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

LiDAR Surveys and Flood Mapping of Canaway River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
University of San Carlos

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 R. S. Otadoy (eds.) (2017), LiDAR Surveys and Flood Mapping of Canaway River, Quezon City: University of the Philippines Training Center for Applied Geodesy and Photogrammetry-103pp.

For questions/queries regarding this report, contact:

Dr. Roland Emerito S. Otadoy
Project Leader, Phil-LiDAR 1 Program
University of San Carlos
Cebu City, Philippines 6000
E-mail: rolandotadoy2012@gmail.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: 978-621-430-178-2

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
ATQ	Antique
AWLS	Automated Water Level Sensor
BA	Bridge Approach
BM	benchmark
CAD	Computer-Aided Design
CN	Curve Number
CSRS	Chief Science Research Specialist
DAC	Data Acquisition Component
DEM	Digital Elevation Model
DENR	Department of Environment and Natural Resources
DOST	Department of Science and Technology
DPPC	Data Pre-Processing Component
DREAM	Disaster Risk and Exposure Assessment for Mitigation [Program]
DRRM	Disaster Risk Reduction and Management
DSM	Digital Surface Model
DTM	Digital Terrain Model
DVBC	Data Validation and Bathymetry Component
FMC	Flood Modeling Component
FOV	Field of View
GiA	Grants-in-Aid
GCP	Ground Control Point
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center - River Analysis System
HC	High Chord
IDW	Inverse Distance Weighted [interpolation method]

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

CHAPTER 1: OVERVIEW OF THE PROGRAM AND CANAWAY RIVER

Enrico C. Paringit, Dr. Eng., Dr. Roland Emerito S. Otadoy, and Engr. Aure Flo Oraya

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 San Carlos (USC). 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 17 river basins in the Central Visayas Region. The university is located in Cebu City in the province of Cebu.

2.2 Overview of Canaway River Basin

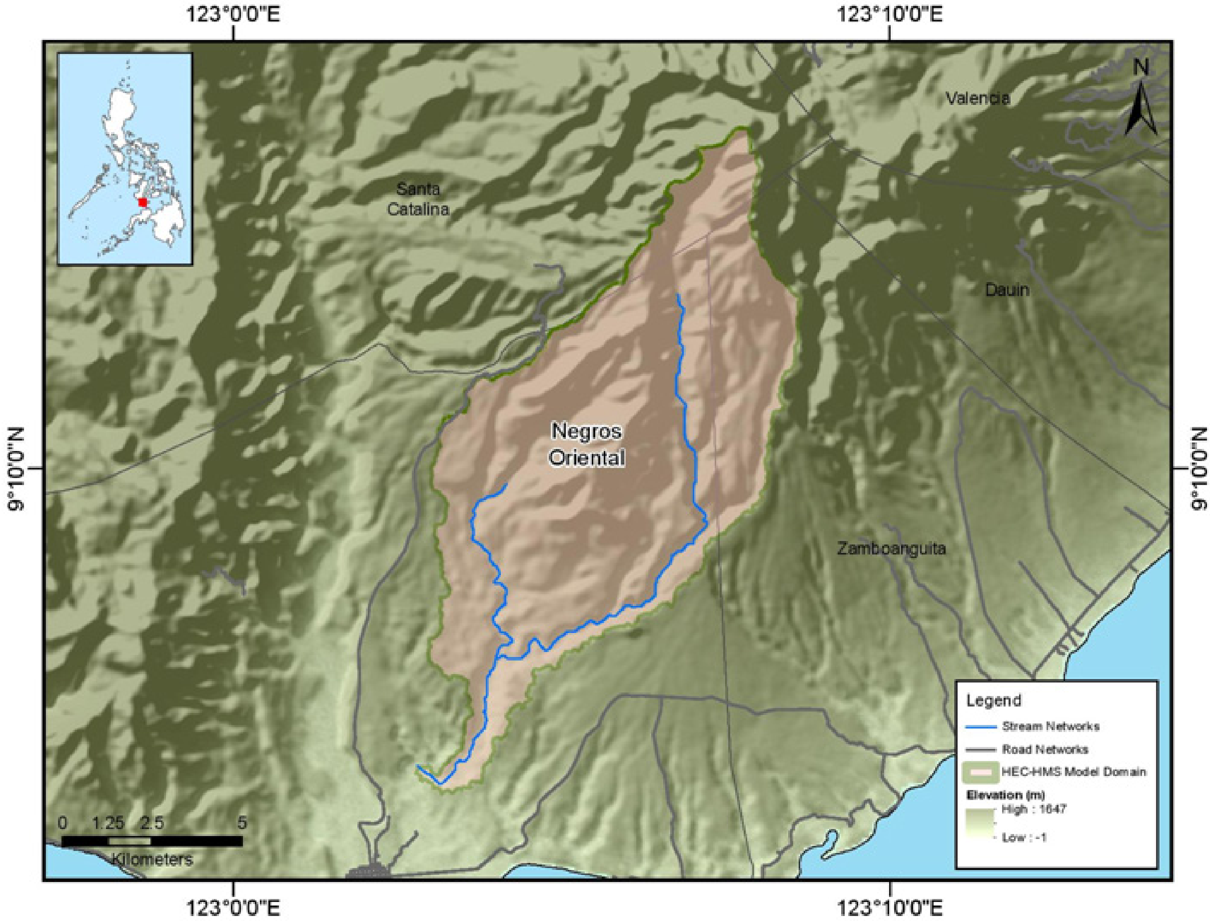


Figure 1. Map of Canaway River (in brown)

The Canaway River Basin covers the Municipalities of Siaton in the province of Negros Oriental. According to DENR - River Basin Control Office it has a drainage area of 120 km2 based from watershed delineation made by DVBC.

Its main stem, Canaway River runs along six barangays in the Municipality of Siaton. Canaway River drains to the Municipality of Siaton. Its upstream watershed boundaries are in the Municipalities of Zamboanguita and Sta Catalina. The weather in the area is classified under Type I weather in the Corona climate classification. It has two pronounced seasons. It is dry from November to April and wet during the rest of the year. According to 2010 National Census of NSO, a total of 11,743 locals are residing in the immediate vicinity of the river which are distributed among the six barangays. The municipality has a vast water resources where shrimps, crabs, and lobsters can be found. The major agricultural products include palay, banana, coconut, vegetables and root crops. The most recent flooding in the area was on November 2013 caused by typhoon Haiyan internationally known as "Yolanda."

Meanwhile, Siaton is a 1st income class municipality with a population of 77,696 based on the 2015 census. Agriculture is the prominent industry in the area. Zamboanguita is a 4th income class municipality with a population of 27,552 based on the 2015 census. Sta Catalina is a 1st income class municipality with a population of 73,306 based on the 2010 census. Its topography us predominantly rolling hills, flat and steep terrain. Its industry is on agro-tourism and fishing.

CHAPTER 2: LIDAR DATA ACQUISITION OF THE CANAWAY FLOODPLAIN

Engr. Louie P. Balicanta, Engr. Christopher Cruz, Lovely Gracia Acuña, Engr. Gerome Hipolito, For. Ma. Verlina Tonga, and Jasmine Alviar

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 Canaway Floodplain in Negros Oriental and Negros Occidental Provinces. These missions were planned for 10 lines that run 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 are found in Table 1. Figure 2 shows the flight plan for Canaway Ffloodplain.

Table 1 Flight planning parameters for Gemini LiDAR System

Block Name	Flying Height (m AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK56A	1000	30	40	100	50	130	5
BLK 56B	1000	30	40	100	50	130	5
BLK 56C	1000	30	40	100	50	130	5
BLK56D	1000	30	40	100	50	130	5
BLK56F	1000	30	40	100	50	130	5

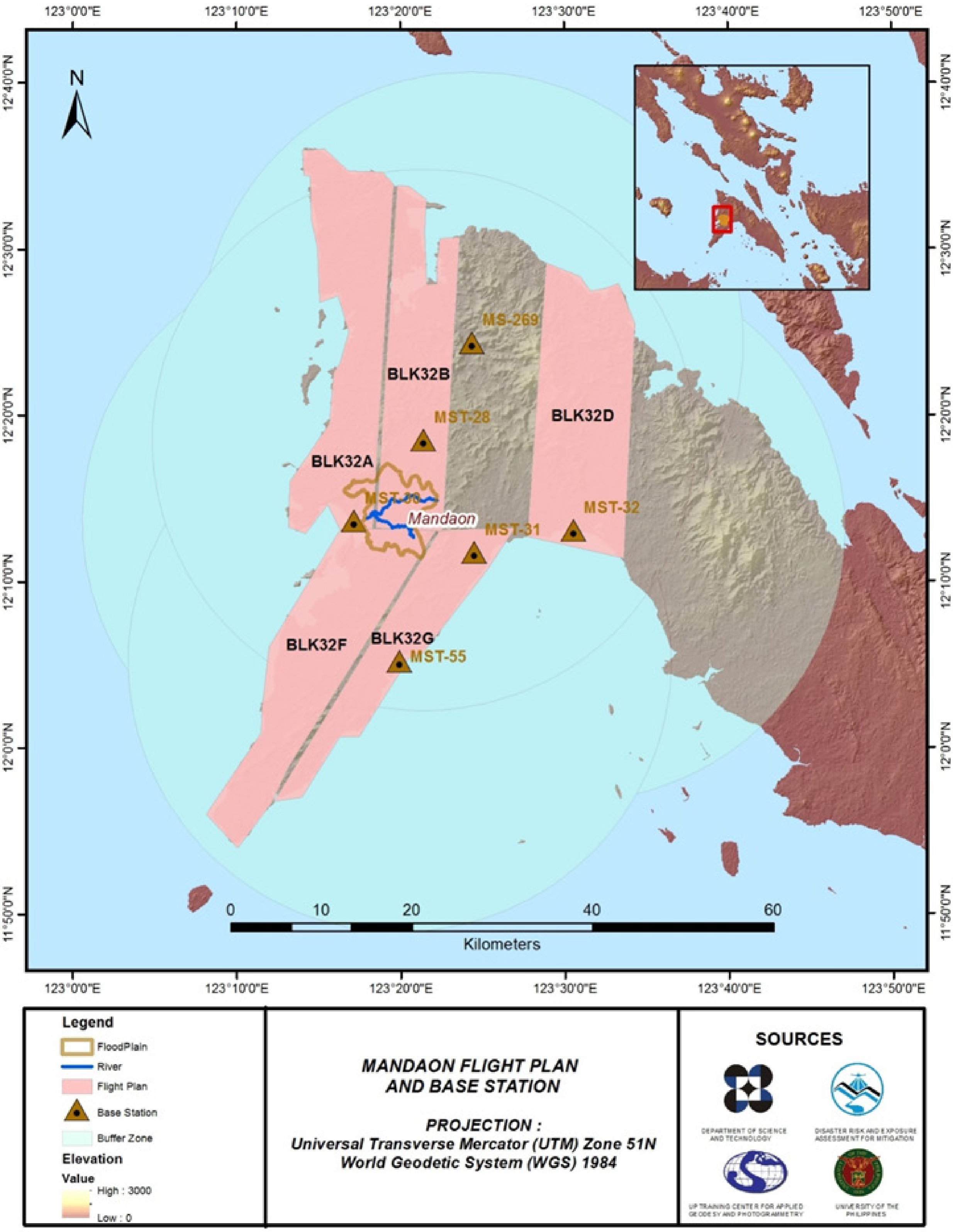


Figure 2 Flight plans and base stations for Canaway Floodplain

2.2 Ground Base Station

The project team was able to recover three (3) NAMRIA horizontal ground control points of second (2nd) order accuracy, NGE-89, NGE-101 and NGE-111. Three (3) NAMRIA benchmarks were recovered: NE-90, T-BM4 and NE-135 which are all of second (2nd) order accuracy. These benchmarks were used as vertical reference points and were also established as ground control points. The certification for the base station is found in Annex 2 while the baseline processing reports for established ground control points are found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey (September 20 – November 15, 2014) especially on the days that flight missions were conducted. Base stations were observed using dual frequency GPS receivers: TRIMBLE SPS 882,SPS 985, and SPS 852. Flight plans and location of base stations used during the aerial LiDAR acquisition in Canaway Floodplain are shown inFigure1in Figure 3.

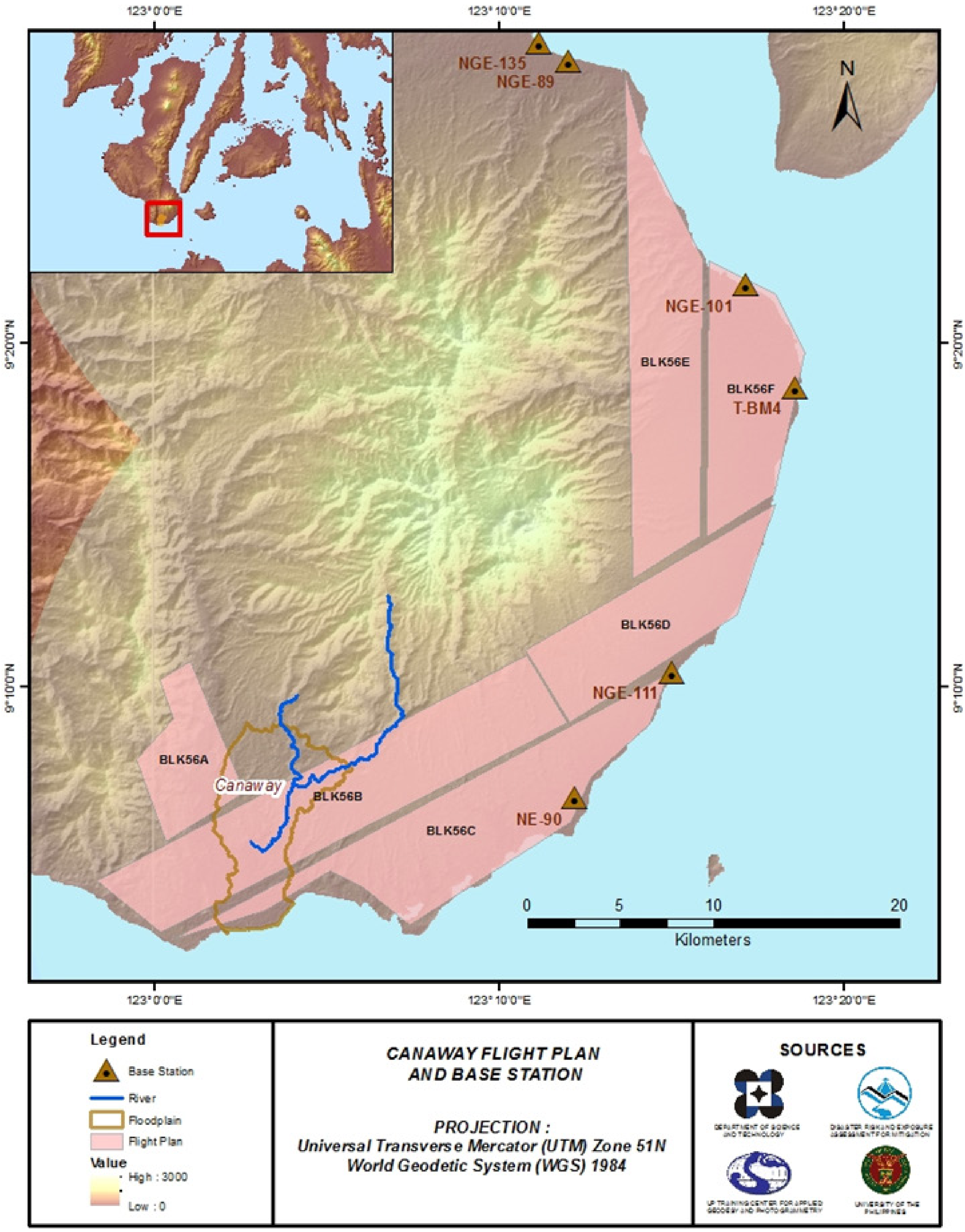


Figure 3 Flight plans and base stations for Canaway Floodplain

Figure 4 to Figure 9 show the recovered NAMRIA reference points within the area. In addition, Table 2 to Table 7 show the details about the following NAMRIA control stations and established points while Table 8 shows the list of all ground control points occupied during the acquisition with the corresponding dates of utilization.

Figure 4 GPS set-up over NGE-89 at the SE corner of Bio-os Bridge in Barangay Bio-os under the Municipality of Amlan (a) and NAMRIA reference point NGE-89 (b) as recovered by the field team

Table 2 Details of the recovered NAMRIA horizontal control point NGE-89 used as base station for the LiDAR Acquisition

Station Name	NGE-89	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	9°28'17.93638" North
	Longitude	123°11'53.99321" East
	Ellipsoidal Height	5.29700 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 4 PRS 92)	Easting	302131.943 meters
	Northing	1047809.850 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9°28'13.96567" North
	Longitude	123°11'59.32102" East
	Ellipsoidal Height	67.20400 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 92	Easting	521895.196 meters

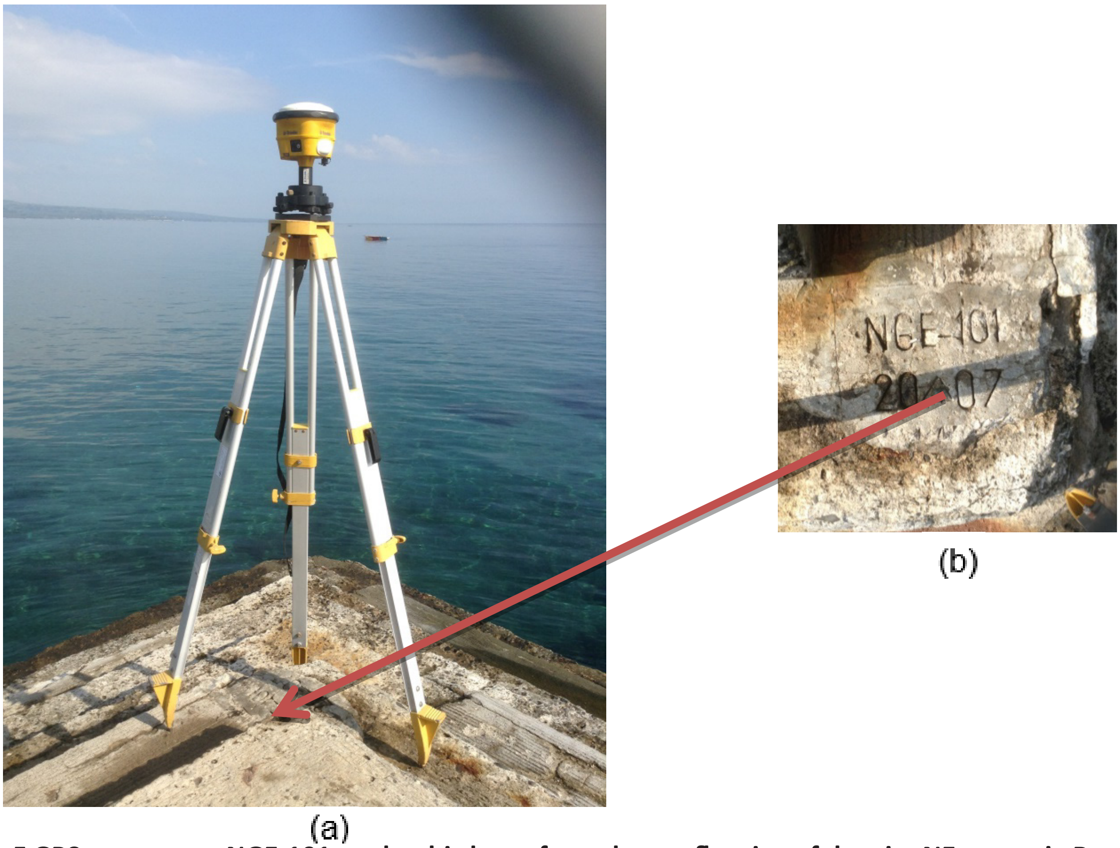


Figure 5 GPS set-up over NGE-101 on the third step from the top flooring of the pier NE corner in Barangay Poblacion under the Municipality of Sibulan (a) and NAMRIA reference point NGE-101 (b) as recovered by the field team

Table 3 Details of the recovered NAMRIA horizontal control point NGE-101 used as base station for the LiDAR Acquisition

Station Name	NGE-101	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 : 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	9°21’46.05028” North
	Longitude	123°17’3.45508” East
	Ellipsoidal Height	2.89700 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 4 PRS 92)	Easting	311516.397 meters
	Northing	1035718.276 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9°21'42.11526" North
	Longitude	123°17’8.79199” East
	Ellipsoidal Height	65.25500 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 92)	Easting	531340.539 meters
	Northing	1034845.884 meters

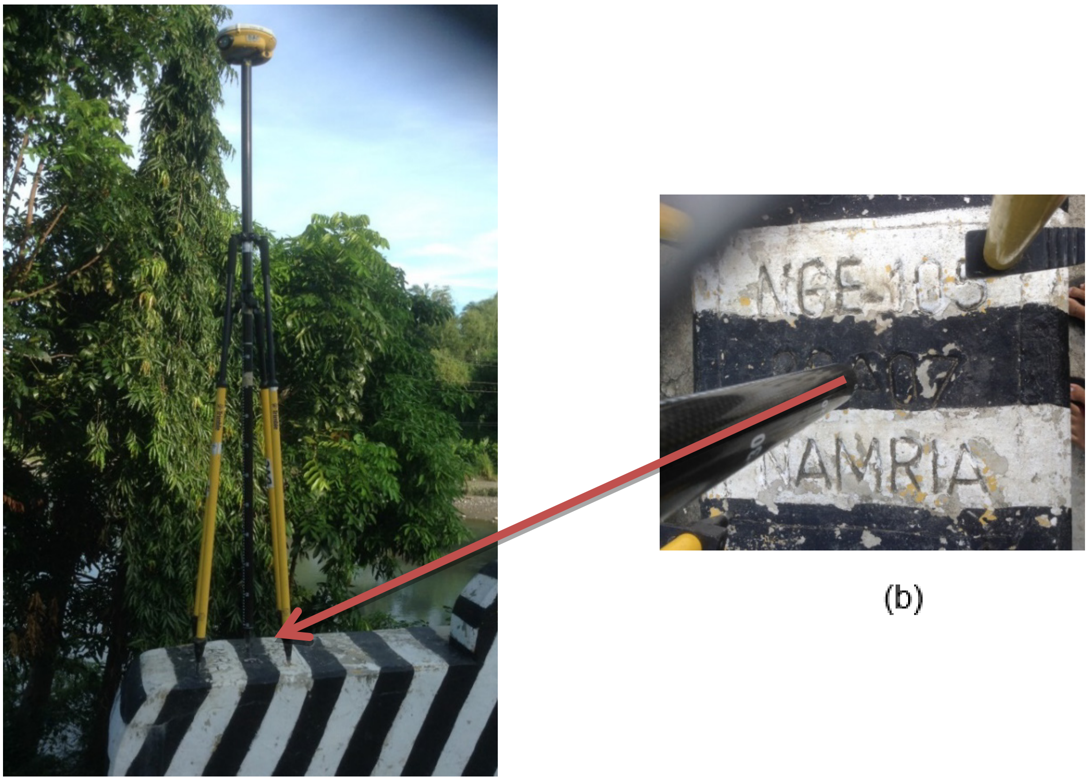
(a)

(b)

Figure 6 GPS set-up over NGE-111 on the concrete sidewalk on the NE approach of the 36 meter long Jagoba Bridge in Barangay Jagoba under the Municipality of Dauin (a) and NAMRIA reference point NGE-111 (b) as recovered by the field team

Table 4 Details of the recovered NAMRIA horizontal control point NGE-111used as base station for the LiDAR Acquisition

Station Name	NGE-111	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	9°10’30.25228” North
	Longitude	123°14’54.26711” East
	Ellipsoidal Height	13.11600 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 4 PRS 92)	Easting	307470.632 meters
	Northing	1014968.138 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9°10’26.36267” North
	Longitude	123°14’59.62110” East
	Ellipsoidal Height	75.79100 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 92)	Easting	527414.069 meters
	Northing	1014090.031 meters



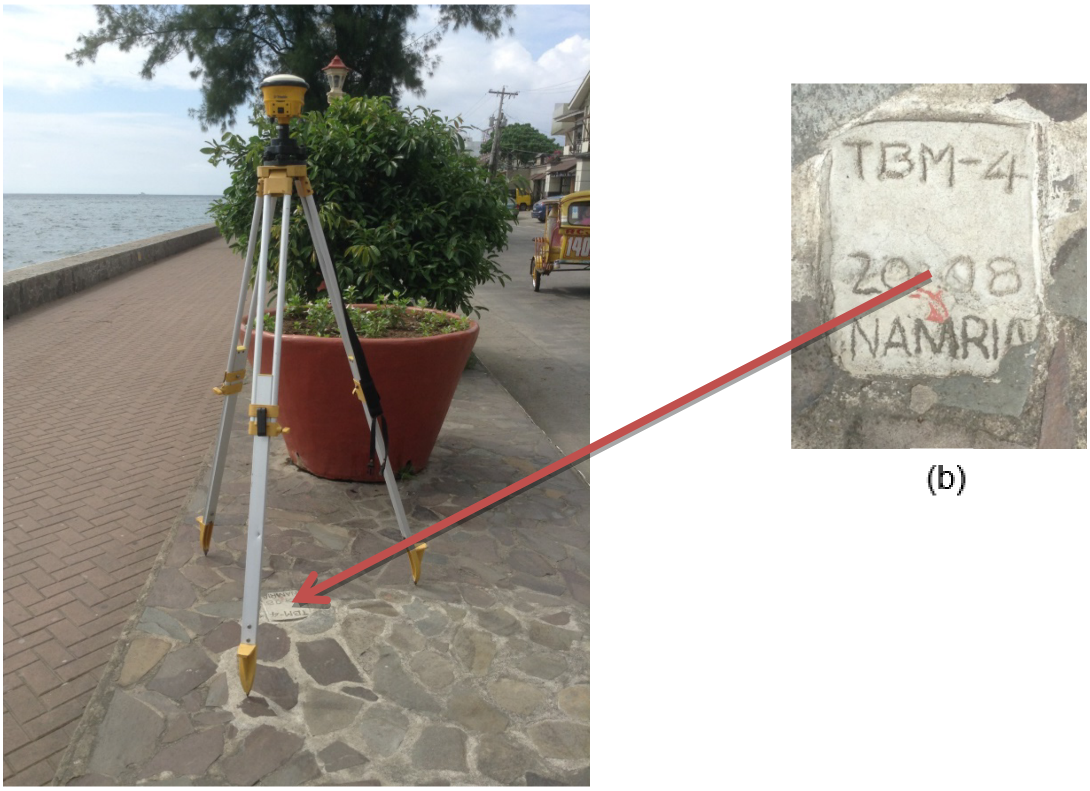
(b)

(a)

Figure 7 GPS set-up over NE-90on a concrete sidewalk of Guinsuan Bridge, 4 meters from the road centerline in Barangay Poblacion under the Municipality of Zamboanguita (a) and NAMRIA benchmark NE-90 (b) as recovered by the field team

Table 5 Details of established ground control point NE-90 used as vertical reference point and established base station for the LiDAR acquisition

Station Name	NE-90	
Order of Accuracy	2nd	
Elevation	6.6968	
Relative Error (horizontal positioning)	1:50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	9°6’42.32060” North
	Longitude	123°12’04.93455” East
	Ellipsoidal Height	7.358 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9°6’38.44322” North
	Longitude	123°12’10.29457” East
	Ellipsoidal Height	70.052 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 92)	Easting	522126.927 meters
	Northing	1007150.356 meters



(a) (b)

Figure 8 GPS set-up over T-BM4 as recovered on top of concrete pathway about 5 meters from the seawall of Dumaguete City's boulevard (a) and NAMRIA benchmark T-BM4 (b) as recovered by the field

Table 6 Details of established ground control point T-BM4used as vertical reference point and established base station for the LiDAR acquisition.

Station Name	T-BM4	
Order of Accuracy	2nd	
Elevation	5.4216	
Relative Error (horizontal positioning)	1:50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	9°18'39.58660" North
	Longitude	123°18'28.47112" East
	Ellipsoidal Height	3.712 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9°18'35.66706" North
	Longitude	123°18'33.81248" East
	Ellipsoidal Height	66.241 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 92)	Easting	533814.622 meters
	Northing	1029185.290 meters

Figure 9 GPS set-up over NE-135 in Busuang Bridge on top of concrete sidewalk in Barangay Bio-os under the Municipality of Amlan (a) and NAMRIA benchmark NE-135 (b) as recovered by the field team.

Table 7 Details of established ground control point NE-135 used as vertical reference point and established base station for the LiDAR acquisition.

Station Name	NE-135	
Order of Accuracy	2nd	
Elevation	5.4216	
Relative Error (horizontal positioning)	1:50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	9°28'39.60020" North
	Longitude	123°11'03.44049" East
	Ellipsoidal Height	5.556 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9°28'35.62671" North
	Longitude	123°11'08.76787" East
	Ellipsoidal Height	67.415 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 92)	Easting	520228.944 meters
	Northing	1047601.845 meters

Table 8 Ground Control points used during LiDAR data acquisition

Date Surveyed	Flight Number	Mission Name	Ground Control Points
24-Sep-14	7514G	2BLK56F267A	NGE-101, T-BM4
25-Sep-14	7516G	2BLK56DC268A	NE-90, NGE-111
26-Sep-14	7518G	2BLK56B269A	NE-90, NGE-111
28-Oct-14	7582G	2BLK56BSES301A	NE-90, NE-135, NGE-89, NGE-111
28-Oct-14	7583G	2BLK56ABS301B + CALIBRATION	NE-90, NE-135, NGE-89, NGE-111

2.3 Flight Missions

Five (5) missions were conducted to complete the LiDAR data acquisition in Canaway Floodplain, for a total of seventeen hours and forty nine minutes (17+49) of flying time for RP-C9322. All missions were acquired using the Gemini LiDAR systems. Table 9 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 10 presents the actual parameters used during the LiDAR data acquisition.

Table 9 Flight missions for LiDAR data acquisition in Canaway Floodplain.

Date Surveyed	Flight Number	Flight Plan Area (km2)	Surveyed Area (km2)	Area Surveyed within Floodplain (km2)	Area Surveyed Outside Floodplain (km2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
24-Sep-14	7514G	109.59	109.58	-	109.58	-	3	47
25-Sep-14	7516G	137.77	208.01	8.93	199.08	-	4	5
26-Sep-14	7518G	103.51	126.14	25.63	100.51	-	2	59
28-Oct-14	7582G	180.46	117.61	4.46	113.15	-	3	23
28-Oct-14	7583G	31.82	64.57	5.26	59.31	-	3	35
TOTAL		563.14	625.90	44.27	581.63	-	17	49

Table 10 Actual parameters used during LiDAR data acquisition

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
7514G	1000	30	40	100	50	130	5
	750	30	50	125	40	130	5
7516G	1000	30	40	100	50	130	5
	900	30	50	125	40	130	5
7518G	1000	30	40	100	50	130	5
	900	30	50	125	40	130	5
7582G	1100	30	40	100	50	130	5
7583G	1100	30	40	100	50	130	5

2.4 Survey Coverage

Canaway Floodplain is located in the province of Negros Oriental and Negros Occidental with majority of the floodplain situated within the municipalities of Bacay and Hinoba-An, respectively. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 11. The actual coverage of the LiDAR acquisition for Canaway Floodplain is presented in Figure 10.

Table 11 List of municipalities and cities surveyed during Canaway floodplain LiDAR survey.

Province	Municipality/City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Negros Oriental	Dumaguete City	30.42	30.22	99%
	Bacong	26.07	25.54	98%
	Zamboanguita	152.83	113.8	74%
	Dauin	80.91	49.59	61%
	Siaton	312.75	156.12	50%
	San Jose	47.09	19.4	41%
	Sibulan	165.36	41.27	25%
	Valencia	144.43	29.85	21%
	TOTAL	959.86	465.79	48.53%

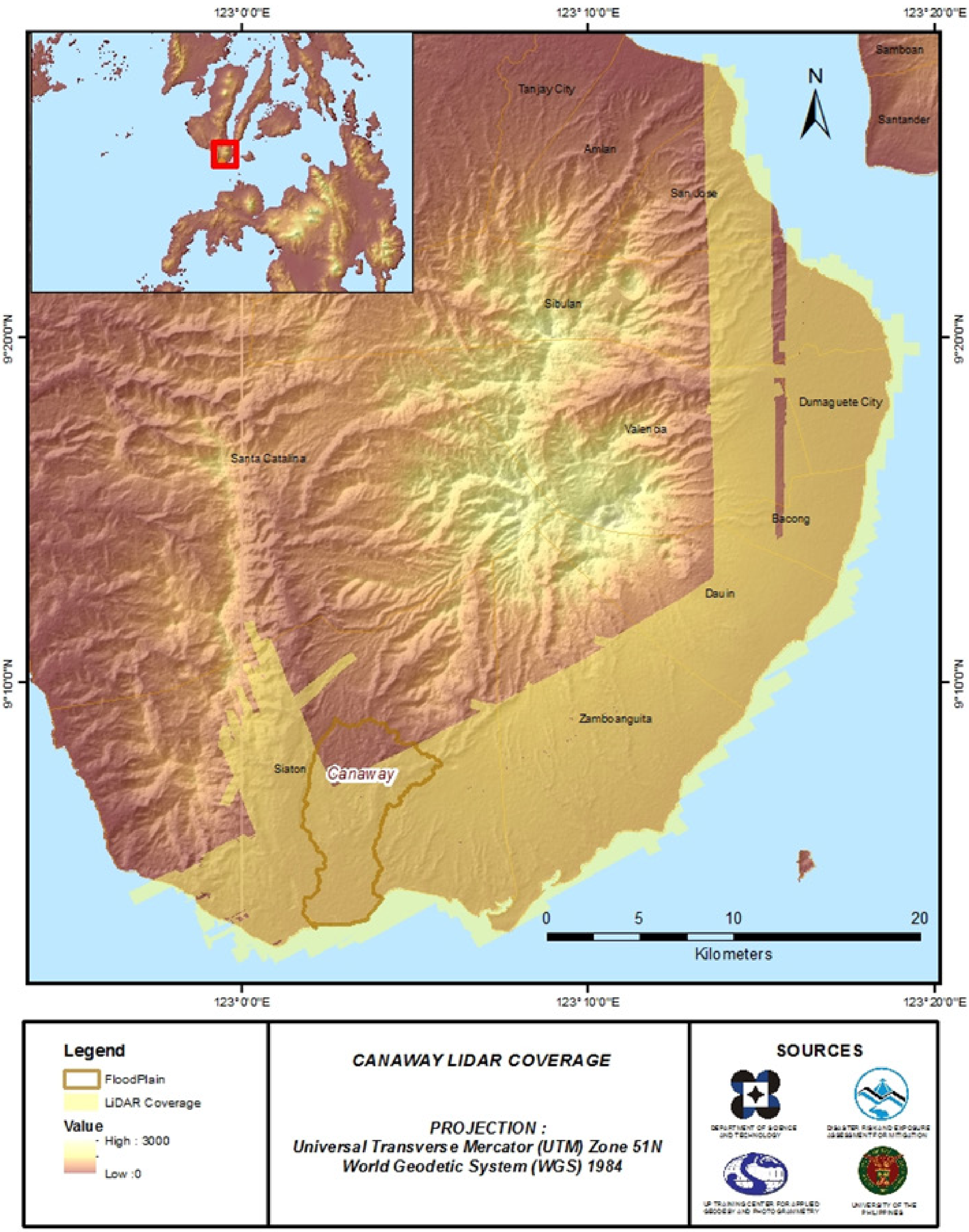


Figure 10 Actual LiDAR survey coverage for Canaway Floodplain .

CHAPTER 3: LIDAR DATA PROCESSING FOR CANAWAY FLOODPLAIN

Engr. Ma. Rosario Concepcion O. Ang, Engr. John Louie D. Fabila, Engr. Sarah Jane D. Samalburo , Engr. Joida F. Prieto , Ailyn G. Biñas , Engr. Jennifer B. Saguran, Engr. Monalyne C. Rabino, Engr. Jovelle Anjeanette S. Canlas , Engr. Ma. Joanne I. Balaga, Engr. Erica Erin E. Elazegui

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 Processing

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

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

These processes are summarized in the flow chart shown in Figure 11.

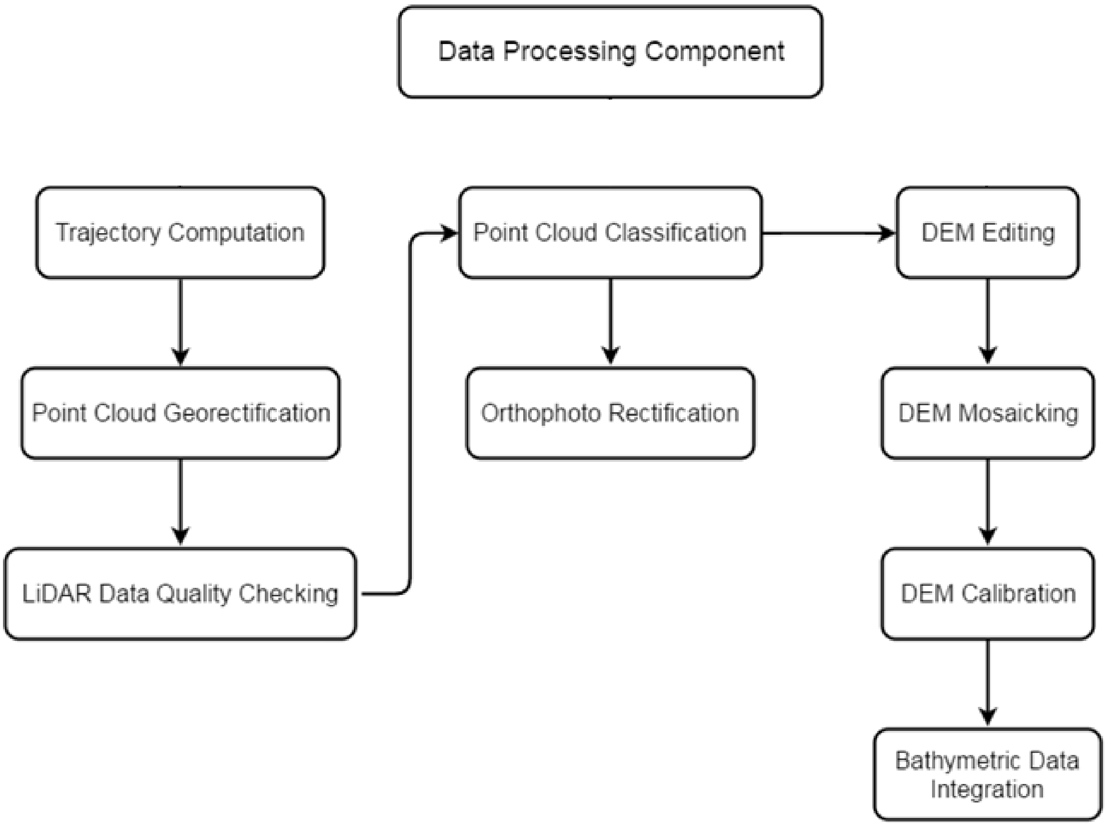


Figure 11. Schematic Diagram for Data Pre-Processing Component

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Canaway Floodplain can be found in Annex 5 Data Transfer Sheets. Missions flown during the first survey conducted on September 2014 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Gemini-CASI system while missions acquired during the second survey on January 2016 were flown using the Aquarius-CASI system over Municipality of Siaton, Negros Oriental. The Data Acquisition Component (DAC) transferred a total of 93.02 Gigabytes of Range data, 1,044.50 Megabytes of POS data, 60.70 Megabytes of GPS base station data, and 34.62 Gigabytes of raw image data to the data server on February 09, 2016. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Canaway was fully transferred on February 15, 2016 as indicated on the Data Transfer Sheets for Canaway Floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 7516G, one of the Canaway flights, which is the North, East, and Down position RMSE values are shown in Figure 12. 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 September 21, 2014 00:00AM. The y-axis is the RMSE value for that particular position.

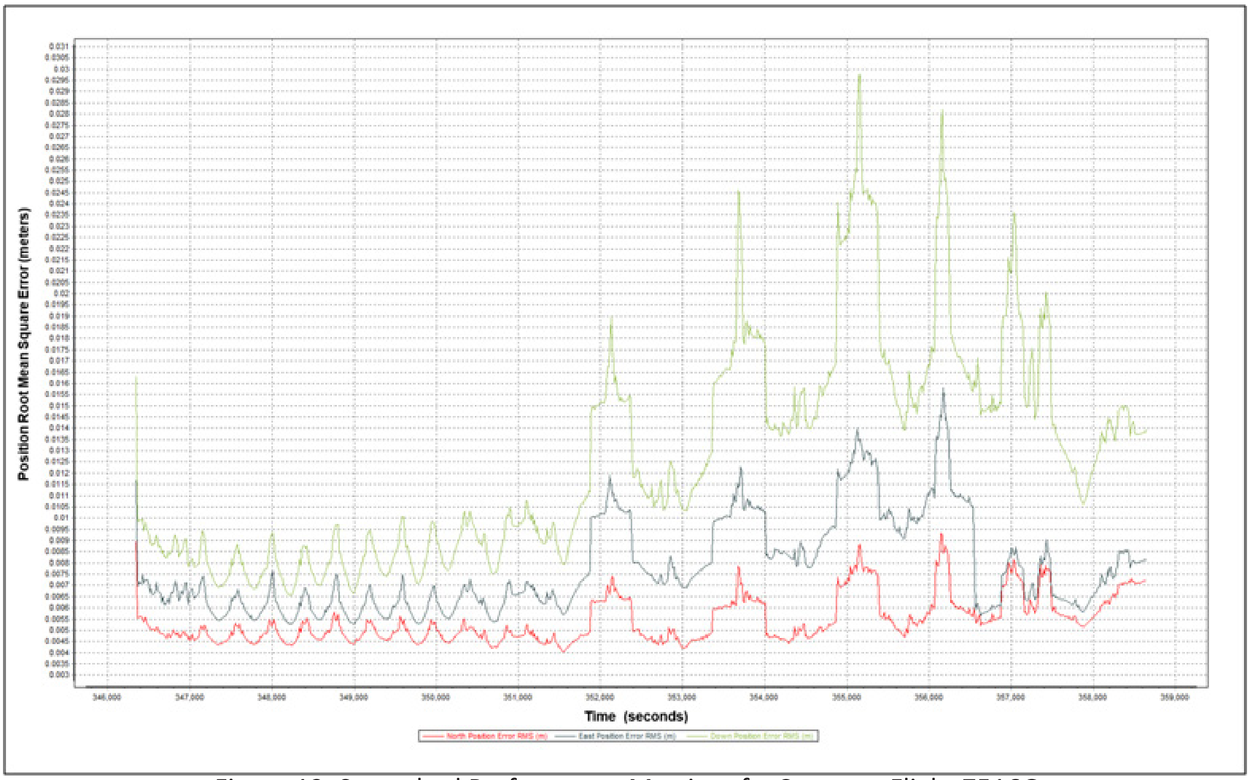


Figure 12. Smoothed Performance Metrics of a Canaway Flight 7516G

The time of flight was from 346,000 seconds to 359,000 seconds, which corresponds to morning of September 25, 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 minimize 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 12 shows that the North position RMSE peaks at 0.95 centimeters, the East position RMSE peaks at 1.59 centimeters, and the Down position RMSE peaks at 2.98 centimeters, which are within the prescribed accuracies described in the methodology.

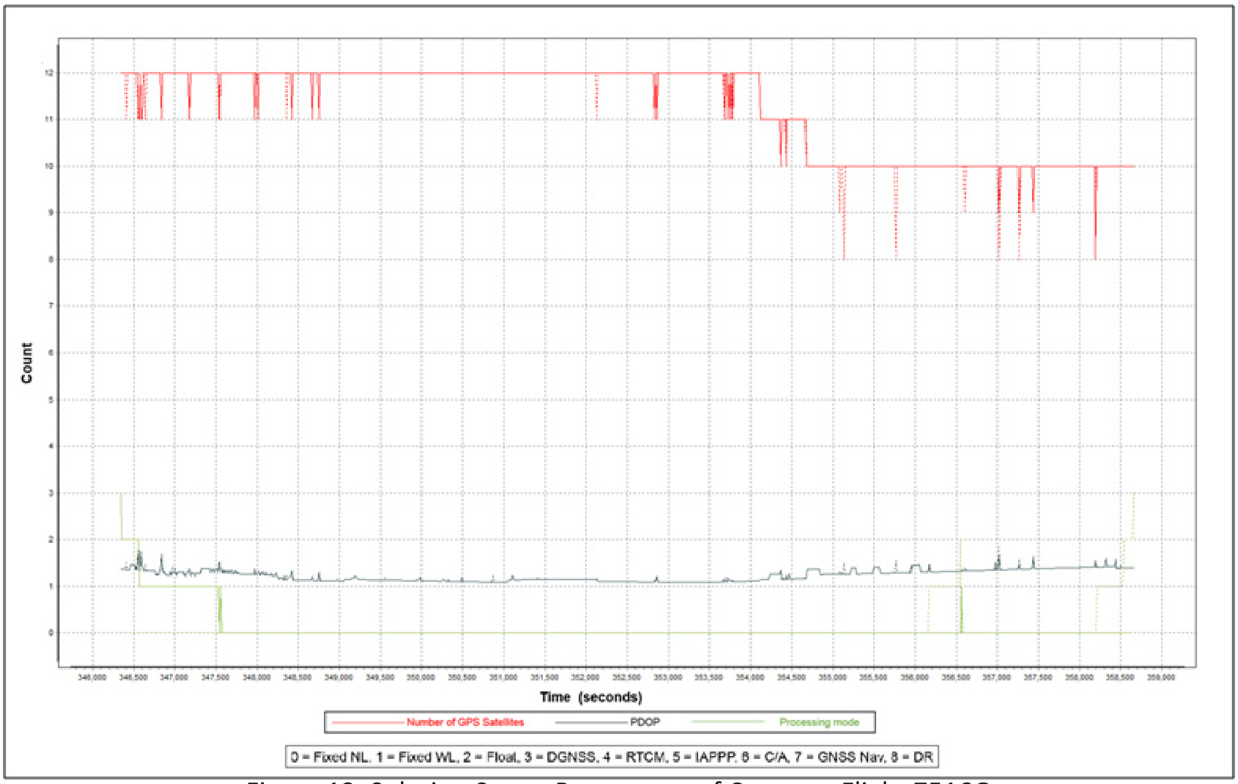


Figure 13. Solution Status Parameters of Canaway Flight 7516G

The Solution Status parameters of flight 7516G, one of the Canaway flights, which indicate the number of GPS satellites, Positional Dilution of Precision, and the GPS processing mode used, are shown in Figure 13. The graphs indicate that the number of satellites during the acquisition did not go down below 8. Most of the time, the number of satellites tracked was between 10 and 12. The PDOP value also did not go above the value of 3, which still indicates indicated optimal GPS geometry. The processing mode remained at 0 for almost the entire survey time with sudden peaks up to 1or 2 attributed to the turn 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 Canaway flights is shown in Figure 14.

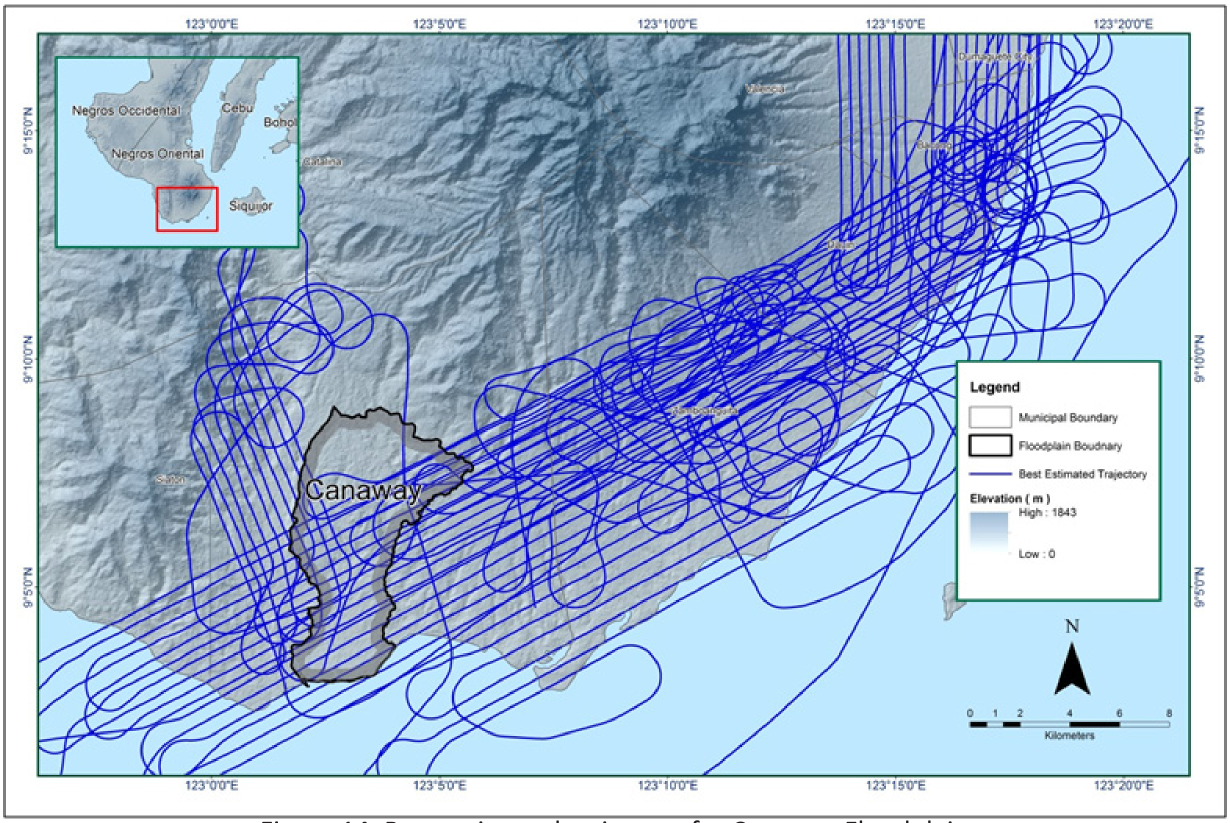


Figure 14. Best estimated trajectory for Canaway Floodplain

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 83 flight lines, each of those flight lines contains only one (1) channel for both Gemini-CASI and Aquarius-CASI systems, since the Gemini-CASI and Aquarius-CASI systems contain only one channel. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Canaway floodplain Floodplain are given in Table 12.

Table 12. Self-Calibration Results values for Canaway flights

Parameter	Computed Value
Boresight Correction stdev (<0.001degrees)	0.000279
IMU Attitude Correction Roll and Pitch Corrections stdev (<0.001degrees)	0.000996
GPS Position Z-correction stdev (<0.01meters)	0.0029

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

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data is shown in Figure B-5. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

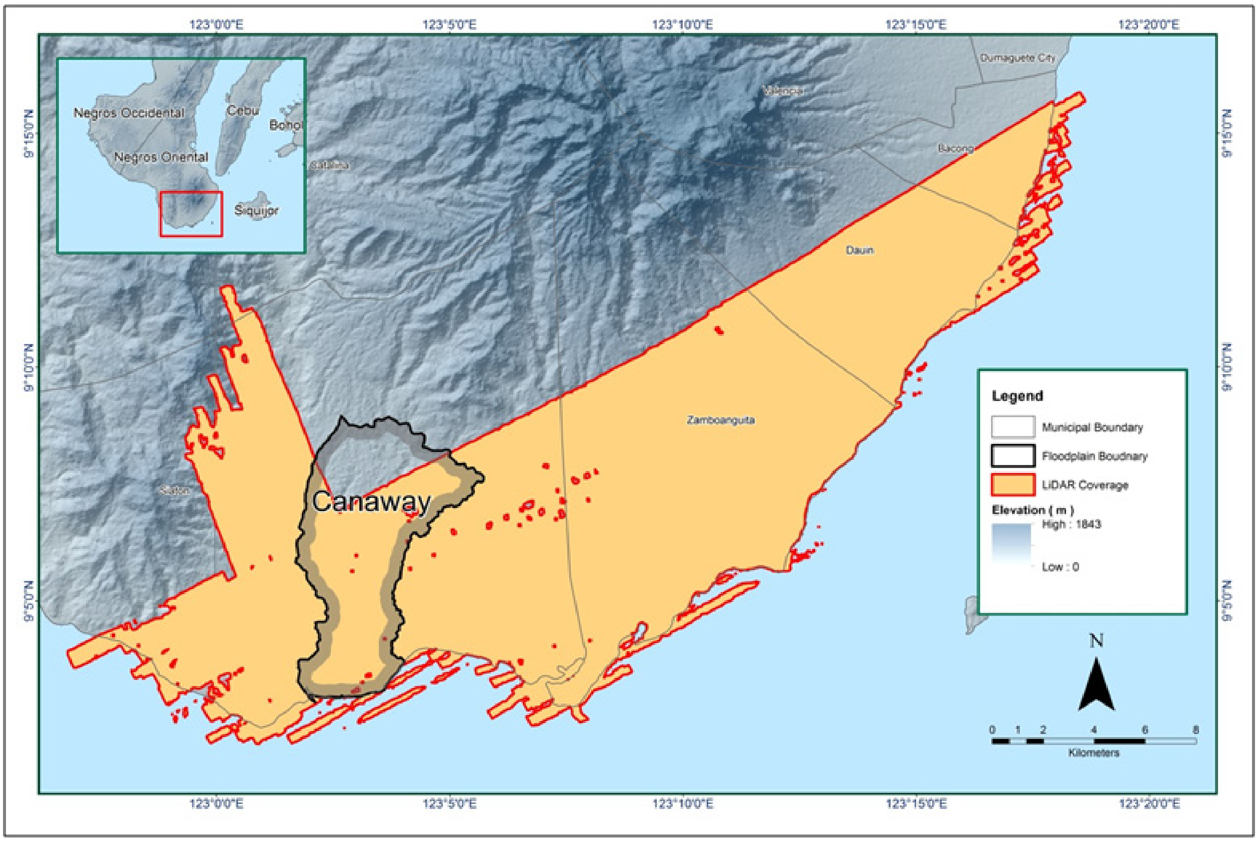


Figure 15. Boundary of the processed LiDAR data on top of a SAR Elevation Data over Canaway Floodplain.

The total area covered by the Canaway missions is 455.82 sq.km that is comprised of five (6) flight acquisitions grouped and merged into five (6) blocks as shown in Table 13.

Table 13. List of LiDAR blocks for Canaway Floodplain

LiDAR Blocks	Flight Numbers	Area (sq. km)
Dumaguete_Blk56A	7583G	37.82
Dumaguete_Blk56B	7518G	128.76
	7582GC	
	7583GC	
Dumaguete_Blk56CD	7514G	191.98
	7516G	
Dumaguete_Blk56CD_additional	7516G	13.20
Dumaguete_Reflights_Blk56A	7583GC	65.07
Dumaguete_Reflights_Blk56C	10077AC	18.99
	TOTAL	455.82

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 16. Since the Gemini-CASI system and Aquarius-CASI systems both employ 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.

