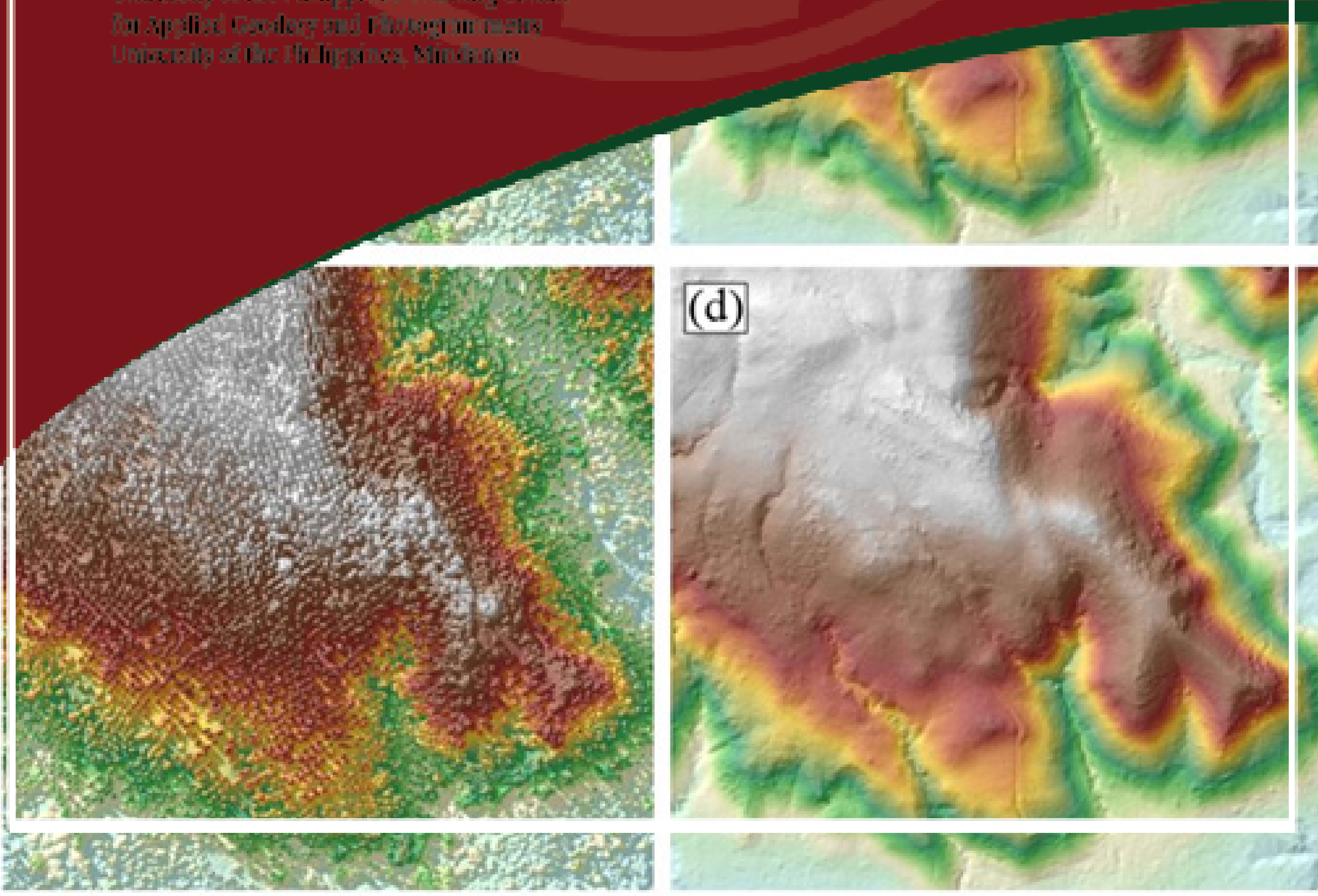
HAZARD MAPPING OF THE PHILIPPINES USING LIDAR (PHIL-LIDAR 1)

LiDAR Surveys and Flood Mapping of Quinonoan River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
University of the 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
NSTC	Northern Subtropical Convergence
PAF	Philippine Air Force
PAGASA	Philippine Atmospheric Geophysical and Astronomical Services Administration
PDOP	Positional Dilution of Precision
PPK	Post-Processed Kinematic [technique]
PRF	Pulse Repetition Frequency
PTM	Philippine Transverse Mercator
QC	Quality Check
QT	Quick Terrain [Modeler]
RA	Research Associate
RIDF	Rainfall-Intensity-Duration-Frequency
RMSE	Root Mean Square Error
SAR	Synthetic Aperture Radar
SCS	Soil Conservation Service
SRTM	Shuttle Radar Topography Mission
SRS	Science Research Specialist
SSG	Special Service Group
TBC	Thermal Barrier Coatings
UPC	University of the Philippines Cebu
UP-TCAGP	University of the Philippines – Training Center for Applied Geodesy and Photogrammetry

CHAPTER 1: OVERVIEW OF THE PROGRAM AND QUINONOAN RIVER

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

1.1 Background of the Phil-LIDAR 1 Program

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

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

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

1.2 Overview of the Quinonoan River Basin

The Quinonoan River is a stream traversing between the borders of Manay and Tarragona Municipalities in the province of Davao Oriental with its slopes leading to the Pacific Ocean (Robles, 2016). It is a major watershed and one of the biggest inland water bodies in Tarragona. The Quinonoan River originates from Mount Mayo and flows north-easterly then south-easterly until it drains to the Philippine Sea (COAL Asia Holdings and Payawal, 2012). The river mouth is situated in Brgy. Jovellar in the Municipality of Tarragona. Tarragona is bounded by the Municipality of Manay on the north, Mayo Bay on the south, Pacific Ocean on the east, the Municipality of Lupon on the northwest, and Mati City on the southwest. Tarragona Municipality has ample marine water fronting the Pacific Ocean (Bugayong et.al., 2016).

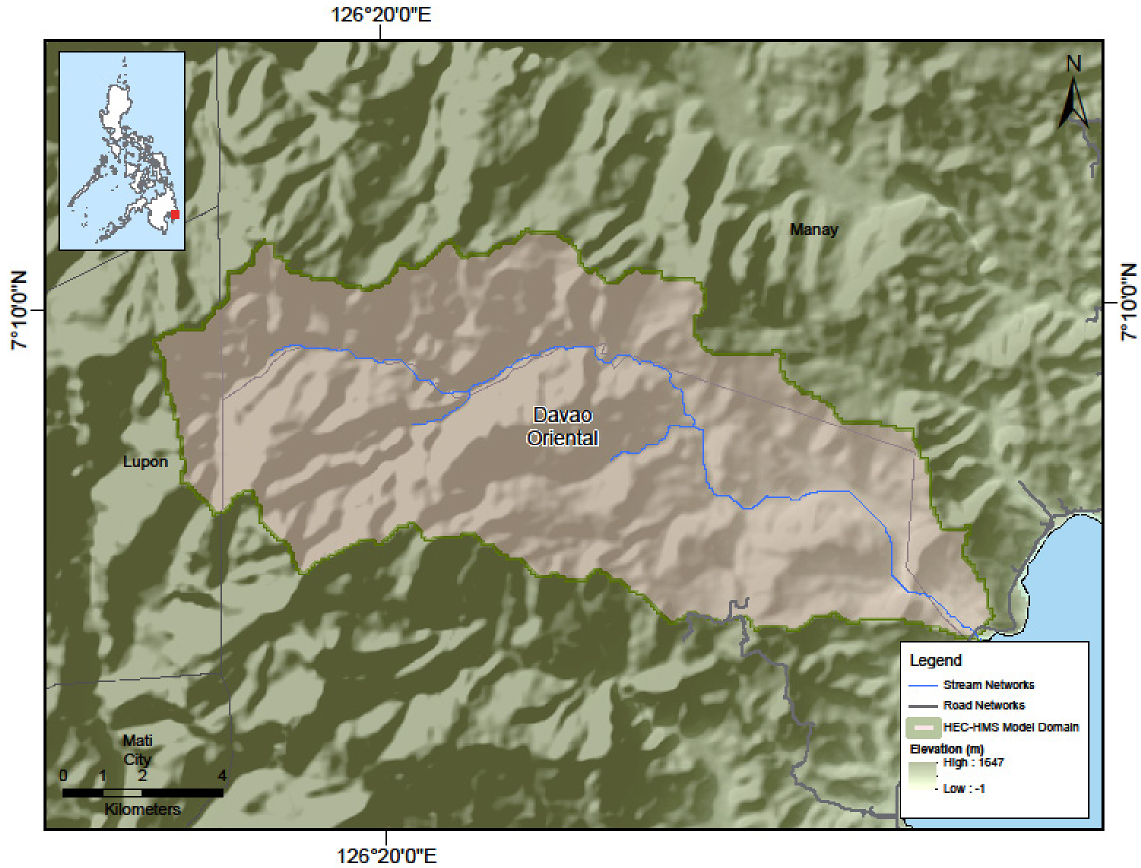

Figure 1. Map of Quinonoan River Basin (in brown).

Tarragona was named after a town in Spain with the same name. It is said to be the hometown of the Spanish Missionary who came to the area from a Caraga Mission. The story indicates that being far away from his home brought the missionary the feeling of loneliness and longing, and so he named his mission to the coastal community in Davao Oriental as Tarragona in remembrance of his hometown (UP Manila, 2000).

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The Kaagans were one of the indigenous groups who were pioneer settlers in Tarragona and Manay. The sitios with the most number of indigenous residents are Tubaon and Maganda. The name Tubaon came from the creek that always had a reddish color of water. The name Maganda or Mallaganda came from a type of tree they called Mallaganda that used to flourish in the area (Lasco, G. and Pinoy Mountaineer, 2014).

Quinonoan Watershed has a drainage area of 381 square kilometers. There are 8 Barangays within the watershed. The Quinonoan basin model consists of 57 sub basins, 28 reaches, and 28 junctions. The basins were identified based on soil and land cover characteristics of the area.

Mt. Tindok, also called Maytindok, is part of Mt. Mayo Range in Davao Oriental and is reportedly the highest of the three peaks of the range namely Mt. Mayo, Mt. Tindok and Mt. Mambukas. The Mt. Mayo Range is bounded to the west by Lupon, to the south by Mati and to the east by Tarragona and it is within the municipal jurisdiction of Tarragona. Puting Bato Falls can also be found in Brgy. Limot, Tarragona (Ponce, 2013; Mindanao Tripod, 2017).

The Quinonoan River is located south of the Coal Project Area of the Titan Mining and Energy Corporation (TMEC) in Davao Oriental. The said project area is situated in Barangays Old Macopa, Holy Cross, San Ignacio, Capasnan, Lambog, Rizal and Brgy. Dadong all in the Municipalities of Manay and Tarragona. Most of the Barangays stated are within the boundaries of the Quinonoan Watershed. Two (2) major rivers drain the coal project: The Casauman River on the north and the Quinonoan River on the south (COAL Asia Holdings and Payawal, 2012).

According to locals, from the year 1954 to 2014, upstream and intense local rainfall are the usual cause of flooding near the river. However, PAGASA only noted typhoon events such as Low Pressure Area (LPA) events, Typhoon Pablo in 2012, Typhoon Yolanda and Tropical Depression Crising in 2013, and Typhoon Agaton in 2014.

CHAPTER 2: LIDAR DATA ACQUISITION OF THE QUINONOAN 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 (Ang, et. al., 2014) and further enhanced and updated in Paringit, et. al. (2017).

2.1 Flight Plans

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

Table 1. Flight planning parameters for the 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)
BLK80A	1000	30	40	125	50	130	5
BLK80B	1000	30	40	125	50	130	5
BLK83A	1000	40	40	100	50	130	5
BLK84B	1000	40	40	100	50	130	5
BLK85C	1200	40	24	100	60	130	5
BLK86B	1000	30	40	125	50	130	5
BLK86C	850	30	40	125	50	130	5

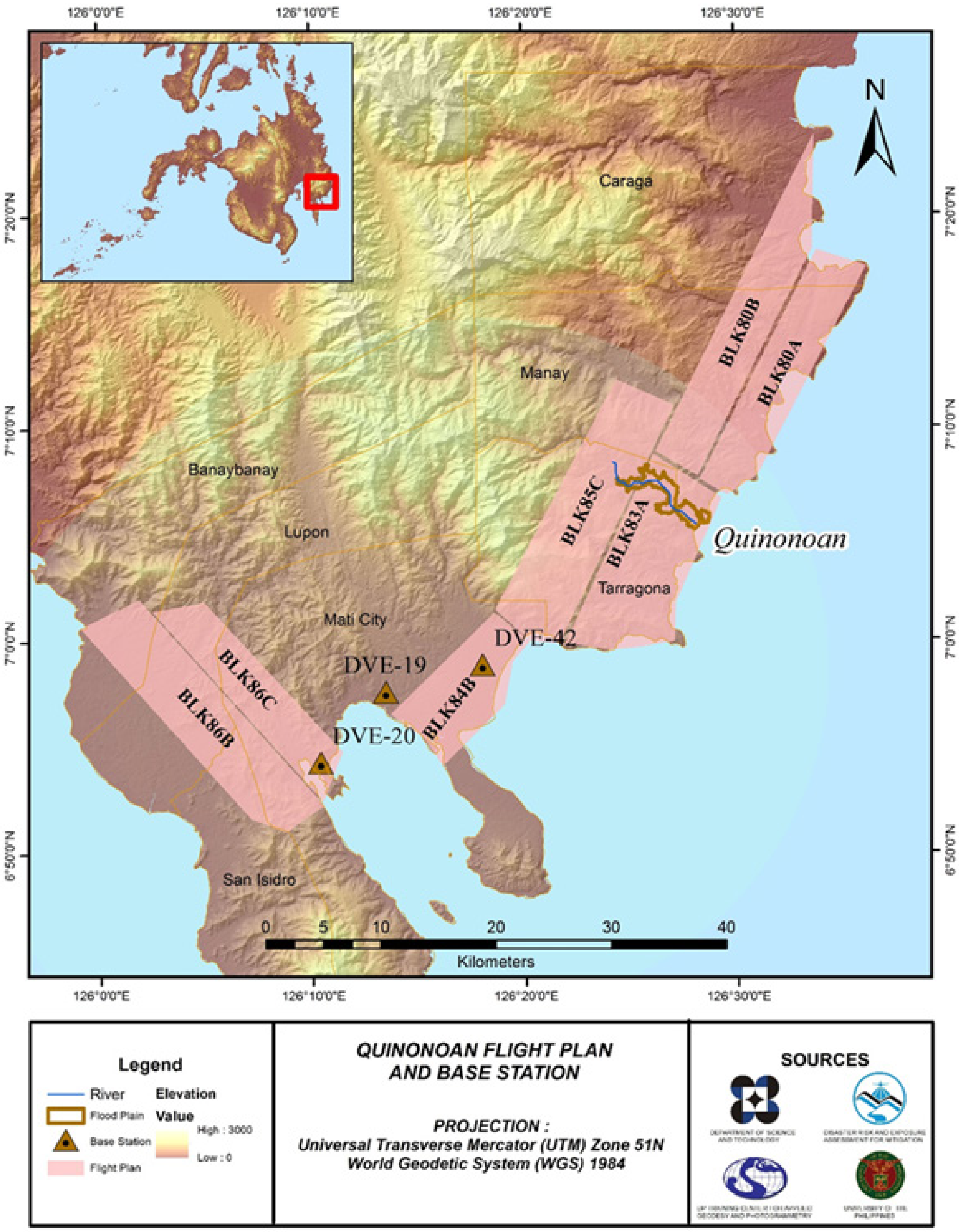


Figure 2. Flight plans and base stations used for Quinonoan floodplain.

2.2 Ground Base Stations

The project team was able to recover four (4) NAMRIA ground control points: DVE-42 (2nd order accuracy), DVE-19 and DVE-20 (3rd order accuracy) and DVE-3088 (4th order accuracy). The third (3rd) and 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 Annex 3. These were used as base stations during flight operations for the entire duration of the survey (June 19 – July 8, 2014). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 882 and SPS 985. Flight plans and location of base stations used during the aerial LiDAR acquisition in Quinonoan floodplain are shown in Figure 2.

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

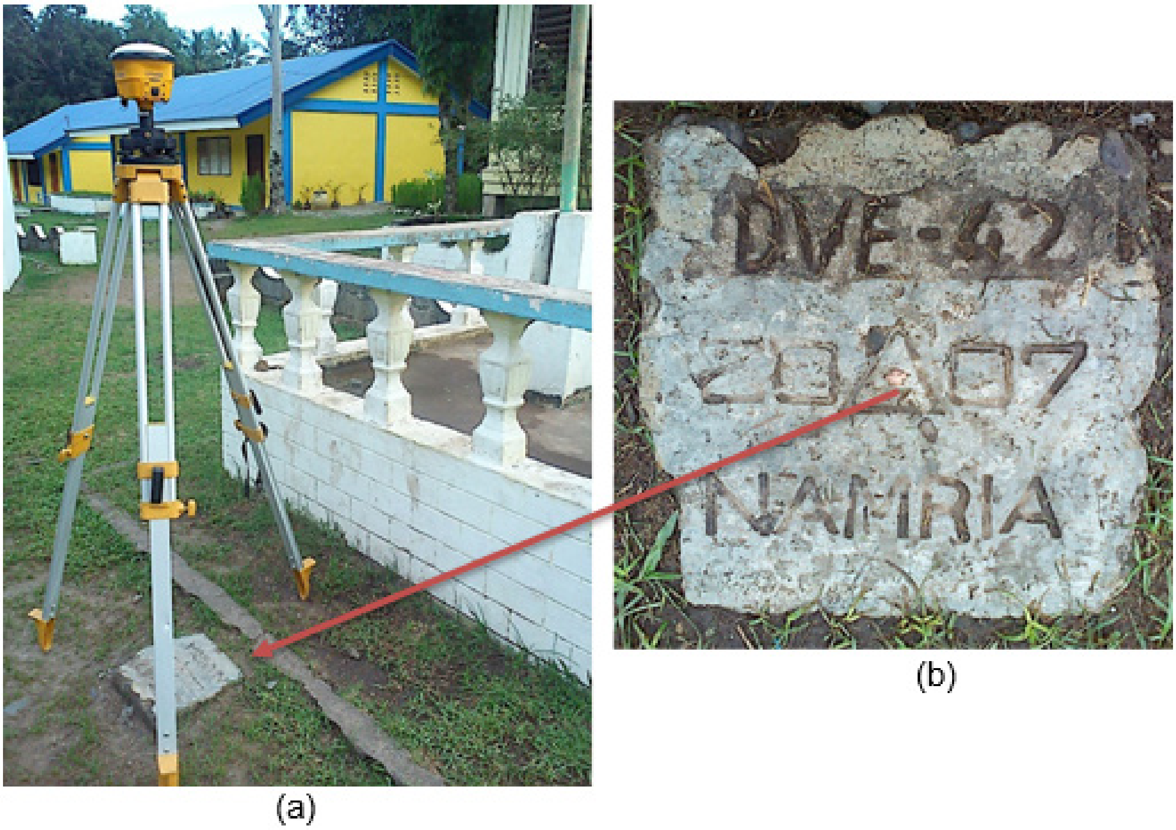


Figure 3. GPS set-up over DVE-42 located inside the premises of Don Enrique Elementary School, in front of the flagpole (a) and NAMRIA reference point DVE-42 (b) as recovered by the field team.

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

Station Name	DVE-19	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7°12'55.40701" North 126°32'20.36757" East -5.263 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84	Latitude Longitude Ellipsoidal Height	7°12'52.33155" North 126°32'25.86780" East 69.522 meters
Grid Coordinates, Universal Transverse Mercator Zone 52 North (UTM 52N PRS 92)	Easting Northing	228220.964 meters 798242.634 meters

(a)

(b)

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

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

Station Name	DVE-19	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7°12’55.40701” North 126°32’20.36757” East -5.263 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	7°12’52.33155” North 126°32’25.86780” East 69.522 meters
Grid Coordinates, Universal Transverse Mercator Zone 52 North (UTM 52N PRS 92)	Easting Northing	228220.964 meters 798242.634 meters

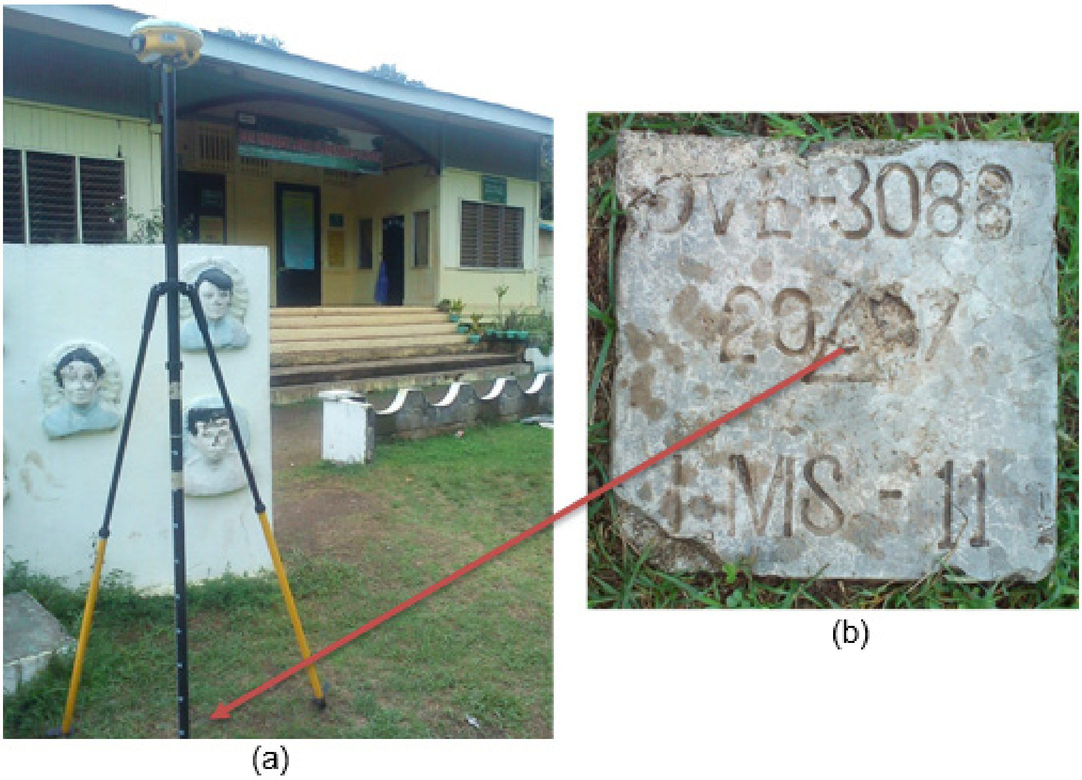
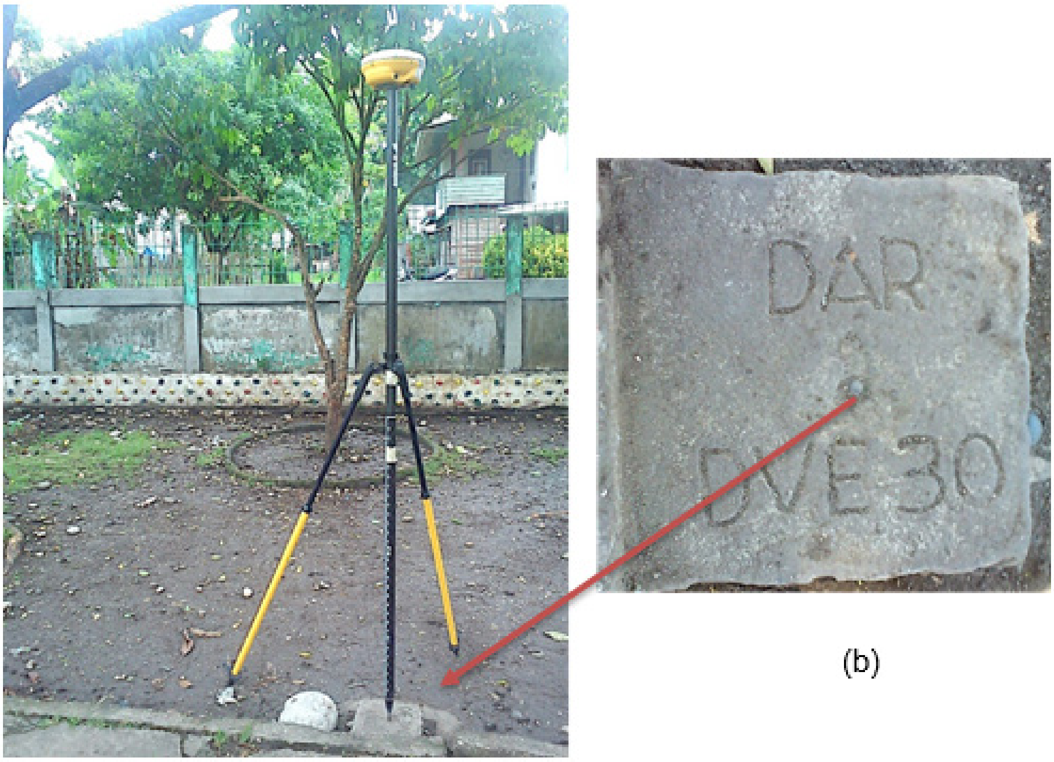


Figure 5. GPS set-up over DVE-3088 located inside Don Enrique Lopez Elementary School (a) and NAMRIA reference point DVE-3088 (b) as recovered by the field team.

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

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



(a) (b)

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

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

Station Name	DVE-20	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7°12’51.11197” North 126°32’20.35543” East -6.215 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	7°12’48.03684” North 126°32’25.85577” East 68.572 meters
Grid Coordinates, Universal Transverse Mercator Zone 52 North (UTM 52N PRS 92)	Easting Northing	228219.879 meters 798110.635 meters

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

Date Surveyed	Flight Number	Mission Name	Ground Control Points
June 19, 2014	7320GC	2BLK83A84B170A	DVE-42 & DVE-3088
June 20, 2014	7322GC	2BLK84AS&86B171A	DVE-42 & DVE-3088
June 20, 2014	7323GC	2BLK86C&83A171B	DVE-42 & DVE-3088
June 23, 2014	7328GC	2BLK80ABS174A	DVE-19 & DVE-20
July 8, 2014	7358GC	2BLK80BS189A	DVE-19 & DVE-20

2.3 Flight Missions

A total of five (5) missions were conducted to complete the LiDAR data acquisition in Quinonoan floodplain, for a total of nineteen hours and fifty three minutes (19+53) of flying time for RP-C9322. All missions were acquired using the Gemini LiDAR system. As shown below, the total area of actual coverage per mission and the corresponding flying hours are depicted in Table 7, while the actual parameters used during the LiDAR data acquisition are presented in Table 8.

Table 7. Flight missions for LiDAR data acquisition in Quinonoan 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 19, 2014	7320GC	190.72	121.57	0.63	120.94	NA	3	47
June 20, 2014	7322GC	251.73	209.19	1.97	207.22	NA	4	11
June 20, 2014	7323GC	199.62	214.08	3.28	210.8	NA	4	9
June 23, 2014	7328GC	211.43	244.67	4.94	239.73	NA	4	23
July 8, 2014	7358GC	138.07	128.52	5.10	123.42	NA	3	23
TOTAL		991.57	918.03	15.92	902.11	NA	19	53

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)
7320GC	1100	40	40	100	50	130	5
7322GC	1100	30	40	100	50	130	5
7323GC	1100	30	40	100	50	130	5
	1200	30	36	100	50	130	5
7328GC	1100	30	40	100	50	130	5
7358GC	1600	40	40	70	50	130	5
	1300	40	24	70	60	130	5

2.4 Survey Coverage

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

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

Province	Municipality/City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Davao Oriental	Tarragona	277.90	154.97	55.76
	Manay	430.89	213.56	49.56
	Lupon	356.28	84.18	23.63
	Mati	797.38	127.60	16.00
	San Isidro	224.84	24.05	10.70
	Banaybanay	385.28	34.94	9.07
	Caraga	569.48	36.17	6.35
Total		3,042.05	675.47	22.20%

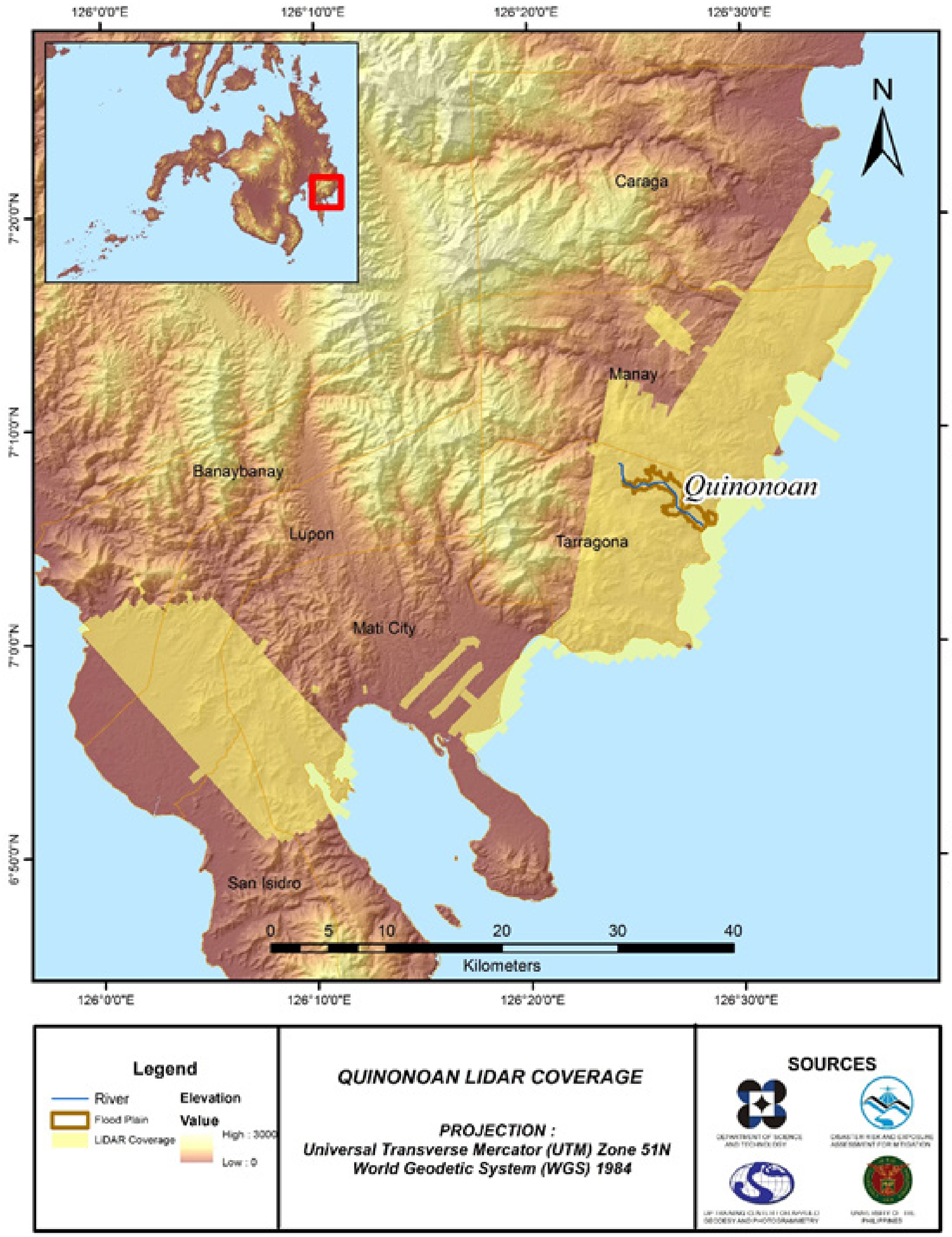


Figure 7. Actual LiDAR survey coverage for Quinonoan floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE QUINONOAN 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 are checked for completeness based on the list of raw files required to proceed with the pre-processing of the LiDAR data. Upon acceptance of the LiDAR field data, georeferencing of the flight trajectory is done in order to obtain the exact location of the LiDAR sensor when the laser was shot. Point cloud georectification is performed to incorporate correct position and orientation for each point acquired. The georectified LiDAR point clouds are subject for quality checking to ensure that the required accuracies of the program, which are the minimum point density, vertical and horizontal accuracies, are met. The point clouds are then classified into various classes before generating Digital Elevation Models such as Digital Terrain Model and Digital Surface Model.

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

These processes are summarized in the flowchart shown in Figure 8

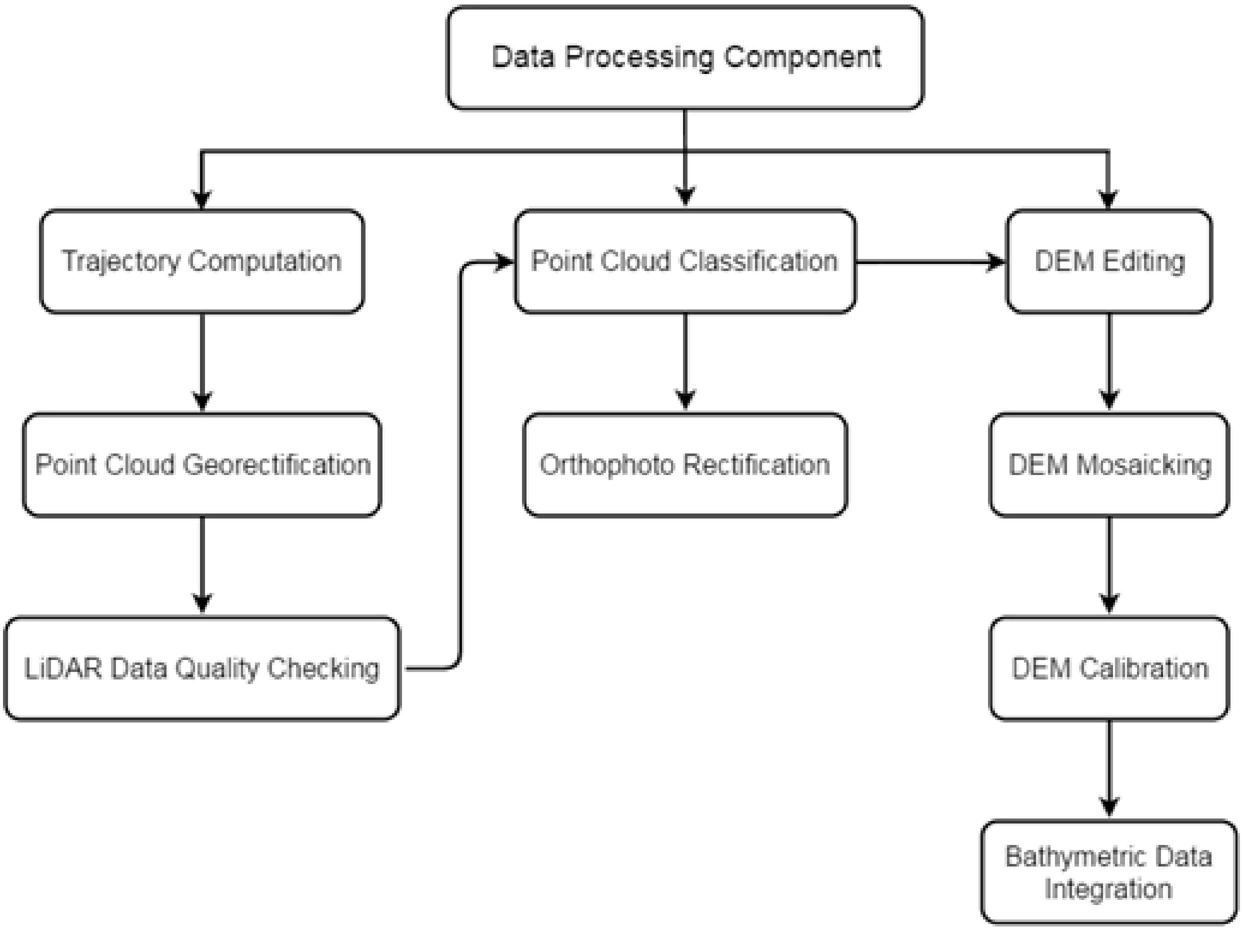

Figure 8. Schematic diagram for the data pre-processing.

3.2 Transmittal of Acquired LiDAR Data

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

The Data Acquisition Component (DAC) transferred a total of 103.7 Gigabytes of Range data, 1.15 Gigabytes of POS data, 23.98 Megabytes of GPS base station data, and 91.3 Gigabytes of raw image data to the data server on November 12, 2015 for the first survey.The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Quinonoan was fully transferred on November 2015, as indicated on the Data Transfer Sheets for Quinonoan floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metric parameters of the computed trajectory for Flight 7322GC, one of the Quinonoan flights, which is the North, East, and Down position RMSE values are shown in Figure 9. The x-axis corresponds to the time of the flight, which was measured by the number of seconds from the midnight of the start of the GPS week, which fell on the date and time of June 20, 2014 00:00AM. The y-axis, on the other hand, represents the RMSE value for that particular position.

Figure 9. Smoothed Performance Metric Parameters of Quinonoan Flight 7322GC.

The time of flight was from 526500 seconds to 533000 seconds, which corresponds to morning of November 7, 2015. 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 2.9 centimeters, the East position RMSE peaks at 3.25 centimeters, and the Down position RMSE peaks at 9.0 centimeters, which are within the prescribed accuracies described in the methodology.

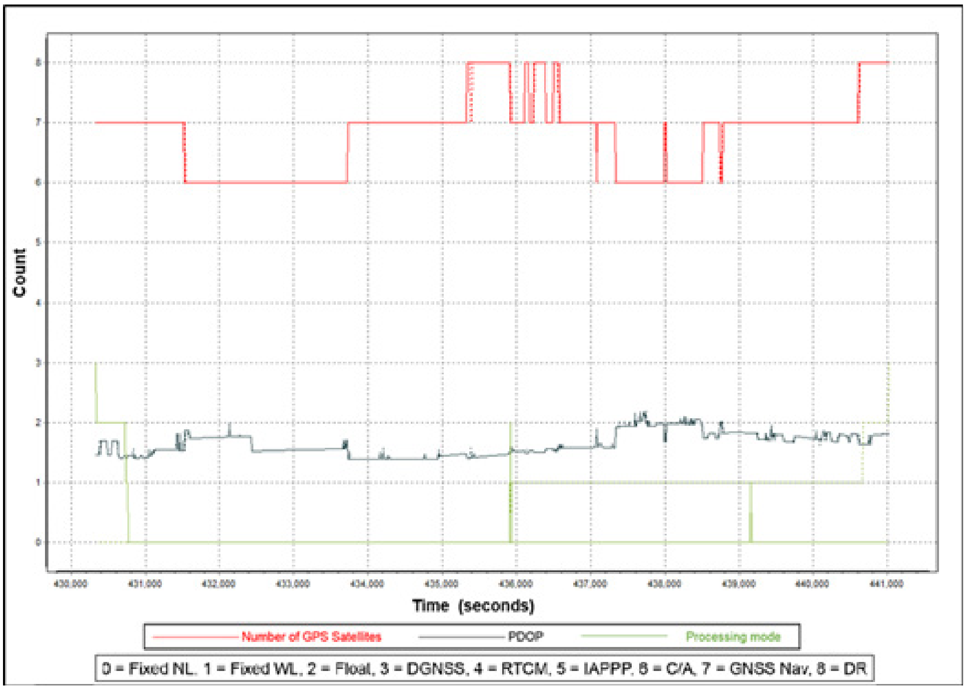

Figure 10. Solution Status Parameters of Quinonoan Flight 7322GC.

The Solution Status parameters, which indicate the number of GPS satellites; Positional Dilution of Precision (PDOP); and the GPS processing mode used for Quinonoan Flight 7322GC are shown in Figure 10. For the Solution Status parameters, the figure above signifies that the number of satellites utilized and tracked during the acquisition were between 7 and 9, not going lower than 7. Similarly, the PDOP value did not go above the value of 3, which indicates optimal GPS geometry. The processing mode also stayed at the value of 3 for the majority of the survey stayed at the value of 0 for majority of the survey with some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane Mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for the POSPAC MMS. Fundamentally, all of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Quinonoan flights is shown in Figure 11.

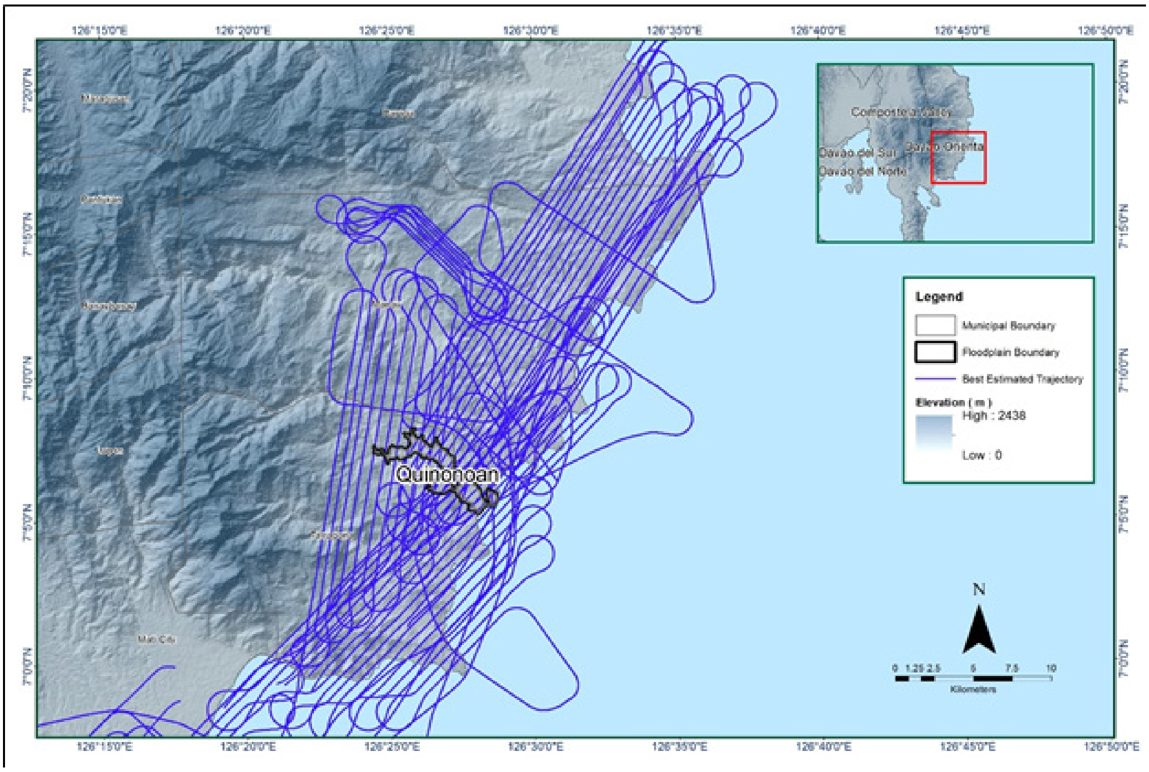

Figure 11. Best Estimated Trajectory of the LiDAR missions conducted over the Quinonoan Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS contains 41 flight lines, with each flight line contains one channel, since the Gemini system contains only one channel only. The summary of the self-calibration results obtained from LiDAR processing in the LiDAR Mapping Suite (LMS) software for all flights over the Quinonoan floodplain are given in Table 10.

