	5-Year
170	6.926638	125.4692	2.42	2.5	0.0064	Heavy rainfall/ January 17, 2011	5-Year
171	6.926655	125.46902	2.7	2.5	0.04	Heavy rainfall/ January 17, 2011	5-Year
172	6.926741	125.46901	2.88	2.5	0.1444	Heavy rainfall/ January 17, 2011	5-Year
173	6.926831	125.46893	2.93	2.5	0.1849	Heavy rainfall/ January 17, 2011	5-Year
174	6.926916	125.46891	3.19	2.5	0.4761	Heavy rainfall/ January 17, 2011	5-Year
175	6.927007	125.46884	2.73	2.5	0.0529	Heavy rainfall/ January 17, 2011	5-Year
176	6.927101	125.46866	2.04	1.56	0.2304	Buhawi/ January 2013	5-Year
177	6.927203	125.46867	2.78	2.1	0.4624	Heavy rainfall/ 2014	5-Year
178	6.927204	125.46884	3.53	2.1	2.0449	Heavy rainfall/ 2014	5-Year
179	6.927281	125.46865	3.13	2.2	0.8649	Heavy rainfall/ 2014	5-Year
180	6.927557	125.46848	3.43	2.3	1.2769	Heavy rainfall/ 2014	5-Year

RMSE 0.689352

Annex 12. Educational Institutions affected by flooding in Sibulan Floodplain

Table A-12.1. Educational Institutions in Santa Cruz, Davao del Sur affected by flooding in Sibulan Floodplain

Davao del Sur				
Santa Cruz				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
ALMENDRAS ELEMENTARY SCHOOL - GRADE 1	Astorga			
ALMENDRAS ELEMENTARY SCHOOL - GRADE 2	Astorga			
ALMENDRAS ELEMENTARY SCHOOL - GRADE 3	Astorga	Low	Low	Low
ALMENDRAS ELEMENTARY SCHOOL - GRADE 4	Astorga			
ALMENDRAS ELEMENTARY SCHOOL - GRADE 5 & COMPUTER *	Astorga			
ALMENDRAS ELEMENTARY SCHOOL - HOME ECONOMICS	Astorga			
CANTEEN	Astorga			
DAY CARE	Astorga			
KINDER GARTEN BUILDING	Astorga			
MAAHAD DARONG AL ISLAMIC	Astorga			
P.O.	Astorga			
SANLOCAN ARABIC ISLAMIC MAD-RASA	Astorga		Low	Low
STAGE/GYM	Astorga			
TRAINING CENTER	Astorga			
DARONG DAY CARE CENTER	Darong		Medium	Medium
DARONG ELEMENTARY SCHOOL	Darong	Low	Medium	Medium
DARONG ELEMENTARY SCHOOL - ARABIC SCHOOL, ALIVE	Darong	Low	Medium	Medium
DARONG ELEMENTARY SCHOOL - GRADE 1	Darong	Low	Medium	Medium
DARONG ELEMENTARY SCHOOL - GRADE 2 & GRADE 3	Darong	Low	Medium	High
DARONG ELEMENTARY SCHOOL - GRADE 3 & GRADE 4	Darong	Medium	Medium	High
DARONG ELEMENTARY SCHOOL - GRADE 4 & GRADE 5	Darong	Medium	High	High
DARONG ELEMENTARY SCHOOL - GRADE 6	Darong	Low	High	Medium
DARONG ELEMENTARY SCHOOL - KINDER	Darong		Medium	Medium
DARONG ELEMENTARY SCHOOL - OFFICE OF THE PRINCIPAL	Darong	Low	High	High
DAY CARE CENTER	Darong		Low	Low
LANDING DAY CARE CENTER	Darong		Low	Low
PUROK MANGGA DAY CARE CENTER	Darong		Low	Medium
SRA. NATIVIDAD IÑIGO OBOZA DAY-CARE CENTER	Darong	Low	Medium	Medium

Annex 13. Health Institutions affected by flooding in Sibulan Floodplain

Table A-13.1. Health Institutions in Santa Cruz, Davao del Sur affected by flooding in Sibulan Floodplain

Davao del Sur				
Santa Cruz				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
SUB-HEALTH CENTER	Astorga			
LINE IN PAANAKAN	Darong			
SAN MIGUEL BEER COMMUNITY CLINIC	Darong		Low	Medium