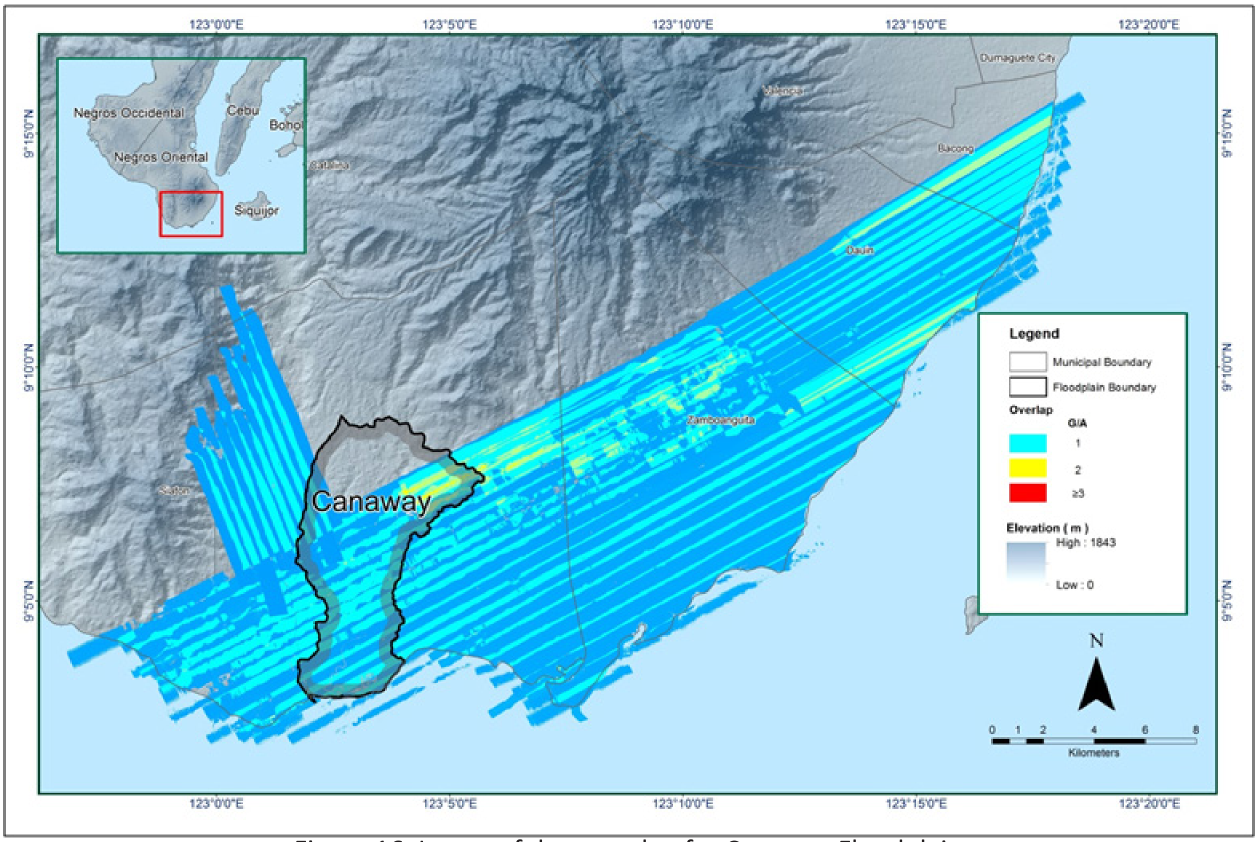


Figure 16. Image of data overlap for Canaway Floodplain

The overlap statistics per block for the Canaway floodplain can be found in Annex 8 Mission Summary Reports. It should be noted that one pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 30.09% and 48.38% respectively, which passed the 25% requirement.

The density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 17. It was determined that all LiDAR data for Canaway Floodplain satisfy the point density requirement, and the average density for the entire survey area is 3.55 points per square meter.

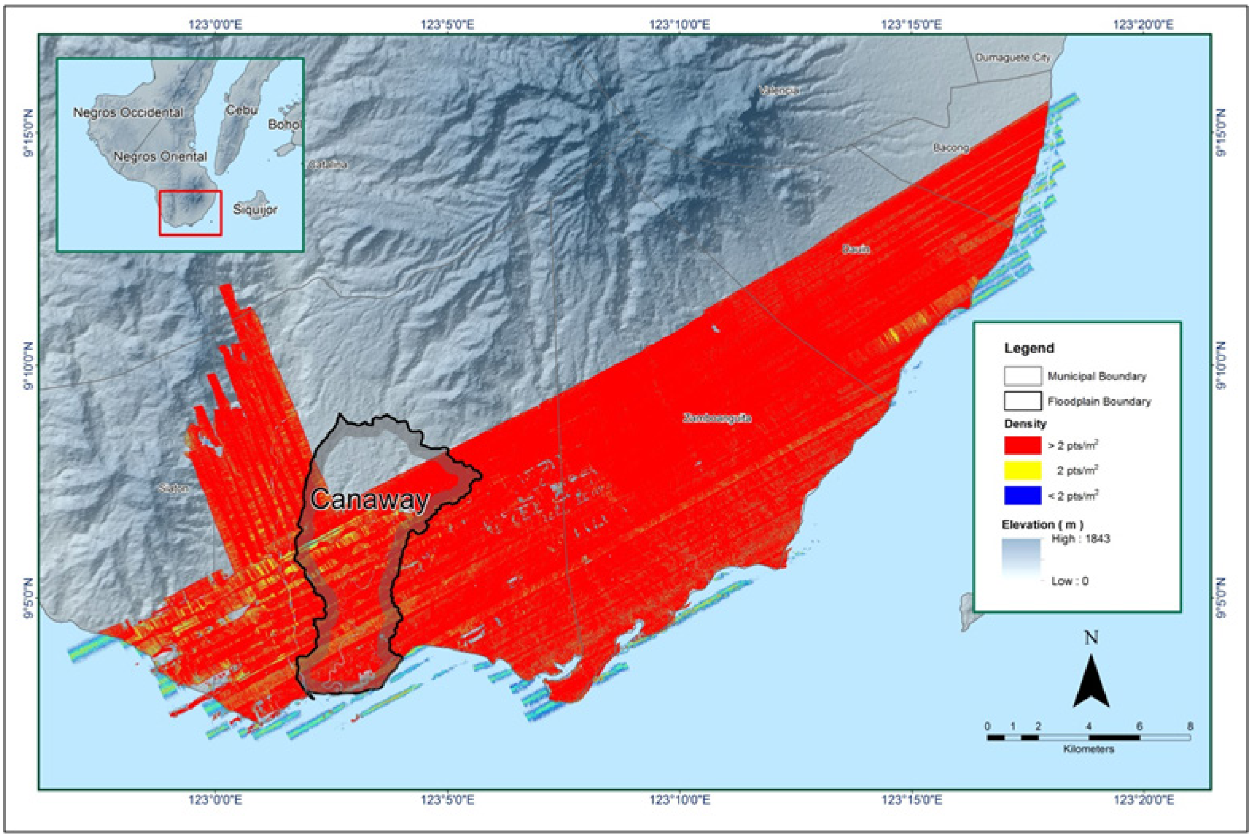


Figure 17. Density map of merged LiDAR data for Canaway Floodplain

The elevation difference between overlaps of adjacent flight lines is shown in Figure 18. 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 0.20 m relative to elevations of its adjacent flight line. Bright red areas indicate portions where elevations of a previous flight line are were lower by more than 0.20 m 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.

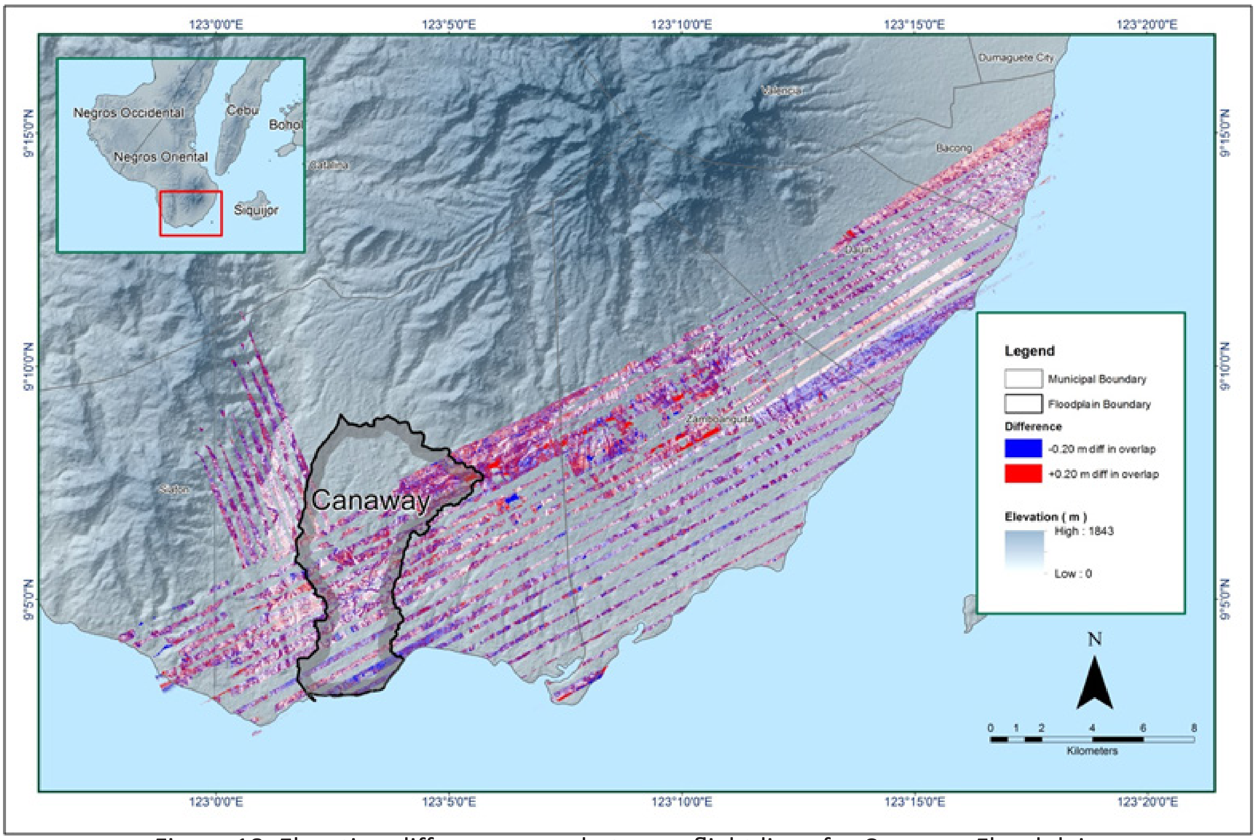


Figure 18. Elevation difference map between flight lines for Canaway Floodplain

A screen capture of the processed LAS data from a Canaway flight 7516G loaded in QT Modeler is shown in Figure 19. 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 were differences in elevation, but the differences do did 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.

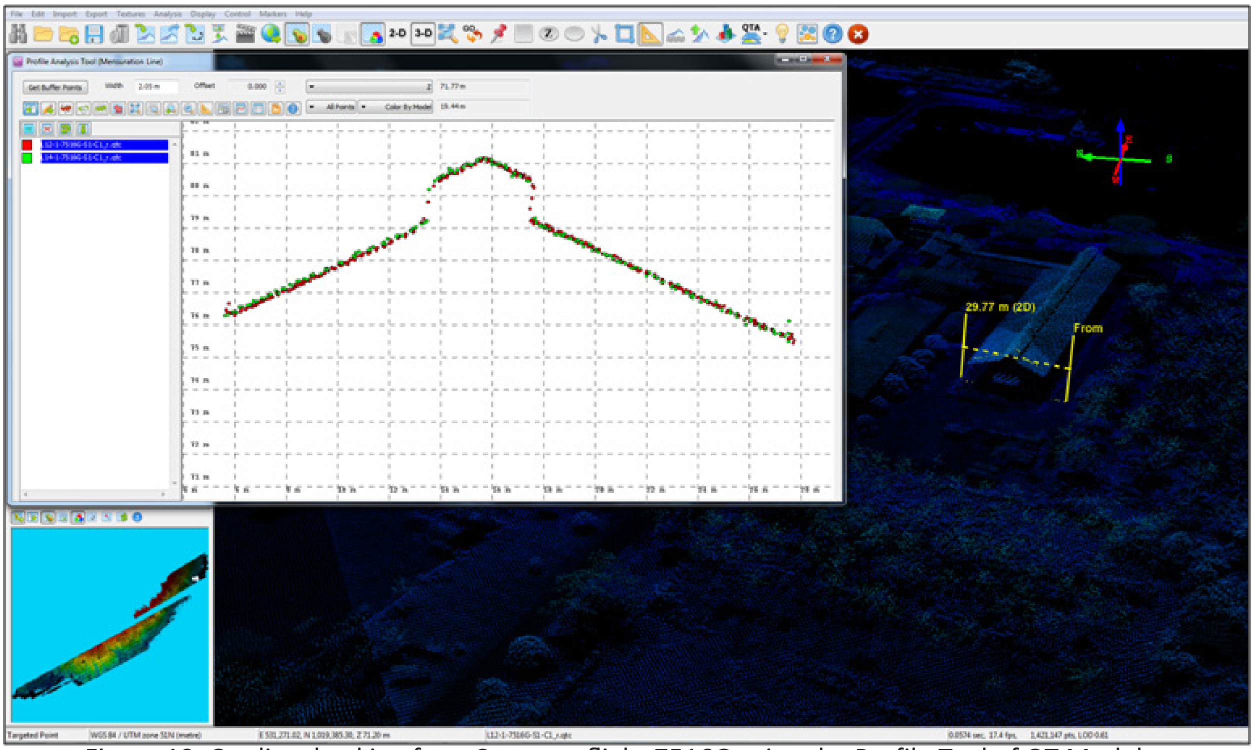


Figure 19. Quality checking for a Canaway flight 7516G using the Profile Tool of QT Modeler

3.6 LiDAR Point Cloud Classification and Rasterization

Table 14. Canaway classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	282,681,116
Low Vegetation	233,003,575
Medium Vegetation	573,168,848
High Vegetation	581,560,482
Building	11,956,725

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Canaway floodplain Floodplain is shown in Figure 20. A total of 737 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 14. The point cloud has had a maximum and minimum height of 766.06 meters and 22.69 meters respectively.

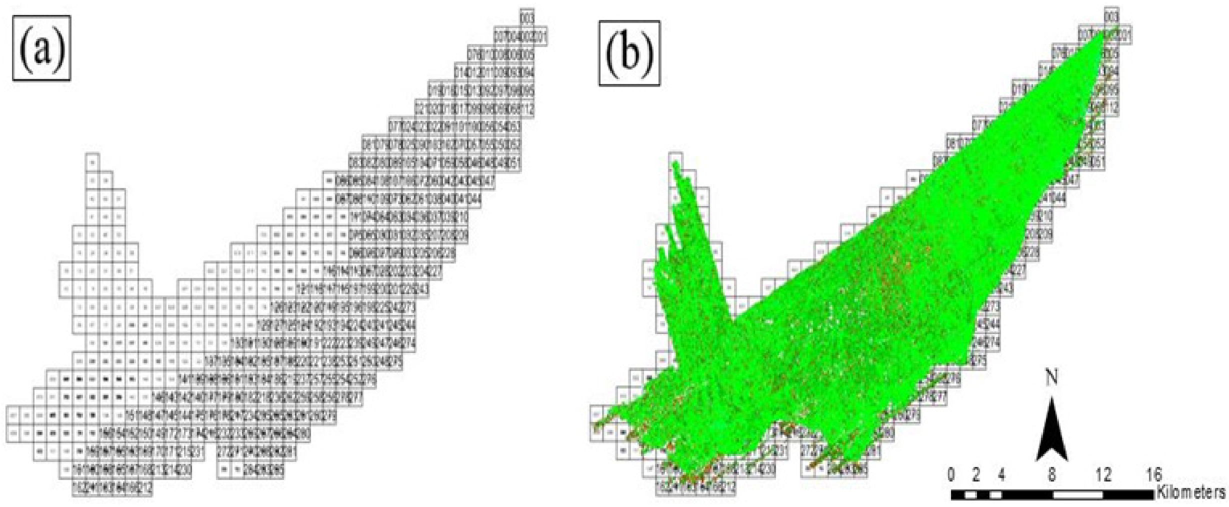


Figure 20. Tiles for Canaway Floodplain (a) and classification results (b) in TerraScan

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

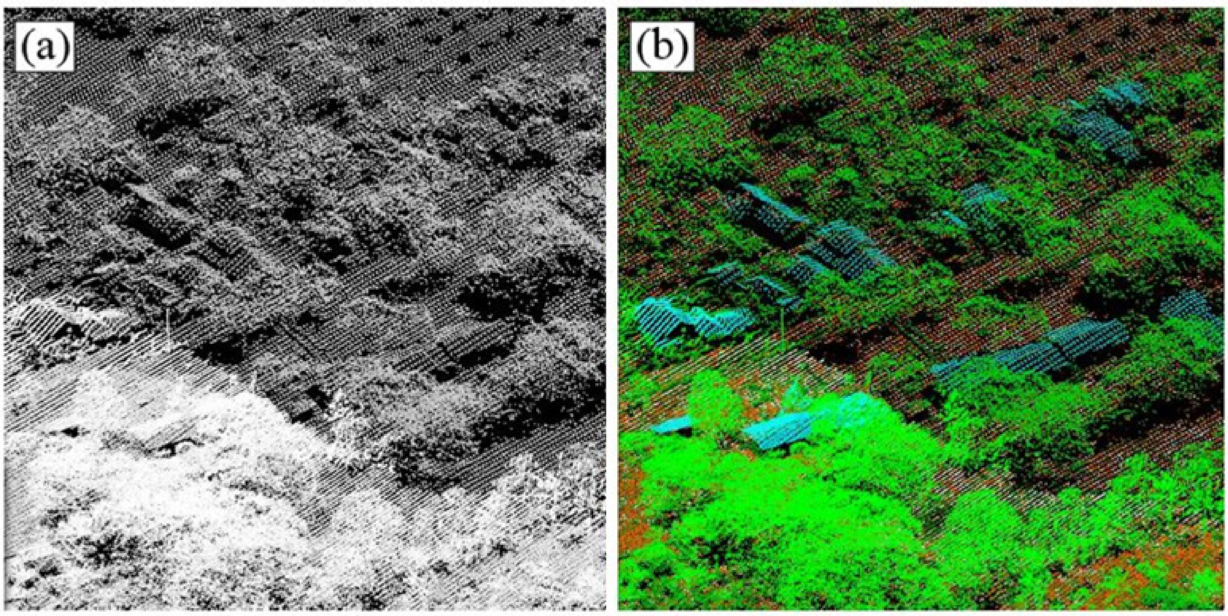


Figure 21. Point cloud before (a) and after (b) classification

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 22. It shows that DTMs are the representation of the bare earth while on the DSMs, all features are present such as buildings and vegetation.

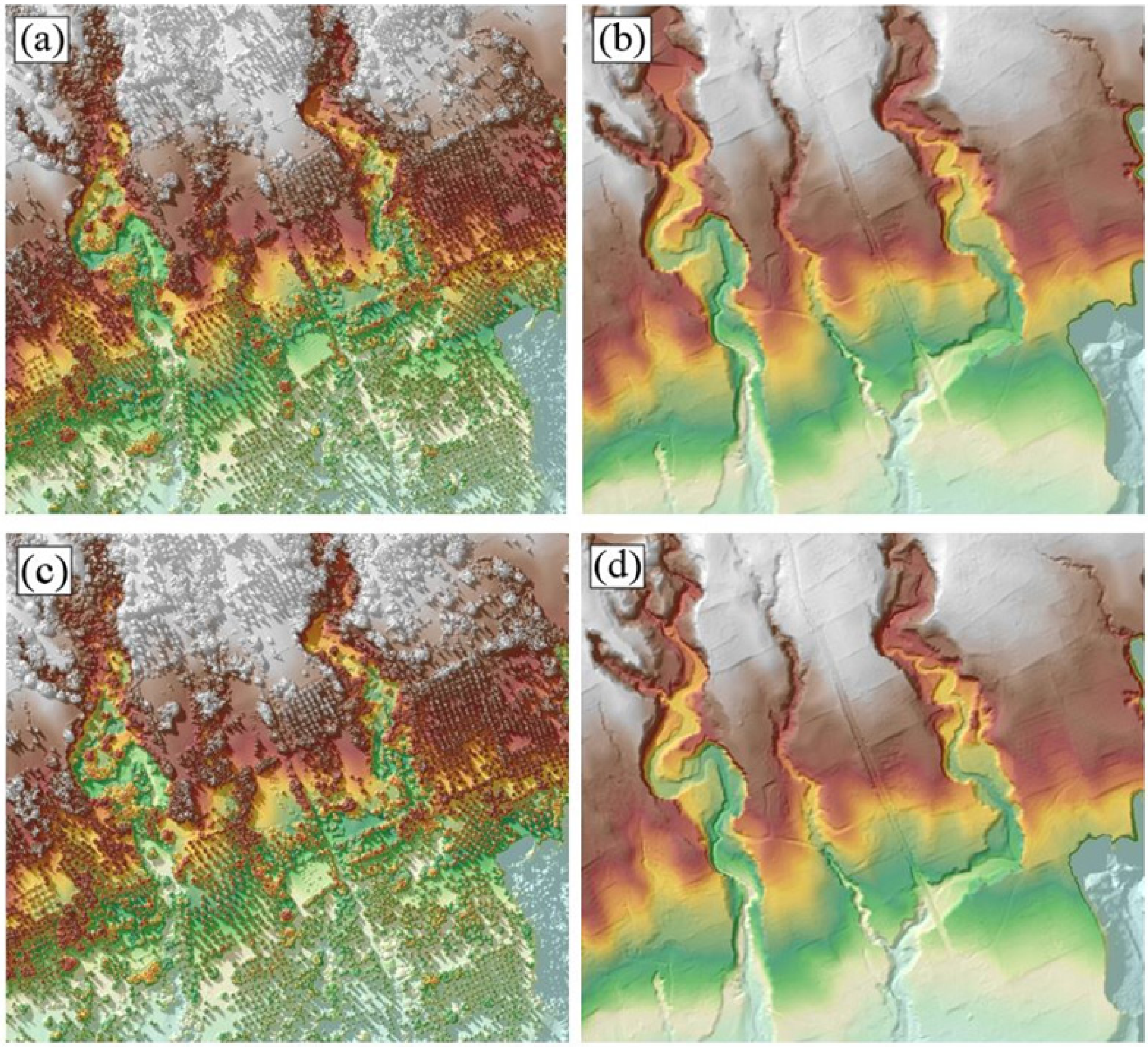


Figure 22. The Production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Canaway Floodplain

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 96 1km by 1km tiles of the block covering the Canaway floodplain Floodplain is shown in Figure 23. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The block covering the Canaway Floodplain has a total of 65.79 sq.km orthophotogaph coverage comprised of 332 images. However, the block does did not have a complete set of orthophotographs and no orthophotographs cover the area of the Canaway floodplainFloodplain. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 24.

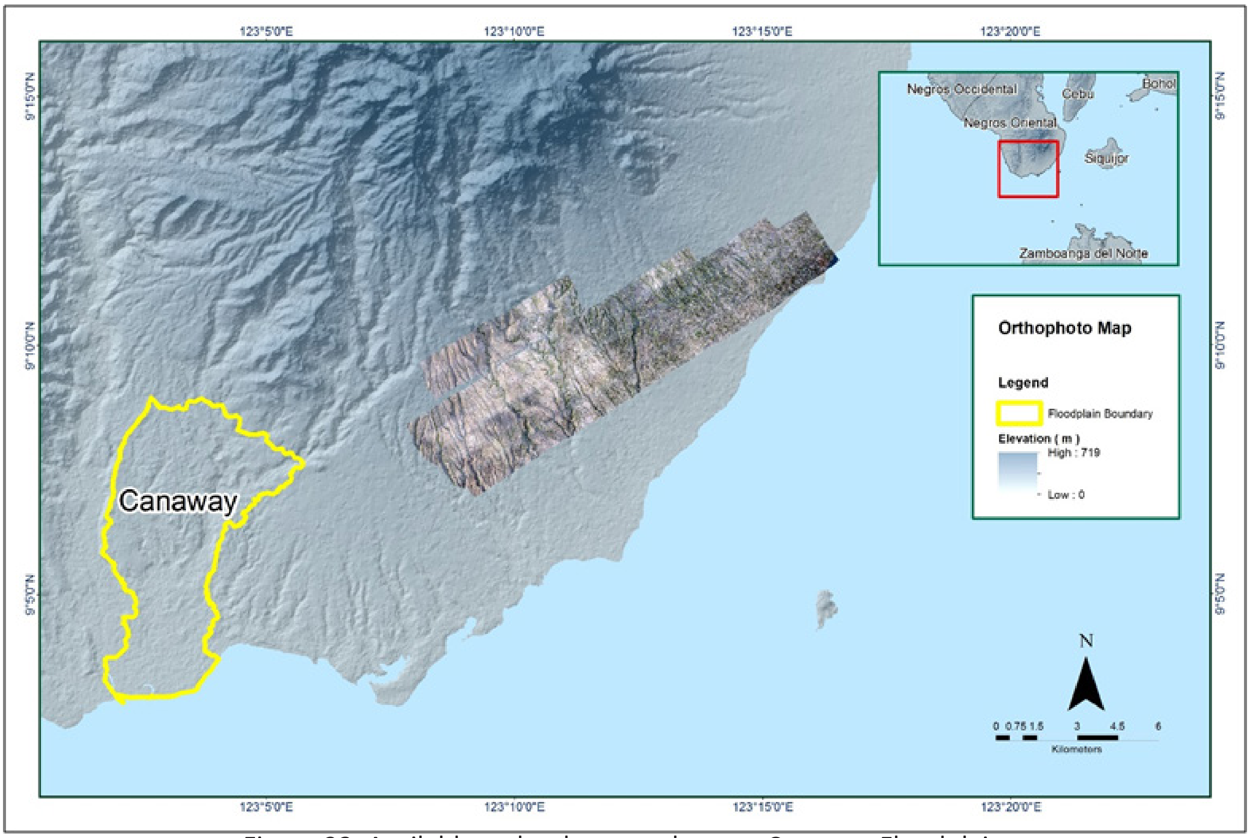


Figure 23. Available orthophotographs near Canaway Floodplain.

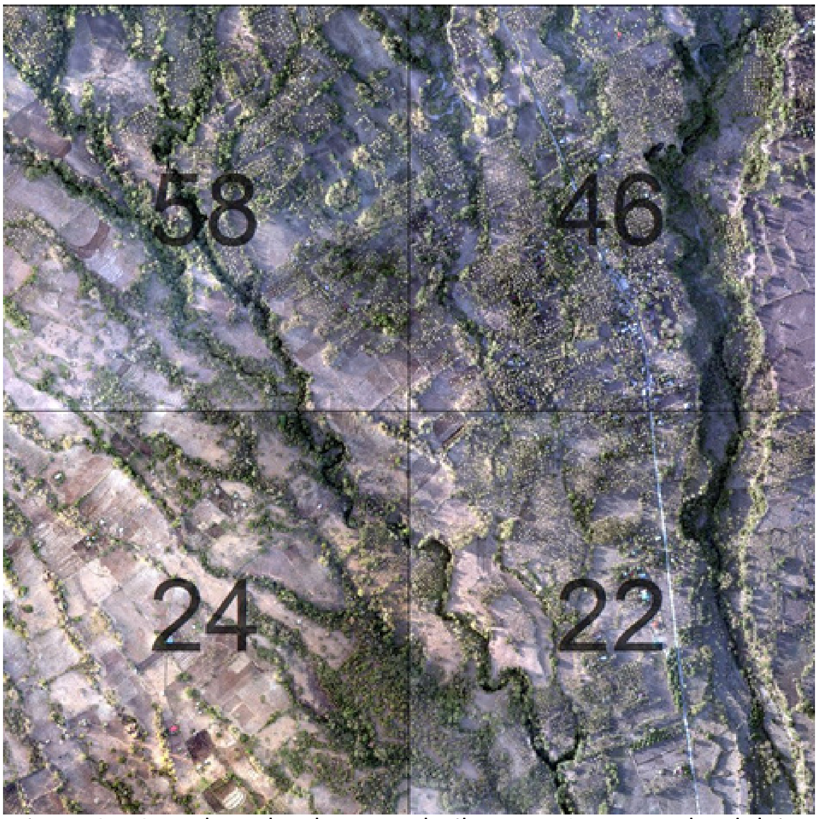


Figure 24. Sample orthophotograph tiles near Canaway Floodplain.

3.8 DEM Editing and Hydro-Correction

Six (6) mission blocks were processed for Canaway flood Floodplain. These blocks are composed of Dumaguete blocks with a total area of 455.82 square kilometers. Table 15 shows the name and corresponding area of each block in square kilometers.

Table 15. LiDAR blocks with its corresponding area

LiDAR Blocks	Area (sq.km)
Dumaguete_Blk56A	37.82
Dumaguete_Blk56B	128.76
Dumaguete_Blk56CD	191.98
Dumaguete_Blk56CD_additional	13.20
Dumaguete_Reflights_Blk56A	65.07
Dumaguete_Reflights_Blk56C	18.99
TOTAL	**455.82 sq.km**

Portions of DTM before and after manual editing are shown in Figure 25. The interpolated area (Figure 25a) has been misclassified during classification process and has to be retrieved to complete the surface (Figure 25b). Another is the bridge (Figure 25c) is also considered to be an impedance to the flow of water and has to be removed (Figure 25d) in order to hydrologically correct the river. These are shown in the figure below.

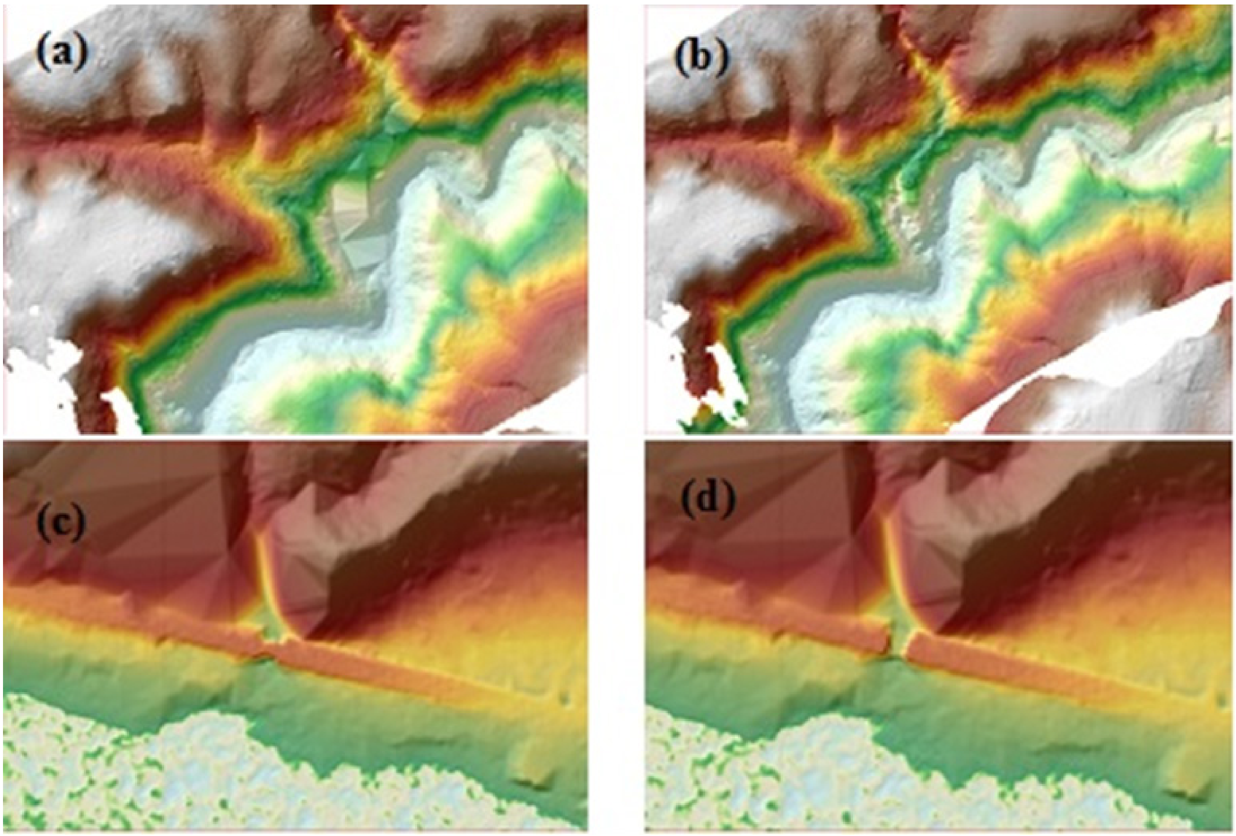


Figure 25. Portions in the DTM of Canaway Floodplain – interpolated area (a) before and (b) after data retrieval; a bridge (c) before and (d) after manual editing.

3.9 Mosaicking of Blocks

Dumaguete_Blk56D_additional was used as the reference block at the start of mosaicking due to the presence of more fixed built-up areas like roads on the flight block compared to the other. Table 16 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Canaway floodplain is shown in Figure 26. It can be seen that the entire Canaway floodplain Floodplain is 90% covered by LiDAR data.

Table 16. Shift Values of each LiDAR Block of Canaway Floodplain

Mission Blocks	Shift Values (m)		
	x	y	z
Dumaguete_Blk56A	0.00	0.00	-0.92
Dumaguete_Blk56B	0.00	0.00	-0.49
Dumaguete_Blk56CD	0.00	0.00	-0.22
Dumaguete_Blk56CD_additional	0.00	0.00	0.47
Dumaguete_reflights_Blk56A	0.00	0.00	0.064
Dumaguete_reflights_Blk56C	0.00	0.00	0.47

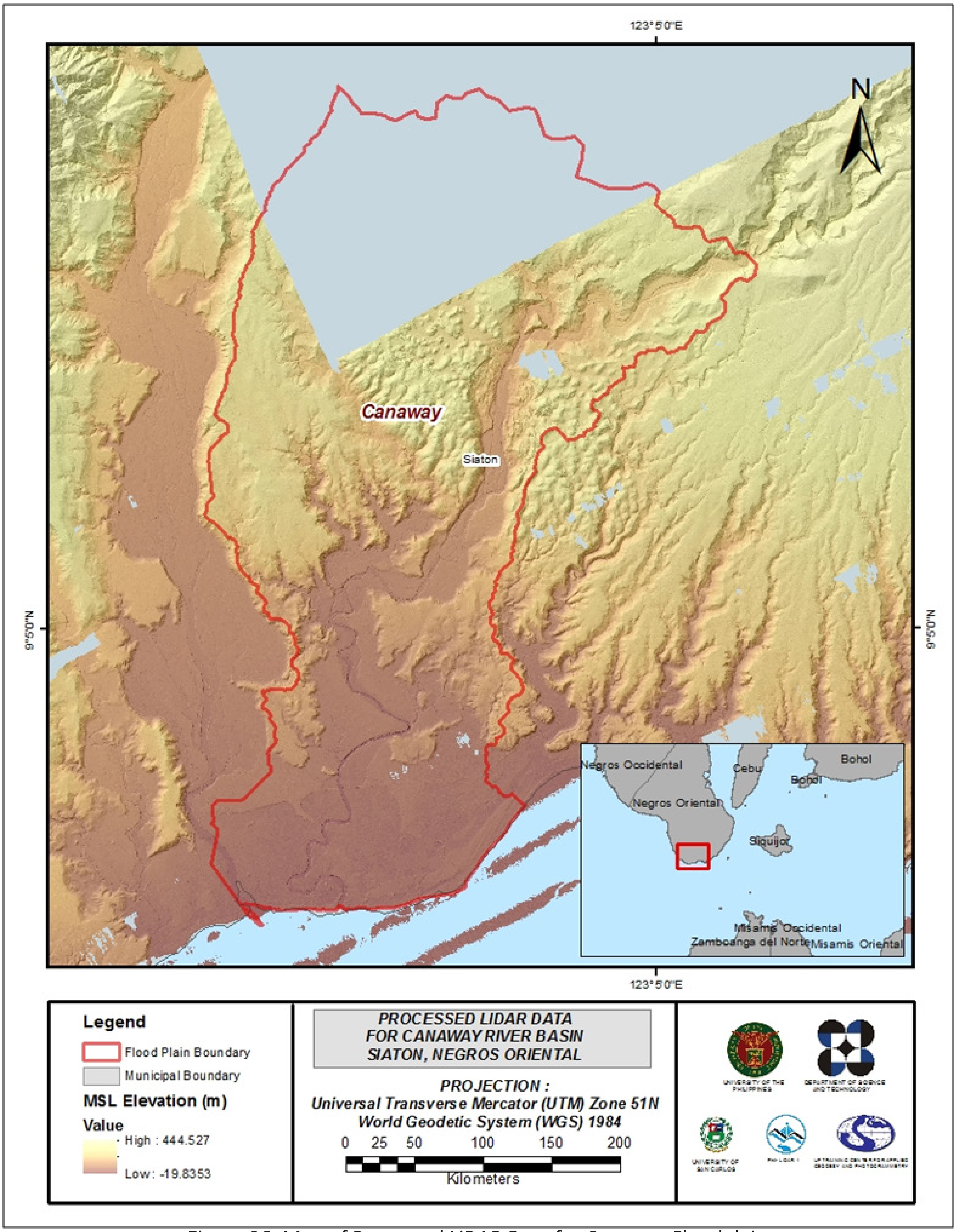


Figure 26. Map of Processed LiDAR Data for Canaway Floodplain

3.10 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Canaway to collect points with which the LiDAR dataset is validated is shown in Figure 27. A total of 14,047 survey points were gathered for all the flood plains within the provinces of Negros Oriental and Negros Occidental wherein the Canaway floodplain is located. Random selection of 80% of the survey points, resulting to 11,237 points, was used for calibration.

A good correlation between the uncalibrated mosaicked LiDAR DTM and ground survey elevation values is shown in Figure 28. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration points is 0.35 meters with a standard deviation of 0.18 meters. Calibration of the LiDAR data was done by subtracting the height difference value, 0.35 meters, to the mosaicked LiDAR data. Table 17 shows the statistical values of the compared elevation values between the LiDAR data and calibration data.

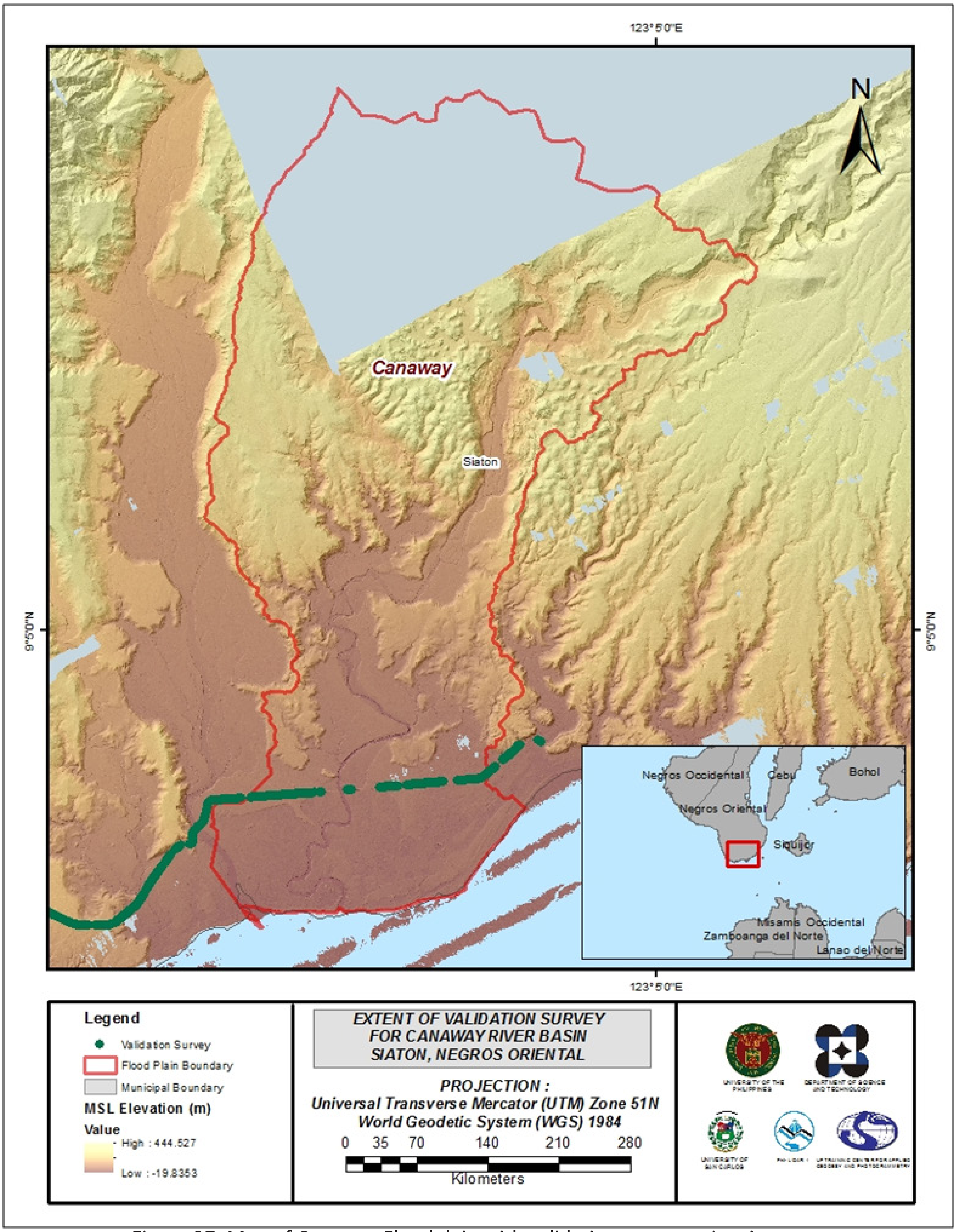


Figure 27. Map of Canaway Floodplain with validation survey points in green

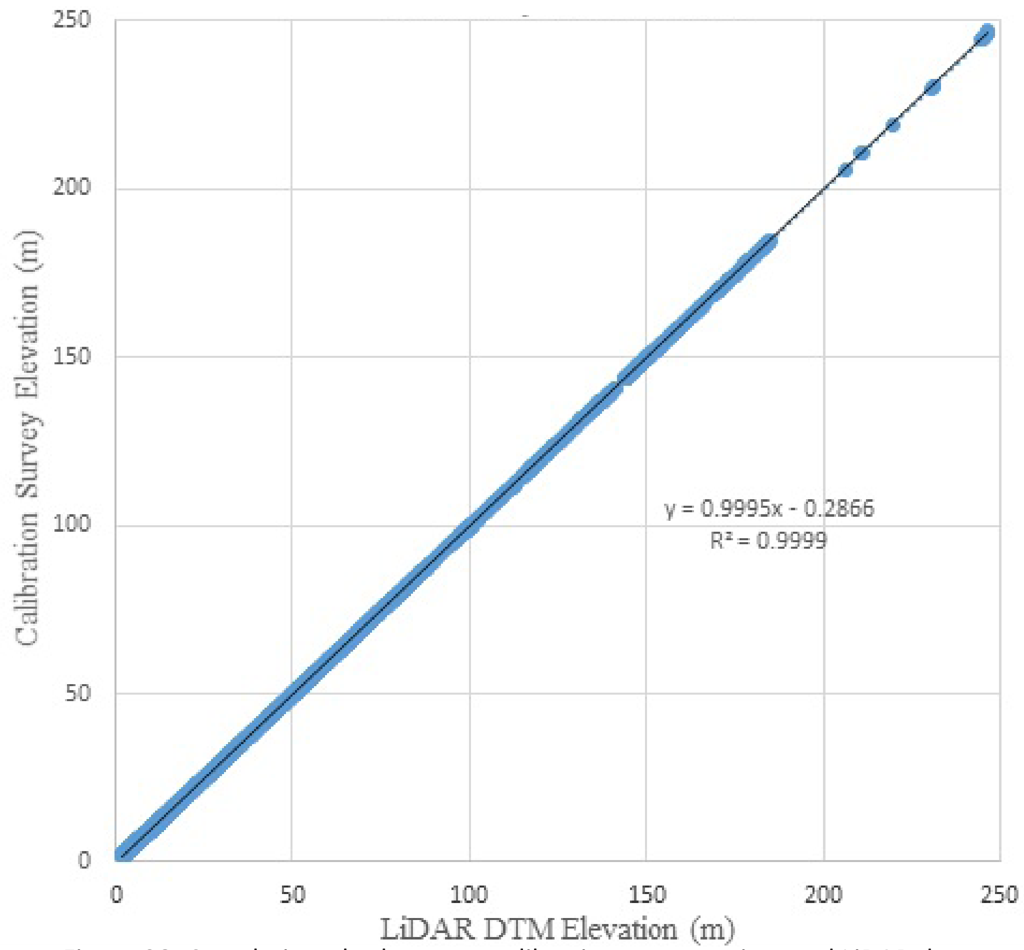


Figure 28. Correlation plot between calibration survey points and LiDAR data

Table 17. Calibration Statistical Measures

Calibration Statistical Measures	Value (meters)
Height Difference	0.35
Standard Deviation	0.18
Average	-2.30
Minimum	-0.57
Maximum	0.30

The remaining 20% of the total survey points were intersected to the flood plain, resulting to 80 points, were used for the validation of calibrated Canaway 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 29. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.19meters with a standard deviation of 0.09 meters, as shown in Table 18.

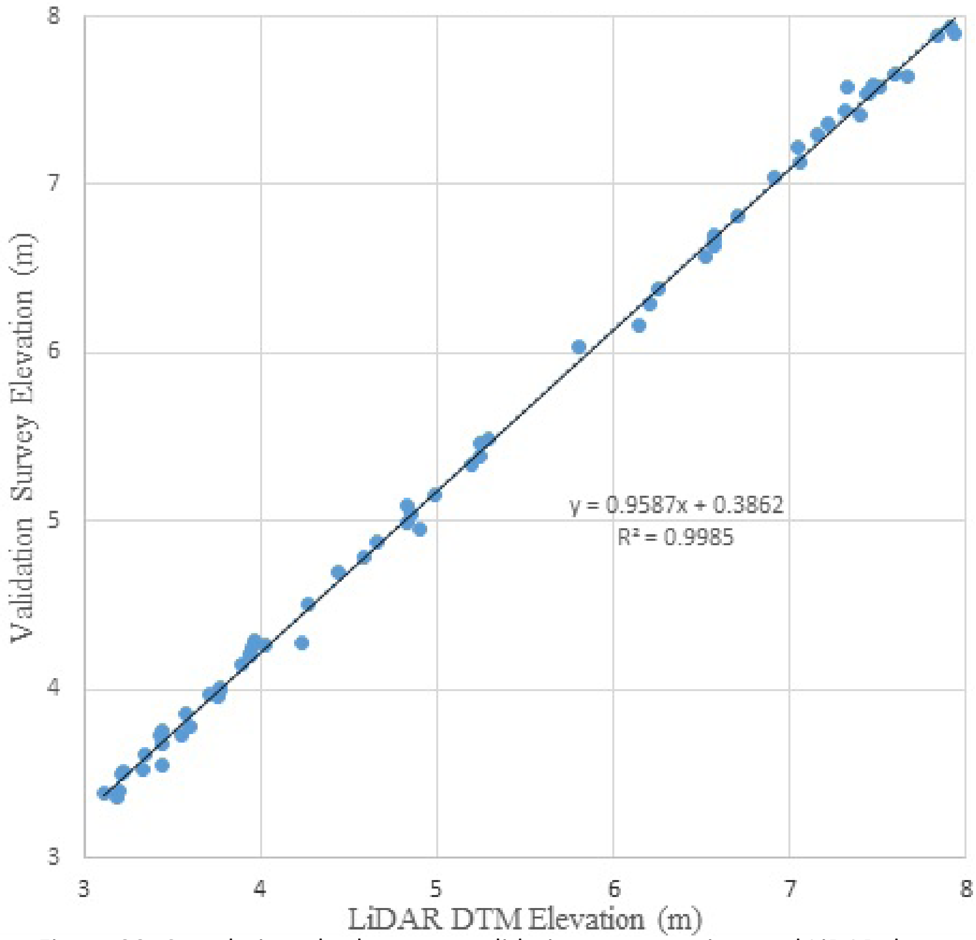


Figure 29. Correlation plot between validation survey points and LiDAR data

Table 18. Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.19
Standard Deviation	0.09
Average	0.17
Minimum	-0.04
Maximum	0.32

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and zigzag data were available for Canaway with 13,964 bathymetric survey points. The resulting raster surface produced was done by Krigging interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is was represented by the computed RMSE value of 0.14 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Canaway integrated with the processed LiDAR DEM is shown in Figure 30.

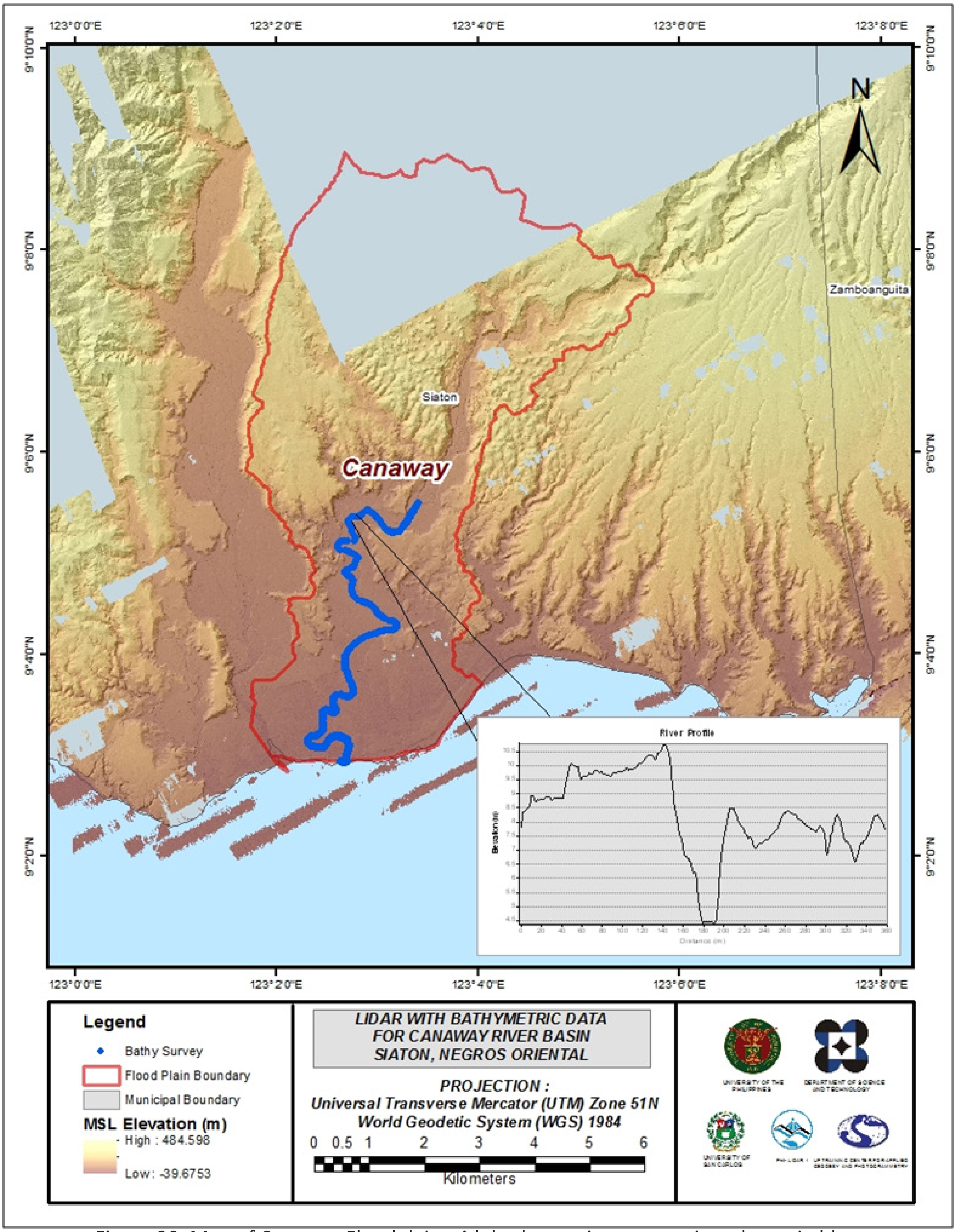


Figure 30. Map of Canaway Floodplain with bathymetric survey points shown in blue

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

Canaway floodplainFloodplain, including its 200 m buffer, has a total area of 52.75 sq km. For this area, a total of 5.00 sq km, corresponding to a total of 423 building features, are considered for QC. Figure 31 shows the QC blocks for Canaway floodplainFloodplain.

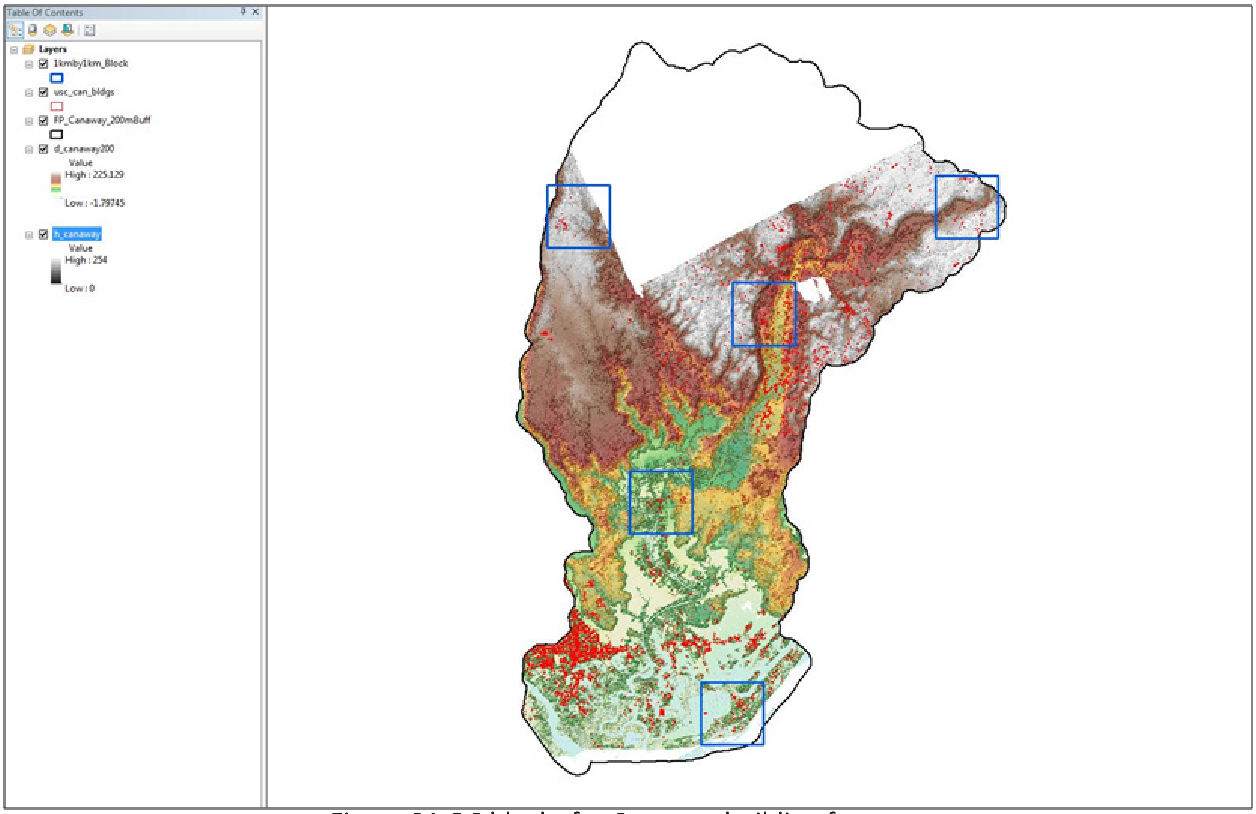


Figure 31.QC blocks for Canaway building features

Quality checking of Canaway building features resulted in the ratings shown in Table B-819.