Table 10. Self-calibration Results values for Quinonoan flights

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

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

3.5 LiDAR Quality Checking

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

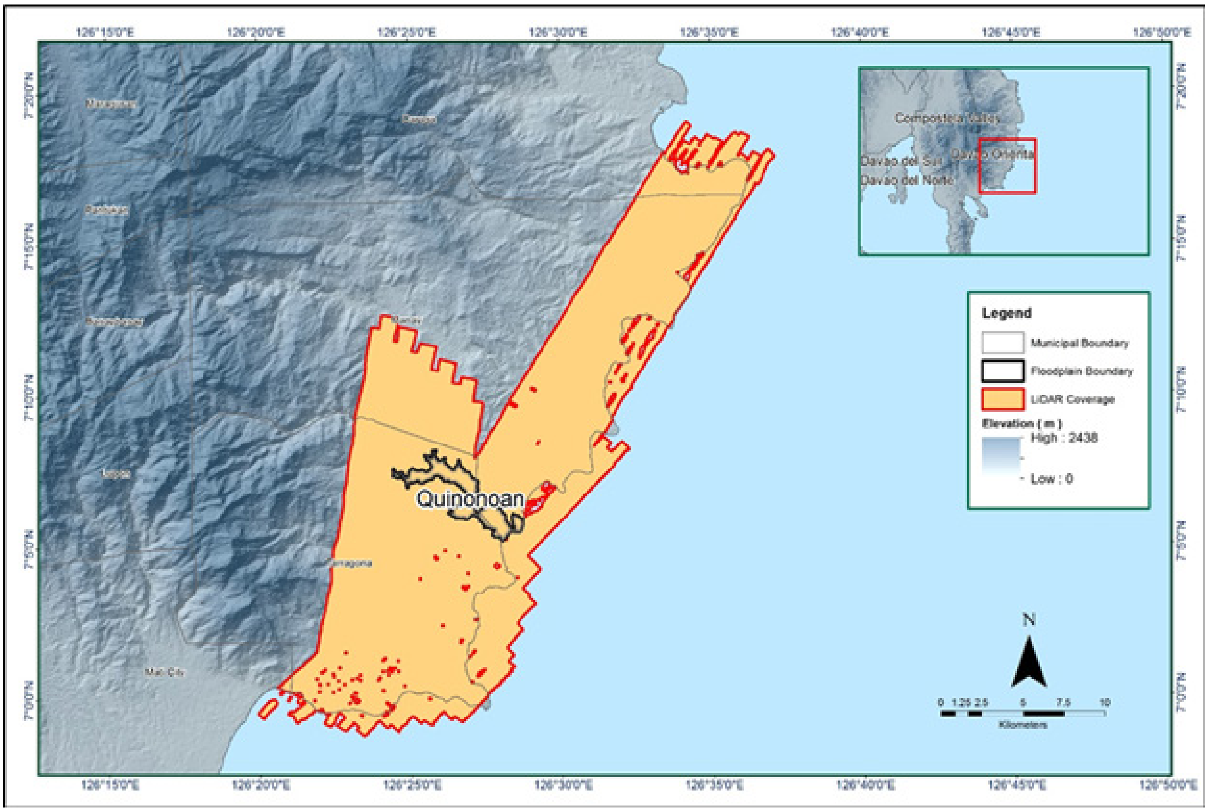

Figure 12. Boundaries of the processed LiDAR data over the Quinonoan

A total area of 409.48 square kilometers (sq. kms.) were covered by the Quinonoan flight missions as a result of five (5) flight acquisitions, which were grouped and merged into three (3) blocks accordingly, as portrayed in Table 11.

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

LiDAR Blocks	Flight Numbers	Area (sq.km)
Davao_Oriental_Blk80A_ supplement	7328GC	174.97
Davao_Oriental_Blk83A	7320GC	217.86
	7322GC	
	7323GC	
Davao_Oriental_Blk85C	7358GC	16.65
TOTAL		409.48 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, we would expect an average value of 1 (blue) for areas where there is limited overlap, and a value of 2 (yellow) or more (red) for areas with three or more overlapping flight lines.

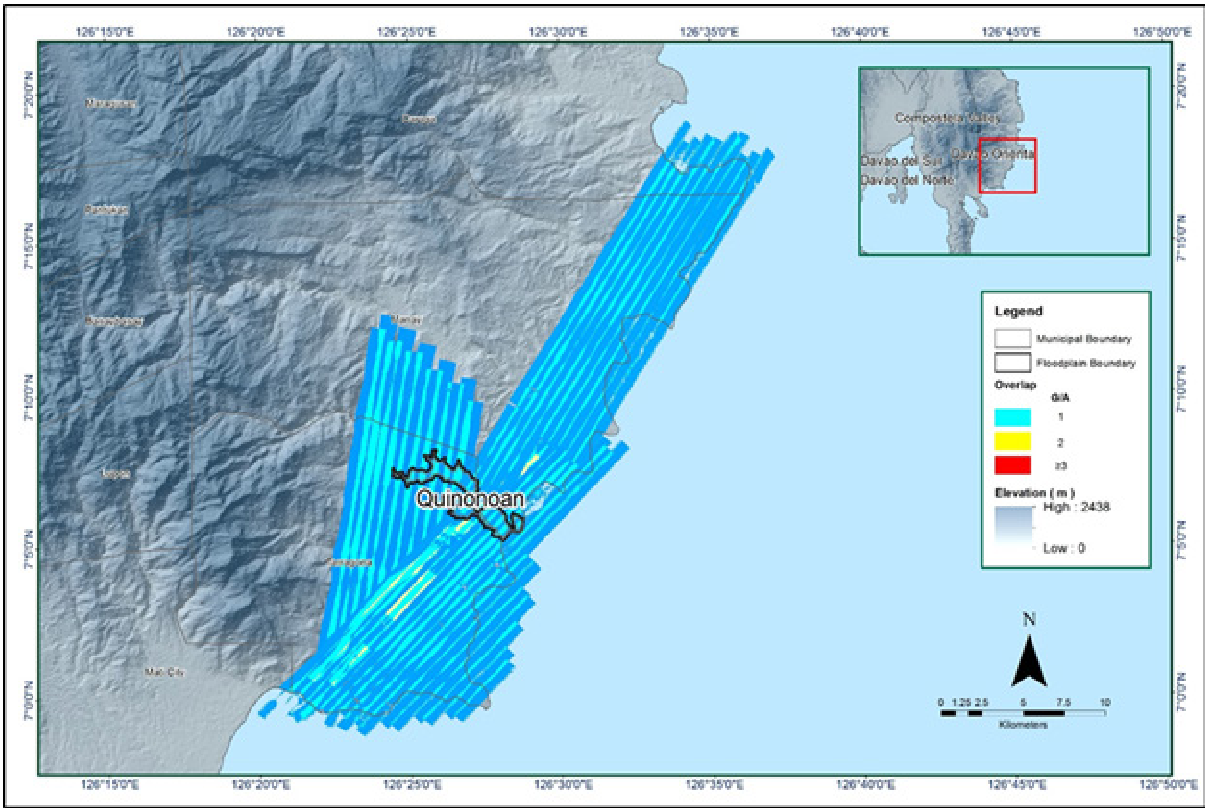

Figure 13. Image of data overlap for Quinonoan floodplain.

The overlap statistics per block for the Quinonoan floodplain can be found in the Mission Summary Reports (Annex 8). One pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 31.39% and 36.47% 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 two (2) points per square meter criterion is shown in Figure 14. As seen in the figure below, it was determined that all LiDAR data for the Quinonoan Floodplain Survey satisfy the point density requirement, as the average density for the entire survey area is 2.73 points per square meter.

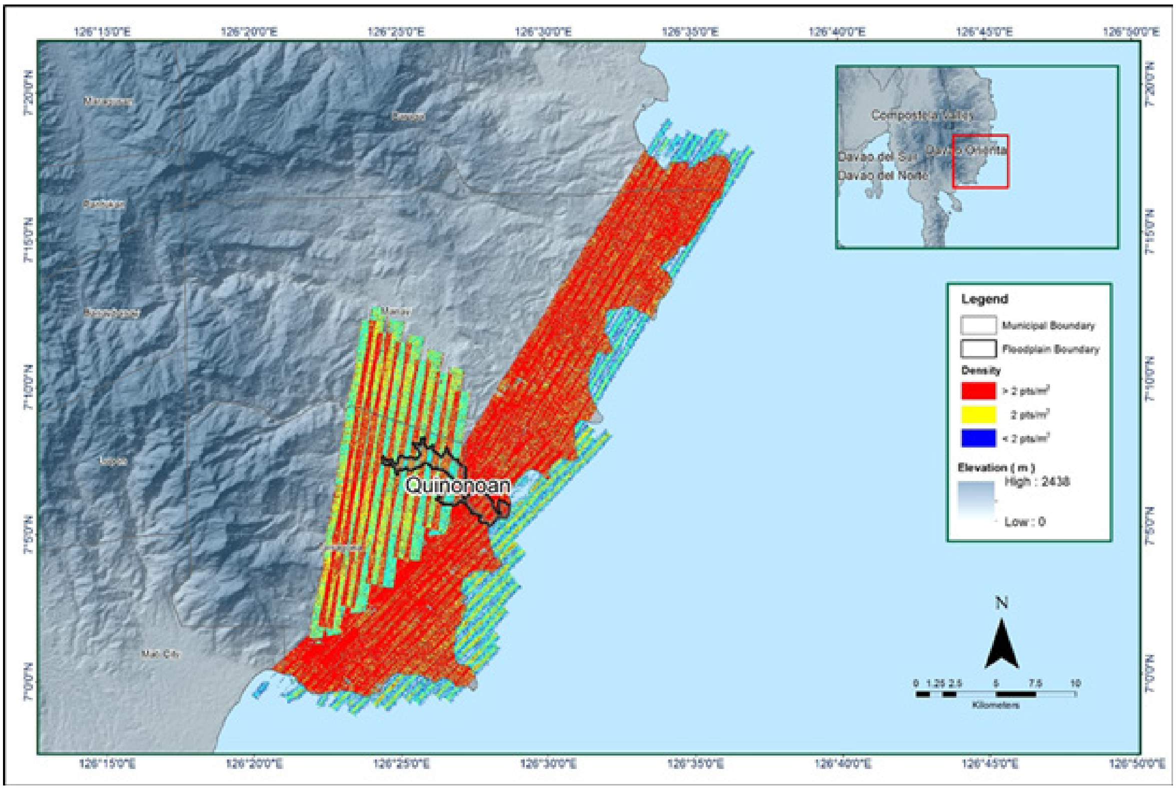

Figure 14. Pulse density map of the merged LiDAR data for Quinonoan floodplain.

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

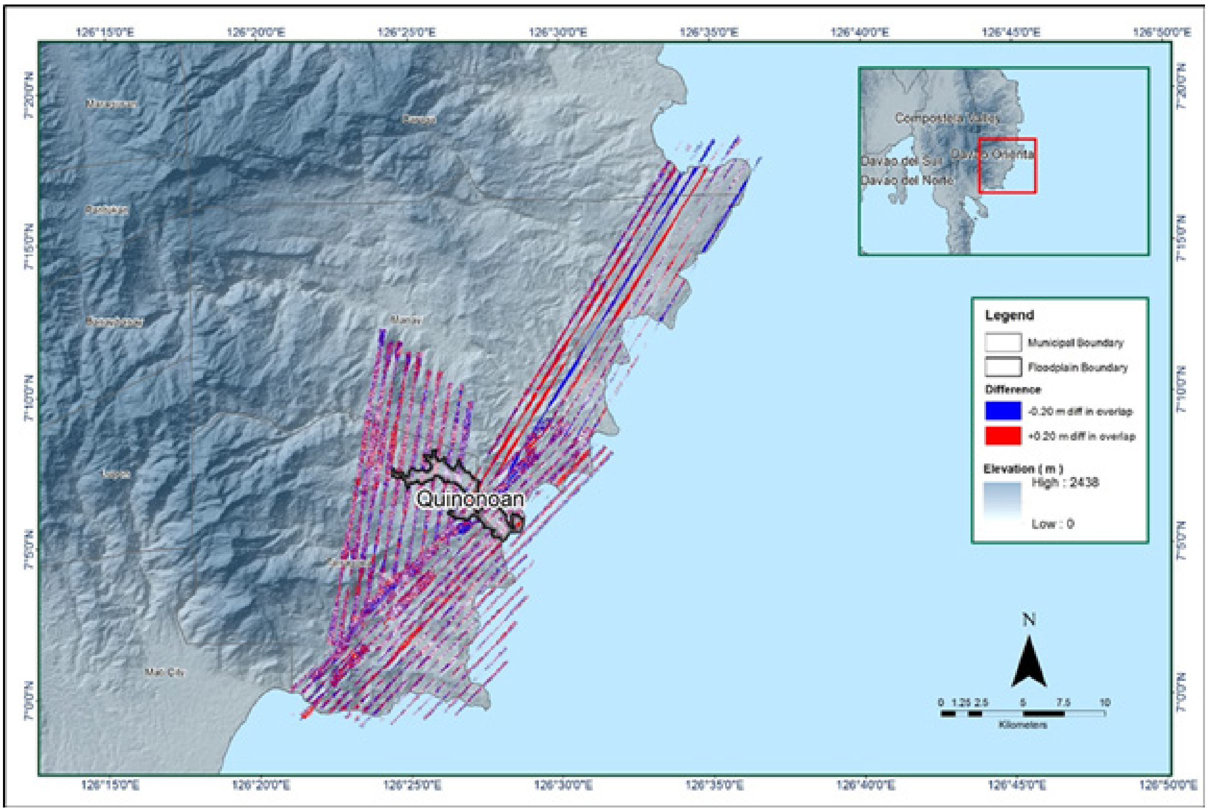

Figure 15. Elevation difference Map between flight lines for the Quinonoan Floodplain Survey.

A screen-capture of the processed LAS data from Quinonoan flight 7322GC 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 red line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data generated satisfactory results. No reprocessing was done for this LiDAR dataset.

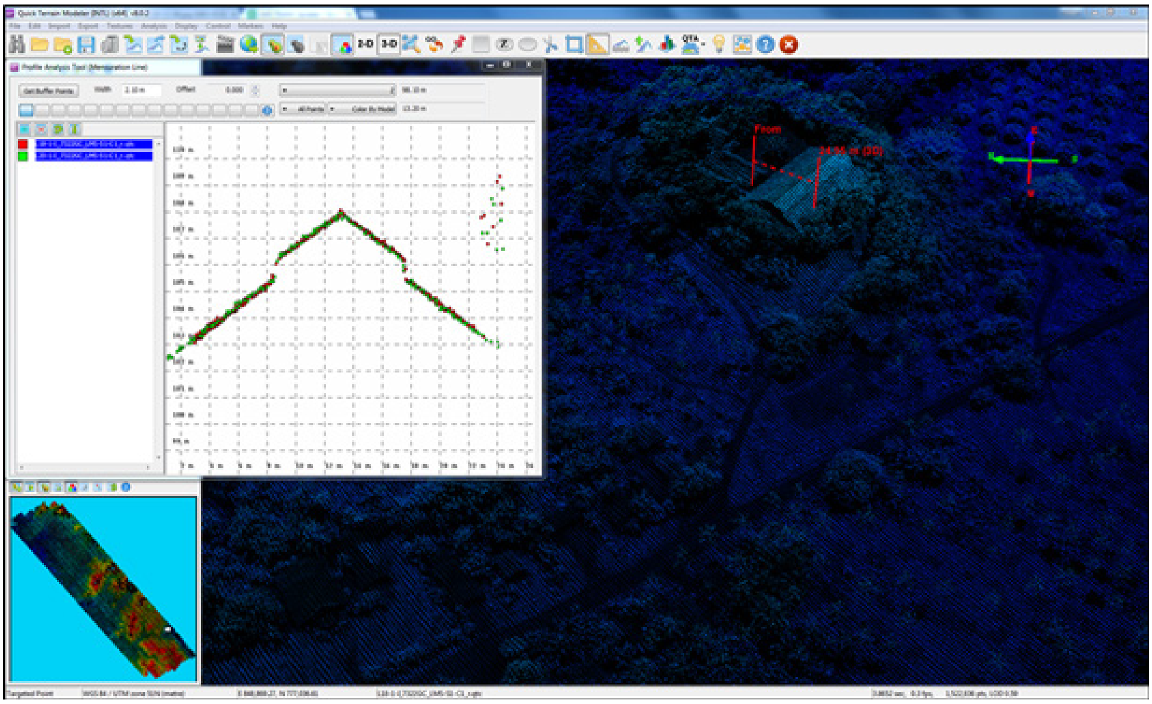

Figure 16. Quality checking for Quinonoan flight 7322GC using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 12. Quinonoan classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	149,269,963
Low Vegetation	70,219,888
Medium Vegetation	225,478,274
High Vegetation	502,029,368
Building	2,796,395

The tile system that TerraScan employed for the LiDAR data as well as the final classification image for a block of the Quinonoan floodplain is shown in Figure 17. A total of 389 tiles with 1 km. X 1 km. (one kilometer by one kilometer) size were produced. Correspondingly, Table 12 summarizes the number of points classified to the pertinent categories. The point cloud has a maximum and minimum height of 1,449.33 meters and 55.88 meters respectively.

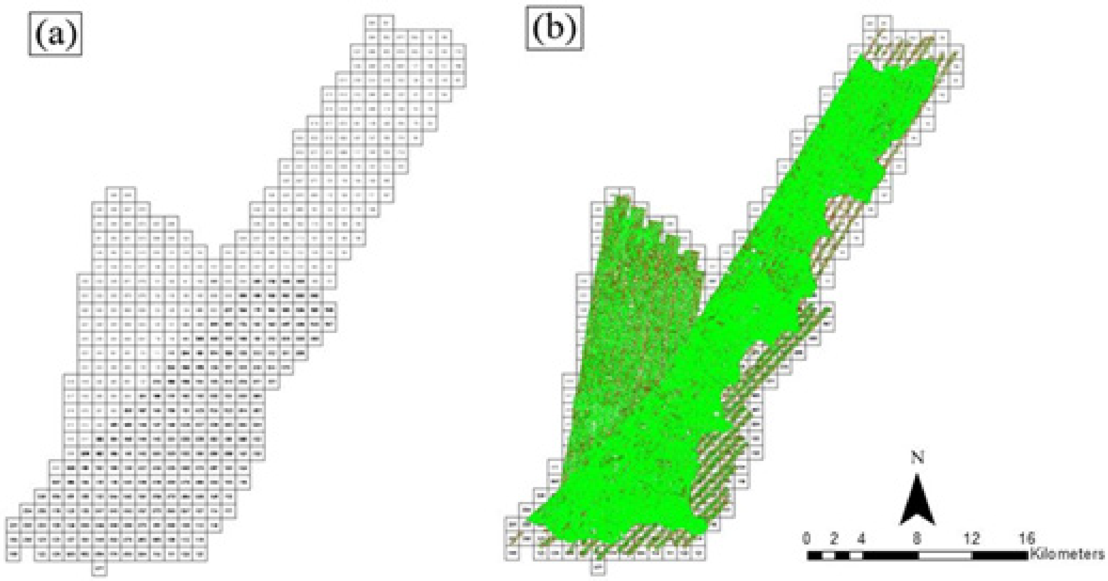

Figure 17. Tiles for Quinonoan floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 18. The ground points are highlighted in orange, while 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 the canopy are classified correctly, due to the density of the LiDAR data.

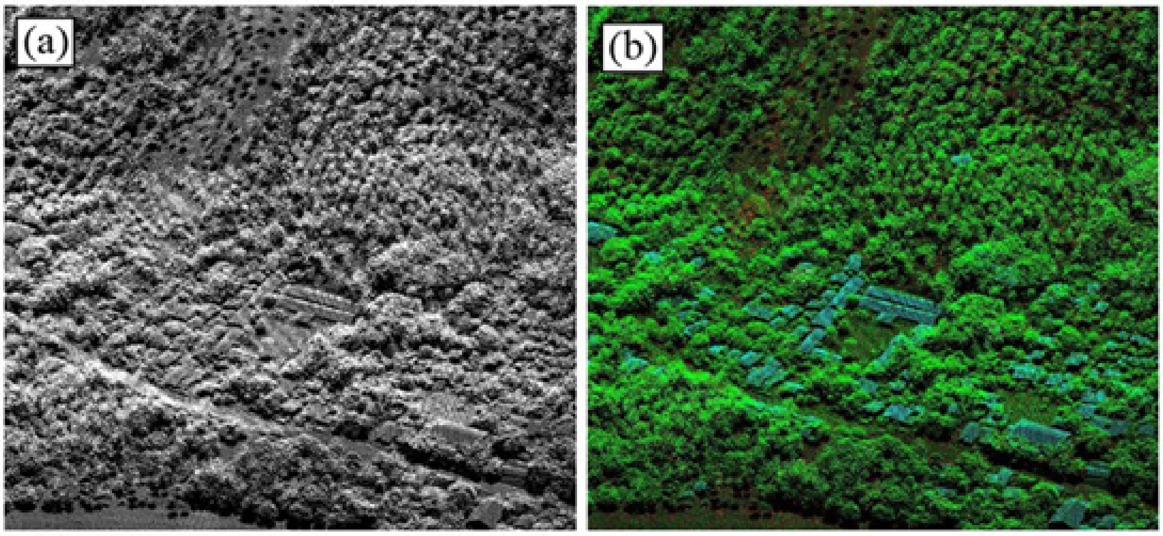

Figure 18. Point cloud before (a) and after (b) classification.

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

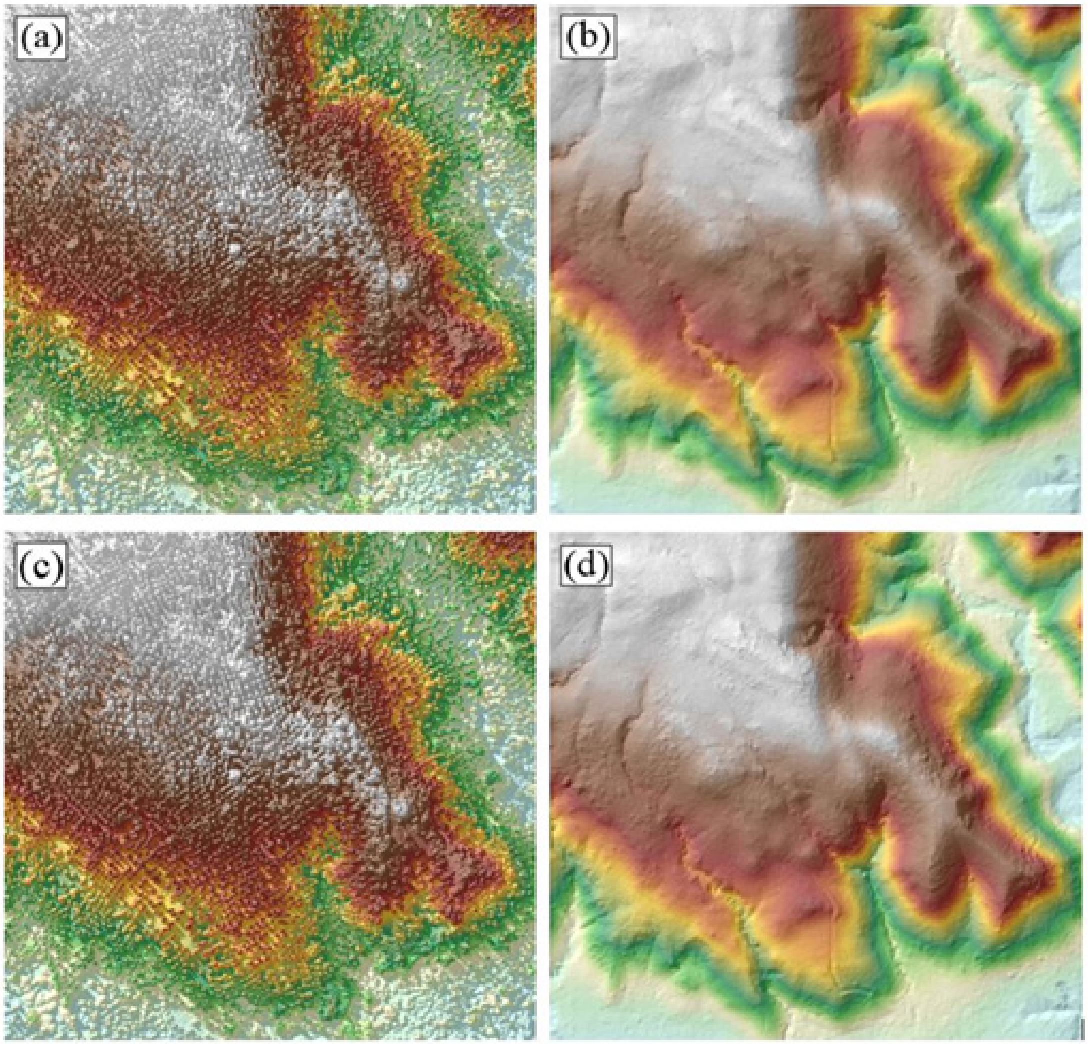

Figure 19. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Quinonoan floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

There are no available orthophotographs for the Quinonoan floodplain.

3.8 DEM Editing and Hydro-Correction

Three (3) mission blocks were processed for the Quinonoan Floodplain Survey. These blocks are composed of Davao Oriental blocks with a total area of 409.48 square kilometers. Table 13 shows the name and corresponding area of each block in square kilometers.

Table 13. LiDAR blocks with its corresponding areas.

LiDAR Blocks	Area (sq. km.)
Davao_Oriental_Blk83A	174.97
Davao_Oriental_Blk85C	217.86
Davao_Oriental_Blk80A_supplement	16.65
TOTAL	409.48 sq.km

Figure 20 shows portions of a DTM before and after manual editing. As evident in the figure, the hilly portion (Figure 20a) was misclassified and removed during the classification process. To complete the surface, the hilly portion (Figure 20b) was retrieved and reclassified through manual editing to allow the correct water flow.

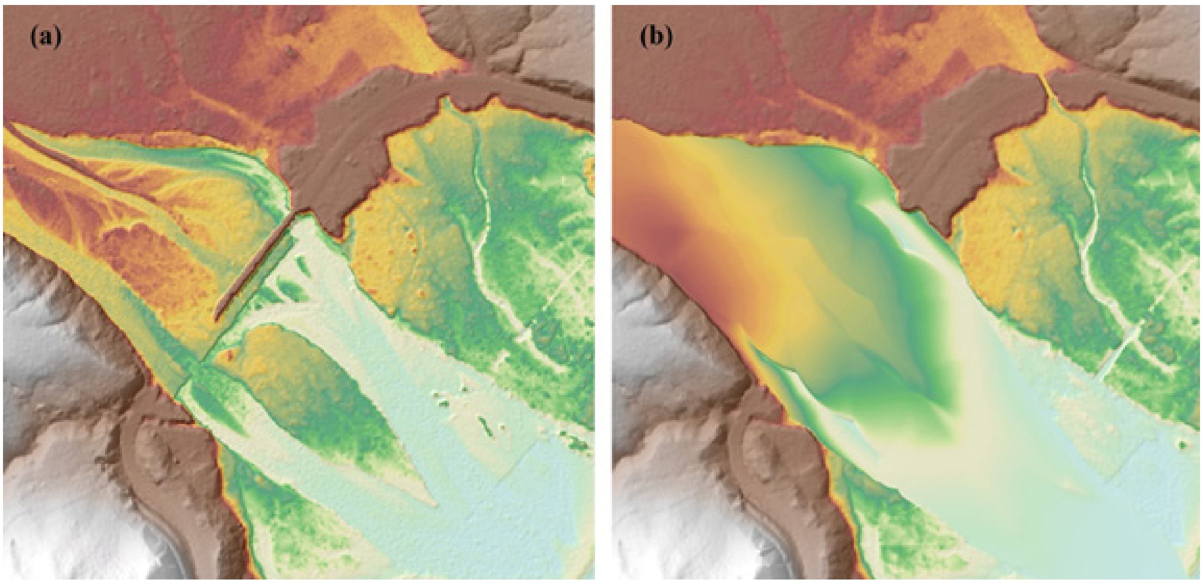

Figure 20. Portions in the DTM of Quinonoan floodplain – a bridge before (a) and after (b) manual editing.

3.9 Mosaicking of Blocks

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

Mosaicked LiDAR DTM for QuinonoanFloodplain is shown in Figure 21. It can be seen that the entire Quinonoan floodplain is 100% covered by LiDAR data.

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

Mission Blocks	Shift Values (meters)		
	x	y	z
Davao_Oriental_Blk83A	1.40	1.70	-2.72
Davao_Oriental_Blk85C	-1.00	3.70	-2.98
Davao_Oriental_Blk80A_supplement	21.00	9.0	-21.20

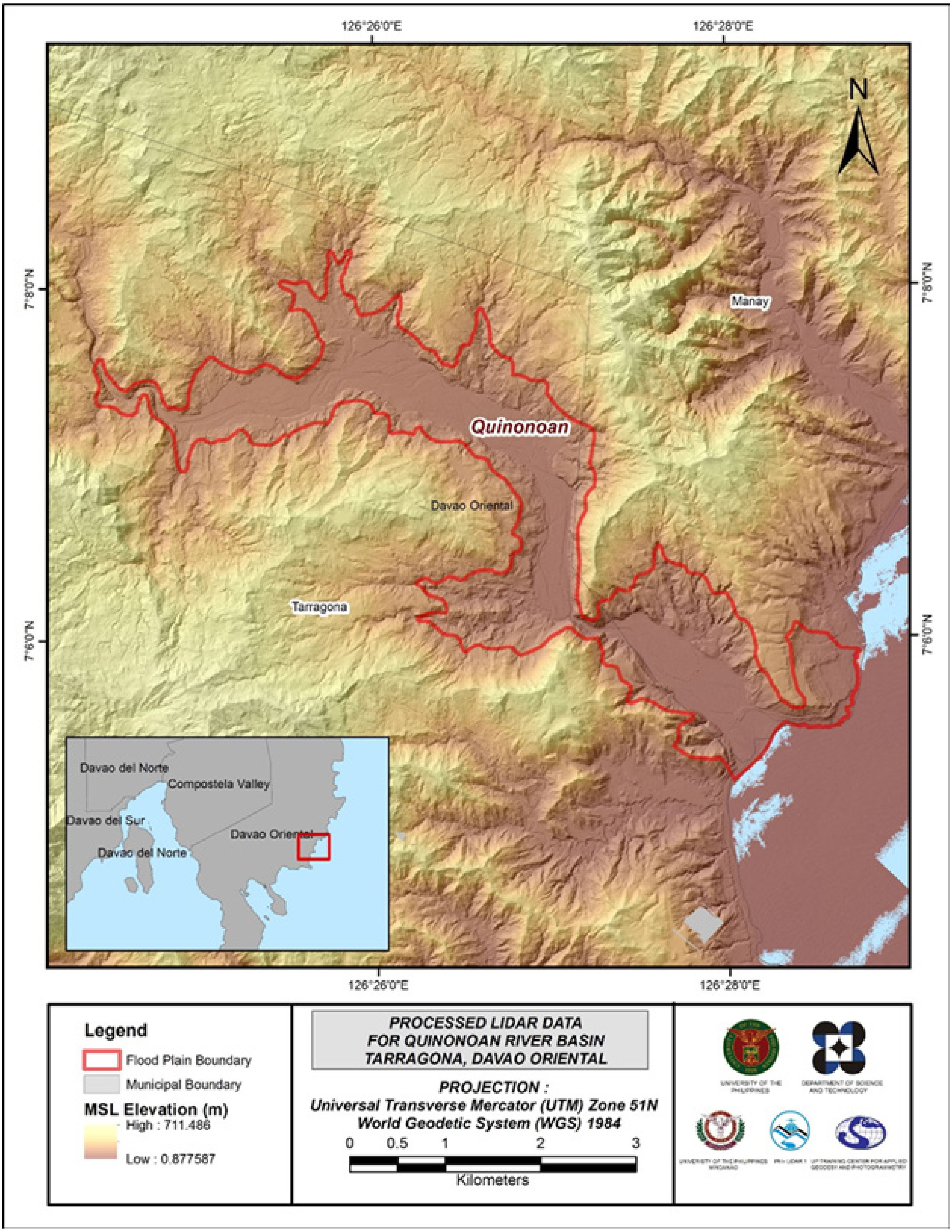

Figure 21. Map of processed LiDAR data for the Quinonoan Floodplain.

3.10 Calibration and Validation of Mosaicked LiDAR DEM

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Quinonoan to collect points with which the LiDAR dataset is validated is shown in Figure 22. A total of 7,104 survey points were used for calibration and validation of Quinonoan LiDAR data. Random selection of 80% of the survey points, resulting to 5,683 points, were used for calibration.

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

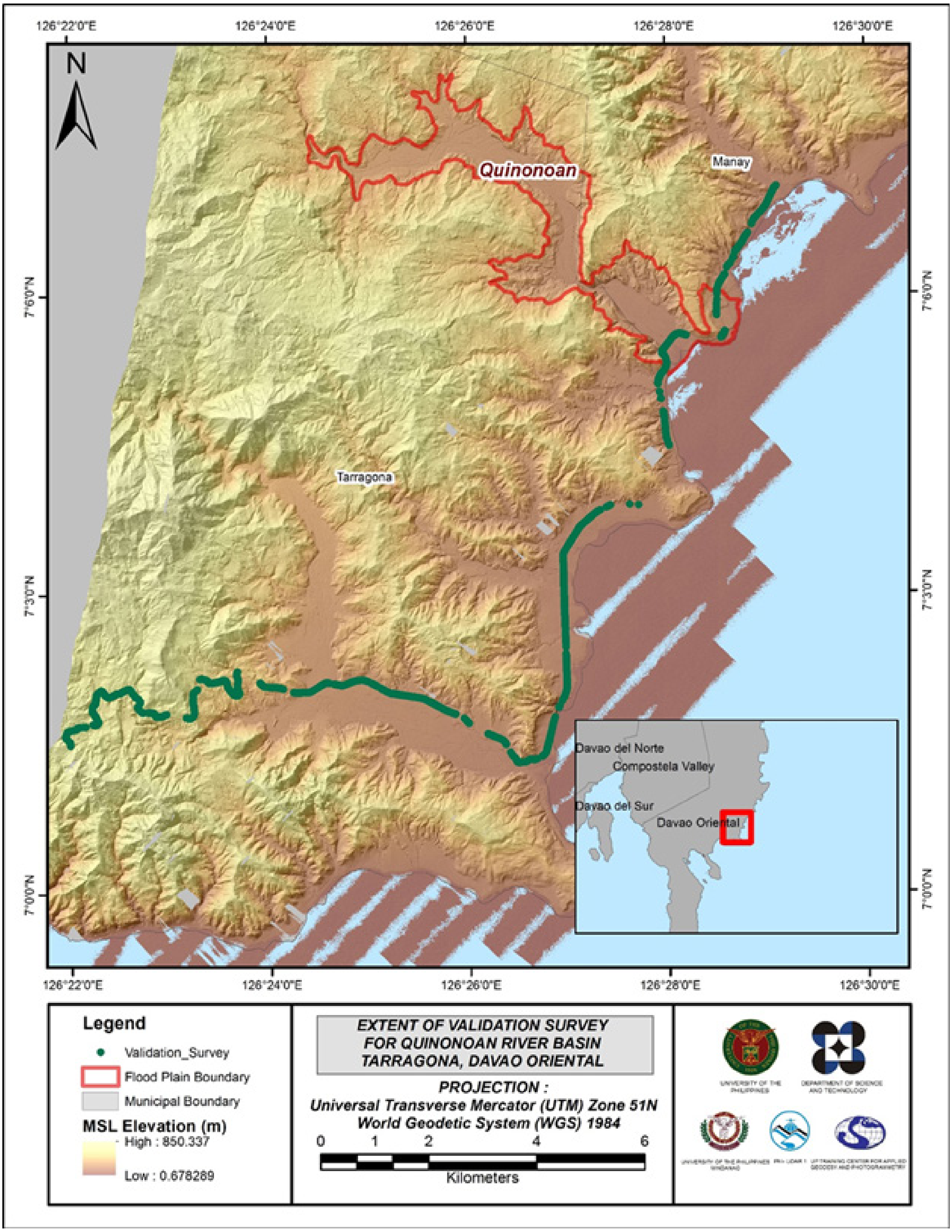

Figure 22. Map of Quinonoan Floodplain with validation survey points in green.

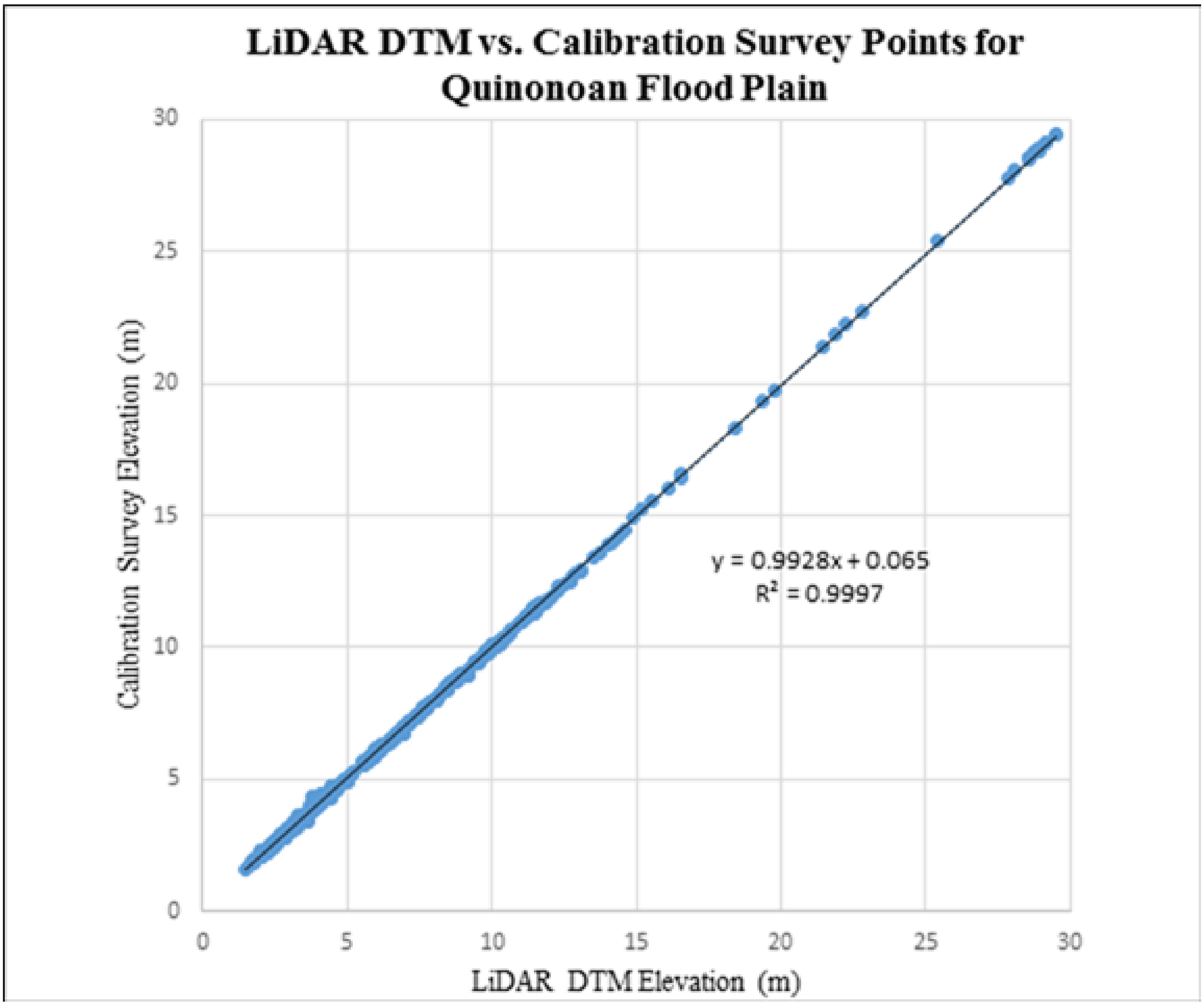

Figure 23. Correlation plot between calibration survey points and LiDAR data.

Table 15. Calibration Statistical Measures.

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

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

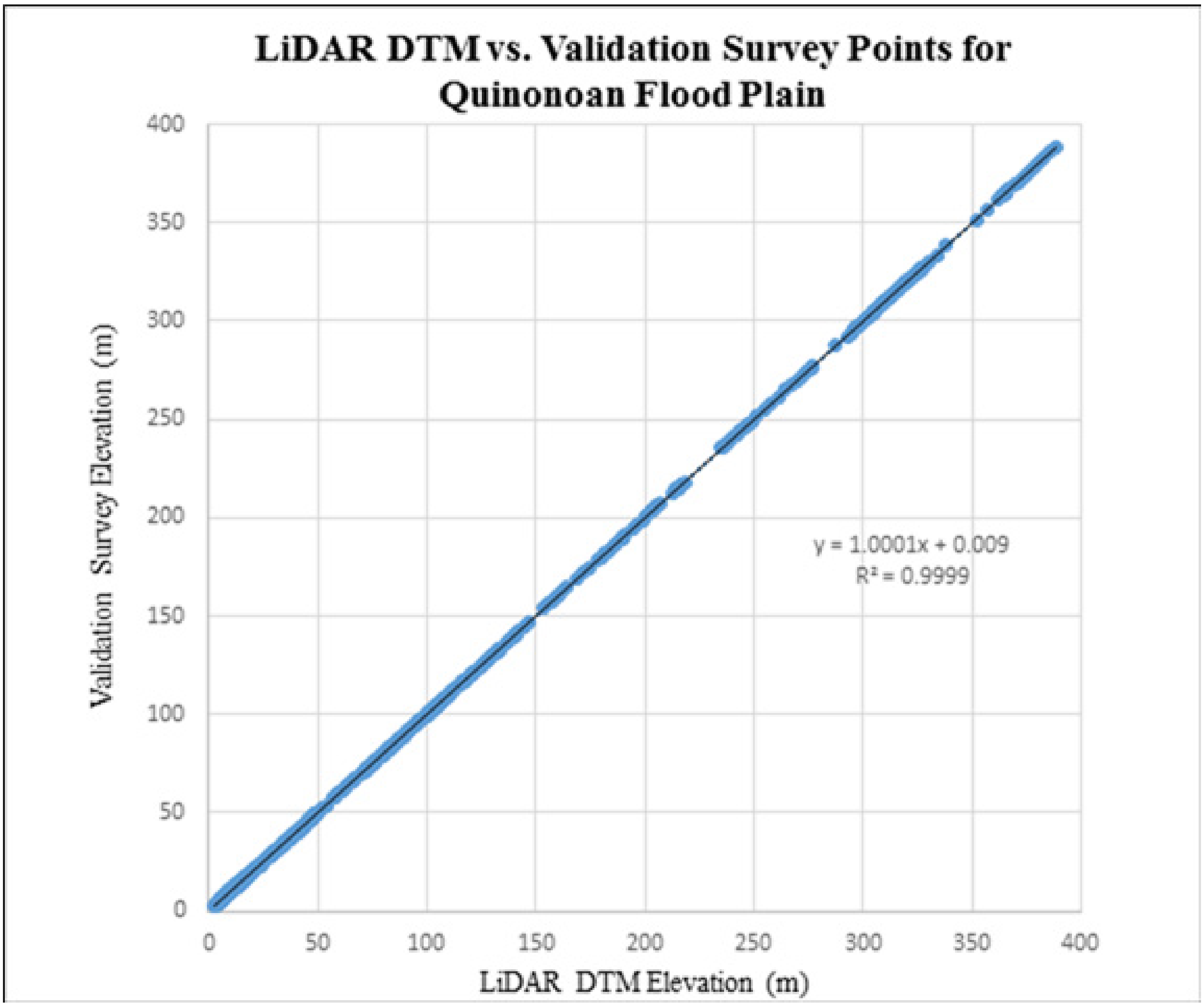

Figure 24. Correlation plot between the validation survey points and the LiDAR data.

Table 16. Validation Statistical Measures

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

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and zigzag data were available for Quinonoan with a total of 1,117 bathymetric survey points. The resulting raster surface produced was done by Kernel Interpolation with Barriers interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.49 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Quinonoan integrated with the processed LiDAR DEM is shown in Figure 24.

