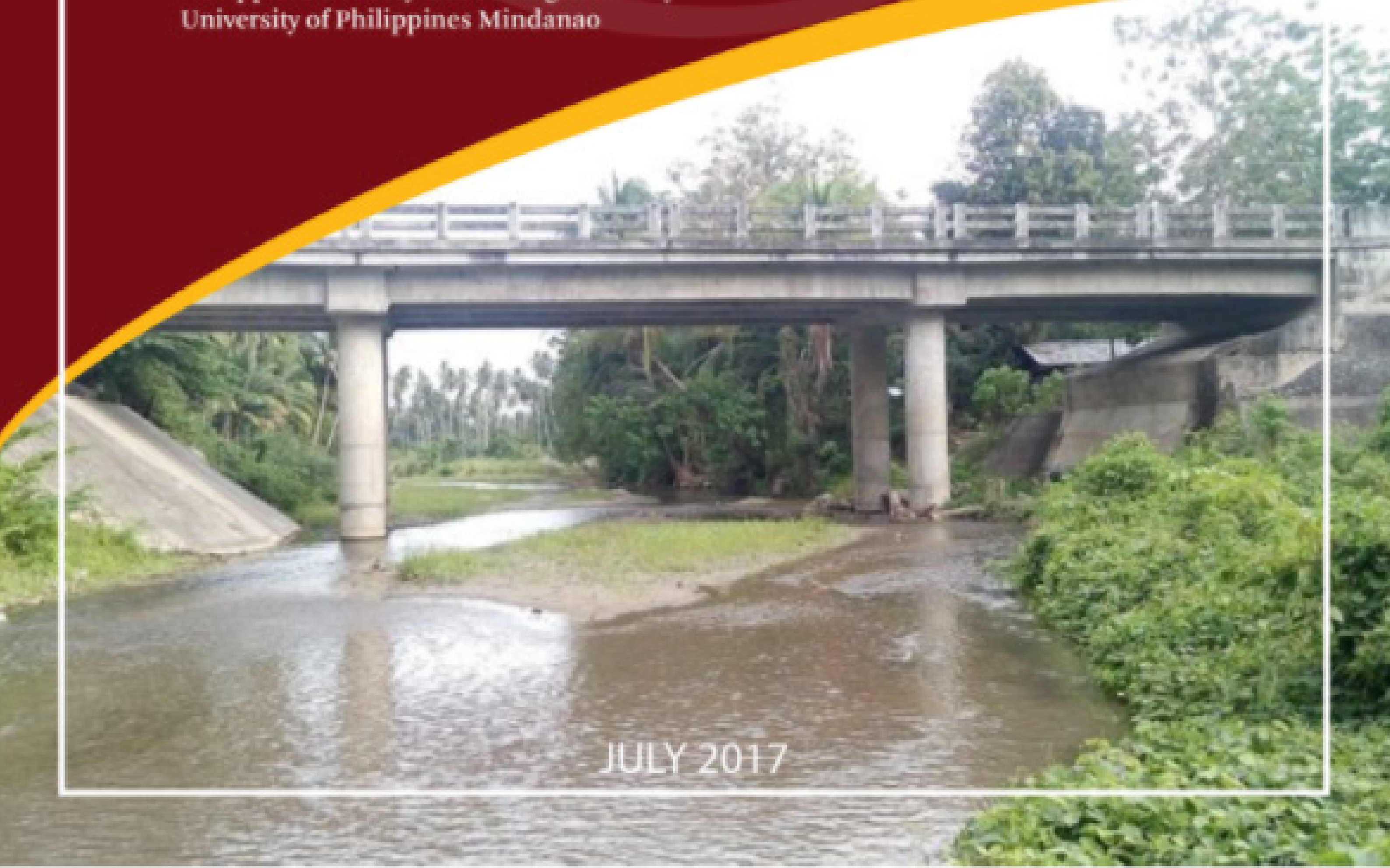
HAZARD MAPPING OF THE PHILIPPINES USING LIDAR (PHIL-LIDAR I)

LiDAR Surveys and Flood Mapping of Bitanagan River

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



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LIST OF ACRONYMS AND ABBREVIATIONS

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

CHAPTER 1: INTRODUCTION

1.1 Background of the Phil-LiDAR 1 Program

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

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

The implementing partner university for the Phil-LiDAR 1 Program is the University of the Philippines Mindanao (UP Min). UP Min 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 30 river basins in the Southern Mindanao. The university is located in Davao City in the province of Davao del Sur.

1.2 Overview of the Bitanagan River Basin

The Bitanagan River Basin covers two (2) municipalities in Davao Oriental—the Municipality of Lupon and the City of Mati. The DENR River Basin Control Office (RBCO) states that the Bitanagan River Basin has a drainage of 93 km^2 and an estimated 186 cubic meter (MCM) annual run-off (RBCO, 2015).

Its main stem, Bitanagan River, a stream or a body of running water moving to a lower level in a channel on land, can be found in the City of Mati, Davao Oriental. It traverses through the City of Mati with its outlet situated at Mayo Bay facing the Pacific Ocean. It has 47 subbasins, 23 junctions, and 23 reaches. It is part of the thirteen (13) river systems under the PHIL-LIDAR 1 Program partner HEI, UP Mindanao.

According to the 2015 national census of PSA, a total of 23,787 persons distributed among barangays Dahican, Don Martin Marundan, and Don Enrique Lopez in the City of Mati are residing within the immediate vicinity of the river.

The primary industries in the Province of Davao Oriental are agriculture, fisheries, and forestry or wood. Coconut, rice, corn, mango, abaca, banana, cassava, and rubber are the major products of the province (Province of Davao Oriental).

Mati comes from the native Mandayan word "Maa-ti" which refers to the town's creek that easily dries up even after a series of heavy rain falls. Historical accounts indicate that the early residents of the locality include the Mandayans, Kalagans, and Maranaos. These tribes' indigenous culture carries strong traces of Indo-Malayan and Arabic influences. The word "Mandaya" is derived from "man" which means "first" and "daya" meaning "upstream" (Sillada, 2013). Mati, along with Baganga and Cateel, was recorded to have been founded by Captain Prudencio Garcia, the pioneer political-military head in 1861, together with his comrade, Juan Nazareno. In 1903, Mati was declared a municipality by virtue of Act No. 21 and by 1907, further reaffirmed the establishment of its local government through Act No. 189. Francisco Rojas was the first appointed mayor while the first elected mayor was Patricio Cunanan in 1923. Mati became the capital of Davao Oriental since 1967. After almost 104 years after its creation, Mati acquired its cityhood status on March 24, 2007 by virtue of Republic Act No. 9408 and ratified through a plebiscite on June 18, 2007 (En.infodesti.com, 2017; Official Website of the City of Mati, 2017; Philippine Cities, 2017; Travelgrove Inc., 2017).

Five (5) barangays in the Bitanagan Watershed that fall under the jurisdiction of the City of Mati, such as

Dahican, Don Enrique Lopez, Don Martin Marundan, Buso, and Taguibo situated along Bitanagan River were confirmed as flood prone areas by the LGU officials and barangay officials present during the courtesy call held at the City Administrator's Conference Room in the City Hall of Mati dated April 30, 2015.

According to locals, from 1988 to 2014, local rainfall and "buhawi" used to be the cause of flooding near the river. However, PAGASA only noted typhoon events such as Pablo in 2012 and Yolanda in 2013. Further, on November 8, 2011, heavy rains brought by the Inter Tropical Convergence Zone (ITCZ) flooded Mati City with one (1) house in Brgy. Central partially damaged as per NDRRMC report (National Disaster Risk Reduction and Management Council, 2011).

Although floods occur every year, it is mostly only along the river banks and does not swell up for long. There are, however, other nearby rivers and creeks that can cause flooding in Mati City. The southern part of the province of Davao Oriental experiences an evenly distributed rainfall throughout the year.

The topography of the area is mountainous and hilly with slopes varying from flat to undulating and steep. The area's soil is characterized as sandy clay loam (Biodiversity Management Bureau, 2016).

The river is under the Protection and Production Forests in the City of Mati. The area is being preserved to achieve ecological balance in the locality. Through the revenues generated from forest activities such as transport permits, minimum utilization of forest products under Community-Based Forest Management (CBFM) program, and other income generating activities, the forestry sector contributes to the economic growth of Mati City in particular and of the country in general.

The Mati Protected Landscape was proclaimed as a Watershed Forest Reserve under Proclamation No. 912 in 2005 signed by President Gloria Macapagal-Arroyo. The protected landscape covers an area of 914.26 hectares (2,259.2 acres) and a buffer zone of 135.76 hectares (335.5 acres). It straddles the coastal sitios of Sudlon and Ugilan. The Mati City Proper borders the protected area and its peripheral zone to the north, the Pujada Bay to the east, the barangay of Badas to the south, and the northern foothills of the Hamiguitan Range to the west. The declaration protects the watershed, including Bitanagan River, which serves as the city waterworks system's source of water supply. Although there are no recorded issues such as illegal logging in the protected area, there is still the threat of illegal entry or occupation (Official Gazette of the Republic of the Philippines, 2005).

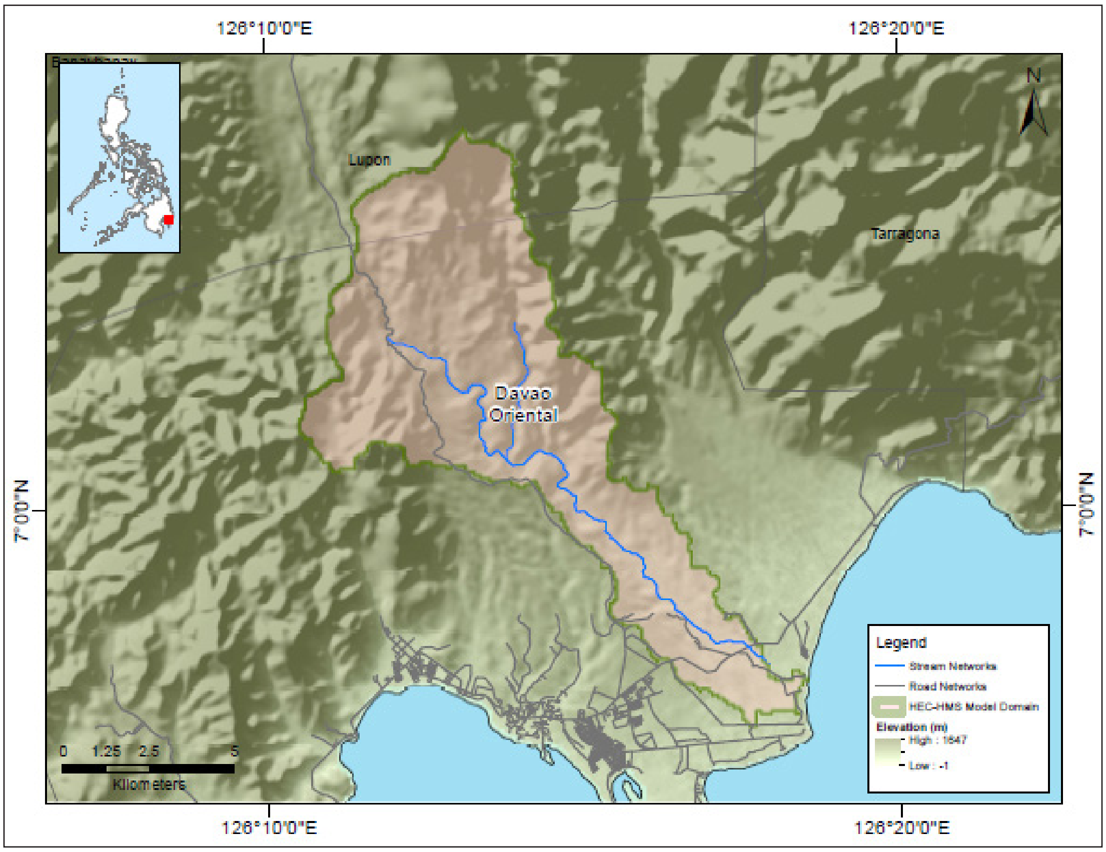

Figure 1. Map of Bitanagan River Basin (in brown)

Chapter 2: LiDAR Acquisition in Bitanagan Floodplain

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

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

2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Bitanagan Floodplain in Davao Oriental. These missions were planned for 16 linesand ran for at most four and a half (4.5) hours including take-off, landing and turning time.The flight planning parameters for the LiDAR system is found in Table 1. Figure 2 shows the flight plans and base stations used for Bitanagan Floodplain.

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)
BLK83A	1000	40	40	100	50	130	5
BLK84A	1000	30	40	125	50	130	5
BLK84B	1000	40	40	100	50	130	5
	1200	40	24	125	60	130	5
BLK84C	1200	30	26	70	60	130	5

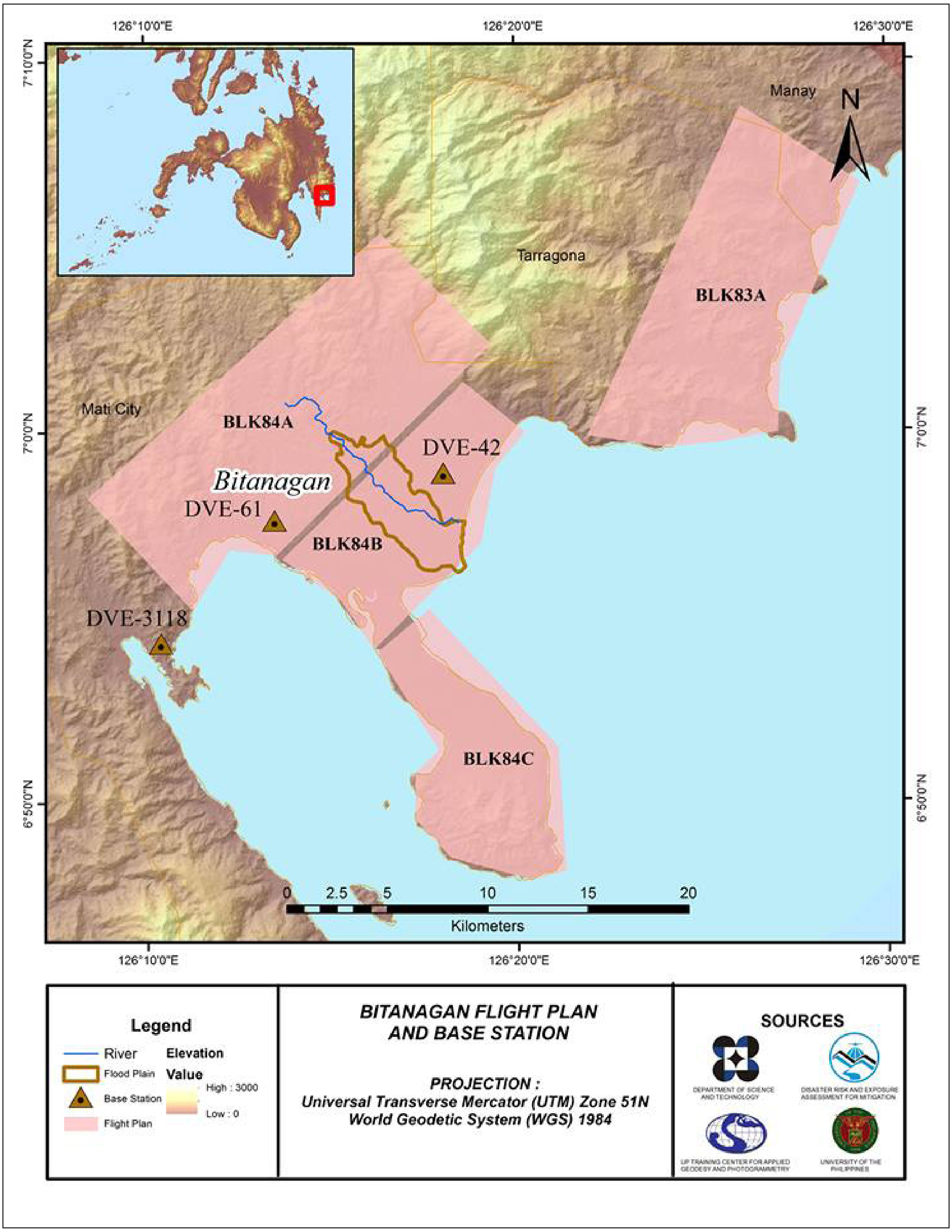

Figure 2. Flight plans and base stations used for Bitanagan Floodplain.

2.2 Ground Base Station

The project team was able to recover four (4) NAMRIA ground control points: DVE-42and DVE-61which areof second (2nd) order accuracy, and DVE-3088 and DVE-3118 which are of fourth (4th) order accuracy. Fourth (4th) order ground control points where then re-processed to obtain coordinates of second (2nd) order accuracy. The certifications for the NAMRIA reference points are found in Annex 2 while the baseline processing reports for the re-processed control points are found in AnnexC3. These were used as base stations during flight operations for the entire duration of the survey (June 18 – July 10, 2014). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 882and SPS 985. Flight plans and location of base stations used during the aerial LiDAR acquisition in Bitanagan Floodplain are shown in Figure12.

Figure 2 to Figure 65show the recovered NAMRIA reference points within the area. In addition,Table 2 to Table 5 present the details about the following NAMRIA control stations and established point, while Table 6tlistf all ground control points occupied during the acquisition with the corresponding dates of utilization.

(a)

(b)

(a)

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

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

Station Name	DVE-42	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	6°58'54.82726" North
	Longitude	126°17'56.05259" East
	Ellipsoidal Height	6.395 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting	643534.636 meters
	Northing	772166.69 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	6°58'51.79295" North
	Longitude	126°18'1.57690" East
	Ellipsoidal Height	81.025 meters
Grid Coordinates, Universal Transverse Mercator Zone 52 North (UTM 52N PRS 92)	Easting	201538.20 meters
	Northing	772554.34 meters

(a)

(b)

(a)

Figure 4. GPS set-up over DVE-61located at the center of the playground of Zign Elementary School, about 10 m W of school flagpole(a) and NAMRIA reference point DVE-61(b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point DVE-61 used as base station for the LiDAR acquisition.

Station Name	DVE-61	
Order of Accuracy	2^{nd}	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	6°57'39.37336" North
	Longitude	126°13'22.44550" East
	Ellipsoidal Height	48.474 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting	635140.8 meters
	Northing	769826.046 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	6°57'36.33777" North
	Longitude	126°13'27.97256" East
	Ellipsoidal Height	122.953 meters
Grid Coordinates, Universal Transverse Mercator Zone 52 North (UTM 52N PRS 92)	Easting	193120.25 meters
	Northing	770283.71 meters

(a)

(b)

(a)

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

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

Station Name	DVE-3088	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	6°58'54.59451" North 126°17'56.18350"East 6.363 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	6°58'51.56021" North 126°18'1.70781" East 80.992 meters
Grid Coordinates, Universal Transverse Mercator Zone 52 North (UTM 52N PRS 92)	Easting Northing	201542.167 meters 772547.163 meters

(a)

(b)

(a)

Figure 6. GPS set-up over DVE-3118 located along the boundary of Barangays Dawan and Badas(a) and NAMRIA reference point DVE-3118(b) as recovered by the field team.

Table 5. Details of the recovered NAMRIA horizontal control point DVE-3118 used as base station for the LiDAR acquisition with established coordinates.

Station Name	DVE-3118	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	6°54'21.10881" North
	Longitude	126°10'17.73137" East
	Ellipsoidal Height	130.004 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	6°54'18.08345" North
	Longitude	126°10'23.26398" East
	Ellipsoidal Height	204.459 meters
Grid Coordinates, Universal Transverse Mercator Zone 52 North (UTM 52N PRS 92)	Easting	187409.530 meters
	Northing	764222.334 meters

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

Date Surveyed	Flight Number	Mission Name	Ground Control Points
June 18, 2014	7318GC	2BLK84A169A	DVE-42 & DVE-3088
June 19, 2014	7320GC	2BLK83A84B170A	DVE-42 & DVE-3088
July 01, 2014	7344GC	2BLK84BCR182A	DVE-42 & DVE-3088
July 10, 2014	7362GC	2BLK85CS191A	DVE-61 & DVE-3118

2.3 Flight Missions

Four (4) missions were conducted to complete the LiDAR data acquisition in Bitanagan Floodplain, for a total of thirteen hours and fifty six minutes (13+56) of flying time for RP-C9322. All missions were acquired using the Gemini LiDAR system. Table 7 shows the total area of actual coverage and the corresponding flying hours per mission while Table 8 presents the actual parameters used during the LiDAR data acquisition.

Table 7. Flight missions for LiDAR data acquisition in Bitanagan Floodplain.

Date Surveyed	Flight Number	Flight Plan Area (km²)	Surveyed Area (km²)	Area Surveyed within the Floodplain (km²)	Area Surveyed outside the Floodplain (km²)	No. of Images (Frames)	Flying Hours	
							Hr	Min
June 18, 2014	7318GC	156.23	139.97	0	139.97	NA	3	47
June 19, 2014	7320GC	138.07	121.57	6.51	115.06	NA	3	47
July 01, 2014	7344GC	71.24	74.47	3.46	67.78	NA	3	11
July 10, 2014	7362GC	227.47	68.35	15.78	211.67	NA	3	11
TOTAL		593.01	404.36	25.75	534.48	NA	13	56

Table 8. 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)
7318GC	1000	30	40	100	50	130	5
7320GC	1000	40	40	100	50	130	5
7344GC	1200	45	26	70	60	130	5
7362GC	1200	40	26	70	60	130	5

2.4 Survey Coverage

This certain LiDAR acquisition survey covered the Bitanagan Floodplain (See Annex 7). Bitanagan Floodplain is located in the province of Davao Oriental, specifically within the city of Mati. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage is shown in Table 9. The actual coverage of the LiDAR acquisition for Bitanagan floodplain is presented in Figure 7.

Table 9. List of municipalities and cities surveyed during Bitanagan Floodplain LiDAR survey.

Province	Municipality/ City	Area of Municipality/ City (km^2)	Total Area Surveyed (km^2)	Percentage of Area Surveyed
Davao Oriental	Manay	430.894	137.905	32.00%
	Banaybanay	385.281	113.955	29.58%
	Mati	797.379	175.831	22.05%
	Tarragona	277.903	38.11	13.71%
	Lupon	356.281	40.392	11.34%
Total		2,247.74	506.193	22.52%

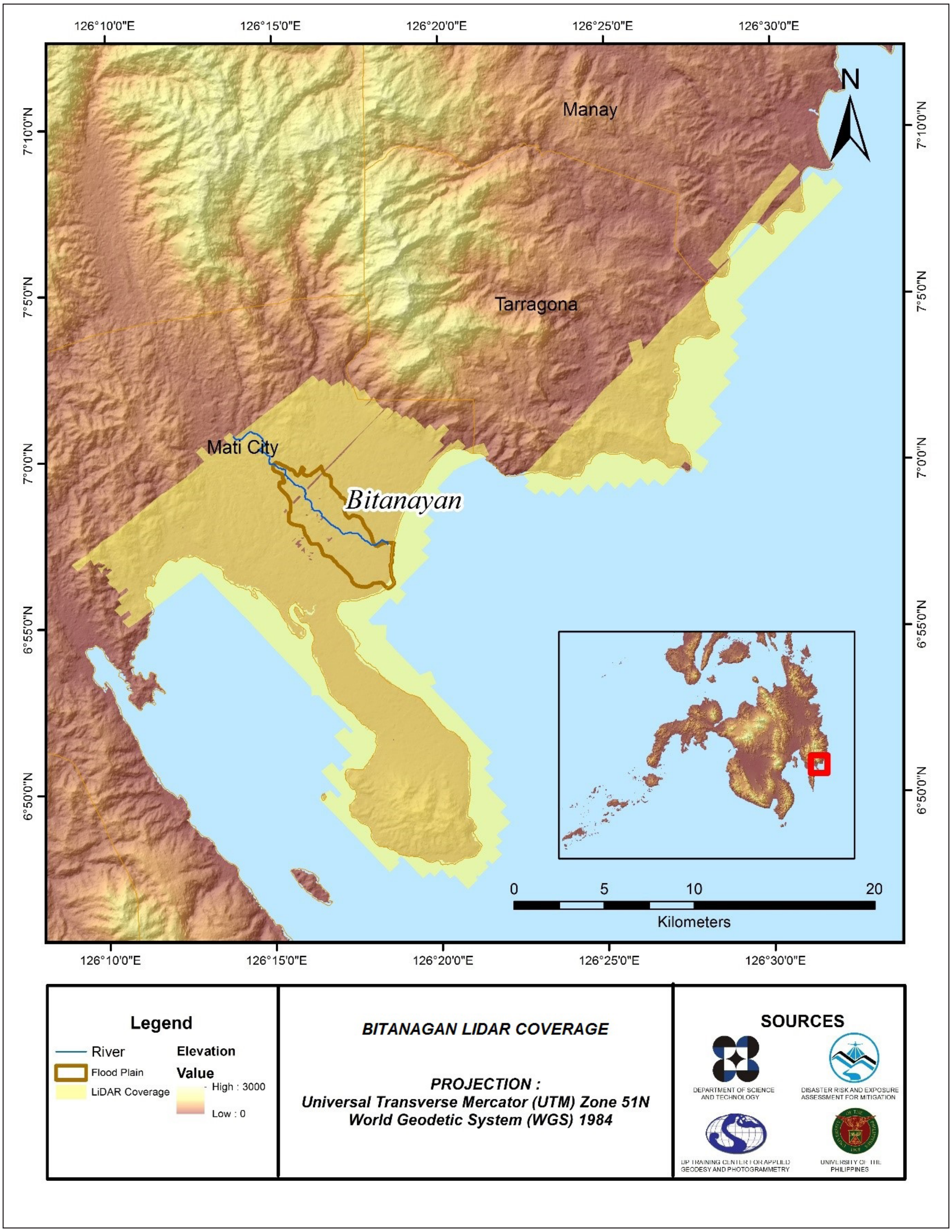

Figure 7. Actual LiDAR survey coverage for Bitanagan Floodplain.

Chapter 3: LiDAR Data Processing for Bitanagan Floodplain

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

3.1 Overview of the LIDAR Data Pre-Processing

The data transmitted by the Data Acquisition Component were checked for completeness based on the list of raw files required to proceed with the pre-processing of the LiDAR data. Upon acceptance of the LiDAR field data, georeferencing of the flight trajectory was done 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, are met. The point clouds were then classified into various classes before generating Digital Elevation Models such as Digital Terrain Model and Digital Surface Model.

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

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

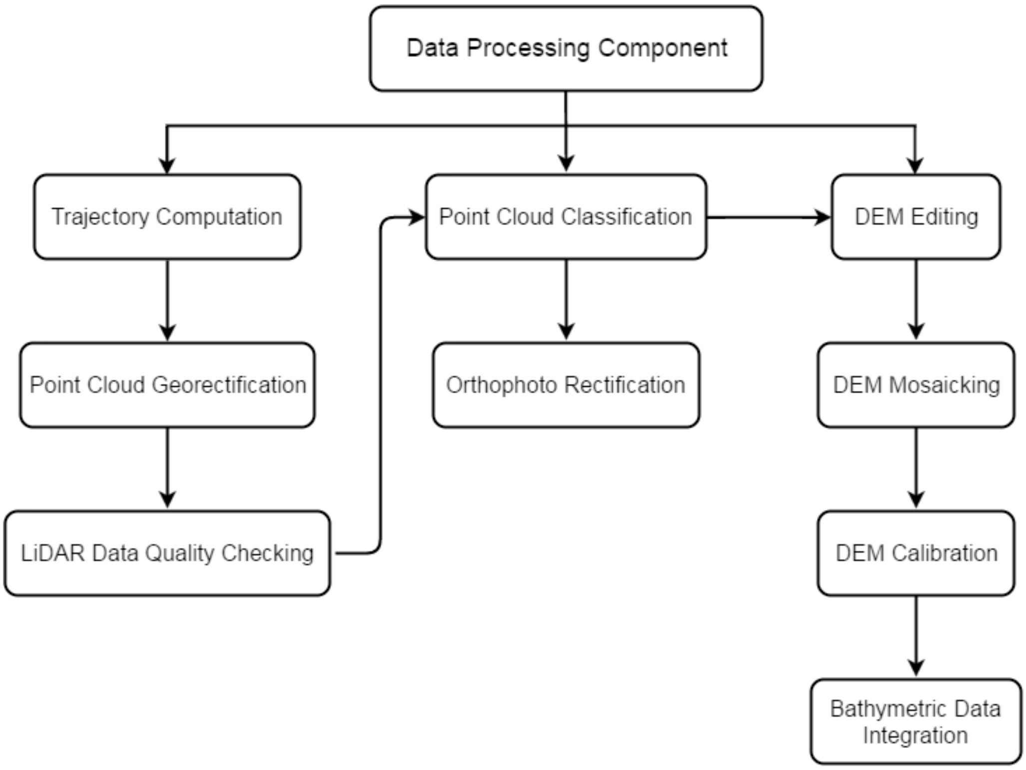

Figure 8. Schematic Diagram for Data Pre-Processing Component

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Bitanagan floodplain can be found in Annex 5. Missions flown during the all surveys conducted from June 2014 to July 2014 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Gemini system over Mati City, Davao Oriental. The Data Acquisition Component (DAC) transferred a total of 79.66 Gigabytes of Range data, 1.39Gigabytes of POS data, 42.05 Megabytes of GPS base station data, and 108.6 Gigabytes of raw image data to the data server on July 2, 2014 for the first survey and July 14, 2014 for the second survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Bitanagan was fully transferred on July 28, 2014, as indicated on the Data Transfer Sheets for Bitanagan Floodplain.

3.3 Trajectory Computation

The *Smoothed Performance Metric* parameters of the computed trajectory for flight 7318GC, one of the Bitanaganflights, which is the North, East, and Down position RMSE values are shown in Figure 9. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on June 15, 2014 00:00AM. The y-axis is the RMSE value for that particular position.

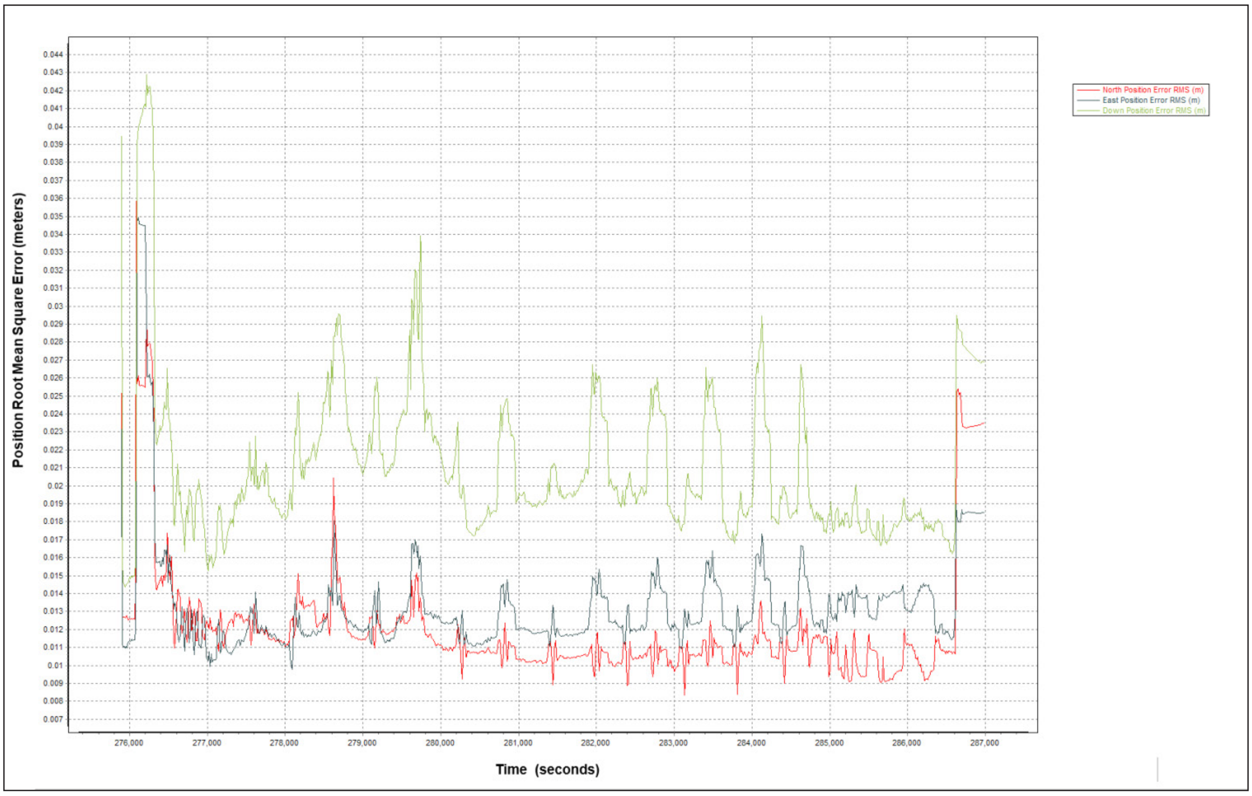

Figure 9. Smoothed Performance Metric Parameters of a Bitanagan Flight 7318GC.

The time of flight was from 276000 seconds to 287000 seconds, which corresponds to morning of June 18, 2014. The initial spike that is seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the POS system starts computing for the position and orientation of the aircraft. Redundant measurements from the POS system quickly minimized the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values correspond to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 9 shows that the North position RMSE peaks at 2.00 centimeters, the East position RMSE peaks at 1.80centimeters, and the Down position RMSE peaks at 3.40centimeters, which are within the prescribed accuracies described in the methodology.

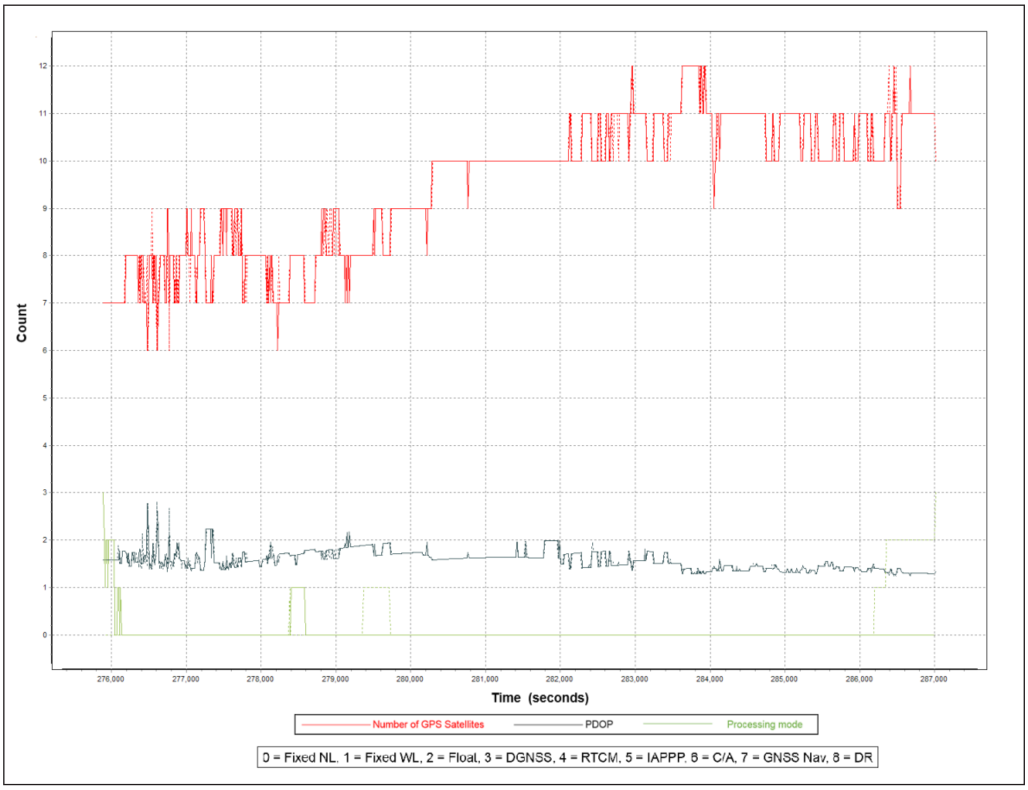

Figure 10. Solution Status Parameters of Bitanagan Flight 7318GC.

The S*olution Status*parameters of flight 7318GC,one of the Bitanaganflights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 10. The graphs indicate that the number of satellites during the acquisition did not go down to 5. Majority of the time, the number of satellites tracked was between 6 and 12. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode stayed at the value of 0 for majority of the survey with some peaks up to 3 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Bitanagan flights is shown in Figure 11.

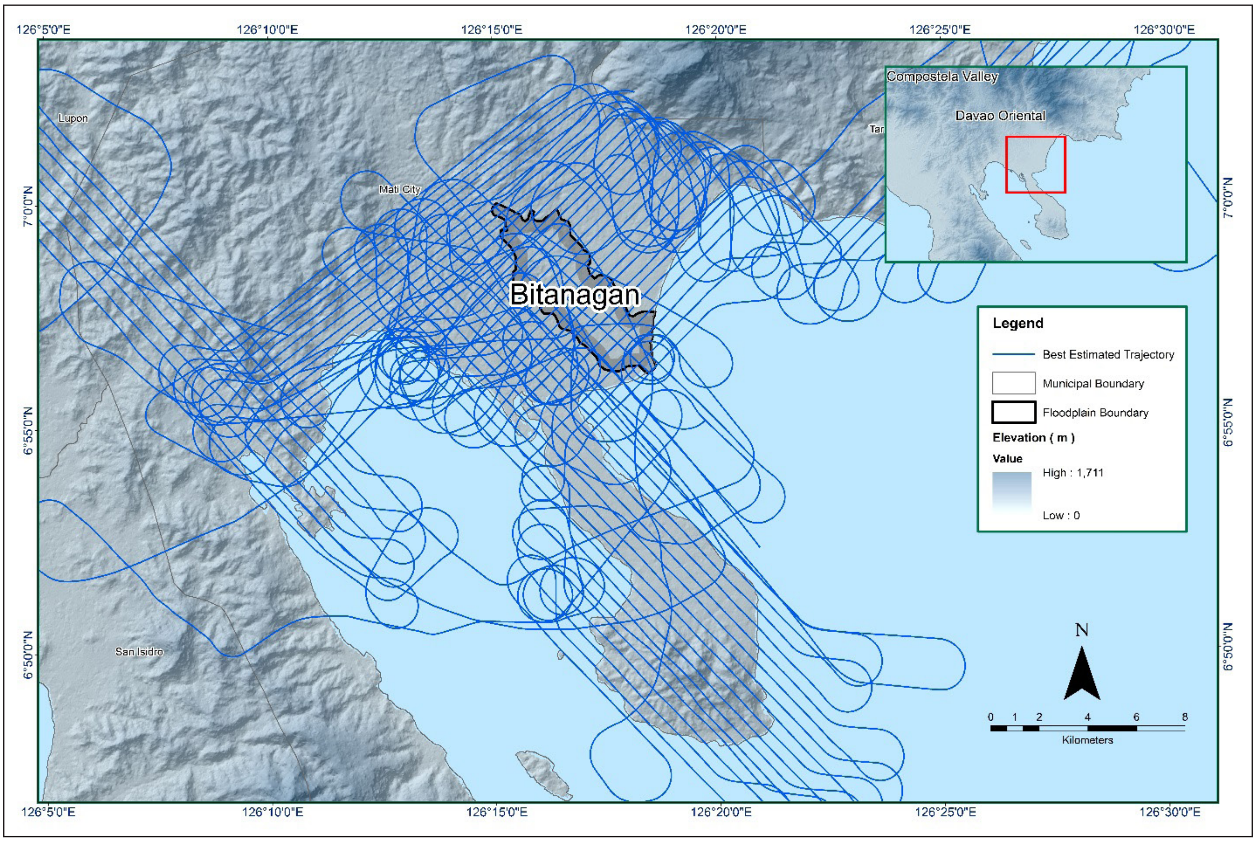

Figure 11. Best Estimated Trajectory for Bitanagan floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 61flight lines, with each flight line containing one channel, since the Geminisystemcontain one channel only. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Bitanagan Floodplain are given in Table 10.

Table 10. Self-Calibration Results values for Bitanagan flights.

Parameter	Value
Boresight Correction stdev(<0.001degrees)	0.000182
IMU Attitude Correction Roll and Pitch Corrections stdev(<0.001degrees)	0.000647
GPS Position Z-correction stdev(<0.01meters)	0.0025

The optimum accuracy was obtained for all Bitanagan flights based on the computed standard deviationsof the corrections of the orientation parameters. Standard deviation values for individual blocks are available in the Annex 8.

3.5 LiDAR Data Quality Checking

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

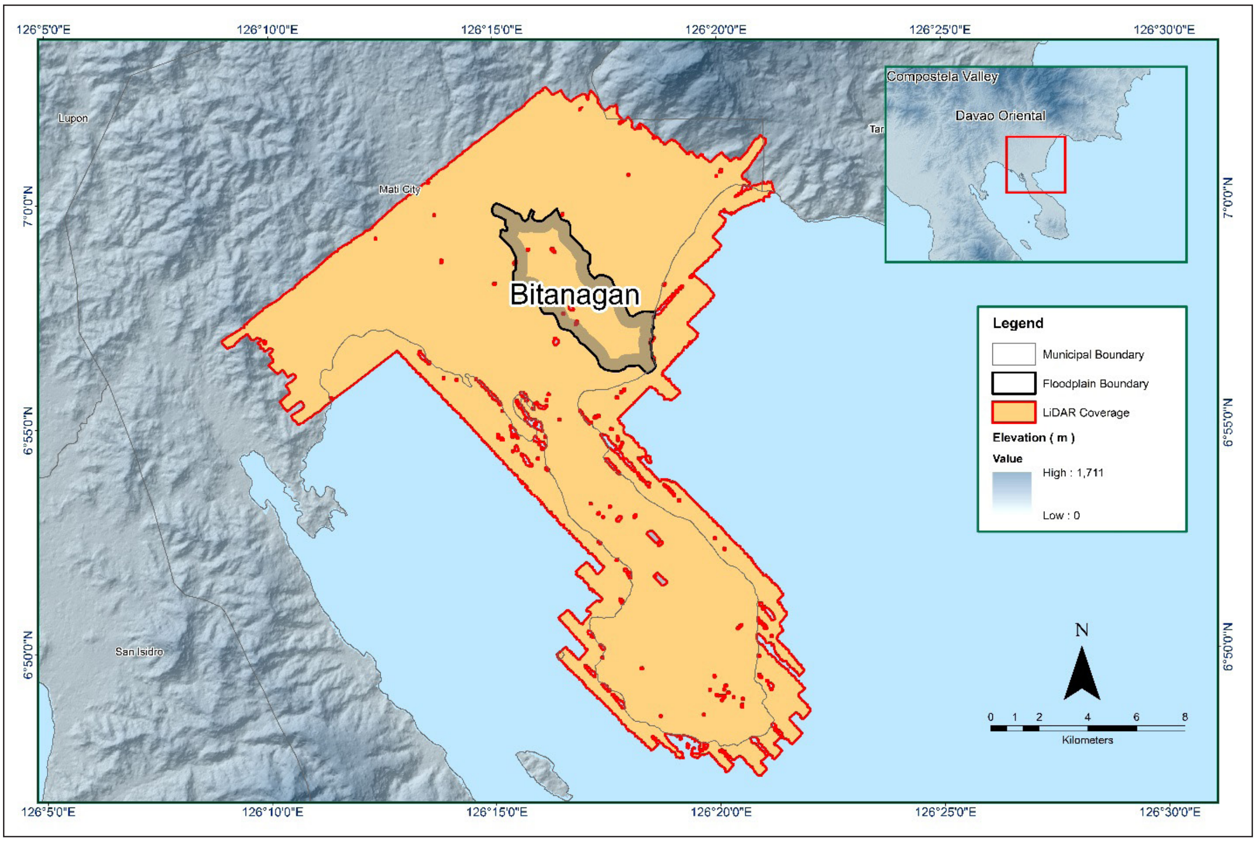

Figure 12. Boundary of the processed LiDAR data over Bitanagan Floodplain

The total area covered by the Bitanagan missions is 224.29 sq.km that is comprised of four (4) flight acquisitions grouped and merged into four (4) blocks as shown in Table 11.

Table 11. List of LiDAR blocks for Bitanagan Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Davao_Oriental_Blk84A	7318GC	128.63
Davao_Oriental_Blk84B	7320GC	68.56
Davao_Oriental_Blk84C	7344GC	27.10
Davao_Oriental_Blk85B_additional	7362GC	69.62
TOTAL		224.29 sq.km

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 13. Since the Gemini system employs one channel, 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 are expected.

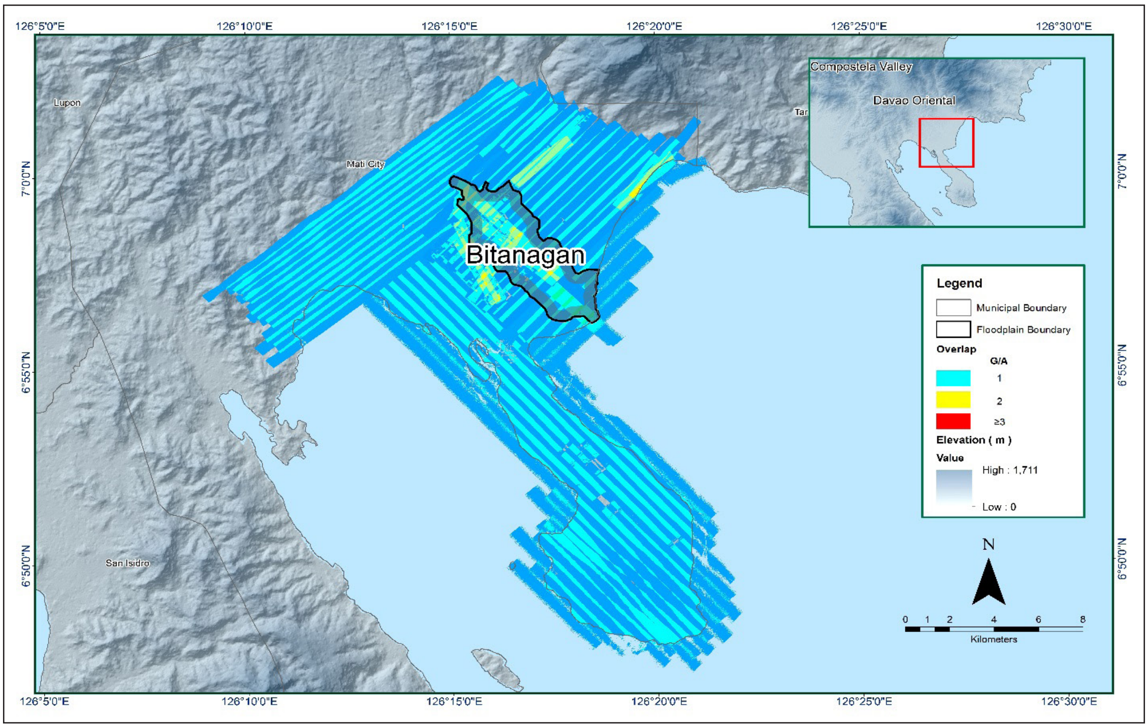

Figure 13. Image of data overlap for Bitanagan Floodplain.

The overlap statistics per block for the Bitanagan Floodplain can be found in Annex 5. One pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlapsare32.47% and 42.20% respectively, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 14. It was determined that all LiDAR data for Bitanagan floodplain satisfy the point density requirement, and the average density for the entire survey area is 3.01 points per square meter.

