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

LiDAR Surveys and Flood Mapping of Vigo River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
Mapua Institute of Technology

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LIST OF ACRONYMS AND ABBREVIATIONS

AAC	Asian Aerospace Corporation
Ab	abutment
ALTM	Airborne LiDAR Terrain Mapper
ARG	automatic rain gauge
AWLS	Automated Water Level Sensor
BA	Bridge Approach
BM	benchmark
CAD	Computer-Aided Design
CN	Curve Number
CSRS	Chief Science Research Specialist
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]
ISU	Isabela State University
IMU	Inertial Measurement Unit
kts	knots
LAS	LiDAR Data Exchange File format
LC	Low Chord
LGU	local government unit
LiDAR	Light Detection and Ranging
LMS	LiDAR Mapping Suite
m AGL	meters Above Ground Level
MIT	MAPUA Institute of Technology
MMS	Mobile Mapping Suite
MSL	mean sea level
NSTC	Northern Subtropical Convergence
PAF	Philippine Air Force
PAGASA	Philippine Atmospheric Geophysical and Astronomical Services Administration
PDOP	Positional Dilution of Precision
PPK	Post-Processed Kinematic [technique]
PRF	Pulse Repetition Frequency
PTM	Philippine Transverse Mercator
QC	Quality Check
QT	Quick Terrain [Modeler]
RA	Research Associate
RIDF	Rainfall-Intensity-Duration-Frequency
RMSE	Root Mean Square Error
SAR	Synthetic Aperture Radar
SCS	Soil Conservation Service
SRTM	Shuttle Radar Topography Mission
SRS	Science Research Specialist
SSG	Special Service Group
TBC	Thermal Barrier Coatings
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 VIGO RIVER

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1.1 Background of the Phil-LiDAR 1 Program

The University of the Philippines Training Center for Applied Geodesy and Photogrammetry (UP-TCAGP) launched a research program entitled "Nationwide Hazard Mapping using LiDAR" or Phil-LiDAR 1, 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.

Also, the program was aimed at producing an up-to-date and detailed national elevation dataset suitable for 1:5,000 scale mapping, with 50 cm and 20 cm horizontal and vertical accuracies, respectively. These accuracies were achieved through the use of the state-of-the-art Light Detection and Ranging (LiDAR) airborne technology procured by the project through DOST.

The implementing partner university for the Phil-LiDAR 1 Program is the MAPUA Institute of Technology (MIT). MIT 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 26 river basins in the Cavite-Batangas-Rizal-Quezon (CABARZON) Region. The university is located in the City of Manila within Metro Manila in the National Capital Region.

1.2 Overview of the Vigo River Basin

The Vigo River Basin stretches from the municipality of San Narcisco and drains towards the Ragay Gulf. It is located in the southernmost part of Quezon province. It covers the Municipalities of San Narciso, San Francisco, San Andres, and Mulanay in Quezon Province. The DENR River Basin Control Office, identified the basin to has a drainage area of 89 km2 and an estimated annual run-off of 142 million cubic meter (MCM) (River Basin Control Office, 2017).

Its main stem, the Vigo River, is part of the 28 river systems in the Southern Tagalog Region. According to the 2015 national census, a total of 5,854 locals are residing in the immediate vicinity of the river which are distributed among two (2) barangays in Municipality of San Narciso namely: Binay and Vigo Central (Philippine Statistics Authority, 2016). A large percentage of the river basin is cultivated land and the main source of livelihood is agriculture and fisheries. The Municipality of San Narciso is abundant with coastal/ marine resources with Ragay Gulf to its immediate east. Within Ragay Gulf are Malapad Reef and Palad Reef that serve as the breeding grounds for a variety of marine life. Mangrove trees are flourishing along the coastline and are protected by the municipality (San Narciso LGU, 2017).

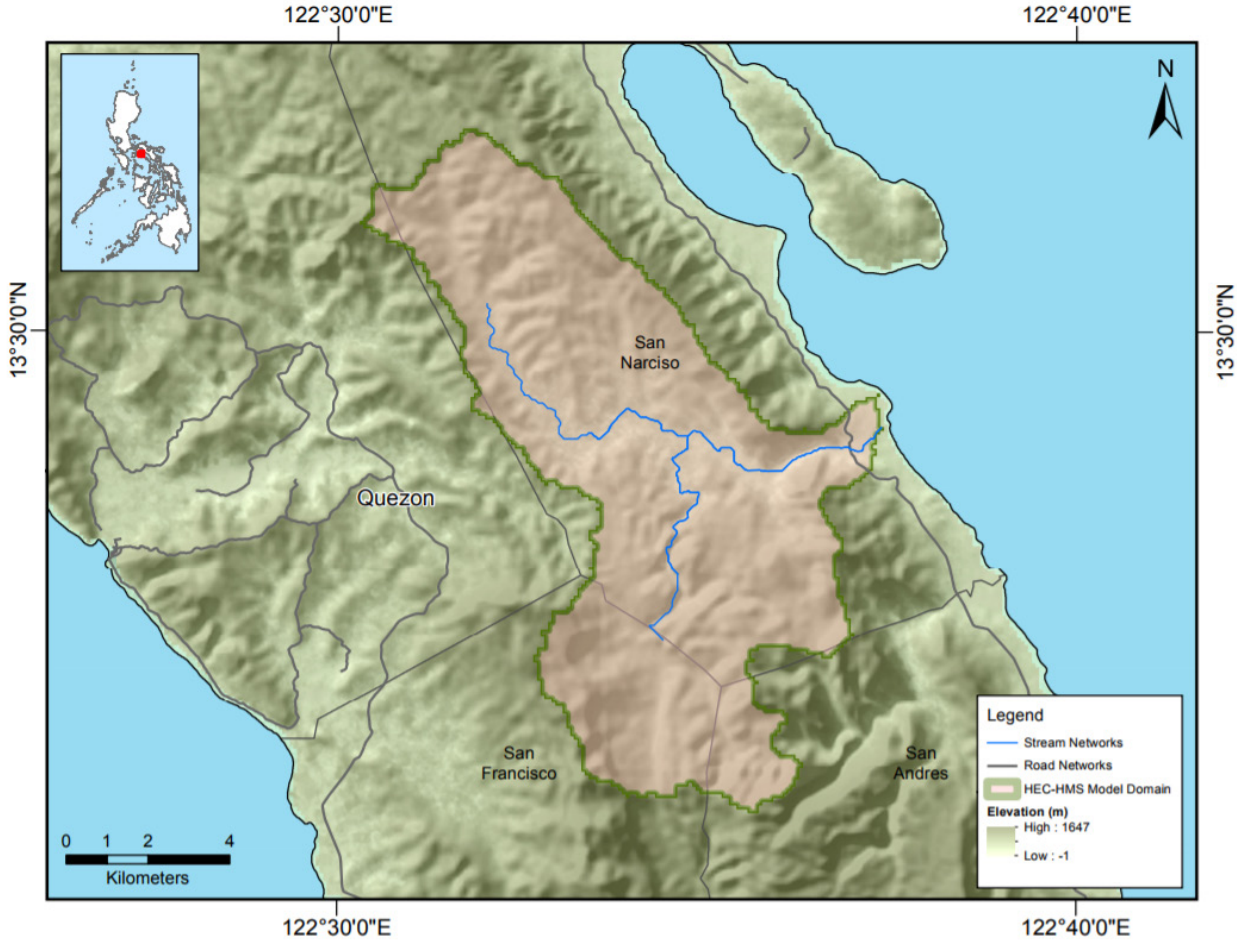

Figure 1. Map of the Vigo River Basin (in brown)

Similar to other river basins in Quezon province, Vigo river basin is not exempted from the danger of natural calamities such as typhoons like Typhoon Nina in 2016. During rainy seasons, the flow of the river is strong enough to cause severe flash floods in the downstream communities. There were reported cases where lives of the residents living near the river were put in danger due to persistent raining. According to the residents, there was a time that the barangay of Vigo was almost wiped out of the map due to a relentless typhoon.

Last December 2014, the Municipality of San Narciso was alerted by Project NOAH, which derives its LiDAR data from the DREAM and Phil-LiDAR 1 Program, of a 1.5 – 2.5 meter-height of storm surge in the coastal areas caused by Typhoon Hagupit, locally known as “Ruby” (Nationwide Operational Assessment of Hazards, 2014, Official list of localities: Typhoon Ruby (Hagupit) Storm Surge Advisory retrieved from http://blog.noah.dost.gov.ph). The aftermath of the typhoon in the province was followed by destroyed homes, road blocks from debris, and evacuation of residents (Eaglenews, 2014, Typhoon “Ruby” Causes Floods in Quezon Province retrieved from http://www.eaglenews.ph).

In this case, a state-of-the-art LiDAR (Light Detection and Ranging) technology and its outputs were employed in order to minimize the damages of severe flooding to the livelihoods of the people. The digital elevation data from LiDAR technology is accurate enough to produce flood maps that is helpful to water resources engineers and urban planners. From elevation values, one can observe the presence of waterbodies (such as rivers, streams, ponds, and lakes) and structures (such as roads, bridges, and buildings). This is greatly needed for flood assessment and mitigation especially in low-lying areas. Gathering of discharge data in Vigo river basin was quite challenging due to the river’s difficult terrain and unpredictable current. However, since these data were critical to floodplain modelling, the team still succeeded and the collected data were incorporated in hydrologic and hydraulic modelling software to produce flood hazard maps. Other maps such as storm surge maps can also be produced from the LiDAR data.

CHAPTER 2: LIDAR DATA ACQUISITION OF THE VIGO 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 Vigo floodplain in Quezon Province. These missions were planned for 10 lines that run for at most four (4) hours including take-off, landing and turning time. The flight planning parameters for the LiDAR system is found in Table 1. Figure 2 shows the flight plan for Vigo floodplain.

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

Block Name	Flying Height (m AGL)	Overlap (%)	Field of view (ø)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK 21E	700, 1000	30	50	200	30	130	5
BLK 21F	1000	30	50	200	30	130	5

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

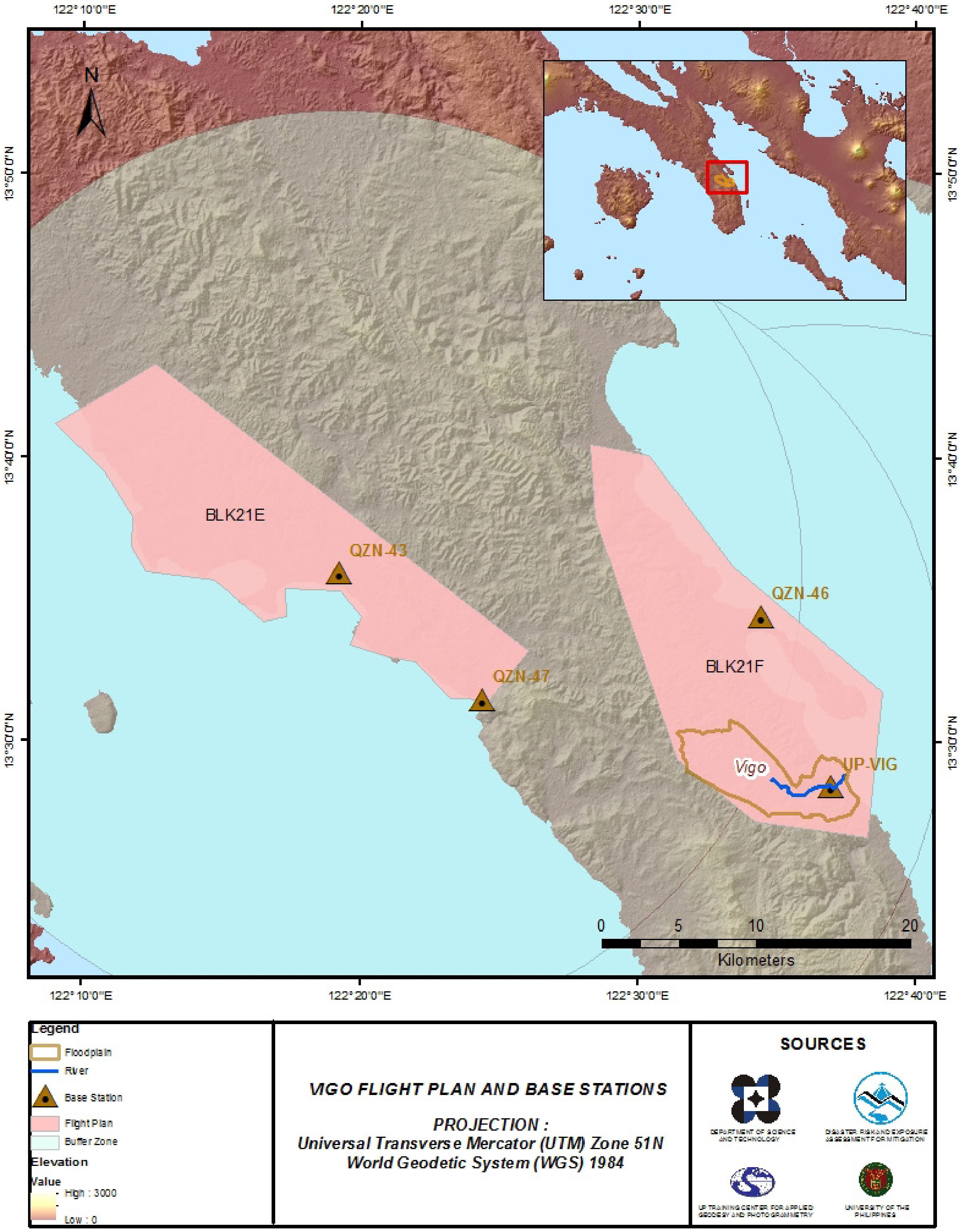


Figure 2. Flight Plan and base stations used for the Pegasus System in the Vigo Floodplain survey.

2.2 Ground Base Stations

The project team was able to recover three (3) NAMRIA ground control points QZN-46, QZN-47 and QZN-43 which are of second (2nd) order accuracy. The project team also used one (1) ground control point, UP-VIG, established by Data Validation and Bathymetry Component (DVBC). The certification for the base stations are found in Annex A-2 while the baseline processing report for the established ground control point is found in Annex A-3. These were used as base stations during flight operations for the entire duration of the survey (May 6, May 15 and May 17, 2016)[Used the dates in the table for base stations not the dates of FW]. Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 852 and TOPCON GR-5. Flight plans and location of base stations used during aerial LiDAR acquisition in Vigo floodplain are shown in Figure 2. The list of team members for LiDAR data acquisition is found in Annex 4.

Figure 3 to Figure 6 show the recovered and established reference points within the area. In addition, Table 2 to Table 5 show the details about the NAMRIA reference point and established control point, while Table 6 shows the list of all ground control points occupied during the acquisition together with the corresponding dates of utilization.

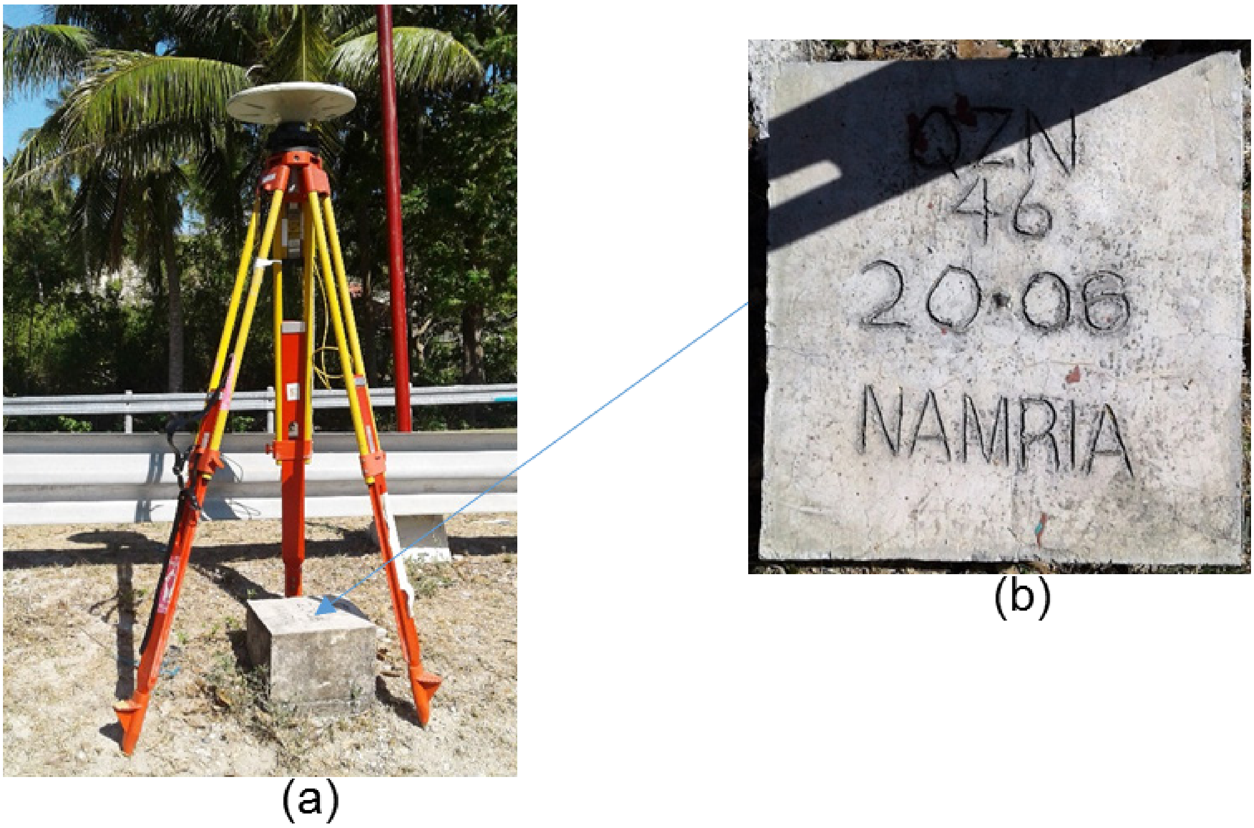
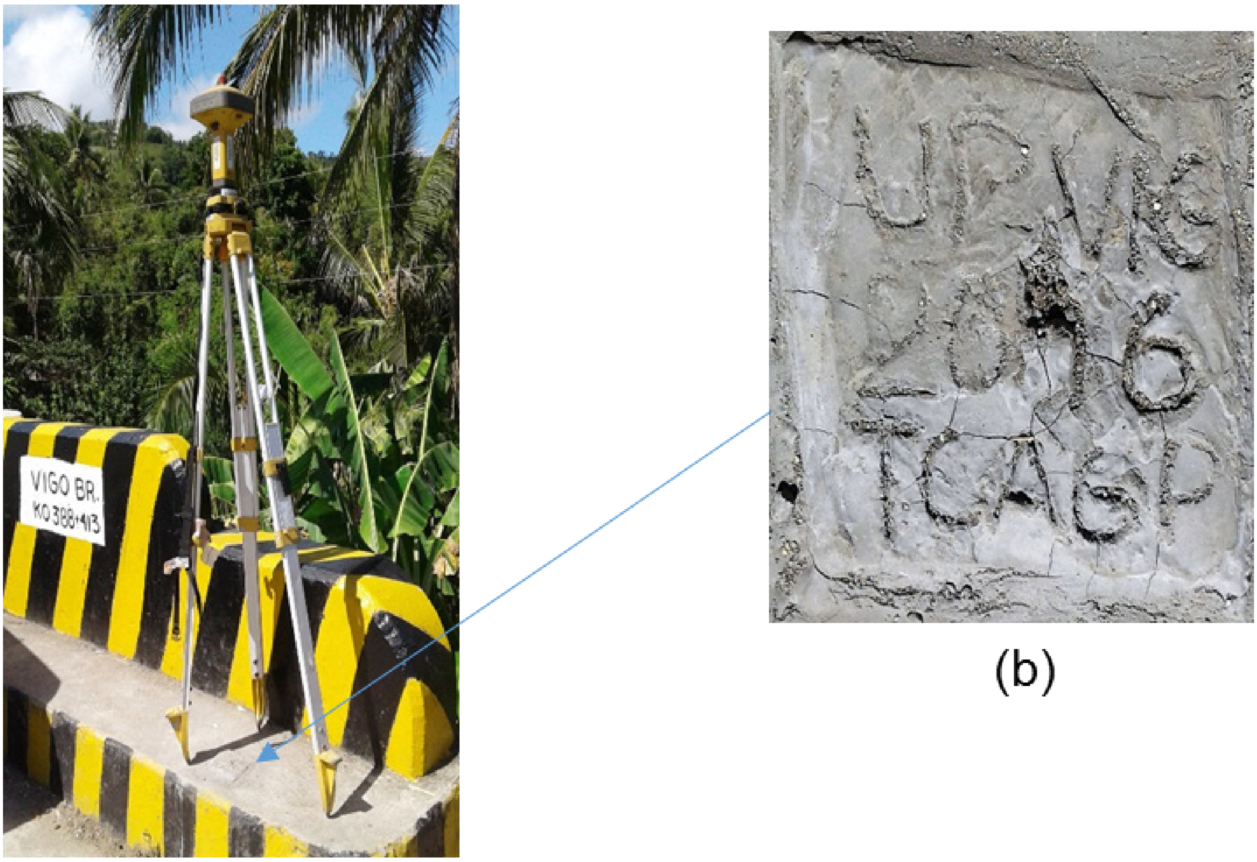


Figure 3. GPS set-up over QZN-46 near the pier in Brgy. Pagdamayan, San Narciso, Quezon (a) and NAMRIA reference point CVT-199 (b) as recovered by the field team.

Table 2. Details of the recovered NAMRIA horizontal control point QZN-46 used as base station for the LiDAR acquisition.

Station Name	**QZN-46**	
Order of Accuracy	**2nd**	
Relative Error (Horizontal positioning)	**1:50,000**	
Geographic Coordinates, Philippine Reference Of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 34' 31.49905" North 122° 34' 24.20658" East 6.55200 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 4 PRS 92)	Easting Northing	1501243.535 meters 453680.181 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 34'26.45178" North 122° 34' 24.20658" East 56.79200 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	1,500,718.07 meters 453,696.39 meters



(a) (b)

Figure 4. GPS set-up over UP-VIG established in Vigo Bridge along San Narciso-San Andres road in Brgy. Binay, San Narciso, Quezon (a) and established reference point UP-VIG (b) as recovered by the field team.

Table 3. Details of the established control point UP-VIG with processed coordinates used as base station for the LiDAR acquisition.[Table caption is different from established and recovered as well as if it is a BM]

Station Name	**UP-VIG**	
Order of Accuracy	**2nd**	
Relative Error (Horizontal positioning)	**1 :50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 28’ 25.87599” North 122° 36’ 56.36154” East 56.297 meters
Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 5 PRS 92)	Easting Northing	458401.422 meters 1489570.975 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 28’ 25.87599” North 122° 36’ 56.36154” East 56.297 meters

Figure 5. GPS set-up over QZN-43 inside the DPWH compound of Brgy.10, Catanauan, Quezon.

Table 4. Details of the recovered NAMRIA horizontal control point QZN-43 used as base station for the LiDAR acquisition.

Station Name	QZN-43	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 :50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 36’ 0.89019” 122° 19’ 8.55832” 3.53354 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 5 PRS 92)	Easting Northing	426309.396 meters 1504052.784 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 35’ 55.81611” North 122° 19’ 13.53031” East 53.08700 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	426,335.19 meters 1,503,526.34 meters

Figure 6. GPS set-up over QZN-47 on the center of Mulanay Elementary School oval, Brgy. DOS, Mulanay, Quezon.

Table 5. Details of the recovered NAMRIA horizontal control point QZN-47 used as base station for the LiDAR acquisition.

Station Name	QZN-47	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 :50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 31’ 34.57412” North 122° 24’ 18.47045” East 5.99800 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 5 PRS 92)	Easting Northing	435605.783 meters 1495844.441 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 31’ 29.52488” North 122° 24’ 23.44821” East 55.96400 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	435,628.32 meters 1,495,320.87 meters

Table 5. Ground control points that were used during the LiDAR data acquisition.

Date Surveyed	Flight Number	Mission Name	Ground Control Points
6 MAY 2016	23324P	1BLK21F127A	QZN-46 & UP-VIG
15 MAY 2016	23354P	1BLK21EF136A	QZN-47 & QZN-43
17 MAY 2016	23362P	1BLK21S138A	QZN-46 & UP-VIG

2.3 Flight Missions

Three (3) missions were conducted to complete the LiDAR Data Acquisition in Vigo floodplain, for a total of twelve hours and eighteen minutes (12+18) of flying time for RP-C9122. All missions were acquired using the Pegasus LiDAR system. Table 7 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 8 presents the actual parameters used during the LiDAR data acquisition.

Table 7. Flight missions for LiDAR data acquisition in Vigo 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
6 MAY 2016	23324P	884.7	194.57	38.14	148.86	NA	4	17
15 MAY 2016	23354P	884.7	191.52	0.84	190.68	NA	4	20
17 MAY 2016	23362P	884.7	78.71	NA	75.83	NA	3	41
TOTAL		2654.1	464.8	38.98	415.37	NA	12	18

Table 8. Actual parameters used during LiDAR data acquisition

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (khz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
23324P	1000	30	50	200	30	130	5
23354P	1000	30	50	200	30	130	5
23362P	700, 1000	30	50	200	30	130	5

2.4 Survey Coverage

Vigo floodplain is situated within the municipalities of Quezon. The municipality of San Narciso is mostly covered by the survey. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 9. The actual coverage of the LiDAR acquisition for Vigo floodplain is presented in Figure 7.

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

Province	Municipality/ City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Quezon	San Narciso	241.20	203.60	84.41%
	General San Narciso	119.16	21.69	18.21%
	Catanauan	267.28	47.74	17.86%
	Mulanay	262.91	21.05	8.01%
	Buenavista	157.40	7.36	4.67%
TOTAL		**1047.95**	**301.44**	**28.76%**

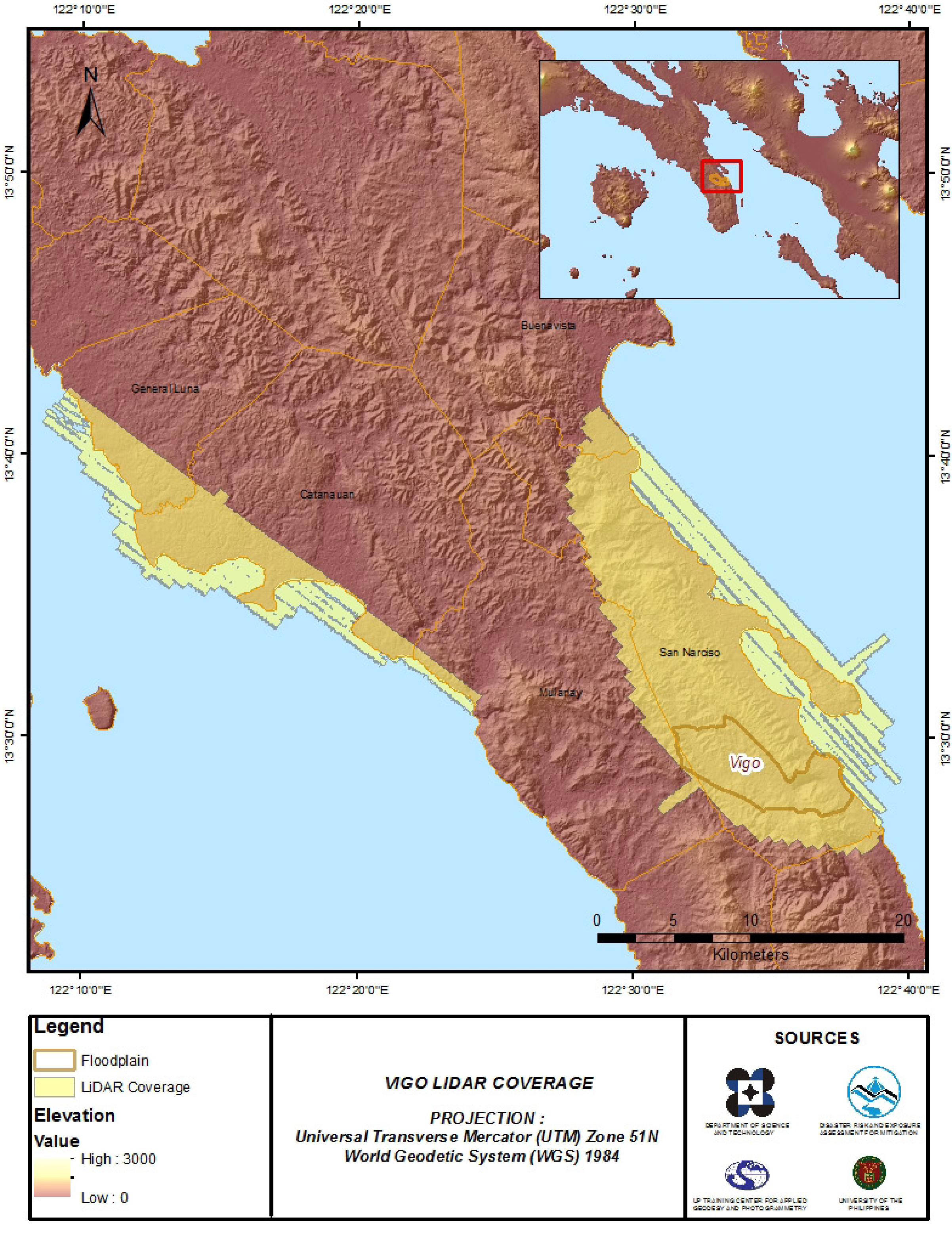


Figure 7. Actual LiDAR survey coverage for Vigo Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE VIGO FLOODPLAIN

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

3.1 Overview of the LiDAR Data Pre-Processing

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

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

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

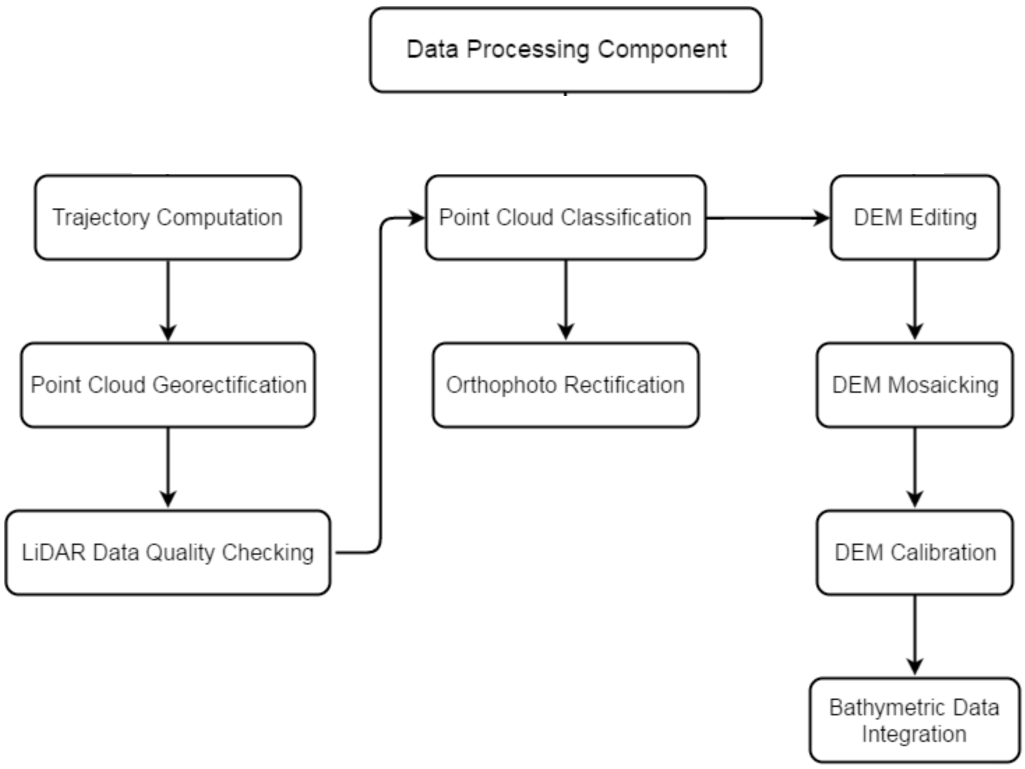

Figure 8. Schematic diagram for Data Pre-Processing Component.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Vigo floodplain can be found in Annex 5. Missions flown during the first survey conducted on May 2016 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus system over San Narciso, Quezon.

The Data Acquisition Component (DAC) transferred a total of 60.13 Gigabytes of Range data, 695 Gigabytes of POS data, 275.4 Megabytes of GPS base station data, and 22.4 Gigabytes of raw image data to the data server on September 9, 2016. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Vigo was fully transferred on September 9, 2016, as indicated on the Data Transfer Sheets for Vigo floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 23324P, one of the Vigo flights, which is the North, East, and Down position RMSE values are shown in Figure 9. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on May 6, 2016 00:00AM. The y-axis is the RMSE value for that particular position.

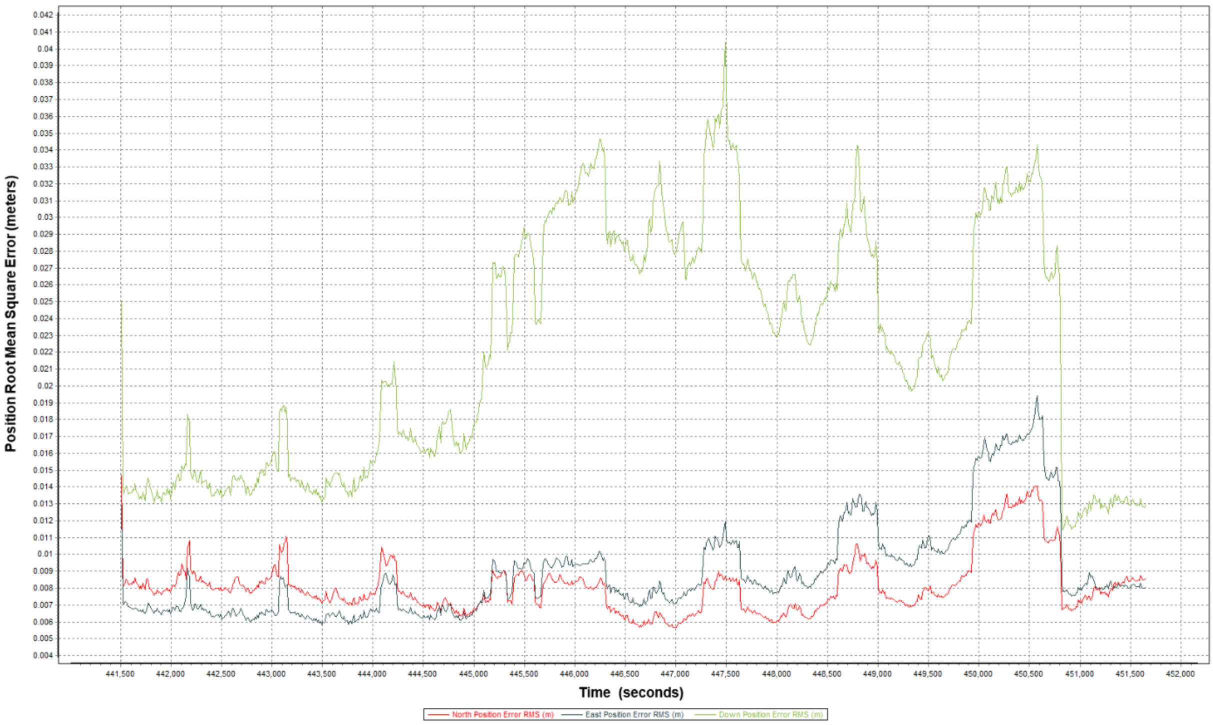

Figure 9. Smoothed Performance Metrics of Vigo Flight 23324P.

The time of flight was from 441,500 seconds to 451,500 seconds, which corresponds to morning of February 7, 2015. The initial spike that is seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the POS system starts computing for the position and orientation of the aircraft.

Redundant measurements from the POS system quickly minimized the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values correspond to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 9 shows that the North position RMSE peaks at 1.40 centimeters, the East position RMSE peaks at 1.90 centimeters, and the Down position RMSE peaks at 4.00 centimeters, which are within the prescribed accuracies described in the methodology.

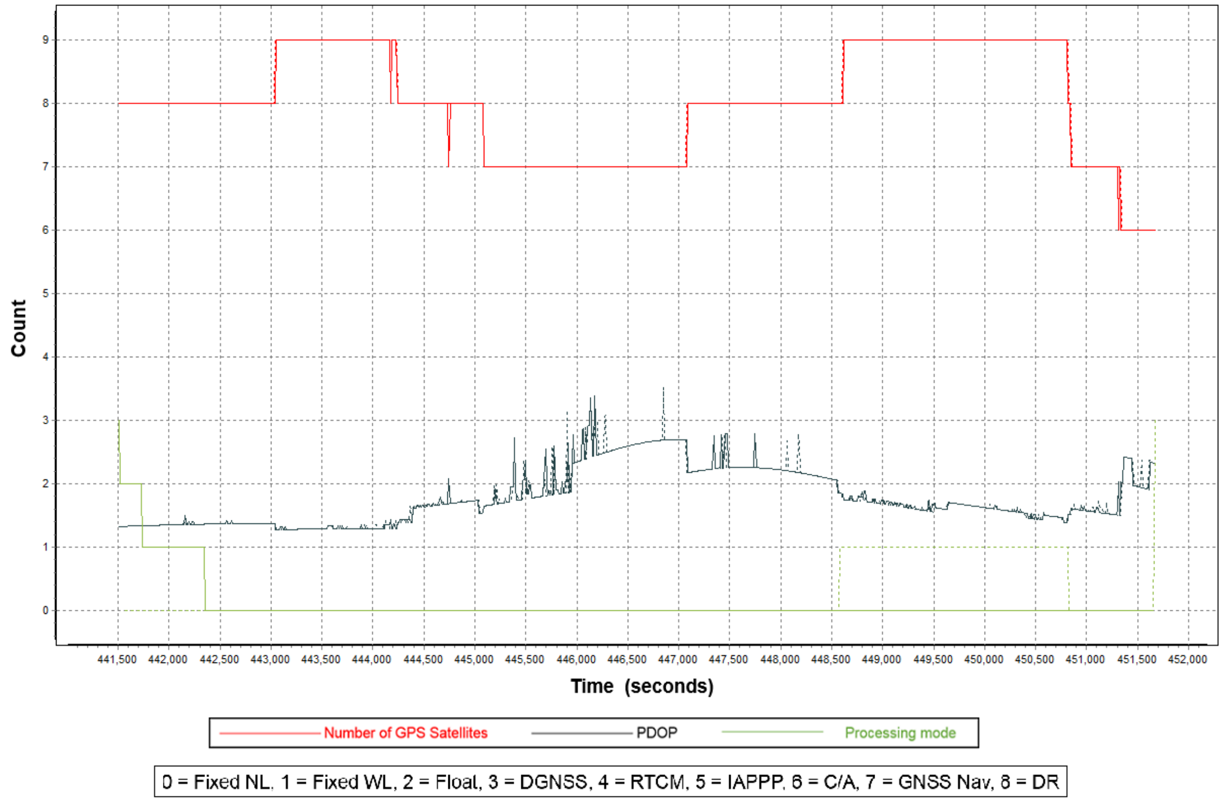

Figure 10. Solution Status Parameters of Vigo Flight 23324P.