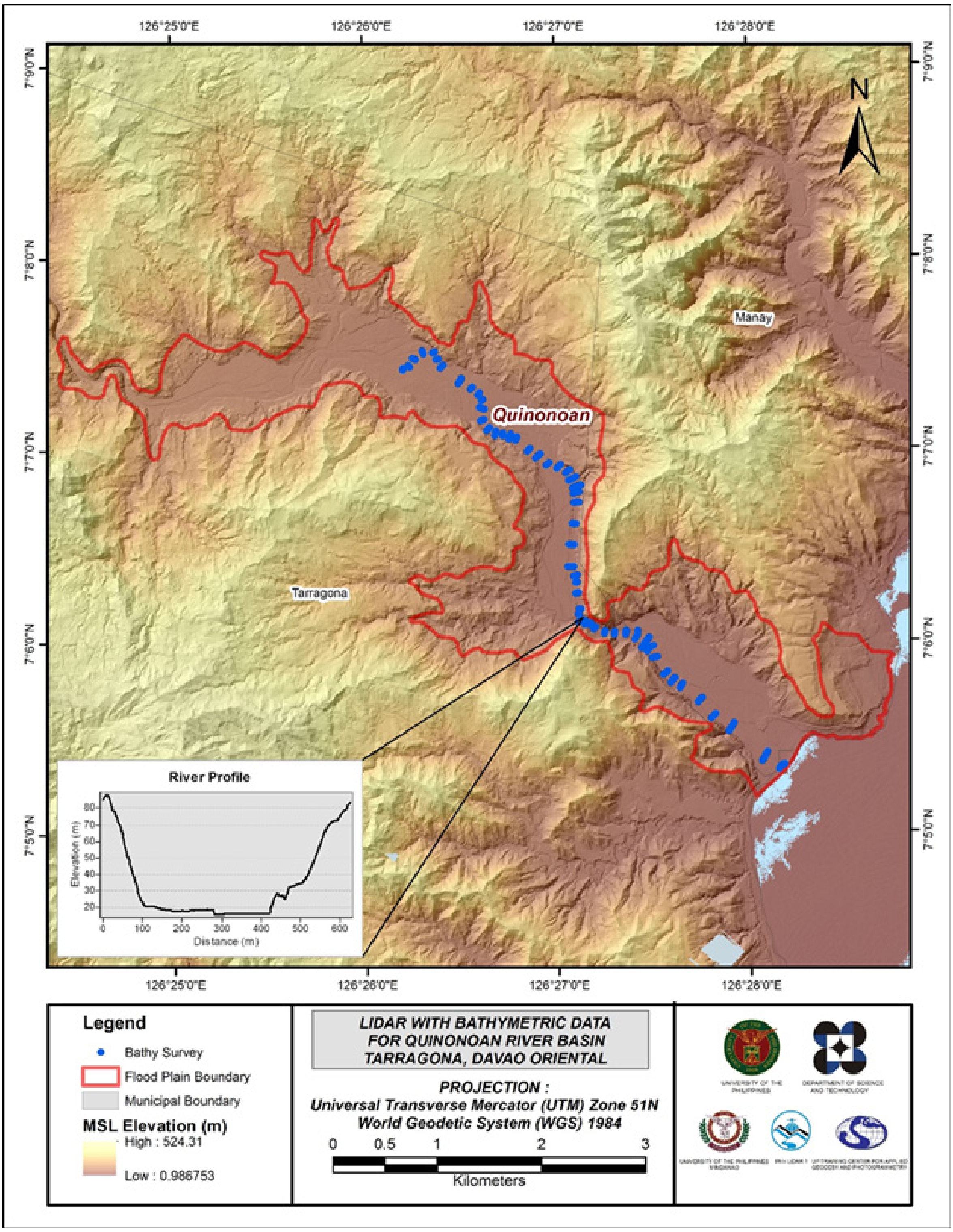

Figure 25. Map of Quinonoan floodplain with bathymetric survey points in blue.

3.12 Feature Extraction

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

3.12.1 Quality Checking (QC) of Digitized Features' Boundary

Quinonoan floodplain, including its 200-m buffer, has a total area of 16.30 sq km. For this area, a total of 5.0 sq. km., corresponding to a total of 210 building features, were considered for QC. Figure 26 shows the QC blocks for the Quinonoan floodplain.

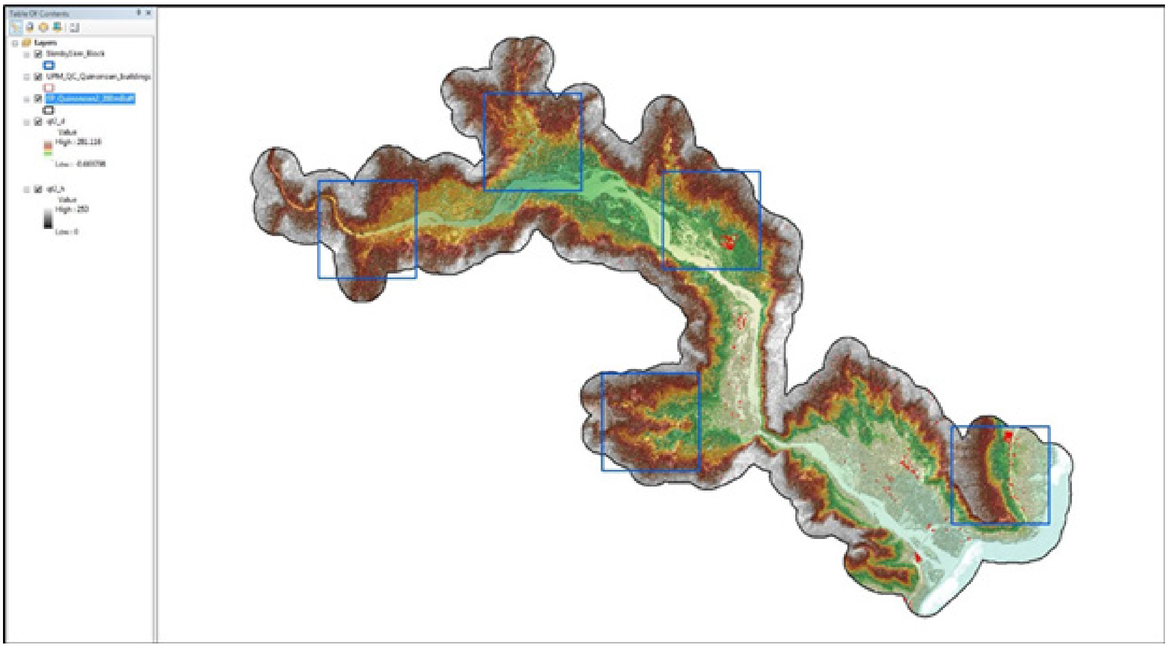

Figure 26. Blocks (in blue) of Quinonoan building features that were subjected to QC.

Quality checking of Quinonoan building features resulted in the ratings shown inTable 17.

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

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Quinonoan	96.20	98.06	93.55	PASSED

3.12.2 Height Extraction

Height extraction was done for 429 building features in Quinonoan floodplain. Of these building features, 12 buildings were filtered out after height extraction, resulting to 417 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 10.88 meters.

3.12.3 Feature Attribution

Field validation for Quinonoan floodplain has already been completed last June 13, 2016. However, due to the change in floodplain scope, new features were found through digitization, and initial attribution was applied through Data Mining, in which the team scans the features in the additional area through reliable sources in the internet like Google Earth. To confirm accuracy and completeness of data gathered, spot checking was conducted last December 15-16, 2016.

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

It was figured out by the Feature Extraction team during the courtesy call that there was a conflict in the boundaries of Tarragona and Manay municipalities. Also, LGUs raised their concern of the Lingayao River which was noted to be covering the center of the Manay municipality and the San Ignacio area and was said to cause flood in large settlement areas in the Municipality. During courtesy call, there was a heavy rain in the afternoon while the spot checking was still ongoing and some of the areas were landslide prone so the team was advised by the barangay captain not to proceed. Hence, validation activities for the areas that were not yet visited was done indoors through the help of barangay officials.

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

Table 18. Building features extracted for Quinonoan Floodplain.

Facility Type	No. of Features
Residential	387
School	14
Market	0
Agricultural/Agro-Industrial Facilities	8
Medical Institutions	1
Barangay Hall	1
Military Institution	0
Sports Center/Gymnasium/Covered Court	1
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	0
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	0
Water Supply/Sewerage	0
Religious Institutions	5
Bank	0
Factory	0
Gas Station	0
Fire Station	0
Other Government Offices	0
Other Commercial Establishments	0
Total	417

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

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/ Municipal Road	Provincial Road	National Road	Others	
Quinonoan	3.56	0.00	0.00	2.96	0.00	6.51

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

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

A total of 1 bridge was also extracted for the floodplain.

3.12.4 Final Quality Checking of Extracted Features

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

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

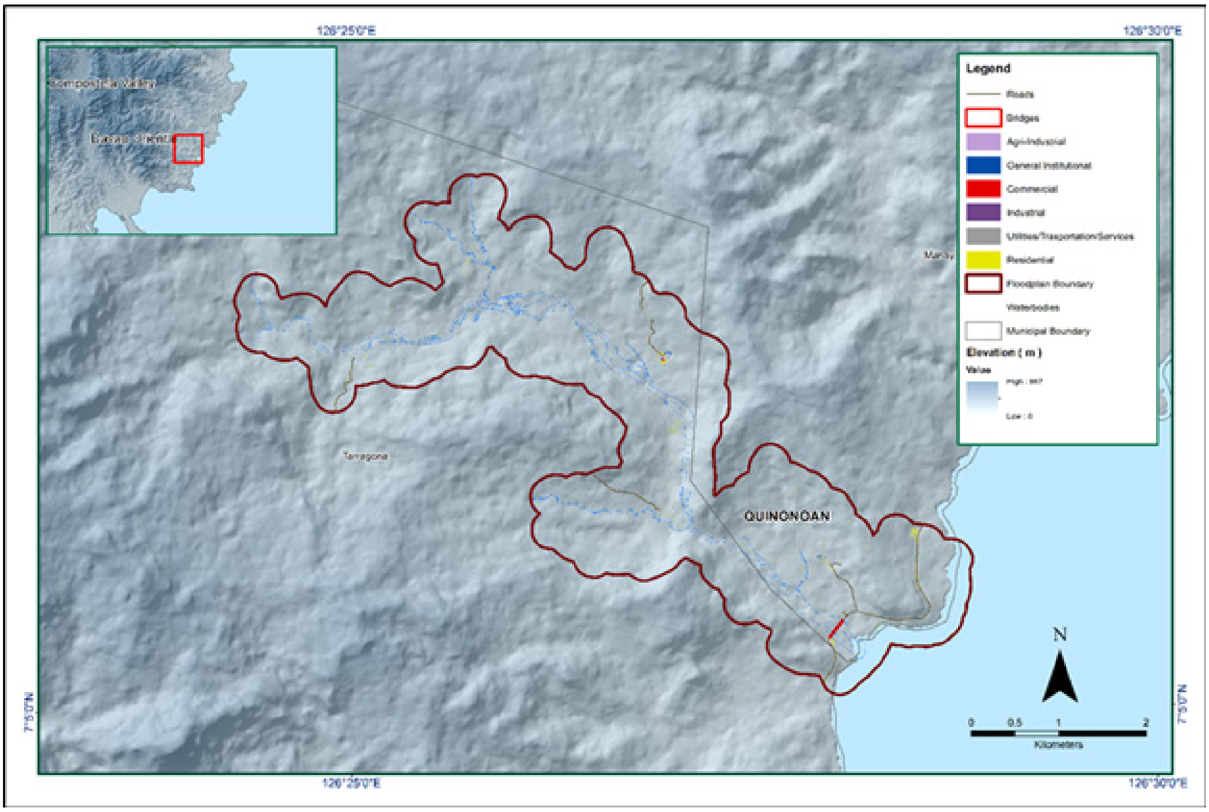

Figure 27. Extracted features of the Quinonoan Floodplain.

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

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

4.1 Summary of Activities

The AB Surveying and Development (ABSD) conducted a field survey in Quinonoan River on February 20, 2016, March 1-3, 2016, March 14, 2016, and March 20, 2016 with the following scope of work: reconnaissance; control survey; cross-section survey of selected riverbed in Quinonoan Bridge, Municipality in Brgy. San Ignacio, Manay, Davao Oriental; and bathymetric survey from its upstream in Brgy. Dadong, Tarragona to the mouth of the river located in Brgy. San Ignacio, Manay, with an approximate length of 6.3 km using a Horizon® Total Station. Random checking points for the contractor's cross-section and bathymetry data were gathered by DVBC on May 10-24, 2016 using a survey grade GNSS receiver Trimble® SPS 985 GNSS PPK survey technique. In addition to this, validation points acquisition survey was conducted covering the Quinonoan River Basin area. The entire survey extent is illustrated in Figure 28.

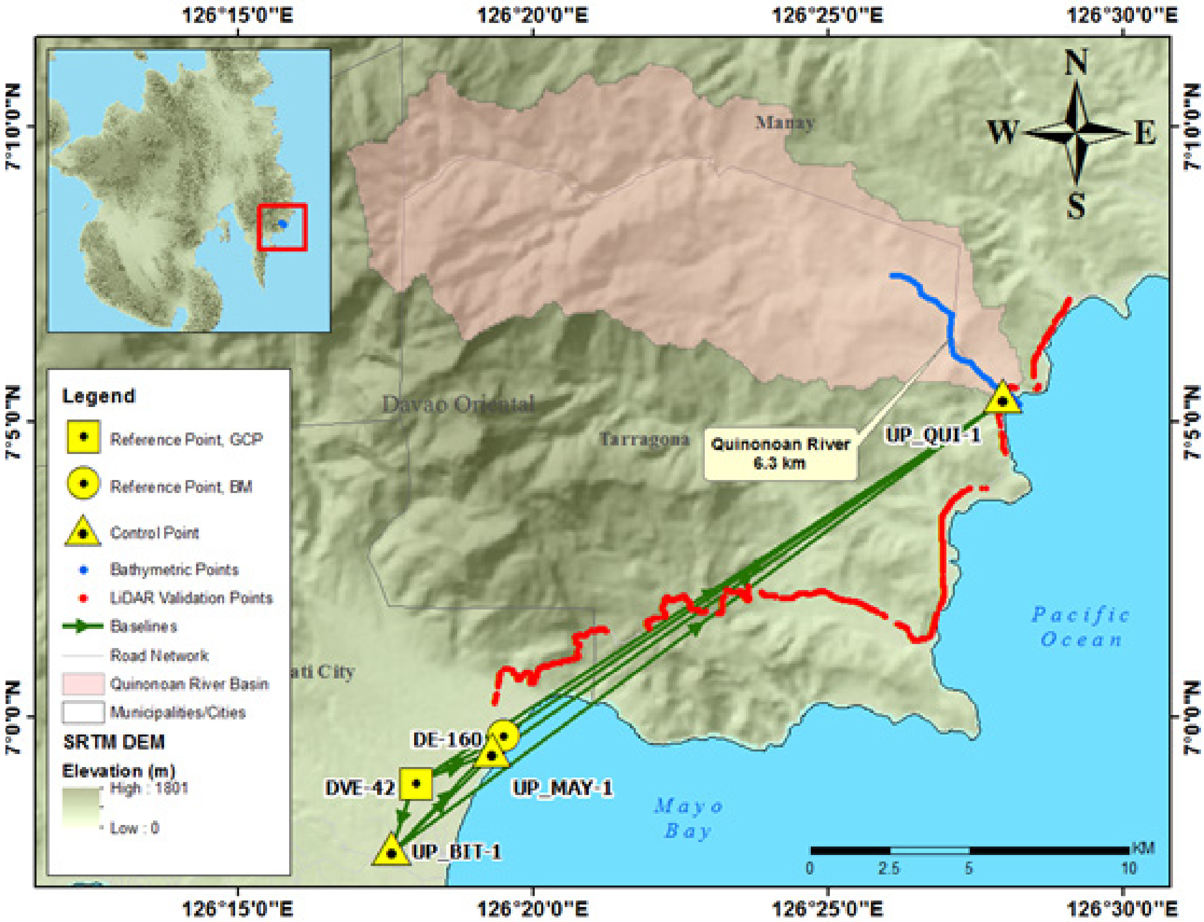


Figure 28. Quinonoan River Survey Extent

4.2 Control Survey

The GNSS network used for Quinonoan 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 Oriental and 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-1 beside 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.

Table 21 depicts the summary of reference and control points utilized, with their corresponding locations, while Figure 30 shows the GNSS network established in the Quinonoan River Survey.

Table 21. List of reference and control points used during the survey in Quinonoan 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

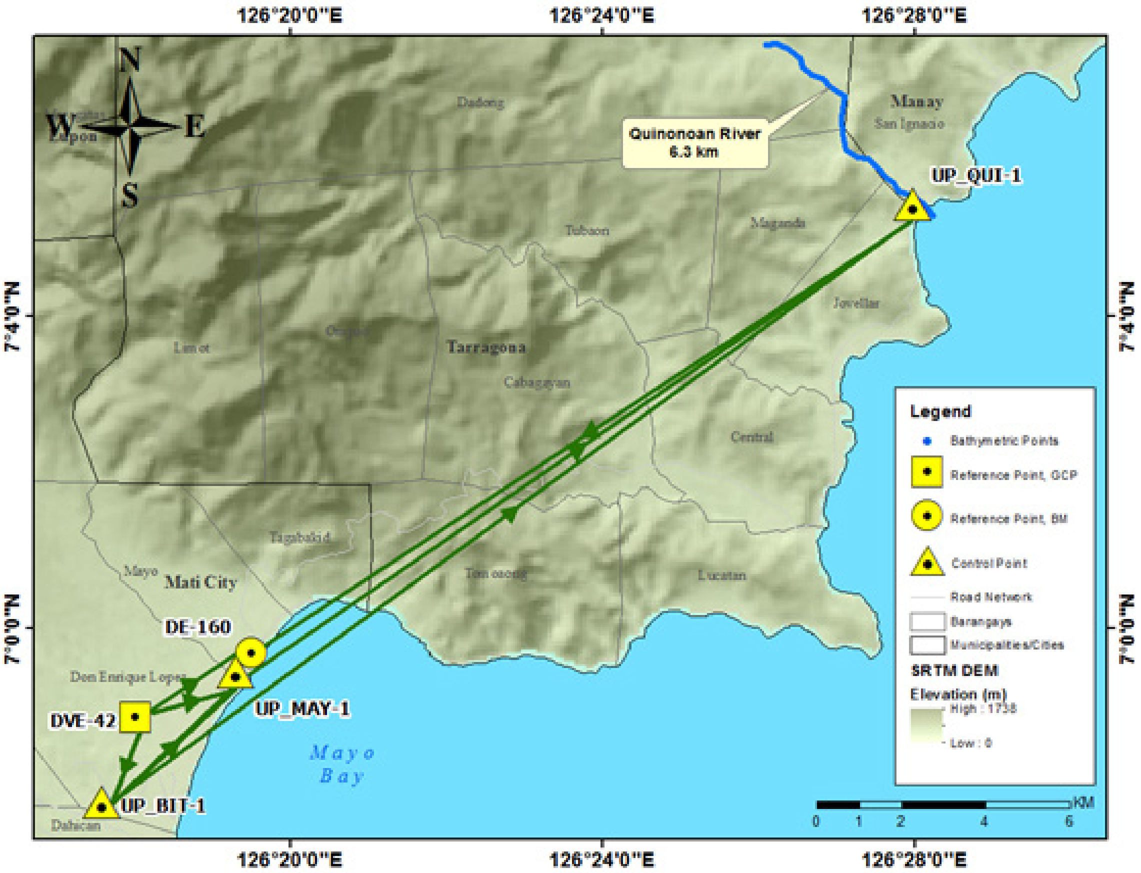


Figure 29. Quinonoan River Basin Control Survey Extent.

Figure 30 to Figure 34 depict the setup of the GNSS on recovered reference points and established control points in the Quinonoan River.

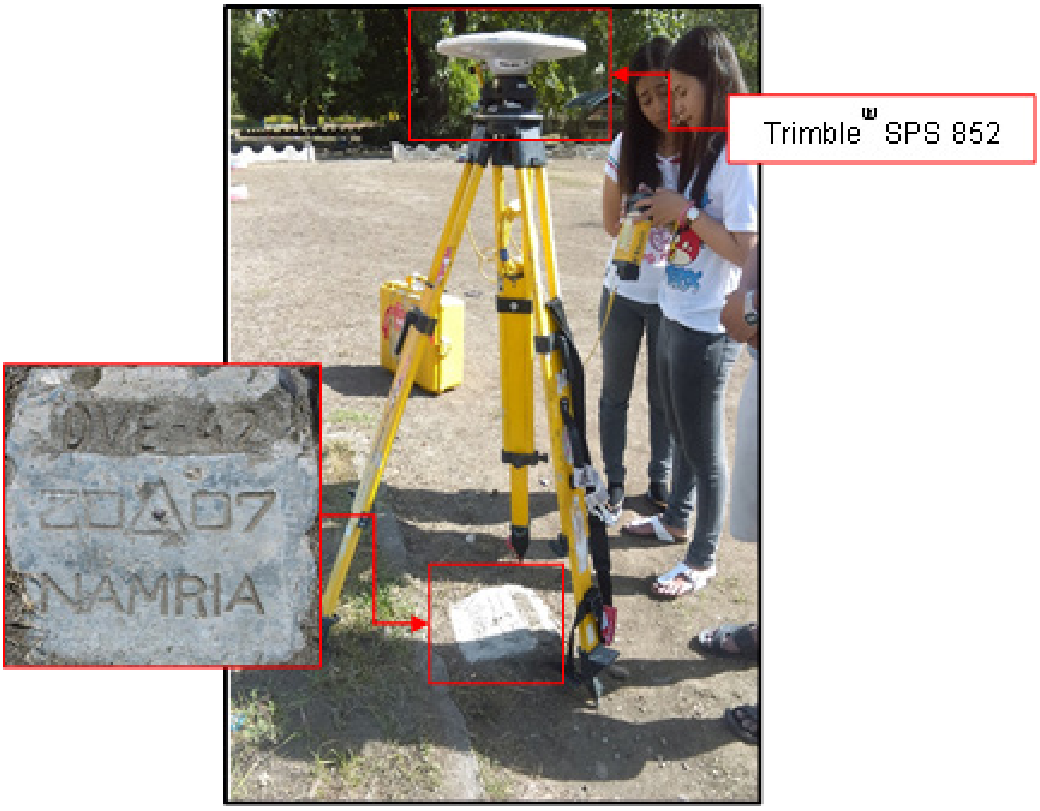


Figure 30. GNSS base set up, Trimble® SPS 852, at DVE-42, located in front of the flagpole inside Don Enrique Lopez Elementary School in Brgy. Don Enrique Lopez, Mati City, Davao Oriental

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. 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

The GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/- 20 cm and +/- 10 cm requirement respectively. In cases where one or more baselines did not meet all of these criteria, masking was performed. Masking is the removal or covering of portions of the baseline data using the same processing software. The data is then repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, a resurvey is initiated. Table 22 presents the baseline processing results of control points in the Quinonoan River Basin, as generated by the TBC software.

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

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
DVE-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 in Table 22, a total of ten (10) baselines were processed with the coordinates of DVE-42, and the elevation value of reference points DE-160 held fixed; it is apparent that all baselines passed the required accuracy.

4.4 Network Adjustment

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

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

where:

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

For complete details, see the Network Adjustment Report shown in Table 23 to Table 26.

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 this reference point, the coordinates and ellipsoidal height of the unknown control points will be computed.

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

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

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

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

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	

The results of the computation for accuracy are as follows:

a. DE-160
horizontal accuracy = $\sqrt{((0.3)^2 + (0.5)^2}$
$= \sqrt{(0.09 + 0.25)}$
$= 0.34 < 20$ cm
vertical accuracy = Fixed

b. DVE-42
horizontal accuracy = Fixed
vertical accuracy = $2.3 < 10$ cm

c. UP_BIT-1
horizontal accuracy = $\sqrt{((0.3)^2 + (0.4)^2}$
$= \sqrt{(0.09 + 0.16)}$
$= 0.25 < 20$ cm
vertical accuracy = $2.5 < 10$ cm

d. UP_MAY-1
horizontal accuracy = $\sqrt{((0.3)^2 + (0.4)^2}$
$= \sqrt{(0.09 + 0.16)}$
$= 0.25 < 20$ cm
vertical accuracy = $0.9 < 10$ cm

e. UP_QUI-1
horizontal accuracy = $\sqrt{((0.4)^2 + (0.7)^2}$
$= \sqrt{(0.16 + 0.49)}$
$= 0.65 < 20$ 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 25. Adjusted geodetic coordinates for control points used in the Quinonoan River Flood Plain validation.

Point ID	Latitude	Longitude	Ellipsoid 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	
DE-160	N6°59'41.20398"	E126°19'30.03464"	71.754	?	e

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

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

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
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

The bridge cross-section and as-built surveys were conducted on March 20, 2016 at the downstream side of Quinonoan Bridge, Brgy. San Ignacio, Manay using the GNSS receiver Horizon® utilizing GNSS RTK survey technique, (Figure 35 and Figure 36).

Figure 35. Quinonoan Bridge facing downstream

Figure 36. As-built survey of Quinonoan Bridge.

The length of the cross-sectional line surveyed at Quinonoan Bridge is about 369 meters (Figure 35) with one hundred seventy-three (173) cross-sectional points using the control points UP_QUI-1 and UP_QUI-2 as the GNSS base stations. The location map, cross-section diagram, and the accomplished bridge data from are shown in Figure 37, Figure 38 and Figure 39 respectively.

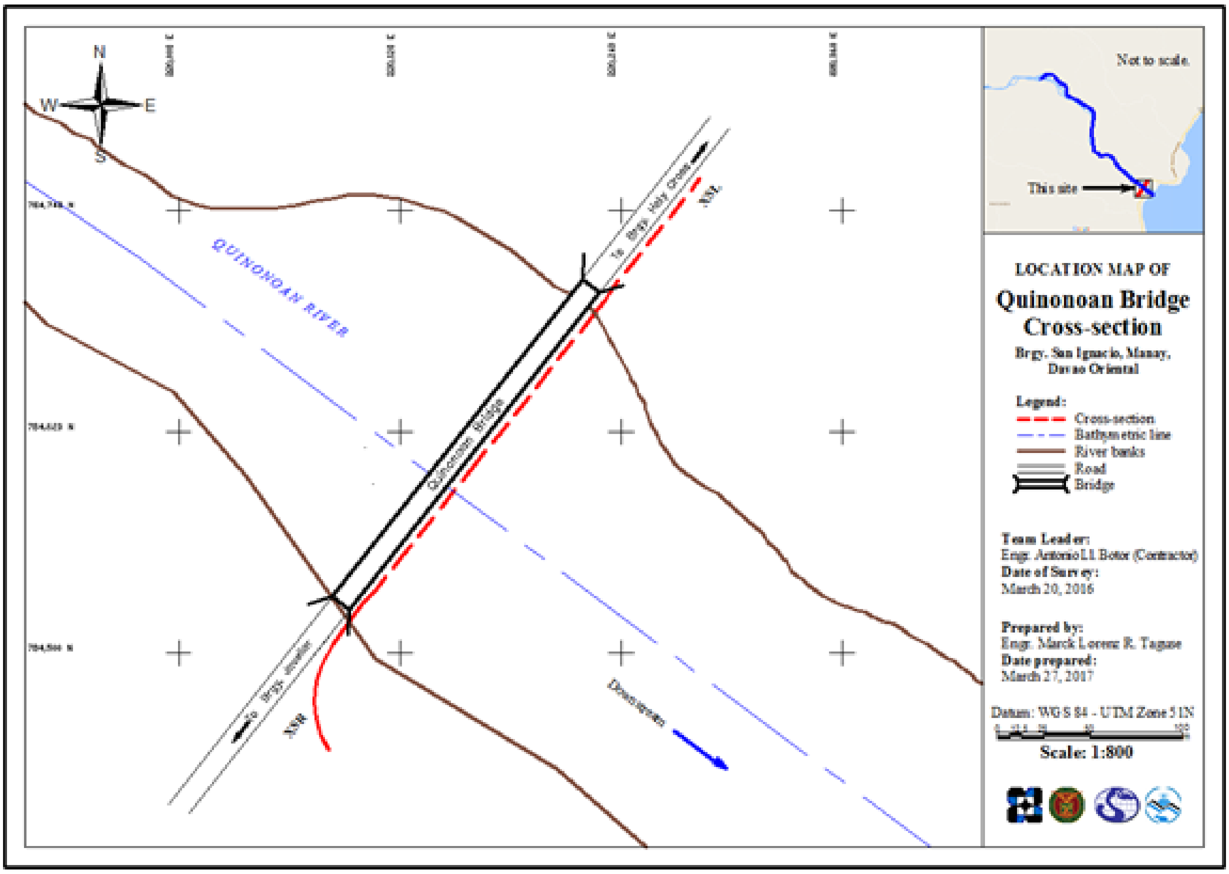


Figure 37. Location map of the Quinonoan Bridge cross section.

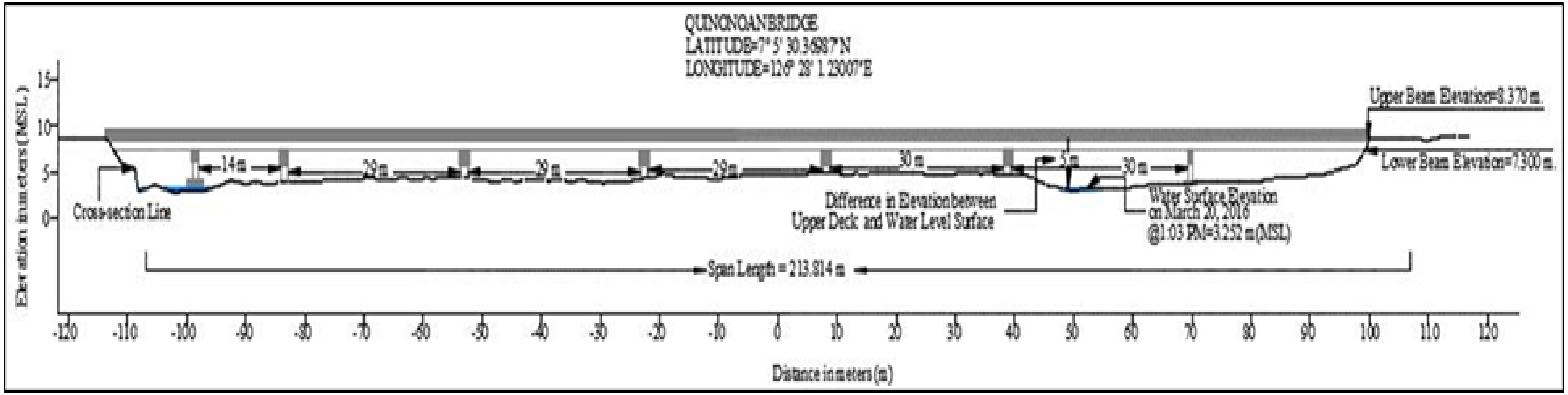


Figure 38. The Quinonoan cross-section survey in Quinonoan Bridge drawn to scale.

Bridge Data Form

Bridge Name: Quinonoan Bridge

River Name: Quinonoan River

Location (Brgy, City, Region): Brgy. San Ignacio, Manay, Davao Oriental

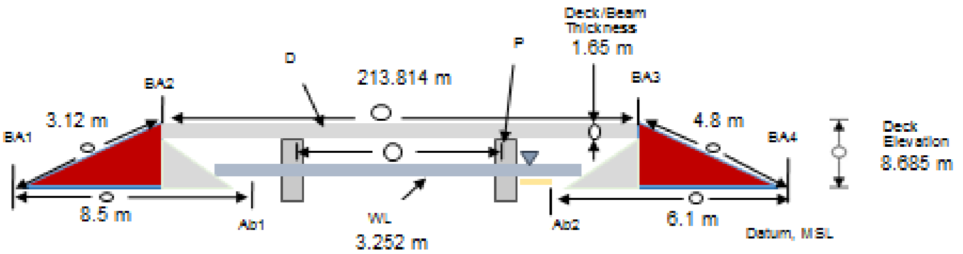
Survey Team: Jayson Ilustre, Ryan Antonio

Date and Time: March 20, 2016, 1:03 P.M.

Flow Condition: low normal ✓ high

Weather Condition: fair rainy ✓

Cross-sectional View (not to scale)



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

Line Segment	Measurement (m)	Remarks
1. BA1-BA2	3.12 m	
2. BA2-BA3	213.814 m	
3. BA3-BA4	4.8 m	
4. BA1-Ab1	8.5 m	Under Construction: Riprap
5. Ab2-BA4	6.1 m	
6. Deck/beam thickness	1.65 m	
7. Deck elevation	8.685 m	

Note: Observer should be facing downstream

Figure 39. Quinonoan Bridge Data Sheet.

The water surface elevation of Quinonoan River was determined by a Horizon® Total Station on March 20, 2016 at 1:03 PM at Quinonoan Bridge area with a value of 3.252 m in MSL as shown in Figure 38. This was translated into marking on the bridge's pier as shown in Figure 40. The marking will serve as reference for flow data gathering and depth gauge deployment of the partner HEI responsible for Quinonoan River, UP Mindanao.

Figure 40. Water-level markings on Quinonoan Bridge.

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted by DVBC on May 14, 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 as shown in Figure 41. 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 topographic mode with UP_QUI-1 occupied as the GNSS base station in the conduct of the survey.

Figure 41. GNSS Rover receiver, Trimble® SPS 985 installed on a vehicle for Ground Validation Survey.

The survey started from Brgy. Mayo, Mati City, Davao Oriental going north east along national high way, traversing one (1) barangay in Mati City, four (4) barangays in Tarragona and ended in Brgy. San Ignacio, Manay, Davao Oriental. A total of 4,051 points were gathered with approximate length of 34.14 km using UP_QUI-1 as GNSS base station for the entire extent validation points acquisition survey, as illustrated in the map in Figure 42.

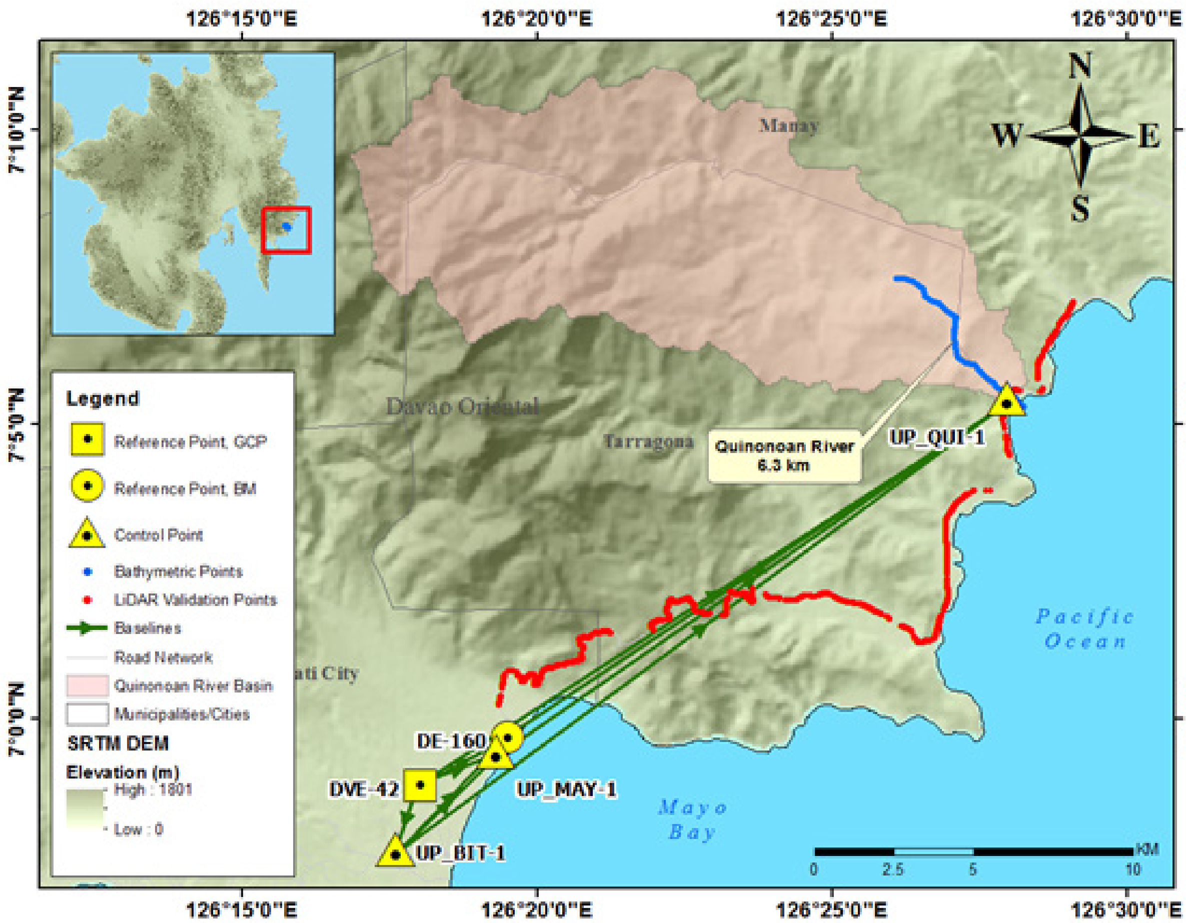


Figure 42. The extent of the LiDAR ground validation survey (in red) for Quinonoan River Basin

4.7 River Bathymetric Survey

A manual bathymetric survey was performed on March 1-3, 2016 and on March 14, 2016 using a Horizon® Total Station as shown in Figure 43.

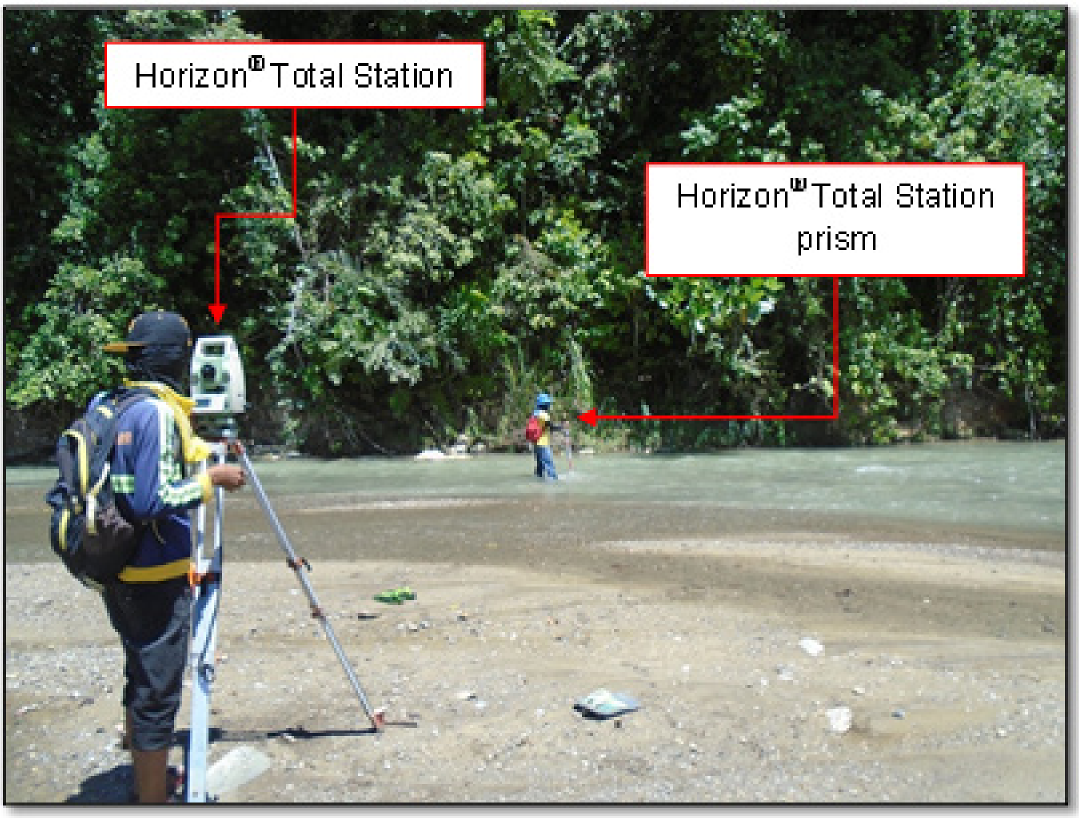


Figure 43. Set up of the bathymetric survey in Quinonoan River

The survey started in Brgy. Dadong, Tarragona, Davao Oriental with coordinates 7° 7’ 24.75944”N, 126° 26’ 11.85148”E and ended at the mouth of the river in Brgy. San Ignacio, Manay, Davao Oriental with coordinates 7° 5’ 20.61189”N, 126° 28’ 10.00302”E. The control points UP_QUI-1 and UP_QUI-2 served as the GNSS base stations all throughout the survey.

Overall, the extent of the bathymetric survey for the Quinonoan River is shown in Figure 44. To further illustrate this, a CAD drawing of the riverbed profile of the Quinonoan River was produced as seen in Figure 46 .

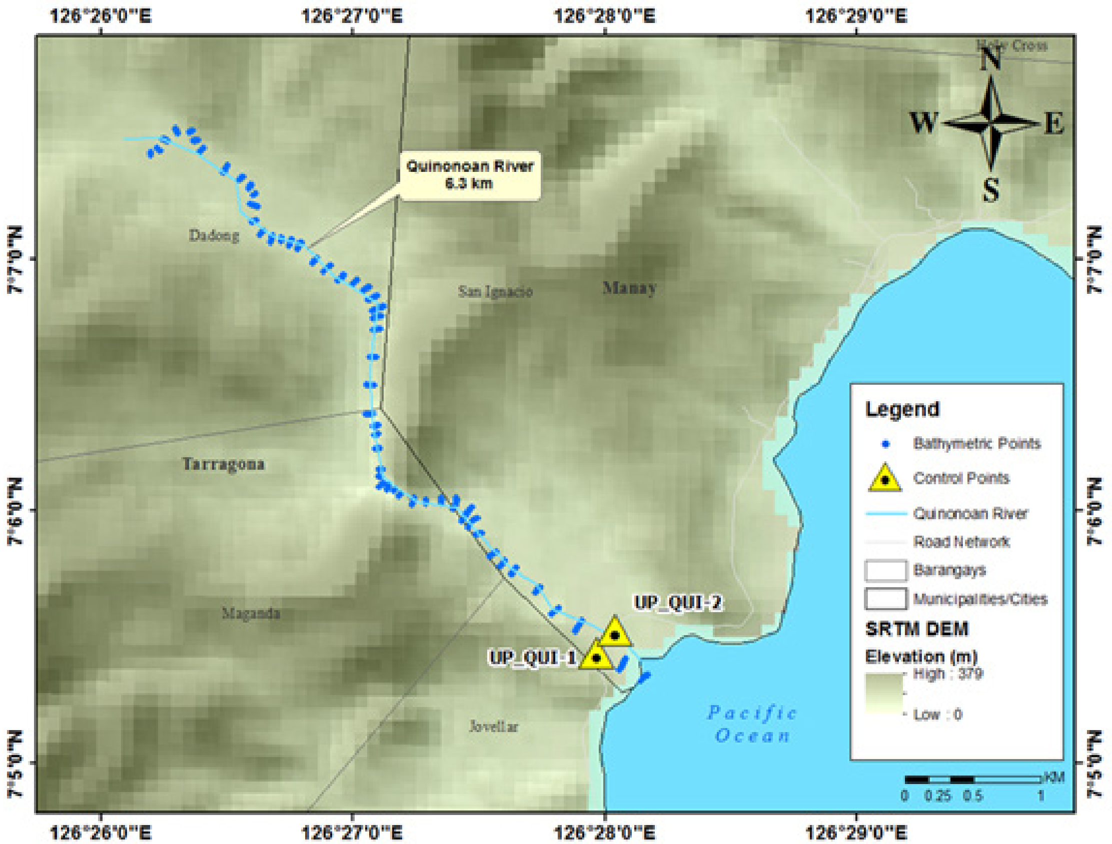


Figure 44. The extent of the Quinonoan River Bathymetry Survey.