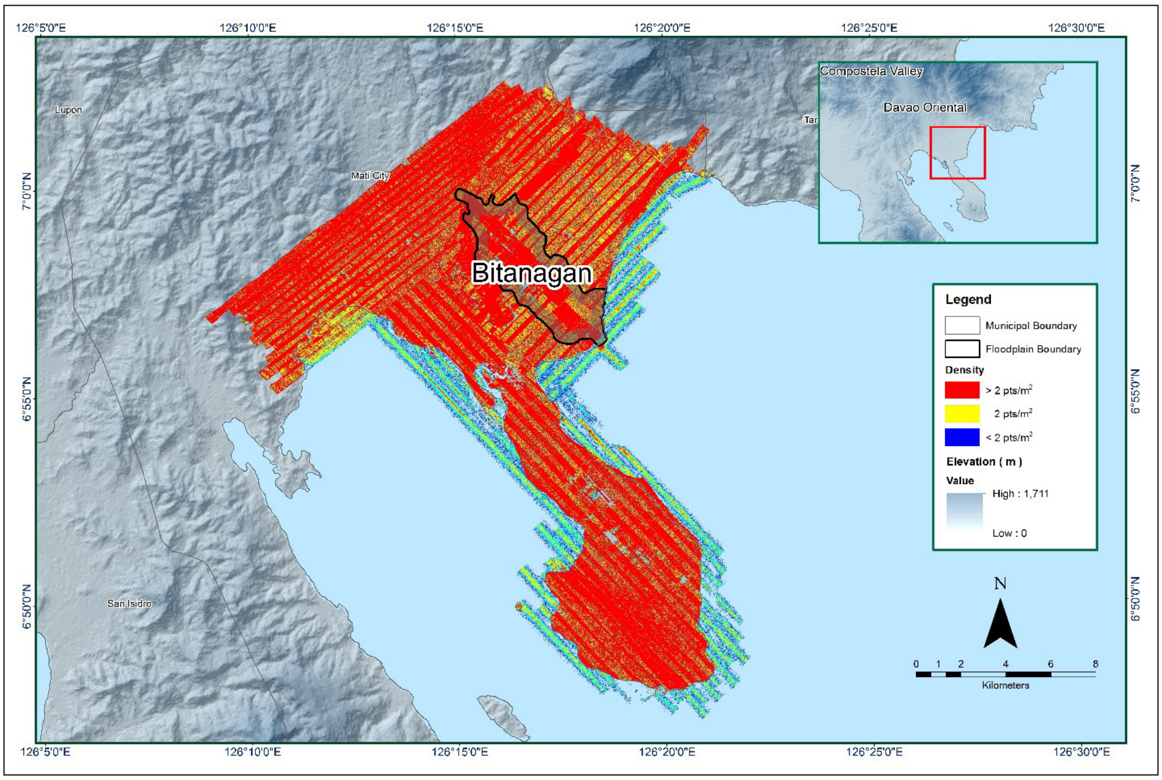

Figure 14. Density map of merged LiDAR data for Bitanagan floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 15. The default color range is from blue to red, where bright blue areas correspond to portions where elevations of a previous flight line, identified by its acquisition time, are higher by more than 0.20m relative to elevations of its adjacent flight line. Bright red areas indicate portions where elevations of a previous flight line are lower by more than 0.20m relative to elevations of its adjacent flight line. Areas with bright red or bright blue need to be investigated further using Quick Terrain Modeler software.

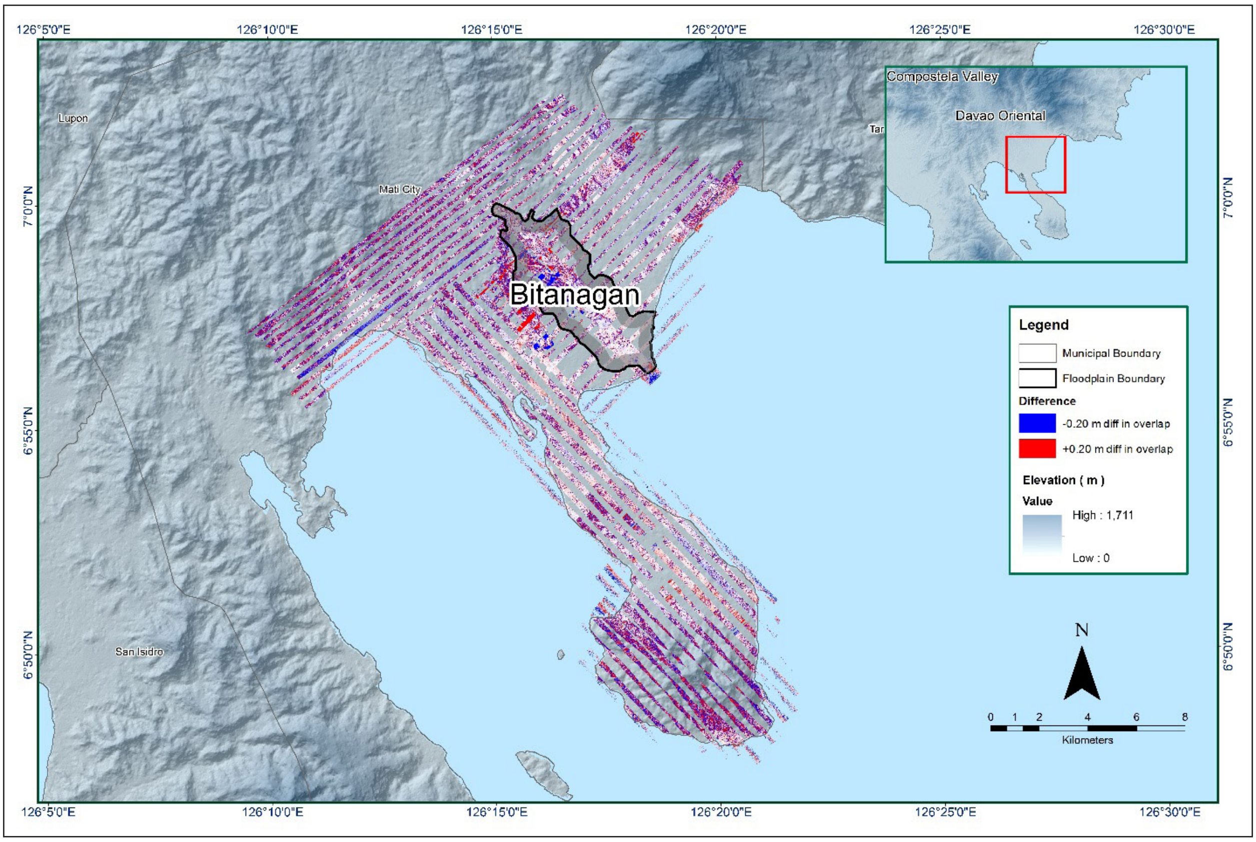

Figure 15. Elevation difference map between flight lines for Bitanagan Floodplain.

A screen capture of the processed LAS datafrom a Bitanagan flight 7318GC loaded in QT Modeler is shown in Figure 16. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed yellow line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

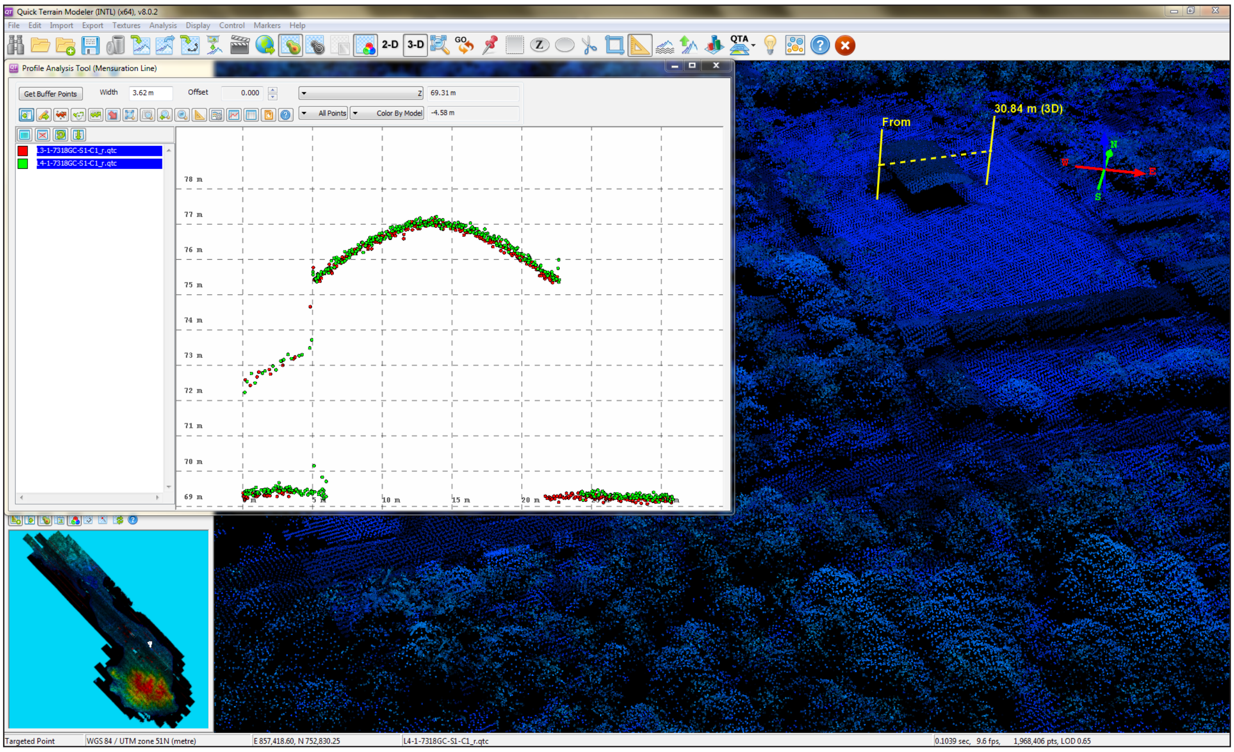

Figure 16. Quality checking for a Bitanagan flight 7318GC using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 12. Bitanagan classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	113,509,569
Low Vegetation	89,522,177
Medium Vegetation	151,293,089
High Vegetation	386,324,445
Building	162,675,994

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Bitanagan Floodplain is shown in Figure 17. A total of 452 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 11. The point cloud has a maximum and minimum height of 623.53 meters and 60.52 meters, respectively.

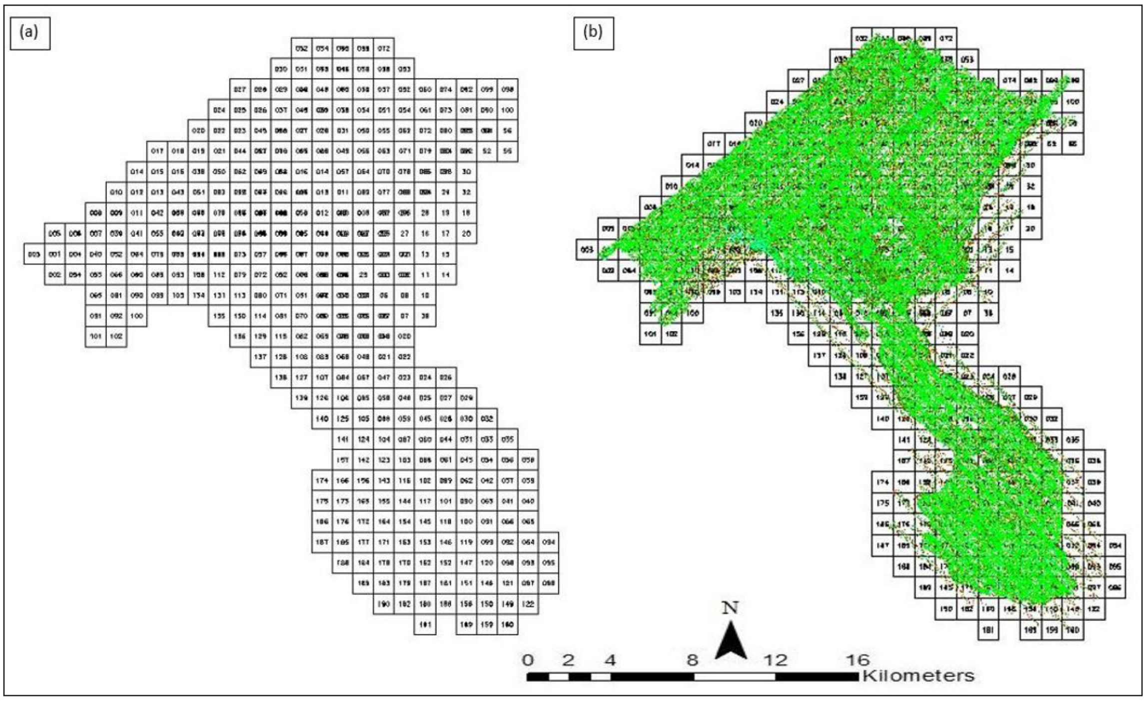

Figure 17. Tiles for Bitanagan Floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 18. The ground points are in orange, the vegetation is in different shades of green, and the buildings are in cyan. It can be seen that residential structures adjacent or even below canopy are classified correctly, due to the density of the LiDAR data.

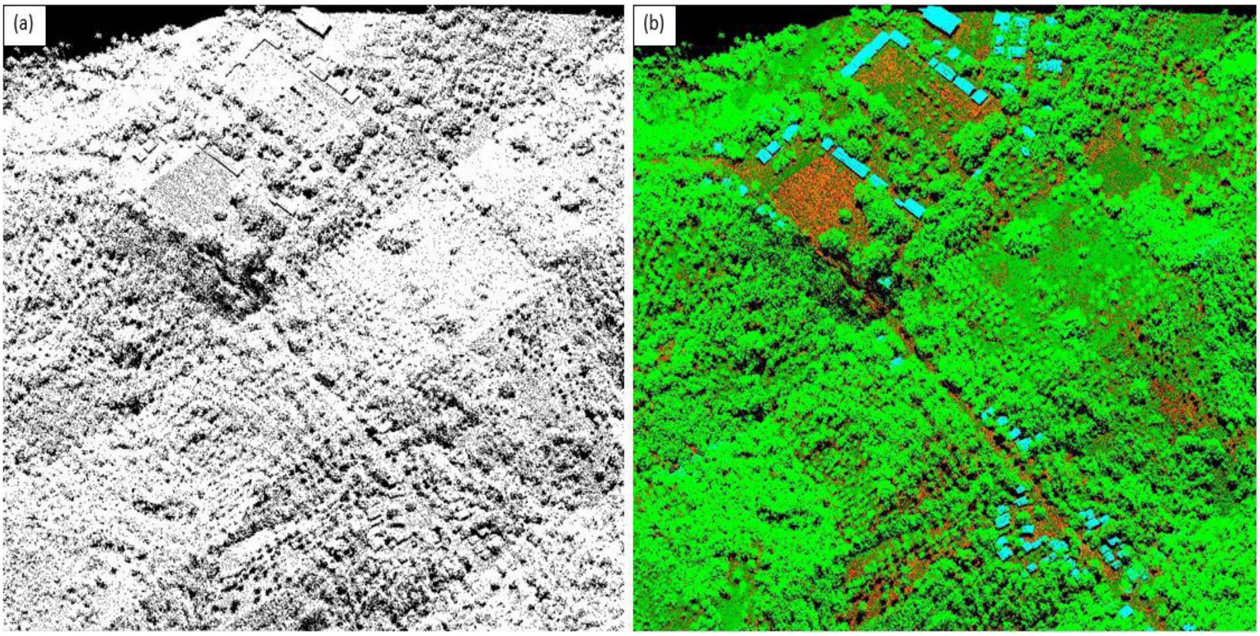

Figure 18. Point cloud before (a) and after (b) classification.

The production of 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 19. It shows that DTMs are the representation of the bare earth while on the DSMs, all features are present such as buildings and vegetation.

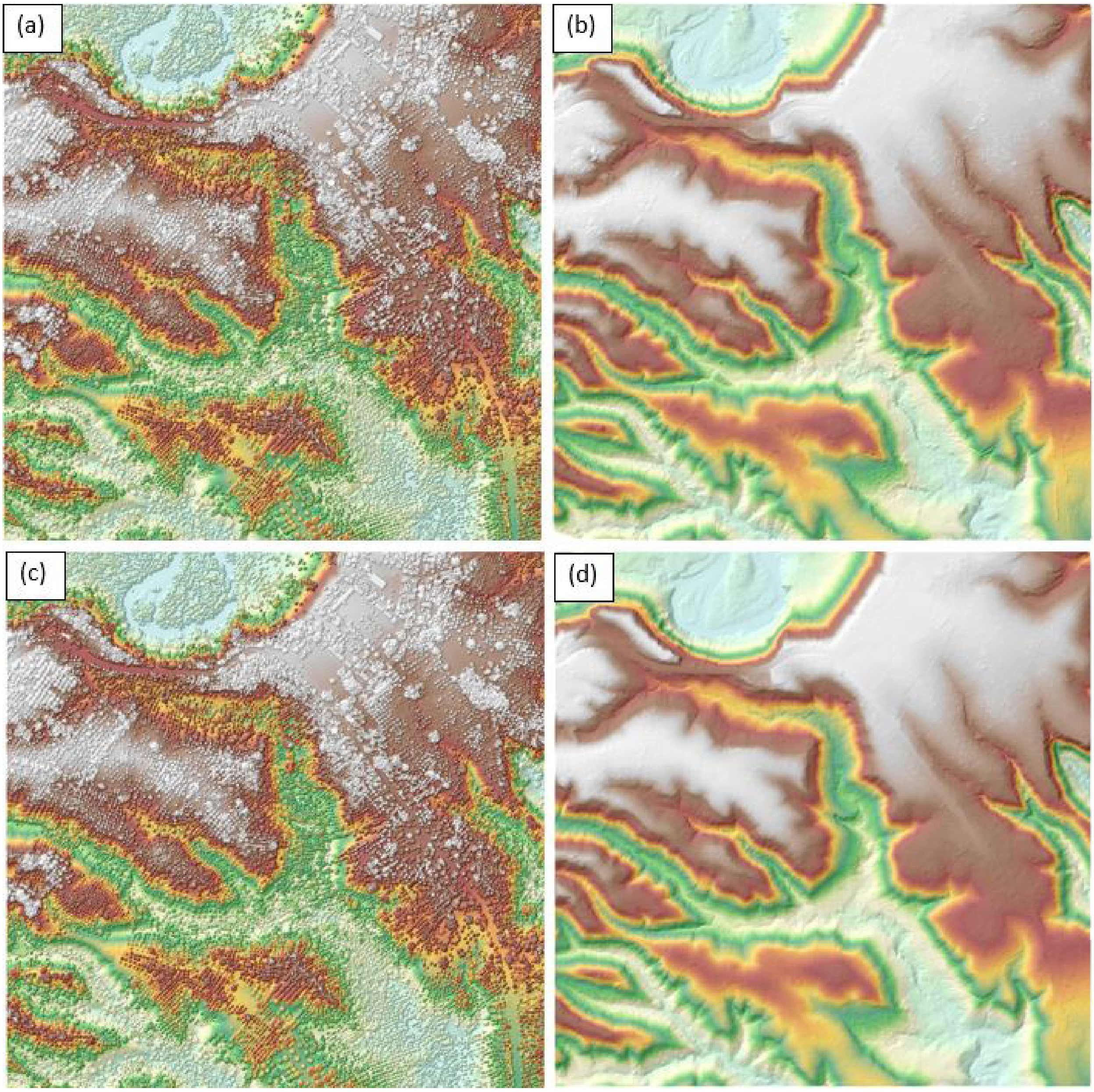

Figure 19. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Bitanagan Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

There are no available orthophotographs for the Bitanagan floodplain.

3.8 DEM Editing and Hydro-Correction

Four (4) mission blocks were processed for Bitanagan Floodplain. These blocks are composed of Davao Oriental blocks with a total area of 224.29 square kilometers. Table 13 shows the name and corresponding area of each block in square kilometers.

Table 13. LiDAR blocks with its corresponding area.

LiDAR Blocks	Area (sq.km)
Davao_Oriental_Blk84A	128.63
Davao_Oriental_Blk84B	68.56
Davao_ Oriental_Blk84C	27.10
Davao_Oriental_Blk85B_additional	69.62
TOTAL	224.29 sq.km

Portions of DTM before and after manual editing are shown in Figure 20. The bridge (Figure 20a) is also considered to be an impedance to the flow of water along the river and has to be removed (Figure 20b) in order to hydrologically correct the river. The paddy field (Figure 20c) has been misclassified and removed during classification process and has to be retrieved to complete the surface (Figure B-13d) to allow the correct flow of water.

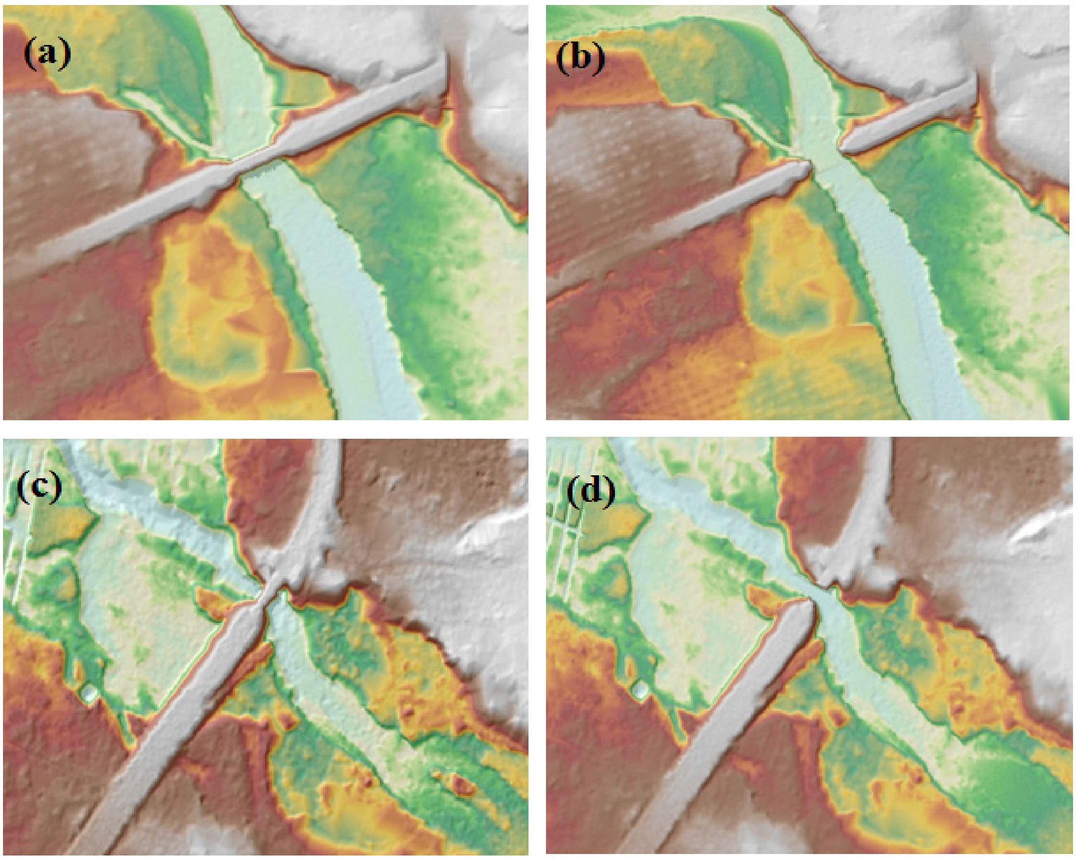

Figure 20. Portions in the DTM of Bitanagan Floodplain– a bridge before (a) and after (b) manual editing; a paddy field before (c) and after (d) data retrieval.

3.9 Mosaicking of Blocks

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

Mosaicked LiDAR DTM for Bitanagan Floodplain is shown in Figure 21. The entire Bitanagan Floodplain is 98.34% covered by LiDAR data while portions with no LiDAR data were patched with the available IFSAR data.

Table 14. Shift Values of each LiDAR Block of Bitanagan Floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
Davao_Oriental_Blk84A	2.80	0.00	-0.23
Davao_Oriental_Blk84B	0.50	-0.10	0.60
Davao_ Oriental_Blk84C	1.10	-0.20	0.15
Davao_Oriental_Blk85B_additional	1.30	0.00	-0.22

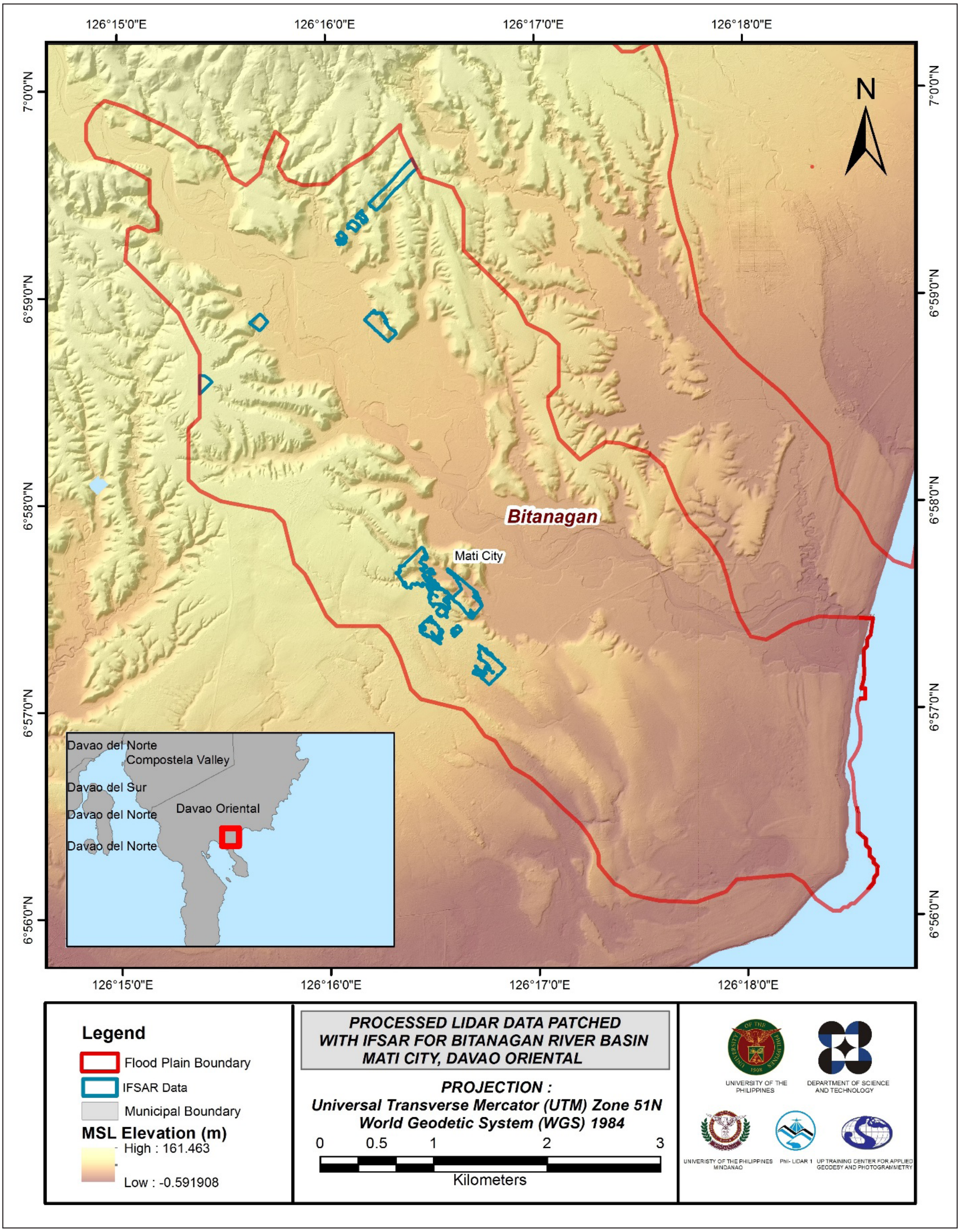

Figure 21. Map of Processed LiDAR Data for Bitanagan Floodplain.

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 Bitanagan to collect points with which the LiDAR dataset is validated is shown in Figure 22. A total of 1274 survey points were used for calibration and validation of Bitanagan LiDAR data. Random selection of 80% of the survey points, resulting to 1020 points, were used for calibration. A good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values are shown in Figure 23. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration elevation values is 0.67 meters with a standard deviation of 0.14 meters. Calibration of Bitanagan LiDAR data was done by subtracting the height difference value, 0.67 meters, to Bitanagan mosaicked LiDAR data. Table 15 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

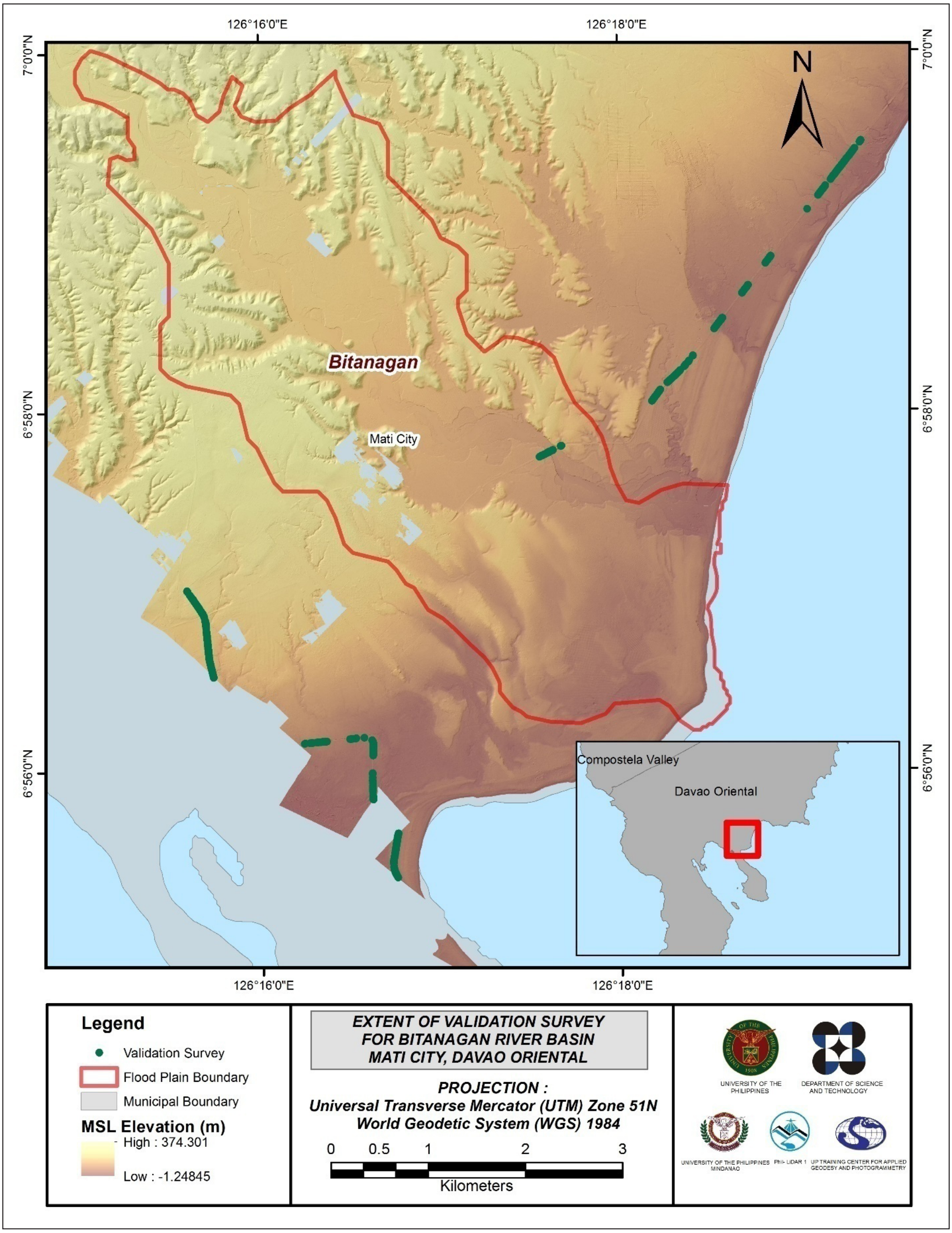

Figure 22. Map of Bitanagan Floodplain with validation survey points in green.

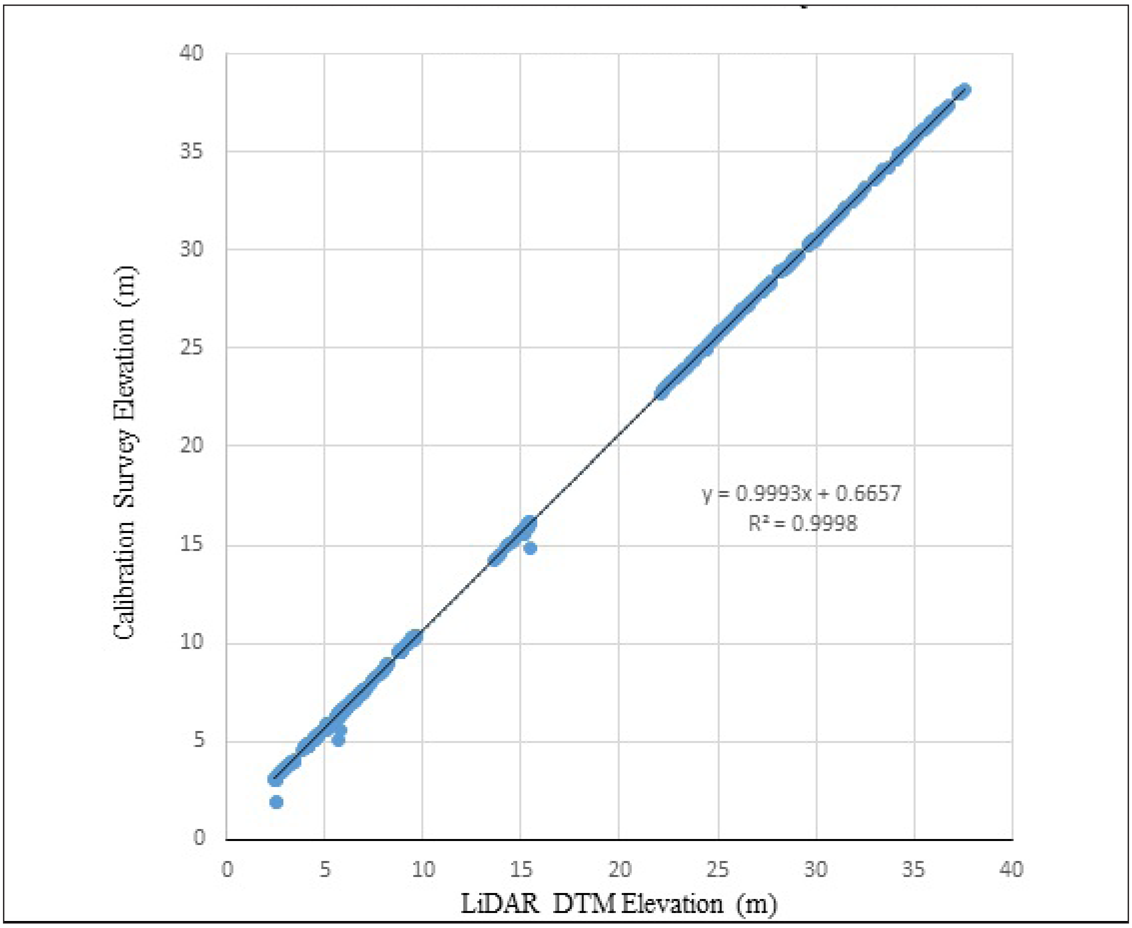

Figure 23. Correlation plot between calibration survey points and LiDAR data.

Table 15. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	0.67
Standard Deviation	0.14
Average	-0.66
Minimum	-0.93
Maximum	-0.38

The remaining 20% of the total survey points, resulting to 254 points, were used for the validation of calibrated Bitanagan 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 24. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.23 meters with a standard deviation of 0.19meters, as shown in Table 16.

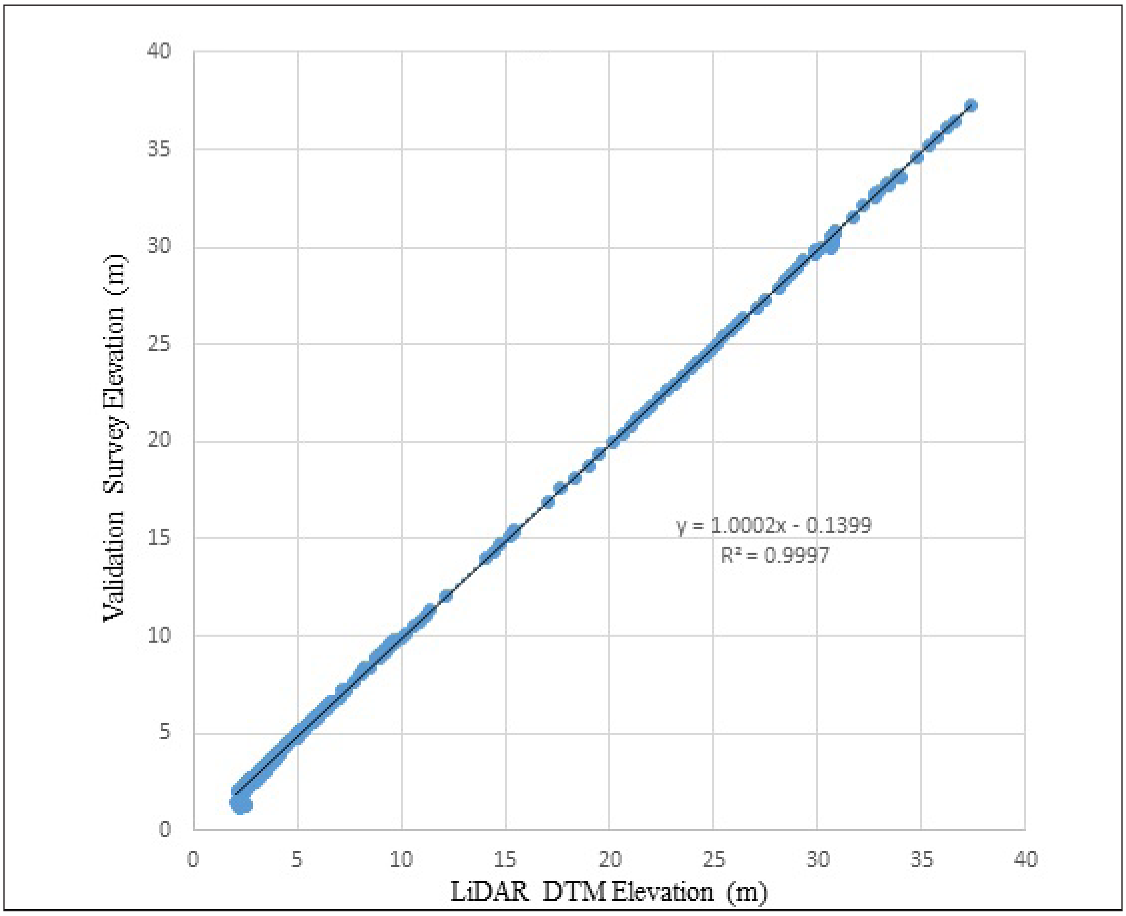

Figure 24. Correlation plot between validation survey points and LiDAR data.

Table 16. Validation Statistical Measures.

Validation Statistical Measures	Value (meters)
RMSE	0.23
Standard Deviation	0.19
Average	0.14
Minimum	-0.24
Maximum	0.52

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and cross-section data were available for Bitanagan with 2180 bathymetric survey points. The resulting raster surface produced was done by Kernel interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.23 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Bitanagan integrated with the processed LiDAR DEM is shown in Figure 25.

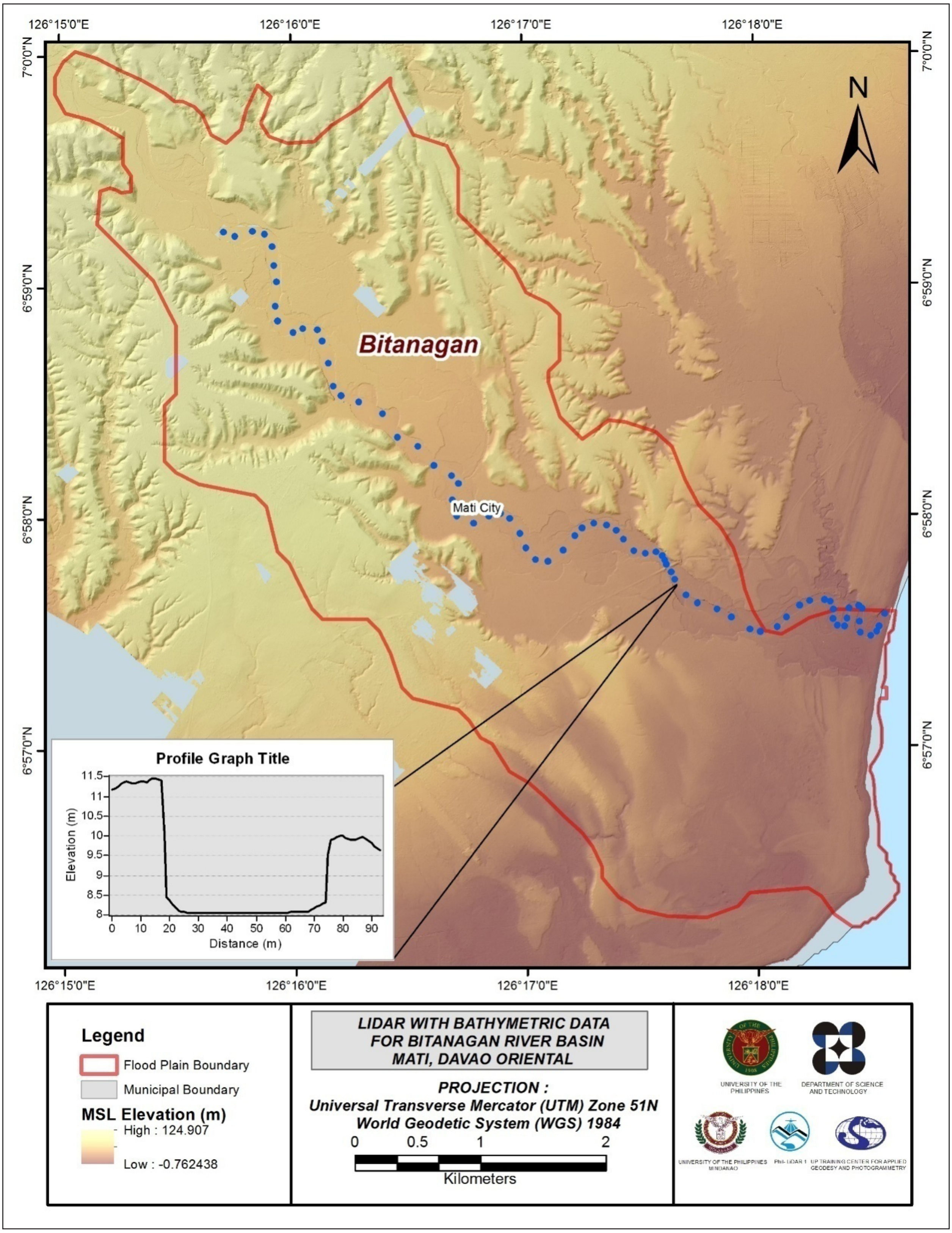

Figure 25. Map of Bitanagan Floodplain with bathymetric survey points shown in blue.

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

Bitanagan Floodplain, including its 200 m buffer, has a total area of 25.33sq km. For this area, a total of 5.0 sq km, corresponding to a total of 463 building features, are considered for QC. Figure 26 shows the QC blocks for Bitanagan Floodplain.

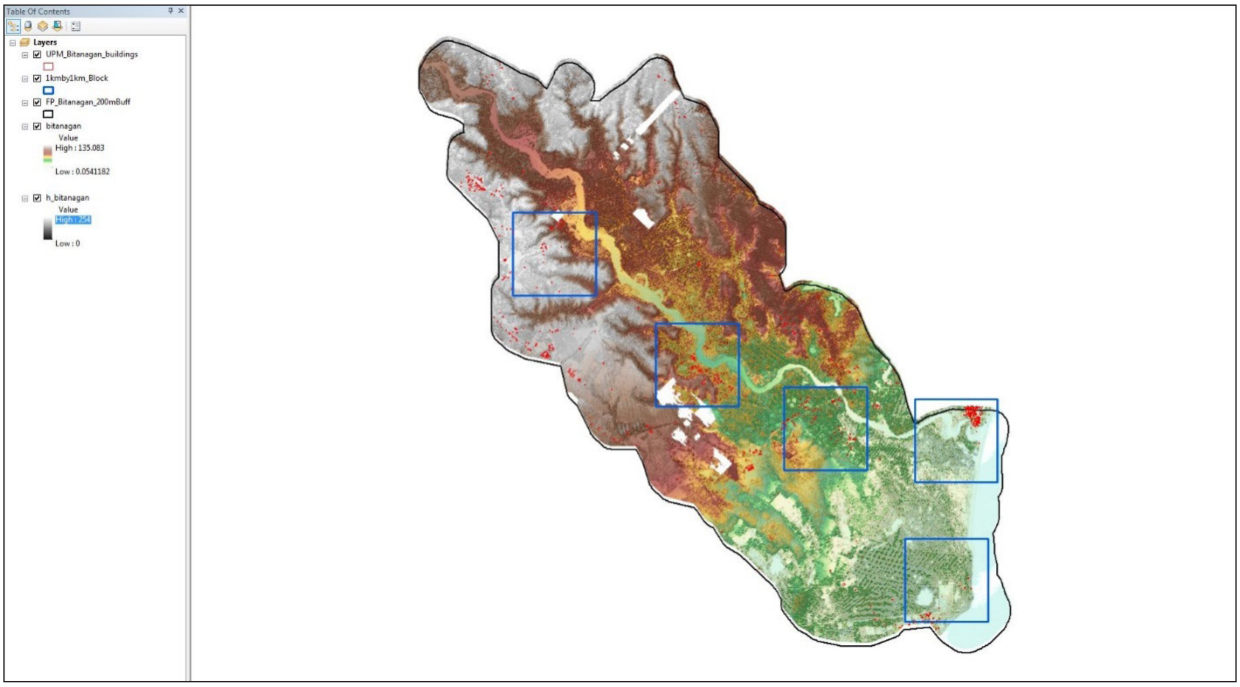

Figure 26. Blocks (in blue) of Bitanagan building features that were subjected in QC.

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

Table 17. Quality Checking Ratings for Bitanagan Building Features.

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Bitanagan	99.13	98.06	96.76	PASSED

3.12.2 Height Extraction

Height extraction was done for 809 building features in Bitanagan Floodplain. Of these building features, 60 was filtered out after height extraction, resulting in 749 buildings with height attributes. The lowest building height is at 2.00 m while the highest building is at 11.94 m. There are156 buildings that were not included in the height extraction since these features were only noted to be existing during field validation but are not found on the LiDAR data processed for the floodplain.

3.12.3 Feature Attribution

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

The courtesy calls and project presentations were done on May 26, 2016. Barangay Health Workers (BHWs) were requested and hired to guide the University of the Philippines Mindanao Phil-LiDAR1 field enumerators during validation. The field work activity was conducted from June 6 - 7, 2016. The local hires deployed by the barangay captains were given a brief orientation by the field enumerators before the actual field work. The team surveyed the three (3) barangays covered by the floodplain namely Dahican, Don Enrique Lopez and Don Martin Marundan, Mati City.

During the courtesy call, Brgy. Don Martin Marundan wanted to get across to the national government some concerns over research projects (which are good, but lack physical reinforcement). They need dikes to protect their flood-prone areas, but lack the resources to have them. They usually buy temporary measures like wood to repair/move residents to safer areas. During the field work proper, some of the validated buildings under Brgy. Don Enrique turned out to be under Brgy. Don Salvador. This was because there was still no settlement over some barangay boundaries in Mati City. Despite this, the enumerators and local hires still managed to finish the field validation.

Table 18 summarizes the number of building features per type. The156 building features that were only noted during field validation but are not present on the LiDAR data are also included in this summary since building types for the features are available.On the other hand, Table 18 shows the total length of each road type, while Table 19 presents the number of water features extracted per type.

Table 18. Building Features Extracted for Bitanagan Floodplain.

Facility Type	No. of Features
Residential	762
School	19
Market	0
Agricultural/Agro-Industrial Facilities	41
Medical Institutions	1
Barangay Hall	1
Military Institution	12
Sports Center/Gymnasium/Covered Court	6
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	11
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	0
Water Supply/Sewerage	0
Religious Institutions	17
Bank	0
Factory	2
Gas Station	0
Fire Station	0
Other Government Offices	8
Other Commercial Establishments	25
Total	905

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

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Bitanagan	23.70	3.63	3.01	3.92	0.00	34.26

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

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

A total of 1 bridge over a small channel that is a part of the river network was also extracted for the floodplain.

3.12.4 Final Quality Checking of Extracted Features

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

Figure 27 shows the Digital Surface Model (DSM) of Bitanagan Floodplain overlaid with its ground features.