The Solution Status parameters of flight 23324P, one of the Vigo flights, which indicate the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 10. The graphs indicate that the number of satellites during the acquisition did not go down to 7. Most of the time, the number of satellites tracked was between 7 and 9. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode remained at 0 for majority of the survey with some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for 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 Vigo flights is shown in Figure 11.

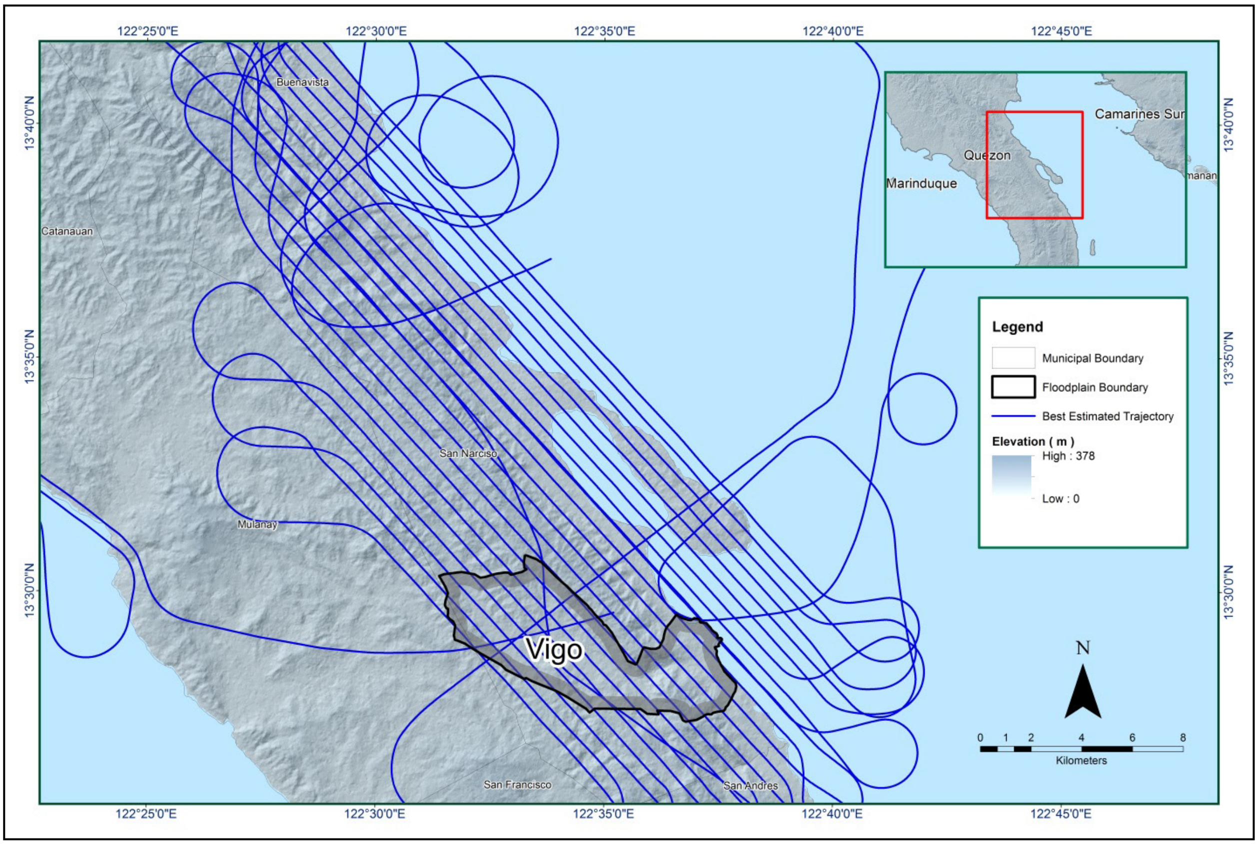

Figure 11. Best estimated trajectory of the LiDAR missions conducted over the Vigo Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 14 flight lines, with each flight line containing two channels, since the Pegasus system contains two channels. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Vigo floodplain are given in Table 10.

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

Parameter	Acceptable Value	Computed Value
Boresight Correction stdev	<0.001degrees	0.000149
IMU Attitude Correction Roll and Pitch Correction stdev	<0.001degrees	0.000901
GPS Position Z-correction stdev	<0.01meters	0.0023

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

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data is shown in Figure 12. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

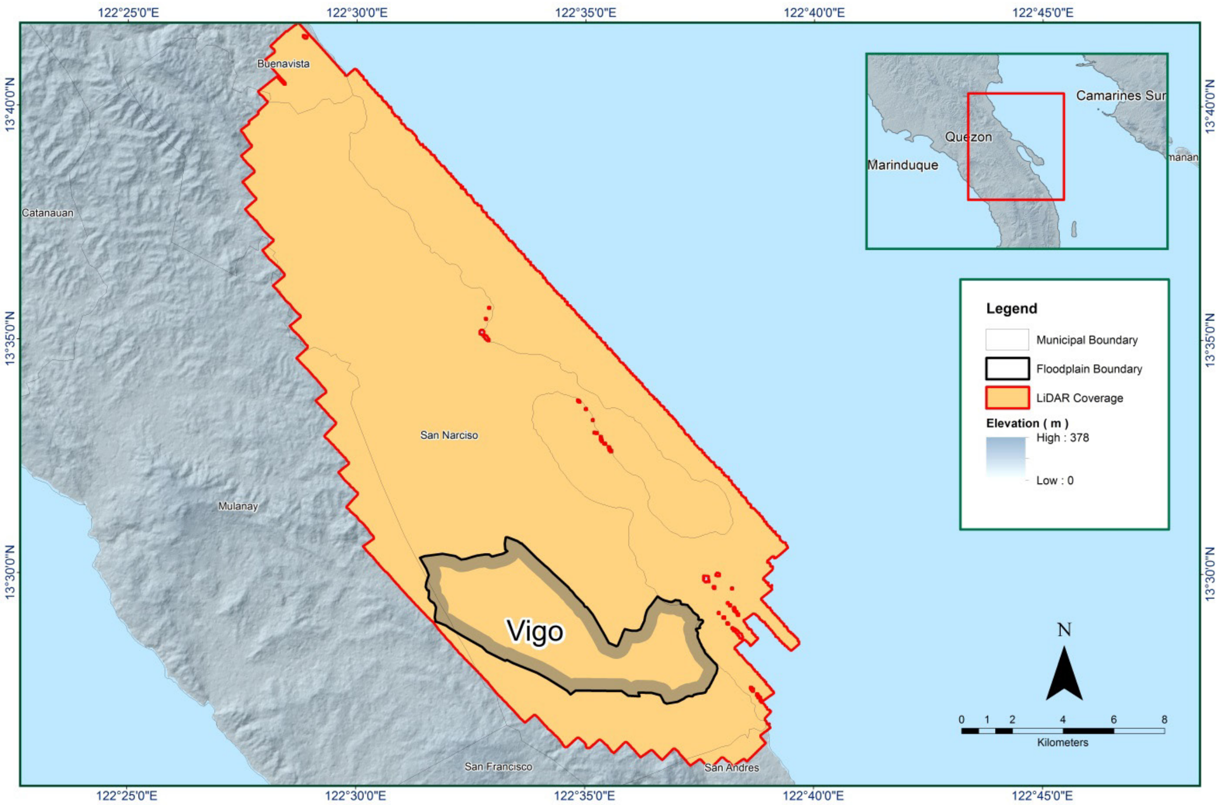

Figure 12. Boundary of the processed LiDAR data on top of a SAR Elevation Data over Vigo Floodplain.

The total area covered by the Vigo missions is 305.23 sq.km that is comprised of three (3) flight acquisitions grouped and merged into one (1) block as shown in Table 11.

Table 11. List of LiDAR blocks for Vigo Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Bagasbas_Blk21F	23324P	305.23
	23354P	
	23362P	
TOTAL		305.23 sq.km

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 13. Since the Pegasus system employs two channels, we would expect an average value of 2 (blue) for areas where there is limited overlap, and a value of 3 (yellow) or more (red) for areas with three or more overlapping flight lines.

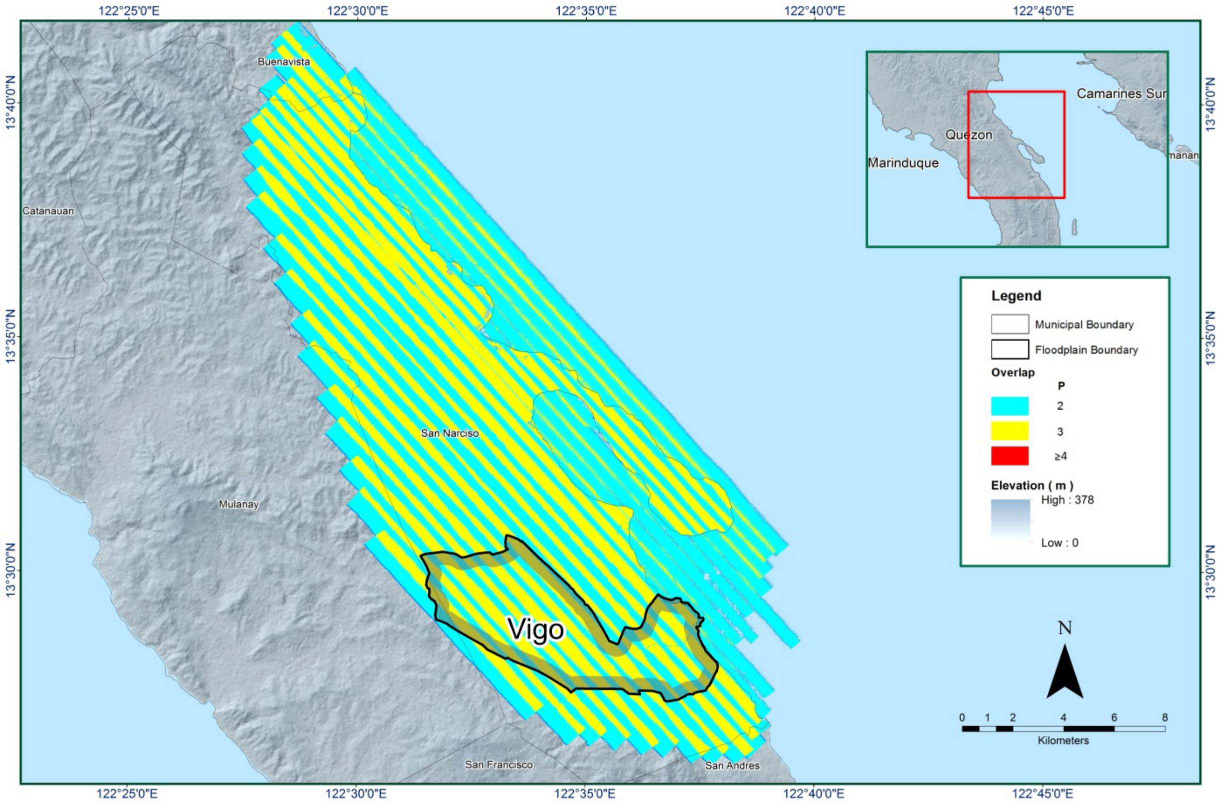

Figure 13. Image of data overlap for Vigo Floodplain.

The overlap statistics per block for the Vigo floodplain can be found in Annex 8. One pixel corresponds to 25.0 square meters on the ground. For this area, the percent overlap is 46.95%, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 14. It was determined that all LiDAR data for Vigo floodplain satisfy the point density requirement, and the average density for the entire survey area is 3.45 points per square meter.

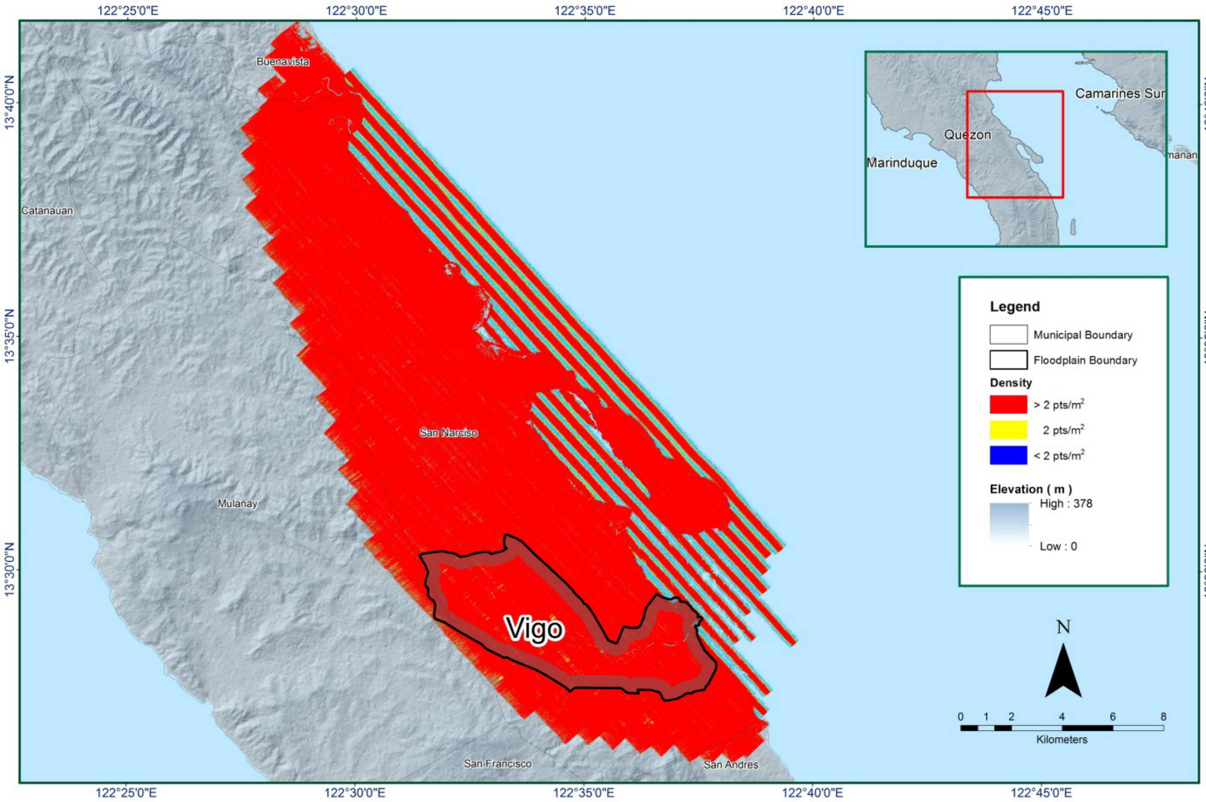

Figure 14. Pulse density map of merged LiDAR data for Vigo Floodplain.

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

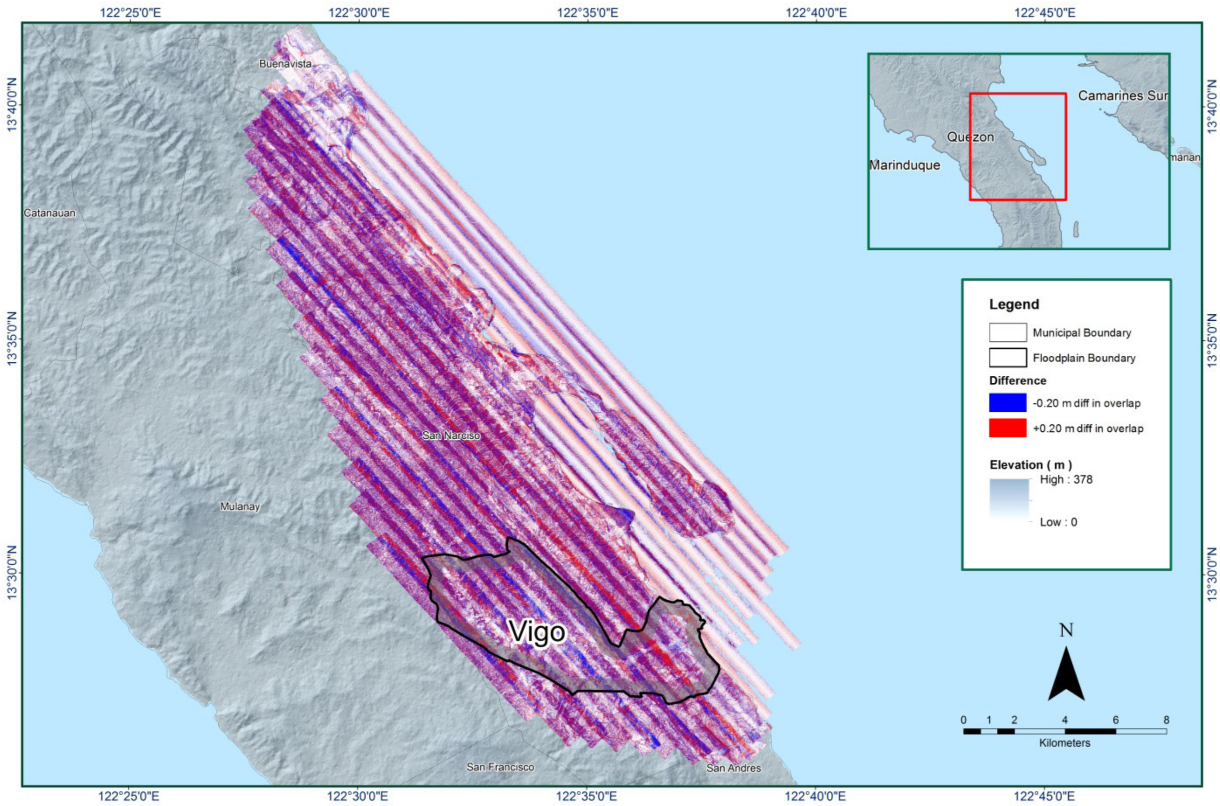

Figure 15. Elevation Difference Map between flight lines for Vigo Floodplain Survey.

A screen capture of the processed LAS data from a Vigo flight 23324P loaded in QT Modeler is shown in Figure 16. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed red line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

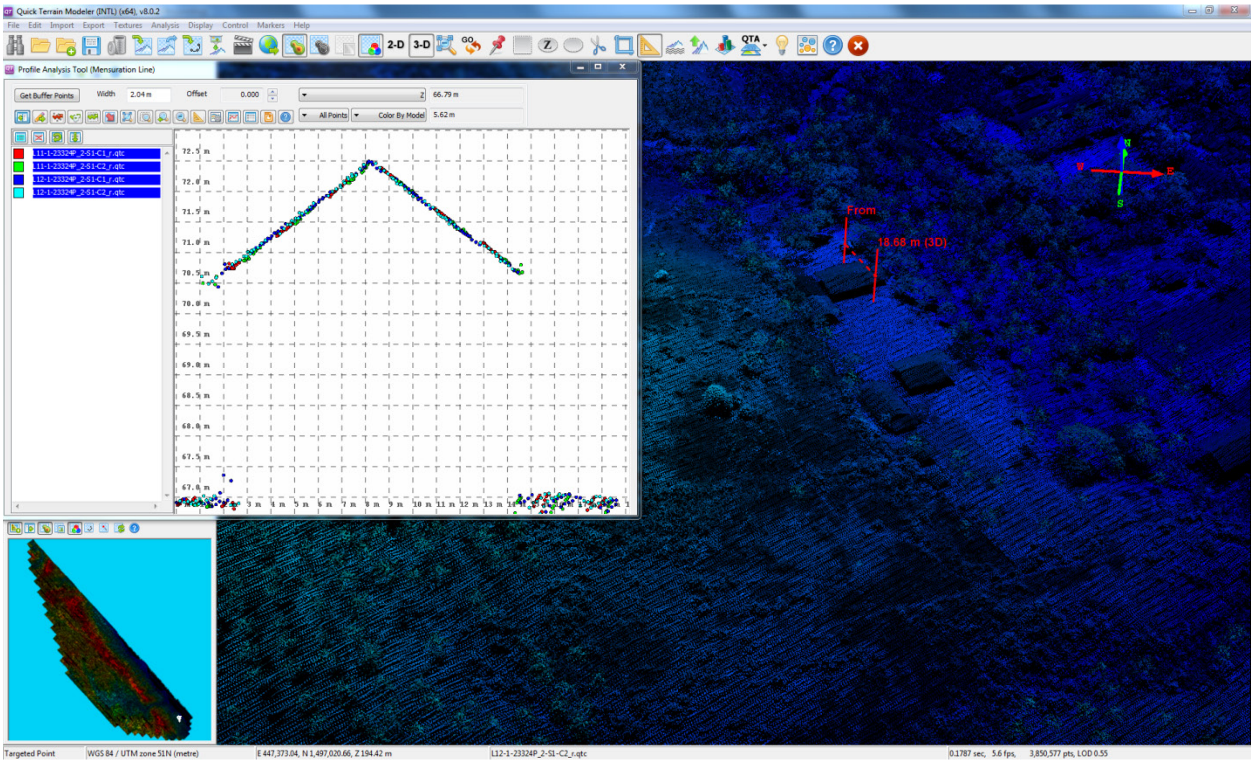

Figure 16. Quality checking for Vigo flight 23324P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 12. Vigo classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	439,161,917
Low Vegetation	216,086,525
Medium Vegetation	417,004,507
High Vegetation	925,276,667
Building	4,896,578

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Vigo floodplain is shown in Figure 17. A total of 366 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 12. The point cloud has a maximum and minimum height of 400.57 meters and 9.92 meters respectively.

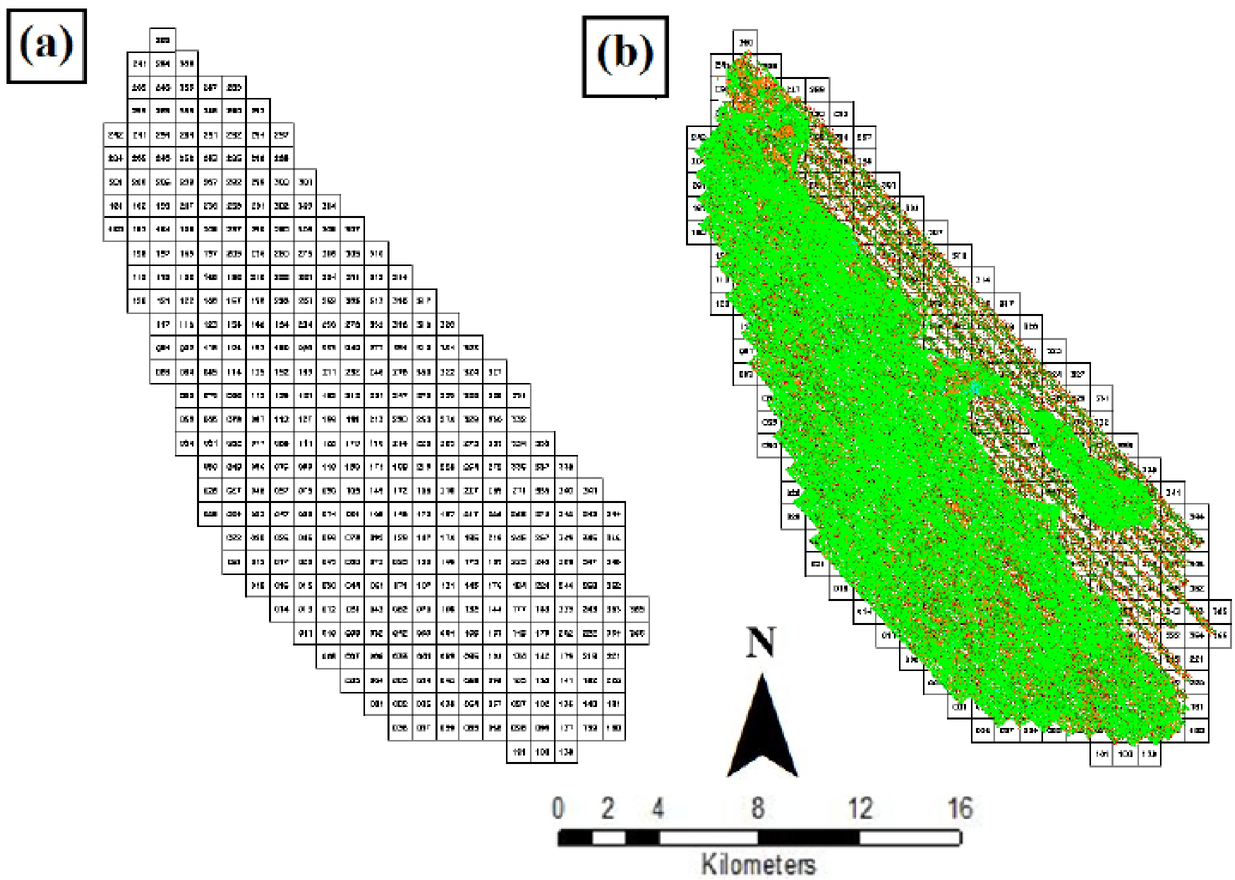

Figure 17. Tiles for Vigo Floodplain (a) and classification results (b) in TerraScan.

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

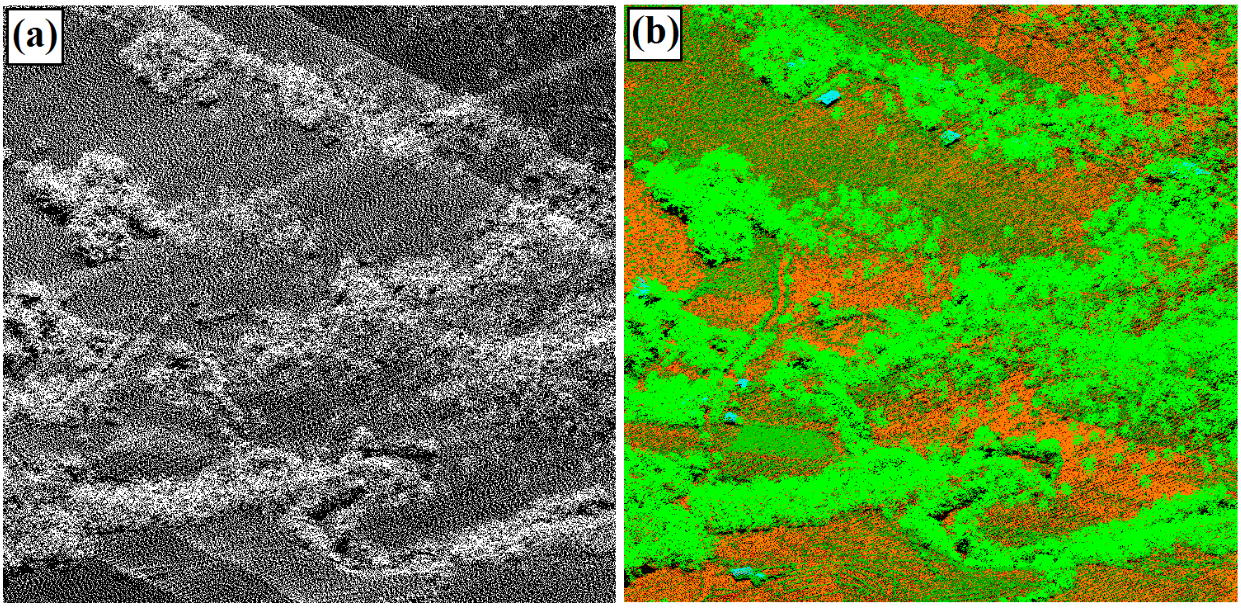

Figure 18. Point cloud before (a) and after (b) classification

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

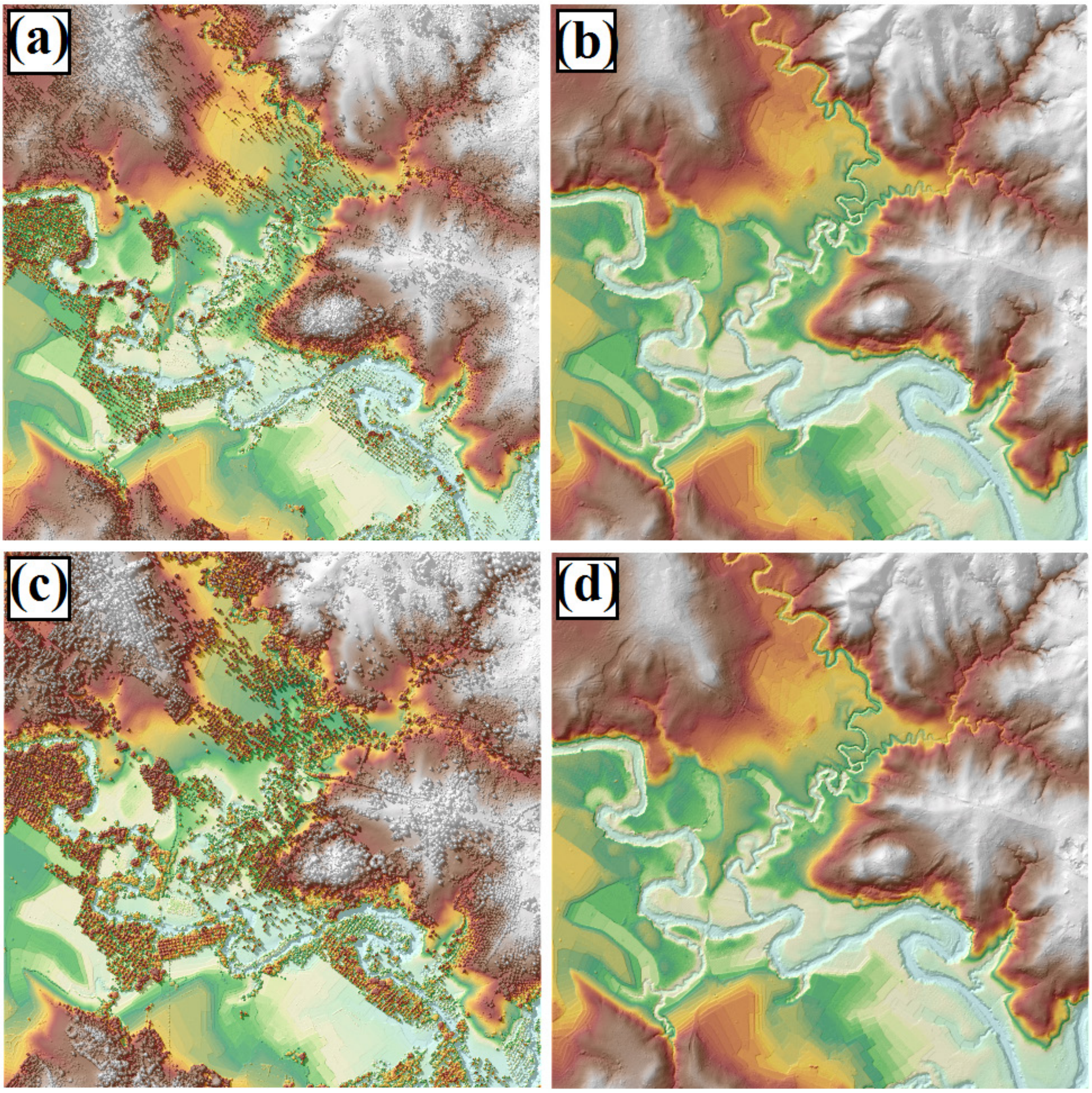

Figure 19. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Vigo Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

There are no available orthophotographs for the Yabaan floodplain The 134 1km by 1km tiles of the block covering the Vigo floodplain is shown in Figure 20. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The block covering the Vigo floodplain has a total of 84.95 sq.km orthophotogaph coverage comprised of 326 images. However, the block does not have a complete set of orthophotographs and no orthophotographs cover the area of the Vigo floodplain. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 21.

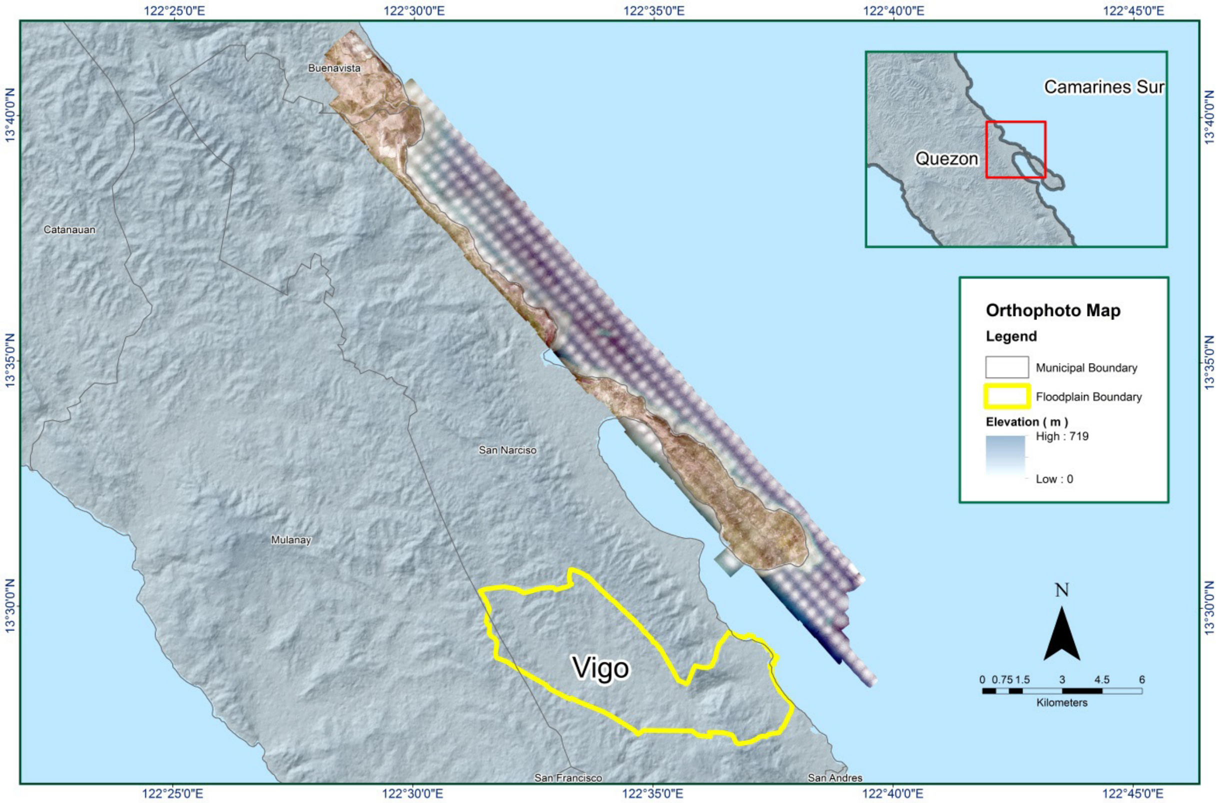

Figure . Vigo Floodplain with available orthophotographs.

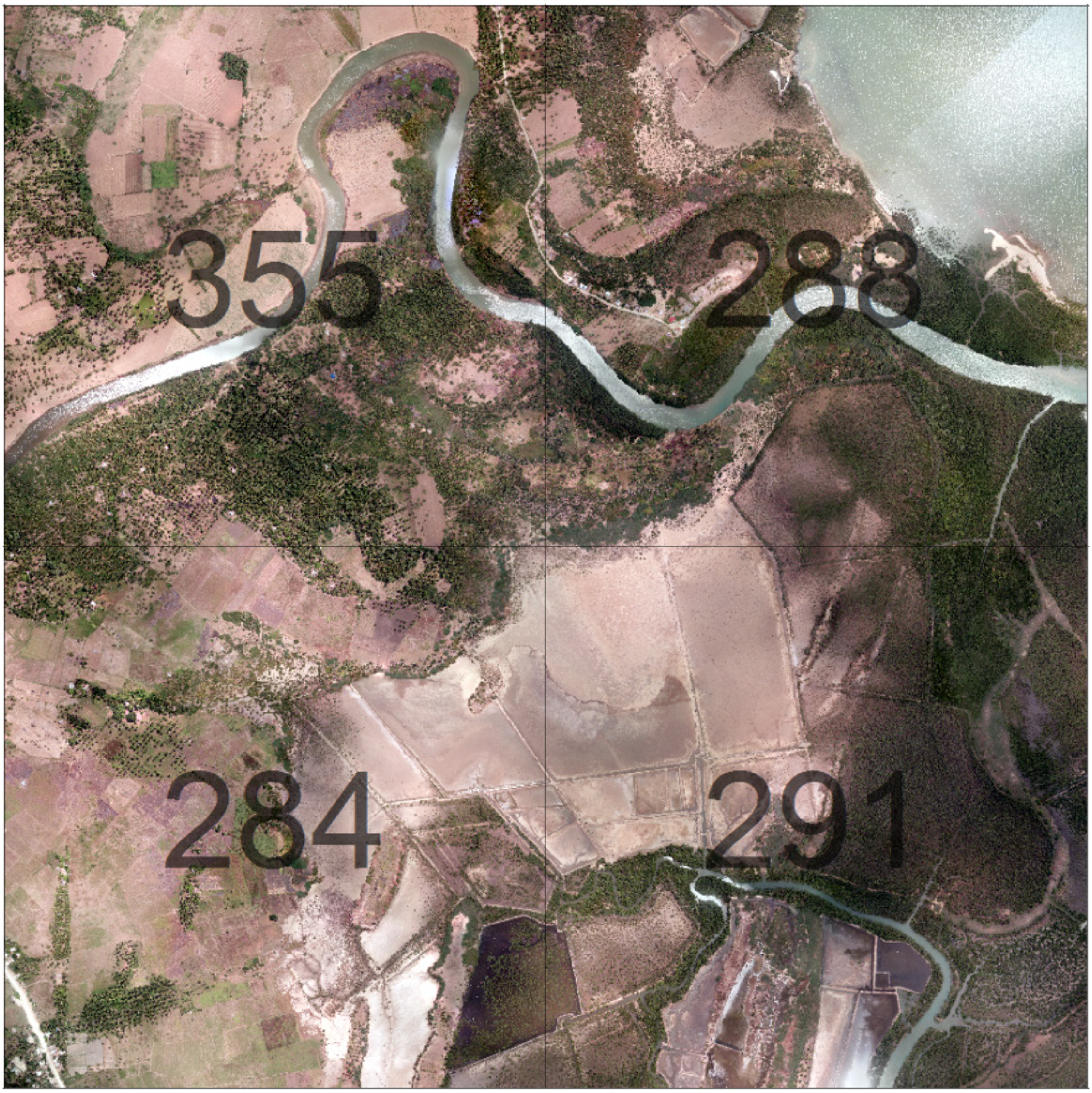

Figure 21. Sample orthophotograph tiles for Vigo Floodplain.

