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

LiDAR Surveys and Flood Mapping of Dalanas River

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

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

CHAPTER 1: OVERVIEW OF THE PROGRAM AND DALANAS RIVER

Enrico C. Paringit, Dr. Eng. and Jonnifer Sinogaya, PhD.

1.1 Background of the Phil-LiDAR 1 Program

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

The program also aimed to produce an up-to-date and detailed national elevation dataset suitable for 1:5,000 scale mapping, with 50 cm and 20 cm horizontal and vertical accuracies, respectively. These accuracies were achieved through the use of the state-of-the-art Light Detection and Ranging (LiDAR) airborne technology procured by the project through DOST. The methods applied in this report are thoroughtly 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 Cebu (UPC). UPC 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 twenty-two (22) river basins in the Western Visayas Region. The university is located in Cebu City in the Province of Cebu.

1.2 Overview of the Dalanas River Basin

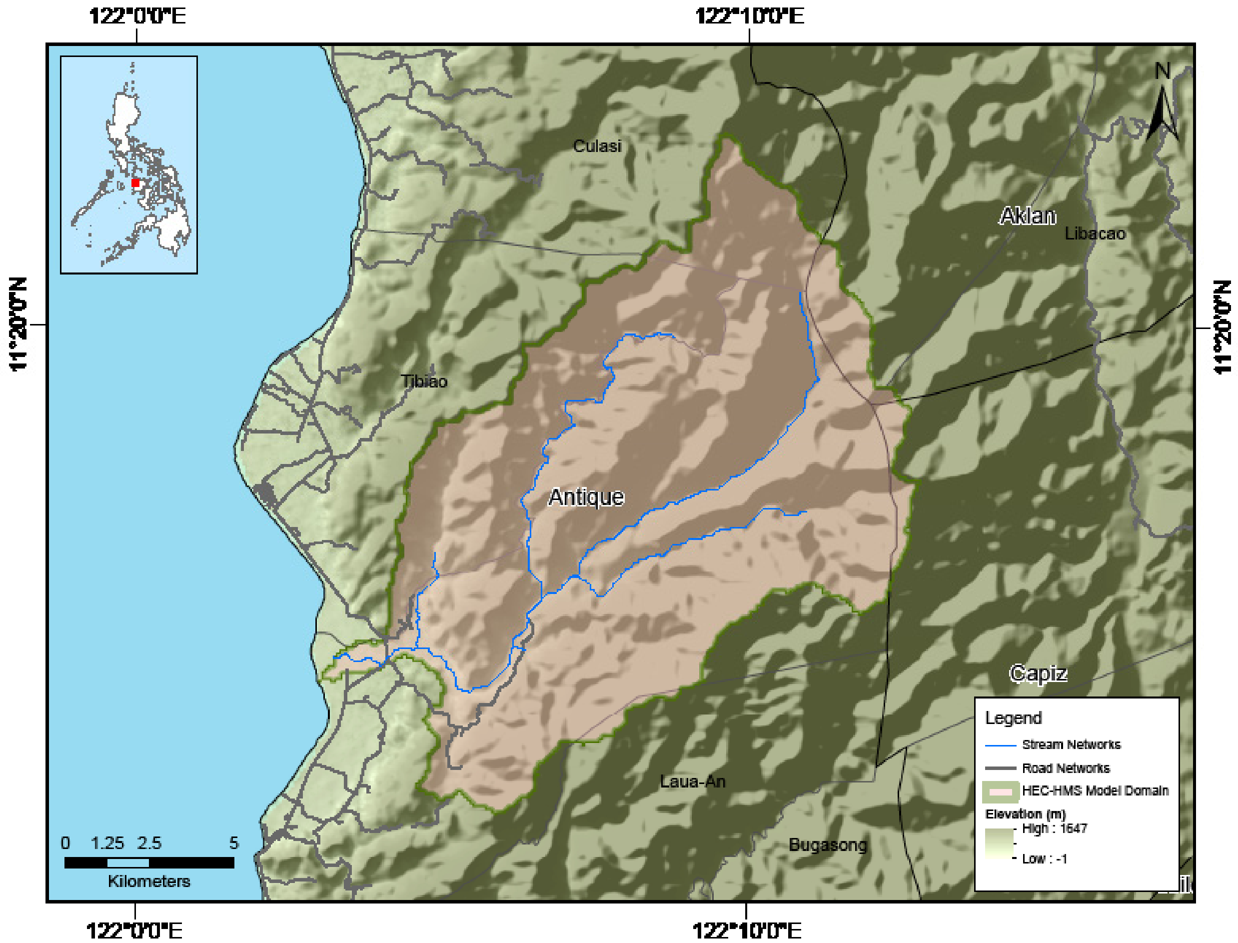

Figure 1. Map of Dalanas River Basin

Dalanas River Basin covers portions of the Municipalities of Tibiao and Culasi, and most of the Municipality of Barbaza in the province of Antique, which is in the west of Panay Island. The DENR River Basin Control Office (RBCO) identified it to be one of the 421 river basins in the Philippines, having a drainage area of 119 km2 and an estimated 151 million cubic meter annual run-off. It is also one of the seven (7) major river basins in Antique.

Its main stem, Dalanas River, passes along the Municipality of Barbaza, and a portion of the Municipalities of Tibiao and Culasi. Dalanas River is part of the 23 river systems in Western Visayas Region. There is a total of 3,867 people residing in the immediate vicinity of the river which is distributed among five (5) barangays, namely: San Antonio, Capoyuan, Soligao, Big-A, and Lombuyan (NSO, 2010). The river is rich in good quality gravel and sand wherein local private quarry companies extract from the riverbed and export abroad (Guntan, 2015).

The Dalanas floodplain and drainage area of 20.01 km2 and 12.99 sq. km. respectively, traverses the Municipalities of Barbaza, Madalag, Jamindan, Tibiao and Culasi. The floodplain is 100% covered with LiDAR data which comprises 1 block. The LiDAR data was calibrated then mosaicked with an RMSE of -0.05 and then bathy burned. The bathy survey conducted reached a total length of 3.44 km starting from Soligao, Barbaza up to the river mouth with 209 points surveyed. There are 1731 buildings, 15.09 km roads, 6 waterbodies and 2 bridges digitized based from the LiDAR data. Feature Extraction Attribution was conducted and among the building features, 1608 of them are residential, eighteen (18) are schools and one (1) is a medical institution.

The produced flood hazard map covers the 7.53 km2, 8.29 km2, 9.27 km2 for the 5-year, 25-year, and 100 year rainfall return period in Barbaza affecting eleven (11) barangays, and Tibiao with four (4) barangays affected. A flood depth validation was conducted using 247 randomly generated points which is spread throughout the six (6) ranges namely 0m-0.2m, 0.21m-0.5m, 0.51m-1m, 1.01m-2m, 2.10m-5m, 5m+ depth using the 25-yr rainfall flood depth map. It yielded 0.578m RMSE.

A rating curve was developed at Brgy Bigaa Flow Site, Barbaza, Antique, which shows the relationship between the observed water levels at Brgy Bigaa Flow Site and the outflow of the watershed in the said location. This rating curve equation, expressed as Q = 2E-175e12.951x, was used to compute the river outflow at Brgy. Bigaa Flow Site for the calibration of the HEC-HMS model. The resulting outflow was used to simulate the flooded areas using HEC-RAS. The simulated model will be an integral part in determining the real-time flood inundation extent of the river after it has been automated and uploaded in the DREAM Website.

CHAPTER 2: LiDAR DATA ACQUISITION OF DALANAS FLOODPLAIN

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

2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Dalanas Floodplain in Antique. These missions were planned for fourteen (14) lines and ran for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameters for the LiDAR System are found in Table 1. Figure 2 shows the flight plan and base station for Dalanas Floodplain.

Table 1. Flight planning parameters for Gemini LiDAR System

Block Name	Flying Height (m AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK43 A	1500	30	40	70	50	125	5

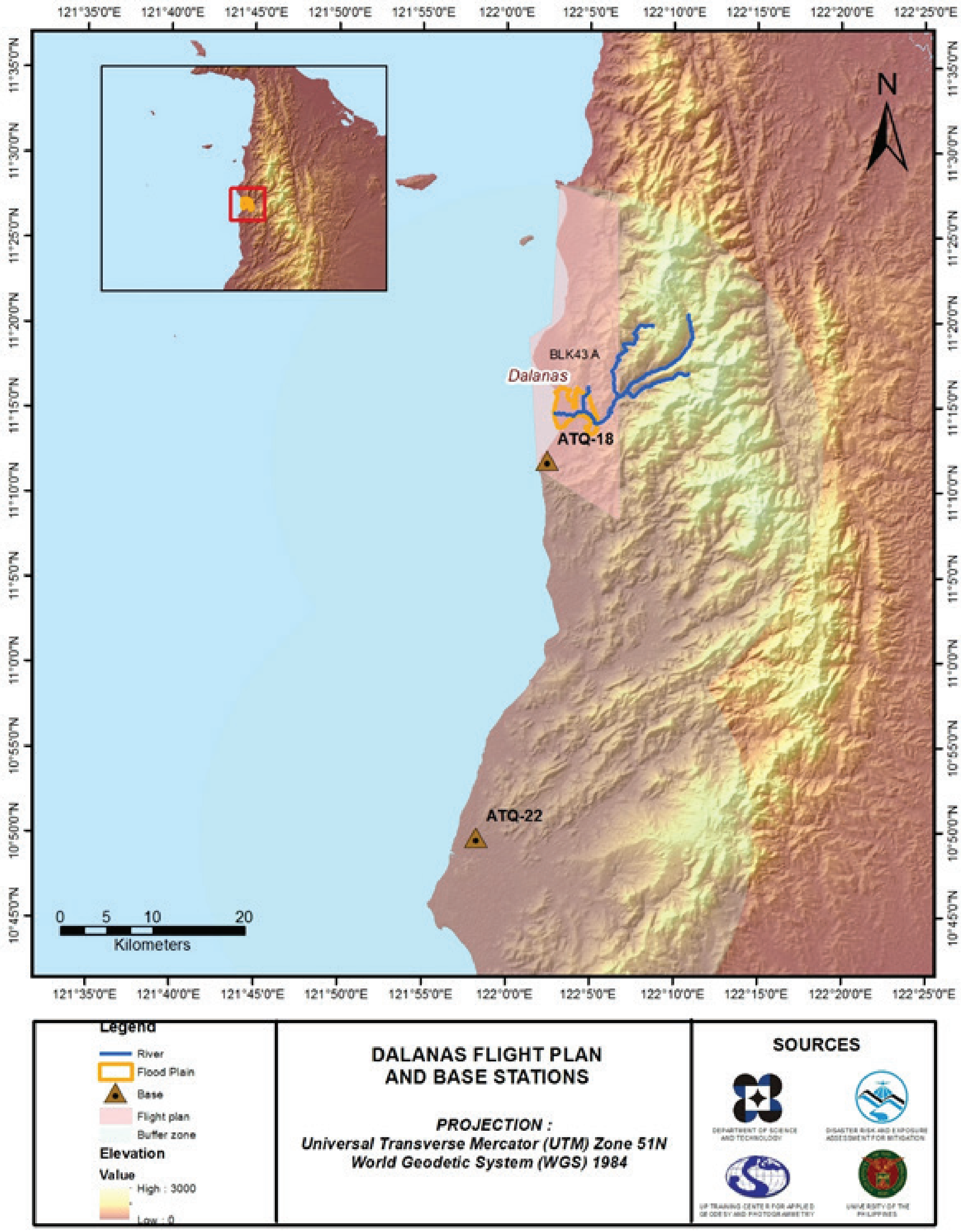

Figure 2. Flight plans and base stations used for Dalanas Floodplain

2.2 Ground Base Stations

The Project Team was able to recover two (2) NAMRIA reference points: ATQ-18 and ATQ-22 which are of second (2nd) order accuracy. The Certification for the base station is found in Annex 2. These were used as base stations during flight operations for the entire duration of the survey (February 2017). Base stations were observed using Dual Frequency GPS Receivers TRIMBLE SPS 852 and SPS 985. Flight plans and location of base stations used during the aerial LiDAR acquisition in Dalanas Floodplain are shown in Figure 2.

Figure 3 and Figure 4 show the recovered NAMRIA control station within the area. In addition, Table 2 and

Table 3 show the details about the following NAMRIA control stations, Table 4 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 ATQ-18 in Barangay Cubay, Barbaza, Province of Antique (a) and NAMRIA reference point ATQ-18 (b) as recovered by the field team

Table 2. Details of the recovered NAMRIA horizontal control point ATQ-18 used as base station for the LiDAR

Station Name	ATQ-18	
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	1° 11’ 58.67081” 122° 2’ 22.83300” 10.902 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	395155.157 meters 1238579.674 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	11° 11’ 54.16068” North 122° 2’ 28.01549” East 65.961 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	395155.87 meters 1238146.15 meters

Figure 4. GPS set-up over ATQ-22 in Barangay Concepcion, Belison, Province of Antique (a) and NAMRIA reference point ATQ-22 (b) as recovered by the field team

Table 3. Details of the recovered NAMRIA horizontal control point ATQ-22 used as base station for the LiDAR acquisition

Station Name	ATQ-22	
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	10° 49' 46.66618" 121° 58' 11.90221" 12.250 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	387365.279 meters 1197676.056 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	10° 49' 42.24271" North 121° 58' 17.11770" East 68.022 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	387404.70 meters 1197256.85 meters

Table 4. Ground Control Points used during LiDAR Data Acquisition

Date Surveyed	Flight Number	Mission Name	Ground Control Points
Feb. 20, 2015	2582G	2BLK43A051A	ATQ-18 and ATQ-22
Feb. 21, 2015	2586G	2BLK43A052A	ATQ-18 and ATQ-22
Feb. 22, 2015	2590G	2BLK43A053A	ATQ-18 and ATQ-22

2.3 Flight Missions

Three (3) missions were conducted to complete LiDAR data acquisition in Dalanas Floodplain, for a total of 11 hours and 3 minutes (11+3) of flying time for RP-C9122. All missions were acquired using the Gemini LiDAR systems. Table 5 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 6 presents the actual parameters used during the LiDAR data acquisition.

Table 5. Flight missions for LiDAR data acquisition in Dalanas 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
Feb. 20, 2015	2582G	282.52	36.48	0	36.48	758	2	59

Feb. 21, 2015	2586G	282.52	163.52	71.22	156.30	224	3	59
Feb. 22, 2015	2590G	282.52	198.57	6.47	192.10	316	4	05
TOTAL		282.52	398.57	77.69	384.88	1298	11	03

Table 6. Actual parameters used during the LiDAR data acquisition of the Dalanas Floodplain

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV	PRF (kHz)	Scan Frequency (Hz)	Average Speed (Kts)	Average TurnTime (Minutes)
2582G	1000	30	40	100	50	120	5
2586G	1500	30	40	70	50	120	5
2590G	1500	30	40	70	50	120	5

2.4 Survey Coverage

The Dalanas Floodplain is located in the Province of Antique with majority of the floodplain situated within the Municipality of Barbaza. The Municipality of Tibiao is mostly covered by the survey (Annex 7). The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 7. The actual coverage of the LiDAR acquisition for Dalanas floodplain is presented in Figure 5.

Table 7. List of municipalities and cities surveyed during the Dalanas Floodplain LiDAR acquisition.

Province	Municipality/City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Antique	Tibiao	95.95	80.36	84
	Barbaza	171.23	70.91	41
	Culasi	201.84	74.73	37
	Laua-An	165.65	31.6	19

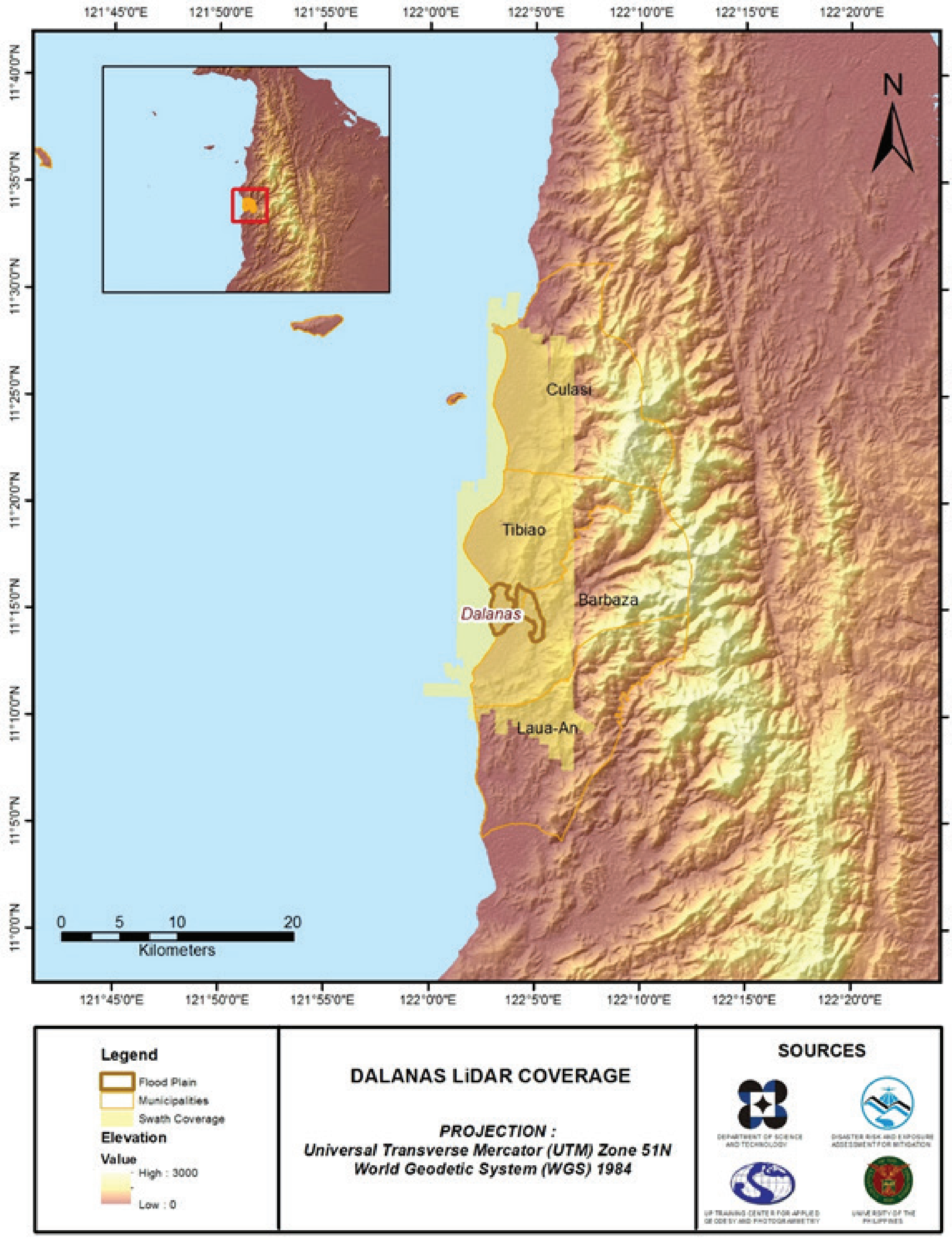

Figure 5. Actual LiDAR survey coverage for Dalanas Floodplain

CHAPTER 3: LIDAR DATA PROCESSING OF THE DALANAS FLOODPLAIN

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

3.1 Overview of the LiDAR Data Pre-Processing

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

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

These processes are summarized in the flowchart shown in Figure 6.

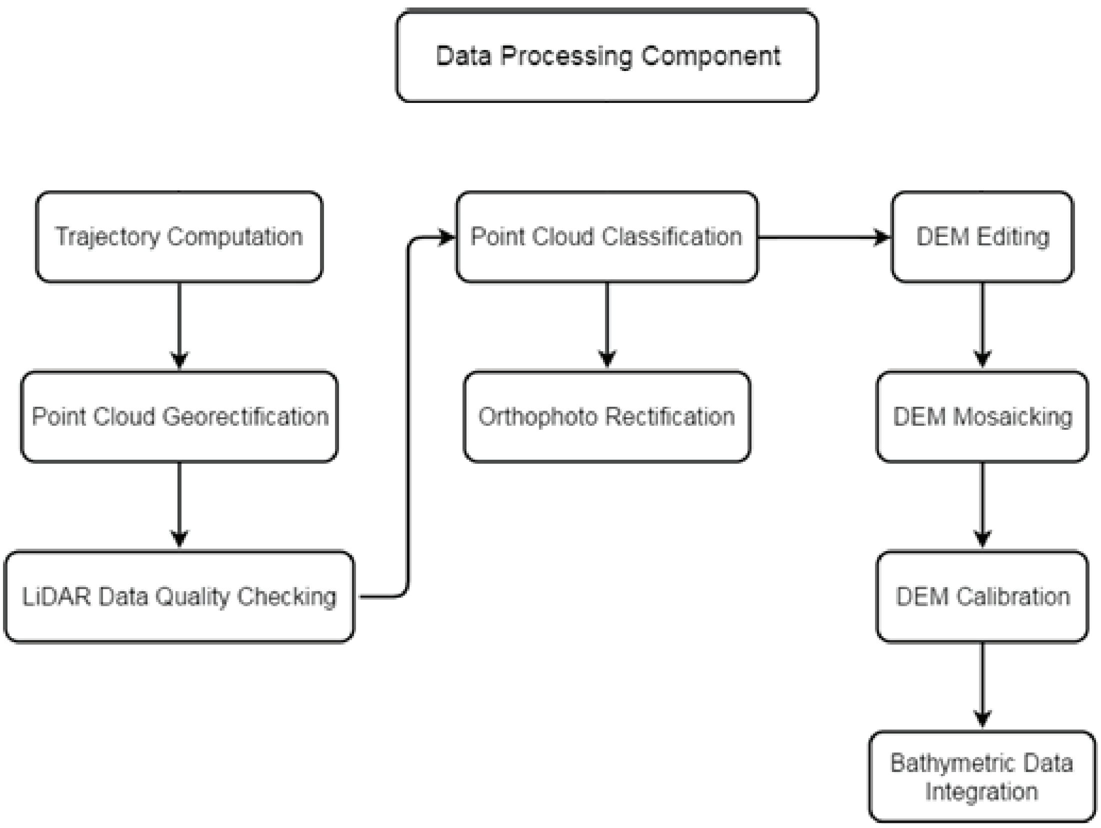


Figure 6. Schematic Diagram for Data Pre-Processing Component

3.2 Transmittal of Acquired LiDAR Data

Data Transfer Sheets for all the LiDAR missions for Dalanas Floodplain can be found in Annex 5. Missions flown during the first survey conducted in February 2015 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Gemini System over Sta. Barbaza, Antique. The Data Acquisition Component (DAC) transferred a total of 25.05 Gigabytes of Range data, 4.86 Gigabytes of POS data, 39.35 Megabytes of GPS base station data, and 43.44 Gigabytes of raw image data to the data server on February 22, 2015. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Dalanas was fully transferred on March 23, 2015, as indicated on the Data Transfer Sheets for Dalanas Floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 2586G, one of the Dalanas flights, which is the North, East, and Down position RMSE values are shown in Figure 7. The x-axis corresponds to the time of flight, which was measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on February 21, 2015 00:00AM. The y-axis is the RMSE value for that particular position.

Figure 7. Smoothed Performance Metrics of a Dalanas Flight 2586G

The time of flight was from 526100 seconds to 531600 seconds, which corresponds to morning of February 21, 2015. The initial spike seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and when the POS system started 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 made a turn to start a new flight line. Figure 7 shows that the North position RMSE peaks at 1.20 centimeters, the East position RMSE peaks at 1.40 centimeters, and the Down position RMSE peaks at 1.90 centimeters, which are within the prescribed accuracies described in the methodology.

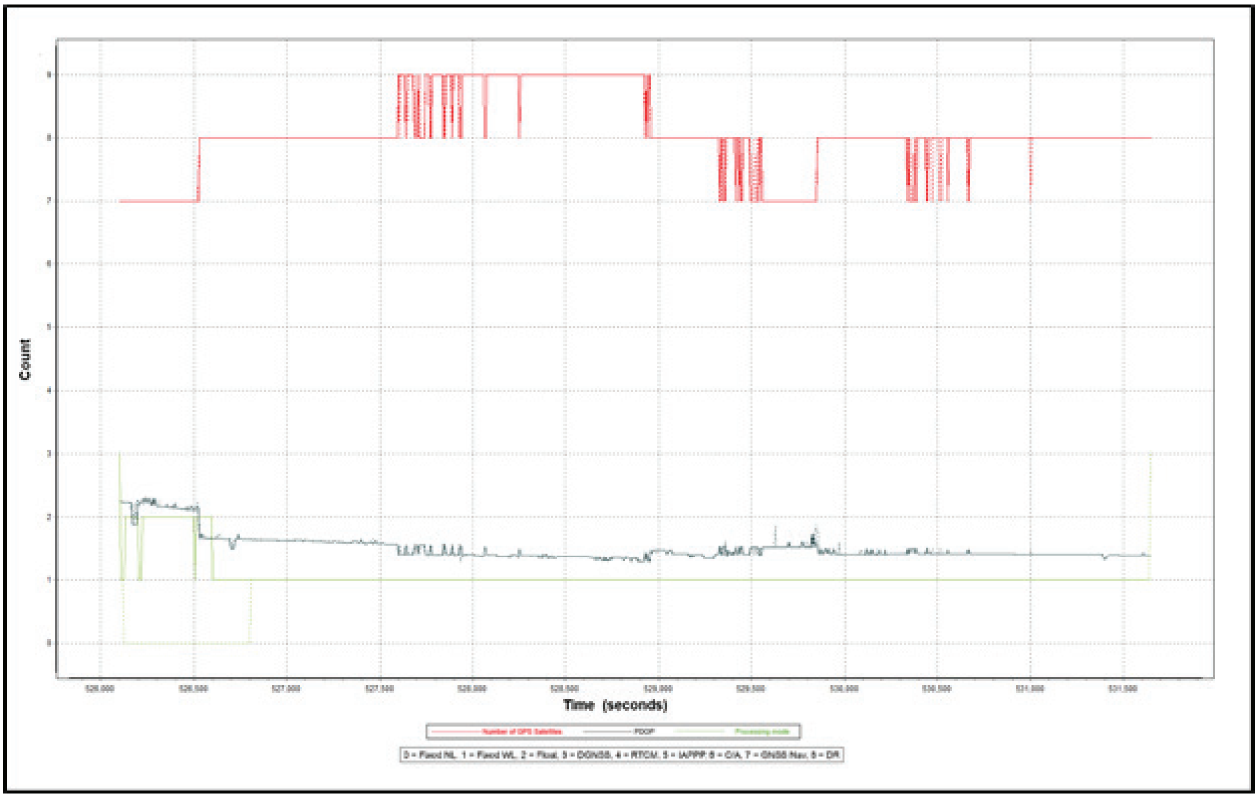


Figure 8. Solution Status Parameters of Dalanas Flight 2586G.

The Solution Status parameters of flight 2586G, one of the Dalanas flights, which indicate the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 8. The graphs indicate that the number of satellites during the acquisition did not go down to six (6). Most of the time, the number of satellites tracked was between seven (7) and (9). The PDOP value also did not go above the value of three (3), which indicates optimal GPS geometry. The processing mode remained at one (1) for majority of the survey with some peaks up to two (2) attributed to the turns performed by the aircraft. The value of zero (0) corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Dalanas flights is shown in Figure 9.

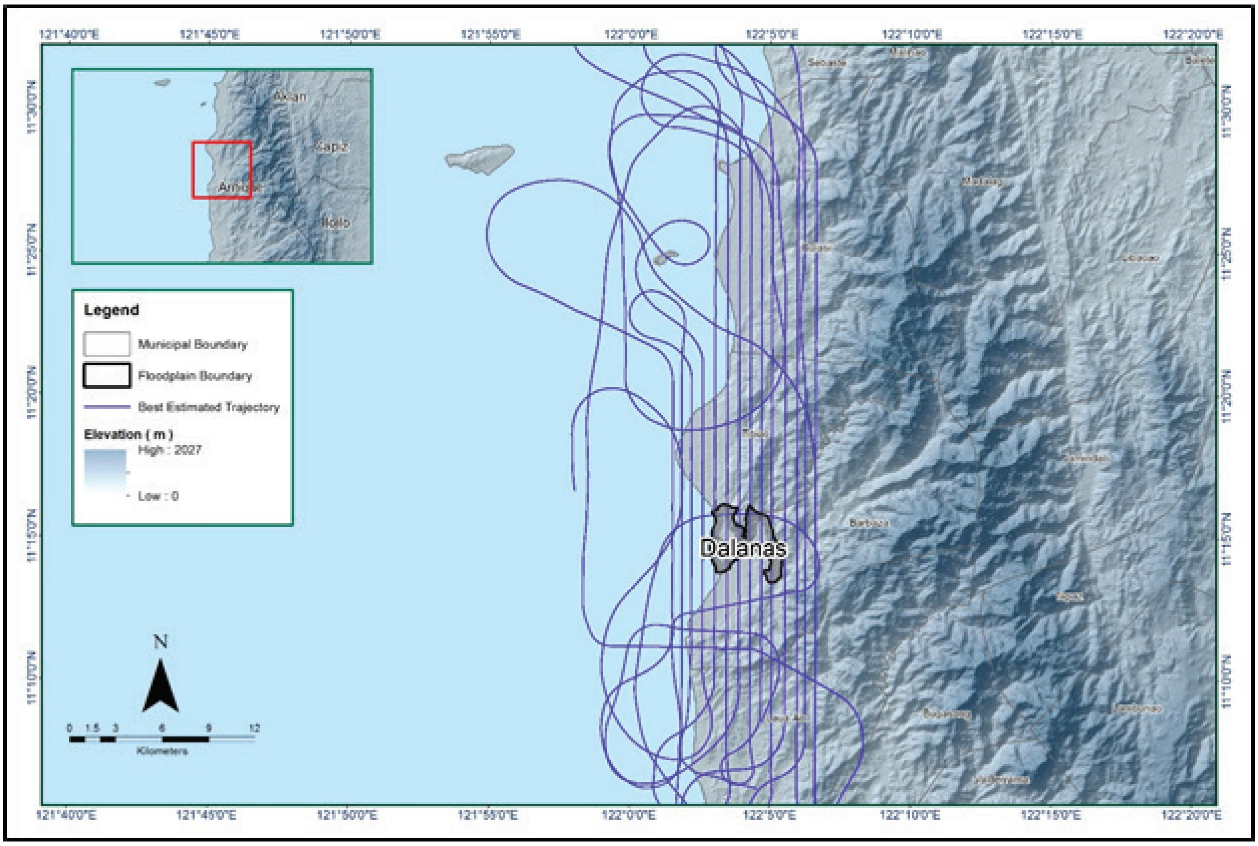


Figure 9. Best estimated trajectory for Dalanas Floodplain

3.4 LiDAR Point Cloud Computation

The produced LAS data contains seventeen (17) flight lines, with each flight line containing one channel, since the Gemini system contains one channel only. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Dalanas Floodplain are given in Table 8.

Table 8. Self-Calibration Results values for Dalanas flights.

Parameter	Acceptable Value	Computed Value
Boresight Correction stdev	(<0.001degrees)	0.000592
IMU Attitude Correction Roll and Pitch Corrections stdev	(<0.001degrees)	0.000705
GPS Position Z-correction stdev	(<0.01meters)	0.0075

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

3.5 LiDAR Quality Checking

The boundary of the processed LiDAR data is shown in Figure 10. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage

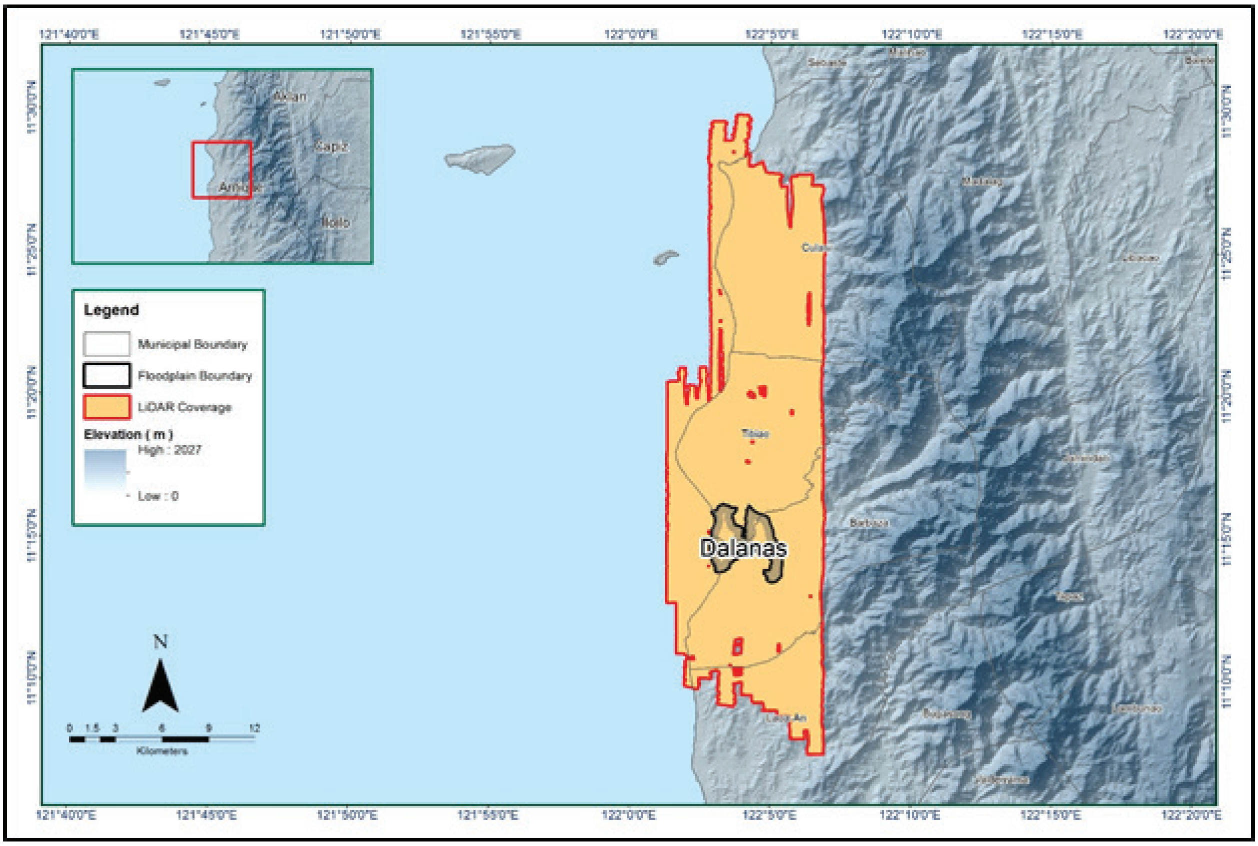


Figure 10. Boundary of the processed LiDAR data on top of a SAR Elevation Data over Dalanas Floodplain.

The total area covered by the Dalanas missions is 297.50 sq.km that is comprised of three (3) flight acquisitions grouped and merged into one (1) block as shown in Table 9.

Table 9. List of LiDAR blocks for Dalanas Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Iloilo_Blk43A	2582G	297.50
	2586G	
	2590G	
	TOTAL	297.50 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 11. 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.

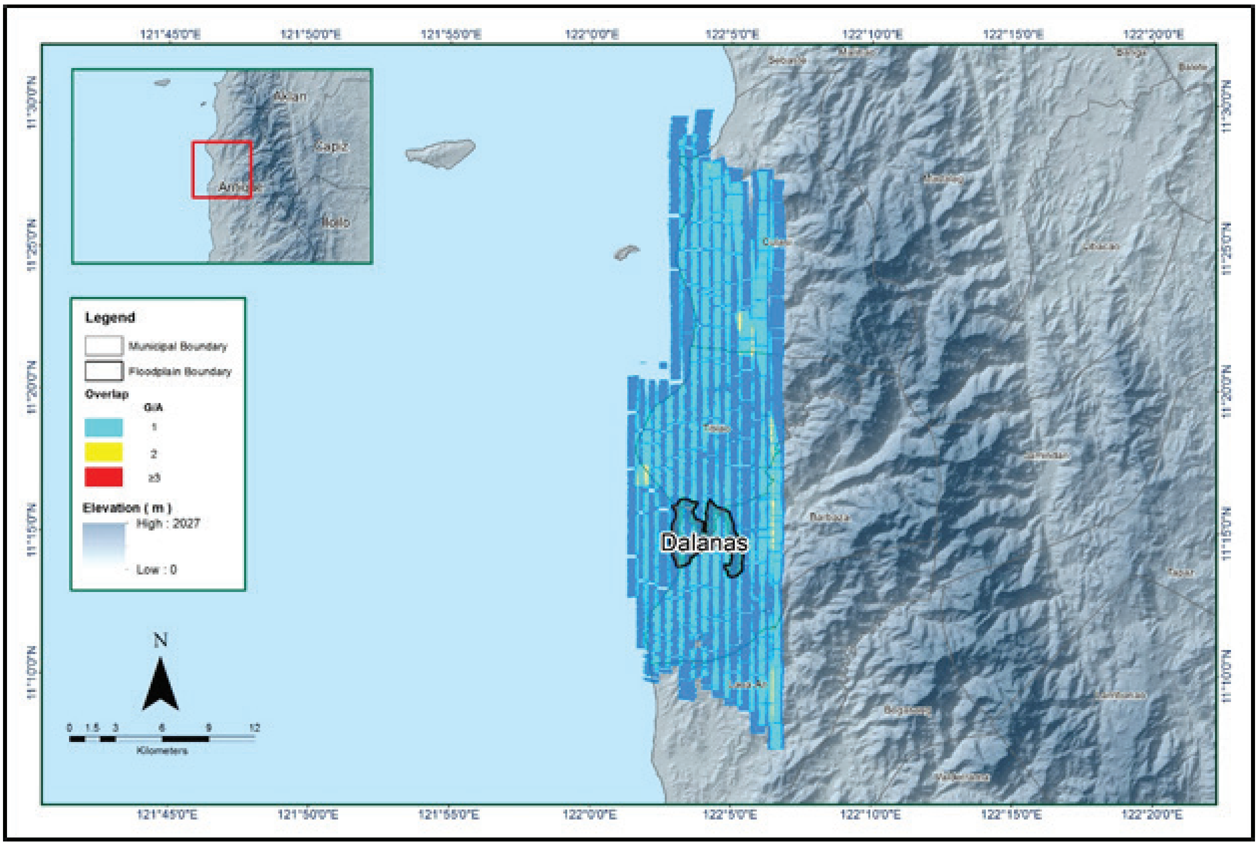


Figure 11. Image of data overlap for Dalanas Floodplain

The overlap statistics per block for the Dalanas floodplain can be found in Annex 7. One pixel corresponds to 25.0 square meters on the ground. For this area, the percent overlap is 38.72%, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 12. It was determined that all LiDAR data for Dalanas Floodplain satisfied the point density requirement, and the average density for the entire survey area is 2.06 points per square meter.

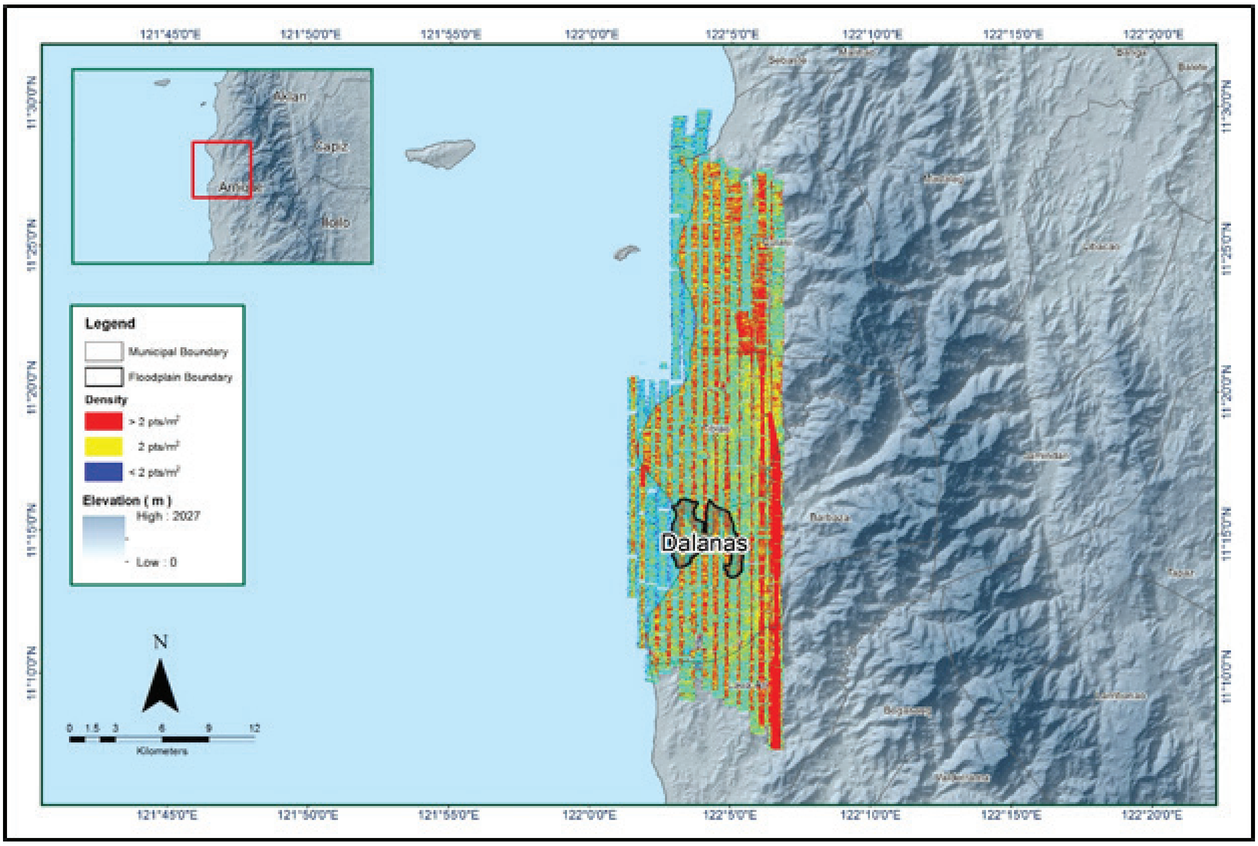


Figure 12. Pulse density map of merged LiDAR data for Dalanas Floodplain

The elevation difference between overlaps of adjacent flight lines is shown in Figure 13. The default color range is from blue to red, where bright blue areas correspond to portions where elevations of a previous flight line, identified by its acquisition time, are higher by more than 0.20m relative to elevations of its adjacent flight line. Bright red areas indicate portions where elevations of a previous flight line are lower by more than 0.20m relative to elevations of its adjacent flight line. Areas with bright red or bright blue need to be investigated further using Quick Terrain Modeler software.