Table 19. Quality Checking Ratings for Canaway Building Features

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Canaway	100.00	100.00	96.24	PASSED

3.12.2 Height Extraction

Height extraction was done for 4,653 building features in Canaway floodplainFloodplain. Of these building features, 82 were filtered out after height extraction, resulting to 4,571 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 16.75 m.

3.12.3 Feature Attribution

In attribution, combination of participatory mapping and actual field validation was done. Representatives from LGU were invited to assist in the determination of the features. The remaining unidentified features were then validated on the field.

Table 20 summarizes the number of building features per type. On the other hand, Table 21 shows the total length of each road type, while Table 22 shows the number of water features extracted per type.

Table 20. Number of Building Features Extracted for Canaway Floodplain

Facility Type	No. of Features
Residential	4,527
School	10
Market	4
Agricultural/Agro-Industrial Facilities	0
Medical Institutions	2
Barangay Hall	4
Military Institution	0
Sports Center/Gymnasium/Covered Court	2
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	0
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	1
Water Supply/Sewerage	0
Religious Institutions	4
Bank	4
Factory	5
Gas Station	0
Fire Station	0
Other Government Offices	2
Other Commercial Establishments	9
Total	**4,571**

Table 21. Total Length of Extracted Roads for Canaway Floodplain

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Canaway	20.33	25.52	0.00	4.42	0.00	50.27

Table 22. Number of Extracted Water Bodies for Canaway Floodplain

Floodplain	Water Body Type					Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Canaway	2	0	0	0	0	2

A total of 3 bridges and culverts over small channels that are part of the river network were also extracted for the floodplain.

3.12.4 Final Quality Checking of Extracted Features

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

Figure 32 shows the Digital Surface Model (DSM) of Canaway floodplain Floodplain overlaid with its ground features.

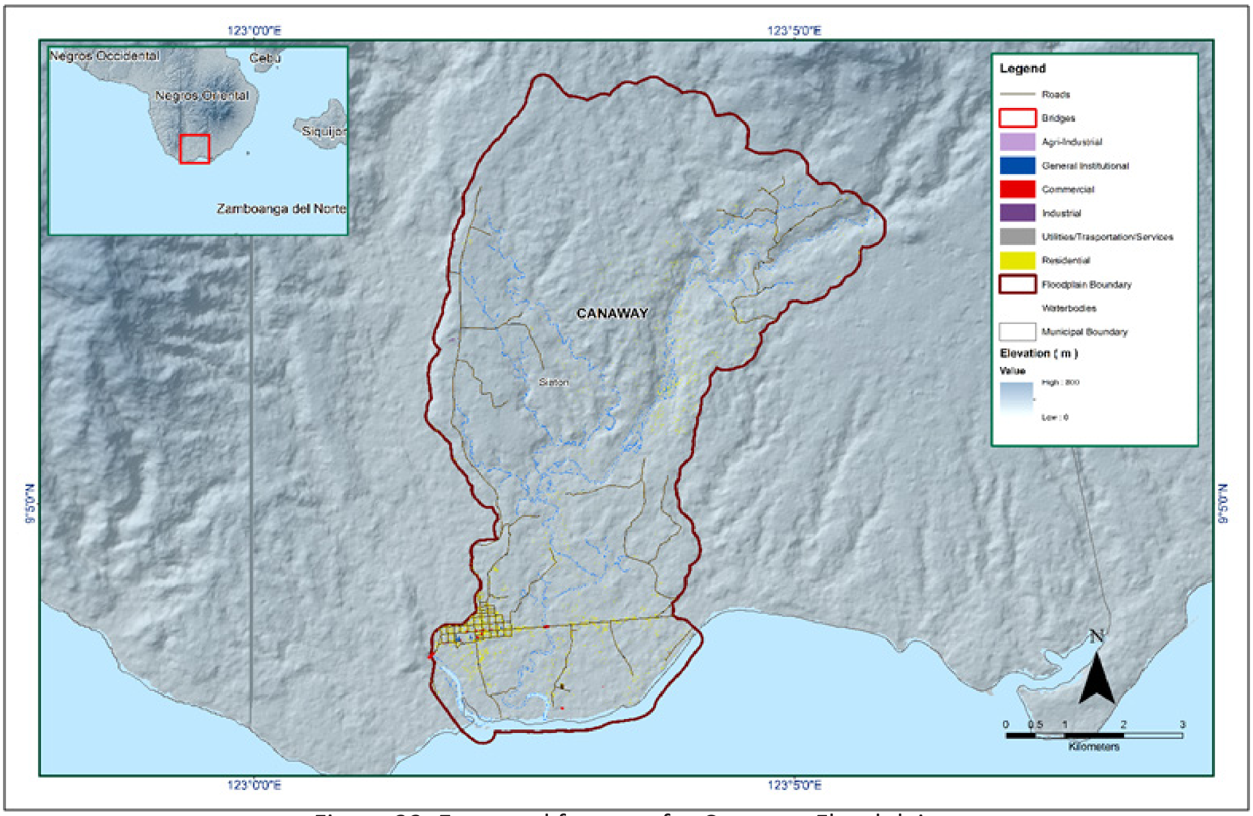


Figure 32. Extracted features for Canaway Floodplain

CHAPTER 4: LIDAR VALIDATION SURVEY AND MEASUREMENTS OF CANAWAY RIVER BASIN

Engr. Louie P. Balicanta, Engr. Joemarie S. Caballero, Ms. Patrizcia Mae. P. dela Cruz, Engr. Kristine Ailene B. Borromeo For. Dona Rina Patricia C. Tajora, and Elaine Bennet Salvador

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 field survey in Canaway River on March 9 to 23, 2016 with the following scope of work: reconnaissance; control survey for the establishment of a control point; cross-section survey on the deployment site located in Barangay Datag, Siaton, Negros Oriental; validation points acquisition survey of about 45 km; and bathymetric survey from Brgy. Datag down to the mouth of the river in Brgy. Poblacion III, both in the Municipality of Saiton with an approximate length of 10.060 km using Ohmex™ single beam echo sounder and Trimble® SPS 882 GNSS PPK survey technique (See Figure 33).

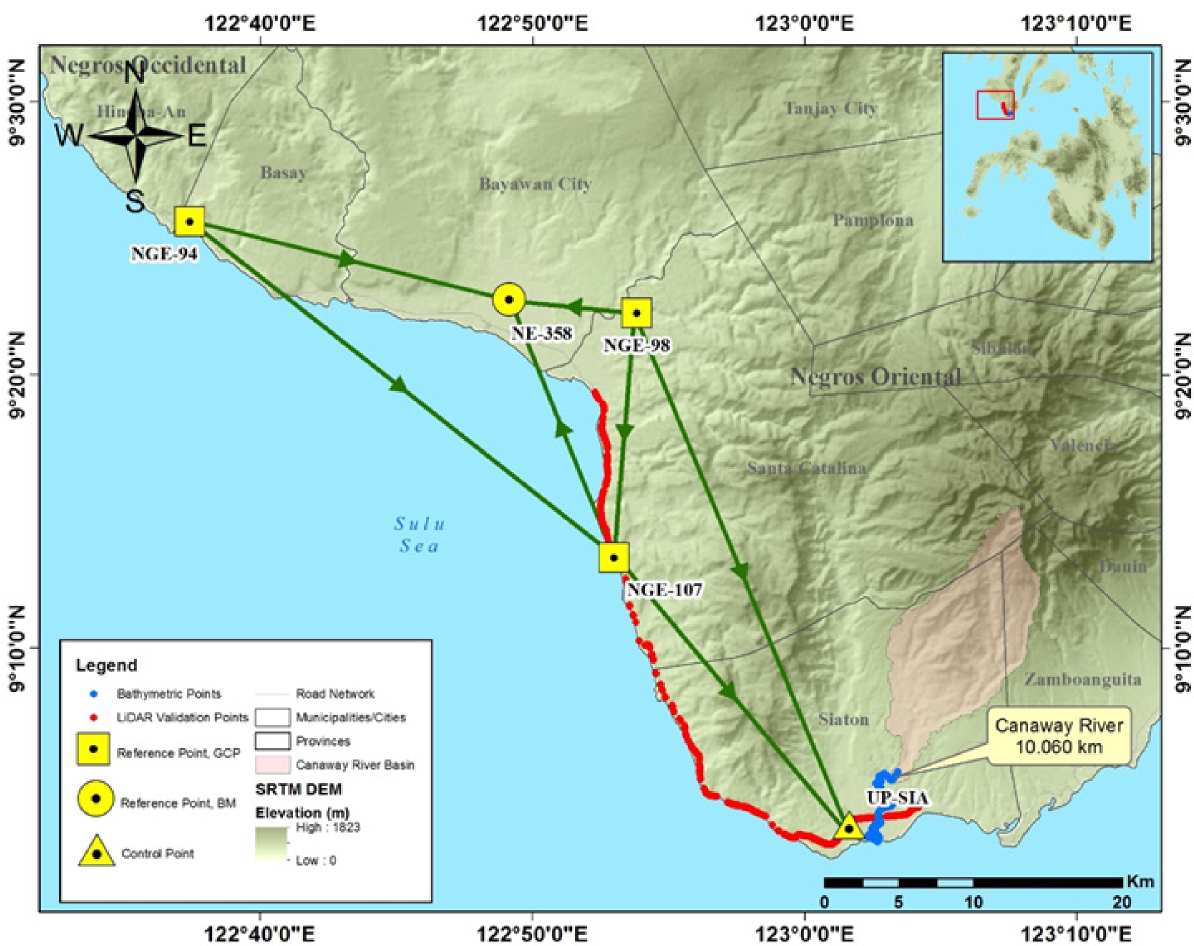


Figure 33 Survey extent for Canaway River Basin

4.2 Control Survey

The GNSS network used for Canaway River Basin is composed of three (3) loops established on March 11, 2016 occupying the following reference points: NGE-98, a second-order GCP, in Brgy. Caranoche, Municipality of Santa Catalina; NGE-107, a second-order GCP, in Brgy. Manalongon, also in Municipality of Santa Catalina; and NE-358, a first-order BM, in Brgy. Ubos, Bayawan City.

A control point was established along the approach of Siaton Bridge, namely UP-SIA, in Brgy. Caticugan, Municiality of Siaton. A NAMRIA established control point, NGE-94 located in Brgy. Bongalonan, Municipality of Basay; was also occupied and used as marker for the network.

The summary of reference and control points and its location is summarized in Table 23 while GNSS network established is illustrated in Figure 34..

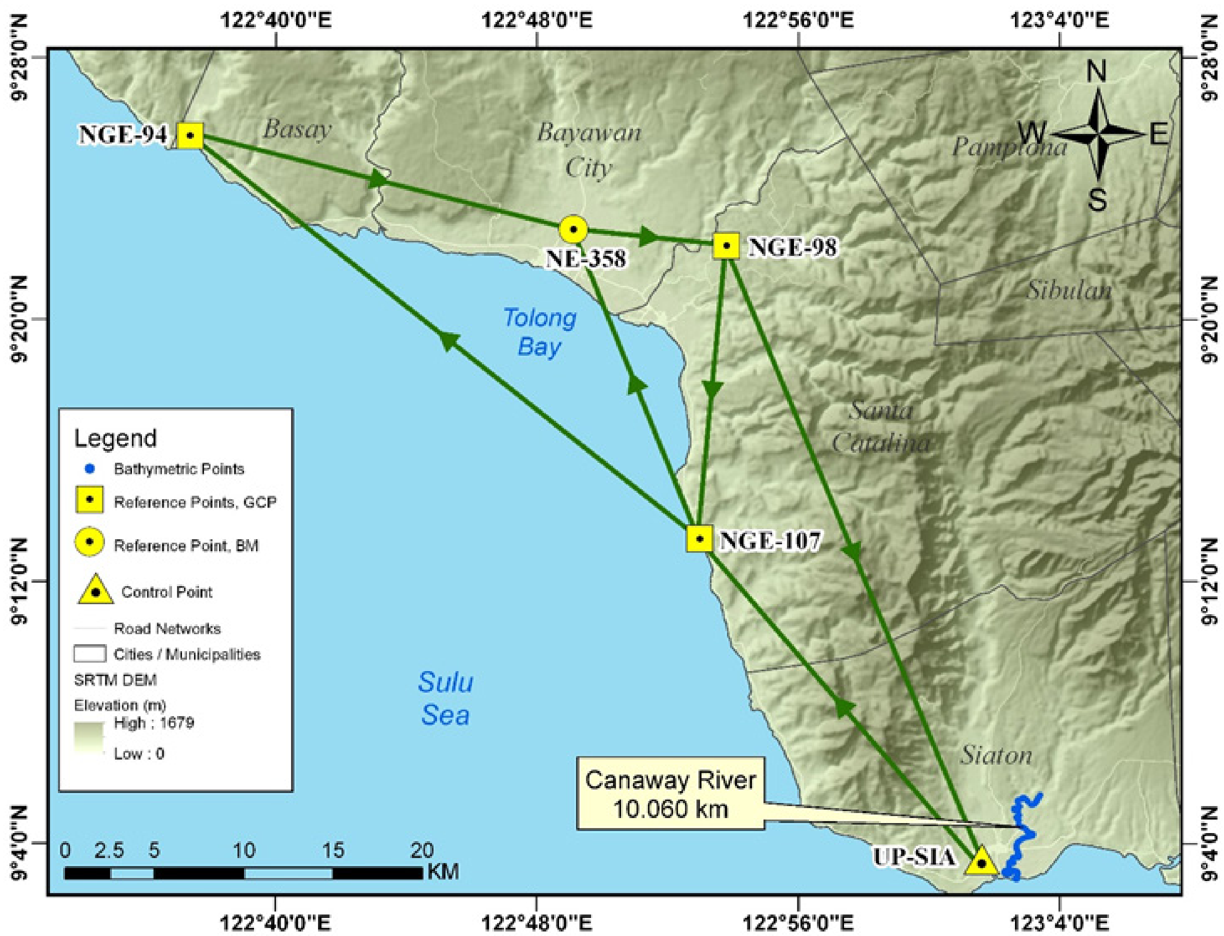


Figure 34 GNSS Network of Canaway River field survey

Table 23 List of reference and control points occupied for Canaway River Survey (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (m)	MSL Elevation (m)	Date Established
NGE-107	2nd Order, GCP	9°13'19.76274"N	122°52'59.03199"E	69.527	-	2007
NGE-98	2nd Order, GCP	9°22'16.41564"N	122°53'48.54064"E	132.087	7.414	2007
NE-358	1st Order, BM	-	-	67.723	5.116	2008
NGE-94	used as marker	-	-	-	-	2007
UP-SIA	Used as marker	-	-	-	-	March 2016

The GNSS set up made in the location of the reference and control points are exhibited are shown in Figure C-3Figure 35 to Figure C-7Figure 39.

Figure 35 GNSS base set up, Trimble® SPS 852, at NGE-98 a second-order GCP located on top of a concrete block along Sta. Catalia-Pamplona Provincial Road, in Brgy. Caranoche, Sta. Catalina, Negros Oriental

Figure 36 GNSS receiver set up, Trimble® SPS 882, at NGE-107, a second order GCP located at the approach of Manalongon Bridge, in Brgy. Manalongon, Sta. Catalina, Negros Oriental

Figure 37 GNSS base set up, Trimble® SPS 855, at NE-358, a first-order BM, located on a culvert along Sta. Caalina-Bayawan Road in Brgy. Ubos, Bayawn City, Negros Oriental

Figure 38 GNSS base set up, Trimble® SPS 855, at NGE-94, a GCP used as marker, located at the approach of Tiabanan's bridge in Brgy. Bongalonan, Basay, Negros Oriental

Figure 39 GNSS receiver set up, Trimble® SPS 882, at UP-SIA, an established control point, located at the approach of Siaton Bridge in Brgy. Caticugan, Siaton, Negros Oriental

4.3 Baseline Processing

GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/-20cm and +/-10cm requirement, respectively. In case where one or more baselines did not meet all of these criteria, masking is was performed. Masking is was done by removing/masking portions of these baseline data using the same processing software. It is was repeatedly processed until all baseline requirements are were met. If the reiteration yields yielded out of the required accuracy, resurvey is was initiated.
Baseline processing result of control points in Canaway River Basin is summarized in Table 24 generated by TBC software.

Table 24 Baseline Processing Report for Canaway River Basin Static Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
NE-358 --- NGE-98	03-11-2016	Fixed	0.004	0.020	276°04'18"	-64.370	-64.370
NGE-98 --- UP-SIA	03-11-2016	Fixed	0.003	0.019	157°29'24"	-61.895	-61.895
NGE-98 --- NGE-107	03-11-2016	Fixed	0.003	0.020	185°14'15"	-62.546	-62.546
NE-358 --- NGE-94	03-11-2016	Fixed	0.005	0.021	103°45'37"	-1.108	-1.108
NE-358 --- NGE-107	03-11-2016	Fixed	0.005	0.032	337°54'15"	-1.830	1.830
UP-SIA --- NGE-107	03-11-2016	Fixed	0.004	0.023	318°46'17"	-0.673	-0.673
NGE-94 --- NGE-107	03-11-2016	Fixed	0.003	0.029	128°25'03"	0.653	0.653

As shown in Table 24, a total of seven (7) baselines were processed with reference points NE-358 fixed for elevation; and NGE-98 and NGE 107 held fixed for grid values. All of them passed the required accuracy.

4.4 Network Adjustment

After the baseline processing procedure, network adjustment is performed using TBC. Looking at the Adjusted Grid Coordinates table 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:
$\sqrt{(x_e)^2+(y_e)^2}<20cm$ and $z_e<10$ cm
Where:
xe is the Easting Error,
yeis the Northing Error, and
zeis the Elevation Error

for each control point. See the Network Adjustment Report shown in TableC-3Table 25 to Table C-5Table 27 for the complete details.

The five (5) control points, NE-358, NGE-98, NE-107, NGE-94 and UP-SIA were occupied and observed simultaneously to form a GNSS loop. Elevation value of NE-358 and coordinates of points NGE-98 and NGE-107 were held fixed during the processing of the control points as presented in Table 3Table 25. Through these reference points, the coordinates and elevation of the unknown control points will bewere computed.

Table 25 Control Point Constraints

Point ID	Type	East σ (Meter	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
LY-338	Grid				Fixed
LYT-737	Local	Fixed	Fixed		
LYT-742	Local	Fixed	Fixed		
Fixed = 0.000001(Meter)					

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table C-4Table 26. The fixed control point NE-358 has no values for elevation error; while NGE-98 and NGE-107 have no values for grid errors.

Table 26 Adjusted Grid Coordinates

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
NGE-98	488670.521	?	1035896.031	?	69.180	0.054	LL
NGE-107	487155.076	?	1019415.410	?	7.670	0.058	LL
NE-358	480099.830	0.009	1036810.192	0.008	5.116	?	e
NGE-94	458621.676	0.015	1042094.324	0.013	7.244	0.058	
UP-SIA	502963.760	0.013	1001378.367	0.011	8.267	0.070	

The network is fixed at reference point NE-358 with known elevation; and NGE-98 and NGE-107 with known coordinates. As shown in Table C-4,Table 26 the standard errors (xe and ye) of NE-358 are 0.90 cm and 0.80 cm; NGE-94 with 1.5 cm and 1.3 cm; and UP-SIA with 1.30 cm and 1.1 cm. With the mentioned equation, $\sqrt{(x_e)^2+(y_e)^2}<20cm$ for horizontal and $z_e<10$ cm for the vertical; the computation for the accuracy are as follows:

a. NGE-98
horizontal accuracy = Fixed
vertical accuracy = 5.40 < 10 cm

b. NGE-107
horizontal accuracy = Fixed
vertical accuracy = 5.80 cm < 10 cm

c. NE-358
horizontal accuracy = √((0.90)² + (0.80)²
= √ (0.81 + 0.64)
= 1.20 cm < 20 cm
vertical accuracy = Fixed

d. NGE-94
horizontal accuracy = √((1.50)² + (1.30)²
= √ (2.25 + 1.69)
= 1.98 cm < 20 cm
vertical accuracy = 5.80 cm < 10 cm

e. UP-SIA
horizontal accuracy = √((1.30)² + (1.10)²
= √ (1.69 + 1.21)
= 1.70 cm < 20 cm
vertical accuracy = 7.0 cm < 10 cm

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

Table 27 Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Ellipsoidal Height (Meter)	Height Error (Meter)	Constraint
NGE-98	N9°22'16.41564"	E122°53'48.54064"	132.087	0.054	LL
NGE-107	N9°13'19.76274"	E122°52'59.03199"	69.527	0.058	LL
NE-358	N9°22'46.06928"	E122°49'07.51892"	67.723	?	e
NGE-94	N9°25'37.57022"	E122°37'23.12090"	68.846	0.058	
UP-SIA	N9°03'32.50400"	E123°01'37.08746"	70.195	0.070	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table C-5Table 27. Based on the result of the computation, the accuracy conditions are satisfied; hence, the required accuracy for the program was met.

The summary of reference and control points used is indicated in Table C-6Table 28.

Table 28 Reference and control points used and its location
(Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing	Easting	BM Ortho (m)
NGE-98	2nd order, GCP	9°22'16.41564"N	122°53'48.54064"E	132.087	1035896.031	488670.521	69.180
NGE-107	Used as marker	9°13'19.76274"N	122°52'59.03199"E	69.527	1019415.410	487155.076	7.670
NE-358	1st order, BM	9°22'46.06928"N	122°49'07.51892"E	67.723	1036810.192	480099.830	5.116
NGE-94	UP Established	9°25'37.57022"N	122°37'23.12090"E	68.846	1042094.324	458621.676	7.244
UP-SIA	UP-Established	9°03'32.50400"N	123°01'37.08746"E	70.195	1001378.367	502963.760	8.267

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

Since there is no bridge located at the upstream of Canaway River, cross-section survey was conducted at the upstream flow measurement and sensors deployment site as shown in Figure C-8Figure 40. The GNSS receiver, Trimble® SPS 882, in PPK survey technique was used to conduct the survey.

Figure 40 The a) left bank and b) right bank of the deployment site when looking upstream

The cross-sectional line length of the selected deployment site is about 41.931 m with 66 cross-sectional points acquired using UP-SIA as the GNSS base station. The cross-section diagram and its location map are shown in Figure C-9Figure 41 and Figure C-10Figure 42, respectively.

Water surface elevation of Canaway River, as shown in Figure C-9Figure 41, was determined on March 17, 2016 at 1:58PM with a value of 10.868 m in MSL. The Partner HEI for Canaway River, USC PHIL-LiDAR 1, will be usingused this data as their reference for flow data gathering and depth gauge deployment for Canaway River. A structure for the installation of an AWLS and water level marking shall bewas constructed along this identified non-bridge flow measurement site.

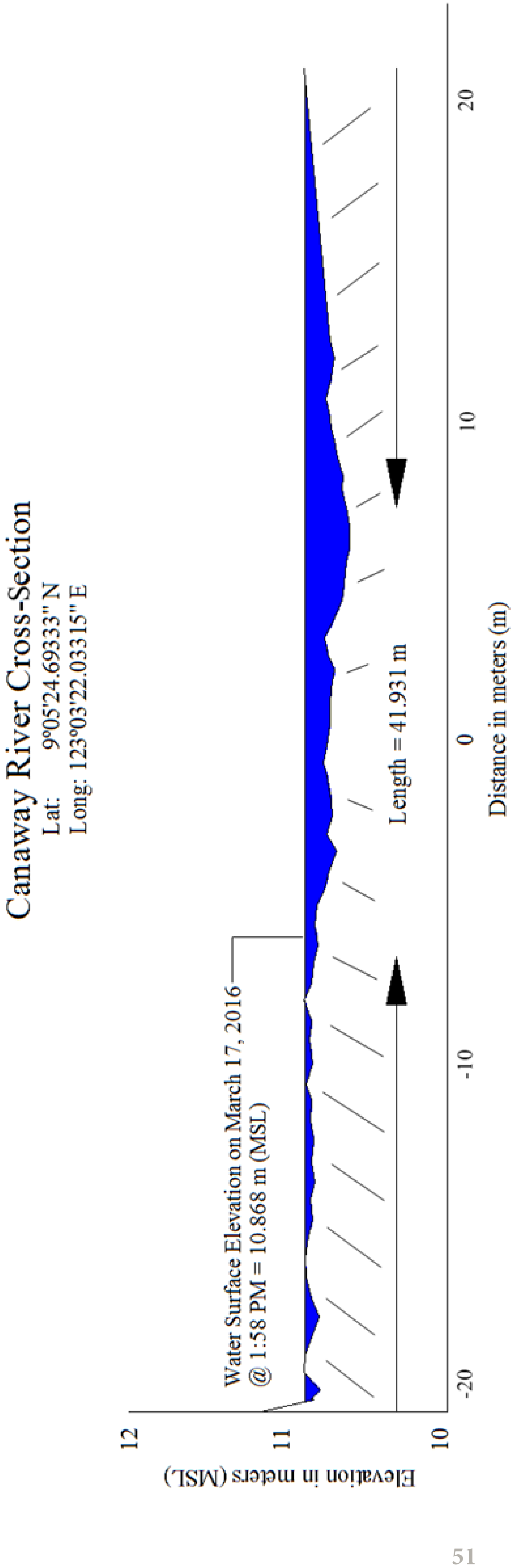


Figure 41 Canaway River deployment site cross-section diagram

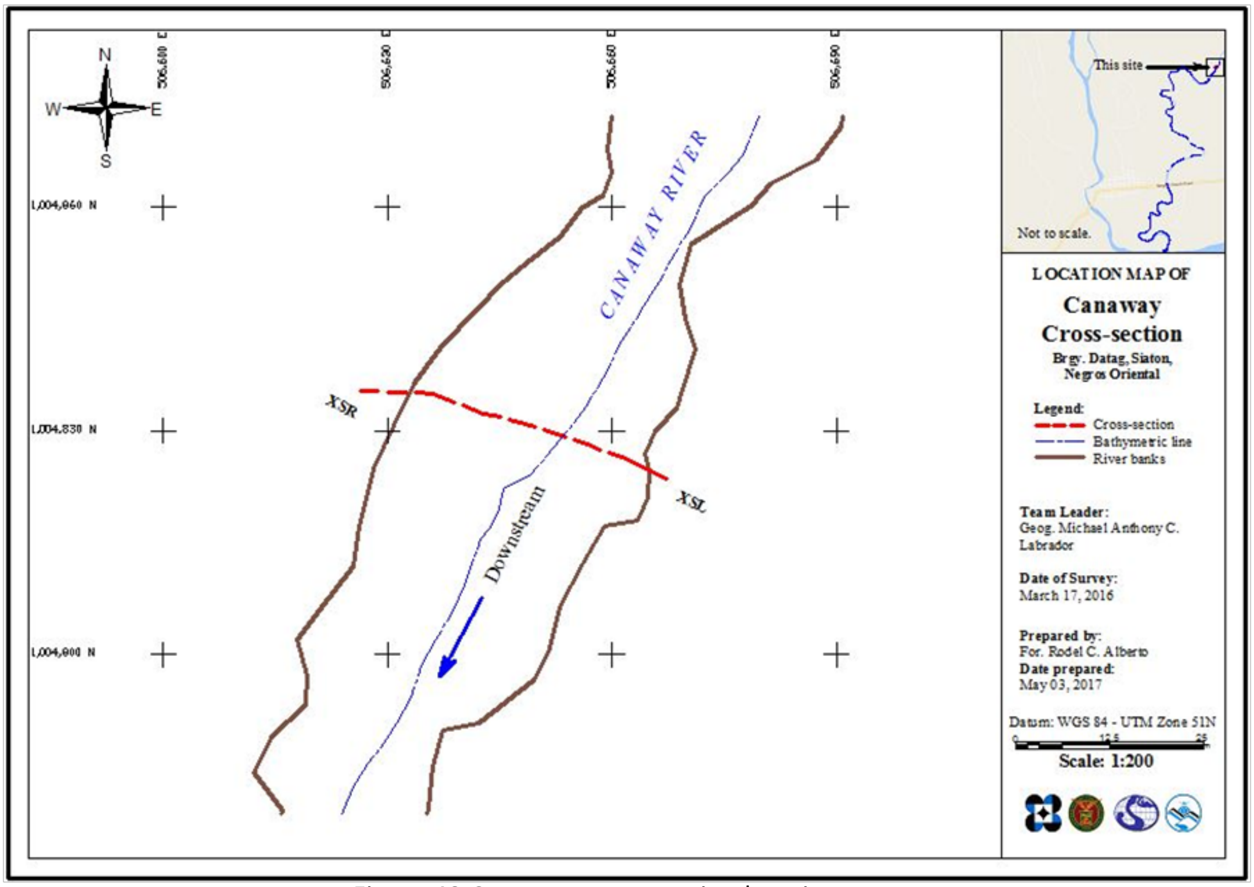


Figure 42 Canaway cross-section location map

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on March 17 and 18, 2016 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted on a pole which was attached to the side of vehicle as shown in Figure C-11. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The antenna height was 2.265 m and measured from the ground up to the bottom of notch of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with UP-SIA occupied as the GNSS base stations in the conduct of the survey.

Figure 43 Validation points acquisition survey set- up

The survey started from Brgy. Poblacion in the Municipality of Santa Catalina going south. The survey traversing transversed 19 barangays towards the Municipality of Siaton which and ended in Brgy. Inalad. This route aims aimed to cut flight strips perpendicularly. It gathered 3,270 points with approximate length of 45 km using UP-SIA as GNSS base for the entire extent validation points acquisition survey as illustrated in the map in Figure C-12Figure 44.

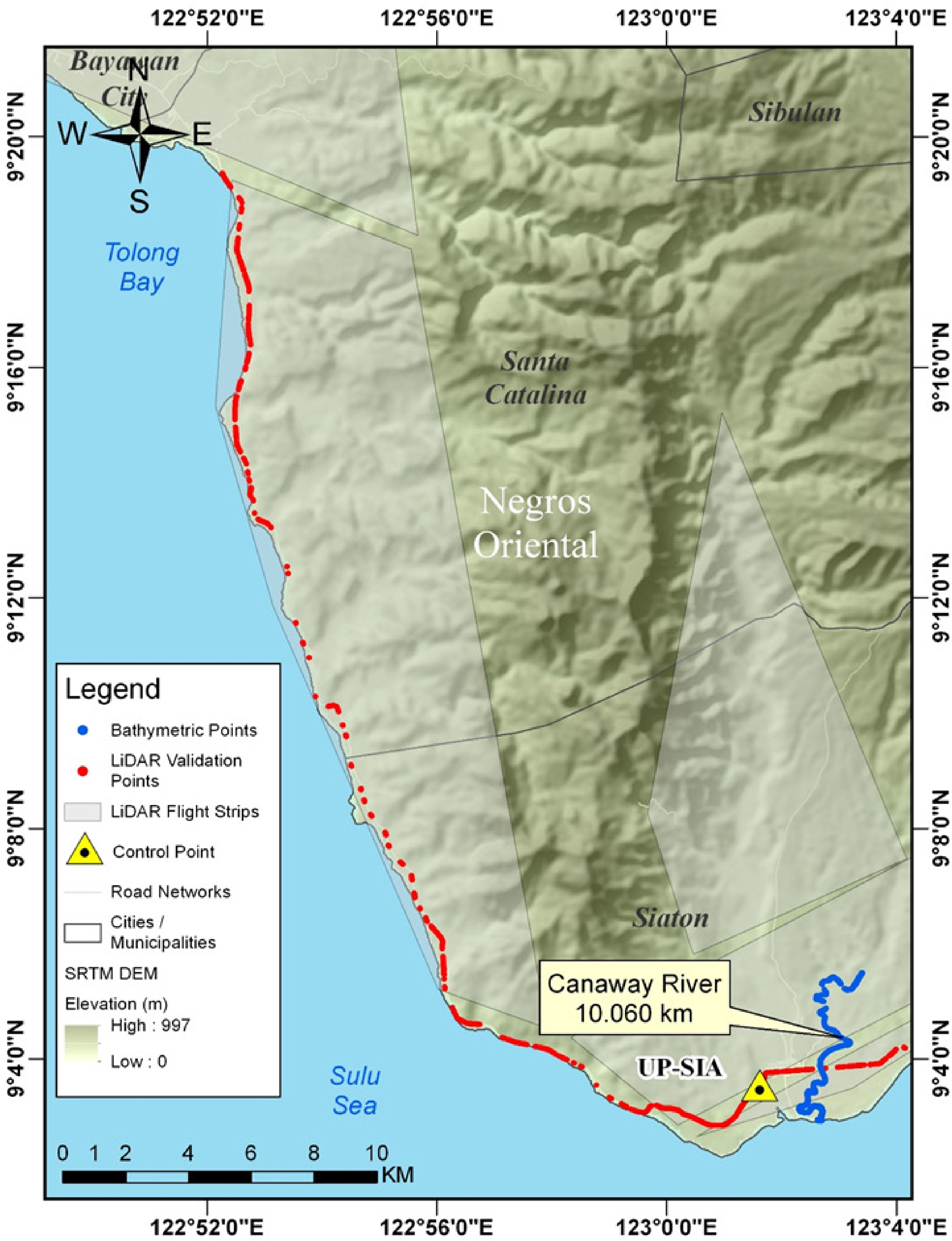


Figure 44 LiDAR Validation points acquisition survey for the Canaway River Basin

4.7 River Bathymetric Survey

Bathymetric survey was executed on March 17, 2016 using a Trimble® SPS 882 in GNSS PPK survey technique and Ohmex™ single beam echo sounder, as illustrated in Figure 45Figure C-13. The extent of the survey is from the upstream portion of the river in Brgy. Datag with coordinates 9°05'29.83477"N, 123°03'24.67405"Edown to the mouth of the river in Brgy. Poblacion III with coordinates 9°02'56.75852"N, 123°02'38.10258"E, both in the Municipality of Siaton.

On the same day, manual bathymetry was also executed using Trimble® SPS 882 in GNSS PPK survey technique. The survey started from the uppermost upmost part of the river in Brgy. Datag with coordinates 9d°4'31.39422"N, 123°02'51.01616"E, traversed down by foot up to the starting point of bathymetry by boat also in Brgy. Datag, in the Municipality of Siaton. Both bathymetric survey technique utilized continuous topo with control point UP-SIA as the GNSS base station.

Figure 45 a) Bathymetry by boat set up with mounted Trimble® SPS 882 and b) manual bathymetry using Topcon Total Station OS-105 for Canaway River survey

A CAD drawing was also produced to illustrate the riverbed profile of Canaway River. As shown in Figure C-15Figure 47, the highest and lowest elevation has a 14-meter difference. The highest elevation observed was 11.063 m above MSL located in Brgy. Datug, while the lowest was 3.761 m below MSL located in Brgy. Poblacion III. The bathymetric survey gathered a total of 14,890 points covering 10.060 km of the river.

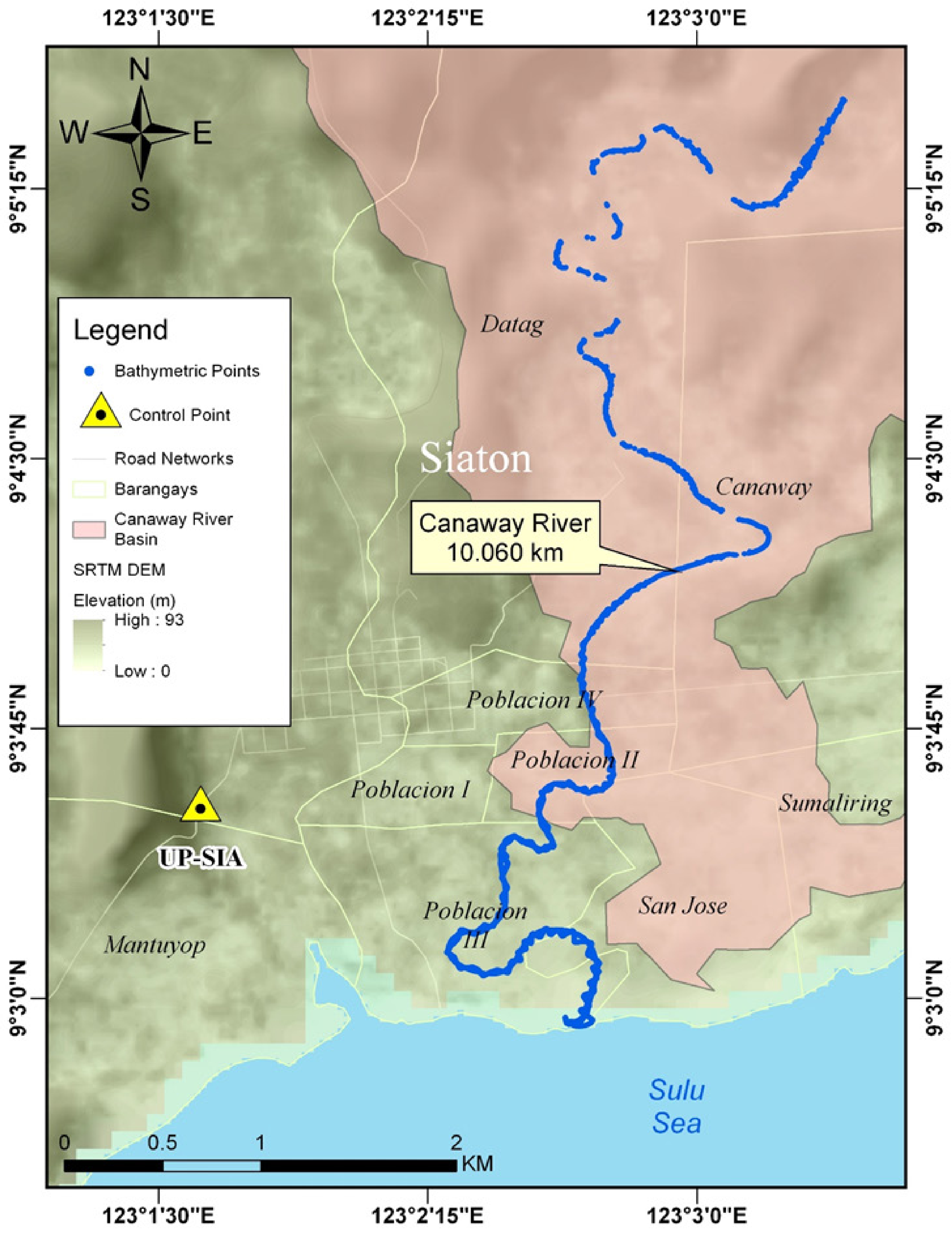


Figure 46 Bathymetric survey of Canaway River

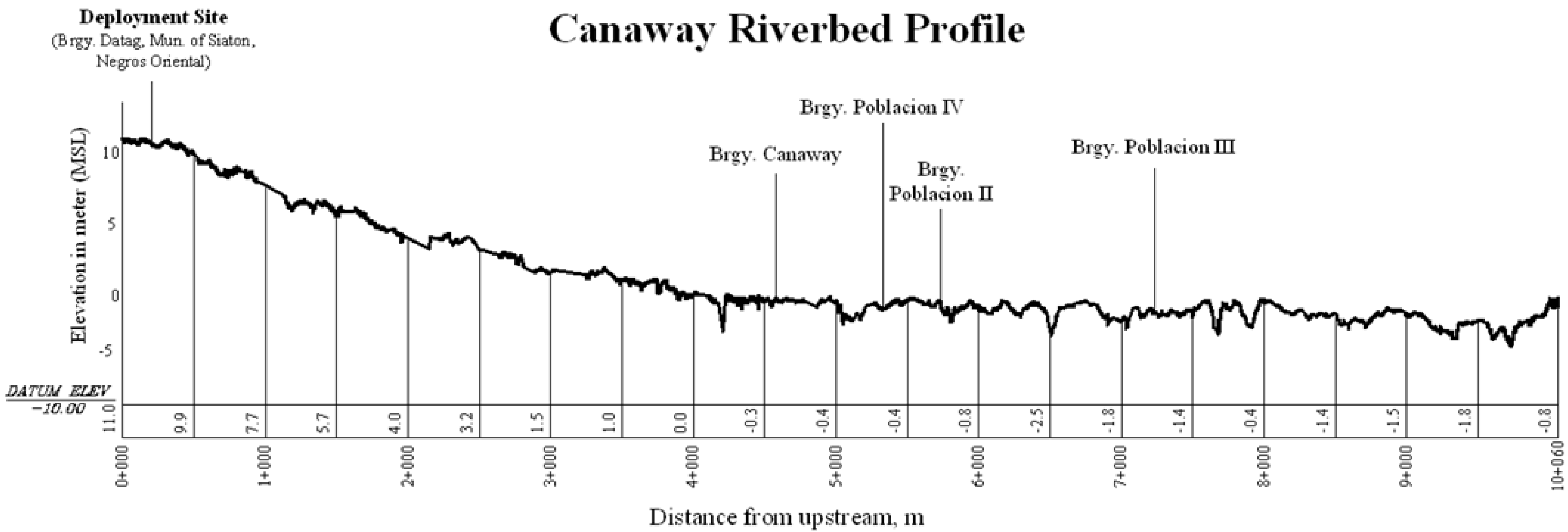


Figure 47 Riverbed profile of Canaway River

CHAPTER 5 : FLOOD MODELING AND MAPPING

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

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

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

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

5.1.2 Precipitation

Precipitation data was taken from rain gauges (RG) installed by the University of San Carlos Phil LiDAR 1 Team. The locations of the RG are in Mainit Elementary School, Brgy. Tayak, Siaton and in Sitio Cambunbun, Brgy. Balanan, Siaton. The location of the rain gauges are as shown in Figure 48.

The total rain from the Brgy. Tayak Station is was 29.7 mm while that of Brgy. Balanan is was 12 mm. The rainfall data from the Brgy. Tayak station peaked to 5.2mm on 17:20 on March 15, 2017. On the other hand, the rainfall data from Brgy. Balanan peaked to 2.2 mm on 12:20 on March 15, 2017.

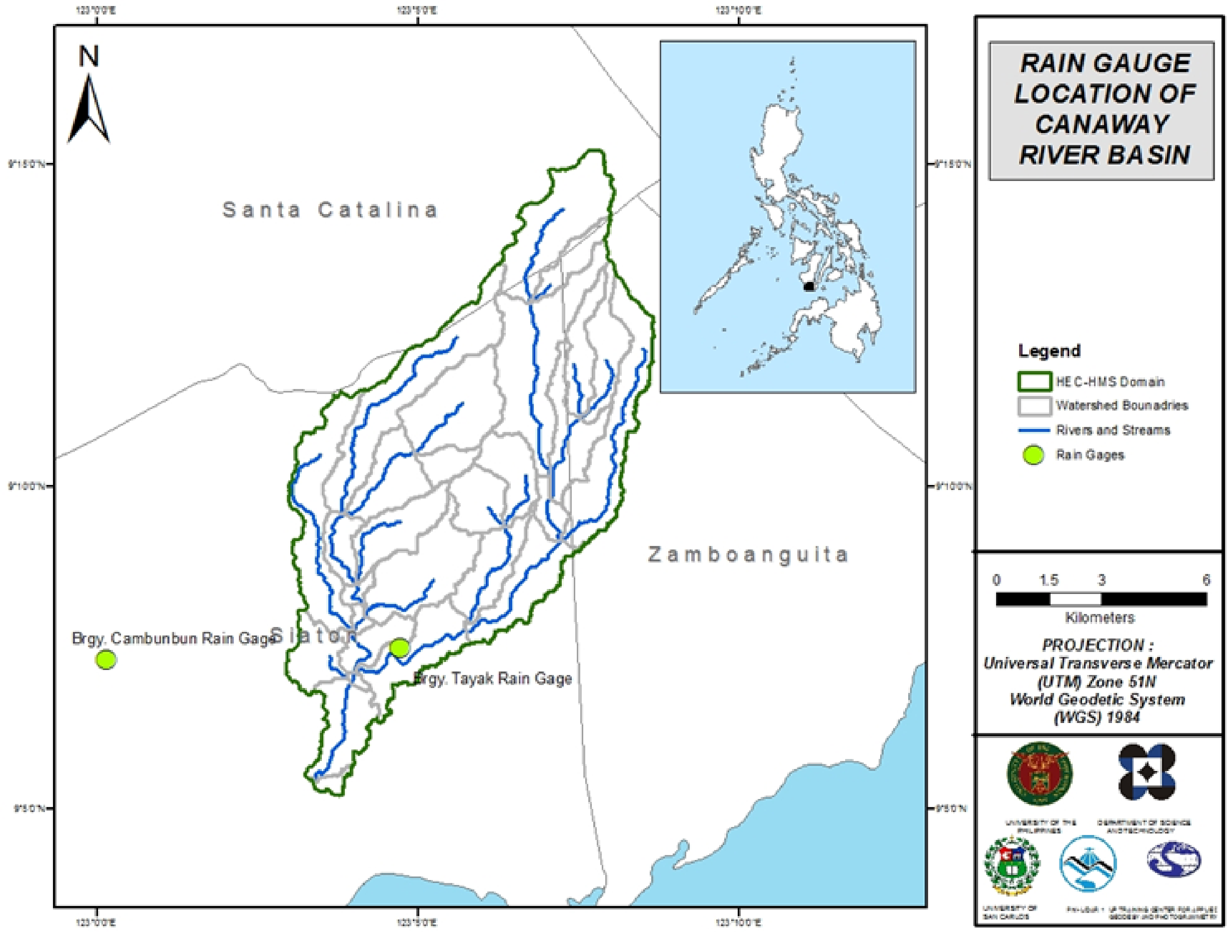


Figure 48 The location map of Canaway HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Brgy. Canaway (9°5’25.3”N 123°3’21.6”E).It gives the relationship between the observed water levels and outflow of the watershed at this location.

For Brgy.Canaway, the rating curve is expressed y=2E-21e^4.4478xas shown in Figure 5Figure 50.

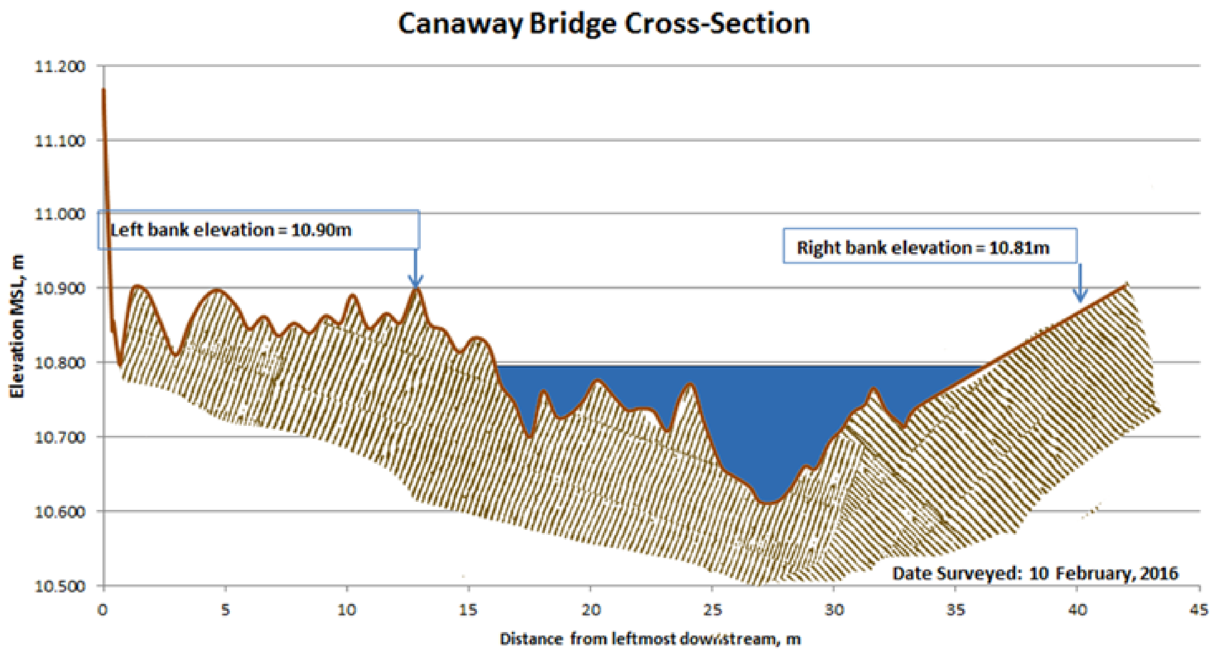


Figure 49 Cross-Section Plot of Canaway Bridge

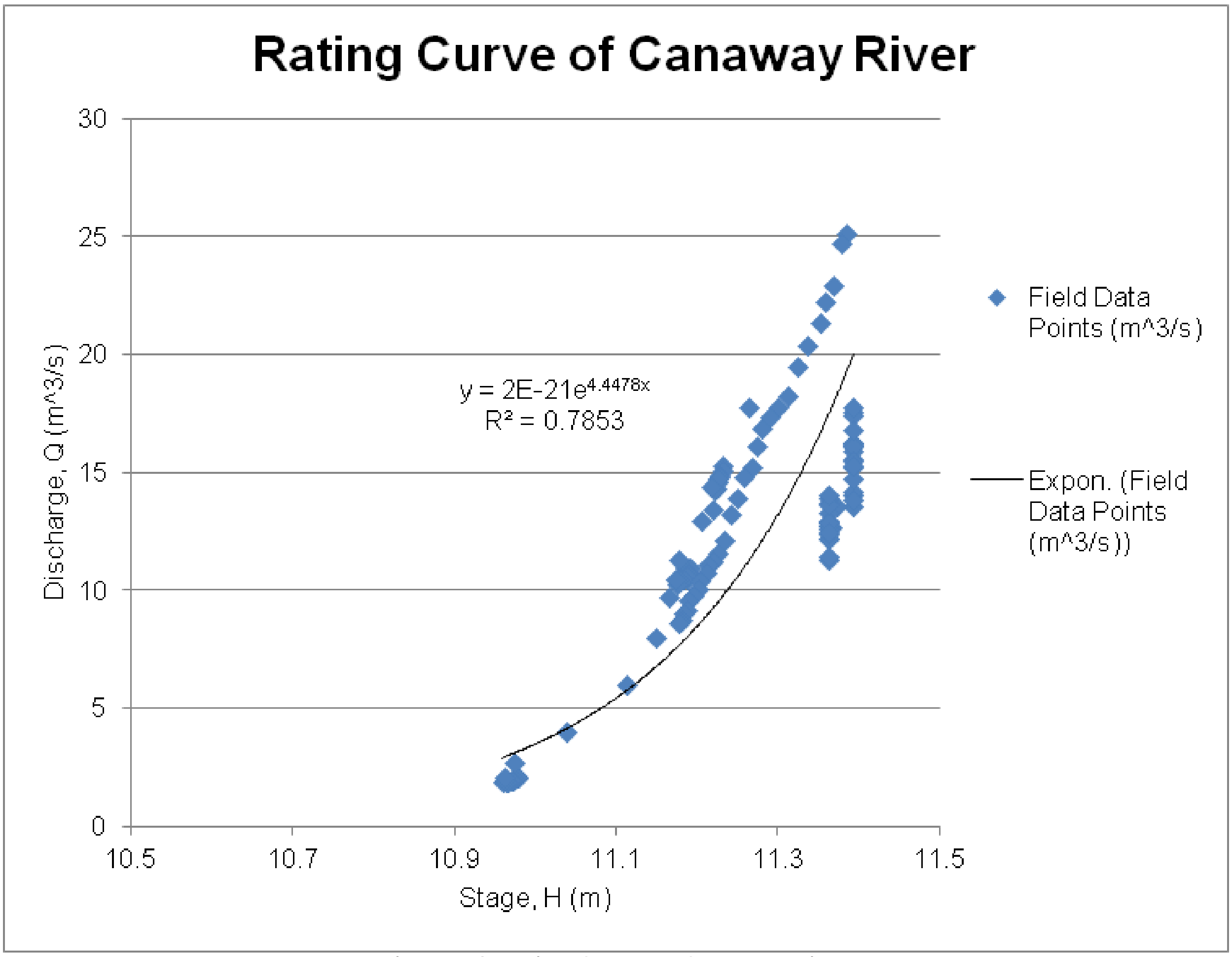


Figure 50 Rating Curve at Canaway River

This rating curve equation was used to compute the river outflow at Brgy.Canaway for the calibration of the HEC-HMS model shown in Figure 651. Peak discharge is was 25.4m3/sat 19:20, March 15, 2017.

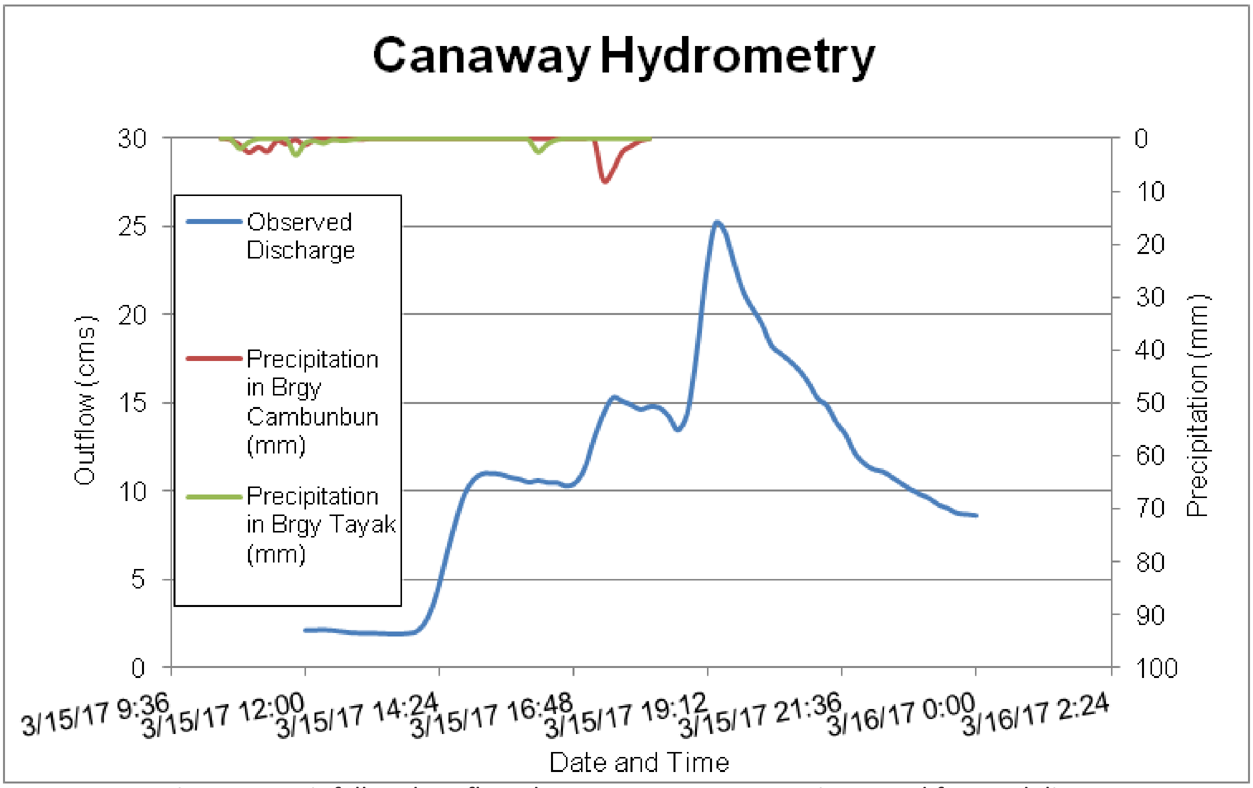


Figure 51 Rainfall and outflow data at Brgy.Canaway, Saiton used for modeling

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Dumaguete Point Gauge. This station was chosen based on its proximity to the Canaway watershed. The extreme values for this watershed were computed based on a 35-year record.