3.8 DEM Editing and Hydro-Correction

One (1) mission block were processed for Vigo flood plain. These blocks are composed of SamarLeyte and Leyte blocks with a total area of 305.23 square kilometers. Table 13 shows the name and corresponding area of each block in square kilometers.

Table 13. LiDAR blocks with its corresponding areas.

LiDAR Blocks	Area (sq.km)
Bagasbas_Blk21F	305.23
TOTAL	305.23 sq.km

Portions of DTM before and after manual editing are shown in Figure 22. The bridge (Figure 22a) is considered to be an impedance to the flow of water along the river and has to be removed (Figure 22b) in order to hydrologically correct the river.

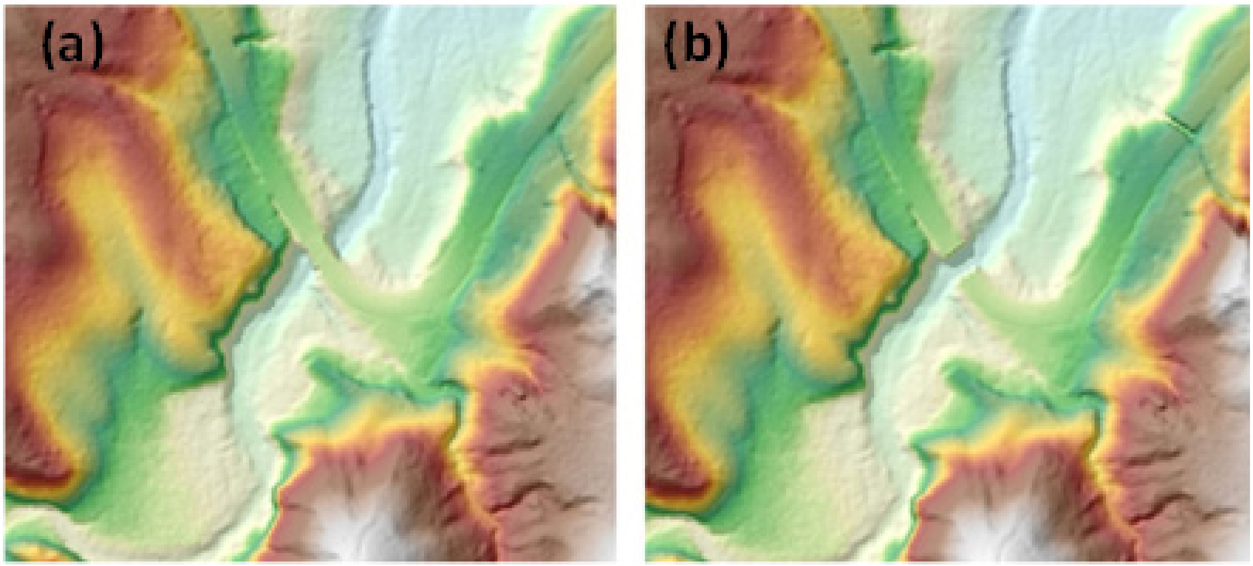

Figure 22. Portions in the DTM of Vigo Floodplain – a bridge before (a) and after (b) manual editing..

3.9 Mosaicking of Blocks

Bagasbas_Blk20F was used as the reference block at the start of the mosaicking because this block is the one at the uppermost right of Bagasbas blocks that can be connected to Bagasbas_Blk21F, the block that contains the Vigo flood plain.. Table 14 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Vigo floodplain is shown in Figure 19. It can be seen that the entire Vigo floodplain is 100% covered by LiDAR data.

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

Mission Blocks	Shift Values (meters)		
	x	y	z
Bagasbas_Blk21F	0.28	1.58	2.85

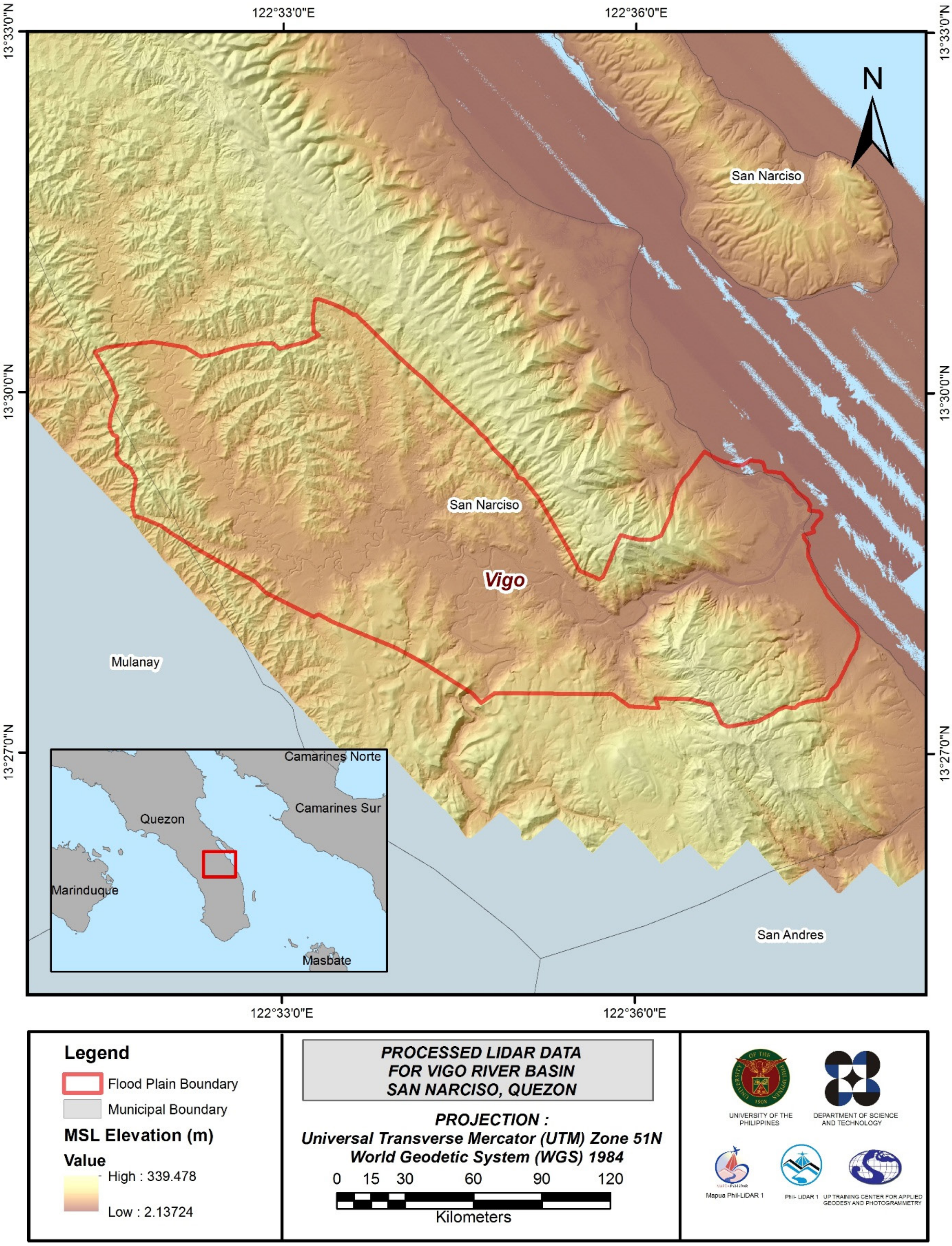

Figure 23 . Map of Processed LiDAR Data for Vigo Floodplain.

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

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Vigo to collect points with which the LiDAR dataset is validated is shown in Figure 24. A total of 15,500 survey points were gathered for all the flood plains within the provinces of Quezon and Camarines Sur wherein the Vigo floodplain is located. Random selection of 80% of the survey points, resulting to 12400 points, was used for calibration.

A good correlation between the uncalibrated mosaicked LiDAR DTM and ground survey elevation values is shown in Figure 25. 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 3.08 meters with a standard deviation of 0.17 meters. Calibration of the LiDAR data was done by subtracting the height difference value, 3.08 meters, to the mosaicked LiDAR data. Table 15 shows the statistical values of the compared elevation values between the LiDAR data and calibration data.

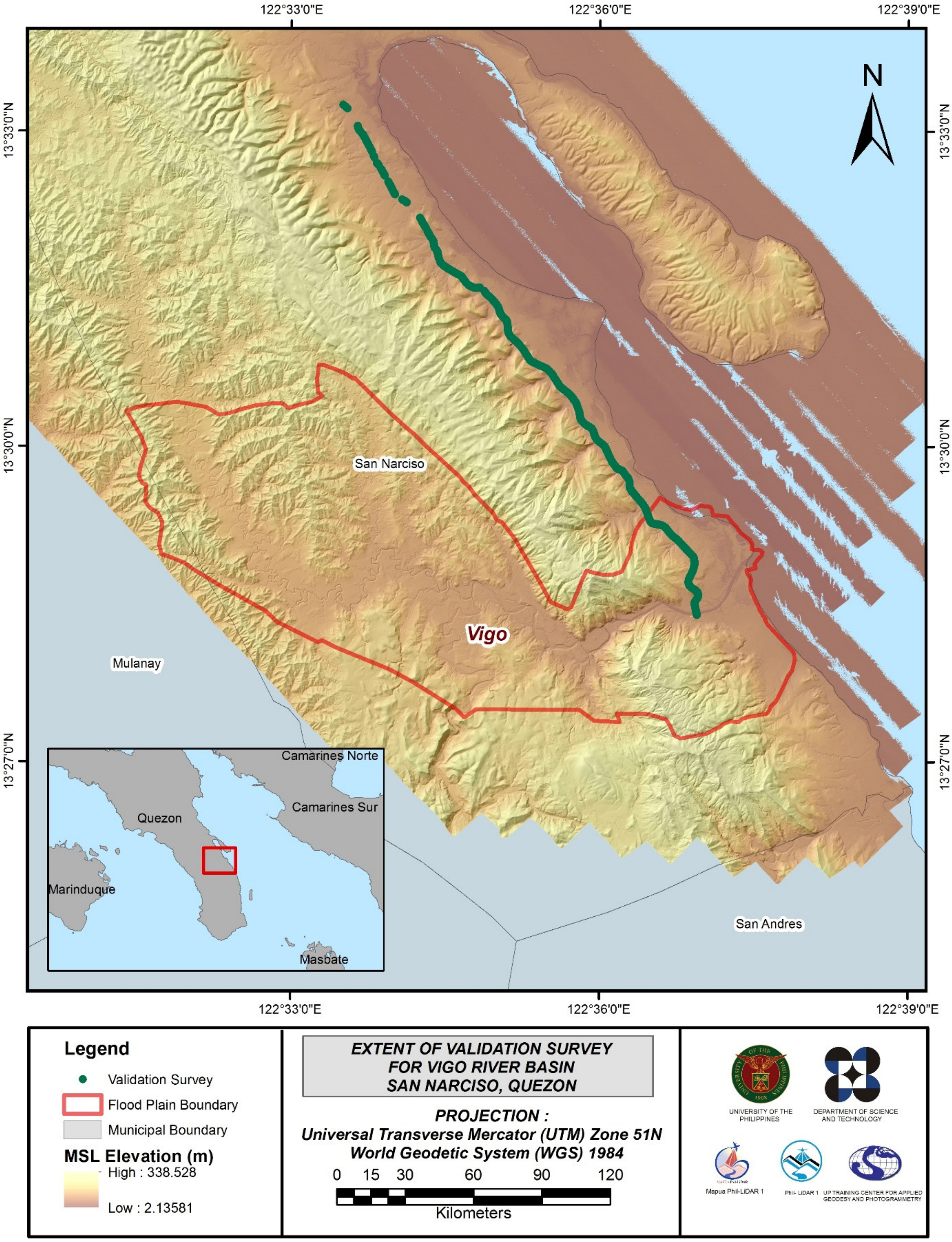

Figure 24. Map of Vigo Floodplain with validation survey points in green.

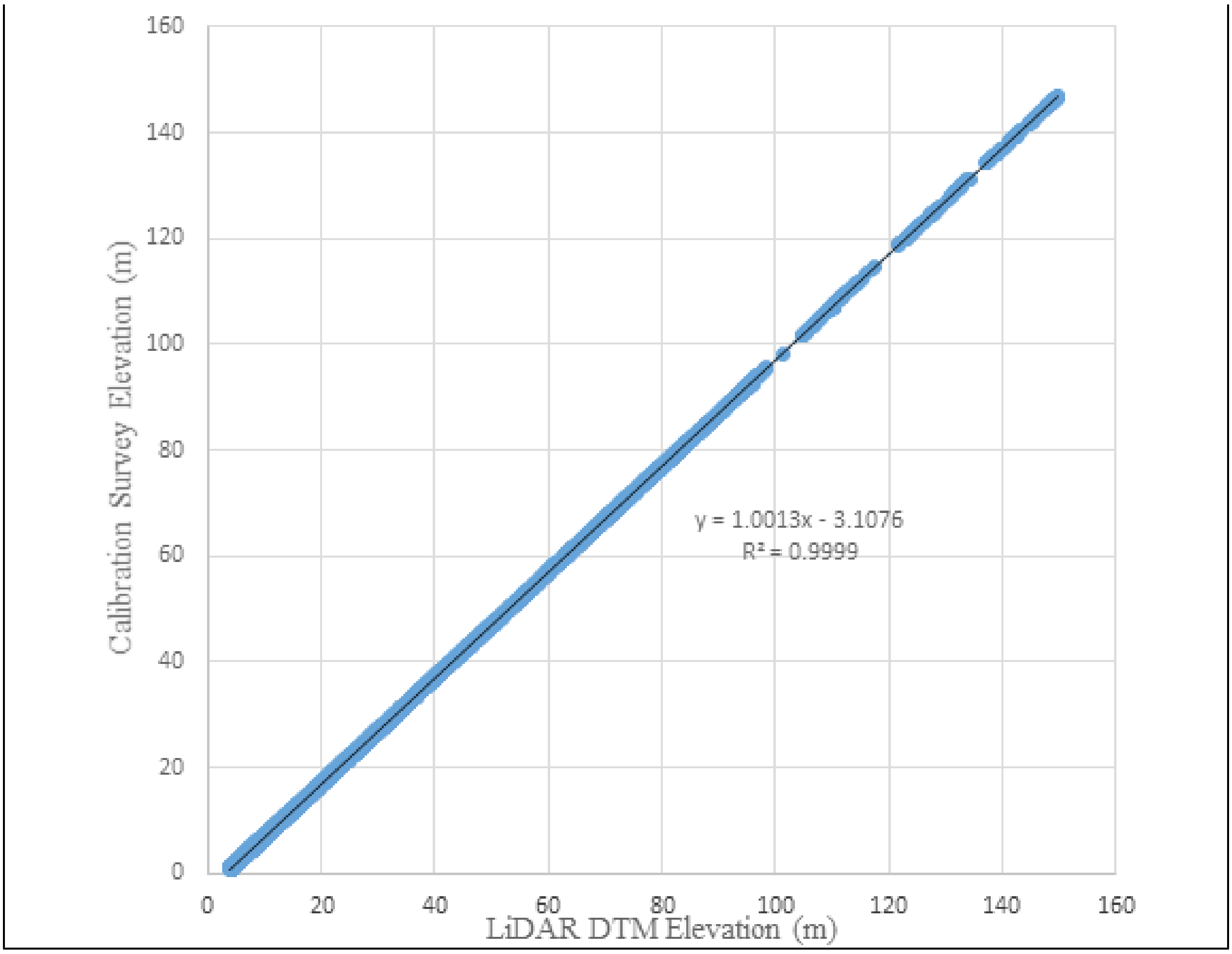

Figure 25. Correlation plot between calibration survey points and LiDAR data.

Table 15. Calibration Statistical Measures

Calibration Statistical Measures	Value (meters)
Height Difference	3.08
Standard Deviation	0.17
Average	-3.07
Minimum	-3.40
Maximum	-2.60

The remaining 20% of the total survey points were intersected to the flood plain, resulting to 56 points, were used for the validation of calibrated Vigo 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 26. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.14 meters with a standard deviation of 0.14 meters, as shown in Table 16.

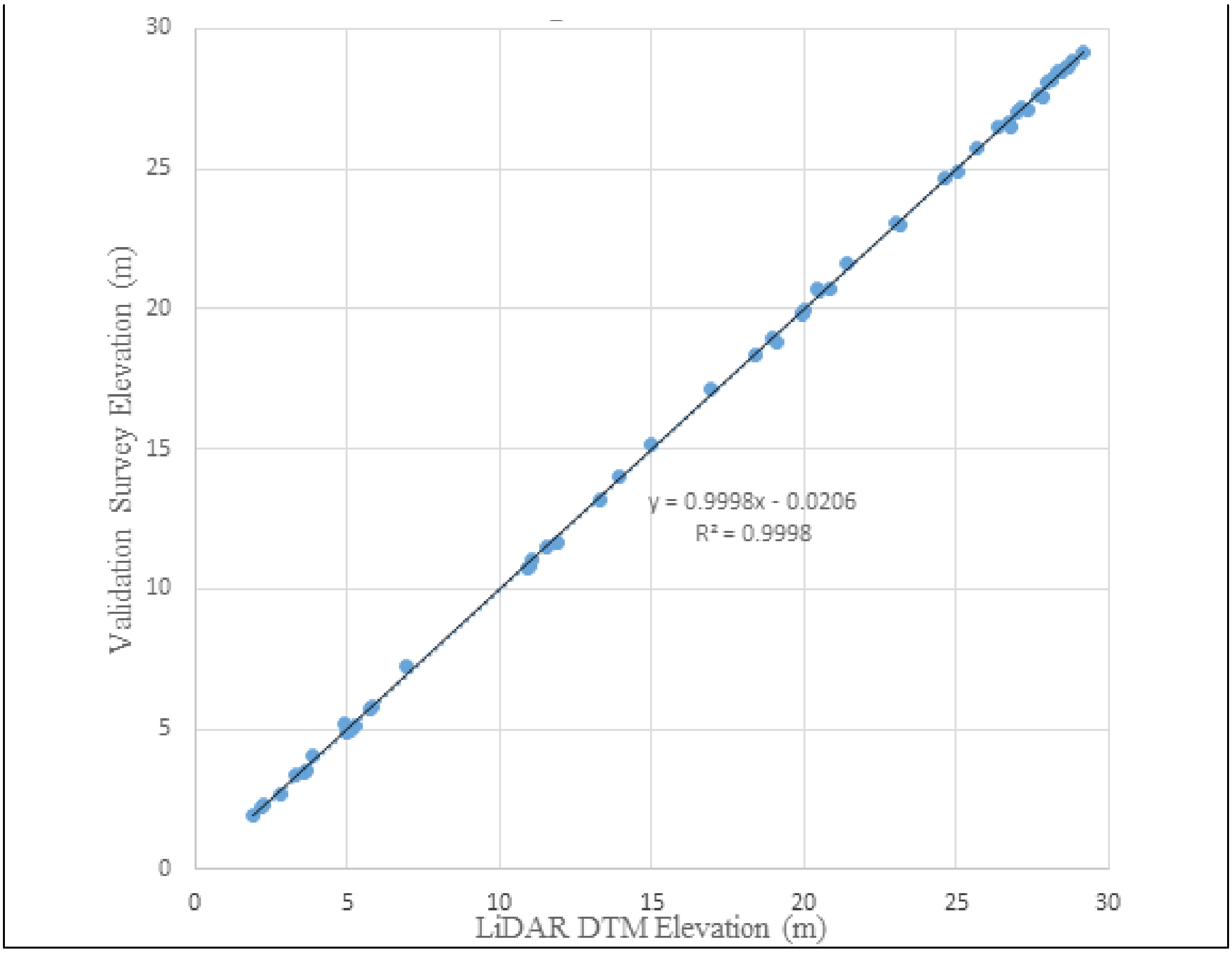

Figure 26. Correlation plot between validation survey points and LiDAR data.

Table 16. Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.14
Standard Deviation	0.14
Average	-0.02
Minimum	-0.30
Maximum	0.31

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, both the centerline and zigzag were available for Vigo with 4,064 bathymetric survey points. The resulting raster surface produced was done by Kernel Interpolation with Barriers method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.21 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Vigo integrated with the processed LiDAR DEM is shown in Figure 27.

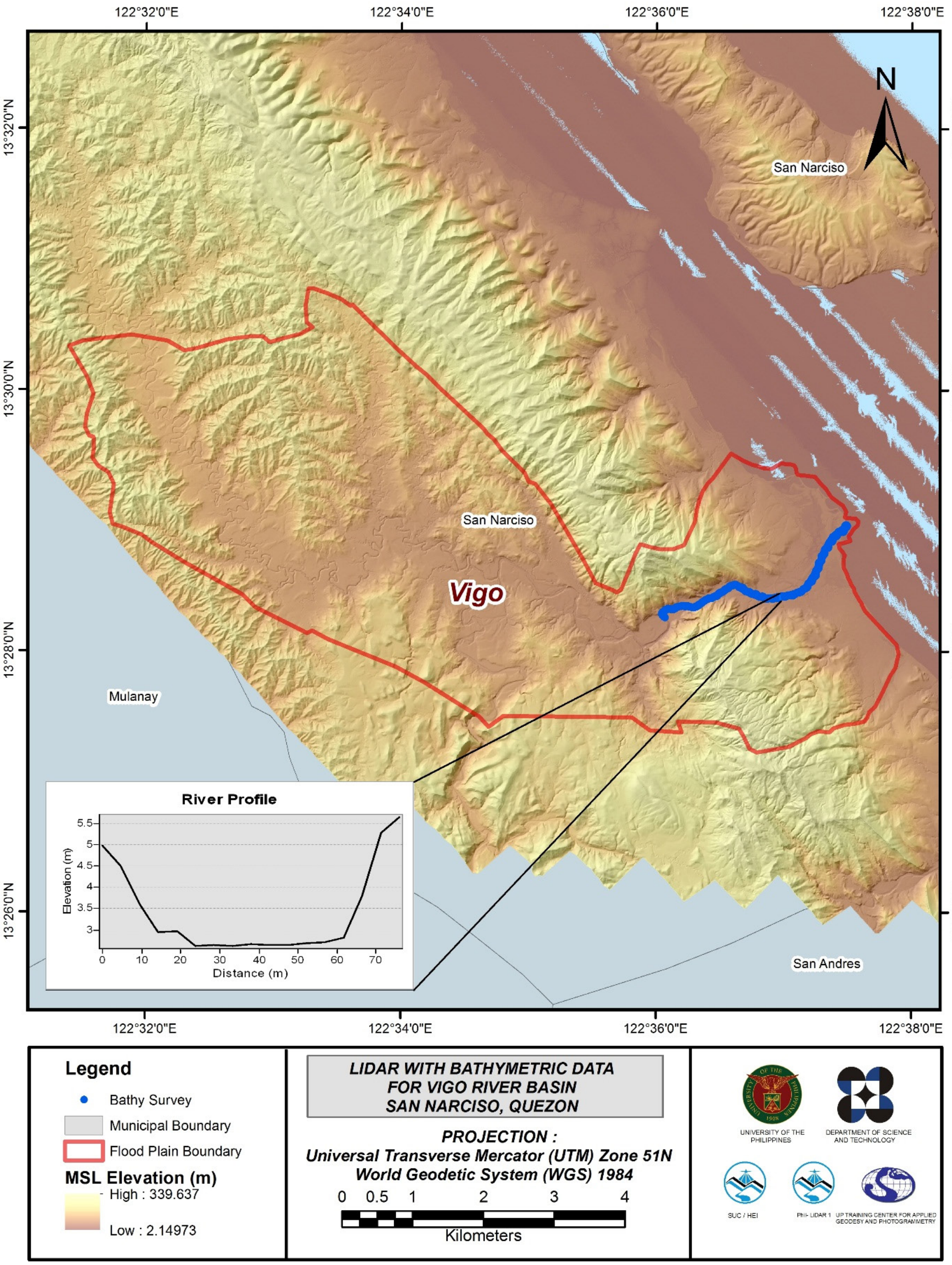

Figure 27. Map of Vigo Floodplain with bathymetric survey points shown in blue.

3.12 Feature Extraction

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

3.12.1 Quality Checking of Digitized Features' Boundary

Vigo floodplain, including its 200 m buffer, has a total area of 44.99 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 471 building features, are considered for QC. Figure 28 shows the QC blocks for Vigo floodplain.

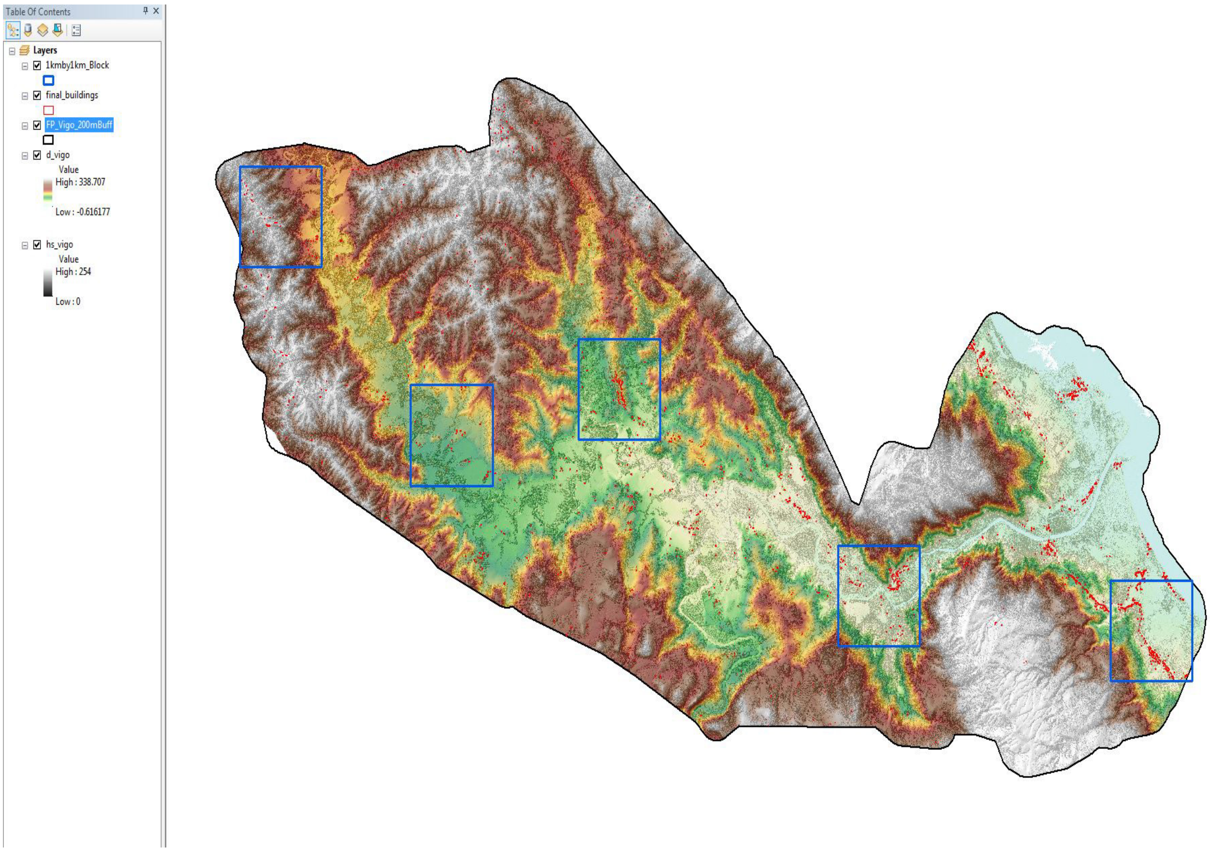

Figure28. Blocks (in blue) of Vigo building features that were subjected to QC

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

Table 17. Quality Checking Ratings for Vigo Building Features

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Vigo	99.82	98.51	81.32	PASSED

3.12.2 Height Extraction

Height extraction was done for 1,725 building features in Vigo floodplain. Of these building features, none was filtered out after height extraction, resulting to 1,560 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 7.79 m.

3.12.3 Feature Attribution

The attributes were obtained by field data gathering. GPS devices were used to determine the coordinates of important features. These points are uploaded and overlaid in ArcMap and are then integrated with the shapefiles.

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

Table 18. Building Features Extracted for Vigo Floodplain.

Facility Type	No. of Features
Residential	1,517
School	28
Market	1
Agricultural/Agro-Industrial Facilities	0
Medical Institutions	3
Barangay Hall	3
Military Institution	0
Sports Center/Gymnasium/Covered Court	0
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	1
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	0
Other Commercial Establishments	0
Total	**1,560**

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

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Vigo	29.68	10.97	5.00	0.00	0.00	45.65

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

Floodplain	Water Body Type					Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Vigo	32	2	0	0	20	2

A total of 20 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 29 shows the Digital Surface Model (DSM) of Vigo floodplain overlaid with its ground features.

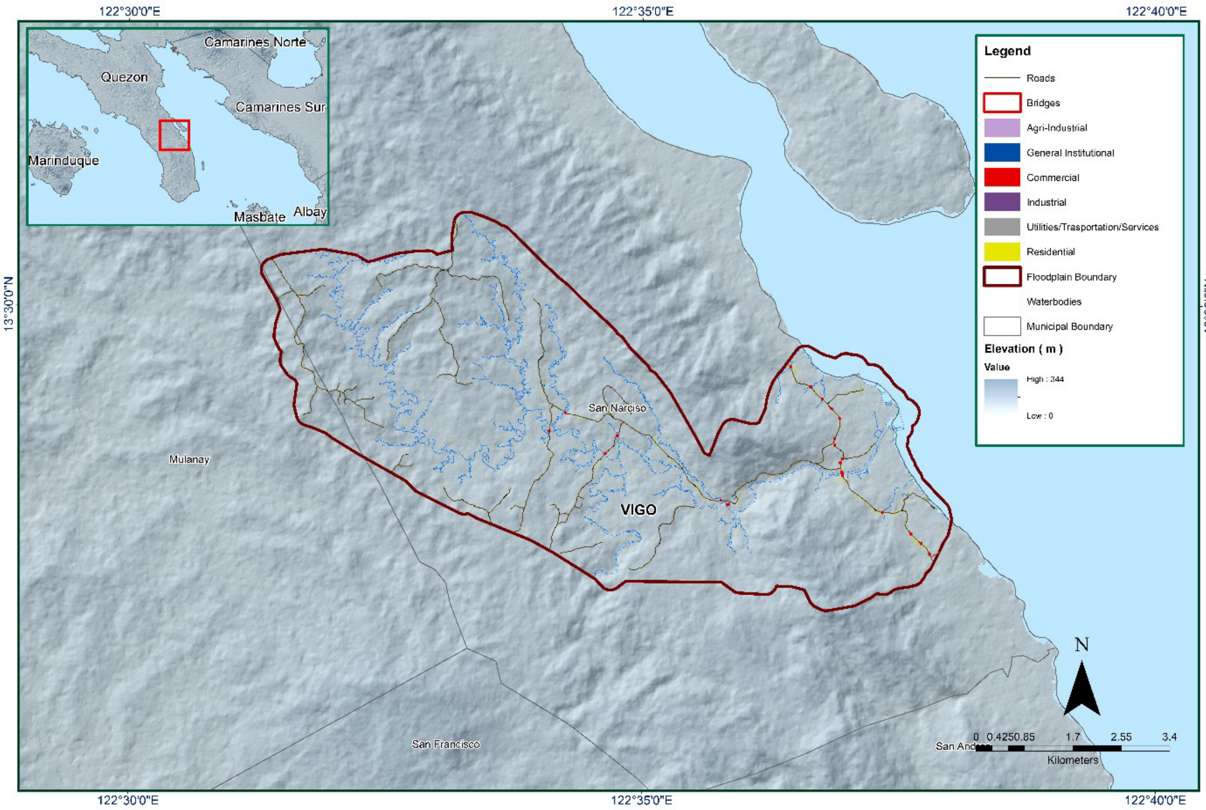

Figure 29. Extracted features for Vigo Floodplain.

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

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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 Vigo River on May 2-16, 2016 with the following scope of work: reconnaissance; control survey; cross-section and as-built survey at Vigo Bridge in Brgy. Vigo Central, Municipality of San Narciso; validation points acquisition of about 11.51 km covering the Vigo River Basin area; and bathymetric survey from its upstream in Brgy. Binay, Municipality of San Narciso down to the mouth of the same barangay, with an approximate length of 3.383 km using Ohmex™ single beam echo sounder and Trimble® SPS 882 GNSS PPK survey technique (Figure 30).

Figure 30. Extent of the bathymetric survey (in blue line) in Vigo River and the LiDAR data validation survey (in red).

4.2 Control Survey

The GNSS network used for Vigo River Basin is composed of nine (9) loops established on May 4 and 11, 2016 occupying the following reference points: QZN-40, a second-order GCP in Brgy. San Jose, Municipality of General San Narciso; QZN-43, a second-order GCP in Brgy. Matandang Sabang Silangan, Municipality of Catanauan; QZN-47, a second order GCP in Barangay II, Municipality of Mulanay; and QZ-415, a BM with Accuracy Class at 95% CL 8cm in Brgy. Pansol, Municipality of Lopez.

There are four (4) UP established control points located at the approach of bridges namely: UP-KAN, at Kanguinsa Bridge in Brgy. Silongin, Municipality of San Francisco; UP-TAL at Talisay Bridge in Brgy. Pagsangahan, also in Municipality of San Francisco; and UP-VIG at Vigo Bridge in Brgy. Vigo Central, Municipality of San Narciso. The UP established control point UP-CAB is located in a residential court in Brgy. Aloneros, Municipality of Guinayangan. A NAMRIA established control point; QZN-41, a second order GCP in Barangay I, Municipality of Calauag was also occupied and used as marker for the network.

The summary of reference and control points and its location is summarized in Table 21 while GNSS network established is illustrated in Figure 31.

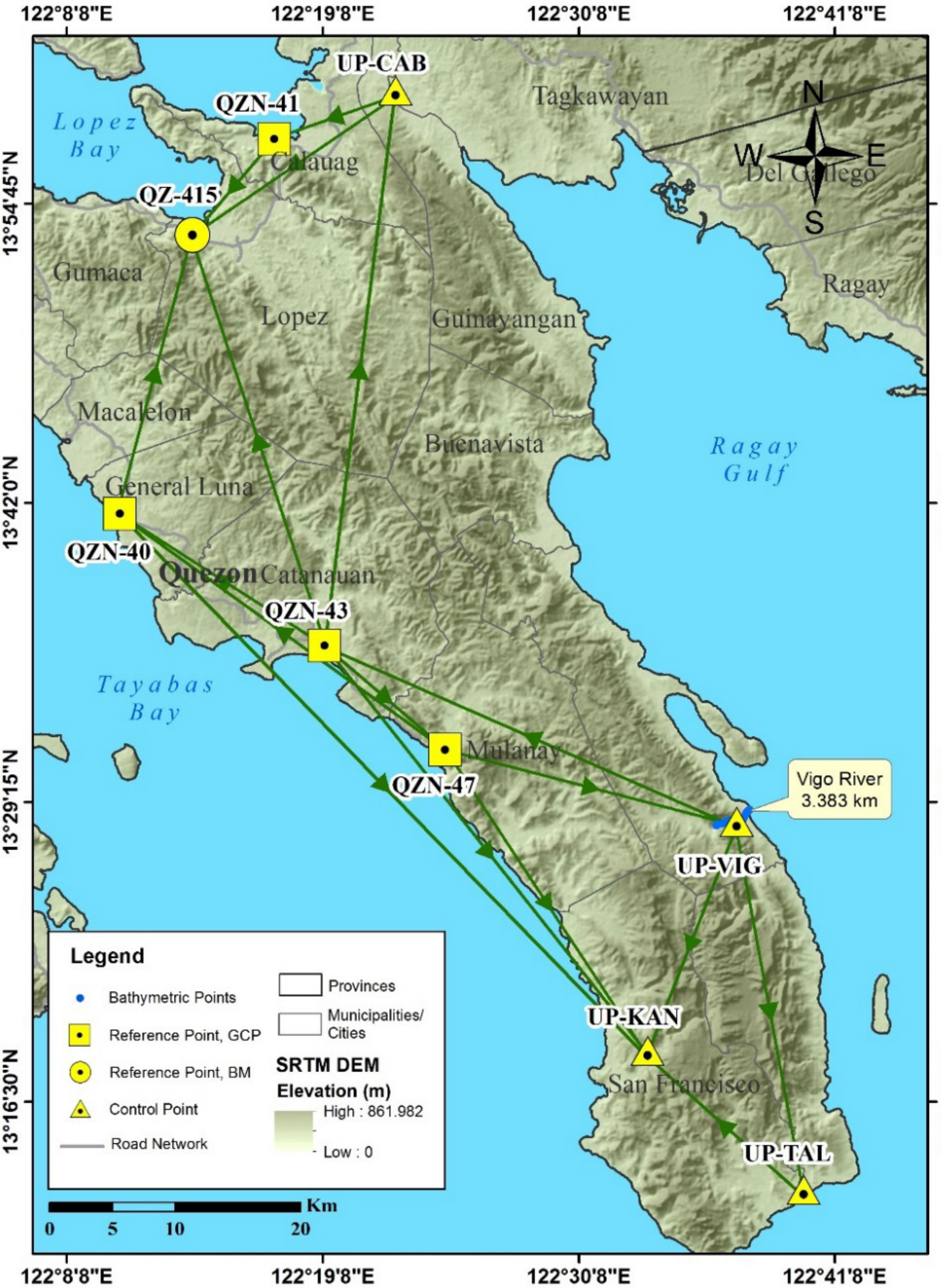


Figure 31. The GNSS Network established in the Vigo River field Survey.