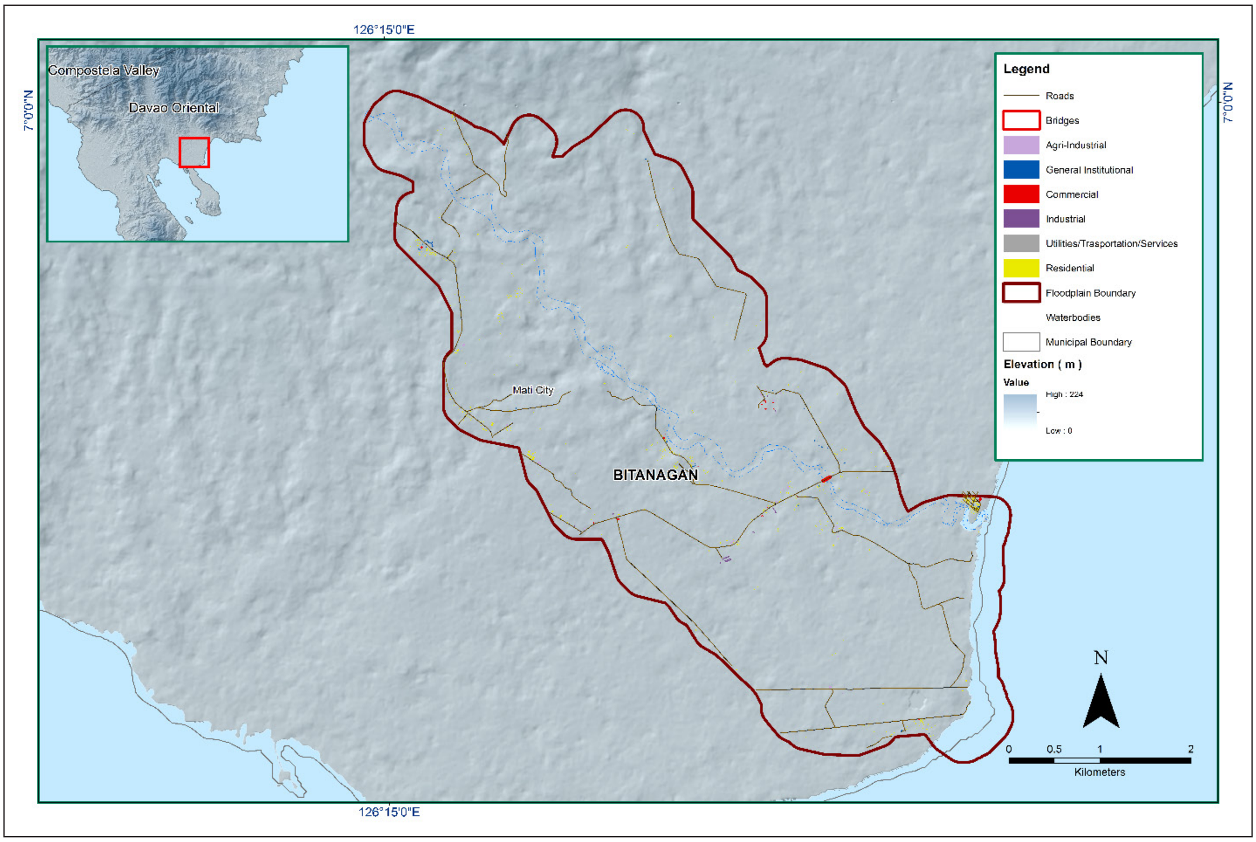

Figure 27. Extracted features for Bitanagan Floodplain.

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

Engr. Louie P. Balicanta, Engr. Joemarie S. Caballero, Ms. Patrizcia Mae. P. dela Cruz, Engr. Kristine Ailene B. Borromeo Ms. Jeline M. Amante, Marie Angelique R. Estipona, Charie Mae V. Manliguez, Engr. Janina Jupiter, Vie Marie Paola M. Rivera

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 AB Surveying and Development (ABSD) conducted a field survey in Bitanagan River on February 26-29, 2016, March 3, 2016, and March 20, 2016 with the following scope: reconnaissance; control survey; cross-section and as-built survey at Bitanagan Bridge in Brgy. Don Enrique Lopez, Mati City, Davao Oriental; and bathymetric survey from its upstream in Brgy. Don Martin Marundan to the mouth of the river located in Brgy. Don Enrique Lopez, Mati City, with an approximate length of 7.96 km using a Nikon Total Station. Random checking points for the contractor's cross-section and bathymetry data were gathered by DVBC on May 10-24, 2016 using a survey grade GNSS receiver Trimble® SPS 985 GNSS PPK survey technique. In addition to this, validation points acquisition survey was conducted covering the Bitanayan River Basin area. The entire survey extent is illustrated in Figure 28.

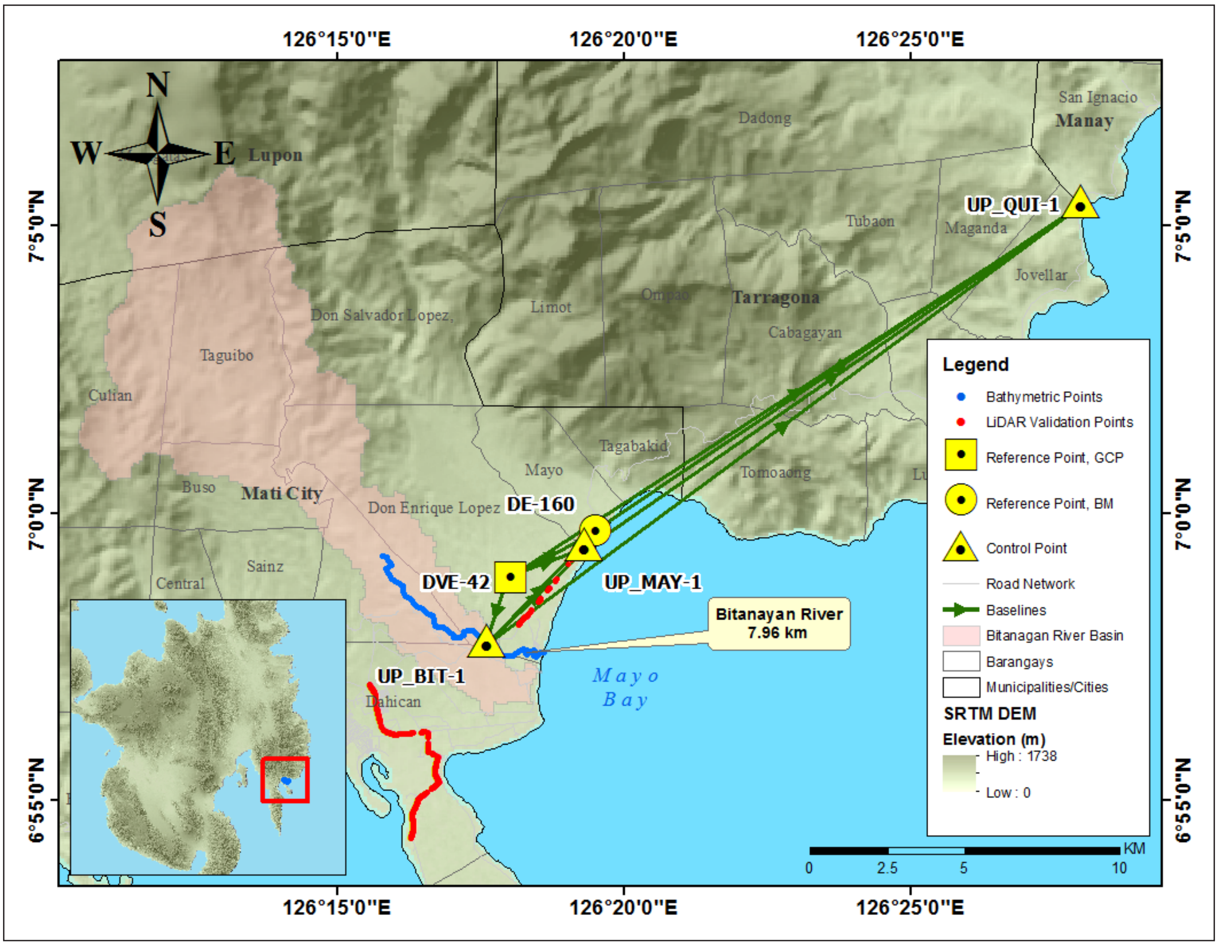

Figure 28. Bitanayan River Survey Extent

4.2 Control Survey

The GNSS network used for Bitanagan River is composed of seven (7) loops established on May 22, 2016 occupying the following reference points: DVE-42 a second-order GCP, in Brgy. Don Enrique Lopez, Mati City, Davao Orientaland DE-160, a first-order BM, in Brgy. Mayo, Mati City, Davao Oriental.

Three (3) control points established in the area by ABSD were also occupied: UP_BIT-1beside the approach of Bitanagan Bridge in Brgy. Don Enrique Lopez, Mati City, Province of Davao Oriental, UP_MAY-1 beside the approach of Mayo Bridge in Brgy. Mayo, Mati City, Davao Oriental, and UP_QUI-1 located beside the approach of Quinonoan Bridge in Brgy. San Ignacio, Manay, Davao Oriental.

The summary of reference and control points and its location is summarized in Table 21 while GNSS network established is illustrated in Figure 29.

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

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoid Height (m)	Elevation (MSL) (m)	Date of Establishment
DVE-42	2nd order, GCP	6°58'51.79295"N	126°18'01.57690"E	80.539	15.122	2007
DE-160	1st order, BM	6°59'41.20398"N	126°19'30.03464"E	71.754	6.419	2009
UP_BIT-1	Established	6°57'46.30507"N	126°17'35.96635"E	80.537	15.21	2-26-16
UP_MAY-1	Established	6°59'26.93722"N	126°19'18.72092"E	73.478	8.152	2-27-16
UP_QUI-1	Established	7°05'25.95862"N	126°27'58.08622"E	70.854	6.305	2-20-16

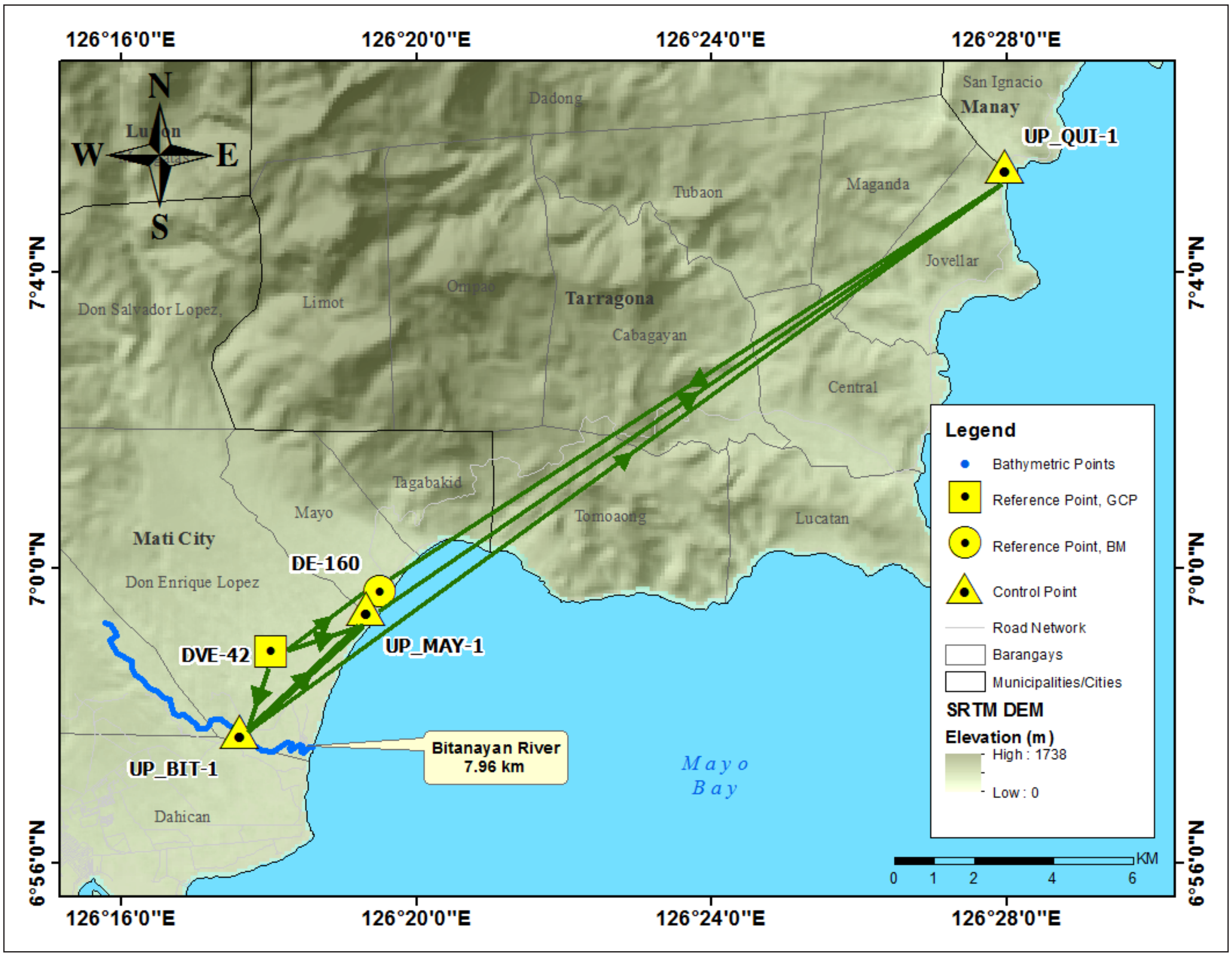

Figure 29. Bitanayan River Basin Control Survey Extent

The GNSS set-ups on recovered reference points and established control points in Bitanagan River are shown from Figure 30 to Figure 34.

Figure 30. GNSS base set up, Trimble® SPS 852, at DVE-42, located in front of the flagpole inside Don Enrique Lopez Elementary School in Brgy. Don Enrique Lopez, Mati City, Davao Oriental

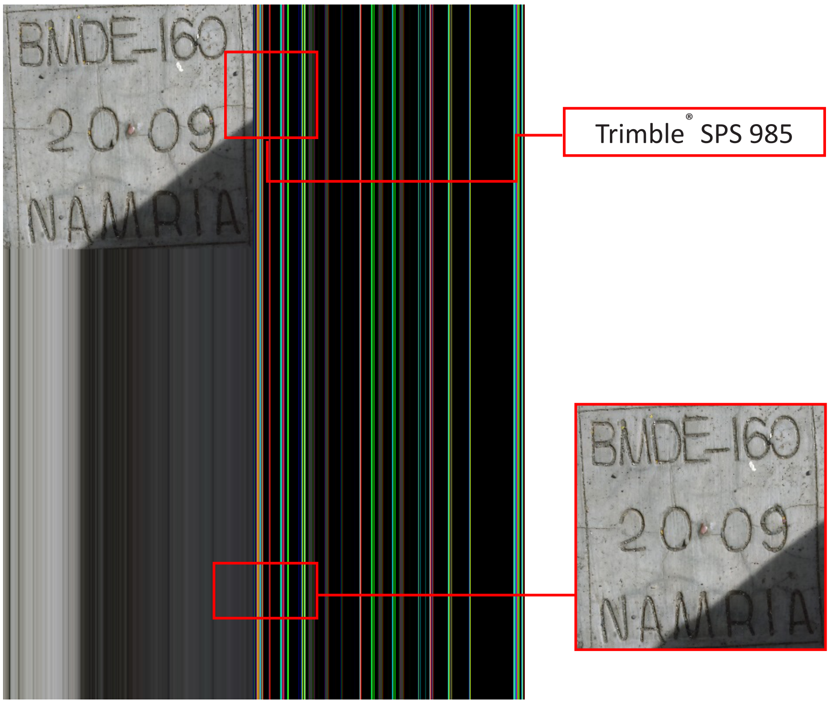

Figure 31. GNSS receiver set up, Trimble® SPS 985, at DE-160, located at approach of Calinan Bridge in Brgy. Mayo, City of Mati, Davao Oriental

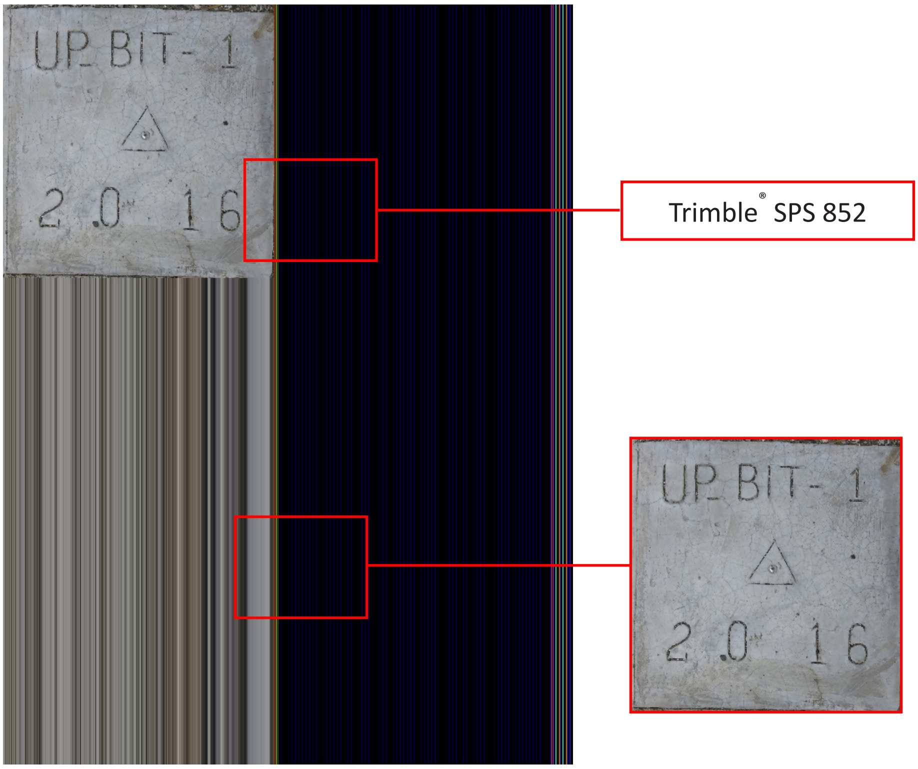

Figure 32. GNSS receiver set up, Trimble® SPS 852, at UP_BIT-1, located at the side of the railing near the approach of Bitanagan Bridge in Brgy. Don Enrique Lopez, City of Mati, Davao Oriental

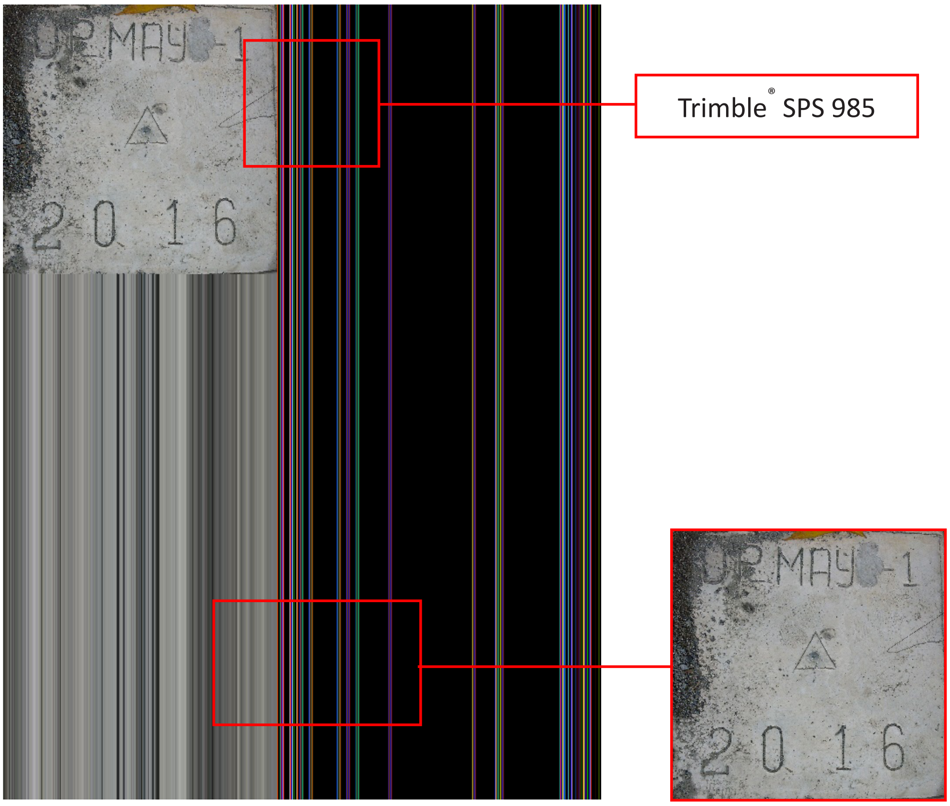

Figure 33. GNSS receiver set up, Trimble® SPS 985, at UP_MAY-1, located beside the approach of Mayo Bridge in Brgy. Mayo, City of Mati, Province of Davao Oriental

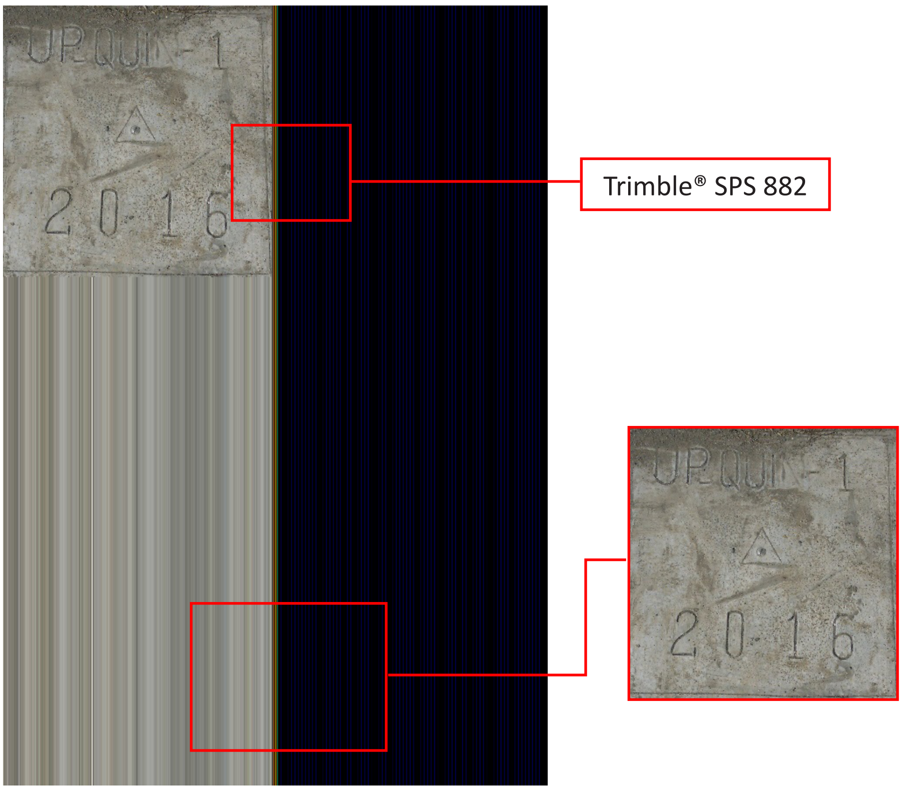

Figure 34. Figure GNSS receiver set up, Trimble® SPS 882, at UP_QUI-1, located beside the approach of Quinonoan Bridge in Brgy. San Ignacio, Municipality of Manay, Province of Davao Oriental

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 +/- 20 cm and +/- 10 cm requirement, respectively. In case where one or more baselines did not meet all of these criteria, masking is performed. Masking is done by removing/masking portions of these baseline data using the same processing software. It is repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, resurvey is initiated. Baseline processing result of control points in Bitanagan River Basin is summarized in Table 22 generated by TBC software.

Table 22. Baseline Processing Report for Bitanagan River Static Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	Height (m)
DVE-42 --- DE-160	5-22-2016	Fixed	0.005	0.026	60°47'28"	3110.595	-8.798
UP_MAY-1 -- DE-160	5-22-2016	Fixed	0.003	0.004	38°23'28"	559.167	-1.723
DVE-42 --- UP_MAY-1	5-22-2016	Fixed	0.003	0.014	65°29'18"	2602.368	-7.064
UP_BIT-1 --- UP_MAY-1	5-22-2016	Fixed	0.004	0.018	45°34'22"	4416.378	-7.047
UP_BIT-1 --- DE-160	5-22-2016	Fixed	0.005	0.025	44°46'00"	4971.649	-8.805
UP_BIT-1 --- DVE-42	5-22-2016	Fixed	0.003	0.015	201°20'38"	2159.894	0.009
UP_BIT-1 --- UP_QUI-1	5-22-2016	Fixed	0.007	0.024	53°30'19"	23747.730	-9.665
UP_MAY-1 --UP_QUI-1	5-22-2016	Fixed	0.009	0.030	55°18'38"	19383.182	-2.630
UP_QUI-1 --- DE-160	5-22-2016	Fixed	0.009	0.035	235°49'23"	18848.927	0.881
DVE-42 --- UP_QUI-1	5-22-2016	Fixed	0.008	0.029	56°30'32"	21949.416	-9.718

As shown Table 22 a total of ten (10) baselines were processed with coordinates of DVE-42 and elevation of DE-160 held fixed. 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 squares of x and y must be less than 20 cm and z less than 10 cm in equation form:

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

Where:

x_e is the Easting error,

y_e is the Northing error, and

z_e is the Elevation error

for each control point. See the Network Adjustment Report shown from Table 23 to Table 24 for the complete details. Refer to Appendix C for the computation for the accuracy of ABSD.

The five (5) control points, DVE-42, DE-160, UP-BIT-1, UP_MAY-1, and UP-QUI-1 were occupied and observed simultaneously to form a GNSS loop. The coordinate values of DVE-42 and elevation of DE-160 were held fixed during the processing of the control points as presented in Table 23. Through these reference points, the coordinates and elevation of the unknown control points will be computed.

Table 23. Control Point Constraints

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
DE-160	Grid				Fixed
DVE-42	Global	Fixed	Fixed		
Fixed = 0.000001(Meter)					

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 24. All fixed control points have no values for grid errors and elevation error.

Table 24. Adjusted Grid Coordinates

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
DE-160	774012.369	0.003	204436.373	0.005	6.419	?	e
DVE-42	772508.970	?	201710.753	?	15.122	0.023	LL
UP_BIT-1	770500.332	0.003	200912.560	0.004	15.210	0.025	
UP_MAY-1	773575.785	0.003	204086.387	0.004	8.152	0.009	
UP_QUI-1	784522.580	0.004	220097.240	0.007	6.305	0.034	

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 24. All fixed control points have no values for grid errors and elevation error.

Table 25. Adjusted Grid Coordinates

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
DE-160	774012.369	0.003	204436.373	0.005	6.419	?	e
DVE-42	772508.970	?	201710.753	?	15.122	0.023	LL
UP_BIT-1	770500.332	0.003	200912.560	0.004	15.210	0.025	
UP_MAY-1	773575.785	0.003	204086.387	0.004	8.152	0.009	
UP_QUI-1	784522.580	0.004	220097.240	0.007	6.305	0.034	

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:

DE-160

horizontal accuracy = √((0.3)² + (0.5)²
= √ (0.09 + 0.25)
= 0.34< 20 cm
vertical accuracy = Fixed

DVE-42

horizontal accuracy = Fixed
vertical accuracy = 2.3 < 10 cm

UP_BIT-1

horizontal accuracy = √((0.3)² + (0.4)²
= √ (0.09 + 0.16)
= 0.25< 20 cm
vertical accuracy = 2.5 < 10 cm

UP_MAY-1

horizontal accuracy = √((0.3)² + (0.4)²
= √ (0.09 + 0.16)
= 0.25< 20 cm
vertical accuracy = 0.9< 10 cm

UP_QUI-1

horizontal accuracy = √((0.4)² + (0.7)²
= √ (0.16 + 0.49)
= 0.65< 20 cm
vertical accuracy = 3.4< 10 cm

Following the given formula, the horizontal and vertical accuracy result of the five (5) occupied control points are within the required precision.

Table 26. Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
DE-160	N6°59'41.20398"	E126°19'30.03464"	71.754	?	e
DVE-42	N6°58'51.79295"	E126°18'01.57690"	80.539	0.023	LL
UP_BIT-1	N6°57'46.30507"	E126°17'35.96635"	80.537	0.025	
UP_MAY-1	N6°59'26.93722"	E126°19'18.72092"	73.478	0.009	
UP_QUI-1	N7°05'25.95862"	E126°27'58.08622"	70.854	0.034	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 26. Based on the result of the computation, the equation is satisfied; hence, the required accuracy for the program was met.

The summary of reference control points used is indicated in Table 27.

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

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (Meter)	Northing (m)	Easting (m)	BM Ortho (m)
DVE-42	2nd order, GCP	6°58'51.79295"N	126°18'01.57690"E	80.539	772508.97	201710.753	15.122
DE-160	1st order, BM	6°59'41.20398"N	126°19'30.03464"E	71.754	774012.369	204436.373	6.419
UP_BIT-1	Established	6°57'46.30507"N	126°17'35.96635"E	80.537	770500.332	200912.56	15.21
UP_MAY-1	Established	6°59'26.93722"N	126°19'18.72092"E	73.478	773575.785	204086.387	8.152
UP_QUI-1	Established	7°05'25.95862"N	126°27'58.08622"E	70.854	784522.58	220097.24	6.305

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

Cross-section and as-built surveys were conducted on March 20, 2016 at the downstream side of Bitanagan Bridge in Brgy. Don Enrique Lopez, City of Mati as shown in Figure 35. A total station was utilized for this survey as shown in Figure936.

Figure 35. Bitanagan Bridge facing downstream

Figure 36. As-built survey of Bitanagan Bridge

The cross-sectional line of Bitanagan Bridge is about 151 m with seventy-nine (79) cross-sectional points using the control points UP_BIT-1 and UP_BIT-2 as the GNSS base stations. The cross-section diagram and the bridge data form are shown in Figure 39 and Figure 40. Gathering of random points for the checking of ABSD's bridge cross-section and bridge points data was performed by DVBC on May 16, 2016 using a survey grade GNSS Rover receiver attached to a 2-m pole, as seen in Figure 37.

Figure 37. Gathering of random cross-section points along the downstream side of Bitanagan River

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

In addition to the Linear square correlation, Root Mean Square (RMSE) analysis is also performed in order to assess the difference in elevation between the DVBC checking points and the contractor's. The RMSE value should only have a maximum radial distance of 5 m and the difference in elevation within the radius of 5 meters should not be beyond 0.50 m. For the bridge cross-section data, a computed value of 0.231 was acquired. The computed R2 and RMSE values are within the accuracy requirement of the program.

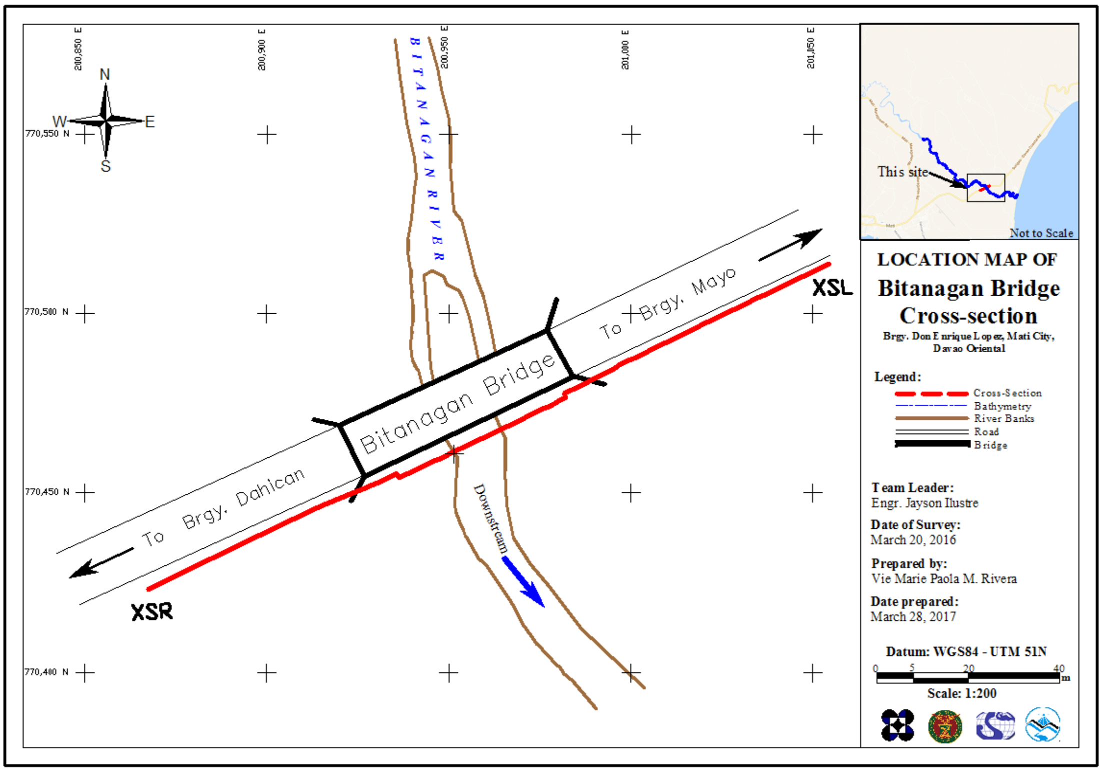

Figure 38. Location map of the Bitanagan Bridge cross section

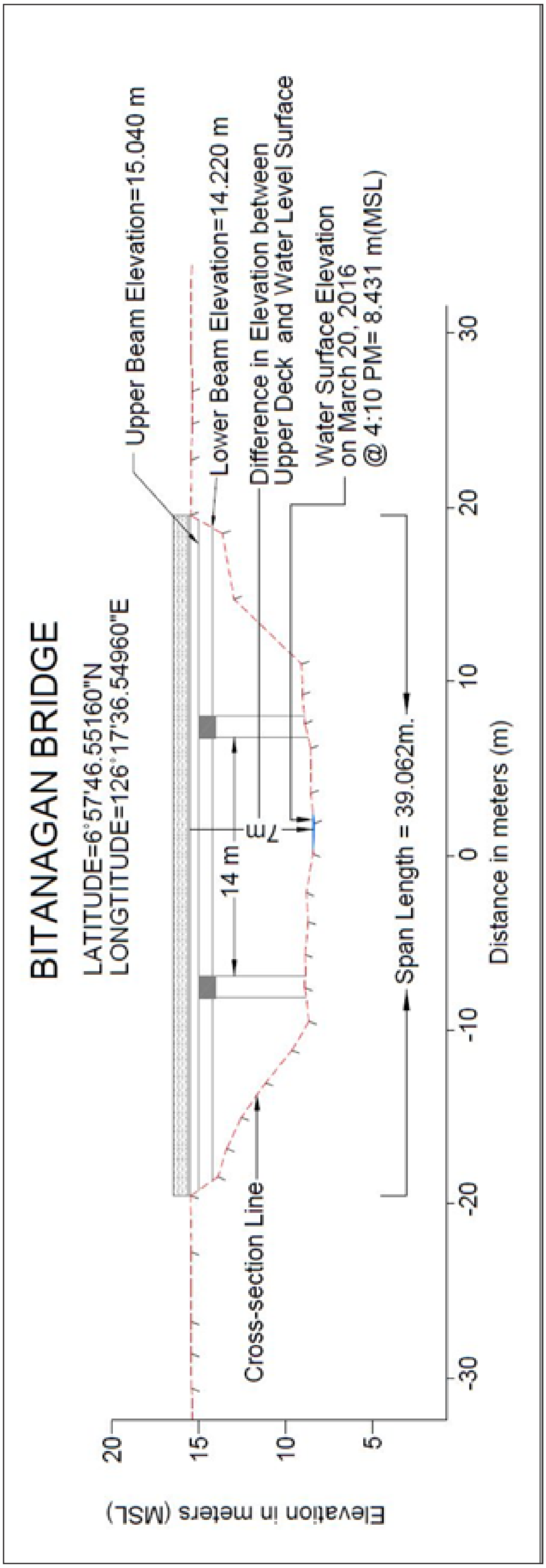

Figure 39. Bitanagan Bridge Cross-section Diagram

Bridge Data Form

Line Segment	Measurement (m)	Remarks
1. BA1-BA2	3.11 m	
2. BA2-BA3	39.062 m	
3. BA3-BA4	3.11 m	
4. BA1-Ab1	7.3 m	
5. Ab2-BA4	11.7 m	
6. Deck/beam thickness	1.3 m	
7. Deck elevation	15.475 m	

Note: Observer should be facing downstream

Figure 40. Bitanagan Bridge Data Sheet

Water surface elevation of Bitanayan River was determined by a Nikon Total Station on March 20, 2016 at 4:10PM at Bitanagan Bridge area with a value of 8.431 m in MSL as shown in Figure 39. This was translated into marking on the bridge's pier as shown in Figure 41. The marking will serve as reference for flow data gathering and depth gauge deployment of the partner HEI responsible for Bitanagan River, UP Mindanao.

Figure 41. Water-level markings on Bitanagan Bridge

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted by DVBC from May 10-24, 2016 using a survey grade GNSS Rover receiver, Trimble® SPS 985, mounted on a range pole which was attached on the front of the vehicle as shown in Figure 42.It was secured with cable ties and ropes to ensure that it was horizontally and vertically balanced. The antenna height was 2.476 m and measured from the ground up to the bottom of the quick release of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with UP_BIT-1 occupied as the GNSS base station in the conduct of the survey.

Figure 42. Validation points acquisition survey set-up for Bitanagan River

The survey started from Brgy. Dahican, Mati City, Davao Oriental going south east along national high way until Brgy. Bobon, Mati City. The survey continued from Bitanagan Bridge in Brgy. Don Enrique Lopez, Mati City going north east and ended in Brgy. Mayo, Mati City, Davao Oriental. The survey gathered a total of 1,272 points with approximate length of 19.2 km using UP_BIT-1 as GNSS base station for the entire extent of validation points acquisition survey as illustrated in the map in Figure 43.

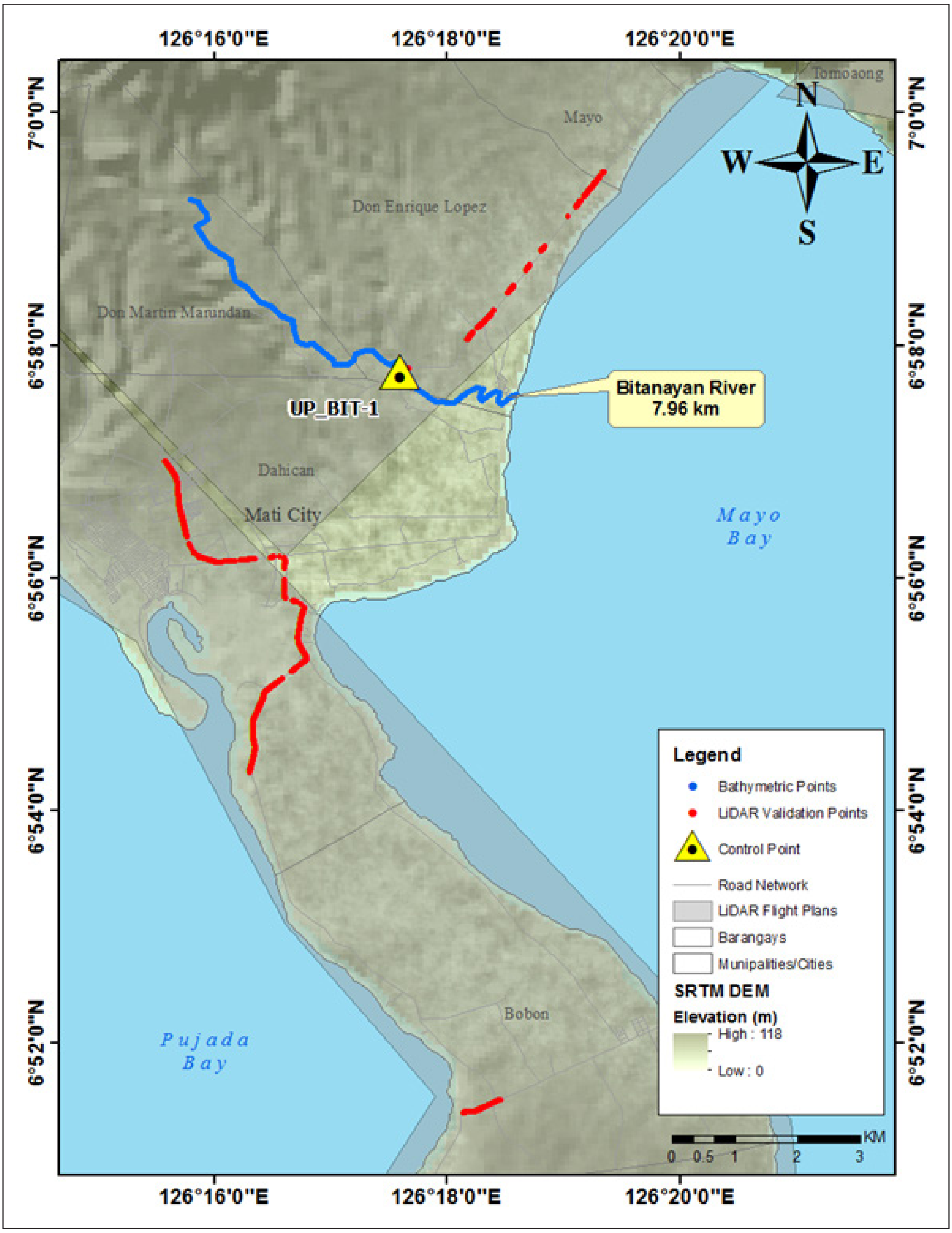

Figure 43. Validation points acquisition covering the Bitanayan River Basin Area

4.7 River Bathymetric Survey

Bathymetric survey was executed manually on February 27-29, 2016 and March 3, 2016 using a Nikon Total Station as seen in Figure 44. The survey started in Brgy. Don Martin Marundan,Mati City, Davao Oriental with coordinates 6° 59’ 12.84262”N, 126° 15’ 40.70160”Eand ended at the mouth of the river in Brgy. Don Enrique Lopez, Mati City, Davao Oriental with coordinates6° 57’ 34.40348”N, 126° 18’ 34.23919”E. The control points AB-1, AB-2, UP_BIT-1, UP_BIT-2, UP_BIT-5, and UP_BIT-6 served as the GNSS base stations all throughout the survey.

Figure 44. Manual bathymetric survey of ABSD at Bitanayan River using Nikon Total Station

Gathering of random points for the checking of ABSD's bathymetric data was performed by DVBC on May 16, 2016 using aGNSS Rover receiver, Trimble® SPS 985 attached to a 2-m pole, see Figure 45. A map showing the DVBC bathymetric checking points is shown in Figure 47.

Figure 45. Gathering of random bathymetric points along Bitanayan River

Linear square correlation (R^2) and RMSE analysis were also performed on the two (2) datasets and a computed R^2value of 0.86 is within the required range for R^2, which is 0.85 to 1. Additionally, an RMSE value of 0.048 was obtained. Both the computed R^2 and RMSE values are within the accuracy required by the program.

The bathymetric survey for Bitanayan River gathered a total of 2,428 points covering 7.96 km of the river traversing BarangaysDon Martin Marundan, Don Enrique Lopez, and Dahican in the City of Mati. A CAD drawing was also produced to illustrate the riverbed profile of Bitanayan River.As shown in Figure 48, the highest and lowest elevation has a 36-m difference. The highest elevation observed was 36.006 m above MSL located in Brgy. Don Martin Marundan, Mati City while the lowest was 0.068 m above MSL located in Brgy. Don Enrique Lopez, Mati City.