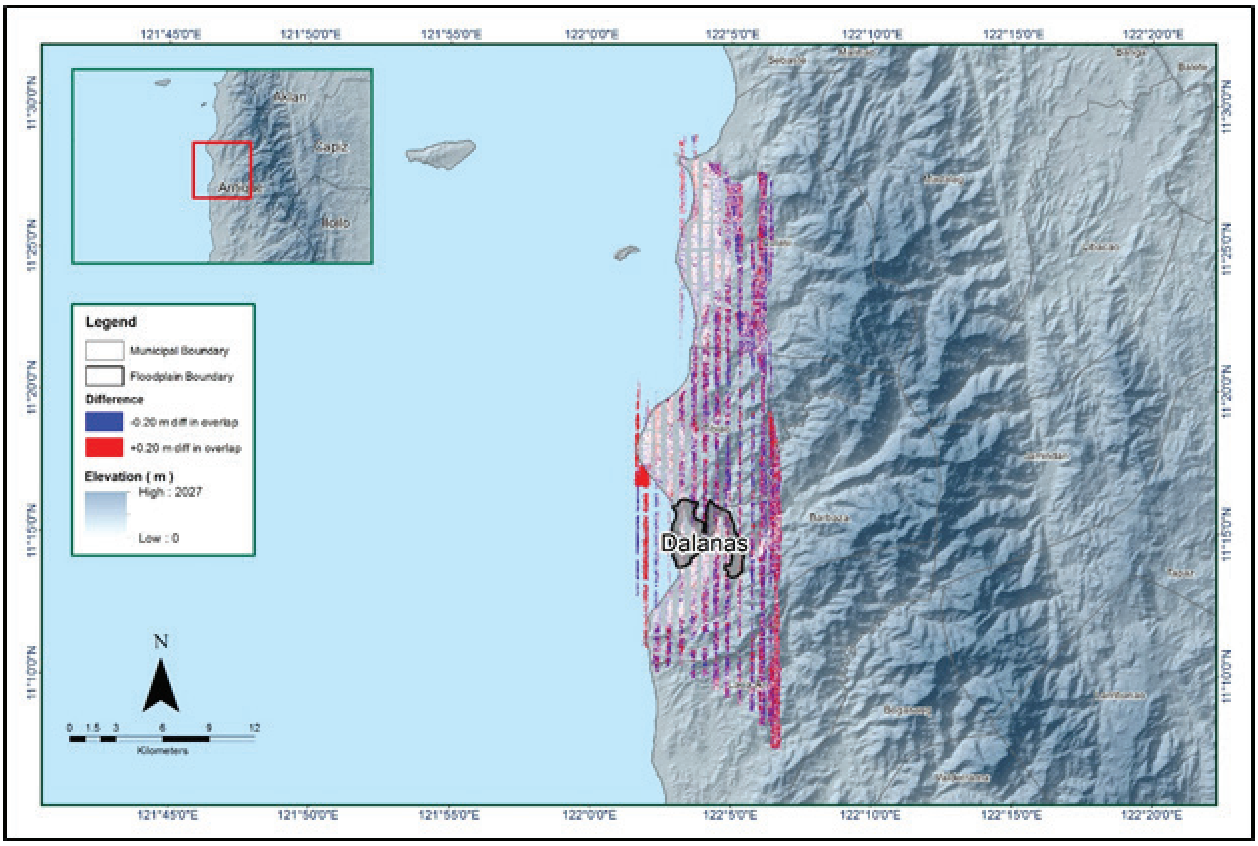


Figure 13. Elevation difference map between flight lines for Dalanas Floodplain

A screen capture of the processed LAS data from a Dalanas flight 2586G loaded in QT Modeler is shown in Figure 14. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed yellow line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

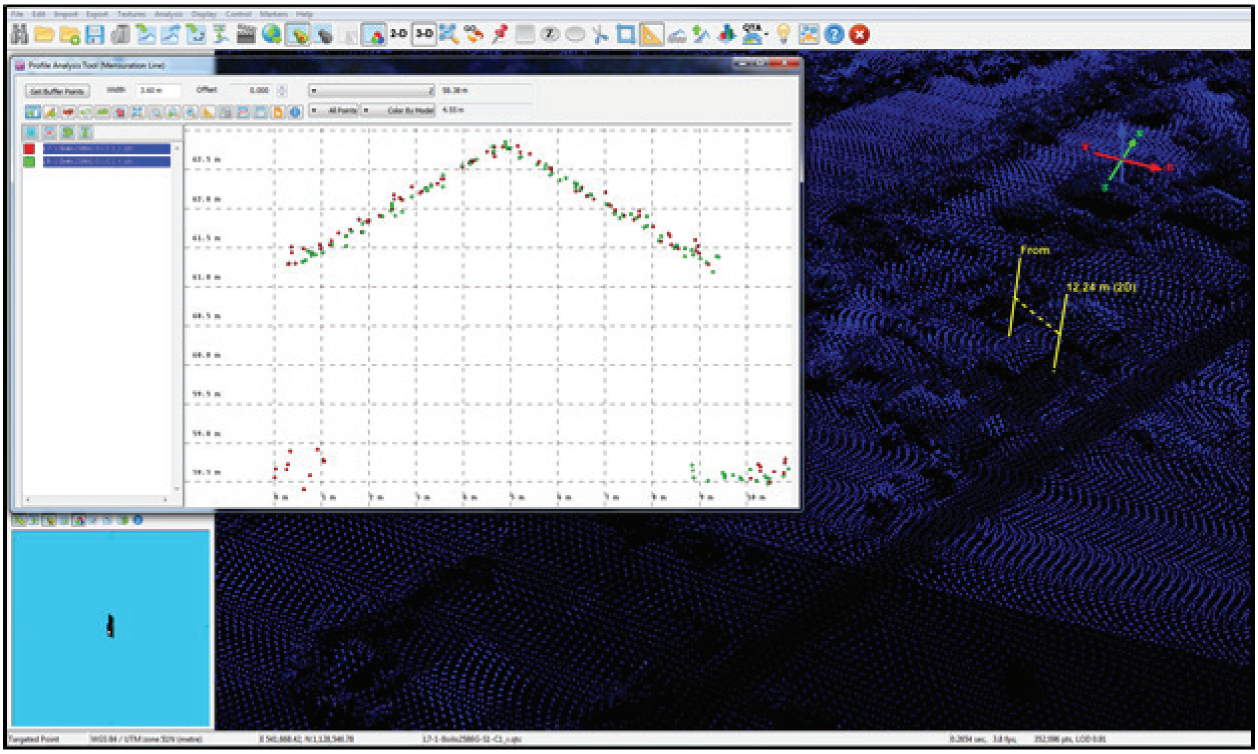


Figure 14. Quality checking for a Dalanas flight 2586G using the Profile Tool of QT Modeler

3.6 LiDAR Point Cloud Classification and Rasterization

Table 10. Dalanas classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	135,250,642
Low Vegetation	62,669,226
Medium Vegetation	153,132,550
High Vegetation	100,964,993
Building	1,254,494

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Dalanas floodplain is shown in Figure 15. A total of 375 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 10. The point cloud has a maximum and minimum height of 885.04 meters and 54.66 meters respectively.

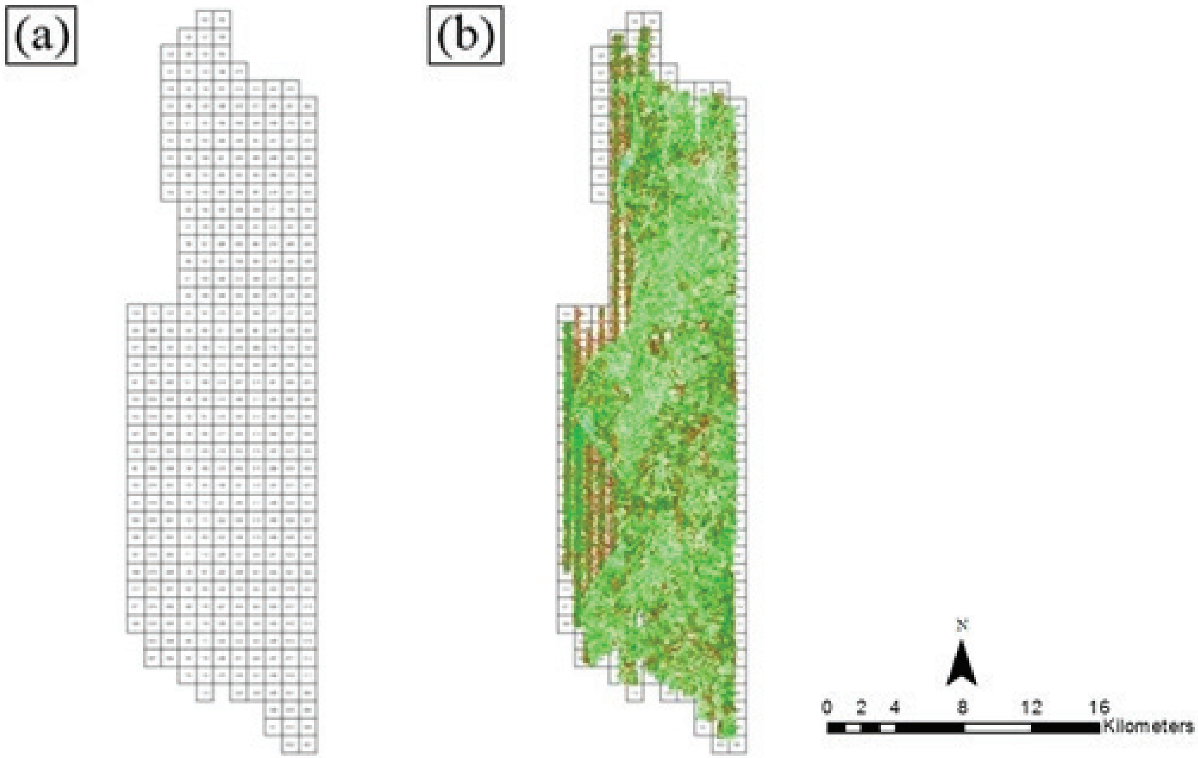


Figure 15. Tiles for Dalanas Floodplain (a) and classification results (b) in TerraScan

An isometric view of an area before and after running the classification routines is shown in Figure 16. The ground points are in orange, the vegetation is in different shades of green, and the buildings are in cyan. It can be seen that residential structures adjacent or even below canopy are classified correctly, due to the density of the LiDAR data.

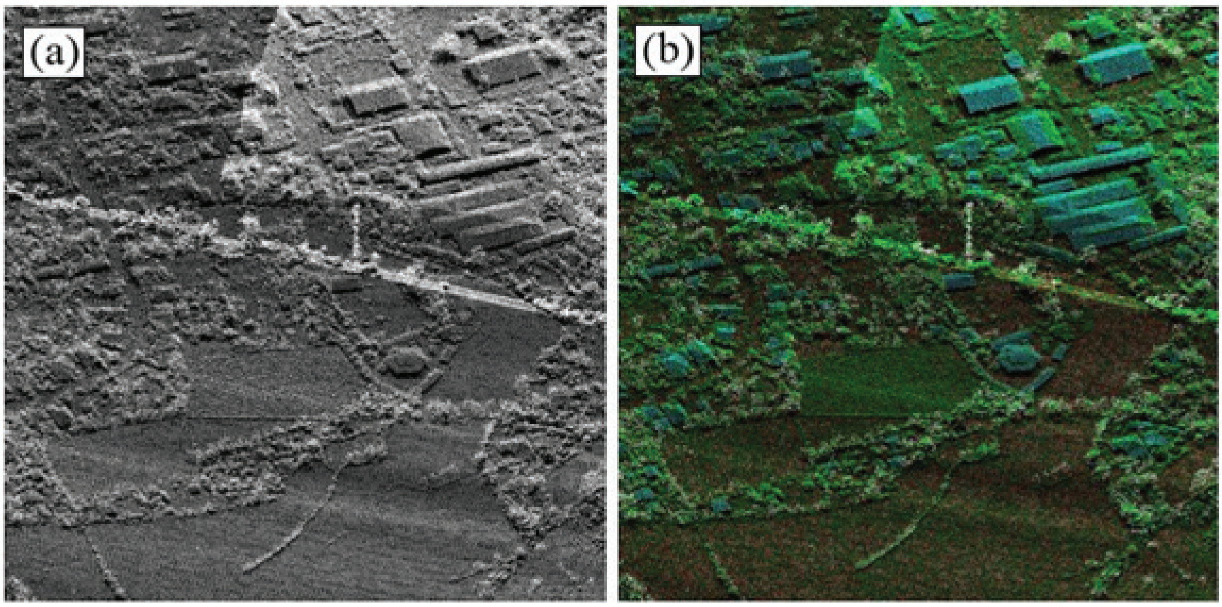


Figure 16. Tiles for Dalanas Floodplain (a) and classification results (b) in TerraScan

The production of last return (V_ASCII) and the secondary (T_ ASCII) DTM, first (S_ ASCII) and last (D_ ASCII) return DSM of the area in top view display are shown in Figure 17. It shows that DTMs are the representation of the bare earth while on the DSMs, all features are present such as buildings and vegetation.

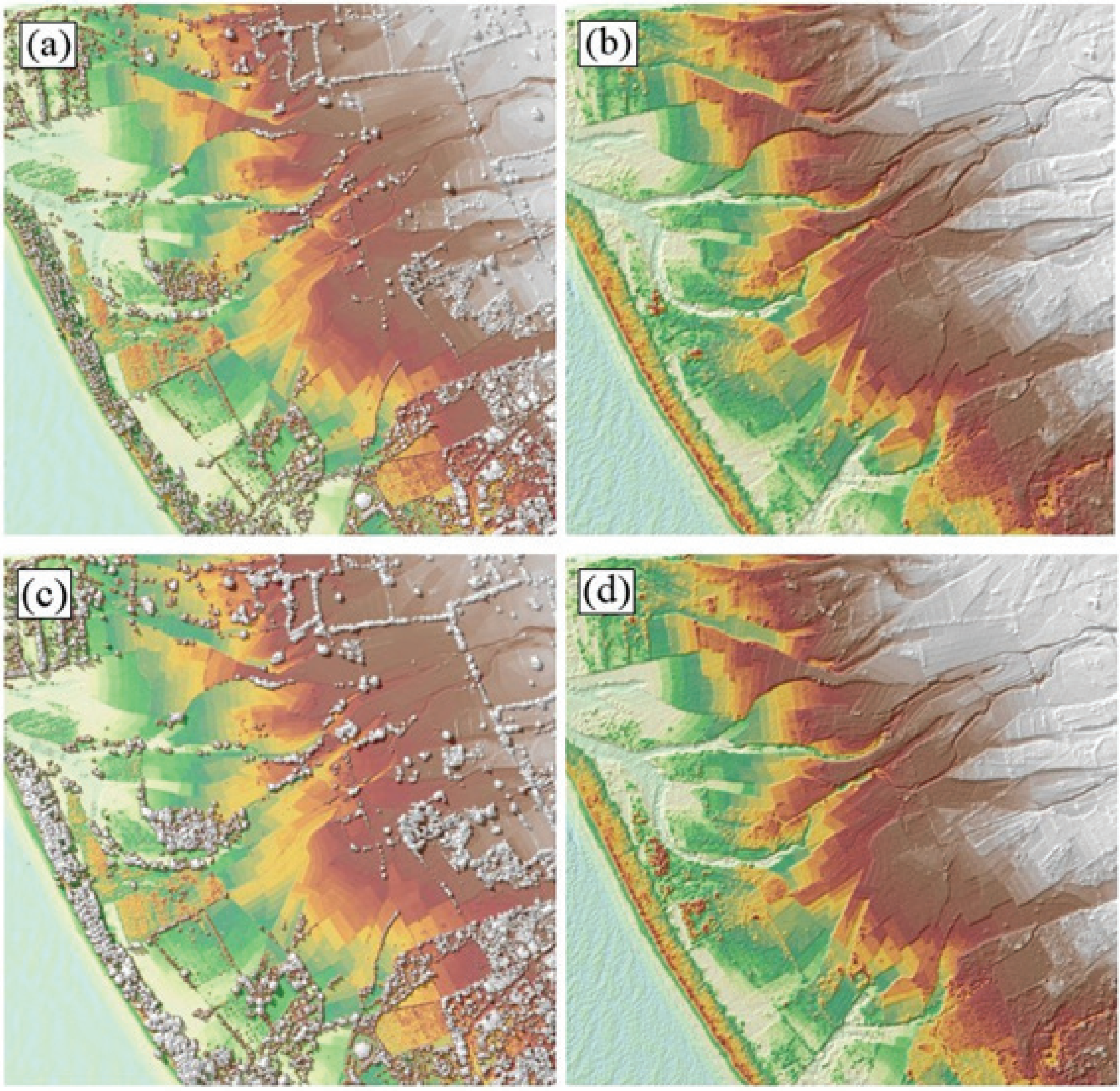


Figure 17. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Dalanas Floodplain

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 341 1km by 1km tiles area covered by Dalanas Floodplain is shown in Figure 18. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Dalanas Floodplain survey attained has a total of 292.90 sq.km orthophotogaph coverage comprised of 507 images. A zoomed-in version of sample orthophotographs named in reference to its tile number is shown in Figure 19.

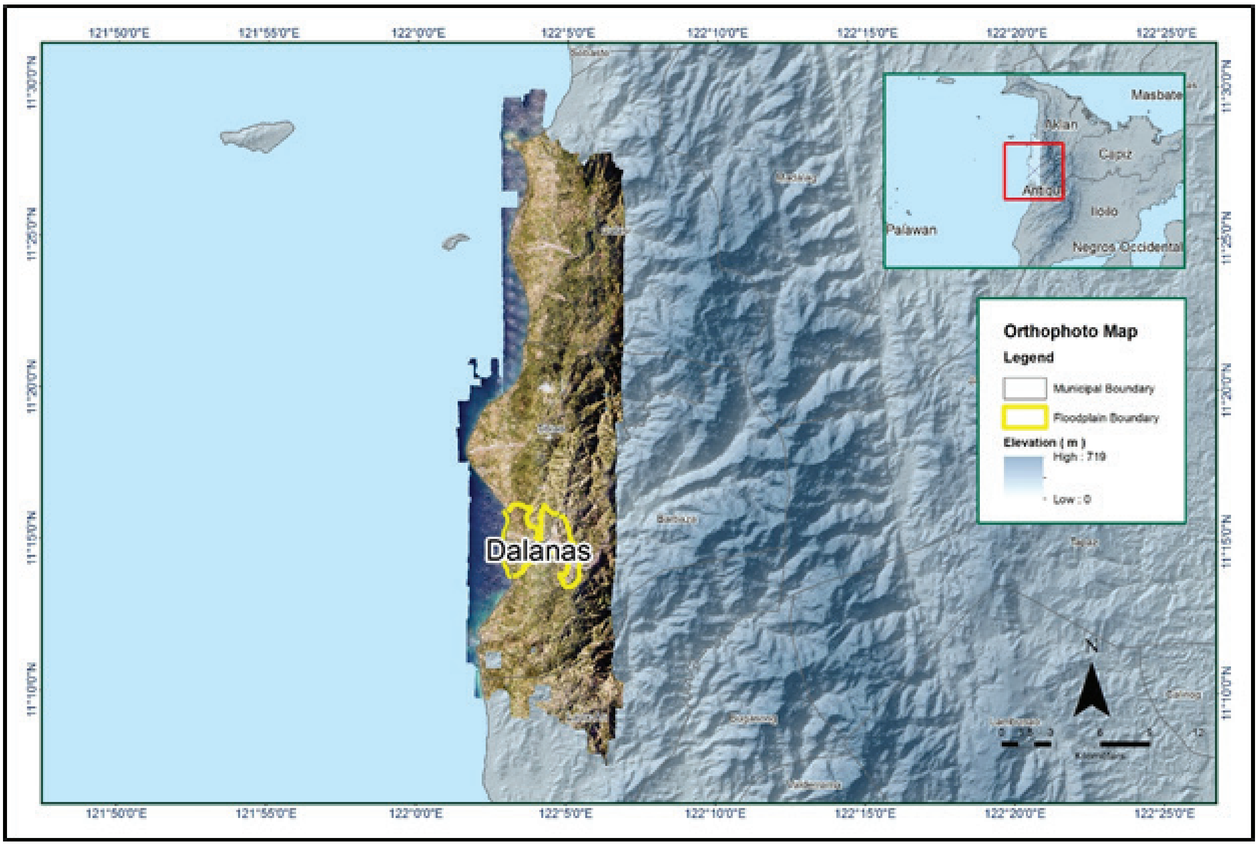


Figure 18. Dalanas Floodplain with available orthophotographs

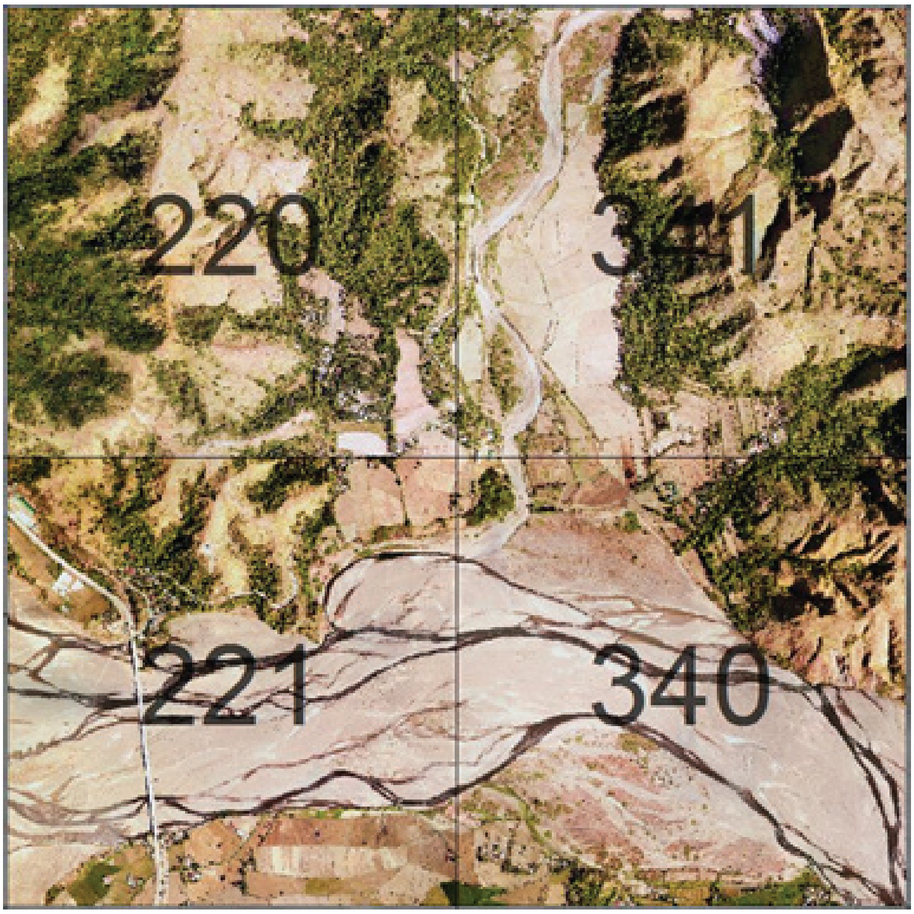


Figure 19. Sample orthophotograph tiles for Dalanas Floodplain

3.8 DEM Editing and Hydro-Correction

One (1) mission block was processed for Dalanas Floodplain. These blocks are composed of Iloilo block with a total area of 297.50 square kilometers. Table 11 shows the name and corresponding area of each block in square kilometers.

Table 11. LiDAR blocks with its corresponding area

LiDAR Blocks	Area (sq.km)
Iloilo_Blk43A	297.50
TOTAL	297.50 sq.km

Portions of DTM before and after manual editing are shown in Figure 20. It shows that the bridges (Figure 20a) would be an impedance to the flow of water along the river and have to be removed (Figure 20b) in order to hydrologically correct the river. Another example is the river bank (Figure 20c) has been misclassified and removed during classification process and has to be retrieved by manual editing to complete the surface Figure 20d).

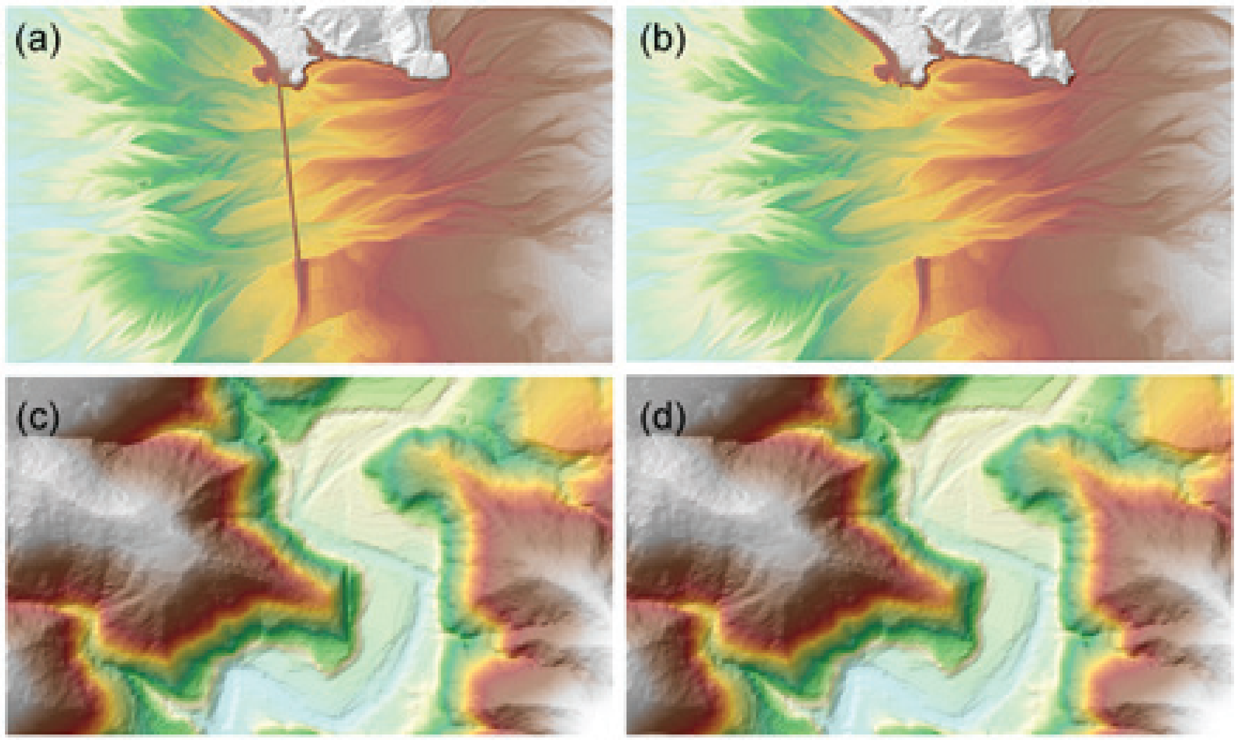


Figure 20. Portions in the DTM of Dalanas Floodplain – bridge before (a) and after (b) manual editing; and a river bank before (c) and after (d) data retrieval

3.9 Mosaicking of Blocks

IloIlo_Blk43B was used as the reference block at the start of mosaicking because it was referred to a base station with an acceptable order of accuracy. Table 12 shows the area of LiDAR block and the shift values applied during mosaicking.

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

Table 12. Shift Values of each LiDAR Block of Dalanas Floodplain

Mission Blocks	Shift Values (meters)		
	x	y	z
Iloilo_Blk43A	0.00	0.00	-1.29

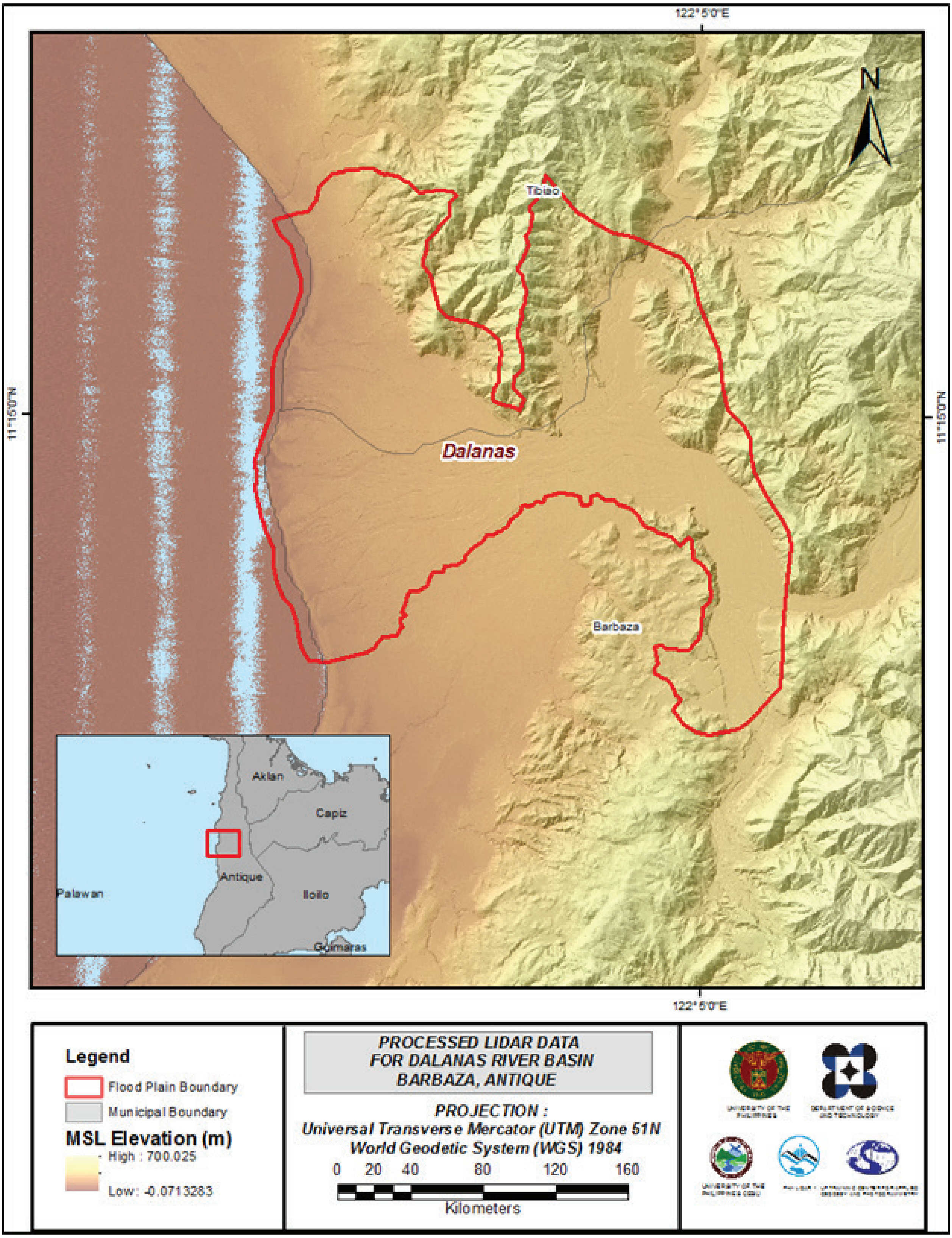


Figure 21. Map of Processed LiDAR Data for Dalanas Floodplain

3.10 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Dalanas to collect points with which the LiDAR dataset is validated is shown in Figure 22. A total of 7511 points were gathered for all the floodplains within the Province of Antique wherein the Dalanas is located. However, the point dataset was not used for the calibration of the LiDAR data for Dalanas because during the mosaicking process, each LiDAR block was referred to the calibrated Jalaur DEM. Therefore, the mosaicked DEM of Dalanas can already be considered as a calibrated DEM.

A good correlation between the uncalibrated Jalaur LiDAR DTM and 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 data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration points is 1.71 meters with a standard deviation of 0.17 meters. Calibration of Jalaur LiDAR data was done by subtracting the height difference value, 1.71 meters, to Jalaur mosaicked LiDAR data. Table 13 shows the statistical values of the compared elevation values between Jalaur LiDAR data and calibration data. These values were also applicable to the Dalanas DEM.

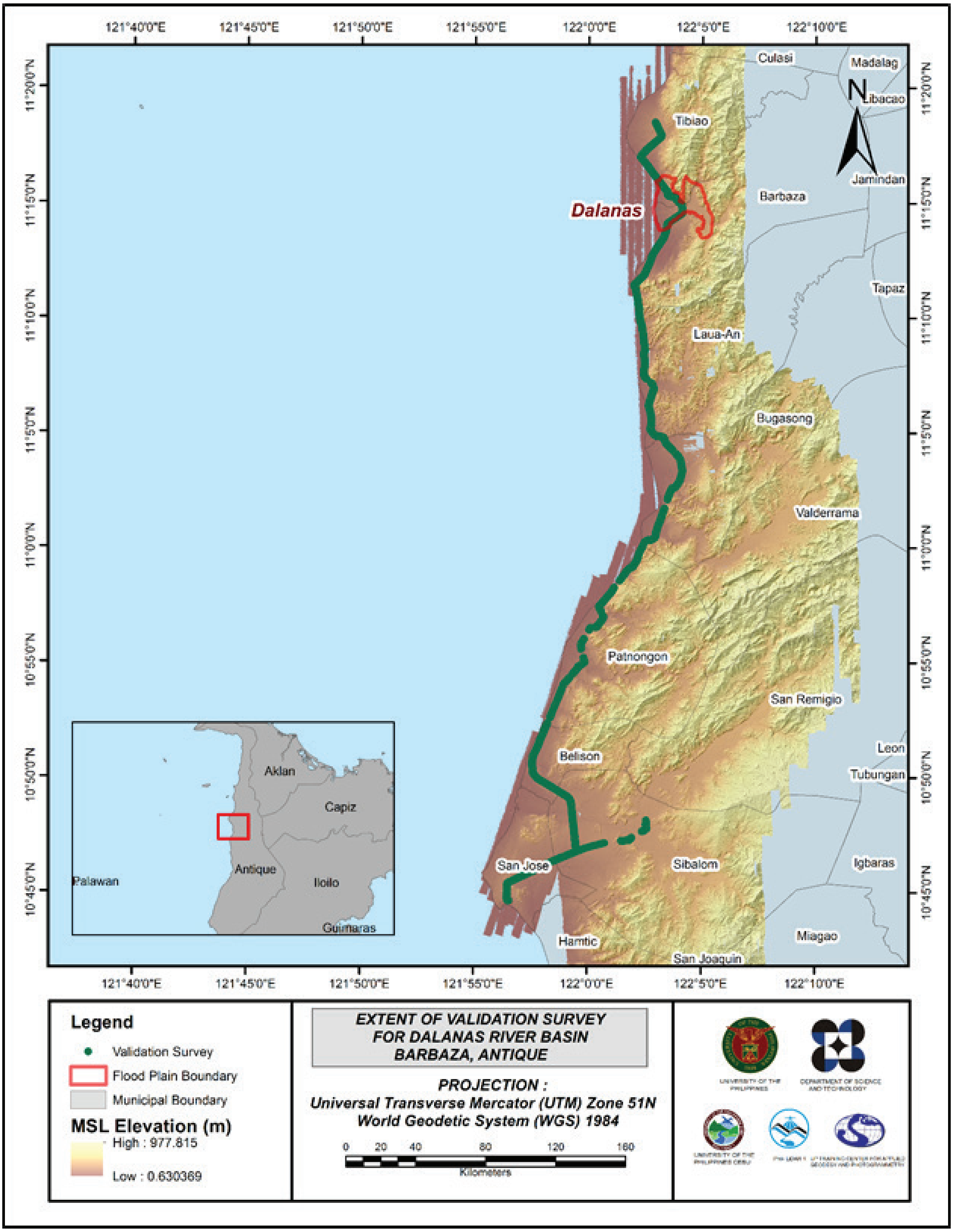


Figure 22. Map of Dalanas Floodplain with validation survey points in green

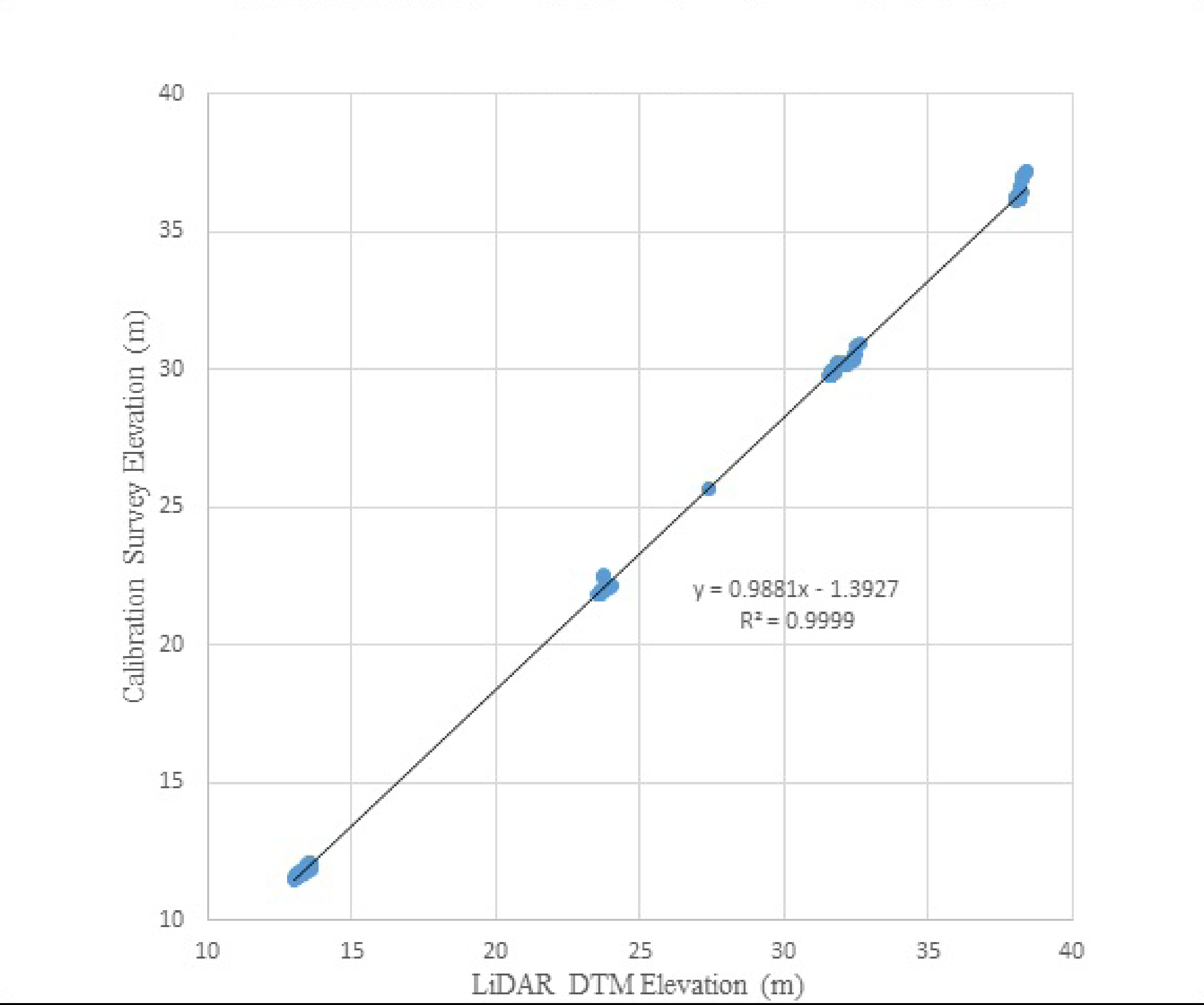


Figure 23. Correlation plot between calibration survey points and LiDAR data

Table 13. Calibration Statistical Measures

Calibration Statistical Measures	Value (meters)
Height Difference	1.71
Standard Deviation	0.17
Average	-1.70
Minimum	-2.13
Maximum	-1.16

A total of 208 survey points that are near Dalanas flood plain were used for the validation of the calibrated Dalanas DTM. A good correlation between the calibrated mosaicked LiDAR elevation values and the ground survey elevation, which reflects the quality of the LiDAR DTM is shown in Figure 24. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.03 meters with a standard deviation of 0.03 meters, as shown in Table 14.

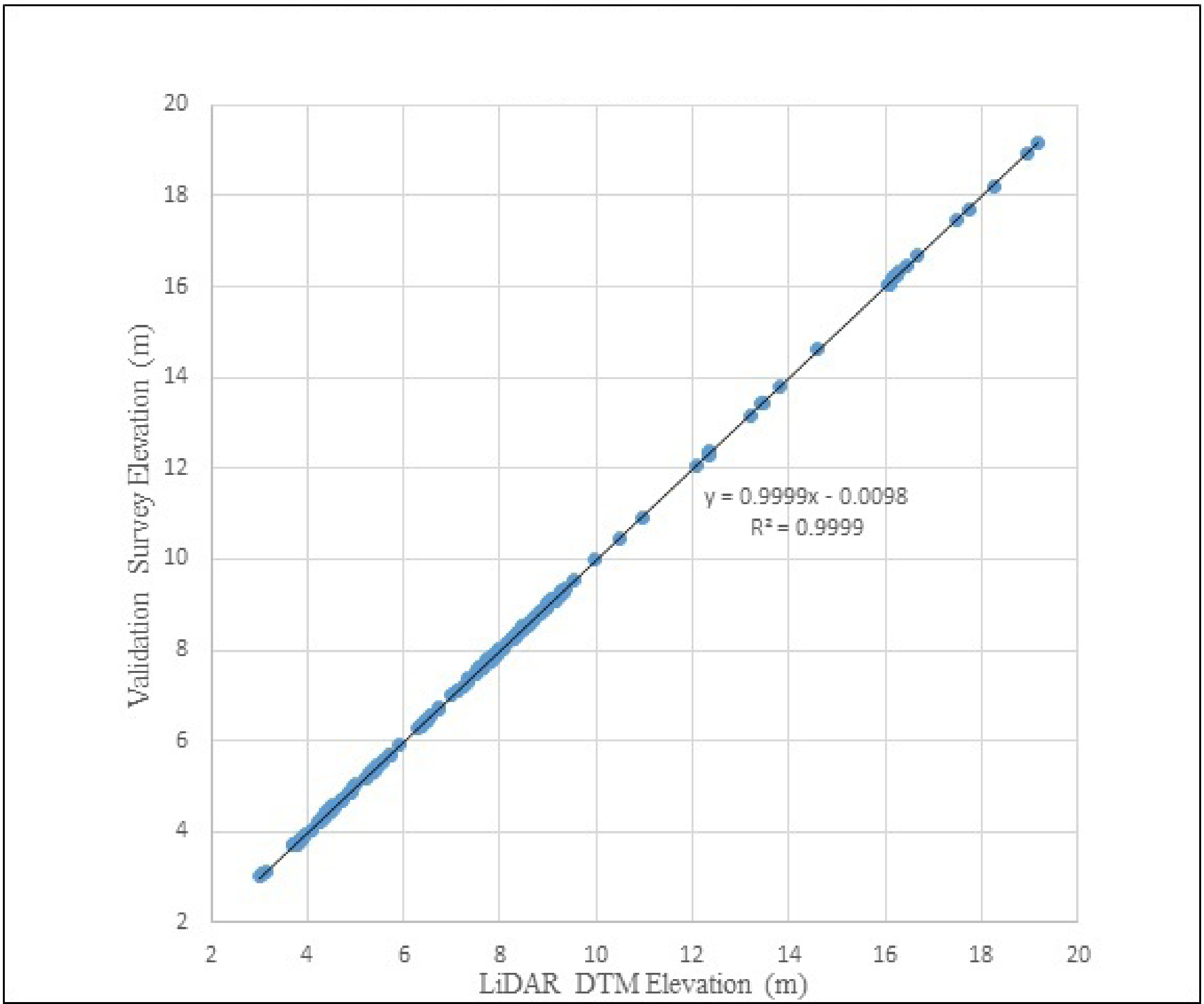


Figure 24. Correlation plot between validation survey points and LiDAR data

Table 14. Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.03
Standard Deviation	0.03
Average	-0.01
Minimum	-0.04
Maximum	-0.01

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, only centerline data were available for Dalanas with 209 bathymetric survey points. The resulting raster surface produced was done by Inverse Distance Weighted (IDW) interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.11 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Dalanas integrated with the processed LiDAR DEM is shown in Figure 25.