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

(Source: NAMRIA; UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (Meter)	Elevation in MSL (Meter)	Date Established
QZN-40	2nd Order, GCP	13°41'32.47595" N	122°10'25.77273" E	51.703	-	2006
QZN-43	2nd Order, GCP	13°35'55.81611" N	122°19'13.53031" E	51.015	-	2006
QZN-47	2nd Order, GCP	13°31'29.52488" N	122°24'23.44821" E	53.862	-	2006
QZ-415	1st order Order, BM	-	-	57.290	8.613	2007
QZN-41	Used as Marker	-	-	-	-	2006
UP-CAB	UP Established	-	-	-	-	05-04-2016
UP-KAN	UP Established	-	-	-	-	05-11-2016
UP-TAL	UP Established	-	-	-	-	05-11-2016
UP-VIG	UP Established	-	-	-	-	05-11-2016

The GNSS set-ups of the reference and control points are exhibited are shown in Figure 32 to Figure 40.

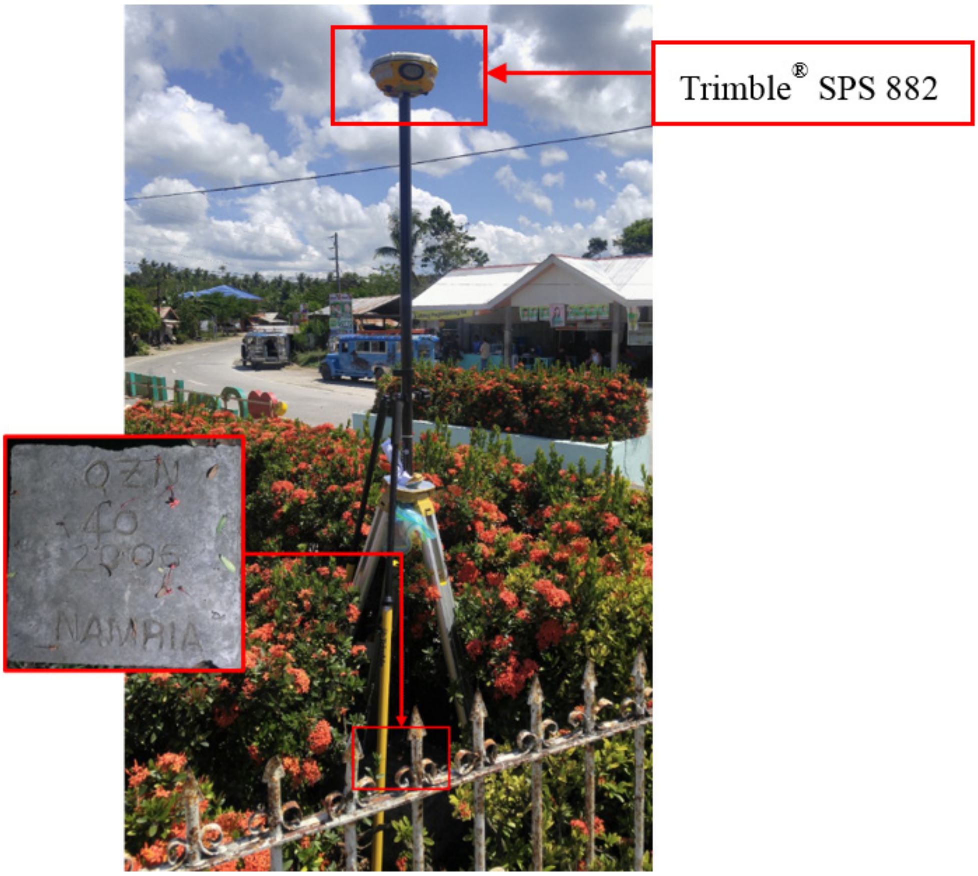


Figure 32. GNSS base set up, Trimble® SPS 882, at QZN-40, located inside a triangular plant area found at the center of a triangular island in Brgy. San Jose, Municipality of Gen. San Narciso, Quezon

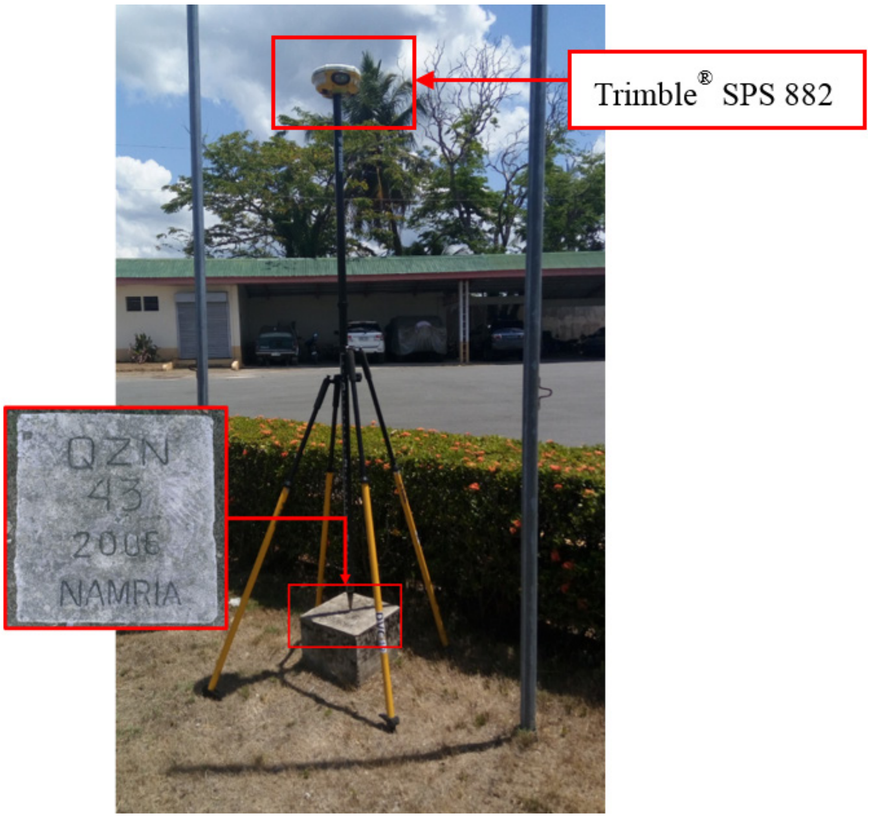


Figure 33. GNSS base set up, Trimble® SPS 882, at QZN-43, located inside the DPWH compound in Brgy. Matandang Sabang Silangan, Municipality of Catanauan, Quezon

Figure 34. GNSS base set up, Trimble® SPS 852, at QZN-47, located at the back of the Principal's Office of Mulanay Elementary School in Barangay II, Municipality of Mulanay, Quezon.

Figure 35. GNSS base set up, Trimble® SPS 985, at QZ-415, located at the approach of Pansol Bridge in Brgy. Pansol, Municipality of Lopez, Quezon

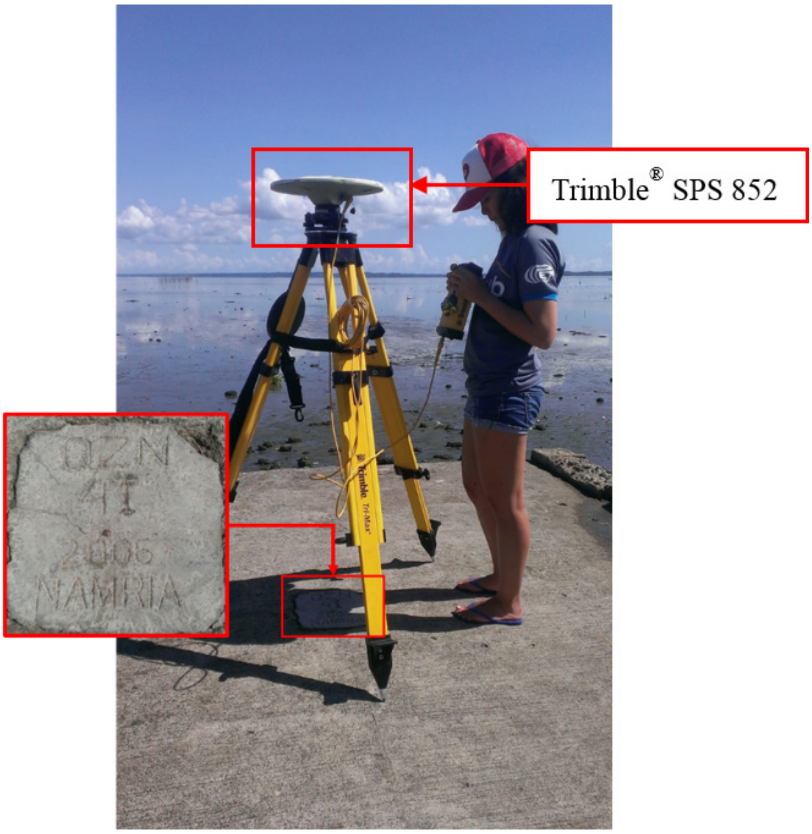


Figure 36. GNSS base set up, Trimble® SPS 852, at QZN-41, located in front of Brgy. Sabang basketball court found in Calauag Port, Barangay I, Municipality of Calauag, Quezon

Figure 37. GNSS base set up, Trimble® SPS 882, at UP-CAB, located inside a basketball court in Brgy. Aloneros, Municipality of Guinayangan, Quezon

Figure 38. GNSS base set up, Trimble® SPS 852, at UP-KAN, located at the approach of Kanguinsa Bridge in Brgy. Silongin, Municipality of San Francisco, Quezon

Figure 39. GNSS base set up, Trimble® SPS 852, at UP-TAL, located at the approach of Talisay Bridge in Brgy. Pagsangahan, Municipality of San Francisco, Quezon

Figure 40. GNSS base set up, Trimble® SPS 882, at UP-VIG, located at the approach of Vigo Bridge in Brgy. Vigo Central, Municipality of San Francisco, Quezon

4.3 Baseline Processing

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

Table 22. Baseline Processing Summary Report for Vigo River Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)
QZN-47 --- QZN-40	05-11-2016	Fixed	0.003	0.011	306°22'36"	31263.486
QZN-47 --- QZN-43	05-11-2016	Fixed	0.003	0.013	131°16'56"	12401.416
QZN-47 --- UP-VIG	05-11-2016	Fixed	0.003	0.012	103°58'19"	23335.323
QZN-47 --- UP-KAN	05-11-2016	Fixed	0.005	0.019	146°21'08"	28388.037
QZN-40 --- QZ-415	05-11-2016	Fixed	0.003	0.023	14°21'16"	22613.475
UP-CAB --- QZ-415	05-04-2016	Fixed	0.004	0.025	234°09'16"	19401.067
QZN-40 --- UP-KAN	05-11-2016	Fixed	0.011	0.027	135°49'24"	58749.581
QZN-43 --- QZ-415	05-11-2016	Fixed	0.006	0.033	342°23'19"	33841.349
QZN-43 --- UP-KAN	05-11-2016	Fixed	0.005	0.018	141°46'15"	40492.330
UP-TAL --- UP-KAN	05-11-2016	Fixed	0.005	0.018	312°01'33"	16293.271
UP-VIG --- UP-TAL	05-11-2016	Fixed	0.003	0.014	169°50'51"	29356.882
UP-VIG --- QZN-43	05-11-2016	Fixed	0.003	0.014	293°25'54"	34821.073
UP-VIG --- UP-KAN	05-11-2016	Fixed	0.005	0.021	201°04'03"	19280.526
QZN-41 --- UP-CAB	05-04-2016	Fixed	0.004	0.024	247°44'12"	10141.643
QZN-41 --- QZ-415	05-04-2016	Fixed	0.003	0.022	220°07'13"	9835.756
QZN-40 --- QZN-43	05-11-2016	Fixed	0.003	0.014	303°07'59"	18937.828
UP-CAB --- QZN-43	05-11-2016	Fixed	0.004	0.019	7°10'02"	43963.480

As shown in Table 22, a total of seventeen (17) baselines were processed with reference points QZN-40, QZN-43 and QZN-47 fixed for grid values; and QZ-415 held fixed for elevation. All of them passed the required accuracy.

4.4 Network Adjustment

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

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

where:

xe is the Easting Error,
ye is the Northing Error, and
ze is the Elevation Error

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

The nine (9) control points, QZN-40, QZN-43, QZN-47, QZ-415, QZN-41, UP-CAB, UP-KAN, UP-TAL and UP-VIG were occupied and observed simultaneously to form a GNSS loop. Elevation value of QZ-415 and coordinates of points QZN-40, QZN-43 and QZN-47 were held fixed during the processing of the control points as presented in Table 23. Through these reference points, the coordinates and elevation of the unknown control points will be computed.

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

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
QZN-40	Global	Fixed	Fixed		
QZN-43	Global	Fixed	Fixed		
QZN-47	Global	Fixed	Fixed		
QZ-415	Grid				Fixed
Fixed = 0.000001(Meter)					

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 24. The fixed control points QZN-40, QZN-43, QZN-47 and QZ-415 have no values for grid and elevation errors, respectively.

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

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
QZN-40	410660.624	?	1513855.137	?	2.622	0.075	LL
QZN-43	426485.118	?	1503462.996	?	1.574	0.073	LL
QZN-47	435778.405	?	1495257.875	?	4.163	0.079	LL
QZ-415	416340.495	0.010	1535736.431	0.010	8.613	?	e
QZN-41	422699.129	0.014	1543236.263	0.014	1.392	0.082	
UP-CAB	432091.726	0.012	1547052.366	0.013	3.211	0.073	
UP-KAN	451445.231	0.012	1471596.832	0.011	25.095	0.086	
UP-TAL	463529.271	0.016	1460676.916	0.014	4.949	0.095	
UP-VIG	458401.312	0.010	1489570.998	0.008	6.030	0.083	

The network is fixed at reference points QZN-40, QZN-43, and QZN-47 with known coordinates, and QZ-415 with known elevation. As shown in Table 24, the standard errors (xe and ye) of QZ-415 are 1.0 cm and 1.0 cm. With the mentioned equation, for horizontal and for the vertical; the computation for the accuracy of the reference and control points are as follows:

a.QZN-40

horizontal accuracy	=	Fixed
vertical accuracy	=	7.5 cm < 10 cm

b.QZN-43

horizontal accuracy	=	Fixed
vertical accuracy	=	7.3 cm < 10 cm

c.QZN-47

horizontal accuracy	=	Fixed
vertical accuracy	=	7.9 cm < 10 cm

d.QZ-415

horizontal accuracy	=	$\sqrt{((1.0)^2 + (1.0)^2}$
	=	$\sqrt{(1.0 + 1.0)}$
	=	1.41cm < 20 cm
vertical accuracy	=	Fixed

e.QZN-41

horizontal accuracy	=	$\sqrt{((1.40)^2 + (1.40)^2}$
	=	$\sqrt{(1.96+ 1.96)}$
	=	1.98cm < 20 cm
vertical accuracy	=	8.2 cm < 10 cm

f.UP-CAB

horizontal accuracy	=	$\sqrt{((1.20)^2 + (1.30)^2}$
	=	$\sqrt{(1.44 + 1.69)}$
	=	1.77 cm < 20 cm
vertical accuracy	=	7.3 cm < 10 cm

g.UP-KAN

horizontal accuracy	=	$\sqrt{((1.20)^2 + (1.10)^2}$
	=	$\sqrt{(1.44 + 1.21)}$
	=	1.63 cm < 20 cm
vertical accuracy	=	8.6 cm < 10 cm

h.UP-TAL

horizontal accuracy	=	$\sqrt{((1.60)^2 + (1.40)^2}$
	=	$\sqrt{(2.56 + 1.96)}$
	=	2.13 cm < 20 cm
vertical accuracy	=	9.5 cm < 10 cm

i.UP-VIG

horizontal accuracy	=	$\sqrt{((1.10)^2 + (0.80)^2}$
	=	$\sqrt{(1.21 + 0.64)}$
	=	1.36 cm < 20 cm
vertical accuracy	=	8.3 cm < 10 cm

Following the given formula, the horizontal and vertical accuracy result of the nine (9) occupied control points are within the required precision.

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

Point ID	Latitude	Longitude	Ellipsoid	Height	Constraint
QZN-40	N13°41'32.47595"	E122°10'25.77273"	51.703	0.075	LL
QZN-43	N13°35'55.81611"	E122°19'13.53031"	51.015	0.073	LL
QZN-47	N13°31'29.52488"	E122°24'23.44821"	53.862	0.079	LL
QZ-415	N13°53'25.29589"	E122°13'32.50380"	57.290	?	e
QZN-41	N13°57'30.05268"	E122°17'03.60722"	50.089	0.082	
UP-CAB	N13°59'35.12930"	E122°22'16.30558"	52.023	0.073	
UP-KAN	N13°18'40.40211"	E122°33'06.07511"	75.768	0.086	
UP-TAL	N13°12'45.55145"	E122°39'48.22322"	55.864	0.095	
UP-VIG	N13°28'25.87675"	E122°36'56.35787"	56.412	0.083	

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

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

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

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
QZN-40	2nd Order GCP	13°41'32.47595" N	122°10'25.77273" E	51.703	1513855.137	410660.624	2.622
QZN-43	2nd Order GCP	13°35'55.81611" N	122°19'13.53031" E	51.015	1503462.996	426485.118	1.574
QZN-47	2nd Order GCP	13°31'29.52488" N	122°24'23.44821" E	53.862	1495257.875	435778.405	4.163
QZ-415	1st Order BM	13°53'25.29589" N	122°13'32.50380" E	57.290	1535736.431	416340.495	8.613
QZN-41	Used as Marker	13°57'30.05268" N	122°17'03.60722" E	50.089	1543236.263	422699.129	1.392
UP-CAB	UP Established	13°59'35.12930" N	122°22'16.30558" E	52.023	1547052.366	432091.726	3.211
UP-KAN	UP Established	13°18'40.40211" N	122°33'06.07511" E	75.768	1471596.832	451445.231	25.095
UP-TAL	UP Established	13°12'45.55145" N	122°39'48.22322" E	55.864	1460676.916	463529.271	4.949
UP-VIG	UP Established	13°28'25.87675" N	122°36'56.35787" E	56.412	1489570.998	458401.312	6.030

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

Cross-section survey was conducted at the downstream part of Vigo Bridge in Brgy. Vigo Central, Municipality of San Narciso on May 12, 2016 using a GNSS receiver, Trimble® SPS 882, in PPK survey technique paired with an Ohmex™ single beam echo sounder as shown in Figure 41.

Figure 41. Cross-Section Survey for Vigo River using (A) Ohmex™ single beam echo sounder in acquiring riverbed elevation for the cross sectional points and (B) Trimble® SPS 882 in PPK survey technique for the acquiring cros section and as-built points

The cross-sectional line length for Vigo River is 175.821m with 78 cross-sectional points acquired using UP-VIG as the GNSS base station. The location map, cross-section diagram, and bridge as-uilt form are shown in Figure 42 to Figure 44.

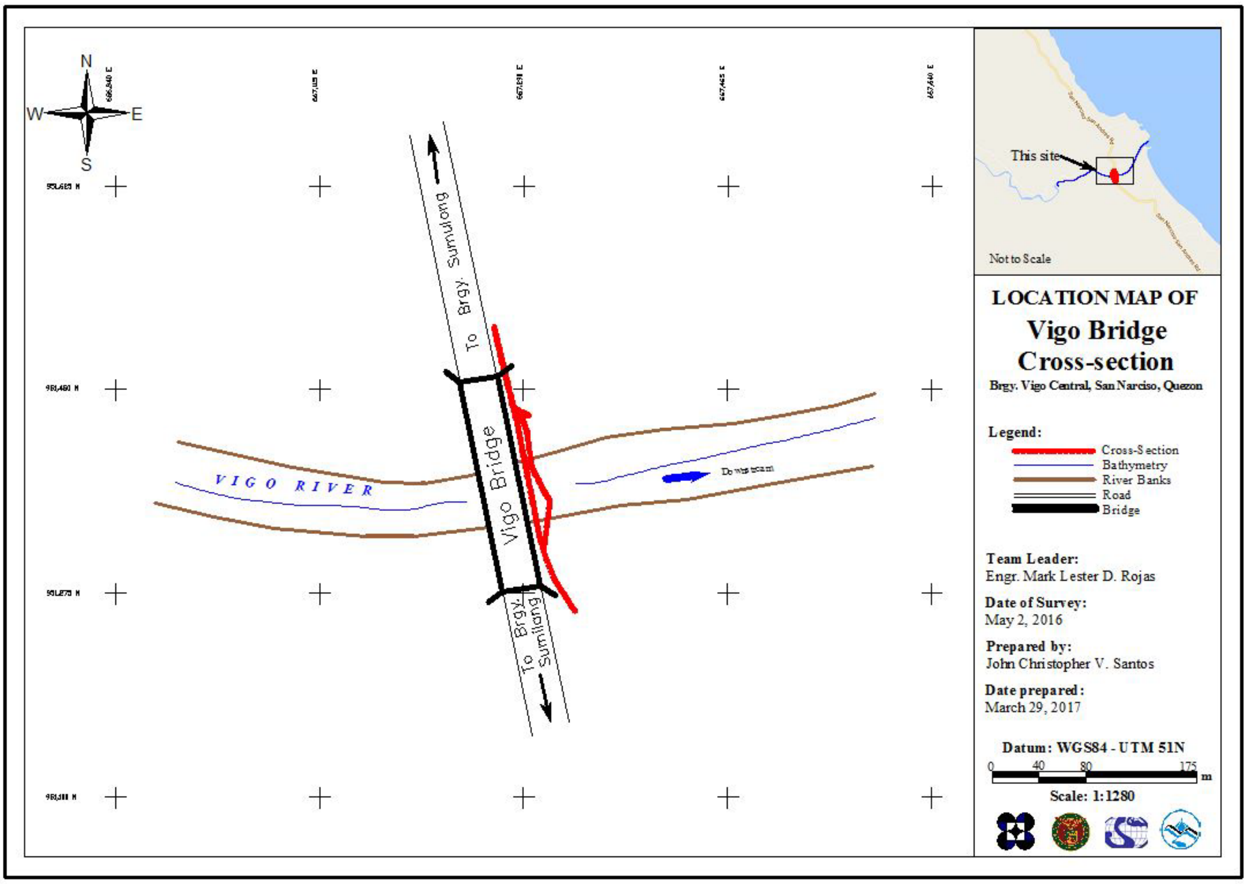


Figure 42. New Vigo bridge cross-section location map

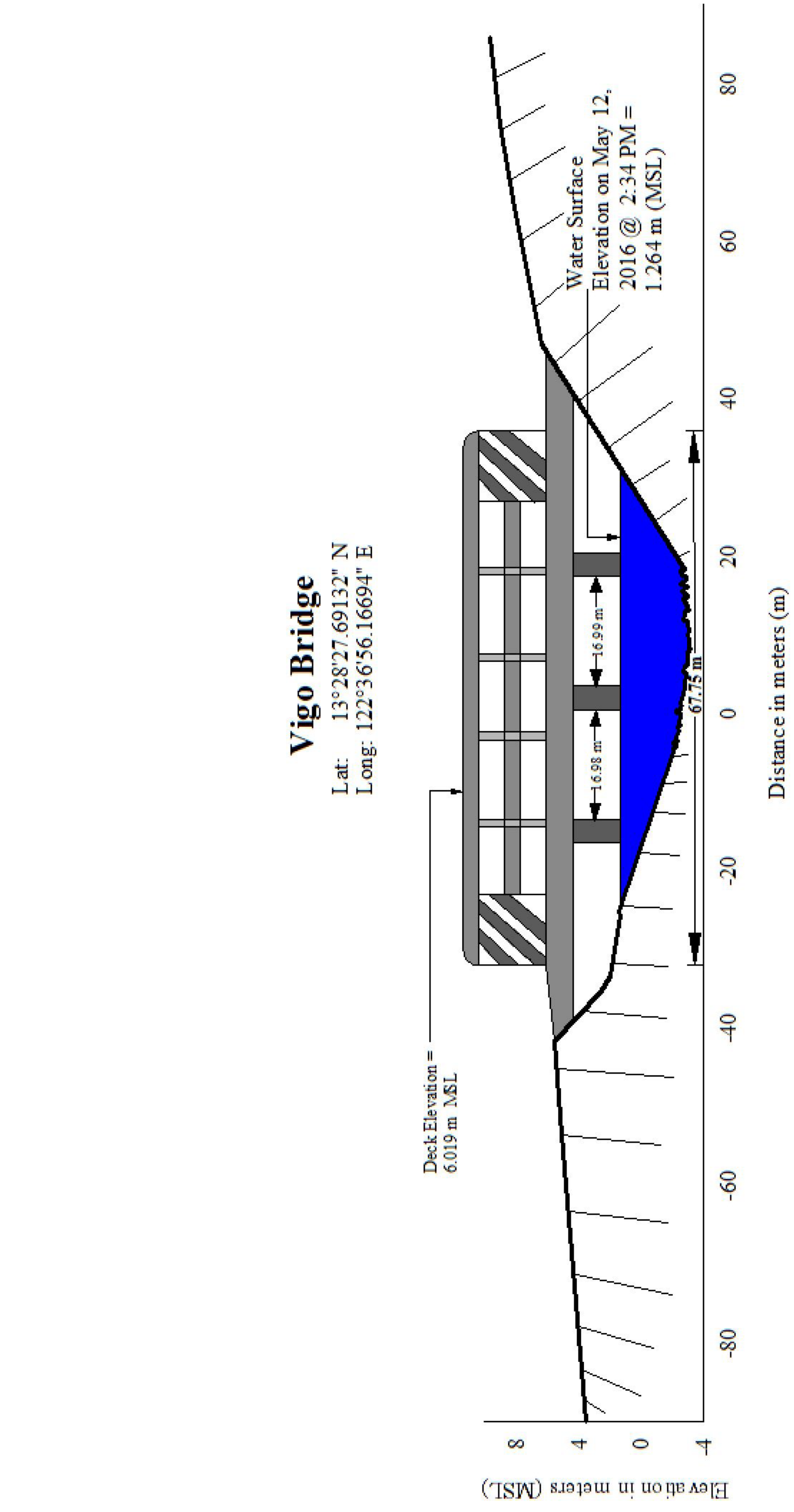


Figure 43. Vigo Bridge cross-section diagram

Bridge Data Form

Bridge Name: Vigo Bridge **Date:** May 12, 2016

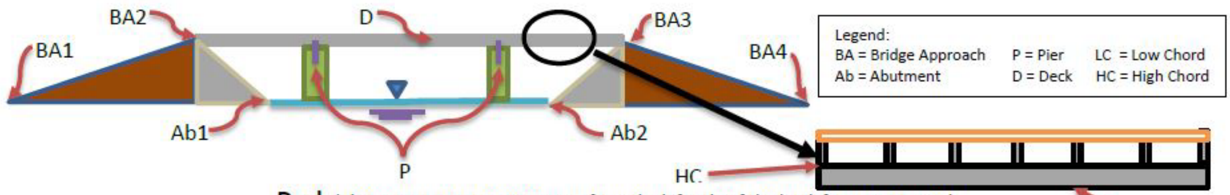
River Name: Vigo River **Time:** 02:31 PM

Location (Brgy, City,Region): Brgy. Vigo Central, Municipality of San Narciso, Quezon

Survey Team: Michael Labrador, Erlan Mendoza, Romalyn Boado, Mark Rojas, Marla Morris, Pauline Racoma

Flow condition: normal **Weather Condition:** fair

Latitude: 13°28'27.69132" N **Longitude:** 122°36'56.16694" E



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

Elevation: 6.019 m **Width:** 7.560 m **Span (BA3-BA2):** 67.748 m

	Station	High Chord Elevation	Low Chord Elevation
1	Not available	Not available	Not available

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	0	3.487 m	BA3	125.775 m	6.039 m
BA2	57.889 m	6.019 m	BA4	175.821 m	9.627 m

Abutment: Is the abutment sloping? **Yes**; If yes, fill in the following information:

	Station (Distance from BA1)	Elevation
Ab1	Not available	Not available
Ab2	Not available	Not available

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

Shape: Oval Number of Piers: 3 Height of column footing: N/A

	Station (Distance from BA1)	Elevation	Pier Width
Pier 1	74.818 m	6.007 m	Not available
Pier 2	91.799 m	5.994 m	Not available
Pier 3	108.793	6.003	Not available

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

Figure 44. Bridge as-built form of New Vigo Bridge

Water surface elevation in MSL of Vigo River was determined using Trimble® SPS 882 on May 12, 2016 at 2:34 PM with a value of 1.264 m in MSL. This was translated onto marking on a bridge's pier using Trimble® SPS 882 PPK survey technique as shown in Figure 45. The markings will serve as their reference for flow data gathering and depth gauge deployment of PHIL-LIDAR 1 partner, Mapua Institute of Technology, for Vigo River.

Figure 45. Water-level markings on New Vigo Bridge

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on May 12, 2016 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted on the roof of the vehicle as shown in Figure 46. It was secured with a cable tie to ensure that it was horizontally and vertically balanced. The antenna height was 1.875 m and measured from the ground up to the bottom of notch of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with UP-VIG occupied as the GNSS base station in the conduct of the survey.

Figure 46. Validation points acquisition survey set up along Vigo River Basin

The survey started from Brgy. Binay in the Municipality of San Narciso, going north traversing Brgy. San Juan and ended in Brgy. Andres Bonifacio also in the Municipality of San Narciso. These routes aim to cut flight strips made by the Data Acquisition Component, perpendicularly. The survey gathered 1,429 points with approximate length of 11.51 km using UP-VIG as GNSS base station for the entire extent validation points acquisition survey as illustrated in the map in Figure 47.

Figure 47. LiDAR validation point acquisition survey for Vigo River basin

4.7 River Bathymetric Survey

Bathymetric survey was executed on May 12, 2016 using a Trimble® SPS 882 in GNSS PPK survey technique and Ohmex™ single beam echo sounder, as illustrated in Figure 48. The extent of the survey is from the upstream part of the river in Brgy Binay, Municipality of San Narciso with coordinates 13°28'15.44739"N, 122°36'04.17054"E, down to the mouth of the river in the same barangay with coordinates 13°28'57.64490"N, 122°37'29.76908"E.

Figure 48. Bathymetric survey using Ohmex™ single beam echo sounder in Vigo River

The bathymetric survey gathered a total of 4,481 points covering 3.83 km of the river traversing Barangays Binay and Vigo Central in the Municipality of San Narciso. Bathymetric line measuring 500 meters on the upstream area was not surveyed due to branching tributaries and absence of community (Figure 49).

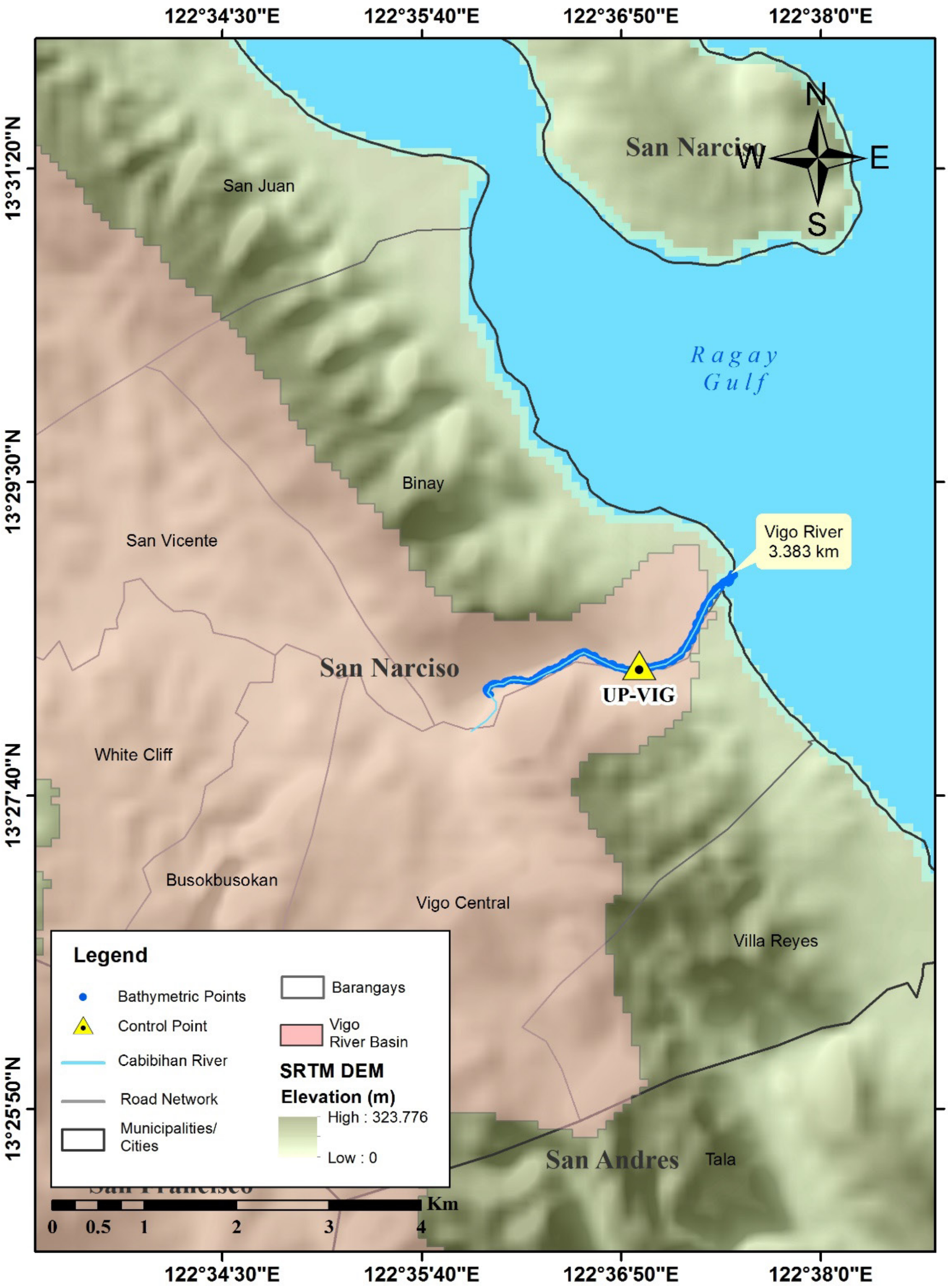


Figure 49. Extent of the Vigo River Bathymetry Survey

A CAD drawing was also produced to illustrate the riverbed profile of Vigo River. As shown in Figure 50, the highest and lowest elevation has a 2.68-meter difference. The highest elevation observed is -0.742 m below MSL located at the upstream portion of the river around Brgy. Binay while the lowest elevation observed is -3.424 m below MSL located still at the upstream of the river also in Brgy. Binay, in Municipality of San Narciso.

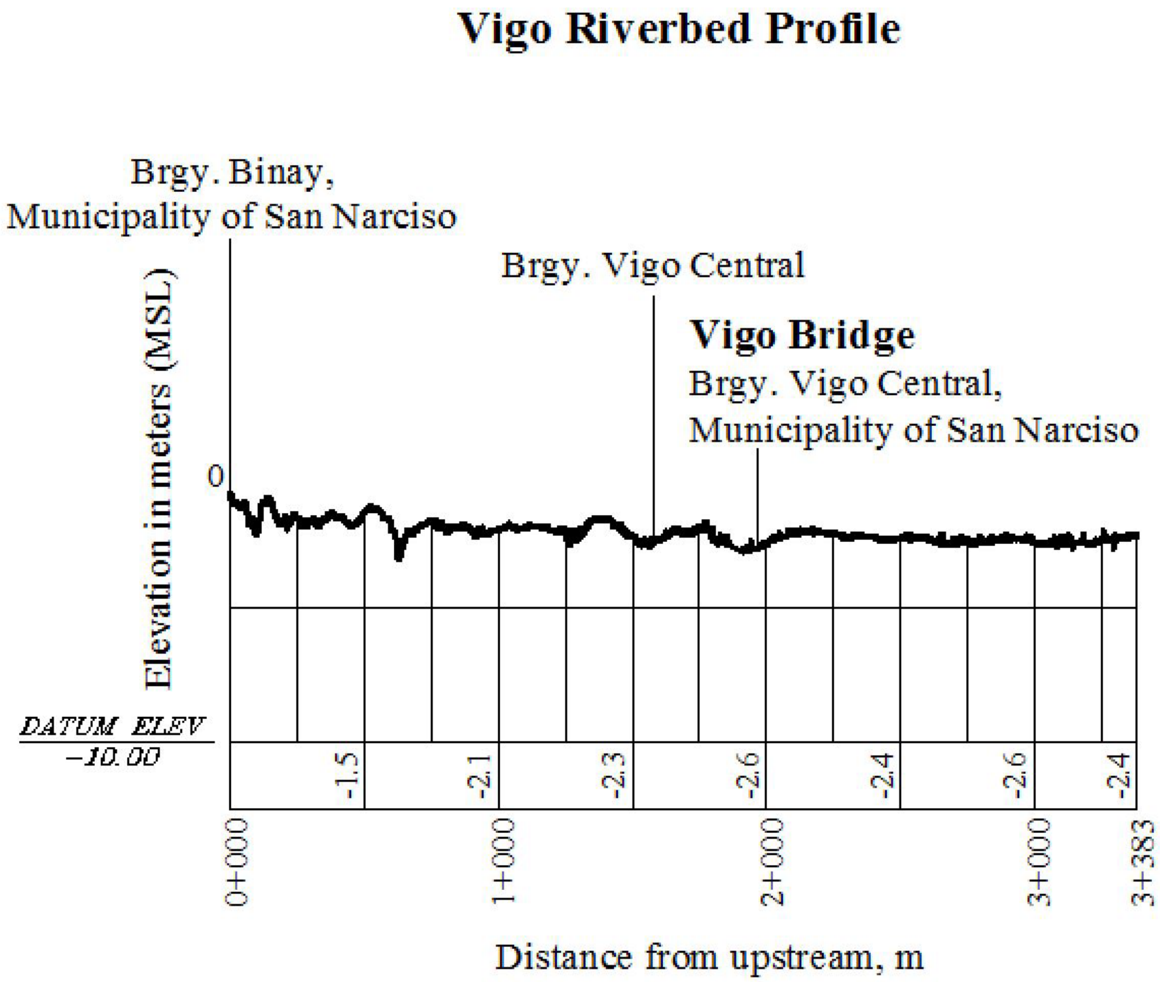


Figure 50. The Vigo riverbed profile.