Table 29 RIDF values for Dumaguete Point 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	16.2	24.8	30.6	39.7	50	55.3	63.4	69.1	76
5	21.8	33.6	42.3	57.1	76.5	87.3	100	109.5	116.5
10	25.6	39.4	50	68.6	94	108.5	124.3	136.3	143.3
15	27.7	42.7	54.3	75.1	103.9	120.5	138	151.4	158.4
20	29.1	45	57.4	79.7	110.8	128.9	147.5	162	169
25	30.3	46.8	59.7	83.2	116.1	135.3	154.9	170.2	177.2
50	33.8	52.3	66.9	94	132.5	155.2	177.6	195.3	202.4
100	37.2	57.7	74.1	104.8	148.8	174.9	200.2	220.2	227.3

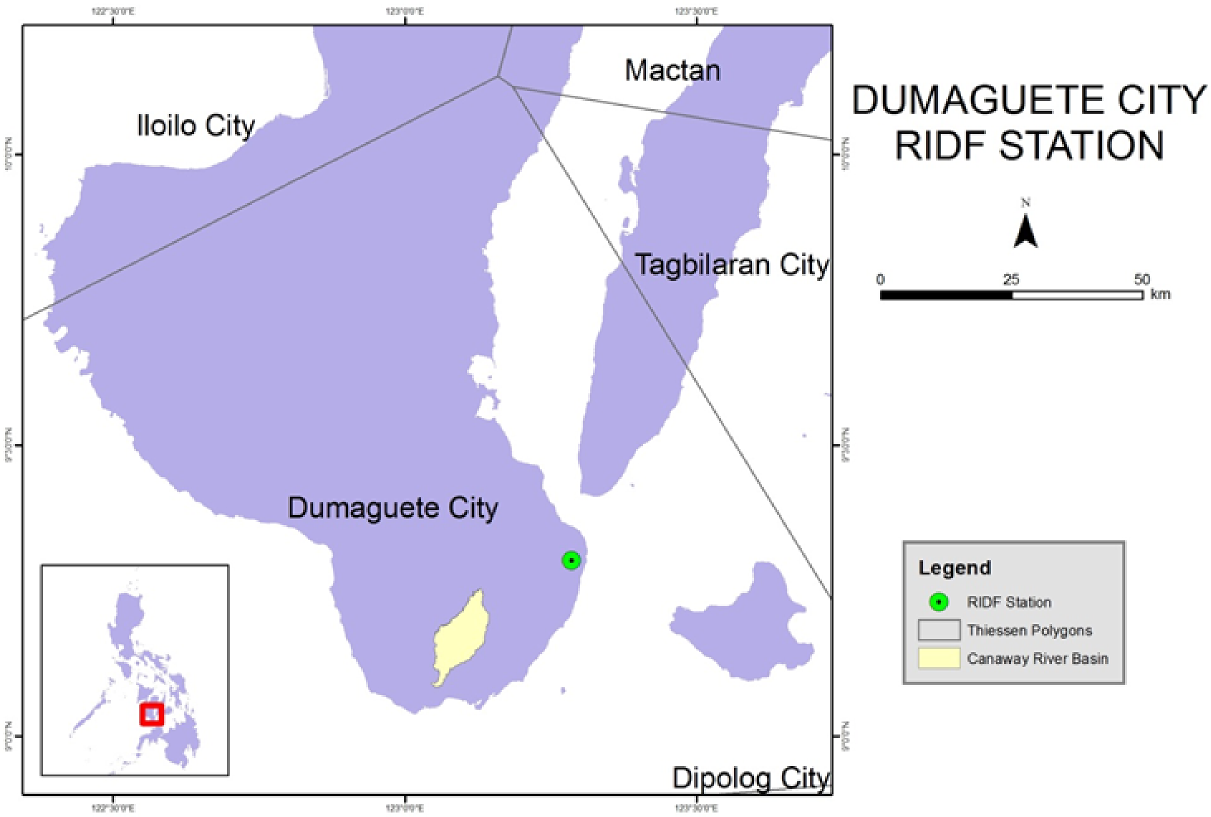


Figure 52 Dumaguete Point RIDF location relative to Ocoy Canaway River Basin

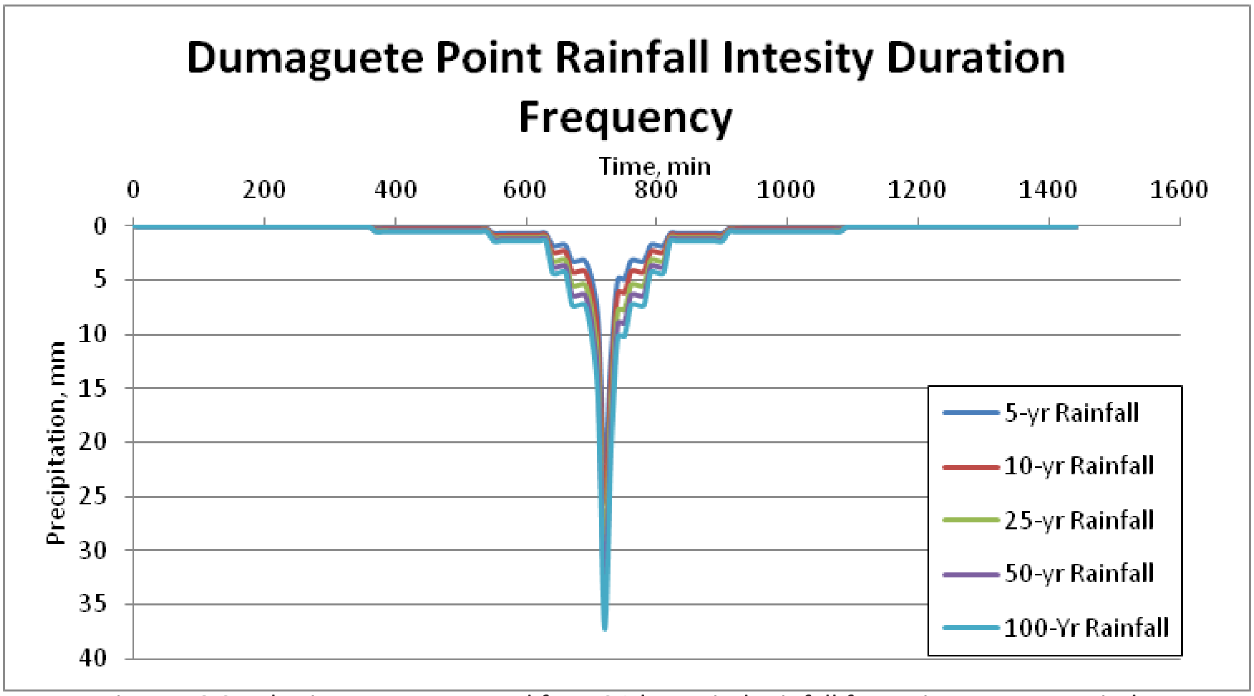


Figure 53 Synthetic storm generated for a 24-hr period rainfall for various return periods

5.3 HMS Model

The soil dataset was generated before 2004 by the Bureau of Soils under the Department of Agriculture (DA). The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA).

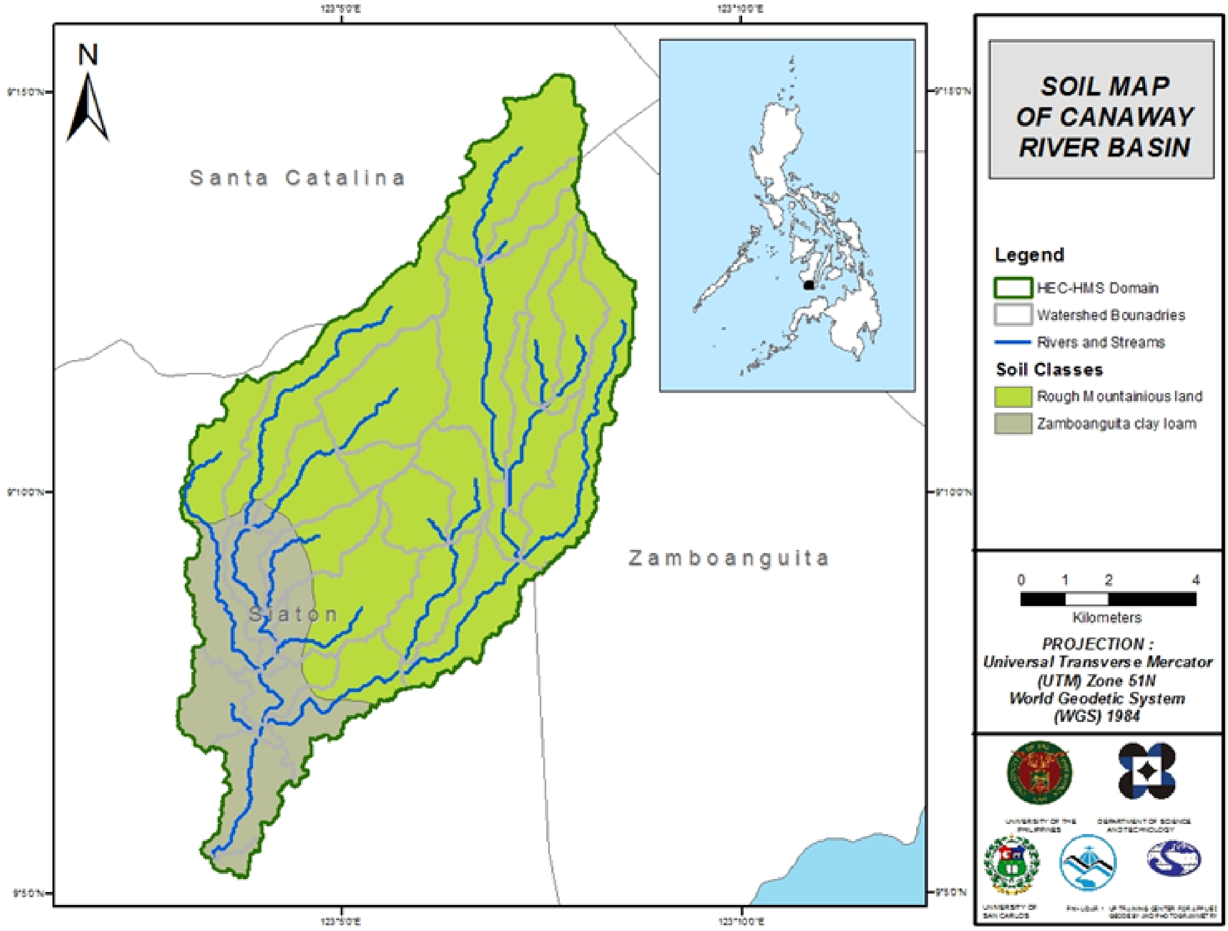


Figure 54 The soil map of the Canaway River Basin used for the estimation of the CN parameter. (Source of data: Digital soil map of the Philippines published by the Bureau of Soil and Water Management – Department of Agriculture)

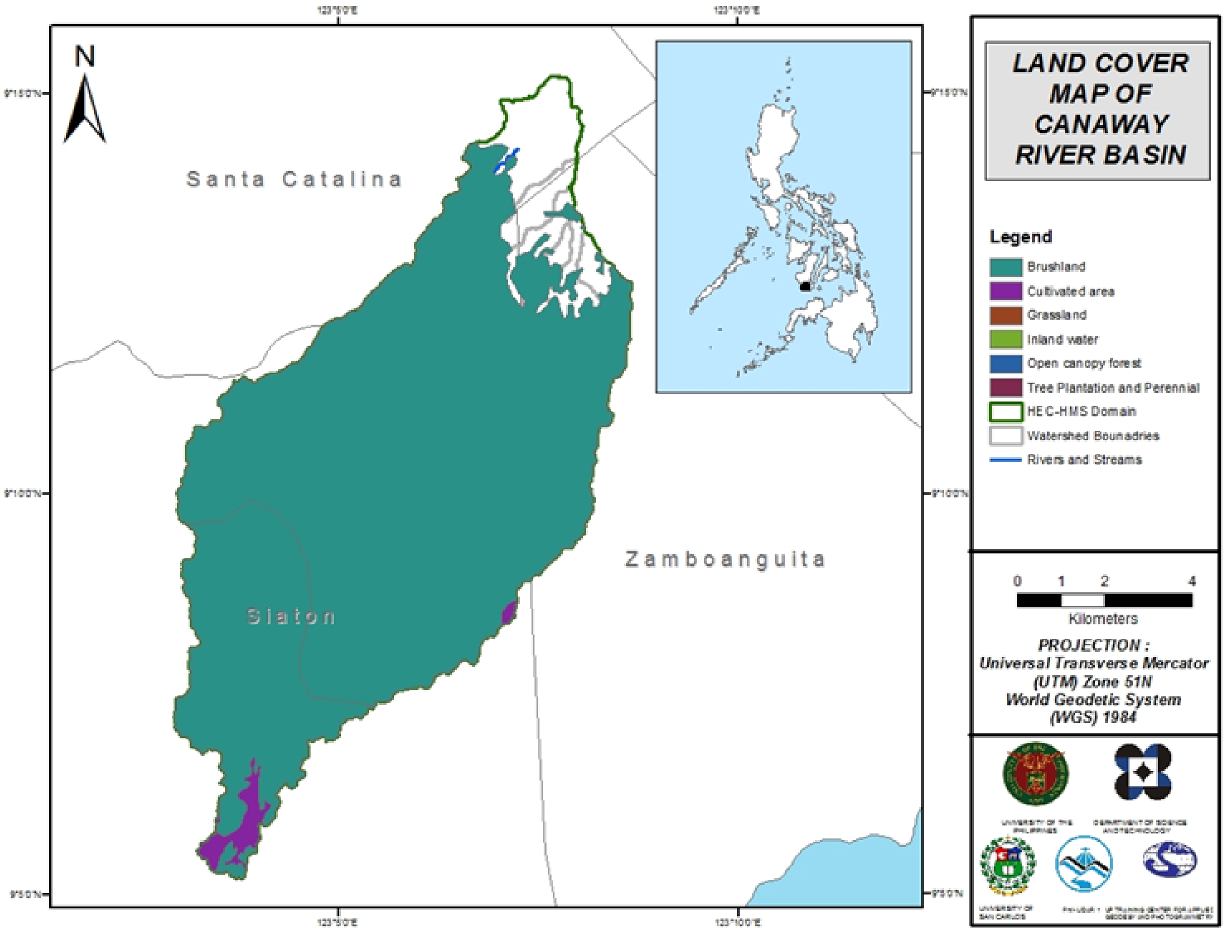


Figure 55 The land cover map of the Canaway River Basin used for the estimation of the CN and watershed lag parameters of the rainfall-runoff model. (Source of data: National Mapping and Resource Information Authority)

For Canaway , two soil classes were identified. These are clay loam and mountain soil. Moreover, the land cover classes identified were brushland and cultivated

This image is not available for this river basin.

Figure 55 The Slope Map of the Canaway River Basin

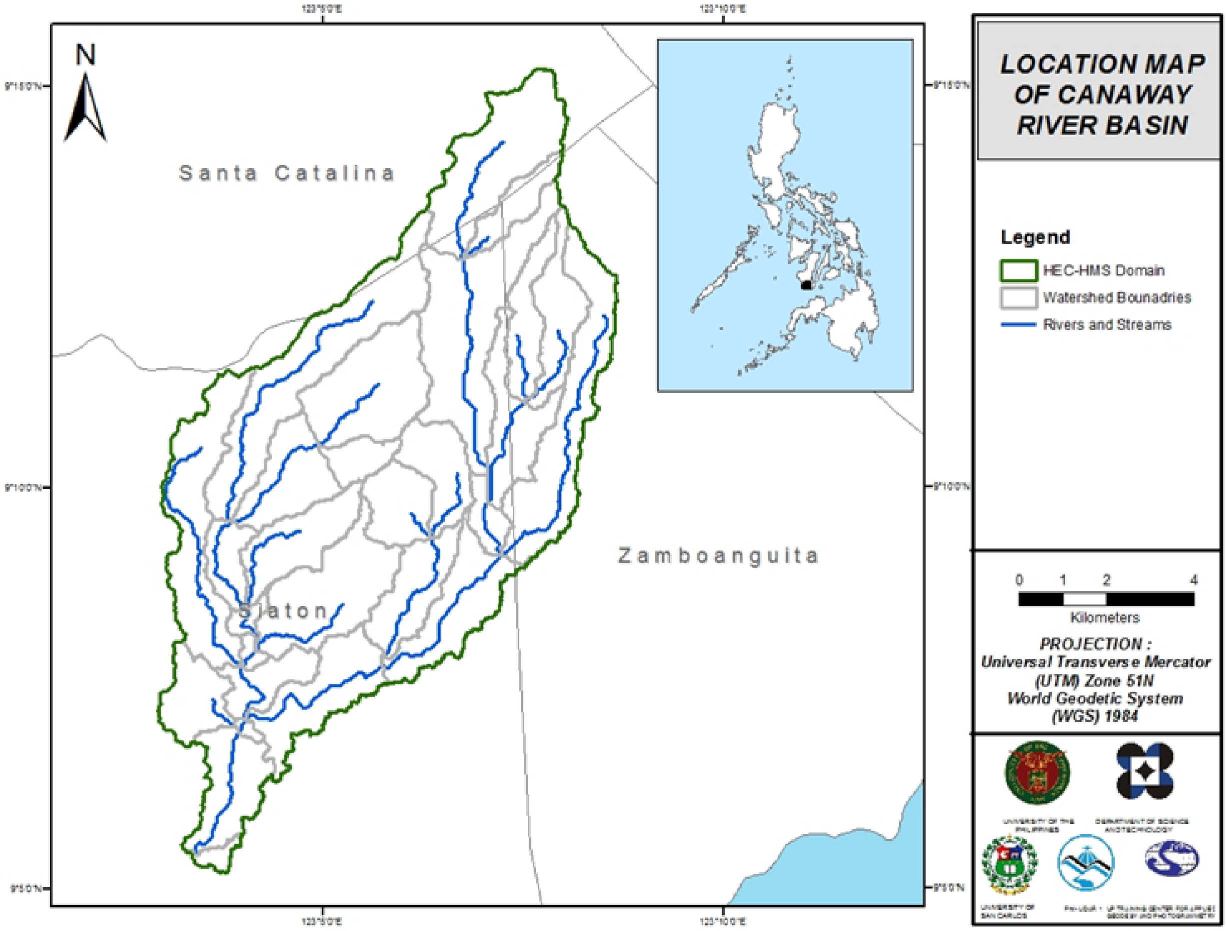


Figure 57 Stream Delineation Map of Canaway River Basin relative to the Philippines

The Canaway basin model comprises 27 sub basins,13 reaches, and 13 junctions. The main outlet is outlet 1. This basin model is illustrated in Figure 9Figure 58. The basins were identified based on soil and land cover characteristic of the area. Precipitation was taken from an installed Rain Gauge near and inside the river basin. Finally, it was calibrated using the data from actual discharge flow gathered in Brgy. Canaway.

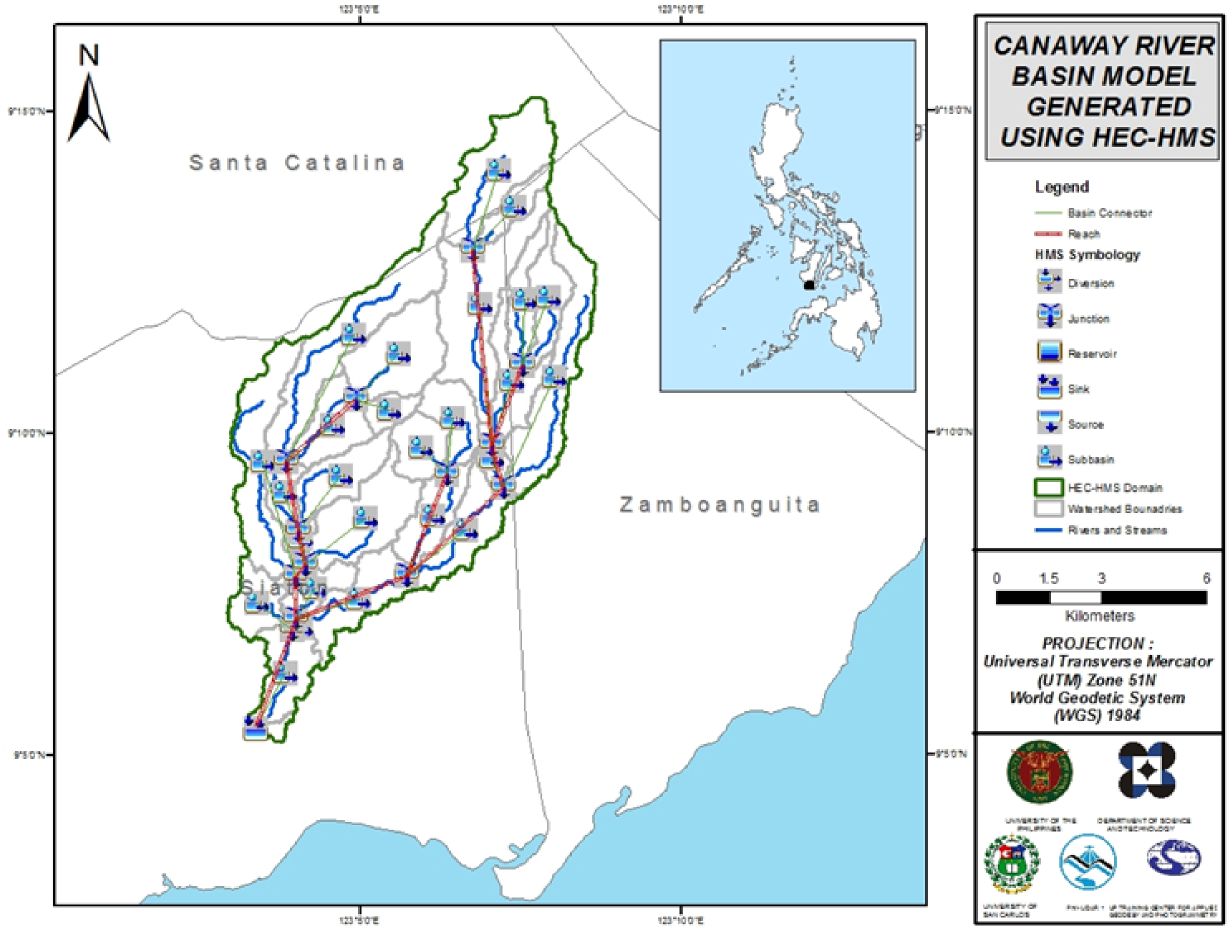


Figure 58 The Canaway River Basin Model Domain generated using HEC-HMS

5.4 Cross-section Data

Riverbed cross-sections of the watershed are crucial in the HEC-RAS model set-up. 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.

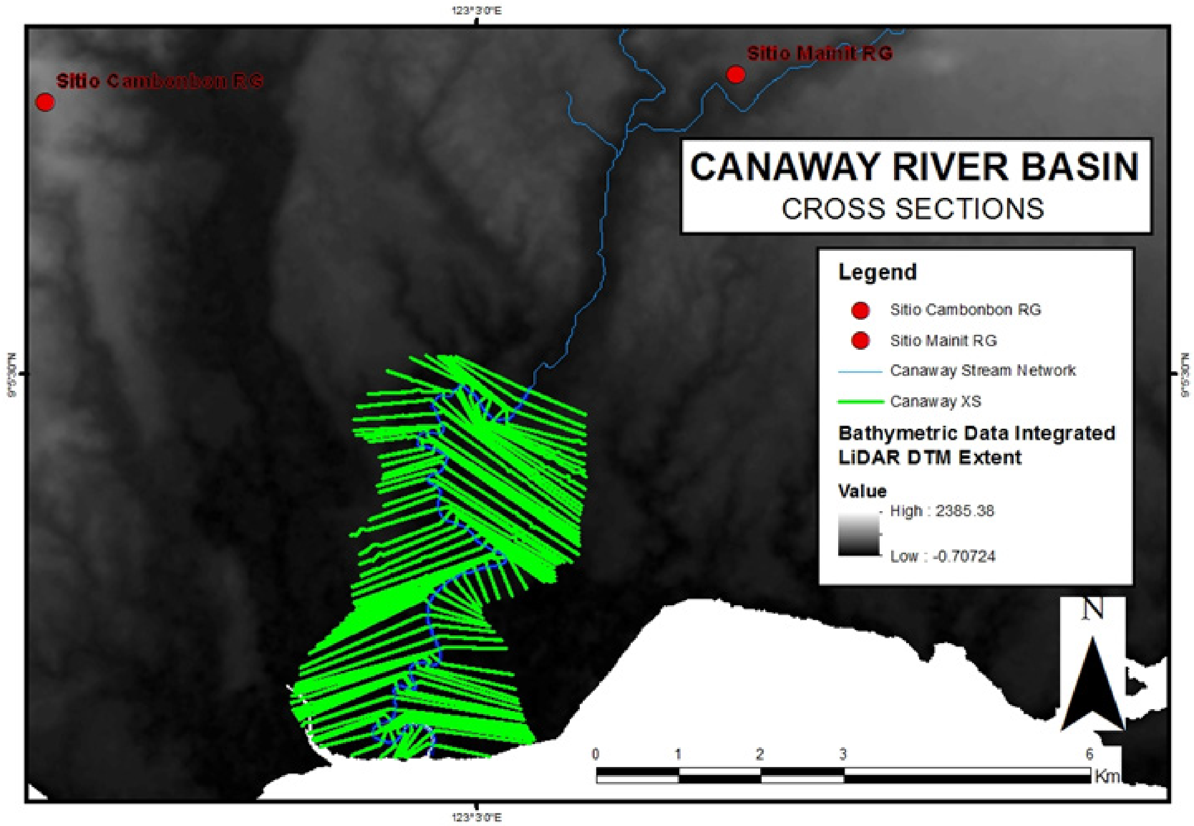


Figure 59 River cross-section of Canaway River generated through Arcmap HEC GeoRAS tool

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 north of the model to the south, following the main channel. As such, boundary elements in those particular regions of the model are assigned as inflow and outflow elements respectively.

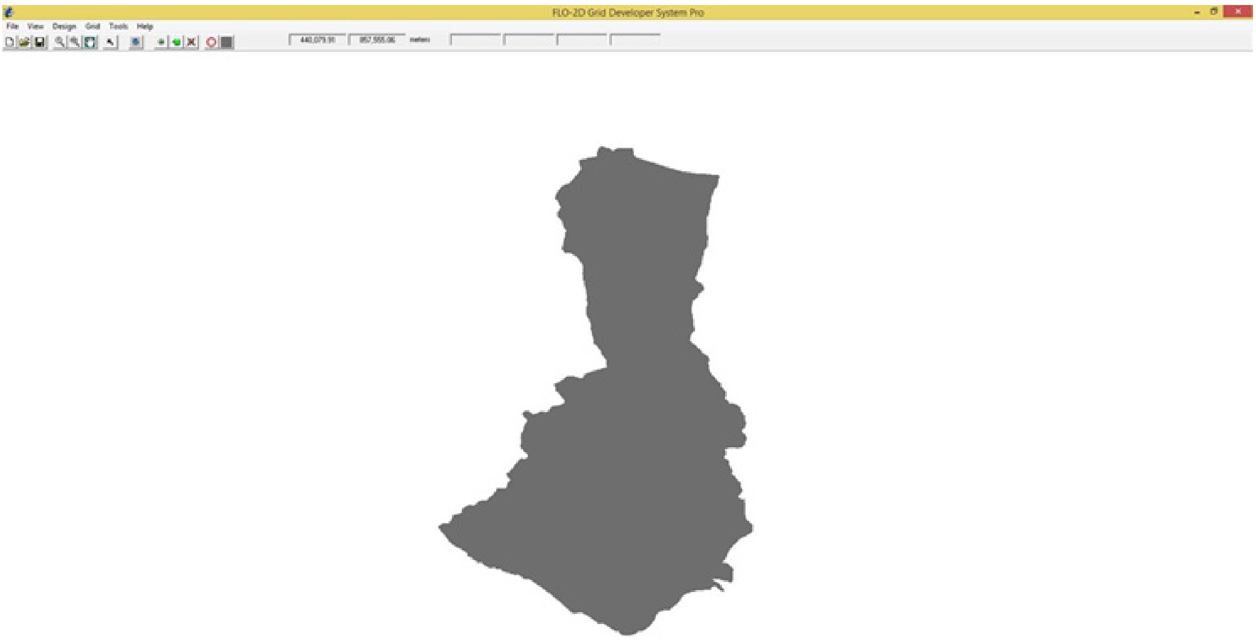


Figure 60 Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 23.91504 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m2/s.

The creation of a flood hazard map from the model also automatically creates a flow depth map depicting the maximum amount of inundation for every grid element. The legend used by default in Flo-2D Mapper is not a good representation of the range of flood inundation values, so a different legend is used for the layout. In this particular model, the inundated parts cover a maximum land area of 38,515,400.00m2.

There is a total of 36,519,889.86m3 of water entering the model. Of this amount, 7,884,112.82 m3 is due to rainfall while 28,635,777.03 m3 is inflow from other areas outside the model. 3,314,226.25 m3 of this water is lost to infiltration and interception, while 1,945,968.08 m3 is stored by the flood plain. The rest, amounting up to 31,259,694.77 m3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Canaway HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 8Figure 61 shows the comparison between the two discharge data.

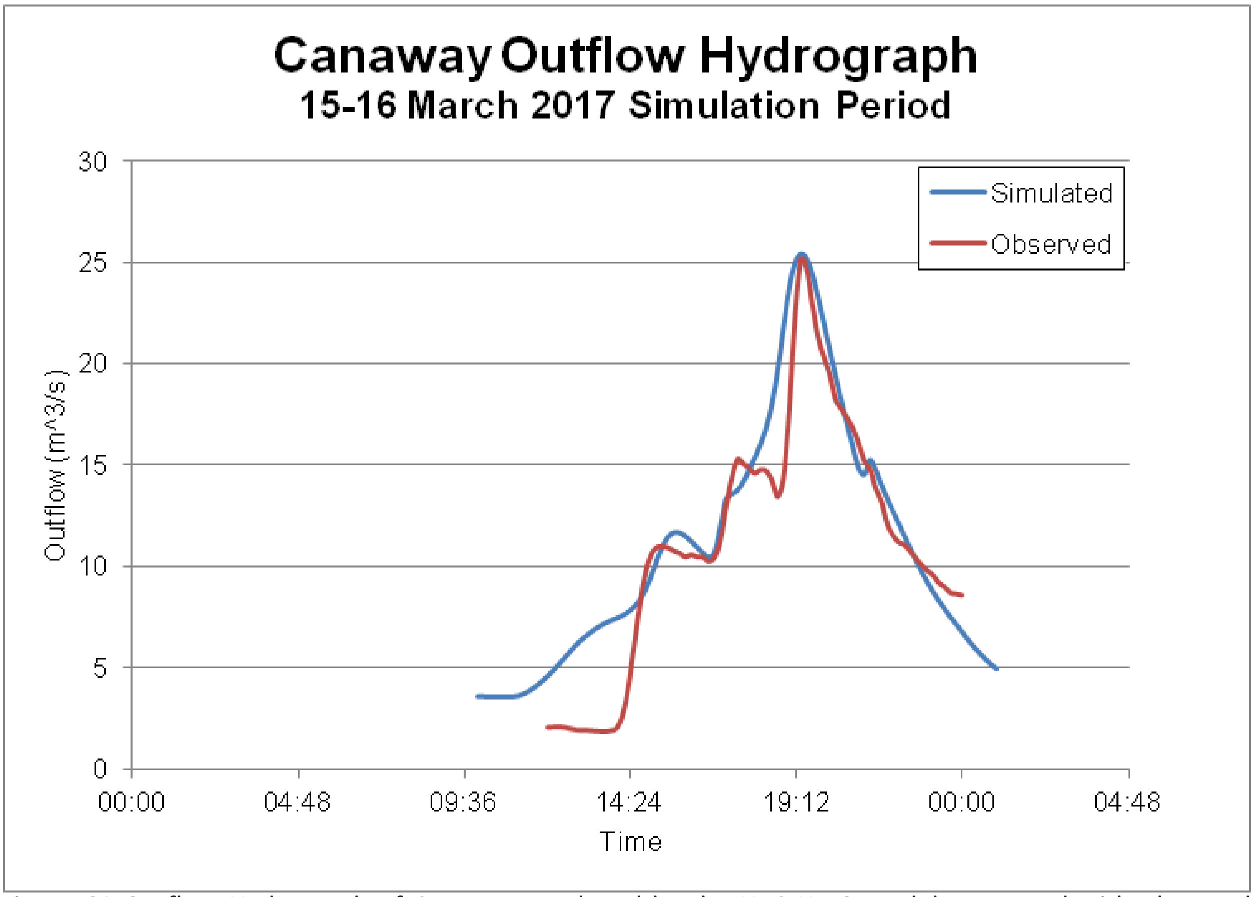


Figure 61 Outflow Hydrograph of Canaway produced by the HEC-HMS model compared with observed outflow

Table 30.Range of calibrated values for the Canaway River Basin.

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve Number	Initial Abstraction (mm)	0.17-11.24
			Curve Number	64-99
			Impervious (%)	0-70
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.73-7.63
			Storage Coefficient (hr)	0.05-1.91
	Baseflow	Recession	Recession Constant	0.06-0.65
			Ratio to Peak	0.03-0.13
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.01-0.74

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 0.17 to 11.24mm signifies that there is minimal to average amount of infiltration or rainfall interception by vegetation.

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 Canaway, the basin mostly consists of brushland and cultivated area. The soil type is clay loam and mountain soil. The curve number is 64 to 99.

The 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 0.73 to 7.63 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, while ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant of 0.06 to 0.65 indicates that the basin will quickly go back to its original_discharge__. Ratio to peak of 0.03 to 0.13 indicates a steeper receding limb of the outflow hydrograph.

Manning's roughness coefficient of 0.01 to 0.74 corresponds to the common roughness in HinatuanCanaway watershed, which is determined to be mostly cultivated areas(Brunner, 2010).

Table 31 Summary of the Efficiency Test of Canaway HMS Model

r2	0.9294
NSE	0.8116
PBIAS	-12.2419
RSR	0.4341

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 2.5868.

The Pearson correlation coefficient (r^2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.9294.

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 0.8116.

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 -12.2419.

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 0.4341.

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 show the Ocoy Canaway outflow using the Dumaguete Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-, 10-, 25-, 50-, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAG-ASA) data. The simulation results revealed significant increase in outflow magnitude as the rainfall intensity increases for a uniform duration of 24 hours and varying return periods.

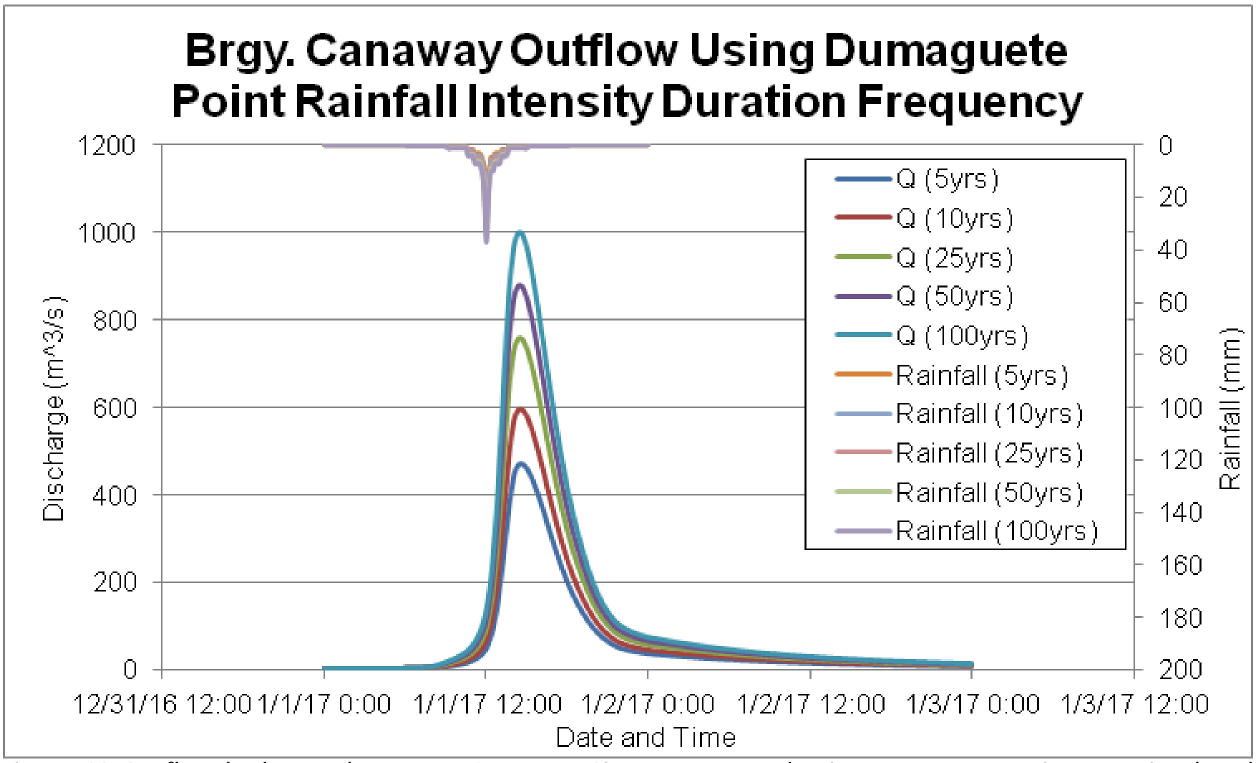


Figure 62 Outflow hydrograph at Brgy. Canaway, Siaton generated using DumaguetePointRIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of the Canaway River discharge using the Dumaguete Point Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 3Table 32.

Table 32 Peak values of the Canaway HECHMS Model outflow using the Dumaguete RIDF

RIDF Period	Total Precipitation (mm)	Peak Rainfall (mm)	Peak Outflow (m^3/s)	Time to Peak
5-year RIDF	116.5	21.8	469.951	02:30
10-year RIDF	143.3	25.6	597.951	02:30
25-year RIDF	177.2	30.3	760.161	02:30
50-year RIDF	202.4	33.8	880.959	02:30
100-year RIDF	227.3	37.2	999.961	02:30

5.8 River Analysis Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. For this publication, only a sample output map river was to beis shown, since only the baseflow was calibrated. The sample generated map of Canaway River using the calibrated HMS baseflow is shown in Figure 63 .

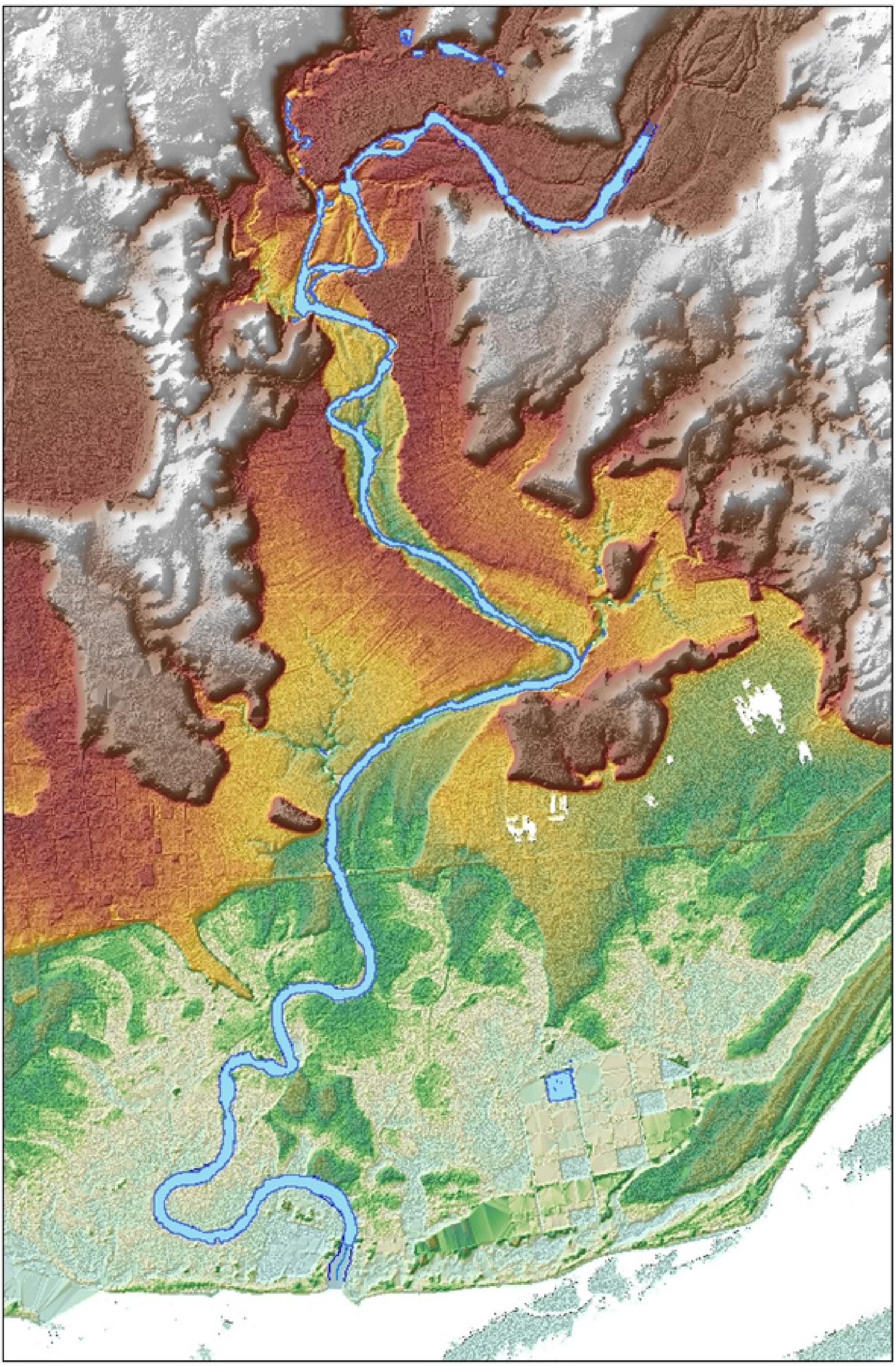


Figure 63 Sample output of Canaway RAS Model

5.9 Flood Hazard and Flow Depth Map

The resulting hazard and flow depth maps have a 10m resolution. Figure 64 to Figure 69 shows the 5-, 25-, and 100-year rainfall return scenarios of the Canaway floodplainFloodplain.

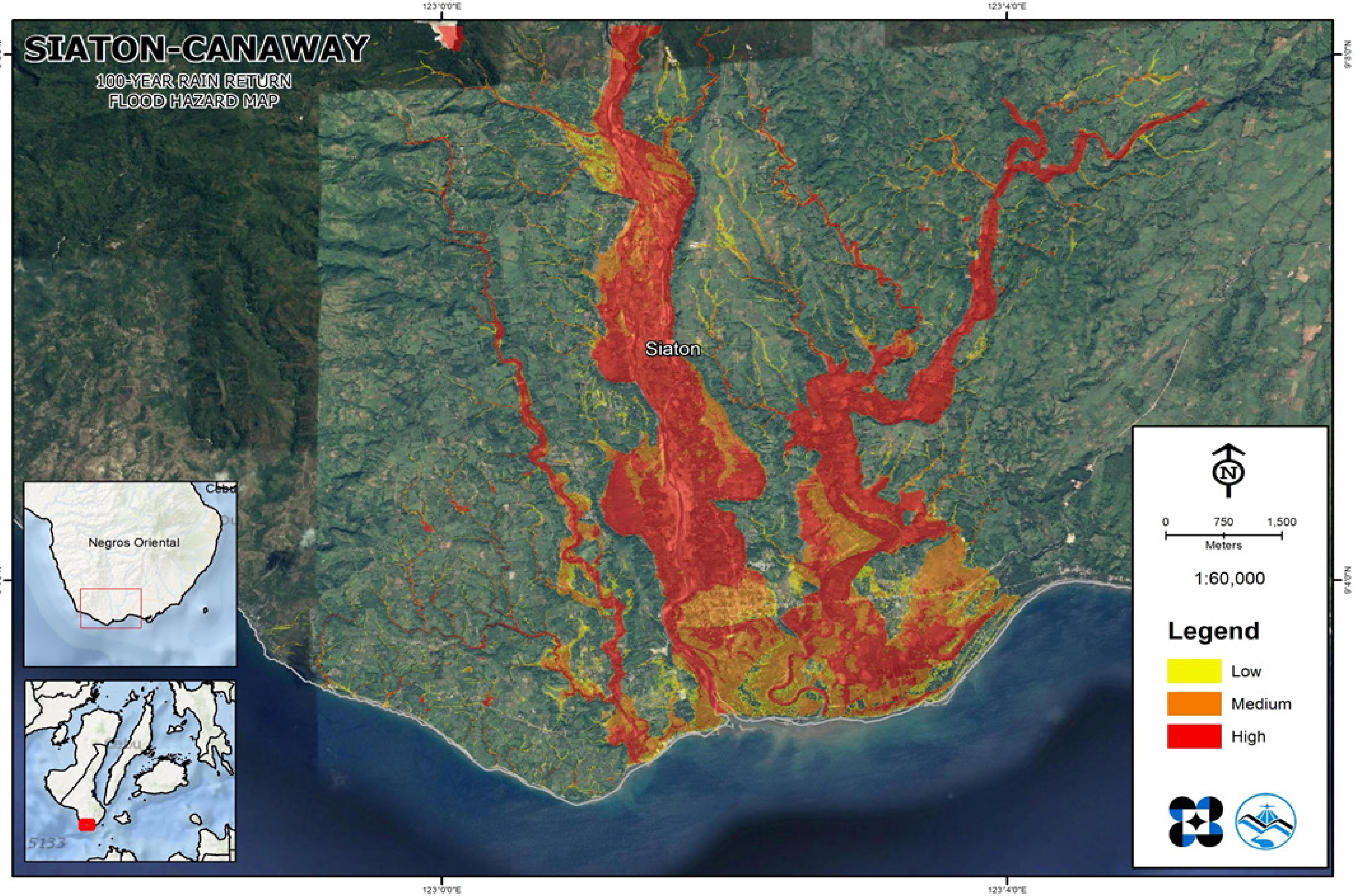


Figure 64. 100-year Flood Hazard Map for Canaway Floodplain overlaid on Google Earth imagery

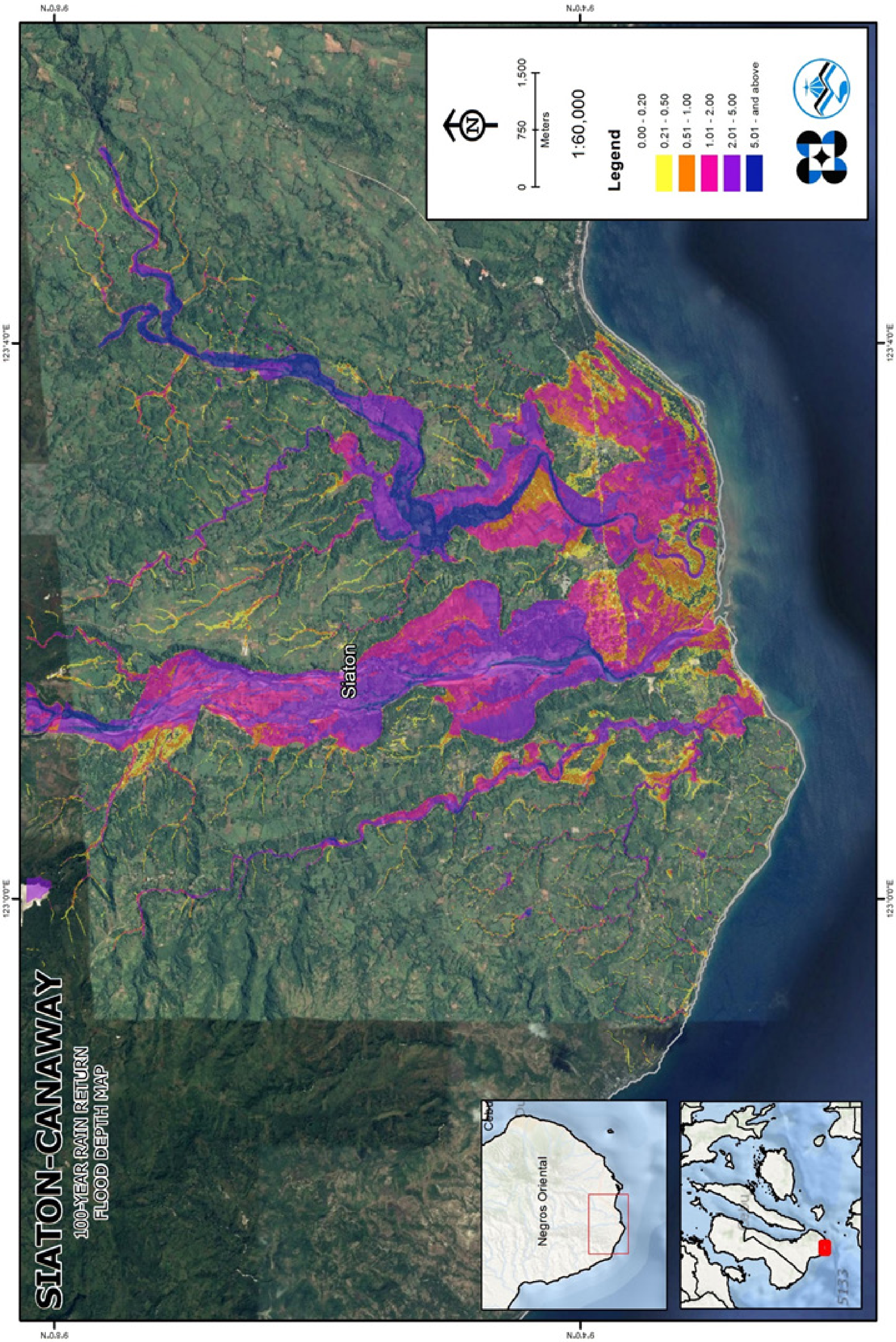


Figure 65. 100-year Flow Depth Map for Canaway Floodplain overlaid on Google Earth imagery

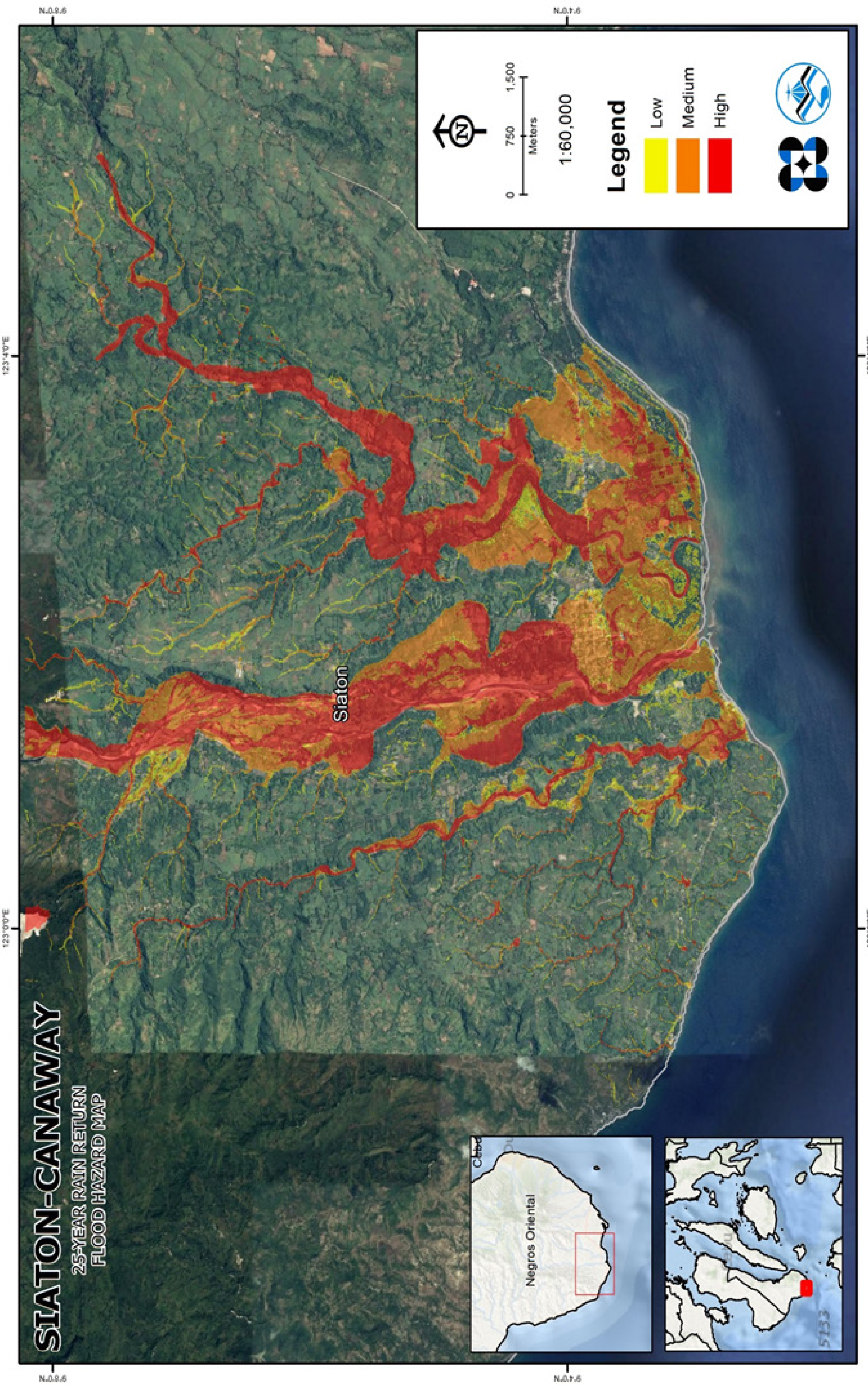


Figure 66. 25-year Flood Hazard Map for Canaway Floodplain overlaid on Google Earth imagery