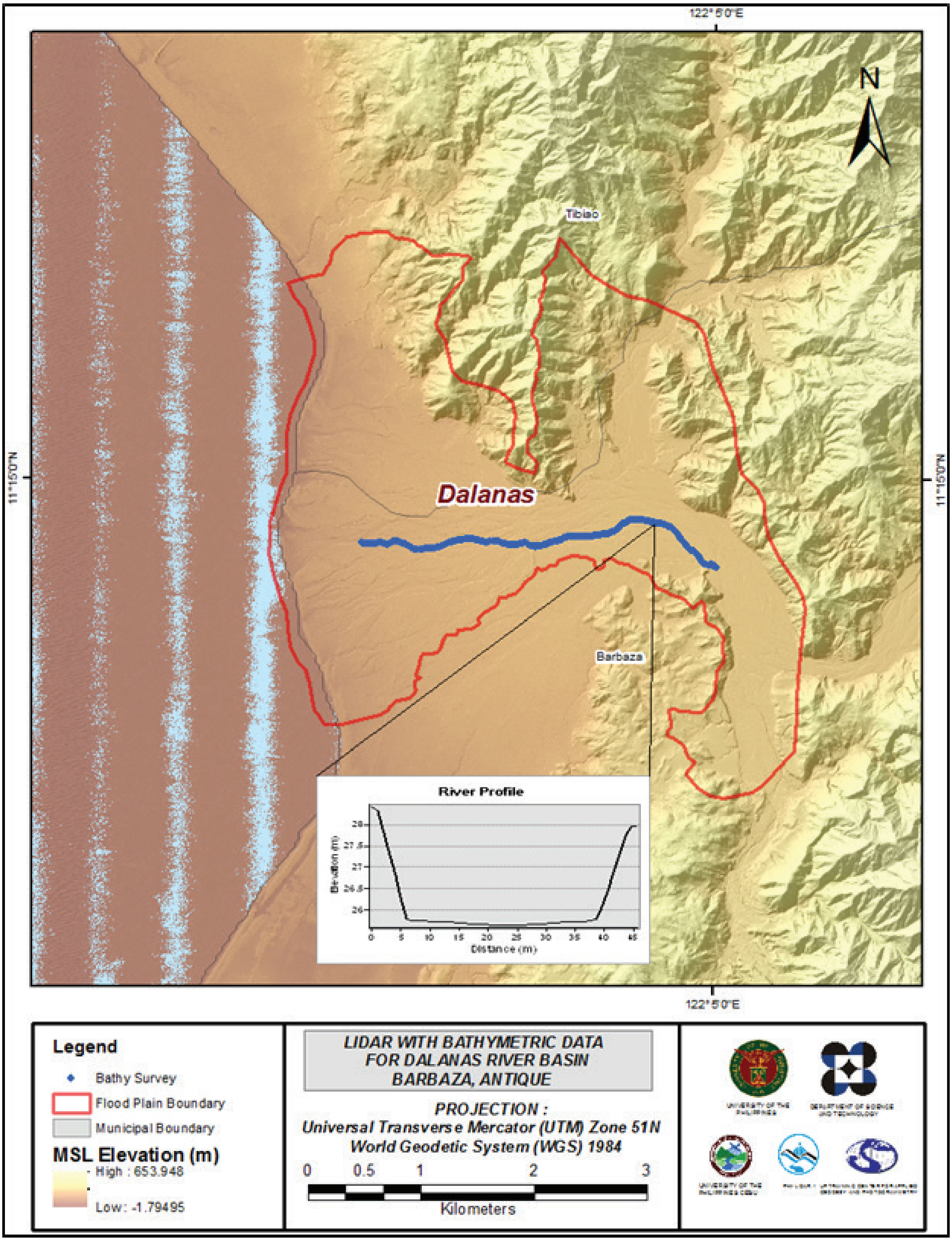


Figure 25. Map of Dalanas Floodplain with bathymetric survey points shown in blue

3.12 Feature Extraction

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

3.12.1 Quality Checking of Digitized Features' Boundary

The Dalanas Floodplain, including its 200 m buffer, has a total area of 17.73 sq km. For this area, a total of 5.0 sq. km, corresponding to a total of 1,084 building features, are considered for QC. Figure 26 shows the QC blocks for Dalanas Floodplain.

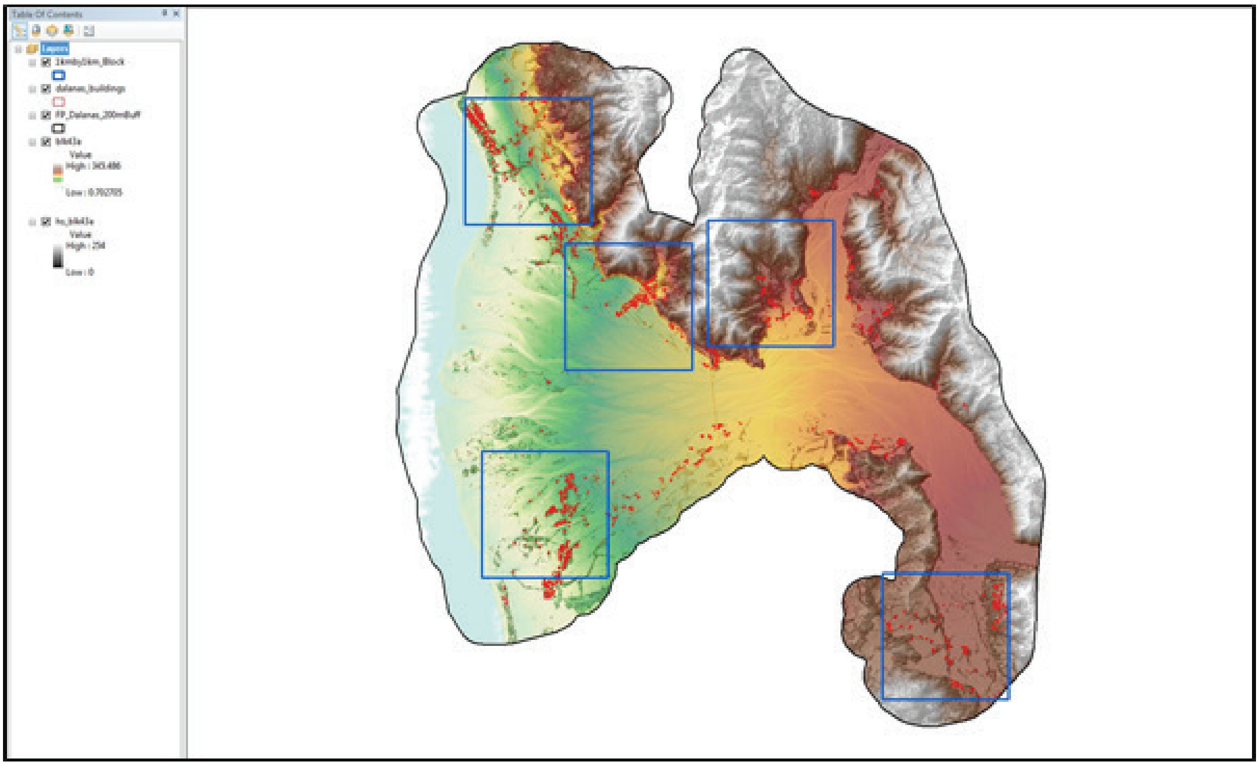


Figure 26. QC blocks for Dalanas building features

Quality checking of Dalanas building features resulted in the ratings shown in Table 15.

Table 15. Quality Checking Ratings for Dalanas Building Features.

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Dalanas	100.00	100.00	99.63	PASSED

3.12.2 Height Extraction

Height extraction was done for 1,759 building features in Dalanas Floodplain. Of these building features, twenty eight (28) were filtered out after height extraction, resulting to 1,731 buildings with height attributes. The lowest building height is at 2.0 m, while the highest building is at 6.78 m.

3.12.3 Feature Attribution

The feature attribution survey was conducted through a participatory community-based mapping in coordination with the Local Government Units of the Municipality/City. The research associates of Phil-LiDAR 1 team visited local barangay units and interviewed key local personnel and officials who possessed expert knowledge of their local environments to identify and map out features.

Maps were displayed on a laptop and were presented to the interviewees for identification. The displayed maps include the orthophotographs, Digital Surface Models, existing landmarks, and extracted feature shapefiles. Physical surveys of the barangay were also done by the Phil-LiDAR 1 team every after interview for validation. The number of days by which the survey was conducted was dependent on the number of features and number of barangays included in the flood plain of the river basin.

Table 16 summarizes the number of building features per type. On the other hand, Table 17 shows the total length of each road type, while Table 18 shows the number of water features extracted per type.

Table 16. Building Features Extracted for Dalanas Floodplain.

Facility Type	No. of Features
Residential	1,608
School	18
Market	4
Agricultural/Agro-Industrial Facilities	40
Medical Institutions	1
Barangay Hall	7
Military Institution	0
Sports Center/Gymnasium/Covered Court	4
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	2
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	0
Water Supply/Sewerage	0
Religious Institutions	7
Bank	0
Factory	0
Gas Station	0
Fire Station	0

Other Government Offices	3
Other Commercial Establishments	19
Others	18
Total	1,731

Table 17. Total Length of Extracted Roads for Dalanas Floodplain

Floodplain	**Road Network Length (km)**					**Total**
	Barangay Road	City/ Municipal Road	Provincial Road	National Road	Others	
Dalanas	9.17	0.00	0.00	5.92	0.00	15.09

Table 18. Number of Extracted Water Bodies for Dalanas Floodplain

Floodplain	**Water Body Type**					**Total**
	Rivers/ Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Dalanas	6	0	0	0	0	6

A total of two (2) bridges and culverts over small channels that are part of the river network were also extracted for the floodplain.

3.12.4 Final Quality Checking of Extracted Features

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

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

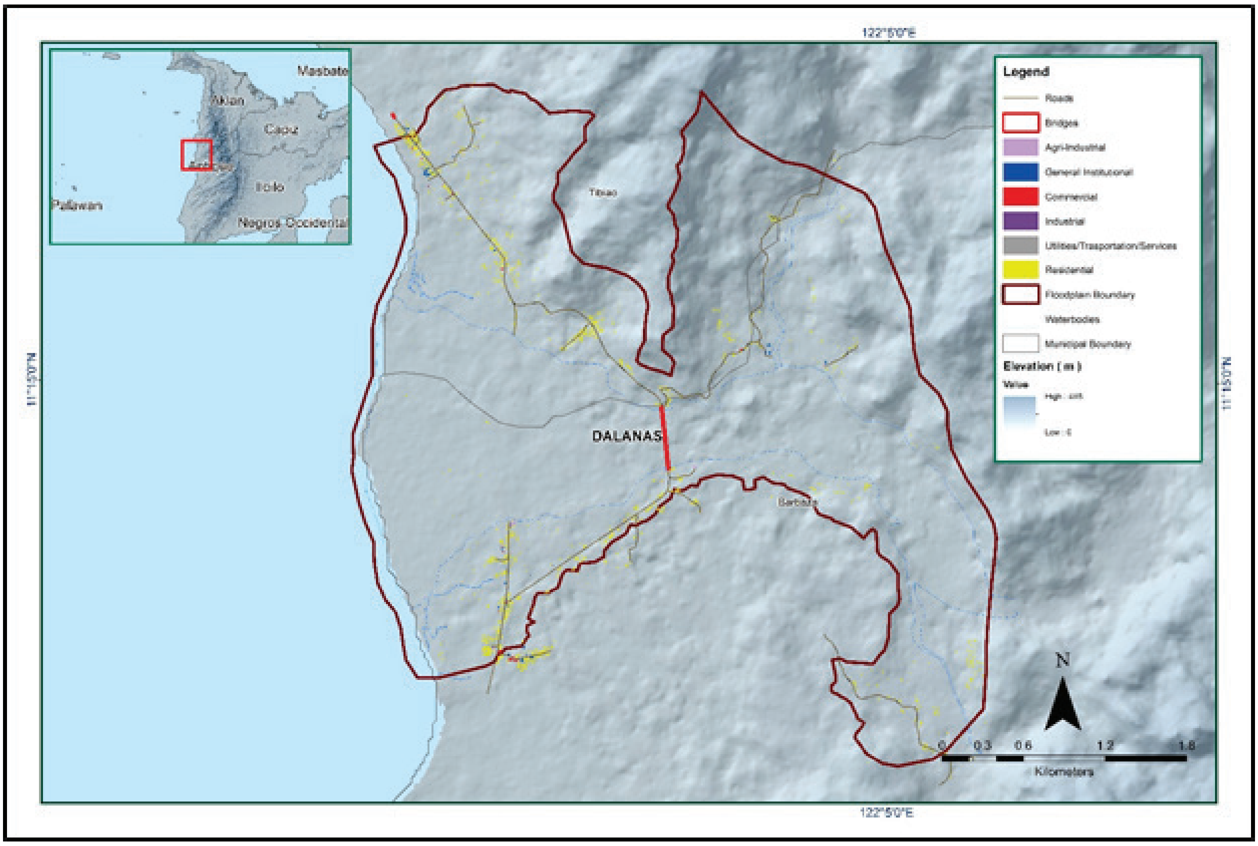


Figure 27. Extracted features for Dalanas Floodplain

CHAPTER 4: LIDAR VALIDATION SURVEY AND MEASUREMENT OF THE DALANAS RIVER BASIN

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

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

4.1 Summary of Activities

The Data Validation and Bathymetry Component (DVBC) conducted a field survey in Dalanas River from September 25 to October 9, 2014 with the following scope of work: reconnaissance; control survey for the establishment of a control point; cross-section, bridge as-built of Dalanas Bridge piers; ground validation data acquisition survey of about 82.264 km (for the whole province of Antique); and bathymetric survey from Brgy. Soligao, Municipality of Barbaza, Antique down to the mouth of the river in Brgy. San Antonio, Municipality of Barbaza, Antique with an estimated length of 3.36 km using GNSS PPK survey technique.

4.2 Control Survey

The GNSS network used in Dalanas River Survey was composed of a single loop established on September 26, 2014 occupying the following reference points: ATQ-20, a second-order GCP, located in Brgy. Zaragoza, Municipality of Bugasong, Antique; and AQ-72, a first-order BM, located in Brgy. Delima, Municipality of Belison, Antique.

A control point was established on the approach of Tipuluan Bridge, namely: TPN-1, in Brgy. Pasong, Brgy. Sibalom, Antique, to use as marker during the survey.

The summary of references and control points used in Dalanas Survey is shown in Table 19, while the GNSS network established is illustrated in Figure 28.

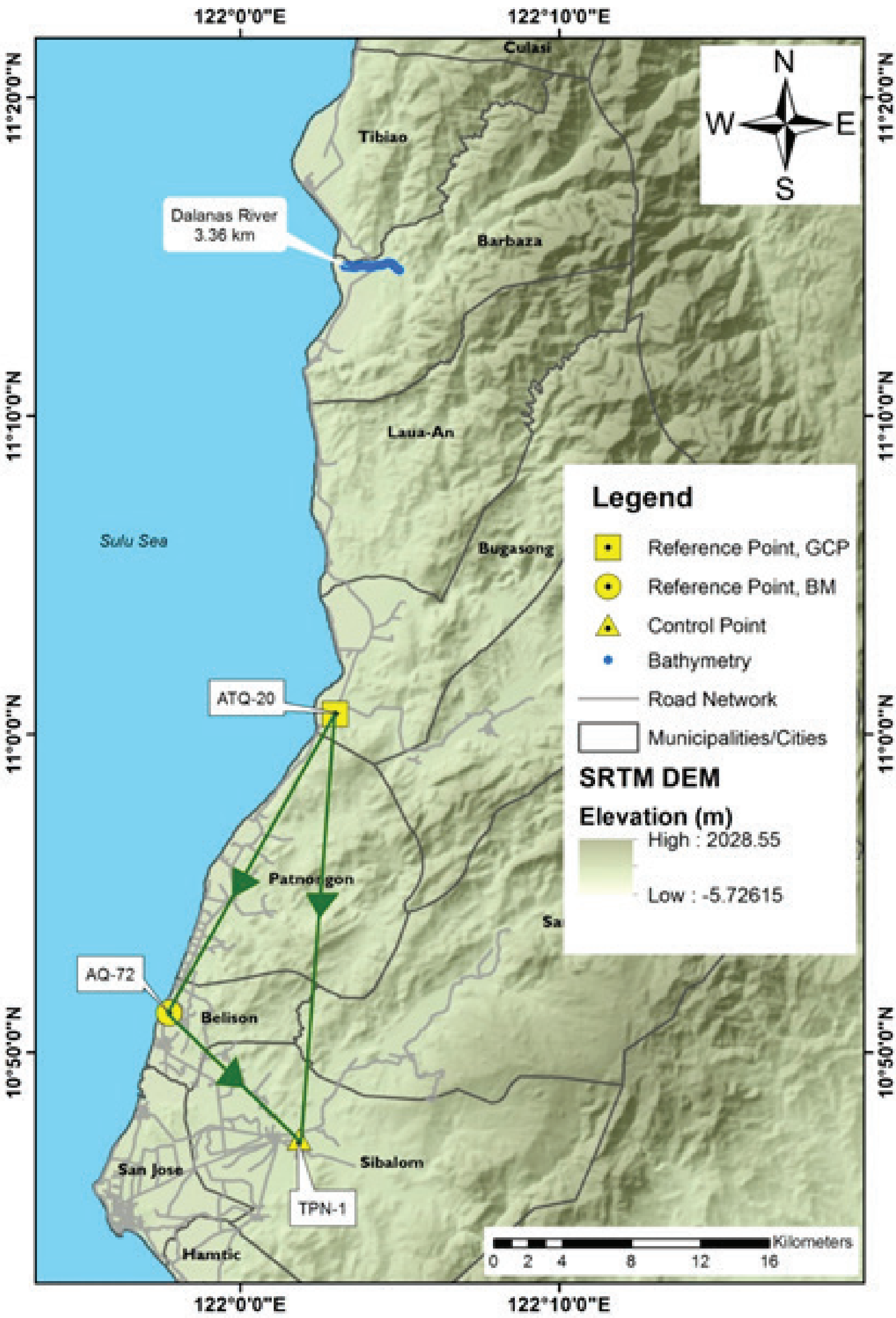


Figure 28. Dalanas GNSS network survey

Table 19. List of references and control points used in Dalanas River survey (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (Meter	BM Ortho (Meter)	Date Established
ATQ-20	2nd	11°00’38.44240” N	122°02’59.27039” E	66.094	-	2009
AQ-72	1st	-	-	61.541	5.5842	2007
TPN-1	-	-	-			September 26, 2014

The GNSS setups of each reference and control point are exhibited in Figure 29, Figure 30, and Figure 31.

Figure 29. GNSS base receiver setup, Trimble® SPS 852 at ATQ-20 in Brgy. Zaragoza, Municipality of Bugasong, Antique

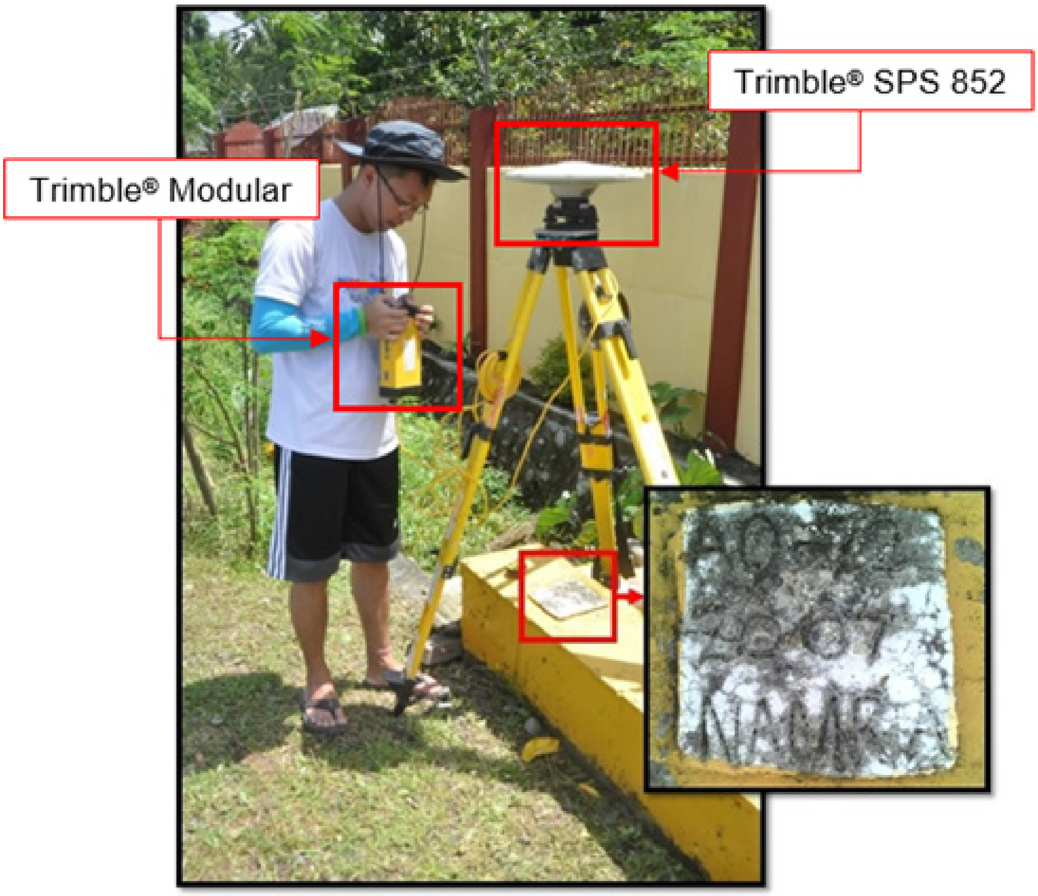


Figure 30. Benchmark, AQ-72, with Trimble® SPS 852 in Brgy. Delima, Municipality of Belison, Antique

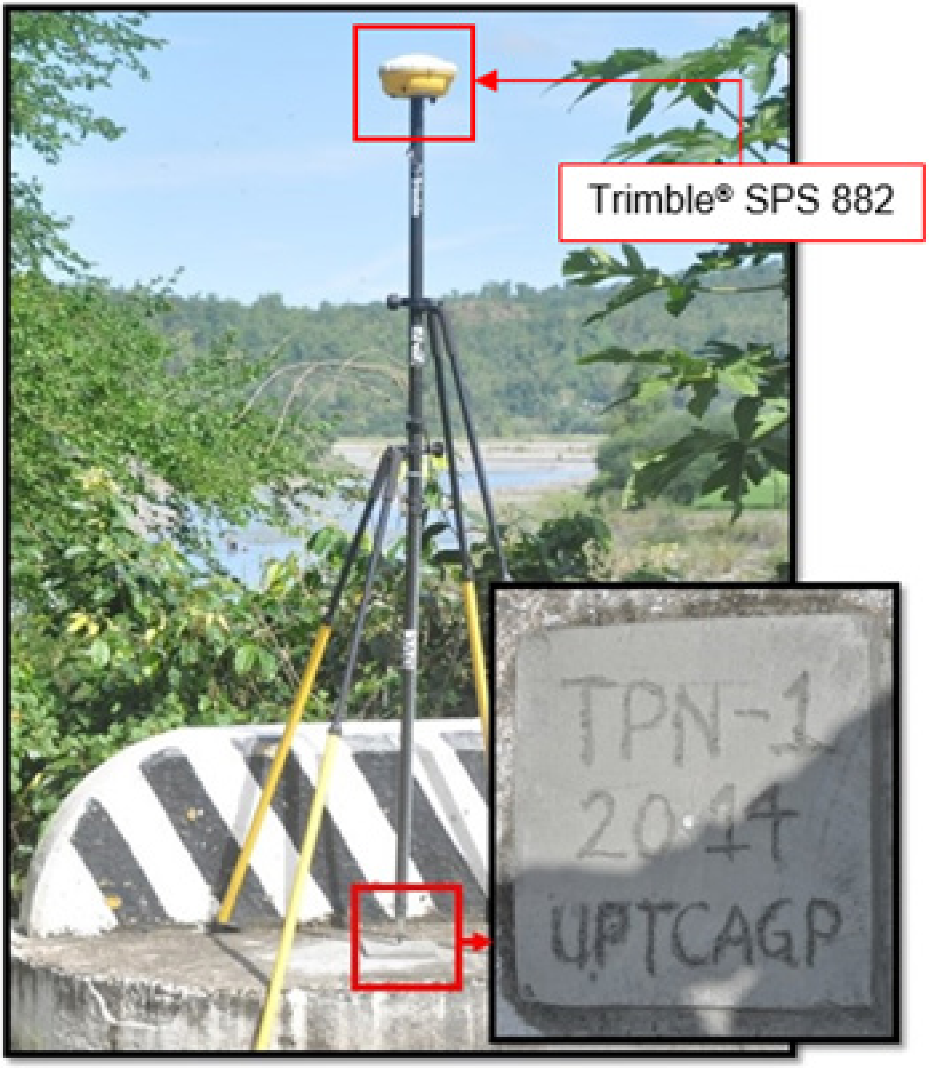


Figure 31. UP-TCAGP established control point, TPN-1, with Trimble® SPS 882 on Tipuluan Bridge in Brgy. Pasong, Municipality of Sibalom, Antique

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

Table 20. Baseline Processing Report for Dalanas River static survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
ATQ-20 --- AQ-72 (B4775)	09-26-2014	Fixed	0.007	0.022	208°43'33"	19743.041	-4.554
ATQ-20 --- TPN-1 (B4775)	09-26-2014	Fixed	0.006	0.021	184°45'37"	24723.786	22.496
AQ-72 --- TPN-1 (B4776)	09-26-2014	Fixed	0.005	0.014	134°32'57"	10438.795	27.074

As shown in Table 20, a total of three (3) baselines were processed with reference points ATQ-20 and AQ-72 held fixed for coordinate and elevation values, respectively. All of them passed the required accuracy.

4.3 Network Adjustment

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

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

Where:

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

for each control point. Table 21 to Table 24 show the results of GNSS network adjustment.

The control point in which the coordinates were fixed during the network adjustment is shown in Table 21. A difference in elevation of 0.9288 m between geoid (EGM2008) and MSL values of the reference point AQ-72 was applied for referring the elevation of the control points to MSL. Through this reference point, the coordinates of the unknown control points were computed.

Table 21. Control Point Constraints

Point ID	Type	East σ (Meter)	North σ (Meter	Height σ (Meter)	Elevation σ (Meter)
ATQ-20	Global	Fixed	Fixed	Fixed	
Fixed = 0.000001(Meter)					

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 22. The fixed control point, ATQ-20, has no values for standard errors.

Table 22. Adjusted Grid Coordinates

Point ID	Easting	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
AQ-72	(Meter)	0.063	1200045.589	0.033	6.513	0.256	
ATQ-20	386654.679	?	1217324.5 63	?	10.798	?	LLh
TPN-1	396195.506	0.058	1192699.1 27	0.031	33.065	0.259	

The network is fixed at the reference point, ATQ-20, with known coordinates. With the mentioned equation, $\sqrt{((x\_e)^2+(y\_e)^2)}<20\text{cm}$ for horizontal and $z\_e<10$ cm for the vertical; the computation for the horizontal and vertical accuracy are as follows:

a. AQ-72

horizontal accuracy = $\sqrt{((6.3)^2 + (3.3)^2}$
= $\sqrt{(39.69 + 10.89)}$
= 7.11 cm < 20 cm

b. TPN-1

horizontal accuracy = $\sqrt{((5.8)^2 + (3.1)^2}$
= $\sqrt{(33.64 + 9.61)}$
= 6.58 cm < 20 cm

The list of adjusted geodetic coordinates: Latitude, Longitude, Height and computed standard errors of the control points in the network are shown in Table 23.

Table 23. Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
AQ-72	N10°51'14.92748"	E121°57'46.85471"	61.541	0.256	
ATQ-20	N11°00'38.44240"	E122°02'59.27039"	66.094	?	LLh
ATQ-20 TPN-1	N10°47'16.56550"	E122°01'51.73167"	88.644	0.259	

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

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

Table 24. Reference and control points used and its location (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing	Easting	MSL Elevation (m)
AQ-72	1st Order BM	10°51'14.92748"N	121°57'46.85471"E	61.541	1217324.563	396195.506	9.8692
TPN-1	UP Established	10°47'16.56550"N	122°01'51.73167"E	88.644	1200045.589	386654.679	5.5842
ATQ-20	2nd Order GCP	10°47’16.56550”N	66.094 122°02’59.27039”E	66.094	1192699.127	394067.041	32.1362

4.4 Cross-section, Bridge As-Built and Water Level Marking

The cross-section and as-built survey were conducted on September 30, 20014 at the downstream side of Dalanas Bridge in Brgy. Capoyuan, Municipality of Barbaza using GNSS receiver Trimble® SPS 882 in PPK survey technique as shown in Figure 32.

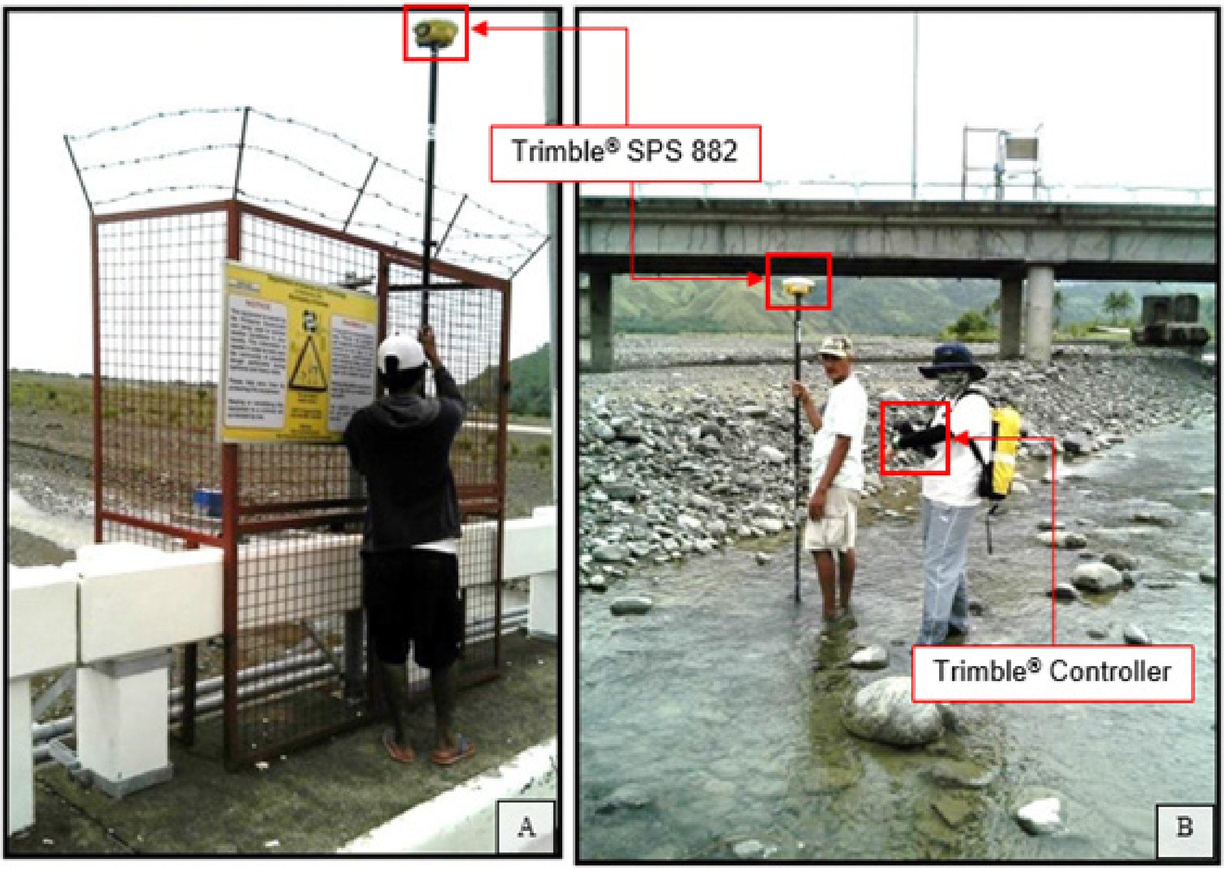


Figure 32. (A) As built survey and (B) Cross section survey in Dalanas Bridge in the Municipality of Barbaza

The cross-sectional line for Dalanas Bridge is about 450 m with 69 points acquired using ATQ-20 as GNSS base station. The location map, cross-section diagram, and bridge as-built form are shown in Figure 33 to Figure 35, respectively.

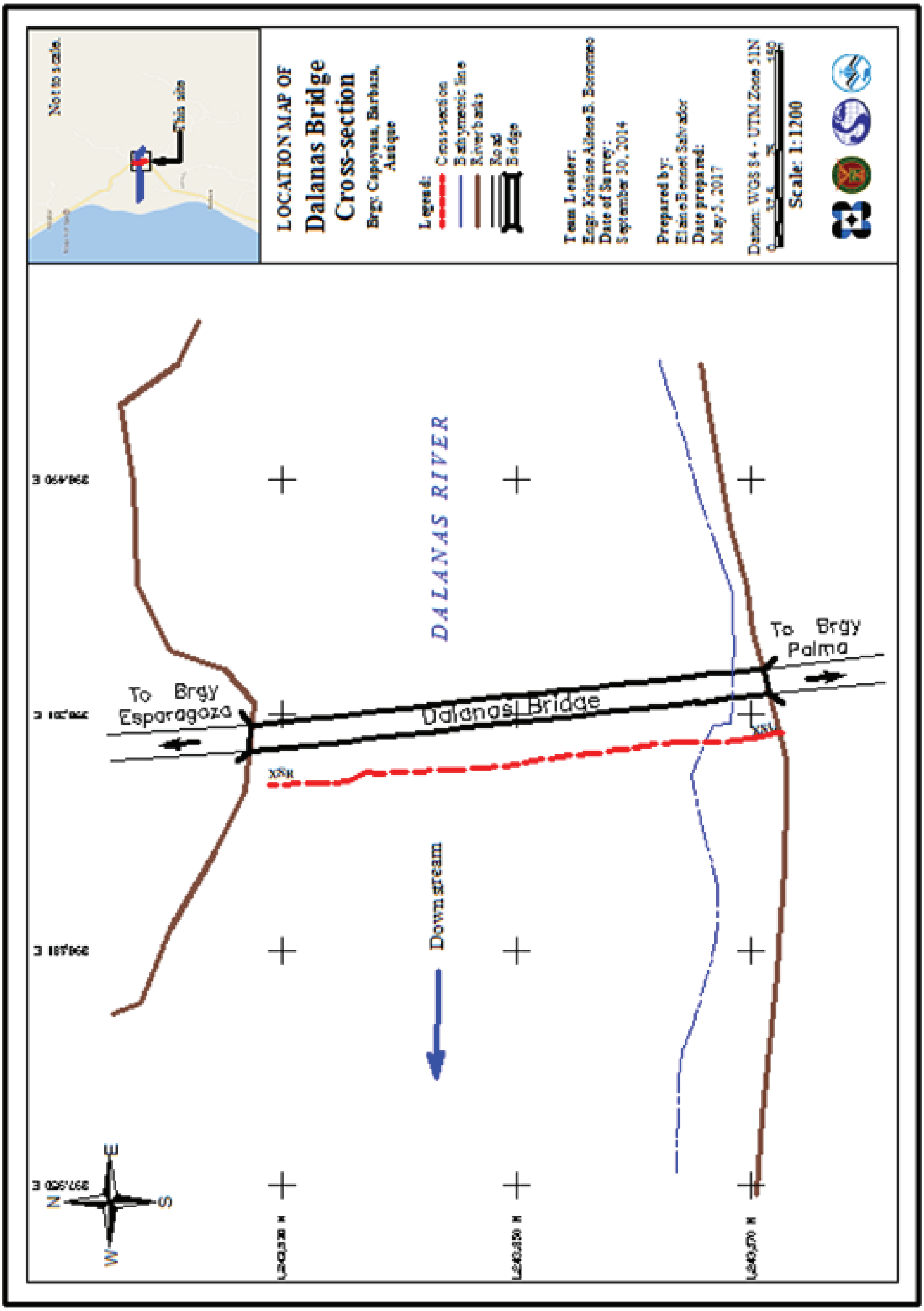


Figure 33. Dalanas Bridge Cross-section Diagram

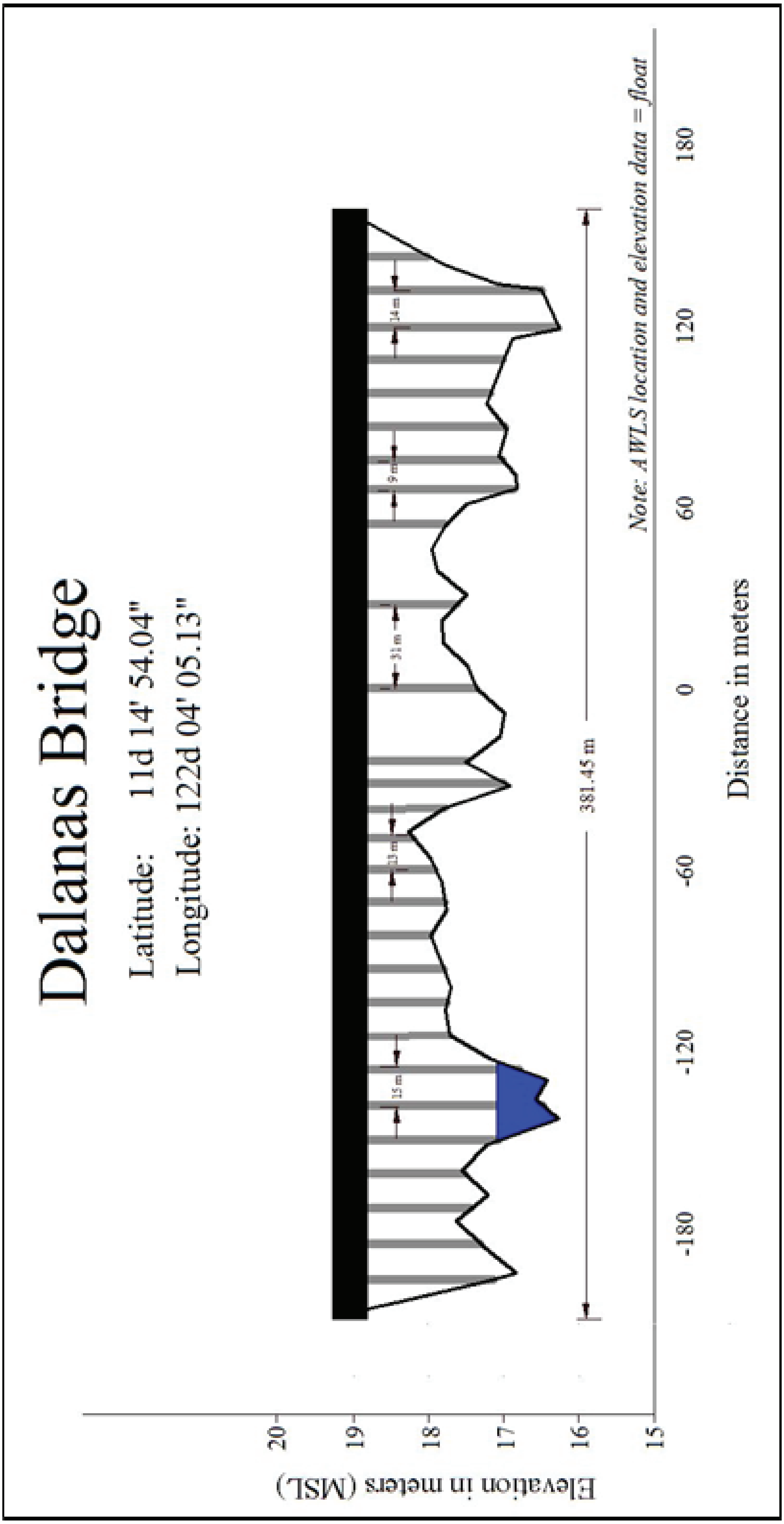


Figure 34. Dalanas Bridge Location Map

Bridge Data Form

Bridge Name: Dalanas Bridge **Date:** September 30, 2014

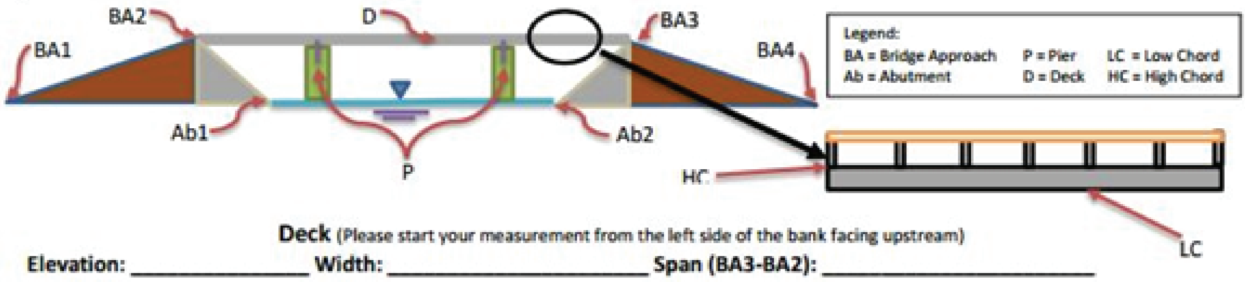
River Name: Dalanas River **Time:** 11:30 AM

Location (Brgy, City,Region): Dalanas, Antique, Region 6

Survey Team: Antique Survey Team

Flow condition: low **normal** high **Weather Condition:** **fair** rainy

Latitude: 11d00'38.44240" **Longitude:** 122d02'59.27039"



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

Elevation: ______________ **Width:** ____________________ **Span (BA3-BA2):** ____________________

	Station	High Chord Elevation	Low Chord Elevation
1			
2			
3			
4			
5			

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

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	n/a	n/a	BA3	451.673	No data
BA2	0	No data	BA4	n/a	n/a

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

	Station (Distance from BA1)	Elevation
Ab1	n/a	n/a
Ab2	n/a	n/a

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

Shape: Circular Number of Piers: 29 Height of column footing: ______________

	Station (Distance from BA1)	Elevation	Pier Width
Pier 1	15.573	No data	
Pier 2	30.663	No data	
Pier 3	45.8574	No data	
Pier 4	60.7168	No data	
Pier 5	75.7325	No data	
Pier 6	91.3303	21.8962	
Pier 7	106.209	21.8882	
Pier 8	120.998	21.8912	

Pier 9	136.13	21.8892	
Pier 10	151.067	21.8552	
Pier 11	166.135	21.8902	
Pier 12	181.022	21.9022	
Pier 13	196.115	21.8922	
Pier 14	211.151	21.9032	
Pier 15	226.15	21.9052	
Pier 16	240.818	No data	
Pier 17	256.19	21.8962	
Pier 18	271.191	21.8902	
Pier 19	286.208	21.9082	
Pier 20	301.196	21.8822	
Pier 21	316.093	21.9362	
Pier 22	331.084	No data	
Pier 23	345.958	No data	
Pier 24	360.951	No data	
Pier 25	375.948	No data	
Pier 26	390.858	No data	
Pier 27	406.203	21.9512	
Pier 28	421.087	No data	
Pier 29	436.068	No data	

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

Figure 35. Dalanas Bridge Data Form

4.5 Validation Points Acquisition Survey

The Validation Points Acquisition Survey was conducted on October 3, 5, and 6, 2014 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted on a pole which was attached in front of the vehicle as shown in Figure 36Error! Reference source not found.. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The antenna height 1.53 m was measured from the ground up to the bottom of the notch of the GNSS Rover receiver. The survey was conducted using PPK technique on a continuous topography mode.