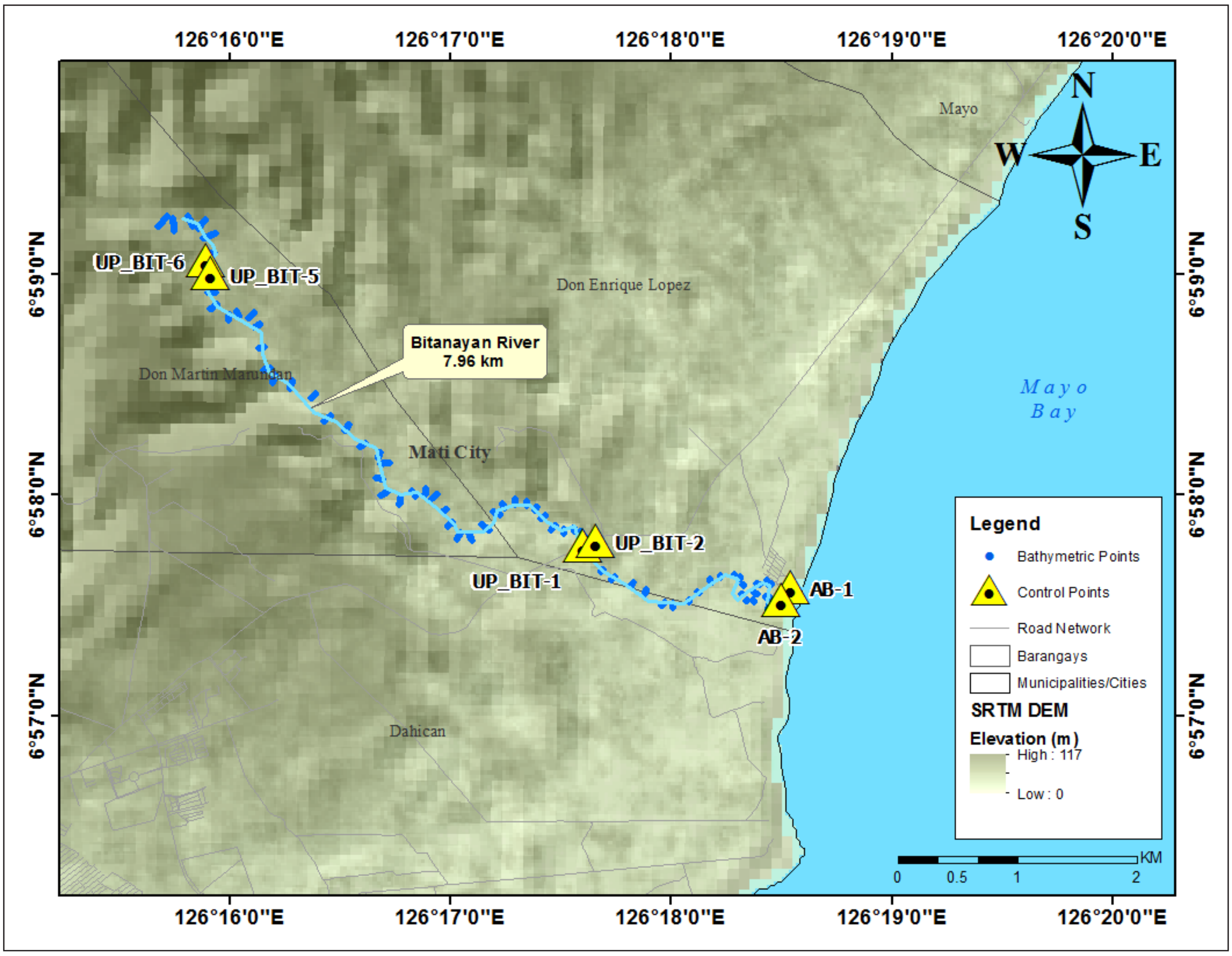

Figure 46. Bathymetric survey of Bitanayan River

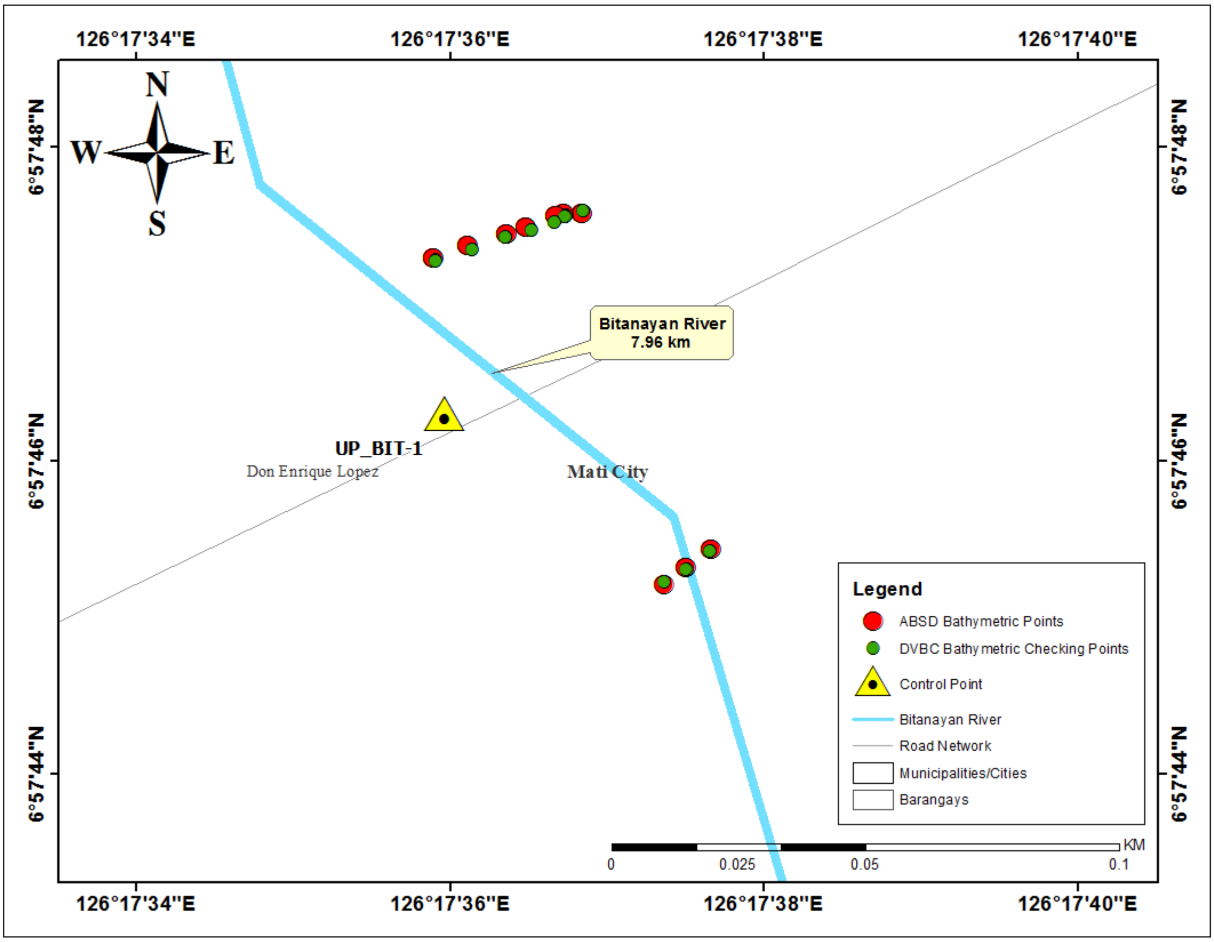

Figure 47. Quality checking points gathered along Bitanayan River by DVBC

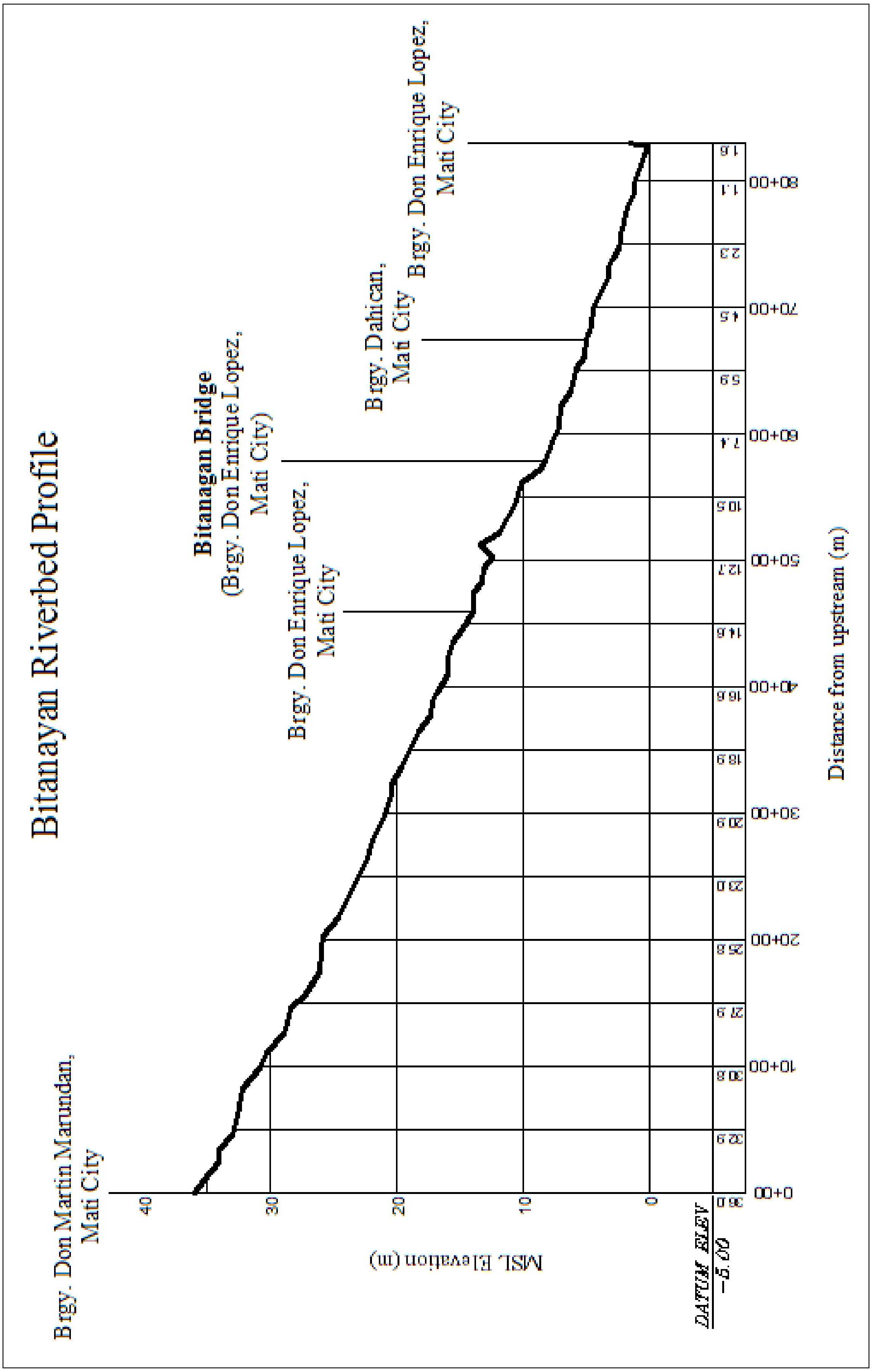

Figure 48. Bitanagan Riverbed Profile

CHAPTER 5: FLOOD MODELING AND MAPPING

Dr. Alfredo Mahar Lagmay, Christopher Uichanco, Sylvia Sueno, Marc Moises, Hale Ines, Miguel del Rosario, Kenneth Punay, Neil Tingin, Narvin Clyd Tan, Hannah Aventurado

The methods applied in this chapter were based on the DREAM methods manual (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 Bitanagan River Basin were monitored, collected, and analyzed. Rainfall, water level, and flow in a certain period of time, which may affect the hydrologic cycle of the Bitanagan River Basin were monitored, collected, and analyzed. `

5.1.2 Precipitation

Precipitation data was taken from the rain gauge installed by the University of the Philippines Mindanao Phil. LiDAR 1. This rain gauge is located in Barangay Don Salvador Lopez, Mati, Davao Oriental with the following coordinates: 7° 2' 3.19" N, 126° 12' 24.59" E (Figure 1).The precipitation data collection started from July 19, 2016 at 12:20PM to July 20, 2016 at 9:50 AM with a 10-minute recording interval.

The total precipitation for this event in the installed rain gauge was 5.6 mm. It has a peak rainfall of 1 mm. on July 19, 2016 at 1:00 PM. The lag time between the peak rainfall and discharge is 6 hours and 50 minutes.

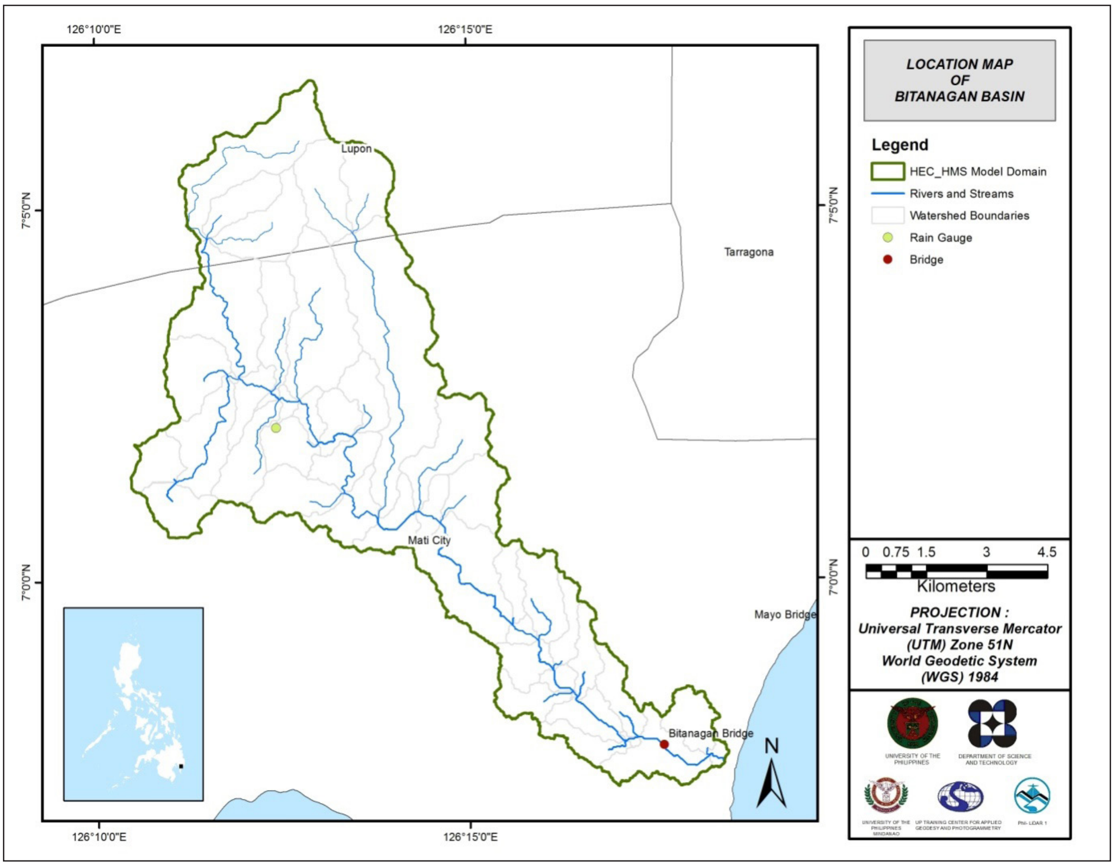

Figure 49. The location map of Bitanagan HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Bitanagan Bridge, Barangay Don Enrique Lopez, Mati, Davao Oriental (6° 57’ 46.22” N, 126° 17’ 36.53” E). It gives the relationship between the observed water level at the Bitanagan Bridge and outflow of the watershed at this location.

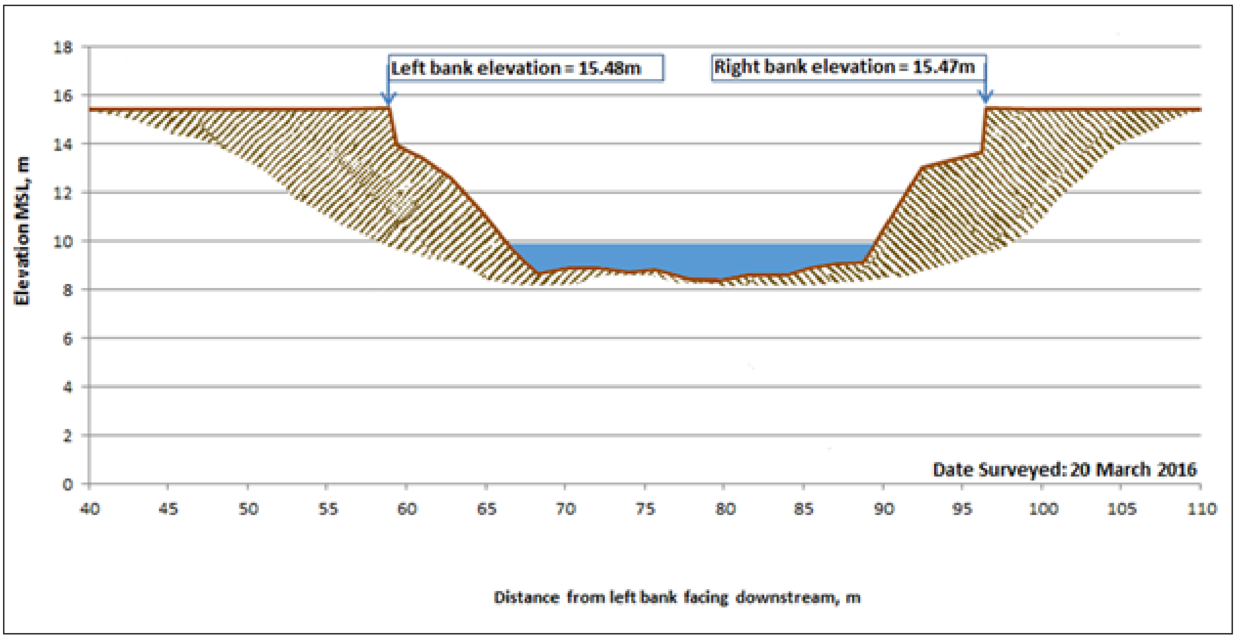

Figure 50. Cross-Section Plot of Bitanagan Bridge

For Bitanagan Bridge, the rating curve is expressed as Q = 4.7066E-94$e^{0.2512x}$as shown in Figure 51.

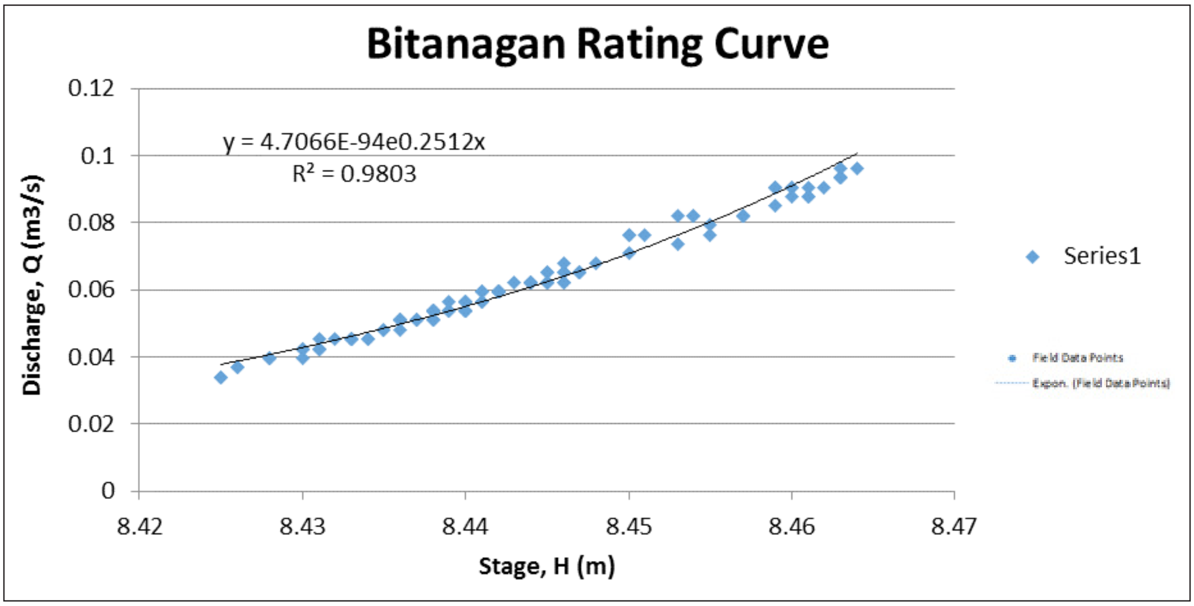

Figure 51. Rating Curve at Bitanagan Bridge, Mati, Davao Oriental

The rating curve equation was used to compute for the river outflow at Bitanagan Bridge for the calibration of the HEC-HMS model for Bitanagan, as shown in Figure 4. The total rainfall for this event is 5.6 mm and the peak discharge is 0.09628 m^3/s at 7:50 PM of July 19, 2016.

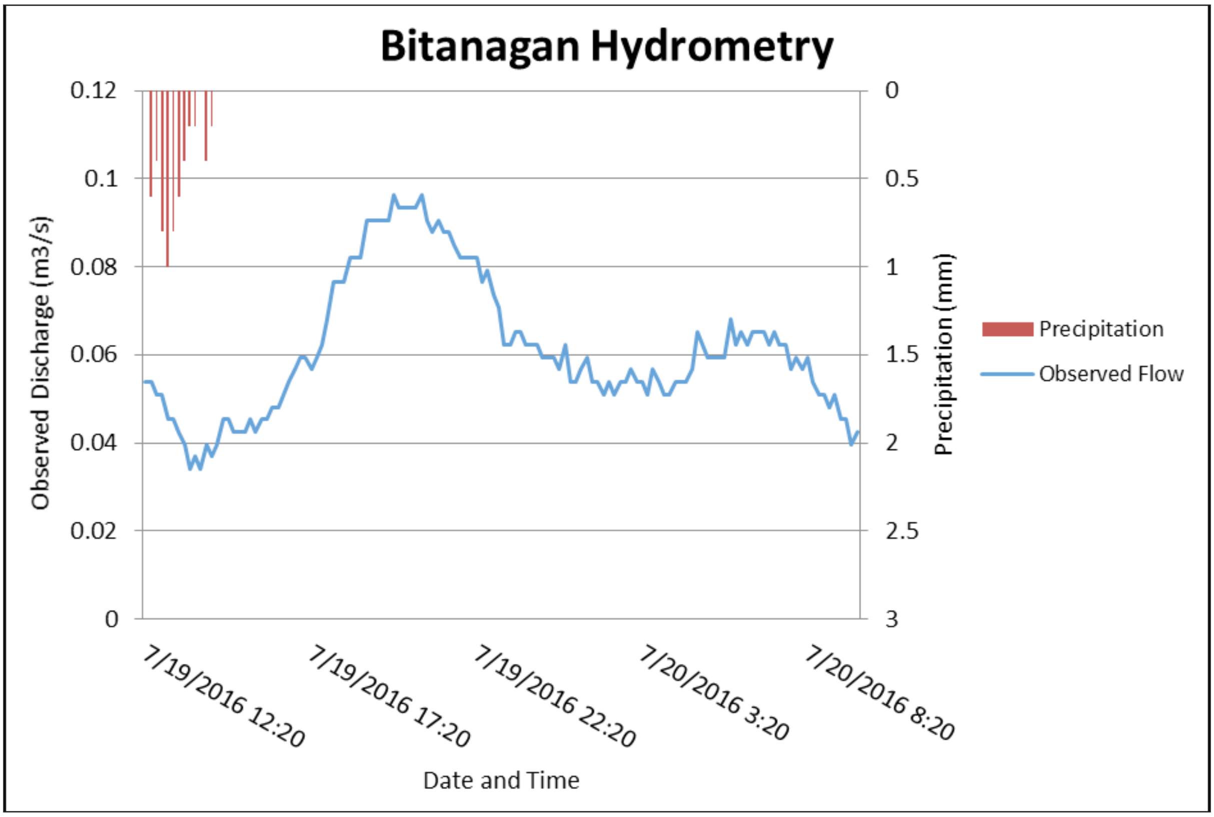

Figure 52. Rainfall and outflow data at Bitanagan Bridge used for modeling

5.2 RIDF Station

The Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed for Rainfall Intensity Duration Frequency (RIDF) values for the Davao Rain Gauge. The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the values in such a way a certain peak value will be attained at a certain time. This station is chosen based on its proximity to the Bitanagan watershed. The extreme values for this watershed were computed based on a 59-year record.

Table 28. RIDF values for Davao Rain Gauge computed by PAGASA

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	10 mins	20 mins	30 mins	1 hr	2 hrs	3 hrs	6 hrs	12 hrs	24 hrs
2	19.5	30	38.2	53.2	65.2	71.6	80.3	85.8	91.4
5	25.1	39.3	51	73.2	88.8	96.4	108.7	114.9	121.1
10	28.8	45.4	59.4	86.5	104.5	112.8	127.5	134.1	140.7
15	30.9	48.9	64.2	94	113.3	122.1	138.1	145	151.8
20	32.4	51.3	67.6	99.3	119.5	128.6	145.5	152.6	159.5
25	33.5	53.2	70.1	103.3	124.2	133.6	151.2	158.5	165.5
50	37	59	78.1	115.8	138.9	149	168.8	176.5	183.9
100	40.5	64.7	85.9	128.1	153.5	164.2	186.3	194.4	202.1

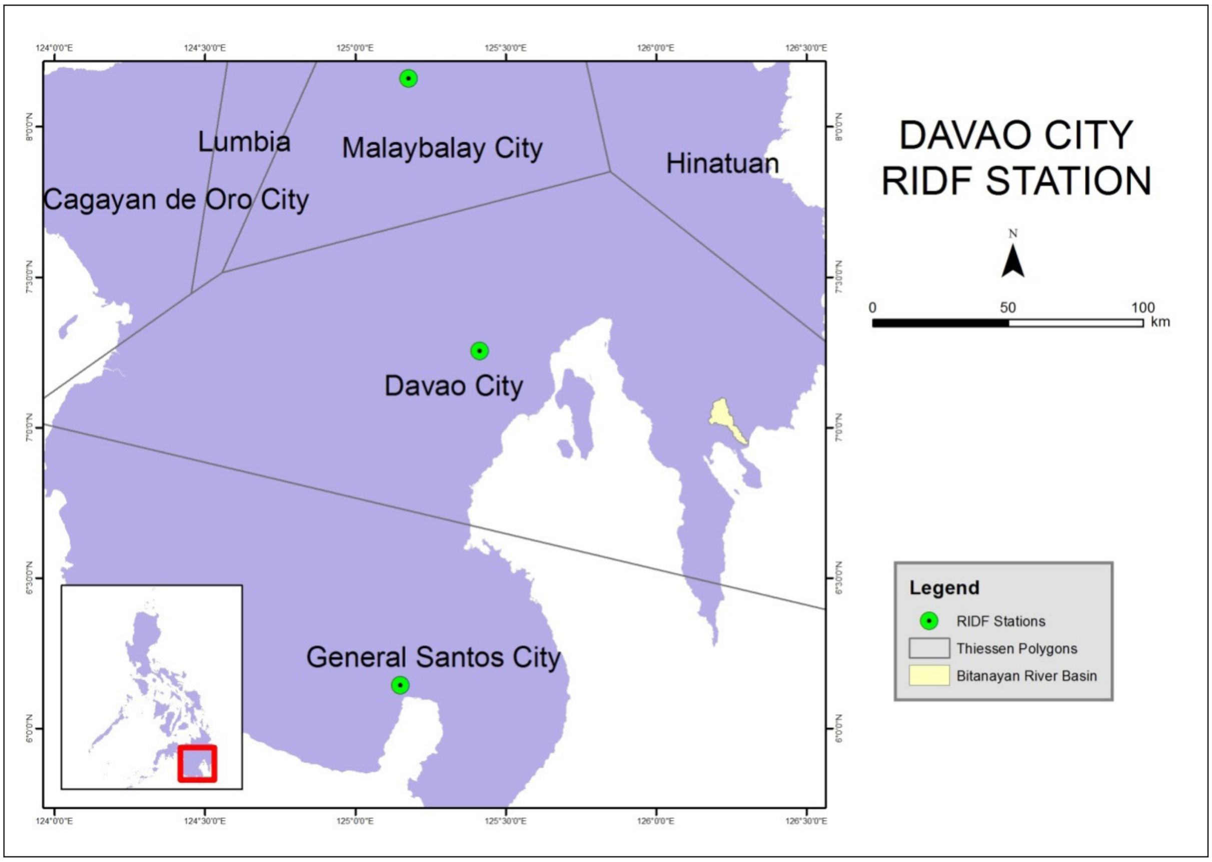

Figure 53. Location of Davao RIDF Station relative to Bitanagan River Basin

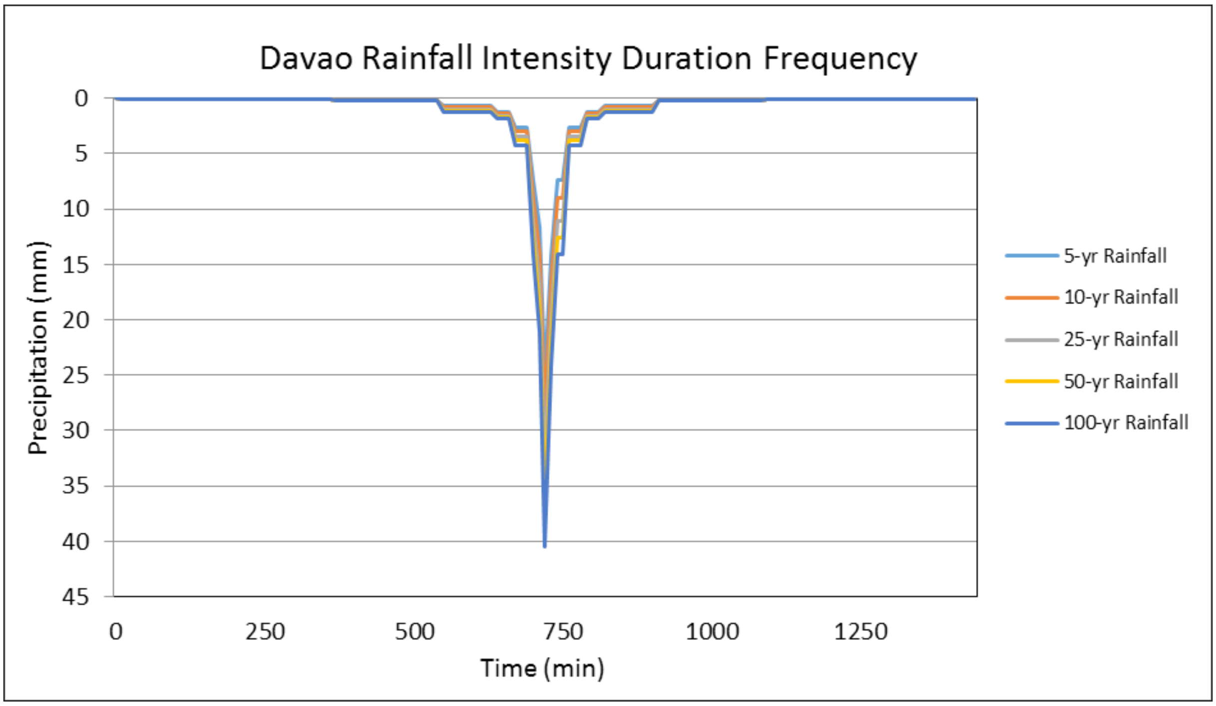

Figure 54. Synthetic storm generated for a 24-hr period rainfall for various return periods

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). The soil and land cover of the Bitanagan River Basin are shown in Figure 55 and Figure 56 respectively.

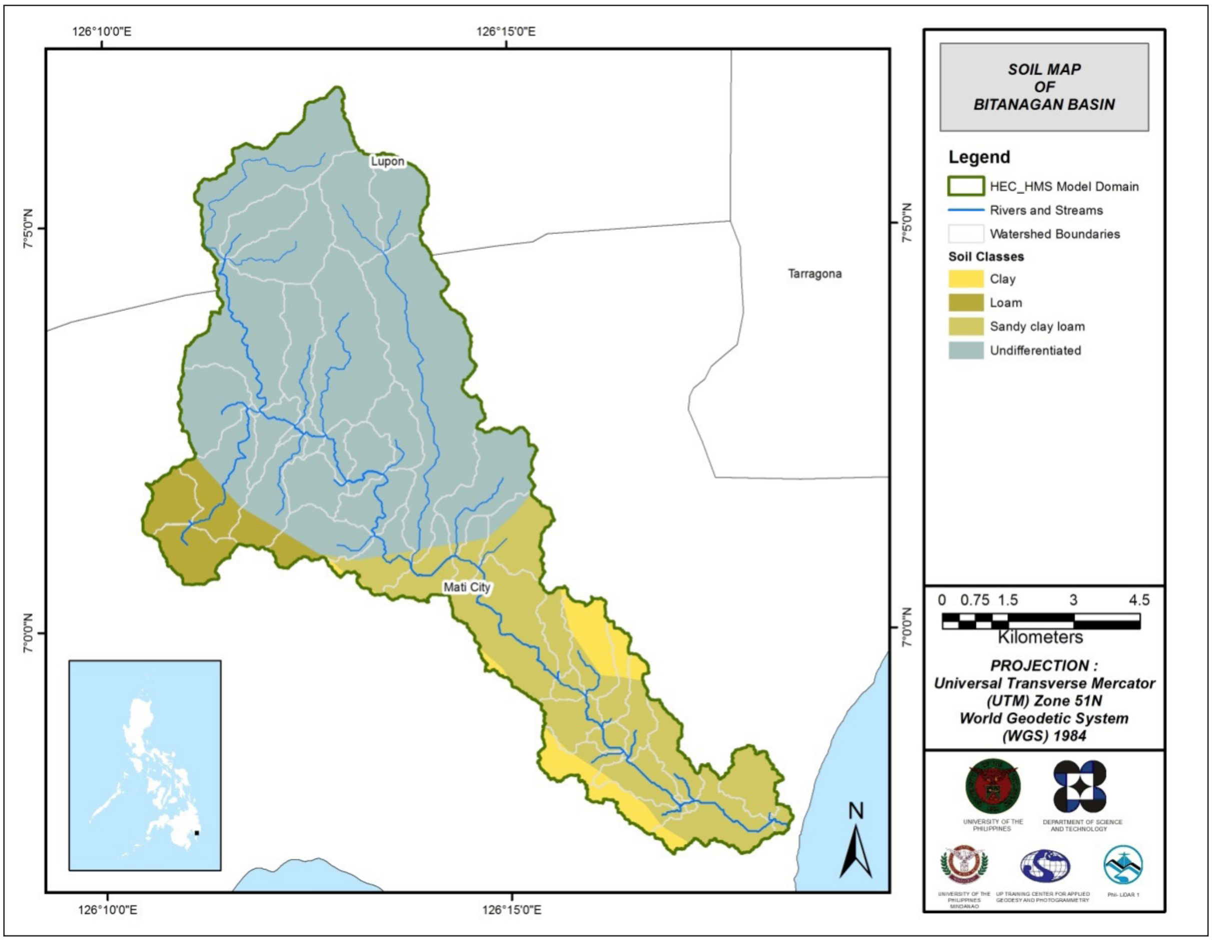

Figure 55. Soil Map of Bitanagan River Basin

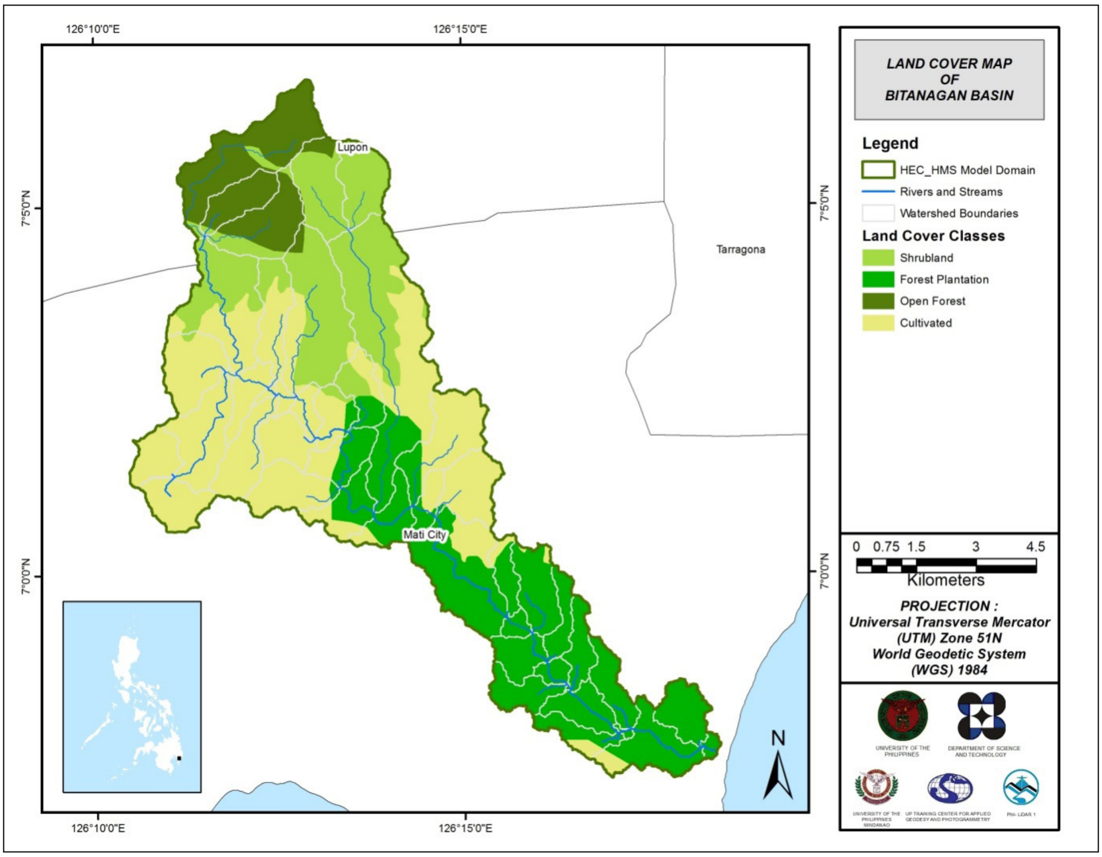

Figure 56. Land Cover Map of Bitanagan River Basin

For Bitanagan, four soil classes were identified. These are clay, loam, sandy clay loam and undifferentiated land. Moreover, four land cover classes were identified. These are shrublands, forest plantations, open forests, and cultivated areas.

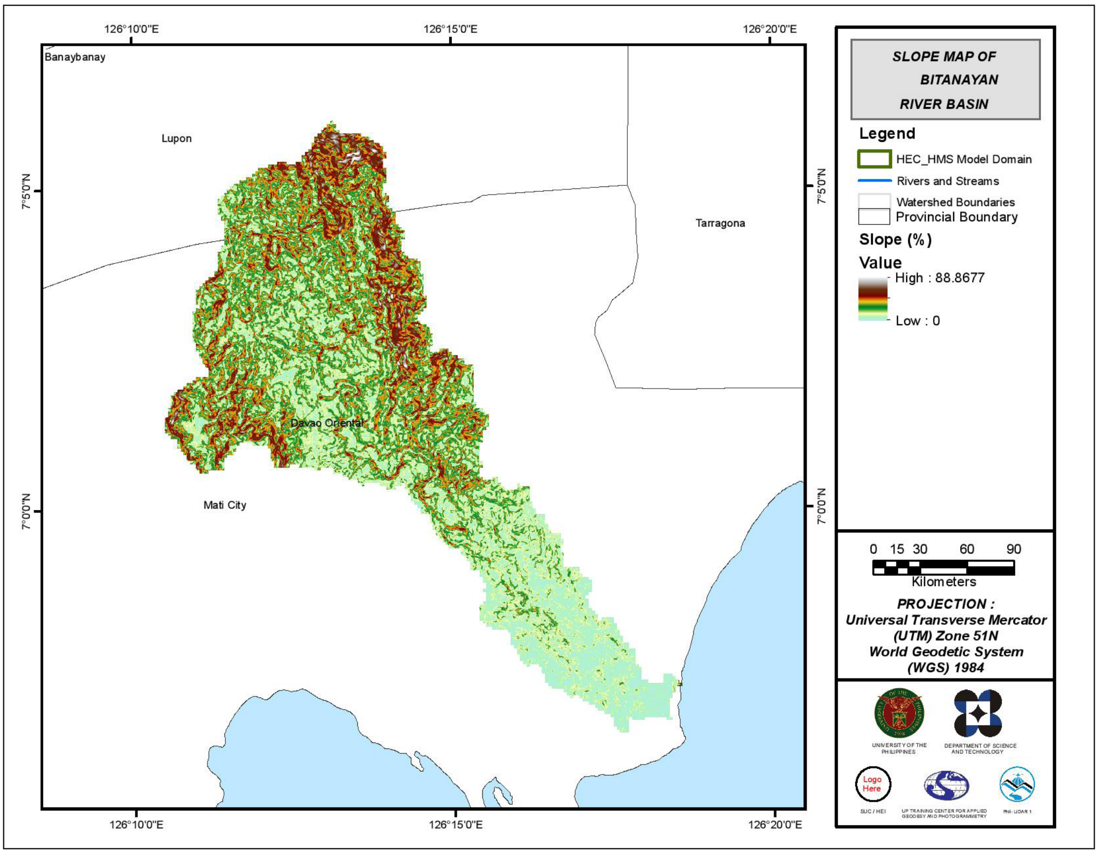

Figure 57. Slope Map of Bitanagan River Basin

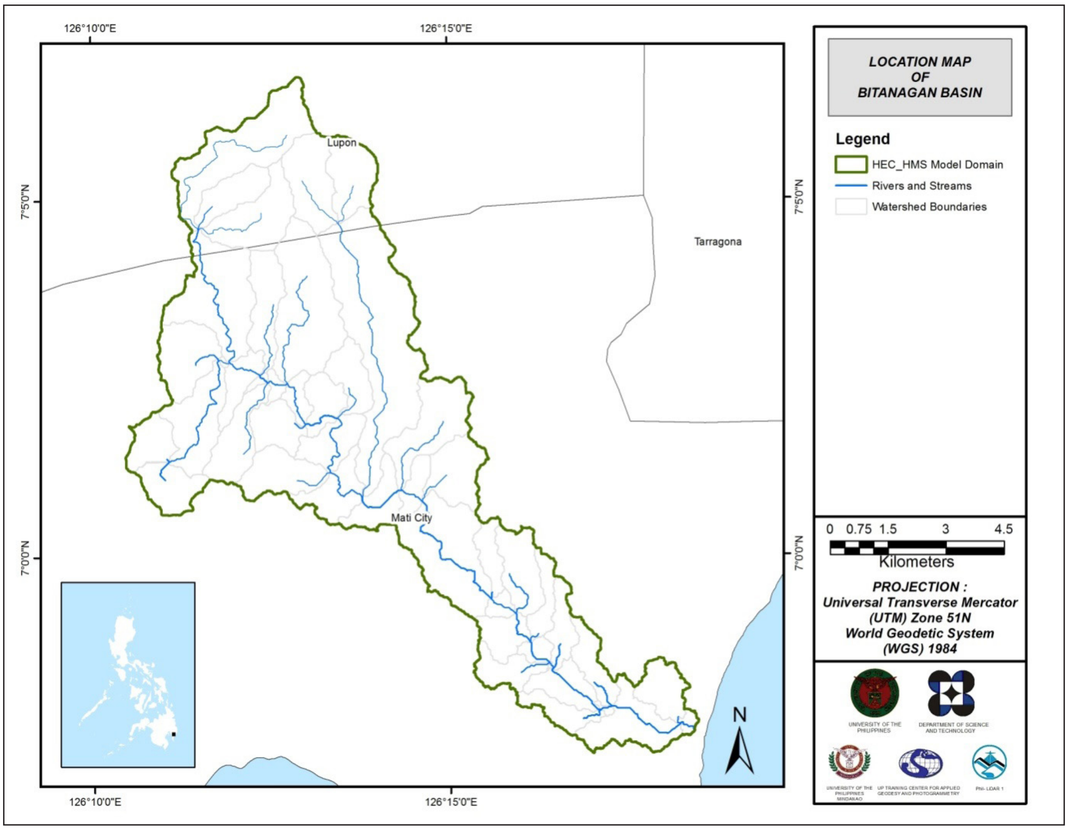

Figure 58. Stream Delineation Map of Bitanagan River Basin

Using the SAR-based DEM, the Bitanagan basin was delineated and further subdivided into subbasins. The model consists of 47 sub basins, 23 reaches, and 23 junctions, as shown in Figure 59. The main outlet is at Bitanagan Bridge.

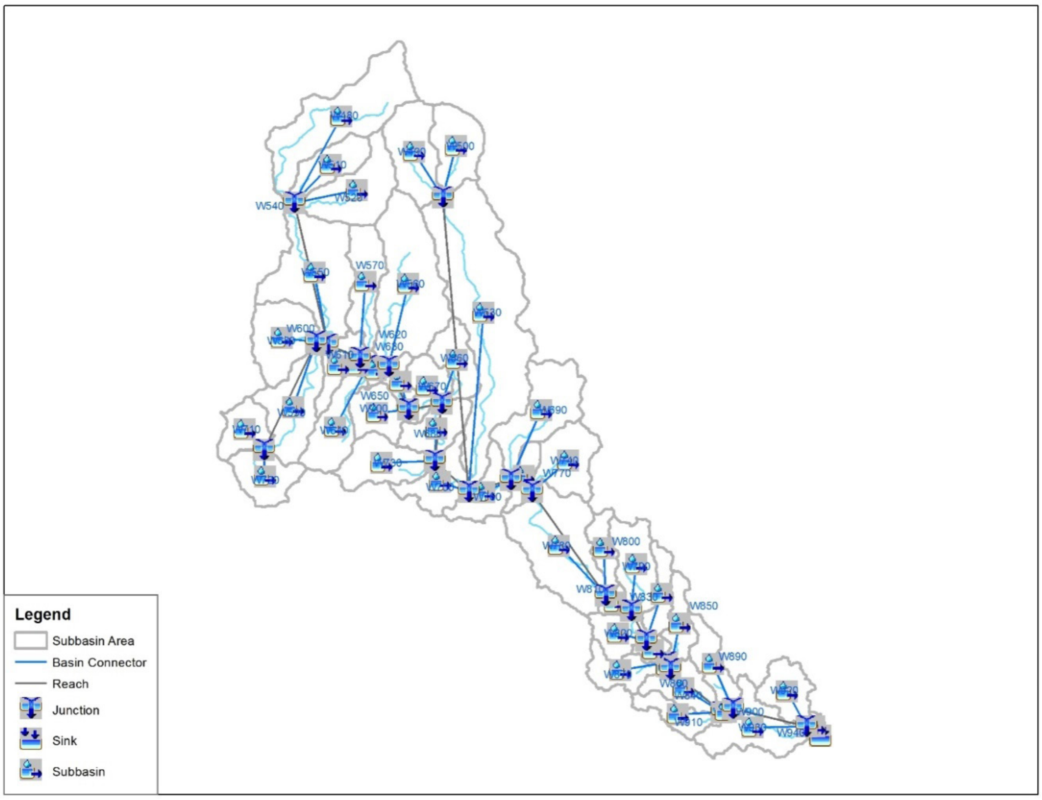

Figure 59. The Bitanagan river basin model generated using HEC-HMS.

5.4 Cross-section Data

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

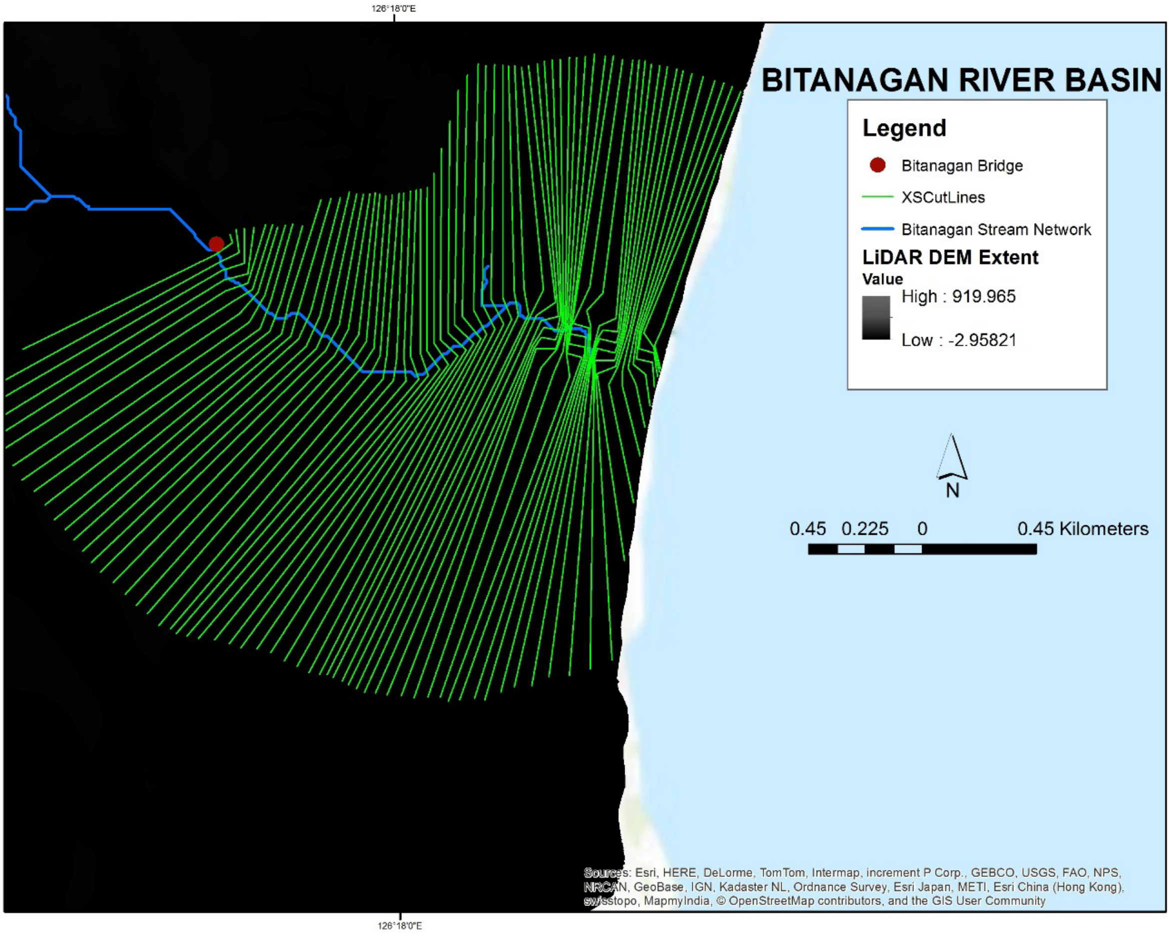

Figure 60. River cross-section of Bitanagan River generated through Arcmap HEC GeoRAS tool

5.5 Flo 2D Model

The automated modeling 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 northwest of the model to the southeast, following the main channel. As such, boundary elements in those particular regions of the model are assigned as inflow and outflow element, respectively.

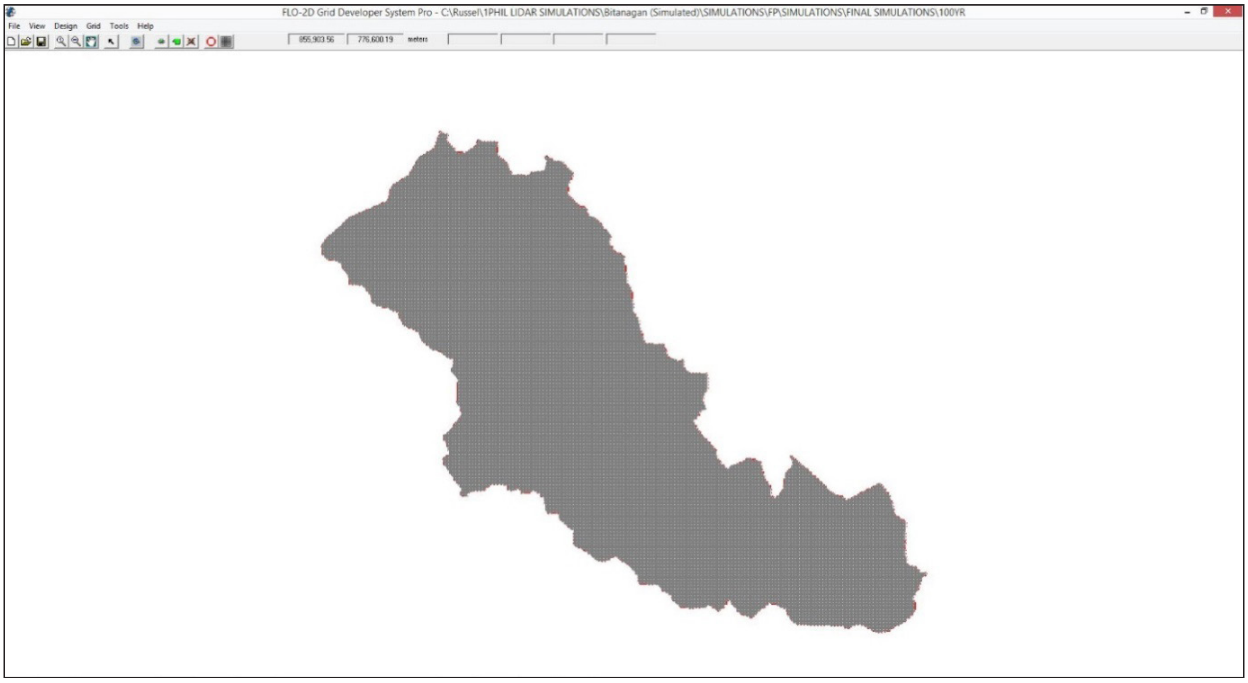

Figure 61. A screenshot of the river subcatchment with the computational area to be modeled in FLO-2D Grid Developer System Pro (FLO-2D GDS Pro)

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 7.84082 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 generated hazard maps for Bitanagan are in Figures __, __, and __.

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 18 946 600.00 m2.The generated flood depth maps for Bitanaganare in Figures __, __, and __.

There is a total of 36 661 256.48 m3 of water entering the model. Of this amount, 8 053 781.05 m3 is due to rainfall while 28 607 475.44 m3 is inflow from other areas outside the model. 1 888 420.38 m3 of this water is lost to infiltration and interception, while 789 913.02 m3 is stored by the floodplain. The rest, amounting up to 33 982 595.82 m3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Bitanagan HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 62 shows the comparison between the two discharge data.