CHAPTER 5: FLOOD MODELING AND MAPPING

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

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

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

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

5.1.2 Precipitation

Precipitation data was taken from automatic rain gauges (ARG) installed by the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI). The locations of the ARG are Brgy. Buenavista and Brgy. Busok-Busokan. The location of the rain gauge is as shown in Figure 51.

The total rain from the Brgy. Buenavista rain gauge is 5.6 mm. It peaked to 1.6 mm at 12:30 on October 11, 2016. The lag time between the peak rainfall and discharge is 9 hours and 40 minutes, as shown in Figure 54.

For Brgy. Busok-Busokan rain gauge, the total rain is 78.8 mm. Peak rain of 16 mm at 19:15 was recorded on October 11, 2016. The lag time between the peak rainfall and discharge is 2 hours and 55 minutes, as shown in Figure 54.

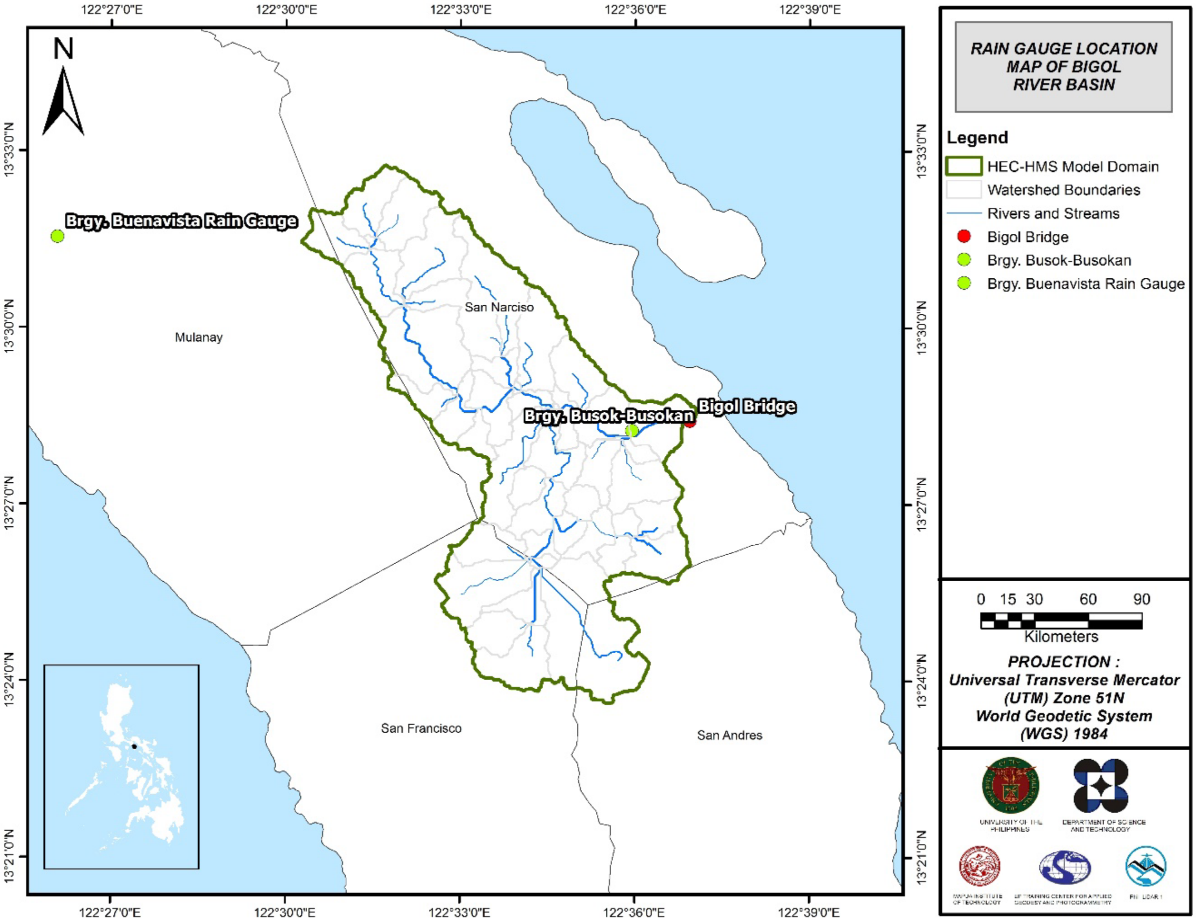


Figure 51. Location map of Vigo (also known as Bigol) HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Bigol Bridge, San Narcisco, Quezon Province (13°28'27.69132"N, 122°36'56.16694"E). It gives the relationship between the observed water levels and outflow of the watershed at this location. It is expressed in the form of the following equation:

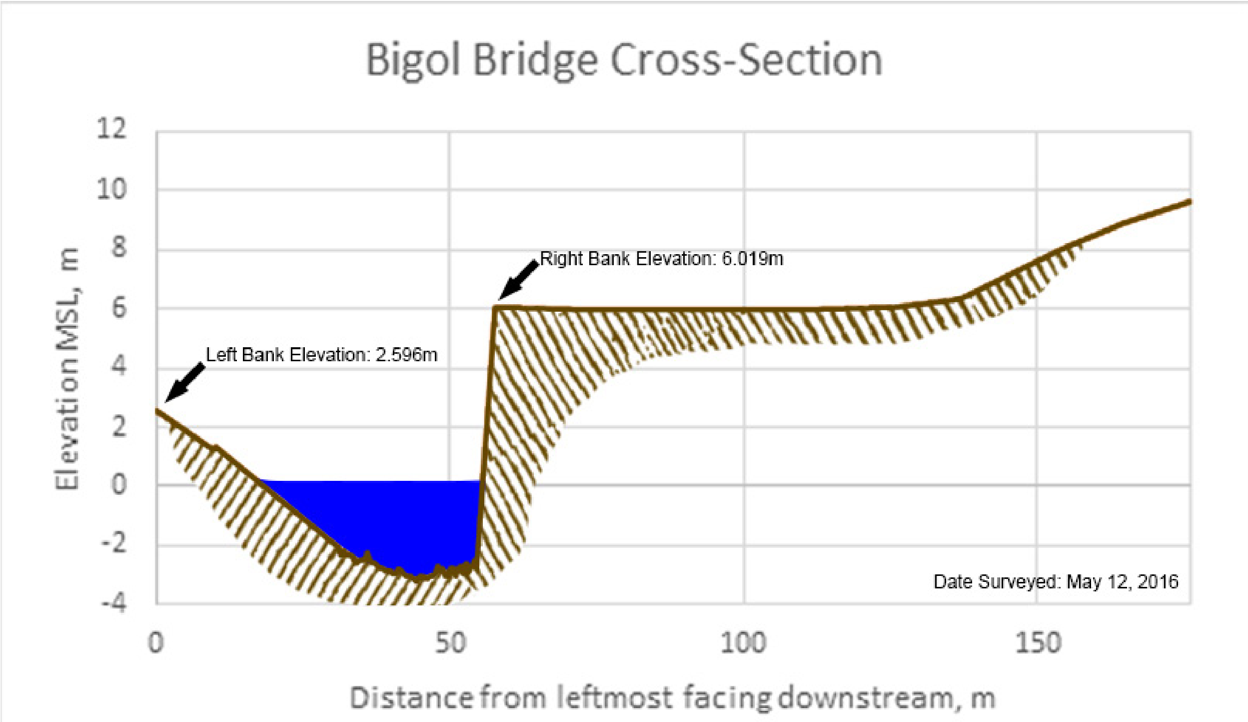


Figure 52. Cross-Section Plot of Vigo (also known as Bigol) Bridge

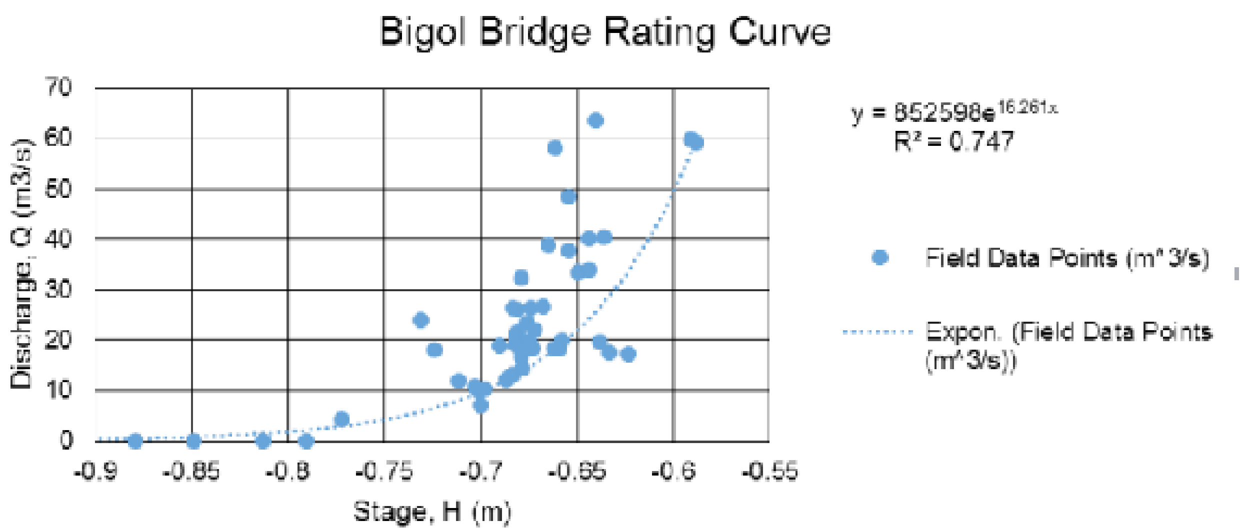


Figure 53. Rating curve at Vigo (also known as Bigol) Bridge, San Andres, Quezon Province

This rating curve equation was used to compute the river outflow at Bigol Bridge for the calibration of the HEC-HMS model shown in Figure 54. Peak discharge is 63.7 m3/s at 22:10, October 11, 2016.

$$Q=anh$$

where, Q : Discharge (m3/s),
h : Gauge height (reading from Linao Bridge depth gauge sensor), and
a and n : Constants.

The Vigo River Rating Curve measured at Vigo Bridge is expressed as Q = 305.63e0.5029x (Figure 50).

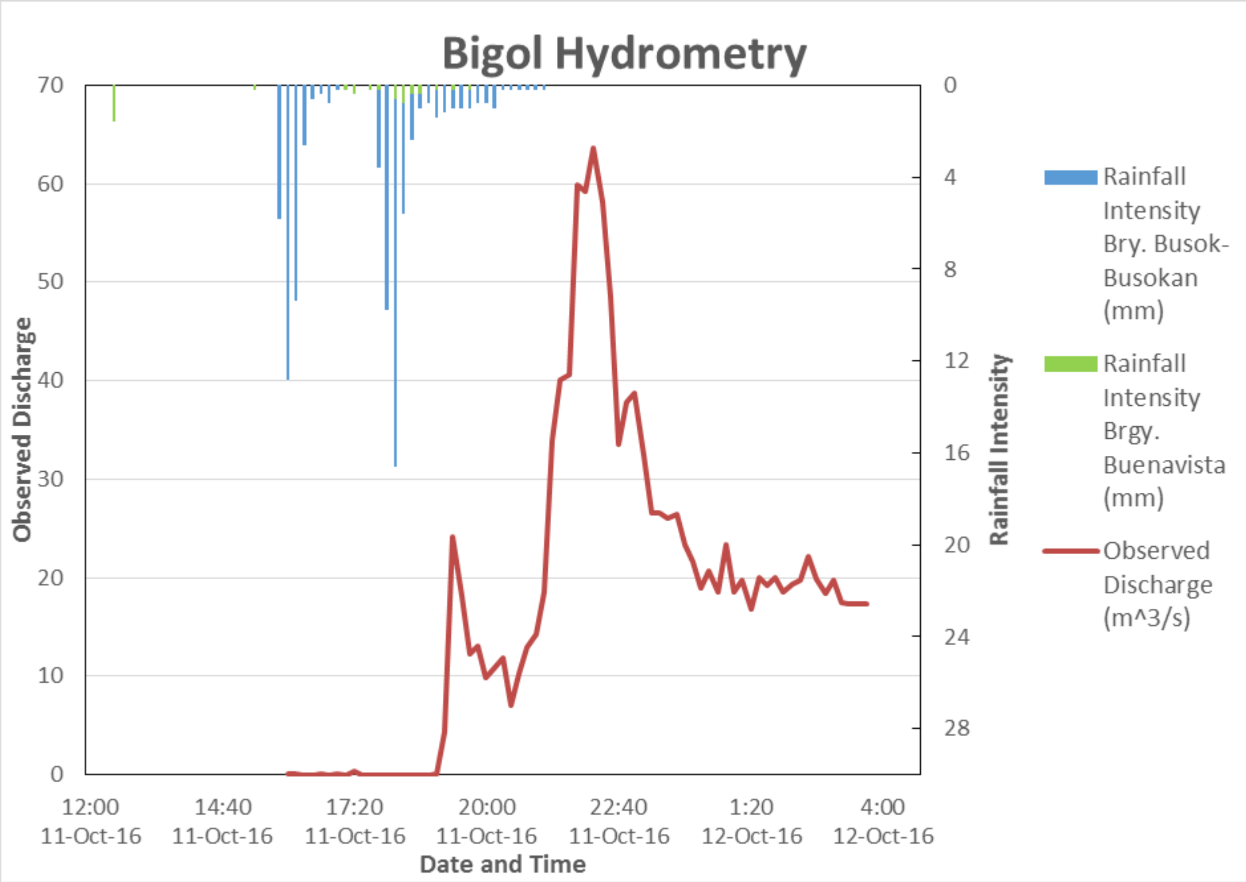


Figure 54. Rainflow and outflow data at Vigo (also known as Bigol) River used for modeling

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Daet Rain Gauge. This station chosen based on its proximity to the Bigol watershed. The extreme values for this watershed were computed based on a 58-year record, as shown in Table 27.

Table 27. RIDF values for Daet Rain Gauge computed by PAGASA

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	10 mins	20 mins	30 mins	1 hr	2 hrs	3 hrs	6 hrs	12 hrs	24 hrs
2	21.8	33.8	43.1	59.6	84	101	130.4	163.2	190.4
5	31.8	47.2	59.1	81.9	120.3	146.8	194.7	236.8	278.7
10	38.5	56.1	69.7	96.7	144.4	177.1	237.2	285.6	337.2
15	42.3	61.1	75.7	105	158	194.1	261.2	313.1	370.2
20	44.9	64.6	79.9	110.8	167.5	206.1	278	332.4	393.3
25	46.9	67.3	83.1	115.3	174.8	215.3	291	347.2	411.1
50	53.2	75.6	93	129.2	197.3	243.7	330.8	392.9	465.9
100	59.4	83.9	102.9	143	219.7	271.9	370.4	438.3	520.3

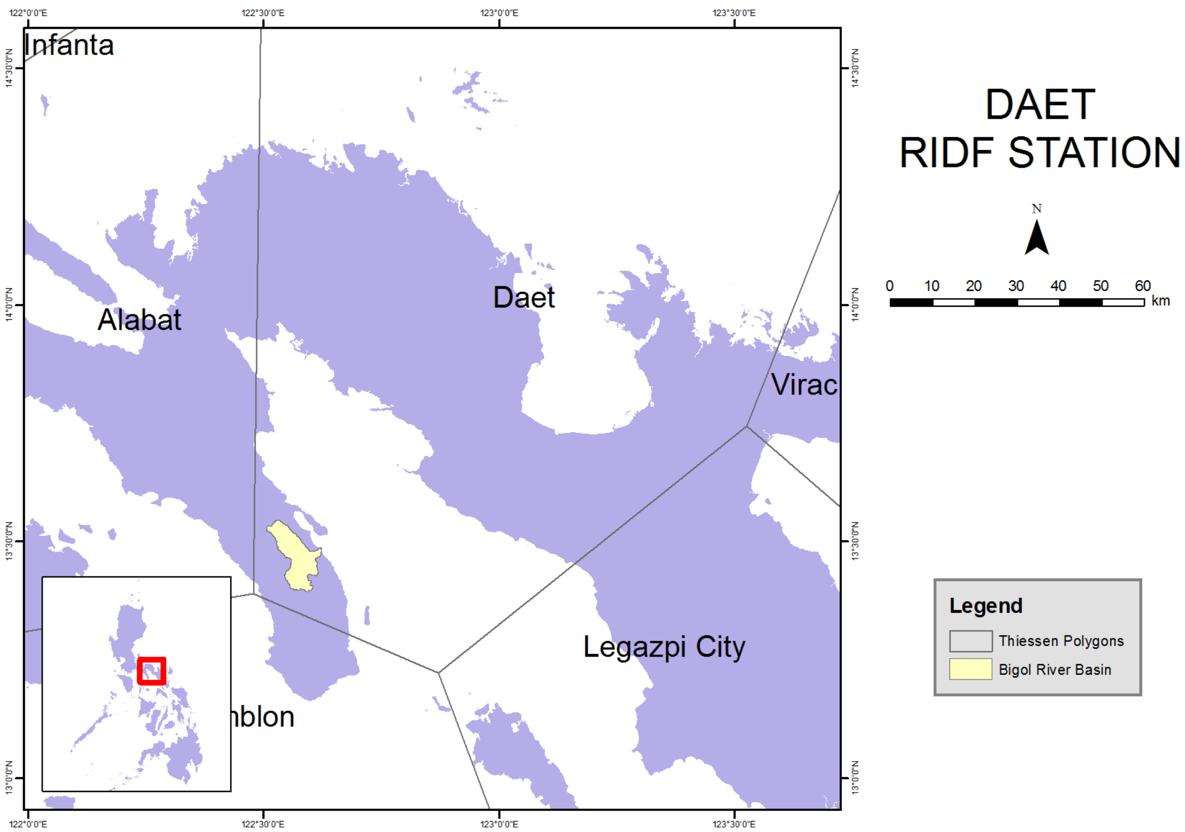


Figure 55. Daet RIDF location relative to Vigo River Basin

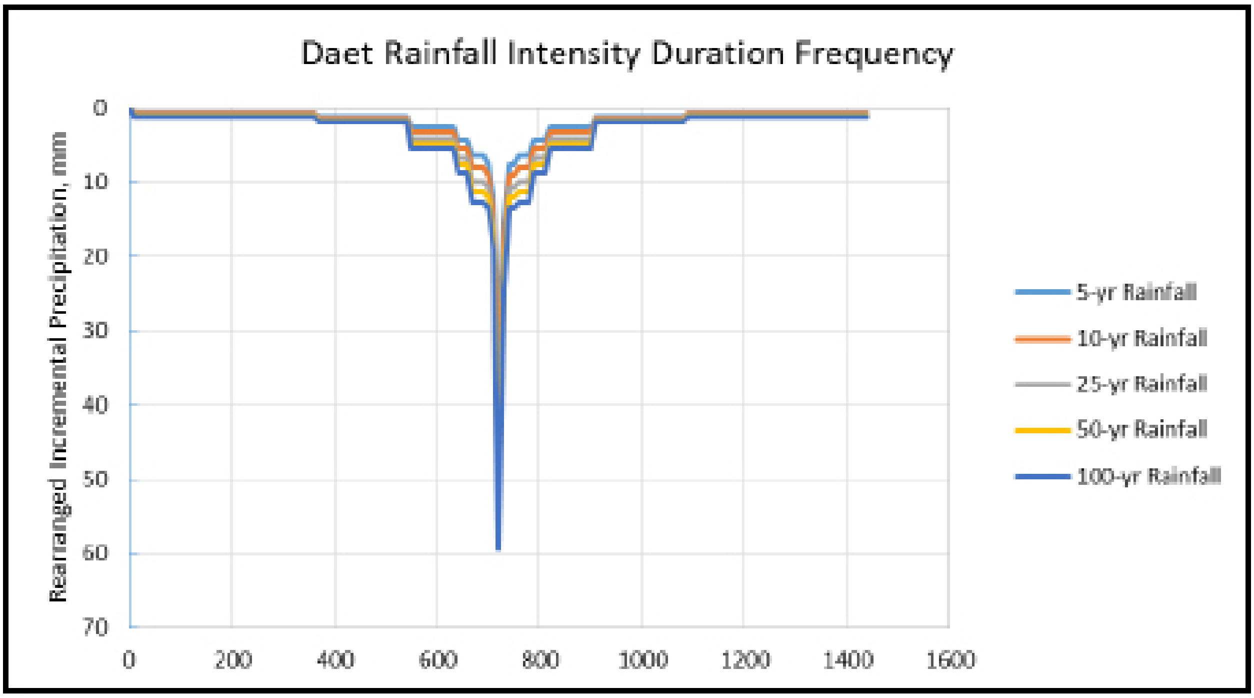


Figure 56. Synthetic storm generated for a 24-hr period rainfall for various return periods.

5.3 HMS Model

The soil dataset was generated before 2004 from the Bureau of Soil and Water Management (BSWM) under the Department of Agriculture (DA). The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Vigo River Basin are shown in Figure 57 and Figure 58, respectively.

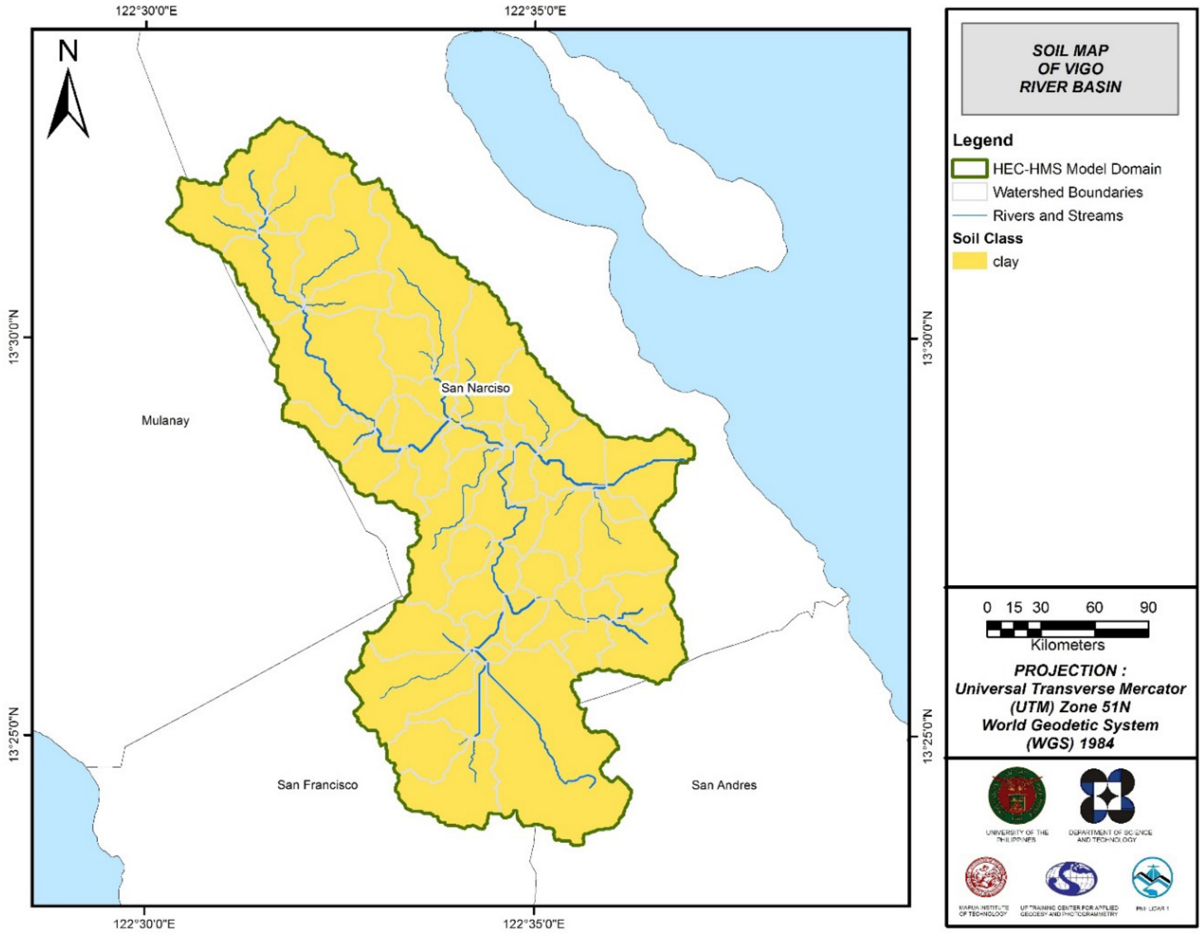


Figure 57. Soil map of the Vigo River Basin (Source: DA)

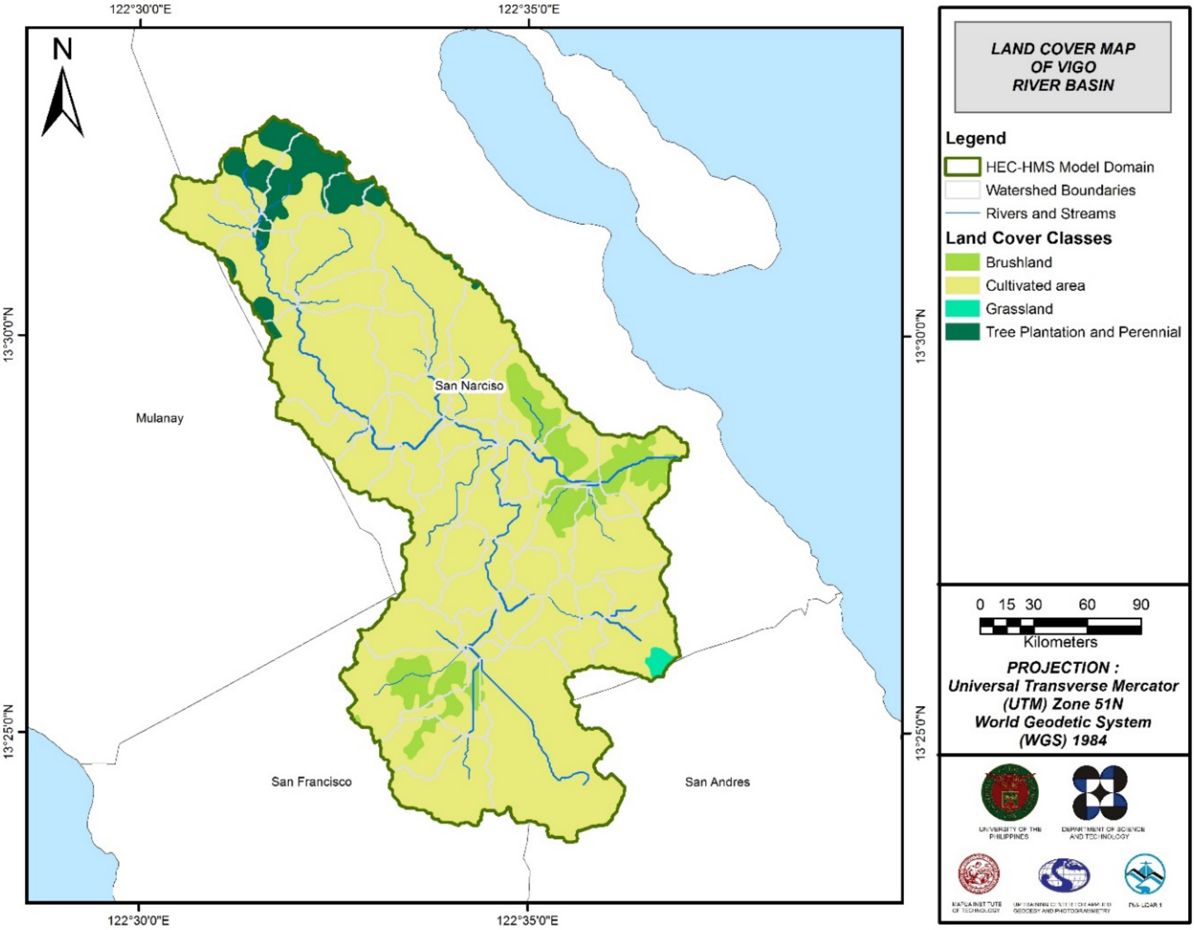


Figure 58. Land cover map of Vigo River Basin (Source: NAMRIA)

For Bigol, the sole soil class identified was clay. The four (4) land cover types identified were brushland, cultivated areas, grassland and tree plantations.

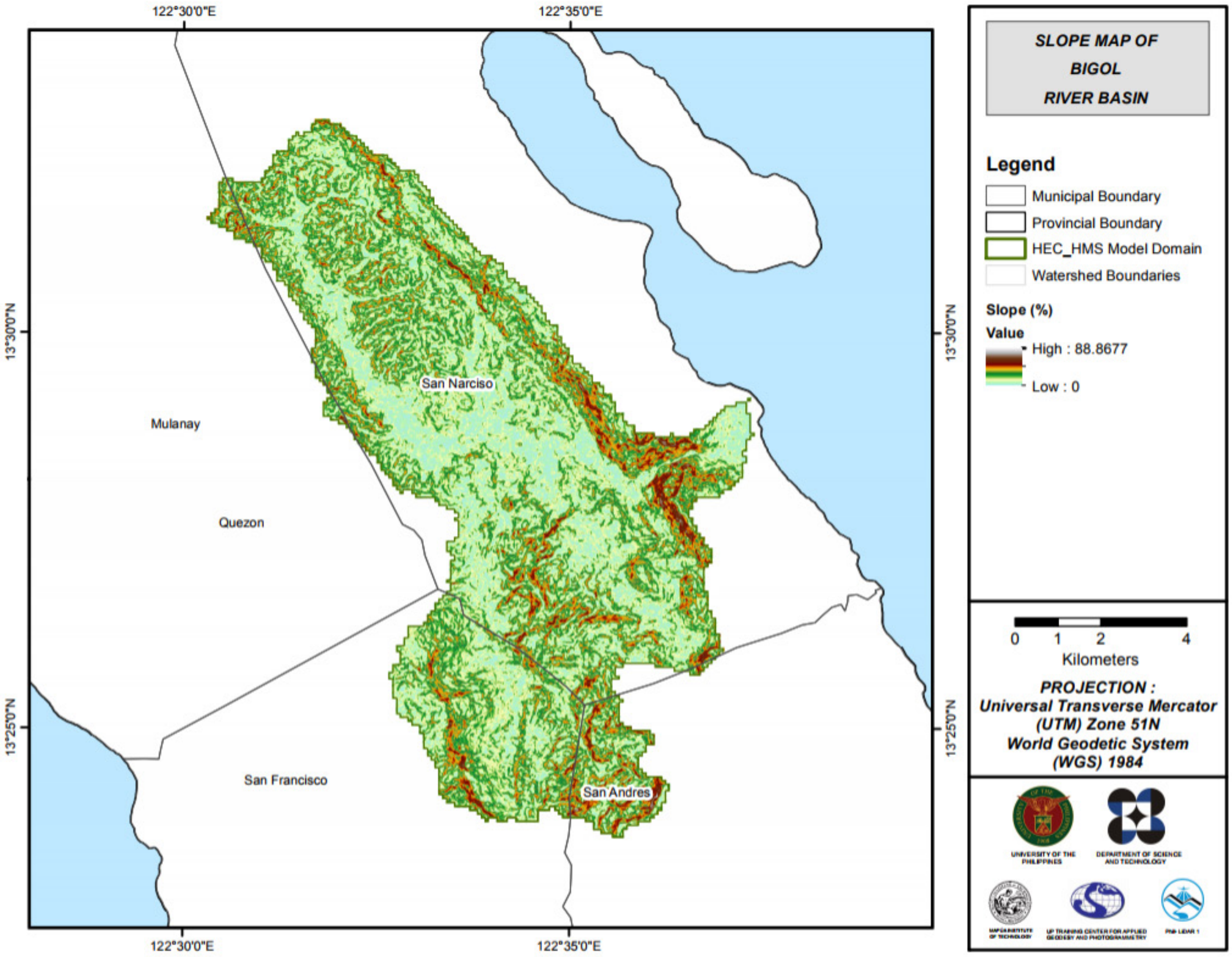


Figure 59. Slope Map of Vigo River Basin

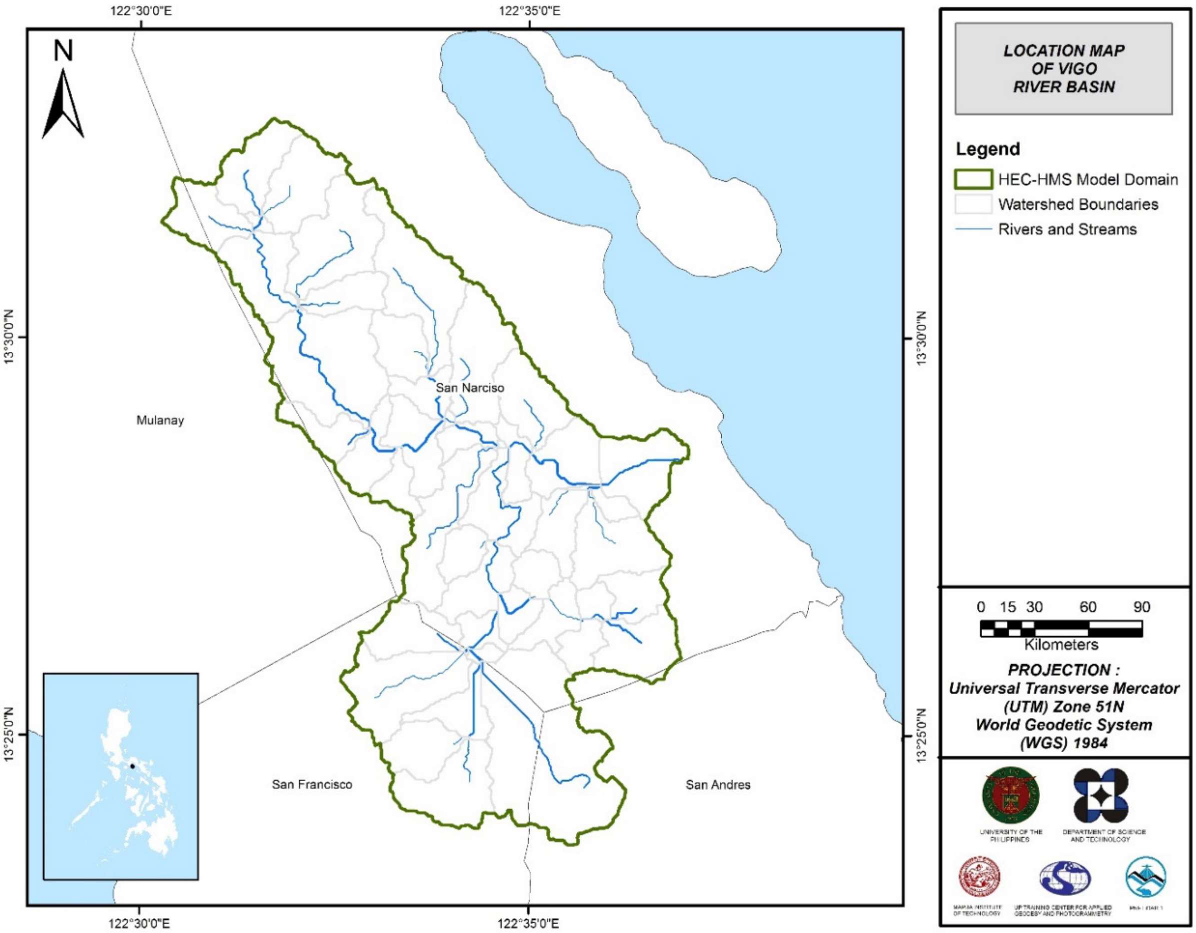


Figure 60. Stream Delineation Map of Vigo River Basin

The Vigo basin model comprises 47 sub basins, 23 reaches, and 23 junctions. The main outlet is outlet 2. This basin model is illustrated in Figure 61. The basins were identified based on soil and land cover characteristic of the area. Precipitation was taken from an installed Rain Gauge near and inside the river basin. Finally, it was calibrated using the data from actual discharge flow gathered in the Bigol Bridge.