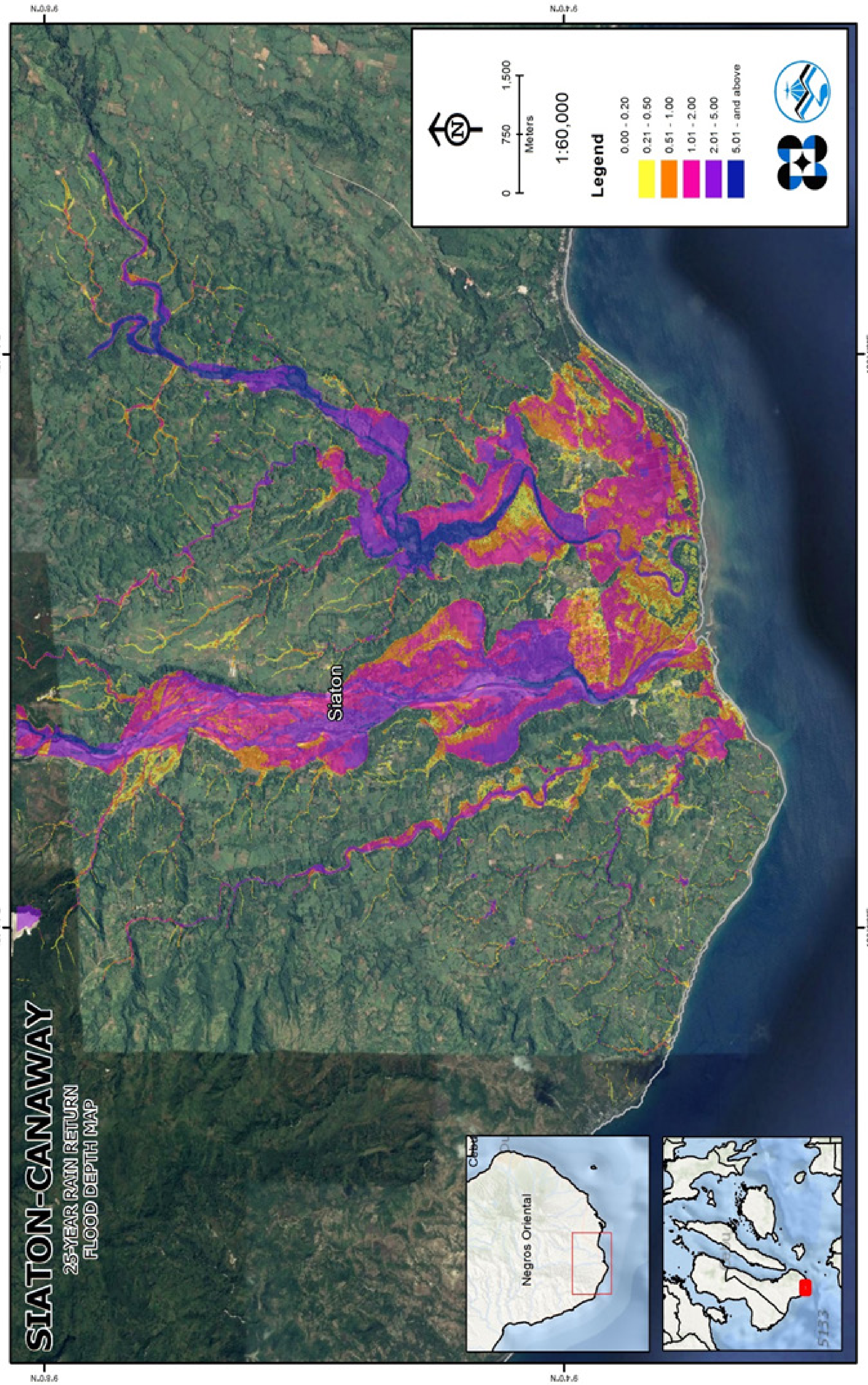


Figure 67. 25-year Flow Depth Map for Canaway Floodplain overlaid on Google Earth imagery

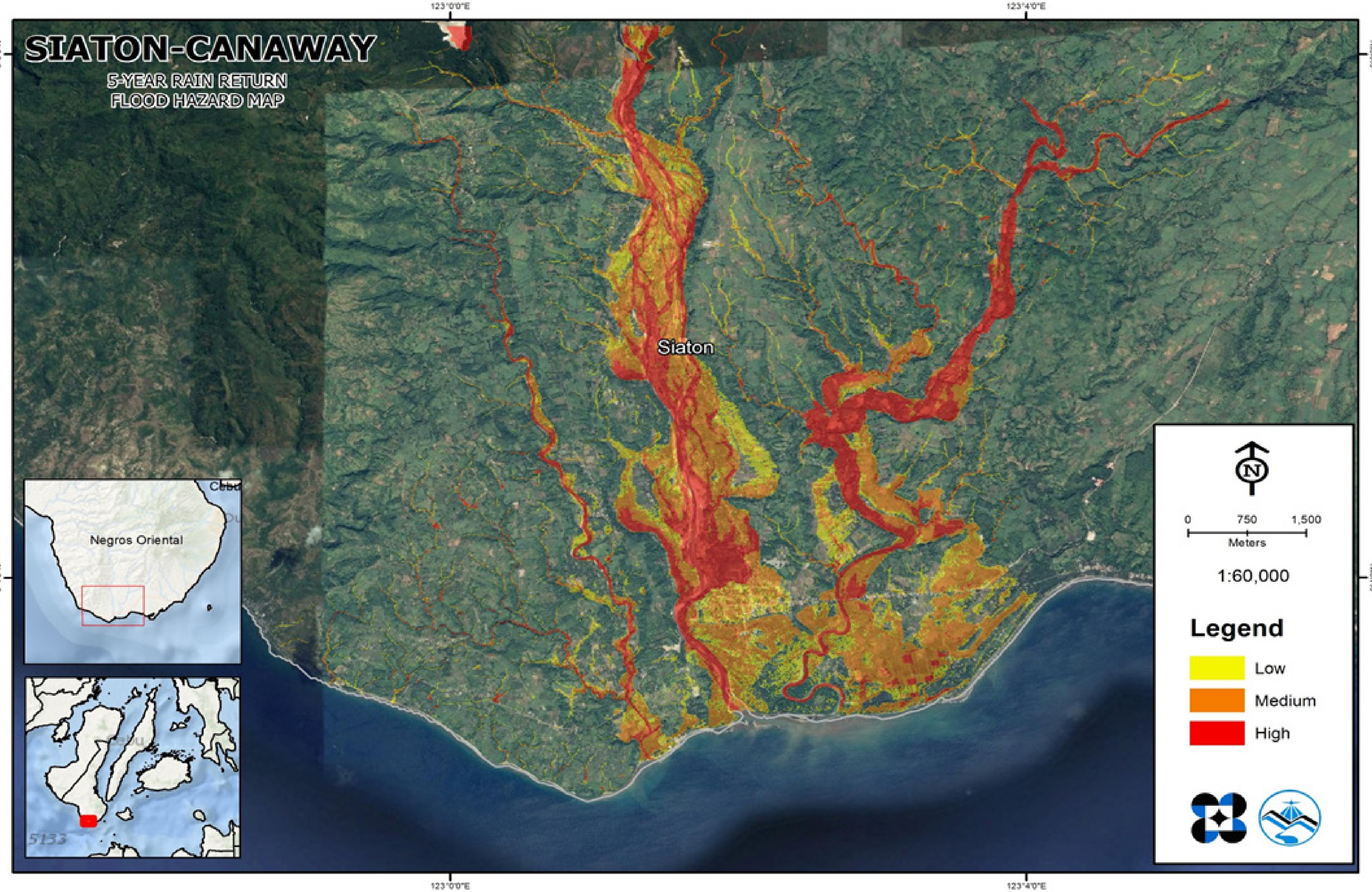


Figure 68. 5-year Flood Hazard Map for Canaway Floodplain overlaid on Google Earth imagery

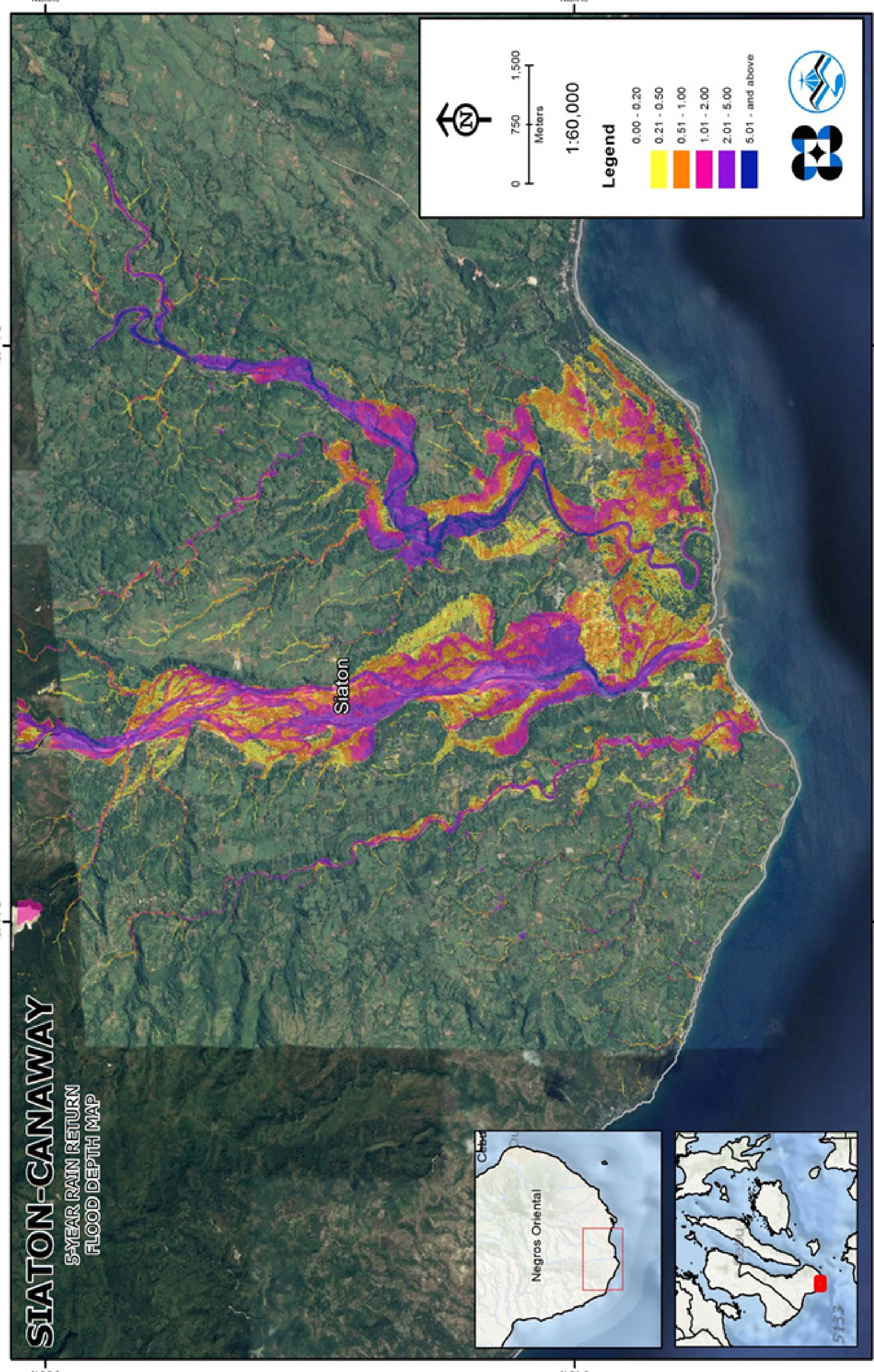


Figure 69. 5-year Flow Depth Map for Canaway Floodplain overlaid on Google Earth imagery

5.10 Inventory of Areas Exposed to Flooding

Affected barangays in the Canaway-Siaton river basin, grouped by municipality, are listed below. For the said basin, one municipality consisting of 19 barangays is expected to experience flooding when subjected to 5-yr rainfall return period.

For the 5-year return period, 13.24% of the municipality of Asturias with an area of 427.32 sq. km. will experience flood levels of less 0.20 meters. 1.19% of the area will experience flood levels of 0.21 to 0.50 meters while 1.39%, 1.27%, 0.93%, and 0.17% 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 33 are the affected areas in square kilometres by flood depth per barangay.

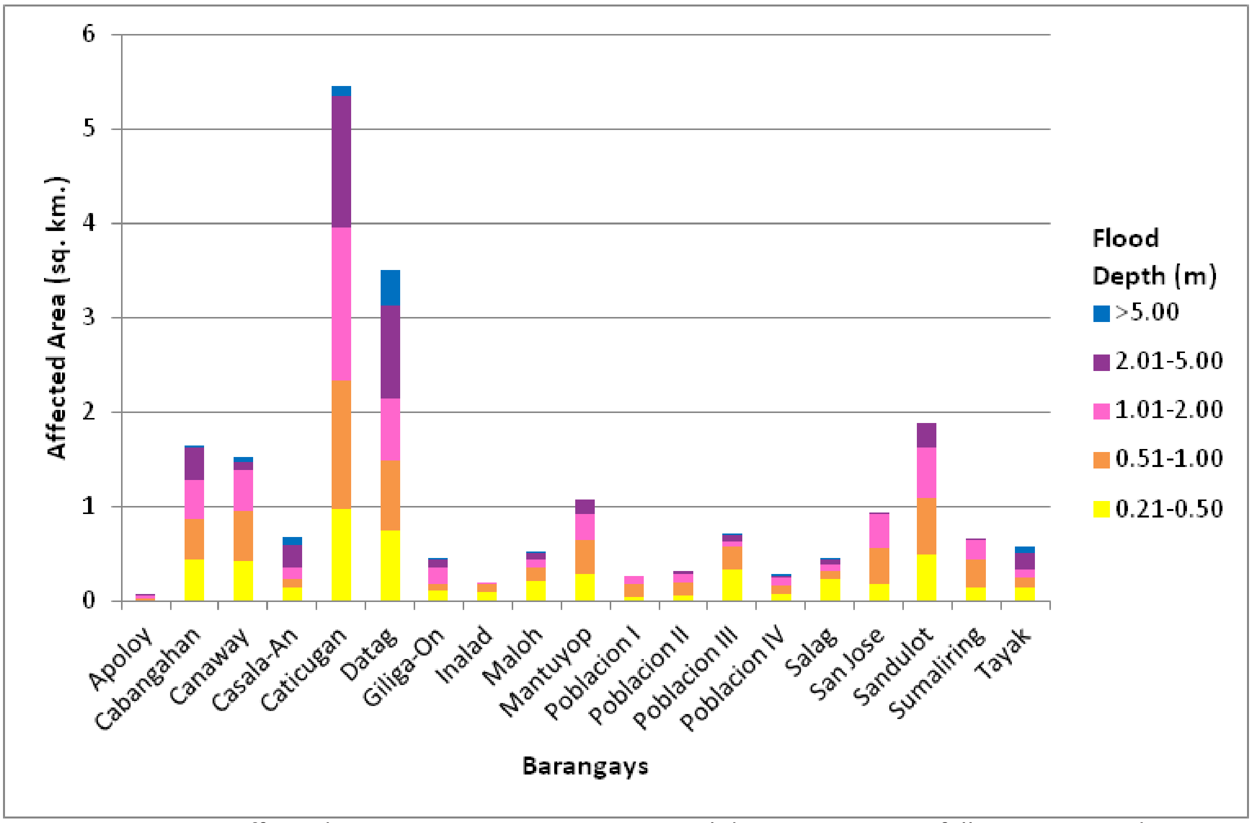


Figure 70 Affected Areas in Siaton, Negros Oriental during 5-Year Rainfall Return Period

Table 33 Affected Areas in Siaton, Negros Oriental during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Bayawan City (in sq. km.)									
	Apoloy	Cabangahan	Canaway	Casala-An	Caticugan	Datag	Giliga-On	Inalad	Maloh	Mantuyop
0.03-0.20	0.37	6.08	2.76	4.57	7.94	5.45	4.08	0.42	5.19	1.75
0.21-0.50	0.011	0.43	0.42	0.14	0.98	0.74	0.1	0.09	0.21	0.28
0.51-1.00	0.015	0.44	0.54	0.092	1.36	0.74	0.082	0.095	0.15	0.36
1.01-2.00	0.027	0.41	0.42	0.12	1.62	0.67	0.16	0.011	0.088	0.29
2.01-5.00	0.016	0.34	0.09	0.23	1.4	0.97	0.092	0	0.061	0.14
> 5.00	0	0.021	0.047	0.082	0.1	0.38	0.0022	0	0.0028	0

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Bayawan City (in sq. km.)								
	Poblacion I	Poblacion II	Poblacion III	Poblacion IV	Salag	San Jose	Sandulot	Sumaliring	Tayak
0.03-0.20	0.049	0.036	0.58	0.22	5.3	0.22	6.51	0.43	4.65
0.21-0.50	0.04	0.053	0.33	0.073	0.23	0.17	0.49	0.14	0.15
0.51-1.00	0.14	0.15	0.24	0.082	0.095	0.38	0.6	0.3	0.099
1.01-2.00	0.086	0.078	0.058	0.096	0.068	0.37	0.54	0.21	0.09
2.01-5.00	0	0.031	0.069	0.018	0.056	0.021	0.26	0.0069	0.16
> 5.00	0	0	0.0007	0.0079	0.0007	0	0	0	0.063

For the 25-year return period, 12.39% of the municipality of Asturias with an area of 427.32 sq. km. will experience flood levels of less 0.20 meters. 0.85% of the area will experience flood levels of 0.21 to 0.50 meters while 1.15%, 1.93%, 1.53%, and 0.35% 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 are the affected areas in square kilometres by flood depth per barangay.

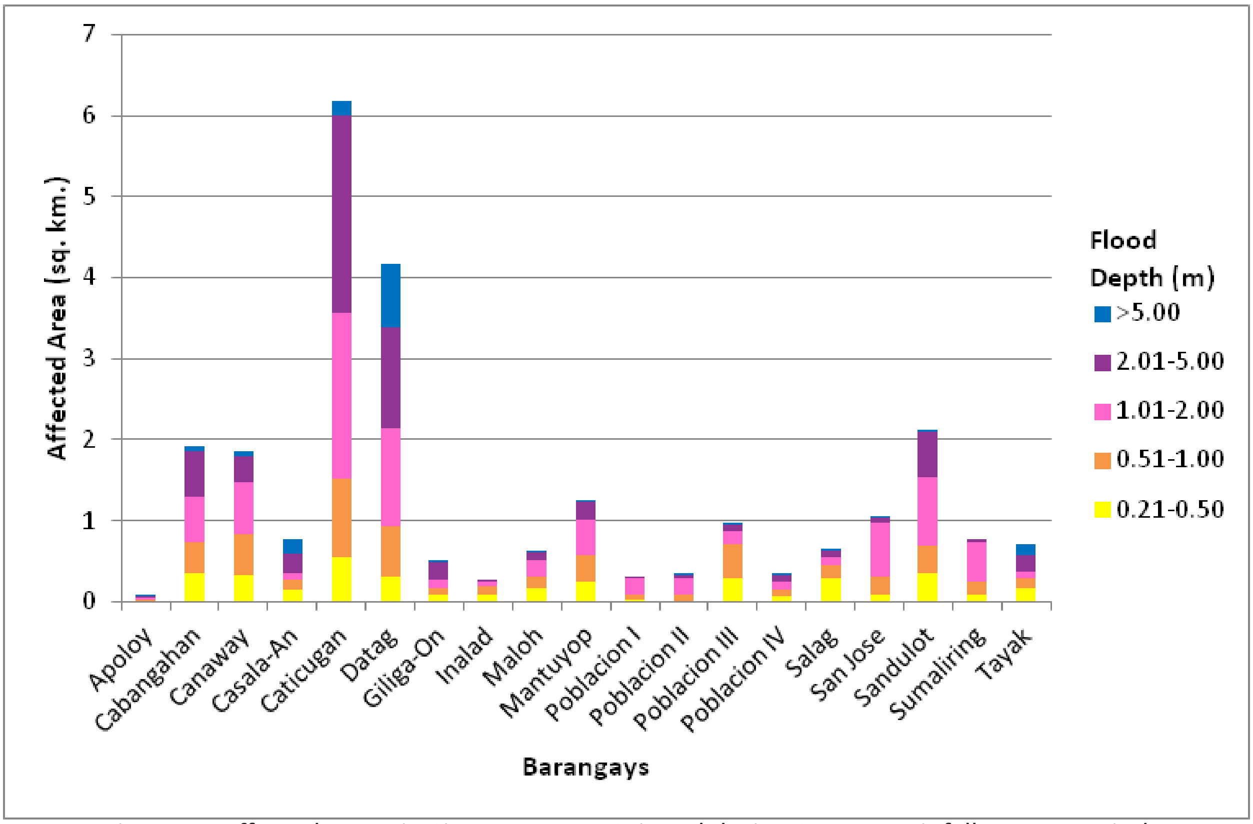


Figure 71 Affected Areas in Siaton, Negros Oriental during 25-Year Rainfall Return Period

Table 34 Affected Areas in Siaton, Negros Oriental during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Bayawan City (in sq. km.)									
	Apoloy	Cabangahan	Canaway	Casala-An	Caticugan	Datag	Giliga-On	Inalad	Maloh	Mantuyop
0.03-0.20	0.36	5.82	2.43	4.46	7.21	4.78	4.01	0.36	5.08	1.58
0.21-0.50	0.011	0.34	0.32	0.15	0.56	0.32	0.094	0.08	0.17	0.24
0.51-1.00	0.014	0.39	0.5	0.11	0.96	0.62	0.075	0.099	0.13	0.33
1.01-2.00	0.024	0.57	0.65	0.072	2.06	1.2	0.1	0.074	0.2	0.45
2.01-5.00	0.024	0.55	0.33	0.24	2.42	1.26	0.22	0.0001	0.11	0.22
> 5.00	0.0062	0.062	0.054	0.2	0.19	0.77	0.02	0	0.0087	0.0014

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Bayawan City (in sq. km.)								
	Poblacion I	Poblacion II	Poblacion III	Poblacion IV	Salag	San Jose	Sandulot	Sumaliring	Tayak
0.03-0.20	0.021	0.015	0.33	0.15	5.12	0.12	6.31	0.3	4.5
0.21-0.50	0.019	0.012	0.28	0.057	0.29	0.078	0.34	0.088	0.16
0.51-1.00	0.067	0.065	0.43	0.089	0.15	0.24	0.35	0.16	0.12
1.01-2.00	0.2	0.21	0.15	0.11	0.097	0.65	0.84	0.49	0.094
2.01-5.00	0.0028	0.035	0.09	0.076	0.084	0.071	0.56	0.043	0.2
> 5.00	0	0.0043	0.001	0.014	0.0012	0.002	0.0004	0	0.15

For the 100-year return period, 12.03% of the municipality of Asturias with an area of 427.32 sq. km. will experience flood levels of less 0.20 meters. 0.79% of the area will experience flood levels of 0.21 to 0.50 meters while 0.89%, 1.93%, 2.05%, and 0.5% 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 are the affected areas in square kilometres by flood depth per barangay.

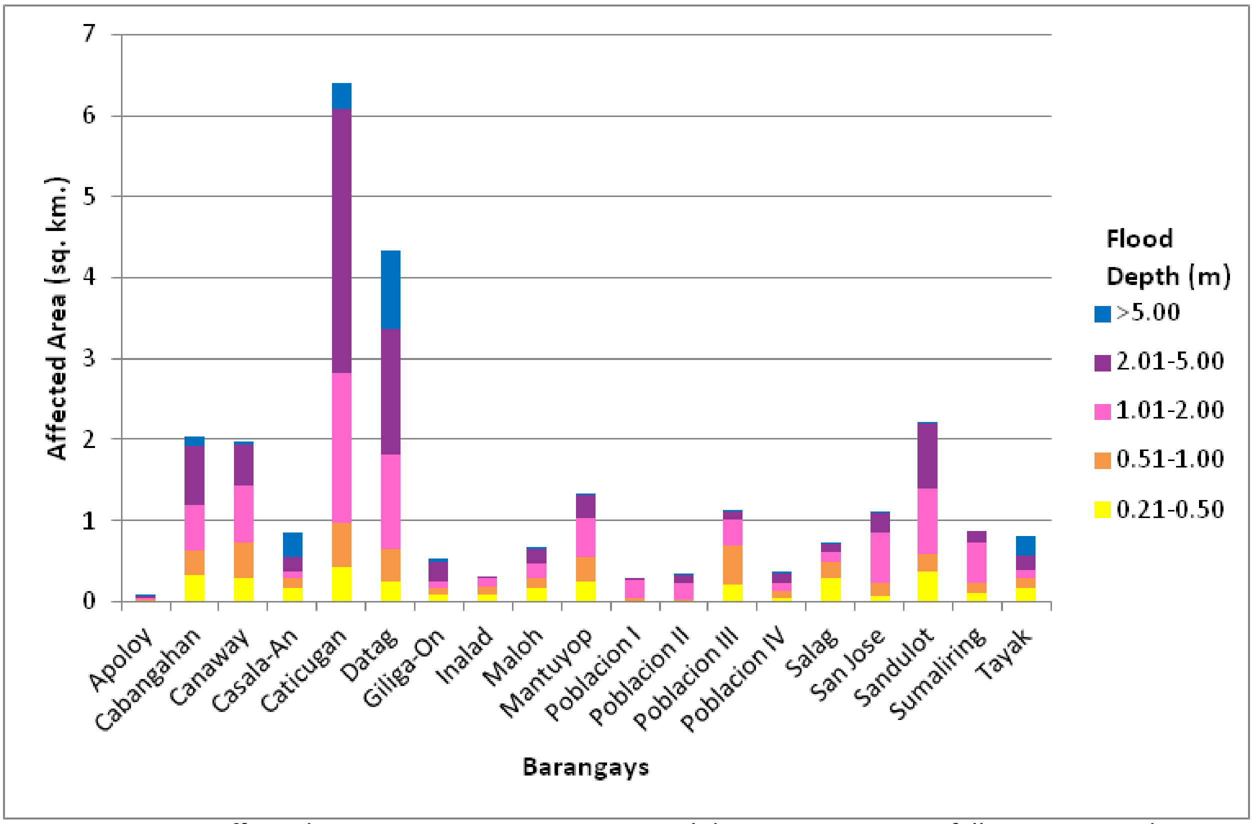


Figure 72 Affected Areas in Siaton, Negros Oriental during 100-Year Rainfall Return Period

Table 35 Affected Areas in Siaton, Negros Oriental during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Bayawan City (in sq. km.)									
	Apoloy	Cabangahan	Canaway	Casala-An	Caticugan	Datag	Giliga-On	Inalad	Maloh	Mantuyop
0.03-0.20	0.35	5.68	2.3	4.4	6.98	4.61	3.98	0.31	5.02	1.5
0.21-0.50	0.0087	0.33	0.29	0.16	0.43	0.25	0.093	0.097	0.18	0.25
0.51-1.00	0.01	0.31	0.44	0.13	0.53	0.39	0.067	0.096	0.11	0.3
1.01-2.00	0.02	0.55	0.7	0.087	1.85	1.17	0.097	0.1	0.18	0.49
2.01-5.00	0.036	0.74	0.49	0.18	3.26	1.55	0.23	0.0017	0.19	0.28
> 5.00	0.0075	0.12	0.059	0.29	0.34	0.97	0.043	0	0.016	0.0037

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Bayawan City (in sq. km.)									
	Poblacion I	Poblacion II	Poblacion III	Poblacion IV	Salag	San Jose	Sandulot	Sumaliring	Tayak	
0.03-0.20	0.016	0.012	0.18	0.13	5.03	0.062	6.21	0.21	4.4	1.5
0.21-0.50	0.0098	0.0043	0.21	0.053	0.3	0.061	0.37	0.11	0.17	0.25
0.51-1.00	0.044	0.03	0.47	0.074	0.19	0.16	0.22	0.12	0.12	0.3
1.01-2.00	0.22	0.2	0.32	0.11	0.12	0.64	0.8	0.5	0.091	0.49
2.01-5.00	0.029	0.085	0.099	0.11	0.1	0.24	0.8	0.14	0.19	0.28
> 5.00	0	0.012	0.0015	0.014	0.0046	0.0028	0.0059	0	0.24	0.0037

Among the barangays in the municipality of Siaton, Caticungan is projected to have the highest percentage of area that will experience flood levels at 3.13%. Meanwhile, Sandulot posted the second highest percentage of area that may be affected by flood depths at 1.97%.
Moreover, the generated flood hazard maps for the Canaway-Siaton Floodplain were used to assess the vulnerability of the educational and medical institutions in the floodplain. Using the flood depth units of PAG-ASA for hazard maps - “Low”, “Medium”, and “High” - the affected institutions were given their individual assessment for each Flood Hazard Scenario (5 yr, 25 yr, and 100 yr).

Table 36 Areas covered by each warning level with respect to the rainfall scenario

Warning Level	Area Covered in sq. km.		
	5 year	**25 year**	**100 year**
Low	5.04	3.61	3.37
Medium	9.32	9.48	7.84
High	7.00	11.90	15.33
TOTAL	**21.36**	**24.99**	**26.54**

Of the 3 identified Education Institutions in the Canaway Flood plain, 2 schools were assessed to be exposed to medium level flooding in all of the three flooding scenarios (5yr, 25yr, and 100yr). See Appendix D 12 for a detailed enumeration of schools in the Canaway floodplainFloodplain.
Of the 2 identified Medical Institutions in the Canaway Floodplain, 2 medical institutions were assessed to be exposed to medium level flooding in all of the three flooding scenarios (5yr, 25yr, and 100yr). See Appendix E 13 for a detailed enumeration of hospitals and clinics in the Canaway floodplainFloodplain.

5.11 Flood Validation

Survey was done along the floodplain of Canaway River to validate the generated flood maps. The team gathered secondary data regarding flood occurrence in the area. Ground validation points were acquired as well as the other necessary details like date of occurrence, name of typhoon and actual flood depth.

During validation, the team was assisted by the local Disaster Risk Reduction and Management representative from the Municipality of Siaton. Residents along the floodplain were interviewed of the historical flood events they experiences.

Actual flood depth acquired from the ground validation were then computed and compared to the flood depth simulated by the model. An RMSE value of 4.04 was obtained. Validation points for a 5-year Flood Depth Map of the Canaway Floodplain.

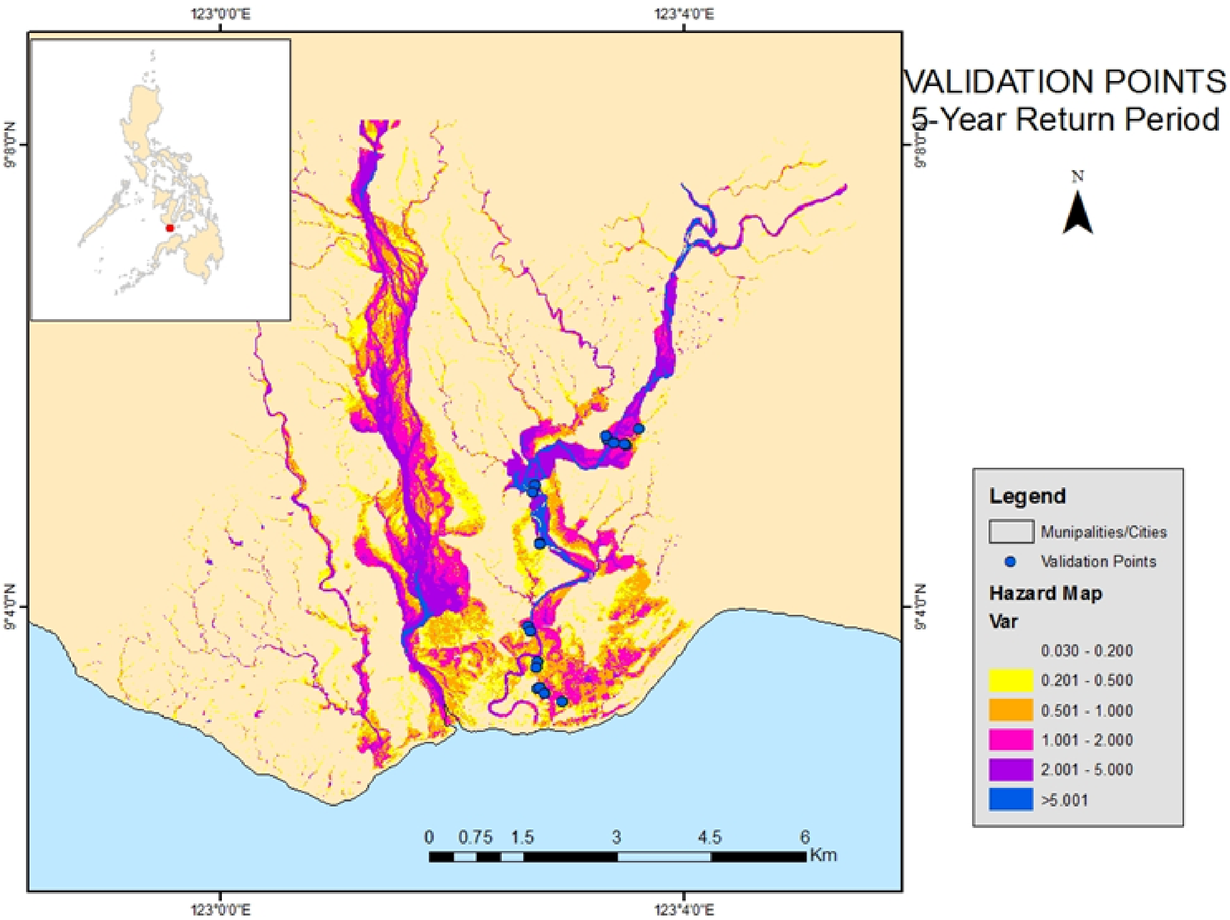


Figure 73 Canaway Flood Validation Points

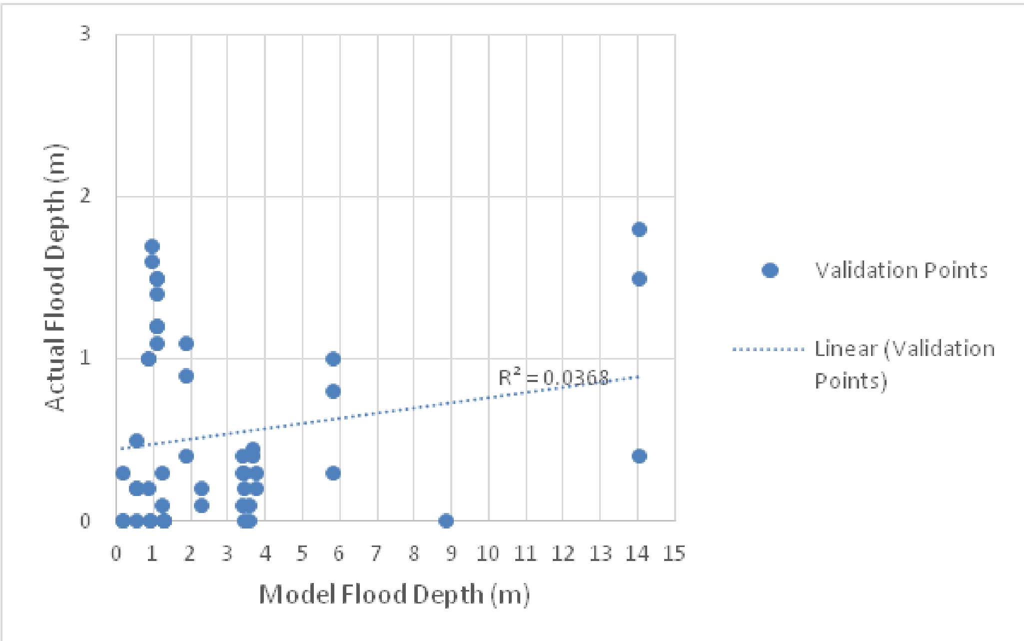


Figure 74 Flood map depth vs actual flood depth

Table 37 Actual flood vs simulated flood depth at different levels in the Canaway River Basin.

CANAWAY BASIN		Modeled Flood Depth (m)						
		0-0.20	**0.21-0.50**	**0.51-1.00**	**1.01-2.00**	**2.01-5.00**	**> 5.00**	**Total**
Actual Flood Depth (m)	0-0.20	2	0	6	4	8	1	21
	0.21-0.50	1	0	1	2	6	2	12
	0.51-1.00	0	0	2	1	0	2	5
	1.01-2.00	0	0	2	7	0	2	11
	2.01-5.00	0	0	0	0	0	0	0
	> 5.00	0	0	0	0	0	0	0
	Total	**3**	0	11	14	14	7	49

The overall accuracy generated by the flood model is estimated at 22.45% with 11 points correctly matching the actual flood depths. In addition, there were 5 points estimated one level above and below the correct flood depths while there were 10 points and 23 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 4 points were overestimated while a total of 3 points were underestimated in the modelled flood depths of Canaway.

Table 38 Summary of the Accuracy Assessment in the Canaway River Basin Survey

No. of Points		%
Correct	11	22.45
Overestimated	35	71.43
Underestimated	3	6.12
Total	49	100.00

REFERENCES

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

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

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

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

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

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

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

ANNEXES

ANNEX 1. OPTECH TECHNICAL SPECIFICATION OF THE GEMINI SENSOR

Parameter	Specification
Operational envelope (1,2,3,4)	150-4000 m AGL, nominal
Laser wavelength	1064 nm
Horizontal accuracy (2)	1/5,500 x altitude, (m AGL)
Elevation accuracy (2)	<5-35 cm, 1 σ
Effective laser repetition rate	Programmable, 33-167 kHz
Position and orientation system	POS AV™ AP50 (OEM); 220-channel dual frequency GPS/GNSS/Galileo/L-Band receiver
Scan width (WOV)	Programmable, 0-50˚
Scan frequency (5)	Programmable, 0-70 Hz (effective)
Sensor scan product	1000 maximum
Beam divergence	Dual divergence: 0.25 mrad (1/e) and 0.8 mrad (1/e), nominal
Roll compensation	Programmable, ±5˚ (FOV dependent)
Range capture	Up to 4 range measurements, including 1st, 2nd, 3rd, and last returns
Intensity capture	Up to 4 intensity returns for each pulse, including last (12 bit)
Video Camera	Internal video camera (NTSC or PAL)
Image capture	Compatible with full Optech camera line (optional)
Full waveform capture	12-bit Optech IWD-2 Intelligent Waveform Digitizer (optional)
Data storage	Removable solid state disk SSD (SATA II)
Power requirements	28 V; 900 W;35 A(peak)

Dimensions and weight	Sensor: 260 mm (w) x 190 mm (l) x 570 mm (h); 23 kg Control rack: 650 mm (w) x 590 mm (l) x 530 mm (h); 53 kg
Operating temperature	-10˚C to +35˚C (with insulating jacket)
Relative humidity	0-95% no-condensing

ANNEX 2 NAMRIA CERTIFICATES OF REFERENCE POINTS USED

1. NGE-89

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

October 15, 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: **NEGROS ORIENTAL**
Station Name: **NGE-89**
Order: **2nd**

Island:	**VISAYAS**	Barangay:	**BIO-OS**		
Municipality:	**AMLAN (AYUQUITAN)**	MSL Elevation:			
		PRS92 Coordinates			
Latitude:	**9° 28' 17.93638"**	Longitude:	**123° 11' 53.99321"**	Ellipsoidal Hgt:	**5.29700 m.**
		WGS84 Coordinates			
Latitude:	**9° 28' 13.96567"**	Longitude:	**123° 11' 59.32102"**	Ellipsoidal Hgt:	**67.20400 m.**
		PTM / PRS92 Coordinates			
Northing:	**1047303.984 m.**	Easting:	**521778.353 m.**	Zone:	**4**
		UTM / PRS92 Coordinates			
Northing:	**1,046,937.41**	Easting:	**521,770.73**	Zone:	**51**

Location Description

NGE-89
The station is on the SE corner of Bio-os Bridge, at km. 23+56. Mark is the head of a 4" copper nail drilled and grouted at the center of a 30 x 30 cm. cement putty embedded on the concrete pavement of the bridge's sidewalk with inscriptions "NGE-89; 2007; NAMRIA".

The station is located along the Dumaguete-San Carlos national road, between the municipalities of Tanjay and Amlan.

Requesting Party: **Phil-LIDAR I**
Purpose: **Reference**
OR Number: **8075810 I**
T.N.: **2014-2467**

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

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

2. NGE-101

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

October 15, 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: **NEGROS ORIENTAL**		
	Station Name: **NGE-101**		
	Order: **2nd**		
Island: **VISAYAS**	Barangay: **POBLACION**		
Municipality: **SIBULAN**	MSL Elevation:		
	PRS92 Coordinates		
Latitude: **9° 21' 46.05028"**	Longitude: **123° 17' 3.45508"**	Ellipsoidal Hgt:	**2.89700 m.**
	WGS84 Coordinates		
Latitude: **9° 21' 42.11526"**	Longitude: **123° 17' 8.79199"**	Ellipsoidal Hgt:	**65.25500 m.**
	PTM / PRS92 Coordinates		
Northing: **1035271.672 m.**	Easting: **531227.453 m.**	Zone:	**4**
	UTM / PRS92 Coordinates		
Northing: **1,034,909.31**	Easting: **531,216.52**	Zone:	**51**

Location Description

NGE-101
The station was established in coordination with the PPA Port manager. The station is on the 3rd step from the top flooring of the pier NE corner. It is on the east side of the Sibulan Town proper, along the shoreline of Tañon Strait, inside the Sibulan Ferry Terminal compound. Mark is the head of a 4" copper nail at the center of a 30 x 30 cm. cement putty embedded on the concrete stairs with inscriptions "NGE-101; 2007; NAMRIA".

Requesting Party: **Phil-LIDAR I**
Purpose: **Reference**
OR Number: **8075810 I**
T.N.: **2014-2466**

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

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

3. NGE-111

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

October 15, 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: **NEGROS ORIENTAL**
Station Name: **NGE-111**
Order: **2nd**

Island: **VISAYAS**
Municipality: **DAUIN**
Barangay: **JAGOBA**
MSL Elevation:

PRS92 Coordinates

Latitude:	**9º 10' 30.25228"**	Longitude:	**123º 14' 54.26711"**	Ellipsoidal Hgt:	**13.11600 m.**

WGS84 Coordinates

Latitude:	**9º 10' 26.36267"**	Longitude:	**123º 14' 59.62110"**	Ellipsoidal Hgt:	**75.79100 m.**

PTM / PRS92 Coordinates

Northing:	**1014508.213 m.**	Easting:	**527300.168 m.**	Zone:	**4**

UTM / PRS92 Coordinates

Northing:	**1,014,153.12**	Easting:	**527,290.61**	Zone:	**51**

Location Description

NGE-111

The station is located on the NE approach of the 36 m. long Jagoba bridge at Km.17+930. The station is about 40 m. SW of km.post # 18. Mark is the head of a 4" copper nail drilled and grouted at the center of a 30 x 30 cm. cement putty embedded on the concrete sidewalk with inscriptions "NGE-111; 2007; NAMRIA".

Requesting Party: **Phil-LIDAR I**
Purpose: **Reference**
OR Number: **8075810 I**
T.N.: **2014-2465**

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

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

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

4. NE-90

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

October 15, 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: **NEGROS ORIENTAL** Station Name: **NE-90**	
Island: **VISAYAS**	Municipality: **ZAMBOANGUITA**	Barangay: **POBLACION**
Elevation: **6.6968 m.**	Order: **1st Order**	Datum: **Mean Sea Level**
Latitude: **9° 6' 38.50000"**	Longitude: **123° 12' 10.10000"**	

Location Description

NE – 90, is in the Province of Negros Oriental, Municipality of Zamboanguita, Barangay Poblacion, along National road.

Station is located on concrete sidewalk, Southeast end of Guinsuan bridge, 0.30 meter above the ground, 4 meters East of the road centerline, 180 meters North of KM Post 27.

Mark is the head of a 4" copper nail, set on a drilled hole and flushed to a 6" x 6" cement putty with inscription "NE – 90, 2007, NAMRIA".

Requesting Party:	**Phil-LIDAR I**
Purpose:	**Reference**
OR Number:	**8075810 I**
T.N.:	**2014-2469**

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

9910152014103455

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

5. NE-135

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

October 15, 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: **NEGROS ORIENTAL** Station Name: **NE-135**	
Island: **VISAYAS**	Municipality: **AMLAN (AYUQUITAN)**	Barangay: **BIO-OS**
Elevation: **3.8430 m.**	Order: **1st Order**	Datum: **Mean Sea Level**
Latitude: **9° 28' 35.80000"**	Longitude: **123° 11' 8.50000"**	

Location Description

NE – 135, is in the Province of Negros Oriental, Municipality of Amlan, Barangay Bio-os, Sitio Busuang, along Amlan - Tanjay highway.

Station is located on top of concrete sidewalk, Southwest end of Busuang bridge, 0.25 meter above the ground, 4 meters West of the road centerline, 200 meters Northwest of KM Post 25.

Mark is the head of a 4" copper nail, set on a drilled hole and flushed to a 6" x 6" cement putty with inscription "NE – 135, 2008, NAMRIA".

Requesting Party: **Phil-LIDAR I**
Purpose: **Reference**
OR Number: **8075810 I**
T.N.: **2014-2470**

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

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

ANNEX 3 BASELINE PROCESSING REPORTS OF REFERENCE POINTS USED

1. NE-90

NE-90 - NGE-111 (7:40:35 AM-11:39:53 AM) (S1)

Baseline observation:	NE-90 --- NGE-111 (B1)
Processed:	11/3/2014 11:10:47 AM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.003 m
Vertical precision:	0.011 m
RMS:	0.003 m
Maximum PDOP:	1.667
Ephemeris used:	Broadcast
Antenna model:	Trimble Relative
Processing start time:	9/25/2014 7:40:39 AM (Local: UTC+8hr)
Processing stop time:	9/25/2014 11:39:49 AM (Local: UTC+8hr)
Processing duration:	03:59:10
Processing interval:	5 seconds

Vector Components (Mark to Mark)

From:	NGE-111				
Grid		Local		Global	
Easting	527290.613 m	Latitude	N9°10'30.25228"	Latitude	N9°10'26.36267"
Northing	1014153.117 m	Longitude	E123°14'54.26711"	Longitude	E123°14'59.62110"
Elevation	12.583 m	Height	13.116 m	Height	75.791 m

To:	NE-90				
Grid		Local		Global	
Easting	522126.927 m	Latitude	N9°06'42.32060"	Latitude	N9°06'38.44322"
Northing	1007150.356 m	Longitude	E123°12'04.93455"	Longitude	E123°12'10.29457"
Elevation	7.044 m	Height	7.358 m	Height	70.052 m

Vector					
ΔEasting	-5163.685 m	NS Fwd Azimuth	216°26'37"	ΔX	3718.151 m
ΔNorthing	-7002.762 m	Ellipsoid Dist.	8704.123 m	ΔY	3758.805 m
ΔElevation	-5.538 m	ΔHeight	-5.758 m	ΔZ	-6914.376 m

Standard Errors

Vector errors:					
σ ΔEasting	0.001 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.003 m
σ ΔNorthing	0.001 m	σ Ellipsoid Dist.	0.001 m	σ ΔY	0.005 m
σ ΔElevation	0.006 m	σ ΔHeight	0.006 m	σ ΔZ	0.001 m

T-BM4 - NGE-101 (2:07:23 PM-6:37:04 PM) (S1)

Baseline observation:	T-BM4 --- NGE-101 (B1)
Processed:	10/20/2014 1:22:33 PM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.005 m
Vertical precision:	0.017 m
RMS:	0.003 m
Maximum PDOP:	1.965
Ephemeris used:	Broadcast
Antenna model:	Trimble Relative
Processing start time:	9/24/2014 2:07:24 PM (Local: UTC+8hr)
Processing stop time:	9/24/2014 6:37:04 PM (Local: UTC+8hr)
Processing duration:	04:29:40
Processing interval:	5 seconds

Vector Components (Mark to Mark)

From:	NGE-101				
Grid		**Local**		**Global**	
Easting	531216.523 m	**Latitude**	N9°21'46.05028"	**Latitude**	N9°21'42.11526"
Northing	1034909.308 m	**Longitude**	E123°17'03.45508"	**Longitude**	E123°17'08.79199"
Elevation	2.110 m	**Height**	2.897 m	**Height**	65.255 m

To:	T-BM4				
Grid		**Local**		**Global**	
Easting	533814.622 m	**Latitude**	N9°18'39.58660"	**Latitude**	N9°18'35.66706"
Northing	1029185.290 m	**Longitude**	E123°18'28.47112"	**Longitude**	E123°18'33.81248"
Elevation	3.094 m	**Height**	3.712 m	**Height**	66.241 m

Vector					
ΔEasting	2598.099 m	**NS Fwd Azimuth**	155°37'59"	**ΔX**	-2679.198 m
ΔNorthing	-5724.018 m	**Ellipsoid Dist.**	6288.490 m	**ΔY**	-646.804 m
ΔElevation	0.985 m	**ΔHeight**	0.815 m	**ΔZ**	-5652.309 m

Standard Errors

Vector errors:					
σ ΔEasting	0.002 m	**σ NS fwd Azimuth**	0°00'00"	**σ ΔX**	0.005 m
σ ΔNorthing	0.001 m	**σ Ellipsoid Dist.**	0.001 m	**σ ΔY**	0.007 m
σ ΔElevation	0.008 m	**σ ΔHeight**	0.008 m	**σ ΔZ**	0.002 m

3. NE-135

NE-135 - NGE-89 (7:32:03 AM-11:39:02 AM) (S1)

Baseline observation:	NE-135 --- NGE-89 (B1)
Processed:	11/3/2014 11:25:27 AM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.006 m
Vertical precision:	0.006 m
RMS:	0.003 m
Maximum PDOP:	3.407
Ephemeris used:	Broadcast
Antenna model:	Trimble Relative
Processing start time:	9/29/2014 7:32:14 AM (Local: UTC+8hr)
Processing stop time:	9/29/2014 11:38:59 AM (Local: UTC+8hr)
Processing duration:	04:06:45
Processing interval:	5 seconds

Vector Components (Mark to Mark)

From:	NGE-89				
Grid		**Local**		**Global**	
Easting	521770.730 m	**Latitude**	N9°28'17.93638"	**Latitude**	N9°28'13.96567"
Northing	1046937.409 m	**Longitude**	E123°11'53.99321"	**Longitude**	E123°11'59.32102"
Elevation	3.905 m	**Height**	5.297 m	**Height**	67.204 m

To:	NE-135				
Grid		**Local**		**Global**	
Easting	520228.944 m	**Latitude**	N9°28'39.60020"	**Latitude**	N9°28'35.62671"
Northing	1047601.845 m	**Longitude**	E123°11'03.44049"	**Longitude**	E123°11'08.76787"
Elevation	4.101 m	**Height**	5.556 m	**Height**	67.415 m

Vector					
ΔEasting	-1541.786 m	**NS Fwd Azimuth**	293°20'47"	**ΔX**	1350.288 m
ΔNorthing	664.437 m	**Ellipsoid Dist.**	1679.526 m	**ΔY**	752.714 m
ΔElevation	0.196 m	**ΔHeight**	0.259 m	**ΔZ**	656.467 m

Standard Errors

Vector errors:					
σ ΔEasting	0.002 m	**σ NS fwd Azimuth**	0°00'00"	**σ ΔX**	0.003 m
σ ΔNorthing	0.001 m	**σ Ellipsoid Dist.**	0.002 m	**σ ΔY**	0.003 m
σ ΔElevation	0.003 m	**σ ΔHeight**	0.003 m	**σ ΔZ**	0.001 m

NE-135 - NGE-89 (7:32:03 AM-11:39:02 AM) (S1)

Baseline observation:	NE-135 --- NGE-89 (B1)
Processed:	11/3/2014 11:25:27 AM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.006 m
Vertical precision:	0.006 m
RMS:	0.003 m
Maximum PDOP:	3.407
Ephemeris used:	Broadcast
Antenna model:	Trimble Relative
Processing start time:	9/29/2014 7:32:14 AM (Local: UTC+8hr)
Processing stop time:	9/29/2014 11:38:59 AM (Local: UTC+8hr)
Processing duration:	04:06:45
Processing interval:	5 seconds

ANNEX 4 THE LIDAR SURVEY TEAM COMPOSITION

Data Acquisition Component Sub-Team	Designation	Name	Agency/ Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	ENGR. LOUIE P. BALICANTA	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUÑA	UP-TCAGP
		LOVELYN ASUNCION	UP-TCAGP
FIELD TEAM			
LiDAR Operation	Senior Science Research Specialist (SSRS)	GEROME HIPOLITO	UP-TCAGP
		AUBREY MATIRA-PAGADOR	UP-TCAGP
LiDAR Operation	Research Associate (RA)	MA. VERLINA E. TONGA	UP-TCAGP
		MA. REMEDIOS VILLANUEVA	
Ground Survey, Data Download and Transfer		JONATHAN ALMALVEZ	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. RAYMUND DOMINI	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. RAUL CZ SAMAR II	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. BRYAN DONGUINES	
		CAPT. NEIL ACHILLES AGAWIN	

ANNEX 5 DATA TRANSFER SHEET FOR CANAWAY FLOODPLAIN FLIGHTS

DATA TRANSFER SHEET
10/20/2014(Dumaguete 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	
24-Sep-14	7514	2BLK56F267A	GEMINI	14.1	198	450	228	NA	NA	20	NA	12	1KB	1KB	3	7/8	Z:\DAC\RAW DATA
24-Sep-14	7515	2BLK54C267B	GEMINI	9.1	119	254	162	NA	NA	12.7	NA	12	1KB	1KB	NA	11	Z:\DAC\RAW DATA
25-Sep-14	7516	2BLK56DC268A	GEMINI	18.2	285	630	236	NA	NA	26.6	NA	7.82	1KB	1KB	3	7	Z:\DAC\RAW DATA
26-Sep-14	7518	2BLK56B269A	GEMINI	14.1	193	173	72.5	NA	NA	15.5	NA	5.54	1KB	1KB	3	8	Z:\DAC\RAW DATA
29-Sep-14	7524	2BLK54C272A	GEMINI	16.8	303	535	248	NA	NA	27	NA	6.07	1KB	1KB	4	8/9	Z:\DAC\RAW DATA
30-Sep-14	7526	2BLK53O55A273A	GEMINI	5.37	91	173	144	NA	NA	7.8	NA	3.6	1KB	1KB	3/8	21	Z:\DAC\RAW DATA
1-Oct-14	7528	2BLK54B274A	GEMINI	7.91	115	219	122	NA	NA	9.25	NA	3.91	1KB	1KB	5/4	12	Z:\DAC\RAW DATA
2-Oct-14	7530	2BLK54BS56E275A	GEMINI	7.09	115	228	132	NA	NA	8.74	NA	3.7	1KB	1KB	3/4	12/7	Z:\DAC\RAW DATA

Received from

Name: [illegible]
Position: [illegible]
Signature:

Received by

Name: JOIDA F. PRIETO
Position: SSRS
Signature: 10/20/2014

DATA TRANSFER SHEET
DUMAGUETE (11/06/2014)