The first day of ground validation started from Municipality of Tibiao and traversed major roads going to Municipality of Patnongon. Meanwhile, the second day of survey started from the Municipality of San Jose up to the Municipality of Patnongon, and the third day of ground validation survey comprised of the remaining areas. The reference point ATQ-20 was used as the base station all throughout the conduct of the survey.

Figure 36. (A) Ground Validation Set-up and (B) occupied base station, ATQ-20, at Municipality of Bugasong

The survey acquired 9,787 ground validation points with an approximate length of 82.264 km using the base station ATQ-20, as shown in the map in Figure 37.

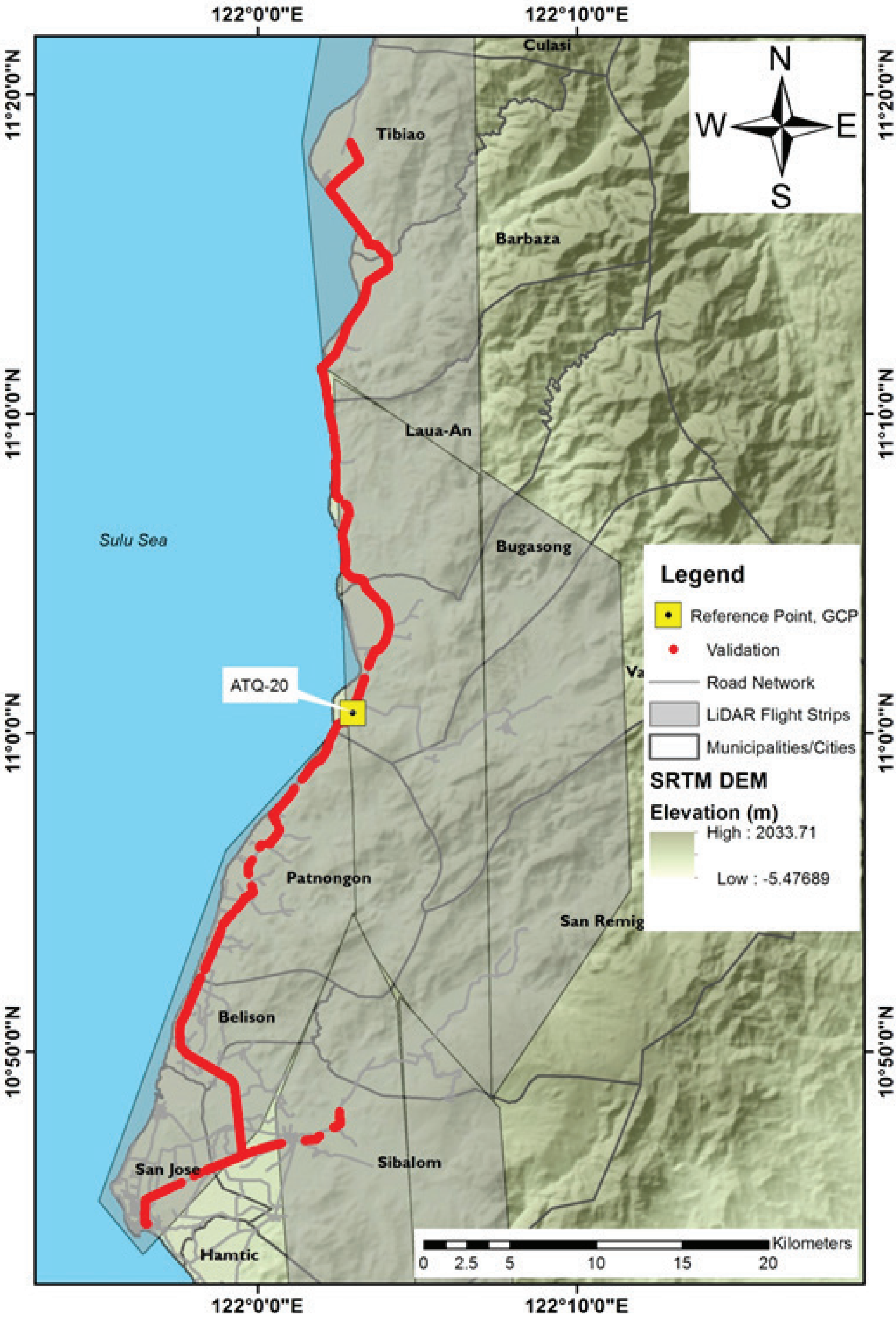


Figure 37. LiDAR Ground Validation Survey along Antique Province

4.6 River Bathymetric Survey

Manual bathymetric survey was done on September 30, 2014 and October 8, 2014 using Trimble® SPS 882 GNSS receiver in PPK survey technique as shown in Figure 38. The survey started in the upstream shallow part of Dalanas River in Brgy. Soligao, Municipality of Barbaza with coordinates 11°14'35.05749" 122°05'00.11045", going downstream by foot and ended in Bry. San Antonio, also in Barbaza with coordinates 11°14'41.34918" 122°03'17.83659".

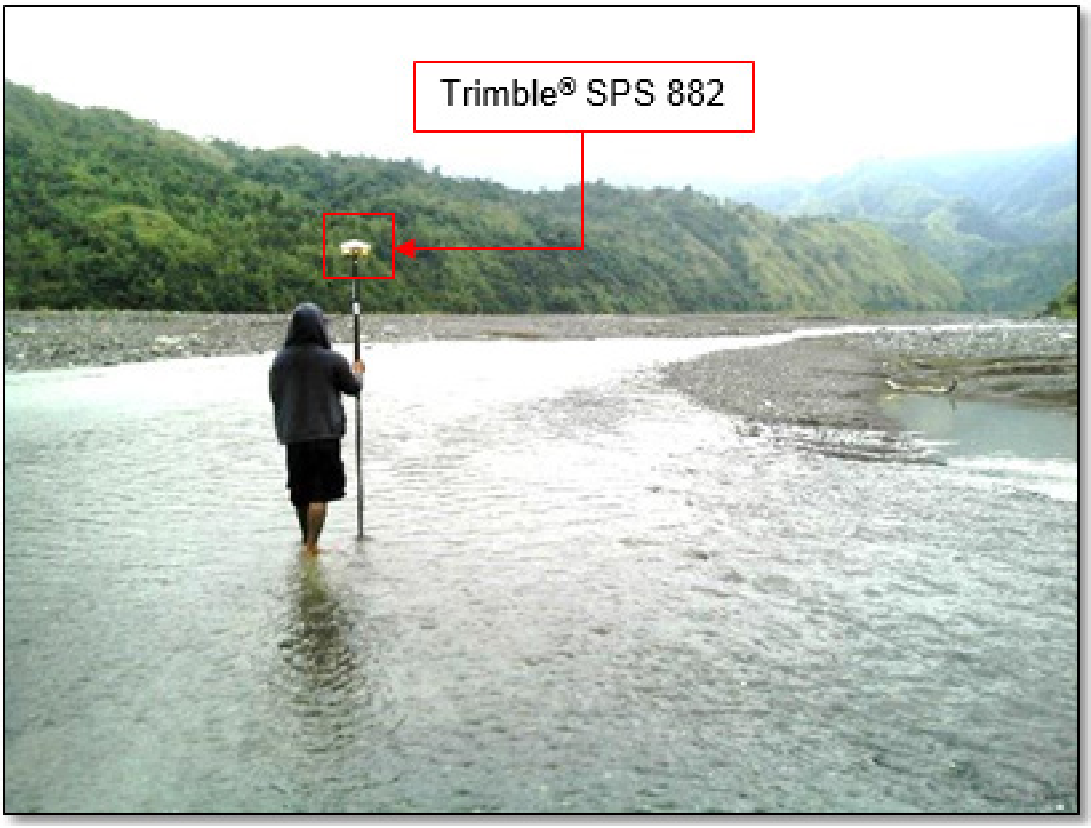


Figure 38. Bathymetric Survey along Dalanas River

The bathymetric line as an estimated length of 3.42 km with 160 points gathered using ATQ-20 as GNSS base station (see Figure 39). A CAD drawing was also produced to illustrate the Dalanas riverbed profile. As shown in Figure 40, there was a change in elevation about 30.942 m MSL from upstream to downstream. The highest elevation was 33.84 m in MSL located in the upstream part of the river, while the lowest elevation observed was 3.82 m below MSL located in the downstream part of the river in Brgy. San Antonio.

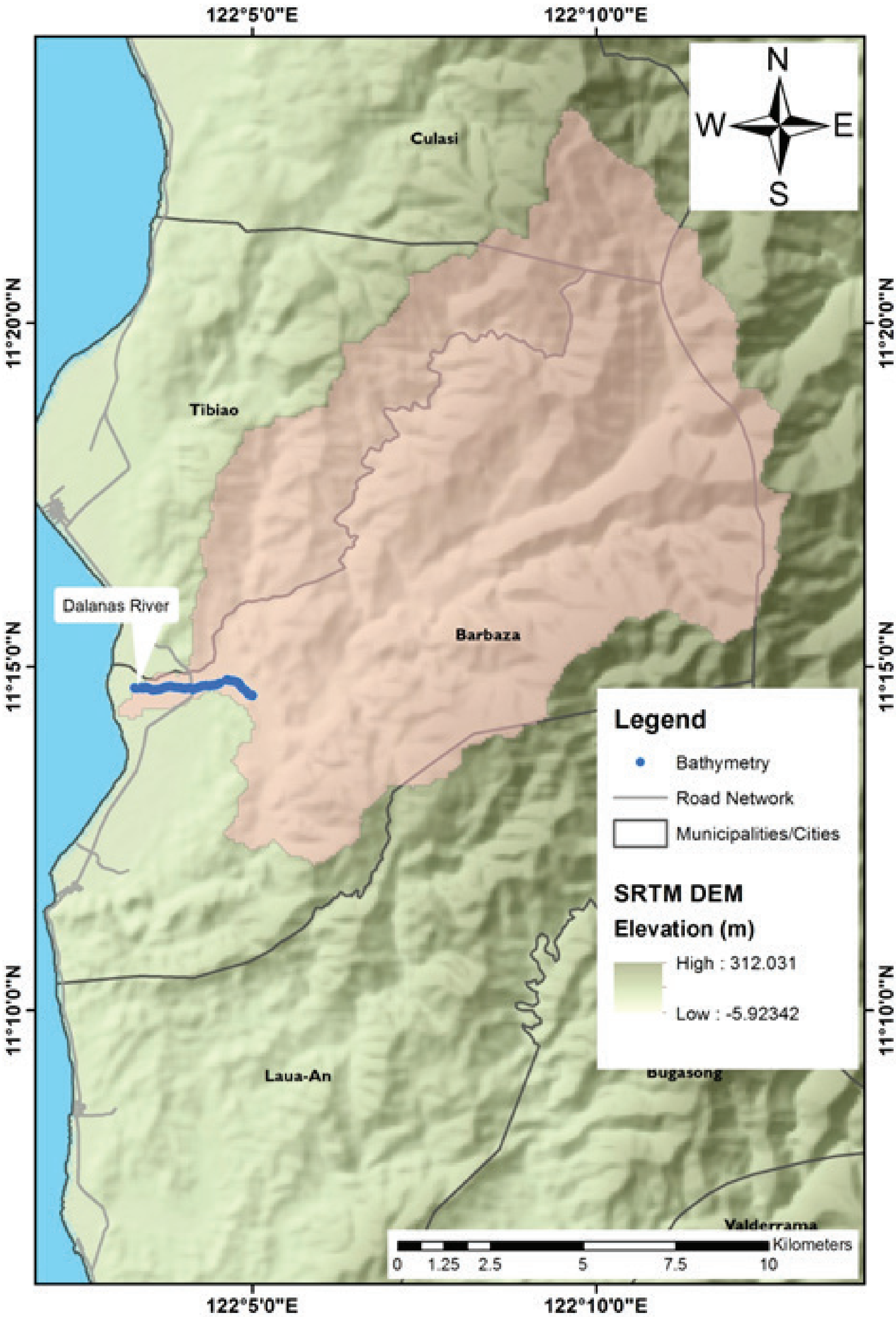


Figure 39. Bathymetric points gathered from Dalanas River

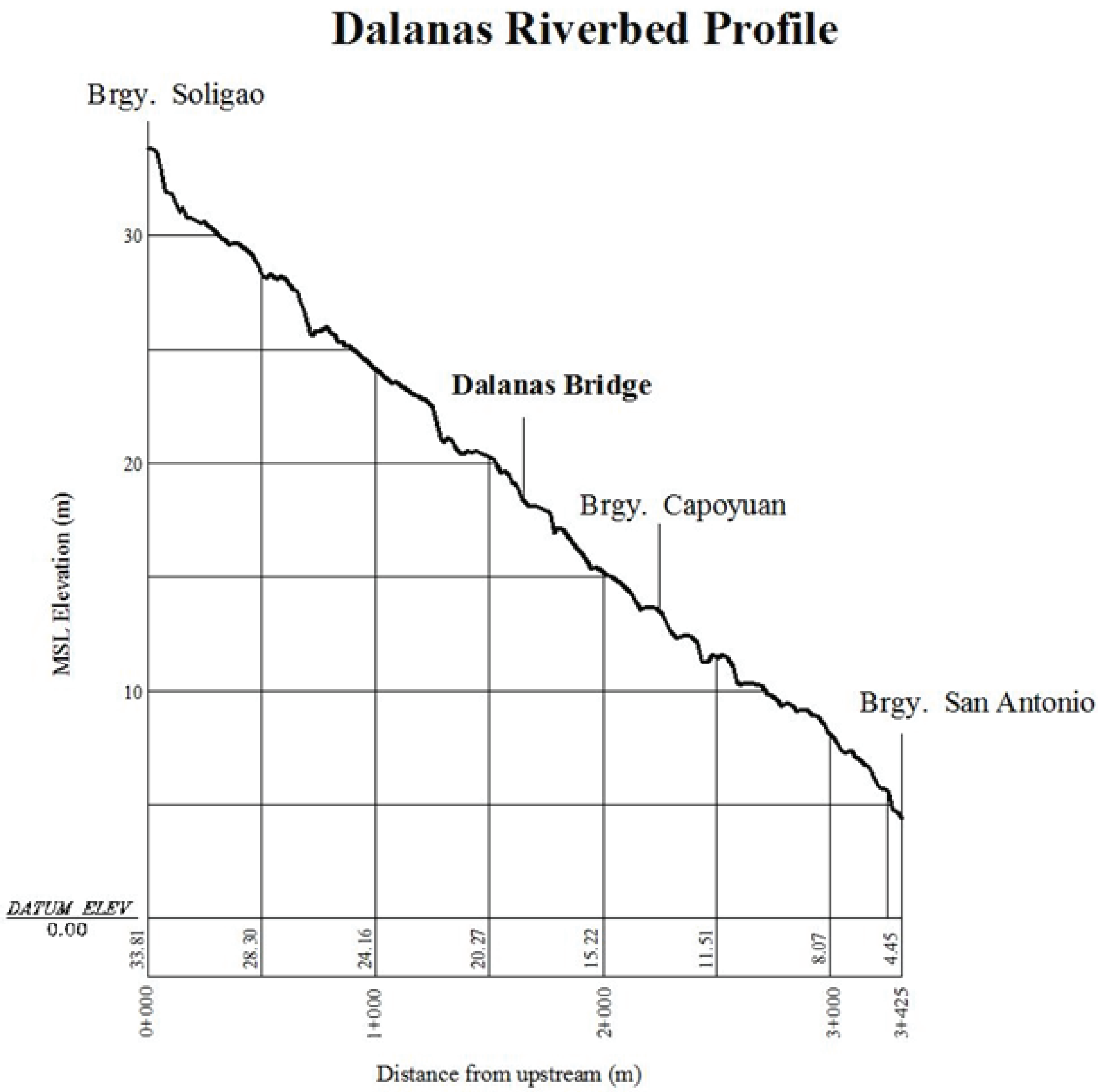


Figure 40. Riverbed Profile of Dalanas River

CHAPTER 5: FLOOD MODELING AND MAPPING

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

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

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

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

5.1.2 Precipitation

The precipitation data were taken from an automatic rain gauge (ARG) deployed by the UP Cebu Flood Modeling Component (FMC) team. The ARG was installed at Brgy. Lomboyan, Barbaza, Antique (Figure 41). The precipitation data collection started from December 13, 2017 at 11:05 AM to 3:30 with 5 minutes recording interval.

The total precipitation for this event in Brgy. Lomboyan ARG was 28.6 mm. It has a peak rainfall of 3.60 mm. on December 13, 2016 at 12:55 in the afternoon. The lag time between the peak rainfall and discharge is 4 hours.

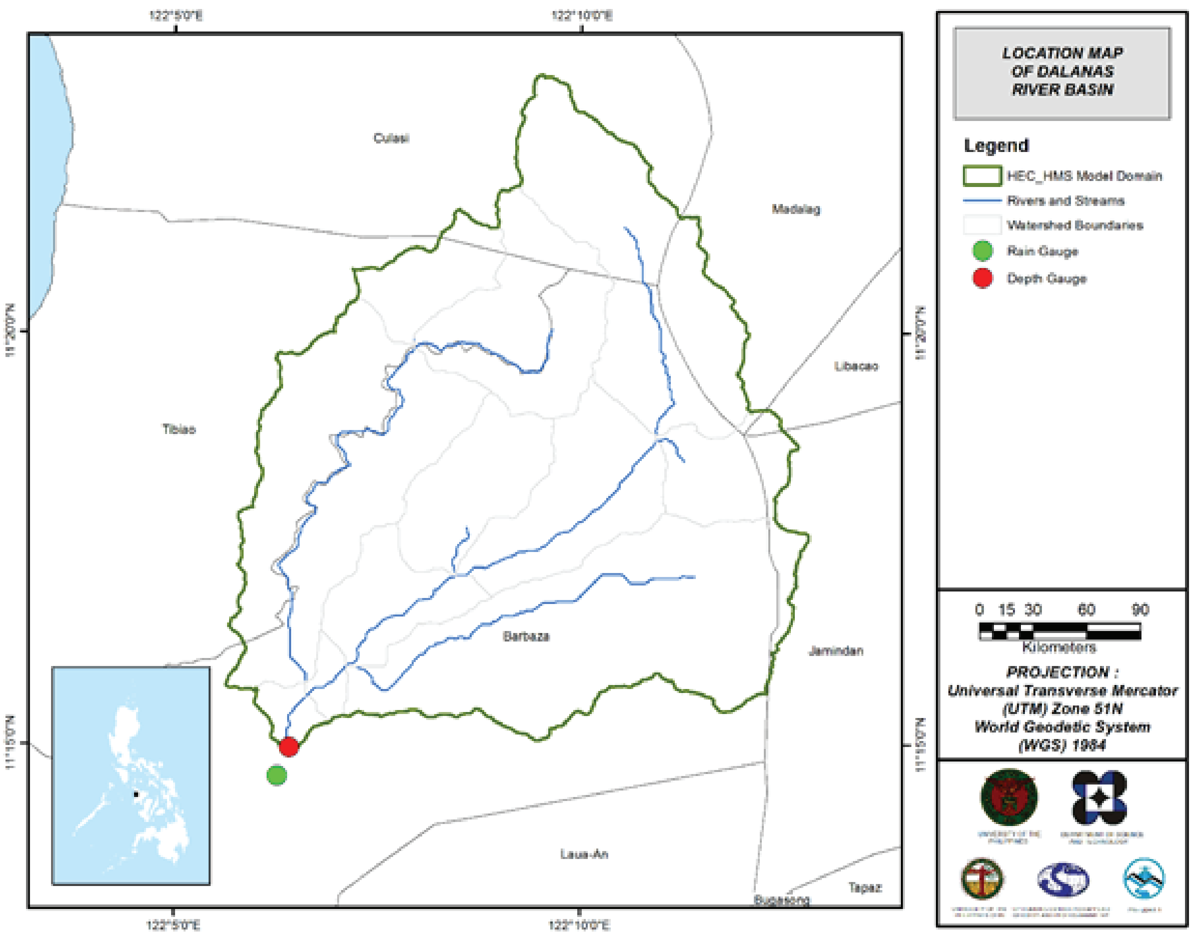


Figure 41. The location map of Dalanas HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Brgy. Bigaa, Barbaza, Antique (11°14'6.43"N 122° 5'27.99"E). It gives the relationship between the observed water levels at Himogaan Bridge and outflow of the watershed at this location.

For Brgy. Bigaa Discharge Point, the rating curve is expressed as Q = 2E-175e12.951x [see y formula] as shown in Figure 43.

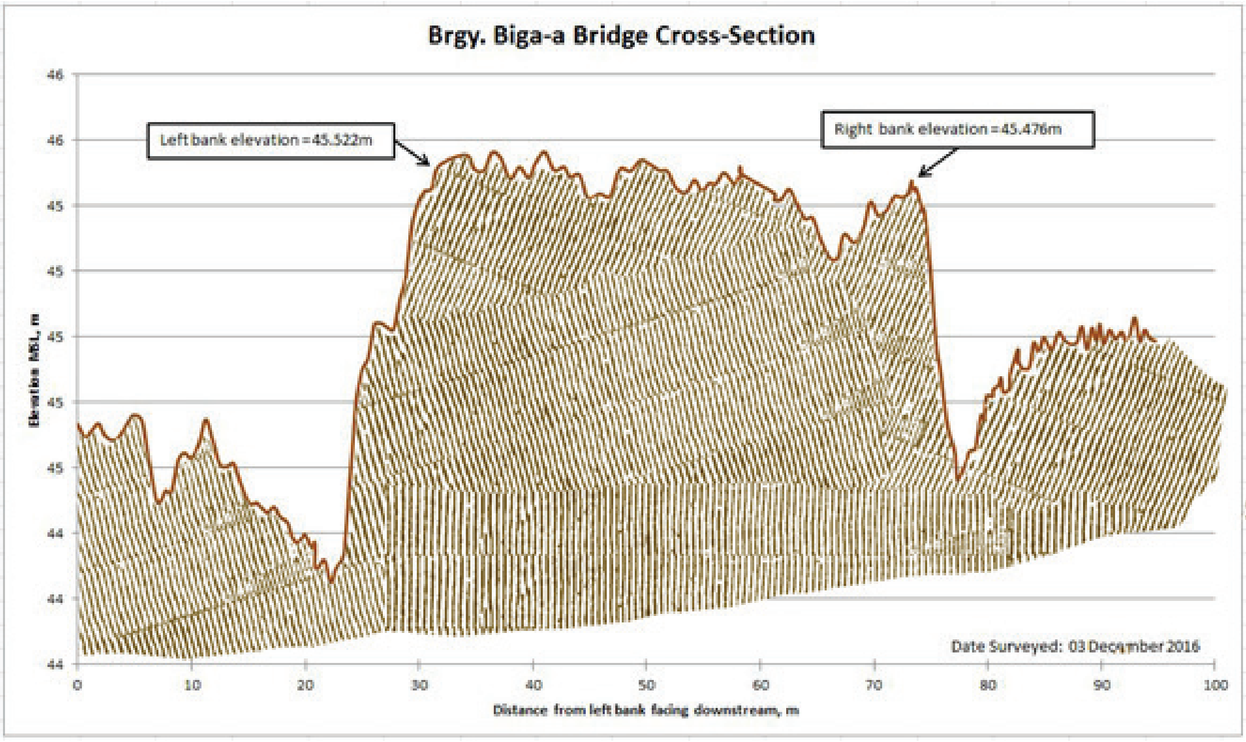


Figure 42. Cross-Section Plot of Brgy Biga-a Bridge

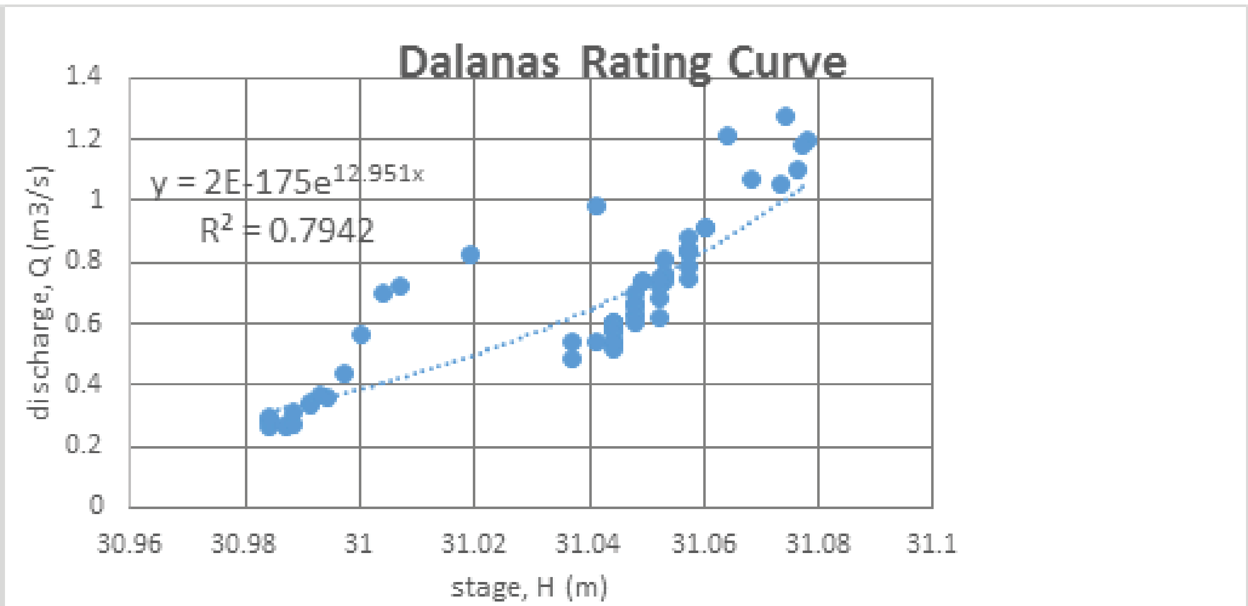


Figure 43. Rating Curve at Brgy Bigaa Flow Site, Barbaza, Antique

This rating curve equation was used to compute the river outflow at Brgy Bigaa Flow Site for the calibration of the HEC-HMS model shown in Figure 44. Peak discharge is 1.280 cubic meters per second at 4:55 PM, December 13, 2016.

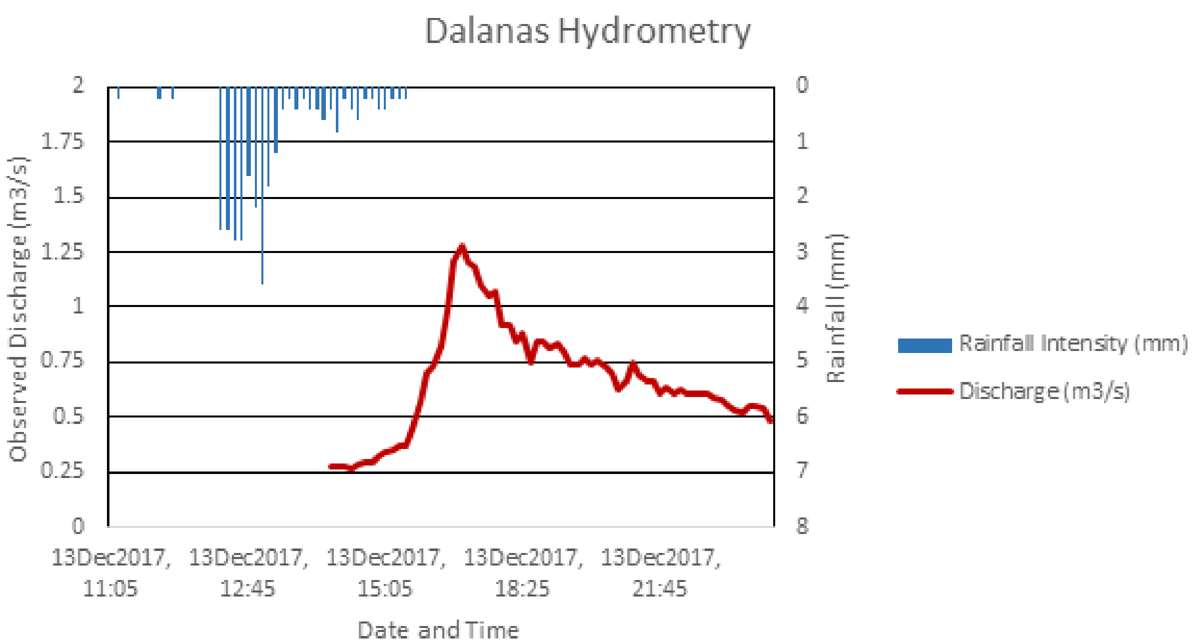


Figure 44. Rainfall and outflow data at Brgy Bigaa Flow Site used for modeling

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Iloilo Rain Gauge (Table 25). The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the value in such a way certain peak value will be attained at a certain time (Figure 46). This station was chosen based on its proximity to the Dalanas watershed (Figure 45). The extreme values for this watershed were computed based on a 59-year record.

Table 25. RIDF values for Iloilo Rain Gauge computed by PAGASA

T (yrs)	10 mins	20 mins	30 mins	1 hr	2 hrs	3 hrs	6 hrs	12 hrs	24 hrs
5	28.7	39.4	48	59.4	74.9	90	114.7	131.7	165.2
10	33.9	45.6	55.6	68.1	85	103.6	133.6	155.4	198.9
25	40.5	53.5	65.3	79.2	97.6	120.8	157.6	185.3	241.5
50	45.4	59.4	72.4	87.3	107	133.5	175.3	207.4	273.1
100	50.3	65.2	79.5	95.4	116.4	146.2	193	229.4	304.5

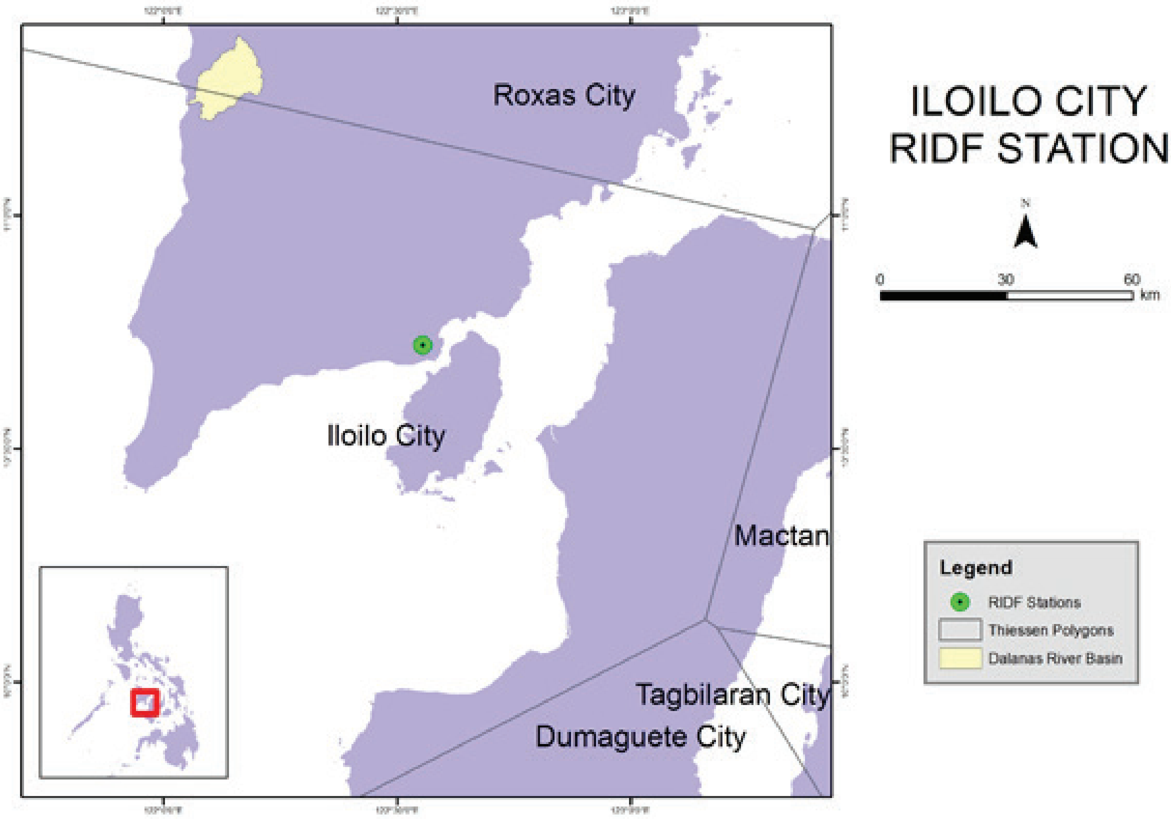


Figure 45. Location of Iloilo RIDF station relative to Dalanas River Basin

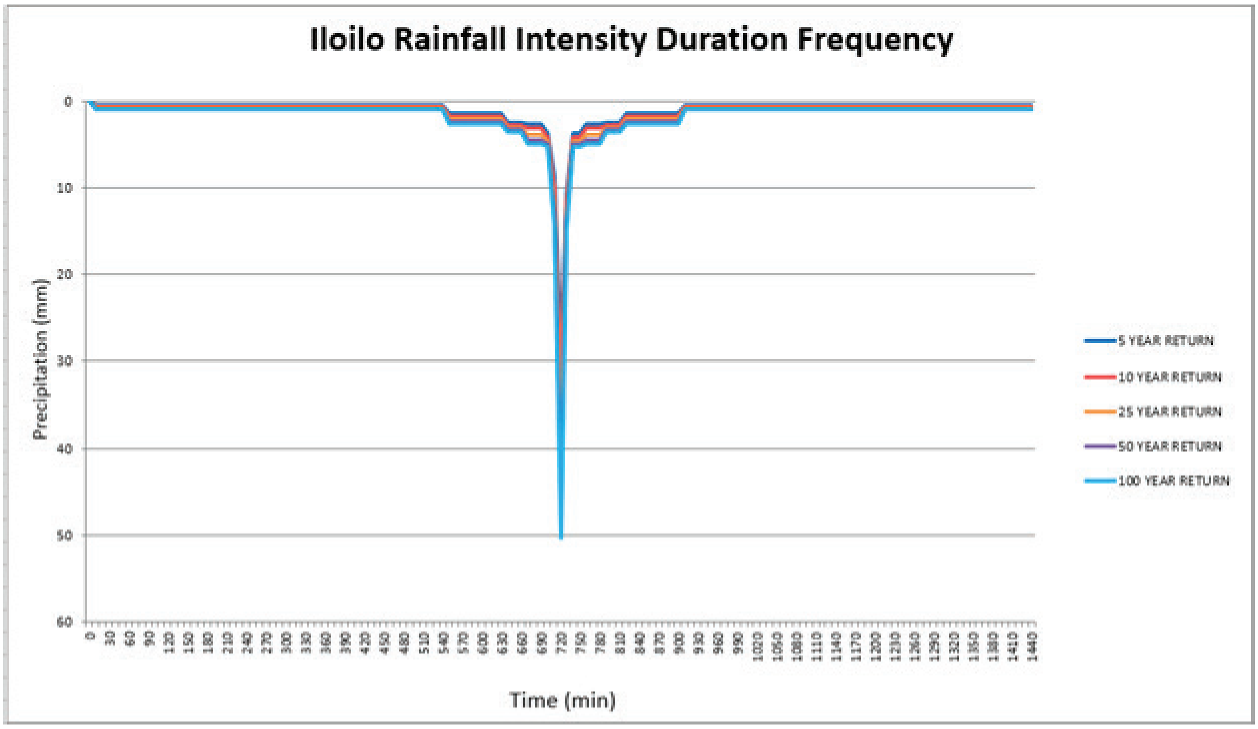


Figure 46. Synthetic storm generated for a 24-hr period rainfall for various return periods

5.3 HMS Model

The soil dataset was generated before 2004 by the Bureau of Soil and Water Management; this is under the Department of Agriculture. The land cover dataset is from the National Mapping and Resource Information Authority (NAMRIA). The soil and land cover of the Dalanas River Basin are shown in Figures 47 and 48, respectively.

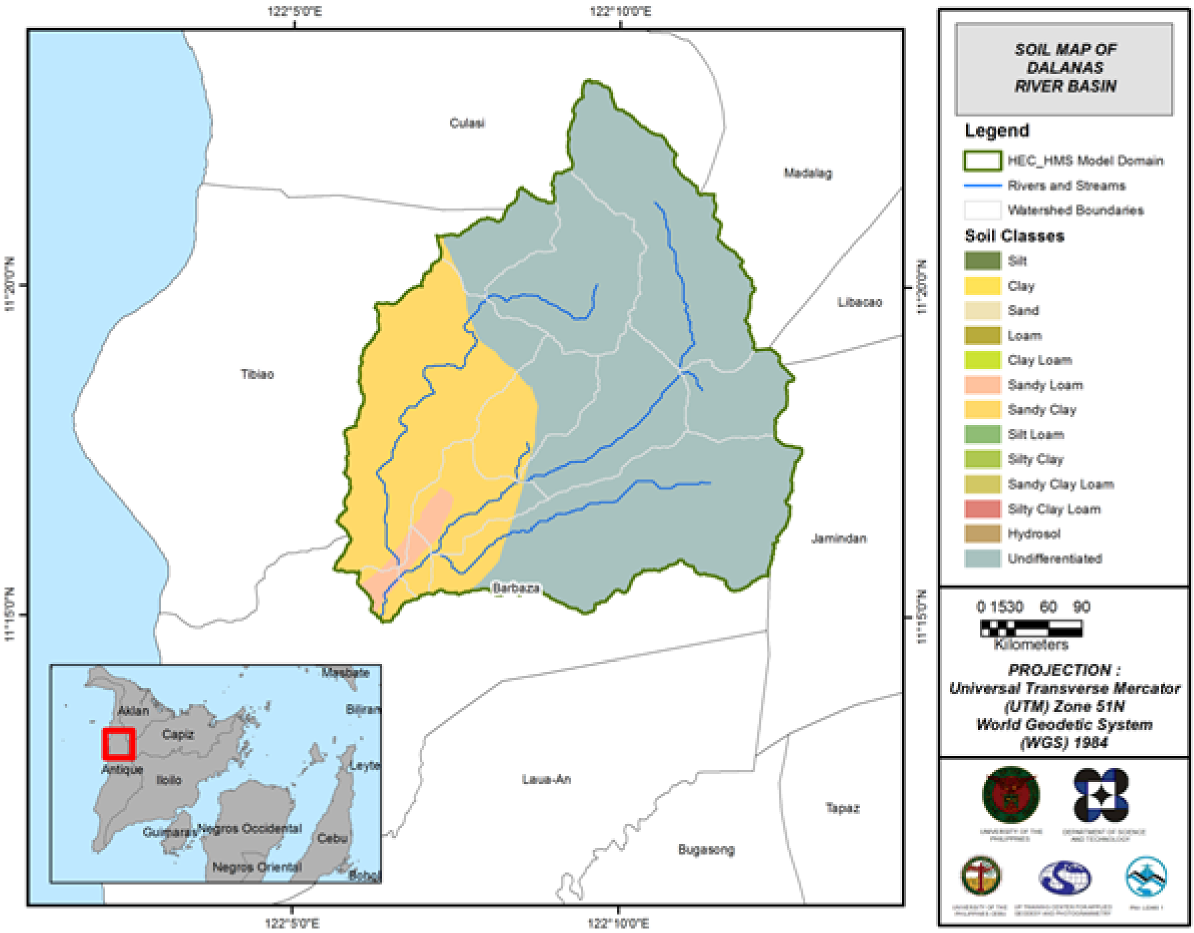


Figure 47. Soil map of the Dalanas River Basin (Source: DA)

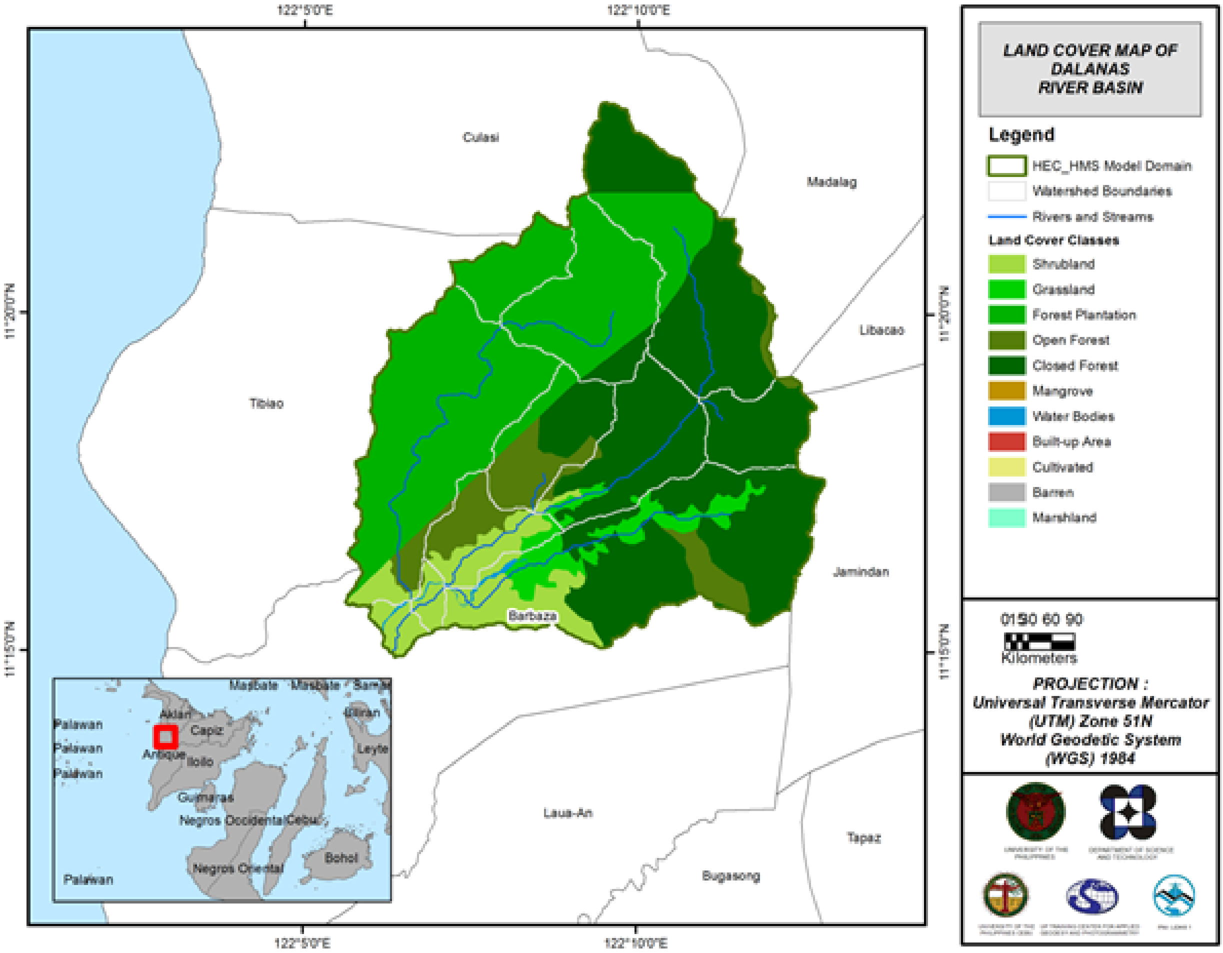


Figure 48. Land Cover Map of the Dalanas River Basin (Source: NAMRIA)

For Dalanas, three (3) soil classes were identified. These are , sandy loam, clay, and undifferentiated soil. Moreover, five (5)land cover classes were identified. These are open and closed forest, forest plantation, shrubland, and grassland.