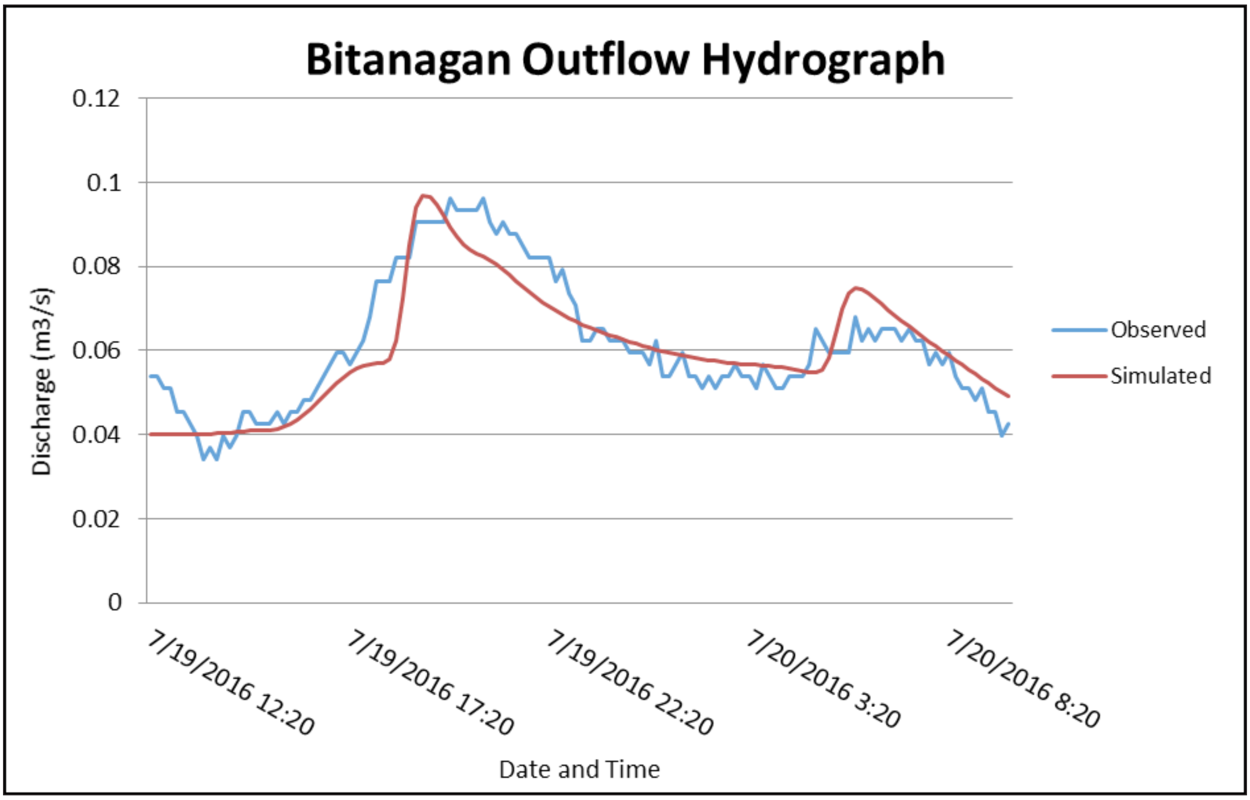

Figure 62. Outflow Hydrograph of Bitanagan produced by the HEC-HMS model compared with observed outflow

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

Table 29. Range of Calibrated Values for Bitanagan

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve Number	Initial Abstraction (mm)	2.54 – 9.32
			Curve Number	45.86 – 82.52
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.05 – 4.75
			Storage Coefficient (hr)	0.083 – 6.26
	Baseflow	Recession	Recession Constant	0.0066 – 0.05
			Ratio to Peak	0.09 – 0.98
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.0545

Initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as initial abstraction decreases. The range of values from 2.54 mm to 9.32 mm means that there is a small initial fraction of the storm depth after which runoff begins, increasing the river outflow.

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

Time of concentration and storage coefficient are the travel time and index of temporary storage of runoff in a watershed. The range of calibrated values from 0.05 hours to 6.26 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant values within the range of 0.0066 to 0.05 indicate that thebasin is highly likely to quickly go back to its original discharge. Values of ratio to peak within the range of 0.09 to 0.98 indicate an average receding limb of the outflow hydrograph.

Manning's roughness coefficients correspond to the common roughness of Philippine watersheds. Bitanagan river basin reaches' Manning's coefficient is 0.0545, showing that the catchment is mostly filled with floodplains with lightbrushlands (Brunner, 2010).

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

RMSE	0.007
r^2	0.803
NSE	0.80
PBIAS	1.75
RSR	0.45

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 0.007 m^3/s.

The Pearson correlation coefficient (r^2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.803.

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 0.80.

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 1.75.

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 0.45.

5.7 Calculated Outflow hydrographs and Discharge Values for different Rainfall Return Periods

5.7.1 Hydrograph using the Rainfall Runoff Model

The summary graph (Figure 63) shows the Bitanagan outflow using the Davao Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

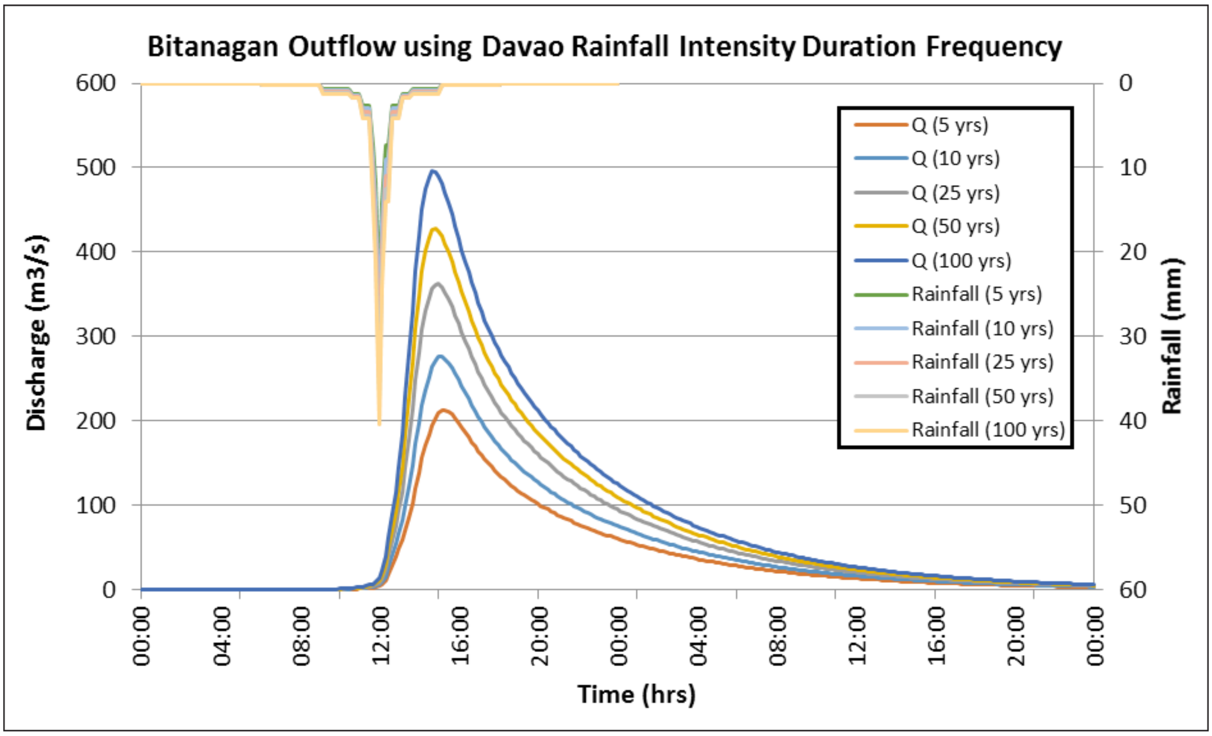

Figure 63. Outflow hydrograph at Bitanagan Station generated using the Davao RIDF simulated in HEC-HMS.

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

Table 31. Peak values of the Bitanagan HEC-HMS Model outflow using the Davao RIDF

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m^3/s)	Time to Peak
5-Year	121.1	25.1	212.5	3 hours, 20 minutes
10-Year	140.7	28.8	275.9	3 hours, 10 minutes
25-Year	165.5	33.5	361.9	3 hours
50-Year	183.9	37	427.6	2 hours, 50 minutes
100-Year	202.1	40.5	495.7	2 hours, 40 minutes

5.8 River Analysis (RAS) Model Simulation

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

Figure 64. Sample output of Bitanagan RAS Model

5.9 Flood Hazard and Flow Depth

The resulting hazard and flow depth maps have a 10m resolution. The 100-, 25-, and 5-year rain return scenarios of the Bitanagan Floodplain are shown in Figure 65 to Figure 70. The floodplain, with an area of 18.95 sq. km., covers only one municipality. Table 32 shows the percentage of area affected by flooding per municipality.

Table 32. Municipality affected in Bitanagan floodplain

Province	Municipality	Total Area	Area Flooded	% Flooded
Davao Oriental	Mati City	797.38	18.95	2.38%

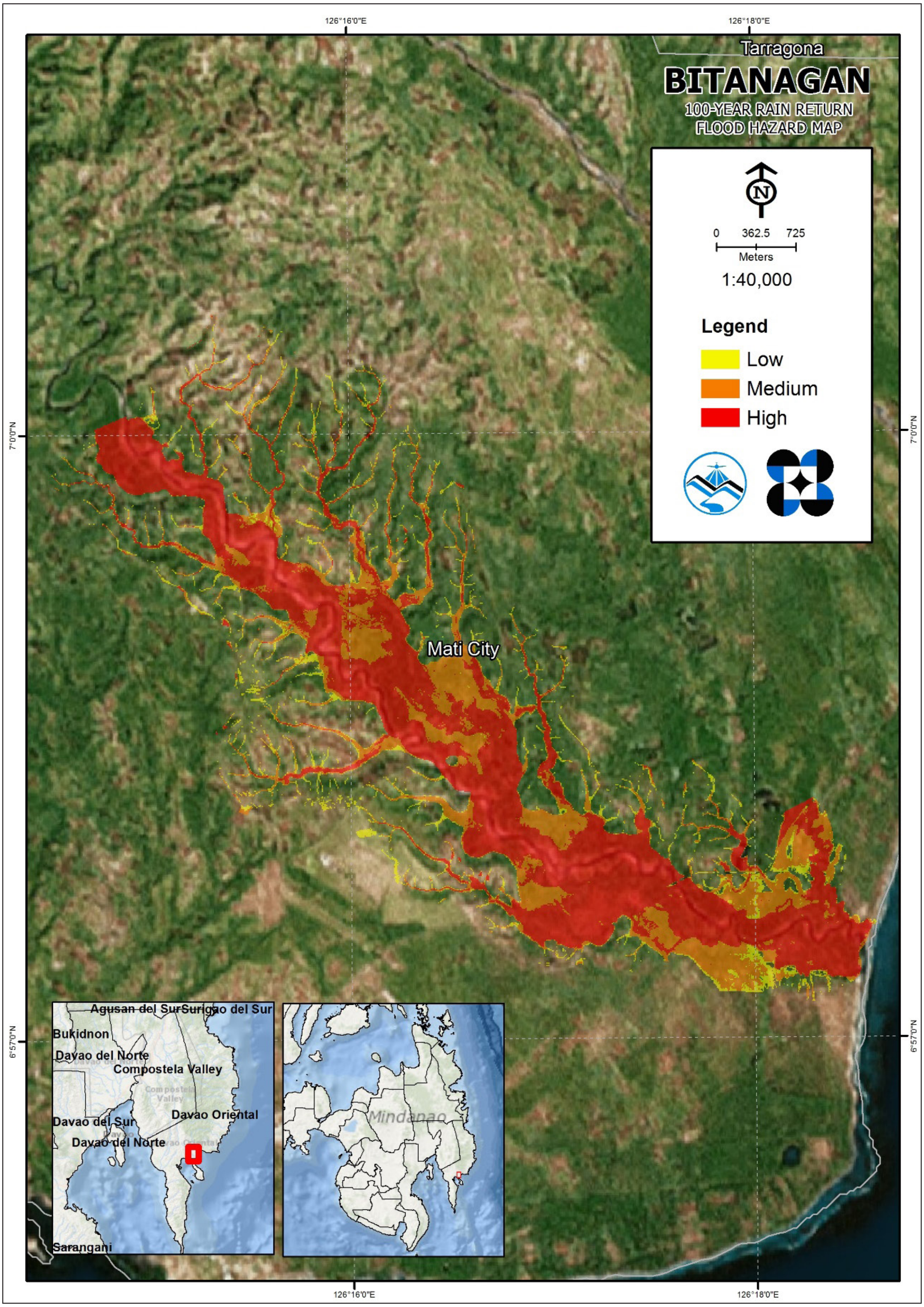

Figure 65. 100-year Flood Hazard Map for Bitanagan Floodplain overlaid on Google Earth imagery

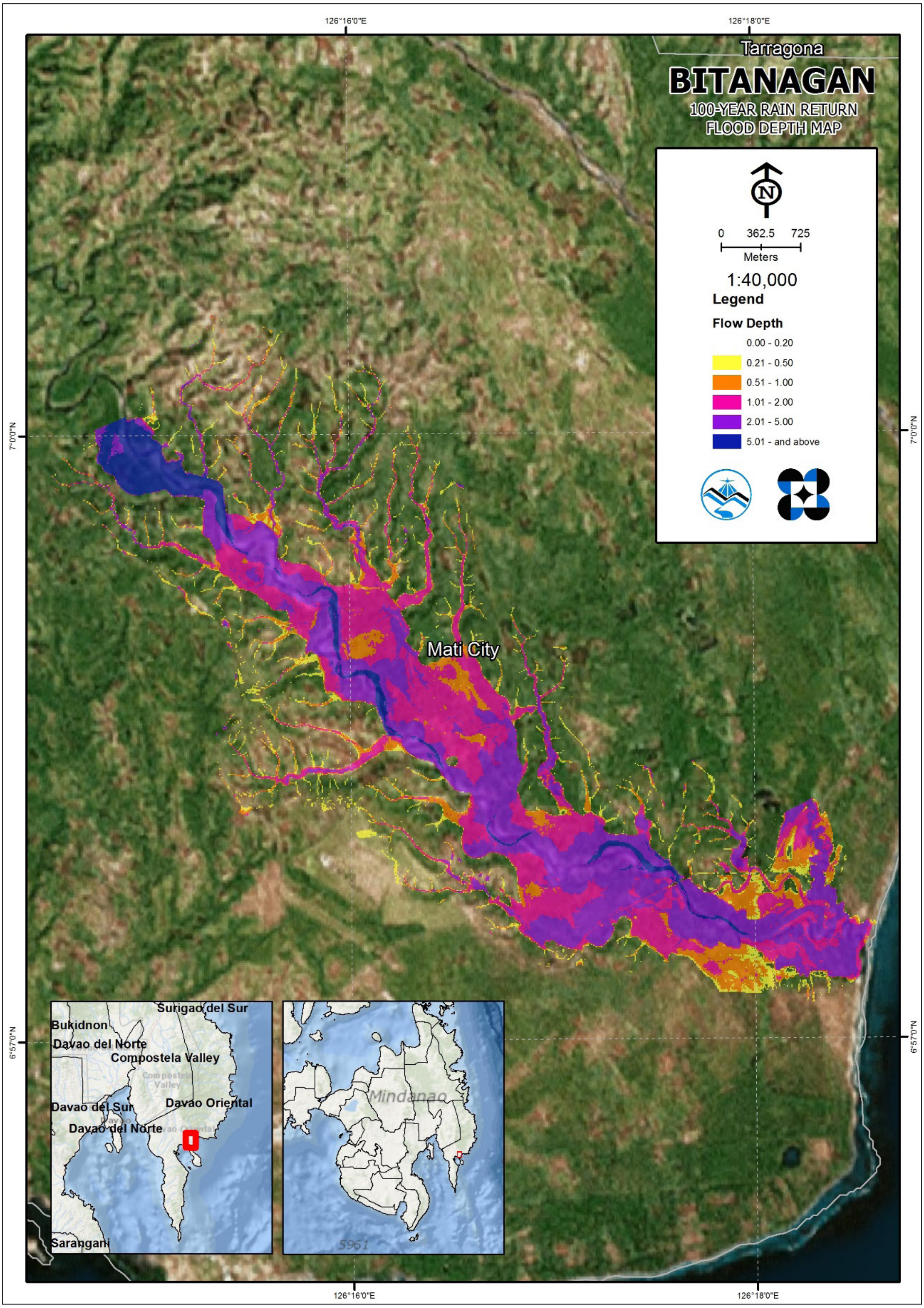

Figure 66. 100-year Flow Depth Map for Bitanagan Floodplain overlaid on Google Earth imagery

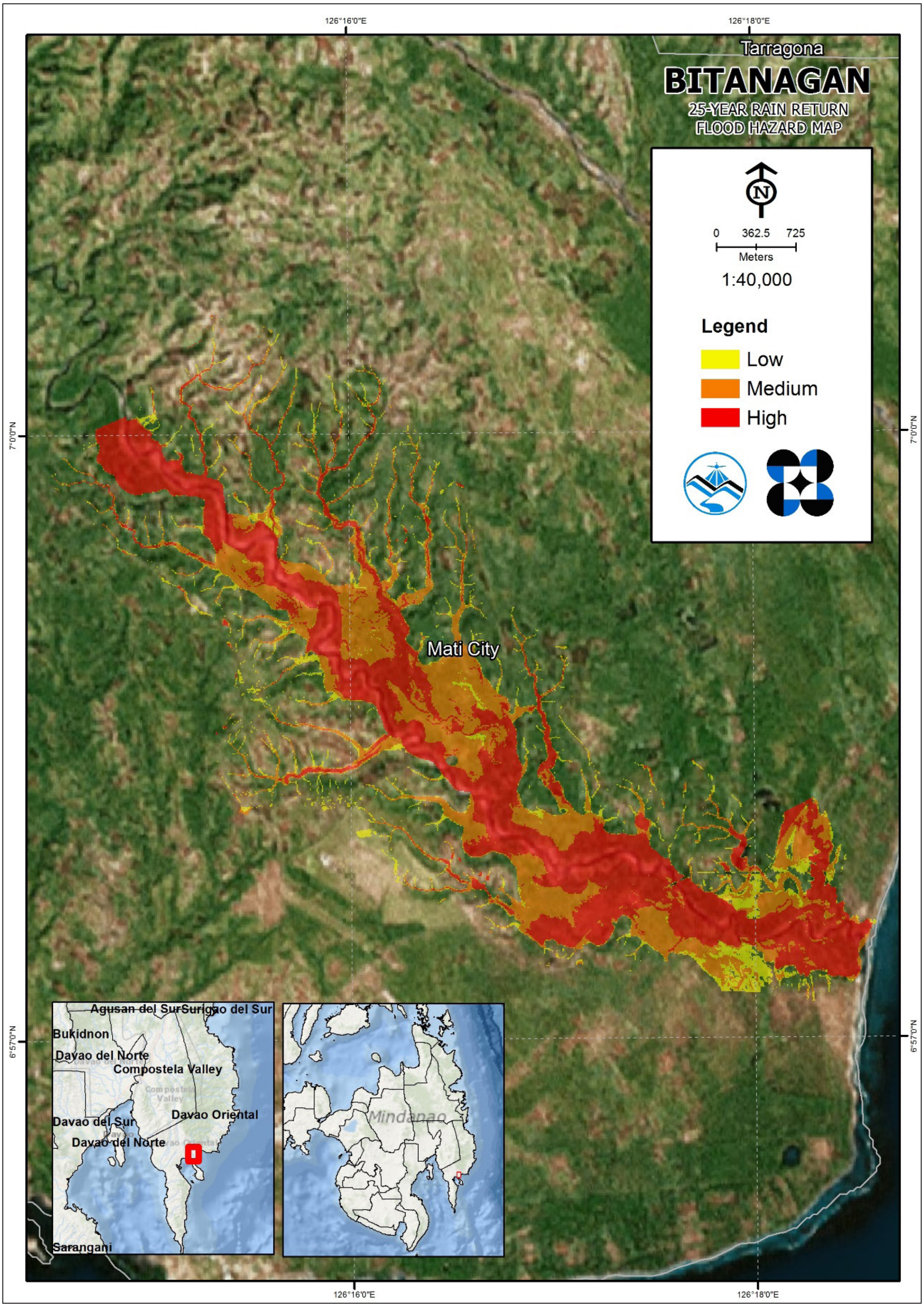

Figure 67. 25-year Flood Hazard Map for Bitanagan Floodplain overlaid on Google Earth imagery

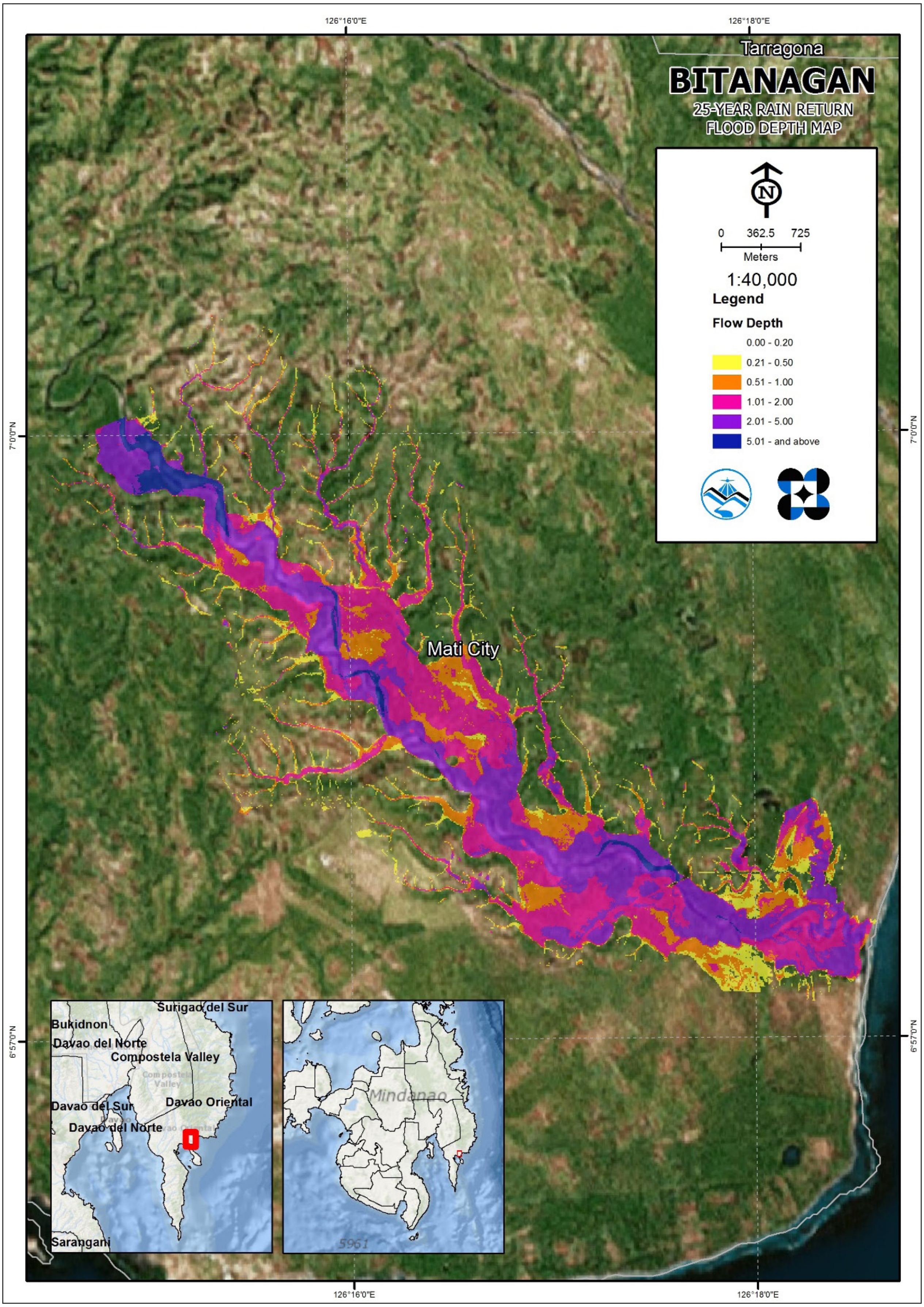

Figure 68. 25-year Flow Depth Map for Bitanagan Floodplain overlaid on Google Earth imagery

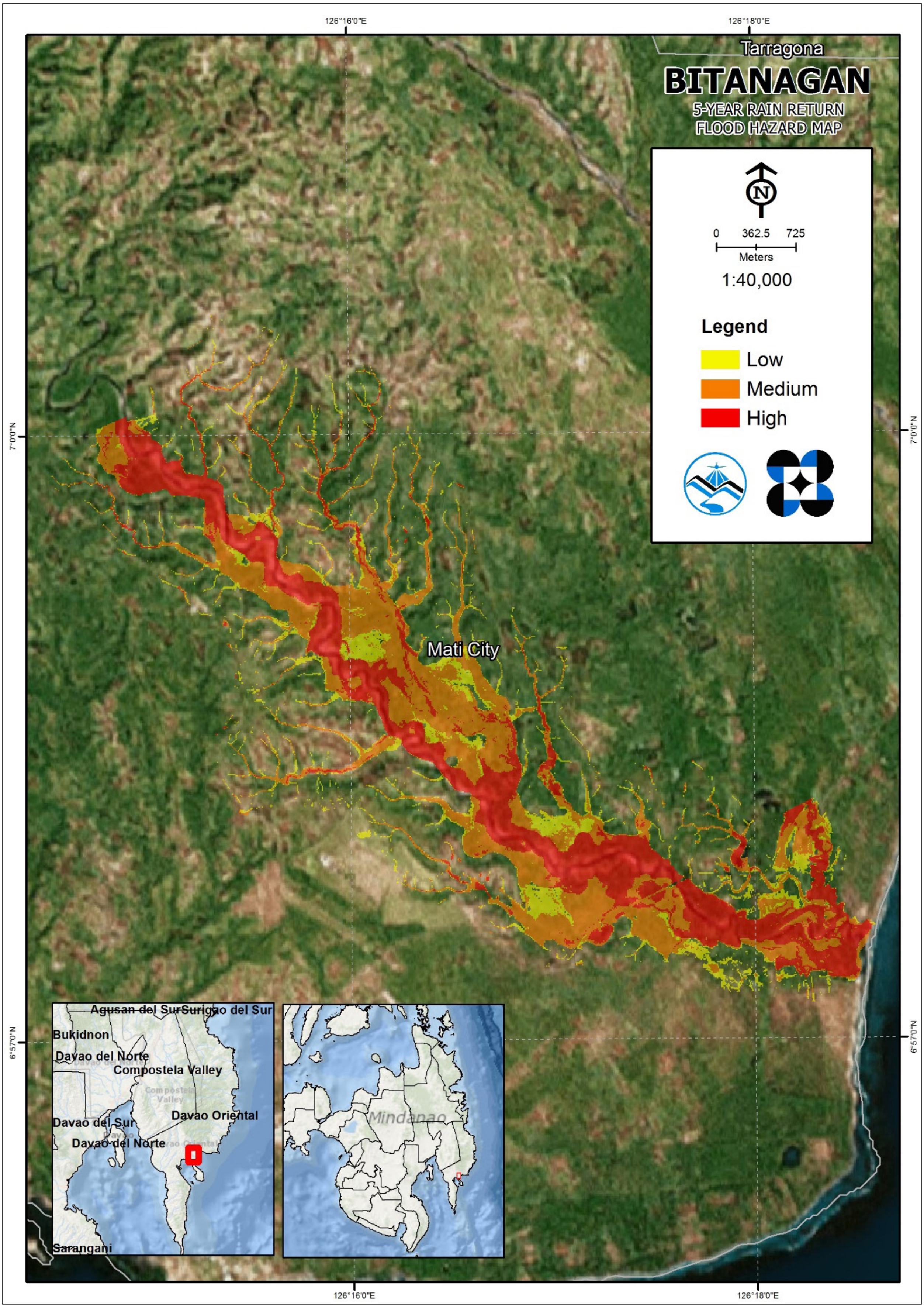

Figure 69. 5-year Flood Hazard Map for Bitanagan Floodplain overlaid on Google Earth imagery

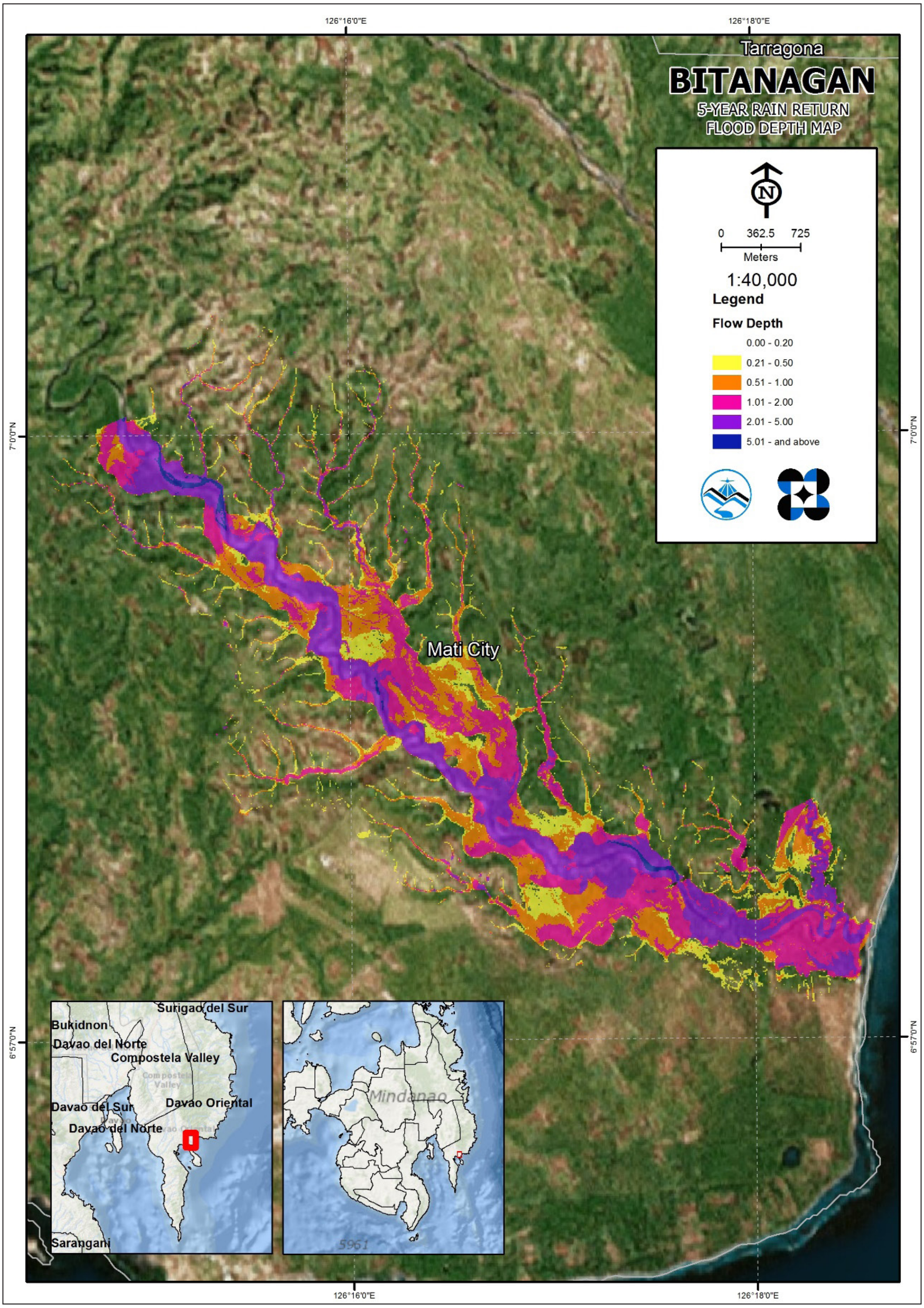

Figure 70. 5-year Flow Depth Map for Bitanagan Floodplain overlaid on Google Earth imagery

5.10 Inventory of Areas Exposed to Flooding

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

For the 5-year return period, 1.43% of the municipality of Mati City with an area of 797.38 sq. km. will experience flood levels of less than 0.20 meters; 0.15% of the area will experience flood levels of 0.21 to 0.50 meters while 0.24%, 0.29%, 0.26%, and 0.01% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in the table are the affected areas in square kilometers by flood depth per barangay.

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

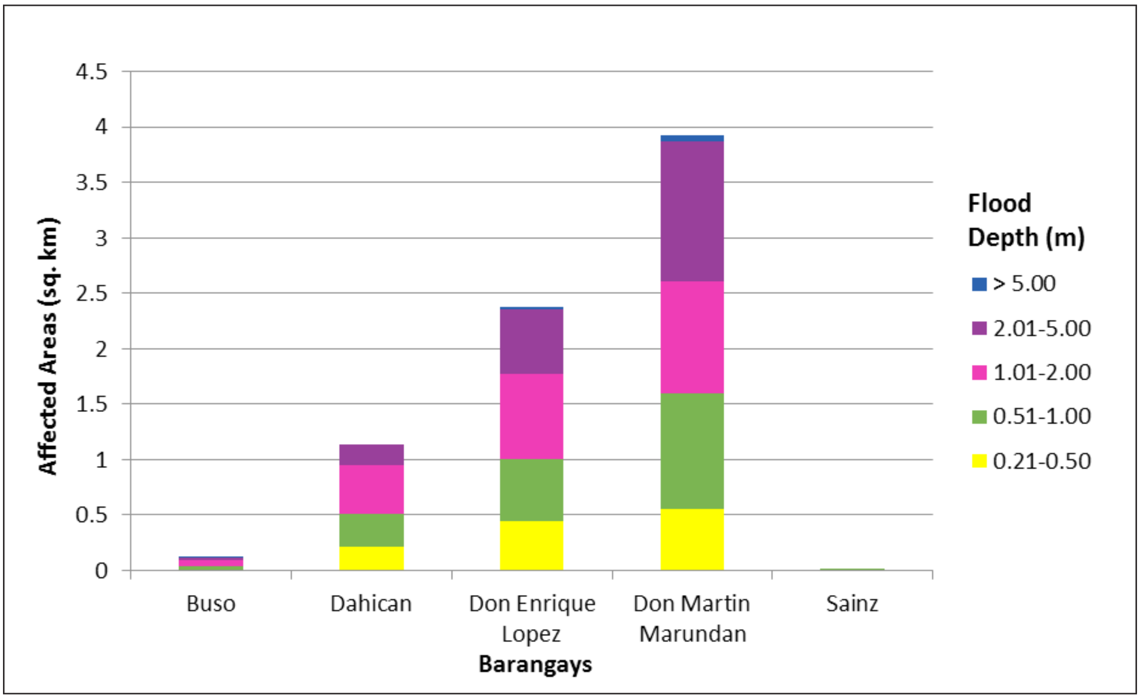

Figure 71. Affected Areas in Mati City, Davao Oriental during 5-Year Rainfall Return Period

For the 25-year return period, 1.35% of the municipality of Mati City with an area of 797.38 sq. km. will experience flood levels of less than 0.20 meters; 0.11% of the area will experience flood levels of 0.21 to 0.50 meters while 0.18%, 0.36%, 0.34%, and 0.04% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in the table are the affected areas in square kilometers by flood depth per barangay.

Table 34. Affected Areas in Mati City, Davao Oriental during 25-Year Rainfall Return Period

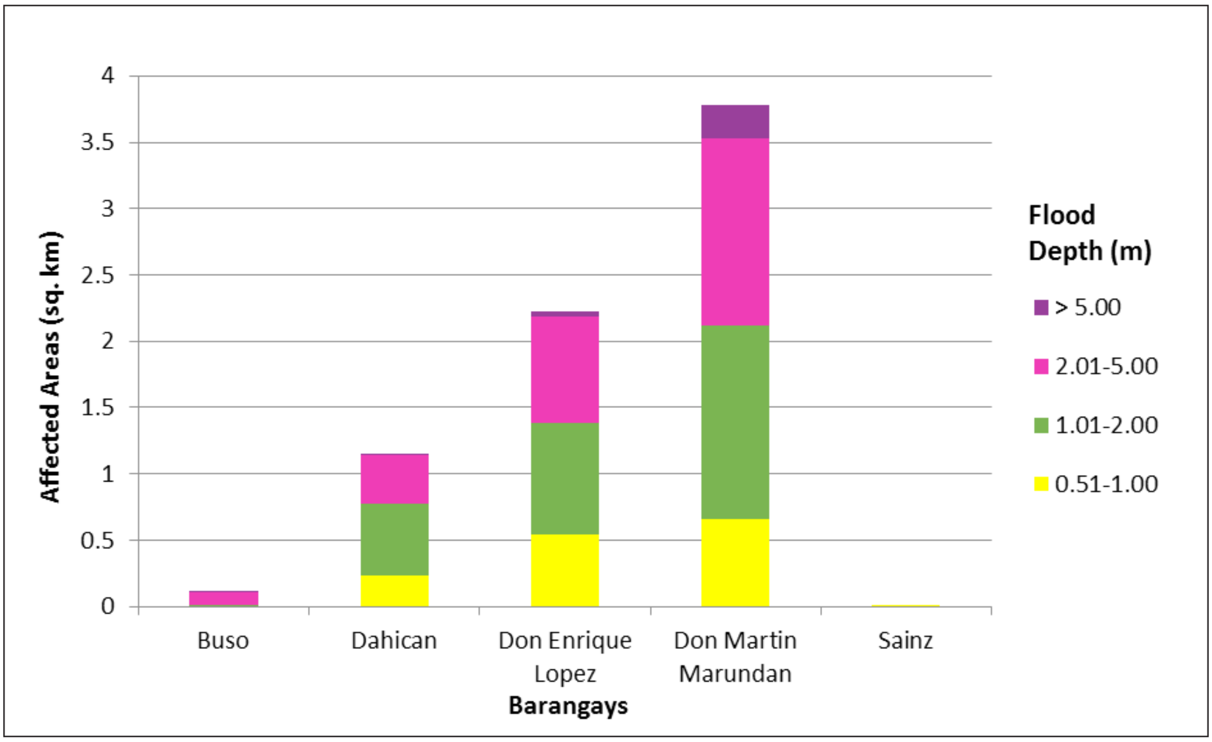

Figure 72. Affected Areas in Mati City, Davao Oriental during 25-Year Rainfall Return Period

For the 100-year return period, 1.32% of the municipality of Mati City with an area of 797.38 sq. km. will experience flood levels of less than 0.20 meters; 0.10% of the area will experience flood levels of 0.21 to 0.50 meters while 0.14%, 0.35%, 0.39%, and 0.08% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in the table are the affected areas in square kilometers by flood depth per barangay.

Table 35. Affected Areas in Mati City, Davao Oriental during 100-Year Rainfall Return Period

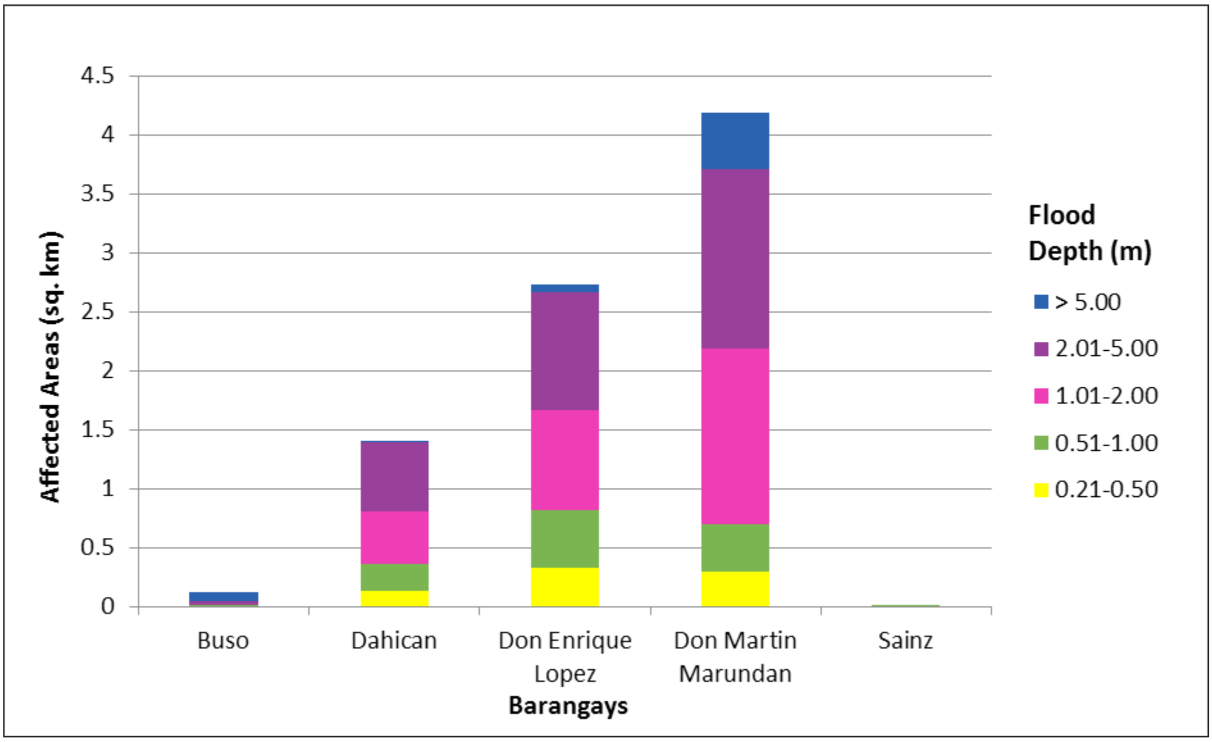

Figure 73. Affected Areas in Mati City, Davao Oriental during 100-Year Rainfall Return Period

Among the barangays in the municipality of Mati City in Davao Oriental, Don Martin Marundan is projected to have the highest percentage of area that will experience flood levels at 1.06%. Meanwhile, Don Enrique Lopez posted the second highest percentage of area that may be affected by flood depths at 1.01%.

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

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

Warning Level	Area Covered in sq. km.		
	5 year	25 year	100 year
Low	1.22	0.92	0.78
Medium	3.32	2.96	2.34
High	3.06	4.35	5.36

Of the four identified educational institutions in the Bitanagan Floodplain, none are supposedly at risk for any of the flood hazards. See Annex 12. Additionally, no medical institutions were identified in the Bitanagan Floodplain.

5.11 Flood Validation

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

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

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

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

The flood validation survey was conducted on January 10-13, 2017. The flood validation consists of 180 points randomly selected all over the Bitanagan Floodplain. It has an RMSE value of 0.88.

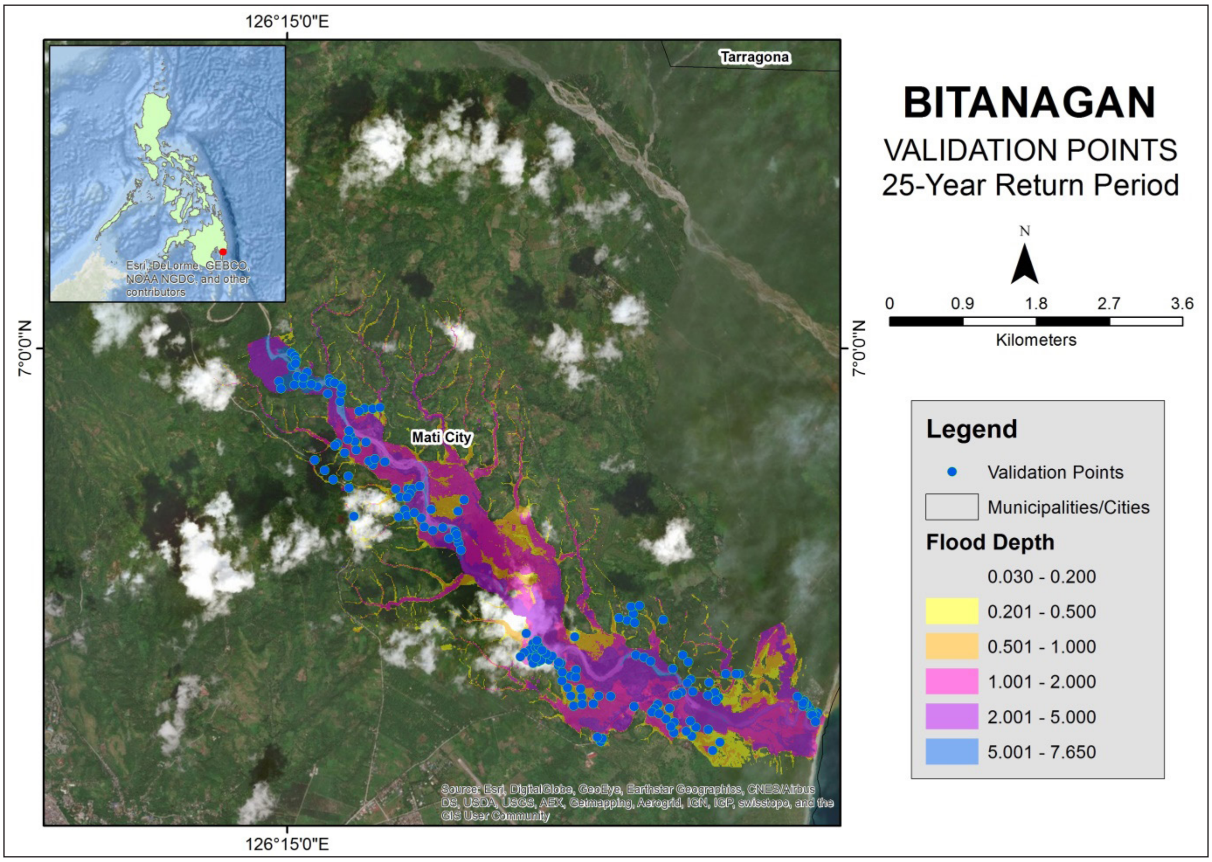

Figure 74. Flood Validation Points of Bitanagan River Basin

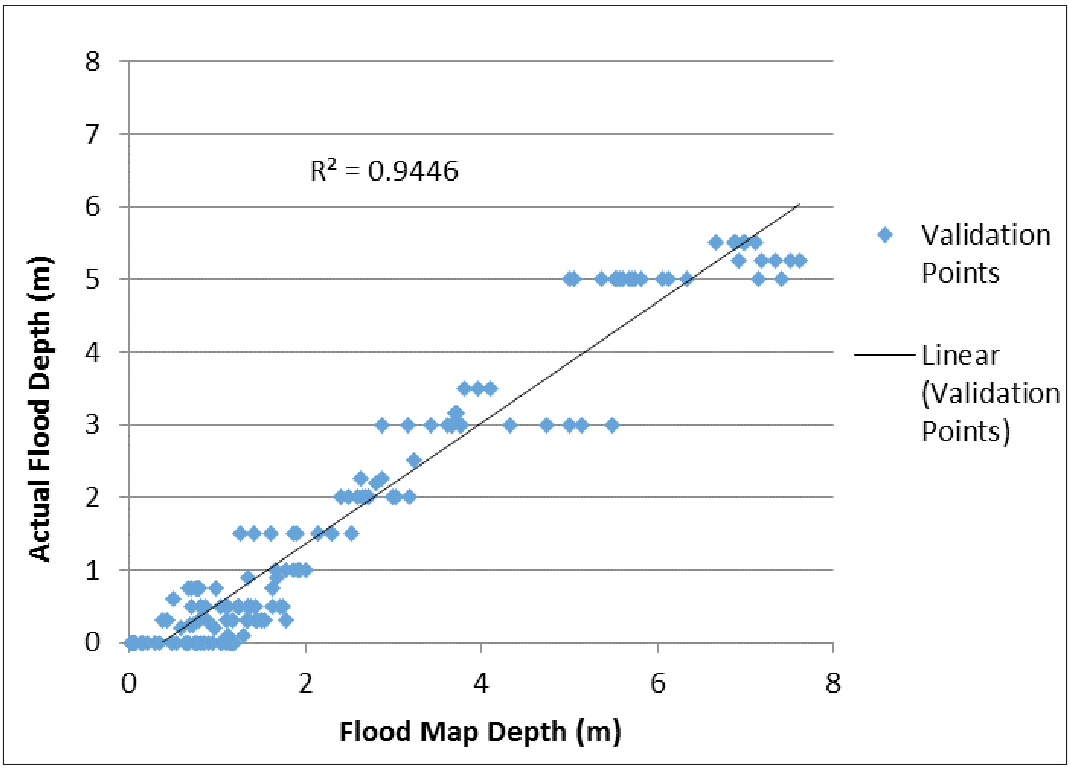

Figure 75. Flood Map Depth vs Actual Flood Depth for Bitanagan

Table 37. Actual Flood Depth vs Simulated Flood Depth in Bitanagan

BITANAGAN 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	33	3	15	11	0	0	62
	0.21-0.50	0	2	8	24	0	0	34
	0.51-1.00	0	1	6	8	1	0	16
	1.01-2.00	0	0	0	5	13	0	18
	2.01-5.00	0	0	0	0	21	18	39
	> 5.00	0	0	0	0	0	11	11
	Total	33	6	29	48	35	29	180

The overall accuracy generated by the flood model is estimated at 43.33%, with 78 points correctly matching the actual flood depths. In addition, there were 51 points estimated one level above and below the correct flood depths while there were 40 points and 11 points estimated two levels above and below, and three or more levels above and below the correct flood depth. A total of 101 points were overestimated while only one point was underestimated in the modelled flood depths of Bitanagan.