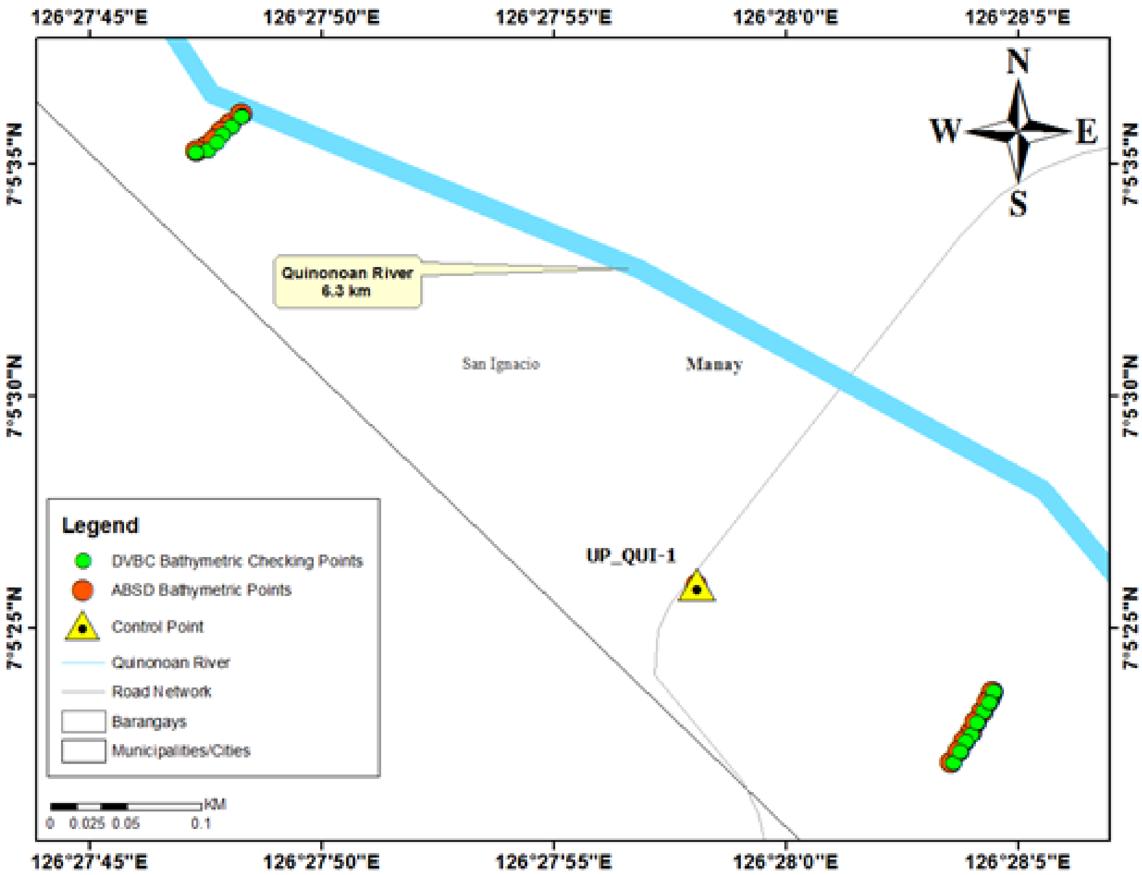


Figure 45. Quality checking points gathered along Quinonoan River by DVBC

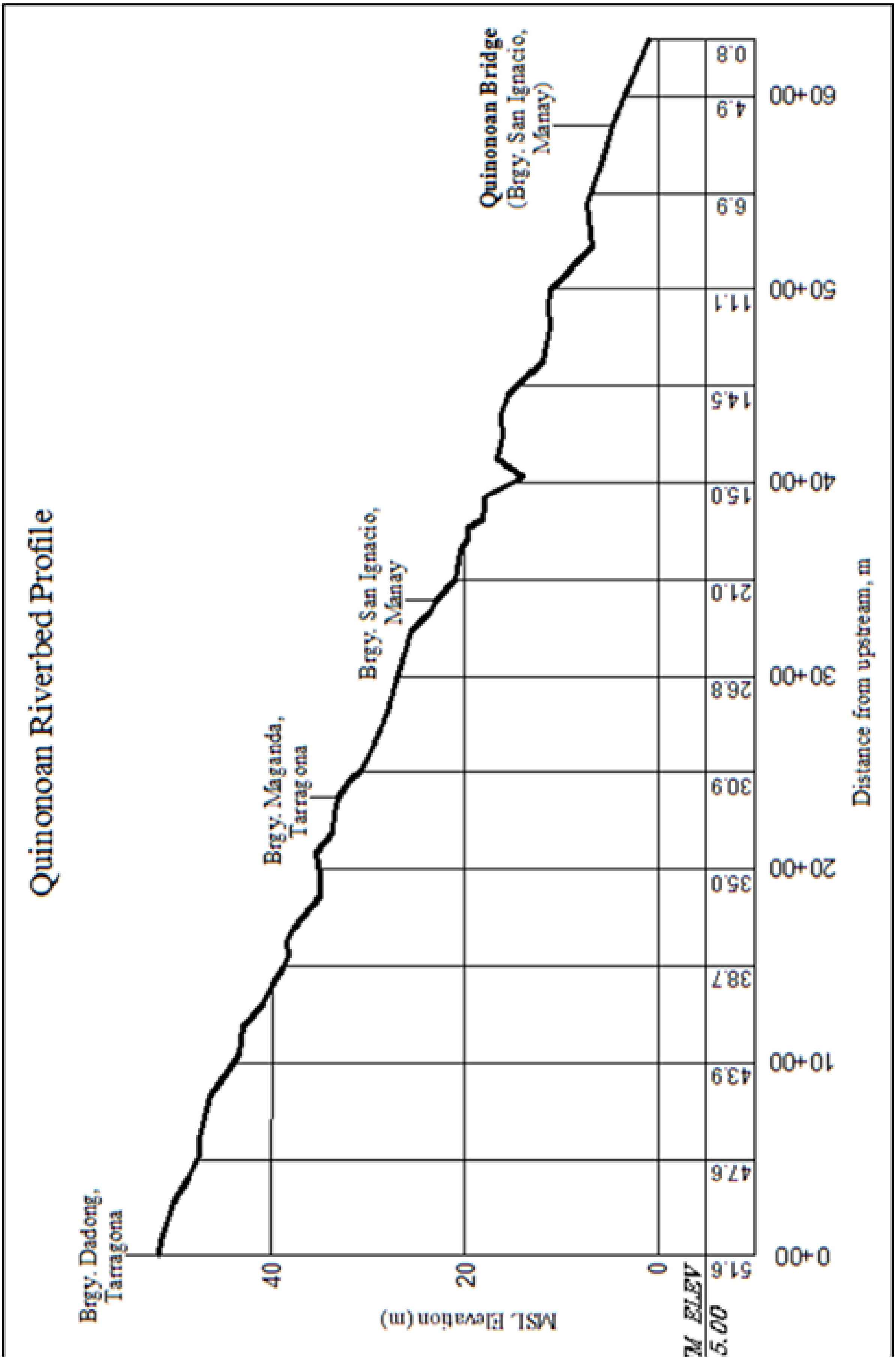


Figure 46. The Quinonoan Riverbed Profile

CHAPTER 5: FLOOD MODELING AND MAPPING

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

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

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

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

5.1.2 Precipitation

Precipitation data was taken from an automatic rain gauge (ARG) installed by the University of the Philippines Mindanao Phil-LiDAR1 team. This rain gauge is located in Barangay Dadong, Tarragona, Davao Oriental with the following coordinates: 7°8’20.9” N, 126°26’22.2” E as illustrated in Figure 47. The precipitation data collection started from January 26, 2016 at 5:00 AM to January 30, 2016 at 3:40 AM a 10-minute.

The total precipitation for this event in the installed rain gauge was 44.6 mm. It has a peak rainfall of 4.2 mm. on January 27, 2016 at 5:50 AM. The lag time between the peak rainfall and discharge is 2 hours and 40 minutes.

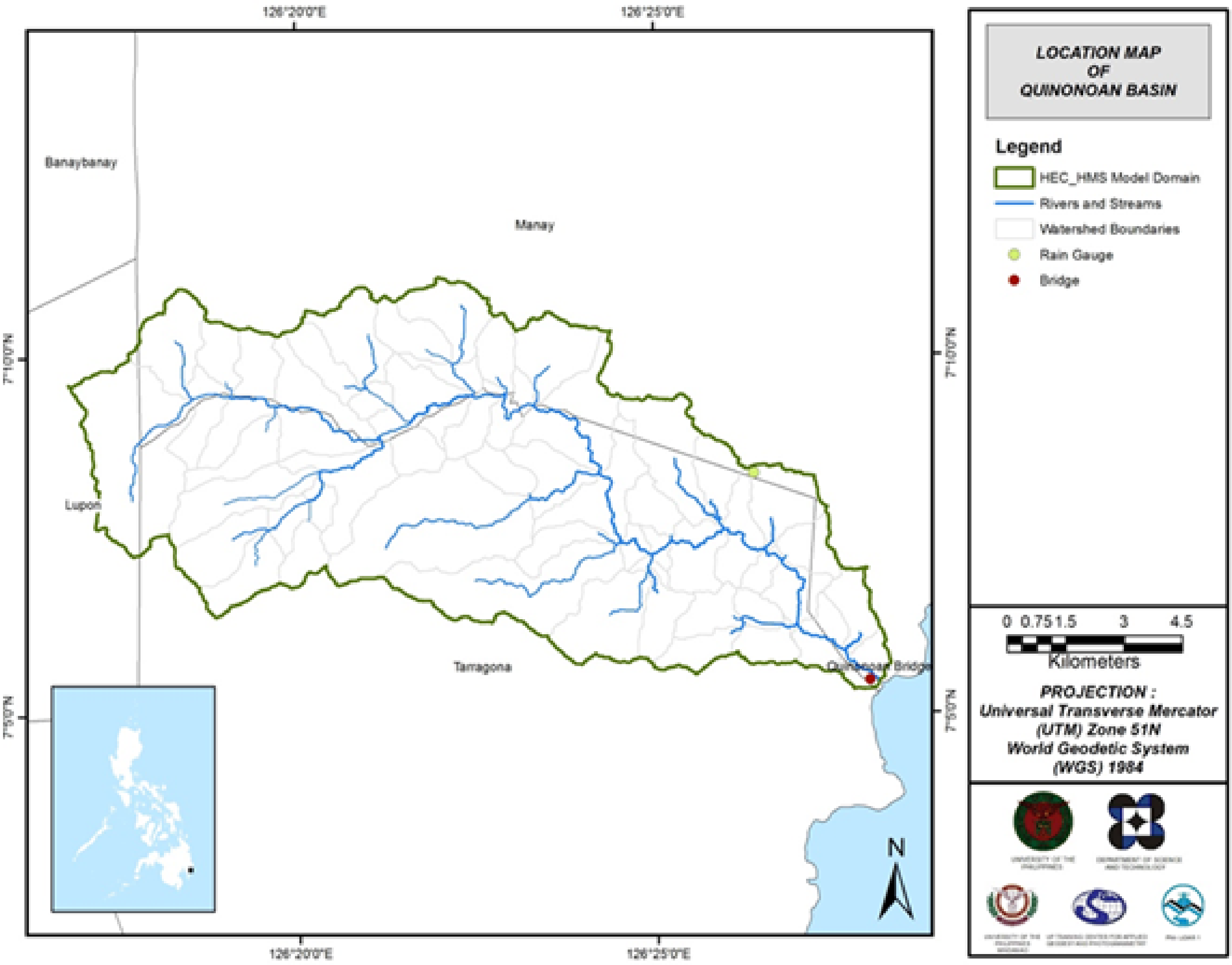


Figure 47. Location Map of the Quinonoan HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Quinonoan Bridge, Brgy. Jovellar, Tarragona, Davao Oriental (7°5'27.17" N, 126°27'58.57" E). It gives the relationship between the observed water level at the Quinonoan Bridge and outflow of the watershed at this location.

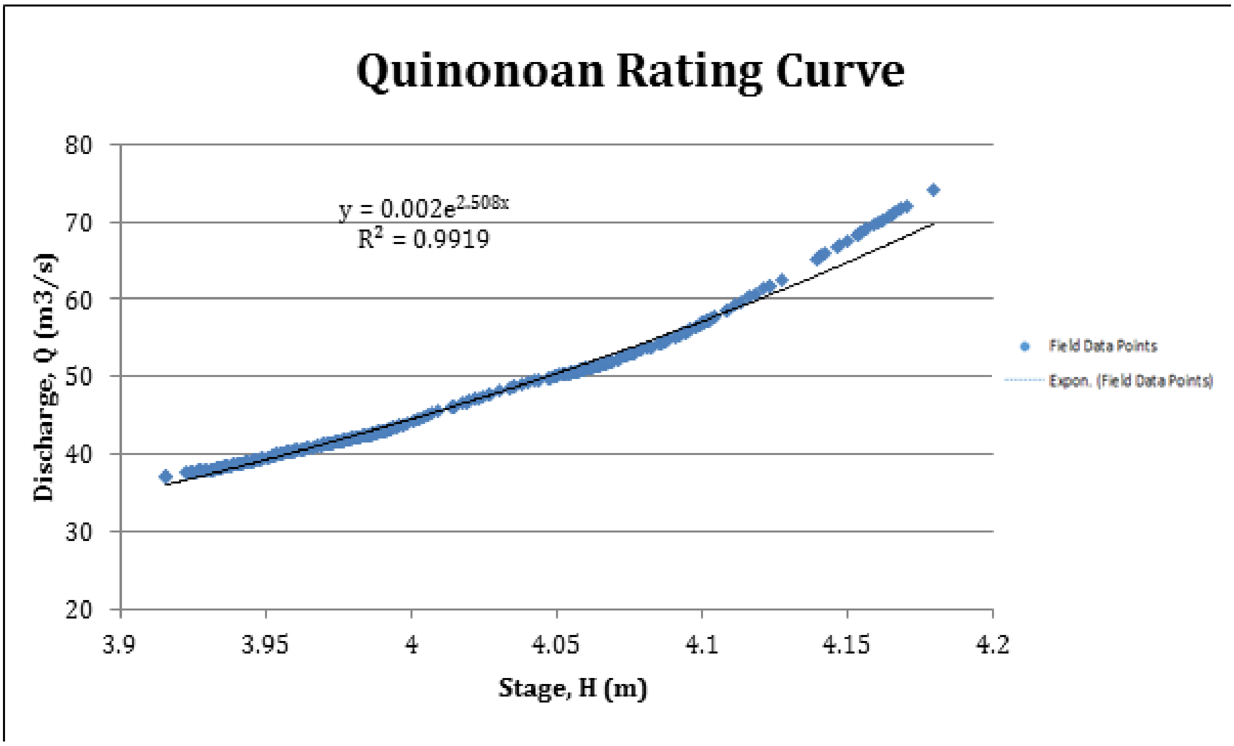


Figure 48. The Rating Curve at Quinonoan Bridge, Tarragona, Davao Oriental.

This rating curve equation was used to compute the river outflow at Quinonoan Bridge for the calibration of the HEC-HMS model shown in Figure 49. The peak discharge is 3.04 m3/s at 5:40 in the morning, May 16, 2016.

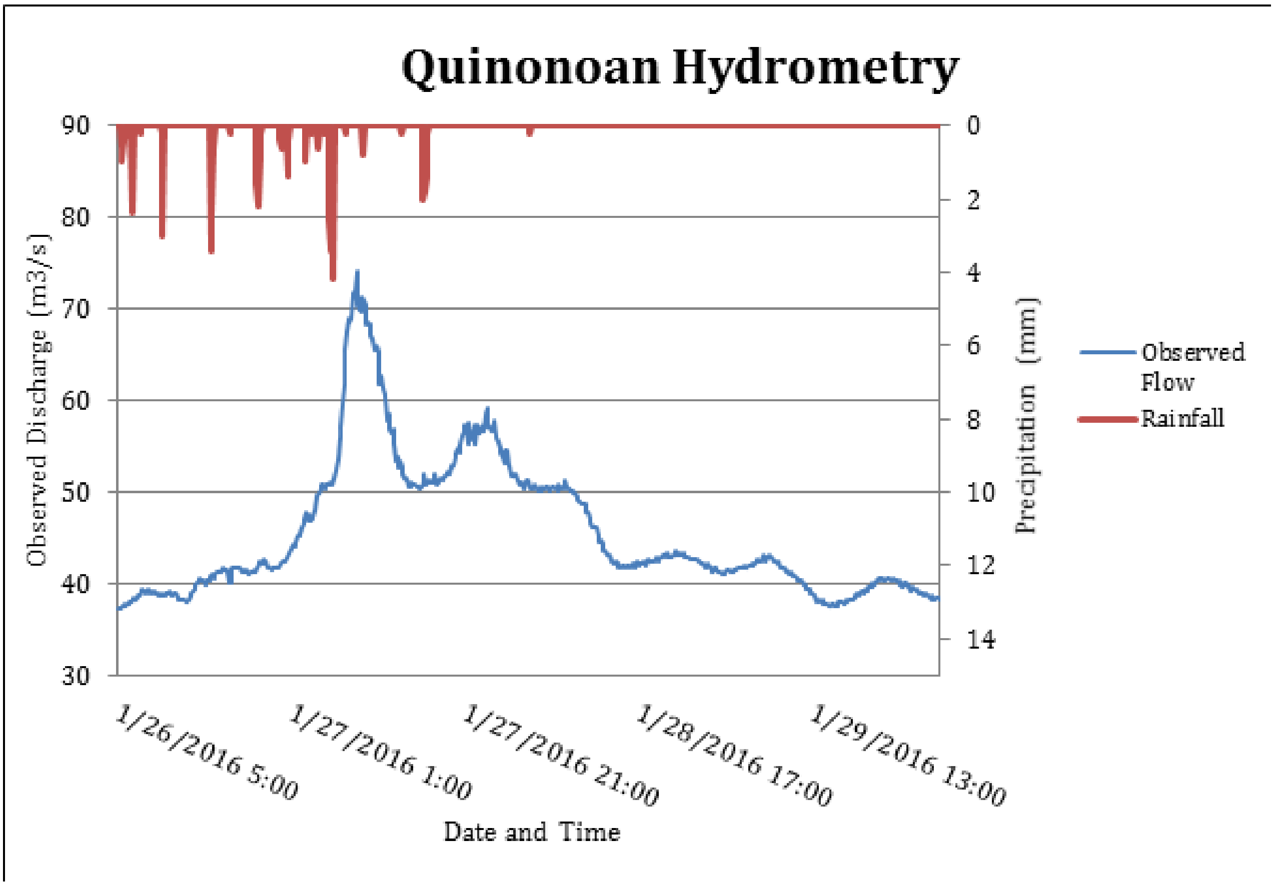


Figure 49. Rainfall and outflow data at Quinonoan Bridge used for modeling

5.2 RIDF Station

PAGASA computed the Rainfall Intensity Duration Frequency (RIDF) values for the Davao Rain Gauge (Table 27). The RIDF rainfall amount for 24 hours was converted into a synthetic storm by interpolating and re-arranging the values in such a way that certain peak values will be attained at a certain time (Figure 46). This station was selected based on its proximity to the Quinonoan watershed. The extreme values for this watershed were computed based on a 59-year record.

Table 27. RIDF values for the Quinonoan River Basin based on average RIDF data of Davao station, as computed by PAGASA

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

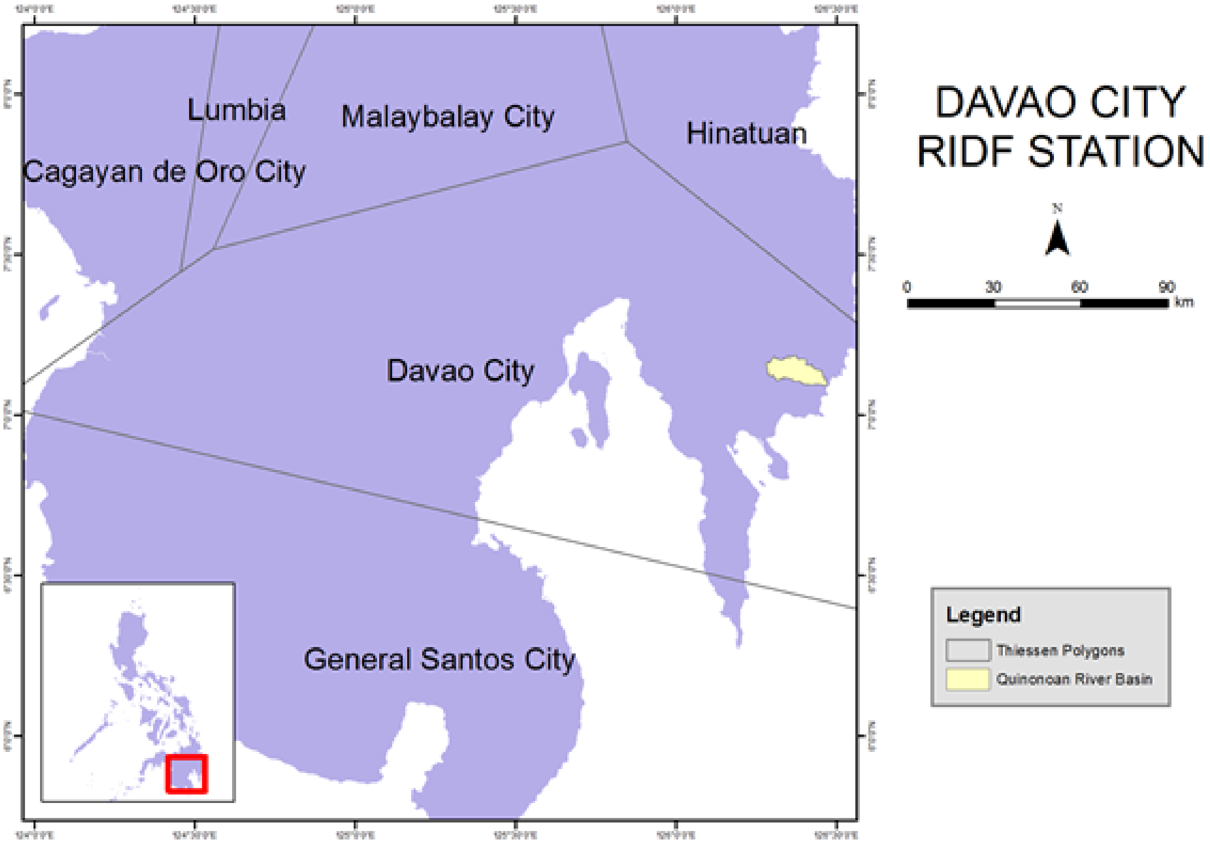


Figure 50. The location of the Davao RIDF station relative to the Quinonoan River Basin.

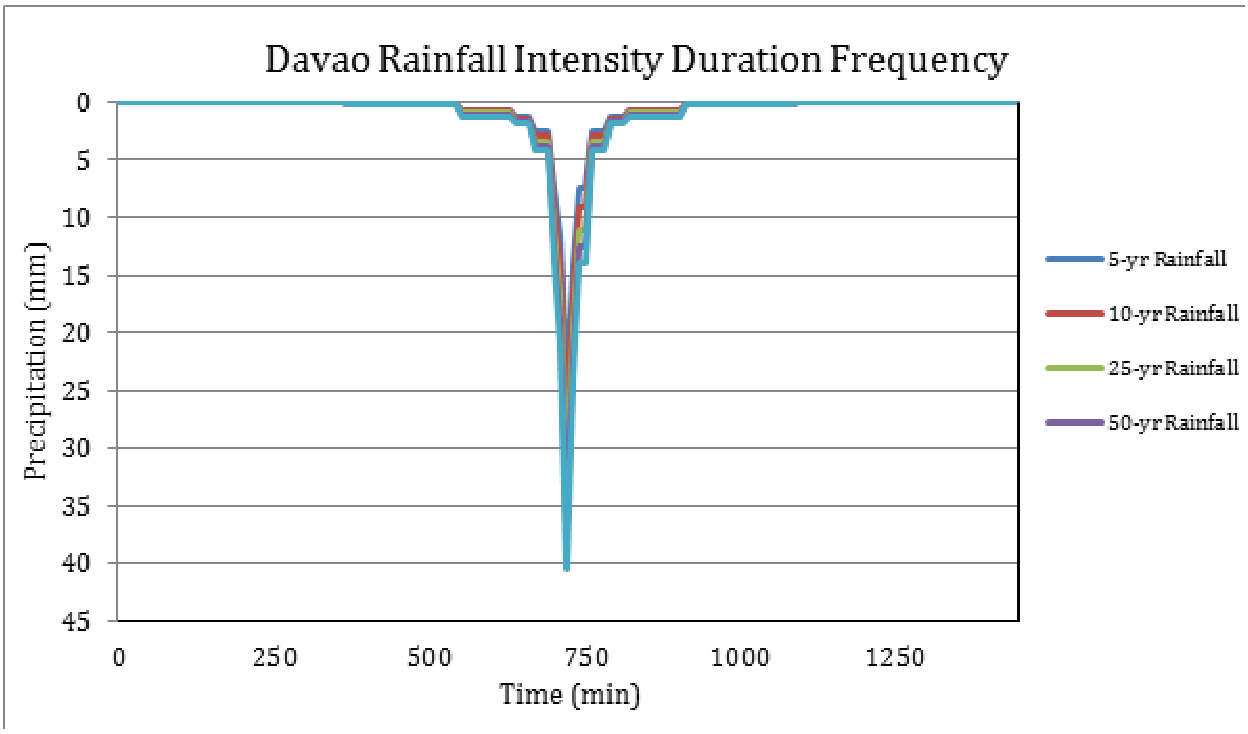


Figure 51. The synthetic storm generated for a 24-hour period rainfall for various return periods

5.3 HMS Model

These soil dataset was taken on 2004 from the Bureau of Soils and Water Management (BSWM). It is under the Department of Environment and Natural Resources Management (DENR). The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Quinonoan River Basin are shown in Figure 52 and Figure 53 respectively.

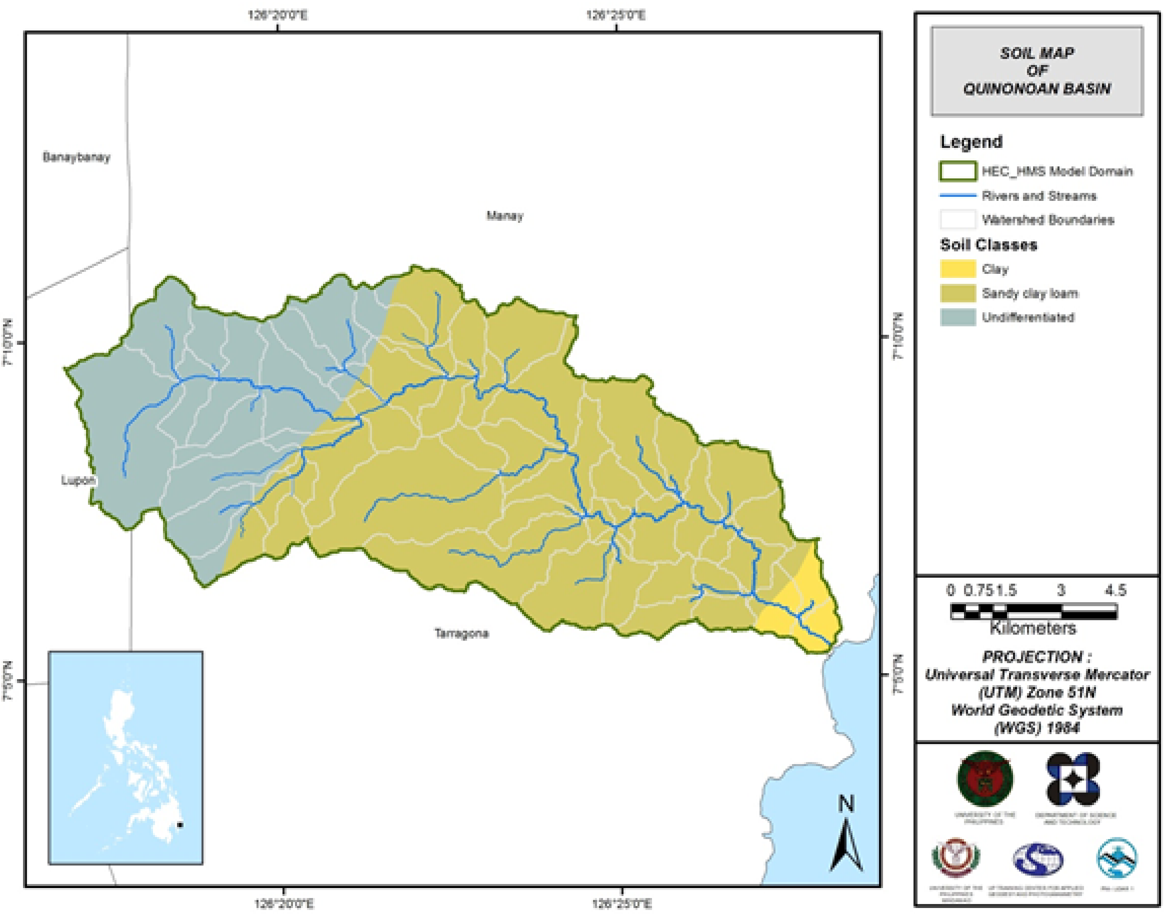


Figure 52. Soil Map of Quinonoan River Basin.

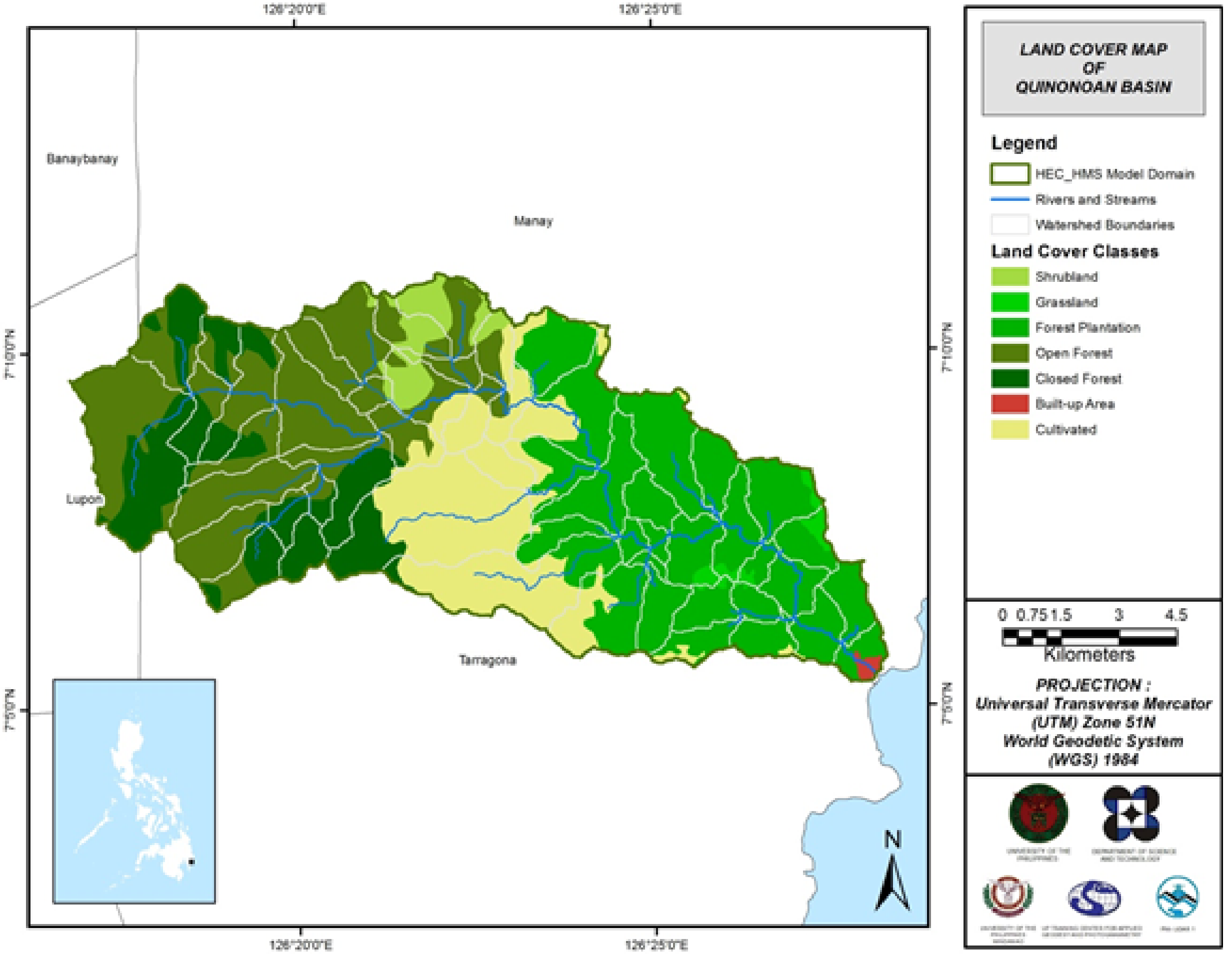


Figure 53. Land Cover Map of Quinonoan River Basin.

For Quinonoan, four soil classes were identified. These are are sand, loam, clay loam and silt loam. Moreover, seven land cover classes were identified. These are forest plantation, grassland, shrubland, cultivated lands, mangrove, built-up and inland water bodies.

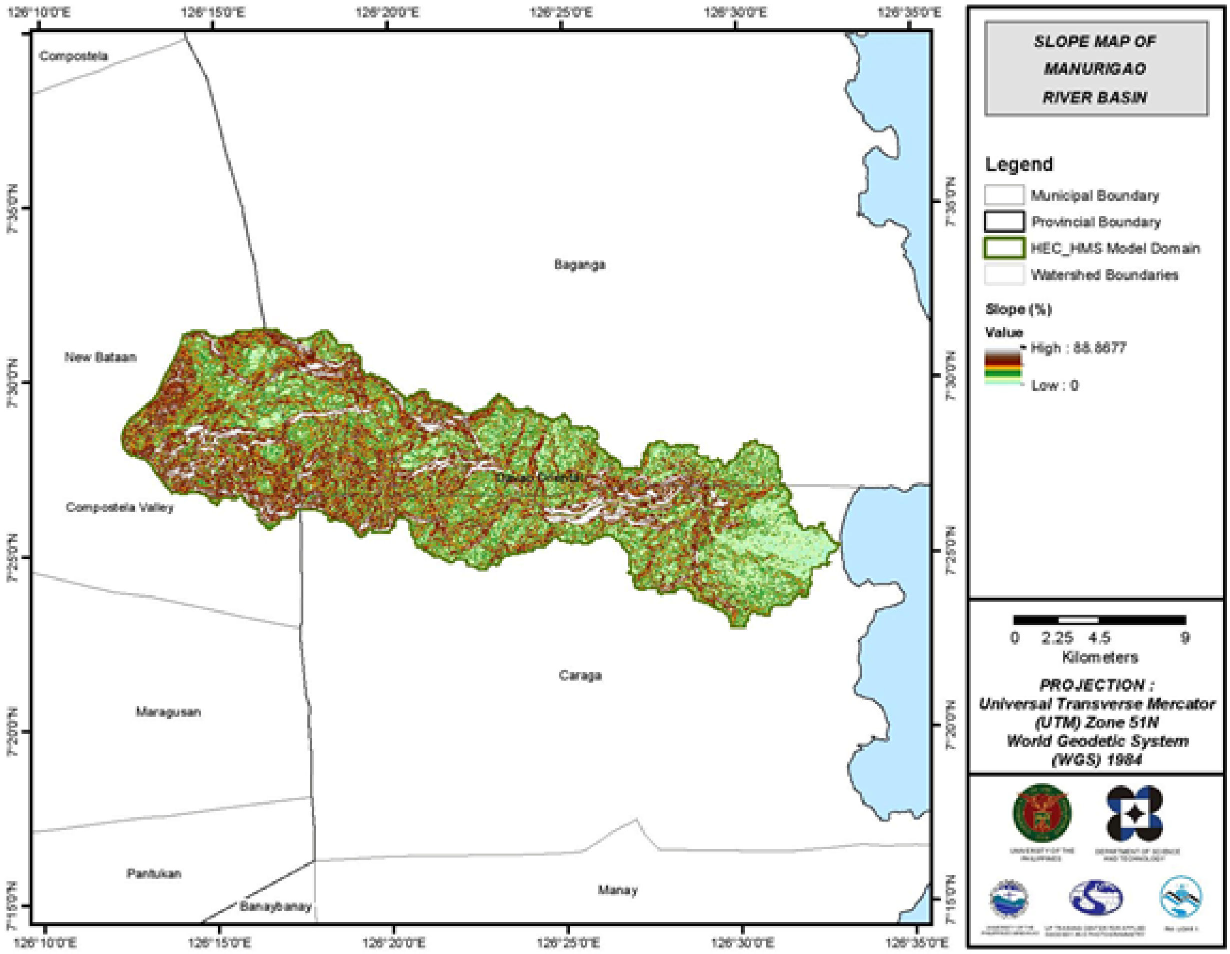


Figure 54. Slope Map of the Quinonoan River Basin.

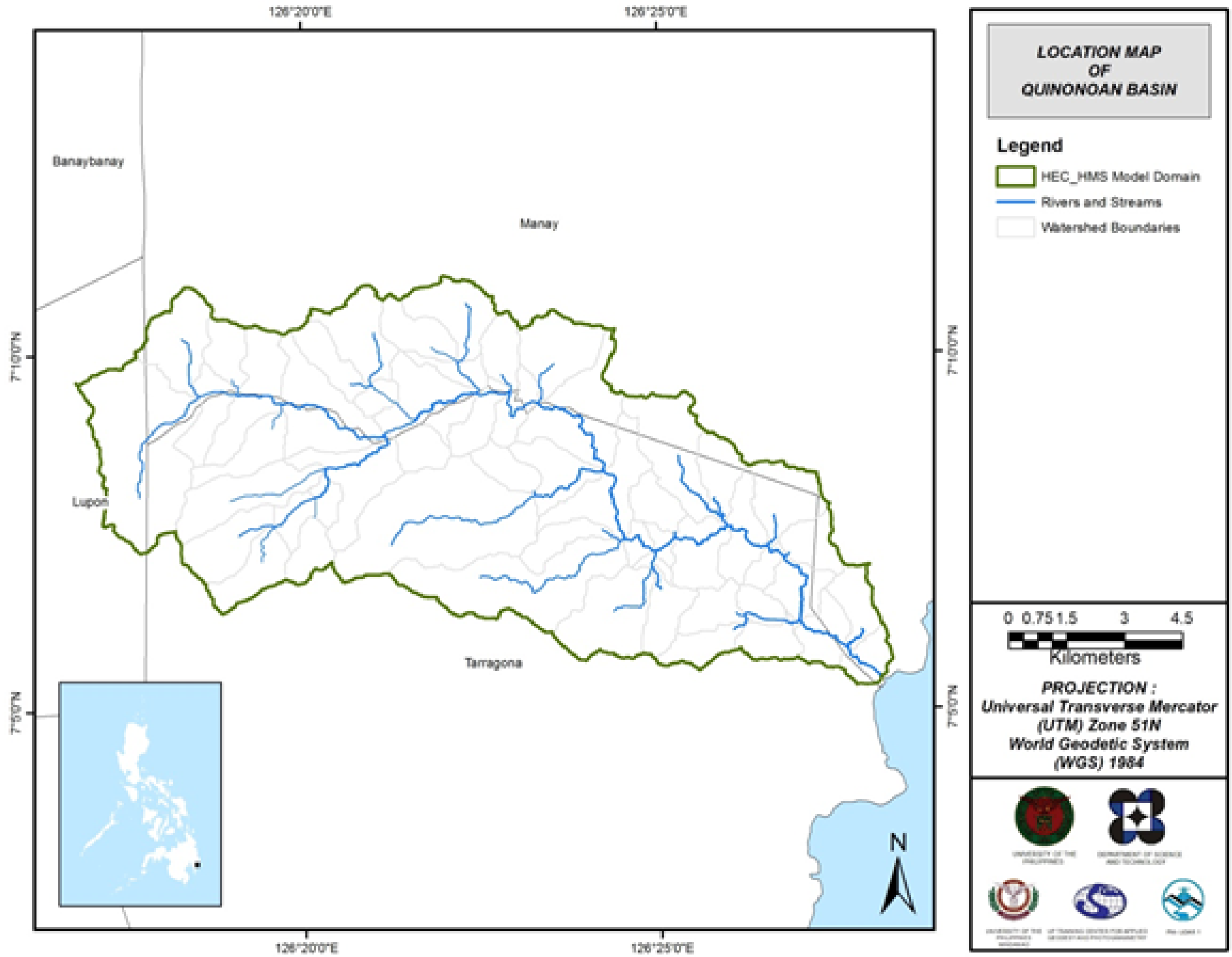


Figure 55. Stream Delineation Map of Quinonoan River Basin

Using the SAR-based DEM, the Quinonoan basin was delineated and further subdivided into subbasins. The model consists of 57 sub basins, 28 reaches, 28 junctions, as shown in Figure 56. The main outlet is at Quinonoan Bridge.

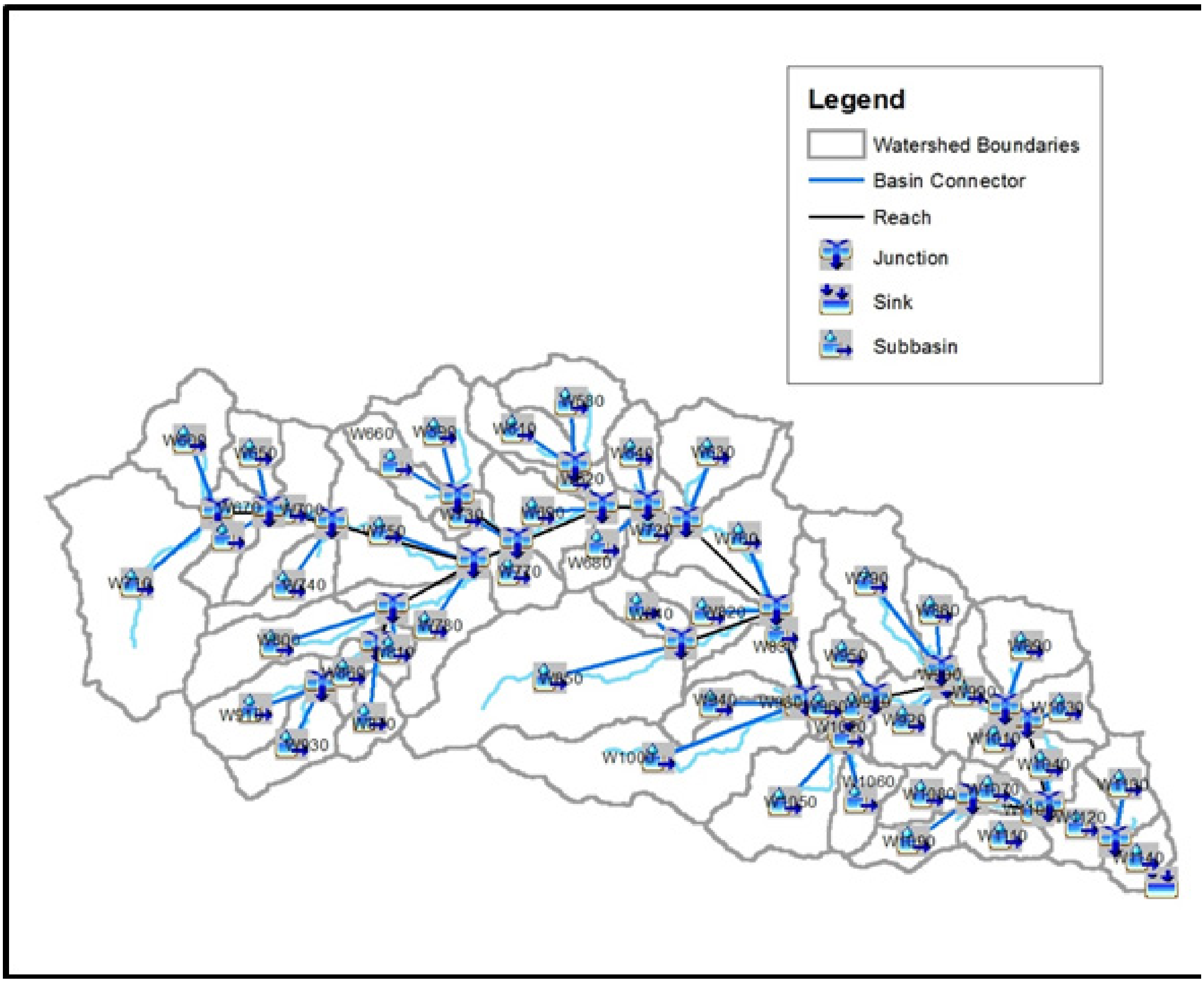


Figure 56. Quinonoan river basin model generated in HEC-HMS.

5.4 Cross-section Data

The riverbed cross-sections of the watershed were necessary in the HEC-RAS model setup. The cross-section data for the HEC-RAS model was derived from the LiDAR DEM data, which was defined using the Arc GeoRAS tool and was post-processed in ArcGIS (Figure 57).