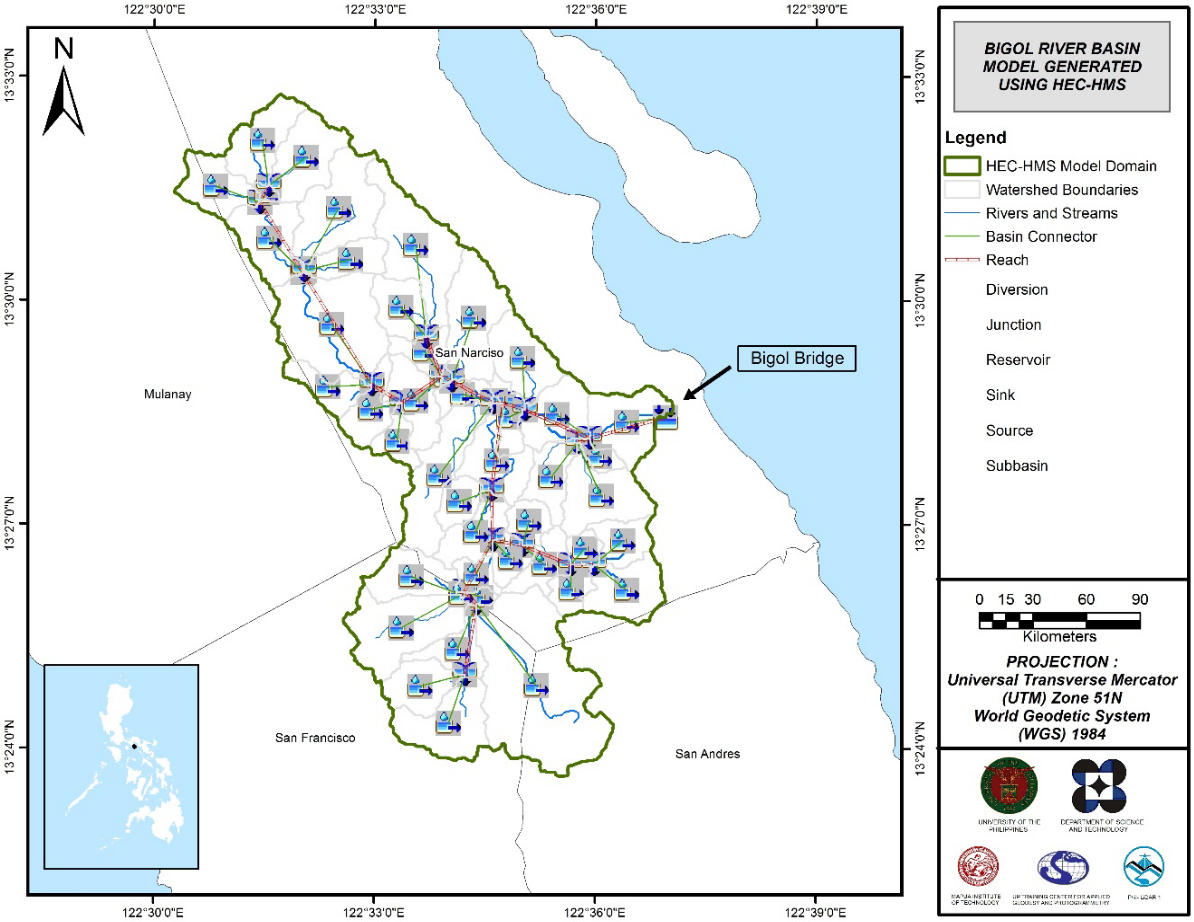


Figure 61. HEC-HMS generated Vigo (also known as Bigol) River Basin Model.

5.4 Cross-section Data

Riverbed cross-sections of the watershed are crucial in the HEC-RAS model setup. The cross-section data for the HEC-RAS model was derived using the LiDAR DEM data. It was defined using the Arc GeoRAS tool and was post-processed in ArcGIS. This is illustrated in Figure 62.

Figure 62. River cross-section of Vigo River generated through Arcmap HEC GeoRAS tool

5.5 Flo 2D Model

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

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

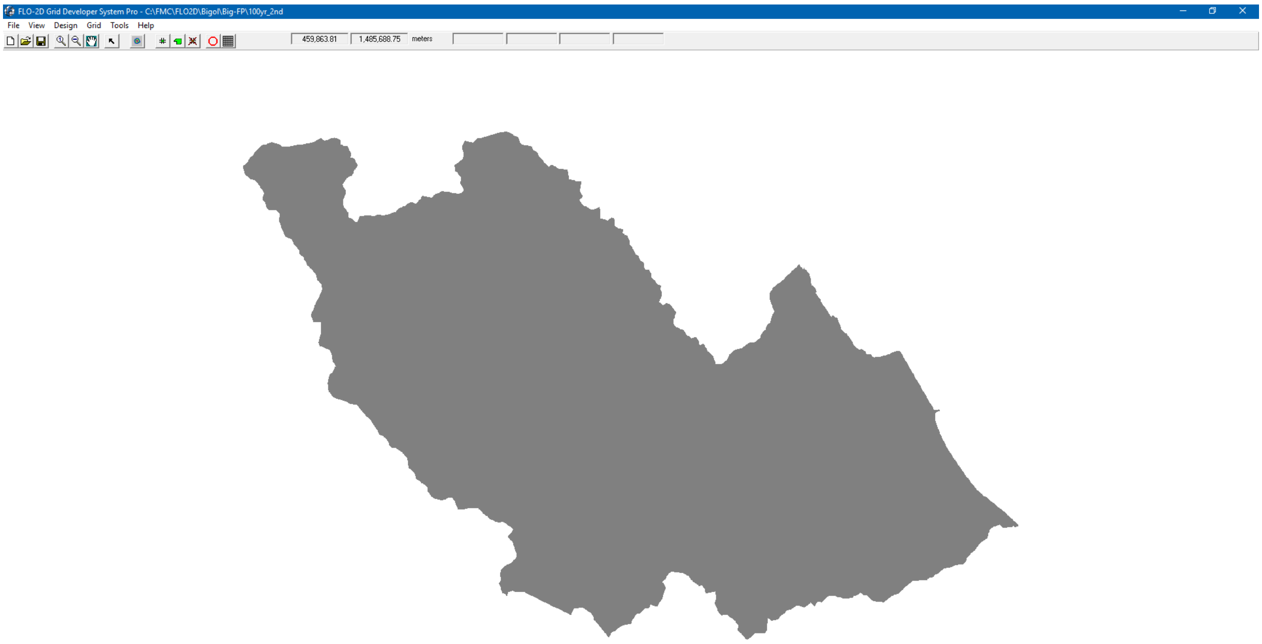


Figure 63. A screenshot of the river sub-catchment with the computational area to be modeled in FLO-2D Grid Developer System Pro (FLO-2D GDS Pro)

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 59.59131 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m2/s.

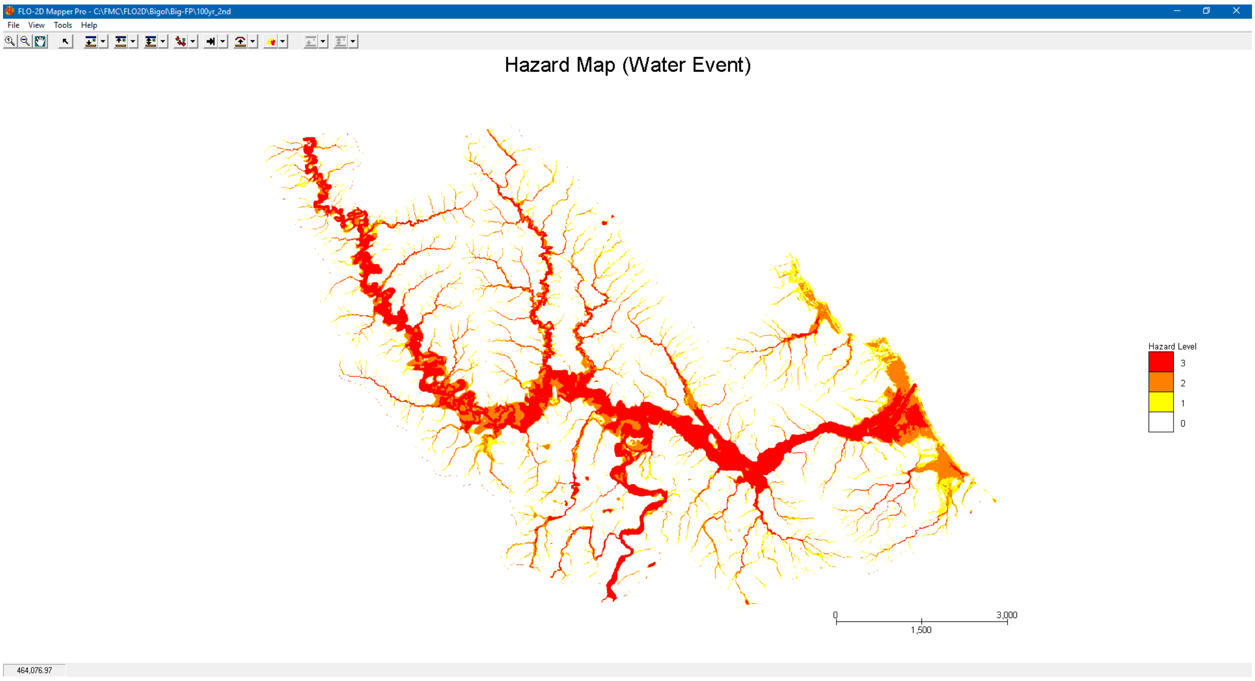


Figure 64. Generated 100-year Rain Return Hazard Map from FLO-2D Mapper

The creation of a flood hazard map from the model also automatically creates a flow depth map depicting the maximum amount of inundation for every grid element. The legend used by default in Flo-2D Mapper is not a good representation of the range of flood inundation values, so a different legend is used for the layout. In this particular model, the inundated parts cover a maximum land area of 57 076 500.00 m2.

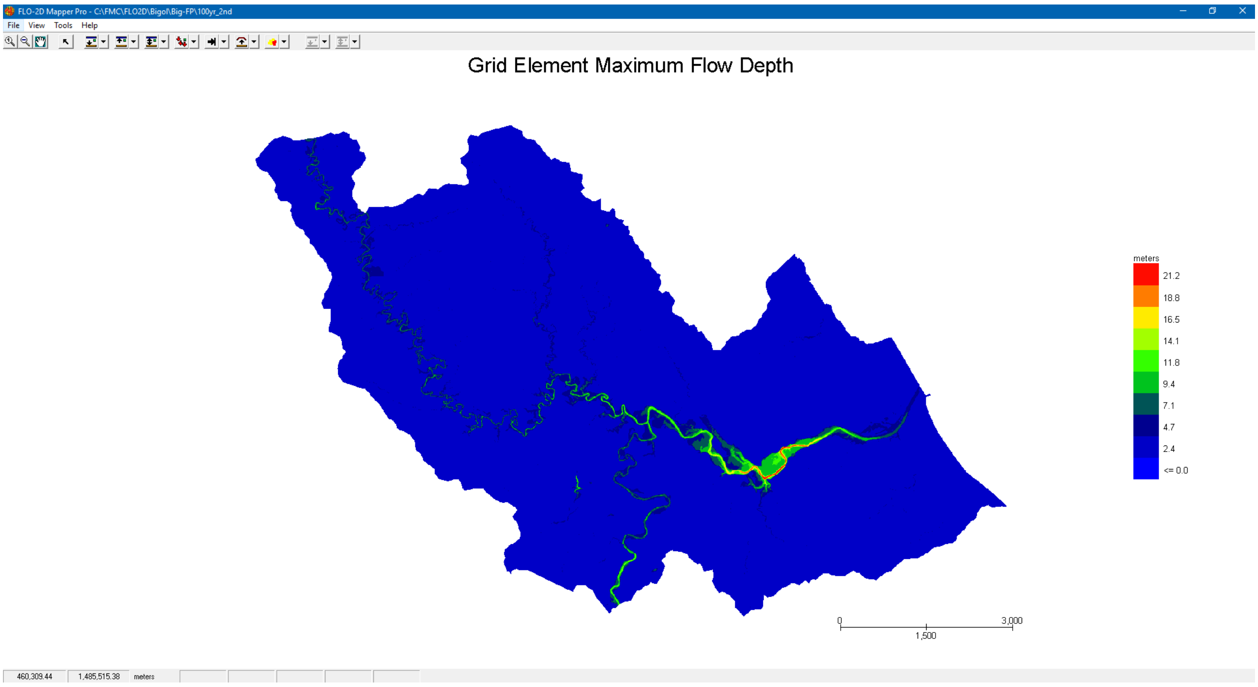


Figure 65. Generated 100-year Rain Return Flow Depth Map from FLO-2D Mapper

There is a total of 35 505 460.84 m3 of water entering the model. Of this amount, 22 225 984.27 m3 is due to rainfall while 13 279 476.57 m3 is inflow from other areas outside the model. 5 097 590.00 m3 of this water is lost to infiltration and interception, while 3 303 915.29 m3 is stored by the flood plain. The rest, amounting up to 27 103 962.30 m3, is outflow.

5.6 Results of HMS Calibration

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

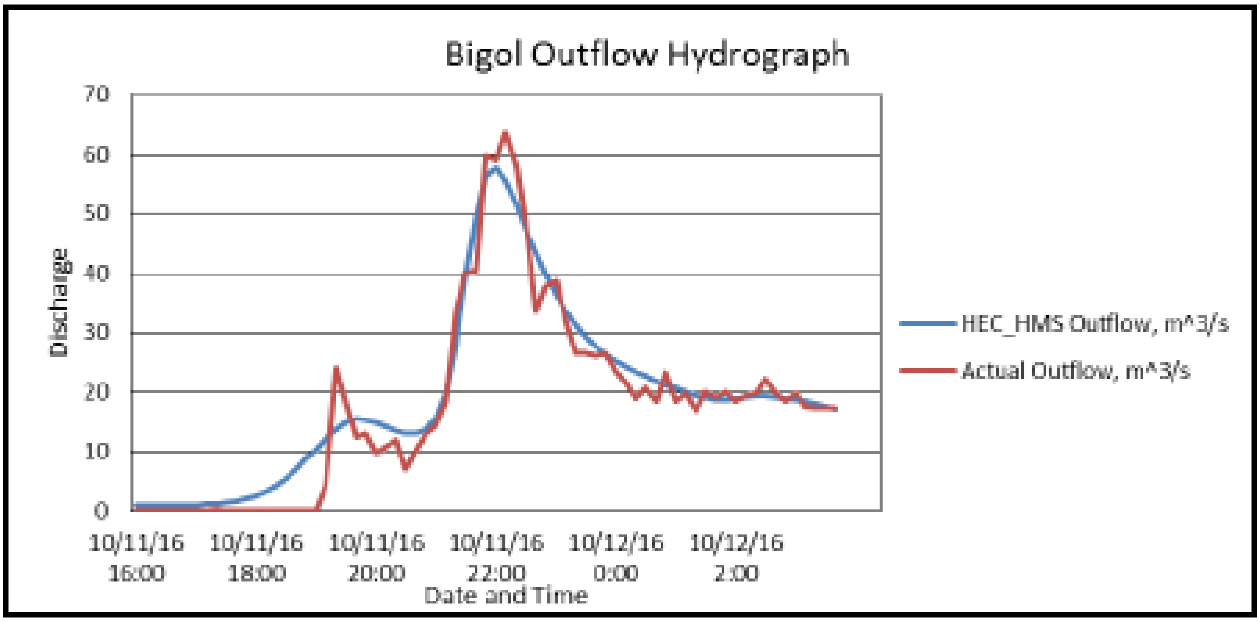


Figure 66. Outflow Hydrograph of Vigo (also known as Bigol) River produced by the HEC-HMS model compared with observed outflow.

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

Table 28. Range of Calibrated Values for Vigo

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	0.070 – 3.66
			Curve Number	35.096 – 99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.017 – 3.60
			Storage Coefficient (hr)	0.11 – 19.94
	Baseflow	Recession	Recession Constant	0.00001 – 0.00079
			Ratio to Peak	0.0028 – 0.5
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.00045 – 0.76

Initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as initial abstraction decreases. The range of values from 0.070mm to 3.66mm means that there is a minimal 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 for curve number among the watershed's subbasins is from 35.096 to 99. For Bigol, the sole soil class identified was clay. The land cover types identified were brushland, cultivated areas, grassland and tree plantations.

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 0.017 hours to 19.94 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. The Recession Constant values range from 0.00001 to 0.00079 while Ratio to Peak ranges from 0.0028 to 0.5. These values influence the receding limb of the outflow hydrograph which in this case is moderately likely to quickly return to its original discharge values.

Manning's roughness coefficient of 0.00045 to 0.76 corresponds to the common roughness in Bigol watershed's subbasins (Brunner, 2010).

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

Accuracy measure	Value
RMSE	3.7
r2	0.951
NSE	0.95
PBIAS	-6.61
RSR	0.23

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 3.7 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 0.951.

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 0.95.

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 -6.61.

The Observation Standard Deviation Ratio, RSR, is an error index. A perfect model attains a value of 0 when the error in the units of the valuable a quantified. The model has an RSR value of 0.23.

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

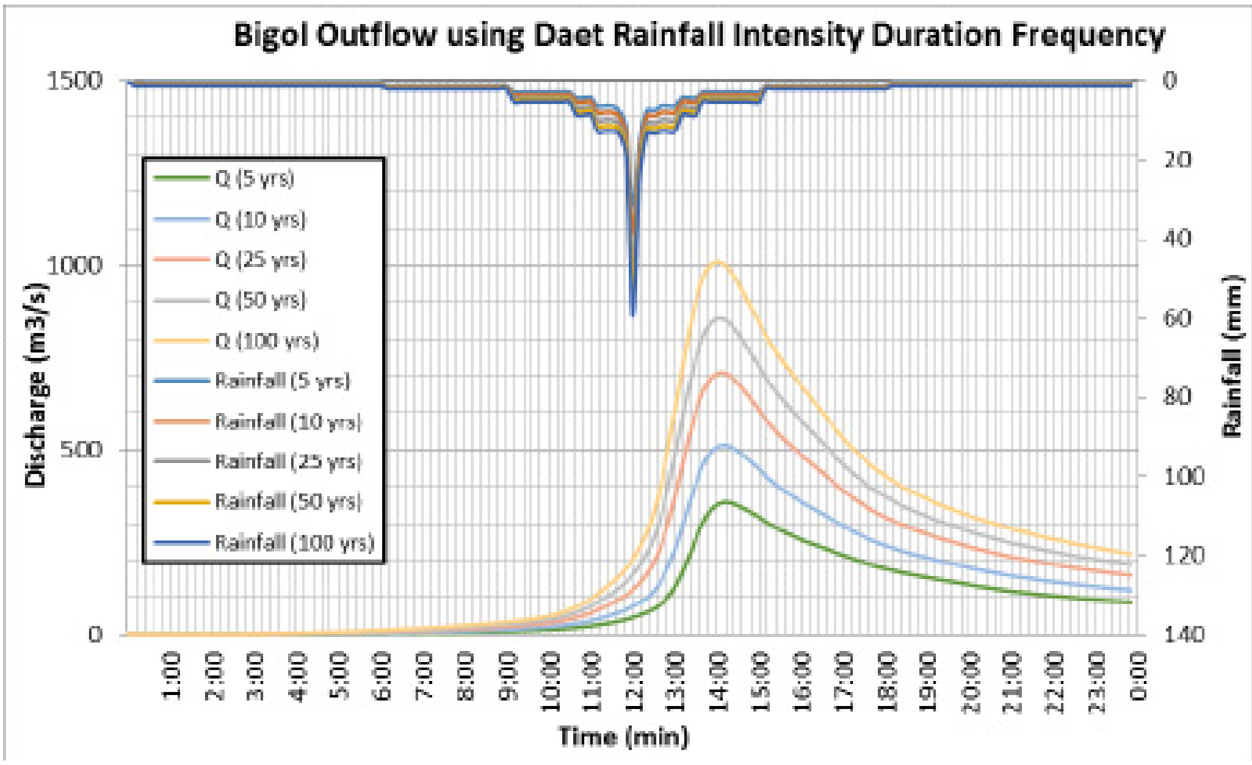


Figure 67. Outflow hydrograph at Vigo (also known as Bigol) Station generated using Daet RIDF simulated in HEC-HMS

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

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

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	278.7	31.8	357.7	14 hours, 10 minutes
10-Year	337.2	38.5	512.4	14 hours, 10 minutes
25-Year	411.1	46.9	708.7	14 hours, 10 minutes
50-Year	465.9	53.2	855.3	14 hours
100-Year	520.3	59.4	1009.7	14 hours

5.8 River Analysis (RAS) Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. For this publication, only a sample output map river was to be shown, since only the Flood Acquisition and Validation Component (MIT-FAVC) base flow was calibrated. The sample generated map of Bigol River using the calibrated HMS base flow is shown in Figure 68.

Figure 68. Sample output of Vigo (also known as Bigol) RAS Model

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. Figure 69 to Figure 74 show the 5-, 25-, and 100-year rain return scenarios of the Vigo floodplain.

Table 31. Municipalities affected in Vigo Floodplain

Municipality	Total Area	Area Flooded	% Flooded
Mulanay	276.022	0.351	0.15%
San Narciso	242.51	56.66	23.37%

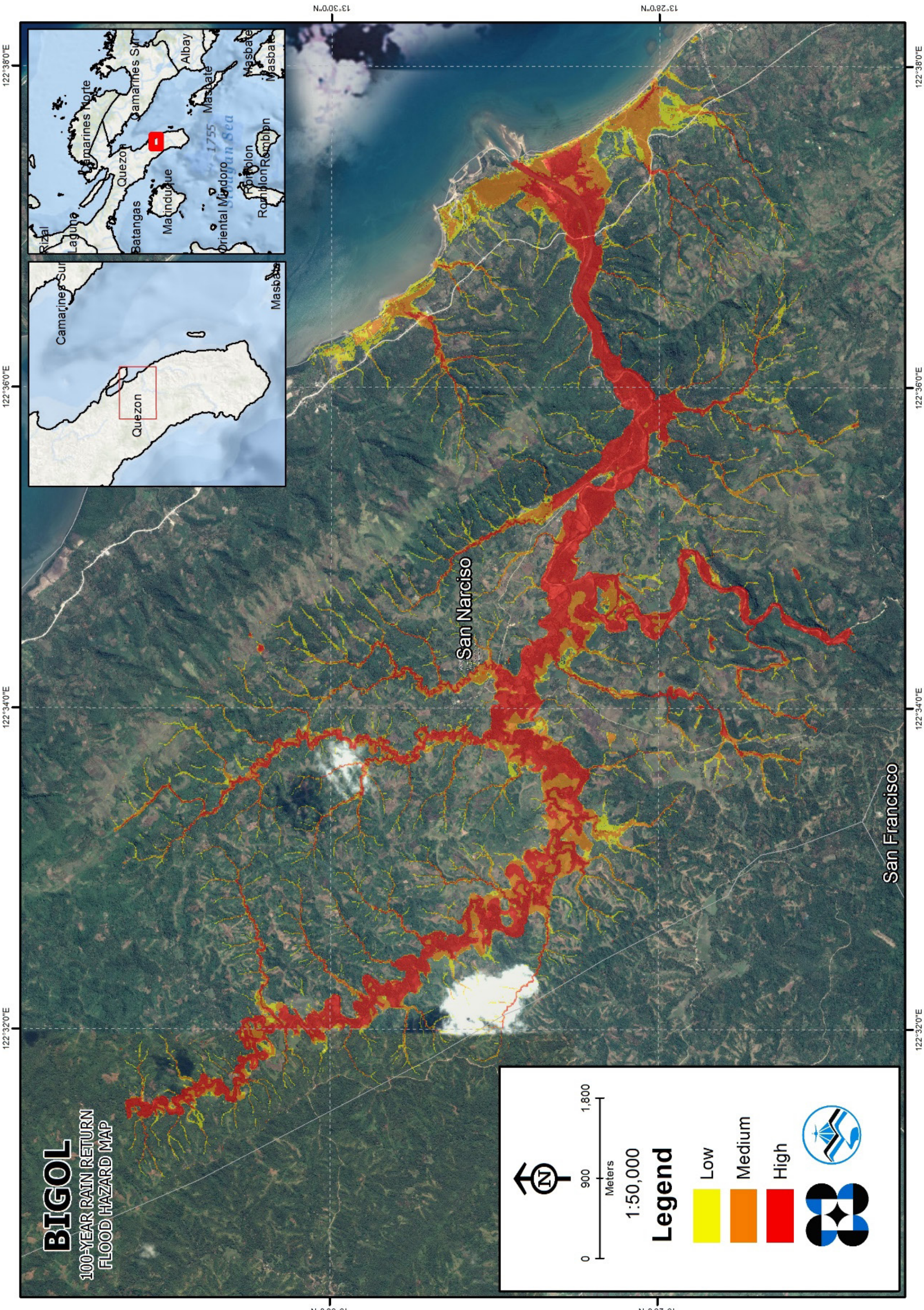


Figure 69. 100-year Flood Hazard Map for Vigo (also known as Bigol) Floodplain overlaid on Google Earth imagery

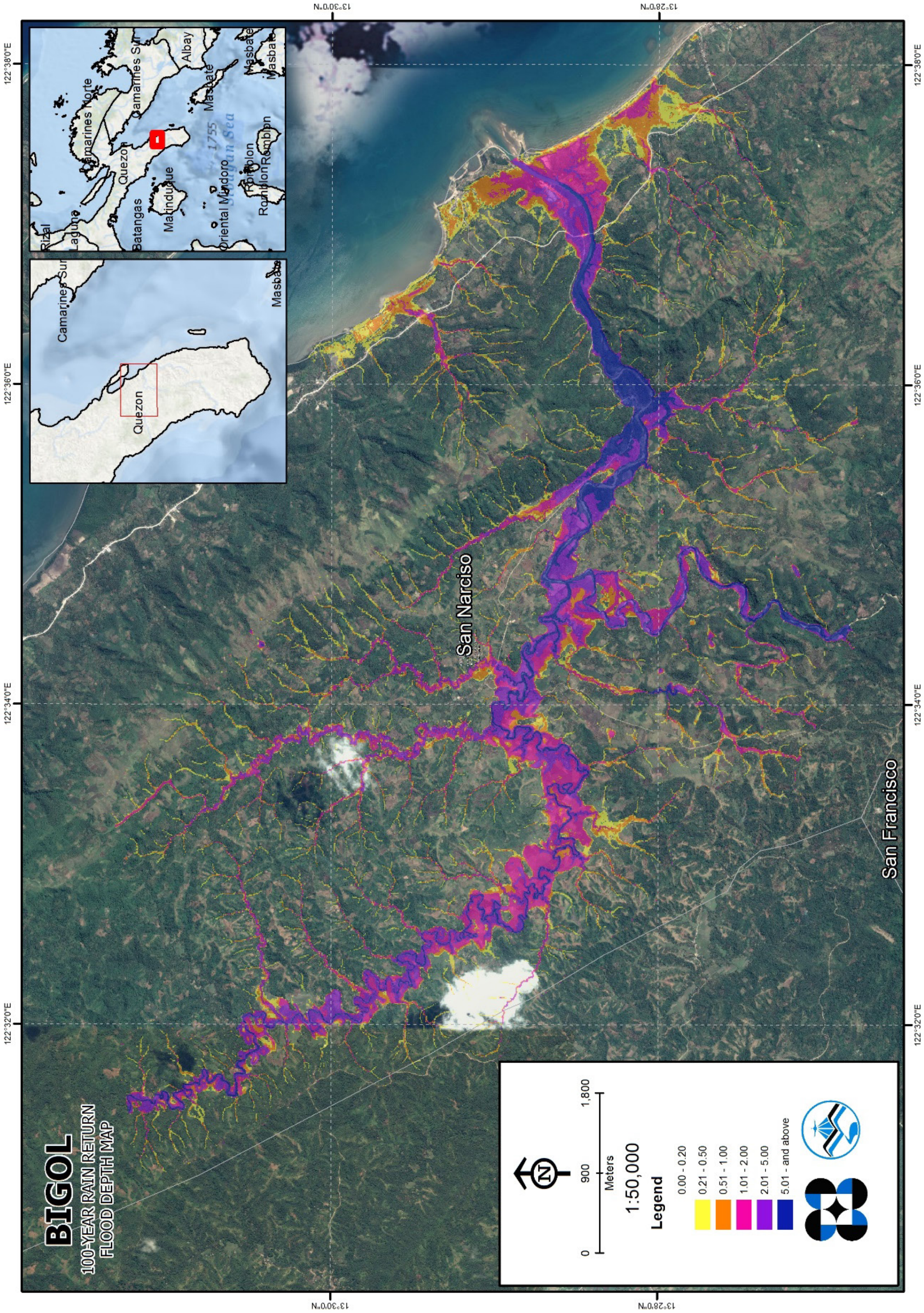


Figure 70. 100-year Flow Depth Map for Vigo (also known as Bigol) Floodplain overlaid on Google Earth imagery

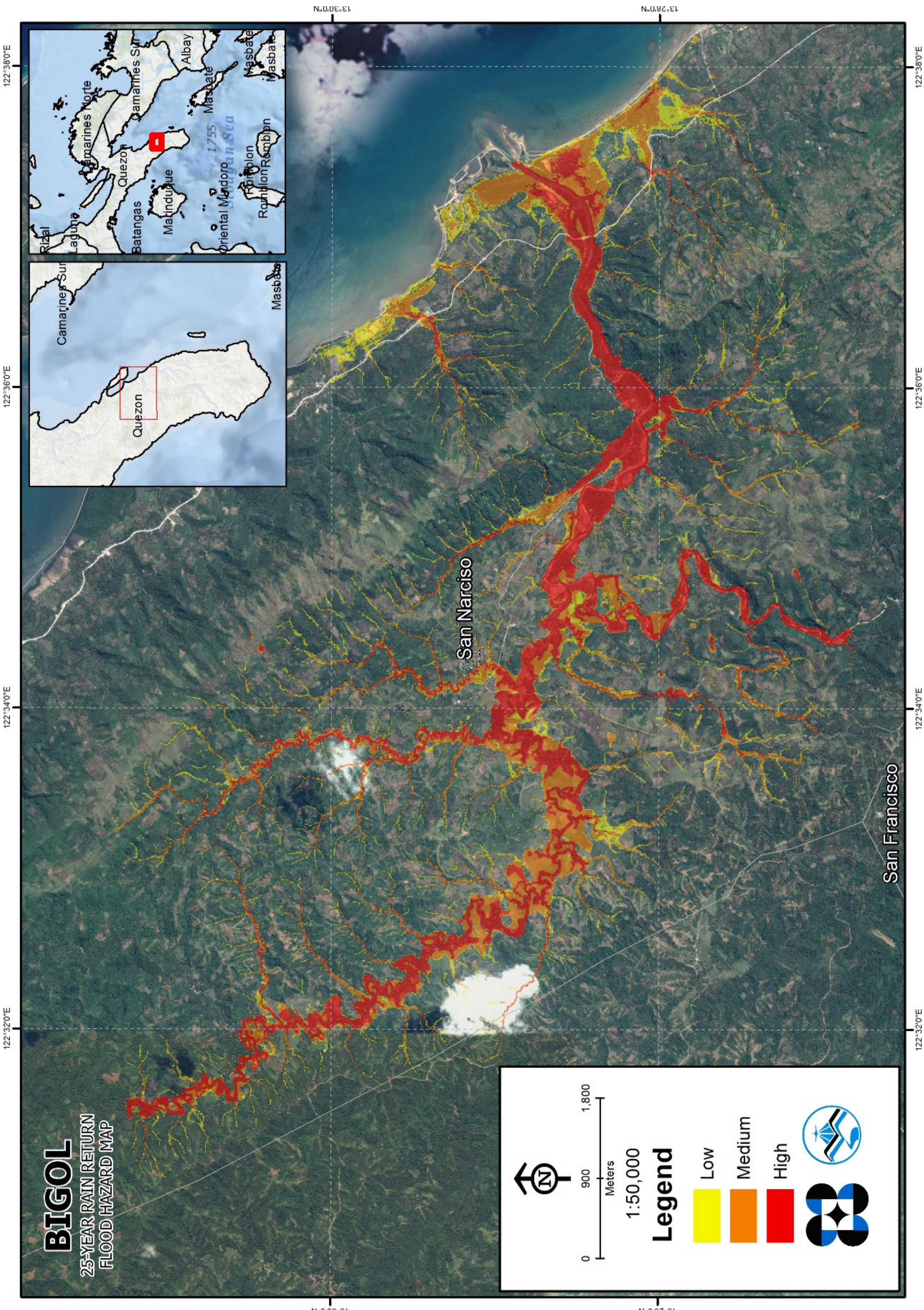


Figure 71. 25-year Flood Hazard Map for Vigo (also known as Bigol) Floodplain overlaid on Google Earth imagery

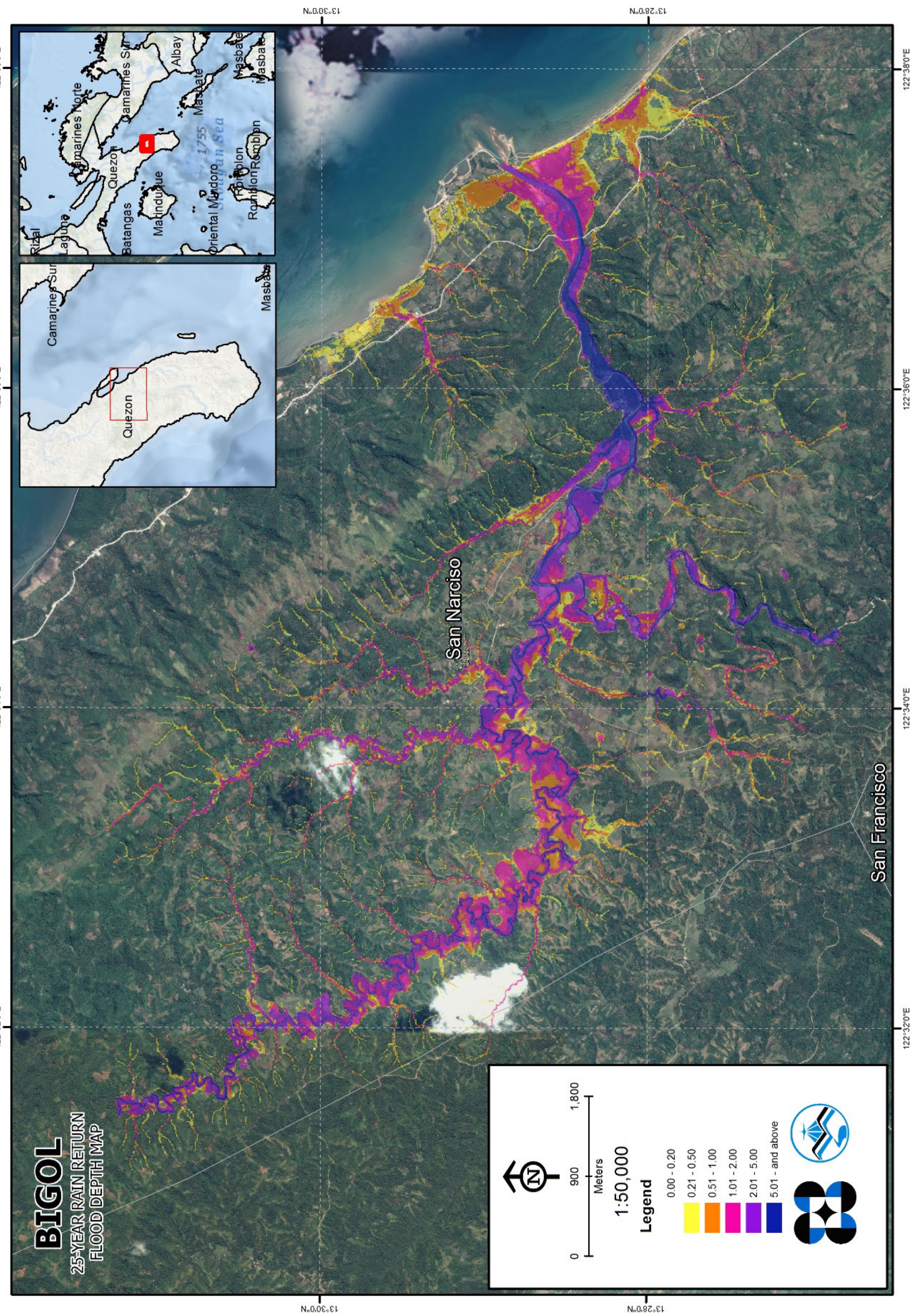


Figure 72. 25-year Flow Depth Map for Vigo (also known as Bigol) Floodplain overlaid on Google Earth imagery

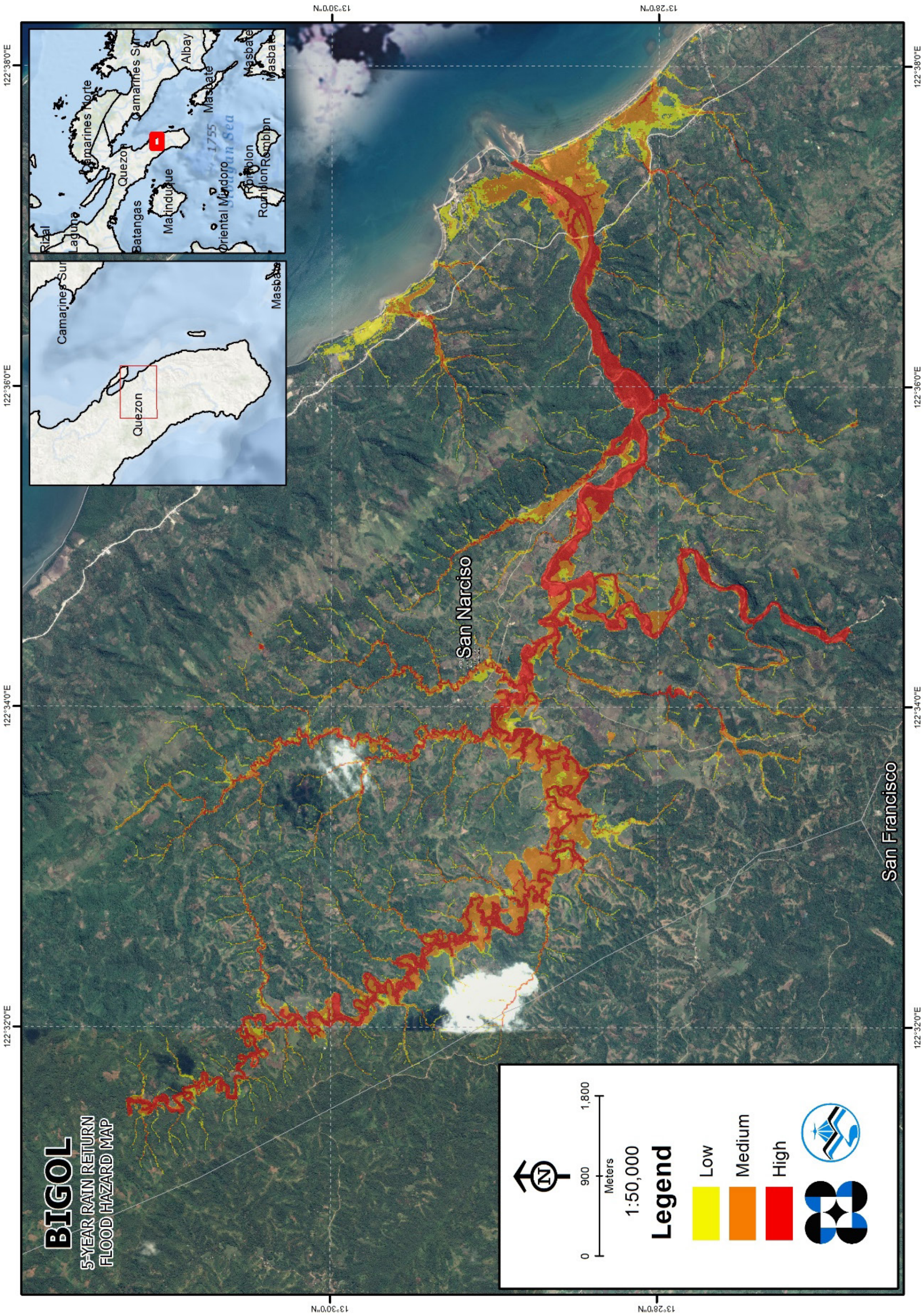


Figure 73. 5-year Flood Hazard Map for Vigo (also known as Bigol) Floodplain overlaid on Google Earth imagery

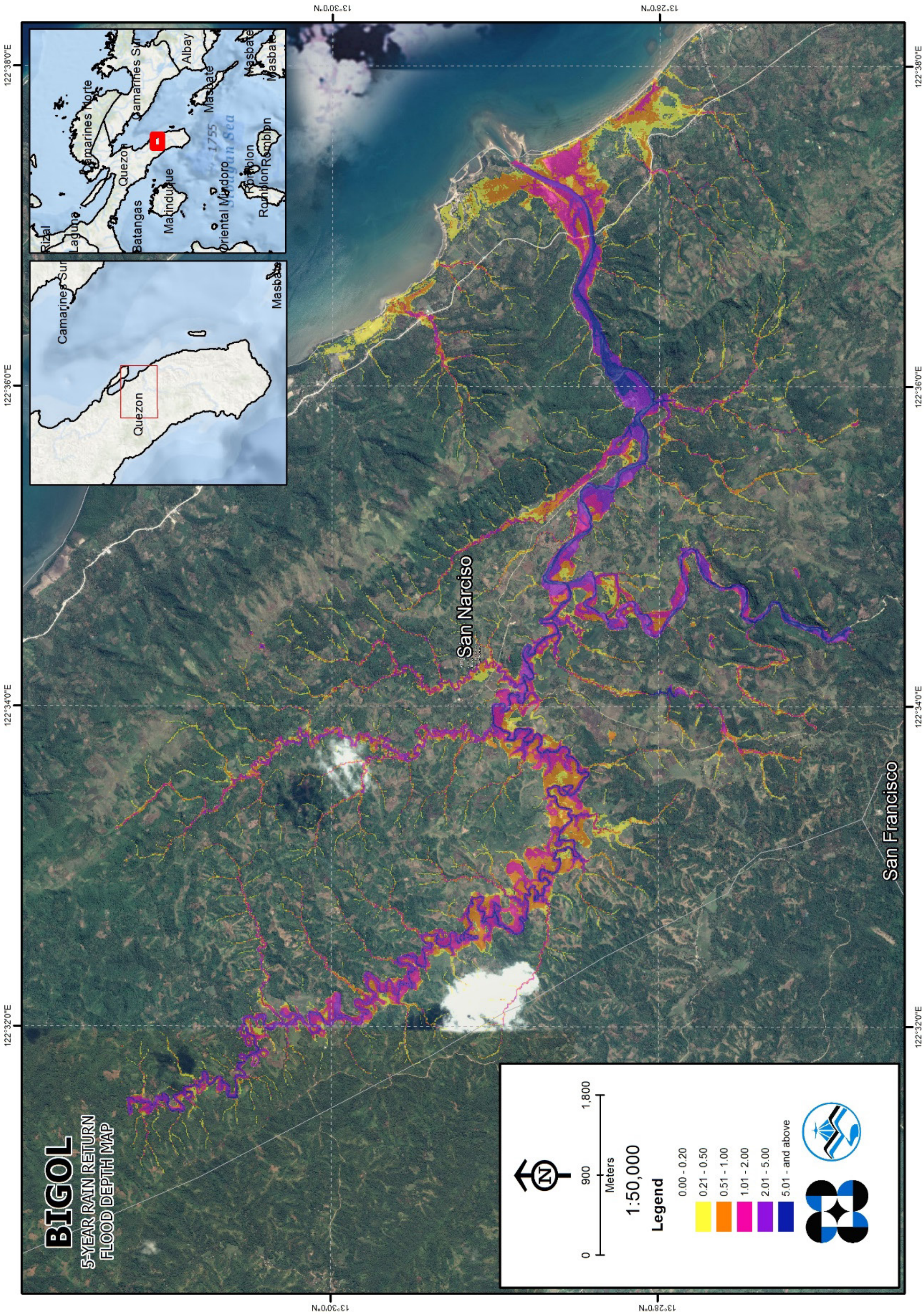


Figure 74. 5-year Flood Depth Map for Vigo (also known as Bigol) Floodplain overlaid on Google Earth imagery

5.10 Inventory of Areas Exposed to Flooding

Listed below are the barangays affected by the Vigo River Basin, grouped accordingly by municipality. For the said basin, two (2) municipalities consisting of ten (10) barangays are expected to experience flooding when subjected to a 5-year rainfall return period.