Table 38. Summary of Accuracy Assessment in Bitanagan

	No. of Points	%
Correct	78	43.33
Overestimated	101	56.11
Underestimated	1	0.56
Total	180	100

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.

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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.

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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.

LDRRM Office of Siay

Philippine Information Agency- IX

Mines and Geosciences Bureau- IX

Annexes

Annex 1. Technical Specifications of the LIDAR Sensors used in the Bitanagan Floodplain Survey

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)

Parameter	Specification
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 Certification of Reference Points Used in LIDAR Survey

DVE-42

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

June 24, 2014

CERTIFICATION

To whom it may concern:

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

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

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

PRS92 Coordinates

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

WGS84 Coordinates

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

PTM Coordinates

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

UTM Coordinates

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

Location Description

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

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

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

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

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

DVE-61

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

July 11, 2014

CERTIFICATION

To whom it may concern:

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

	Province: **DAVAO ORIENTAL**	
	Station Name: **DVE-61**	
	Order: **2nd**	
Island: **MINDANAO**		Barangay: **UPPER BLISS**
Municipality: **MATI (CAPITAL)**		MSL Elevation:
	PRS92 Coordinates	
Latitude: **6° 57' 39.37336"**	Longitude: **126° 13' 22.44550"**	Ellipsoidal Hgt: **48.47400 m.**
	WGS84 Coordinates	
Latitude: **6° 57' 36.33777"**	Longitude: **126° 13' 27.97256"**	Ellipsoidal Hgt: **122.95300 m.**
	PTM / PRS92 Coordinates	
Northing: **769826.046 m.**	Easting: **635140.8 m.**	Zone: **5**
	UTM / PRS92 Coordinates	
Northing: **770,283.71**	Easting: **193,120.25**	Zone: **52**

Location Description

DVE-61
"DVE-61" is in Barangay Upper Bliss, Gov. Mati City, Davao Oriental. To reach the station travel for about 2.5 kms. from City Hall of mati, going east towards brgy. Zign, Mati City. Station is located at the center of the playground of Zign Elem. School, about 10 m "W" of school flagpole. Mark is the head of 4" copper nail embedded in a 0.30x0.30x1.0 m. concrete monument with inscription "DVE-61 2007 NAMRIA".

Requesting Party: **UP TCAGP / Engr. Christopher Cruz**
Pupose: **Reference**
OR Number: **8796507 A**
T.N.: **2014-1586**

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

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

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

NAMRIA OFFICES:
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Branch : 421 Barraca St. San Nicolas, 1010 Manila, Philippines, Tel. No. (632) 241-3494 to 98
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Annex 3. Baseline Processing Reports of Control Points used in the LIDAR Survey

DVE-3088

Processing Summary

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

Vector Components (Mark to Mark)

From:	DVE-42				
Grid		Local		Global	
Easting	201638.187 m	Latitude	N6°58'54.82727"	Latitude	N6°58'51.79296"
Northing	772654.341 m	Longitude	E126°17'56.05269"	Longitude	E126°18'01.67690"
Elevation	15.607 m	Height	6.396 m	Height	81.025 m

To:	DVE-3088				
Grid		Local		Global	
Easting	201642.172 m	Latitude	N6°58'54.69466"	Latitude	N6°58'51.66037"
Northing	772647.168 m	Longitude	E126°17'56.18365"	Longitude	E126°18'01.70797"
Elevation	15.582 m	Height	6.370 m	Height	80.999 m

Vector					
ΔEasting	3.986 m	NS Fwd Azimuth	160°37'05"	ΔX	-3.741 m
ΔNorthing	-7.173 m	Ellipsoid Dist.	8.200 m	ΔY	-1.703 m
ΔElevation	-0.026 m	ΔHeight	-0.026 m	ΔZ	-7.096 m

Standard Errors

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

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000004144		
Y	-0.0000001656	0.0000006443	
Z	-0.0000000528	0.0000000816	0.0000000908

DVE-3118

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
DVE-61 --- DVE-3118 (B7)	DVE-61	DVE-3118	Fixed	0.017	0.060	222°57'30"	8321.258	81.506
DVE-61 --- DVE-3118 (B10)	DVE-61	DVE-3118	Fixed	0.013	0.039	222°57'30"	8321.246	81.578
DVE-61 --- DVE-3118 (B11)	DVE-61	DVE-3118	Fixed	0.017	0.043	222°57'29"	8321.266	81.487

Vector Components (Mark to Mark)

From:	DVE-61				
Grid		Local		Global	
Easting	193120.234 m	Latitude	N6°57'39.37336"	Latitude	N6°57'36.33777"
Northing	770283.711 m	Longitude	E126°13'22.44561"	Longitude	E126°13'27.97256"
Elevation	57.158 m	Height	48.473 m	Height	122.963 m

To:	DVE-3118				
Grid		Local		Global	
Easting	187409.531 m	Latitude	N6°54'21.10869"	Latitude	N6°54'18.08333"
Northing	764222.331 m	Longitude	E126°10'17.73142"	Longitude	E126°10'23.26403"
Elevation	138.503 m	Height	129.978 m	Height	204.433 m

Vector					
ΔEasting	-5710.703 m	NS Fwd Azimuth	222°57'30"	ΔX	4093.802 m
ΔNorthing	-6061.381 m	Ellipsoid Dist.	8321.258 m	ΔY	4007.271 m
ΔElevation	81.346 m	ΔHeight	81.506 m	ΔZ	-6036.086 m

Standard Errors

Vector errors:					
σ ΔEasting	0.007 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.016 m
σ ΔNorthing	0.005 m	σ Ellipsoid Dist.	0.006 m	σ ΔY	0.021 m
σ ΔElevation	0.025 m	σ ΔHeight	0.025 m	σ ΔZ	0.006 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0002242317		
Y	-0.0002729544	0.0004576374	
Z	-0.0000517484	0.0000689019	0.0000341757

Annex 4. The LIDAR Survey Team Composition

Data Acquisition Component Sub-Team	Designation	Name	Agency/ Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	ENGR. CZAR JAKIRI SARMIENTO	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUÑA	UP-TCAGP
		ENGR. LOVELYN ASUNCION	UP-TCAGP
FIELD TEAM			
LiDAR Operation	Senior Science Research Specialist (SSRS)	JULIE PEARL MARS	UP-TCAGP
	Research Associate (RA)	FOR. MA. VERLINA TONGA	UP-TCAGP
	RA	ENGR. LARAH KRISELLE PARAGAS	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	ENGR. KENNETH QUISADO	UP-TCAGP
LiDAR Operation	Airborne Security	TSG. MIKE DIAPANA	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. RAUL CZ SAMAR II	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. BRYAN JOHN DONGUINES	AAC

Annex 5. Data Transfer Sheet For Bitanagan Floodplain

DATA TRANSFER SHEET
07/08/2014(Davao Oriental - ready)

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
6/27/2014	7337GC	2BLK86A178A	Gemini	NA	209/70	366	163	NA	NA	16.9	NA	7.59	1KB	1KB	4/4/5/5/5/4	24	Z:\Airborne_Raw\7337GC
6/28/2014	7339GC	2BLK79C179A	Gemini	NA	179/11	367	74.8	NA	NA	14.3	NA	5.08	1KB	1KB	5	179/11	Z:\Airborne_Raw\7339GC
6/29/2014	7340GC	2BLK79B180A	Gemini	NA	119	580	265	NA	NA	28.2	NA	4.68	1KB	1KB	5	119	Z:\Airborne_Raw\7339
7/1/2014	7344GC	2BLK84B182A	Gemini	NA	158/22	188	174	NA	NA	2.90/6.69	NA	6.95	1KB	1KB	9	158/22	Z:\Airborne_Raw\1634A
7/2/2014	7346GC	2BLK79BSA183A	Gemini	NA	376	612	279	NA	NA	29.7	NA	5.32	1KB	1KB	9	376	Z:\Airborne_Raw\1636A
7/3/2014	7348GC	2BLK79V184A	Gemini	NA	597	200	212	NA	NA	6.58	NA	6.49	1KB	1KB	14	597	Z:\Airborne_Raw\1636A
7/4/2014	7350GC	2BLK85B185A	Gemini	NA	300	499	258	NA	NA	23.8	NA	7.05	1KB	1KB	8	300	Z:\Airborne_Raw\1636A

Received from

Name Kristine Andaya
Position R.A.
Signature

Received by

Name LIDA F. PRIETO
Position SSRS
Signature 7/14/14

DATA TRANSFER SHEET
07/08/2014(Davao Oriental - ready)

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
7/7/2014	7356GC	2BLK80AS188A	Gemini	NA	347/11	589	265	NA	NA	27.7	NA	9.58	1KB	1KB	4	374/11	Z:\Airborne_Raw
7/7/2014	7357GC	2BLK80BS188B	Gemini	NA	406	111	79.8	NA	NA	5.05	NA	7.68	1KB	1KB	4	406	Z:\Airborne_Raw
7/8/2014	7358GC	2BLK80BS189A	Gemini	NA	165/7/14	318	196	NA	NA	20.1		4.83	1KB	1KB	7/3	165/7/14	Z:\Airborne_Raw
7/10/2014	7362GC	2BLK85CS191A	Gemini	NA	138	244	188	NA	NA	7.95	NA	4.7	1KB	1KB	8/5/4	138	Z:\Airborne_Raw
7/11/2014	7364GC	2BLK85V192A	Gemini	NA	234/9/12	488	207	NA	NA	27.3	NA	5.8	1KB	1KB	4/9	234/9/12	Z:\Airborne_Raw
7/12/2014	7366GC	2BLK79D80BV193A	Gemini	NA	60	409	241	NA	NA	12.2	NA	4.89	1KB	1KB	5/7	14/17	Z:\Airborne_Raw
7/15/2014	7372GC	2BLK79E196A	Gemini	NA	30/6	68.7	158	NA	NA	3.47	NA	4.56	1KB	1KB	3	30/6	Z:\Airborne_Raw
7/16/2014	7374GC	2BLK79ES197A	Gemini	NA	139	239	156	NA	NA	9.01	NA	3.42	1KB	1KB	3/4	139	Z:\Airborne_Raw

Received from

Name TIN ANYTAVIA
Position KA
Signature

Received by

Name JOIDA F. PRIETO
Position SSRS
Signature 7/28/14

Annex 6. Flight Logs for the Flight Missions

Flight Log for 7318GC Mission

DREAM Data Acquisition Flight Log **Flight Log No.:** 7318

1 LiDAR Operator: MV Tonga	2 ALTM Model: Gemini/CASI	3 Mission Name: 2BLK84A169A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RP-C9322
7 Pilot: R. Samaril	8 Co-Pilot: B. Dongunes	9 Route:			
10 Date: 6-18-14	12 Airport of Departure (Airport, City/Province): RPMQ		12 Airport of Arrival (Airport, City/Province): RPMQ		
13 Engine On: 12+11	14 Engine Off: 15+58	15 Total Engine Time: 3+47	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather					

20 Remarks:

Completed Blk 84A and conducted CASI test

21 Problems and Solutions:

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

Flight Log for 7320GC Mission

DREAM Data Acquisition Flight Log

Flight Log No.: 7320

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

20 Remarks:

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

Conducted CASI test

21 Problems and Solutions:

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

Flight Log for 7344GC Mission

DREAM Data Acquisition Flight Log — **Flight Log No.:** 7344

1 LiDAR Operator: MVE TONGA	2 ALTM Model: GEM+ OASI	3 Mission Name: 2BLK79182A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9322
7 Pilot: R. SAMAR	8 Co-Pilot: B. DONGUINES	9 Route: MATI			
10 Date: JUNE 09, 2014	12 Airport of Departure (Airport, City/Province): MATI		12 Airport of Arrival (Airport, City/Province):		
13 Engine On: 9:23	14 Engine Off: 12:34	15 Total Engine Time: 3+11	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: cloudy					
20 Remarks: Survey 13 line of BLK 79C (without OASI)					

21 Problems and Solutions:

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

Flight Log for 7362GC Mission

DREAM Data Acquisition Flight Log — **Flight Log No.:** 7362

1 LiDAR Operator: LK Paragas	2 ALTM Model: Gem+CAS	3 Mission Name: 2BLK85CSHIA	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9322
7 Pilot: X. Samar	8 Co-Pilot: B. Donguines	9 Route: MATI			
10 Date: July 10, 2014	12 Airport of Departure (Airport, City/Province): MATI		12 Airport of Arrival (Airport, City/Province):		
13 Engine On: 7:37	14 Engine Off: 10:48	15 Total Engine Time: 3+11	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather Fair					
20 Remarks: Completed BLK84C (without CASI)					

21 Problems and Solutions:

/

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

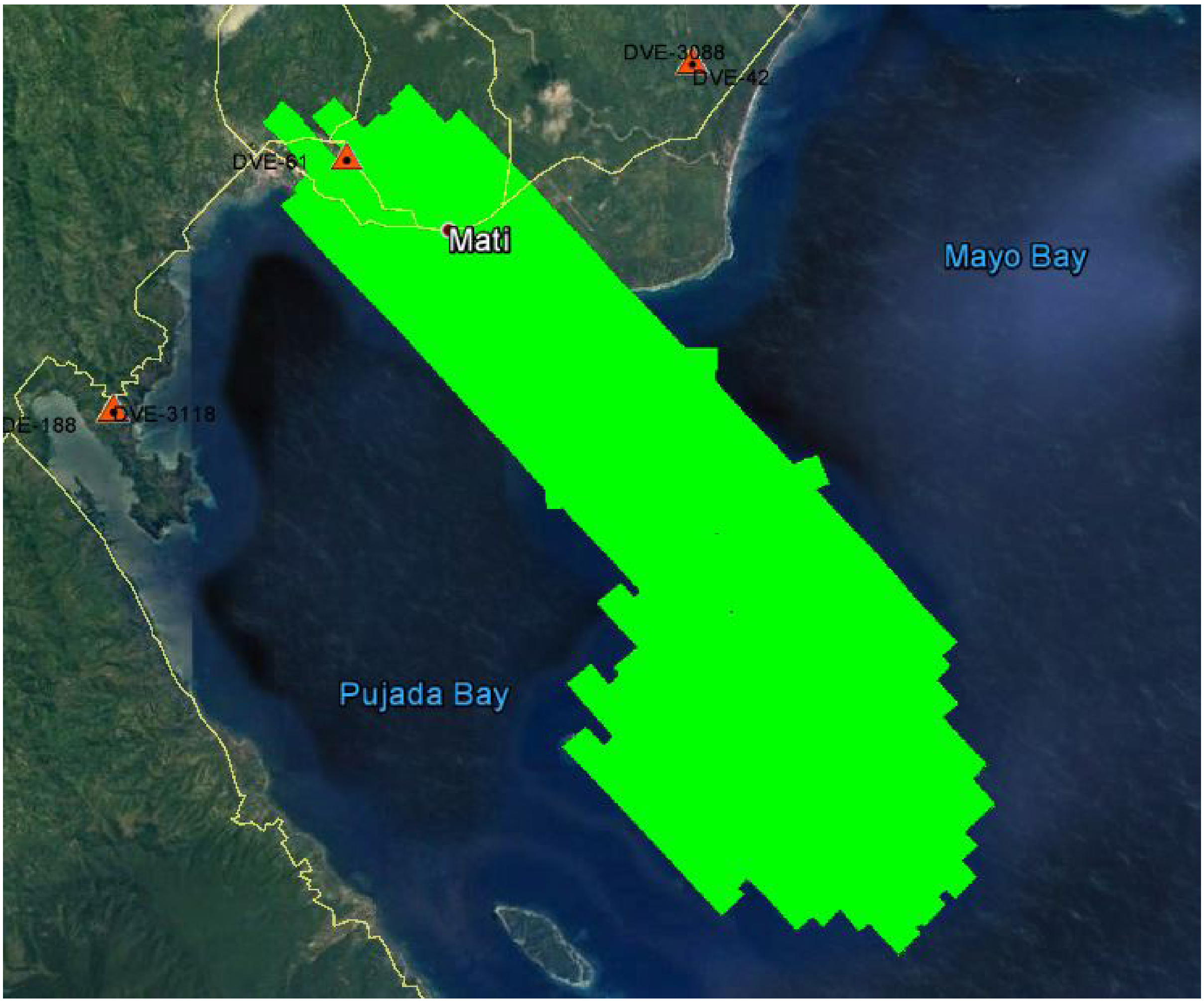
Annex 7. Flight Status Reports

DAVAO ORIENTAL
(June 16 - July 16, 2014)

FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
7318G	BLK84A	2BLK84A169A	MV TONGA	June 18, 2014	6 lines flown with CASI in different scenario. Complied with min number of satellites in all events
7320GC	BLK84B	2BLK83A84B170A	LK PARAGAS	June 19, 2014	Started with 86B. Moved to 84B due to high terrain (6 lines). Moved to 83A due to clouds (9 lines). *CASI testing at the end of the mission flight
7344GC	BLK84C	2BLK84BCR182A	MV TONGA	July 01, 2014	Encountered abnormal POS behavior. Completed 14 lines. Lines cut due to clouds.
7362GC	BLK85B_ additional	2BLK85CS191A	LK PARAGAS	July 10, 2014	Covered BLK85B at 1200m. Experienced strong head wind.

LAS BOUNDARIES PER FLIGHT

Flight No. :	7318GC	
Area:	BLK84A	
Mission name:	2BLK84A169A	
Parameters:	Altitude: 1000 m;	Scan Frequency: 50 Hz;
Scan Angle: 20 deg;	Overlap: 30 %	
Area covered:	139.97 km²	



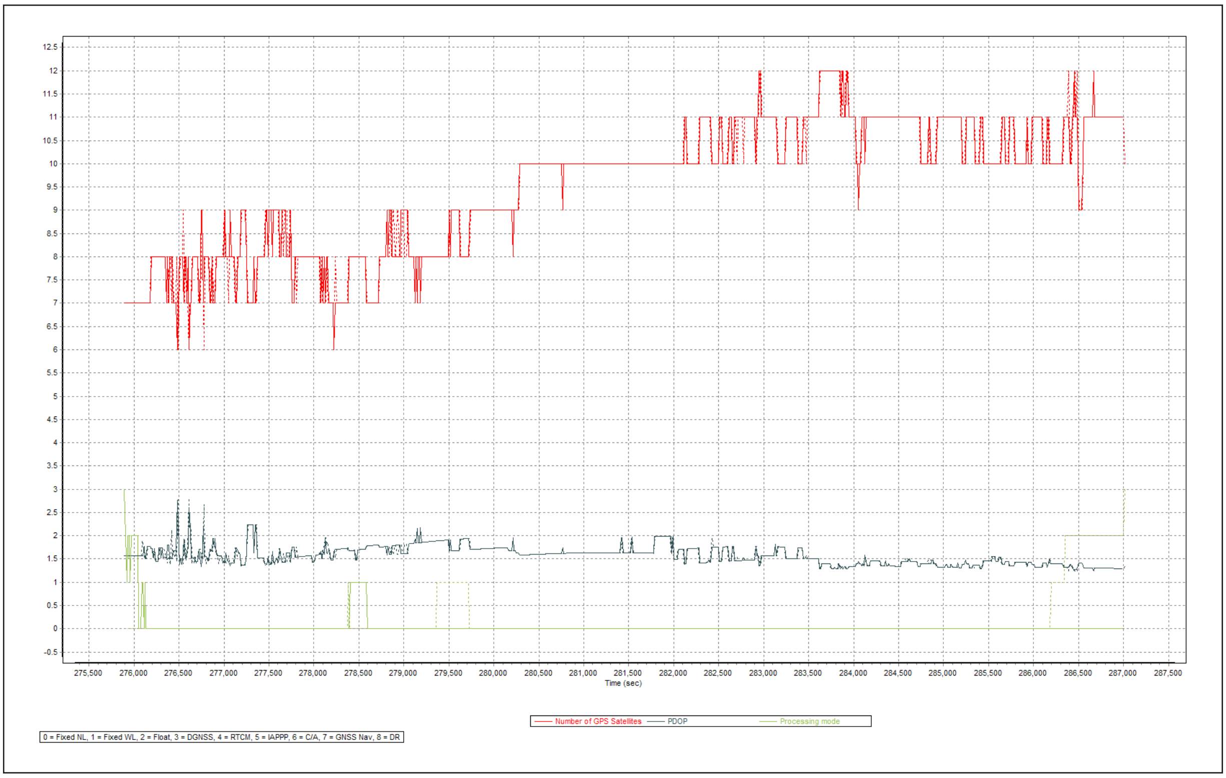
Flight No. :	7320GC	
Area:	BLK84B	
Mission name:	2BLK83A84B170A	
Parameters:	Altitude: 1000m;	Scan Frequency: 50Hz;
Scan Angle: 20deg;	Overlap: 40 %	
Area covered:	121.57km^2	

Flight No. :	7344GC	
Area:	BLK84C	
Mission name:	2BLK84BCR182A	
Parameters:	Altitude: 1200m;	Scan Frequency: 60Hz;
Scan Angle: 13deg;	Overlap: 45 %	
Area covered:	74.47 km^2	

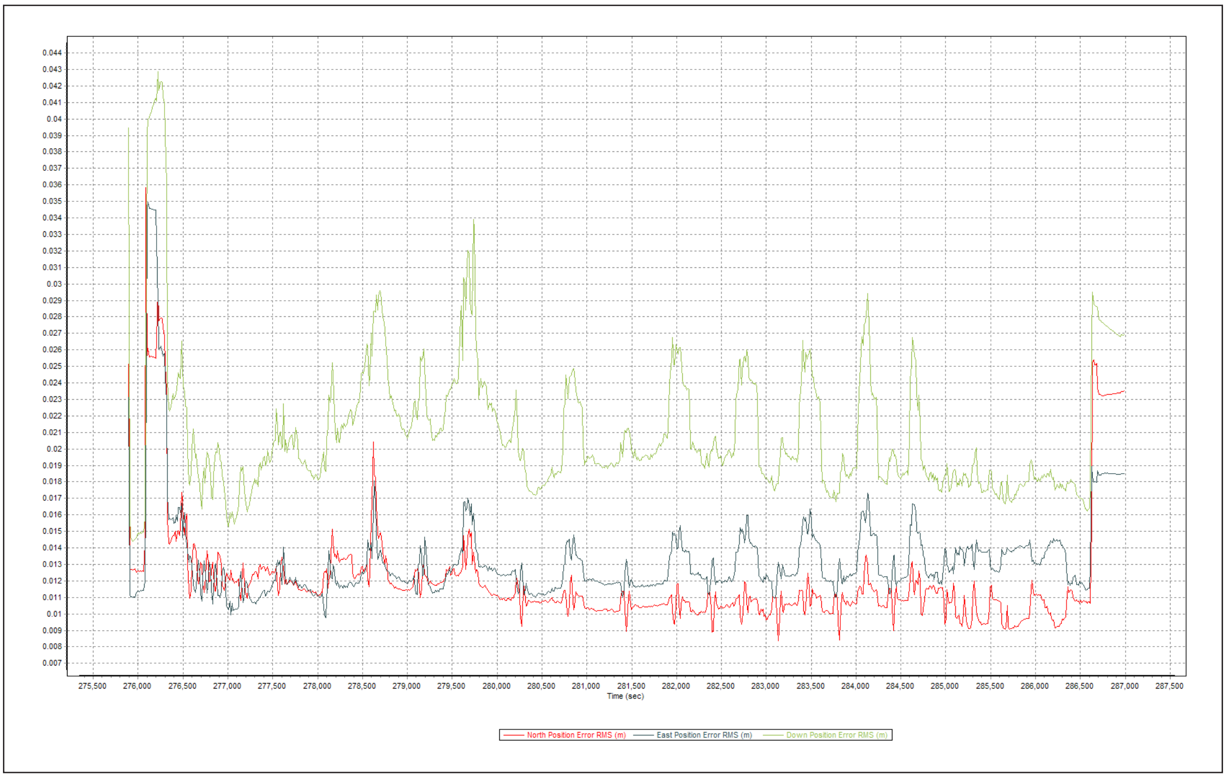
Flight No. :	7362GC	
Area:	BLK85B_additional	
Mission name:	2BLK85CS191A	
Parameters:	Altitude: 1200m;	Scan Frequency: 60Hz;
Scan Angle: 13deg;	Overlap: 40 %	
Area covered:	68.35 km^2	

Annex 8. Flight Status Reports

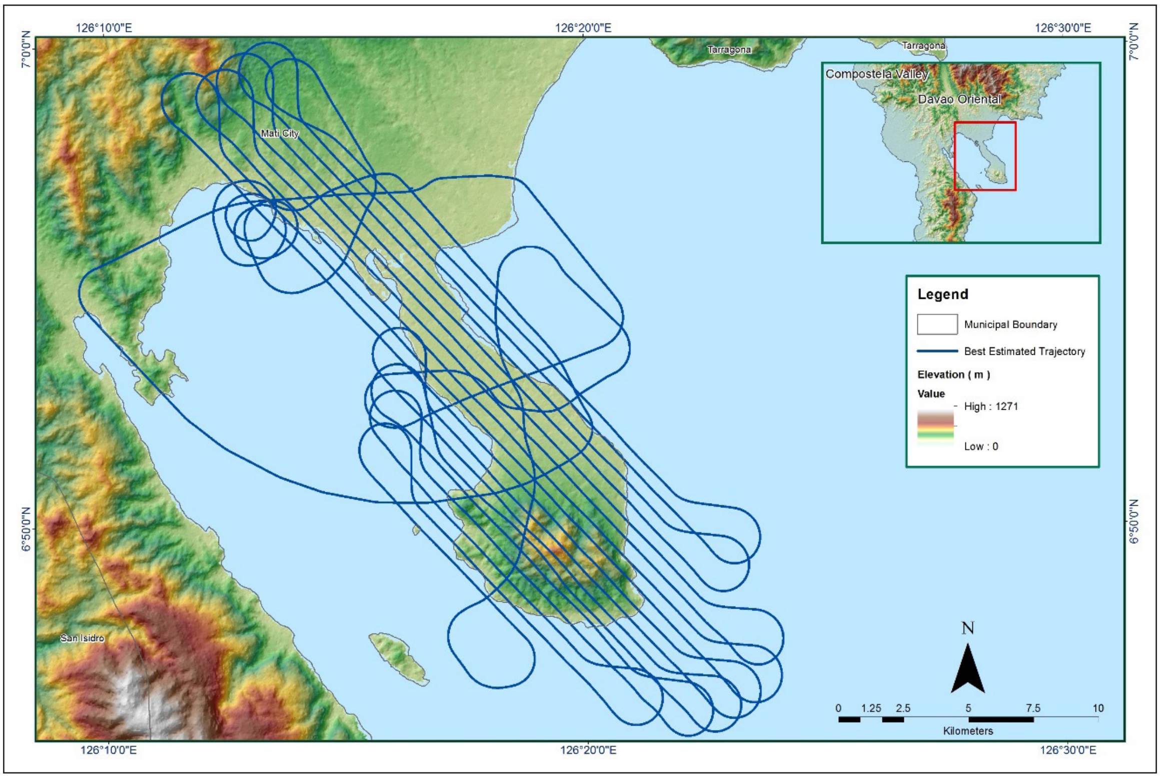
Flight Area	Davao Oriental
Mission Name	Blk84A
Inclusive Flights	7318G
Range data size	17.5 GB
POS	217 MB
Image	Na
Transfer date	July 2, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	2.95
RMSE for East Position (<4.0 cm)	3.5
RMSE for Down Position (<8.0 cm)	4.3
Boresight correction stdev (<0.001deg)	0.000182
IMU attitude correction stdev (<0.001deg)	0.0022
GPS position stdev (<0.01m)	0.0113
Minimum % overlap (>25)	32.47%
Ave point cloud density per sq.m. (>2.0)	2.83
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	190
Maximum Height	607.99 m
Minimum Height	60.52 m
Classification (# of points)	
Ground	40174203
Low vegetation	34943788
Medium vegetation	61572173
High vegetation	156295331
Building	156295331
Orthophoto	No
Processed by	Engr. Angelo Carlo Bongat, Donna Tavora, Engr. Gladys Mae Apat



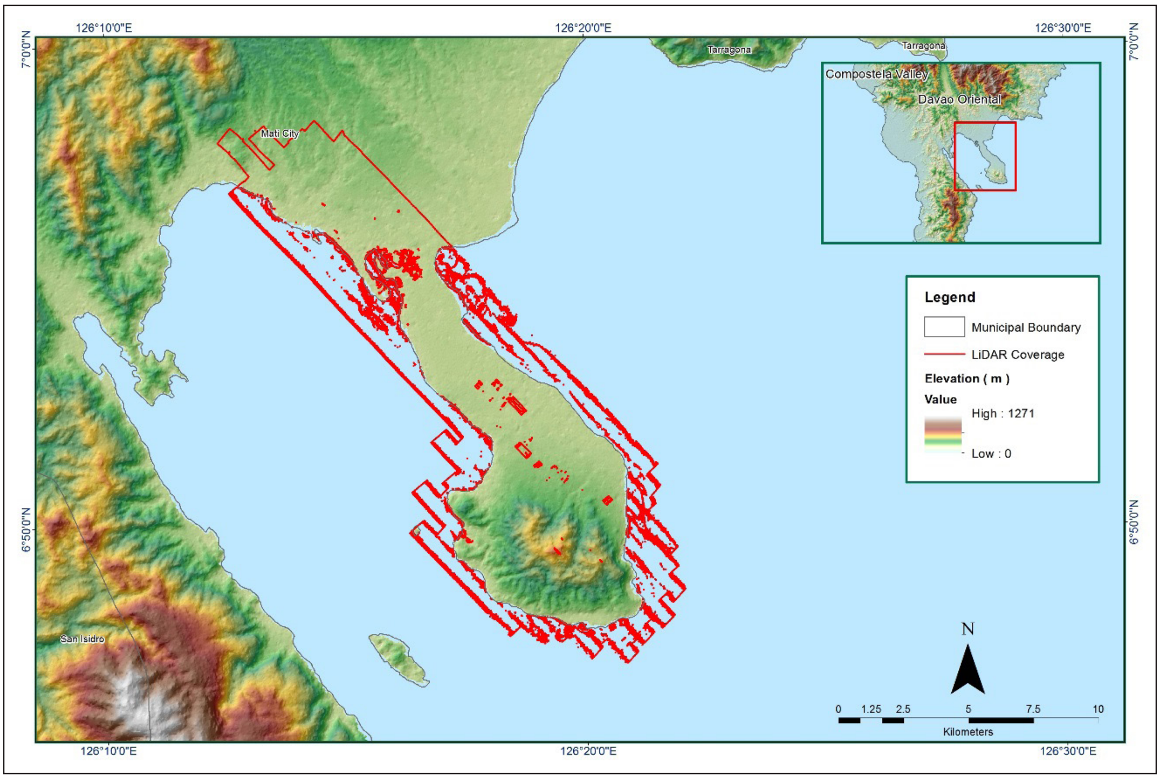
Solution Status



Smoothed Performance Metric Parameters



Best Estimated Trajectory



Coverage of LiDAR data

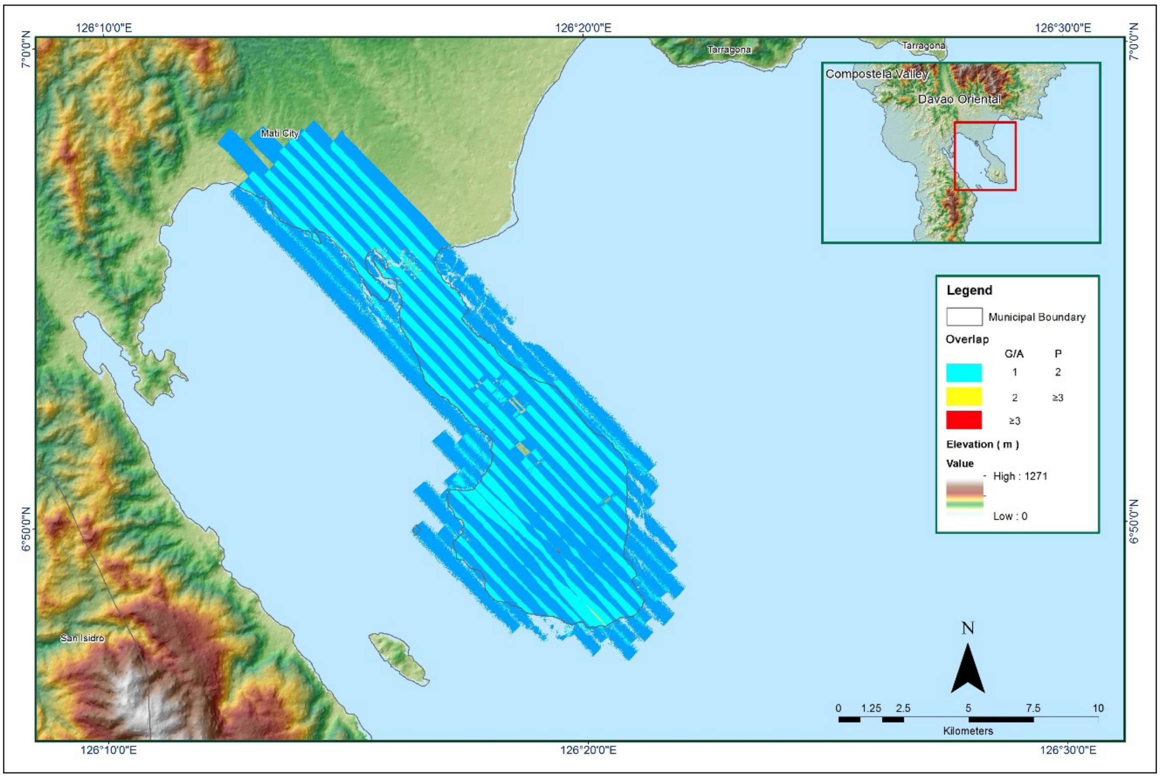
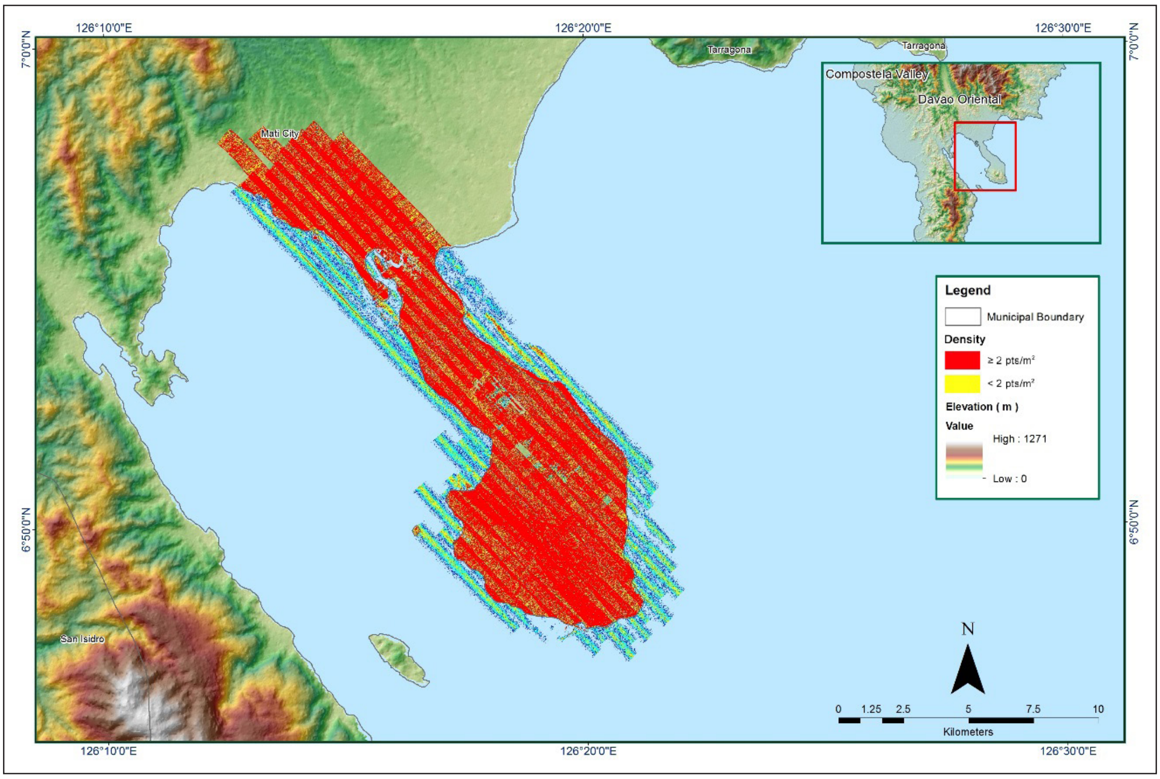
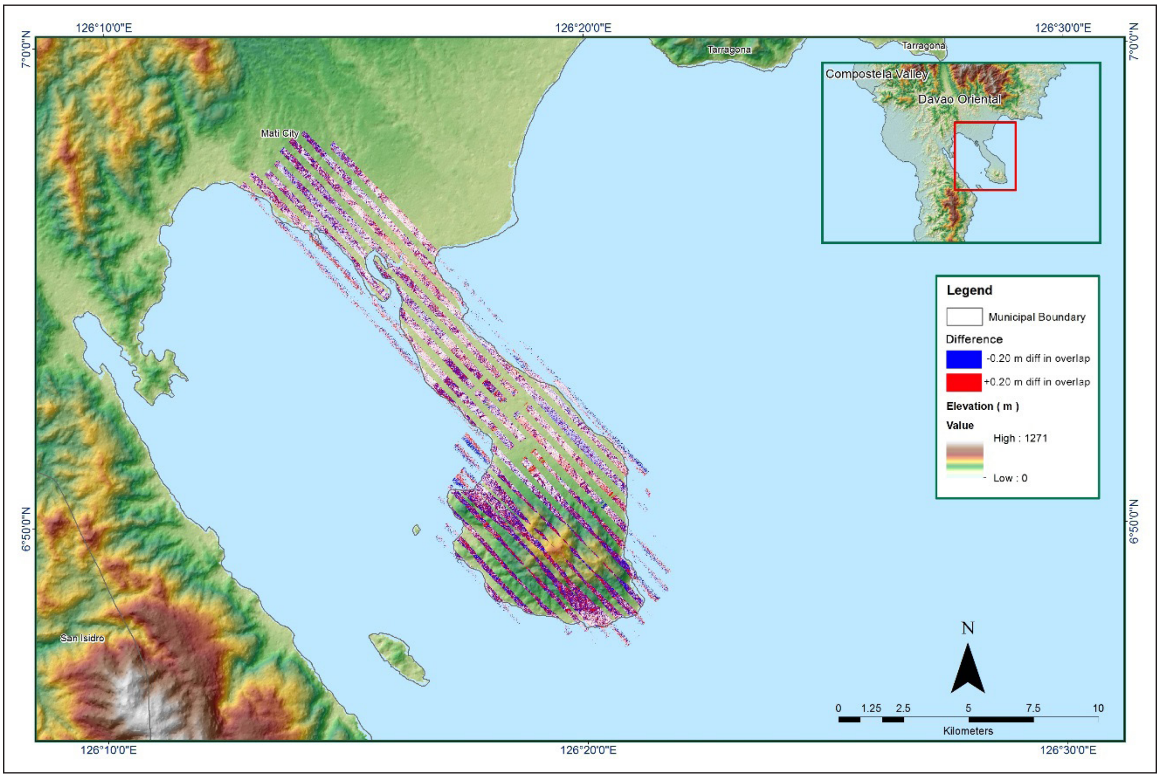


Image of data overlap



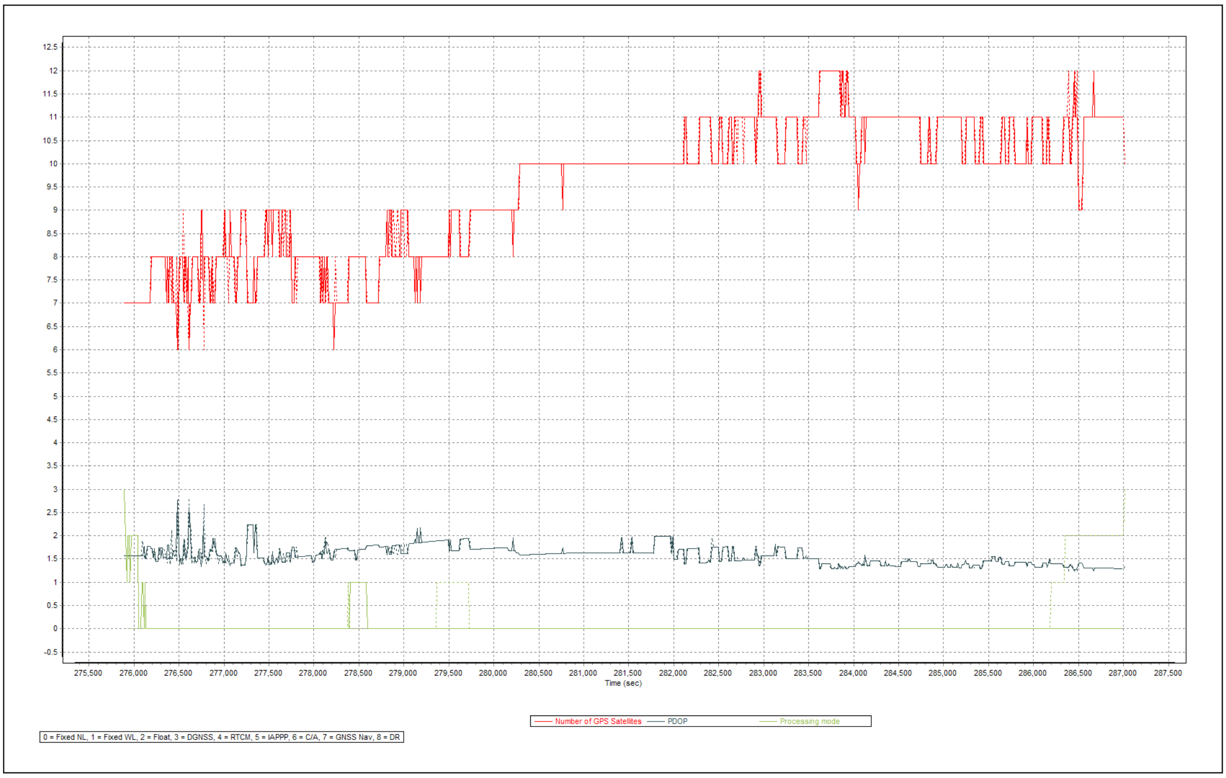
Density map of merged LiDAR data



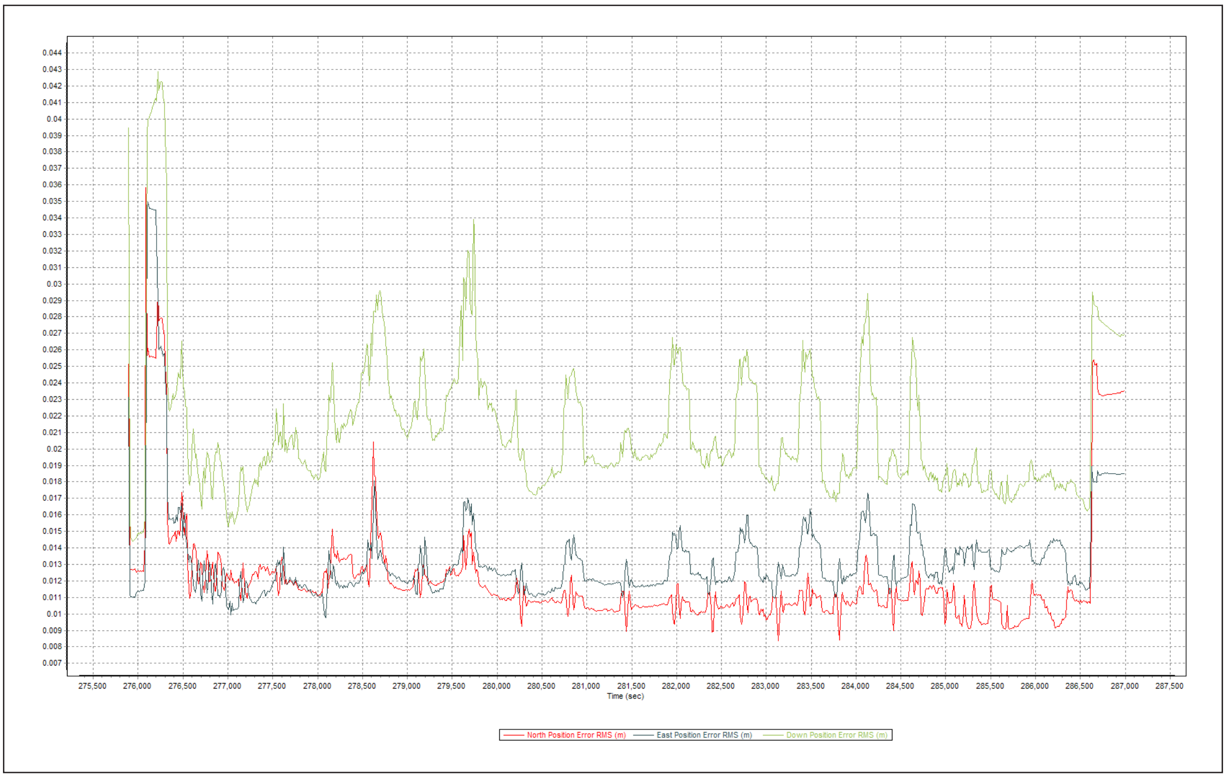
Elevation difference between flight lines

Annex 8. Mission Summary Report

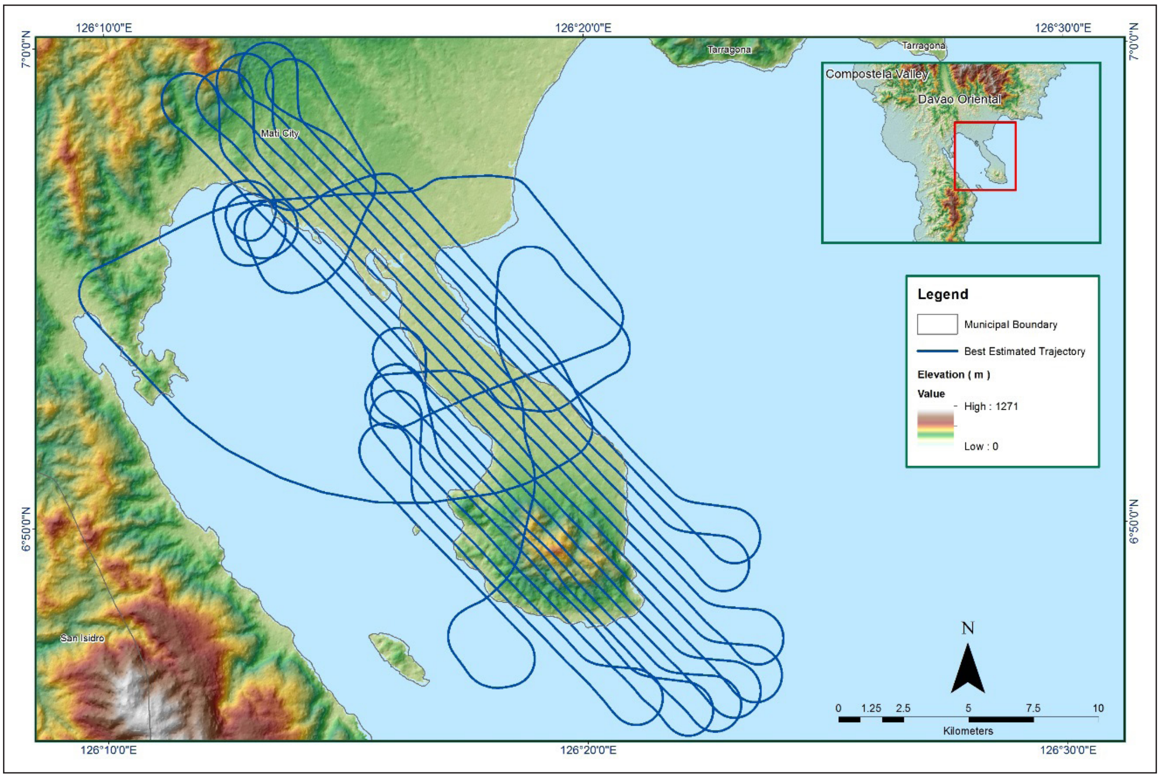
Flight Area	Davao Oriental
Mission Name	Blk84A
Inclusive Flights	7318G
Range data size	17.5 GB
POS	217 MB
Image	na
Transfer date	July 2, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	2.95
RMSE for East Position (<4.0 cm)	3.5
RMSE for Down Position (<8.0 cm)	4.3
Boresight correction stdev (<0.001deg)	0.000182
IMU attitude correction stdev (<0.001deg)	0.0022
GPS position stdev (<0.01m)	0.0113
Minimum % overlap (>25)	32.47%
Ave point cloud density per sq.m. (>2.0)	2.83
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	190
Maximum Height	607.99 m
Minimum Height	60.52 m
Classification (# of points)	
Ground	40174203
Low vegetation	34943788
Medium vegetation	61572173
High vegetation	156295331
Building	156295331
Orthophoto	No
Processed by	Engr. Angelo Carlo Bongat, Donna Tavora, Engr. Gladys Mae Apat