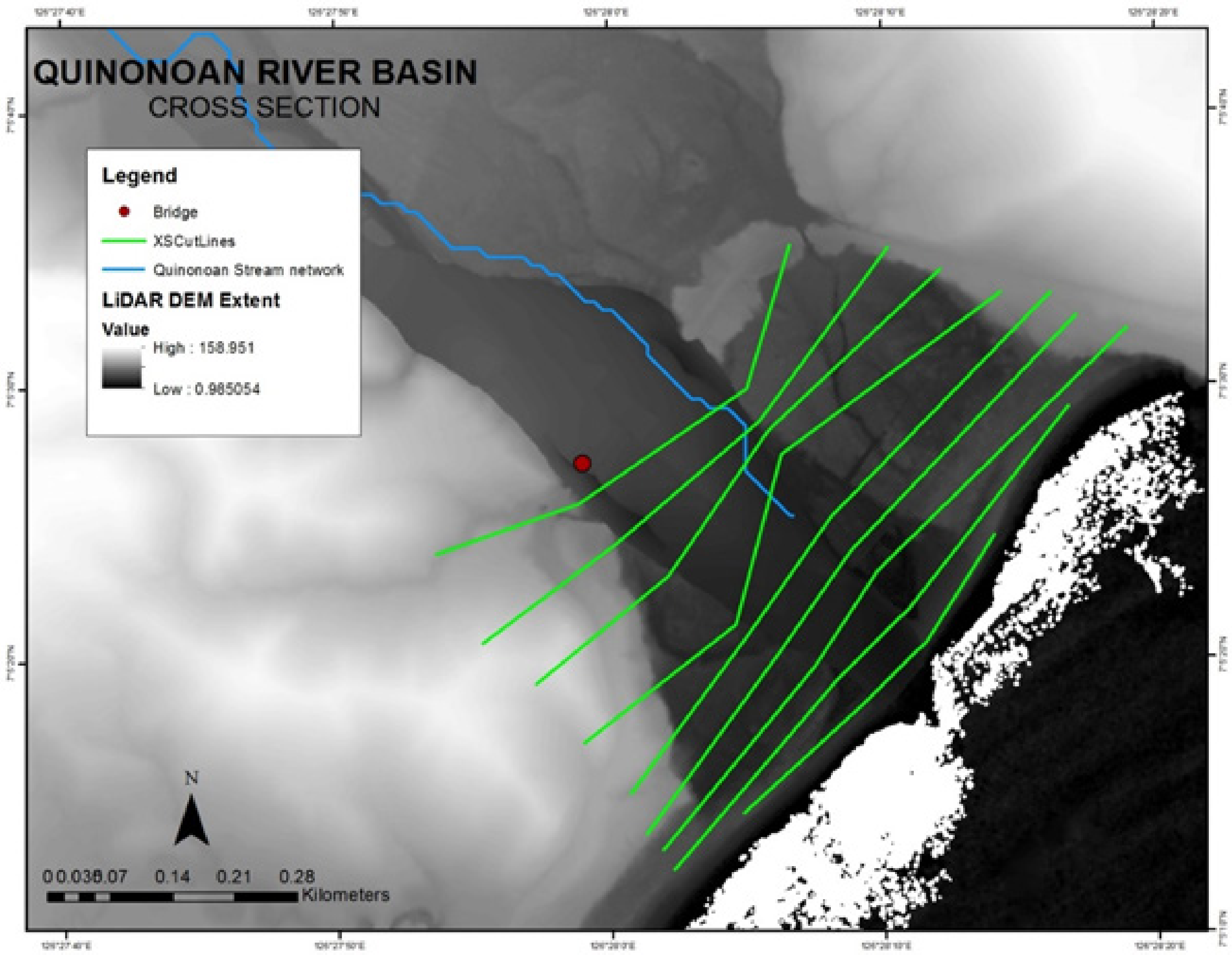


Figure 57. River cross-section of Quinonoan River generated through Arcmap HEC GeoRAS tool.

5.5 Flo 2D Model

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

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

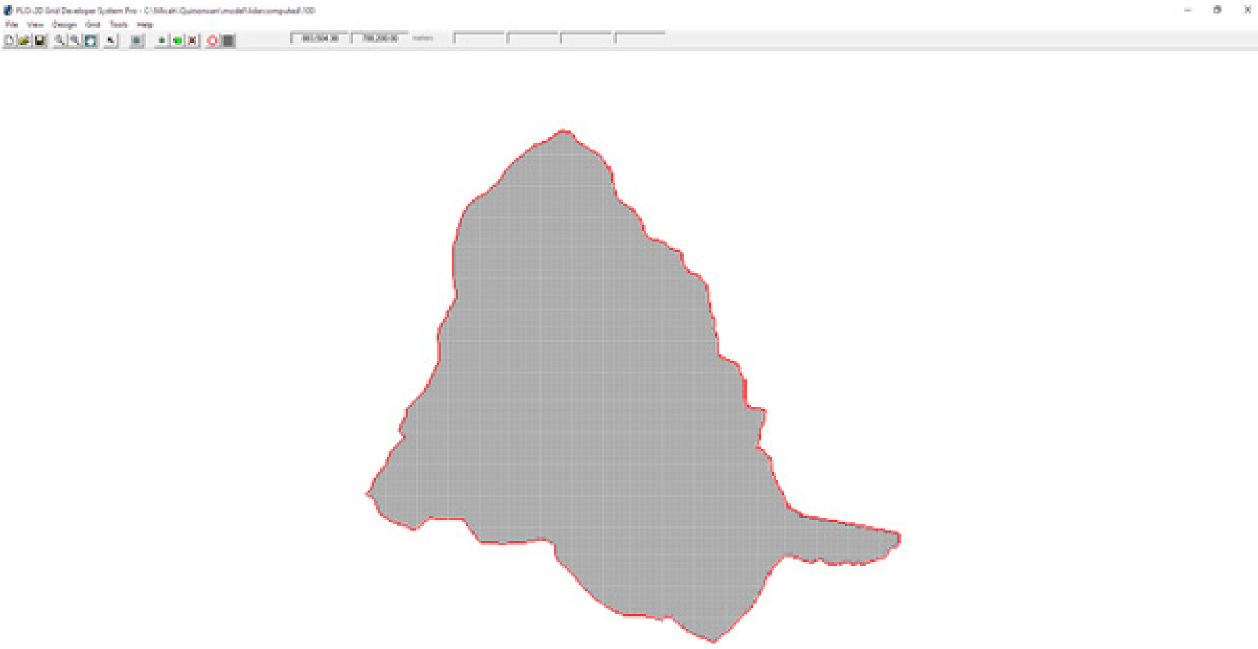


Figure 58. A Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro.

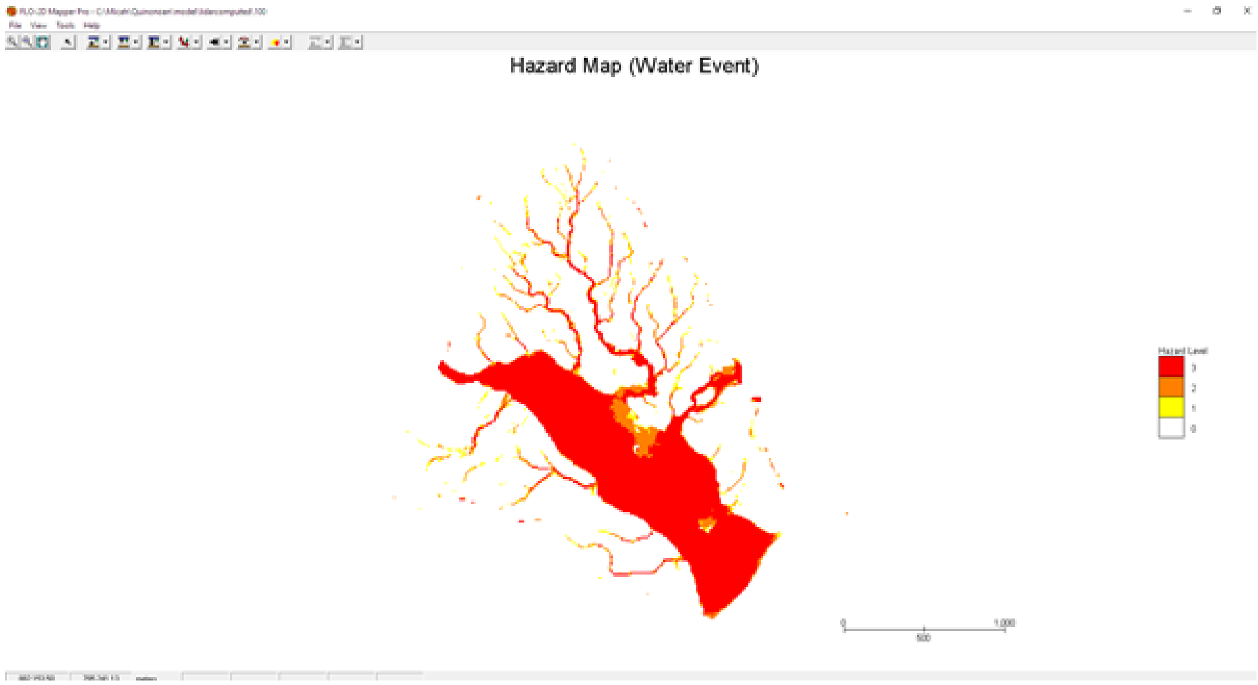


Figure 59. Generated 100-year rain return hazard map from FLO-2D Mapper

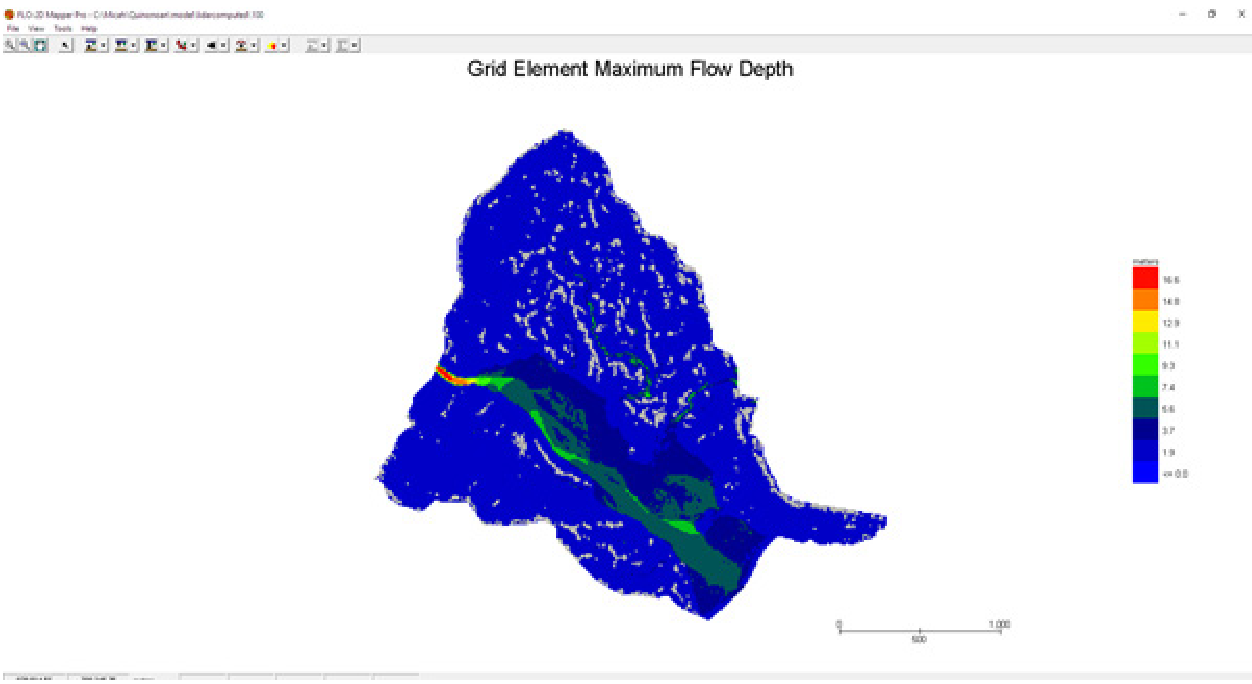


Figure 60. Generated 100-year rain return flow depth map from FLO-2D Mapper

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 22.20007 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 Surigao are in Figure 62, 64 and 66.

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 22958400.00 m2. The generated flood depth maps for Surigao are in Figure 63, 65, and 67.

There is a total of 61783670.89 m3 of water entering the model. Of this amount, 6072171.66 m3 is due to rainfall while 55711499.22 m3 is inflow from other areas outside the model 4363573.50 m3 of this water is lost to infiltration and interception, while 33831397.31 m3 is stored by the flood plain. The rest, amounting up to 23588699.98 m3, is outflow.

5.6 Results of HMS Calibration

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

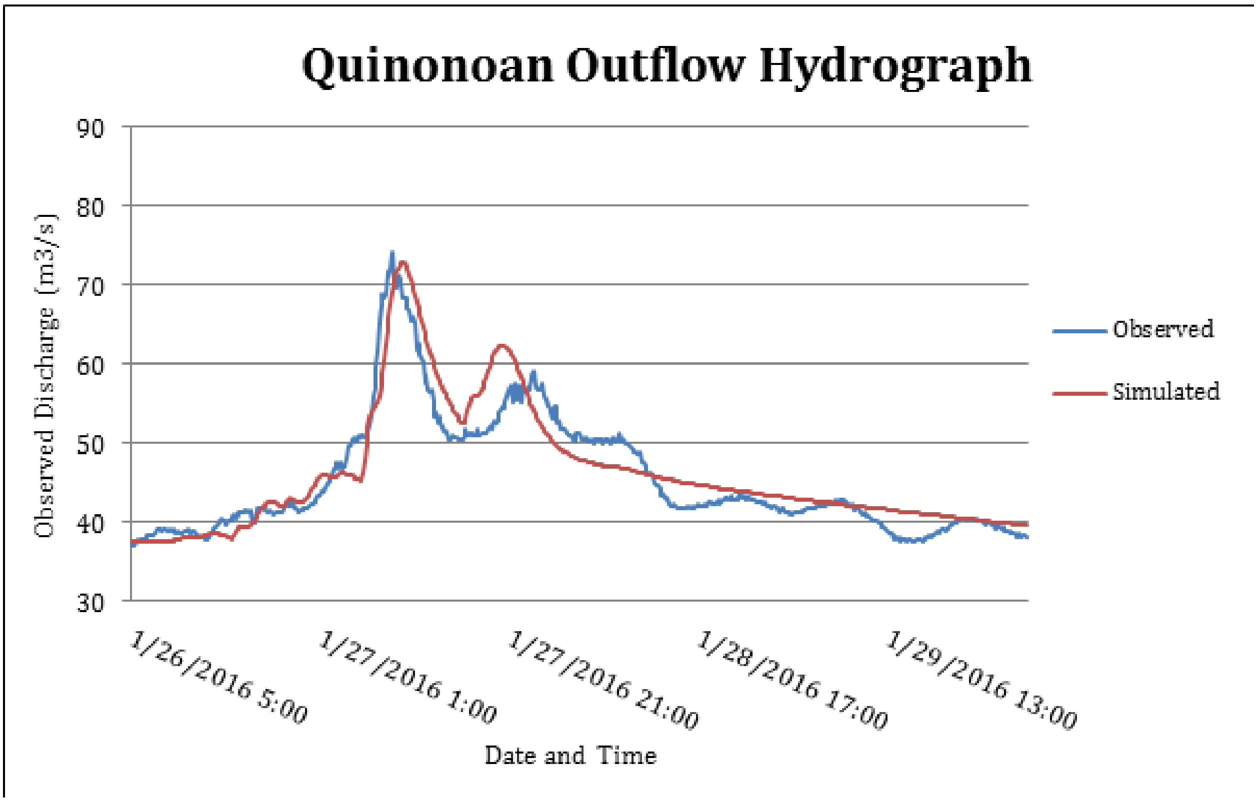


Figure 61. Outflow Hydrograph of Quinonoan produced by the HEC-HMS model compared with observed outflow

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

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

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve Number	Initial Abstraction (mm)	1.318 – 5.82
			Curve Number	45.876 - 99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.0103 – 0.159
			Storage Coefficient (hr)	0.2067 – 3.817
	Baseflow	Recession	Recession Constant	0.912 – 0.935
			Ratio to Peak	0.27 – 0.595
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.0148 – 0.0518

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 1.318 mm to 5.82 mm means that there is a very small initial fraction of the storm depth after which runoff begins, increasing the river outflow.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 65 to 90 for curve number is advisable for Philippine watersheds depending on the soil and land cover of the area (M. Horritt, personal communication, 2012). For Quinonoan, the basin consists mainly of forests and cultivated areas and the soil consists of mostly undifferentiated land and 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 0.0103 hours to 3.817 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 0.912 to 0.935 indicate that the basin is unlikely to quickly go back to its original discharge. Values of ratio to peak within the range of 0.27 to 0.595 indicate a steeper receding limb of the outflow hydrograph.

Manning's roughness coefficients correspond to the common roughness of Philippine watersheds. Quinonoan river basin reaches' Manning's coefficients range from 0.0148 to 0.0518, showing that there is variety in surface roughness all over the catchment (Brunner, 2010).

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

Accuracy measure	Value
RMSE	2.9
r2	0.87
NSE	0.85
PBIAS	-1.27
RSR	0.38

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 2.9 m3/s.

The Pearson correlation coefficient (r2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.87.

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 0.85.

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 -1.27.

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 0.38.

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

5.7.1 Hydrograph using the Rainfall Runoff Model

The summary graph (Figure 62) shows the Quinonoan outflow using the Davao Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods

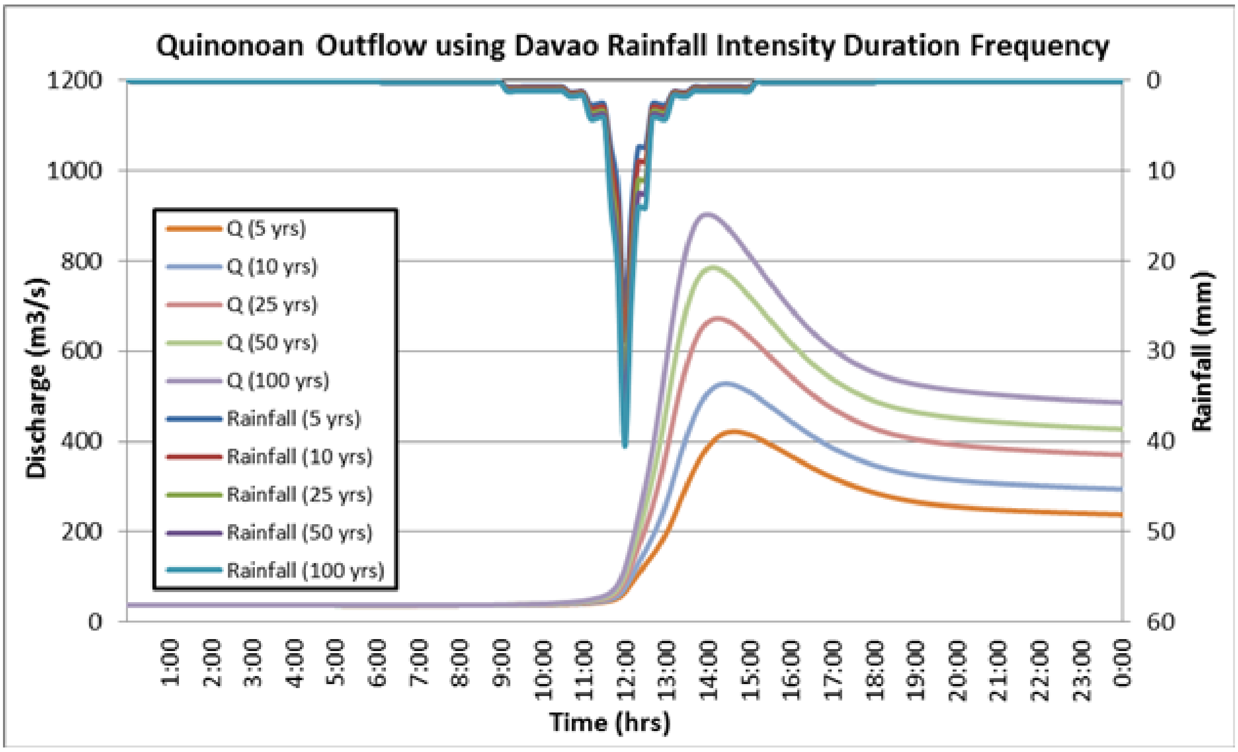


Figure 62. The Outflow hydrograph at the Quinonoan Bridge, generated using the Davao RIDF simulated in HEC-HMS.

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

Table 30. The peak values of the Quinonoan 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	422	2 hours, 40 minutes
10-Year	140.7	28.8	528.3	2 hours, 30 minutes
25-Year	165.5	33.5	672.2	2 hours, 20 minutes
50-Year	183.9	37	785	2 hours, 10 minutes
100-Year	202.1	40.5	903.2	2 hours

5.8 River Analysis (RAS) Model Simulation

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

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

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. Figure 64 to Figure 69 shows the 5-, 25-, and 100-year rain return scenarios of the Quinonoan floodplain. The floodplain, with an area of 4.53 sq. km., covers two municipalites namely Manay and Tarragona. Table 31 shows the percentage of area affected by flooding per municipality.

Table 31. Municipalities affected in Quinonoan floodplain.

Municipality	Total Area	Area Flooded	% Flooded
Davao Oriental	Manay	430.89	3.3563
Davao Oriental	Tarragona	277.9	1.1398

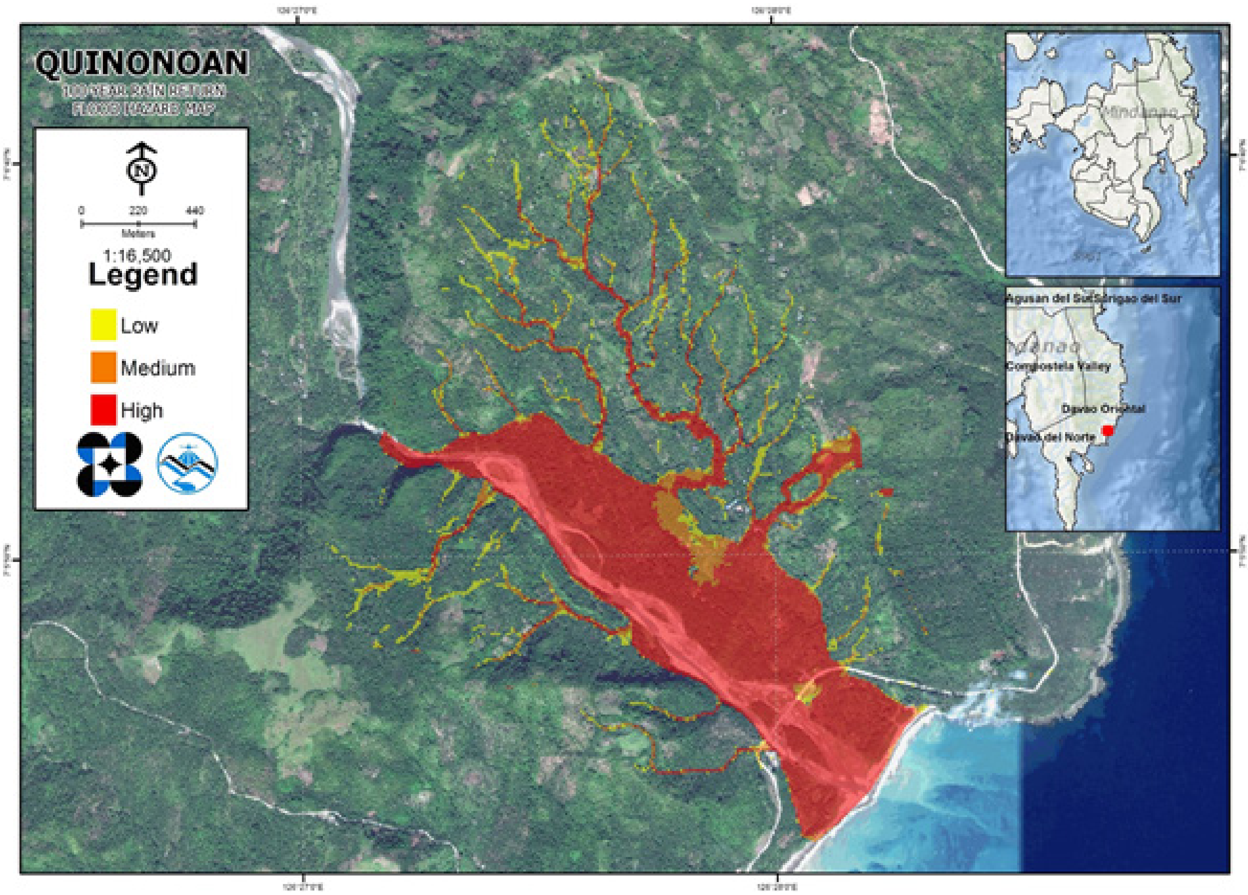


Figure 64. A 100-year Flood Hazard Map for Quinonoan Floodplain overlaid on Google Earth imagery.

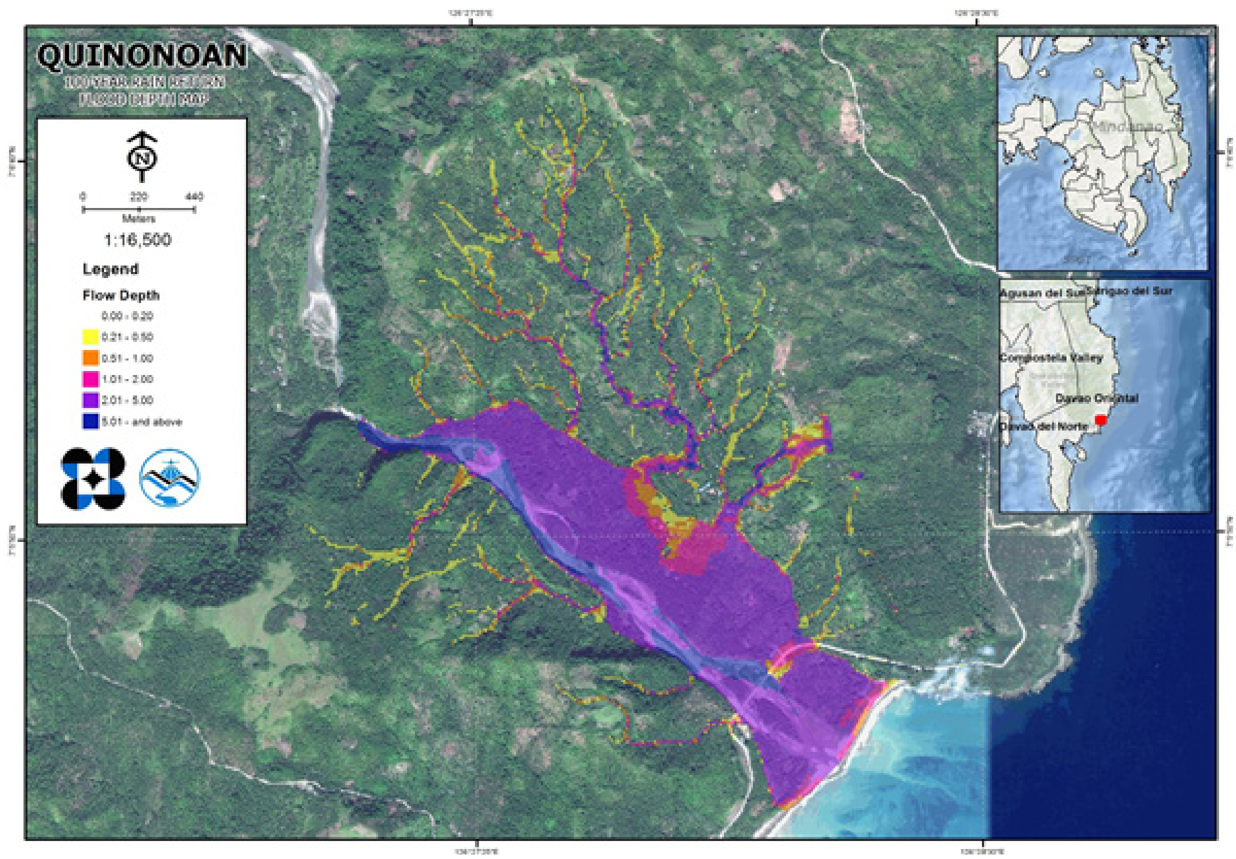


Figure 65. A 100-year Flow Depth Map for Quinonoan Floodplain overlaid on Google Earth imagery.

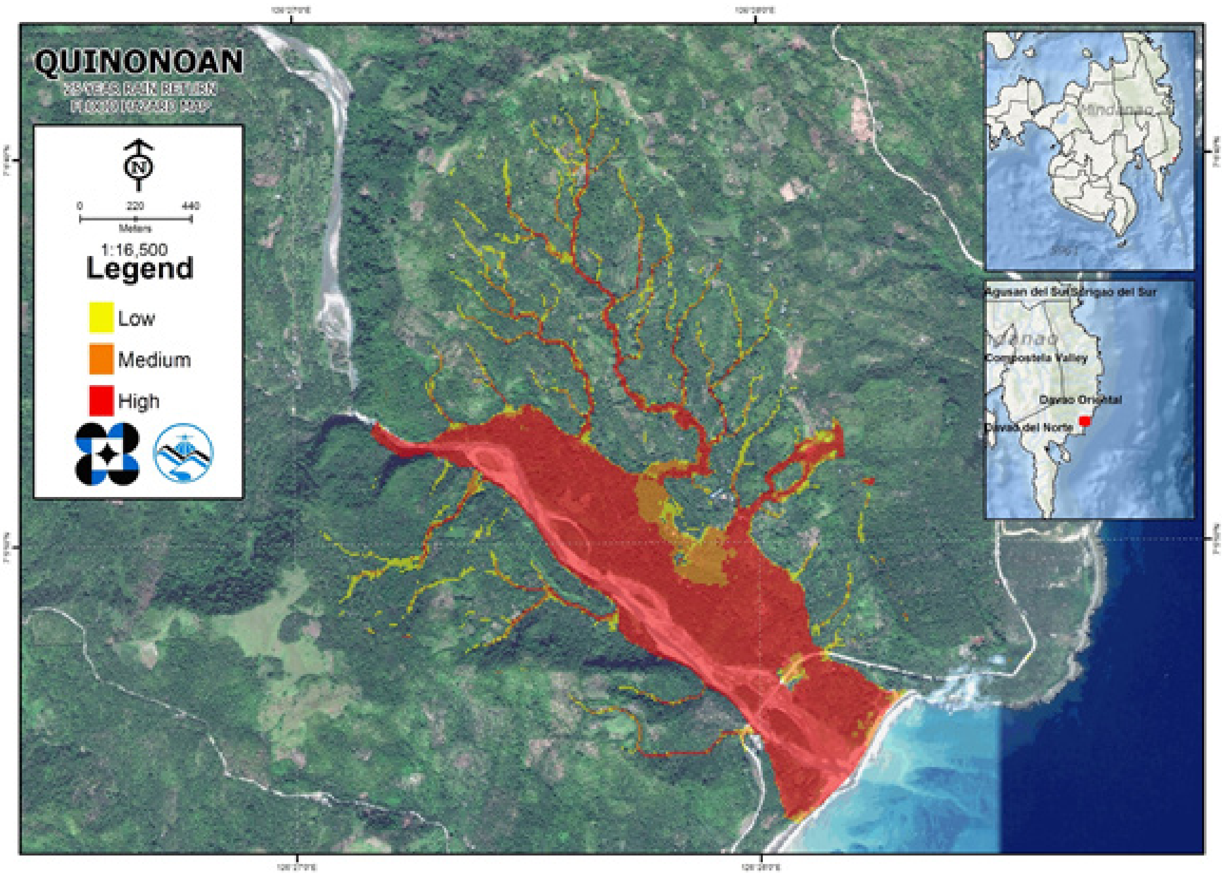


Figure 66. A 25-year Flood Hazard Map for Quinonoan Floodplain overlaid on Google Earth imagery.

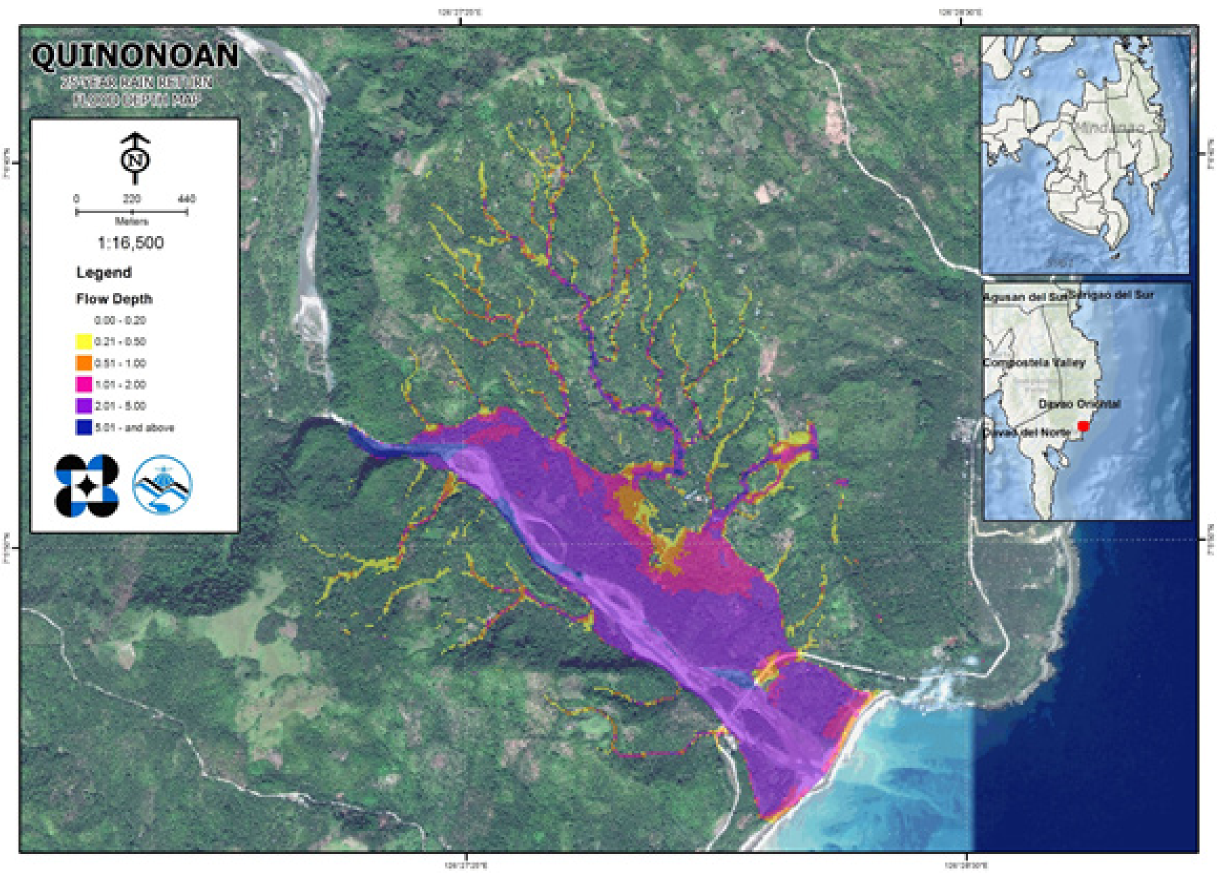


Figure 67. A 25-year Flow Depth Map for Quinonoan Floodplain overlaid on Google Earth imagery.

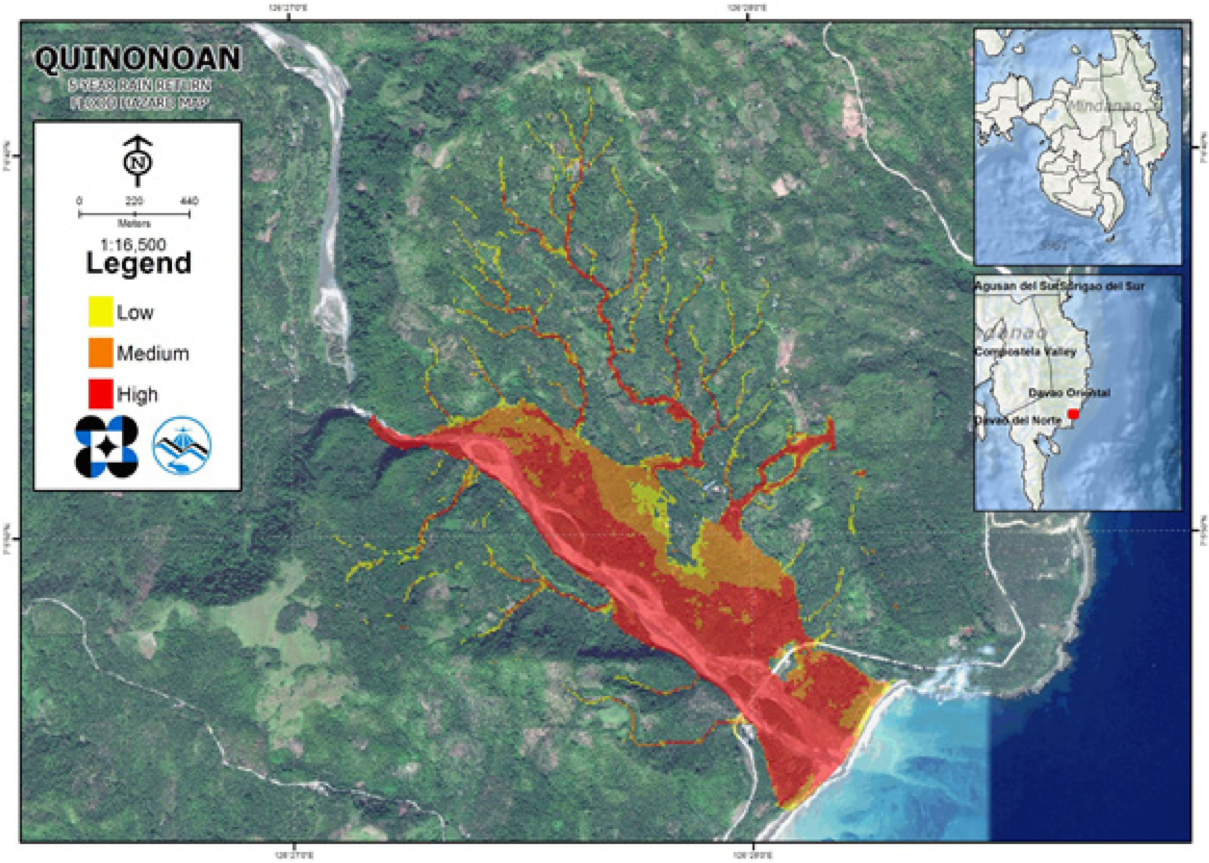


Figure 68. A 5-year Flood Hazard Map for Quinonoan Floodplain overlaid on Google Earth imagery.

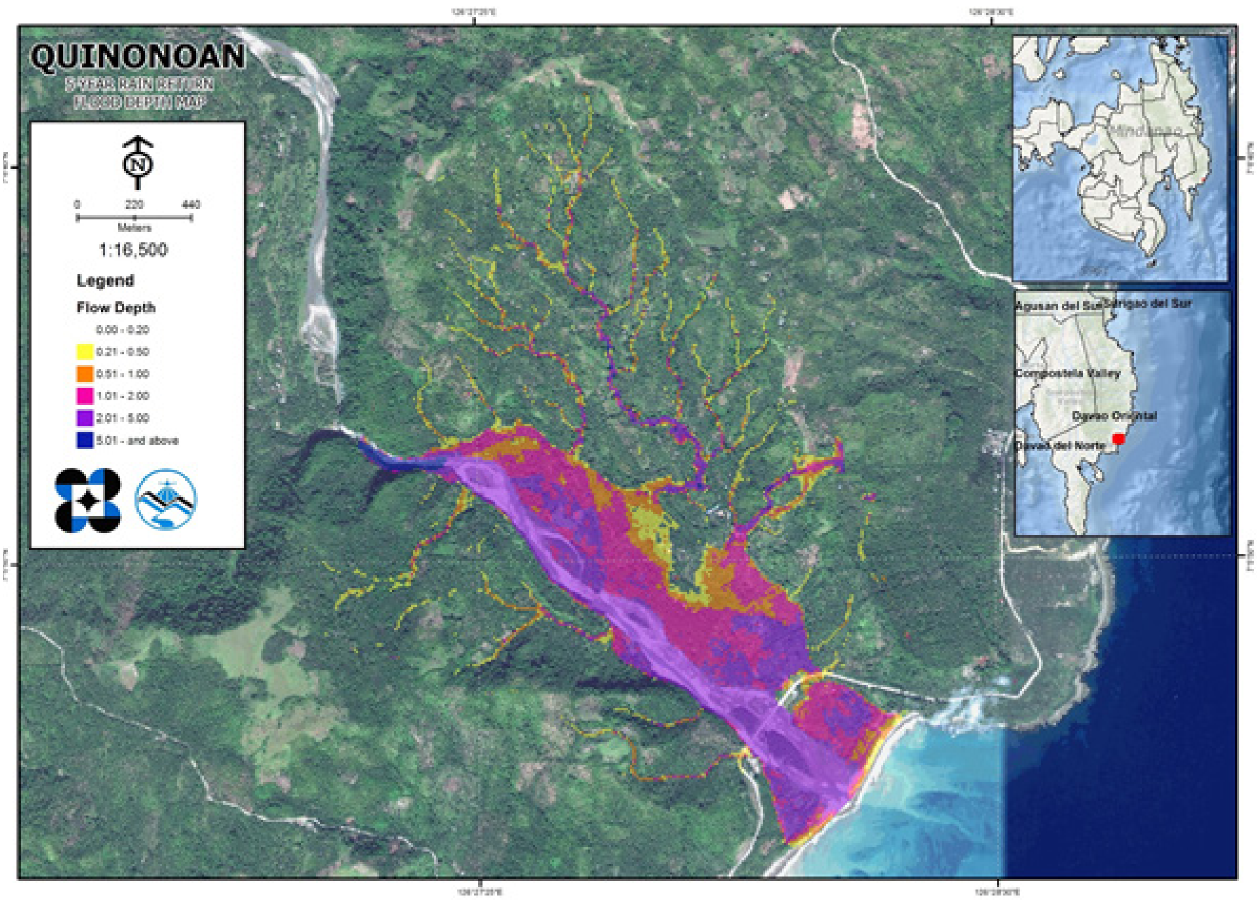


Figure 69. A 5-year Flow Depth Map for Quinonoan Floodplain overlaid on Google Earth imagery.

5.10 Inventory of Areas Exposed to Flooding

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

For the 5-year return period, 0.53% of the municipality of Manay with an area of 430.894 sq. km. will experience flood levels of less than 0.20 meters. 0.03% of the area will experience flood levels of 0.21 to 0.50 meters while 0.04%, 0.08%, and 0.10% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, and 2.01 to 5 meters, respectively. Listed in the table Table 32 are the affected areas in Manay in square kilometers by flood depth per barangay.

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

Affected area (sq. km.) by flood depth (in m.)	Areas of affected Barangays in Manay
	San Ignacio
0-0.20	2.28
0.21-0.50	0.14
0.51-1.00	0.15
1.01-2.00	0.34
2.01-5.00	0.44
> 5.00	0.0021

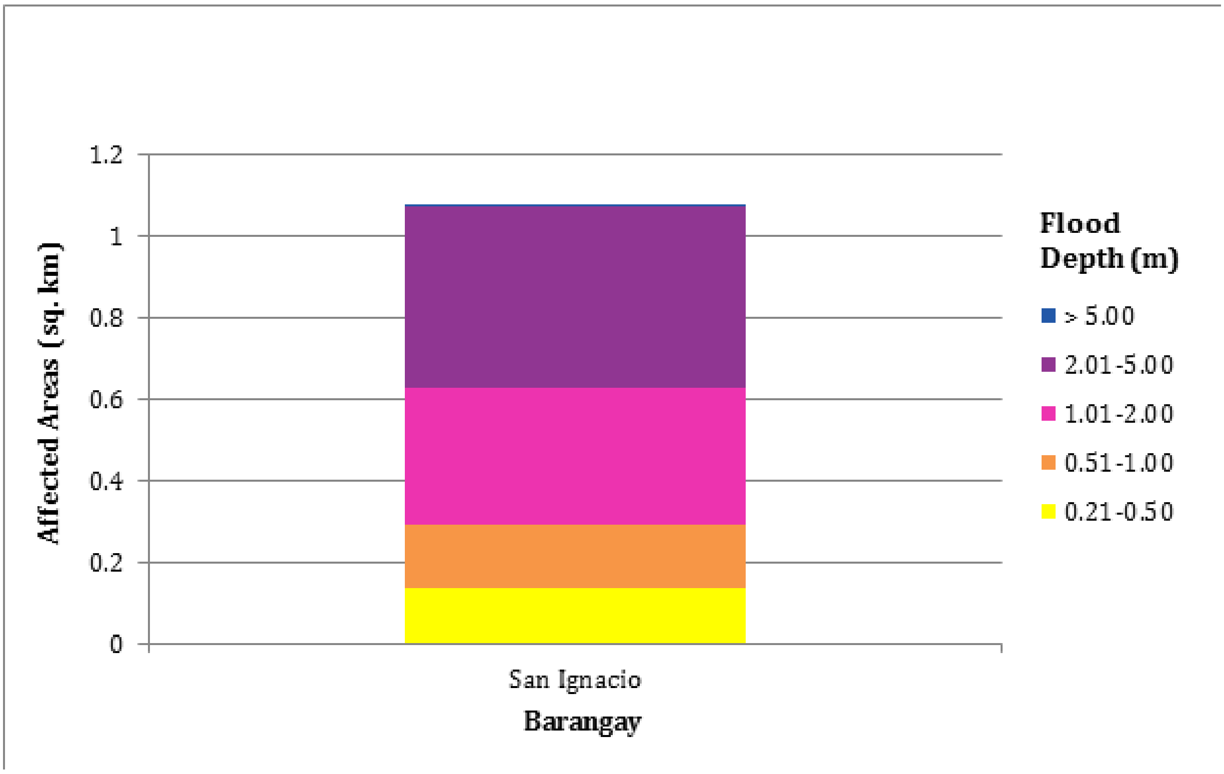


Figure 70. Affected Areas in Manay, Davao Oriental during 5-Year Rainfall Return Period.