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS	POS (MB)	RAW IMAGES / CASI	MISSION LOG FILE / CASI LOGS	RANGE (GB)	DIGITIZER (GB)	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION/S	BASE INFO (.txt)		ACTUAL	KML	
6-Oct-14	7538	2BLK54BS279A	GEMINI-CASI	N/A	64.3 KB	136 KB	109	N/A	N/A	5.59	N/A	3.61	1 KB	1 KB	4 KB	N/A	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
7-Oct-14	7540	2BLK55A55BK5280A	GEMINI-CASI	N/A	157 KB	299 KB	208	N/A	N/A	13.1	N/A	4.94	1 KB	1 KB	116 KB	6.76 KB	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
17-Oct-14	7560	2BLK55A290A	GEMINI-CASI	N/A	257 KB	N/A	121	N/A	N/A	19.6	N/A	5.34	1 KB	1 KB	366 KB	N/A	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
18-Oct-14	7562	2BLK53I291A	GEMINI-CASI	N/A	302 KB	511 KB	248	N/A	N/A	24.1	N/A	6.40	1 KB	1 KB	236	7.6 KB	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
20-Oct-14	7566	2BLK53JK293A	GEMINI-CASI	17.1 GB	200 KB	617 KB	210	70.5 GB	118 KB	19	N/A	6.05	1 KB	1 KB	372 KB	N/A	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
21-Oct-14	7568	2BLK53K5294A	GEMINI-CASI	7.4 GB	265 KB	224 KB	192	21 GB	101 KB	9.89	N/A	6.01	1 KB	1 KB	198 KB	20.5 KB	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
22-Oct-14	7570	2BLK53H295A	GEMINI-CASI	18 GB	242 KB	416 KB	246	75.5	106 KB	21.5	N/A	6.57	1 KB	1 KB	352 KB	7.84 KB	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
24-Oct-14	7574	2BLK53I297A	GEMINI-CASI	18.2 GB	490 KB	433 KB	258	N/A	N/A	20.2	N/A	5.78	1 KB	1 KB	351 KB	N/A	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
25-Oct-14	7576	2BLK53H298A	GEMINI-CASI	14.6 GB	208 KB	354 KB	228	N/A	N/A	17.1	N/A	4.91	1 KB	1 KB	151 KB	8.55 KB	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
26-Oct-14	7578	2BLK55H5GF299A	GEMINI-CASI	6.74 GB	426 KB	411 KB	259	N/A	N/A	18.1	N/A	6.18	1 KB	1 KB	672 KB	16.4 KB	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
27-Oct-14	7580	2BLK58E58LK55F5300A	GEMINI-CASI	2.10 GB	122 KB	240 KB	229	N/A	N/A	10.9	N/A	5.16	1 KB	1 KB	141 KB	7.89 KB	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
28-Oct-14	7582	2BLK58BSES301A	GEMINI-CASI	12.7 GB	272 KB	344 KB	165	7.62 GB	61.1 KB	16.7	N/A	8.47	1 KB	1 KB	193 KB	N/A	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
28-Oct-14	7583	2BLK56AB5301B	GEMINI-CASI	N/A	82.1 KB	307 KB	145	N/A	N/A	9.86	N/A	8.47	1 KB	1 KB	N/A	11.8 KB	\\aquinas.lan.dream.upd.edu.ph\RAWDATA

RECEIVED FROM:

NAME: C. Joaquin
POSITION:
SIGNATURE:

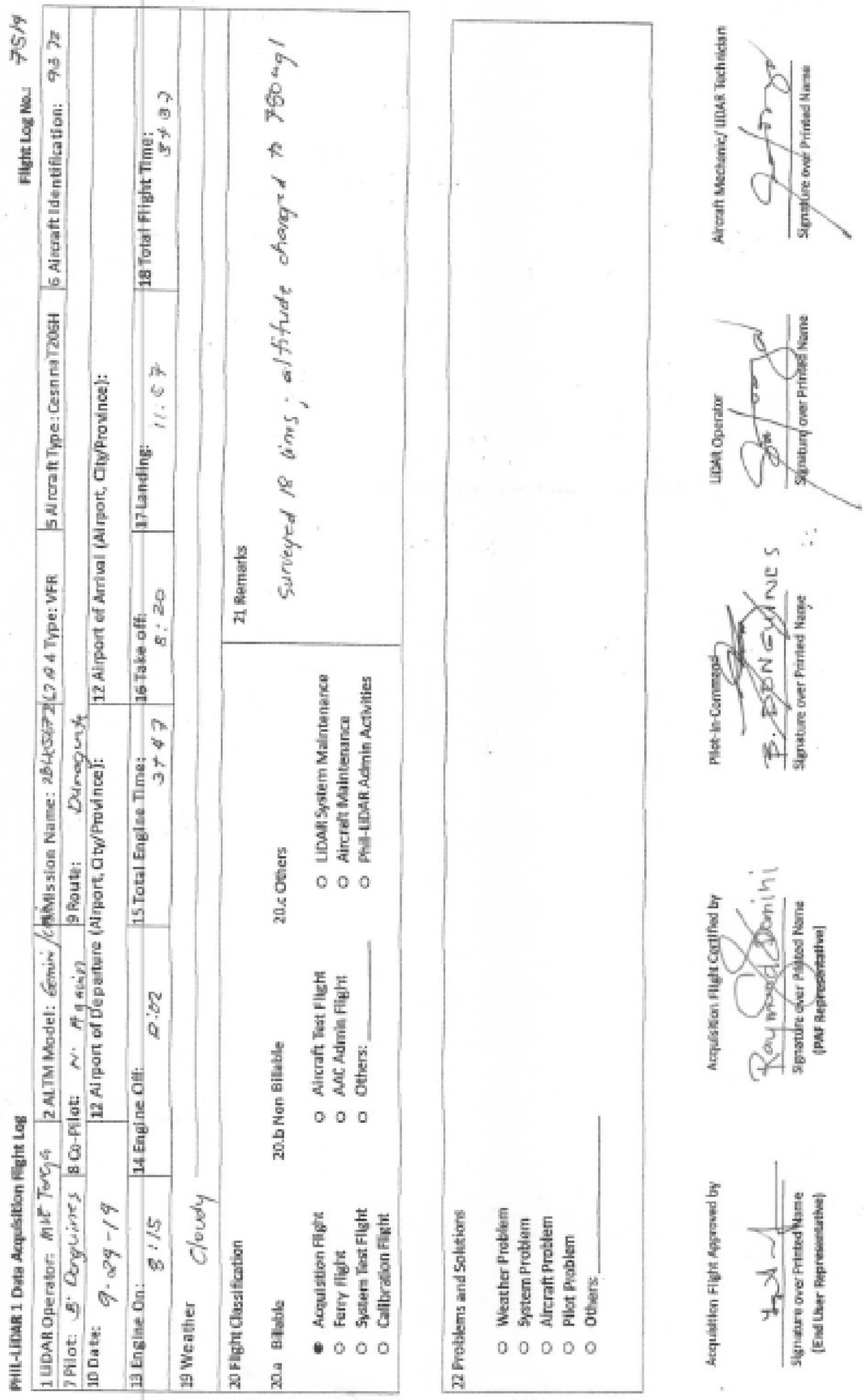
RECEIVED BY:

NAME: IRIDA PRIETO
POSITION: CSRS
SIGNATURE:

DATE: NOV/06/2014

ANNEX 6 FLIGHT LOGS FOR THE FLIGHT MISSIONS

Flight Log for 7514G Mission



PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 7514

1 LIDAR Operator: MVE Tonga | 2 ALTM Model: Gemini | 3 Mission Name: 2BLK53F272A | 4 Type: VFR | 5 Aircraft Type: Cesnna T206H | 6 Aircraft Identification: 9322

7 Pilot: B. Donguines | 8 Co-Pilot: N. Aquino | 9 Route: Dumaguete

10 Date: 9-29-19 | 12 Airport of Departure (Airport, City/Province): | 12 Airport of Arrival (Airport, City/Province):

13 Engine On: 8:15 | 14 Engine Off: 12:02 | 15 Total Engine Time: 3+47 | 16 Take off: 8:20 | 17 Landing: 11:57 | 18 Total Flight Time: 3+37

19 Weather: Cloudy

20 Flight Classification

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

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

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

21 Remarks

Surveyed 18 lines; altitude changed to 750 agl

22 Problems and Solutions
- ○ Weather Problem
- ○ System Problem
- ○ Aircraft Problem
- ○ Pilot Problem
- ○ Others: ____

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

Acquisition Flight Certified by: Raymond Dominic, Signature over Printed Name (PAF Representative)

Pilot-in-Command: B. DONGUINES, Signature over Printed Name

LIDAR Operator: Signature over Printed Name

Aircraft Mechanic/ LIDAR Technician: Signature over Printed Name

Flight Log for 7516G Mission

PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 7516

1 LIDAR Operator: MVE Tongco	2 ALTM Model: Gemini	3 Mission Name: 2BLK5L DG262A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9322
7 Pilot: B. Donguines	8 Co-Pilot: N. Aganin	9 Route: Dumaguete			
10 Date: 9-25-14	12 Airport of Departure (Airport, City/Province):		12 Airport of Arrival (Airport, City/Province):		
13 Engine On: 7:47	14 Engine Off: 11:52	15 Total Engine Time: [illegible]	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: Cloudy					
20 Remarks: Mission completed; altitude was changed due to cloud build up					

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
Lovely Acuña	Raymund Domine	B. Donguines	[illegible]
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

Flight Log for 7518G Mission

PHIL-LiDAR 1 Data Acquisition Flight Log

Flight Log No.: 7518

1 LiDAR Operator: MVE Tong	2 ALTM Model: Gem CAS	3 Mission Name: 2BLK CLB259A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9073
7 Pilot: B. Donguines	8 Co-Pilot: N. Adrain	9 Route: Dumaguete			
10 Date: 9-26-14	12 Airport of Departure (Airport, City/Province):		12 Airport of Arrival (Airport, City/Province):		
13 Engine On: 7:56	14 Engine Off: 10:55	15 Total Engine Time: 2+59	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: Cloudy					
20 Remarks: Surveyed 11 lines; heavy cloud build-up					

21 Problems and Solutions:

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

Flight Log for 7582G Mission

PHIL-LiDAR 1 Data Acquisition Flight Log

Flight Log No.: 7582GC

1 LIDAR Operator: MVE Tongga	2 ALTM Model: Gemini CASI	3 Mission Name: 2BLK36BSES301A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9322
7 Pilot: R. Samar	8 Co-Pilot: N. Agawin	9 Route: Dumaguete			
10 Date: Oct 28, 2014	12 Airport of Departure (Airport, City/Province): Dumaguete		12 Airport of Arrival (Airport, City/Province): Dumaguete		
13 Engine On: 0604	14 Engine Off: 0927	15 Total Engine Time: 3+23	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather	Cloudy				

20 Remarks:

Mission completed (without CASI due to intermitent grounding connection)

21 Problems and Solutions:

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

Flight Log for 7583G Mission

PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 7583GC

1 LiDAR Operator: MR Villanueva	2 ALTM Model: Gemini/CASI	3 Mission Name: 2BLK5CABS301B+ CALIBRATION	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9122
7 Pilot: R. Samar	8 Co-Pilot: N. Agawin	9 Route: Dumaguete			
10 Date: Oct. 28, 2014	12 Airport of Departure (Airport, City/Province): Dumaguete		12 Airport of Arrival (Airport, City/Province): Dumaguete		
13 Engine On: 1355	14 Engine Off: 1730	15 Total Engine Time: 3+35	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: Fair					

20 Remarks:

Mission completed plus calibration of Gemini (without CASI due to intermittent grounding connection)

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
Gemmel Hipolito	Sg Raymund Damini	R. Samar	MR Villanueva
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

ANNEX 7 FLIGHT STATUS REPORTS

NEGROS ORIENTAL

September 20 – November 15, 2014 and January 21–February 1, 2016

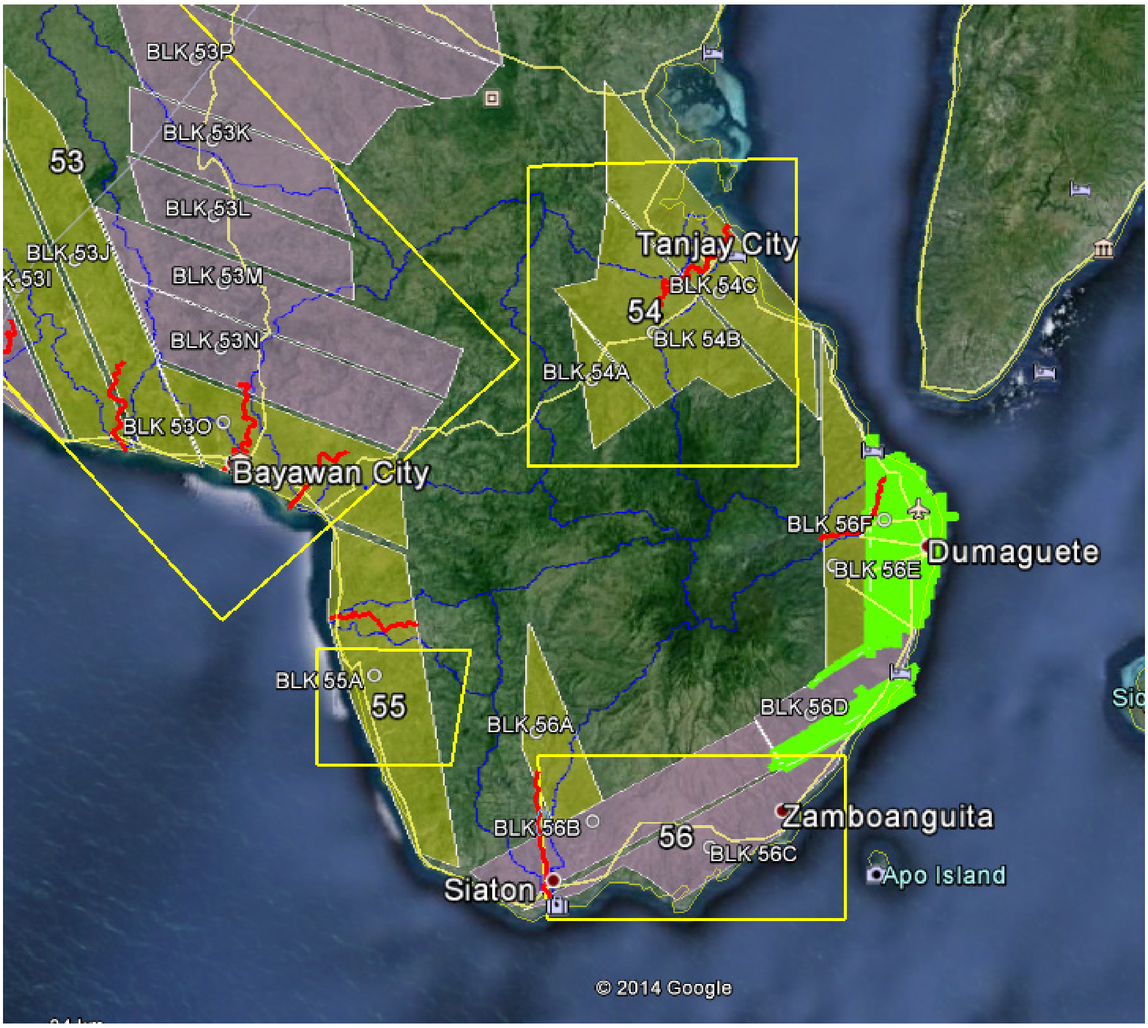
FLIGHT NO.	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
7514	BLK56F	2BLK56F267A	MVE TONGA	24 SEPT 14	Surveyed 18 lines
7515	BLK54C	2BLK54C267B	MR VILLANUEVA	24 SEPT 14	Surveyed 7 lines
7516	BLK 56C & BLK56D	2BLK56DC268A	MVE TONGA	25 SEPT 14	Mission com- pleted
7582	BLK56B & BLK56E	2BLK56BSES301A	MVE Tonga	28 OCT 14	Mission completed
7583	BLK56A & BLK56B	2BLK56ABS301B + CALIBRATION	MR VILLANUEVA	28 OCT 14	Mission completed plus calibration of Gemini

SWATH COVERAGE

Flight No. : 7514

Area: BLK56F

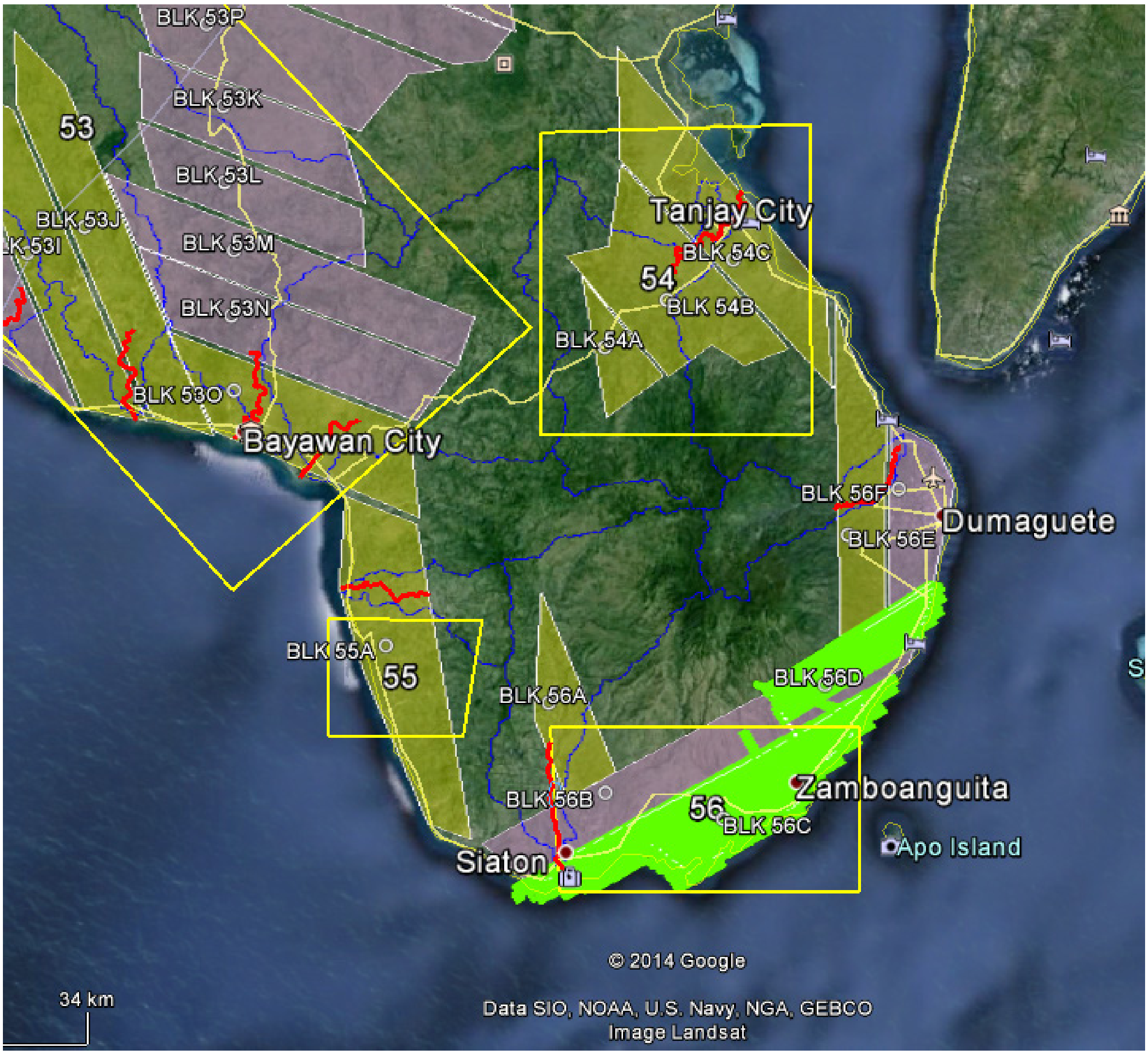
Mission Name: 2BLK56F267A



Flight No. : 7516

Area: BLK56D & BLK56C

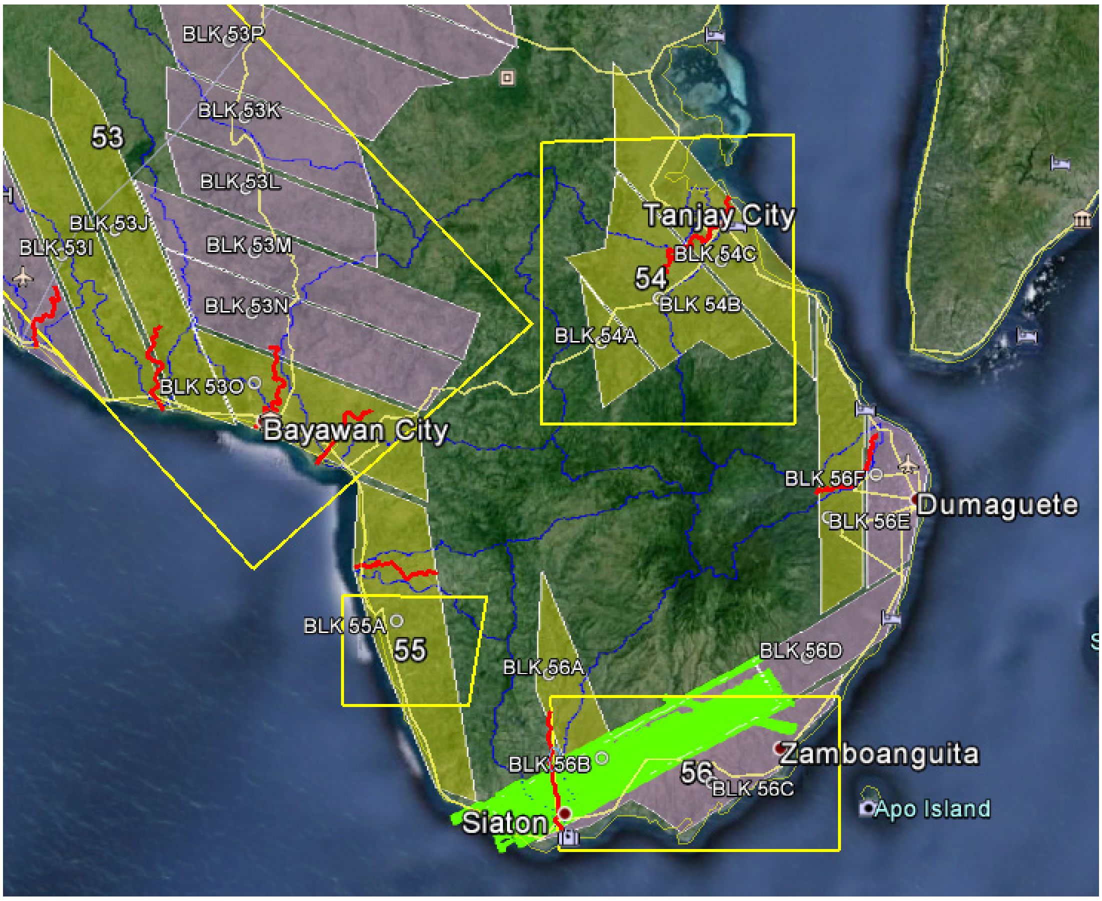
Mission Name: 2BLK56DC268A



Flight: 7518

Area: BLK56B

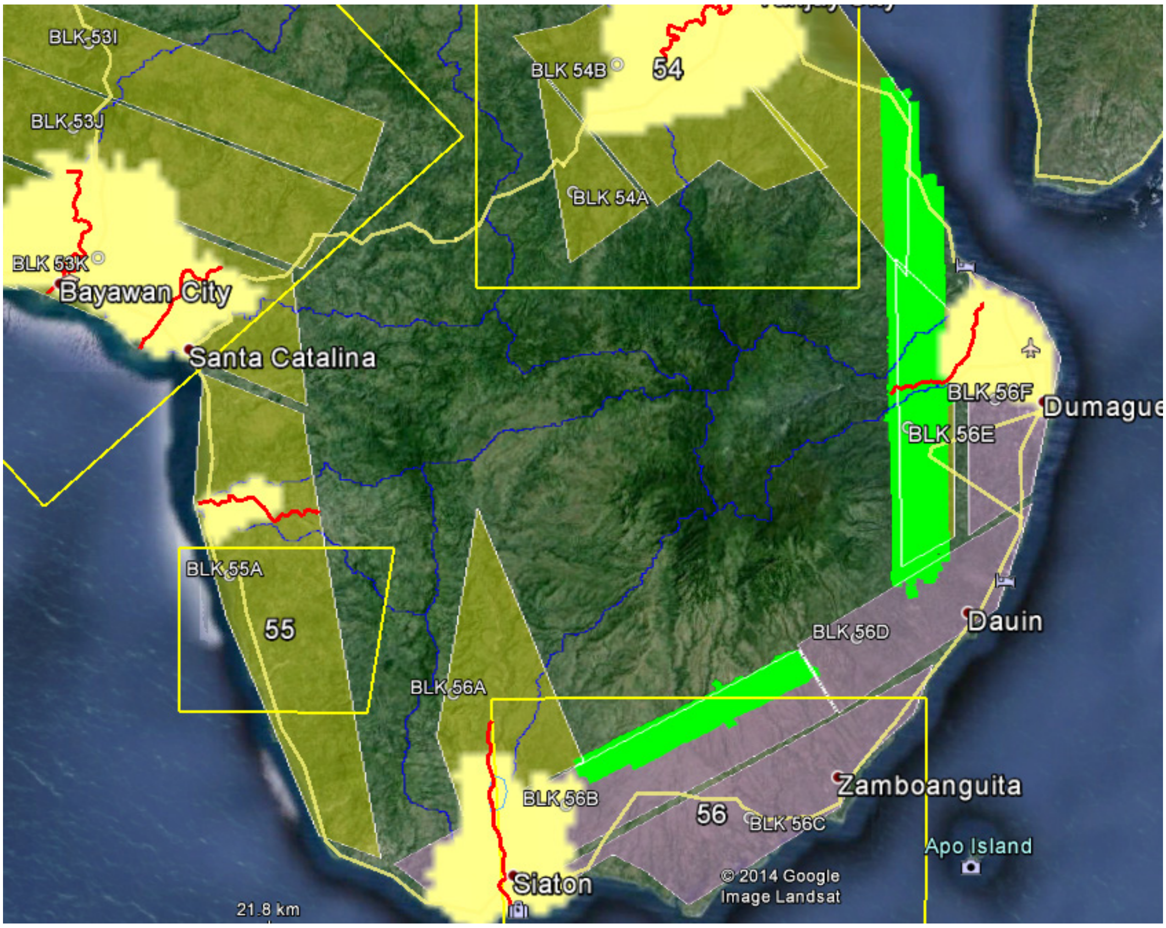
Mission Name: 2BLK56B269A



Flight No. : 7582

Area: BLK 56B & BLK 56E

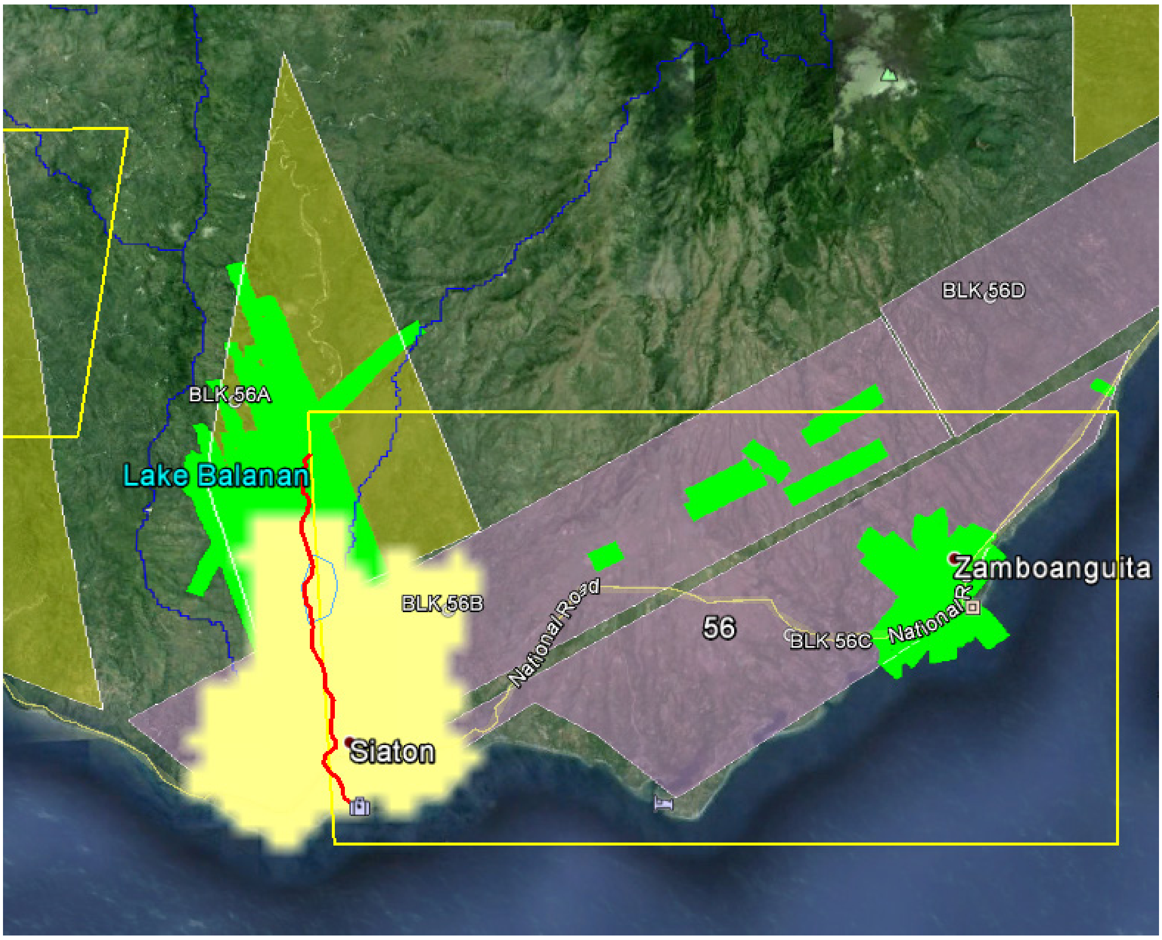
Mission Name: 2BLK56BSES301A



Flight No. : 7583

Area: BLK 56A & BLK 56B, LMS CALIBRATION

Mission Name: 2BLK56ABS301B + CALIBRATION



ANNEX 8 MISSION SUMMARY REPORTS

Table A-8.1 MISSION SUMMARY REPORT for Mission Blk56A

Flight Area	**Dumaguete**
Mission Name	Blk56A
Inclusive Flights	7583G
Range data size	9.86 GB
POS data size	145 MB
Base data size	3.61 MB
Image	na
Transfer date	October 6, 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)	1.15
RMSE for East Position (<4.0 cm)	1.2
RMSE for Down Position (<8.0 cm)	3.15
Boresight correction stdev (<0.001deg)	0.000212
IMU attitude correction stdev (<0.001deg)	0.000358
GPS position stdev (<0.01m)	0.0012
Minimum % overlap (>25)	30.09%
Ave point cloud density per sq.m. (>2.0)	3.61
Elevation difference between strips (<0.20m)	Yes
Number of 1km x 1km blocks	59
Maximum Height	766.06 m
Minimum Height	70.85 m
Classification (# of points)	
Ground	15596658
Low vegetation	14714328
Medium vegetation	45897016
High vegetation	52003822
Building	848685
Orthophoto	No
Processed by	Engr. Angelo Carlo Bongat, Engr. Christy Lubiano, JovyNarisma

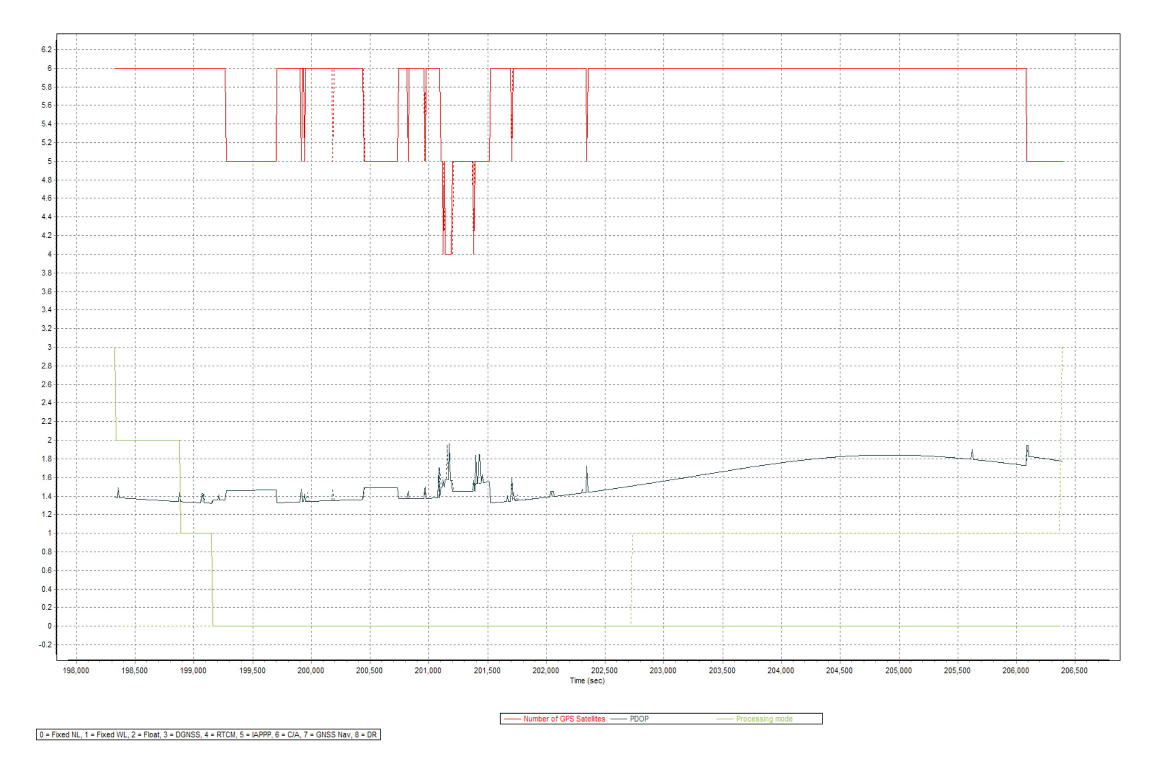


Figure A-8.1 Solution Status

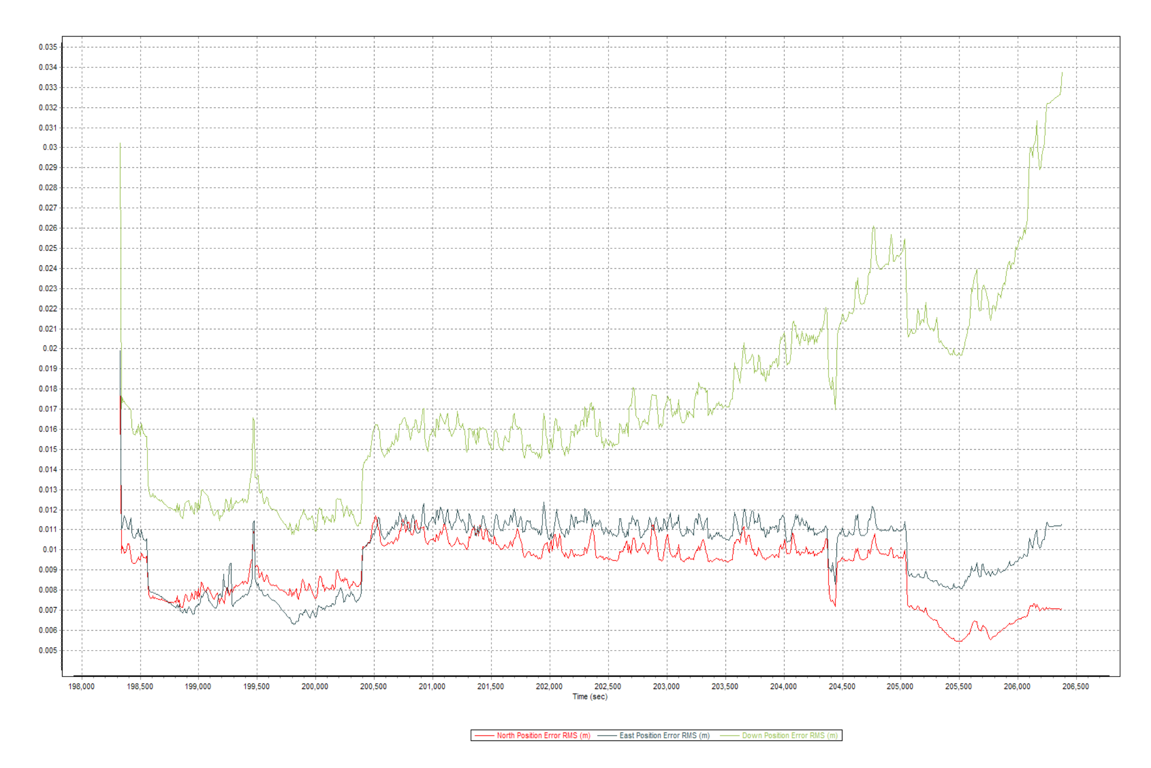


Figure A-8.2 Smoothed Performance Metric Parameters

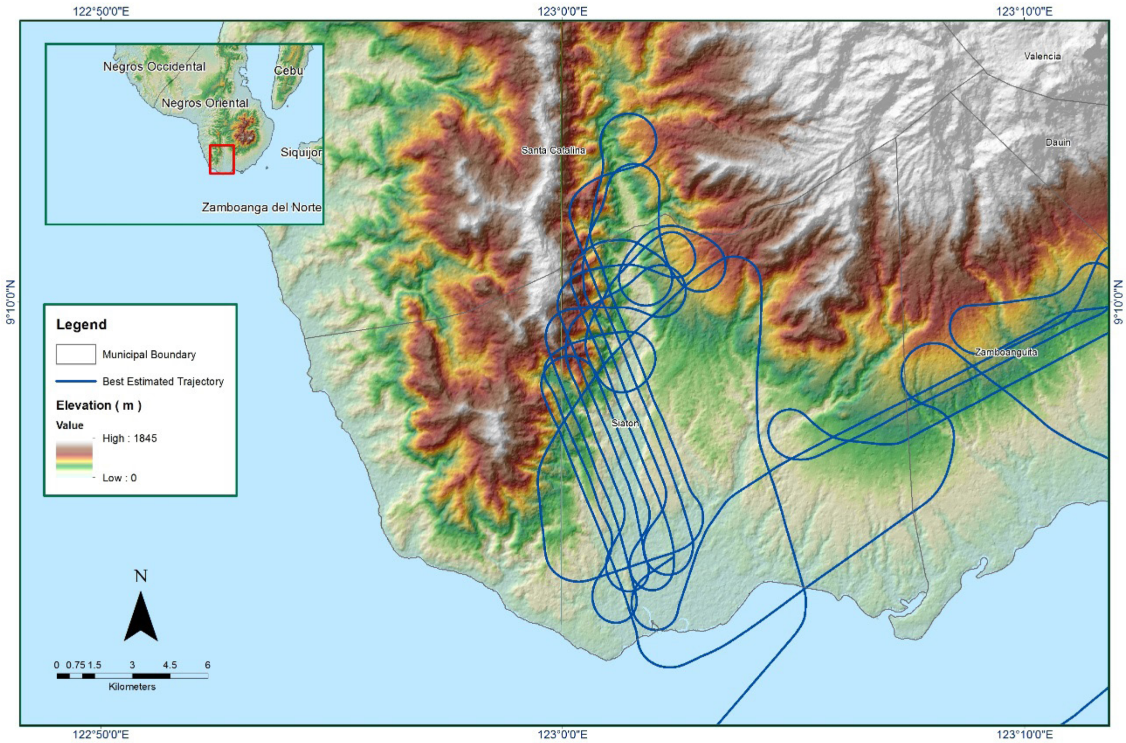


Figure A-8.3 *Best Estimated Trajectory*

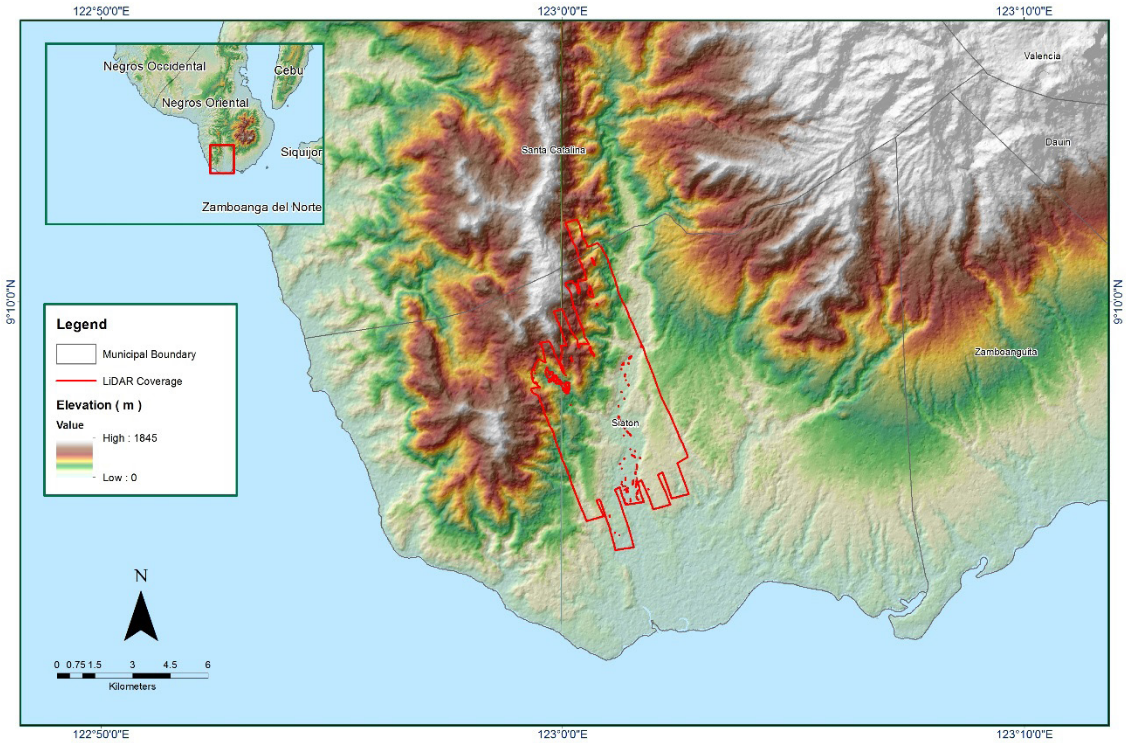


Figure A-8.4 Coverage of LiDAR data

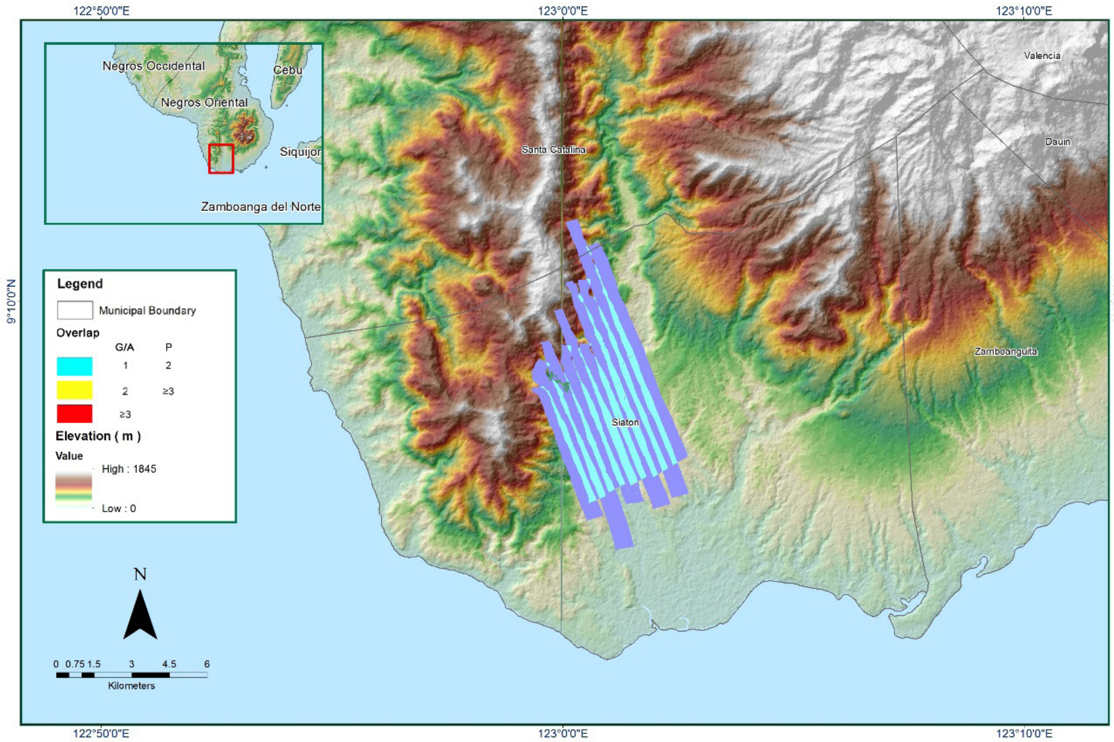


Figure A-8.5 Image of data overlap

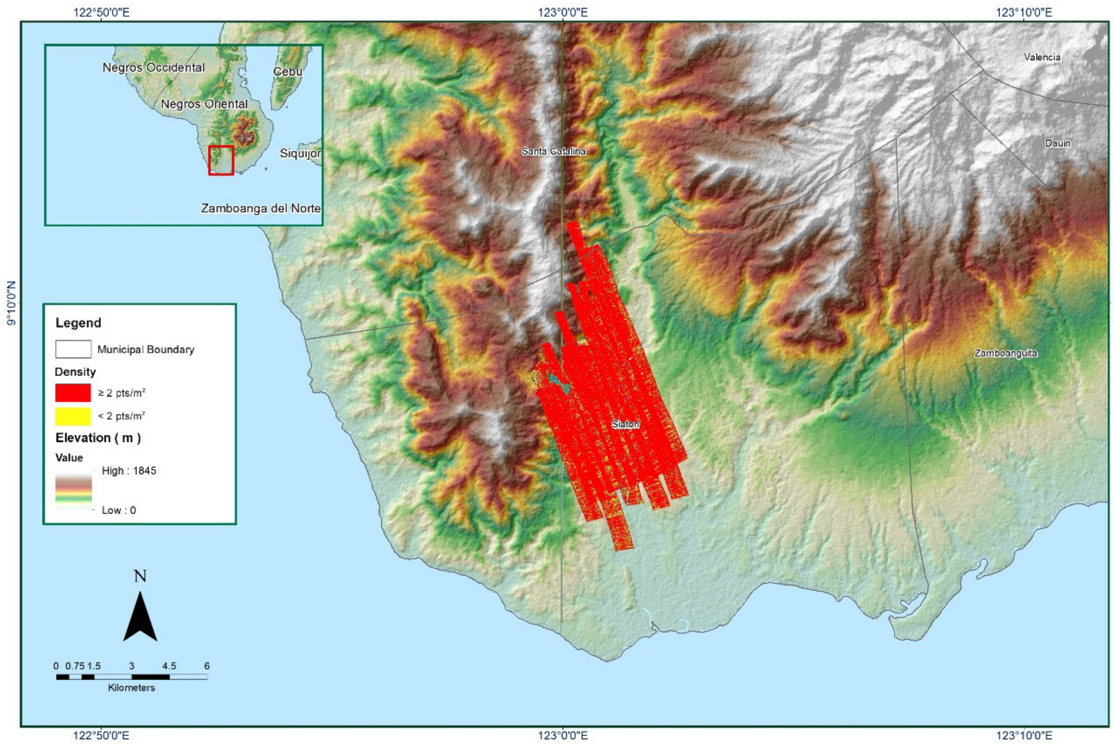


Figure A-8.6 *Density map of merged LiDAR data*

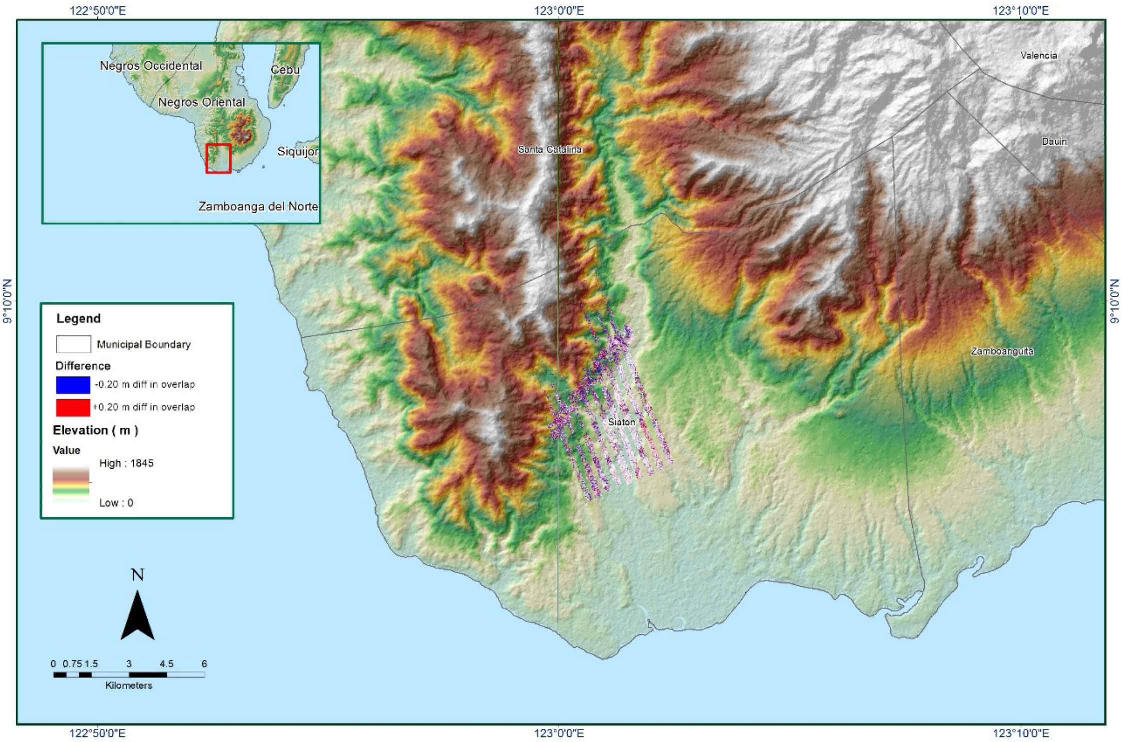


Figure A-8.7 *Elevation difference between flight lines*

Table A-8.2 Mission Summary Report for Mission Blk56B

Flight Area	Dumaguete
Mission Name	Blk56B
Inclusive Flights	7518G,7582G,7583G
Range data size	42.06 GB
POS data size	483 MB
Base data size	22.48 MB
Image	na
Transfer date	October 28, 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)	0.084
RMSE for East Position (<4.0 cm)	1.26
RMSE for Down Position (<8.0 cm)	2.85
Boresight correction stdev (<0.001deg)	0.000268
IMU attitude correction stdev (<0.001deg)	0.0042
GPS position stdev (<0.01m)	0.0070
Minimum % overlap (>25)	48.38%
Ave point cloud density per sq.m. (>2.0)	4.54
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	182
Maximum Height	576.01
Minimum Height	59.74
Classification (# of points)	
Ground	58567635
Low vegetation	63718874
Medium vegetation	199599866
High vegetation	131154661
Building	2517030
Orthophoto	No
Processed by	Engr. Kenneth Solidum, Engr. Chelou Prado, Engr. Jeffrey Delica