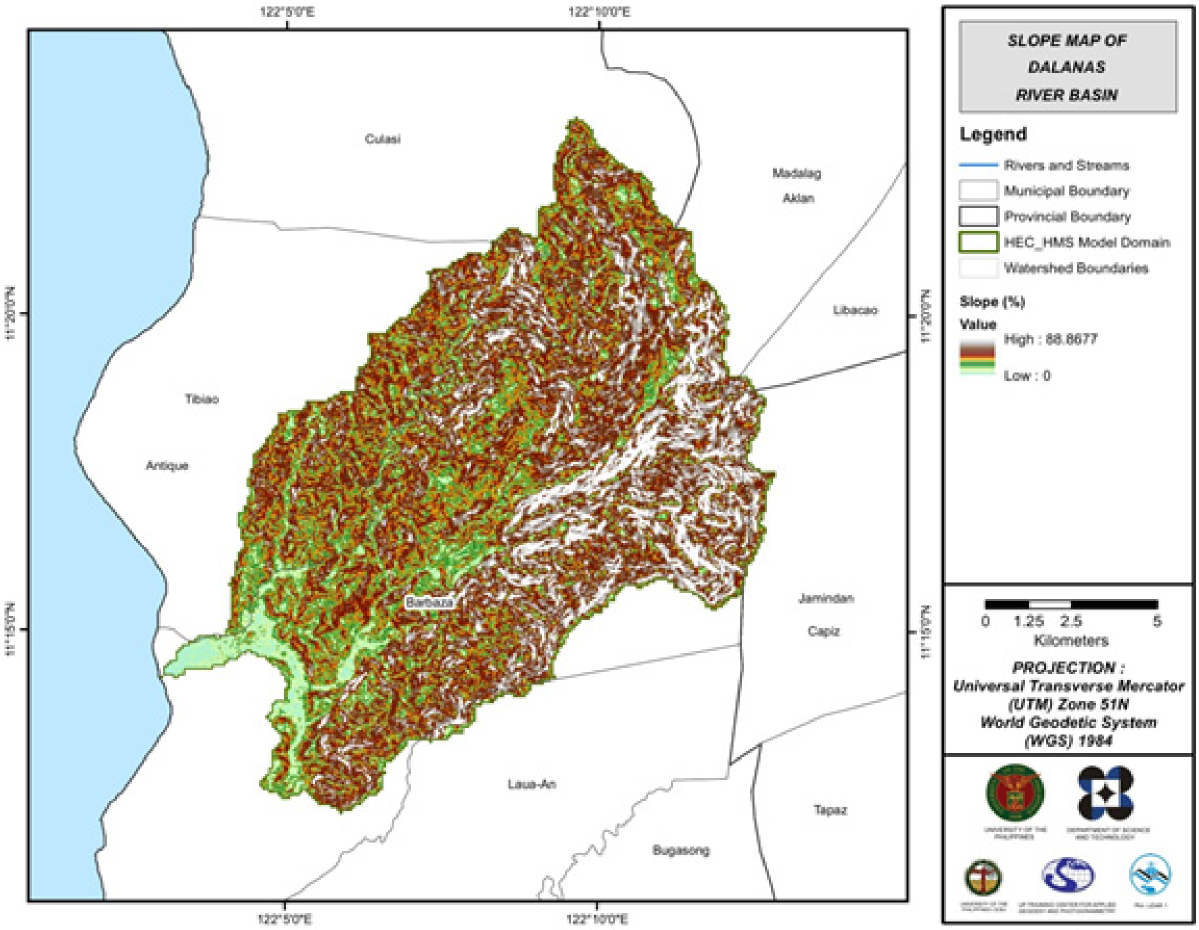


Figure 49. Slope map of the Dalanas River Basin

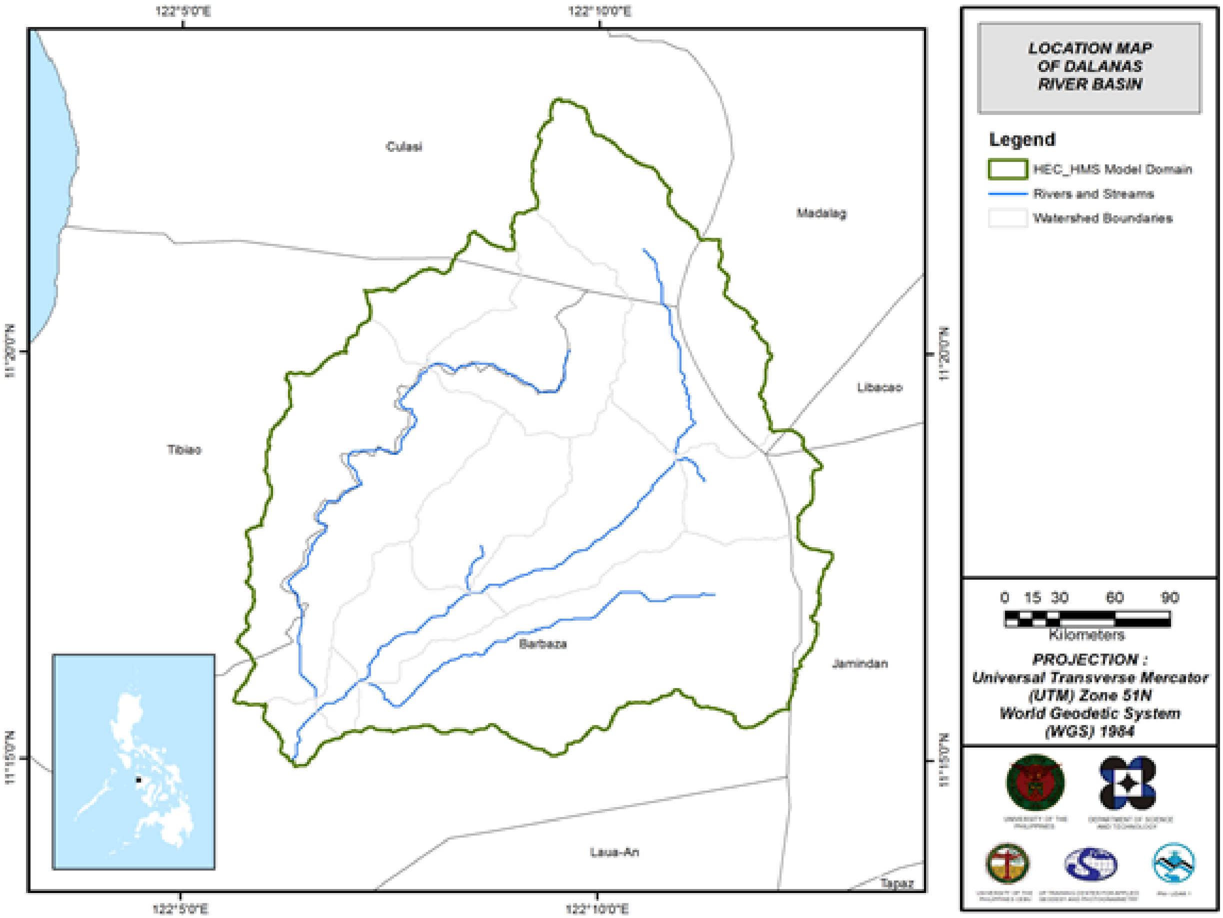


Figure 50. Stream Delineation Map of the Dalanas River Basin

Using the SAR-based DEM, the Dalanas basin was delineated and further subdivided into subbasins. The model consists of 11 sub basins, 5 reaches, and 5 junctions as shown in Figure 7. The main outlet is at Brgy. Biga-a Bridge.

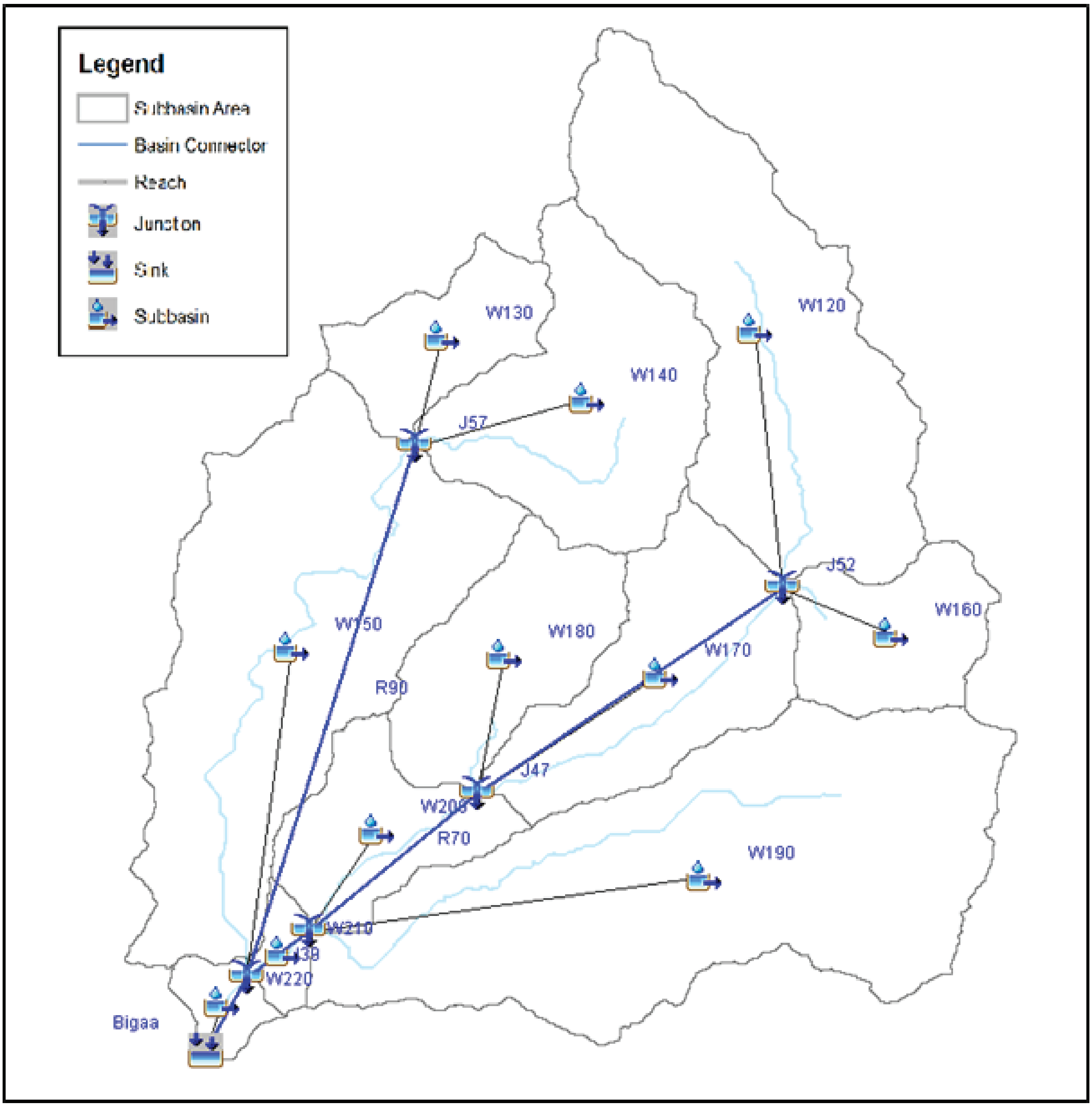


Figure 51. The Dalanas river basin model generated using HEC-HMS

5.4 Cross-section Data

The riverbed cross-sections of the watershed (Figure 52) are necessary in the HEC-RAS model setup. The cross-section data for the HEC-RAS model was derived from the LiDAR DEM data. It was defined using the Arc GeoRAS tool and was post-processed in ArcGIS.

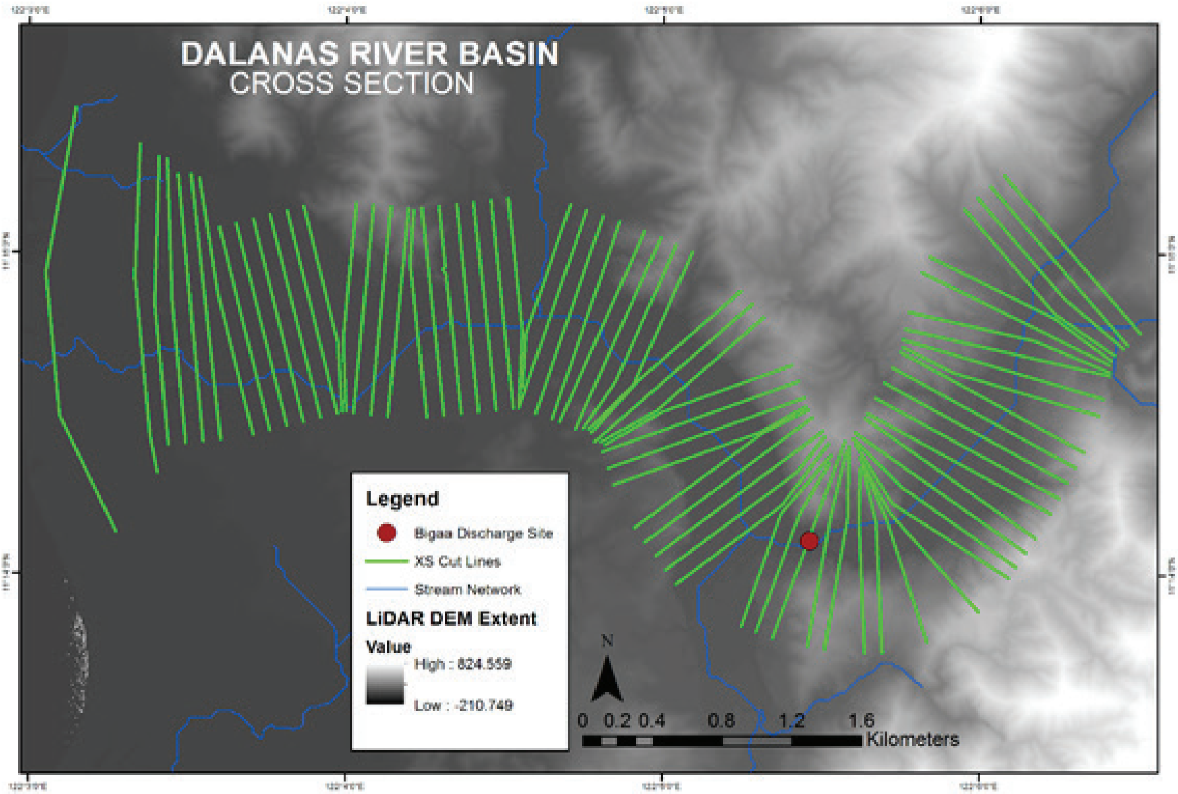


Figure 52. River cross-section of Dalanas River generated through Arcmap HEC GeoRAS tool

5.5 Flo 2D Model

The automated modelling process allows the creation of a model with boundaries that are almost exactly coincidental with that of the catchment area (Figure 49). As such, they have approximately the same land area and location. The entire area is divided into square grid elements, each 10 by 10 meters 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, and southwest).

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

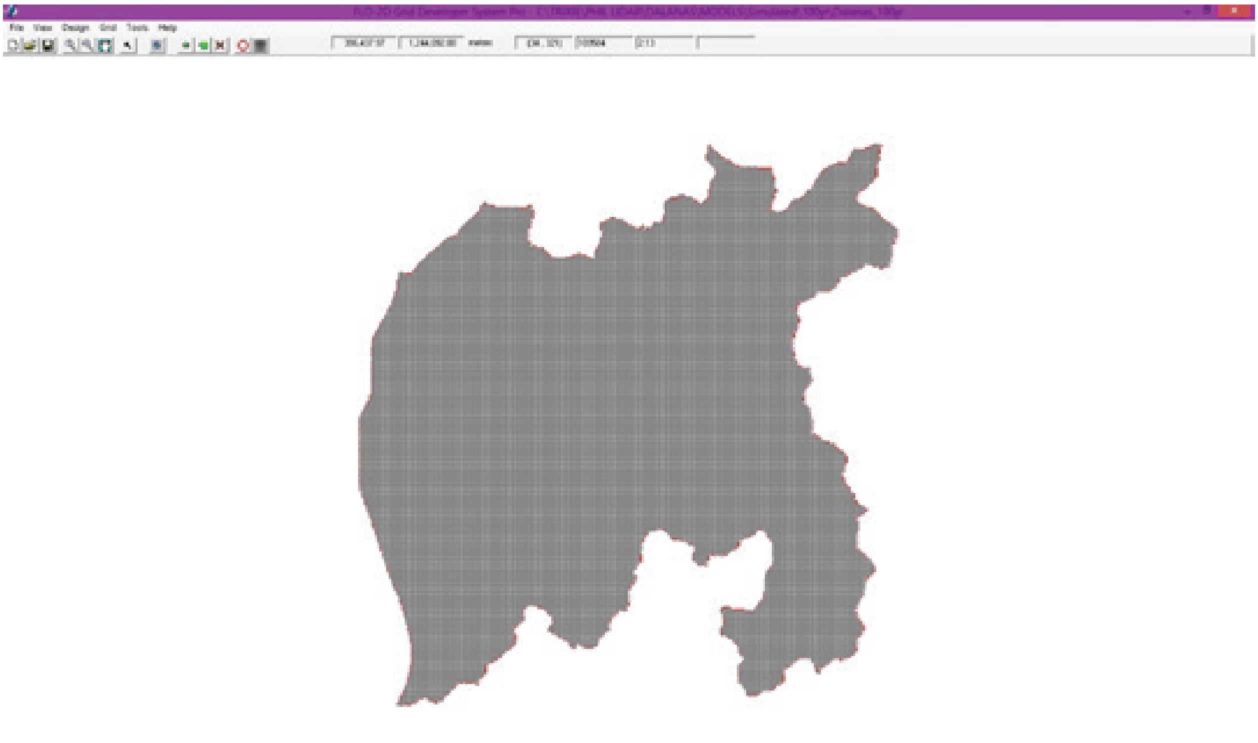


Figure 53. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro n of Dalanas River generated through Arcmap HEC GeoRAS tool

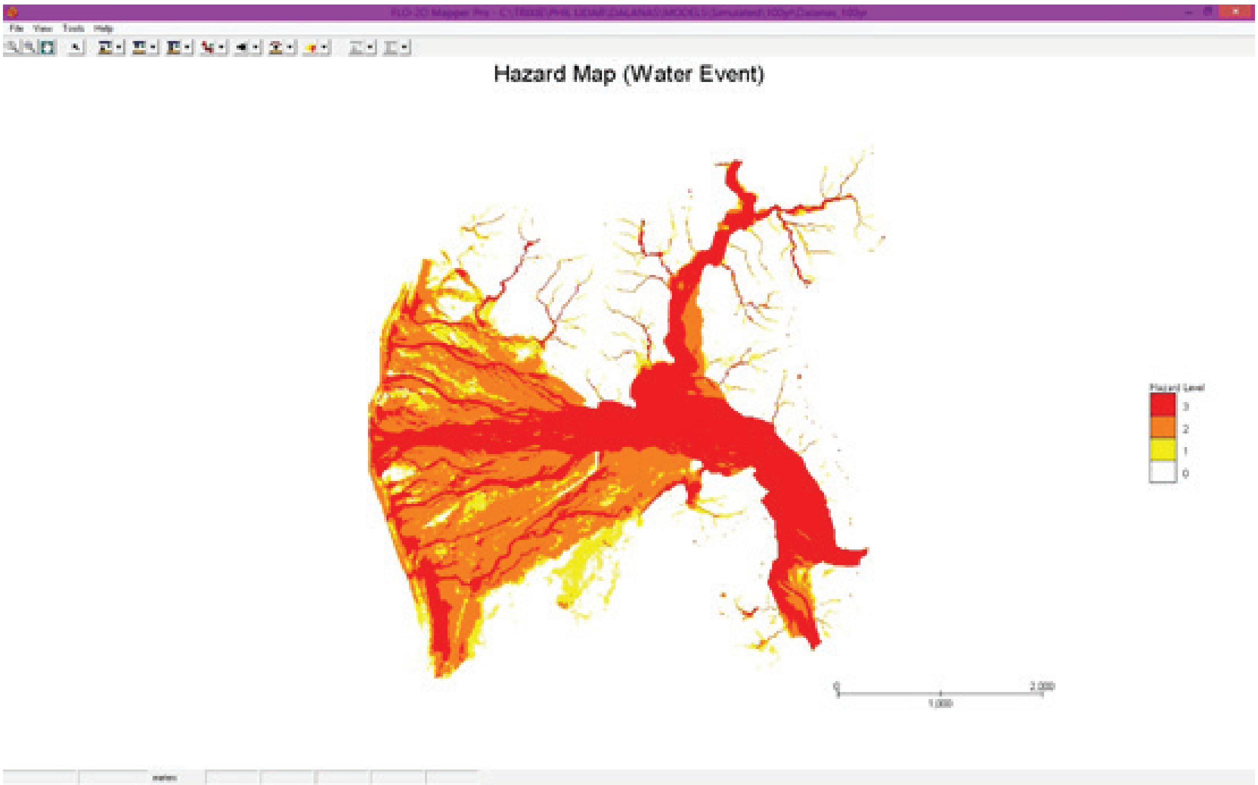


Figure 54. Generated 100-year rain return hazard map from FLO-2D Mapper

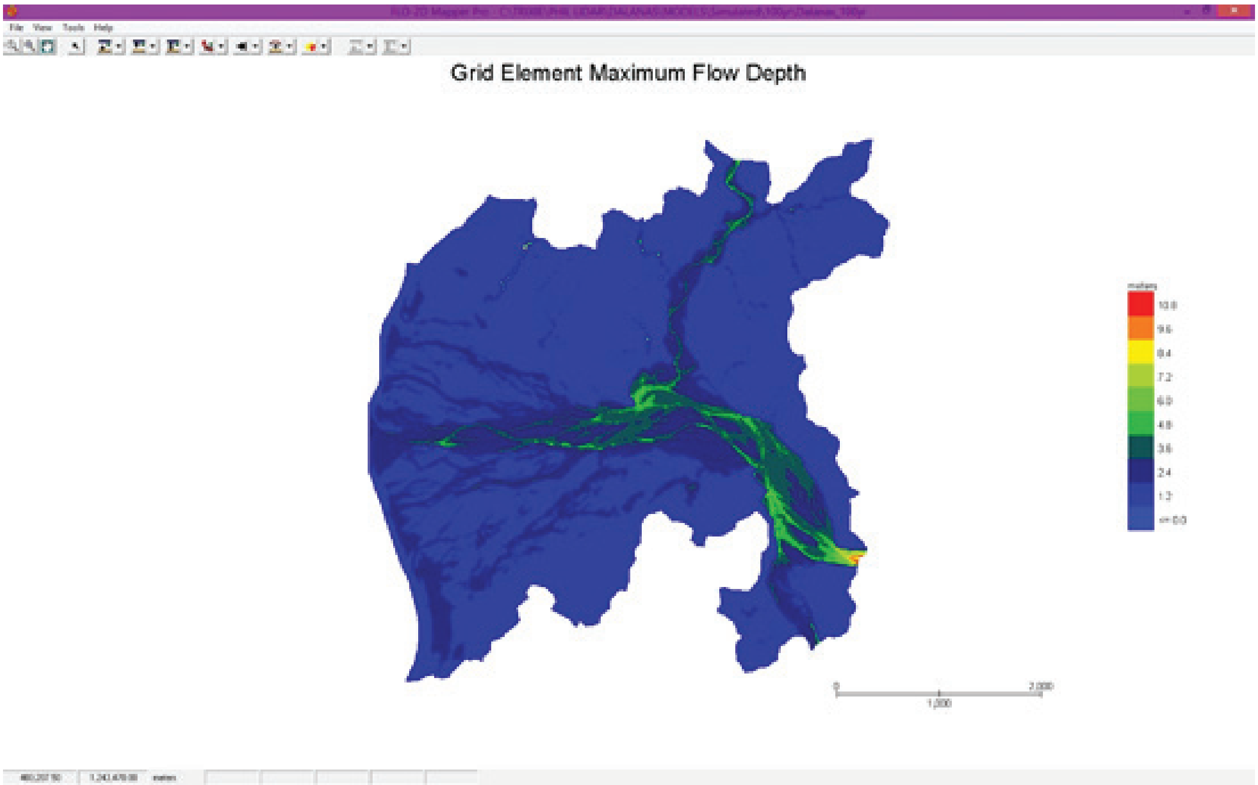


Figure 55. Generated 100-year rain return flow depth map from FLO-2D Mapper

5.6 Results of HMS Calibration

After calibrating the Dalanas HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 56 shows the comparison between the two discharge data.

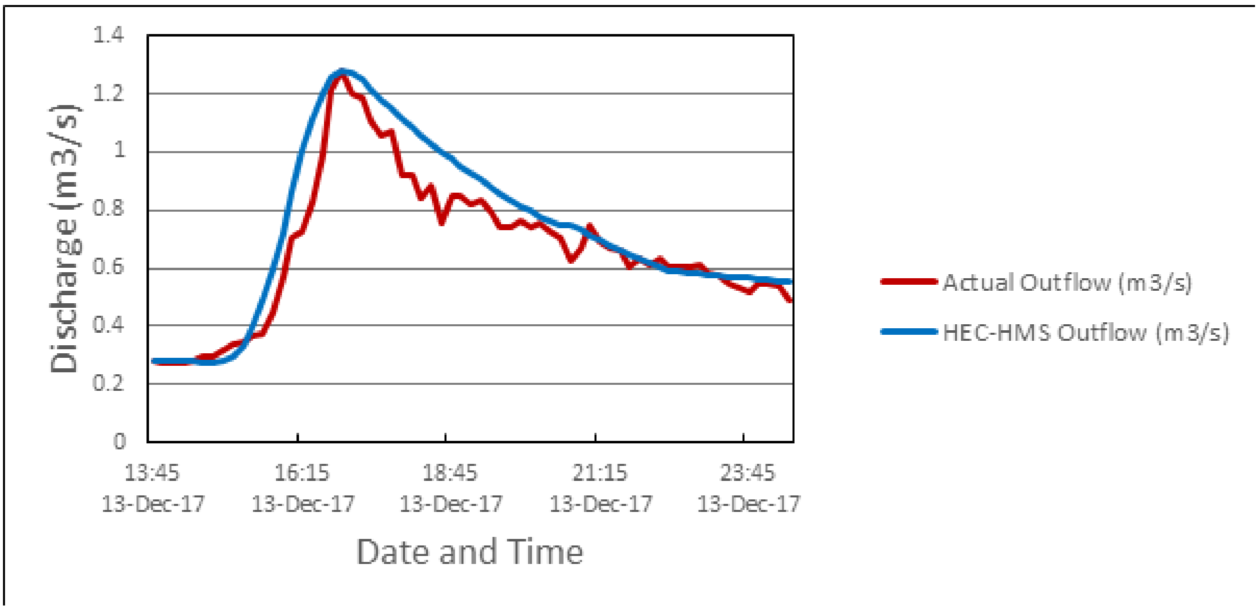


Figure 56. Outflow Hydrograph of Dalanas produced by the HEC-HMS model compared with observed outflow

Enumerated in Table 26 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 26. Range of Calibrated Values for Dalanas

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	1.8-5.9
			Curve Number	70.3-99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.62-2.94
			Storage Coefficient (hr)	1.3-6.4
	Baseflow	Recession	Recession Constant	0.5
			Ratio to Peak	0.35
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.018-0.077

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 1.8 mm to 5.9 mm means that there is minimal to average amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 70.3 to 99 for curve number is advisable for Philippine watersheds depending on the soil and land cover of the area. For Dalanas, the basin mostly consists of closed and open forests, forest plantation, and shrublands, and the soil consists of clay, sandy loam, and undifferentiated soils.

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 0.62 hours to 6.4 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant of 0.5 indicates that the basin is unlikely to quickly go back to its original discharge and instead, will be higher. Ratio to peak of 0.35 indicates a receding limb of the outflow hydrograph.

Manning’s roughness coefficient of 0.018-0.077 corresponds to the common roughness of Philippine watersheds. Dalanas river basin is determined to be predominantly excavated earth, with straight and uniform features like fishponds.

Table 27. Summary of the Efficiency Test of Dalanas HMS Model

RMS Error	0.1
r2	0.9687
NSE	0.84
RSR	-8.280
PBIAS	.40

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 0.1 (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 0.9687.

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 0.84.

A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate bias towards over-prediction. Again, the optimal value is 0. In the model, the PBIAS is 0.40.

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 -8.28.

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 57) shows the Dalanas outflow using the Iloilo 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 (PAG-ASA) data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

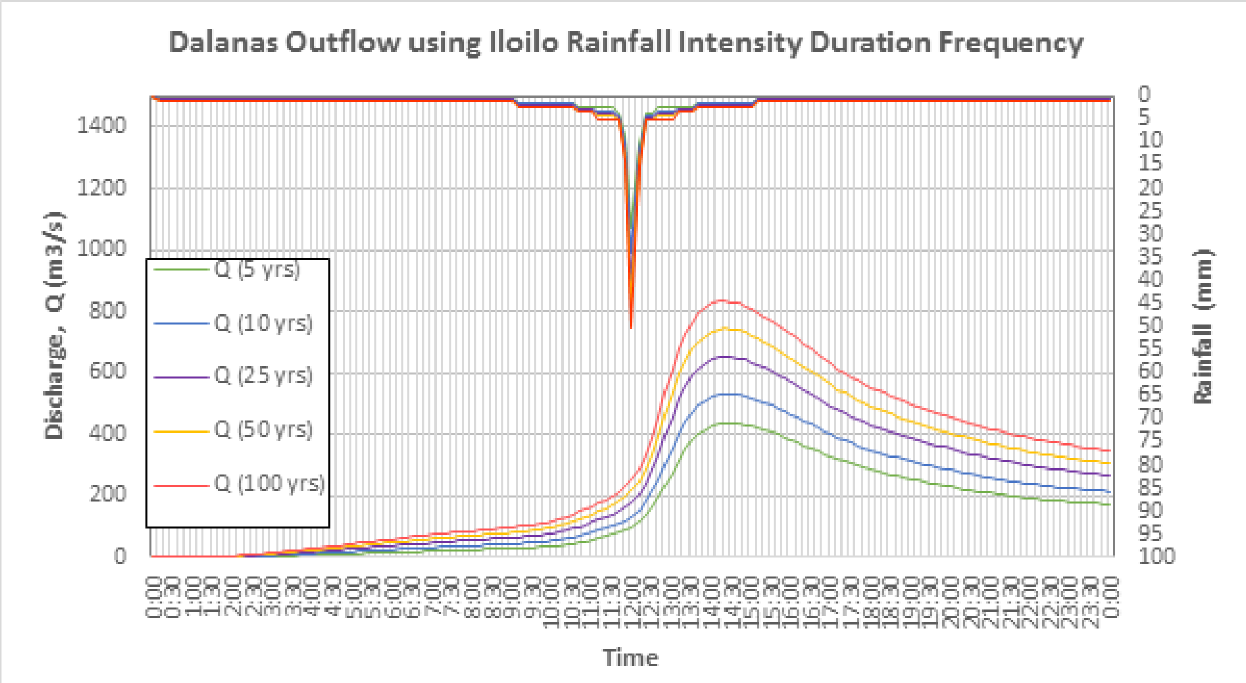


Figure 57. Outflow hydrograph at Dalanas Station generated using Iloilo RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of the Dalanas discharge using the Iloilo Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 28.

Table 28. Peak values of the Dalanas HEC-HMS Model outflow using the Iloilo RIDF

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	165.2	28.7	435.99	2 hours, 30 minutes
10-Year	198.9	33.9	531.43	2 hours, 20 minutes
25-Year	241.5	40.5	653.57	2 hours, 20 minutes
50-Year	273.1	45.4	743.86	2 hours, 20 minutes
100-Year	304.5	50.3	833.98	2 hours, 20 minutes

5.8 River Analysis Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. The sample generated map of Dalanas River using the calibrated HMS event flow is shown in Figure 54.

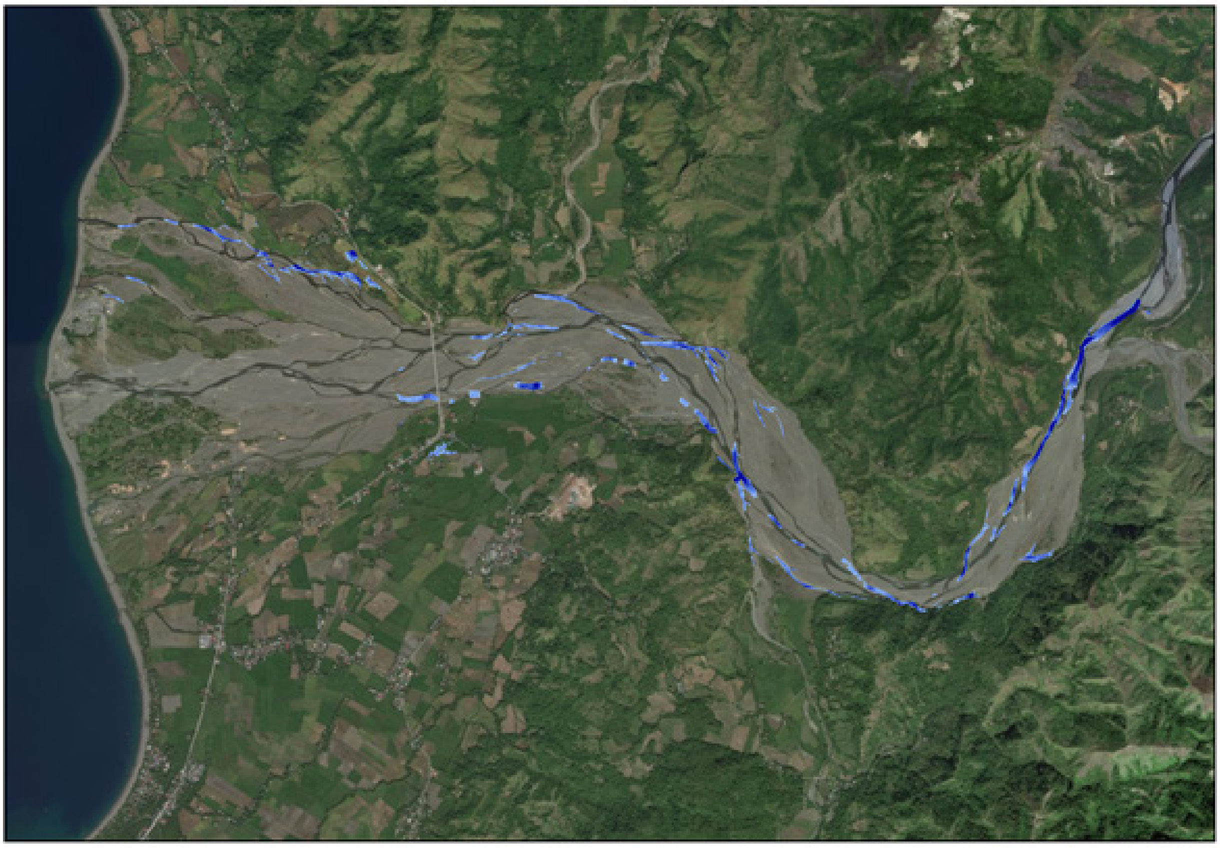


Figure 58. Sample output of Dalanas RAS Model

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. Figure 59 to Figure 64 shows the 5-, 25-, and 100-year rain return scenarios of the Dalanas floodplain.