For the municipality of Tarragona with an area of 277.904 sq. km, 0.38% will experience flood levels of less than 0.20 meters. 0.01% of the area will experience flood levels of 0.21 to 0.50 meters 0.01of the area will experience flood depths of 0.51 to 1 meter. Listed in Table 33 are the affected areas in Tarragona in square kilometers by flood depth per barangay.

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

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Tarragona	
	Jovellar	Maganda
0-0.20	0.32	0.72
0.21-0.50	0.0053	0.023
0.51-1.00	0.005	0.012
1.01-2.00	0.0057	0.006
2.01-5.00	0.007	0.015
> 5.00	0	0.014

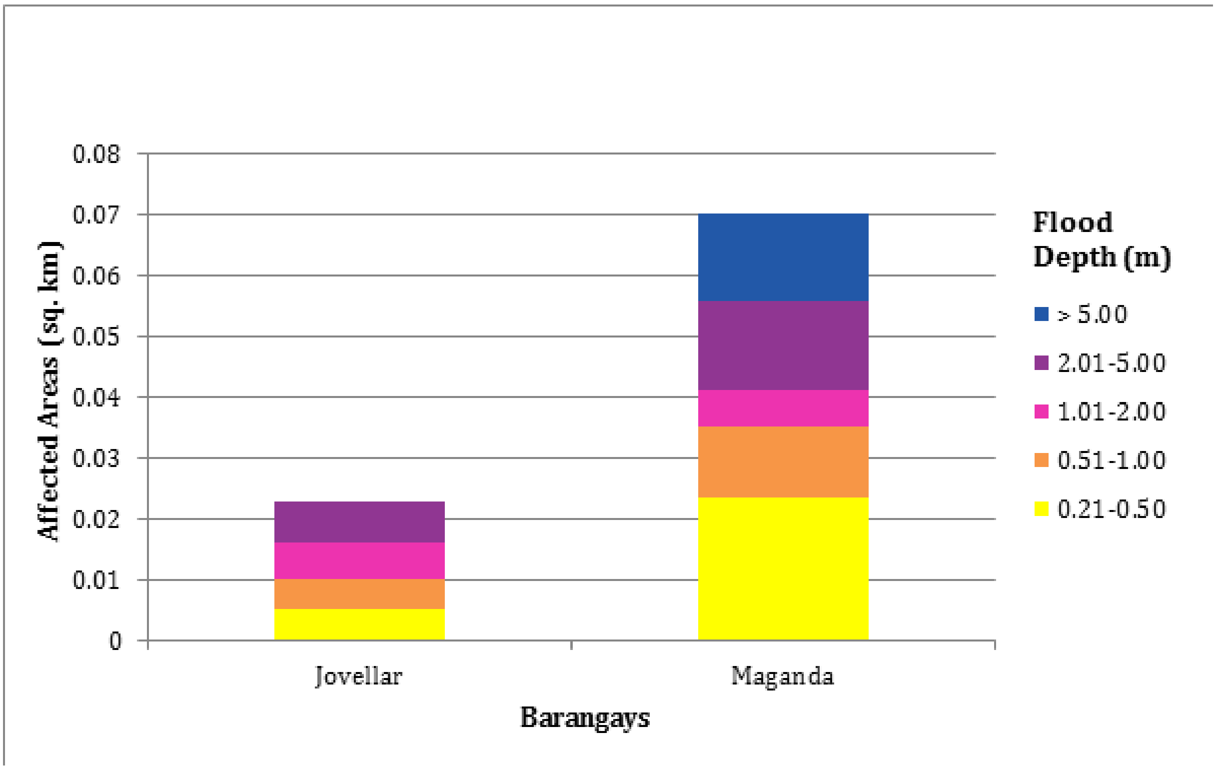


Figure 71. Affected Areas in Tarragona, Davao Oriental during 5-Year Rainfall Return Period.

For the municipality of Manay with an area of 430.894 sq. km. will experience flood levels of less than 0.20 meters. 0.03% of the area will experience flood levels of 0.21 to 0.50 meters while 0.02%, 0.05%, 0.16%, 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 Table 34 are the affected areas in Manay in square kilometers by flood depth per barangay.

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

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Manay
	San Ignacio
0-0.20	2.19
0.21-0.50	0.13
0.51-1.00	0.1
1.01-2.00	0.2
2.01-5.00	0.7
> 5.00	0.033

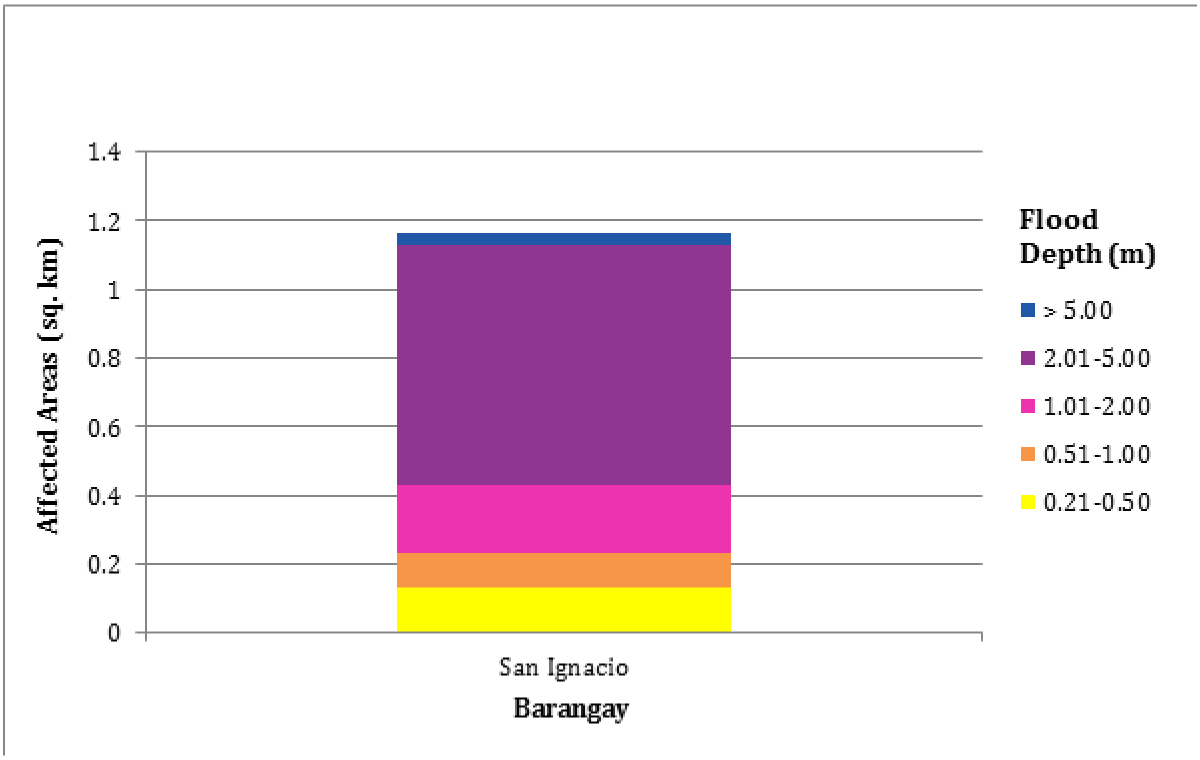


Figure 72. Affected Areas in Manay, Davao Oriental during 25-Year Rainfall Return Period.

For the municipality of Tarragona with an area of 277.904 sq. km. will experience flood levels of less than 0.20 meters. 0.01% of the area will experience flood levels of 0.21 to 0.50 meters while 0.01% of the area will experience flood depths of 0.51 to 1 meter., respectively. Listed in Table 35 are the affected areas in Tarragona in square kilometers by flood depth per barangay.

Table 35. Affected Areas in Tarragona, Davao Oriental during 25-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Tarragona	
	Jovellar	Maganda
0-0.20	0.32	0.7
0.21-0.50	0.0056	0.036
0.51-1.00	0.0056	0.014
1.01-2.00	0.0053	0.0072
2.01-5.00	0.0099	0.015
> 5.00	0	0.02

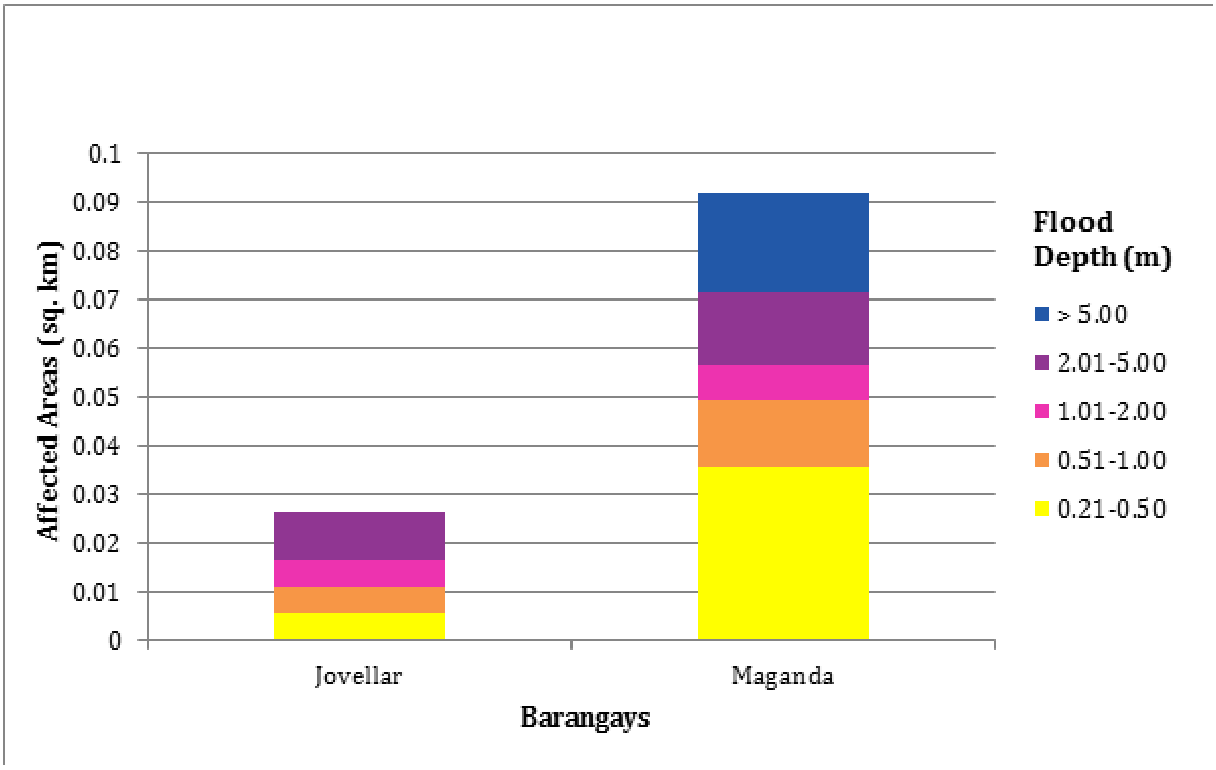


Figure 73. Affected Areas in Tarragona, Davao Oriental during 25-Year Rainfall Return Period

For the the municipality of Manay with an area of 430.894 sq. km. will experience flood levels of less than 0.20 meters. 0.03% of the area will experience flood levels of 0.21 to 0.50 meters while 0.02%, 0.03%, 0.17%, and 0.02% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 36 are the affected areas in Manay in square kilometers by flood depth per barangay.

Table 36. Affected Areas in Manay, Davao Oriental during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Manay
	San Ignacio
0-0.20	2.15
0.21-0.50	0.14
0.51-1.00	0.095
1.01-2.00	0.13
2.01-5.00	0.74
> 5.00	0.1

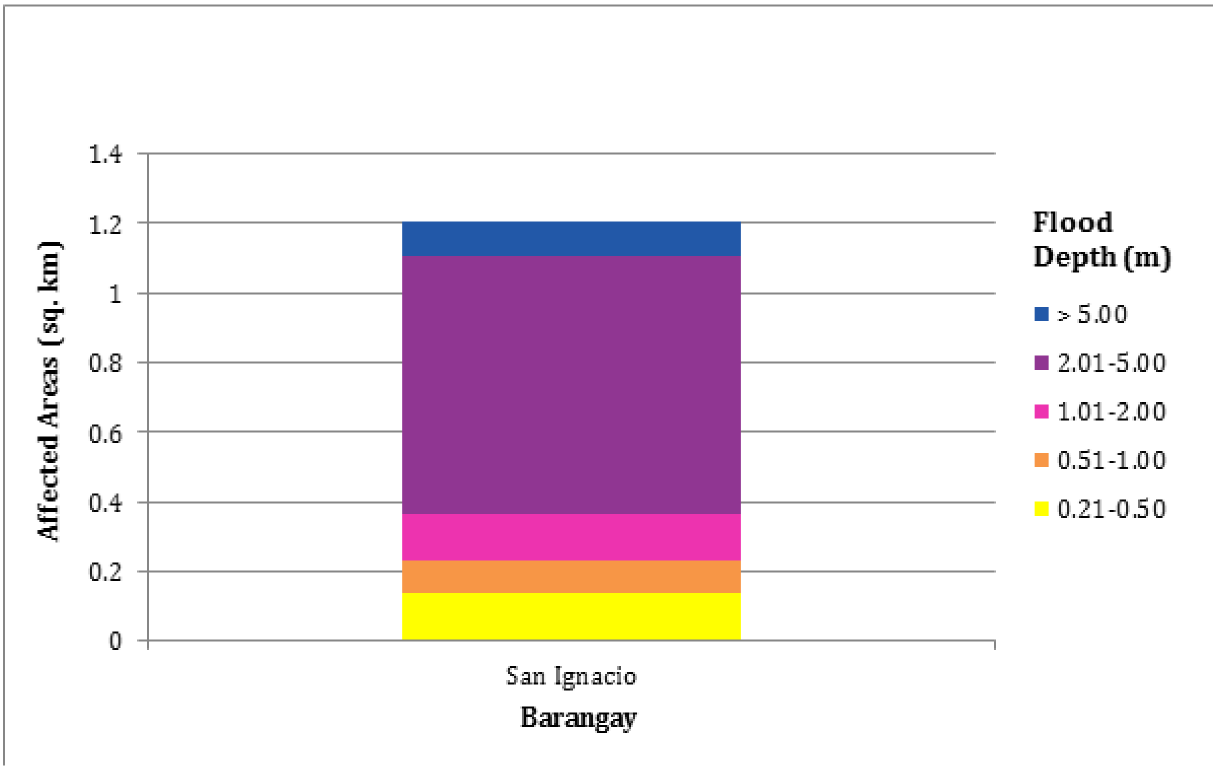


Figure 74. Affected Areas in Manay, Davao Oriental during 100-Year Rainfall Return Period

For the municipality of Tarragona with an area of 277.904 sq. km. will experience flood levels of less than 0.20 meters. 0.02% of the area will experience flood levels of 0.21 to 0.50 meters while 0.01% of the area will experience flood depths of 0.51 to 1 meter, respectively. Listed in Table 37 are the affected areas in Tarragona in square kilometers by flood depth per barangay.

Table 37. Affected Areas in Tarragona, Davao Oriental during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Tarragona	
	Jovellar	Maganda
0-0.20	0.32	0.69
0.21-0.50	0.0067	0.044
0.51-1.00	0.0049	0.015
1.01-2.00	0.0051	0.0082
2.01-5.00	0.011	0.012
> 5.00	0	0.026

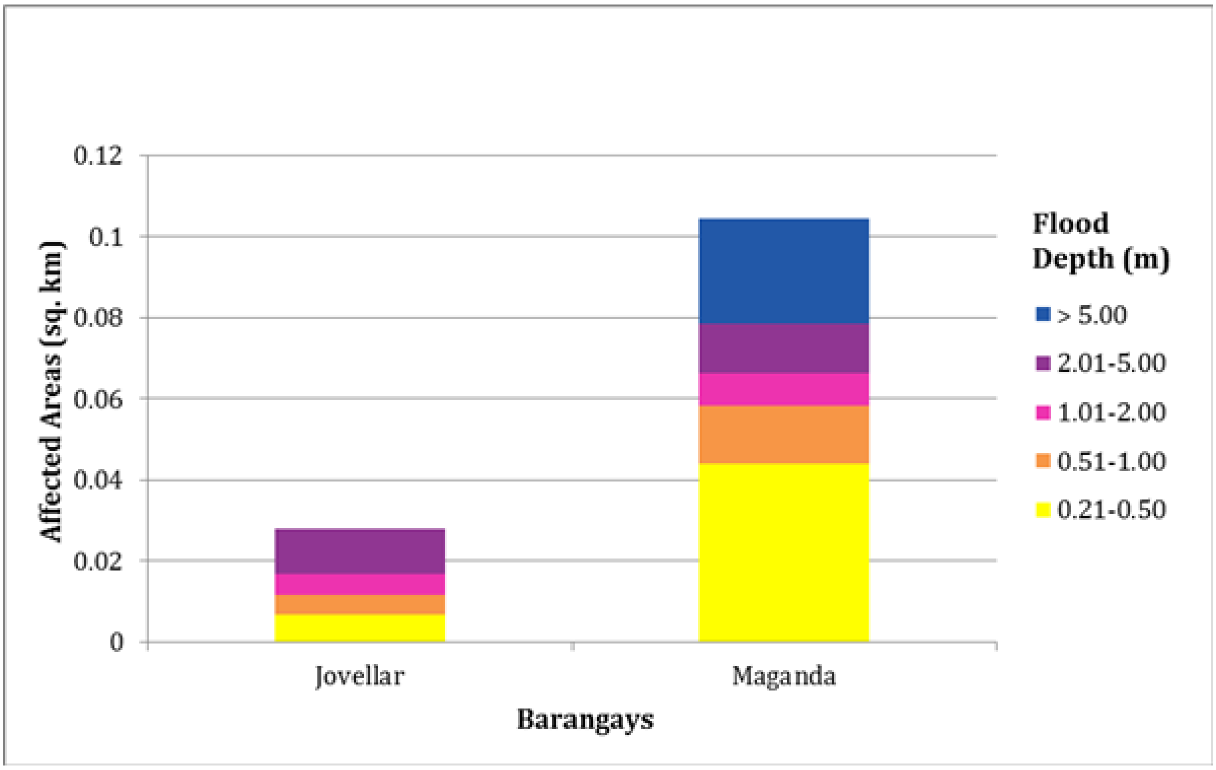


Figure 75. Affected Areas in Tarragona, Davao Oriental during 100-Year Rainfall Return Period.

Brgy. San Ignacio is the only barangay affected in the municipality of Manay in Davao Oriental. The barangay is projected to experience flood in 0.78% of the municipality.

Among the barangays in the municipality of Tarragona in Davao Oriental, Maganda is projected to have the highest percentage of area that will experience flood levels at 0.29%. Meanwhile, Jovellar posted the second highest percentage of area that may be affected by flood depths at 0.12%.

Moreover, the generated flood hazard maps for the Quinonoan 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 38. Area covered by each warning level with respect to the rainfall scenarios

Warning Level	Area Covered in sq. km.		
	5 year	25 year	100 year
Low	0.15315	0.15652	0.16761
Medium	0.31632	0.19045	0.16419
High	0.73306	0.96915	1.04159

Of the three (3) identified educational institutions in the Quinonoan floodplain, none are supposedly at risk for any of the flood hazards. See Annex 12. Additionally, no medical institutions were identified in the said 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 November 8-11, 2016. The flood validation consists of 180 points randomly selected all over the Quinonoan flood plain. It has an RMSE value of 1.708.

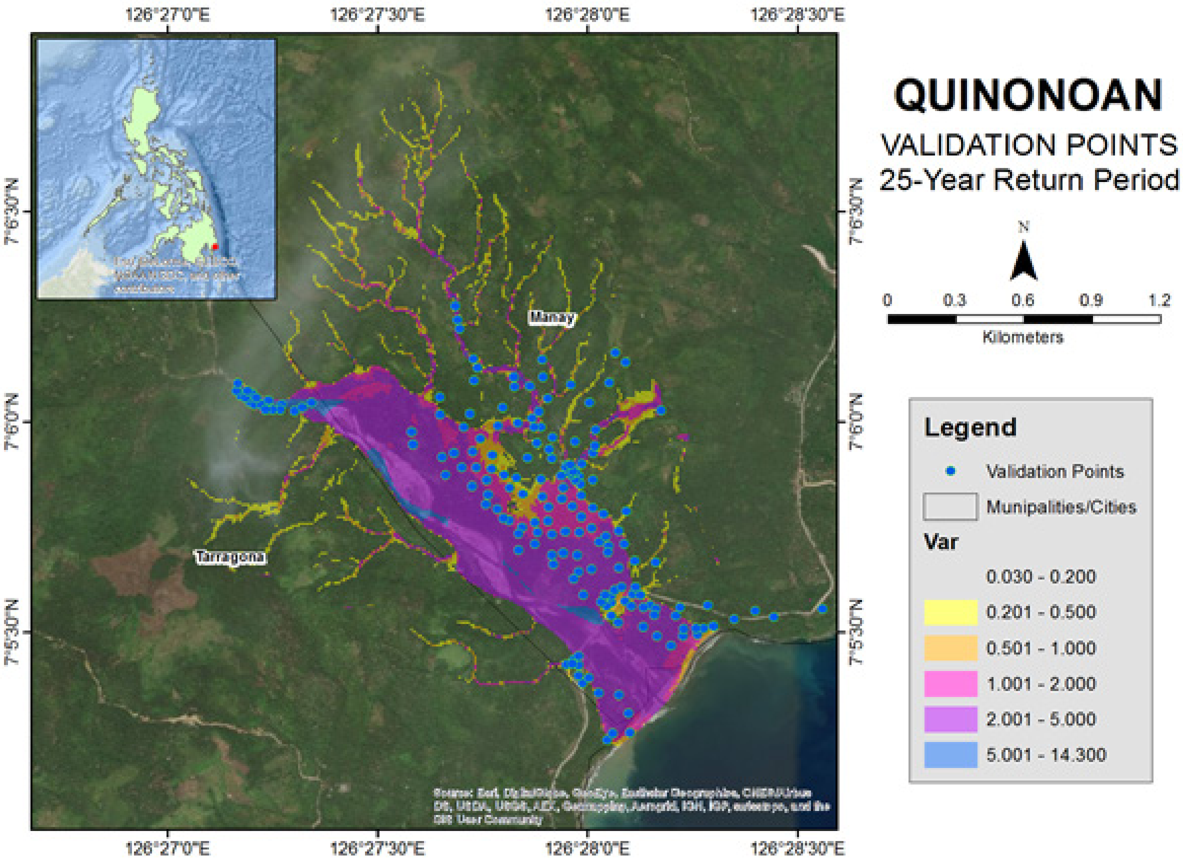


Figure 76. Validation Points for a 25-year Flood Depth Map of the Quinonoan Floodplain.

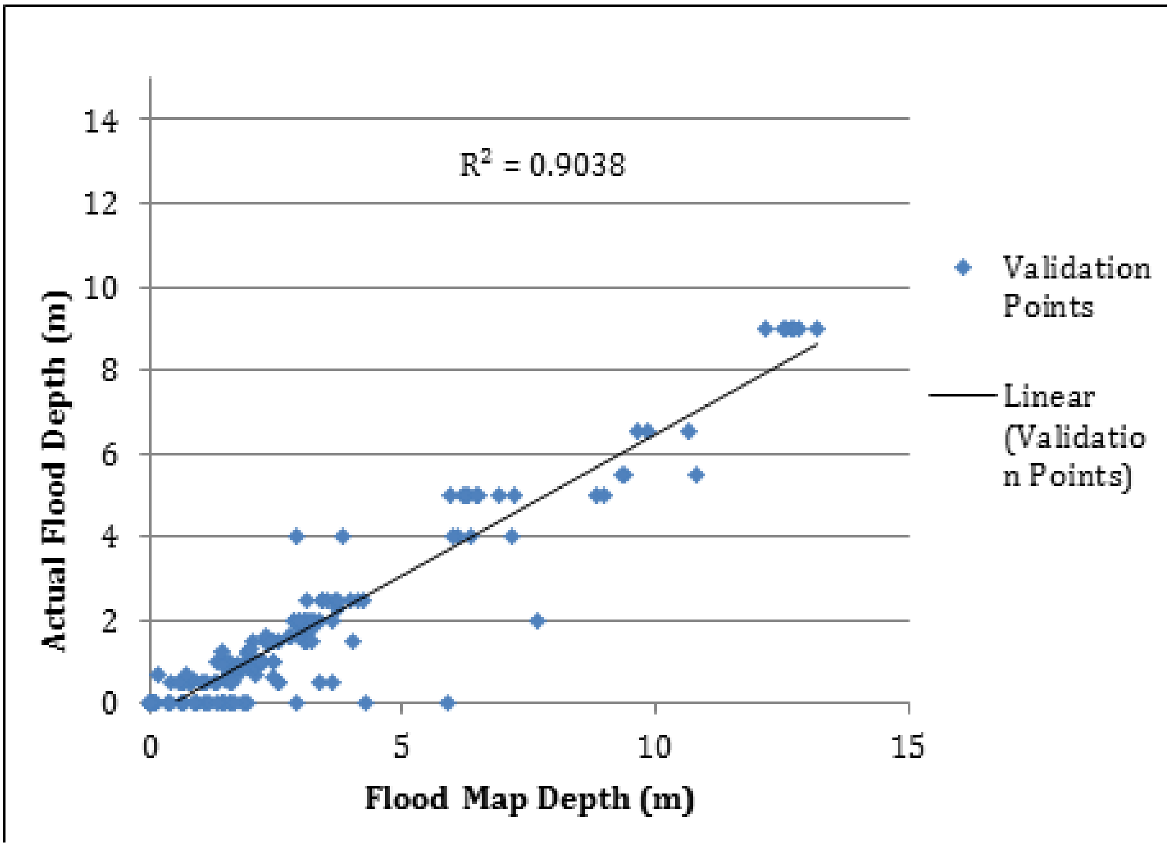


Figure 77. Flood Map Depth vs Actual Flood Depth for Quinonoan

Table 39. Actual Flood Depth versus Simulated Flood Depth at different levels in the Quinonoan River Basin.

QUINONOAN 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	27	3	7	15	2	1	55
	0.21-0.50	0	1	7	7	4	0	19
	0.51-1.00	1	0	2	18	9	0	30
	1.01-2.00	0	0	0	3	33	1	37
	2.01-5.00	0	0	0	0	12	14	26
	> 5.00	0	0	0	0	0	13	13
	Total	28	4	16	43	60	29	180

On the whole, the overall accuracy generated by the flood model is estimated at 32.22%, with 58 points correctly matching the actual flood depths. In addition, there were 75 points estimated one level above and below the correct flood depths while there were 25 points and 22 points estimated two levels above and below, and 22 points. A total of 121 points were overestimated while a total of 1 point were underestimated in the modelled flood depths of Quinonoan. Table 40 depicts the summary of the Accuracy Assessment in the Quinonoan River Basin Flood Depth Map.

Table 40. Summary of the Accuracy Assessment in the Quinonoan River Basin Survey.

	No. of Points	%
Correct	58	32.22
Overestimated	121	67.22
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.

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

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

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

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

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

ANNEXES

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

1. GEMINI SENSOR

Figure A-1.1. Gemini Sensor

Table A-1.1. Parameters and Specifications of Gemini Sensor

Parameter	Specification
Operational envelope (1,2,3,4)	150-4000 m AGL, nominal
Laser wavelength	1064 nm
Horizontal accuracy (2)	1/5,500 x altitude, (m AGL)
Elevation accuracy (2)	<5-35 cm, 1 σ
Effective laser repetition rate	Programmable, 33-167 kHz
Position and orientation system	POS AV™ AP50 (OEM);
220-channel dual frequency GPS/GNSS/Galileo/L-Band receiver	
Scan width (WOV)	Programmable, 0-50˚
Scan frequency (5)	Programmable, 0-70 Hz (effective)
Sensor scan product	1000 maximum
Beam divergence	Dual divergence: 0.25 mrad (1/e) and 0.8 mrad (1/e), nominal
Roll compensation	Programmable, ±5˚ (FOV dependent)
Range capture	Up to 4 range measurements, including 1st, 2nd, 3rd, and last returns
Intensity capture	Up to 4 intensity returns for each pulse, including last (12 bit)
Video Camera	Internal video camera (NTSC or PAL)
Image capture	Compatible with full Optech camera line (optional)
Full waveform capture	12-bit Optech IWD-2 Intelligent Waveform Digitizer (optional)
Data storage	Removable solid state disk SSD (SATA II)
Power requirements	28 V; 900 W;35 A(peak)
Dimensions and weight	Sensor: 260 mm (w) x 190 mm (l) x 570 mm (h); 23 kg
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)

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

1. DVE-42

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

June 24, 2014

CERTIFICATION

To whom it may concern:

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

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

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

	PRS92 Coordinates	
Latitude: **6° 58' 54.82726"**	Longitude: **126° 17' 56.05259"**	Ellipsoidal Hgt: **6.39500 m.**
	WGS84 Coordinates	
Latitude: **6° 58' 51.79295"**	Longitude: **126° 18' 1.57690"**	Ellipsoidal Hgt: **81.02500 m.**
	PTM Coordinates	
Northing: **772166.69 m.**	Easting: **643534.636 m.**	Zone: **5**
	UTM Coordinates	
Northing: **772,554.34**	Easting: **201,538.20**	Zone: **52**

Location Description

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

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

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

9906242014111842

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.1. DVE-42

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

1. DVE-3088

Table A-3.1. DVE-3088

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
DVE-3088 --- DVE-42 (B1)	DVE-42	DVE-3088	Fixed	0.001	0.002	150°37'05"	8.200	-0.026
DVE-3088 --- DVE-42 (B2)	DVE-42	DVE-3088	Fixed	0.001	0.002	150°36'35"	8.199	-0.029
DVE-42 --- DVE-3088 (B3)	DVE-42	DVE-3088	Fixed	0.001	0.002	150°36'48"	8.202	-0.036
DVE-3088 --- DVE-42 (B4)	DVE-42	DVE-3088	Fixed	0.001	0.002	150°40'50"	8.200	-0.031
DVE-3088 --- DVE-42 (B5)	DVE-42	DVE-3088	Fixed	0.001	0.001	150°40'52"	8.202	-0.036
DVE-42 --- DVE-3088 (B6)	DVE-42	DVE-3088	Fixed	0.001	0.001	150°40'53"	8.203	-0.034

Vector Components (Mark to Mark)

From:	DVE-42				
Grid		Local		Global	
Easting	201538.187 m	Latitude	N6°58'54.82727"	Latitude	N6°58'51.79295"
Northing	772554.341 m	Longitude	E126°17'56.05259"	Longitude	E126°18'01.57690"
Elevation	15.607 m	Height	6.396 m	Height	81.025 m

To:	DVE-3088				
Grid		Local		Global	
Easting	201542.172 m	Latitude	N6°58'54.59466"	Latitude	N6°58'51.56037"
Northing	772547.168 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	3.985 m	NS Fwd Azimuth	150°37'05"	ΔX	-3.741 m
ΔNorthing	-7.173 m	Ellipsoid Dist.	8.200 m	ΔY	-1.703 m
ΔElevation	-0.025 m	ΔHeight	-0.026 m	ΔZ	-7.095 m

Standard Errors

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

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000004144		
Y	-0.0000001655	0.0000005443	
Z	-0.0000000528	0.0000000815	0.0000000908

2. DVE-19

Table A-3.2. DVE-19

Vector Components (Mark to Mark)

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

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

Vector					
ΔEasting	41405.322 m	NS Fwd Azimuth	167°41'20"	ΔX	-50724.032 m
ΔNorthing	-196355.628 m	Ellipsoid Dist.	200641.192 m	ΔY	-3061.661 m
ΔElevation	-1.243 m	ΔHeight	-9.391 m	ΔZ	-193987.320 m

Standard Errors

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

Aposteriori Covariance Matrix (Meter²)

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

Occupations

	From	To
Point ID:	SRS-51	DVE-19
Data file:	C:\Users\Windows User\Documents \Business Center - HCE\DVE-19 DVE-201\SRS51 (Modular) 7-8-14 [1.629m].T02	C:\Users\Windows User\Documents \Business Center - HCE\DVE-19 DVE-201\DVE-19 07-08-2014.T02
Receiver type:	SPS852	SPS985
Receiver serial number:	5203K81512	5245F15419
Antenna type:	Zephyr Geodetic 2	SPS985 Internal
Antenna serial number:	--------	--------
Antenna height (measured):	1.629 m	1.481 m
Antenna method:	Bottom of notch	Bottom of antenna mount

3. DVE-20

Table A-3.3. DVE-20

Vector Components (Mark to Mark)

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

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

Vector					
ΔEasting	0.855 m	NS Fwd Azimuth	0°03'43"	ΔX	9.390 m
ΔNorthing	131.995 m	Ellipsoid Dist.	131.930 m	ΔY	-12.905 m
ΔElevation	0.599 m	ΔHeight	0.614 m	ΔZ	130.962 m

Standard Errors

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

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0001243942		
Y	-0.0000742449	0.0001516896	
Z	-0.0000004836	0.0000124527	0.0000328557

Occupations

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

Annex 4. The LiDAR Survey Team Composition

Table A-4.1. The LiDAR Survey Team Composition

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

Annex 5. Data Transfer Sheet for Quinonoan Floodplain

DATA TRANSFER SHEET
[illegible]/DAVAO ORIENTAL - raw(s)

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 (swaths)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
6/18/2014	7318GC*	2BLK84A169A	GEMINI	NA	217	6.21	217	17.3	106KB	17.5	NA	4.96	1KB	2KB	3	9	Z:\Airborne_Raw\7318GC
6/19/2014	7320G	2BLK81A84B170A	GEMINI	NA	116/38	330	224	na	na	13.3	NA	3.62	1KB	1KB	4	NA	Z:\Airborne_Raw\7320GC
6/20/2014	7322G	2BLK84AS86B171A	GEMINI	NA	405	524	242	na	na	23	NA	4.66	1KB	1KB	6	9	Z:\Airborne_Raw\7322GC
6/20/2014	7323G	2BLK86C83A171B	GEMINI	NA	393/191	509	244	na	na	20.4	NA	5.26	1KB	1KB	4	na	Z:\Airborne_Raw\7323GC
6/22/2014	7326G	2BLK80B173A	GEMINI	NA	335	533	252	na	na	23.4	NA	7	1KB	1KB	4	9	Z:\Airborne_Raw\7326G
6/23/2014	7328GC*	2BLK80A8174A	GEMINI	NA	na	582	238	91.3	177kb	20.9	NA	5.81	1KB	1KB	8	na	Z:\Airborne_Raw\7328GC

Received from:
Name C. Joaquin
Position
Signature

Received by:
Name Ida F. Prieto
Position
Signature 07/03/2014

*PRIORITY FLIGHTS WITH CASI DATA

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

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	2BLK79D808V193A	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 AGOYAWIA
Position
Signature

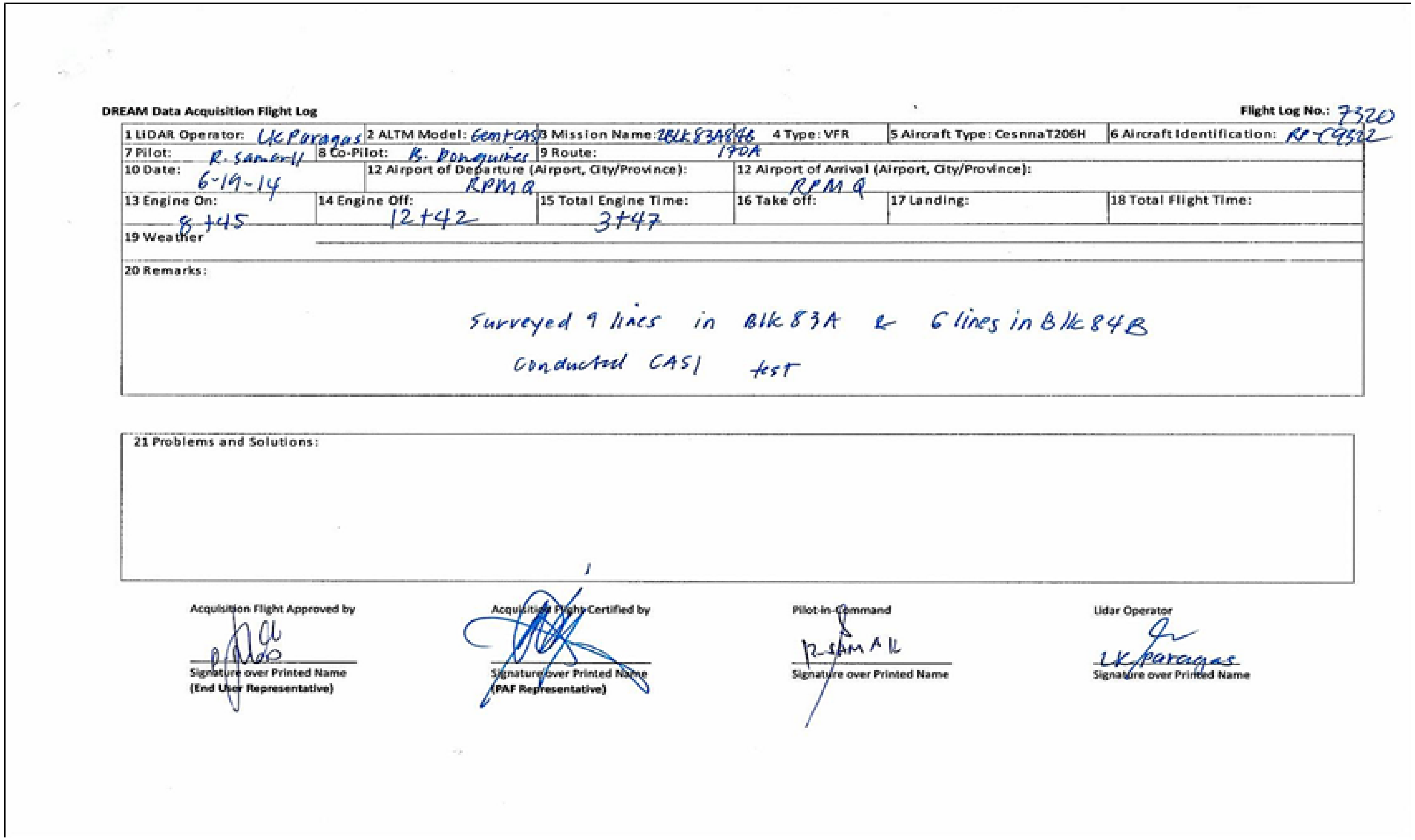
Received by

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

Figure A-5.2. Transfer Sheet for Quinonoan Floodplain - B

Annex 6. Flight logs for the flight missions

1.Flight Log for 7320GC Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 7320

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

20 Remarks:

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

Conducted CASI test

21 Problems and Solutions:

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

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

Pilot-in-Command
R. SAMONTE
Signature over Printed Name

Lidar Operator
LK Paragas
Signature over Printed Name

Figure A-6.1. Flight Log for Mission 7320GC

2.Flight Log for 7322GC Mission

DREAM Data Acquisition Flight Log — **Flight Log No.:** 7322

1 LiDAR Operator: MV Tonga	2 ALTM Model: Gem+CAS	3 Mission Name: 2BLK83AS 86B179A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RP-C9322
7 Pilot: R. Samar-4	8 Co-Pilot: B. Donguines	9 Route:			
10 Date: 6-20-14	12 Airport of Departure (Airport, City/Province): RPMQ		12 Airport of Arrival (Airport, City/Province): RPMQ		
13 Engine On: 6+48	14 Engine Off: 10+59	15 Total Engine Time: 4+11	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather					

20 Remarks:

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

21 Problems and Solutions:

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

Figure A-6.2. Flight Log for Mission 7322GC

3.Flight Log for 7323GC Mission

DREAM Data Acquisition Flight Log — Flight Log No.: 7323

1 LIDAR Operator: LK Paragas	2 ALTM Model: Gemini	3 Mission Name: 1BLK86C93A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RP-C9322
7 Pilot: R. Samar II	8 Co-Pilot: B. Dongumier	9 Route: 17LB			
10 Date: 6-20-14	12 Airport of Departure (Airport, City/Province): RPMQ		12 Airport of Arrival (Airport, City/Province): RPMQ		
13 Engine On: 1344	14 Engine Off: 1723	15 Total Engine Time: 4+9	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather					

20 Remarks:

Completed 83A & 86E (without CASI)

21 Problems and Solutions:

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

Figure A-6.3. Flight Log for Mission 7323GC

4.Flight Log for 7328GC Missi

DREAM Data Acquisition Flight Log

Flight Log No.: 7328

1 LiDAR Operator: LK Paragas	2 ALTM Model: Gemini	3 Mission Name: 2BLK80S174A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RP-C9322
7 Pilot: R. Samarez	8 Co-Pilot: B. Dongiuines	9 Route:			
10 Date: 6-23-14	12 Airport of Departure (Airport, City/Province): RPMQ		12 Airport of Arrival (Airport, City/Province): RPMQ		
13 Engine On: 817	14 Engine Off: 12:30	15 Total Engine Time: 4+23	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather					
20 Remarks: Completed Block 80A and Block 80B (with CASI)					
21 Problems and Solutions:					

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

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

Pilot-in-Command
R. SAMARES
Signature over Printed Name

Lidar Operator
LK Paragas
Signature over Printed Name

Figure A-6.4. Flight Log for Mission 7328GC

5.Flight log for 7358GC Mission

DREAM Data Acquisition Flight Log — 2BLK80BS+ — Flight Log No.: 7358

1 LIDAR Operator: MVE TONGA	2 ALTM Model: GEM+CASI	3 Mission Name: 2BLK80BS+	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9322
7 Pilot: K. SAMIAR	8 Co-Pilot: B. Donguines	9 Route: MATI			
10 Date: July 8, 2014	12 Airport of Departure (Airport, City/Province): MATI		12 Airport of Arrival (Airport, City/Province):		
13 Engine On: 8:28	14 Engine Off: 11:51	15 Total Engine Time: 3+23	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: Fair					

20 Remarks:

Completed BLK 80B and voids (without CASI)

21 Problems and Solutions:

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

Figure A-6.5. Flight Log for Mission 7358GC

Annex 7. Flight status reports

Davao Mission
June 16 to July 16, 2014

Table A-7.1. Flight Status Report

FLIGHT NO.	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
7320GC	BLK84B	2BLK83A84B170A	LK PARAGAS	June 19, 2014	Started with 86B. Moved to 84B due to high terrain (6 lines). Moved to 83A due to clouds (9 lines). *CASI testing at the end of the mission flight
7322GC	BLK83A, BLK86B	2BLK84AS&86B171A	MV TONGA	June 20, 2014	BLK 83A (3 lines). Moved to 86B (13 lines)
7323GC	BLK86C, BLK83A	2BLK86C&83A171B	LK PARAGAS	June 20, 2014	BLK84A (3 lines) changed area due to rain. BLK86C (10 lines). Cloudy/ rainy moved to BLK83A (7 lines)
7328GC	BLK80A, BLK80B	2BLK80ABS174A	LK PARAGAS	June 23, 2014	With CASI (19 lines)
7358GC	BLK85C	2BLK80BS189A	MV TONGA	July 8, 2014	Covered BLK 85C at 1500m. covered voids at BLK80B at 1200m

SWATH PER FLIGHT MISSION

Flight No. : 7320GC
Area: BLK83A, BLK84B
Mission Name: 2BLK83A84B170A
Parameters:
Altitude: 1100

Scan Frequency: 50

Scan Angle: 40

Overlap: 40

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

Flight No. : 7322GC
Area: BLK83A, BLK86B
Mission Name: 2BLK84AS86B171A
Parameters:
Altitude: 1100
Scan Frequency: 50
Scan Angle: 40
Overlap: 30