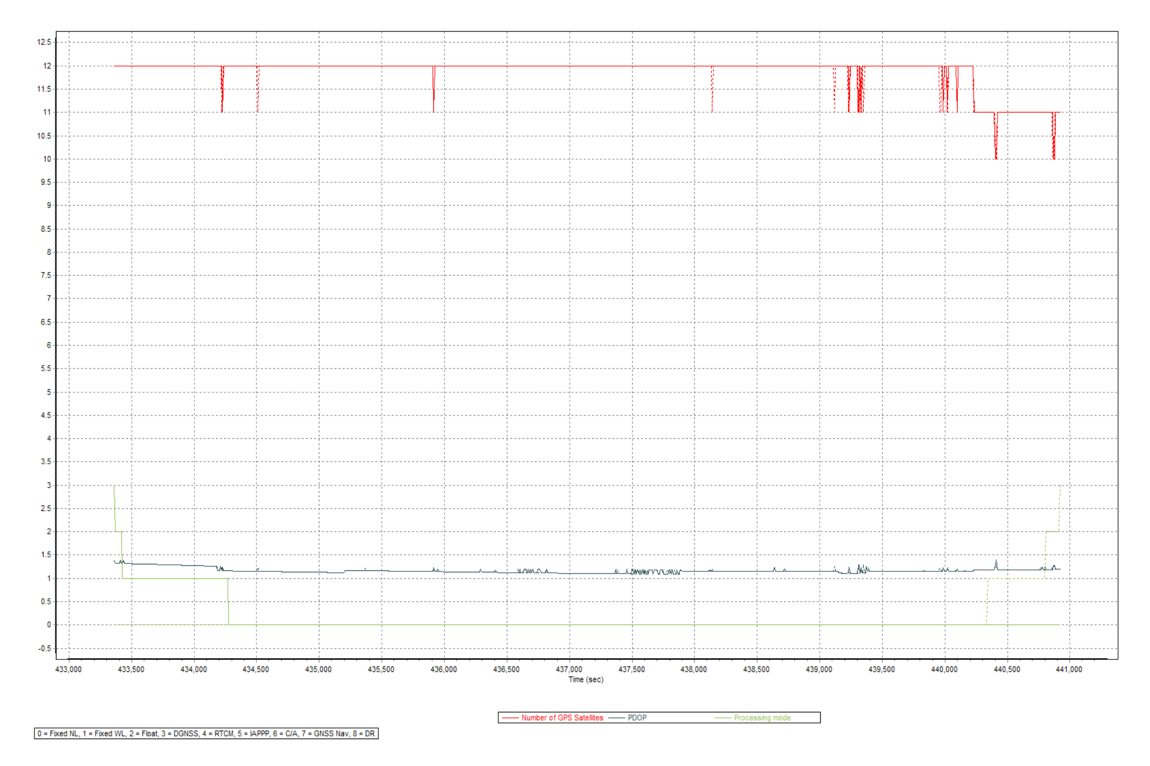


Figure A-8.8 Solution Status

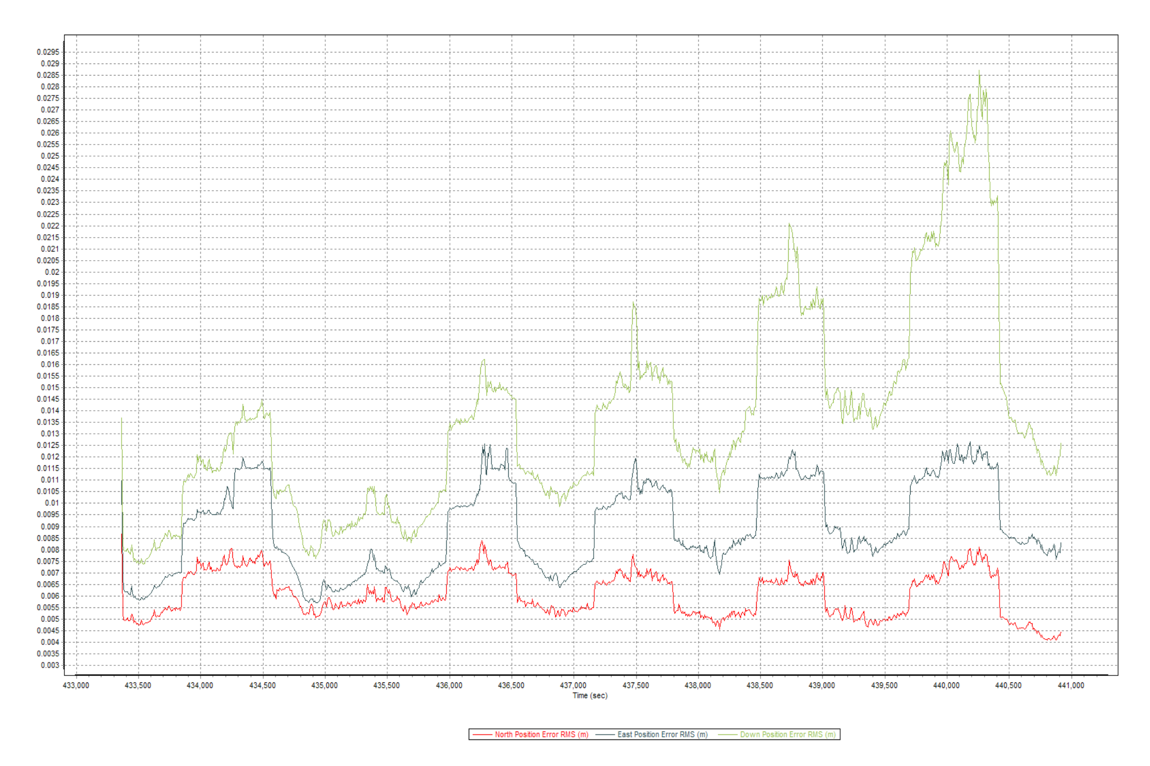


Figure A-8.9 Smoothed Performance Metric Parameters

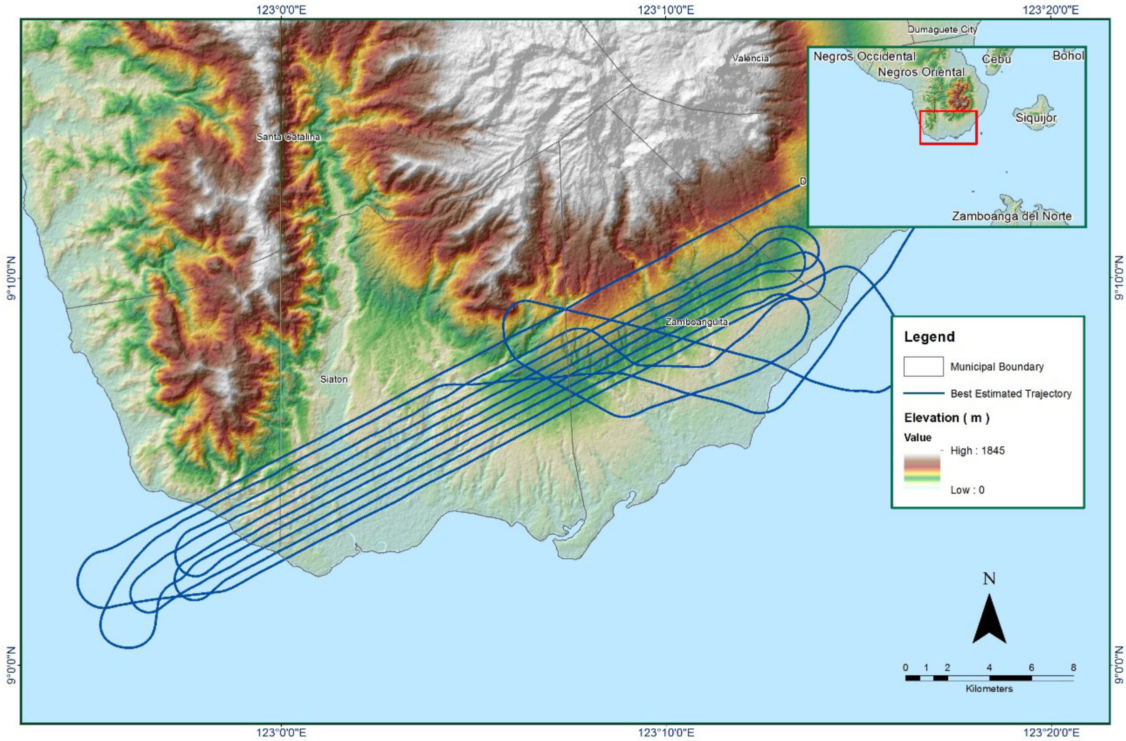


Figure A-8.10 Best Estimated Trajectory

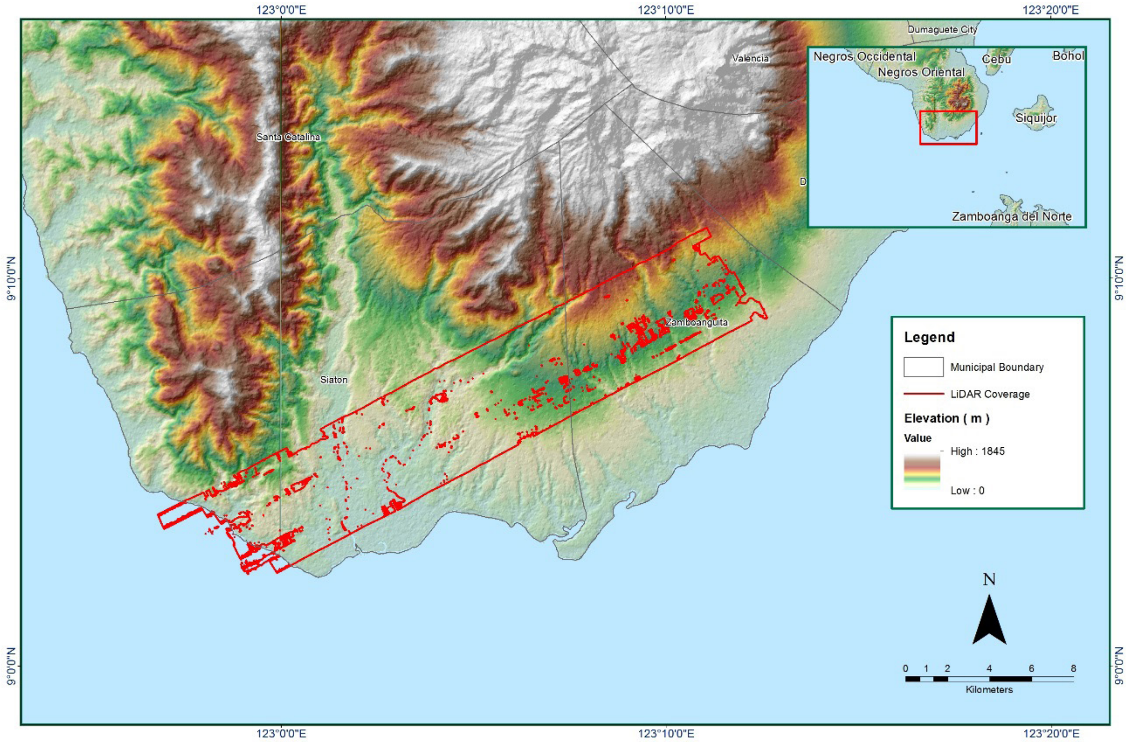


Figure A-8.11 Coverage of LiDAR data

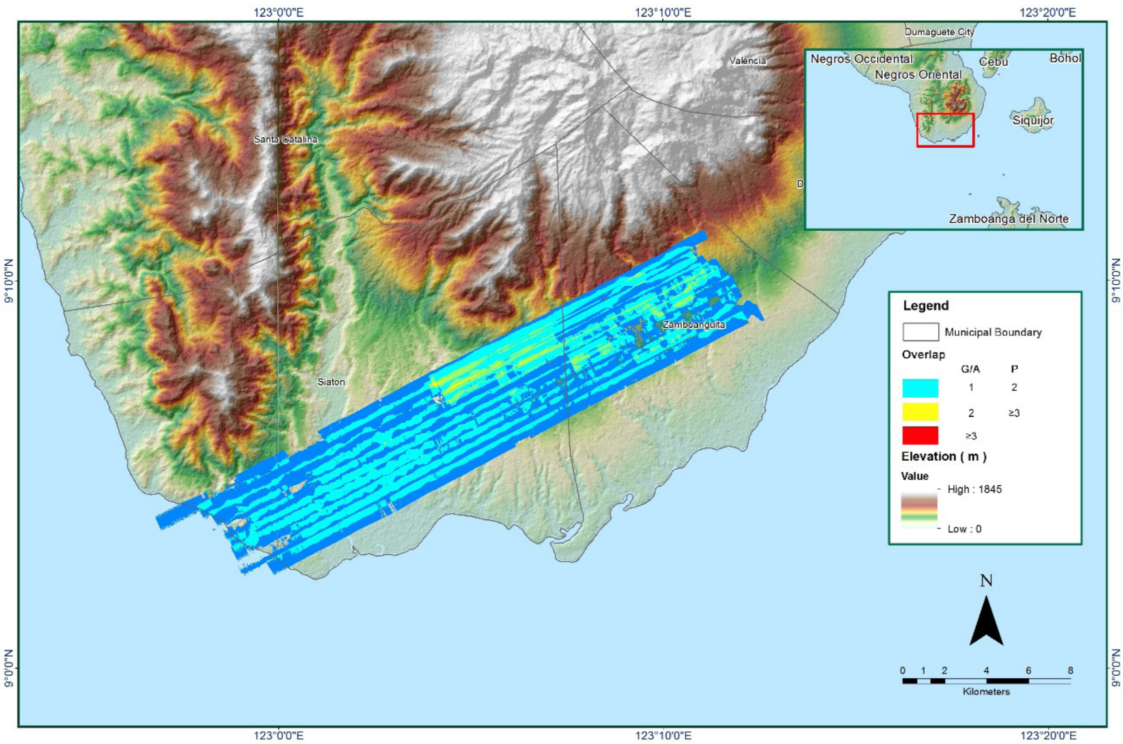


Figure A-8.12 Image of data overlap

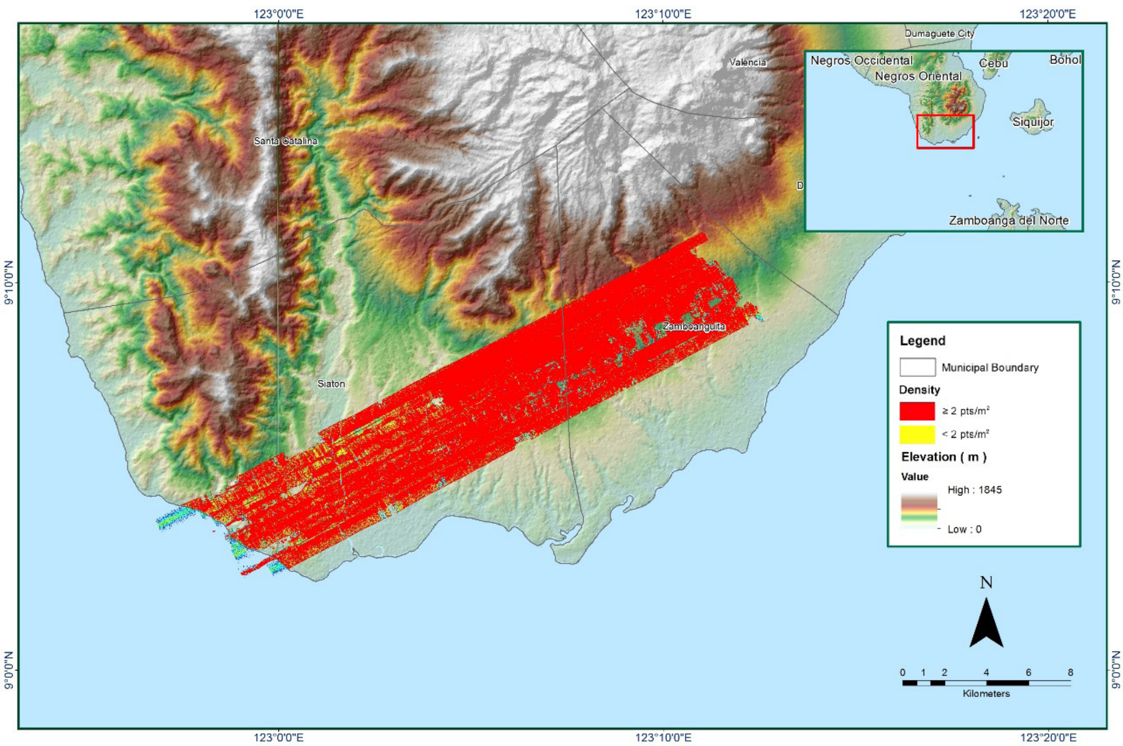


Figure A-8.13 *Density map of merged LiDAR data*

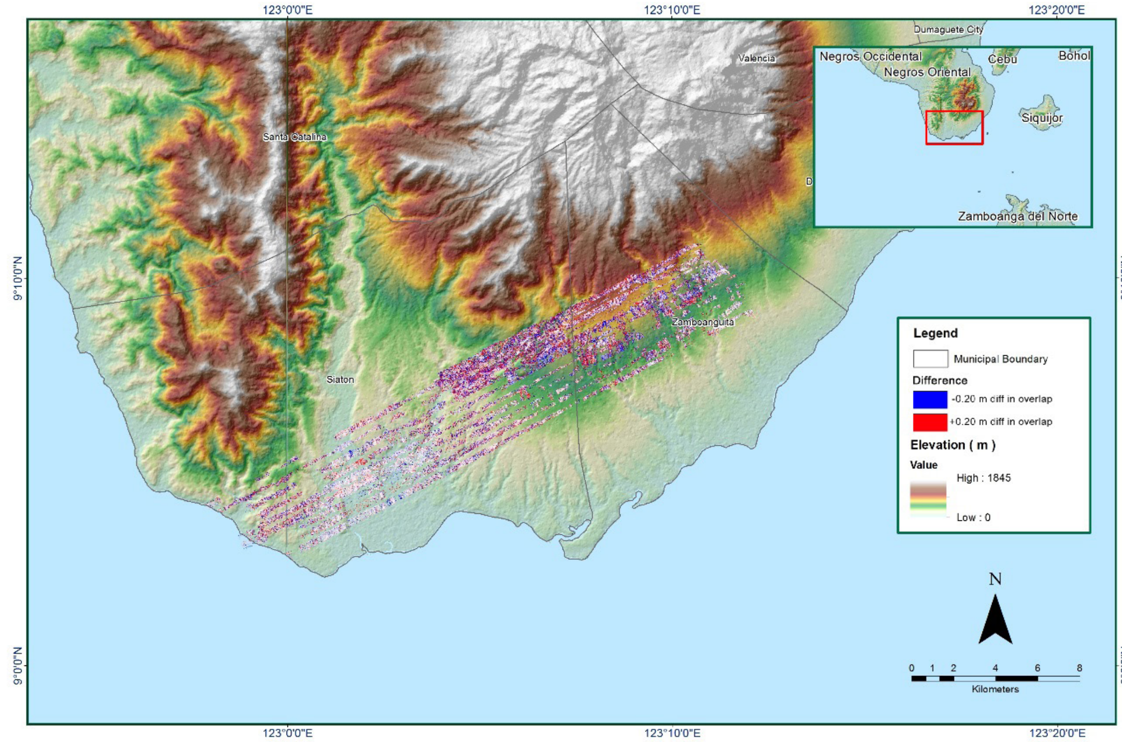


Figure A-8.14 *Elevation difference between flight lines*

Table A-8.3 Mission Summary Report for Mission Blk56CD

Flight Area	Dumaguete
Mission Name	Blk56CD
Inclusive Flights	7516G,7514G
Range data size	61 GB
POS data size	464 MB
Base data size	19.82 MB
Image	na
Transfer date	October 25, 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)	0.093
RMSE for East Position (<4.0 cm)	1.58
RMSE for Down Position (<8.0 cm)	2.95
Boresight correction stdev (<0.001deg)	0.000279
IMU attitude correction stdev (<0.001deg)	2.024948
GPS position stdev (<0.01m)	0.0029
Minimum % overlap (>25)	33.02%
Ave point cloud density per sq.m. (>2.0)	3.85
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	284
Maximum Height	561.01 m
Minimum Height	22.69 m
Classification (# of points)	
Ground	67459329
Low vegetation	75476828
Medium vegetation	253361960
High vegetation	262909449
Building	6198265
Orthophoto	No
Processed by	Engr. Angelo Carlo Bongat, Engr. JovelleAnjea-nette Canlas, Engr. Ma. AilynOlanda

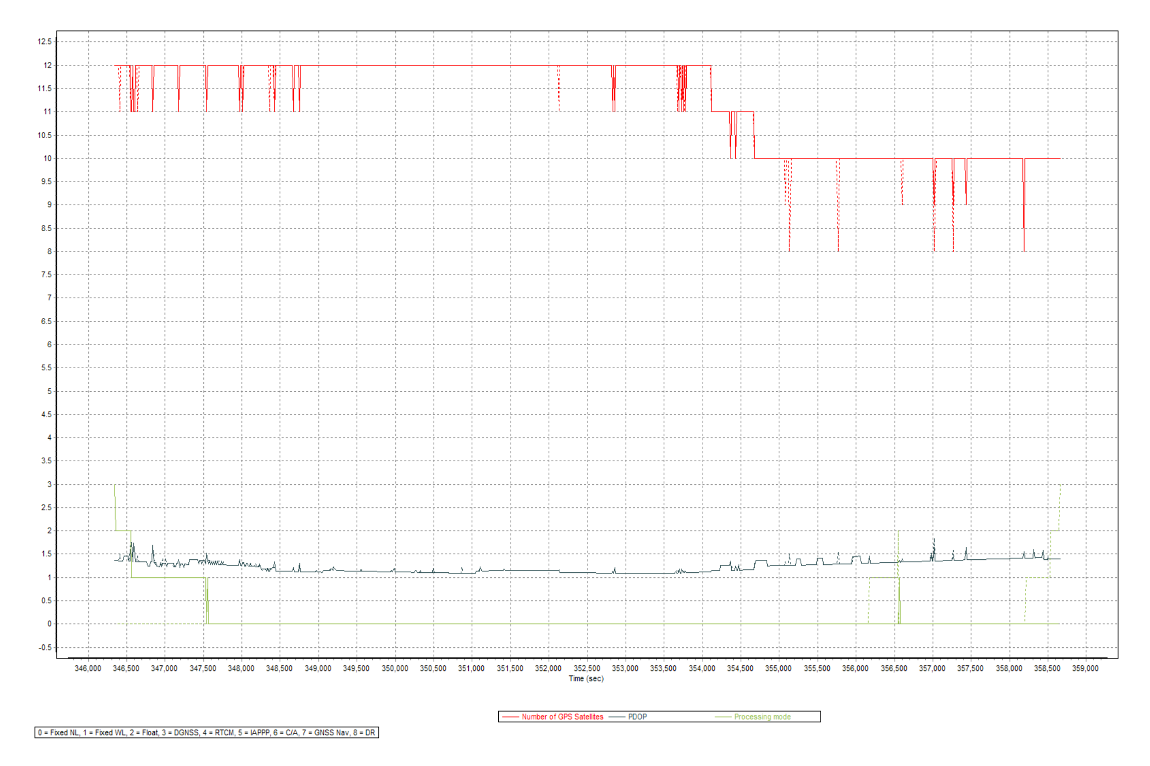


Figure A-8.15 Solution Status

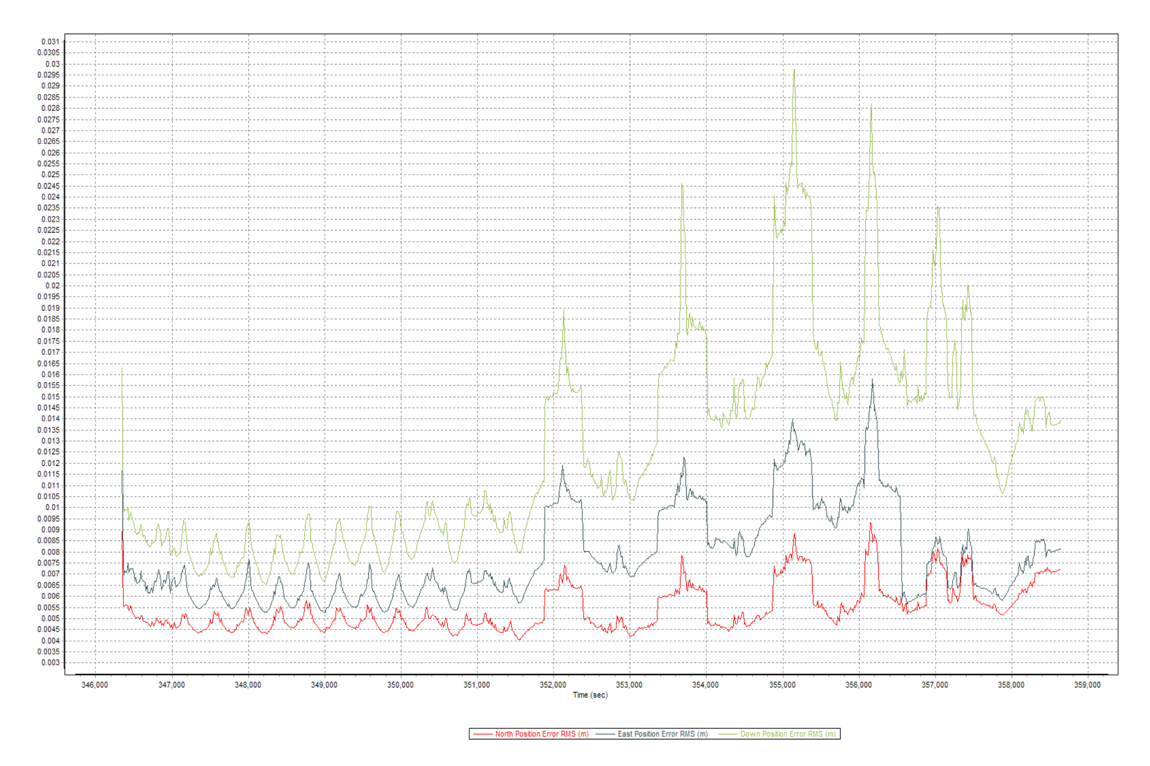


Figure A-8.16 Smoothed Performance Metric Parameters

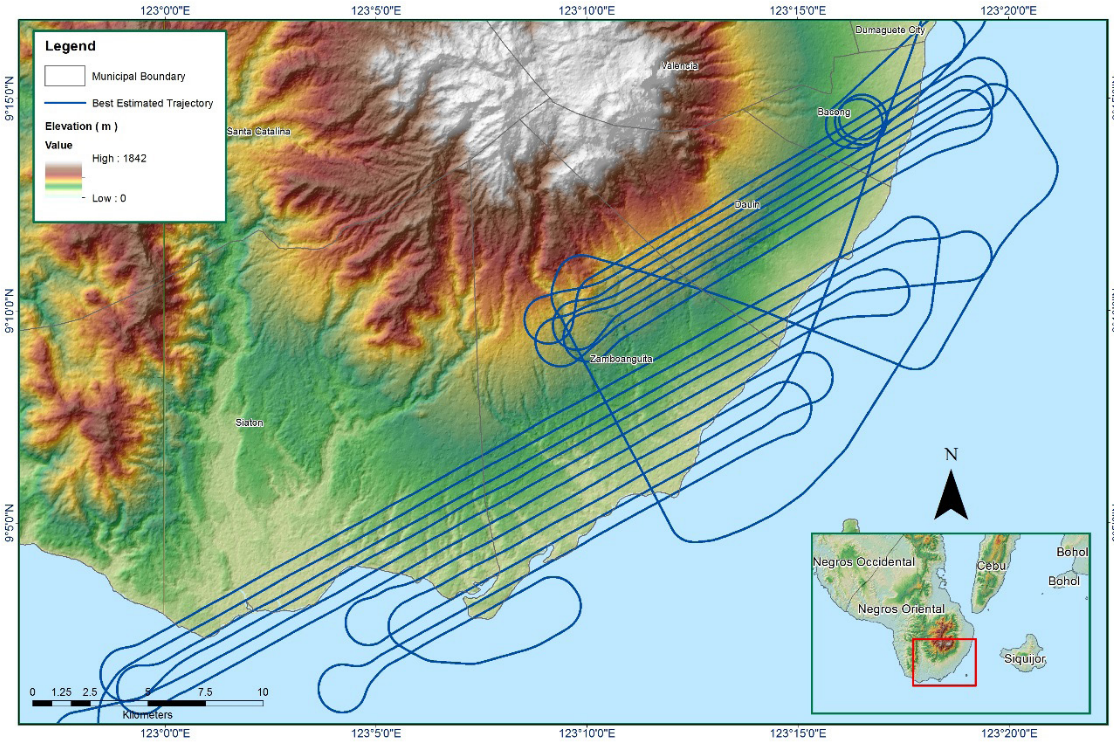


Figure A-8.17 *Best Estimated Trajectory*

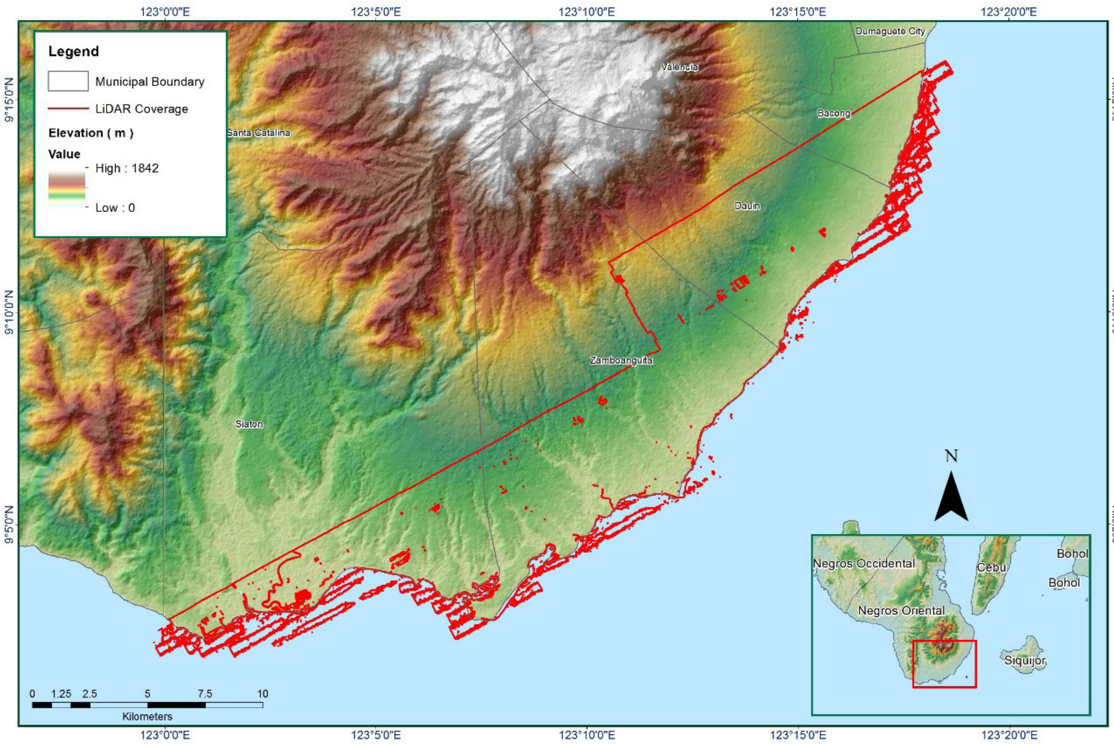


Figure A-8.18Coverage of LiDAR data

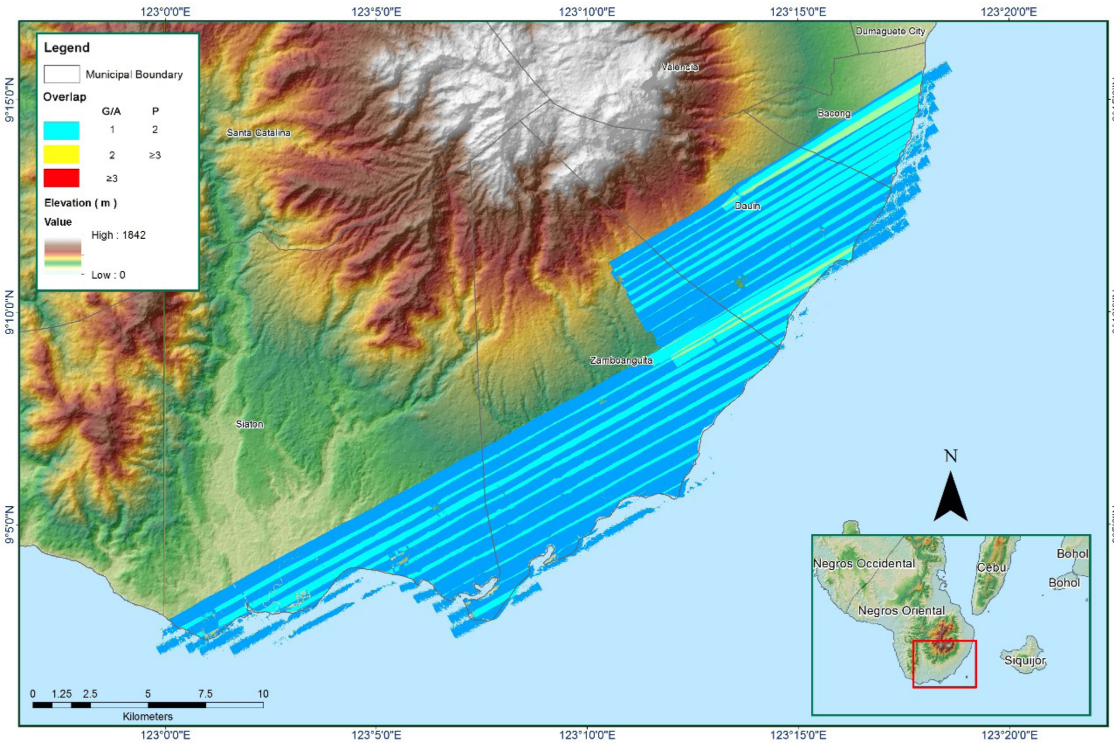


Figure A-8.19 ***Image of data overlap***

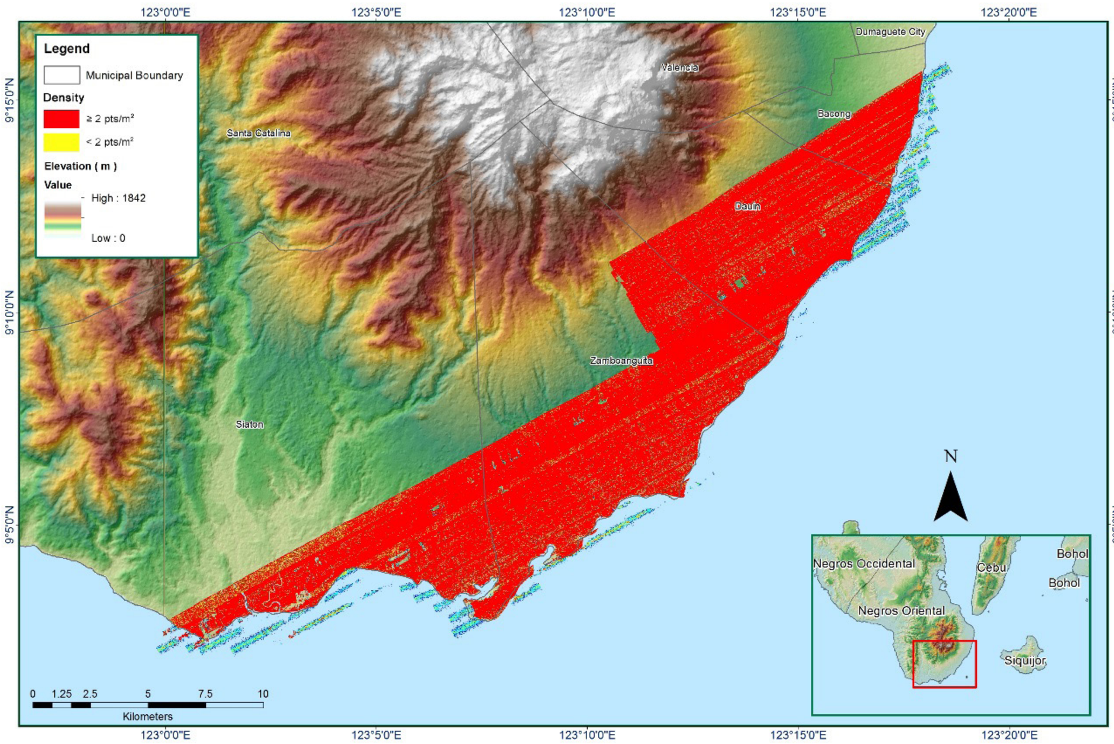


Figure A-8.20 *Density map of merged LiDAR data*

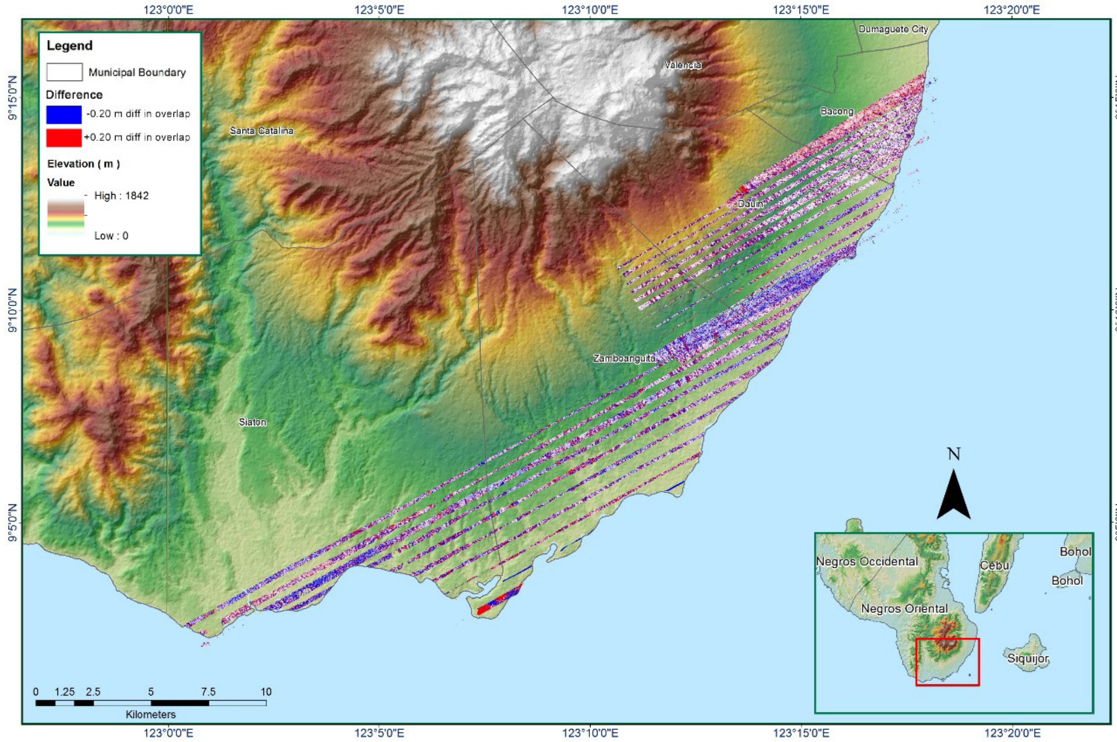


Figure A-8.21 *Elevation difference between flight lines*

Table A-8.4 Mission Summary Report for Mission Blk56CD_additional

Flight Area	Dumaguete
Mission Name	Blk56CD_additional
Inclusive Flights	7516G
Range data size	25.5 GB
POS	236 MB
Image	NA
Base Station	7.82 MB
Transfer date	October 20, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	0.93
RMSE for East Position (<4.0 cm)	1.58
RMSE for Down Position (<8.0 cm)	2.98
Boresight correction stdev (<0.001deg)	NA
IMU attitude correction stdev (<0.001deg)	NA
GPS position stdev (<0.01m)	NA
Minimum % overlap (>25)	NA
Ave point cloud density per sq.m. (>2.0)	2.87
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	42
Maximum Height	154.66 m
Minimum Height	66.17 m
Classification (# of points)	
Ground	2,871,359
Low vegetation	2,095,923
Medium vegetation	10,736,410
High vegetation	13,766,322
Building	102,819
Orthophoto	No
Processed by	Engr. Angelo Carlo Bongat, Engr. Chelou Prado, Engr. Krisha Marie Bautista

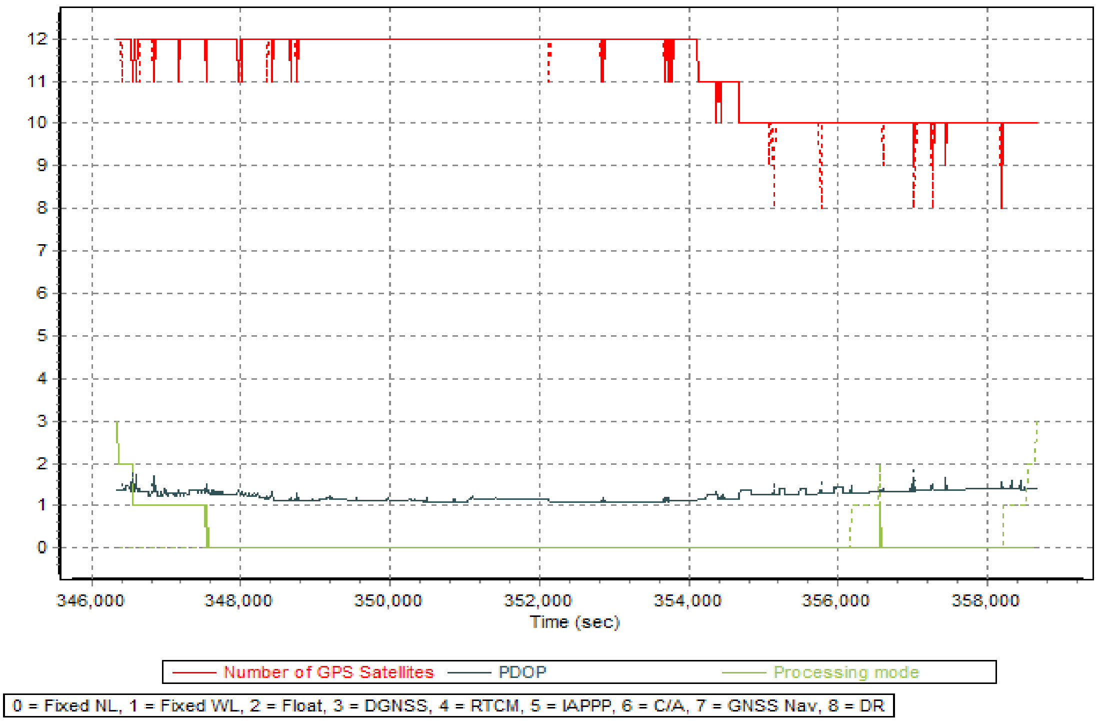


Figure A-8.22 Solution Status

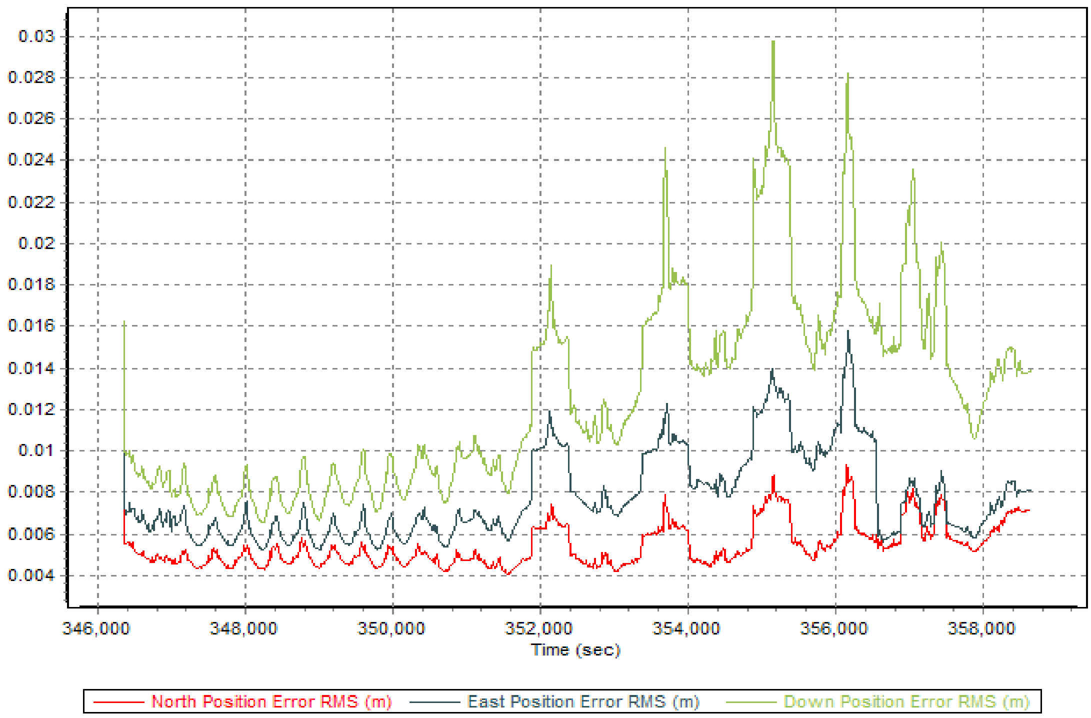


Figure A-8.23 Smoothed Performance Metric Parameters

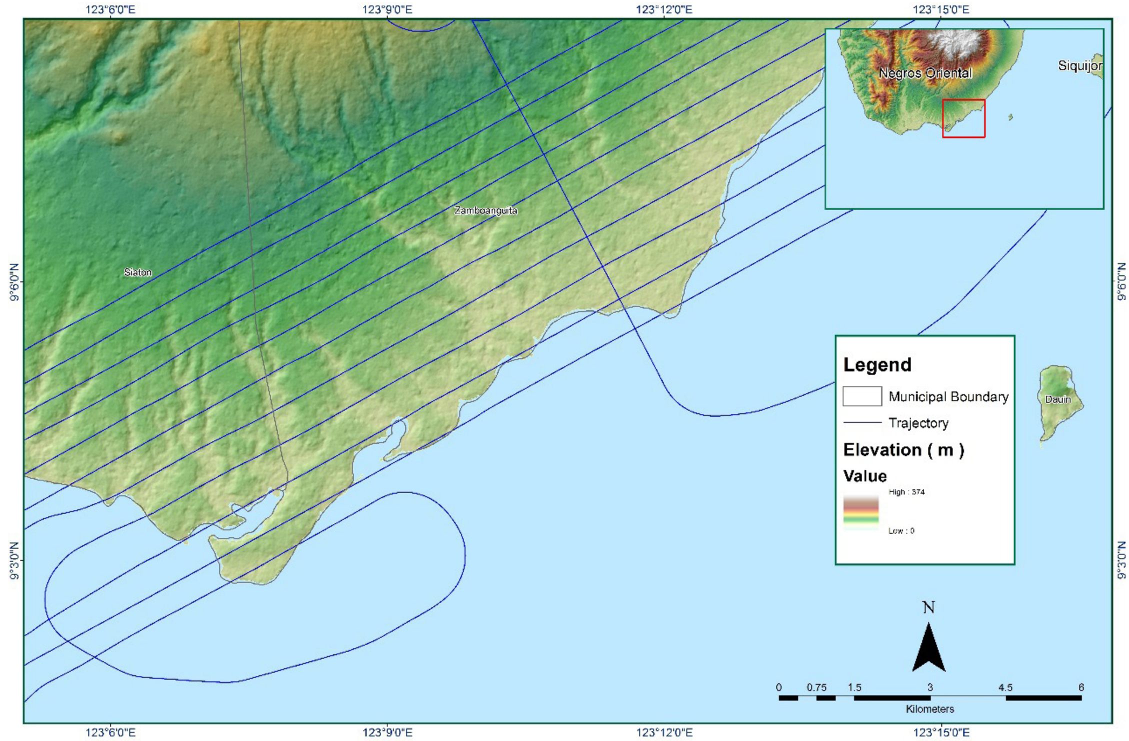


Figure A-8.24 *Best Estimate Trajectory*

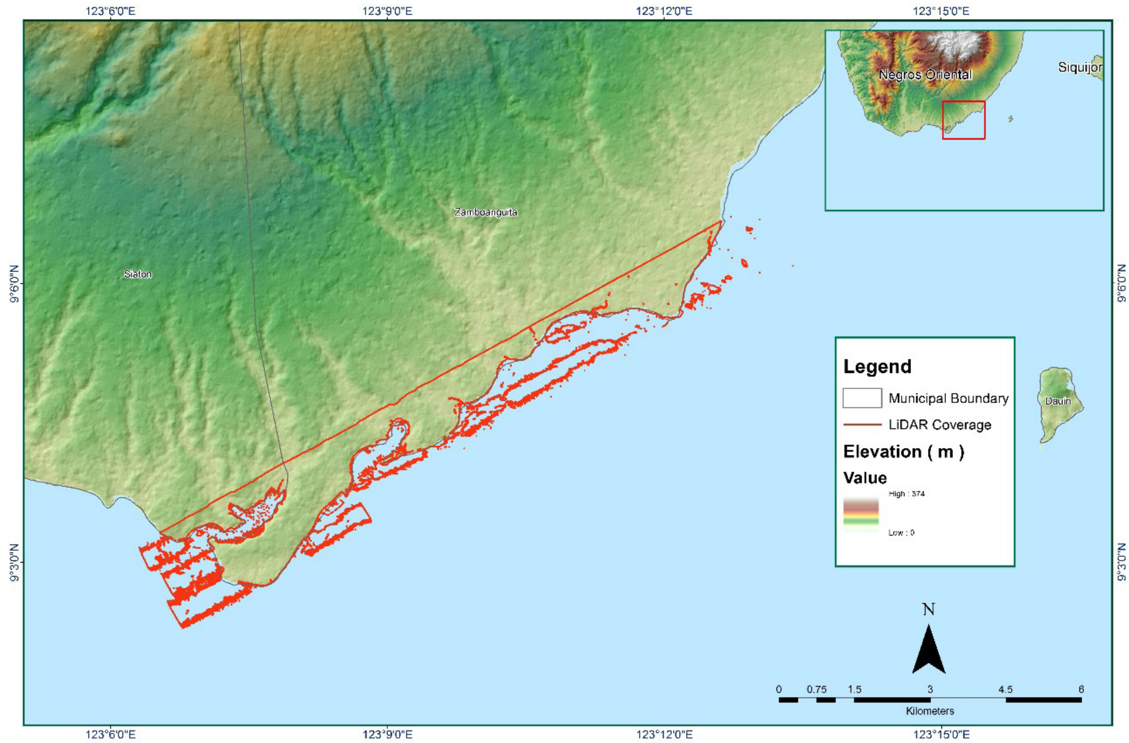


Figure A-8.25 Coverage of LiDAR data

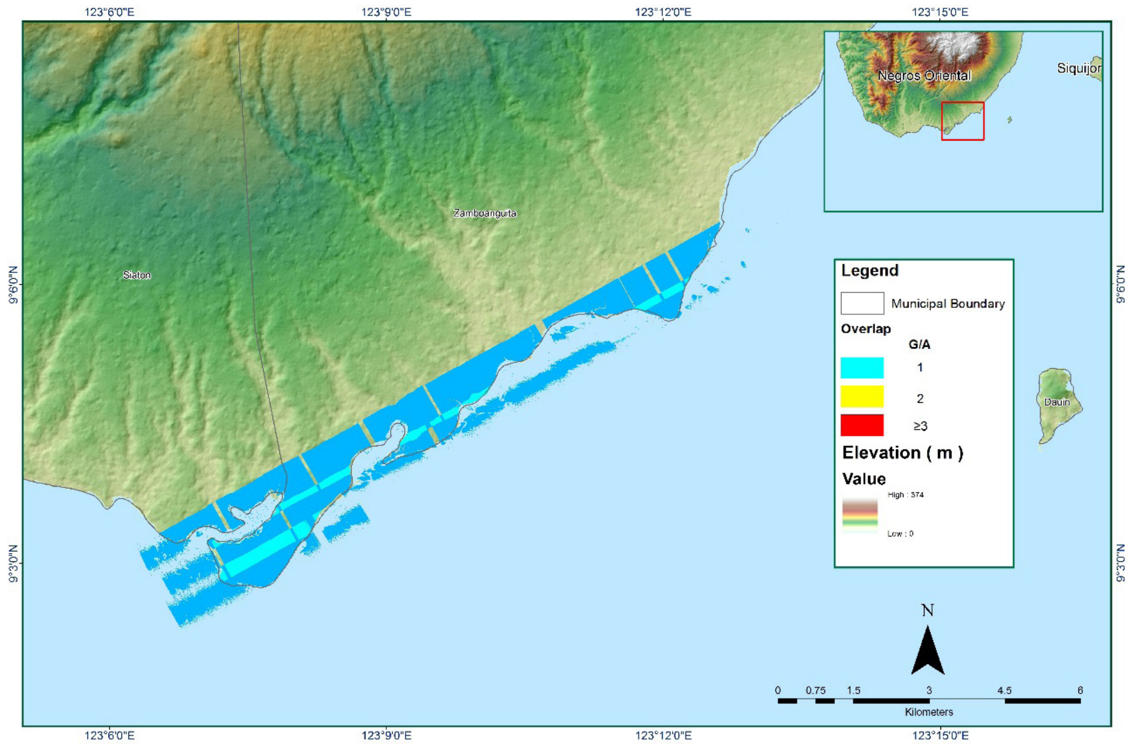


Figure A-8.26 Image of data overlap

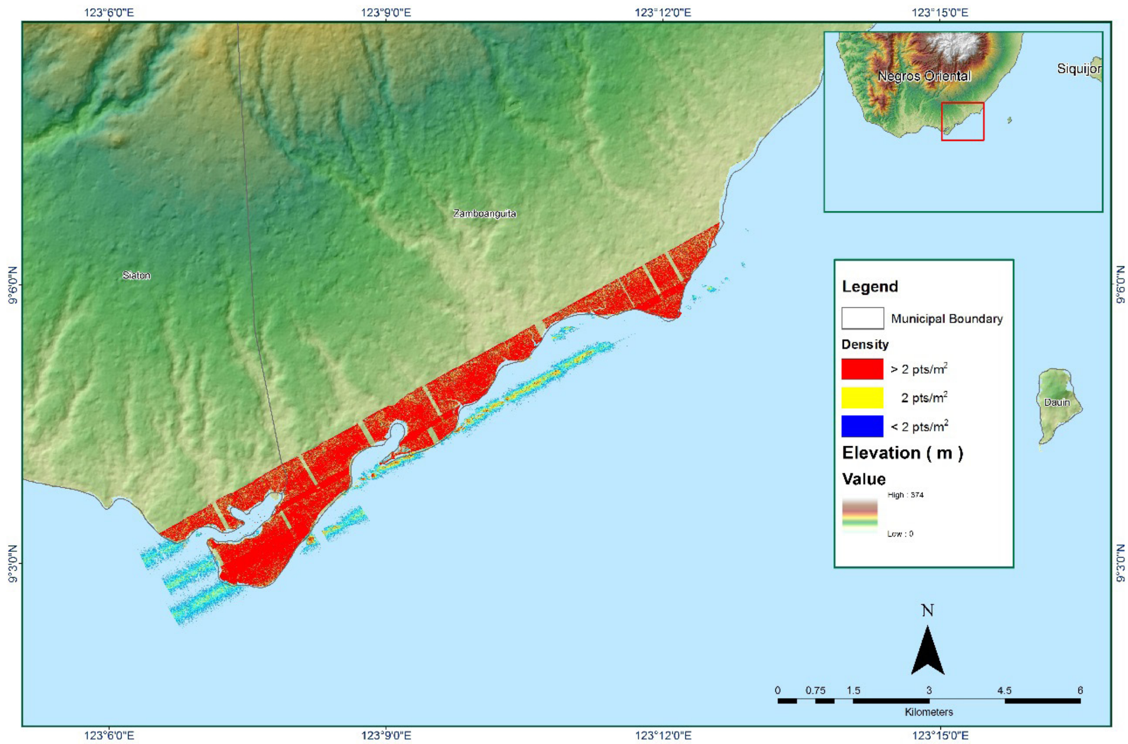


Figure A-8.27 Density Map of merged LiDAR data

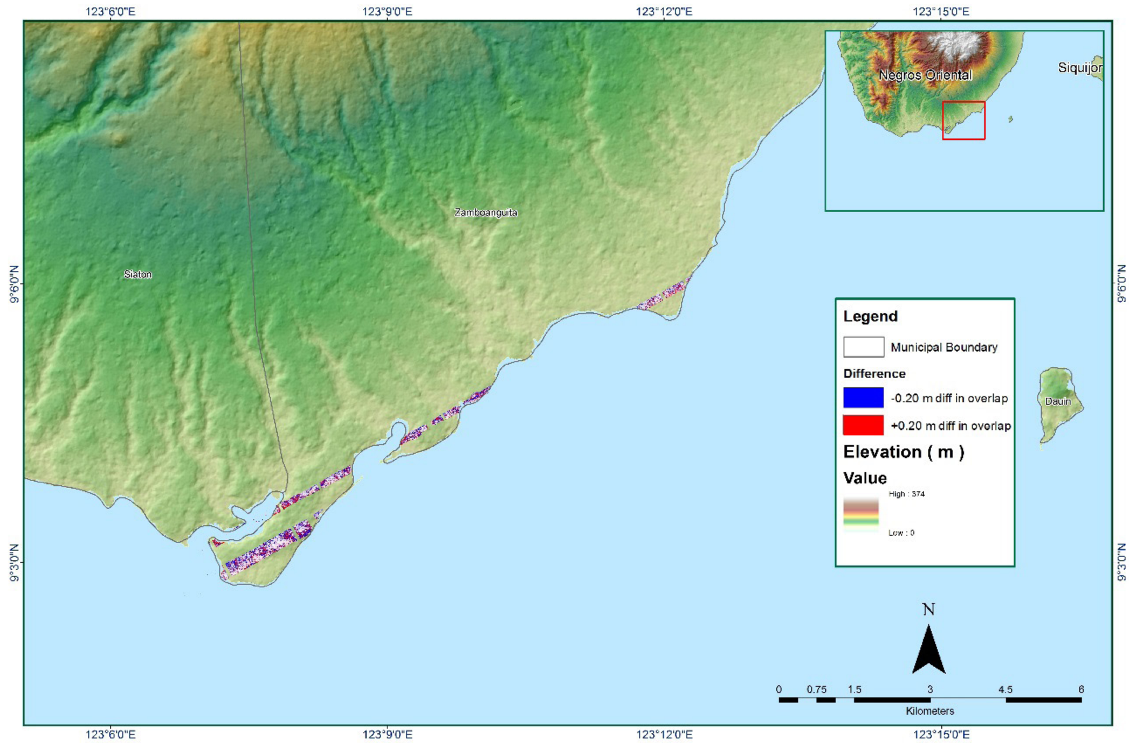


Figure A-8.28 *Elevation Difference Between flight lines*

Table A-8.5 Mission Summary Report for Mission Blk56A **(DumagueteReflights)**

Flight Area	**DumagueteReflights**
Mission Name	Blk56A
Inclusive Flights	10147L
RawLaser	13.43 GB
GnssImu	600 MB
Base data size	235 MB
Image	66.3 GB
Transfer date	May 13, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Combined Separation (-0.1 up to 0.1)	Yes
Estimated Position Accuracy (in cm)	
Estimated Standard Devation for North Position (<4.0 cm)	0.45
Estimated Standard Devation for East Position (<4.0 cm)	0.5
Estimated Standard Devation for Height Position (<8.0 cm)	0.85
Minimum % overlap (>25)	12.45%
Ave point cloud density per sq.m. (>2.0)	6.02
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	96
Maximum Height	591.90 m
Minimum Height	63.07 m
Classification (# of points)	
Ground	113,901,068
Low vegetation	64,441,304
Medium vegetation	52,343,070
High vegetation	119,181,759
Building	2,289,794
Orthophoto	Yes
Processed by	Engr. Angelo Carlo Bongat, Engr. JovelleAnjeanette Canlas, Engr. MonalyneRabino