For the 5-year return period, 19.31% of the municipality of San Narciso with an area of 242.51 sq. km. will experience flood levels of less than 0.20 meters. 1.08% of the area will experience flood levels of 0.21 to 0.50 meters while 1.00%, 0.93%, 0.73%, and 0.31% 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 and shown in Figure 75 are the affected areas in square kilometers by flood depth per barangay.

Table 32. Affected areas in San Narciso, Quezon during a 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in San Narciso (in sq. km.)							
	Binay	Busokbusokan	San Juan	San Vicente	Vigo Central	Villa Aurin	Villa reyes	White Cliff
0.03-0.20	8.45	2.88	11.62	7.46	9.14	0.44	0.63	6.21
0.21-0.50	0.6	0.11	0.44	0.47	0.61	0.021	0.034	0.34
0.51-1.00	0.34	0.084	0.38	0.82	0.43	0.013	0.013	0.35
1.01-2.00	0.25	0.11	0.48	0.83	0.31	0.02	0.0066	0.25
2.01-5.00	0.27	0.16	0.4	0.62	0.11	0.02	0.0003	0.19
> 5.00	0.21	0.12	0.06	0.25	0.04	0.0018	0	0.064

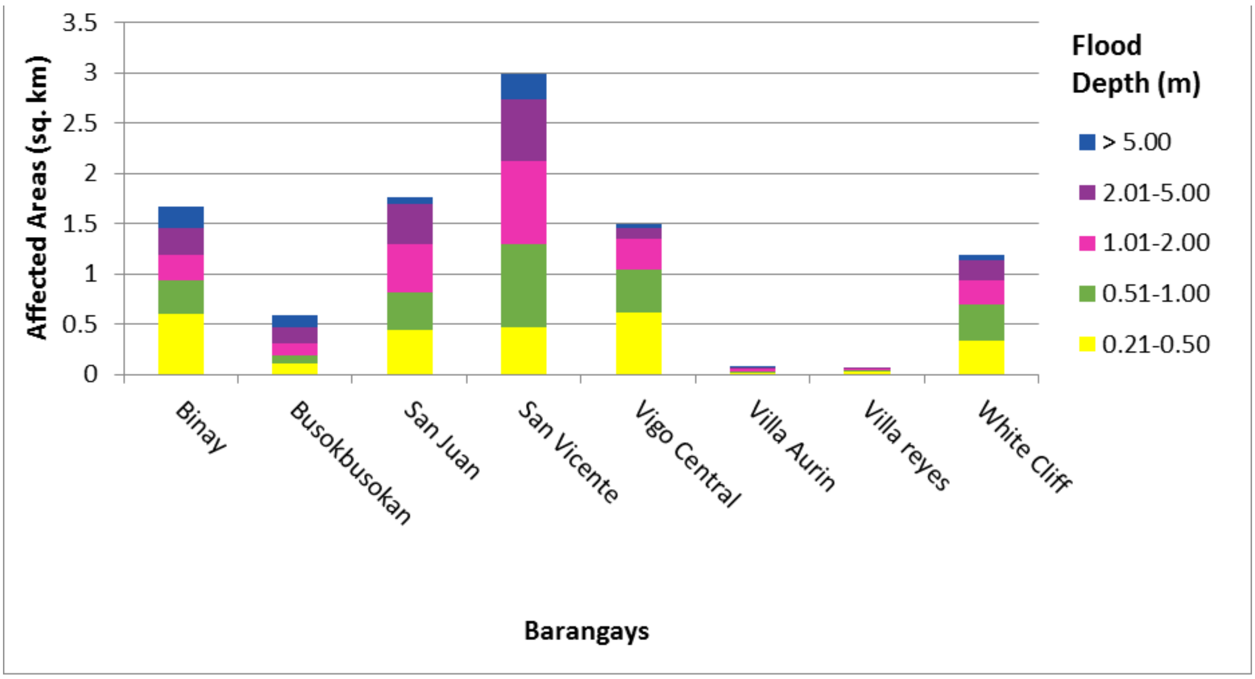


Figure 75. Affected areas in San Narciso, Quezon during a 5-Year Rainfall Return Period.

For the municipality of Pinabacdao, with an area of 118.377 sq. km., 14.04% will experience flood levels of less 0.20 meters. 0.52% of the area will experience flood levels of 0.21 to 0.50 meters while 0.77%, 0.76%, and 0.13% of the area will experience flood depths of 0.51 to 1 meter, and 1.01 to 2 meters, respectively. Table 33 and Figure 76 depicts the affected areas in square kilometers by flood depth per barangay.

Table 33. Affected areas in Mulanay, Quezon during a 5-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Mulanay (in sq. km.)	
	Ilayang Yuni	Pakiing
0.03-0.20	0.29	0.062
0.21-0.50	0.0086	0.0012
0.51-1.00	0.0043	0.000011
1.01-2.00	0.003	0.0001
2.01-5.00	0.0004	0
> 5.00	0	0

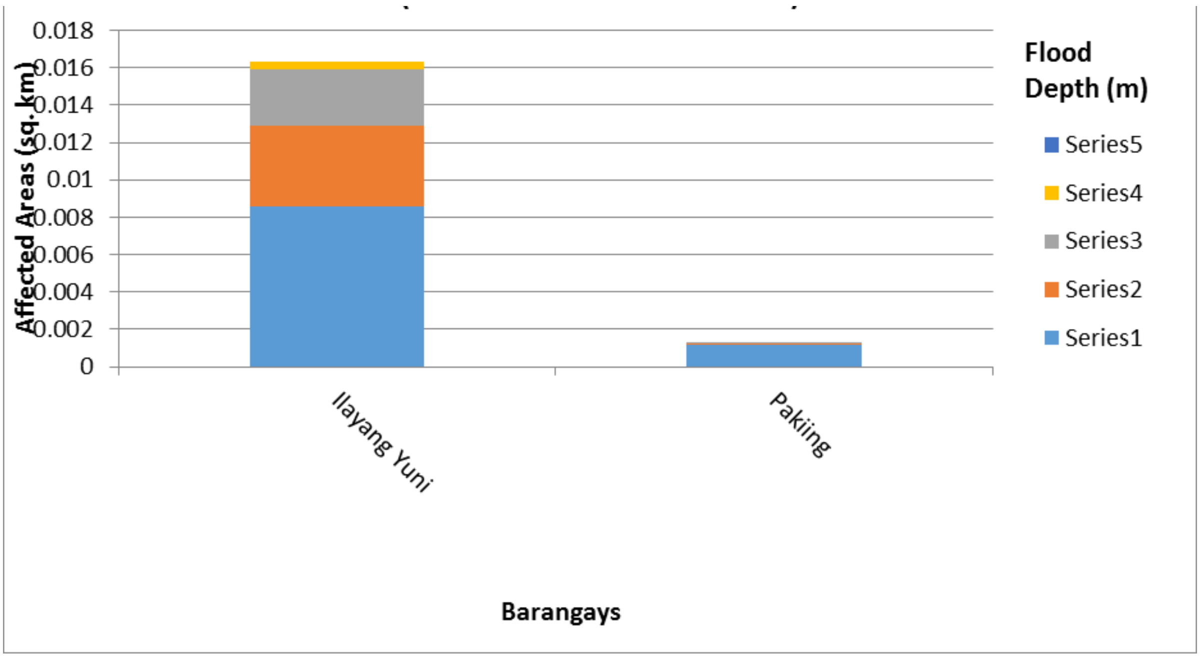


Figure 76. Affected areas in Mulanay, Quezon during 5-Year Rainfall Return Period rainfall event.

For the 25-year return period, 18.68% of the municipality of San Narciso with an area of 242.51 sq. km. will experience flood levels of less than 0.20 meters. 1.12% of the area will experience flood levels of 0.21 to 0.50 meters while 0.97%, 1.20%, 0.94%, and 0.46% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 34 and shown Figure 77 are the affected areas in square kilometers by flood depth per barangay.

Table 34. Affected Areas in San Narciso, Quezon during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in San Narciso (in sq. km.)							
	Binay	Busokbusokan	San Juan	San Vicente	Vigo Central	Villa Aurin	Villa reyes	White Cliff
0.03-0.20	8.21	2.82	11.35	7.12	8.84	0.43	0.61	5.93
0.21-0.50	0.65	0.11	0.47	0.39	0.63	0.02	0.046	0.39
0.51-1.00	0.39	0.094	0.38	0.61	0.48	0.013	0.018	0.36
1.01-2.00	0.29	0.13	0.55	1.1	0.45	0.018	0.0083	0.36
2.01-5.00	0.21	0.19	0.51	0.9	0.16	0.027	0.001	0.28
> 5.00	0.37	0.13	0.11	0.34	0.076	0.0056	0	0.086

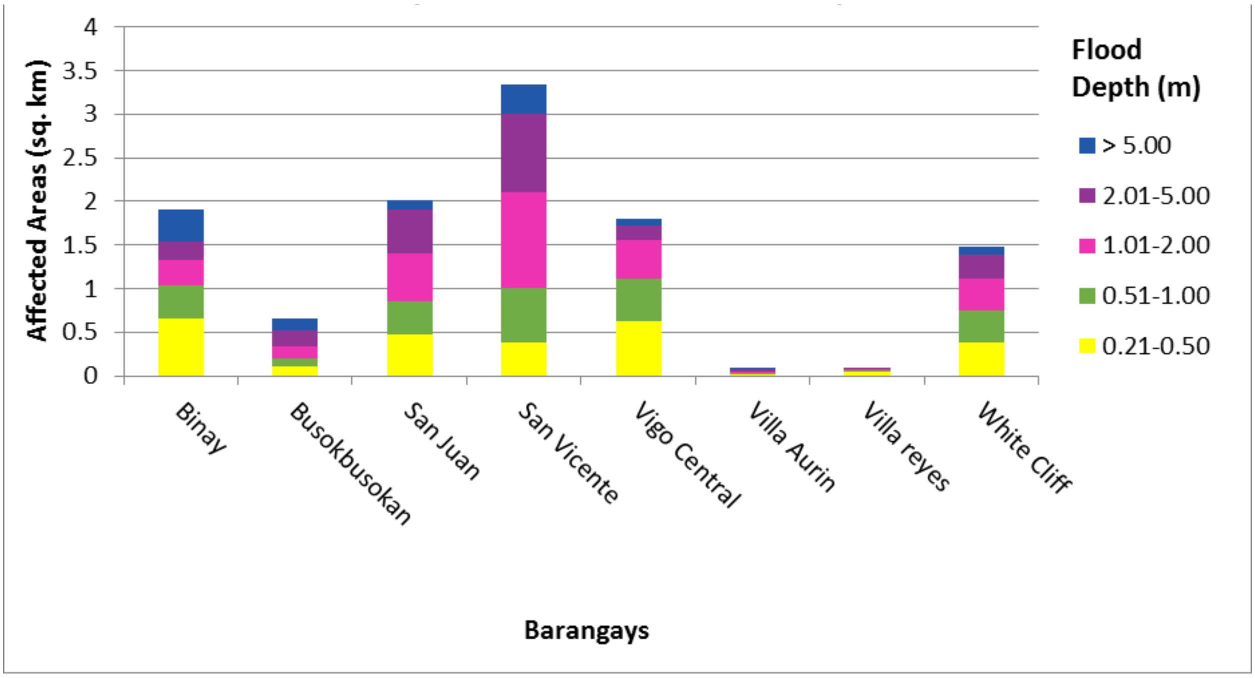


Figure 77. Affected Areas in San Narciso, Quezon during 25-Year Rainfall Return Period

For the 25-year return period, 0.14% of the municipality of Mulanay with an area of 276.022 sq. km. will experience flood levels of less than 0.20 meters. 0.00% of the area will experience flood levels of 0.21 to 0.50 meters while 0.00%, 0.00%, 0.00%, and 0.00% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 35 and shown in Figure 78 are the affected areas in square kilometers by flood depth per barangay.

Table 35. Affected Areas in Mulanay, Quezon during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Mulanay (in sq. km.)	
	Ilayang Yuni	Pakiing
0.03-0.20	0.29	0.061
0.21-0.50	0.0082	0.0018
0.51-1.00	0.0058	0.00021
1.01-2.00	0.004	0.0001
2.01-5.00	0.001	0
> 5.00	0	0

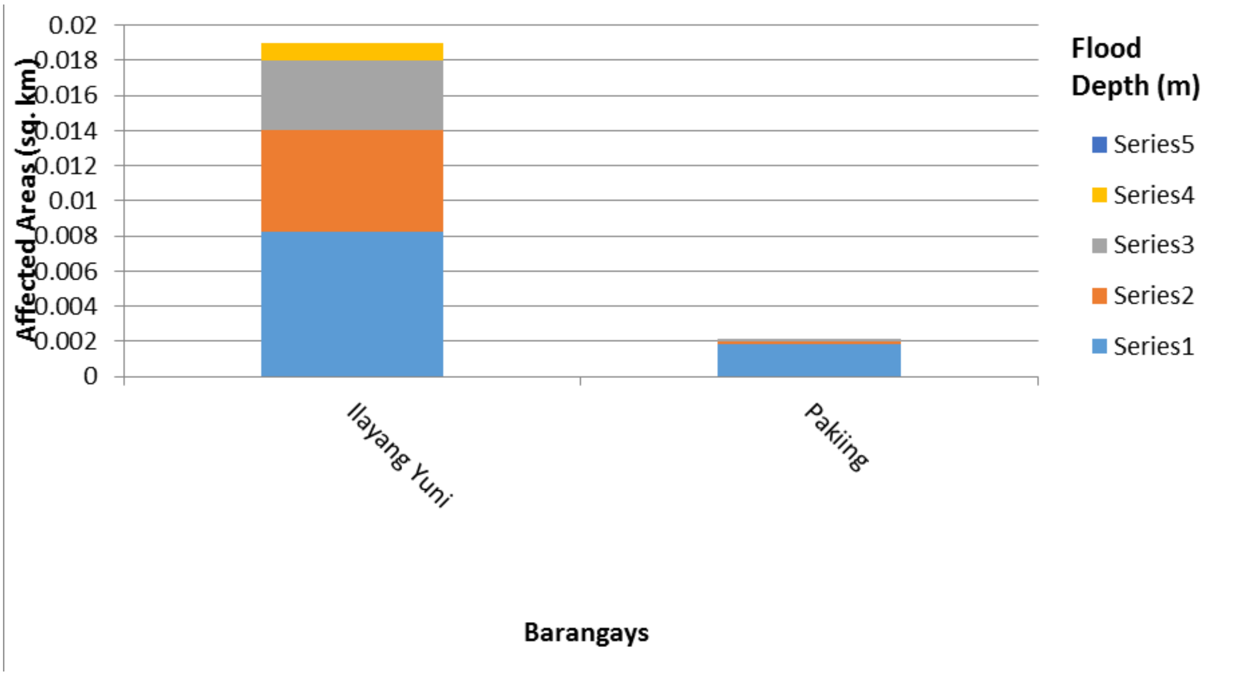


Figure 78. Affected Areas in Mulanay, Quezon during 25-Year Rainfall Return Period

For the 100-year return period, 18.25% of the municipality of San Narciso with an area of 242.51 sq. km. will experience flood levels of less than 0.20 meters. 1.13% of the area will experience flood levels of 0.21 to 0.50 meters while 0.93%, 1.29%, 1.16%, and 0.61% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 36 and shown in Figure 79 are the affected areas in square kilometers by flood depth per barangay.

Table 36. Affected Areas in San Narciso, Quezon during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in San Narciso (in sq. km.)							
	Binay	Busokbusokan	San Juan	San Vicente	Vigo Central	Villa Aurin	Villa reyes	White Cliff
0.03-0.20	8.02	2.76	11.15	6.91	8.63	0.43	0.6	5.76
0.21-0.50	0.68	0.12	0.5	0.37	0.64	0.02	0.051	0.35
0.51-1.00	0.44	0.09	0.39	0.44	0.49	0.015	0.022	0.36
1.01-2.00	0.29	0.13	0.56	1.15	0.52	0.014	0.009	0.46
2.01-5.00	0.28	0.21	0.63	1.07	0.21	0.034	0.0017	0.37
> 5.00	0.41	0.16	0.14	0.52	0.14	0.0068	0	0.11

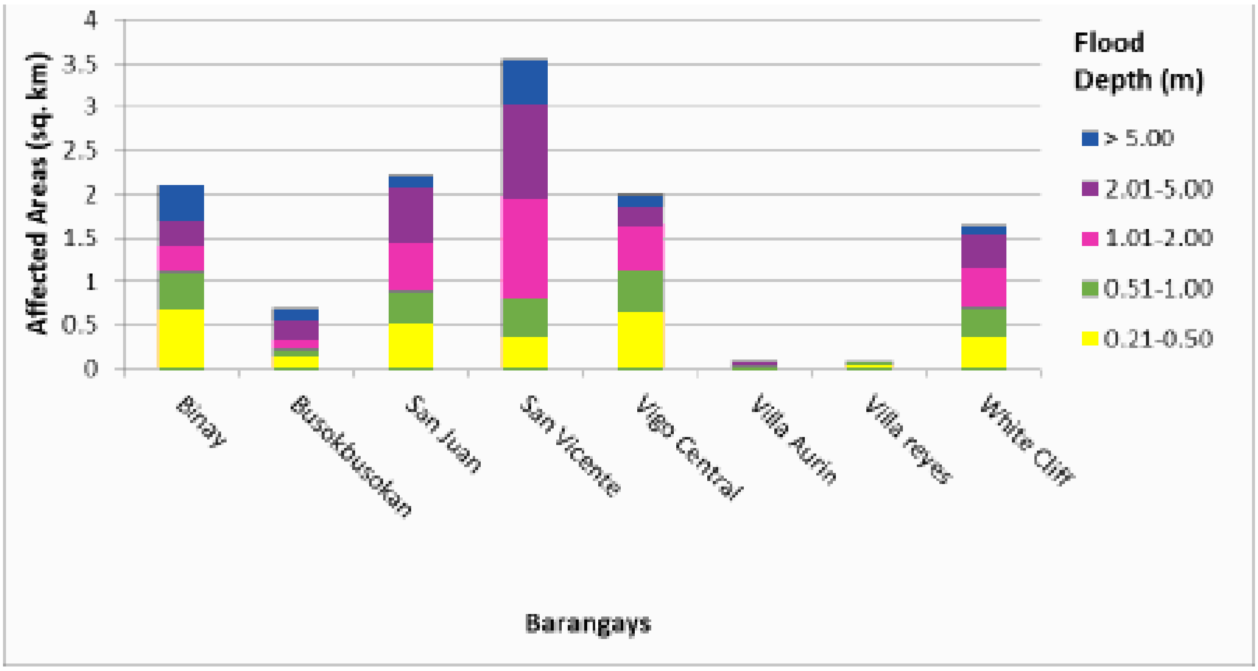


Figure 79. Affected Areas in San Narciso, Quezon during 100-Year Rainfall Return Period

For the 100-year return period, 0.14% of the municipality of Mulanay with an area of 276.022 sq. km. will experience flood levels of less than 0.20 meters. 0.00% of the area will experience flood levels of 0.21 to 0.50 meters while 0.00%, 0.00%, 0.00%, and 0.00% 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 37 and shown in Figure 80 are the affected areas in square kilometers by flood depth per barangay.

Table 37. Affected Areas in Mulanay, Quezon during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Mulanay (in sq. km.)	
	Ilayang Yuni	Pakiing
0.03-0.20	0.29	0.061
0.21-0.50	0.0075	0.0019
0.51-1.00	0.0068	0.0002
1.01-2.00	0.0043	0.0002
2.01-5.00	0.0016	0
> 5.00	0	0

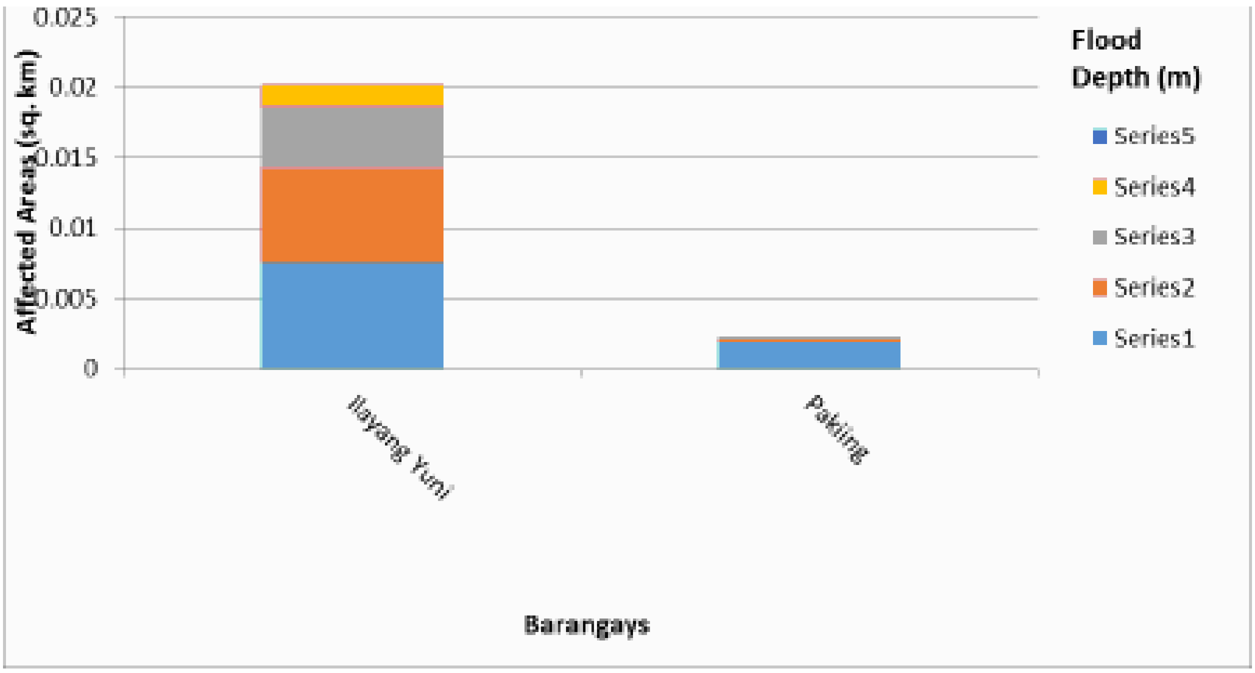


Figure 80. Affected Areas in Mulanay, Quezon during 100-Year Rainfall Return Period

Moreover, the generated flood hazard maps for the Vigo 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-year, 25-year, and 10-year).

Table 39. Areas covered by each warning level with respect to the rainfall scenarios

Warning Level	Area Covered in sq. km.		
	5 year	25 year	100 year
Low	2.68	2.73	2.75
Medium	3.85	3.99	3.86
High	3.46	4.78	5.95
TOTAL	**9.98**	**11.50**	**12.57**

Of the seven (7) identified education institutions in Vigo floodplain, two (2) schools were discovered exposed to low-level flooding during a 5-year scenario, while two (2) schools were found exposed to high-level flooding in the same scenario.

In the 25-year scenario, three (2) schools were found exposed to low-level flooding, while two (2) schools were discovered exposed to high-level flooding.

For the 100-year scenario, one (1) school was discovered exposed to low-level flooding, while one (1) school was exposed to medium-level flooding. In the same scenario, two (2) schools were found exposed to high-level flooding. The educational institutions affected by flooding in the Vigo floodplain are shown in Annex 12.

Apart from this, two (2) medical institutions were identified in the Vigo Floodplain, yet none were assessed to be exposed to any flood level for any scenario. The medical or health institutions affected by flooding in the Vigo floodplain are shown in Annex 13.

5.11 Flood Validation

In order to check and validate the extent of flooding in different river systems, there is a need to perform validation survey work. Field personnel 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.

The validation personnel went to the specified points identified in a river basin and gathered data regarding the actual flood level in each location. Data gathering was done through a local DRRM office, obtaining maps or situation reports about the past flooding events and through interview with some residents who have knowledge of or have had experienced flooding in a particular area.

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 points in the flood map versus its corresponding validation depths are shown in Figure 82.

The flood validation consisted of 180 points randomly selected all over the Yabaan floodplain (Figure 81). Comparing it with the flood depth map of the nearest storm event, the map has an RMSE value of 1.12m. Table 40 shows a contingency matrix of the comparison.

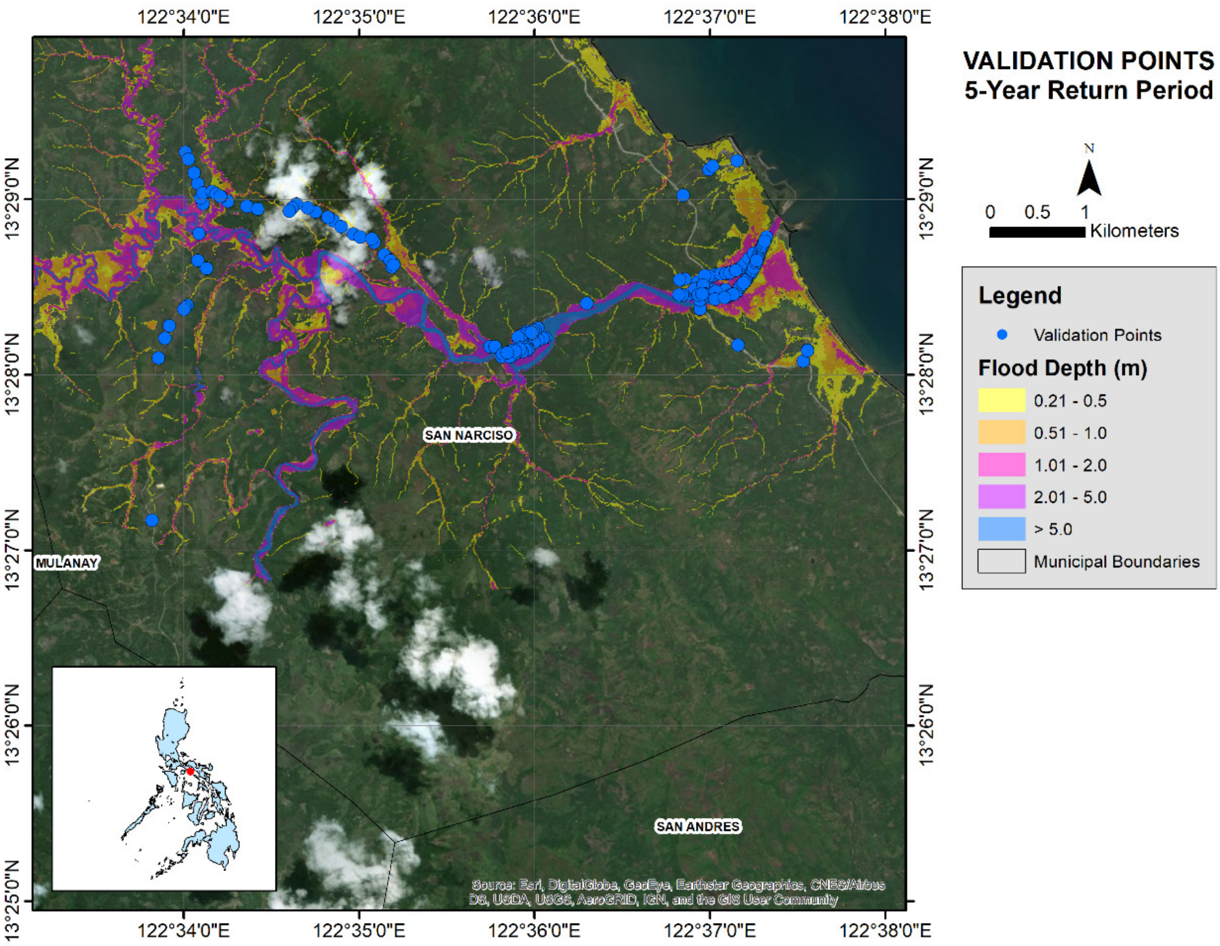


Figure 81. Validation points for 5-year Flood Depth Map of Vigo Floodplain

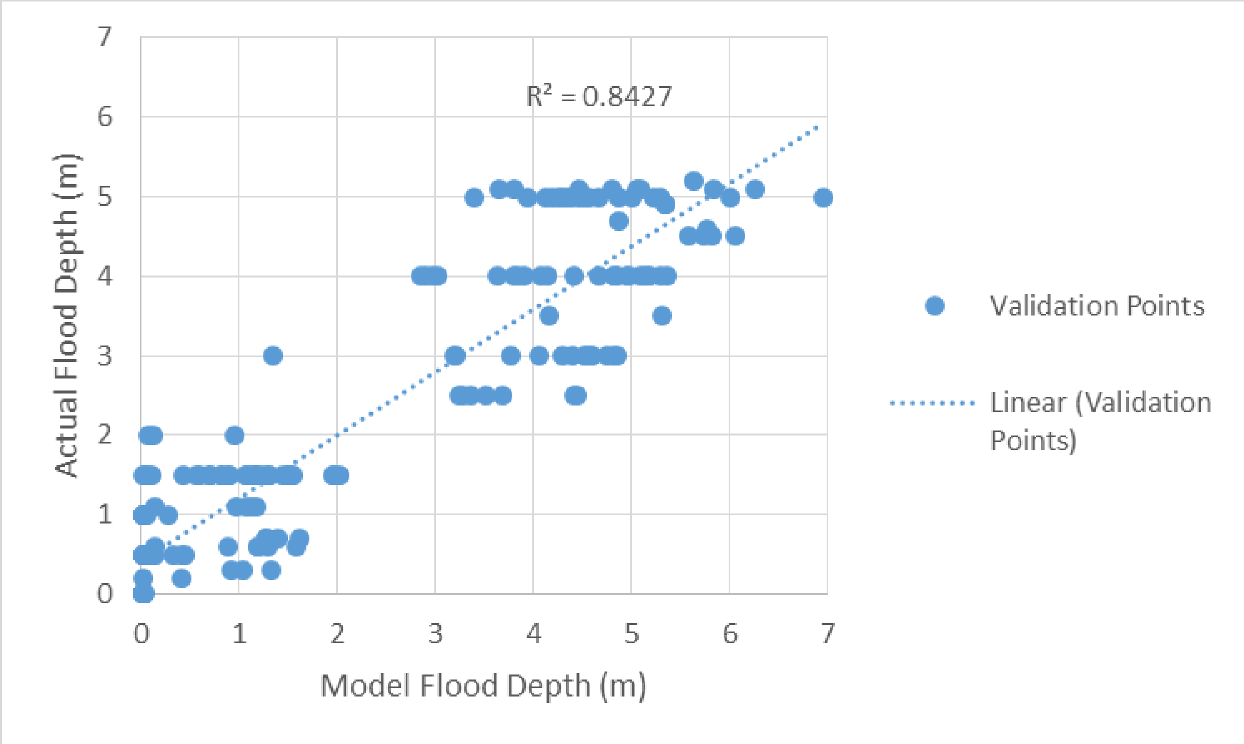


Figure 82. Flood map depth vs. actual flood depth

Table 40. Actual flood vs simulated flood depth at different levels in the Vigo River Basin.

Actual Flood Depth (m)	Modeled Flood Depth (m)						
	0-0.20	0.21-0.50	0.51-1.00	1.01-2.00	2.01-5.00	> 5.00	Total
0-0.20	28	1	0	0	0	0	29
0.21-0.50	8	3	1	2	0	0	14
0.51-1.00	7	1	1	9	0	0	18
1.01-2.00	7	1	10	18	1	0	37
2.01-5.00	0	0	0	1	54	18	73
> 5.00	0	0	0	0	4	5	9
Total	50	6	12	30	59	23	180

The overall accuracy generated by the flood model is estimated at 60.56% with 109 points correctly matching the actual flood depths. In addition, there were 53 points estimated one level above and below the correct flood depths while there were 10 points and 7 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 4 points were overestimated while a total of 39 points were underestimated in the modelled flood depths of Vigo. Table 41 depicts the summary of the Accuracy Assessment in the Vigo River Basin Survey.