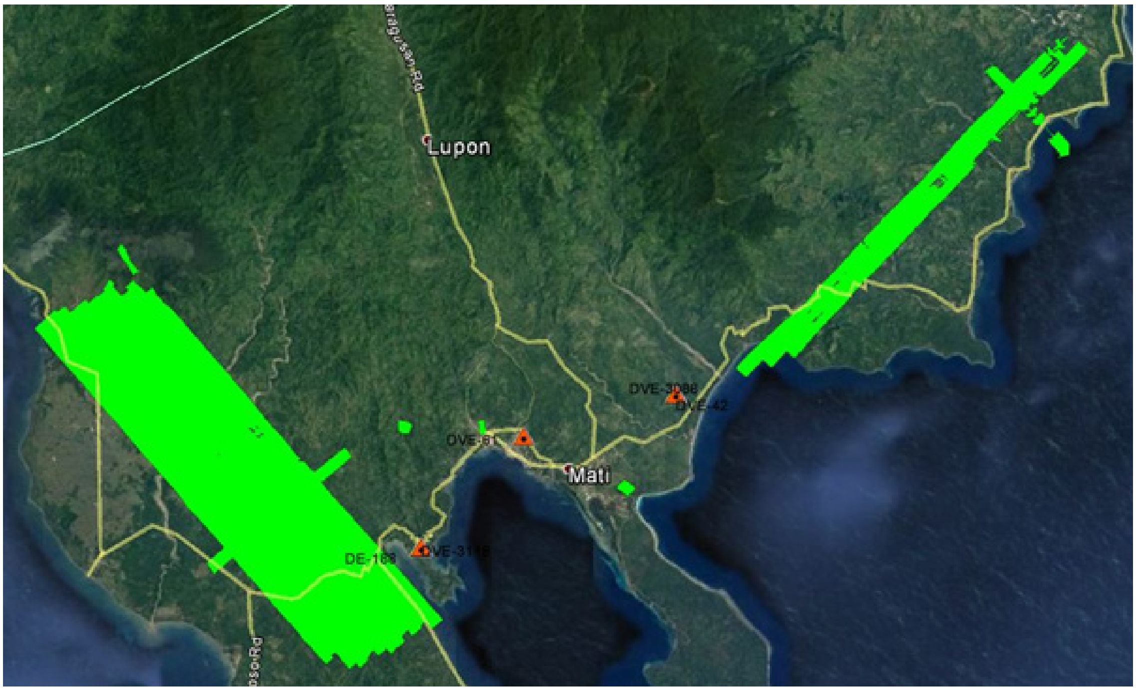


Figure A-7.2. Las for Flight No. 7322GC

Flight No. : 7323GC
Area: BLK86C, BLK83A
Mission Name: 2BLK86C83A171B
Parameters:
Altitude: 1100 / 1200
Scan Frequency: 50
Scan Angle: 40 / 36
Overlap: 30

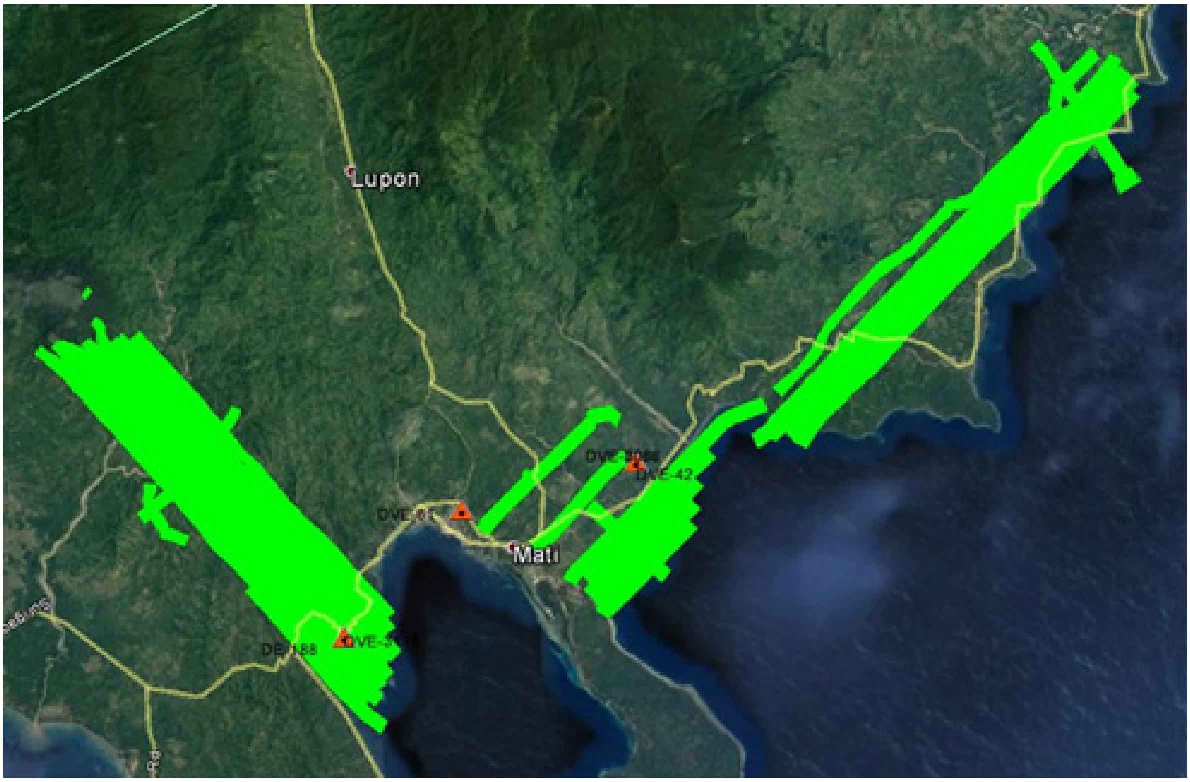


Figure A-7.3. LaS for Flight No. 7323GC

Flight No. : 7328GC
Area: BLK80A, BLK80B
Mission Name: 2BLK80AB174A
Parameters:
Altitude: 1100
Scan Frequency: 50
Scan Angle: 40
Overlap: 30

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

Flight No. : 7358GC
Area: BLK85C
Mission Name: 2BLK80BS189A
Parameters:
Altitude: 1600 / 1300
Scan Frequency: 60
Scan Angle: 24
Overlap: 40

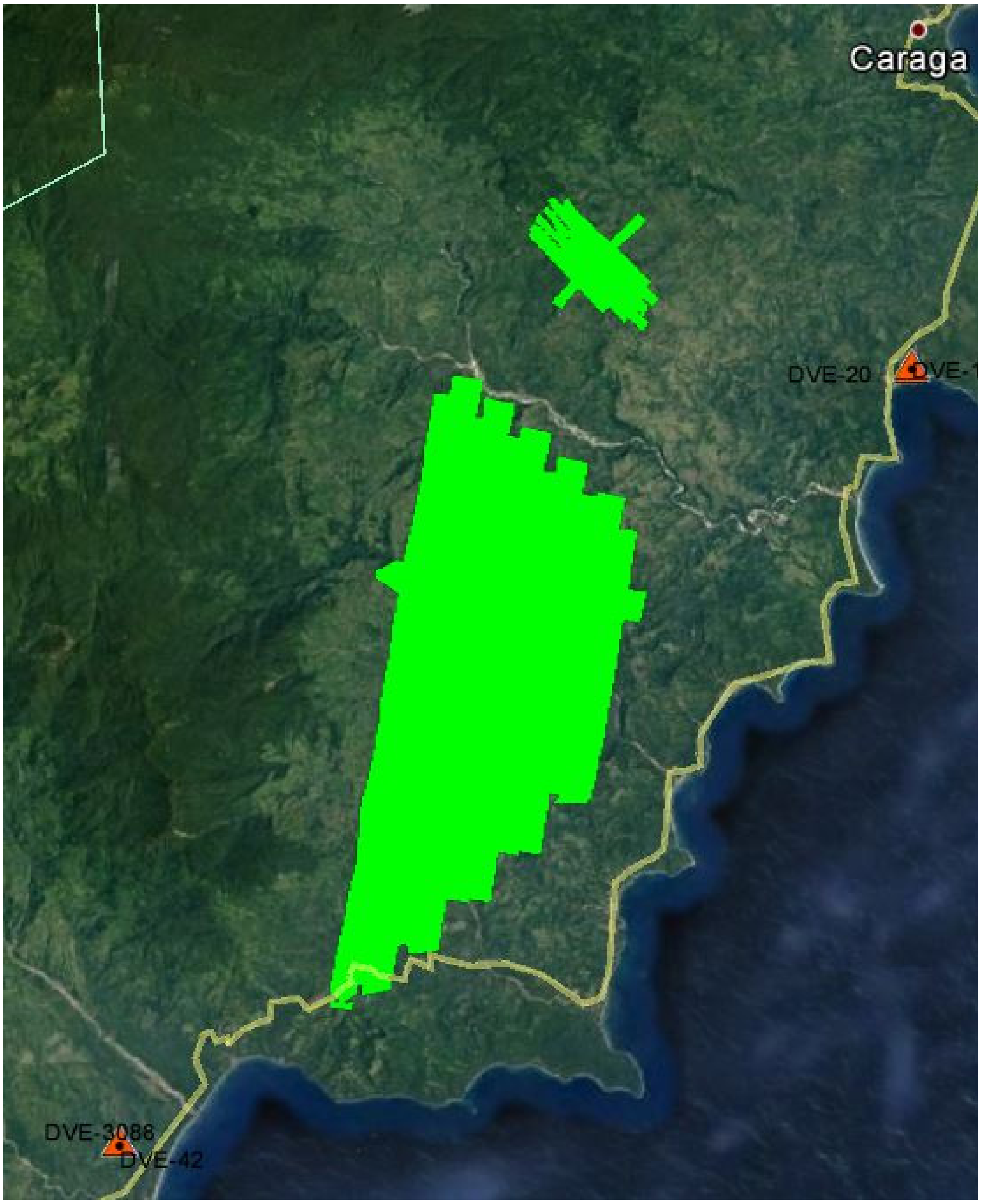


Figure A-7.5. Las for Flight No. 7358GC

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Blk83A

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

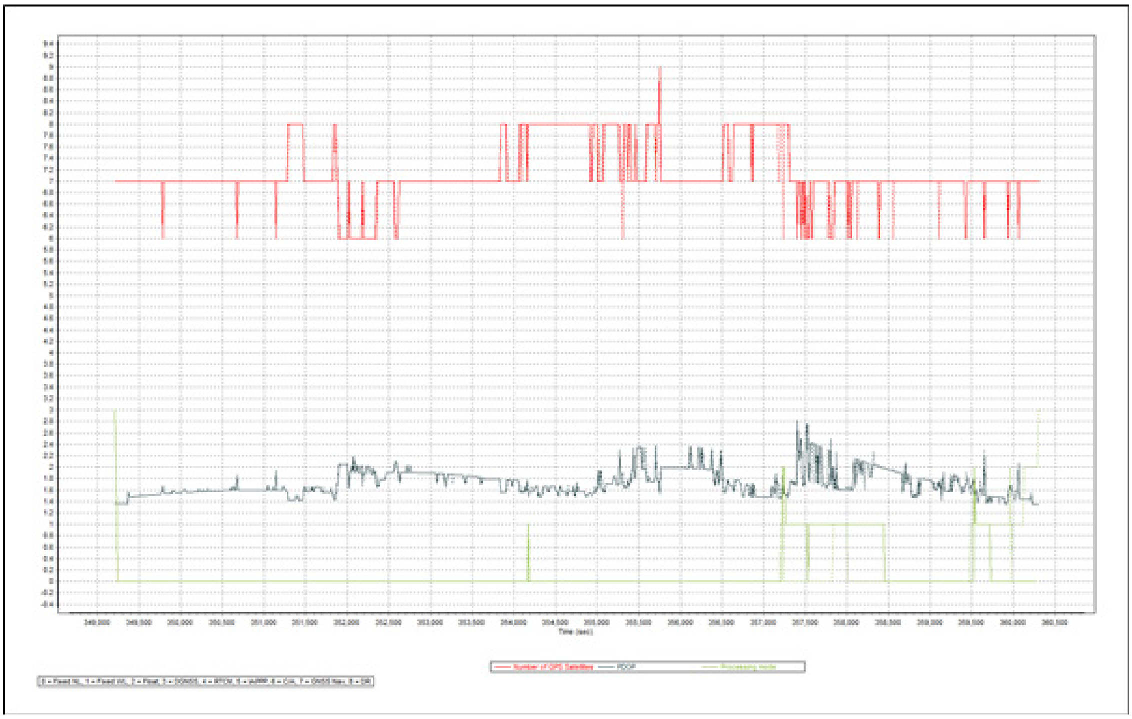


Figure A-8.1 Solution Status

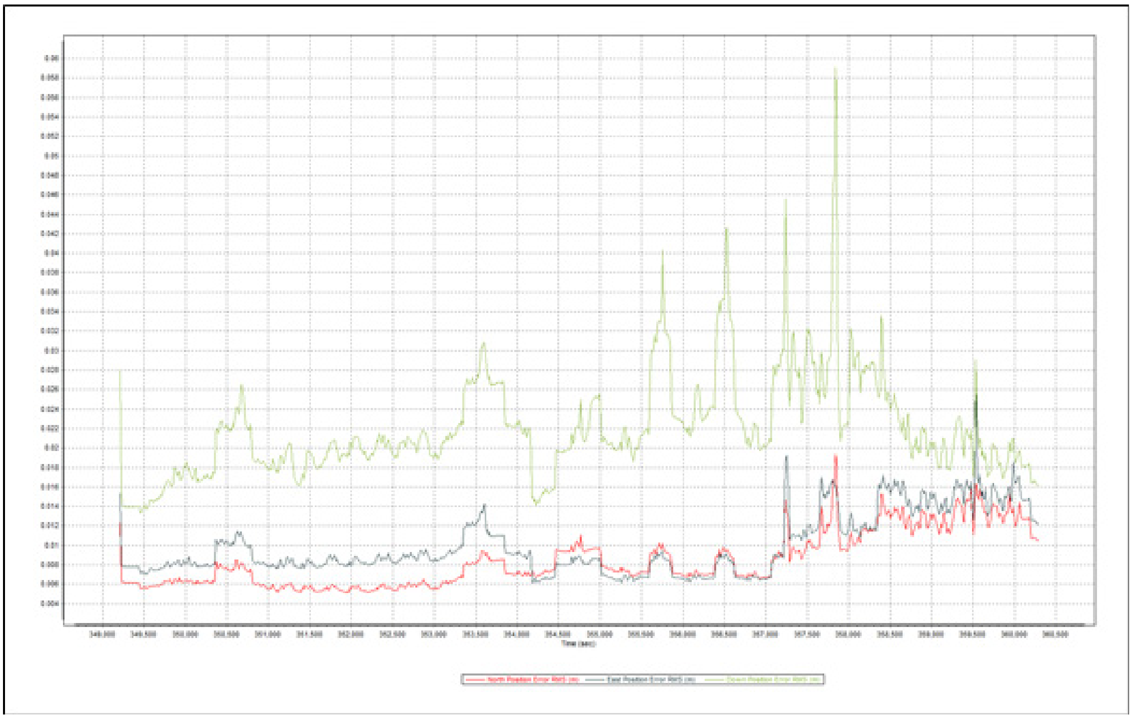


Figure A-8.2 Smoothed Performance Metric Parameters

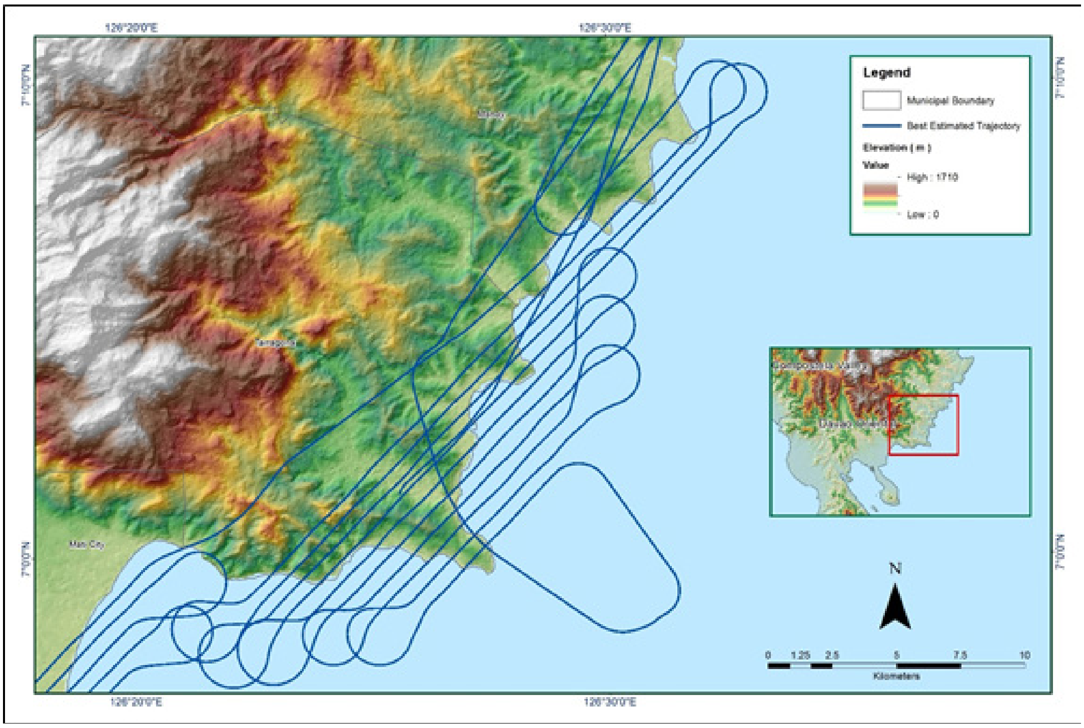


Figure A-8.3 Best Estimated Trajectory

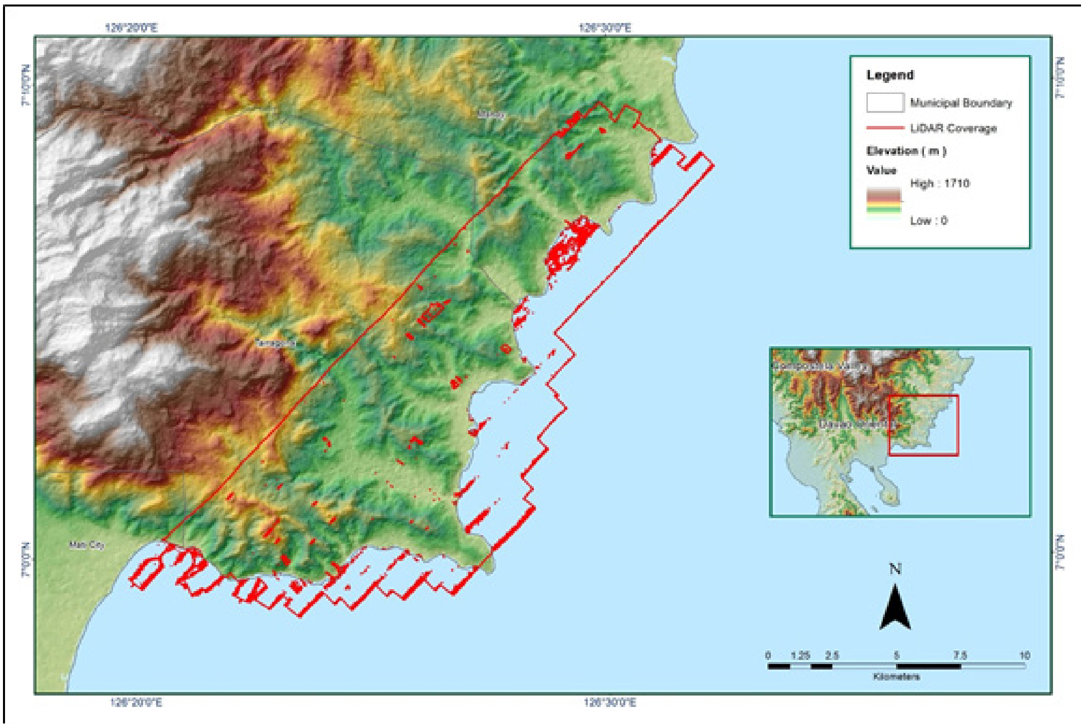


Figure A-8.4 Coverage of LiDAR data

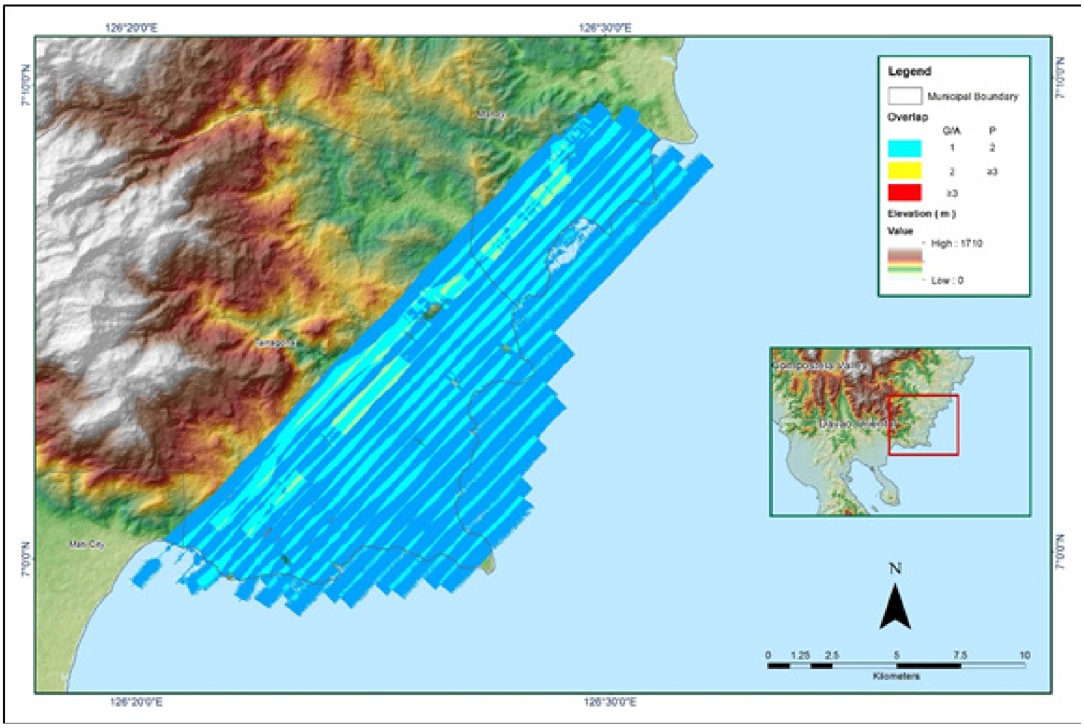


Figure A-8.5 Image of data overlap

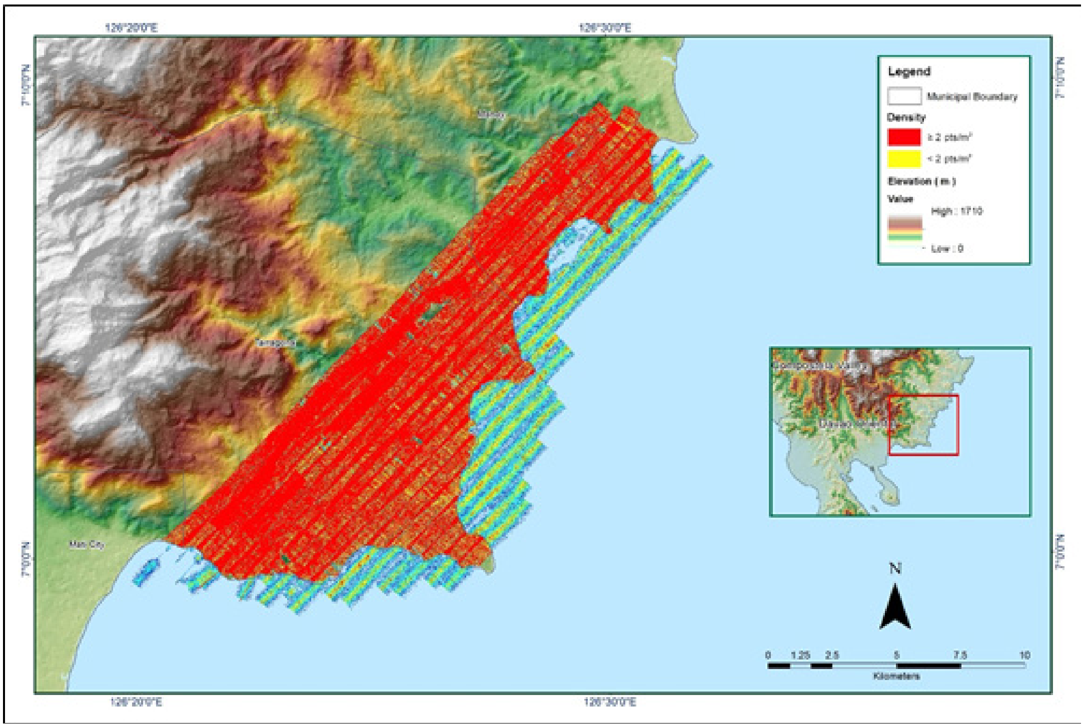


Figure A-8.6 Density map of merged LiDAR data

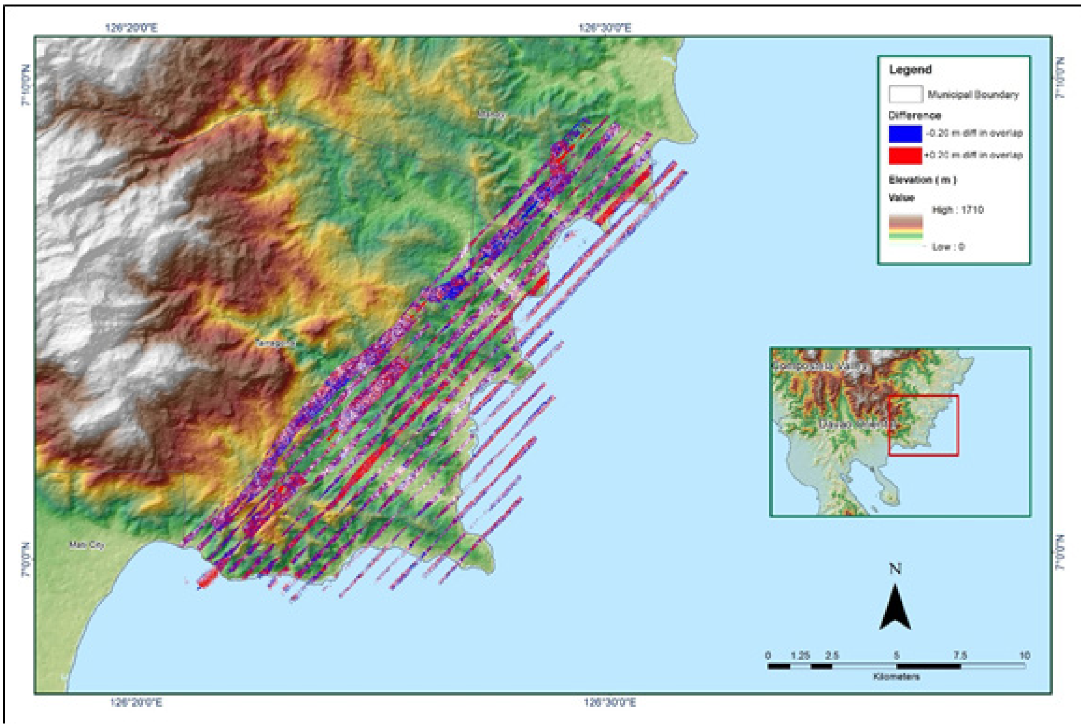


Figure A-8.7 Elevation difference between flight lines

Table A-8.2. Mission Summary Report for Mission Blk85C

Flight Area	Davao Oriental
Mission Name	Blk85C
Inclusive Flights	7358G
Range data size	20.1 GB
POS	196 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)	3.4
RMSE for East Position (<4.0 cm)	3.2
RMSE for Down Position (<8.0 cm)	5.5
Boresight correction stdev (<0.001deg)	0.000806
IMU attitude correction stdev (<0.001deg)	0.001274
GPS position stdev (<0.01m)	0.0118
Minimum % overlap (>25)	36.47%
Ave point cloud density per sq.m. (>2.0)	2.40
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	157
Maximum Height	1449.33 m
Minimum Height	93.19 m
Classification (# of points)	
Ground	47587575
Low vegetation	17258521
Medium vegetation	69558418
High vegetation	66403945
Building	128689
Orthophoto	No