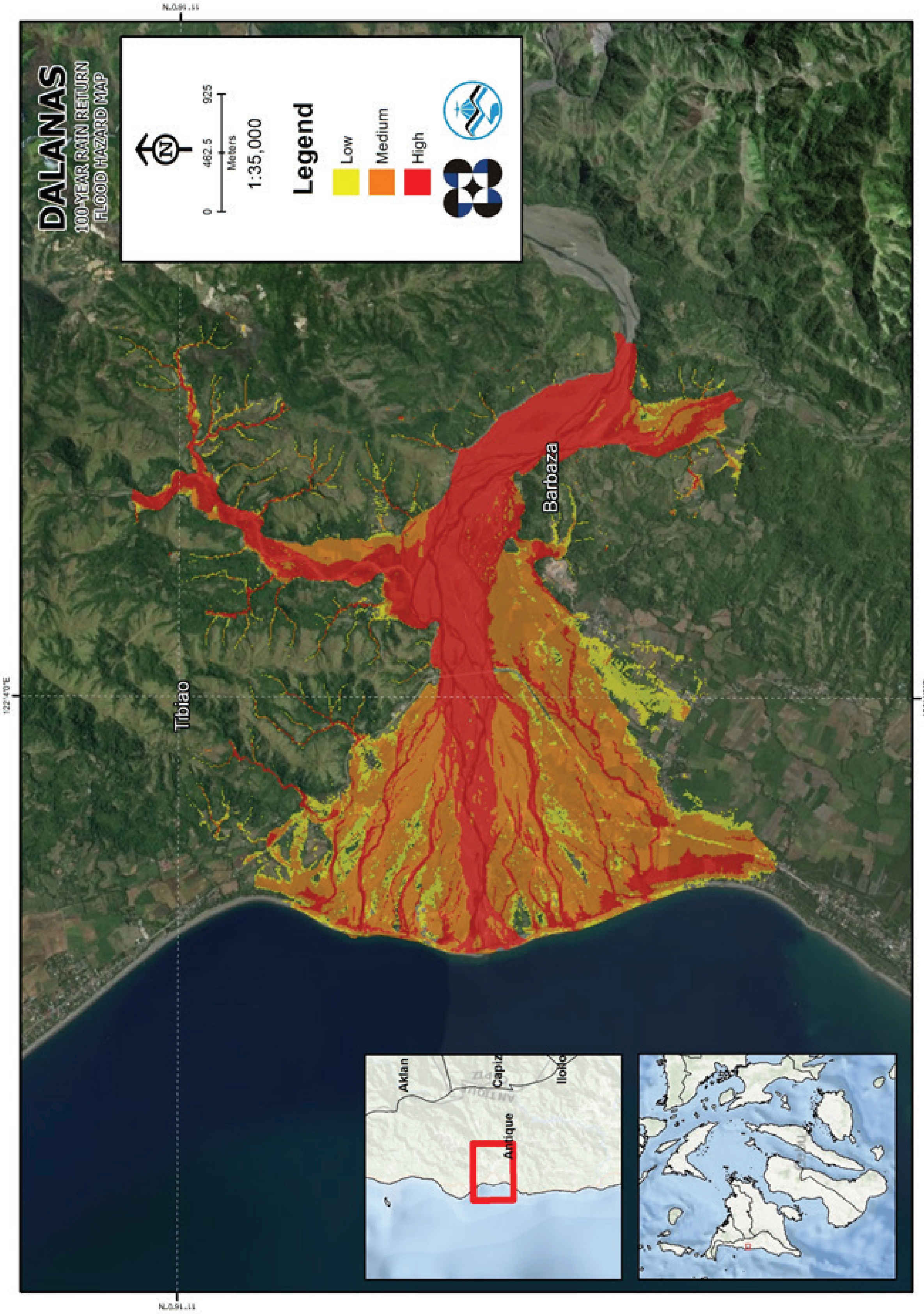


Figure 59. 100-year Flood Hazard Map for Dalanas Floodplain

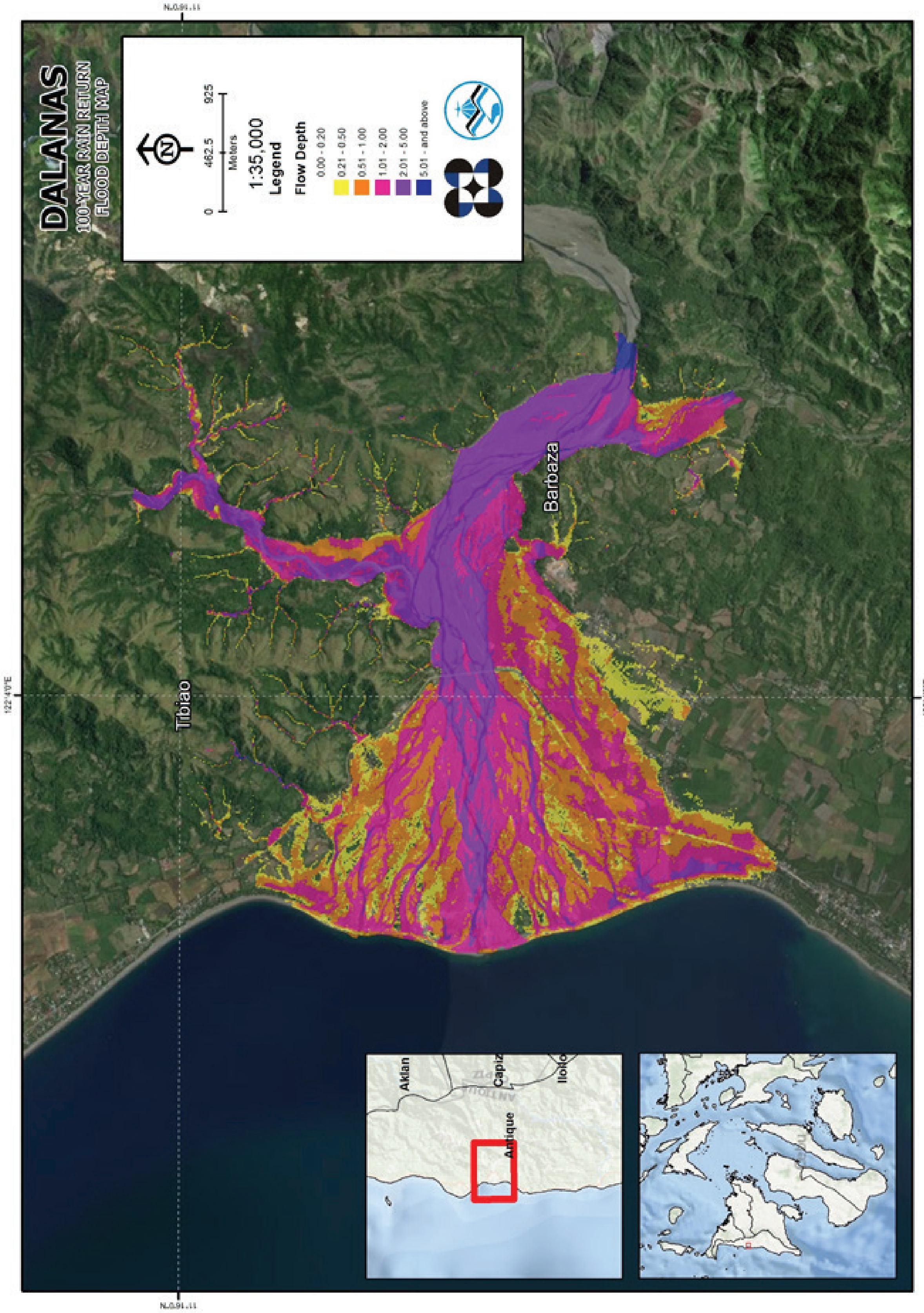


Figure 60. 100-year Flow Depth Map for Dalanas Floodplain

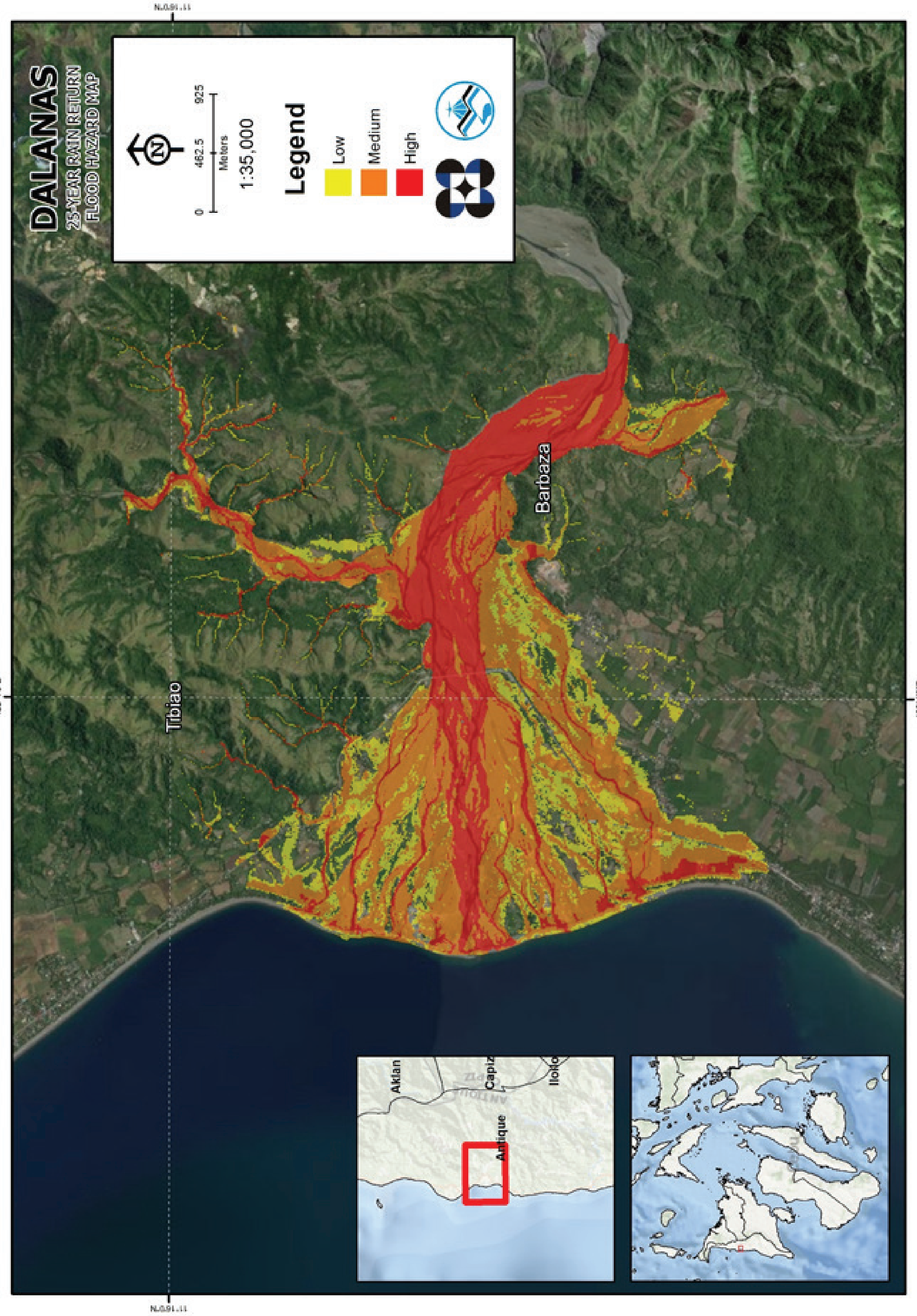


Figure 61. 25-year Flood Hazard Map for Dalanas Floodplain

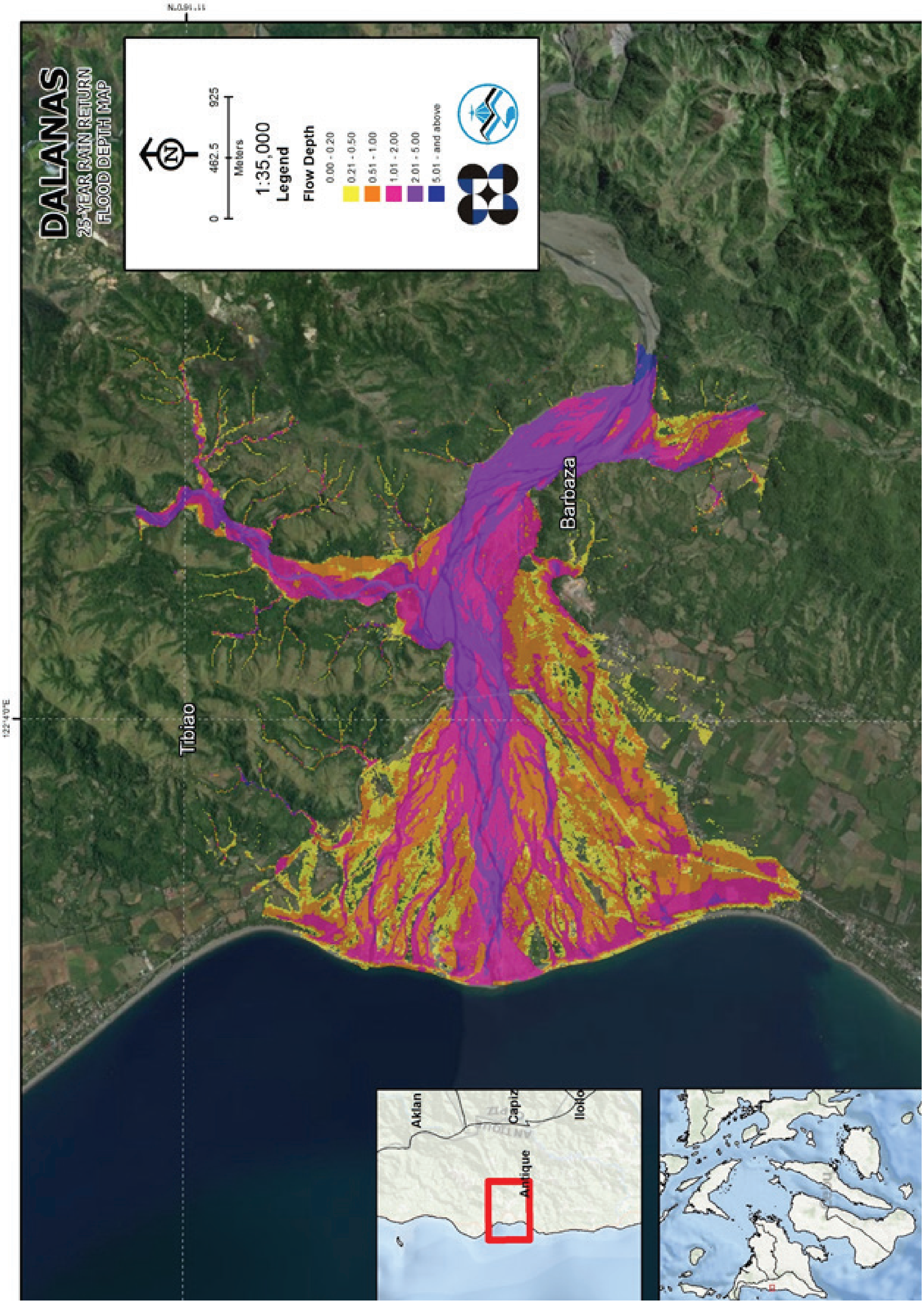


Figure 62. 25-year Flow Depth Map for Dalanas Floodplain

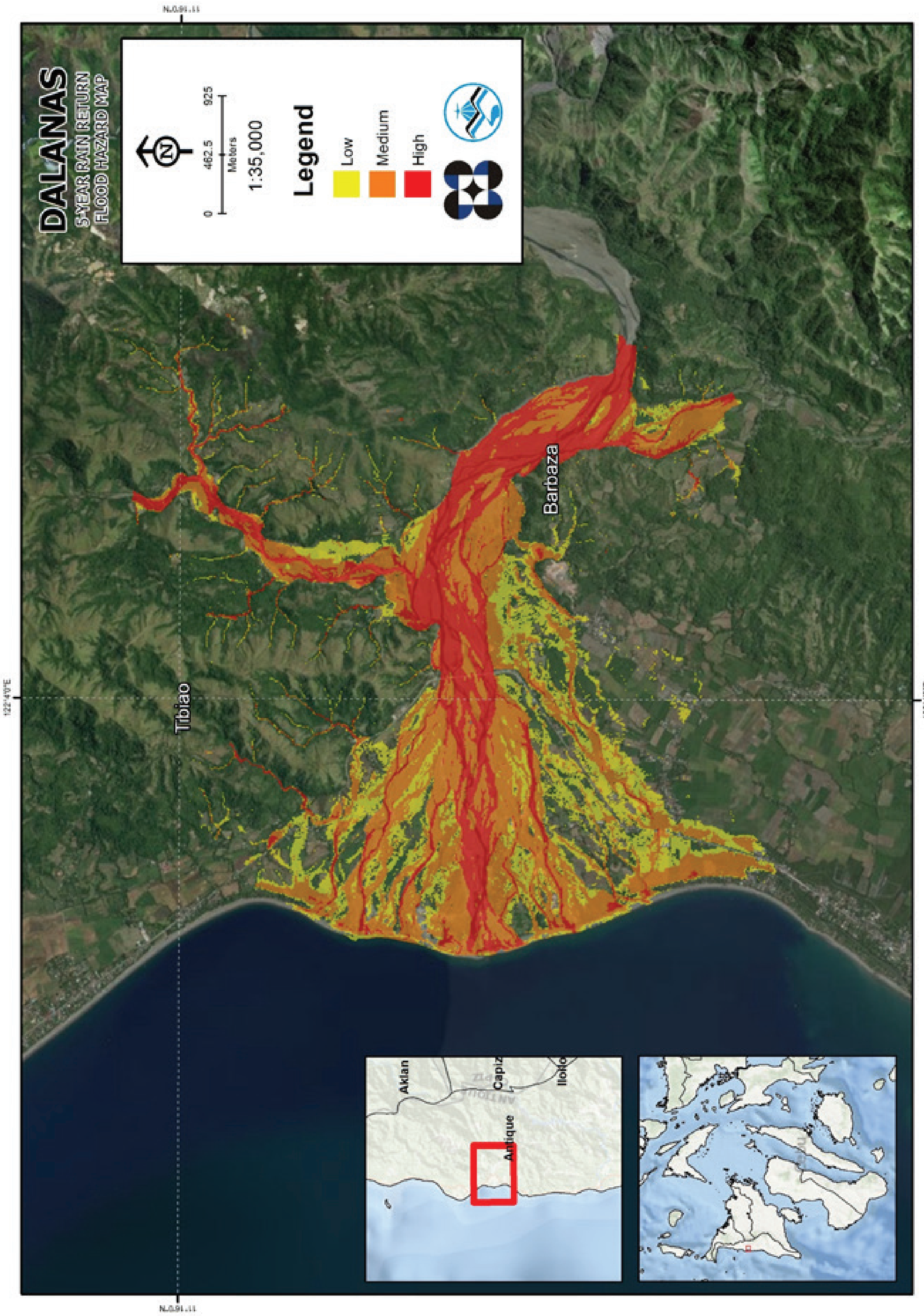


Figure 63. 5-year Flood Hazard Map for Dalanas Floodplain

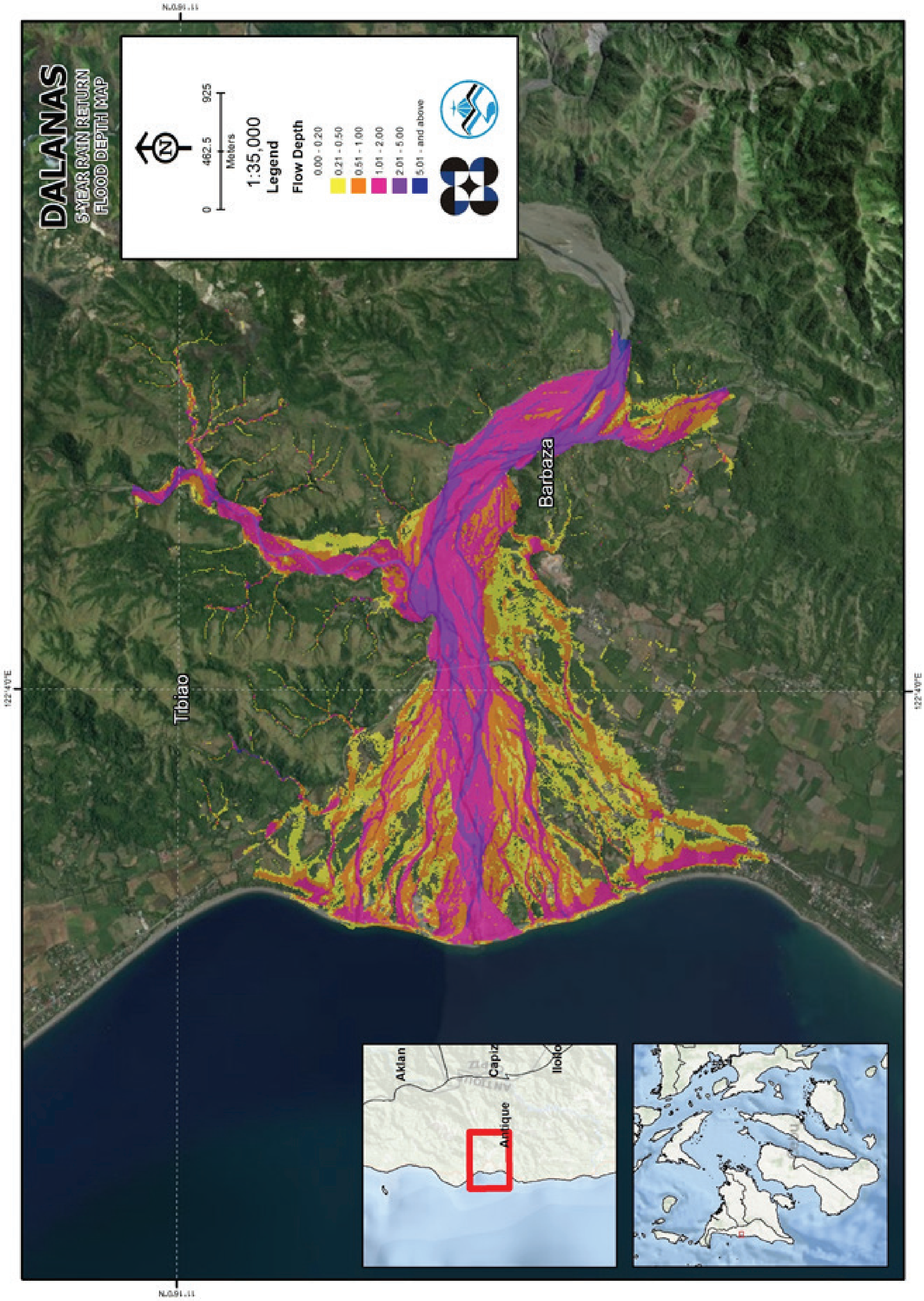


Figure 64. 5-year Flood Depth Map for Dalanas Floodplain

5.10 Inventory of Areas Exposed to Flooding

Affected barangays in the Dalanas river basin, grouped by municipality, are listed below. For the said basin, two municipalities consisting of 16 barangays are expected to experience flooding when subjected to 5-yr rainfall return period.

For the 5-year return period, 3.33% of the municipality of Barbaza with an area of 176.52 sq. km. will experience flood levels of less 0.20 meters. 0.8% of the area will experience flood levels of 0.21 to 0.50 meters while 0.86%, 1.26%, 0.51%, and 0.005% 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 29 are the affected areas in square kilometres by flood depth per barangay.

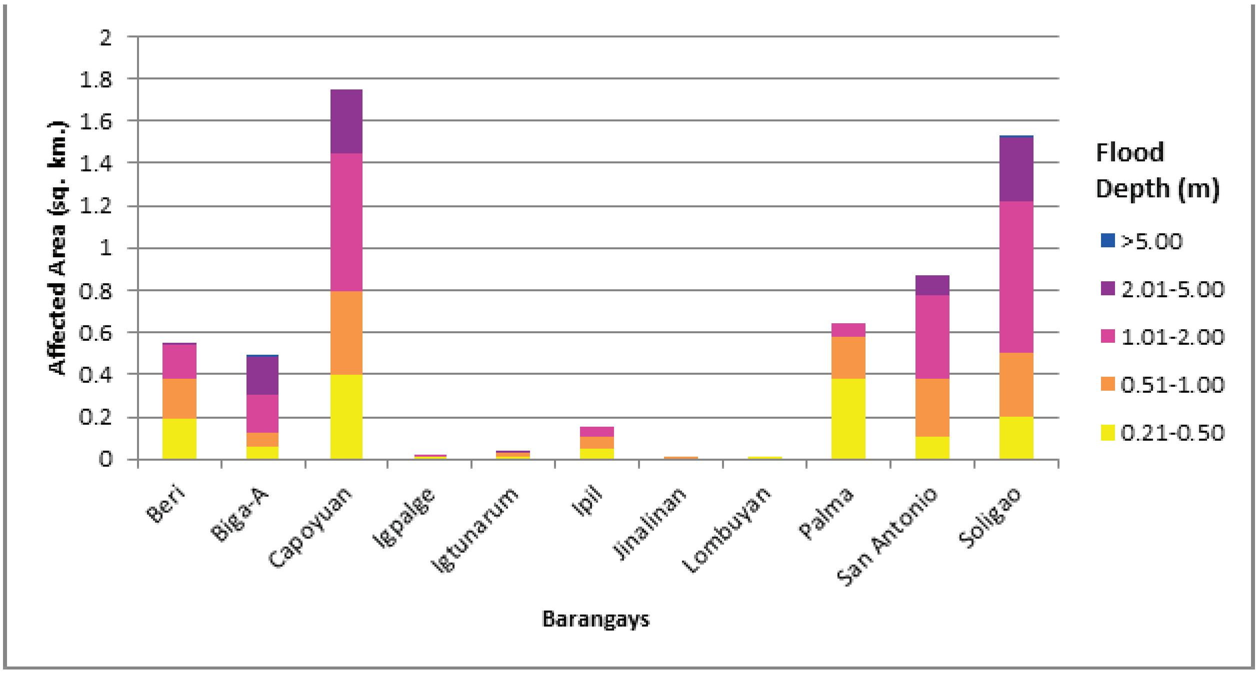


Figure 65. Affected Areas in Barbaza, Antique during 5-Year Rainfall Return Period

Table 29. Affected Areas in Barbaza, Antique during 5-Year Rainfall Return Period

Affected Areas (in sq. km.) by flood depth (in m.)	Affected Barangays in Barbaza					
	Beri	Biga-A	Capoyuan	Igpalge	Igtunarum	Ipil
0.03-0.20	0.25	0.44	0.54	0.29	0.4	0.21
0.21-0.50	0.19	0.055	0.4	0.011	0.016	0.052
0.51-1.00	0.19	0.072	0.4	0.00024	0.01	0.057
1.01-2.00	0.16	0.18	0.65	0.0002	0.0065	0.043
2.01-5.00	0.0062	0.18	0.3	0	0.0011	0
> 5.00	0	0.0089	0	0	0	0
Affected Areas (in sq. km.) by flood depth (in m.)						
	Jinalinan	Lomabuyan	Palma	San Antonio	Soligao	
0.03-0.20	0.025	0.00063	0.88	0.053	2.79	
0.21-0.50	0.0022	0.0001	0.38	0.1	0.2	
0.51-1.00	0.0009	0	0.2	0.28	0.3	
1.01-2.00	0	0	0.073	0.39	0.72	
2.01-5.00	0	0	0	0.096	0.31	
> 5.00	0	0	0	0	0.00018	

For the municipality of Tibiao, with an area of 99.87 sq. km., 3.86% will experience flood levels of less 0.20 meters. 0.56% of the area will experience flood levels of 0.21 to 0.50 meters while 0.53%, 0.30%, 0.04%, and 0.002% 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 30 are the affected areas in square kilometres by flood depth per barangay.

Table 30. Affected Areas in Tibiao, Antique during 5-Year Rainfall Return Period

Affected Areas (in sq. km.) by flood depth (in m.)	Affected Barangays in Tibiao				
	Alegre	Castillo	Esparagoza	Santa Ana	Santo Rosario
0.03-0.20	0.0033	0.39	2.19	0.51	0.74
0.21-0.50	0	0.013	0.12	0.31	0.11
0.51-1.00	0	0.012	0.089	0.36	0.056
1.01-2.00	0	0.025	0.048	0.19	0.033
2.01-5.00	0	0.02	0.0097	0.0096	0.0028
> 5.00	0	0	0.0002	0.0002	0.0011

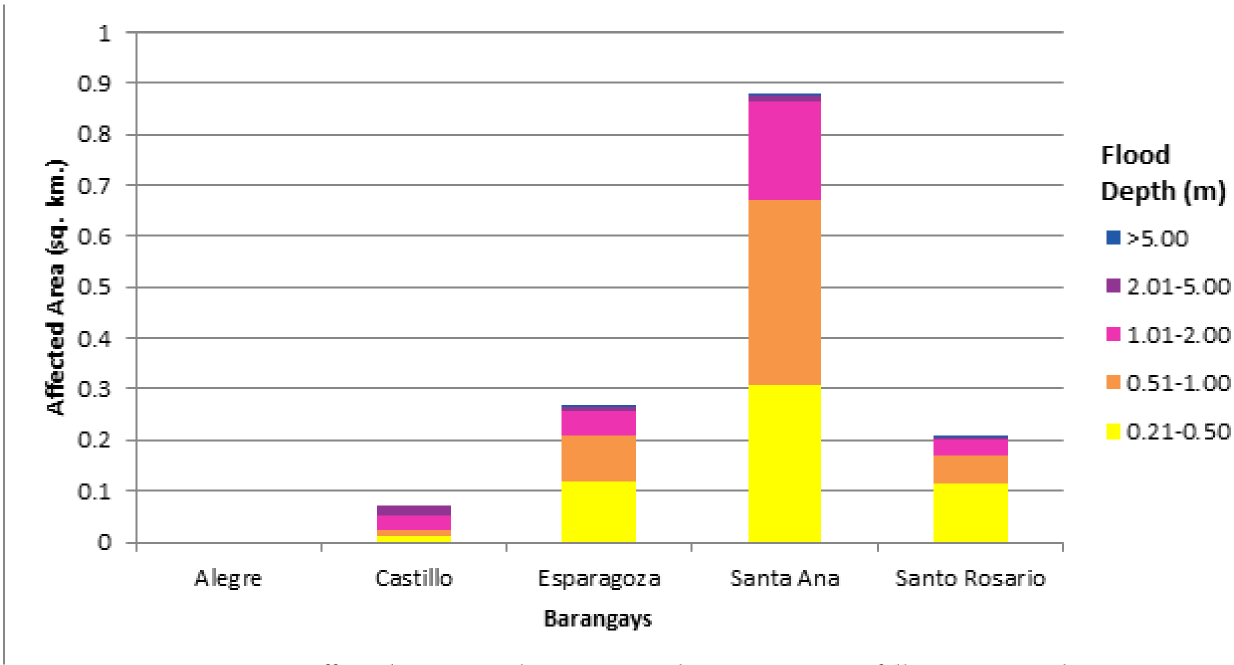


Figure 66. Affected Areas in Tibiao, Antique during 5-Year Rainfall Return Period

For the 25-year return period, 2.75% of the municipality of Barbaza with an area of 176.52 sq. km. will experience flood levels of less 0.20 meters. 0.55% of the area will experience flood levels of 0.21 to 0.50 meters while 1.12%, 1.42%, 0.9%, and 0.016% 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 31 are the affected areas in square kilometres by flood depth per barangay.

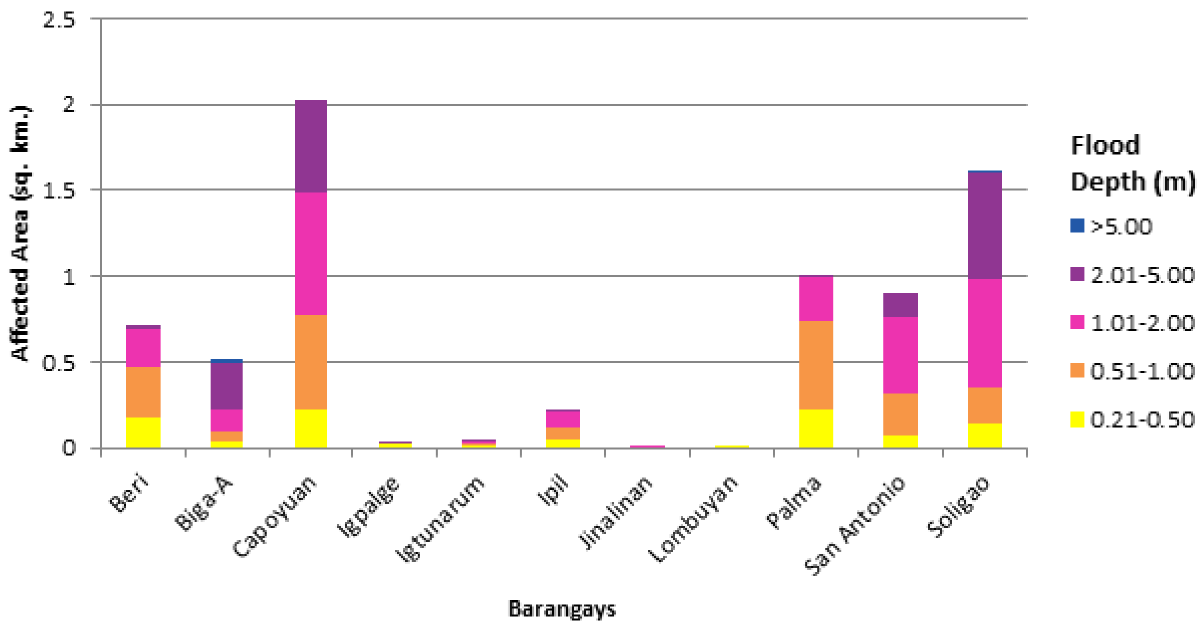


Figure 67. Affected Areas in Barbaza, Antique during 25-Year Rainfall Return Period

Table 31. Affected Areas in Barbaza, Antique during 25-Year Rainfall Return Period

Affected Areas (in sq. km.) by flood depth (in m.)	Affected Barangays in Barbaza					
	Beri	Biga-A	Capoyuan	Igpalge	Igtunarum	Ipil
0.03-0.20	0.081	0.42	0.27	0.27	0.39	0.15
0.21-0.50	0.18	0.04	0.22	0.026	0.018	0.047
0.51-1.00	0.3	0.051	0.56	0.003	0.013	0.078
1.01-2.00	0.22	0.14	0.71	0.0001	0.01	0.088
2.01-5.00	0.017	0.26	0.54	0.0002	0.0026	0.0013
> 5.00	0	0.026	0	0	0	0
Affected Areas (in sq. km.) by flood depth (in m.)	Jinalinan	Lomabuyan	Palma	San Antonio	Soligao	
0.03-0.20	0.023	0.00063	0.52	0.022	2.7	
0.21-0.50	0.0025	0.0001	0.23	0.07	0.14	
0.51-1.00	0.0023	0	0.51	0.25	0.21	
1.01-2.00	0.000084	0	0.25	0.45	0.63	
2.01-5.00	0	0	0.013	0.13	0.63	
> 5.00	0	0	0	0	0.0013	

For the municipality of Tibiao, with an area of 99.87 sq. km., 3.86% will experience flood levels of less 0.20 meters. 0.56% of the area will experience flood levels of 0.21 to 0.50 meters while 0.53%, 0.30%, 0.04%, and 0.002% 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 32 are the affected areas in square kilometres by flood depth per barangay.

Table 32. Affected Areas in Tibiao, Antique during 25-Year Rainfall Return Period

Affected Areas (in sq. km.) by flood depth (in m.)	Affected Barangays in Tibiao					
	Alegre	Castillo	Esparagoza	Santa Ana	Santo Rosario	Ipil
0.03-0.20	0.0033	0.38	2.13	0.35	0.7	0.150168
0.21-0.50	0	0.012	0.11	0.25	0.11	0.046577
0.51-1.00	0	0.011	0.1	0.44	0.085	0.077968
1.01-2.00	0	0.018	0.087	0.32	0.051	0.088071
2.01-5.00	0	0.036	0.019	0.023	0.0024	0.001262
> 5.00	0	0	0.0006	0.0005	0.0019	0

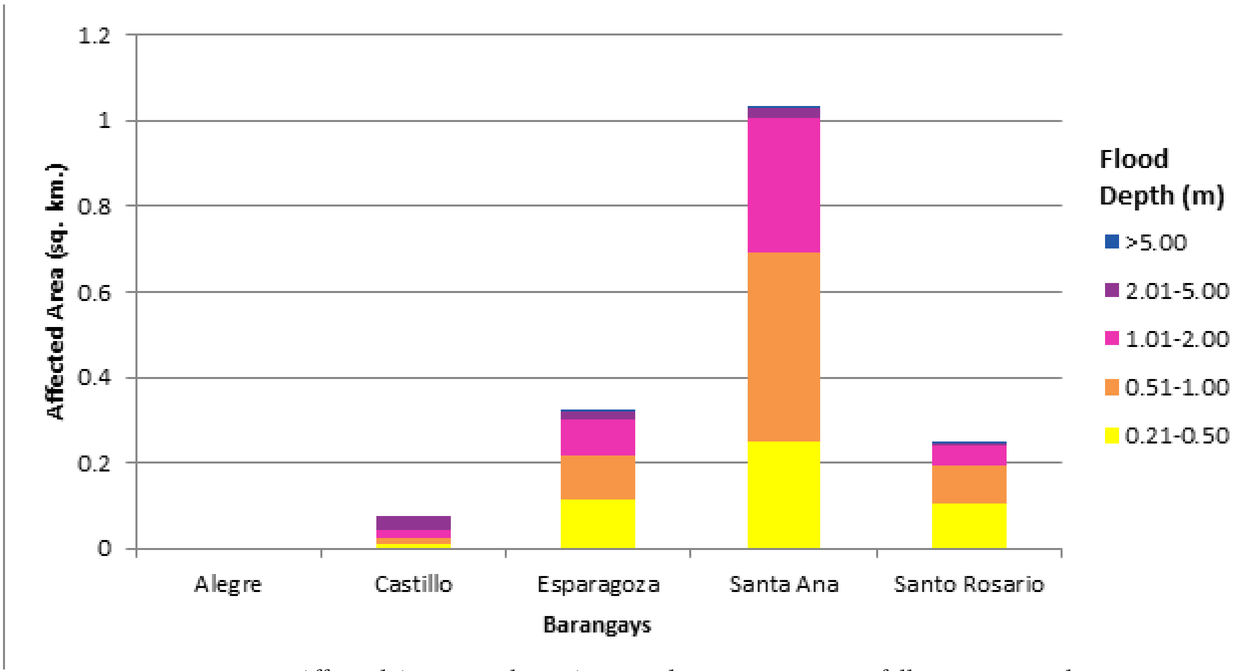


Figure 68. Affected Areas in Tibiao, Antique during 25-Year Rainfall Return Period

For the 100-year return period, 2.54% of the municipality of Barbaza with an area of 176.52 sq. km. will experience flood levels of less 0.43 meters. 0.55% of the area will experience flood levels of 0.21 to 0.50 meters while 0.98%, 1.55%, 1.22%, 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 33 are the affected areas in square kilometres by flood depth per barangay.

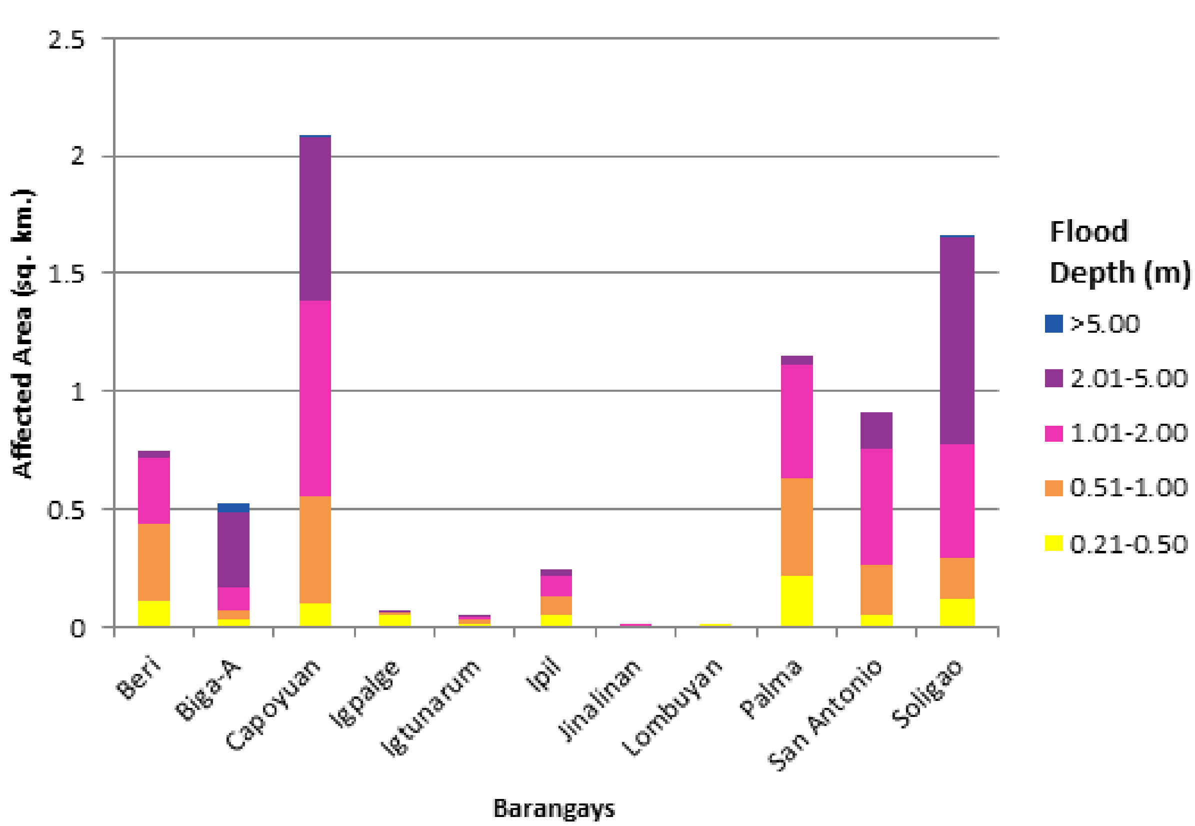


Figure 69. Affected Areas in Barbaza, Antique during 100-Year Rainfall Return Period

Table 33. Affected Areas in Barbaza, Antique during 100-Year Rainfall Return Period

Affected Areas (in sq. km.) by flood depth (in m.)	Affected Barangays in Barbaza					
	Beri	Biga-A	Capoyuan	Igpalge	Igtunarum	Ipil
0.03-0.20	0.046	0.41	0.22	0.24	0.38	0.12
0.21-0.50	0.11	0.031	0.11	0.056	0.018	0.05
0.51-1.00	0.33	0.045	0.45	0.0071	0.016	0.078
1.01-2.00	0.28	0.09	0.83	0.00029	0.012	0.092
2.01-5.00	0.03	0.32	0.7	0.0002	0.0036	0.021
> 5.00	0	0.039	0.0007	0	0	0
Affected Areas (in sq. km.) by flood depth (in m.)	**Jinalinan**	**Lomabuyan**	**Palma**	**San Antonio**	**Soligao**	
0.03-0.20	0.022	0.00063	0.37	0.014	2.66	
0.21-0.50	0.0021	0.0001	0.22	0.052	0.12	
0.51-1.00	0.0033	0	0.41	0.22	0.17	
1.01-2.00	0.0002	0	0.47	0.49	0.48	
2.01-5.00	0	0	0.046	0.16	0.88	
> 5.00	0	0	0	0	0.0029	

For the municipality of Tibiao, with an area of 99.87 sq. km., 3.48% will experience flood levels of less 0.20 meters. 0.43% of the area will experience flood levels of 0.21 to 0.50 meters while 0.68%, 0.61%, 0.11%, and 0.004% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 34 are the affected areas in square kilometres by flood depth per barangay.

Table 34. Affected Areas in Tibiao, Antique during 100-Year Rainfall Return Period

Affected Areas (in sq. km.) by flood depth (in m.)	Affected Barangays in Tibiao				
	Alegre	Castillo	Esparagoza	Santa Ana	Santo Rosario
0.03-0.20	0.0033	0.37	2.1	0.29	0.67
0.21-0.50	0	0.013	0.1	0.2	0.1
0.51-1.00	0	0.0096	0.11	0.45	0.1
1.01-2.00	0	0.019	0.11	0.41	0.064
2.01-5.00	0	0.041	0.029	0.032	0.0032
> 5.00	0	0	0.0008	0.0007	0.0024

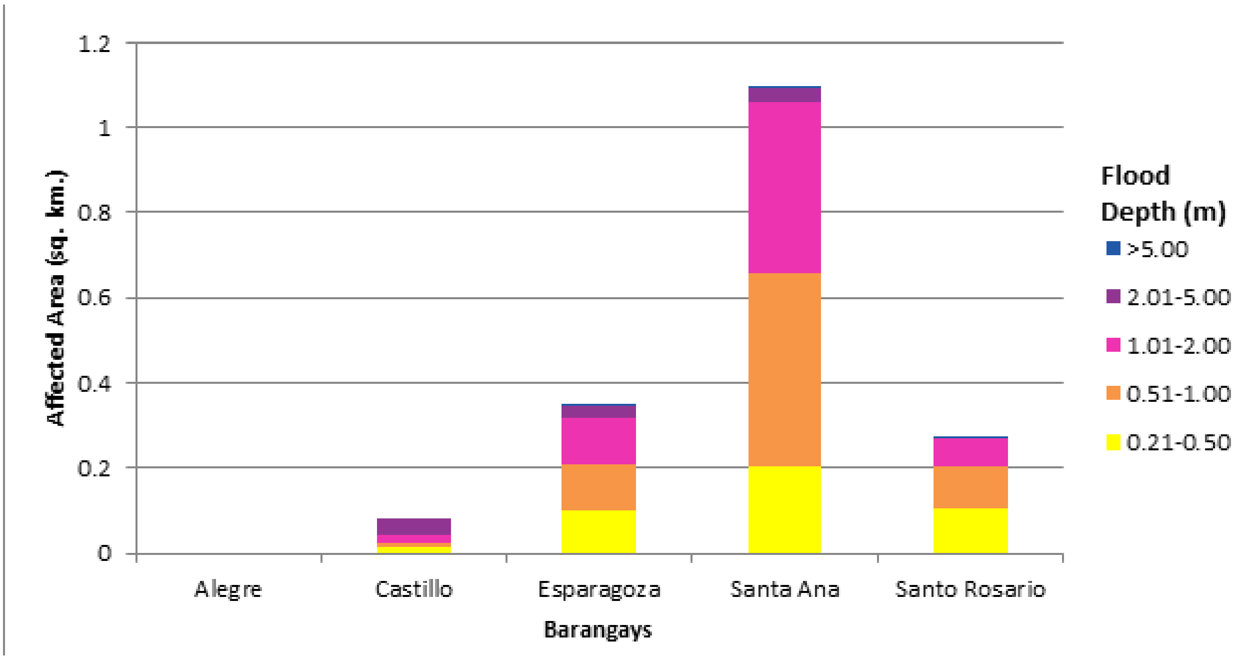


Figure 70. Affected Areas in Tibiao, Antique during 100-Year Rainfall Return Period

Among the barangays in the municipality of Barbaza, Soligao is projected to have the highest percentage of area that will experience flood levels at 2.44%. Meanwhile, Palma posted the second highest percentage of area that may be affected by flood depths at 0.52%.