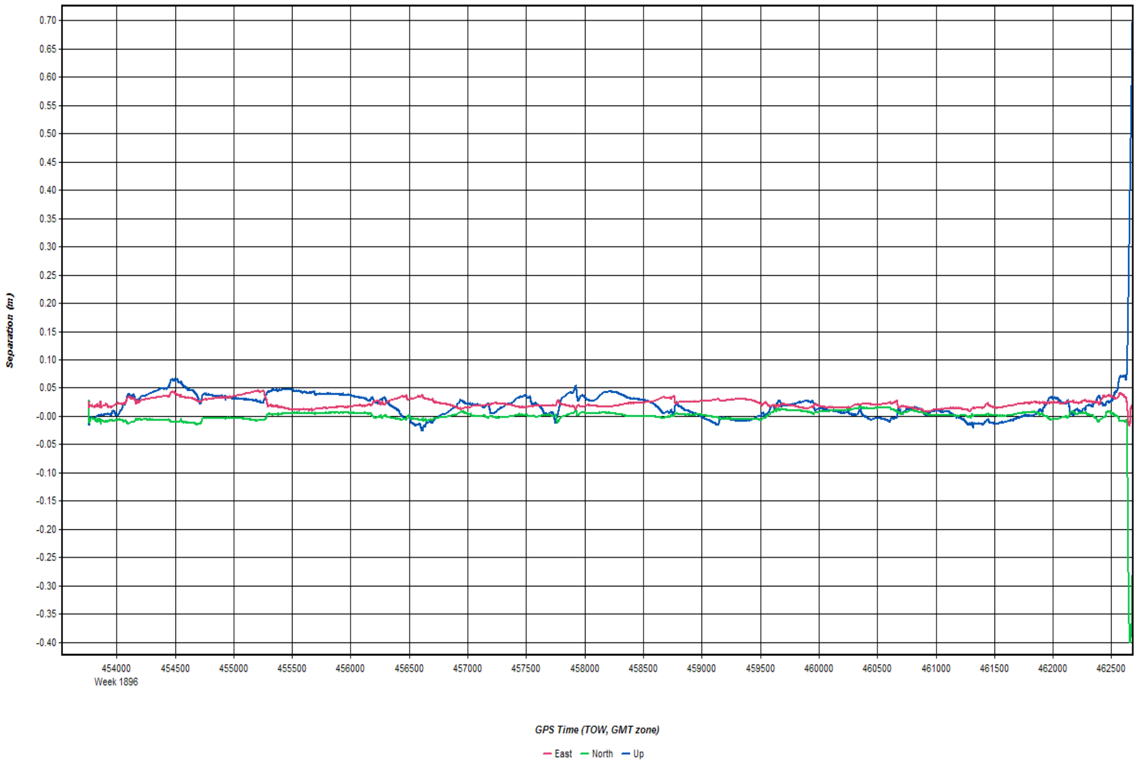


Figure A-8.29 Combined Separation

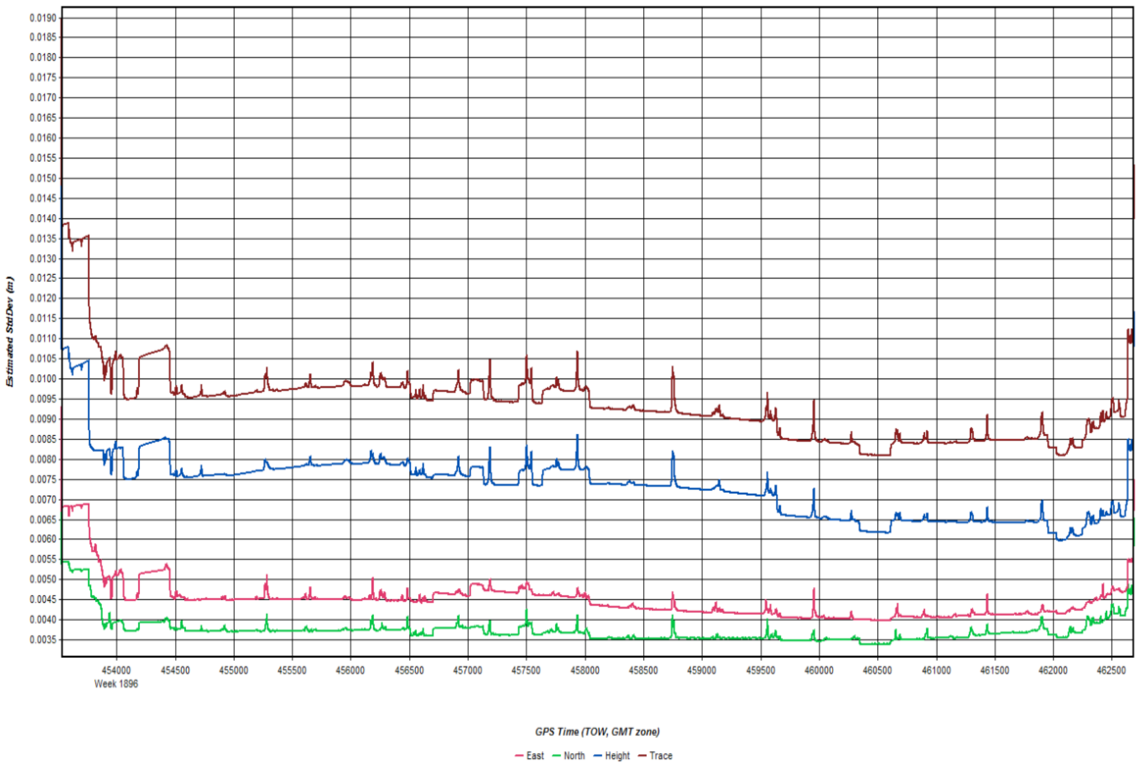


Figure A-8.30 Estimated Position of Accuracy

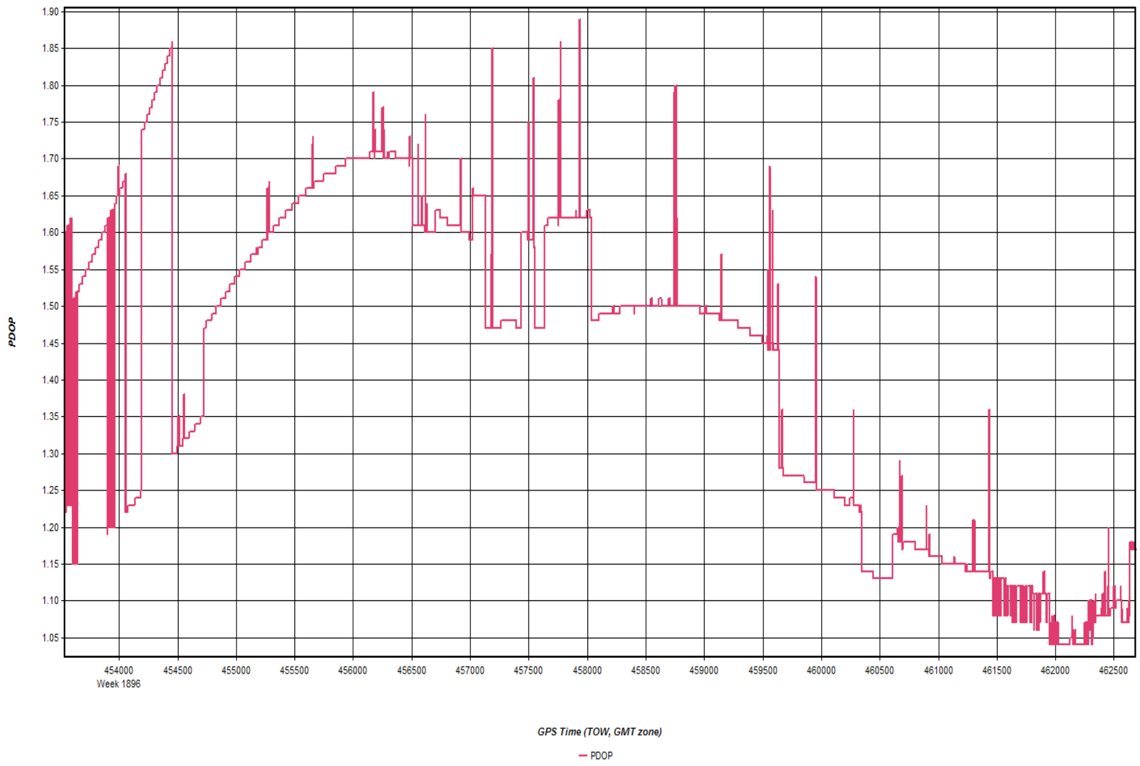


Figure A-8.31 PDOP

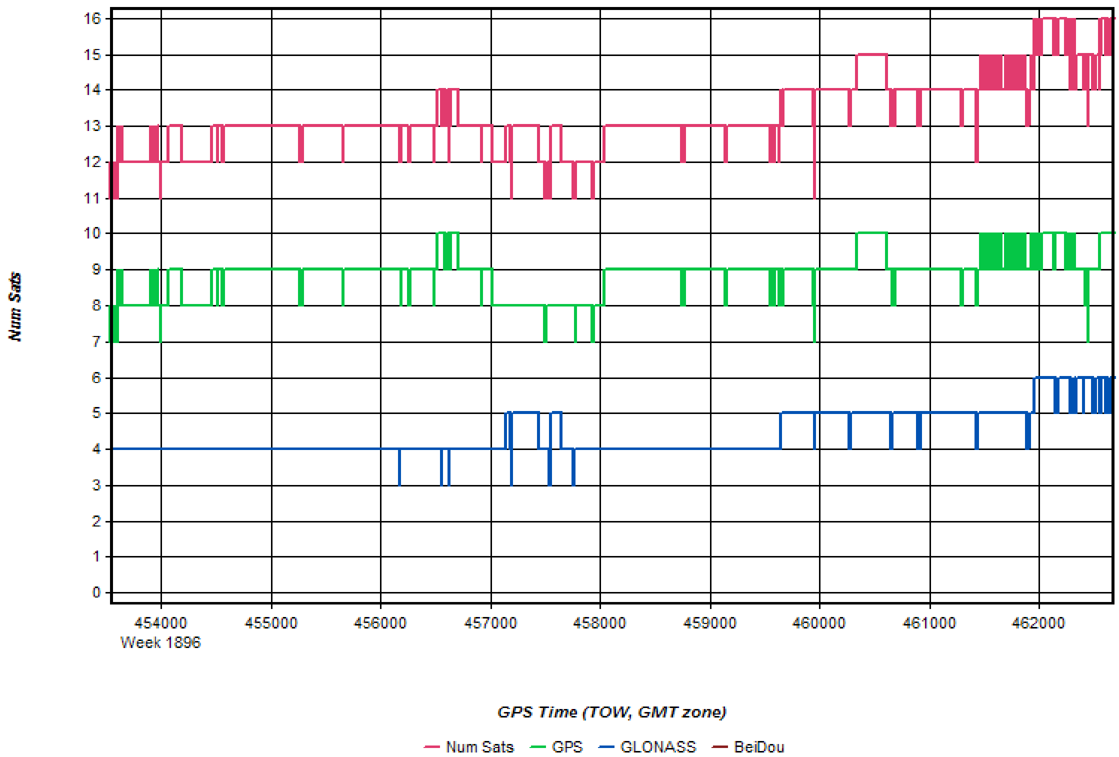


Figure A-8.32 Number of Satellites

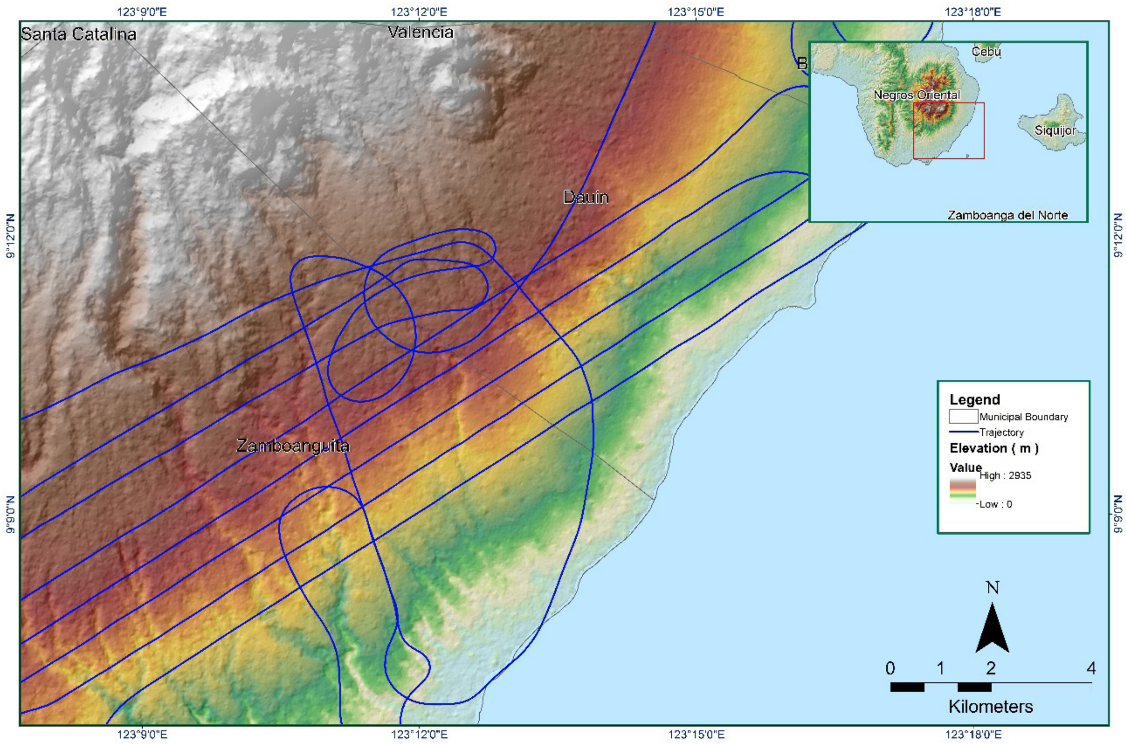


Figure A-8.33 *Best Estimated Trajectory*

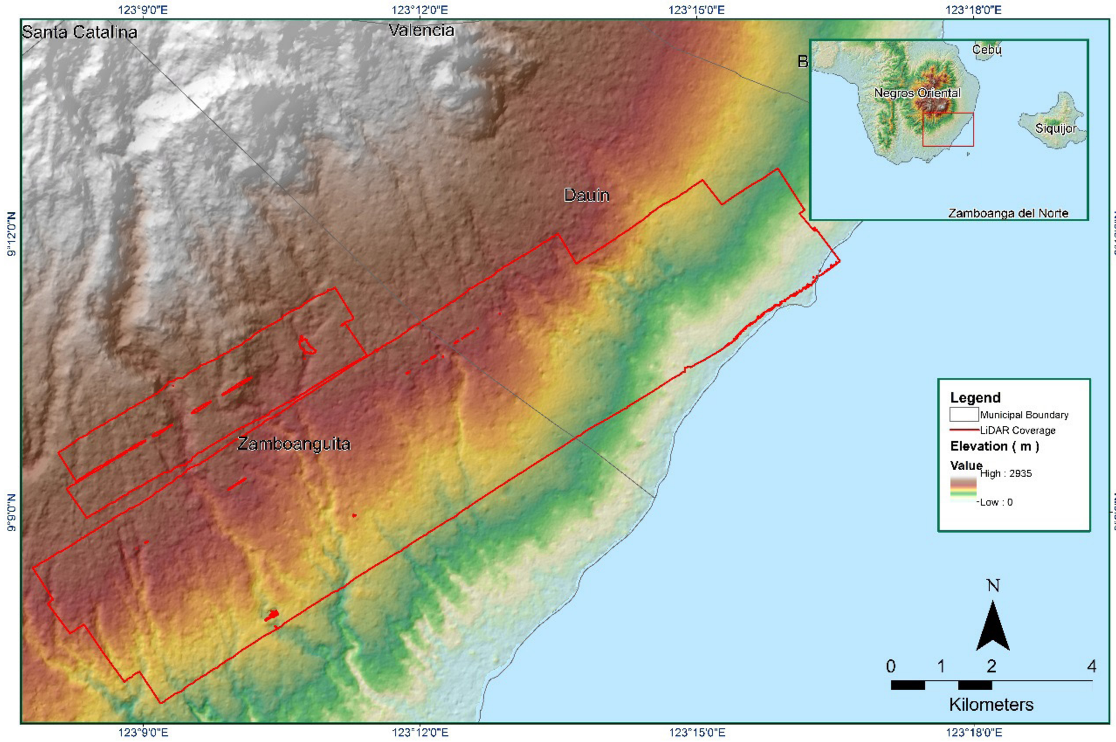


Figure A-8.34 ***Coverage of LiDAR data***

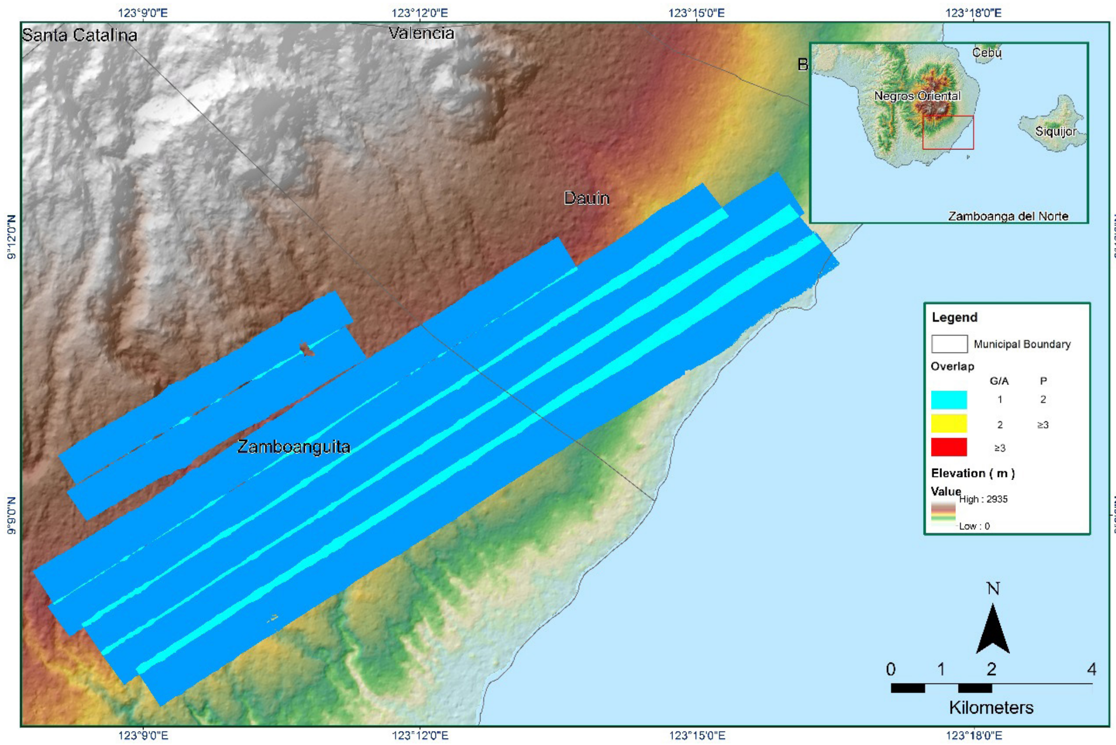


Figure A-8.35 ***Image of data overlap***

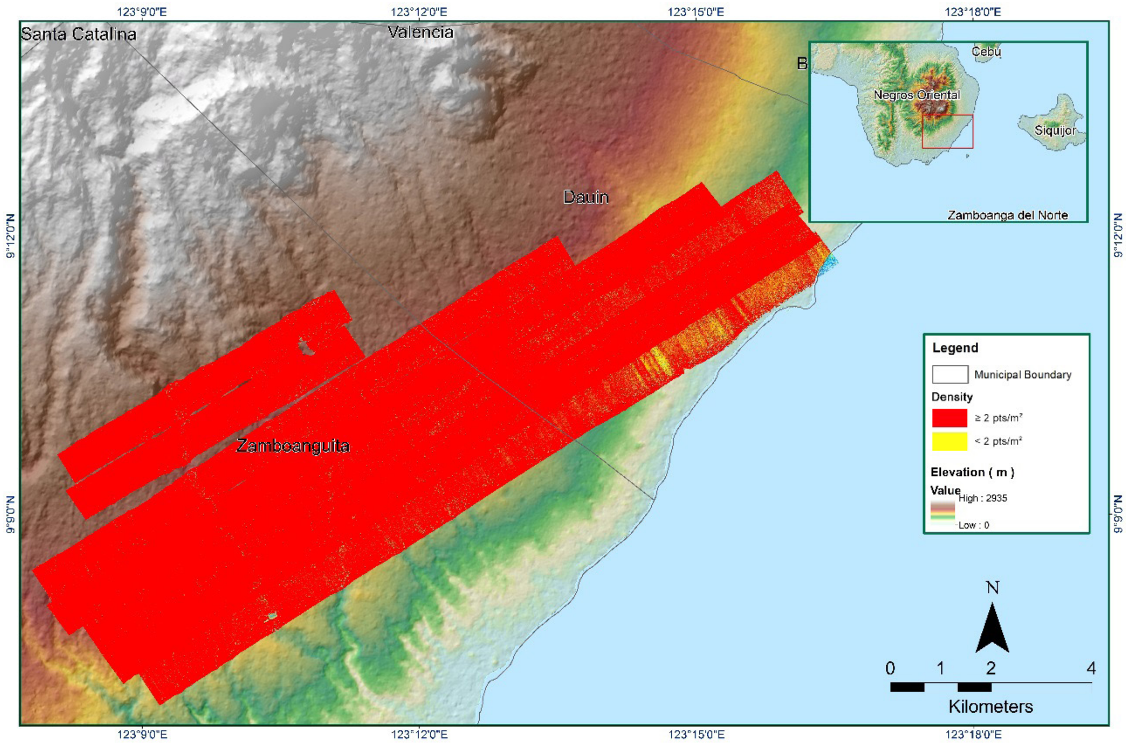


Figure A-8.36 *Density map of merged LiDAR data*

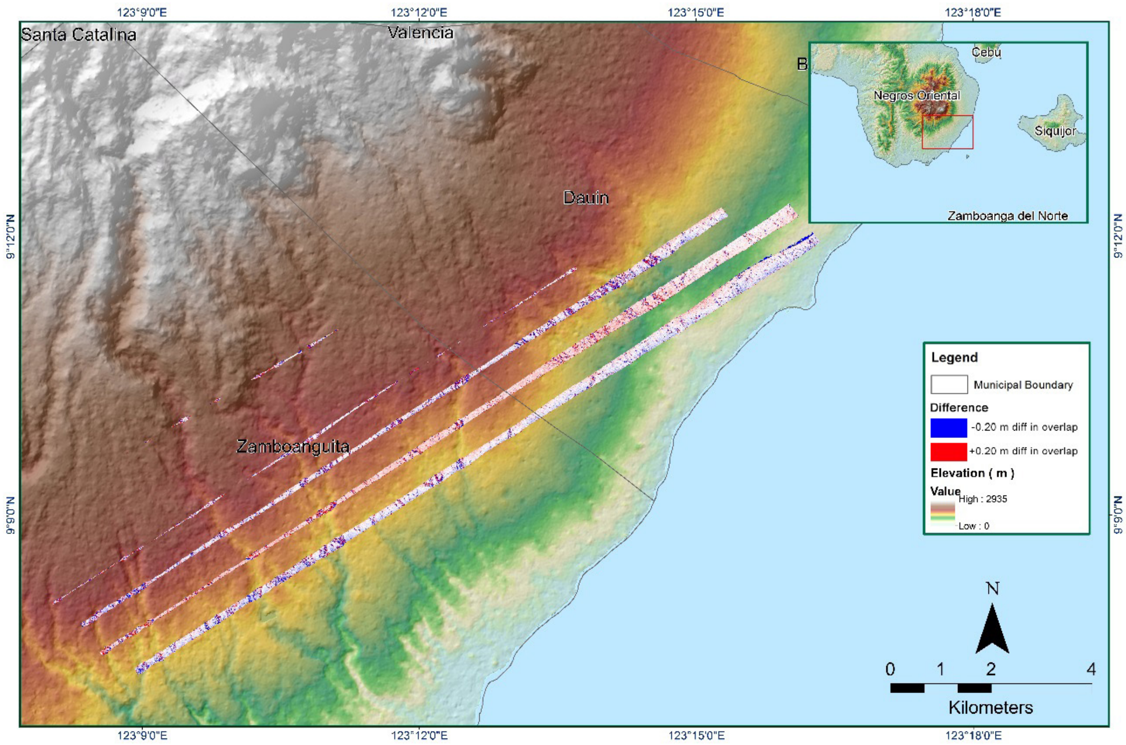


Figure A-8.37 *Elevation difference between flight lines*

Table A-8.6 Mission Summary Report for Mission Blk56C **(DumagueteReflights)**

Flight Area	**DumagueteReflights**
Mission Name	**Blk56C**
Inclusive Flights	10077AC
Range data size	5.46 GB
POS	198 MB
Image	27 MB
Transfer date	February 15, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.04
RMSE for East Position (<4.0 cm)	1.23
RMSE for Down Position (<8.0 cm)	2.32
Boresight correction stdev (<0.001deg)	0.000600
IMU attitude correction stdev (<0.001deg)	0.002069
GPS position stdev (<0.01m)	0.0239
Minimum % overlap (>25)	20.88%
Ave point cloud density per sq.m. (>2.0)	3.80
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	74
Maximum Height	275.61 m
Minimum Height	51.59 m
Classification (# of points)	
Ground	24,210,420
Low vegetation	12,510,181
Medium vegetation	10,925,033
High vegetation	2,324,182
Building	0
Orthophoto	No
Processed by	

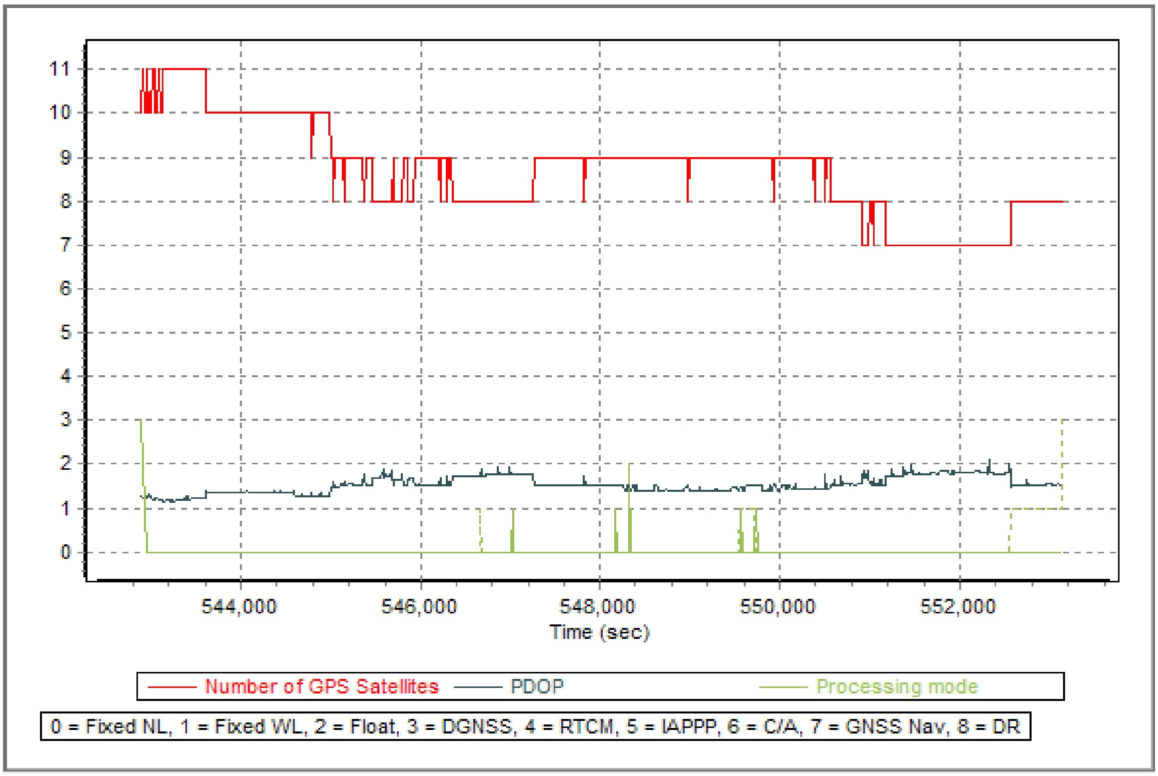


Figure A-8.38 Solution Status

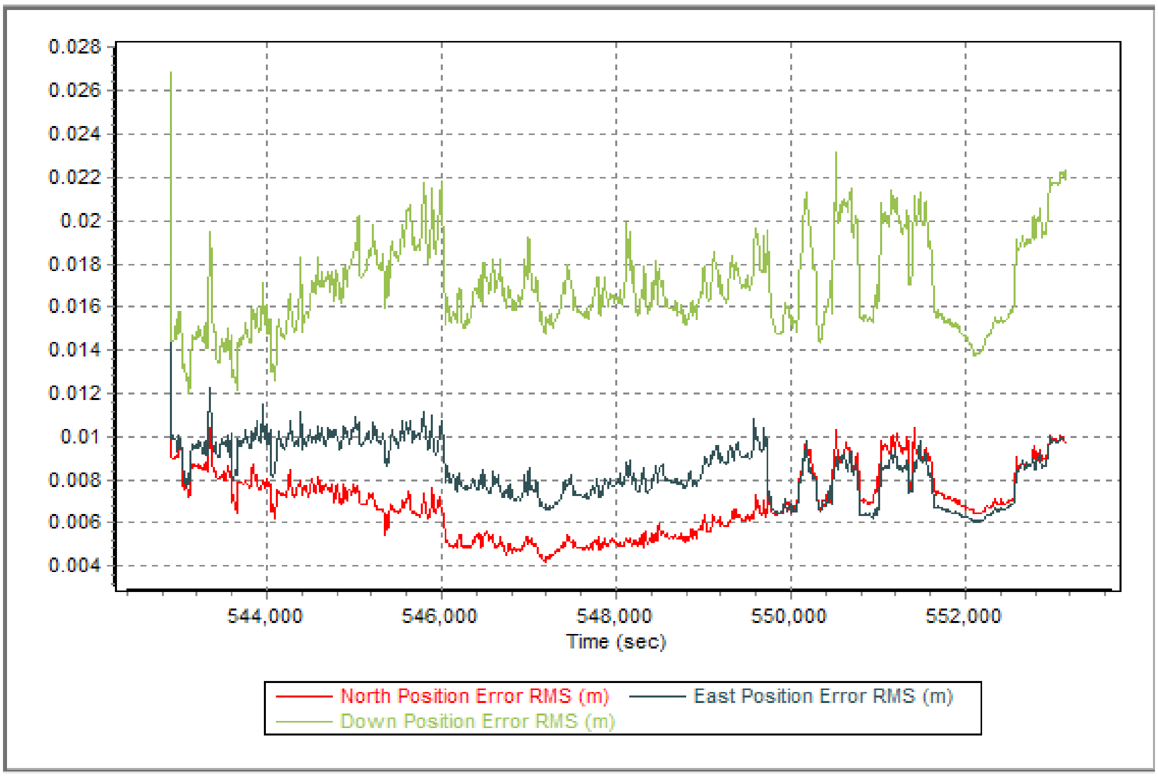


Figure A-8.39 Smoothed Performance Metric Parameters

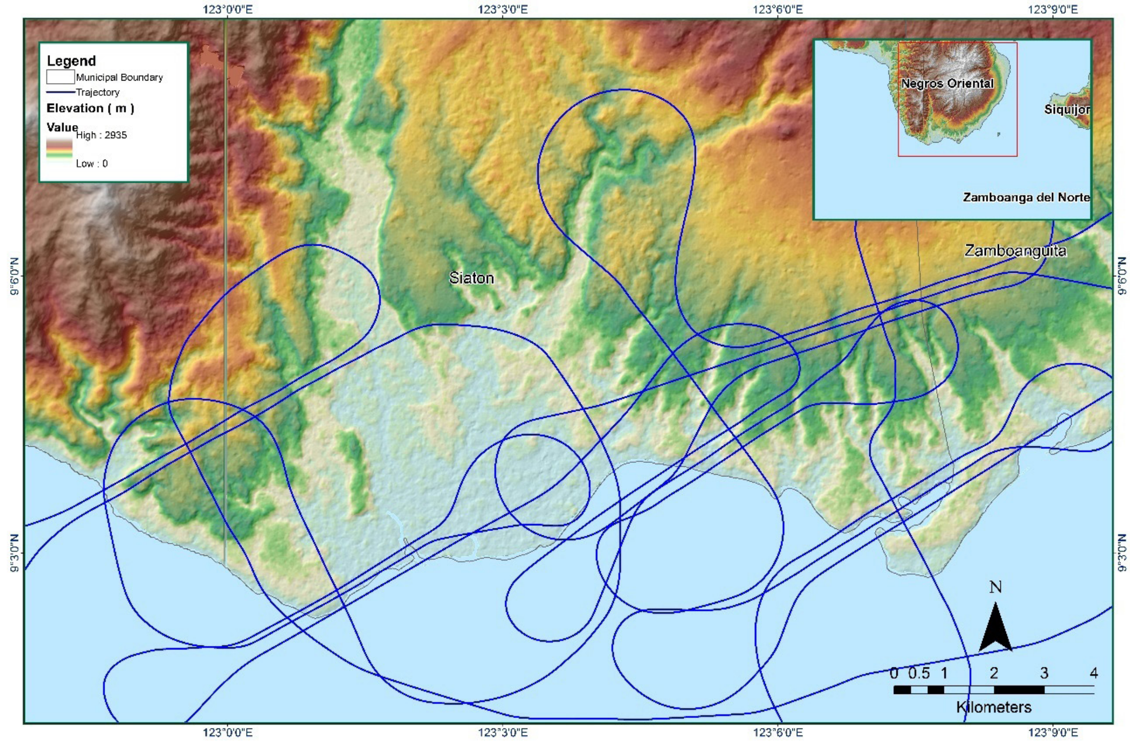


Figure A-8.40 Best Estimated Trajectory

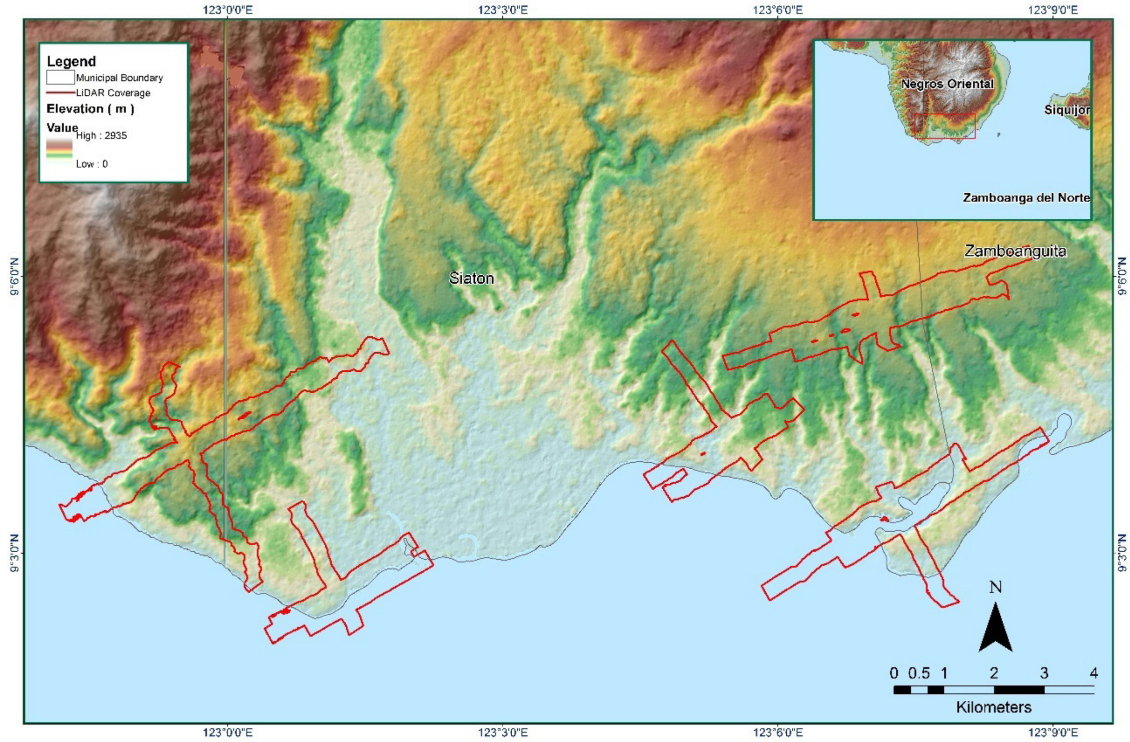


Figure A-8.41 Coverage of LiDAR data

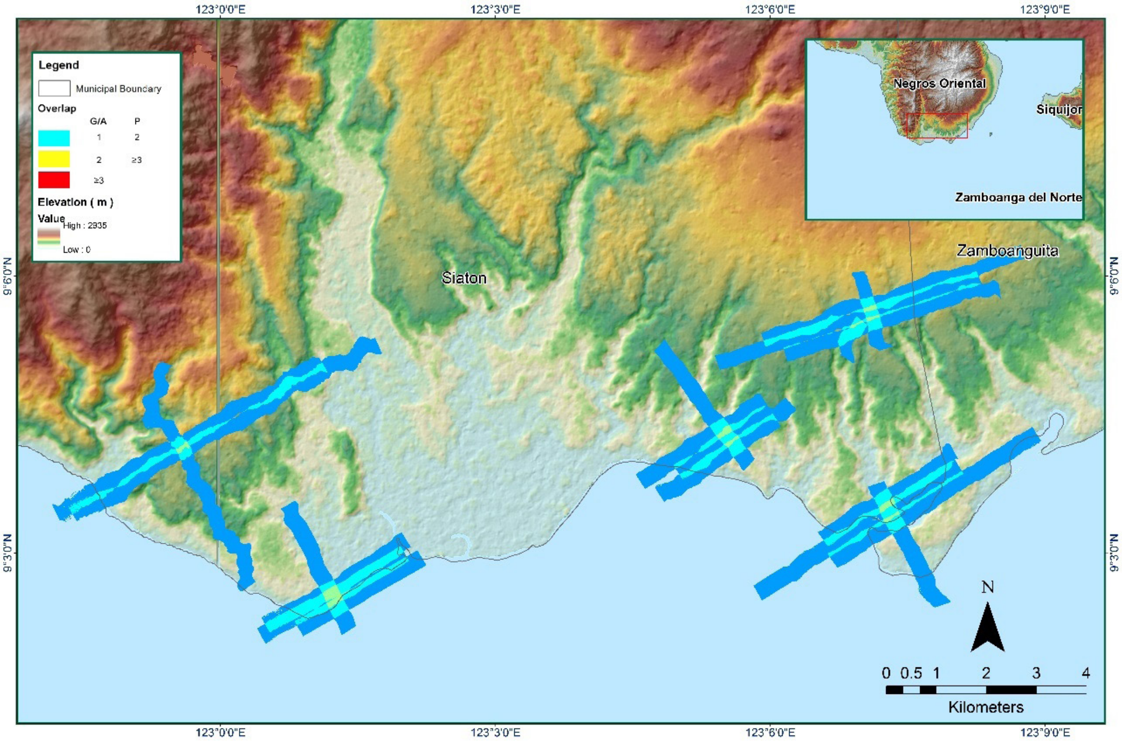


Figure A-8.42 Image of data overlap

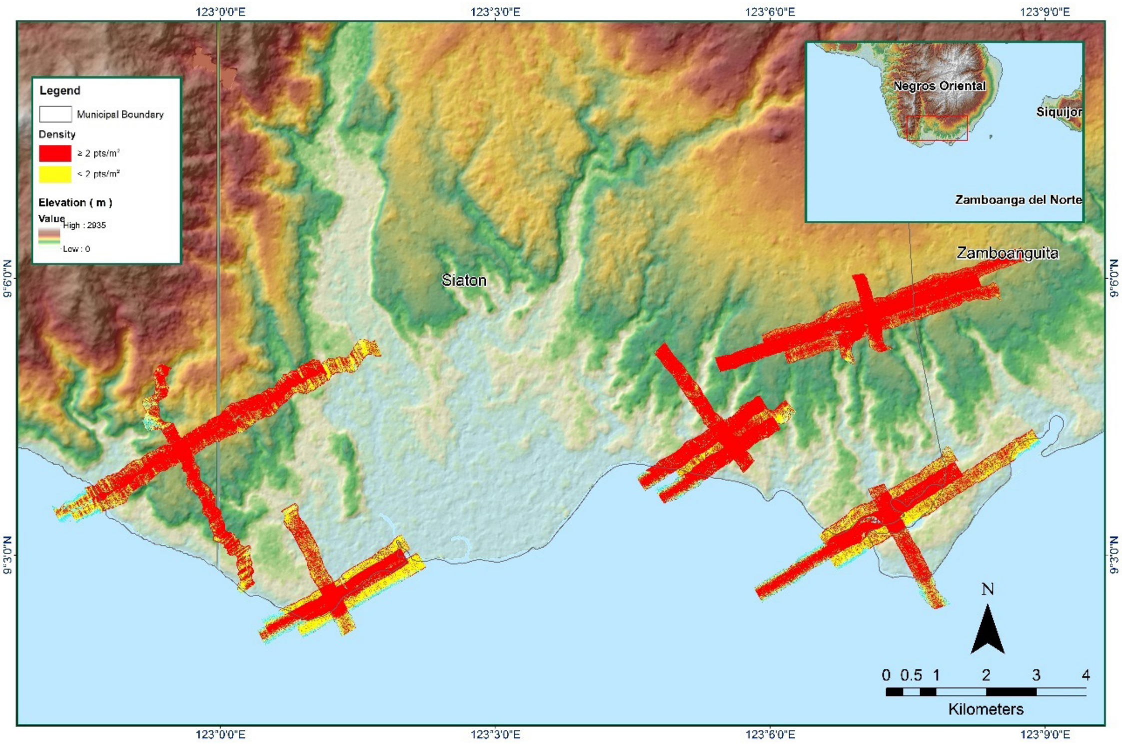


Figure A-8.43 Density map of merged LiDAR data

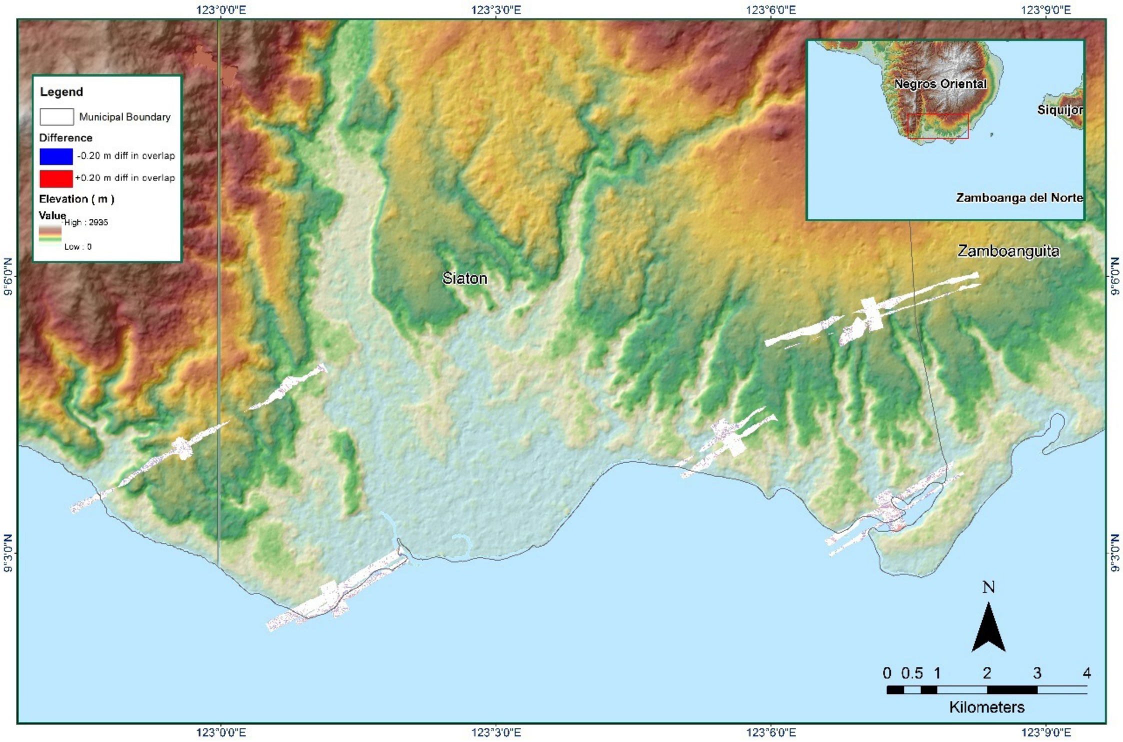


Figure A-8.44 Elevation difference between flight lines

ANNEX 9 CANAWAY MODEL BASIN PARAMETERS

Basin Number	SCS Curve Number Loss Model			Clark Transform Model		Recession Constant Baseflow Model				
	Initial Abstraction	Curve Number	Impervious (%)	Time of Concentration	Storage Coefficient	Initial Type	Initial Discharge	Recession Constant	Threshold Type	Ratio to Peak
W280	2.5252	99	30	2.9058568	0.345508	Discharge	0.24648	0.13032	Ratio to Peak	0.0882
W290	3.4306	99	0	0.98394	0.3585744	Discharge	0.0629031	0.13033	Ratio to Peak	0.0294523
W300	10.84363	94.58953	30	5.8147496	1.588072	Discharge	0.3205	0.19452	Ratio to Peak	0.09
W310	4.760857	64.02	70	6.619722	0.79464	Discharge	0.32179	0.13298	Ratio to Peak	0.09
W320	10.914	99	10	5.084	1.163952	Discharge	0.26239	0.08864	Ratio to Peak	0.09
W330	10.476	99	10	4.0128	0.601956	Discharge	0.10701	0.13032	Ratio to Peak	0.09
W340	10.978	99	10	4.7844	0.4073256	Discharge	0.0917183	0.29037	Ratio to Peak	0.09
W350	4.8643	99	0	1.8326	0.394832	Discharge	0.21605	0.19753	Ratio to Peak	0.12699
W360	7.6292	99	0	3.7351	0.506712	Discharge	0.1237	0.19158	Ratio to Peak	0.06
W370	4.995	99	0	2.3857	0.216488	Discharge	0.0482015	0.65333	Ratio to Peak	0.0801206
W380	4.2131	99	0	3.7008	0.411032	Discharge	0.13002	0.1988	Ratio to Peak	0.0855545
W390	4.7273	99	10	5.01906	1.30832	Discharge	0.24923	0.0886578	Ratio to Peak	0.09
W400	11.23842	67.07511	10	2.468268	0.534032	Discharge	0.10385	0.13031	Ratio to Peak	0.09
W410	4.9202	99	10	1.183856	0.297128	Discharge	0.0394764	0.53444	Ratio to Peak	0.0378349
W420	11.23939	67.07511	10	2.098612	0.486992	Discharge	0.0934446	0.13297	Ratio to Peak	0.09
W430	0.69613	99	0	1.67762	0.96264	Discharge	0.0617385	0.0883556	Ratio to Peak	0.0263921
W440	3.9149	99	0	1.947548	0.636448	Discharge	0.12711	0.0882232	Ratio to Peak	0.0262354
W450	4.96543	77.90736	0	6.650036	1.03208	Discharge	0.11792	0.0886598	Ratio to Peak	0.09
W460	6.960041	78.77293	0	4.145428	1.52472	Discharge	0.15804	0.0886578	Ratio to Peak	0.09
W470	0.69623	99	0	1.650756	0.95576	Discharge	0.0192926	0.15294	Ratio to Peak	0.058491
W480	5.565472	78.78303	0	7.6251	1.23976	Discharge	0.21742	0.13032	Ratio to Peak	0.09
W490	3.4552	99	0	0.88782	0.0456315	Discharge	0.0125072	0.0886479	Ratio to Peak	0.0868326
W500	3.4057	99	25	5.325972	0.93296	Discharge	0.15909	0.0883556	Ratio to Peak	0.09
W510	2.1413	95.509	0	3.413936	1.91384	Discharge	0.0735342	0.0886637	Ratio to Peak	0.09
W520	0.6753625	92.757	0	2.292364	0.65128	Discharge	0.0928305	0.057357	Ratio to Peak	0.0846629
W530	3.4552	99	0	0.7293484	0.187568	Discharge	0.0073695	0.19753	Ratio to Peak	0.12638
W540	0.1738	99	0	3.533996	1.22088	Discharge	0.1303	0.0588188	Ratio to Peak	0.0890762

ANNEX 10 CANAWAY MODEL REACH PARAMETERS

Reach Number	Muskingum Cunge Routing Model						
	Time step ratio	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R100	Automatic Fixed Interval	3129.2	0.04942	0.01109	Trapezoid	20	1
R130	Automatic Fixed Interval	1496.1	0.06065	0.24409	Trapezoid	20	1
R150	Automatic Fixed Interval	2744.2	0.02634	0.02366	Trapezoid	20	1
R170	Automatic Fixed Interval	1352.3	0.02136	0.20005	Trapezoid	20	1
R190	Automatic Fixed Interval	3840.5	0.04123	0.2715	Trapezoid	20	1
R210	Automatic Fixed Interval	490.12	0.02867	0.73769	Trapezoid	20	1
R220	Automatic Fixed Interval	4439.7	0.02873	0.11803	Trapezoid	20	1
R230	Automatic Fixed Interval	1869.9	0.0199	0.13127	Trapezoid	20	1
R240	Automatic Fixed Interval	4323.6	0.01748	0.04462	Trapezoid	20	1
R260	Automatic Fixed Interval	359.71	0.01188	0.33576	Trapezoid	20	1
R270	Automatic Fixed Interval	3523.4	0.0001	0.30214	Trapezoid	20	1
R70	Automatic Fixed Interval	6215	0.04659	0.12782	Trapezoid	20	1
R80	Automatic Fixed Interval	2763.1	0.05344	0.03806	Trapezoid	20	1

ANNEX 11 CANAWAY FIELD VALIDATION POINTS

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error (m)	Event / Date	Return Period of Event
	Longitude	Latitude					
1	123.0556	9.0910	3.41	0.3	9.6721	Ruping	100-Year
2	123.0556	9.0910	3.41	0	11.6281	Sendong	100-Year
3	123.0556	9.0910	3.41	0.2	10.3041	Nitang	100-Year
4	123.0555	9.0915	3.63	0.45	10.1124	Ruping	100-Year
5	123.0555	9.0915	3.63	0.4	10.4329	Nitang	100-Year
6	123.0566	9.0904	3.74	0.3	11.8336	Ruping	100-Year
7	123.0566	9.0904	3.74	0.2	12.5316	Nitang	100-Year
8	123.0583	9.0901	3.53	0.1	11.7649	Ruping	100-Year
9	123.0583	9.0901	3.53	0	12.4609	Nitang	100-Year
10	123.0582	9.0903	3.39	0.1	10.8241	Sendong	100-Year
11	123.0582	9.0903	3.39	0.4	8.9401	Ruping	100-Year
12	123.0582	9.0903	3.39	0.3	9.5481	Nitang	100-Year
13	123.0601	9.0924	2.27	0.2	4.2849	Ruping	100-Year
14	123.0601	9.0924	2.27	0.1	4.7089	Nitang	100-Year
15	123.0452	9.0844	5.82	1.0	23.2324	Ruping	100-Year
16	123.0452	9.0844	5.82	0.8	25.2004	Nitang	100-Year
17	123.0452	9.0844	5.82	0.3	30.4704	Sendong	100-Year
18	123.0450	9.0833	14.02	1.8	149.328	Ruping	100-Year
19	123.0450	9.0833	14.02	1.5	156.75	Nitang	100-Year
20	123.0450	9.0833	14.02	0.4	185.504	Sendong	100-Year
21	123.0460	9.0761	8.82	0	77.7924	Nitang	100-Year
22	123.0460	9.0759	0.9	0	0.81	Ruping	100-Year
23	123.0460	9.0759	0.9	0	0.81	Sendong	100-Year
24	123.0456	9.0590	1.09	1.2	0.0121	Ruping	100-Year
25	123.0456	9.0590	1.09	1.2	0.0121	Sendong	100-Year
26	123.0456	9.0590	1.09	1.1	0.0001	Nitang	100-Year

27	123.0455	9.0581	1.09	1.5	0.1681	Ruping	100-Year
28	123.0455	9.0581	1.09	1.5	0.1681	Sendong	100-Year
29	123.0455	9.0581	1.09	1.4	0.0961	Nitang	100-Year
30	123.0454	9.0580	0.95	1.7	0.5625	Ruping	100-Year
31	123.0454	9.0580	0.95	1.6	0.4225	Nitang	100-Year
32	123.0456	9.0551	0.16	0.3	0.0196	Ruping	100-Year
33	123.0456	9.0551	0.16	0	0.0256	Nitang	100-Year
34	123.0456	9.0551	0.16	0	0.0256	Teryang	100-Year
35	123.0459	9.0552	0.53	0	0.2809	Sendong	100-Year
36	123.0459	9.0552	0.53	0.5	0.0009	Ruping	100-Year
37	123.0459	9.0552	0.53	0.2	0.1089	Nitang	100-Year
38	123.0459	9.0552	0.53	0.2	0.1089	Teryang	100-Year
39	123.0492	9.0531	0.84	1.0	0.0256	Ruping	100-Year
40	123.0492	9.0531	0.84	1.0	0.0256	Ondoy	100-Year
41	123.0492	9.0531	0.84	0.2	0.4096	Sendong	100-Year
42	123.0466	9.0544	1.25	0	1.5625	Ruping	100-Year
43	123.0466	9.0544	1.25	0	1.5625	Ondoy	100-Year
44	123.0466	9.0544	1.25	0	1.5625	Sendong	100-Year
45	123.0443	9.0640	1.83	1.1	0.5329	Ruping	100-Year
46	123.0443	9.0640	1.83	0.9	0.8649	Nitang	100-Year
47	123.0443	9.0640	1.83	0.4	2.0449	Sendong	100-Year
48	123.0446	9.0633	1.19	0.1	1.1881	Sendong	100-Year
48	123.0446	9.0633	1.19	0.3	0.7921	Ruping	100-Year

ANNEX 12 EDUCATIONAL INSTITUTIONS AFFECTED BY FLOODING IN CANAWAY FLOODPLAIN

Negros Oriental				
Siaton				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Felipe Tayco Memorial ES	Caticugan	Medium	Medium	Medium
Felipe Tayco Memorial ES	Caticugan	Medium	Medium	Medium
Canaway Elementary School	Datag			

ANNEX 13 HEALTH INSTITUTIONS AFFECTED BY FLOODING IN CANAWAY FLOODPLAIN

Negros Oriental				
Siaton				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Canaway Brgy Health Center	Datag	Medium	Medium	Medium
Lamberto Macias Memorial Hospital	Poblacion I	Medium	Medium	Medium