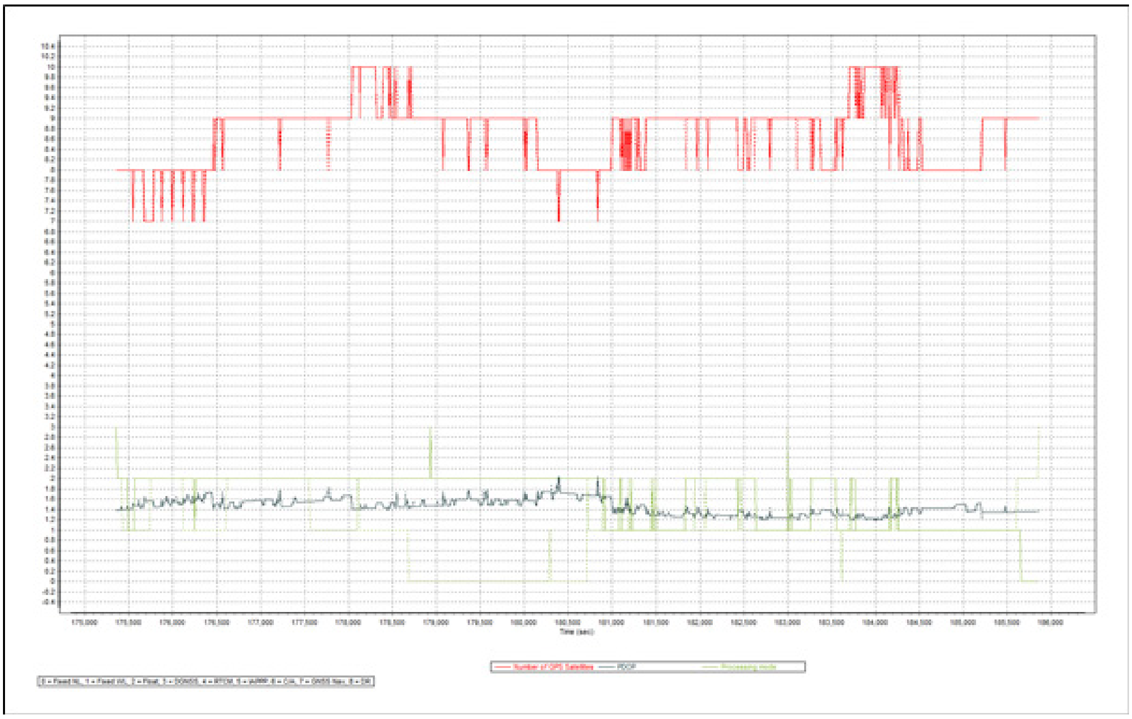


Figure A-8.8 Solution Status

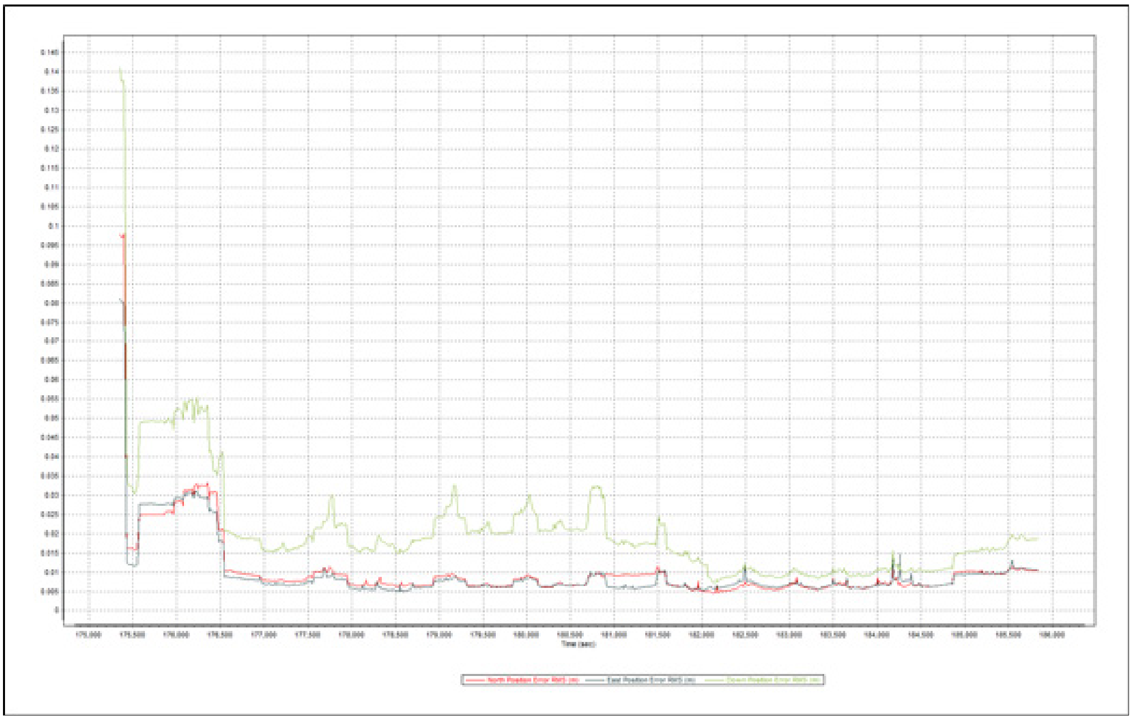


Figure A-8.9 Smoothed Performance Metric Parameters

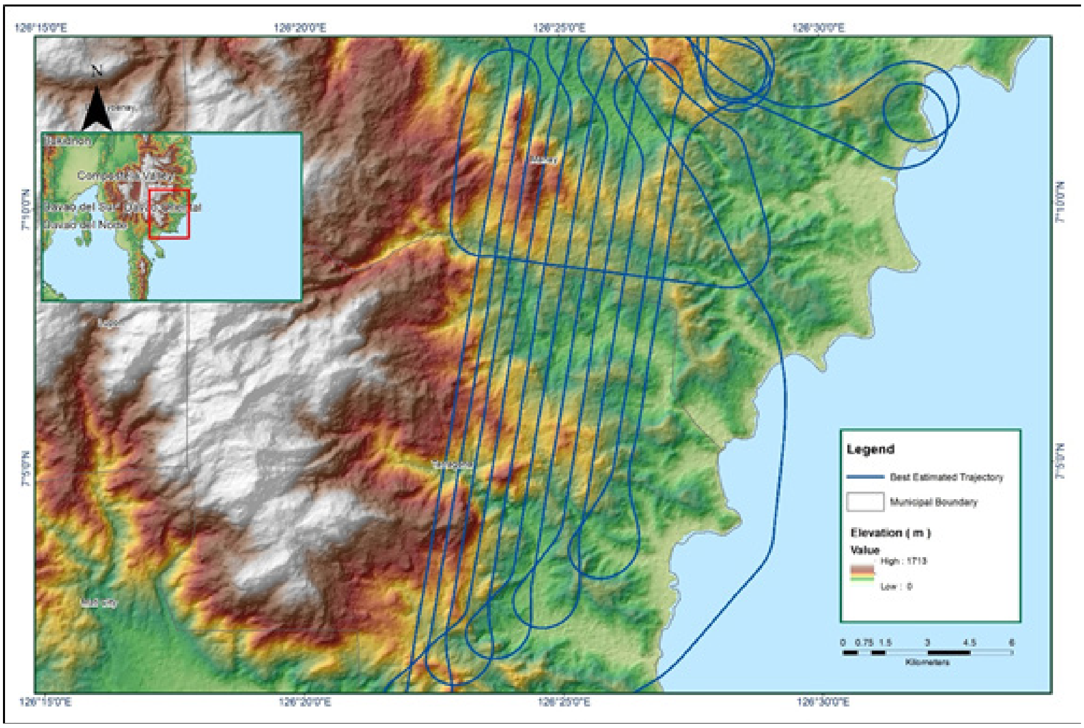


Figure A-8.10 Best Estimated Trajectory

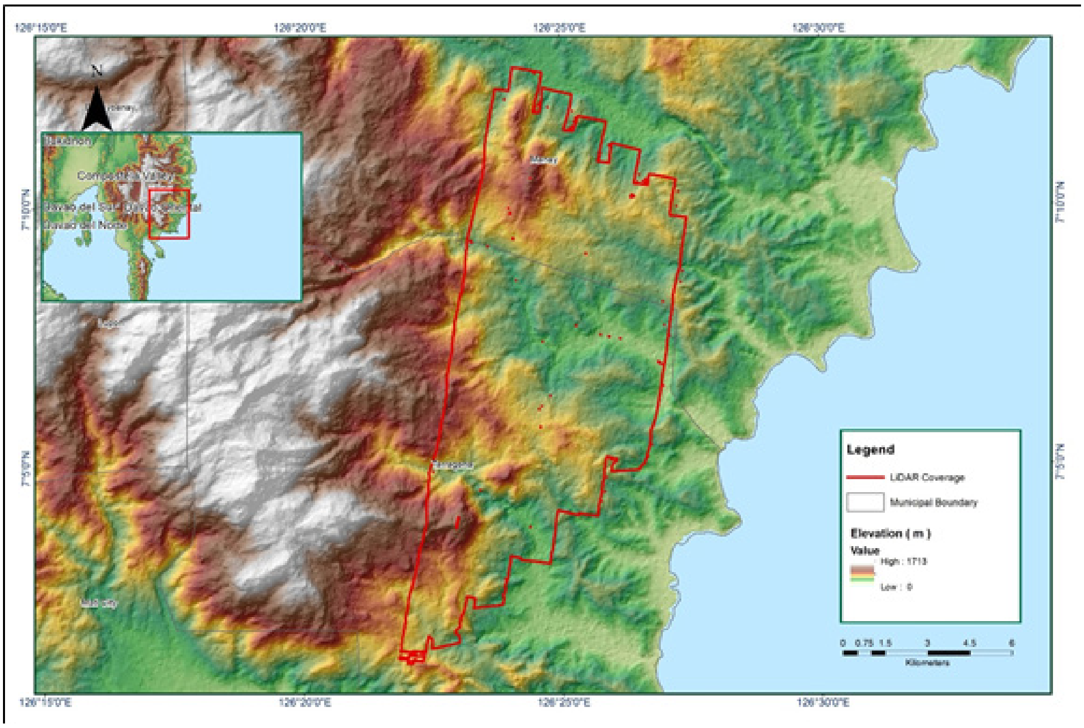


Figure A-8.11 Coverage of LiDAR data

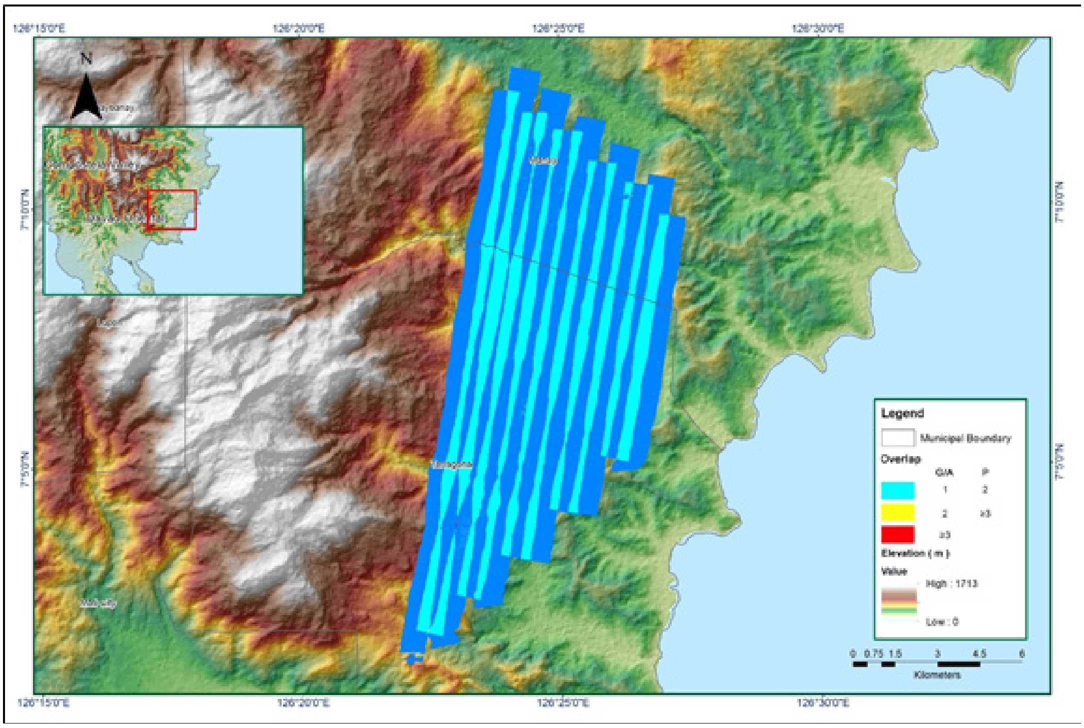


Figure A-8.12 Image of data overlap

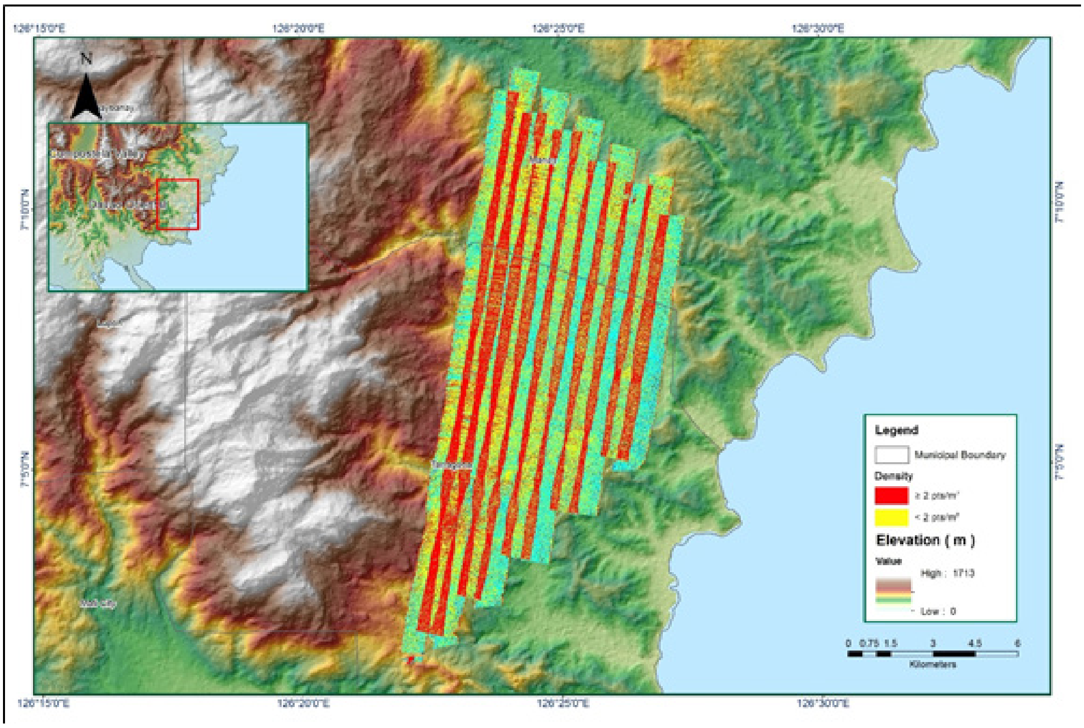


Figure A-8.13 Density map of merged LiDAR data

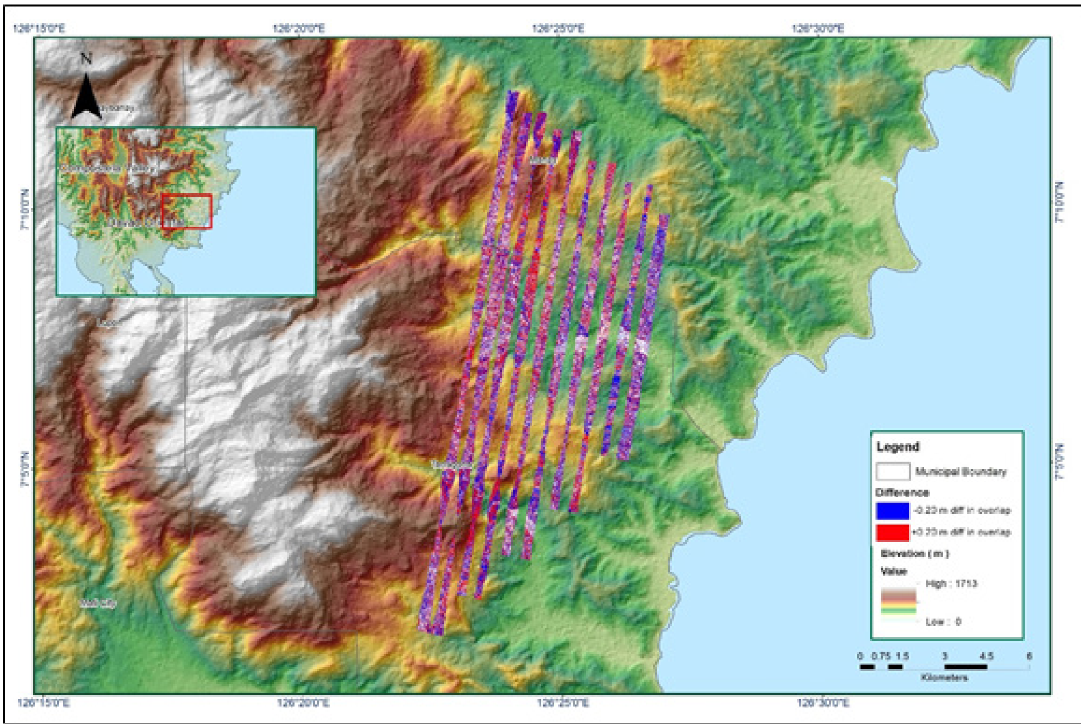


Figure A-8.14 Elevation difference between flight lines

Table A-8.3. Mission Summary Report for Mission Blk80A_supplement

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

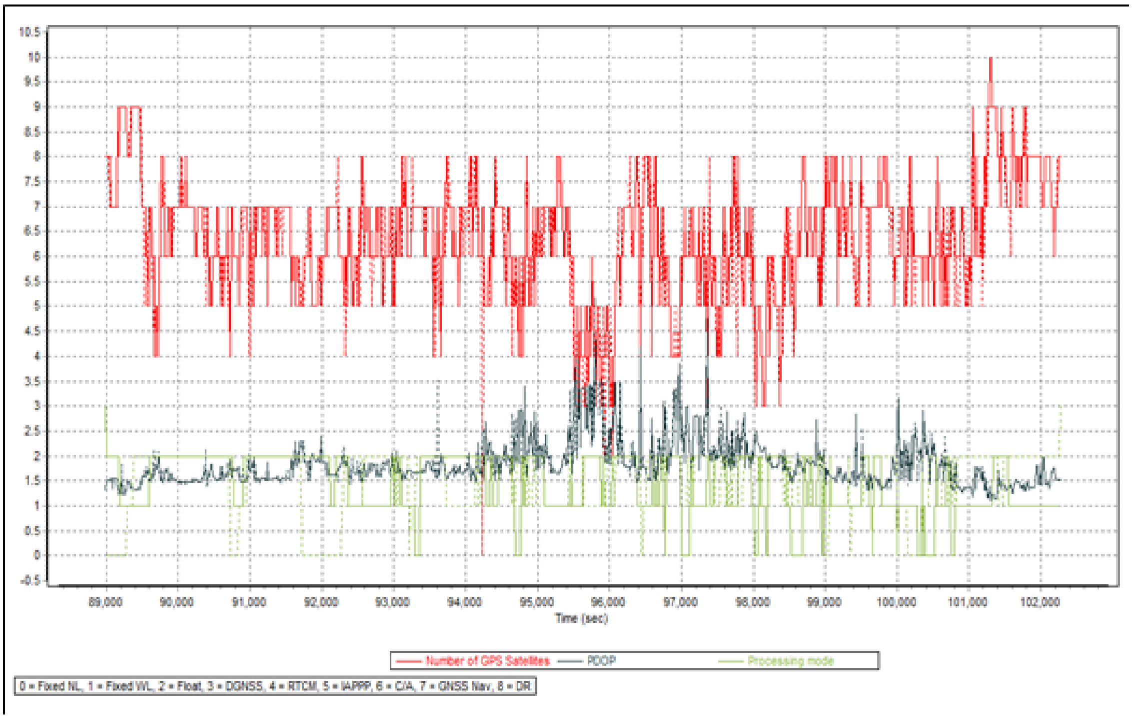


Figure A-8.15 Solution Status

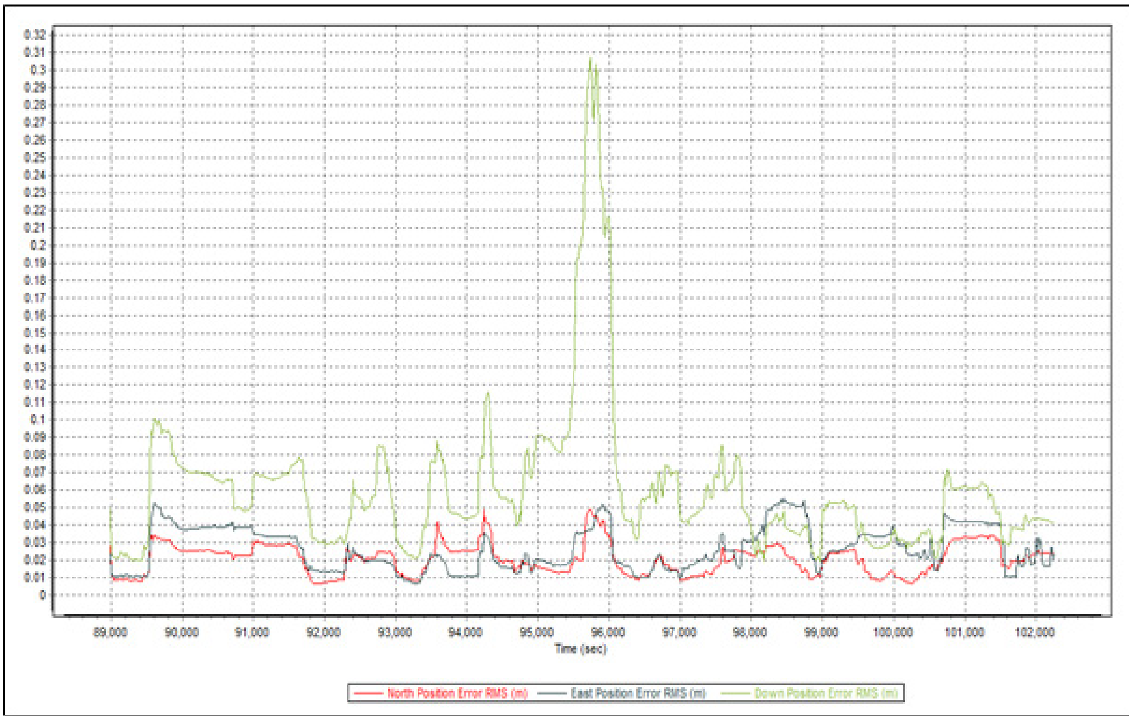


Figure A-8.16 Smoothed Performance Metric Parameters

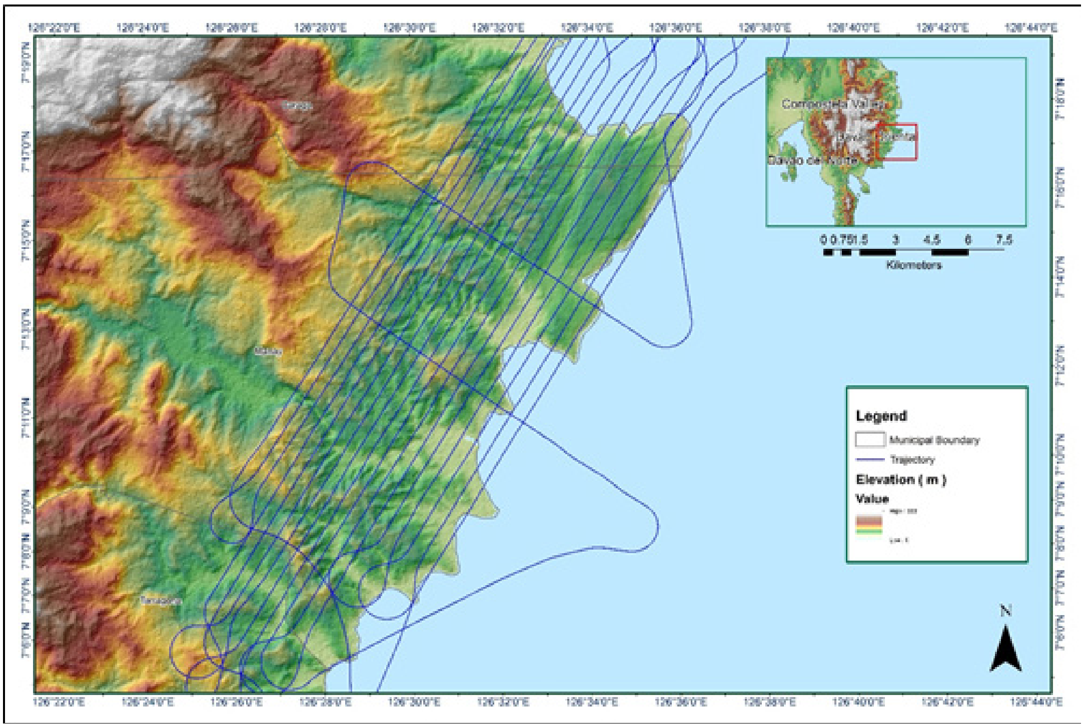


Figure A-8.17 Best Estimated Trajectory

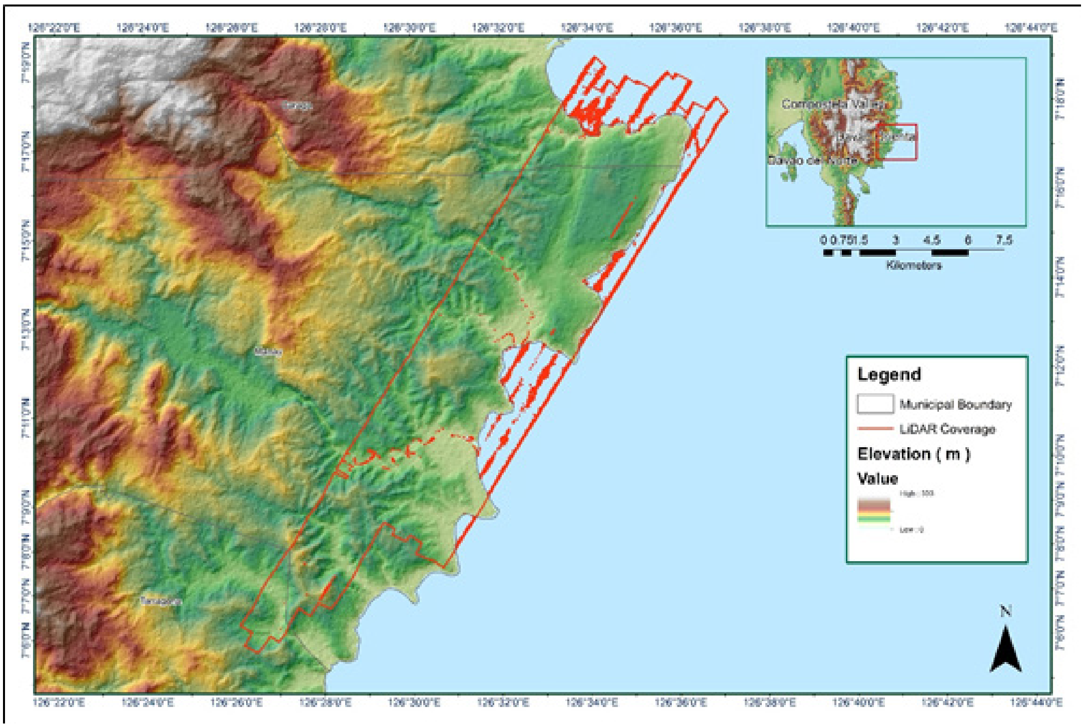


Figure A-8.18 Coverage of LiDAR data

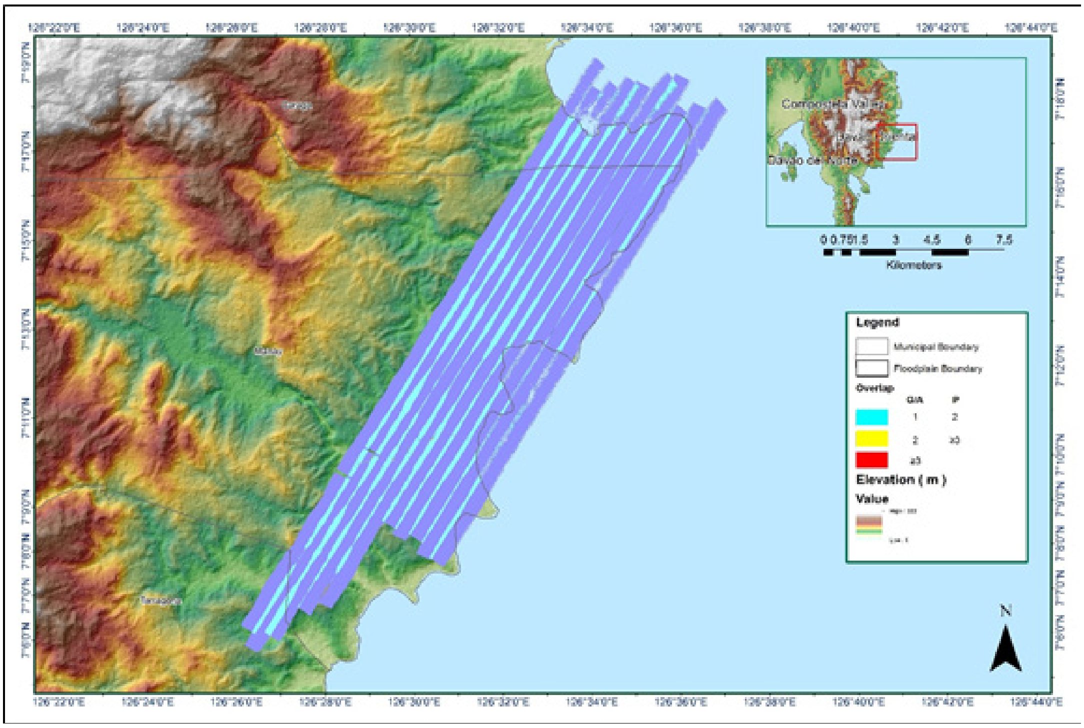


Figure A-8.19 Image of data overlap

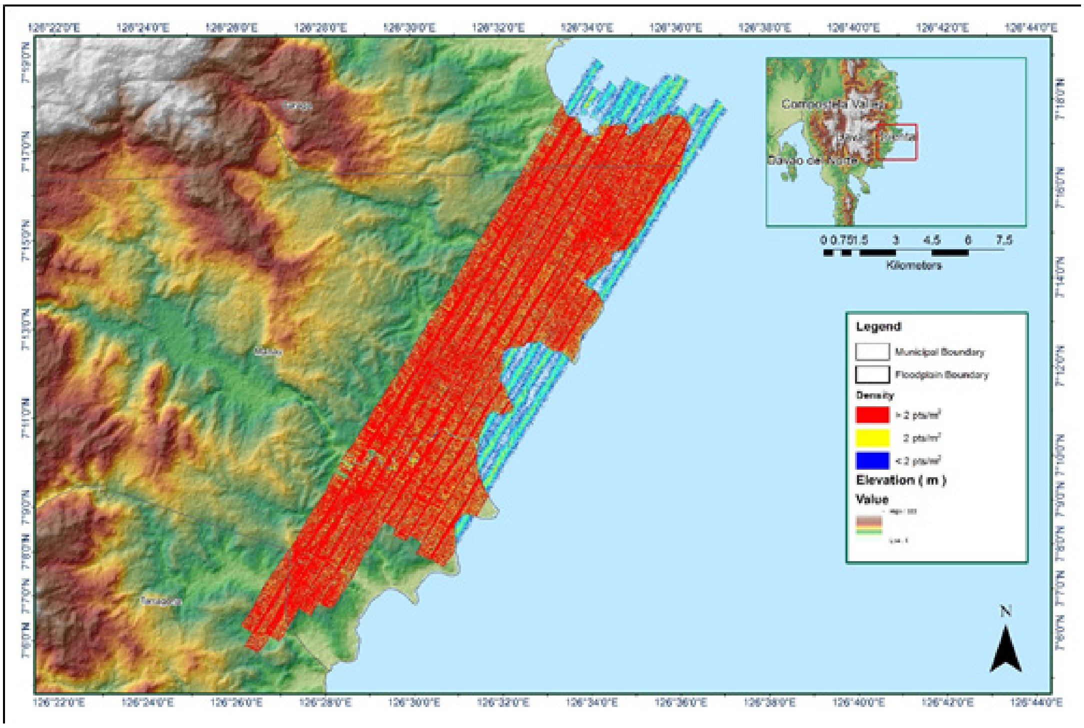


Figure A-8.20 Density map of merged LiDAR data

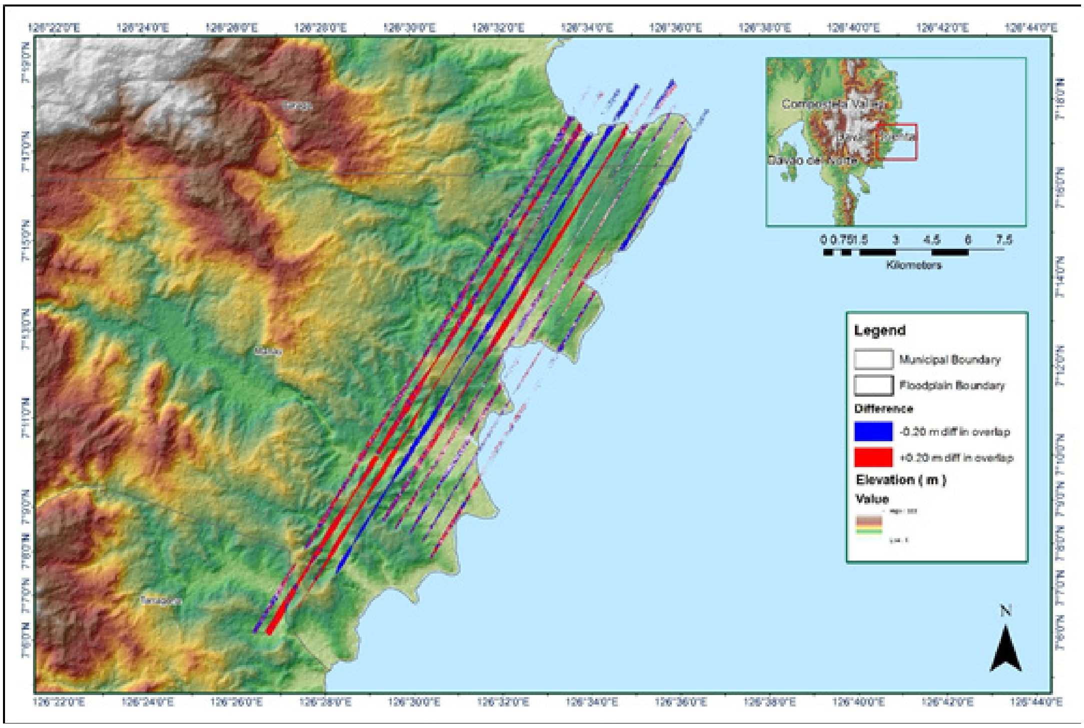


Figure A-8.21 Elevation difference between flight lines

Annex 9. Quinonoan Model Basin Parameters

Table A-9.1. Quinonoan 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
W1000	1.64877	78.33056	0	0.13879	2.38768	Discharge	2.1487	0.8379	Ratio to Peak	0.398574
W1010	3.5265	73.10576	0	0.0263595	1.0271652	Discharge	0.20189	0.91238	Ratio to Peak	0.398862
W1020	1.5174	98.175	0	0.018514	0.7251612	Discharge	0.088245	0.91238	Ratio to Peak	0.3969
W1030	2.34495	73.00272	0	0.0282	1.105368	Discharge	0.46606	0.91238	Ratio to Peak	0.398826
W1040	2.30958	71.67888	0	0.053585	2.06664	Discharge	0.49127	0.9344104	Ratio to Peak	0.271332
W1050	2.72868	76.85328	0	0.09437	2.25472	Discharge	1.1742	0.91238	Ratio to Peak	0.3987
W1060	3.414	72.9904	0	0.036733	1.443	Discharge	0.50427	0.9316958	Ratio to Peak	0.398808
W1070	2.46579	71.25776	0	0.035115	1.32084	Discharge	0.26558	0.91238	Ratio to Peak	0.59535
W1080	2.37141	72.25456	0	0.0341105	1.96392	Discharge	0.43079	0.931	Ratio to Peak	0.398808
W1090	1.48722	73.64112	0	0.041549	2.39244	Discharge	0.41988	0.931	Ratio to Peak	0.398808
W1100	1.5174	71.83792	0	0.0130915	0.5127696	Discharge	0.0214269	0.9353708	Ratio to Peak	0.3969
W1110	2.28615	73.0184	0	0.0326585	1.22856	Discharge	0.37818	0.9320584	Ratio to Peak	0.398826
W1120	1.81731	77.11424	0	0.028347	1.066332	Discharge	0.51591	0.931	Ratio to Peak	0.39879
W1130	1.75575	77.43232	0	0.03703	1.39296	Discharge	0.4726	0.9342144	Ratio to Peak	0.270396
W1140	1.431	80.24128	0	0.0269055	1.0274628	Discharge	0.37052	0.91238	Ratio to Peak	0.398808
W580	2.63229	72.11344	0	0.13407	5.90796	Discharge	0.81284	0.931	Ratio to Peak	0.3969
W590	4.9824	65.6656	0	0.14894	3.81696	Discharge	0.83165	0.931	Ratio to Peak	0.405

W600	5.6286	82.13296	0	0.11587	6.80768	Discharge	0.91476	0.931	Ratio to Peak	0.405
W610	4.5759	68.21024	0	0.0536	3.09624	Discharge	0.54416	0.931	Ratio to Peak	0.3969
W620	3.4887	66.73072	0	0.035896	2.11908	Discharge	0.26454	0.931	Ratio to Peak	0.398736
W630	2.03196	73.95696	0	0.085468	3.36368	Discharge	0.90723	0.931	Ratio to Peak	0.271098
W640	3.3168	66.05424	0	0.037494	1.47576	Discharge	0.43533	0.931	Ratio to Peak	0.398682
W650	5.7417	61.8912	0	0.041148	1.5618	Discharge	0.42253	0.931	Ratio to Peak	0.405
W660	4.572	65.688	0	0.059855	2.34456	Discharge	0.48143	0.931	Ratio to Peak	0.405
W670	5.82	52.92784	0	0.044251	1.74852	Discharge	0.53133	0.931	Ratio to Peak	0.405
W680	1.73049	77.58128	0	0.029372	1.1606148	Discharge	0.42665	0.931	Ratio to Peak	0.27036
W690	3.1386	65.31168	0	0.047978	1.25904	Discharge	0.79398	0.931	Ratio to Peak	0.27
W700	5.3754	63.07616	0	0.12381	2.1248	Discharge	0.96139	0.931	Ratio to Peak	0.405
W710	5.4408	83.31232	0	0.21341	8.27552	Discharge	2.8571	0.931	Ratio to Peak	0.405
W720	1.89276	74.73312	0	0.0307135	1.21344	Discharge	0.38955	0.931	Ratio to Peak	0.3969
W730	3.7449	61.57536	0	0.032064	1.82088	Discharge	0.21996	0.931	Ratio to Peak	0.3969
W740	5.7042	62.61024	0	0.065015	2.54652	Discharge	0.56248	0.931	Ratio to Peak	0.405
W750	4.6776	58.78656	0	0.15948	2.78608	Discharge	1.2691	0.931	Ratio to Peak	0.405
W760	2.84466	74.704	0	0.10408	2.44592	Discharge	1.3059	0.931	Ratio to Peak	0.3969
W770	2.61858	81.05664	0	0.0231295	0.905946	Discharge	0.5324	0.931	Ratio to Peak	0.3969
W780	3.2382	66.70832	0	0.10991	1.92272	Discharge	0.97081	0.931	Ratio to Peak	0.27
W790	2.20344	66.1584	0	0.13654	2.38544	Discharge	1.1908	0.931	Ratio to Peak	0.3969
W800	5.1018	65.4304	0	0.15615	5.9936	Discharge	1.0462	0.931	Ratio to Peak	0.405
W810	2.90166	61.90576	0	0.026521	1.20036	Discharge	0.21069	0.931	Ratio to Peak	0.394758
W820	2.65068	77.27888	0	0.037054	1.66896	Discharge	0.64255	0.931	Ratio to Peak	0.27

W830	2.14668	73.94352	0	0.10883	2.79856	Discharge	0.965	0.931	Ratio to Peak	0.27
W840	1.31784	99	0	0.0227625	0.8915676	Discharge	0.38081	0.931	Ratio to Peak	0.388962
W850	2.07588	75.42752	0	0.12575	3.28688	Discharge	2.9975	0.931	Ratio to Peak	0.3969
W860	3.1503	66.3432	0	0.0336955	1.31976	Discharge	0.28171	0.931	Ratio to Peak	0.27
W870	3.2598	65.31952	0	0.0377215	2.21616	Discharge	0.38295	0.931	Ratio to Peak	0.3969
W880	2.23059	71.83792	0	0.0409715	1.60296	Discharge	0.50336	0.931	Ratio to Peak	0.3969
W890	2.28639	71.76288	0	0.04004	1.76748	Discharge	0.79181	0.931	Ratio to Peak	0.394002
W900	2.23059	98.175	0	0.0111035	0.43491	Discharge	0.0105725	0.931	Ratio to Peak	0.3969
W910	5.0742	45.87632	0	0.053775	3.15936	Discharge	0.74766	0.931	Ratio to Peak	0.405
W920	2.29554	71.6968	0	0.05201	2.02656	Discharge	0.63584	0.931	Ratio to Peak	0.405
W930	3.9687	62.59792	0	0.045473	1.78716	Discharge	0.62468	0.931	Ratio to Peak	0.3969
W940	1.98303	50.3608	0	0.0402795	1.81428	Discharge	0.40796	0.931	Ratio to Peak	0.46575
W950	2.2761	73.5504	0	0.0352325	1.38612	Discharge	0.40488	0.931	Ratio to Peak	0.406764
W960	2.2761	98.175	0	0.030939	1.1875248	Discharge	0.1715	0.931	Ratio to Peak	0.405
W970	2.23059	48.86896	0	0.021978	0.8608416	Discharge	0.14142	0.931	Ratio to Peak	0.405
W980	2.04849	71.83792	0	0.0102775	0.2067156	Discharge	0.0063435	0.931	Ratio to Peak	0.405
W990	2.29323	71.7136	0	0.051935	1.35612	Discharge	0.60796	0.931	Ratio to Peak	0.405504

Annex 10. Quinonoan Model Reach Parameters

Table A-10.1. Quinonoan 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	1087.7	0.088543	0.034512	Trapezoid	220	1
R120	Automatic Fixed Interval	1459.4	0.040544	0.03456	Trapezoid	220	1
R130	Automatic Fixed Interval	1688.5	0.041062	0.03456	Trapezoid	220	1
R140	Automatic Fixed Interval	1561.4	0.20419	0.0228971	Trapezoid	220	1
R150	Automatic Fixed Interval	2442.1	0.028849	0.034575	Trapezoid	220	1
R170	Automatic Fixed Interval	1150.7	0.086776	0.03462	Trapezoid	220	1
R180	Automatic Fixed Interval	3580.4	0.055769	0.0228011	Trapezoid	220	1
R190	Automatic Fixed Interval	2730.4	0.074493	0.0230677	Trapezoid	220	1
R200	Automatic Fixed Interval	3357.8	0.020866	0.0231297	Trapezoid	220	1
R220	Automatic Fixed Interval	2405.5	0.064014	0.023111	Trapezoid	220	1
R240	Automatic Fixed Interval	1168.3	0.072591	0.03456	Trapezoid	220	1
R290	Automatic Fixed Interval	295.56	0.036286	0.0148431	Trapezoid	220	1
R300	Automatic Fixed Interval	1817.3	0.089428	0.0229084	Trapezoid	220	1
R330	Automatic Fixed Interval	2300.7	0.01598	0.034683	Trapezoid	220	1
R350	Automatic Fixed Interval	150.71	0.075799	0.034704	Trapezoid	220	1
R360	Automatic Fixed Interval	1884.1	0.014365	0.034731	Trapezoid	220	1

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R390	Automatic Fixed Interval	1633.7	0.006733	0.05184	Trapezoid	220	1
R400	Automatic Fixed Interval	1131.5	0.020237	0.03456	Trapezoid	220	1
R410	Automatic Fixed Interval	648.41	0.003674	0.05184	Trapezoid	220	1
R420	Automatic Fixed Interval	635.98	0.017689	0.0229552	Trapezoid	220	1
R450	Automatic Fixed Interval	483.85	0.063283	0.034374	Trapezoid	220	1
R500	Automatic Fixed Interval	2241.7	0.000267	0.034725	Trapezoid	220	1
R510	Automatic Fixed Interval	1366	0.054769	0.0225792	Trapezoid	220	1
R520	Automatic Fixed Interval	244.85	0.051357	0.0213256	Trapezoid	220	1
R550	Automatic Fixed Interval	1661	0.009059	0.0231016	Trapezoid	220	1
R570	Automatic Fixed Interval	1415.2	0.01483	0.0231533	Trapezoid	220	1
R60	Automatic Fixed Interval	1161.2	0.093393	0.0231011	Trapezoid	220	1
R80	Automatic Fixed Interval	988.41	0.042793	0.02304	Trapezoid	220	1

Annex 11. Quinonoan Field Validation Points

Table A-11.1. Quinonoan Field Validation Points

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error (m)	Event/Date	Rain Return/ Scenario
	Lat	Long					
1	7.100428	126.455063	4.017	1.50	6.3353		25-Year
2	7.100740	126.455708	6.52	5.00	2.3104		25-Year
3	7.100843	126.453991	9.416	5.50	15.3351		25-Year
4	7.100658	126.454532	10.792	5.50	28.0053		25-Year
5	7.101031	126.452907	8.825	5.00	14.6306		25-Year
6	7.100758	126.453267	8.965	5.00	15.7212		25-Year
7	7.100562	126.455345	7.214	5.00	4.9018		25-Year
8	7.101118	126.453360	9.325	5.50	14.6306		25-Year
9	7.101213	126.452728	9.868	6.50	11.3434		25-Year
10	7.101535	126.452773	9.665	6.50	10.0172		25-Year
11	7.100461	126.454460	10.646	6.50	17.1893		25-Year
12	7.100480	126.454169	12.192	9.00	10.1889		25-Year
13	7.100666	126.453447	12.707	9.00	13.7418		25-Year
14	7.100664	126.453718	12.591	9.00	12.8953		25-Year
15	7.100940	126.453088	12.832	9.00	14.6842		25-Year
16	7.100936	126.453540	12.759	9.00	14.1301		25-Year
17	7.100482	126.453898	12.547	9.00	12.5812		25-Year
18	7.101210	126.453180	13.176	9.00	17.4390		25-Year
19	7.089614	126.466481	0.031	0.00	0.0010		25-Year
20	7.089919	126.466324	0.031	0.00	0.0010		25-Year
21	7.087378	126.467439	0.646	0.50	0.0213	Pablo/ December 01, 2012	25-Year
22	7.090420	126.466188	0.417	0.50	0.0069	Agaton/ January 01, 2014	25-Year
23	7.090330	126.466326	0.927	0.00	0.8593		25-Year
24	7.090553	126.466129	0.63	0.50	0.0169	Agaton/ January 01, 2014	25-Year
25	7.090365	126.465836	0.797	0.50	0.0882	Agaton/ January 01, 2014	25-Year
26	7.090380	126.466083	1.318	1.00	0.1011	Agaton/ January 01, 2014	25-Year
27	7.089837	126.466744	2.276	1.50	0.6022	Pablo/ December 01, 2012	25-Year
28	7.089240	126.467127	2.805	1.60	1.4520	Agaton/ January 01, 2014	25-Year
29	7.088436	126.468317	3.045	2.00	1.0920	Yolanda/ November 01, 2013	25-Year
30	7.090702	126.466311	3.622	2.00	2.6309		25-Year
31	7.087623	126.467671	3.109	2.50	0.3709	Pablo/ December 01, 2012	25-Year
32	7.089150	126.467928	3.381	2.50	0.7762	Agaton/ January 01, 2014	25-Year
33	7.094433	126.469384	0.031	0.00	0.0010		25-Year
34	7.094478	126.468561	0.032	0.00	0.0010		25-Year
35	7.092154	126.472510	0.034	0.00	0.0012		25-Year
36	7.092564	126.476023	0.041	0.00	0.0017		25-Year
37	7.092700	126.471449	0.038	0.00	0.0014		25-Year
38	7.092483	126.473320	0.047	0.00	0.0022		25-Year
39	7.092309	126.467611	0.603	0.00	0.3636		25-Year

40	7.092241	126.474087	0.079	0.00	0.0062		25-Year
41	7.092639	126.470344	0.111	0.00	0.0123		25-Year
42	7.093167	126.468475	1.113	0.00	1.2388		25-Year
43	7.091873	126.471682	0.675	0.50	0.0306	Pablo/ December 01, 2012	25-Year
44	7.092818	126.467603	1.43	0.00	2.0449		25-Year
45	7.093141	126.468779	1.079	0.00	1.1642		25-Year
46	7.092880	126.468177	1.437	0.00	2.0650		25-Year
47	7.092015	126.467885	1.933	1.00	0.8705	Agaton/ January 01, 2014	25-Year
48	7.091540	126.471028	1.586	1.00	0.3434	Pablo/ December 01, 2012	25-Year
49	7.091796	126.471292	1.491	1.00	0.2411	Pablo/ December 01, 2012	25-Year
50	7.093092	126.467611	2.219	1.00	1.4860	Agaton/ January 01, 2014	25-Year
51	7.092683	126.468408	2.557	0.50	4.2312	Intense local rainfall/ July 03, 1905	25-Year
52	7.091798	126.470969	2.049	1.50	0.3014	Pablo/ December 01, 2012	25-Year
53	7.092700	126.469164	2.457	1.00	2.1228	Intense local rainfall/ July 03, 1905	25-Year
54	7.092680	126.467426	2.428	1.50	0.8612	Pablo/ July 04, 1905	25-Year
55	7.094049	126.466331	2.553	0.50	4.2148		25-Year
56	7.092637	126.468878	2.547	1.50	1.0962		25-Year
57	7.091497	126.470463	2.354	1.53	0.6790	Pablo/ December 01, 2012	25-Year
58	7.092588	126.469381	2.826	2.00	0.6823		25-Year
59	7.091849	126.468888	2.946	2.00	0.8949		25-Year
60	7.092302	126.470178	2.876	0.00	8.2714		25-Year
61	7.094157	126.466841	3.1	1.50	2.5600		25-Year
62	7.092330	126.469320	3.031	1.50	2.3440		25-Year
63	7.092847	126.467238	3.079	2.00	1.1642		25-Year
64	7.093114	126.466510	3.172	2.00	1.3736		25-Year
65	7.091120	126.469981	2.85	2.00	0.7225	Pablo/ December 01, 2012	25-Year
66	7.091490	126.469435	3.032	2.00	1.0650	Pablo/ December 01, 2012	25-Year
67	7.093765	126.466121	3.418	2.50	0.8427		25-Year
68	7.091774	126.470481	3.27	2.00	1.6129	Pablo/ December 01, 2012	25-Year
69	7.093127	126.467377	3.53	2.50	1.0609	Agaton/ January 01, 2014	25-Year
70	7.093318	126.467767	3.657	2.50	1.3386	Agaton/ January 01, 2014	25-Year
71	7.094201	126.467910	4.113	2.50	2.6018	Agaton/ January 01, 2014	25-Year
72	7.093427	126.468574	3.971	2.50	2.1638	Agaton/ January 01, 2014	25-Year
73	7.093441	126.468037	4.209	2.50	2.9207	Agaton/ January 01, 2014	25-Year
74	7.087653	126.468354	0.767	0.50	0.0713	Pablo/ December 01, 2012	25-Year
75	7.097813	126.466365	0.087	0.00	0.0076		25-Year
76	7.097682	126.466911	0.032	0.00	0.0010		25-Year
77	7.097508	126.466397	0.06	0.00	0.0036		25-Year
78	7.097754	126.463872	0.139	0.66	0.2714	Pablo/ December 01, 2012	25-Year
79	7.097142	126.464113	0.649	0.50	0.0222		25-Year
80	7.097700	126.464827	0.622	0.00	0.3869		25-Year
81	7.096001	126.464576	1.156	0.00	1.3363		25-Year
82	7.097371	126.463571	1.091	0.50	0.3493		25-Year

83	7.098118	126.462851	0.893	0.56	0.1109	Upstream rainfall/ July 02, 1905	25-Year
84	7.096453	126.468236	0.652	0.00	0.4251		25-Year
85	7.097695	126.462661	1.488	0.56	0.8612	Upstream rainfall/ July 02, 1905	25-Year
86	7.097882	126.463369	0.695	0.66	0.0012	Pablo/ December 01, 2012	25-Year
87	7.096587	126.466889	1.144	0.50	0.4147	Cosme/ May 01, 2008	25-Year
88	7.097675	126.466168	0.929	0.00	0.8630		25-Year
89	7.095611	126.464686	1.613	0.00	2.6018		25-Year
90	7.096613	126.465116	1.31	0.50	0.6561		25-Year
91	7.095803	126.464089	1.572	0.00	2.4712		25-Year
92	7.095629	126.465802	1.552	0.65	0.8136		25-Year
93	7.095144	126.468137	1.725	0.70	1.0506		25-Year
94	7.095533	126.465267	1.862	0.00	3.4670		25-Year
95	7.096050	126.465095	1.414	0.00	1.9994		25-Year
96	7.097026	126.464880	1.278	0.50	0.6053		25-Year
97	7.096320	126.467324	1.64	0.75	0.7921		25-Year
98	7.096094	126.463554	1.767	0.85	0.8409	Agaton/ January 01, 2014	25-Year
99	7.095789	126.466839	1.662	0.87	0.6273	Yolanda/ November 01, 2013	25-Year
100	7.095055	126.467506	1.878	0.95	0.8612	Yolanda/ November 01, 2013	25-Year
101	7.097067	126.466427	1.42	0.95	0.2209		25-Year
102	7.095677	126.467911	1.919	0.95	0.9390		25-Year
103	7.096942	126.465643	1.44	1.25	0.0361	Agaton/ January 01, 2014	25-Year
104	7.095608	126.466342	1.749	0.95	0.6384	Yolanda/ November 01, 2013	25-Year
105	7.095236	126.467138	1.989	0.95	1.0795	Yolanda/ November 01, 2013	25-Year
106	7.095545	126.463954	1.926	0.00	3.7095		25-Year
107	7.096155	126.463332	1.975	0.85	1.2656	Agaton/ January 01, 2014	25-Year
108	7.097871	126.466004	1.727	0.85	0.7691	Cosme/ May 01, 2008	25-Year
109	7.097990	126.466205	1.938	0.85	1.1837	Cosme/ May 01, 2008	25-Year
110	7.096220	126.466415	1.922	1.21	0.5069	Yolanda/ November 01, 2013	25-Year
111	7.095460	126.467392	2.344	1.45	0.7992	Yolanda/ November 01, 2013	25-Year
112	7.097394	126.465720	1.918	1.25	0.4462	Agaton/ January 01, 2014	25-Year
113	7.096646	126.466066	2.002	1.31	0.4785	Yolanda/ November 01, 2013	25-Year
114	7.095150	126.464571	2.44	0.98	2.1316	Upstream rainfall	25-Year
115	7.098294	126.465839	2.082	0.71	1.8824	Typhoon	25-Year
116	7.097112	126.462737	2.457	1.50	0.9158	Upstream rainfall/ July 07, 1905	25-Year
117	7.096534	126.463085	2.434	0.62	3.2906		25-Year
118	7.097996	126.465911	2.089	0.85	1.5351	Cosme	25-Year
119	7.098184	126.465807	2.196	1.00	1.4304	Pablo/ December 01, 2012	25-Year
120	7.098154	126.466064	2.266	1.60	0.4436	Typhoon	25-Year
121	7.098003	126.466092	2.384	1.50	0.7815	Cosme	25-Year
122	7.094883	126.463962	2.734	1.60	1.2860	Upstream rainfall	25-Year
123	7.094693	126.465258	2.966	1.60	1.8660	Agaton/ January 01, 2014	25-Year
124	7.094714	126.466262	3.068	1.80	1.5826	Agaton/ January 01, 2014	25-Year
125	7.097441	126.462104	3.013	1.80	1.4714	Upstream rainfall/ July 02, 1905	25-Year
126	7.096716	126.462638	3.123	1.80	1.7503	Upstream rainfall/ July 07, 1905	25-Year

127	7.094796	126.465707	3.208	1.80	1.9825	Agaton/ January 01, 2014	25-Year
128	7.094333	126.465336	3.211	2.00	1.4665	Agaton/ January 01, 2014	25-Year
129	7.097862	126.465633	2.961	2.00	0.9235	Agaton/ January 01, 2014	25-Year
130	7.094806	126.467489	3.73	2.30	2.0449	Yolanda/ November 01, 2013	25-Year
131	7.098304	126.465998	3.69	2.50	1.4161	Typhoon	25-Year
132	7.098528	126.465262	0.03	0.00	0.0009		25-Year
133	7.099371	126.465282	0.03	0.00	0.0009		25-Year
134	7.098562	126.464296	0.03	0.00	0.0009		25-Year
135	7.102342	126.468189	0.03	0.00	0.0009		25-Year
136	7.098888	126.465149	0.03	0.00	0.0009		25-Year
137	7.101556	126.467546	0.03	0.00	0.0009		25-Year
138	7.101786	126.464903	0.03	0.00	0.0009		25-Year
139	7.102456	126.464886	0.031	0.00	0.0010		25-Year
140	7.100979	126.460830	0.031	0.00	0.0010		25-Year
141	7.101626	126.462162	0.031	0.00	0.0010		25-Year
142	7.099217	126.466177	0.032	0.00	0.0010		25-Year
143	7.100299	126.462004	0.031	0.00	0.0010		25-Year
144	7.100557	126.463307	0.031	0.00	0.0010		25-Year
145	7.100740	126.466766	0.031	0.00	0.0010		25-Year
146	7.099140	126.464647	0.368	0.00	0.1354		25-Year
147	7.102739	126.467793	0.358	0.00	0.1282		25-Year
148	7.101462	126.466019	0.392	0.00	0.1537		25-Year
149	7.098756	126.466899	0.644	0.00	0.4147		25-Year
150	7.098683	126.462887	0.572	0.50	0.0052	Upstream rainfall/ July 02, 1905	25-Year
151	7.099943	126.463913	0.871	0.00	0.7586		25-Year
152	7.099776	126.461748	1.498	0.00	2.2440		25-Year
153	7.098313	126.466453	1.569	0.00	2.4618	Pablo/ July 04, 1905	25-Year
154	7.099317	126.462415	1.035	0.50	0.2862	Upstream rainfall/ July 02, 1905	25-Year
155	7.098824	126.462131	1.584	0.50	1.1751	Upstream rainfall/ July 03, 1905	25-Year
156	7.100275	126.460807	1.826	0.00	3.3343		25-Year
157	7.098182	126.462259	1.643	0.50	1.3064		25-Year
158	7.101397	126.463766	1.658	0.00	2.7490		25-Year
159	7.099835	126.463107	1.304	0.00	1.7004		25-Year
160	7.098759	126.461387	2.119	1.00	1.2522		25-Year
161	7.098190	126.461676	2.21	1.00	1.4641		25-Year
162	7.099577	126.459689	3.204	1.50	2.9036		25-Year
163	7.099773	126.464829	2.886	4.00	1.2410	Yolanda/ July 05, 1905	25-Year
164	7.099099	126.459753	3.353	2.00	1.8306	Yolanda/ July 05, 1905	25-Year
165	7.097868	126.461030	3.372	0.50	8.2484		25-Year
166	7.098585	126.460892	3.591	0.50	9.5543		25-Year
167	7.101403	126.464384	4.243	0.00	18.0030		25-Year
168	7.100922	126.465113	3.792	4.00	0.0433	Typhoon/ June 22, 1905	25-Year
169	7.099026	126.466983	6.099	4.00	4.4058		25-Year
170	7.104037	126.461518	5.92	5.00	0.8464		25-Year

171	7.101763	126.463760	5.913	0.00	34.9636		25-Year
172	7.100132	126.464471	5.992	4.00	3.9681		25-Year
173	7.103675	126.461605	6.289	5.00	1.6615		25-Year
174	7.104580	126.461431	6.209	5.00	1.4617		25-Year
175	7.102135	126.462317	6.253	5.00	1.5700		25-Year
176	7.100401	126.464745	6.368	4.00	5.6074		25-Year
177	7.100454	126.469610	6.453	5.00	2.1112		25-Year
178	7.102498	126.462139	6.882	5.00	3.5419		25-Year
179	7.099771	126.464559	7.153	4.00	9.9414		25-Year
180	7.099662	126.466999	7.688	2.00	32.3533		25-Year
				RMSE	1.708031		

Annex 12. Educational Institutions affected by flooding in Quinonoan Flood

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

Quinonoan Flood Plain

Davao Oriental				
Manay				
Barangay	Building Name	Rainfall Scenario		
		5-year	25-year	100-year
San Ignacio	APMAMADA ELEMENTARY SCHOOL			
San Ignacio	DAYCARE CENTER			
San Ignacio	MAMADA ELEMENTARY SCHOOL			