Among the barangays in the municipality of Tibiao, Esparagoza is projected to have the highest percentage of area that will experience flood levels at 2.48%. Meanwhile, Santa Ana posted the second highest percentage of area that may be affected by flood depths at 1.4%.

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

Table 35. Area covered by each warning level with respect to the rainfall scenario

Warning Level	Area Covered in sq. km.		
	5 year	25 year	100 year
Low	1.94	1.79	1.15
Medium	3.47	3.95	4.29
High	2.13	2.56	3.84
TOTAL	**7.54**	**8.3**	**9.28**

Of the 10 identified education institutions in the Dalanas floodplain, two (2) schools were assessed to be exposed to the low-level flooding during a 5-year scenario. In the 25-year scenario, two (2) schools were assessed to be exposed to the low-level flooding while 2 schools were assessed to be exposed to medium-level flooding. For the 100-year scenario, four (4) schools were assessed for medium-level flooding.

Lastly, no medical or health institutions were assessed to be exposed to all flooding scenarios.

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 gathered 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 were identified for validation (Figure 71).

The validation personnel went to the specified points identified in the Dalanas river basin and gathered 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 by interviewing some residents with knowledge of or have had experienced flooding in a particular area. The flood validation points were obtained on December 13, 2016.

After which, the actual data from the field was 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 consisted of 244 points randomly selected all over the Dalanas Floodplain. It has an RMSE value of 1.69.

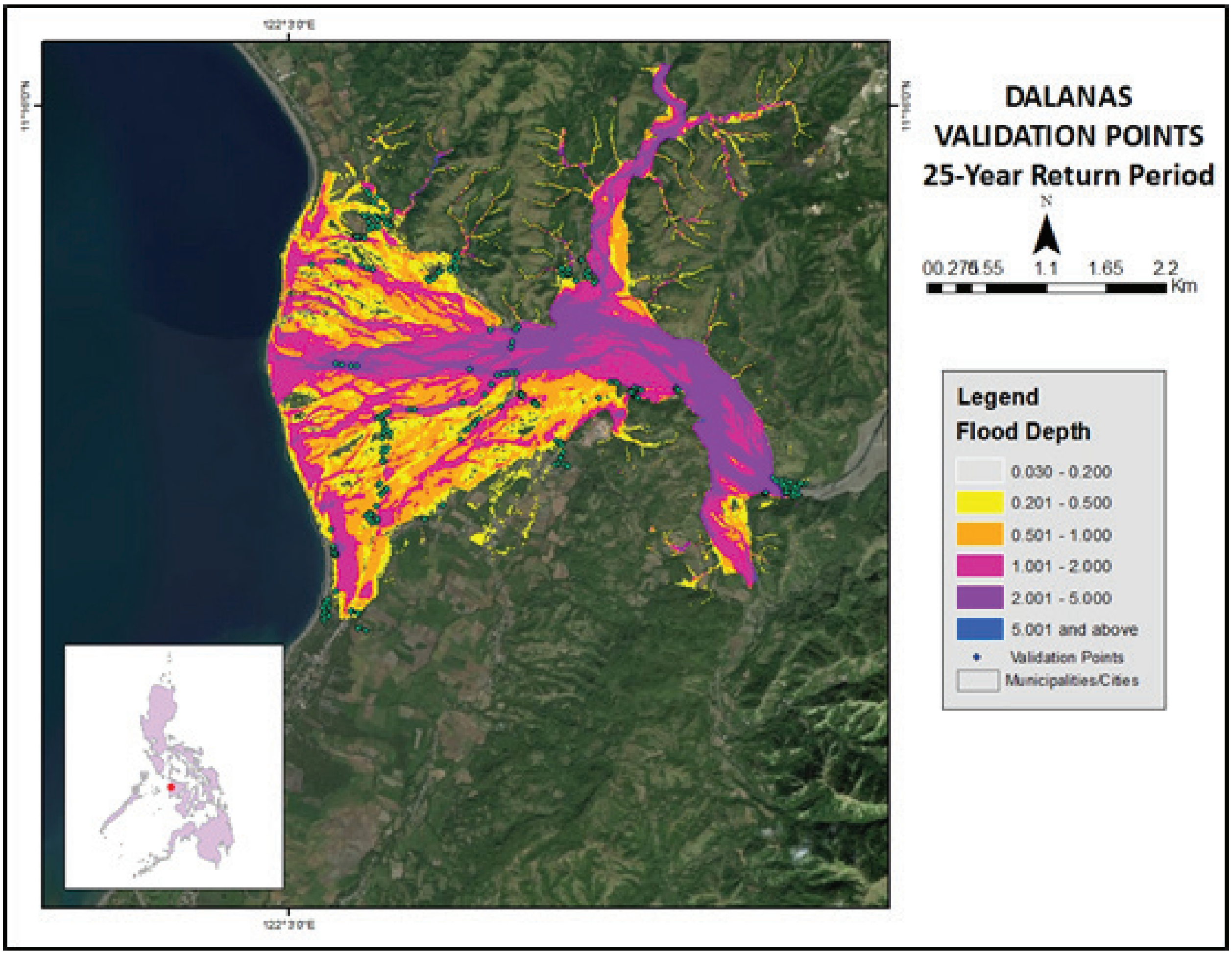


Figure 71. Validation points for 25-year Flood Depth Map of Dalanas Floodplain

Table 36. Actual Flood Depth vs Simulated Flood Depth in Dalanas

Actual Flood Depth (m)	Modeled Flood Depth (m)						
	0-0.20	0.21-0.50	0.51-1.00	1.01-2.00	2.01-5.00	> 5.00	Total
0-0.20	52	8	5	6	0	0	71
0.21-0.50	24	9	10	7	1	3	54
0.51-1.00	19	4	9	15	0	4	51
1.01-2.00	8	1	5	4	5	11	34
2.01-5.00	1	1	0	3	20	11	36
> 5.00	0	0	0	0	1	0	1
Total	104	23	29	35	27	29	247

The overall accuracy generated by the flood model is estimated at 38.06%, with 94 points correctly matching the actual flood depths. In addition, there were 86 points estimated one level above and below the correct flood depths while there were 38 points and 21 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 86 points were overestimated while a total of 67 points were underestimated in the modelled flood depths of Dalanas (Table 37).

Table 37. Summary of Accuracy Assessment in Dalanas River Basin Survey

	No. of Points	%
Correct	94	38.06
Overestimated	86	34.82
Underestimated	67	27.13
Total	247	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.

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

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

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

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

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

ANNEXES

Annex 1. Technical Specifications of LiDAR Sensors Used in the Dalanas Floodplain Survey

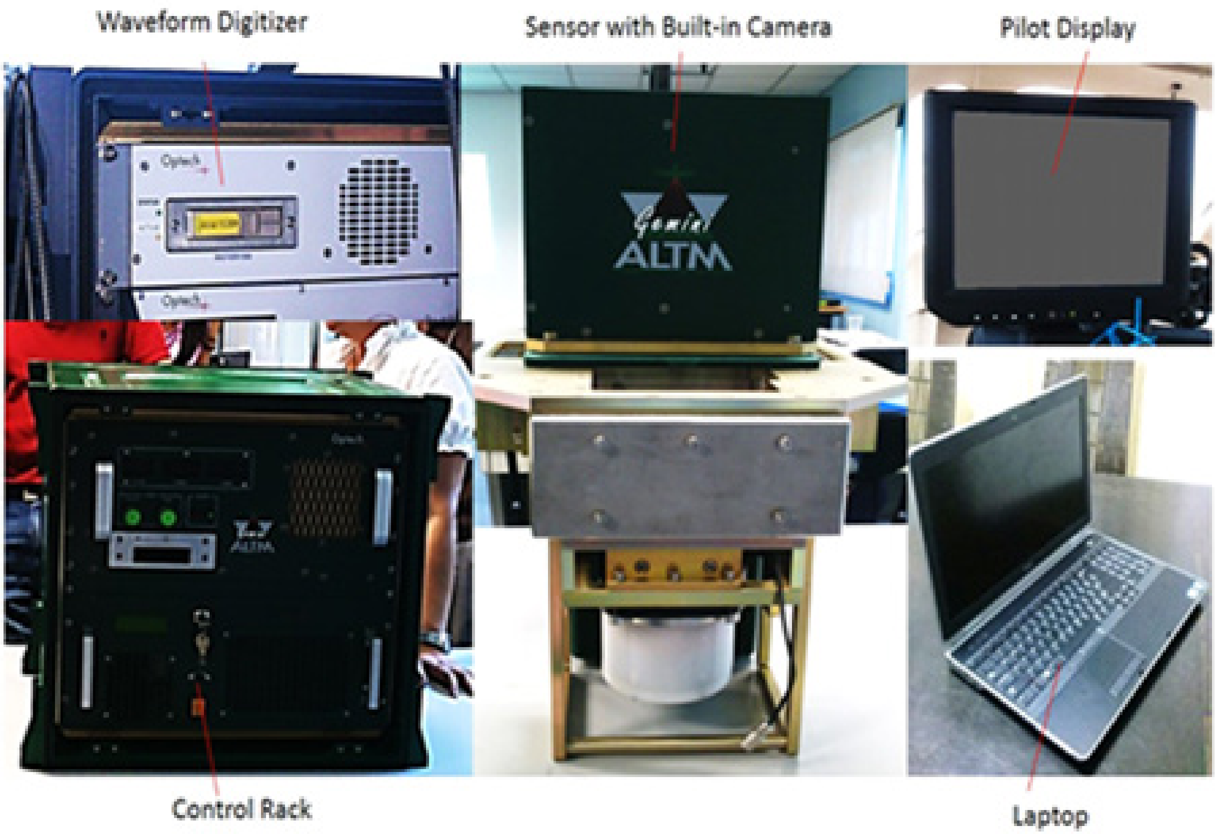


Figure A-1.1. Gemini Sensor

Table A-1.1. Optech Technical Specifications of the Gemini Sensor

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

Parameter	Specification
Camera Head	
Sensor type	60 Mpix full frame CCD, RGB
Sensor format (H x V)	8, 984 x 6, 732 pixels
Pixel size	6µm x 6 µm
Frame rate	1 frame/2 sec.
FMC	Electro-mechanical, driven by piezo technology (patented)
Shutter	Electro-mechanical iris mechanism 1/125 to 1/500++ sec. f-stops: 5.6, 8, 11, 16
Lenses	50 mm/70 mm/120 mm/210 mm
Filter	Color and near-infrared removable filters
Dimensions (H x W x D)	200 x 150 x 120 mm (70 mm lens)
Weight	~4.5 kg (70 mm lens)
Controller Unit	
Computer	Mini-ITX RoHS-compliant small-form-factor embedded computers with AMD TurionTM 64 X2 CPU computers with AMD TurionTM 64 X2 CPU IEEE 1394 Firewire interface
Removable storage unit	~500 GB solid state drives, 8,000 images
Power consumption	~8 A, 168 W
Dimensions	2U full rack; 88 x 448 x 493 mm
Weight	~15 kg
Image Pre-Processing Software	
Capture One	Radiometric control and format conversion, TIFF or JPEG
Image output	8,984 x 6,732 pixels 8 or 16 bits per channel (180 MB or 360 MB per image)

Annex 2. NAMRIA Certification of Reference Points used in the LiDAR Survey

1. ATQ-18

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

March 02, 2015

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: **ANTIQUE**
Station Name: **ATQ-18**
Order: **2nd**

Island:	**VISAYAS**	Barangay:	**CUBAY**		
Municipality:	**BARBAZA**	MSL Elevation:			
PRS92 Coordinates					
Latitude:	**11° 11' 58.67081"**	Longitude:	**122° 2' 22.83300"**	Ellipsoidal Hgt:	**10.90200 m.**
WGS84 Coordinates					
Latitude:	**11° 11' 54.16068"**	Longitude:	**122° 2' 28.01549"**	Ellipsoidal Hgt:	**65.96100 m.**
PTM / PRS92 Coordinates					
Northing:	**1238579.674 m.**	Easting:	**395119.157 m.**	Zone:	**4**
UTM / PRS92 Coordinates					
Northing:	**1,238,146.15**	Easting:	**395,155.87**	Zone:	**51**

Location Description

ATQ-18
From San Jose, travel N to the Mun. of Barbaza. Then from the town proper, proceed to Brgy. Cubay. Station is located on the NE approach of Binangbang Bridge, about 600 m. NE of Barbaza Town Hall, 4 m. from the road centerline, 50 m. SE of Barbaza Multi-Purpose Coop./Natco Network and 25 m. SE of a funeral service outlet. Mark is the head of a 4 in. copper nail centered on a 30 cm. x 30 cm. cement putty, with inscriptions "ATQ-18 2007 NAMRIA".

Requesting Party: **PHIL-LIDAR 1**
Purpose: **Reference**
OR Number: **8077754 I**
T.N.: **2015-0504**

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

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

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. ATQ-18

2. ATQ-22

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

March 02, 2015

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: **ANTIQUE**	
	Station Name: **ATQ-22**	
	Order: **2nd**	
Island: **VISAYAS**	Barangay: **CONCEPCION**	
Municipality: **BELISON**	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **10° 49' 46.66618"**	Longitude: **121° 58' 11.90221"**	Ellipsoidal Hgt: **12.25000 m.**
	WGS84 Coordinates	
Latitude: **10° 49' 42.24271"**	Longitude: **121° 58' 17.11770"**	Ellipsoidal Hgt: **68.02200 m.**
	PTM / PRS92 Coordinates	
Northing: **1197676.056 m.**	Easting: **387365.279 m.**	Zone: **4**
	UTM / PRS92 Coordinates	
Northing: **1,197,256.85**	Easting: **387,404.70**	Zone: **51**

Location Description

ATQ-22

From San Jose, travel N to Belison for about 20 km. Station is located on top of the N edge of the NW draft on an irrigation canal, 60 m. NE to the nat'l. highway centerline, 120 m. N of the road going to the brgy. proper and about 300 m. E of Km. Post No. 110. Mark is the head of a 4 in. copper nail centered on a 30 cm. x 30 cm. cement putty, with inscriptions "ATQ-22 2007 NAMRIA".

Requesting Party: **PHIL-LIDAR 1**
Purpose: **Reference**
OR Number: **8077754 I**
T.N.: **2015-0503**

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

9903022015130958

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.2. ATQ-22

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

The LiDAR team did not establish ground control points during the survey, thus no baseline processing reports are necessary.

Annex 4. The LiDAR Survey Team

Table A-4.1. 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
		LOVELYN ASUNCION	
LiDAR Operation	Senior Science Research Specialist (SSRS)	ENGR. GEROME HIPOLITO; LOVELYN ASUNCION	UP-TCAGP
LiDAR Operation	Research Associate (RA)	FOR. MA. VERLINA TONGA; REGINA FELISMINO	UP-TCAGP
	RA	CATHERINE BALIGUAS	UP-TCAGP
Ground Survey	RA	JONATHAN ALMALVEZ; KENNETH QUISADO; IRO NIEL ROXAS	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. LEE JAY PUNZALAN; SSG. JAYCO MANZANO	PILIPPINE AIR FORCE (PAF)
LiDAR Operation	Pilot	CAPT. JEFFREY JEREMY ALAJAR; CAPT. BRYAN	ASIAN AEROSPACE CORPORATION (AAC)
LiDAR Operation	Pilot	CAPT. ALBERT LIM; CAPT. JERICHO JECIEL	AAC

Annex 5. Data Transfer Sheets for the Dalanas Floodplain Flights

DATA TRANSFER SHEET
03/23/2015(Iloilo-gem)

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	
16-Feb-15	2566G	2BLK37V047A	gemini	na	1517	1.13	209	28	206	13	1.36	10.7	1KB	1KB	19	19	Z:\DAC\RAW DATA
16-Feb-15	2568G	2BLK37GSIV047B	gemini	na	952	1.34	222	46.8	383	21.9	2.12	6.61	1KB	1KB	7/4	15/12	Z:\DAC\RAW DATA
17-Feb-15	2570G	2BLK43H048A	gemini	na	1078	1.43	222	48.5	342	21.7	3.4	14.4	1KB	1KB	3	3	Z:\DAC\RAW DATA
19-Feb-15	2578G	2BLK43GV050A	gemini	na	586	891	184	8.07	67.8	15.4	na	11.1	1KB	1KB	7	na	Z:\DAC\RAW DATA
19-Feb-15	2580G	2BLK43F050B	gemini	na	740	990	163	25.6	203	16.2	3.29	4.11	1KB	1KB	4	8	Z:\DAC\RAW DATA
20-Feb-15	2582G	2BLK43A051A	gemini	na	169	254	106	6.84	57.4	4.65	na	11	1KB	1KB	6	13	Z:\DAC\RAW DATA
21-Feb-15	2586G	2BLK43A052A	gemini	na	613	670	182	15.4	63.9	8.3	1.43	11.5	1KB	1KB	5	10	Z:\DAC\RAW DATA
22-Feb-15	2590G	2BLK43A053A	gemini	na	694	0.97	198	21.2	94.4/628	12.1	na	17	1KB	1KB	5	10	Z:\DAC\RAW DATA
23-Feb-15	2594G	2BLK43C054A	gemini	na	856	1.05	240	28.2	17.2/163	16.3	na	11.6	1KB	1KB	6	14	Z:\DAC\RAW DATA

Received from

Name C. Joaquin
Position FA
Signature

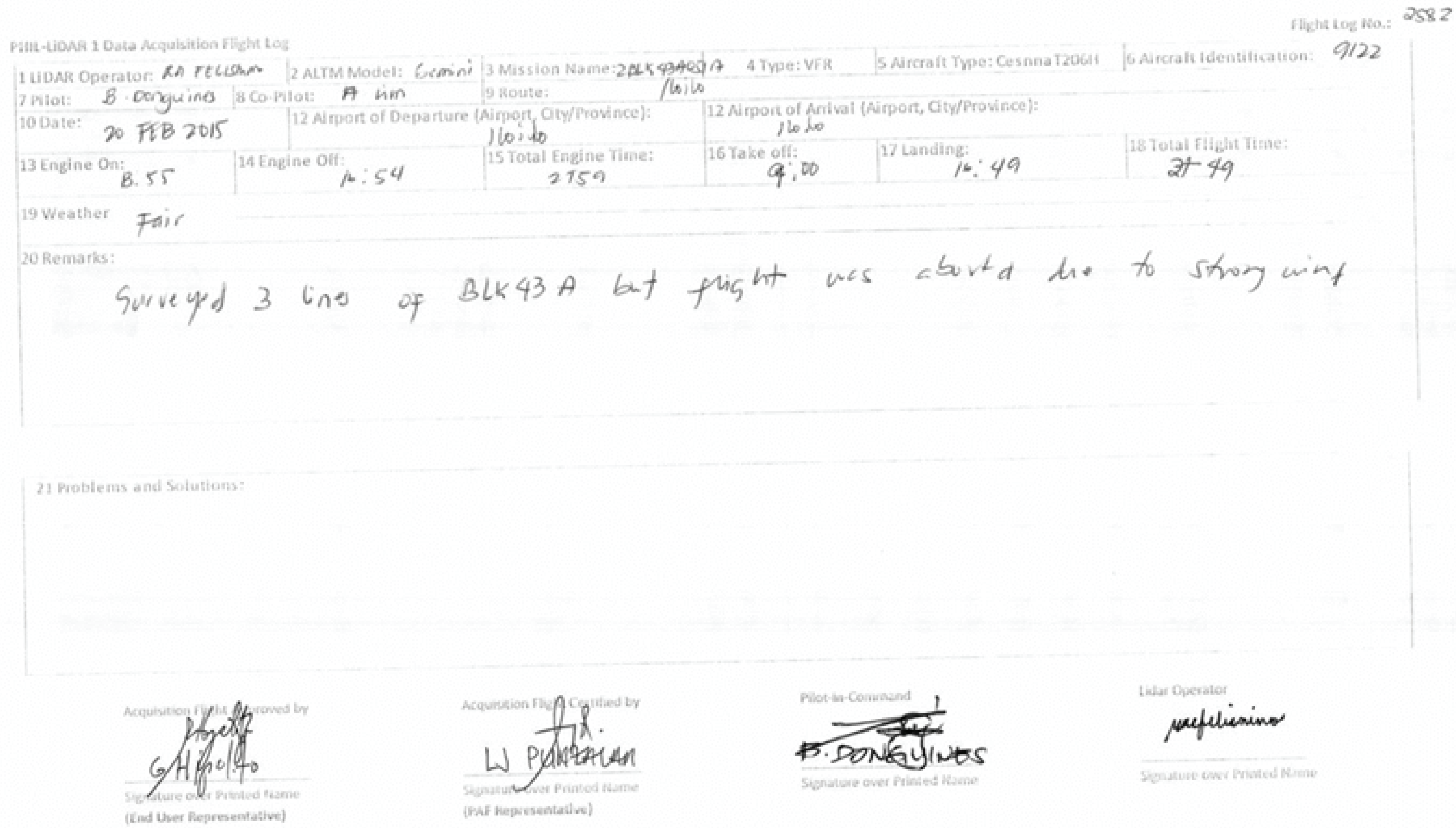
Received by

Name JOIDA F. PRIETO
Position SSRS
Signature
3/23/2015

Figure A-5.1. Transfer Sheet for Dalanas Floodplain

Annex 6. Flight logs for the Flight Missions

1. Flight Log for 2582G Mission


Flight Log No.: 2582

PHIL-LIDAR 1 Data Acquisition Flight Log

1 LiDAR Operator: RA Felismino
2 ALTM Model: Gemini
3 Mission Name: 2BLK43A051A
4 Type: VFR
5 Aircraft Type: Cesnna T206H
6 Aircraft Identification: 9122
7 Pilot: B. Donguines
8 Co-Pilot: A. Lim
9 Route: Iloilo
10 Date: 20 FEB 2015
12 Airport of Departure (Airport, City/Province): Iloilo
12 Airport of Arrival (Airport, City/Province): Iloilo
13 Engine On: 8:55
14 Engine Off: 11:54
15 Total Engine Time: 2+59
16 Take off: 9:00
17 Landing: 11:49
18 Total Flight Time: 2+49
19 Weather: Fair
20 Remarks:
Surveyed 3 lines of BLK43A but flight was aborted due to strong wind

21 Problems and Solutions:

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

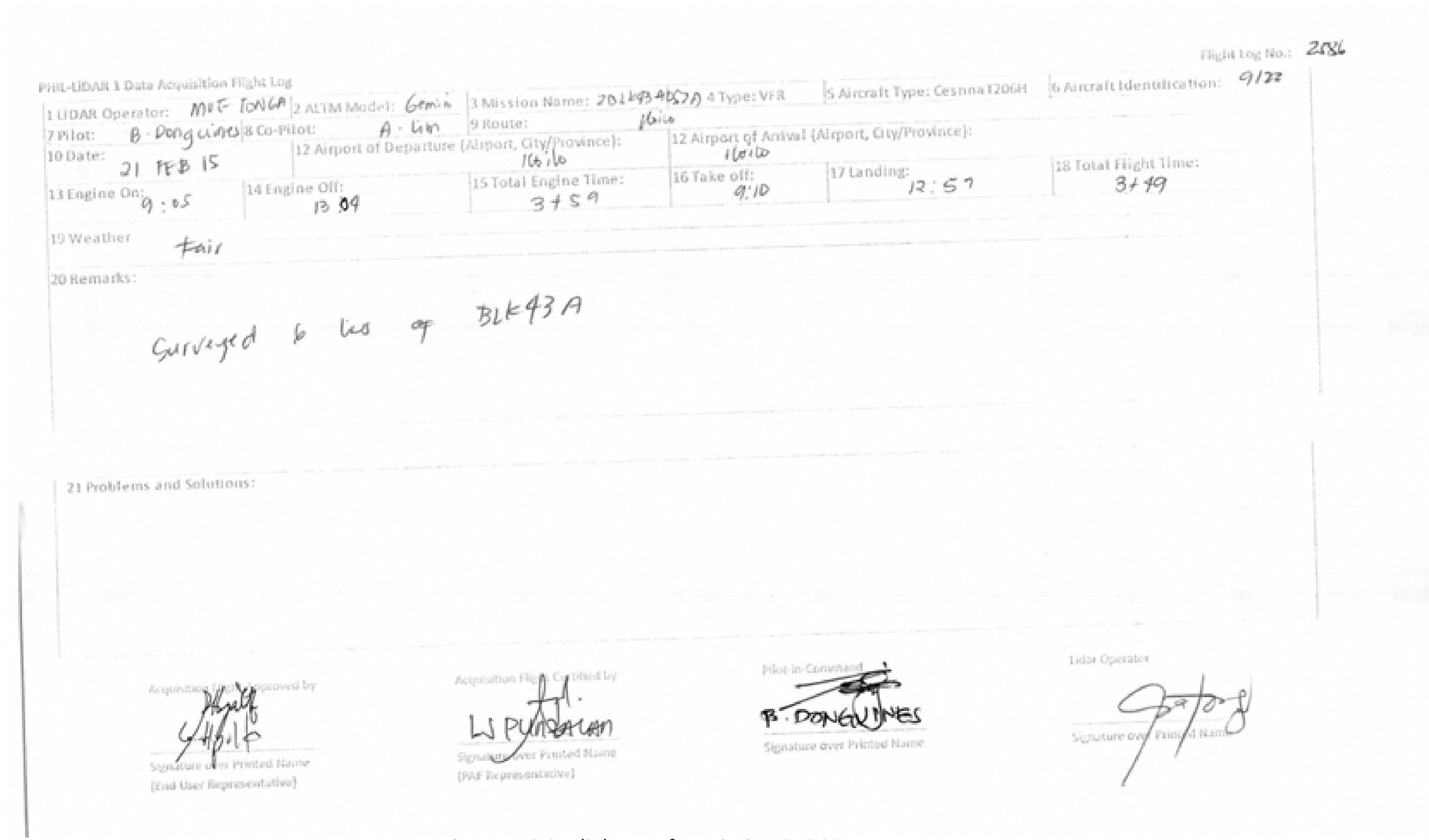
Acquisition Flight Certified by
Signature over Printed Name
(PAF Representative)

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

Lidar Operator
Signature over Printed Name

Figure A-6.1. Flight Log for Mission 2582G

2. Flight Log for 2586G Mission


Flight Log No.: 2586

PHIL-LIDAR 1 Data Acquisition Flight Log

1 LIDAR Operator: MOT TONGA | 2 ALTM Model: Gemini | 3 Mission Name: 2BLK43ADS7A | 4 Type: VFR | 5 Aircraft Type: Cesnna T206H | 6 Aircraft Identification: 9122

7 Pilot: B. Donguines | 8 Co-Pilot: A. Lim | 9 Route: Iloilo

10 Date: 21 FEB 15 | 12 Airport of Departure (Airport, City/Province): Iloilo | 12 Airport of Arrival (Airport, City/Province): Iloilo

13 Engine On: 9:05 | 14 Engine Off: 13:04 | 15 Total Engine Time: 3+59 | 16 Take off: 9:10 | 17 Landing: 12:57 | 18 Total Flight Time: 3+49

19 Weather: Fair

20 Remarks:

Surveyed 6 lines of BLK43A

21 Problems and Solutions:

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

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

Pilot-in-Command — B. DONGUINES — Signature over Printed Name

Lidar Operator — Signature over Printed Name

Figure A-6.2. Flight Log for Mission 2586G

3. Flight Log for 2590G Mission

PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 2590

1 LIDAR Operator: RA Fabonuag	2 ALTM Model: Gemini	3 Mission Name: 2BLK43A053A	4 Type: VFR	5 Aircraft Type: Cessna 1206H	6 Aircraft Identification: 9122
7 Pilot: B Donguines	8 Co-Pilot: A Lim	9 Route: Iloilo			
10 Date: 22 FEB 2015	12 Airport of Departure (Airport, City/Province): Iloilo		12 Airport of Arrival (Airport, City/Province): Iloilo		
13 Engine On: 6:40	14 Engine Off: 10:45	15 Total Engine Time: 4+5	16 Take off: 6:45	17 Landing: 10:40	18 Total Flight Time: 3+55

19 Weather: Fair

20 Remarks:

Completed the remaining lines of BLK43A

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
G. Hipol. Jr.	LJ Pamintuan	B. Donguines	Fabonuag
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 2590G

Annex 7. Flight Status Report

FLIGHT STATUS REPORT
DALANAS
February 2015

Table A-7.1. Flight Status Report

FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
2582G	BLK 43A	2BLK43A051A	RA FELISMINO	20 FEB 15	3 lines of BLK43A. Aborted due to strong winds
2586G	BLK 43A	2BLK43A052A	MVE TONGA	21 FEB 15	6 lines 43A
2590G	BLK 43A	2BLK43A053A	RA FELISMINO	22 FEB 15	Completed remaining BLK 43A

LAS/SWATH BOUNDARIES PER MISSION FLIGHT

Flight No. : 2582G
Area: BLK 43A
Mission Name: 2BLK43A051A
Total Area Surveyed: 36.4833 sq km

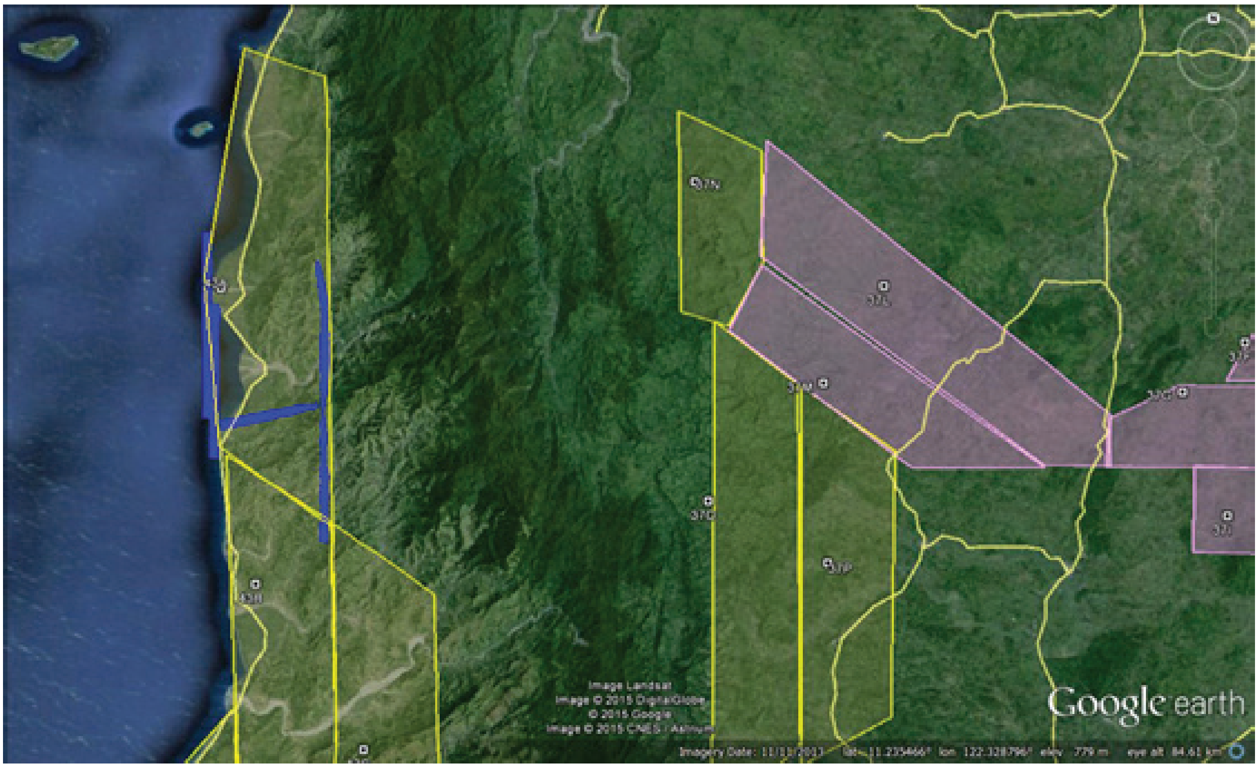


Figure A-7.1. Swath for Flight No. 2582G

Flight No. : 2586G
Area: BLK 43A
Mission Name: 2BLK43A052A
Total Area Surveyed: 137.706 sq km

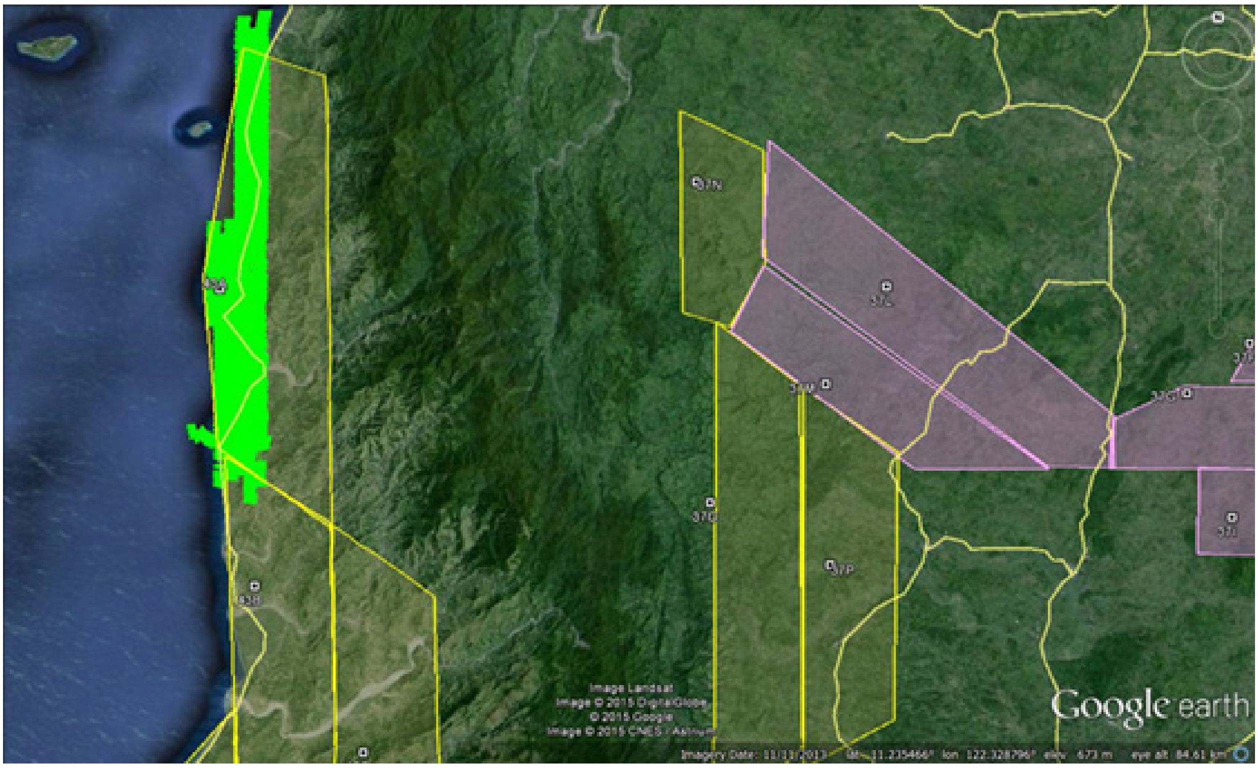


Figure A-7.2. Swath for Flight No. 2586G

Flight No. : 2590G
Area: BLK 43A
Mission Name: 2BLK43A053A
Total Area Surveyed: 200.818 sq km

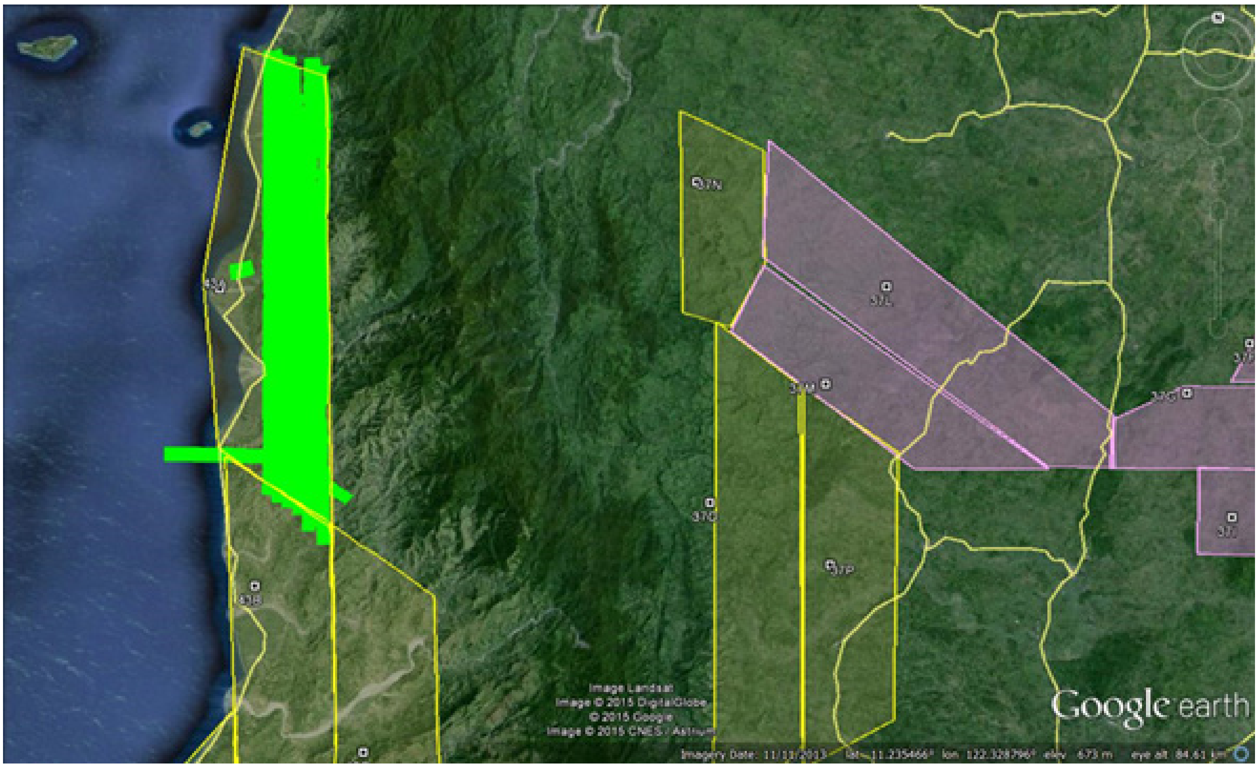


Figure A-7.3. Swath for Flight No. 2590G

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Iloilo_Blk43A

Flight Area	Iloilo
Mission Name	Blk43A
Inclusive Flights	2582G, 2586G, 2590G
Range data size	25.05 GB
Base data size	39.5 MB
POS	486 MB
Image	43.44 GB
Transfer date	March 23, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.22
RMSE for East Position (<4.0 cm)	1.26
RMSE for Down Position (<8.0 cm)	3.93
Boresight correction stdev (<0.001deg)	0.000592
IMU attitude correction stdev (<0.001deg)	0.025649
GPS position stdev (<0.01m)	0.0289
Minimum % overlap (>25)	38.72%
Ave point cloud density per sq.m. (>2.0)	2.06
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	109
Maximum Height	881.61 m
Minimum Height	54.56
Classification (# of points)	
Ground	40,,031,989
Low vegetation	18,192,805
Medium vegetation	47,956,243
High vegetation	30,567,353
Building	261,552
Orthophoto	Yes
Processed by	Engr. Jommer Medina, Engr. Melanie Hingpit, Engr. Melissa Fernandez