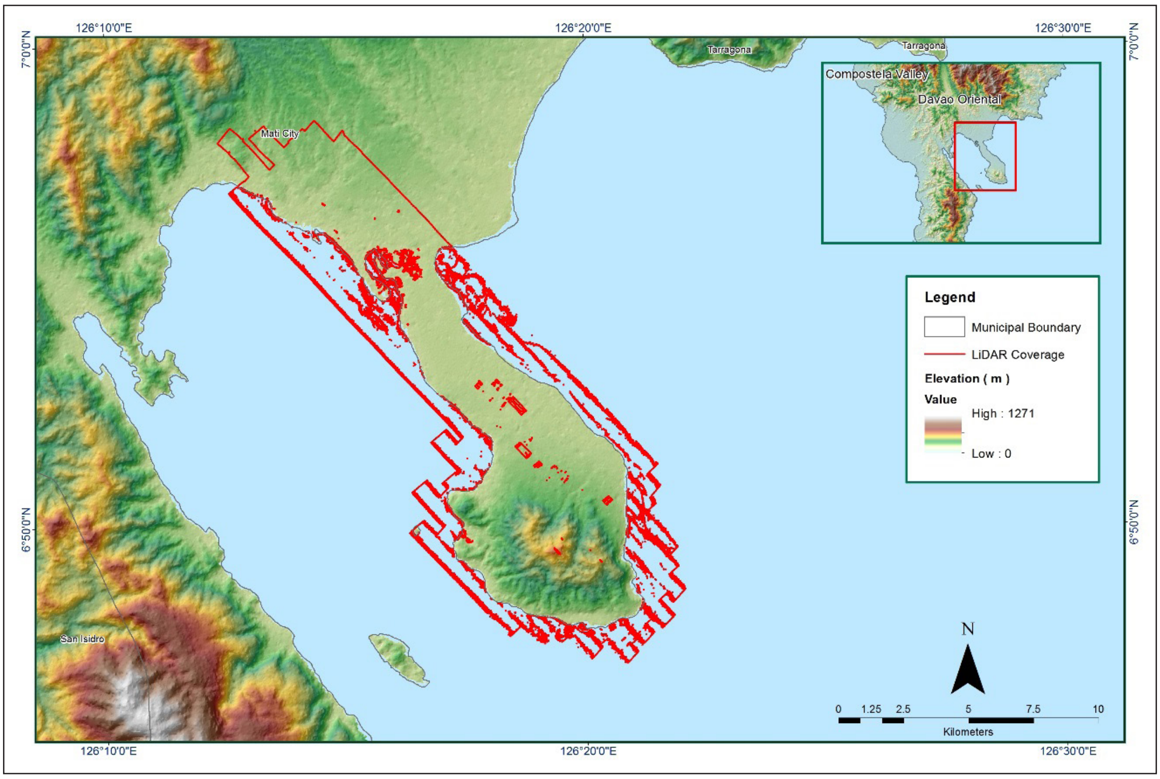
Solution Status



Smoothed Performance Metric Parameters



Best Estimated Trajectory



Coverage of LiDAR data

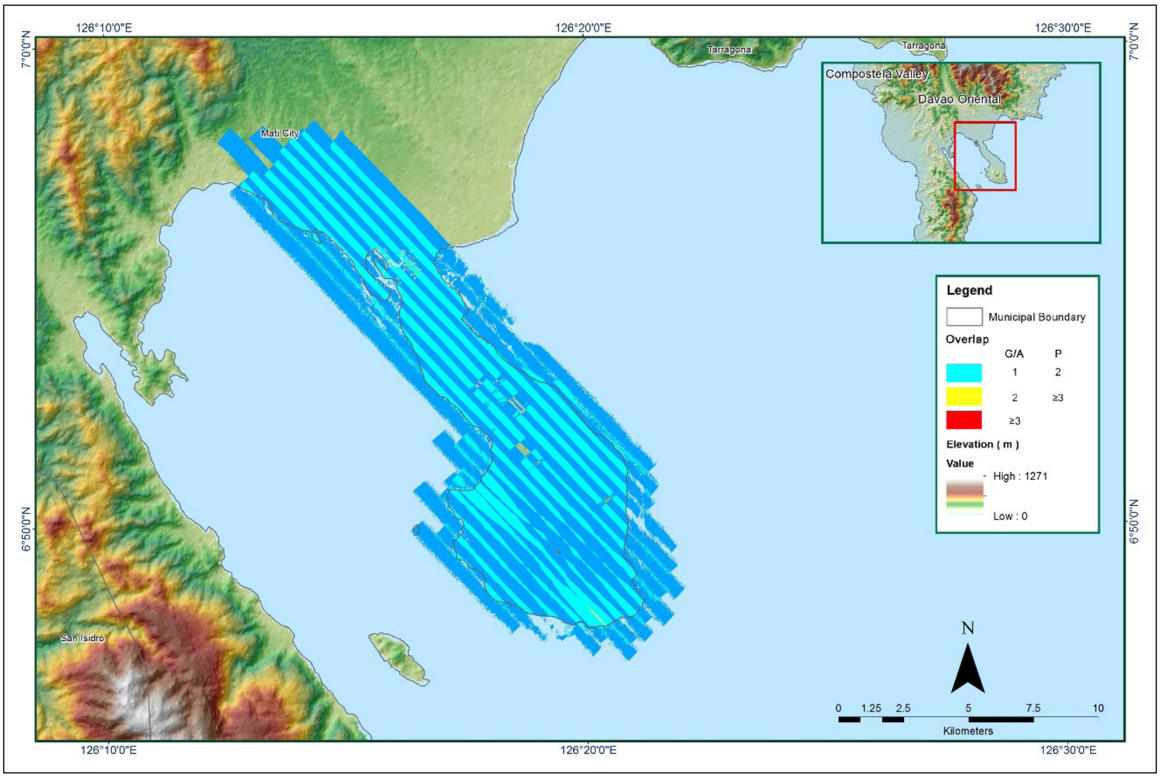
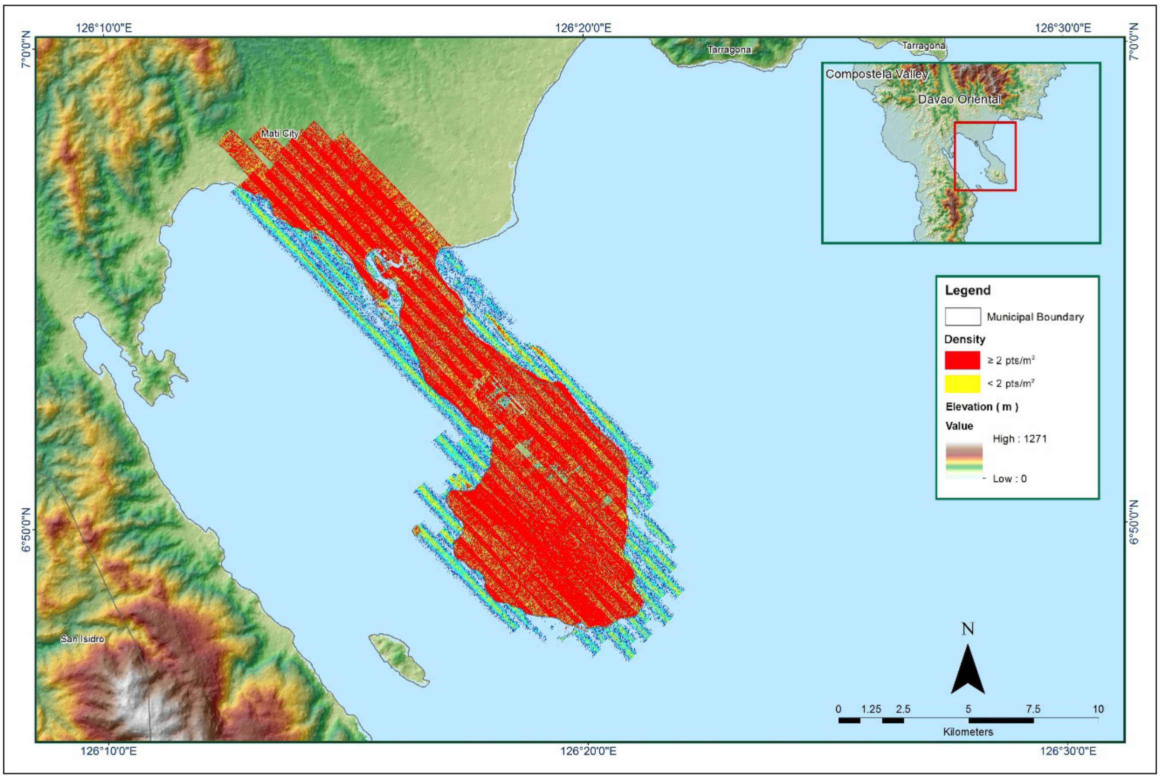
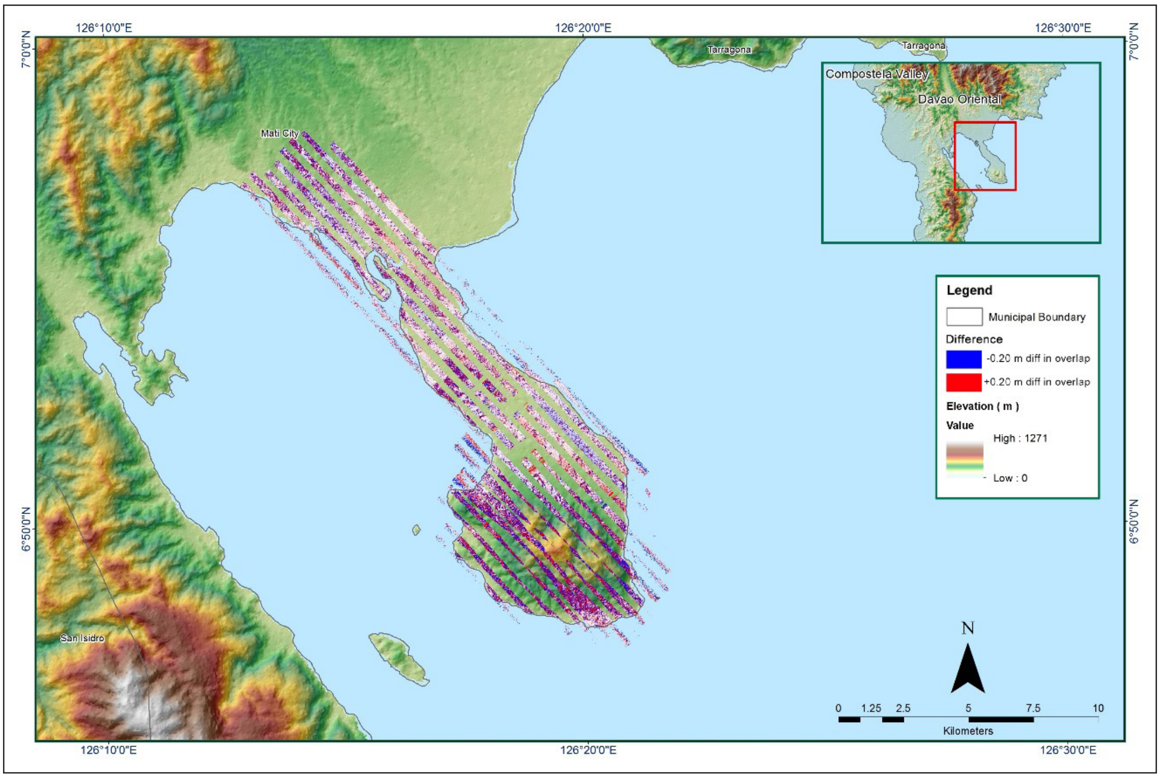


Image of data overlap

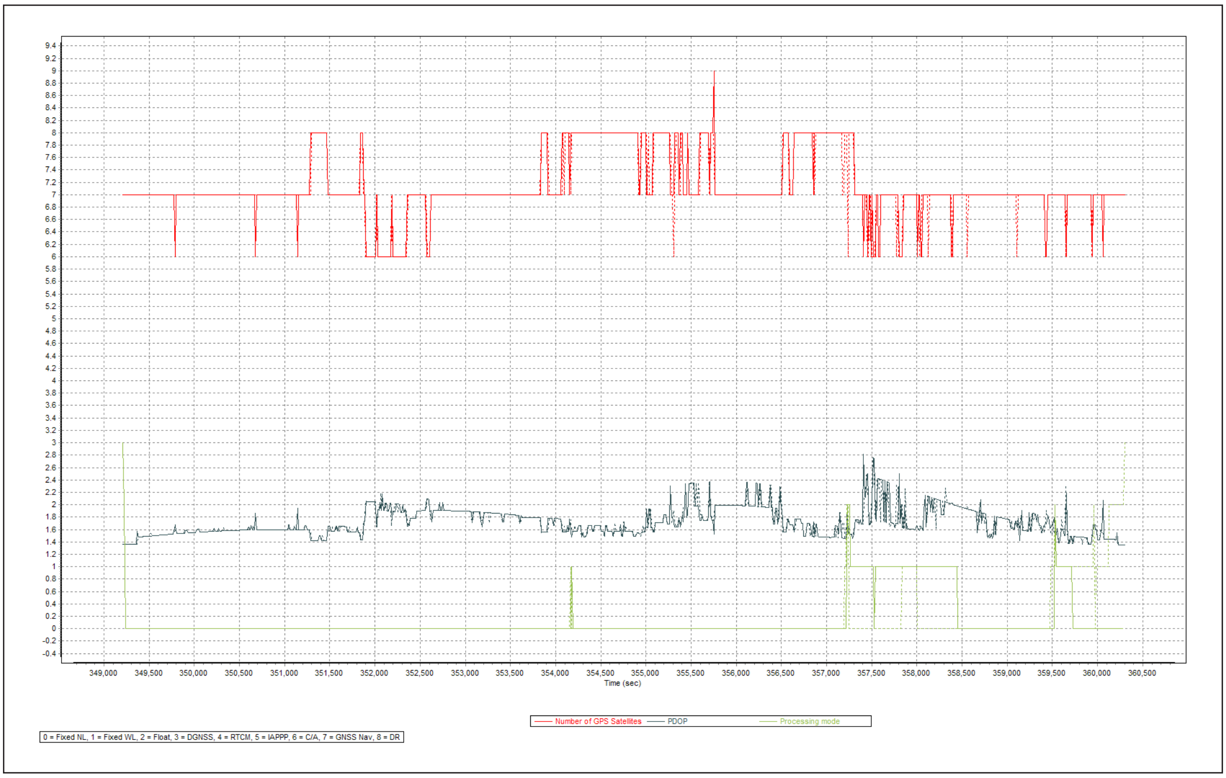


Density map of merged LiDAR data

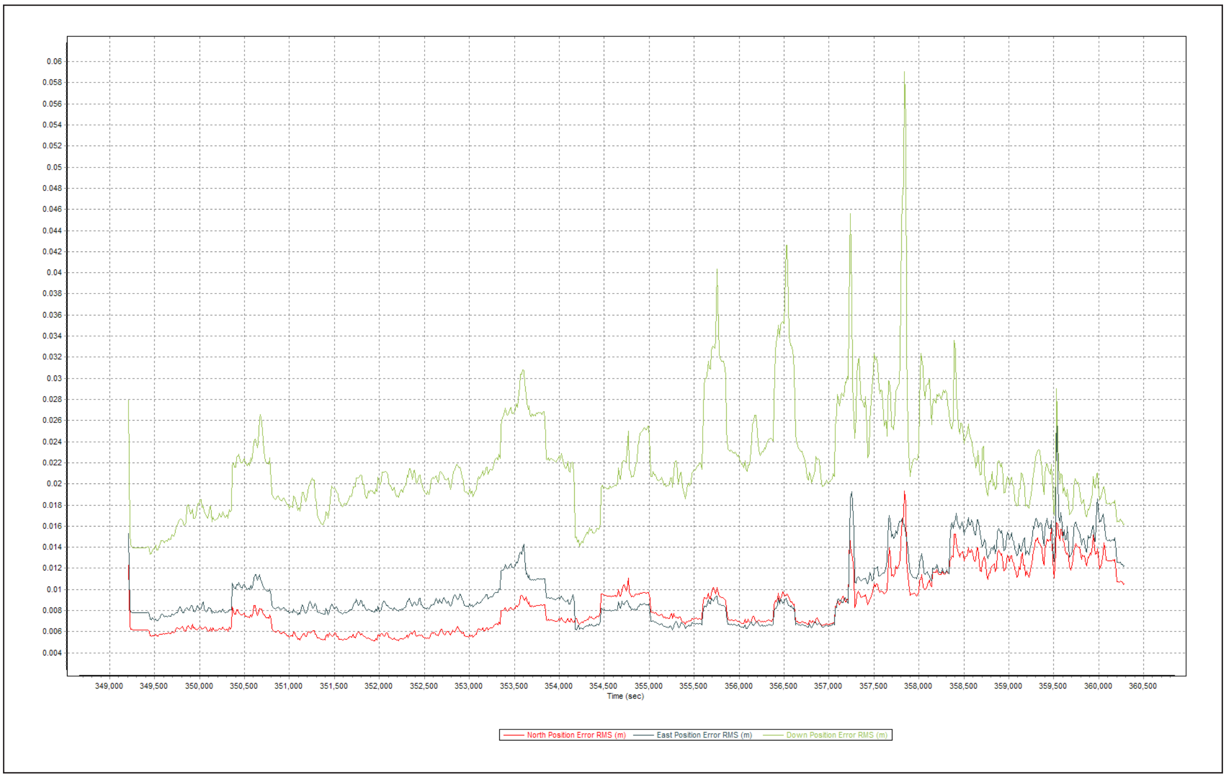


Elevation difference between flight lines

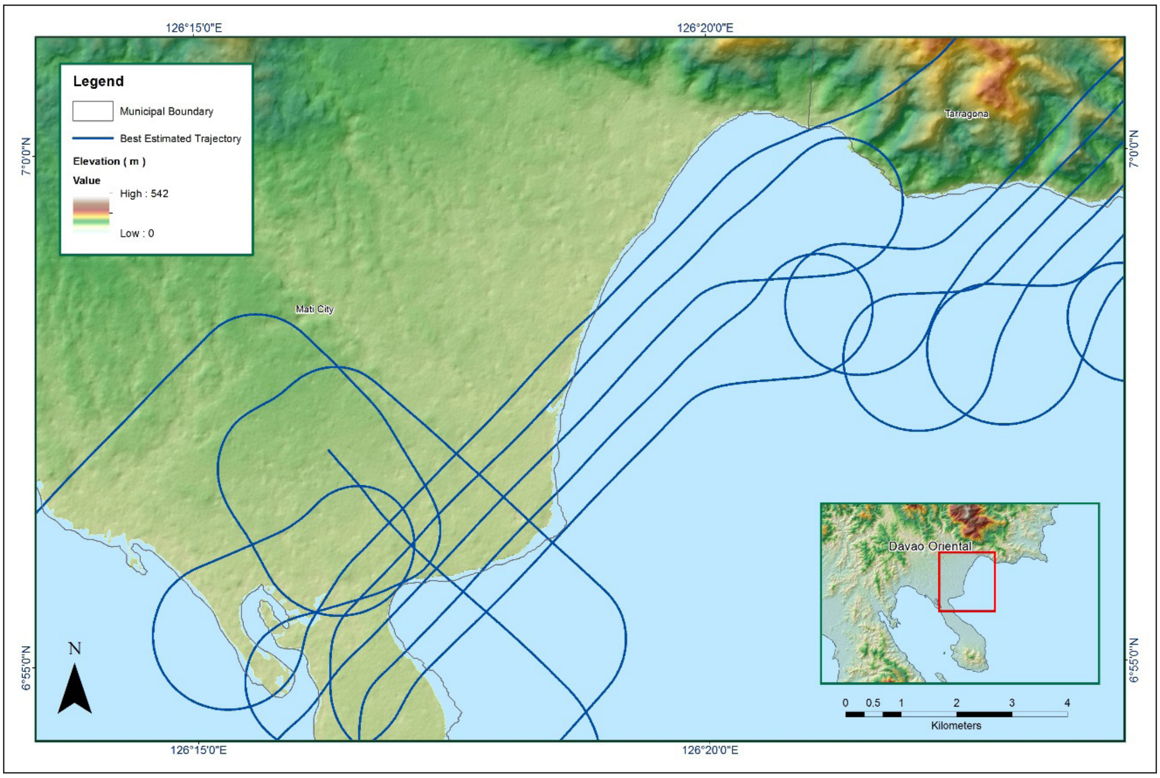
Flight Area	Davao Oriental
Mission Name	Blk84B
Inclusive Flights	7320G
Range data size	13.3 GB
POS	224 MB
Image	na
Transfer date	July 2, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.9
RMSE for East Position (<4.0 cm)	2.85
RMSE for Down Position (<8.0 cm)	5.9
Boresight correction stdev (<0.001deg)	0.001015
IMU attitude correction stdev (<0.001deg)	0.003791
GPS position stdev (<0.01m)	0.0154
Minimum % overlap (>25)	18.56%
Ave point cloud density per sq.m. (>2.0)	2.00
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	55
Maximum Height	174.12 m
Minimum Height	64.32 m
Classification (# of points)	
Ground	8850939
Low vegetation	7945747
Medium vegetation	10023612
High vegetation	14747454
Building	150055
Orthophoto	No
Processed by	Engr. Jennifer Saguran, Engr. Antonio Chua Jr., Engr. Gladys Mae Apat



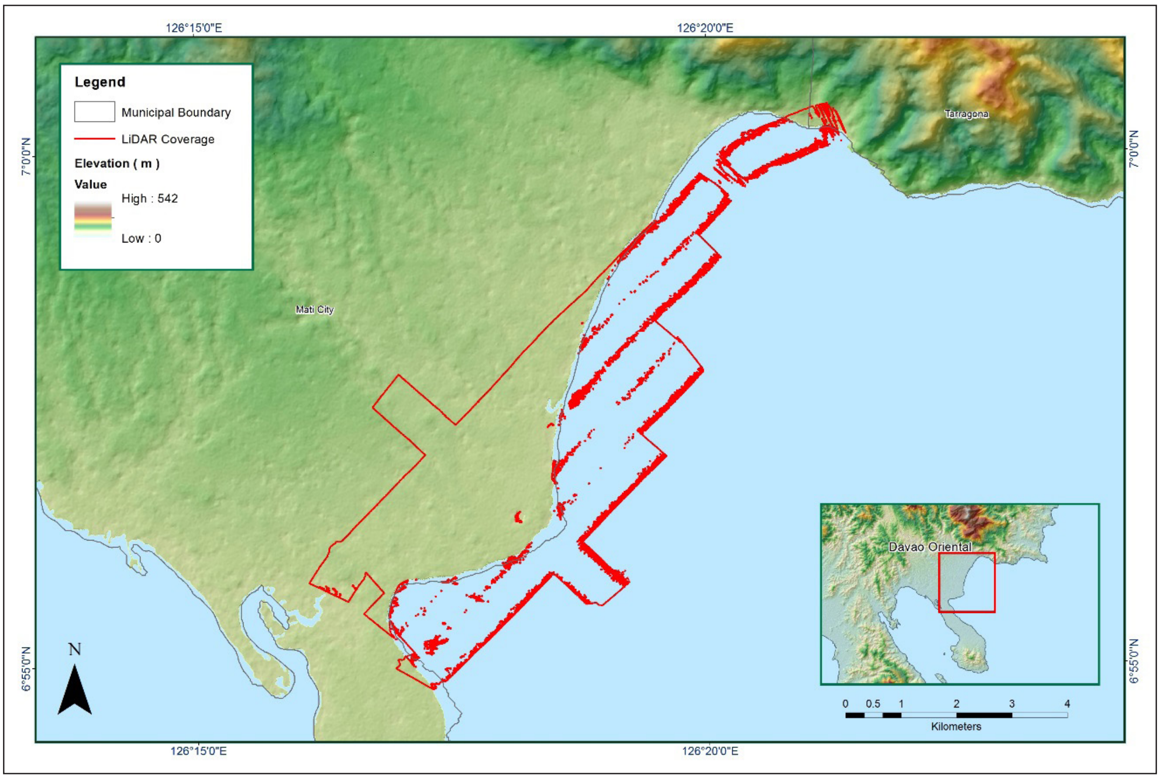
Solution Status



Smoothed Performance Metric Parameters



Best Estimated Trajectory



Coverage of LiDAR data

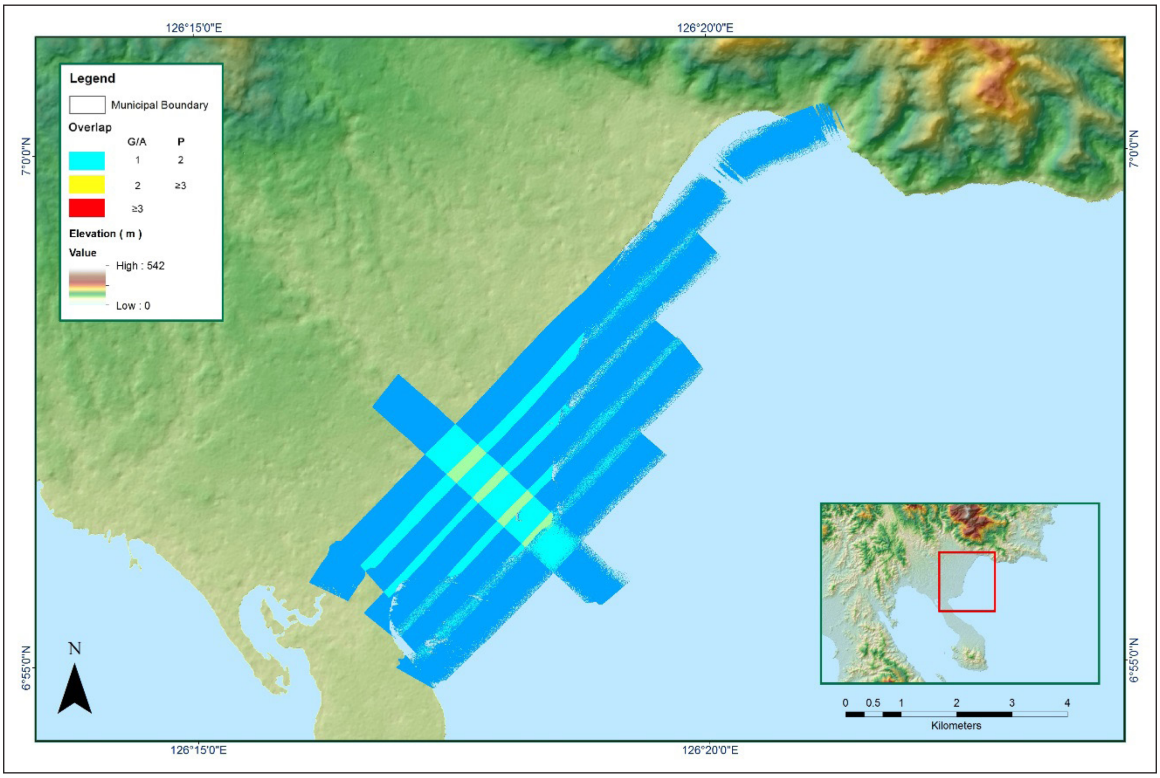
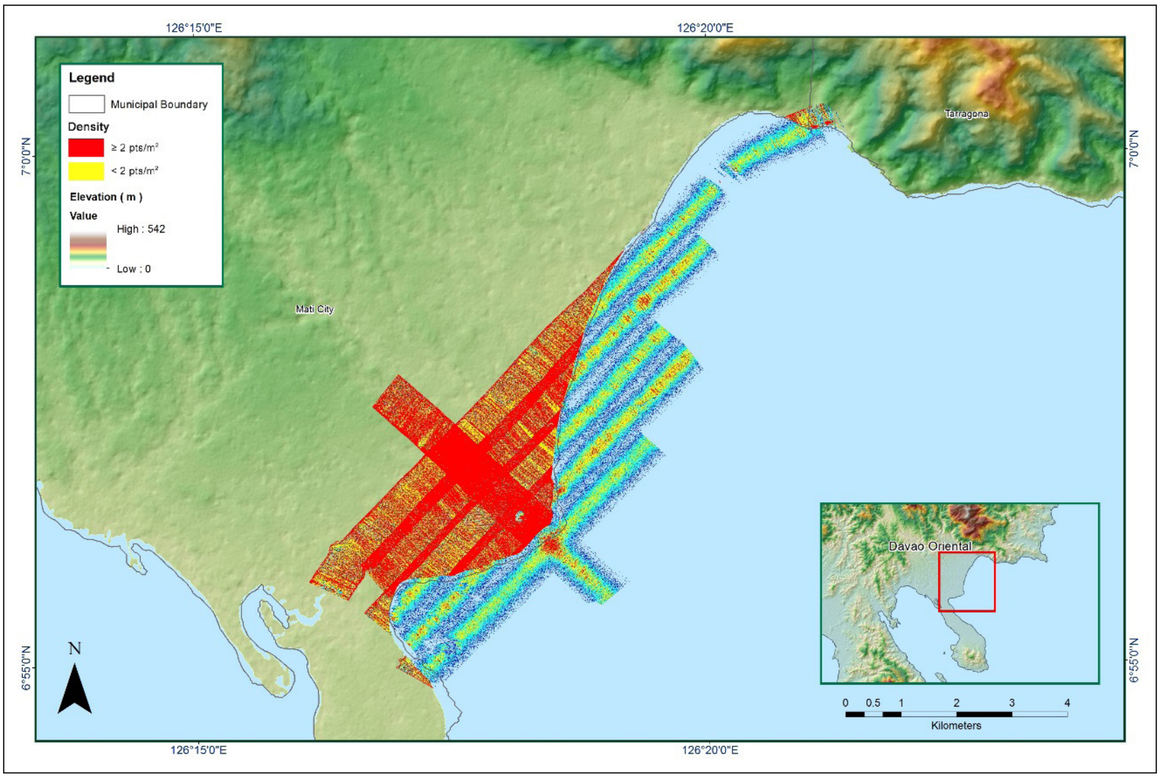
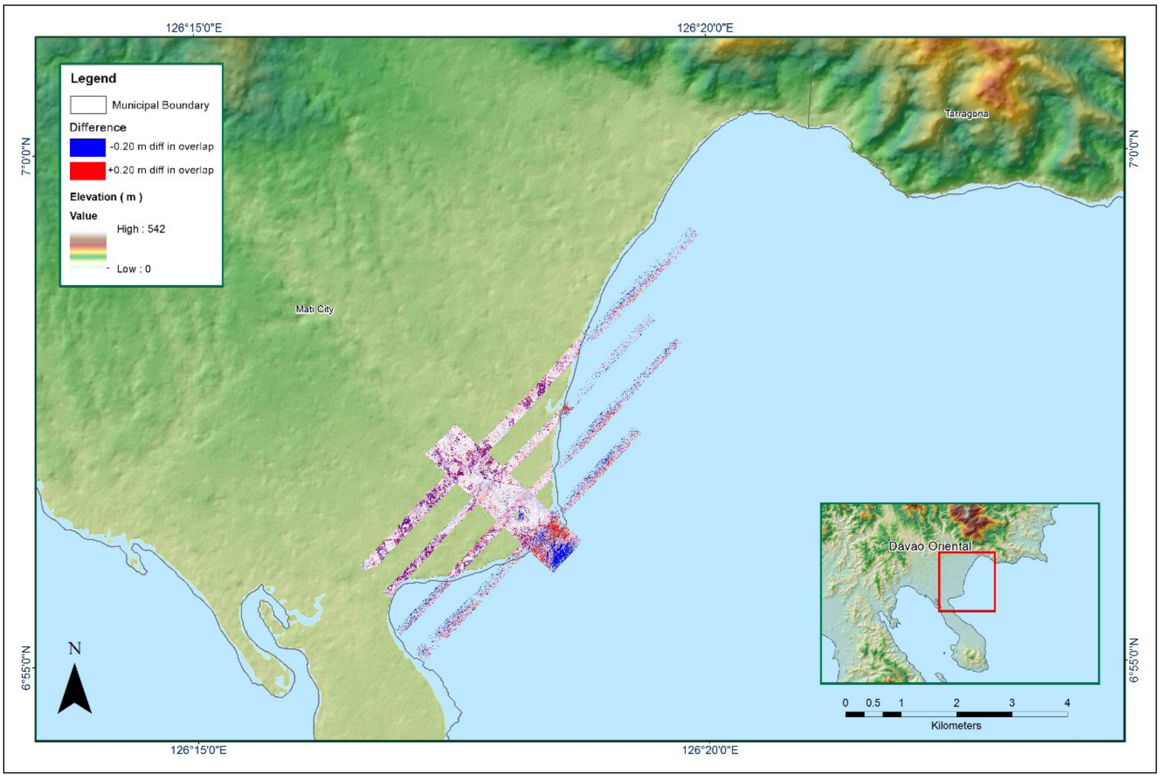


Image of data overlap

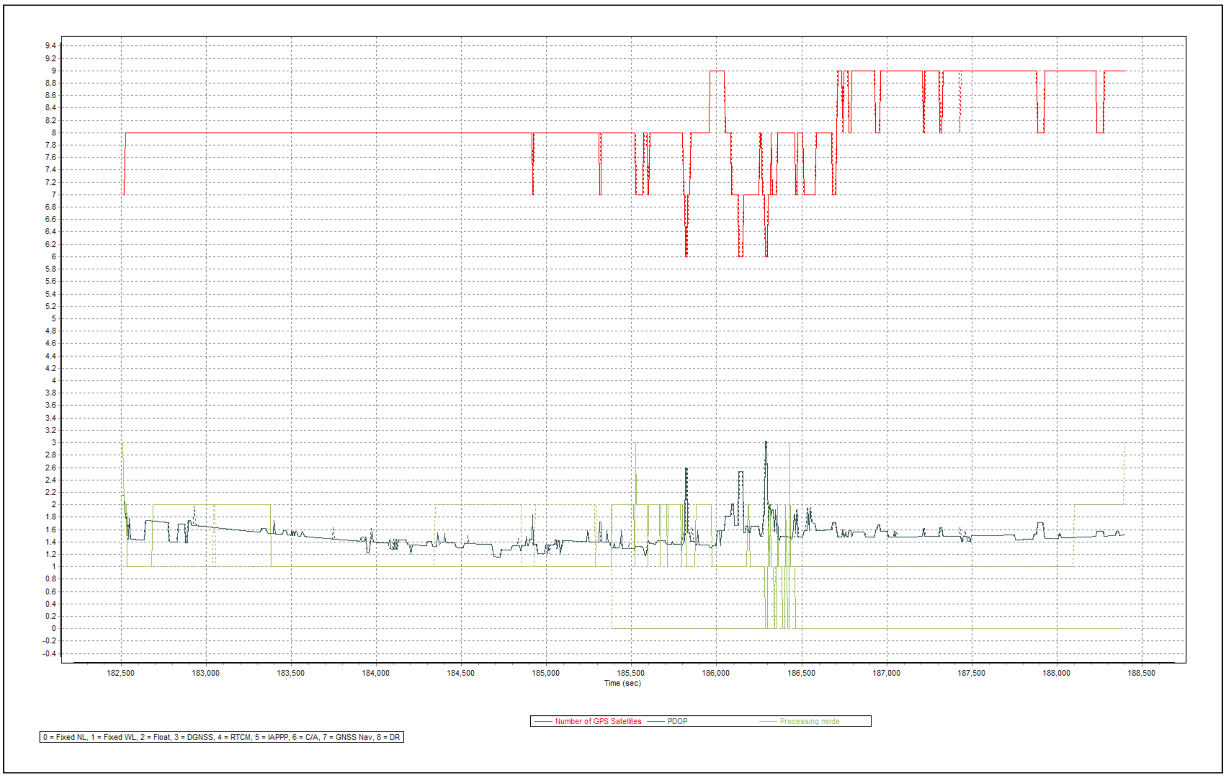


Density map of merged LiDAR data



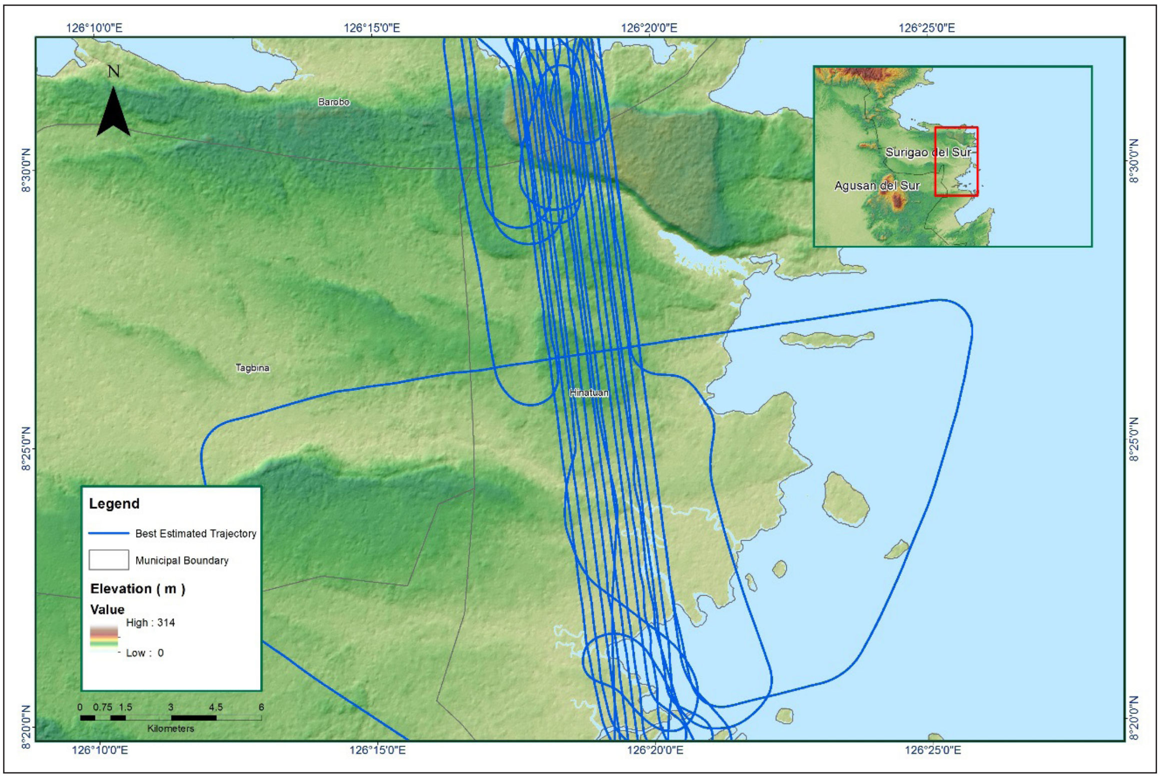
Elevation difference between flight lines

Flight Area	Davao Oriental
Mission Name	Blk84C
Inclusive Flights	7344G
Range data size	9.59 GB
POS	174 MB
Image	na
Transfer date	July 14, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	2.2
RMSE for East Position (<4.0 cm)	1.36
RMSE for Down Position (<8.0 cm)	3.05
Boresight correction stdev (<0.001deg)	0.000261
IMU attitude correction stdev (<0.001deg)	0.000618
GPS position stdev (<0.01m)	0.0085
Minimum % overlap (>25)	3.56
Ave point cloud density per sq.m. (>2.0)	33.97%
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	107
Maximum Height	623.53
Minimum Height	65.88
Classification (# of points)	
Ground	31722177
Low vegetation	20570463
Medium vegetation	43158414
High vegetation	111404774
Building	3500224
Orthophoto	No
Processed by	Engr. Jommer Medina, Engr. Mark Joshua Salvacion, Engr. RoaShalemar Redo

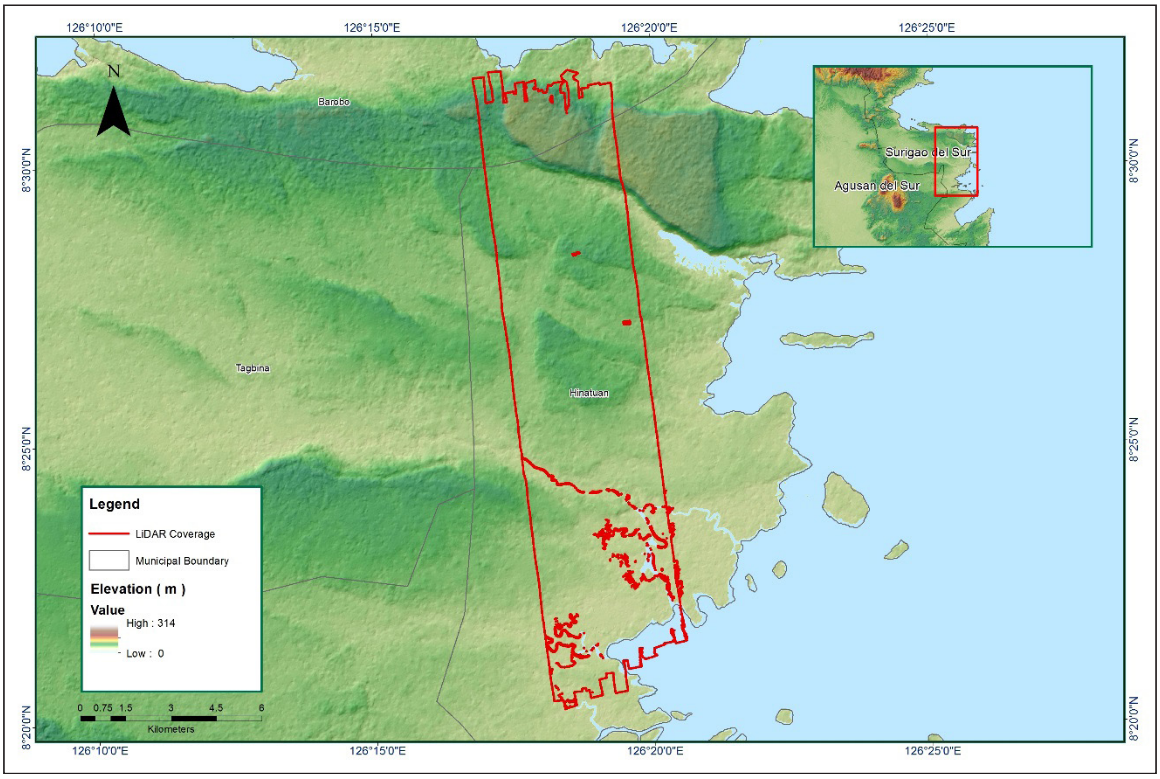


Solution Status

Smoothed Performance Metric Parameters



Best Estimated Trajectory



Coverage of LiDAR data

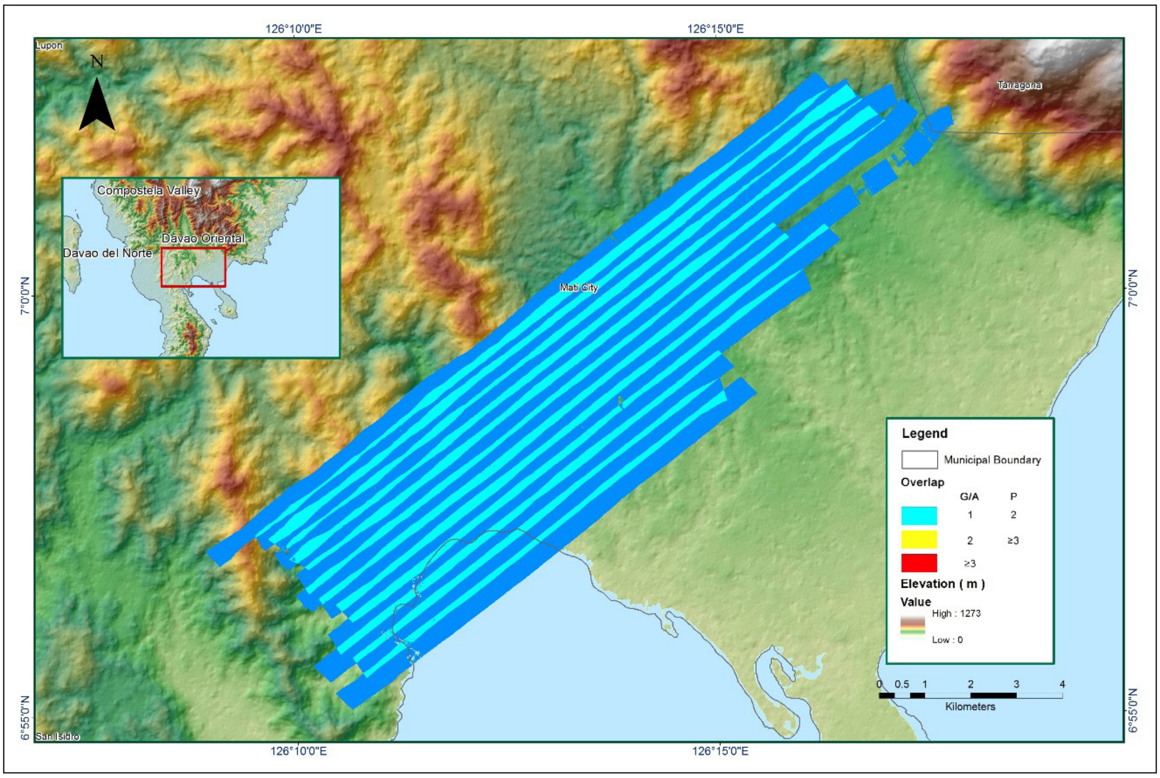
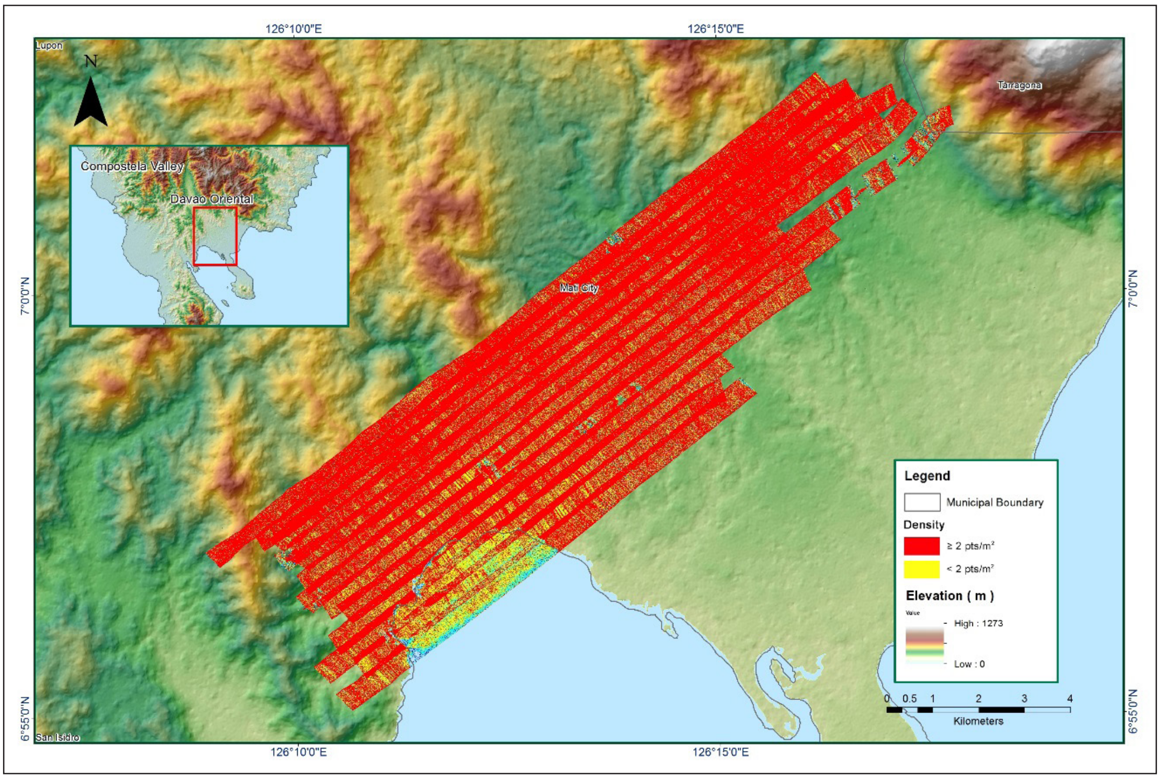
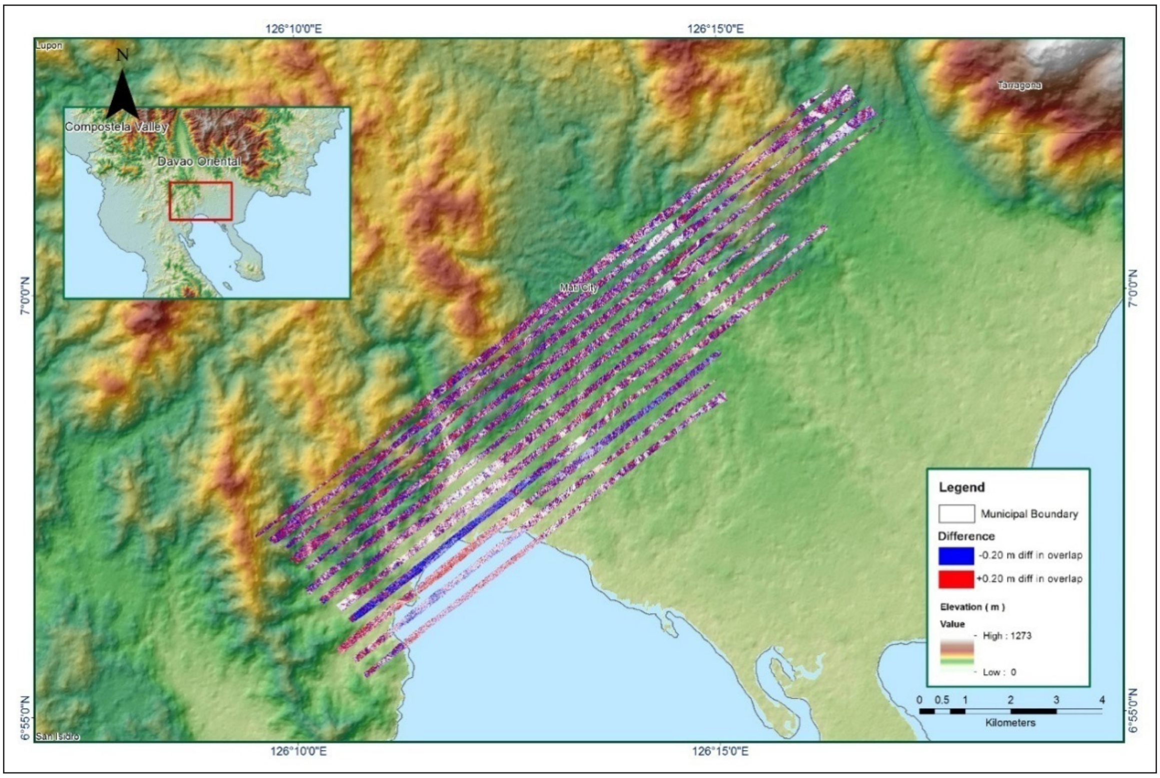