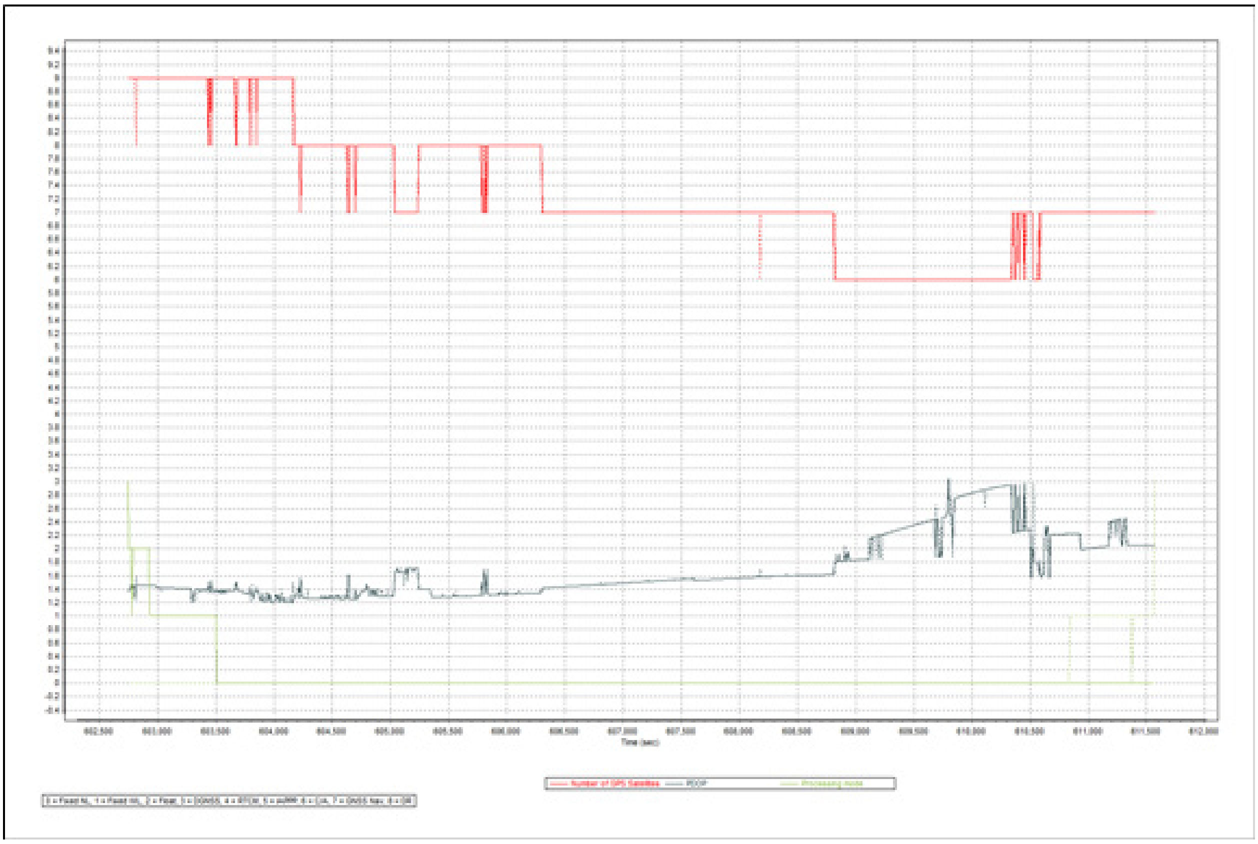


Figure-A.8.1. Solution Status

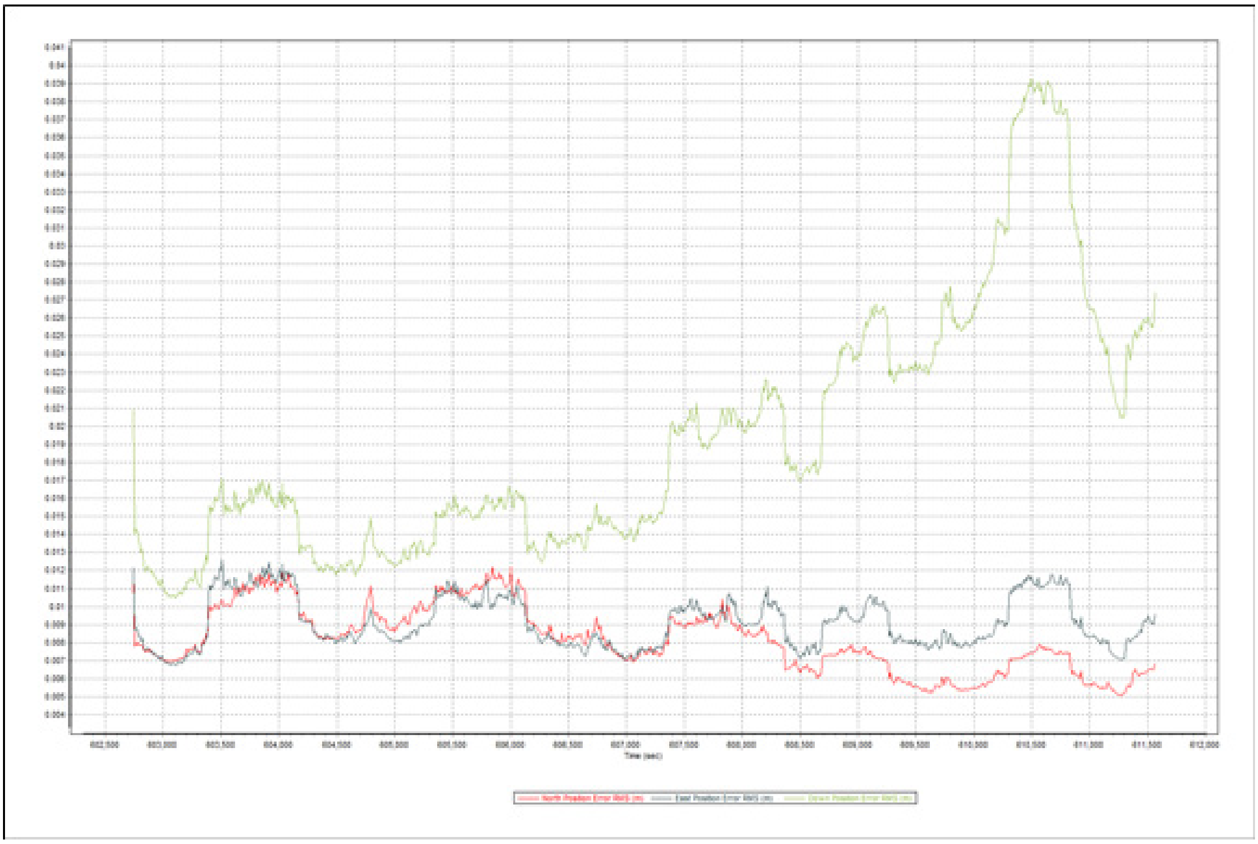


Figure-A.8.2. Smoothed Performance Metric Parameters

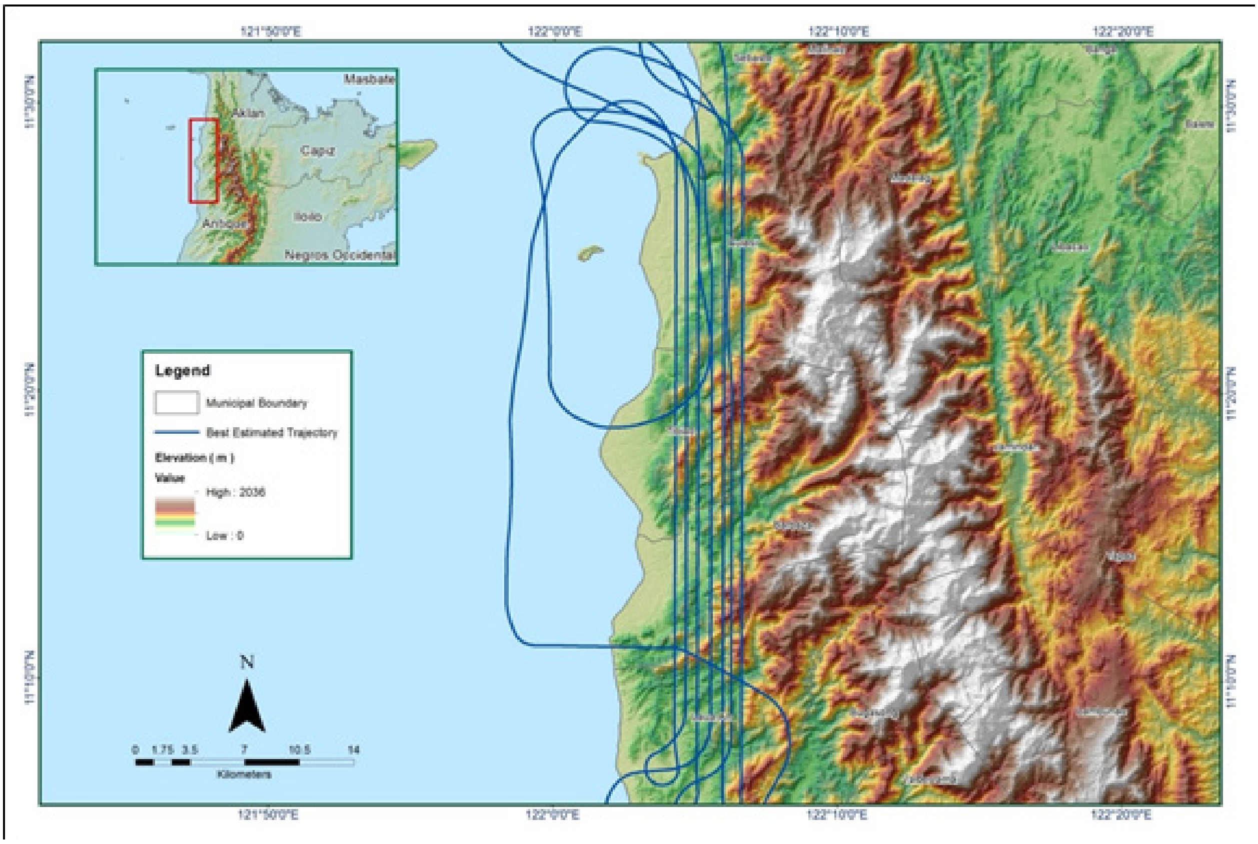


Figure-A.8.3. Best Estimated Trajectory

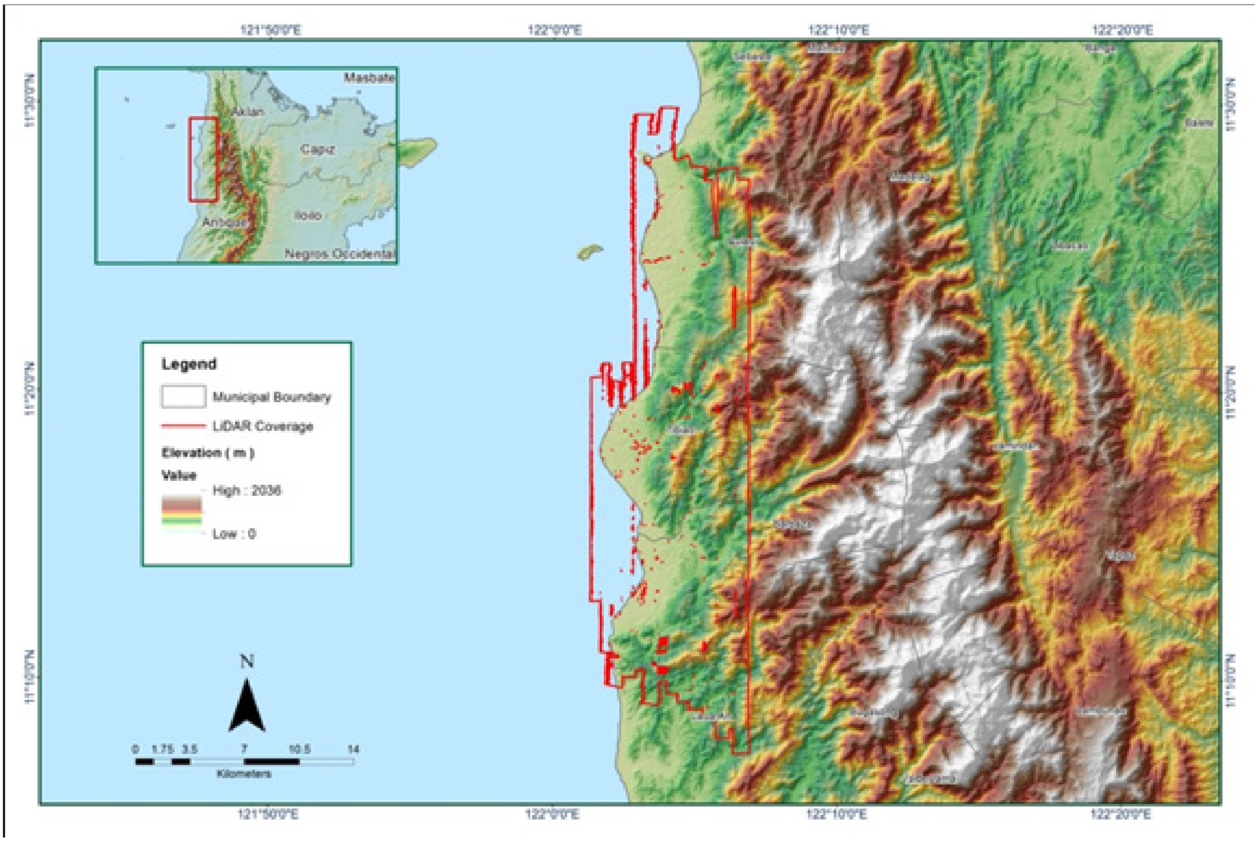


Figure-A.8.4. Coverage of LiDAR data

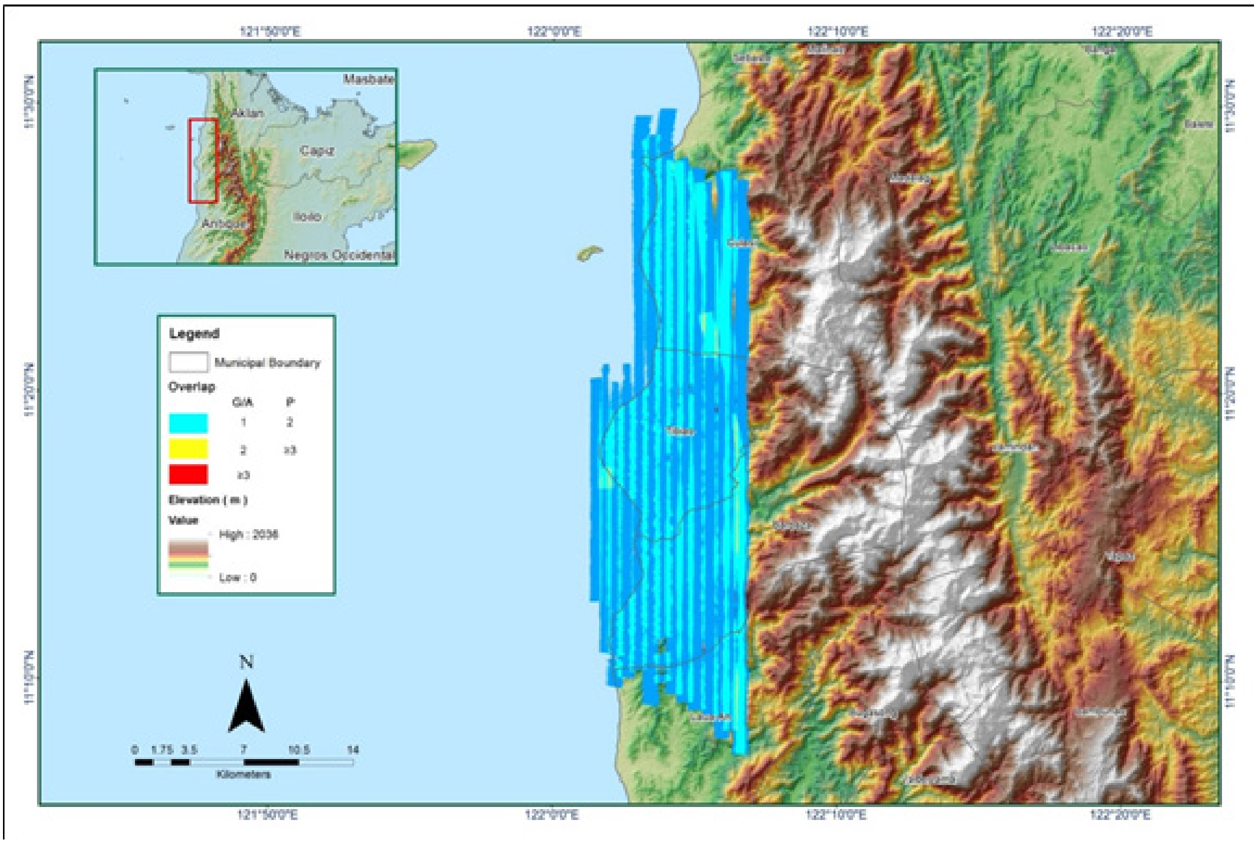


Figure-A.8.5. Image of data overlap

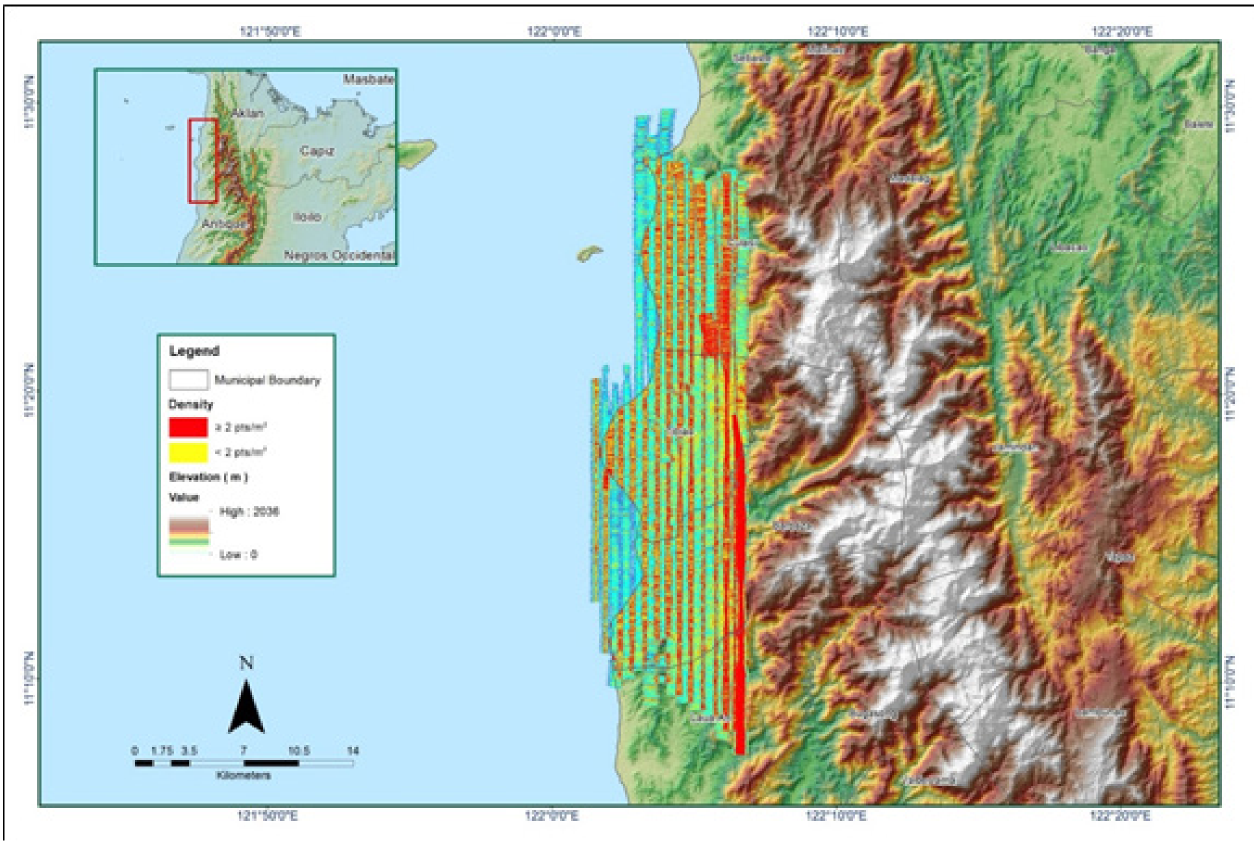


Figure-A.8.6. Density map of merged LiDAR data

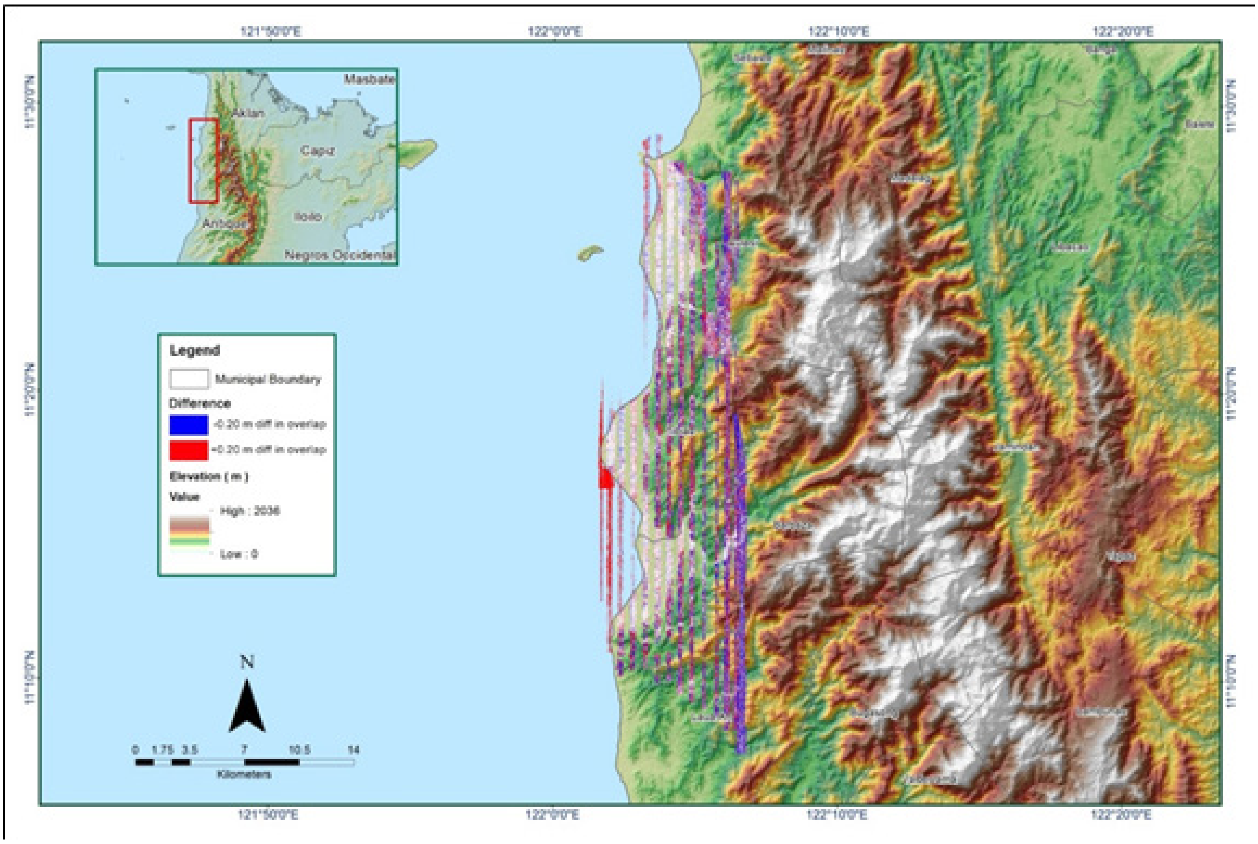


Figure-A.8.7. Elevation difference between flight lines

Annex 9. Dalanas Model Basin Parameters

Table A-9.1. Dalanas Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
W120	5.11035	74.6263	0	2.559075	5.5686	Discharge	0.0451013	0.5	Ratio to Peak	0.35
W130	3.547392	85.3013	0	0.87075	1.8948	Discharge	0.0110651	0.5	Ratio to Peak	0.35
W140	3.726789	83.92	0	1.6896	3.6765	Discharge	0.0281693	0.5	Ratio to Peak	0.35
W150	1.84326	99	0	2.09385	4.5563	Discharge	0.05442	0.5	Ratio to Peak	0.35
W160	5.757444	70.9688	0	1.004775	2.1864	Discharge	0.0127017	0.5	Ratio to Peak	0.35
W170	5.635242	71.63	0	2.063775	4.4908	Discharge	0.0239002	0.5	Ratio to Peak	0.35
W180	2.669658	88.5213	0	0.980025	2.1325	Discharge	0.0173798	0.5	Ratio to Peak	0.35
W190	5.352894	73.2113	0	2.93115	6.3782	Discharge	0.0653757	0.5	Ratio to Peak	0.35
W200	3.191667	88.6325	0	0.963675	2.097	Discharge	0.0131376	0.5	Ratio to Peak	0.35
W210	4.817028	76.4163	0	0.629655	1.3701	Discharge	0.0026659	0.5	Ratio to Peak	0.35
W220	5.879646	70.3163	0	0.7401975	1.6107	Discharge	0.0032915	0.5	Ratio to Peak	0.35

Annex 10. Dalanas Model Reach Parameters

Table A-10.1. Dalanas Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R60	Automatic Fixed Interval	5893.9	0.1	0.0188238	Trapezoid	131.09	1
R70	Automatic Fixed Interval	3606.2	0.1	0.0766319	Trapezoid	131.09	1
R90	Automatic Fixed Interval	11322	0.1	0.0290454	Trapezoid	131.09	1
R100	Automatic Fixed Interval	1232.7	0.1	0.0294104	Trapezoid	131.09	1
R110	Automatic Fixed Interval	1452.5	0.1	0.0514912	Trapezoid	131.09	1

Annex 11. Dalanas Field Validation Points

Table A-11.1. Dalanas Field Validation Points

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/ Date	Rain Return/ Scenario
	Lat	Long					
0	11.252772	122.0729	0.09	0.4	0.096	Seniang	5-Year
1	11.252839	122.072758	0.07	0.05	0.000	Yolanda	5-Year
2	11.25288	122.07252	0.04	0	0.002	Yolanda	5-Year
3	11.252901	122.072735	0.2	0	0.040	Frank	100-Year
4	11.252576	122.074698	0.03	0.15	0.014	Yolanda	5-Year
5	11.253939	122.074101	0.03	0	0.001		
6	11.253029	122.074764	0.03	0	0.001		
7	11.253227	122.063548	0.14	0.05	0.008	Yolanda	5-Year
8	11.253265	122.063366	0.12	0	0.014	Yolanda	5-Year
9	11.2531	122.062503	0.03	0.2	0.029	Yolanda	5-Year
10	11.252348	122.061437	0.31	0.4	0.008	Frank	100-Year
11	11.253856	122.063629	1.78	0.3	2.190	Frank	100-Year
12	11.253097	122.063915	0.03	0	0.001		
13	11.259669	122.056462	1.41	0.5	0.828	Frank	100-Year
14	11.258799	122.056872	0.03	0.4	0.137	Frank	100-Year
15	11.257567	122.057196	0.04	0.4	0.130	Yolanda	5-Year
16	11.257095	122.056524	0.03	0.05	0.000	Marce	5-Year
17	11.256813	122.056786	0.06	0	0.004	Frank	100-Year
18	11.256482	122.056654	0.03	0	0.001	Yolanda	5-Year
19	11.255761	122.05631	0.08	1	0.846	Frank	100-Year
20	11.25581	122.055512	0.12	0	0.014	Frank	100-Year
21	11.257206	122.057987	0.77	1.1	0.109	Frank	100-Year
22	11.257533	122.057847	0.14	0.4	0.068	Frank	100-Year
23	11.257647	122.058519	1.03	0.2	0.689	Frank	100-Year
24	11.223971	122.052929	0	0.1	0.010	Frank	100-Year
25	11.224549	122.053081	0.03	0.5	0.221	Yolanda	5-Year
26	11.22473	122.053018	0.03	1.25	1.488	Frank	100-Year
27	11.225168	122.05336	0.03	0.8	0.593	Frank	100-Year
28	11.225579	122.053084	0.03	0.4	0.137	Yolanda	5-Year
29	11.226441	122.053916	1.14	1	0.020	Frank	100-Year
30	11.224645	122.055671	0.53	1.2	0.449	Frank	100-Year
31	11.223494	122.055937	0	1.6	2.560	Frank	100-Year

32	11.232215	122.057211	1.44	0.95	0.240	Frank	100-Year
33	11.229462	122.053928	1.48	2	0.270	Frank	100-Year
34	11.229656	122.053877	1.57	2	0.185	Frank	100-Year
35	11.229632	122.053803	0.03	0.4	0.137	Milenyo	5-Year
36	11.238934	122.072099	0.61	0.4	0.044	Frank	100-Year
37	11.238789	122.072405	0.33	0.5	0.029	Yolanda	5-Year
38	11.237634	122.072459	0.13	0.65	0.270	Frank	100-Year
39	11.237502	122.072473	0.12	0.65	0.281	Yolanda	5-Year
40	11.237092	122.072298	0.03	0.3	0.073	Frank	100-Year
41	11.242904	122.069138	0.91	0.7	0.044	Frank	100-Year
42	11.236975	122.072031	0.1	0.65	0.303	Frank	100-Year
43	11.242563	122.069305	1.81	1	0.656	Frank	100-Year
44	11.242067	122.07017	0.8	0.6	0.040	Frank	100-Year
45	11.24192	122.07061	0.28	0.35	0.005	Yolanda	5-Year
46	11.243817	122.076609	1.08	0.8	0.078	Frank	100-Year
47	11.243196	122.081987	1.85	0.4	2.103	Frank	100-Year
48	11.243365	122.078623	1.32	0.7	0.384	Marce	5-Year
49	11.243013	122.078323	1.64	0.7	0.884	Frank	100-Year
50	11.242718	122.078522	0.03	0	0.001		
51	11.242459	122.075621	0.64	0.4	0.058	Frank	100-Year
52	11.235001	122.058038	1.06	0.8	0.068	Frank	100-Year
53	11.240818	122.065754	0.03	0.3	0.073	Yolanda	5-Year
54	11.241792	122.067508	0.03	0.3	0.073	Yolanda	5-Year
55	11.232838	122.056913	1.17	0.35	0.672	Frank	100-Year
56	11.23287	122.056785	1.18	0.8	0.144	Frank	100-Year
57	11.232815	122.056385	0.58	0.4	0.032	Yolanda	5-Year
58	11.232796	122.056407	0	0.65	0.423	Yolanda	5-Year
59	11.233495	122.057281	0.79	0.45	0.116	Frank	100-Year
60	11.234571	122.057607	0.32	0.45	0.017	Yolanda	5-Year
61	11.23472	122.057852	1.19	0.85	0.116	Frank	100-Year
62	11.235216	122.057441	0.77	0.45	0.102	Frank	100-Year
63	11.240375	122.057869	0.11	0.4	0.084	Yolanda	5-Year
64	11.239829	122.058052	0.47	1.2	0.533	Frank	100-Year
65	11.239523	122.058394	0.37	0.4	0.001	Frank	100-Year

66	11.237968	122.057748	0.73	0.4	0.109	Frank	100-Year
67	11.237267	122.057923	0.61	1	0.152	Yolanda	5-Year
68	11.252718	122.073149	0.05	0	0.003		
69	11.252769	122.07317	0.15	0	0.023		
70	11.252681	122.072714	0	0	0.000		
71	11.252853	122.072919	0.1	0	0.010		
72	11.253064	122.072837	0.06	0	0.004		
73	11.253113	122.073115	0.06	0	0.004		
74	11.253145	122.072645	0.03	0	0.001		
75	11.25321	122.072546	0.09	0	0.008		
76	11.252742	122.074555	0.03	0	0.001		
77	11.252458	122.074793	0.03	0	0.001		
78	11.252179	122.075383	0.03	0.9	0.757	Frank	100-Year
79	11.252001	122.075286	1.6	0.5	1.210	Frank	100-Year
80	11.253951	122.074227	0	0	0.000		
81	11.252214	122.073754	0.17	0.1	0.005	Frank	100-Year
82	11.253267	122.063306	0	0	0.000		
83	11.253099	122.063313	0.46	0.2	0.068	Frank	100-Year
84	11.252875	122.062392	0.03	0	0.001		
85	11.252433	122.061953	0.17	0.9	0.533	Frank	100-Year
86	11.252224	122.06161	0.65	0.9	0.063	Frank	100-Year
87	11.253468	122.063797	1.46	0.2	1.588	Frank	100-Year
88	11.25347	122.063811	0	0.2	0.040	Frank	100-Year
89	11.254145	122.064043	0.03	0	0.001		
90	11.254541	122.0639	0.03	0	0.001		
91	11.25444	122.063815	0.03	0	0.001		
92	11.259377	122.056677	0.04	0.4	0.130	Frank	100-Year
93	11.258677	122.057043	0.03	0	0.001		
94	11.25914	122.0573	0.33	0	0.109		
95	11.258234	122.057772	0.32	0	0.102		
96	11.257501	122.057172	0	0	0.000		
97	11.257636	122.056581	0.24	0	0.058		
98	11.257648	122.056048	0.03	0	0.001		
99	11.257545	122.056277	0.03	0	0.001		

100	11.256724	122.056965	0.03	0.15	0.014	Nitang	5-Year
101	11.255722	122.055846	0.77	0.1	0.449	Frank	100-Year
102	11.255727	122.05584	0	0.1	0.010	Frank	100-Year
103	11.25585	122.05579	0.03	0.4	0.137	Frank	100-Year
104	11.25578	122.055625	0	0.4	0.160	Frank	100-Year
105	11.257297	122.057338	0.03	0	0.001		
106	11.257123	122.058313	0.62	0	0.384		
107	11.257013	122.058315	0.4	0	0.160		
108	11.256737	122.058334	0.34	0	0.116		
109	11.256828	122.058075	0.49	0.3	0.036	Yolanda	5-Year
110	11.25667	122.057389	0.03	0	0.001		
111	11.224171	122.052757	0.03	0.8	0.593	Frank	100-Year
112	11.22415	122.052722	0.03	2	3.881	Yolanda	5-Year
113	11.224298	122.052924	0.03	0.8	0.593	Frank	100-Year
114	11.224481	122.05336	0.03	0	0.001		
115	11.224601	122.052866	0.03	1.3	1.613	Yolanda	5-Year
116	11.224845	122.052992	0.03	0.4	0.137	Frank	100-Year
117	11.225112	122.052858	0.03	0.8	0.593	Frank	100-Year
118	11.225111	122.05334	0.13	0.4	0.073	Frank	100-Year
119	11.225429	122.053244	0.03	0.1	0.005	Yolanda	5-Year
120	11.225513	122.053068	0.03	0.4	0.137	Frank	100-Year
121	11.225828	122.053226	0.03	0.8	0.593	Frank	100-Year
122	11.2249	122.055217	0.6	1.4	0.640	Frank	100-Year
123	11.224826	122.055127	0.57	1.35	0.608	Frank	100-Year
124	11.223458	122.055706	0	1.2	1.440	Frank	100-Year
125	11.223261	122.056385	0	1.6	2.560	Frank	100-Year
126	11.23245	122.061219	0.03	0	0.001		
127	11.233647	122.062758	0.04	0	0.002		
128	11.232231	122.056872	1.19	0.7	0.240	Frank	100-Year
129	11.232471	122.056634	0.9	0.7	0.040	Frank	100-Year
130	11.232483	122.057299	0.76	0.9	0.020	Yolanda	5-Year
131	11.229512	122.053676	0.03	0.8	0.593	Yolanda	5-Year
132	11.229609	122.053783	0	1.2	1.440	Frank	100-Year
133	11.22984	122.053756	1.04	1.2	0.026	Frank	100-Year

134	11.230073	122.053718	1.33	0.9	0.185	Frank	100-Year
135	11.230154	122.053735	0.75	0.4	0.123	Yolanda	5-Year
136	11.231626	122.053494	1.12	0.9	0.048	Yolanda	5-Year
137	11.238698	122.072371	0	0.3	0.090	Yolanda	5-Year
138	11.238915	122.072432	0.08	0.7	0.384	Yolanda	5-Year
139	11.238557	122.072544	0.26	0.1	0.026	Yolanda	5-Year
140	11.237986	122.072635	0.23	0.8	0.325	Yolanda	5-Year
141	11.236959	122.072799	0	0.6	0.360	Yolanda	5-Year
142	11.236871	122.073013	0	0	0.000		
143	11.242799	122.069039	1.91	0.9	1.020	Frank	100-Year
144	11.24289	122.069095	2.23	0.4	3.349	Frank	100-Year
145	11.242883	122.069236	0	0.9	0.810	Frank	100-Year
146	11.242815	122.069244	0	0.8	0.640	Yolanda	5-Year
147	11.24215	122.070363	0.98	0.2	0.608	Frank	100-Year
148	11.241974	122.070367	0	0.4	0.160	Frank	100-Year
149	11.243797	122.076909	0.45	0.4	0.003	Yolanda	5-Year
150	11.243732	122.077186	1.44	0	2.074	Frank	100-Year
151	11.243301	122.081992	1.89	0.9	0.980	Undang	5-Year
152	11.243252	122.082138	1.98	0.4	2.496	Frank	100-Year
153	11.243186	122.082212	0	0.4	0.160	Frank	100-Year
154	11.243207	122.078875	1.03	0.2	0.689	Marce	5-Year
155	11.243137	122.079061	0.93	0.4	0.281	Yolanda	5-Year
156	11.243129	122.079176	0.9	0.4	0.250	Yolanda	5-Year
157	11.242602	122.078792	1.02	0	1.040		
158	11.242507	122.078892	0.51	0	0.260		
159	11.242864	122.078387	0.82	0	0.672		
160	11.242991	122.078438	1.11	0	1.232		
161	11.242976	122.078315	0	0	0.000		
162	11.234919	122.058115	0.34	0.5	0.026	Undang	5-Year
163	11.239048	122.064198	0.22	0	0.048		
164	11.239782	122.064529	0.03	0.2	0.029	Yolanda	5-Year
165	11.2399	122.064811	0.03	0	0.001		
166	11.240344	122.065368	0.03	0	0.001		
167	11.240652	122.065499	0.03	0	0.001		

168	11.240742	122.065672	0.03	0.4	0.137	Yolanda	5-Year
169	11.232887	122.056945	0	0.4	0.160	Frank	100-Year
170	11.23292	122.056644	1.1	0.4	0.490	Frank	100-Year
171	11.23289	122.056739	0	0.4	0.160	Yolanda	5-Year
172	11.234471	122.057584	1.07	0.7	0.137	Frank	100-Year
173	11.2354	122.05751	0.85	1.35	0.250	Frank	100-Year
174	11.240596	122.05785	0.58	0.4	0.032	Frank	100-Year
175	11.240353	122.057842	0	0.5	0.250	Frank	100-Year
176	11.239954	122.057941	0.31	0.8	0.240	Frank	100-Year
177	11.239808	122.058148	0.47	0.9	0.185	Frank	100-Year
178	11.239629	122.057787	0.24	0.4	0.026	Frank	100-Year
179	11.239157	122.057698	0.55	0.9	0.123	Frank	100-Year
180	11.238403	122.05785	0.56	0.8	0.058	Frank	100-Year
181	11.238428	122.058224	0.4	0.6	0.040	Yolanda	5-Year
182	11.238094	122.058007	0.11	1.6	2.220	Undang	5-Year
183	11.237451	122.057763	0.95	0.8	0.023	Frank	100-Year
184	11.237265	122.057732	1.25	1.6	0.123	Frank	100-Year
185	11.23592796	122.0900539	5.86	1.51	18.923	Frank	100-Year
186	11.2354775	122.090605	5.96	2	15.682	Frank	100-Year
187	11.23529804	122.0910635	6.19	2.1	16.728	Frank	100-Year
188	11.23511831	122.0914305	6.9	2.4	20.250	Frank	100-Year
189	11.23493913	122.0919807	8.29	3.5	22.944	Frank	100-Year
190	11.23539378	122.0928036	0	3	9.000	Frank	100-Year
191	11.23539127	122.0919792	6.48	1.95	20.521	Frank	100-Year
192	11.23560047	122.0911	5.73	1.65	16.646	Frank	100-Year
193	11.23565891	122.0907876	6.27	3	10.693	Frank	100-Year
194	11.23475632	122.09134	8.7	1.8	47.610	Frank	100-Year
195	11.23439507	122.0914908	6.29	0.3	35.880	Frank	100-Year
197	11.23530223	122.0924375	8.11	2.2	34.928	Frank	100-Year
198	11.23516431	122.0907891	6.66	2.35	18.576	Frank	100-Year
199	11.23539043	122.0917044	6.24	1.75	20.160	Frank	100-Year
200	11.23488704	122.0916601	8.23	4	17.893	Frank	100-Year
201	11.23461089	122.0893743	5.58	1.28	18.490	Frank	100-Year
202	11.23461117	122.0894652	5.47	0.9	20.885	Frank	100-Year

203	11.23463495	122.0894168	0	0.94	0.884	Frank	100-Year
205	11.23565752	122.0903296	6.33	3	11.089	Frank	100-Year
207	11.23502704	122.091156	7.32	2.5	23.232	Frank	100-Year
208	11.23470366	122.0909198	5.43	1	19.625	Frank	100-Year
209	11.23471962	122.0911311	8.31	1.8	42.380	Frank	100-Year
210	11.23444687	122.0920738	0	0.7	0.490	Frank	100-Year
211	11.23521097	122.092163	10.13	1.2	79.745	Frank	100-Year
212	11.23548253	122.0922538	5.09	1.95	9.860	Frank	100-Year
213	11.23538791	122.09088	6.18	2.1	16.646	Frank	100-Year
214	11.23551678	122.0914292	5.88	3.9	3.920	Frank	100-Year
215	11.24531026	122.0539326	2.79	2.6	0.036	Frank	100-Year
216	11.24522129	122.0543909	2.57	2.6	0.001	Frank	100-Year
217	11.24513319	122.0551241	3.7	2.5	1.440	Frank	100-Year
218	11.24513465	122.0555821	2.45	2.5	0.002	Frank	100-Year
219	11.24488052	122.0649853	3.43	3.8	0.137	Frank	100-Year
220	11.24454323	122.0687749	3.64	2.9	0.548	Frank	100-Year
221	11.24454208	122.0684084	2.49	2.9	0.168	Frank	100-Year
222	11.24445051	122.0680423	2.44	2.75	0.096	Frank	100-Year
223	11.24444936	122.0676759	2.42	3	0.336	Frank	100-Year
224	11.2443575	122.0672182	2.39	3	0.372	Frank	100-Year
225	11.24272654	122.0661774	2.18	1.76	0.176	Frank	100-Year
226	11.24358933	122.0667627	1.39	2.13	0.548	Frank	100-Year
227	11.24208792	122.0643858	2.35	2	0.123	Frank	100-Year
228	11.24089013	122.0573363	2.46	2.7	0.058	Frank	100-Year
229	11.24098143	122.0576108	2.31	2.7	0.152	Frank	100-Year
230	11.24134487	122.0581593	2.54	2.6	0.004	Frank	100-Year
231	11.24116315	122.057885	2.47	2.6	0.017	Frank	100-Year
232	11.24153151	122.0599907	2.51	2.3	0.044	Frank	100-Year
233	11.24153267	122.0603571	2.34	1.65	0.476	Frank	100-Year
234	11.23439585	122.0917465	7.41	0.5	47.748	Frank	100-Year
235	11.23466701	122.0917067	8.35	0.8	57.003	Frank	100-Year
236	11.25318694	122.0569299	1.58	2.5	0.846	Frank	100-Year
237	11.25327591	122.0564716	2.31	2.75	0.194	Frank	100-Year
238	11.25354574	122.0560127	0.38	2.75	5.617	Frank	100-Year

239	11.25372164	122.0544548	2.45	2.2	0.063	Frank	100-Year
240	11.25386734	122.0540672	2.04	2.3	0.068	Frank	100-Year
241	11.24806986	122.0687635	3.15	2	1.323	Frank	100-Year
242	11.24843214	122.0689456	2.33	2.8	0.221	Frank	100-Year
243	11.24815369	122.0666564	2.36	1.7	0.436	Frank	100-Year
244	11.24671232	122.0684015	2.74	5.2	6.052	Frank	100-Year
245	11.24716474	122.0684916	3.42	2.3	1.254	Frank	100-Year
246	11.25349827	122.0518906	1.11	4.5	11.492	Frank	100-Year

Annex 12. Educational Institutions Affected by Flooding in Dalanas Floodplain

Table A-12.1. Educational Institutions in Barbaza, Antique Affected by Flooding in the Dalanas Floodplain

Antique				
Barbaza				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
San Antonio Day Care Center	Beri		Low	Medium
Beri Day Care Center	Palma	Low	Medium	Medium
Palma Day Care Center	Palma	Low	Medium	Medium
Sitio Highway Beri Day Care Center	Palma		Low	Medium
Esparagoza Elementary School	Soligao			
Soligao Elementary School	Soligao			

Annex 13. Health Institutions Affected by Flooding in Dalanas Floodplain

There are no medical or health institutions affected by flooding in the Dalanas floodplain.

Annex 14. UPC Phil-LiDAR 1 Team Composition

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