Image of data overlap

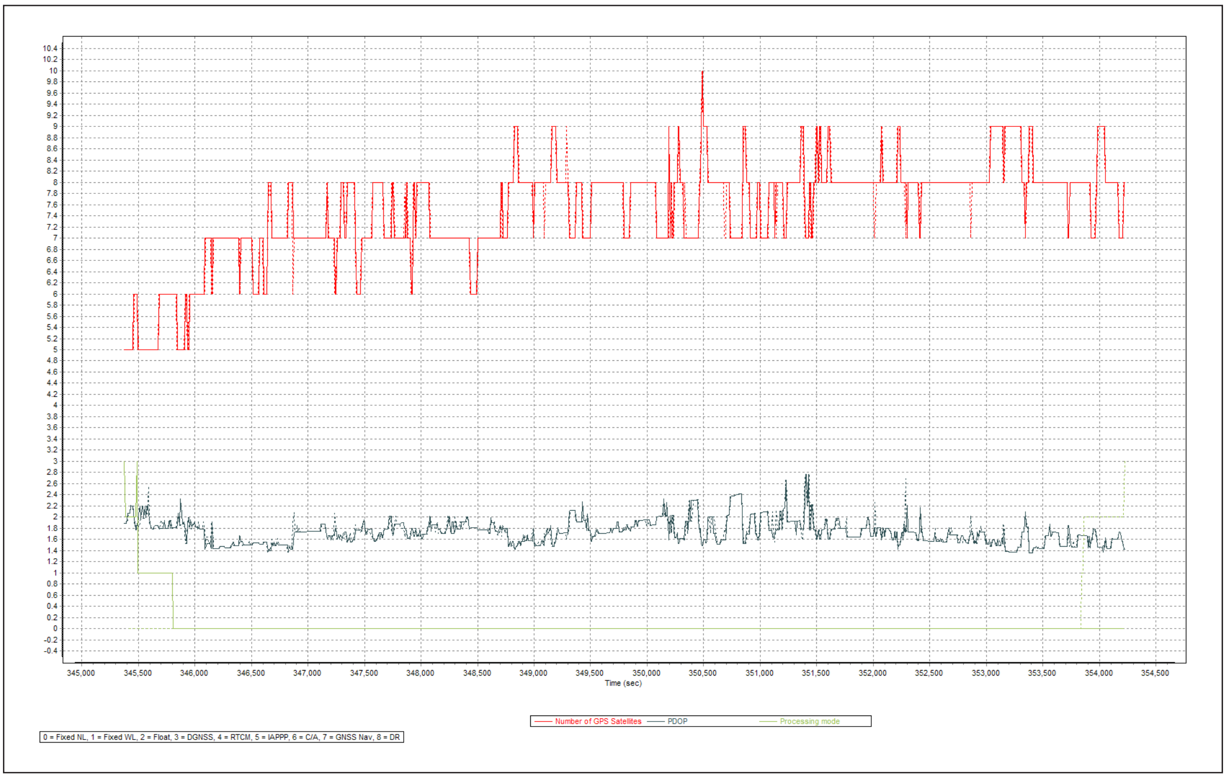


Density map of merged LiDAR data

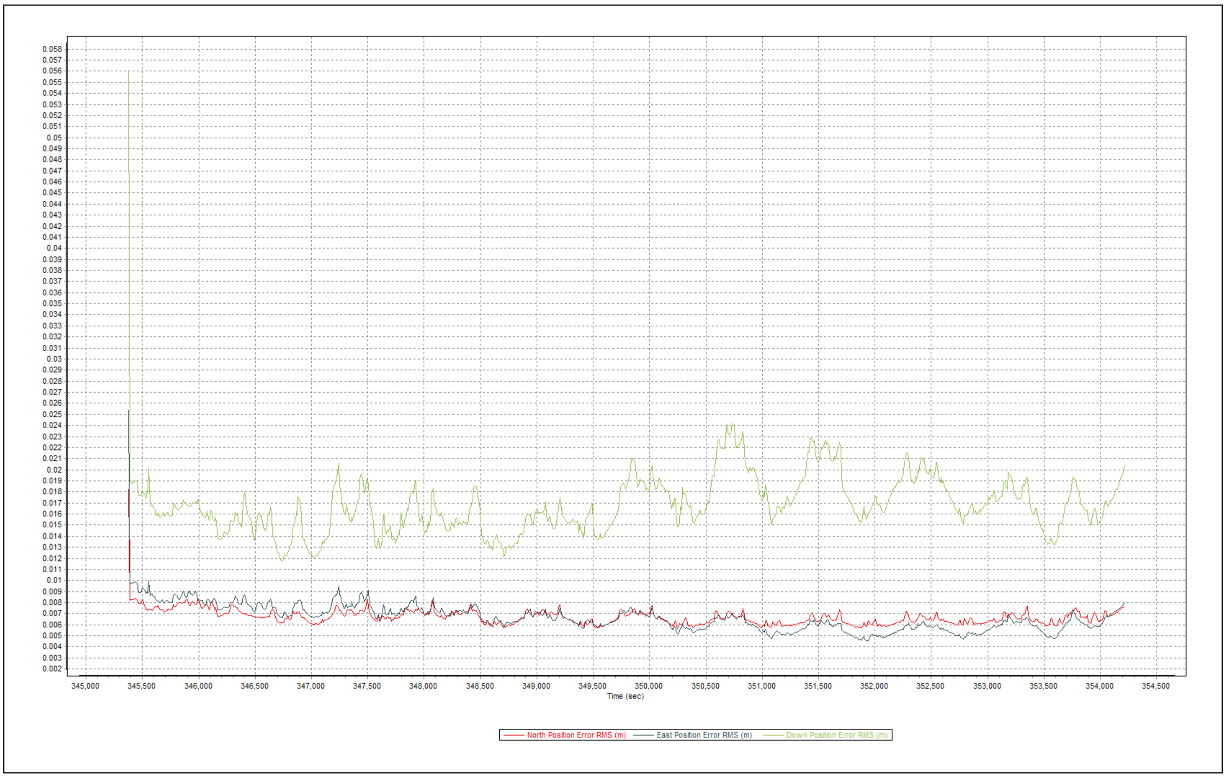


Elevation difference between flight lines

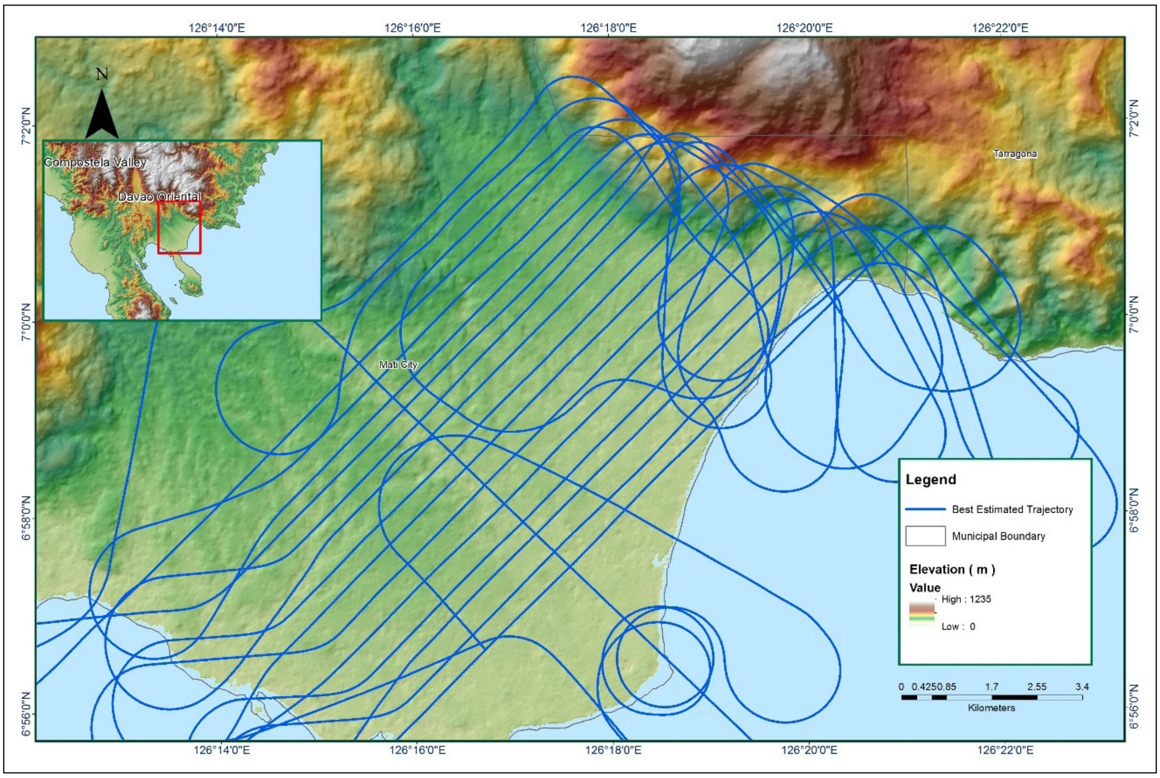
Flight Area	Davao Oriental
Mission Name	Blk85B_Additional
Inclusive Flights	7362G,7364G
Range data size	43.2 GB
POS	395 MB
Image	na
Transfer date	July 28, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	0.085
RMSE for East Position (<4.0 cm)	1.0
RMSE for Down Position (<8.0 cm)	2.4
Boresight correction stdev (<0.001deg)	0.000237
IMU attitude correction stdev (<0.001deg)	0.0074
GPS position stdev (<0.01m)	0.000612
Minimum % overlap (>25)	42.20%
Ave point cloud density per sq.m. (>2.0)	3.63
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	100
Maximum Height	473.31 m
Minimum Height	64.36 m
Classification (# of points)	
Ground	32762250
Low vegetation	26062179
Medium vegetation	36538890
High vegetation	103876886
Building	2730384
Orthophoto	No
Processed by	Engr. Kenneth Solidum, Engr. Melanie Hingpit, Engr. AnalynNaldo



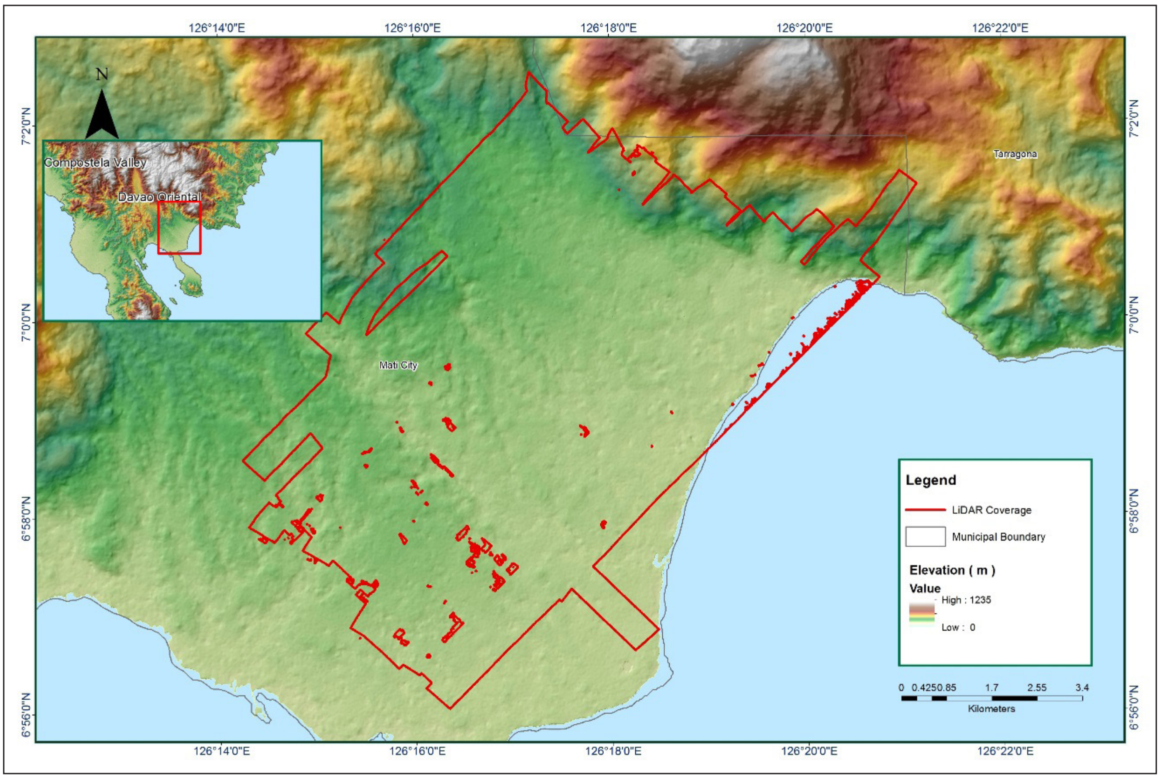
Solution Status



Smoothed Performance Metric Parameters



Best Estimated Trajectory



Coverage of LiDAR data

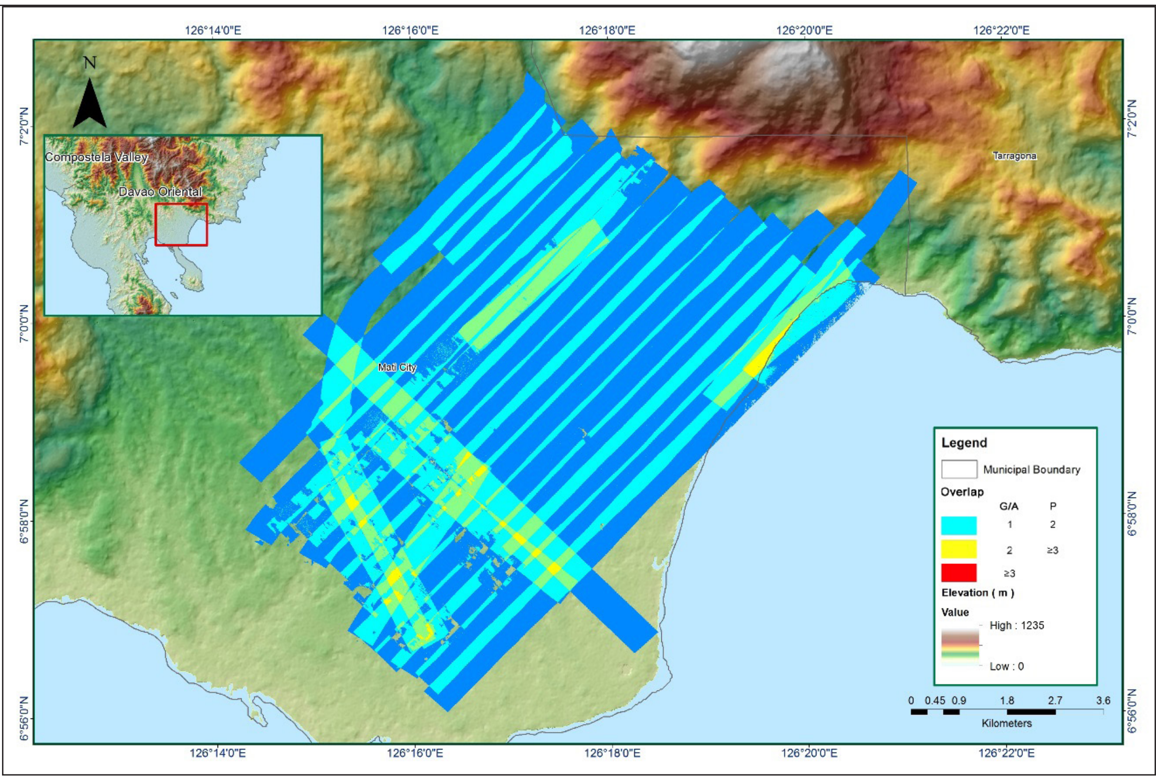
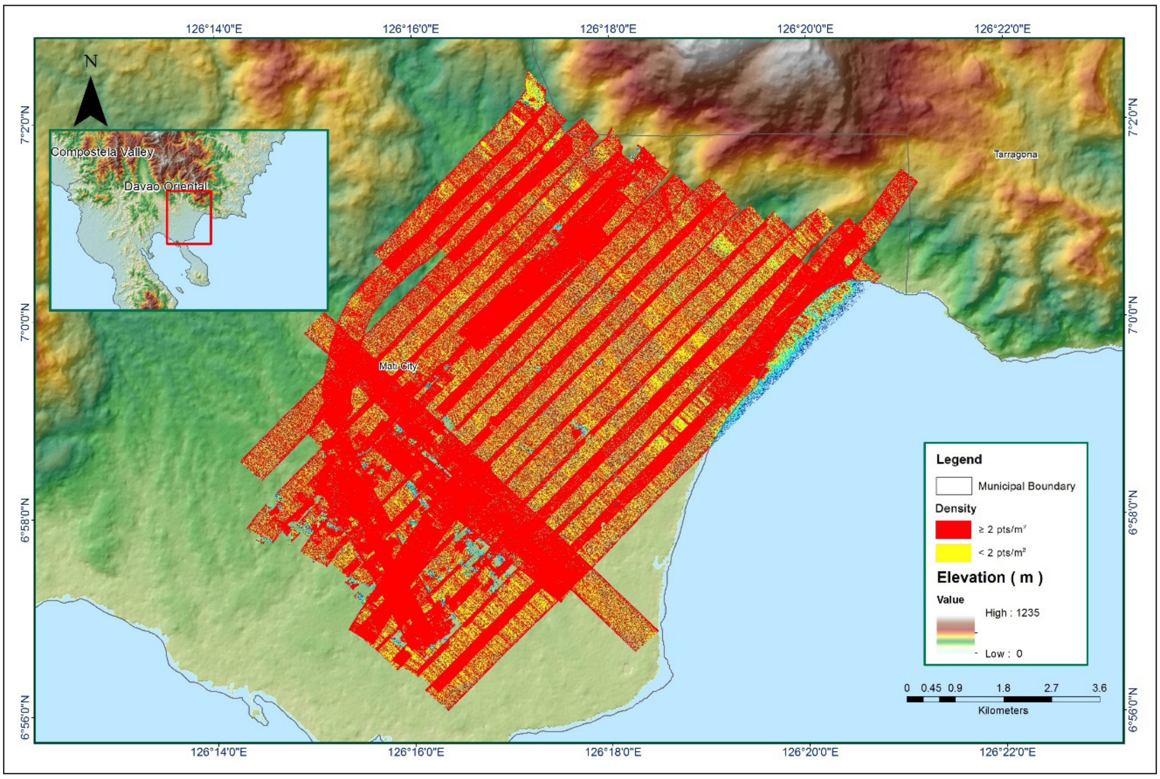
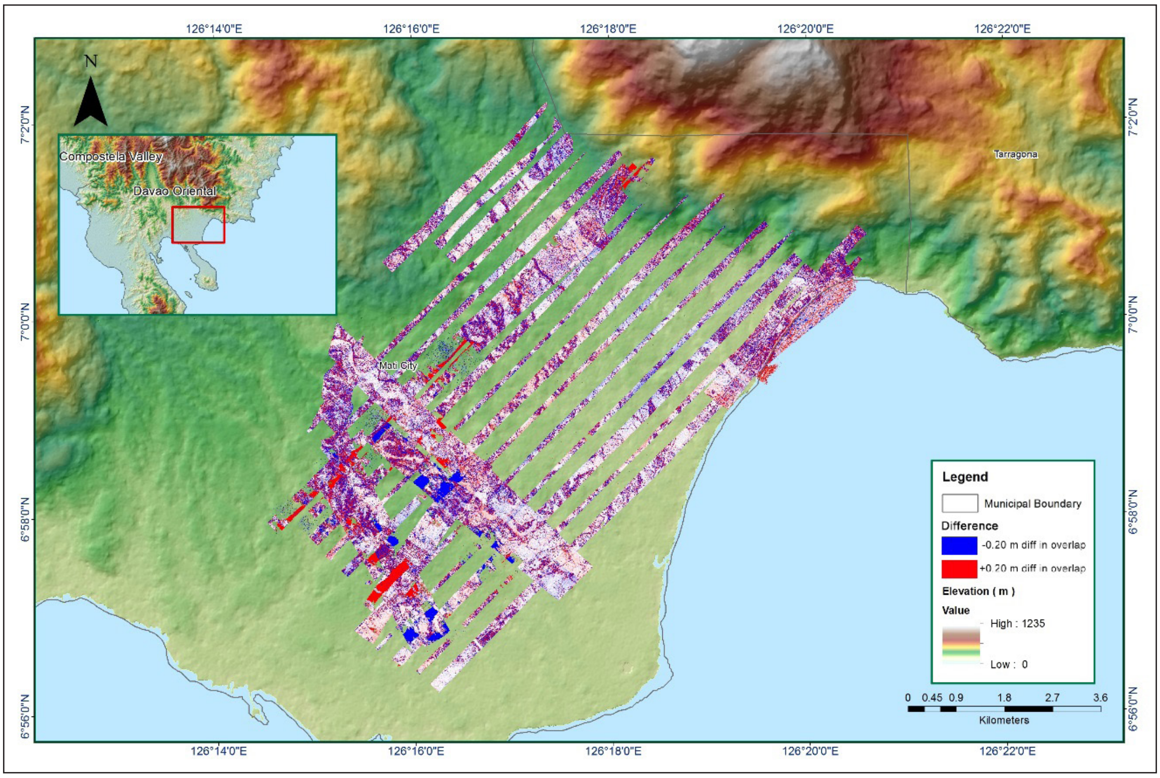


Image of data overlap



Density map of merged LiDAR data



Elevation difference between flight lines

Annex 9. Bitanagan Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (cms)	Recession Constant	Threshold Type	Ratio to Peak
W480	8.5873	59.6594	0	2.4609	4.0162	Discharge	0.002328	0.05	Ratio to Peak	0.5
W490	11.442	52.605	0	1.1724	1.9133	Discharge	0.001179	0.05	Ratio to Peak	0.5
W500	13.425	48.613	0	1.204	1.9648	Discharge	0.000967	0.04	Ratio to Peak	0.5
W510	8.519	59.851	0	1.0882	1.776	Discharge	0.000725	0.05	Ratio to Peak	0.5
W520	9.1269	58.184	0	1.6035	2.617	Discharge	0.001283	0.05	Ratio to Peak	0.5
W530	8.8514	58.928	0	3.837	6.2619	Discharge	0.004603	0.05	Ratio to Peak	0.5
W540	13.758	47.99952	0	0.050834	0.082962	Discharge	1.39E-07	0.05	Ratio to Peak	0.5
W550	8.9842	58.567	0	3.2336	5.2773	Discharge	0.002136	0.05	Ratio to Peak	0.5
W560	9.2196	57.938	0	2.273	3.7096	Discharge	0.002526	0.05	Ratio to Peak	0.5
W570	7.2579	63.633	0	1.6286	2.6579	Discharge	0.000941	0.05	Ratio to Peak	0.5
W580	5.9228	50.793	0	0.83247	2.0481	Discharge	0.00112	0.05	Ratio to Peak	0.5
W590	5.3404	76.43924	0	1.1728	2.7227	Discharge	0.001314	0.05	Ratio to Peak	0.49723
W600	5.3732	77.99922	0	0.20938	0.34171	Discharge	2.23E-05	0.05	Ratio to Peak	0.4975
W610	5.1604	77.99922	0	0.804	1.5089	Discharge	0.000517	0.05	Ratio to Peak	0.5
W620	5.3732	77.99922	0	0.28162	0.45961	Discharge	5.89E-05	0.05	Ratio to Peak	0.5
W630	3.1717	77.60922	0	0.37299	1.05	Discharge	0.000128	0.05	Ratio to Peak	0.4975
W640	3.4755	51.99948	0	1.008	2.4675	Discharge	0.000932	0.05	Ratio to Peak	0.38333
W650	4.5243	74.352	0	0.67443	1.6511	Discharge	0.000298	0.05	Ratio to Peak	0.5635
W660	9.3192	57.676	0	1.4514	2.3687	Discharge	0.000689	0.05	Ratio to Peak	0.5
W670	5.3419	70.435	0	0.73014	1.1916	Discharge	0.000563	0.05	Ratio to Peak	0.5
W680	6.627	74.19	0	1.1314	1.8464	Discharge	0.00072	0.05	Ratio to Peak	0.5
W690	6.4329	74.755	0	1.2019	1.9615	Discharge	0.00141	0.006584	Ratio to Peak	0.5
W700	3.5656	51.99948	0	0.69729	1.1323	Discharge	0.000665	0.05	Ratio to Peak	0.50079
W710	3.5413	76.43924	0	0.82395	1.3652	Discharge	0.000598	0.05	Ratio to Peak	0.4975
W720	3.5821	76.43924	0	0.45856	2.5512	Discharge	0.000758	0.05	Ratio to Peak	0.4975
W730	5.3412	76.53923	0	0.75008	1.2241	Discharge	0.00096	0.05	Ratio to Peak	0.5
W740	3.7031	54.736	0	0.65045	3.4954	Discharge	0.000967	0.008889	Ratio to Peak	0.80421

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (cms)	Recession Constant	Threshold Type	Ratio to Peak
W750	3.8729	51.157	0	1.1607	2.4465	Discharge	0.000787	0.05	Ratio to Peak	0.575
W760	3.967	73.327	0	2.3306	2.5579	Discharge	0.000663	0.019208	Ratio to Peak	0.33333
W770	3.9503	45.864	0	1.541	2.5149	Discharge	0.000375	0.031216	Ratio to Peak	0.4802
W780	3.4811	75.521	0	1.057	0.96473	Discharge	0.002184	0.014815	Ratio to Peak	0.091094
W790	4.31	78.385	0	1.1677	1.916	Discharge	0.000925	0.01474	Ratio to Peak	0.20044
W800	6.6042	79.601	0	1.1875	1.2976	Discharge	0.000422	0.0195	Ratio to Peak	0.49
W810	3.8157	73.95	0	1.7331	1.9496	Discharge	0.000184	0.02	Ratio to Peak	0.30131
W820	3.7994	50.374	0	2.079	2.3662	Discharge	5.59E-04	0.032823	Ratio to Peak	0.20646
W830	4.8212	76.706	0	3.0138	0.95612	Discharge	4.35E-04	0.033497	Ratio to Peak	0.30231
W840	3.8304	73.95	0	4.5852	1.5238	Discharge	0.000212	0.022222	Ratio to Peak	0.4428
W850	3.5885	75.03925	0	4.753	5.1065	Discharge	0.000516	0.022222	Ratio to Peak	0.31896
W860	3.8307	73.95	0	0.19234	0.8022	Discharge	9.33E-06	0.0196	Ratio to Peak	0.31821
W870	4.5188	77.694	0	4.6683	2.2652	Discharge	0.000574	0.033333	Ratio to Peak	0.22333
W880	3.6559	74.313	0	0.55669	0.88024	Discharge	0.000651	0.021778	Ratio to Peak	0.21116
W890	2.5402	82.521	0	0.46323	0.79465	Discharge	0.000606	0.032013	Ratio to Peak	0.49159
W900	2.5414	98.99901	0	0.1763	0.63744	Discharge	3.90E-05	0.04706	Ratio to Peak	0.74545
W910	4.268	53.42	0	0.3019	1.3673	Discharge	0.000503	0.032825	Ratio to Peak	0.47321
W920	3.7935	75.45925	0	3.4115	1.12	Discharge	0.000692	0.047514	Ratio to Peak	0.50293
W930	3.4768	77.046	0	3.6504	0.97164	Discharge	0.001149	0.032325	Ratio to Peak	0.22316
W940	3.7357	73.95	0	1.1362	1.2254	Discharge	0.000105	0.051221	Ratio to Peak	0.98064

Annex 10. Bitanagan Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R100	Automatic Fixed Interval	986.4	0.019495	0.054472	Trapezoid	38	0.5
R120	Automatic Fixed Interval	307.99	0.009294	0.054472	Trapezoid	38	0.5
R140	Automatic Fixed Interval	604.56	0.017319	0.054472	Trapezoid	38	0.5
R160	Automatic Fixed Interval	1385.4	0.019955	0.054472	Trapezoid	38	0.5
R170	Automatic Fixed Interval	1079.1	0.007612	0.054472	Trapezoid	38	0.5
R210	Automatic Fixed Interval	3867.5	0.02409	0.054472	Trapezoid	38	0.5
R220	Automatic Fixed Interval	2130.4	0.019202	0.054472	Trapezoid	38	0.5
R260	Automatic Fixed Interval	1680.7	0.014385	0.054472	Trapezoid	38	0.5
R270	Automatic Fixed Interval	8401.5	0.047241	0.054472	Trapezoid	38	0.5
R280	Automatic Fixed Interval	657.7	0.013401	0.054472	Trapezoid	38	0.5
R300	Automatic Fixed Interval	1300.2	0.009504	0.054472	Trapezoid	38	0.5
R310	Automatic Fixed Interval	4199.3	0.010873	0.054472	Trapezoid	38	0.5
R330	Automatic Fixed Interval	812.55	0.013447	0.054472	Trapezoid	38	0.5
R350	Automatic Fixed Interval	1051.5	0.003152	0.054472	Trapezoid	38	0.5
R370	Automatic Fixed Interval	883.55	0.003579	0.054472	Trapezoid	38	0.5
R380	Automatic Fixed Interval	214.85	0.015501	0.054472	Trapezoid	38	0.5
R420	Automatic Fixed Interval	1773.5	0.00551	0.054472	Trapezoid	38	0.5
R430	Automatic Fixed Interval	307.28	0.001	0.054472	Trapezoid	38	0.5

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R460	Automatic Fixed Interval	520.92	0.001	0.054472	Trapezoid	38	0.5
R470	Automatic Fixed Interval	2291.1	0.006388	0.054472	Trapezoid	38	0.5
R50	Automatic Fixed Interval	14.142	0.001	0.054472	Trapezoid	38	0.5
R70	Automatic Fixed Interval	4740.7	0.025967	0.054472	Trapezoid	38	0.5
R80	Automatic Fixed Interval	321.42	0.064645	0.054472	Trapezoid	38	0.5

Annex 11. Bitanagan Field Validation Points

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error (m)	Event/Date	Rain Return/ Scenario
	Lat	Long					
1	6.966109	126.2937	0.03	0	0.0009		25-Year
2	6.959725	126.3086	0.03	0	0.0009		25-Year
3	6.960166	126.3078	0.03	0	0.0009		25-Year
4	6.960624	126.3075	0.04	0	0.0016		25-Year
5	6.961445	126.2977	0.35	0	0.1225		25-Year
6	6.963077	126.2967	0.03	0	0.0009		25-Year
7	6.96534	126.2943	0.05	0	0.0025		25-Year
8	6.961964	126.2973	0.2	0	0.04		25-Year
9	6.959676	126.3082	0.53	0	0.2809		25-Year
10	6.959421	126.3084	0.5	0.6	0.01	Pablo/ December 2012	25-Year
11	6.963407	126.2946	0.9	0	0.81		25-Year
12	6.959717	126.308	1.15	0	1.3225		25-Year
13	6.960626	126.3071	1.27	1.5	0.0529	Buhawi/ August 2013	25-Year
14	6.96106	126.3071	1.41	1.5	0.0081	Buhawi/ August 2013	25-Year
15	6.959535	126.3079	1.51	0.3	1.4641	Pablo/ December 2012	25-Year
16	6.959462	126.308	1.54	0.3	1.5376	Pablo/ December 2012	25-Year
17	6.964012	126.3	1.61	1.5	0.0121	Intense local rainfall	25-Year
18	6.964011	126.2985	1.87	1.5	0.1369	Intense local rainfall	25-Year
19	6.964021	126.2996	1.9	1.5	0.16	Intense local rainfall	25-Year
20	6.960469	126.307	2.15	1.5	0.4225	Buhawi/ August 2013	25-Year
21	6.958719	126.3084	2.4	2	0.16		25-Year
22	6.963016	126.2942	2.72	2	0.5184		25-Year
23	6.960822	126.307	2.52	1.5	1.0404	Buhawi/ August 2013	25-Year
24	6.961505	126.3064	2.69	2	0.4761	Yolanda/ November 2013	25-Year
25	6.961641	126.2965	3	2	1	Intense local rainfall/ 2009	25-Year
26	6.961042	126.2974	3.02	2	1.0404	Intense local rainfall/ 2009	25-Year
27	6.962073	126.2948	3.18	2	1.3924	Intense local rainfall/ 2009	25-Year
28	6.993334	126.2585	0.49	0	0.2401		25-Year
29	6.993327	126.2594	0.63	0	0.3969		25-Year
30	6.993473	126.2603	0.66	0	0.4356		25-Year
31	6.993032	126.2579	0.81	0	0.6561		25-Year
32	6.996664	126.2546	6.06	5	1.1236		25-Year
33	6.999488	126.2505	5.37	5	0.1369		25-Year
34	6.999124	126.2508	7.4	5	5.76		25-Year
35	6.994098	126.2558	6.12	5	1.2544		25-Year
36	6.99625	126.2547	6.67	5.5	1.3689		25-Year
37	6.995053	126.256	6.89	5.5	1.9321		25-Year
38	6.995974	126.2558	6.87	5.5	1.8769		25-Year
39	6.996217	126.2552	6.97	5.5	2.1609		25-Year
40	6.99567	126.256	6.99	5.5	2.2201		25-Year
41	6.985866	126.2568	0.03	0	0.0009		25-Year
42	6.986515	126.2541	0.03	0	0.0009		25-Year
43	6.987641	126.2531	0.03	0	0.0009		25-Year
44	6.984576	126.2568	0.03	0	0.0009		25-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error (m)	Event/Date	Rain Return/ Scenario
	Lat	Long					
45	6.981418	126.2573	0.04	0	0.0016		25-Year
46	6.985508	126.2551	0.05	0	0.0025		25-Year
47	6.990357	126.257	0.69	0.25	0.1936		25-Year
48	6.989705	126.2575	0.72	0.25	0.2209		25-Year
49	6.987128	126.2595	0.99	0.75	0.0576	Yolanda/ November 2013	25-Year
50	6.984452	126.2633	0.81	0.5	0.0961		25-Year
51	6.989492	126.2555	0.7	0.5	0.04	Intense local rainfall	25-Year
52	6.988448	126.2563	1.04	0.5	0.2916	Intense local rainfall/ January 2017	25-Year
53	6.983569	126.2625	1.13	0.5	0.3969		25-Year
54	6.988762	126.2576	1.25	0.5	0.5625	Intense local rainfall/ January 2017	25-Year
55	6.989951	126.2567	1.25	0.5	0.5625	Intense local rainfall/ January 2017	25-Year
56	6.984442	126.262	1.44	0.5	0.8836		25-Year
57	6.989261	126.2553	1.34	0.9	0.1936	Yolanda/ November 2013	25-Year
58	6.987529	126.259	1.66	1	0.4356	Yolanda/ November 2013	25-Year
59	6.982142	126.263	2.3	1.5	0.64	Yolanda/ November 2013	25-Year
60	6.984461	126.2638	2.64	2	0.4096		25-Year
61	6.98779	126.2597	2.72	2	0.5184	Yolanda/ November 2013	25-Year
62	6.984781	126.2646	2.87	3	0.0169		25-Year
63	6.996365	126.2491	5	3	4	Intense local rainfall/ May 2013	25-Year
64	6.989639	126.2587	3.16	3	0.0256		25-Year
65	6.995565	126.2493	5.14	3	4.5796	Intense local rainfall/ May 2013	25-Year
66	6.983952	126.2636	3.67	3	0.4489		25-Year
67	6.997367	126.2522	4.75	3	3.0625		25-Year
68	6.9909	126.2568	3.67	3	0.4489		25-Year
69	6.983519	126.2632	3.75	3	0.5625		25-Year
70	6.994974	126.2545	4.33	3	1.7689		25-Year
71	6.987474	126.2608	3.96	3.5	0.2116		25-Year
72	6.995985	126.2508	5.49	3	6.2001	Yolanda/ November 2013	25-Year
73	6.995767	126.2533	6.34	5	1.7956		25-Year
74	6.998032	126.2505	7.15	5	4.6225		25-Year
75	6.996043	126.2518	6.93	5.25	2.8224		25-Year
76	6.996908	126.2511	7.34	5.25	4.3681		25-Year
77	6.998671	126.251	7.52	5.25	5.1529		25-Year
78	6.996772	126.2518	7.19	5.25	3.7636		25-Year
79	6.998314	126.2509	7.62	5.25	5.6169		25-Year
80	6.996055	126.2527	7.12	5.5	2.6244		25-Year
81	6.983241	126.2695	0.76	0.75	0.0001	Agaton/ January 2014	25-Year
82	6.982198	126.2659	0.79	0.75	0.0016	Agaton/ January 2014	25-Year
83	6.982013	126.2689	0.77	0.75	0.0004	Agaton/ January 2014	25-Year
84	6.983241	126.2695	0.68	0.75	0.0049	Agaton/ January 2014	25-Year
85	6.982198	126.2659	0.7	0.75	0.0025	Agaton/ January 2014	25-Year
86	6.980192	126.2672	5.06	5	0.0036	Agaton/ January 2014	25-Year
87	6.979813	126.2686	5.52	5	0.2704	Agaton/ January 2014	25-Year
88	6.978487	126.2689	5.53	5	0.2809	Agaton/ January 2014	25-Year
89	6.979004	126.2688	5.58	5	0.3364	Agaton/ January 2014	25-Year
90	6.979425	126.2687	5.61	5	0.3721	Agaton/ January 2014	25-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error (m)	Event/Date	Rain Return/ Scenario
	Lat	Long					
91	6.95653	126.2846	0.03	0	0.0009		25-Year
92	6.956863	126.2849	0.04	0	0.0016		25-Year
93	6.957123	126.2947	0.03	0	0.0009		25-Year
94	6.956471	126.2978	0.04	0	0.0016		25-Year
95	6.955559	126.297	0.03	0	0.0009		25-Year
96	6.960199	126.2922	0.03	0	0.0009		25-Year
97	6.960166	126.2906	0.06	0	0.0036		25-Year
98	6.959796	126.2903	0.07	0	0.0049		25-Year
99	6.957522	126.2927	0.14	0	0.0196		25-Year
100	6.958217	126.2924	0.15	0	0.0225		25-Year
101	6.959024	126.2919	0.68	0	0.4624		25-Year
102	6.961594	126.2814	0.58	0.2	0.1444	Intense local rainfall/ 1980s	25-Year
103	6.96049	126.2817	0.97	0.2	0.5929	Intense local rainfall/ 1980s	25-Year
104	6.981526	126.2632	0.37	0.3	0.0049	Yolanda/ November 2013	25-Year
105	6.981353	126.2623	0.43	0.3	0.0169	Yolanda/ November 2013	25-Year
106	6.961478	126.2826	0.8	0.3	0.25	Intense local rainfall/ 1980s	25-Year
107	6.960687	126.2826	1.1	0.3	0.64	Intense local rainfall/ 1980s	25-Year
108	6.968472	126.2764	0.88	0.3	0.3364		25-Year
109	6.960704	126.2838	1.1	0.5	0.36	Intense local rainfall/ 1980s	25-Year
110	6.96238	126.2824	0.82	0.5	0.1024	Intense local rainfall/ 1980s	25-Year
111	6.962508	126.281	0.87	0.5	0.1369	Intense local rainfall/ 1980s	25-Year
112	6.967342	126.2772	1.13	0.1	1.0609	Intense local rainfall	25-Year
113	6.966664	126.2768	1.33	0.3	1.0609	Intense local rainfall	25-Year
114	6.963238	126.2804	1.03	0	1.0609		25-Year
115	6.966938	126.2775	1.3	0.1	1.44	Intense local rainfall	25-Year
116	6.961597	126.2844	1.23	0.5	0.5329	Intense local rainfall/ 1980s	25-Year
117	6.966374	126.2762	1.45	0.3	1.3225	Intense local rainfall	25-Year
118	6.964482	126.2819	1.18	0.3	0.7744	Agaton/ January 2014	25-Year
119	6.96154	126.2858	1.35	0.5	0.7225	Intense local rainfall/ 1980s	25-Year
120	6.965918	126.2758	1.51	0.3	1.4641	Intense local rainfall	25-Year
121	6.964904	126.28	1.35	0.5	0.7225	Yolanda/ November 2013	25-Year
122	6.963786	126.2813	1.35	0.3	1.1025	Agaton/ January 2014	25-Year
123	6.964184	126.2804	1.34	0.5	0.7056	Yolanda/ November 2013	25-Year
124	6.963639	126.2819	1.44	0.3	1.2996	Yolanda/ November 2013	25-Year
125	6.965359	126.2778	1.62	0.75	0.7569	Intense local rainfall/ 1980s	25-Year
126	6.965584	126.2789	1.67	0.9	0.5929	Yolanda/ November 2013	25-Year
127	6.965744	126.277	1.78	1	0.6084	Intense local rainfall/ 1990s	25-Year
128	6.965887	126.2781	1.78	0.3	2.1904	Intense local rainfall	25-Year
129	6.965177	126.2803	1.63	0.5	1.2769	Yolanda/ November 2013	25-Year
130	6.966074	126.2775	1.87	1	0.7569	Intense local rainfall/ 1990s	25-Year
131	6.965293	126.28	1.71	0.5	1.4641	Yolanda/ November 2013	25-Year
132	6.965173	126.2772	1.94	1	0.8836	Intense local rainfall/ 1990s	25-Year
133	6.965518	126.2781	1.92	1	0.8464	Intense local rainfall	25-Year
134	6.965809	126.2775	2.01	1	1.0201	Intense local rainfall/ 1990s	25-Year
135	6.967059	126.2778	2.6	2	0.36	Yolanda/ November 2013	25-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error (m)	Event/Date	Rain Return/ Scenario
	Lat	Long					
136	6.980274	126.2652	2.63	2.25	0.1444	Yolanda/ November 2013	25-Year
137	6.981251	126.2648	2.87	2.25	0.3844	Yolanda/ November 2013	25-Year
138	6.965988	126.2793	3.23	2.5	0.5329	Yolanda/ November 2013	25-Year
139	6.981803	126.264	3.42	3	0.1764	Yolanda/ November 2013	25-Year
140	6.967677	126.2776	3.71	3.15	0.3136	Yolanda/ November 2013	25-Year
141	6.96625	126.2786	3.72	3.15	0.3249	Yolanda/ November 2013	25-Year
142	6.978988	126.2679	3.8	3.5	0.09		25-Year
143	6.966612	126.2782	4.11	3.5	0.3721		25-Year
144	6.979871	126.2661	5	5	0		25-Year
145	6.977725	126.2692	5.74	5	0.5476		25-Year
146	6.95653	126.2846	0.03	0	0.0009		25-Year
147	6.956863	126.2849	0.03	0	0.0009		25-Year
148	6.957123	126.2947	0.64	0	0.4096		25-Year
149	6.956471	126.2978	0.76	0	0.5776		25-Year
150	6.955559	126.297	0.75	0	0.5625		25-Year
151	6.960199	126.2922	0.68	0	0.4624		25-Year
152	6.957658	126.2941	0.95	0	0.9025		25-Year
153	6.958669	126.2928	0.85	0	0.7225		25-Year
154	6.96067	126.291	1.05	0	1.1025		25-Year
155	6.960166	126.2906	1.14	0	1.2996		25-Year
156	6.959796	126.2903	1.15	0	1.3225		25-Year
157	6.957522	126.2927	1.1	0	1.21		25-Year
158	6.958217	126.2924	1.11	0	1.2321		25-Year
159	6.961984	126.2936	1.38	0.5	0.7744	Yolanda/ November 2013	25-Year
160	6.959024	126.2919	1.19	0	1.4161		25-Year
161	6.961671	126.2927	1.18	0	1.3924		25-Year
162	6.961717	126.2931	2.49	2	0.2401		25-Year
163	6.958123	126.2952	2.8	2.2	0.36		25-Year
164	6.958816	126.2946	3.61	3	0.3721		25-Year
165	6.957855	126.2966	3.78	3	0.6084		25-Year
166	6.959603	126.2911	0.04	0	0.0016		25-Year
167	6.970663	126.2882	0.03	0	0.0009		25-Year
168	6.969927	126.2876	0.03	0	0.0009		25-Year
169	6.969658	126.2884	0.03	0	0.0009		25-Year
170	6.969995	126.2916	0.06	0	0.0036		25-Year
171	6.971453	126.288	0.05	0	0.0025		25-Year
172	6.971566	126.2889	0.06	0	0.0036		25-Year
173	6.970216	126.2867	0.3	0	0.09		25-Year
174	6.9681	126.2818	0.77	0	0.5929		25-Year
175	6.966116	126.2885	5.71	5	0.5041		25-Year
176	6.965846	126.2894	5.68	5	0.4624		25-Year
177	6.964596	126.2926	5.52	5	0.2704		25-Year
178	6.965411	126.2902	5.82	5	0.6724		25-Year
179	6.95701	126.2843	0.03	0	0.0009		25-Year
180	6.960422	126.2883	1.74	0.5	1.5376	Upstream rainfall	25-Year
				RMSE	0.880605		

Annex 12. Educational Institutions affected by flooding in Bitanagan Floodplain

Davao Oriental				
Mati City				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
ARABIC SCHOOL	Don Enrique Lopez			
DAVAO ORIENTAL STATE COLLEGE OF SCIENCE & TECHNOL*	Don Enrique Lopez			
DON ENRIQUE LOPEZ DAY CARE CENTER	Don Enrique Lopez			
CABABUANAN ELEMENTARY SCHOOL	Don Martin Marundan			

Annex 13. Health Institutions affected by flooding in Bitanagan Floodplain