Table 41. Summary of the Accuracy Assessment in the Vigo River Basin Survey

	No. of Points	%
Correct	109	60.56
Overestimated	32	17.78
Underestimated	39	21.67
Total	180	100.00

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ANNEXES

Annex 1. Optech Technical Specification of the Pegasus Sensor

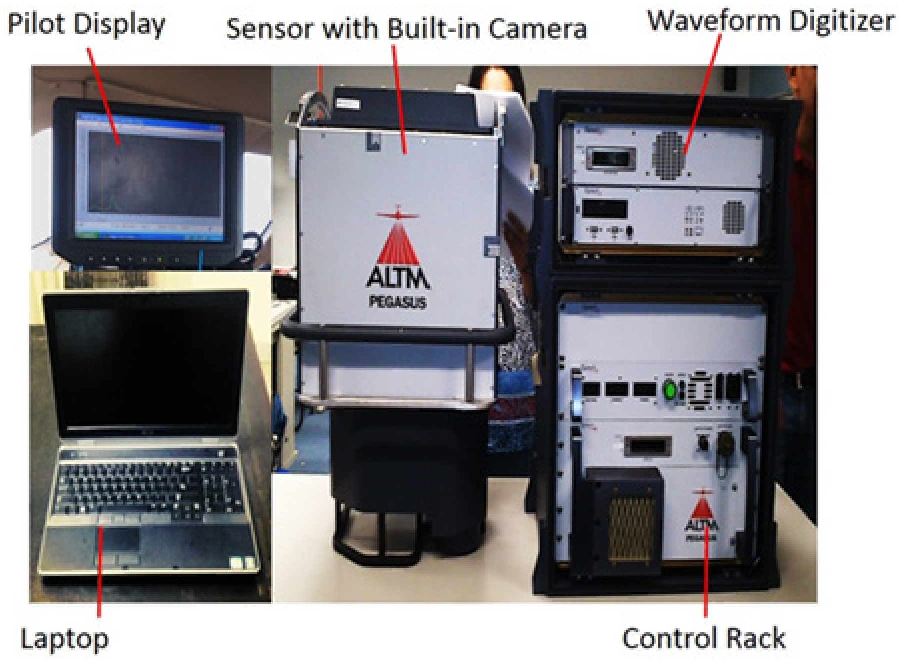

Figure A-1.1 Pegasus Sensor

Table A-1.1 Pegasus Sensor Parameters and Specification

Parameter	Specification
Operational envelope (1,2,3,4)	150-5000 m AGL, nominal
Laser wavelength	1064 nm
Horizontal accuracy (2)	1/5,500 x altitude, 1σ
Elevation accuracy (2)	< 5-20 cm, 1σ
Effective laser repetition rate	Programmable, 100-500 kHz
Position and orientation system	POS AV ™AP50 (OEM)
Scan width (FOV)	Programmable, 0-75 ˚
Scan frequency (5)	Programmable, 0-140 Hz (effective)
Sensor scan product	800 maximum
Beam divergence	0.25 mrad (1/e)
Roll compensation	Programmable, ±37˚ (FOV dependent)
Vertical target separation distance	<0.7 m
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)
Image capture	5 MP interline camera (standard); 60 MP full frame (optional)

Full waveform capture	12-bit Optech IWD-2 Intelligent Waveform Digitizer
Data storage	Removable solid state disk SSD (SATA II)
Power requirements	28 V, 800 W, 30 A
Dimensions and weight	Sensor: 630 x 540 x 450 mm; 65 kg;
	Control rack: 650 x 590 x 490 mm; 46 kg
Operating Temperature	-10°C to +35°C
Relative humidity	0-95% non-condensing

1 Target reflectivity ≥20%

2 Dependent on selected operational parameters using nominal FOV of up to 40° in standard atmospheric conditions with 24-km visibility

3 Angle of incidence ≤20°

4 Target size ≥ laser footprint5 Dependent on system configuration

Annex 2. NAMRIA Certificates of Reference Points Used

1. QZN-46

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

May 17, 2016

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: **QUEZON**
Station Name: **QZN-46**
Order: **2nd**

Island: **LUZON**	Barangay: **PAGDADAMAYAN**	
Municipality: **SAN NARCISO**	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **13° 34' 31.49905"**	Longitude: **122° 34' 19.23417"**	Ellipsoidal Hgt: **6.55200 m.**
	WGS84 Coordinates	
Latitude: **13° 34' 26.45178"**	Longitude: **122° 34' 24.20658"**	Ellipsoidal Hgt: **56.79200 m.**
	PTM / PRS92 Coordinates	
Northing: **1501243.535 m.**	Easting: **453680.181 m.**	Zone: **4**
	UTM / PRS92 Coordinates	
Northing: **1,500,718.07**	Easting: **453,696.39**	Zone: **51**

Location Description

QZN-46
From San Narciso Municipal Hall, travel along D. Nieva St. going to Abuyon Natl. Rd., then turn right to the natl. road until reaching the pier, 293 Km. Post, about 1 km. from the town church. Station is located along the ESE side of the national road, about 5.1 m. from the centerline of the road. It is situated between the 3rd and 4th concrete support of the railing (start counting from the km. post), about 0.64 m. from the railing and 11.56 m. S from the said km. post. It is also approx. 90 m. NE from a very beautiful house. Mark is the head of a 4 in. copper nail centered on a 30 cm. x 30 cm. concrete monument protruding 20 cm. above ground surface, with inscriptions "QZN-46 2006 NAMRIA".

Requesting Party: **UP-DREAM**
Purpose: **Reference**
OR Number: **8090370 I**
T.N.: **2016-1116**

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

9905172016100028

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

CIP/4701/12/09/814

Figure A-2.1 QZN-46

2. QZN-47

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

May 06, 2016

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: **QUEZON**
Station Name: **QZN-47**
Order: **2nd**

Island: **LUZON**
Municipality: **MULANAY**
Barangay: **DOS**
MSL Elevation:

PRS92 Coordinates

Latitude: **13° 31' 34.57412"**	Longitude: **122° 24' 18.47045"**	Ellipsoidal Hgt: **5.99800 m.**

WGS84 Coordinates

Latitude: **13° 31' 29.52488"**	Longitude: **122° 24' 23.44821"**	Ellipsoidal Hgt: **55.96400 m.**

PTM / PRS92 Coordinates

Northing: **1495844.441 m.**	Easting: **435605.783 m.**	Zone: **4**

UTM / PRS92 Coordinates

Northing: **1,495,320.87**	Easting: **435,628.32**	Zone: **51**

Location Description

QZN-47
Is located on the center of Mulanay Elem. School oval. It is directly at the back of the Principal's Office with a distance of about 40 m. The Mulanay Municipal Hall is located 300 m. E of the station. Mark is the head of a 4 in. copper nail centered on a 30 cm. x 30 cm. concrete monument flushed and leveled on the ground, with inscriptions "QZN-47 2006 NAMRIA".

Requesting Party: **U.P DREAM**
Purpose: **Reference**
OR Number: **8090312 I**
T.N.: **2016-1057**

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

9905062016100032

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
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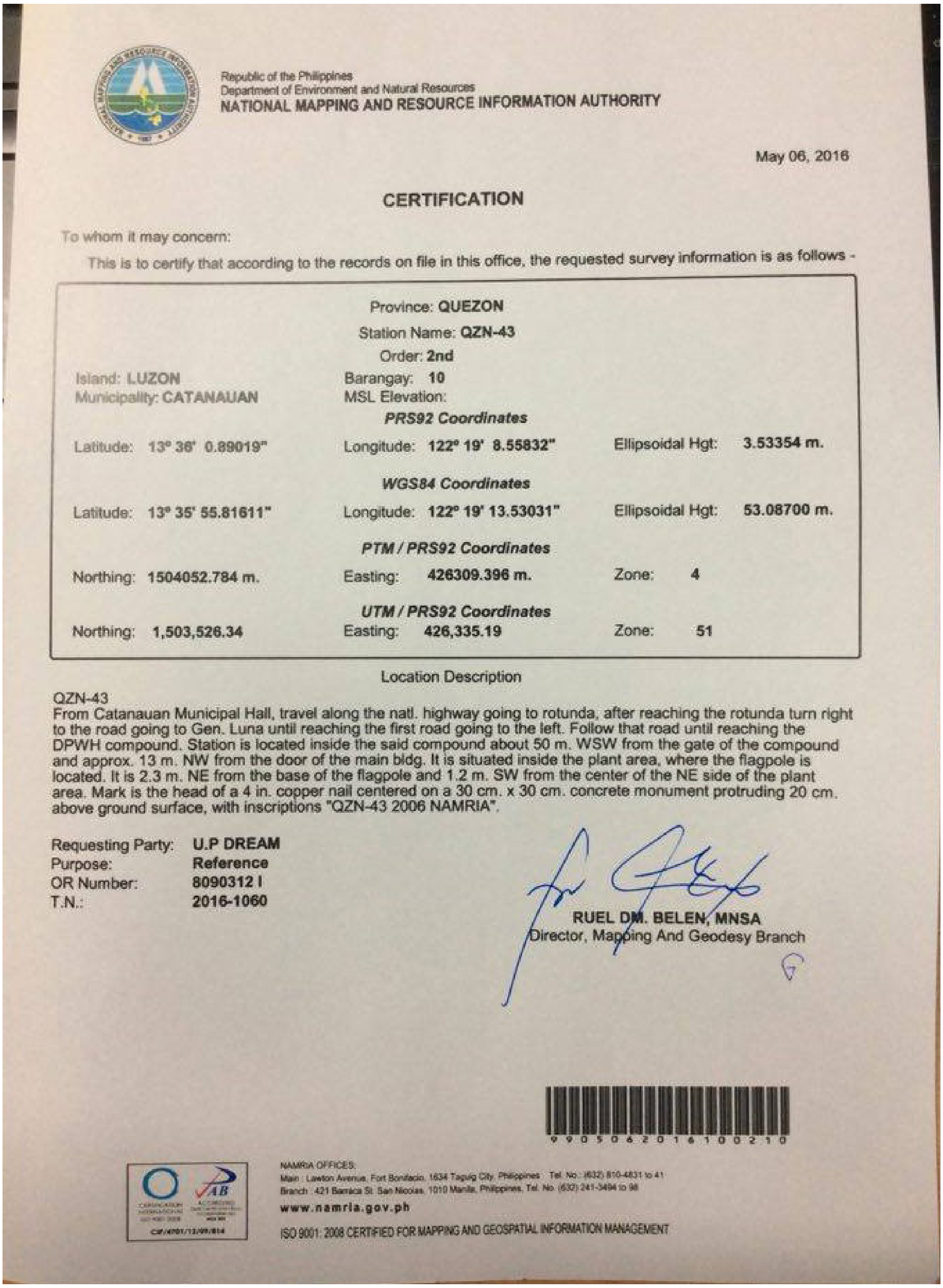
Figure A-2.2 QZN-47

3. QZN-43



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

May 06, 2016

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: QUEZON
Station Name: QZN-43
Order: 2nd

Island: LUZON	Barangay: 10		
Municipality: CATANAUAN	MSL Elevation:		
	PRS92 Coordinates		
Latitude: 13° 36' 0.89019"	Longitude: 122° 19' 8.55832"	Ellipsoidal Hgt:	3.53354 m.
	WGS84 Coordinates		
Latitude: 13° 35' 55.81611"	Longitude: 122° 19' 13.53031"	Ellipsoidal Hgt:	53.08700 m.
	PTM / PRS92 Coordinates		
Northing: 1504052.784 m.	Easting: 426309.396 m.	Zone:	4
	UTM / PRS92 Coordinates		
Northing: 1,503,526.34	Easting: 426,335.19	Zone:	51

Location Description

QZN-43
From Catanauan Municipal Hall, travel along the natl. highway going to rotunda, after reaching the rotunda turn right to the road going to Gen. Luna until reaching the first road going to the left. Follow that road until reaching the DPWH compound. Station is located inside the said compound about 50 m. WSW from the gate of the compound and approx. 13 m. NW from the door of the main bldg. It is situated inside the plant area, where the flagpole is located. It is 2.3 m. NE from the base of the flagpole and 1.2 m. SW from the center of the NE side of the plant area. Mark is the head of a 4 in. copper nail centered on a 30 cm. x 30 cm. concrete monument protruding 20 cm. above ground surface, with inscriptions "QZN-43 2006 NAMRIA".

Requesting Party: U.P DREAM
Purpose: Reference
OR Number: 8090312 I
T.N.: 2016-1060

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

9 9 0 5 0 6 2 0 1 6 1 0 0 2 1 0

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
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Figure A-2.3 QZN-43

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

1. UP-VIG

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
QZN-47 --- QZN-40 (B31)	QZN-47	QZN-40	Fixed	0.003	0.011	306°22'36"	31263.486	-2.177
QZN-47 --- QZN-43 (B27)	QZN-43	QZN-47	Fixed	0.003	0.013	131°16'56"	12401.416	2.822
QZN-47 --- UP-VIG (B23)	QZN-47	UP-VIG	Fixed	0.003	0.012	103°58'19"	23335.323	2.557
QZN-47 --- UP-KAN (B36)	QZN-47	UP-KAN	Fixed	0.005	0.019	146°21'08"	28388.037	21.906
QZN-40 --- QZ-415 (B14)	QZN-40	QZ-415	Fixed	0.003	0.023	14°21'16"	22613.475	5.492
UP-CAB --- QZ-415 (B15)	UP-CAB	QZ-415	Fixed	0.004	0.025	234°09'16"	19401.067	5.290
QZN-40 --- UP-KAN (B33)	QZN-40	UP-KAN	Fixed	0.011	0.027	135°49'24"	58749.581	24.083
QZN-43 --- QZ-415 (B20)	QZN-43	QZ-415	Fixed	0.006	0.033	342°23'19"	33841.349	6.326
QZN-43 --- UP-KAN (B34)	QZN-43	UP-KAN	Fixed	0.005	0.018	141°46'15"	40492.330	24.748
UP-TAL --- UP-KAN (B35)	UP-TAL	UP-KAN	Fixed	0.005	0.018	312°01'33"	16293.271	19.903
UP-VIG --- UP-TAL (B25)	UP-VIG	UP-TAL	Fixed	0.003	0.014	169°50'51"	29356.882	-0.547
UP-VIG --- QZN-43 (B28)	UP-VIG	QZN-43	Fixed	0.003	0.014	293°25'54"	34821.073	-5.389
UP-VIG --- UP-KAN (B37)	UP-VIG	UP-KAN	Fixed	0.005	0.021	201°04'03"	19280.526	19.353
QZN-41 --- UP-CAB (B18)	UP-CAB	QZN-41	Fixed	0.004	0.024	247°44'12"	10141.643	-1.873
QZN-41 --- QZ-415 (B16)	QZN-41	QZ-415	Fixed	0.003	0.022	220°07'13"	9835.756	7.245
QZN-40 --- QZN-43 (B29)	QZN-43	QZN-40	Fixed	0.003	0.014	303°07'59"	18937.828	0.672
UP-CAB --- QZN-43 (B22)	QZN-43	UP-CAB	Fixed	0.004	0.019	7°10'02"	43963.480	1.070

1

Acceptance Summary

Processed	Passed	Flag	Fail
17	17	0	0

Figure A-2.1 Baseline Processing Report - A

Vector Components (Mark to Mark)

From:	UP-VIG				
Grid		Local		Global	
Easting	458401.422 m	Latitude	N13°28'25.87599"	Latitude	N13°28'25.87599"
Northing	1489570.975 m	Longitude	E122°36'56.36154"	Longitude	E122°36'56.36154"
Elevation	5.915 m	Height	56.297 m	Height	56.297 m

To:	UP-TAL				
Grid		Local		Global	
Easting	463529.419 m	Latitude	N13°12'45.54766"	Latitude	N13°12'45.54766"
Northing	1460676.800 m	Longitude	E122°39'48.22813"	Longitude	E122°39'48.22813"
Elevation	4.834 m	Height	55.749 m	Height	55.749 m

Vector					
ΔEasting	5127.997 m	NS Fwd Azimuth	169°50'51"	ΔX	-7951.962 m
ΔNorthing	-28894.175 m	Ellipsoid Dist.	29356.882 m	ΔY	2826.041 m
ΔElevation	-1.081 m	ΔHeight	-0.547 m	ΔZ	-28117.966 m

Standard Errors

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

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000147120		
Y	-0.0000202520	0.0000324907	
Z	-0.0000059864	0.0000096550	0.0000038376

Figure A-2.2 Baseline Processing Report - B

Annex 4. The LiDAR Survey Team Composition

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. LOUIE P. BALICANTA	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUNA	UP TCAGP
		ENGR. LOVELYN ASUNCION	UP TCAGP
FIELD TEAM			
LiDAR Operation	Senior Science Research Specialist (SSRS)	JASMINE ALVIAR	UP-TCAGP
	Research Associate (RA)	KRISTINE JOY ANDAYA	UP-TCAGP
		JERIEL PAUL ALAMBAN	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	JASMIN DOMINGO	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. ERWIN DELOS SANTOS	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. CESAR ALFONSO III	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. KHALIL ANTHONY CHI	AAC

Annex 5. Data Transfer Sheet for Vigo Floodplain Flights

DATA TRANSFER SHEET
09/06/2016 ~~NAGA B~~ Bagasbas

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	
5/6/2016	23324P	1BLK21F127A	PEGASUS	2.55	62.1	10.5	240	NA	NA	26.5	NA	55.5	1KB	1KB	53/70/63/5	NA	Z:\DAC\RAWDATA
5/7/2016	23326P	1BLK21E128A	PEGASUS	3.13	43.7	13.8	283	NA	NA	31	NA	81.2	1KB	1KB	74/41/185/	NA	Z:\DAC\RAWDATA
5/10/2016	23334P	1BLK21D131A	PEGASUS	3.57	48.9	13.1	301	NA	NA	36.2	NA	33	1KB	1KB	53/48/41/36/33/51/64/39/51	NA	Z:\DAC\RAWDATA
5/12/2016	23342P	1BLK21G133A	PEGASUS	3.42	38.4	15.5	290	NA	NA	35	NA	180	1KB	1KB	258	NA	Z:\DAC\RAWDATA
5/13/2016	23346P	1BLK21GS134A	PEGASUS	2.43	54.4	13	270	NA	NA	26.7	NA	134	1KB	1KB	43/176	NA	Z:\DAC\RAWDATA
5/15/2016	23354P	1BLK21EF136A	PEGASUS	1.99	93	13.1	277	NA	NA	24.2	NA	121	1KB	1KB	176	NA	Z:\DAC\RAWDATA
5/16/2016	23358P	1BLK21H137A	PEGASUS	3.21	40.1	11.7	214	7.27	NA	31.6	NA	121	1KB	1KB N/A	301	NA	Z:\DAC\RAWDATA
5/17/2016	23362P	1BLK21S138A	PEGASUS	628	55.3	7.29	178	22.4	NA	9.43	NA	98.9	1KB	1KB	228	NA	Z:\DAC\RAWDATA

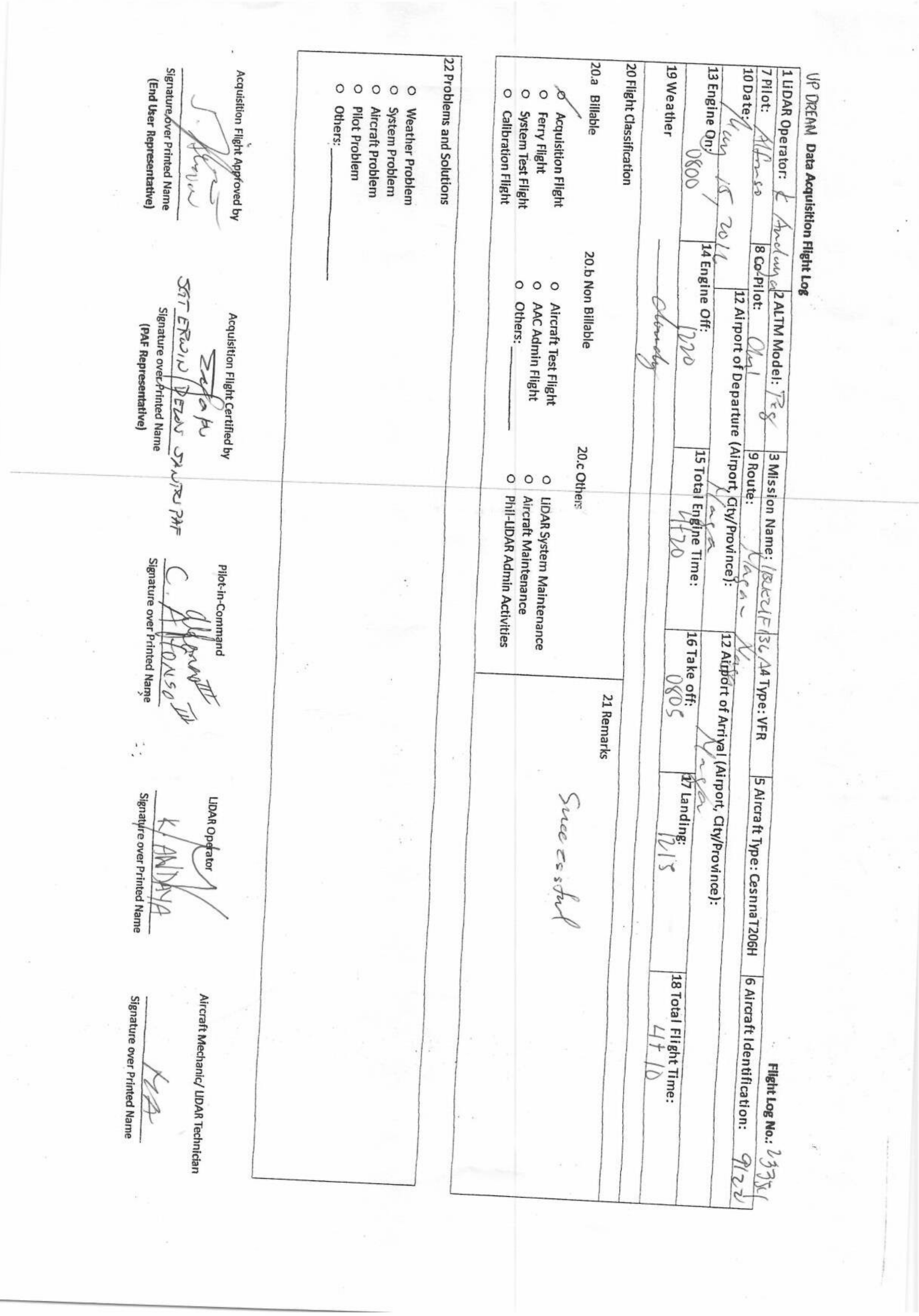
Name DARRYL AUSTRIA
Position R.A.
Signature

Name AC Bongat
Position SSRS
Signature

Figure A-5.1 Data Transfer Sheet for Vigo Floodplain - A

Annex 6. Flight Logs

1. Flight Log for 23324P Mission



UP DREAM Data Acquisition Flight Log

Flight Log No.: 2332[illegible]

1 LiDAR Operator: K Andaya	2 ALTM Model: Peg	3 Mission Name: 1BLK21F136A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9122
7 Pilot: Alfonso	8 Co-Pilot: Obal	9 Route: Naga - Naga			
10 Date: May 15, 2016	12 Airport of Departure (Airport, City/Province): Naga		12 Airport of Arrival (Airport, City/Province): Naga		
13 Engine On: 0800	14 Engine Off: 1220	15 Total Engine Time: 4+20	16 Take off: 0805	17 Landing: 1215	18 Total Flight Time: 4+10
19 Weather: cloudy					

20 Flight Classification

20.a Billable
- ✓ Acquisition Flight
- o Ferry Flight
- o System Test Flight
- o Calibration Flight

20.b Non Billable
- o Aircraft Test Flight
- o AAC Admin Flight
- o Others: ___

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

21 Remarks

Successful

22 Problems and Solutions
- o Weather Problem
- o System Problem
- o Aircraft Problem
- o Pilot Problem
- o Others: ___

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

Acquisition Flight Certified by: SGT ERWIN DELOS SANTOS PAF, Signature over Printed Name (PAF Representative)

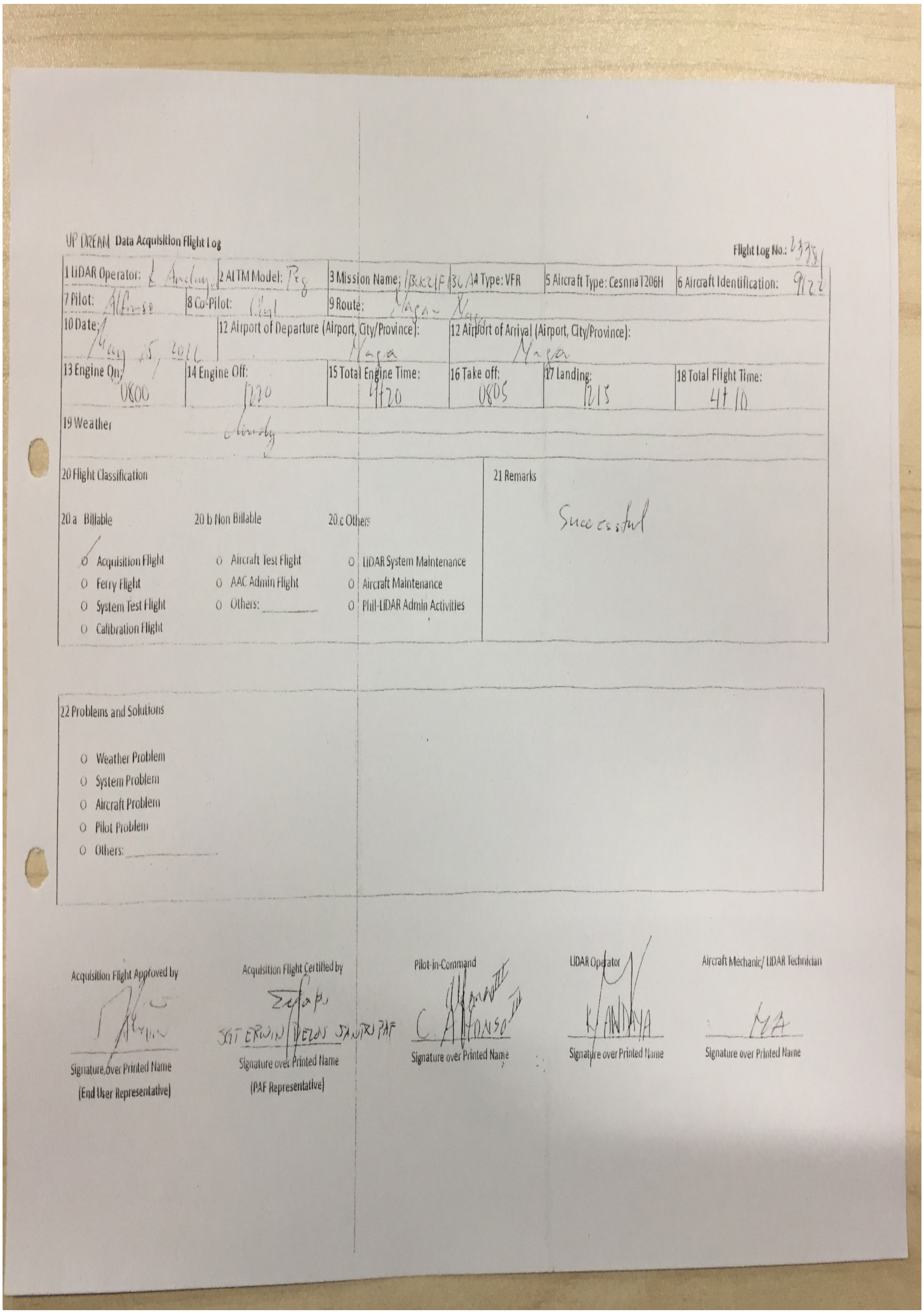
Pilot-in-Command: C. ALFONSO III, Signature over Printed Name

LIDAR Operator: K. ANDAYA, Signature over Printed Name

Aircraft Mechanic/ LIDAR Technician: Signature over Printed Name

Figure A-6.1 Flight log for 23324P Mission

2. Flight Log for 23354P Mission



UP DREAM Data Acquisition Flight Log

Flight Log No.: 23354

1 LiDAR Operator: K Andaya	2 ALTM Model: Peg	3 Mission Name: 1BLK21F	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9122
7 Pilot: Alfonso	8 Co-Pilot: Chal	9 Route: Naga – Naga			
10 Date: May 15, 2016	12 Airport of Departure (Airport, City/Province): Naga		12 Airport of Arrival (Airport, City/Province): Naga		
13 Engine On: 0800	14 Engine Off: 1220	15 Total Engine Time: 4+20	16 Take off: 0805	17 Landing: 1215	18 Total Flight Time: 4+10
19 Weather: Cloudy					

20 Flight Classification

20 a Billable
- ✓ Acquisition Flight
- o Ferry Flight
- o System Test Flight
- o Calibration Flight

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

20 c Others
- o LiDAR System Maintenance
- o Aircraft Maintenance
- o Phil-LiDAR Admin Activities

21 Remarks

Successful

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

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

Acquisition Flight Certified by: SGT ERWIN DELOS SANTOS PAF — Signature over Printed Name (PAF Representative)

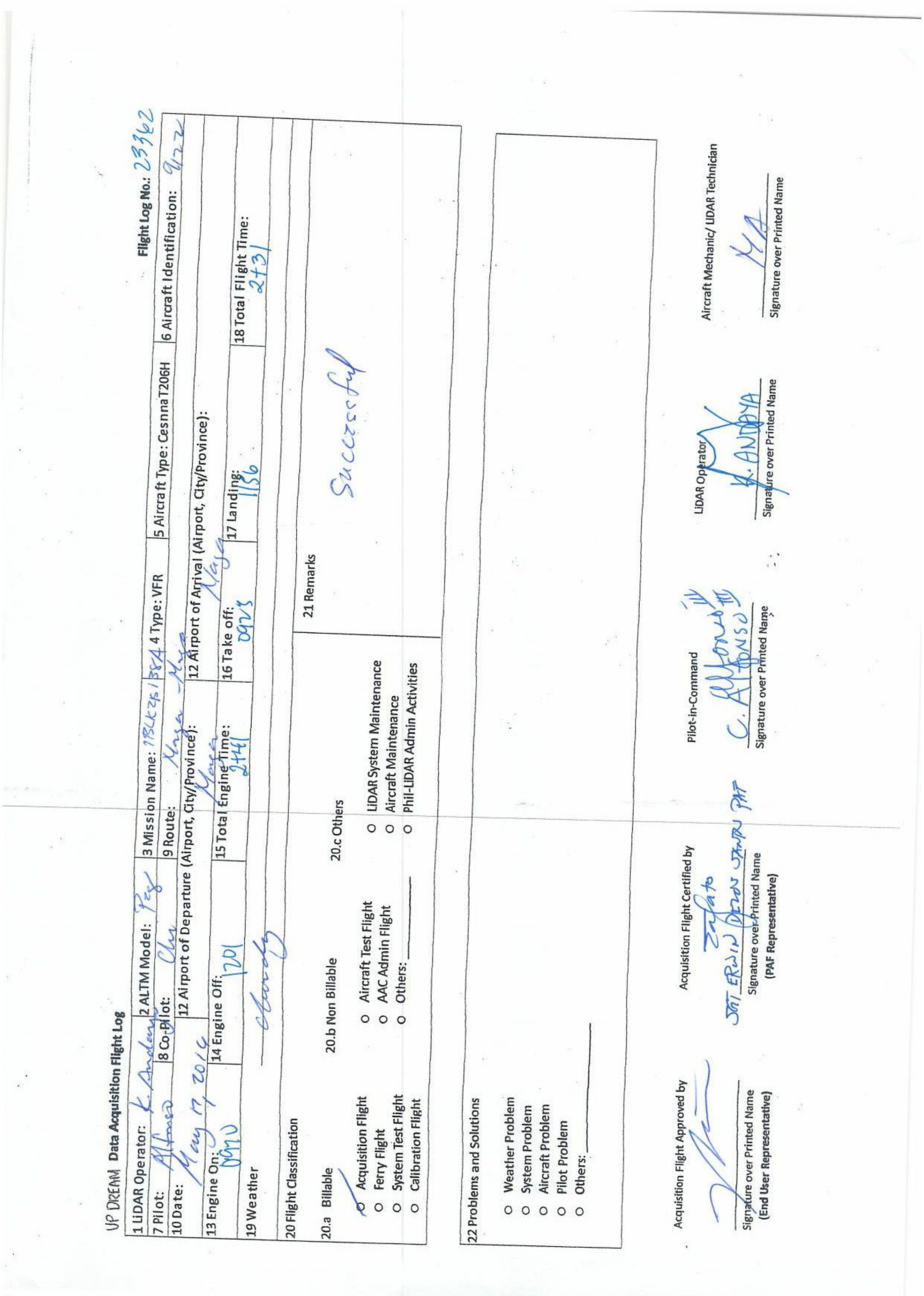
Pilot-in-Command: C. ALFONSO III — Signature over Printed Name

LiDAR Operator: K ANDAYA — Signature over Printed Name

Aircraft Mechanic/ LiDAR Technician: MA — Signature over Printed Name

Figure A-6.2 Flight log for 23354P Mission

3. Flight Log for 23362P Mission


UP DREAM Data Acquisition Flight Log

Flight Log No.: 23362

1 LiDAR Operator: K. Andaya	2 ALTM Model: Peg	3 Mission Name: 1BLK28I138A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9122
7 Pilot: Alfonso	8 Co-Pilot: Chu	9 Route: Naga			
10 Date: May 17, 2016	12 Airport of Departure (Airport, City/Province): Naga		12 Airport of Arrival (Airport, City/Province): Naga		
13 Engine On: 0910	14 Engine Off: 1201	15 Total Engine Time: 2+41	16 Take off: 0915	17 Landing: 1156	18 Total Flight Time: 2+31
19 Weather: cloudy					

20 Flight Classification

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

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

20.c Others
- LiDAR System Maintenance
- Aircraft Maintenance
- Phil-LiDAR Admin Activities

21 Remarks

Successful

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

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

Acquisition Flight Certified by
SSGT ERWIN DELOS SANTOS PAF
Signature over Printed Name
(PAF Representative)

Pilot-in-Command
C. ALFONSO III
Signature over Printed Name

LIDAR Operator
K. ANDAYA
Signature over Printed Name

Aircraft Mechanic/ LIDAR Technician
Signature over Printed Name

Figure A-6.3 Flight log for 23362P Mission

Annex 7. Flight Status Report

Table A-7.1 Flight Status Report

CAMARINES SUR & QUEZON
(May 10-17, 2016)

FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
23324P	BLK 21F VIGO FP	1BLK-21F127A	JP ALAMBAN	May 6	SURVEYED BLK 21F; FLOODPLAIN FULLY COVERED BUT NOT THE FLIGHT PLAN
23354P	BLK 21EF CATANAUAN AND VIGO FPs	1BLK21E-F136A	K ANDAYA	MAY 15	SURVEYED BLK 21EF; 217.94 SQ.KM
23362P	BLK 21F VIGO FP	1BLK-21S138A	K ANDAYA	MAY 17	SURVEYED MACALELON, CALAUAG, PANDANAN 76.67 SQ.KM

LAS BOUNDARIES PER FLIGHT

FLIGHT NO.: 23324P

AREA: Quezon (Vigo FP)

MISSION NAME: 1BLK21F127A

ALT: 1000M SCAN FREQ: 30 SCAN ANGLE: 50

SURVEYED AREA: 187 SQ KM

LAS

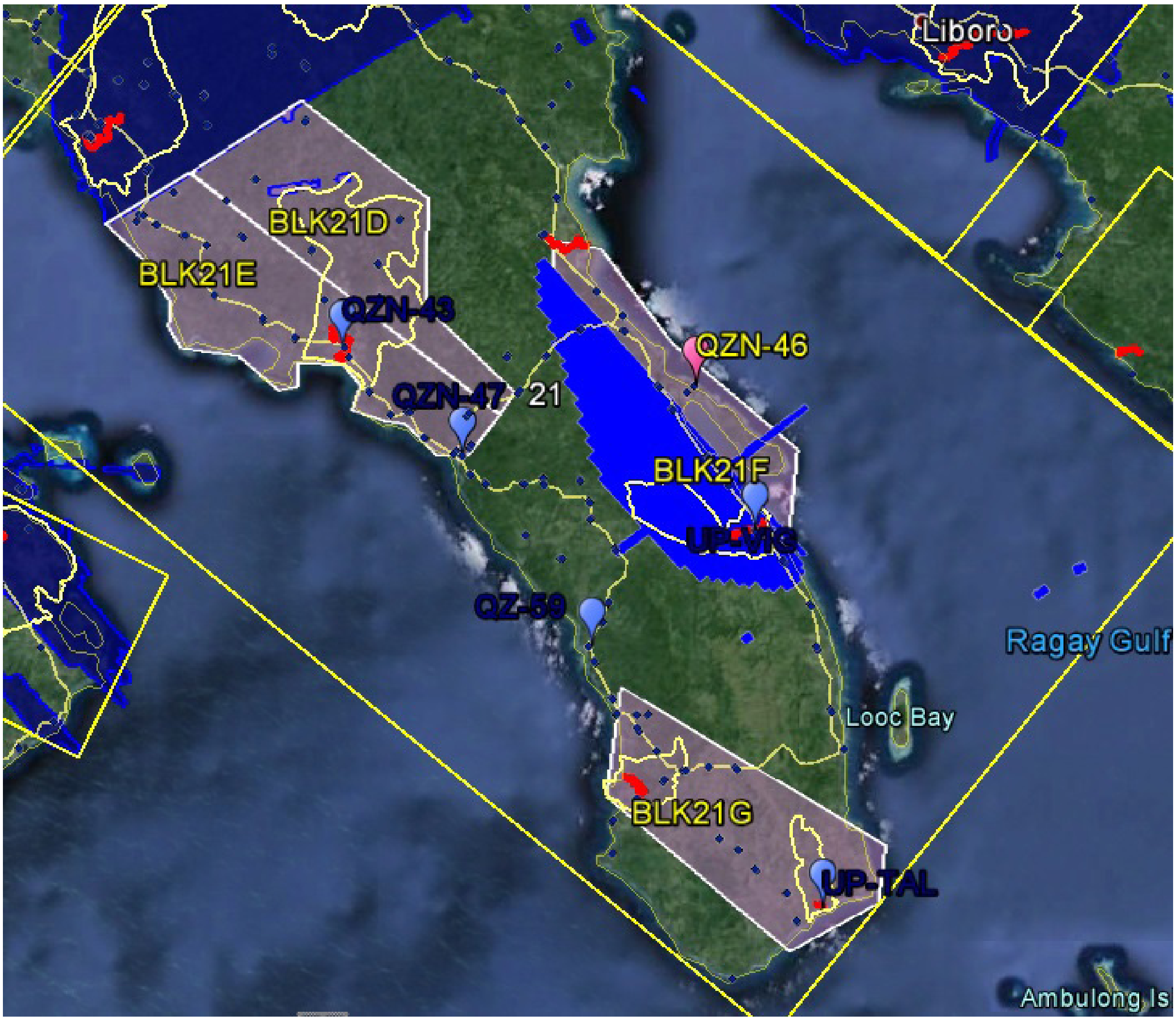


Figure A-7.1 Swath for Flight No. 23324P

FLIGHT NO.:	23354P	
AREA:	Quezon (Vigo FP)	
MISSION NAME:	1BLK21EF136A	
ALT: 1000M	SCAN FREQ: 30	SCAN ANGLE: 50
SURVEYED AREA:	217.94 SQ KM	

LAS

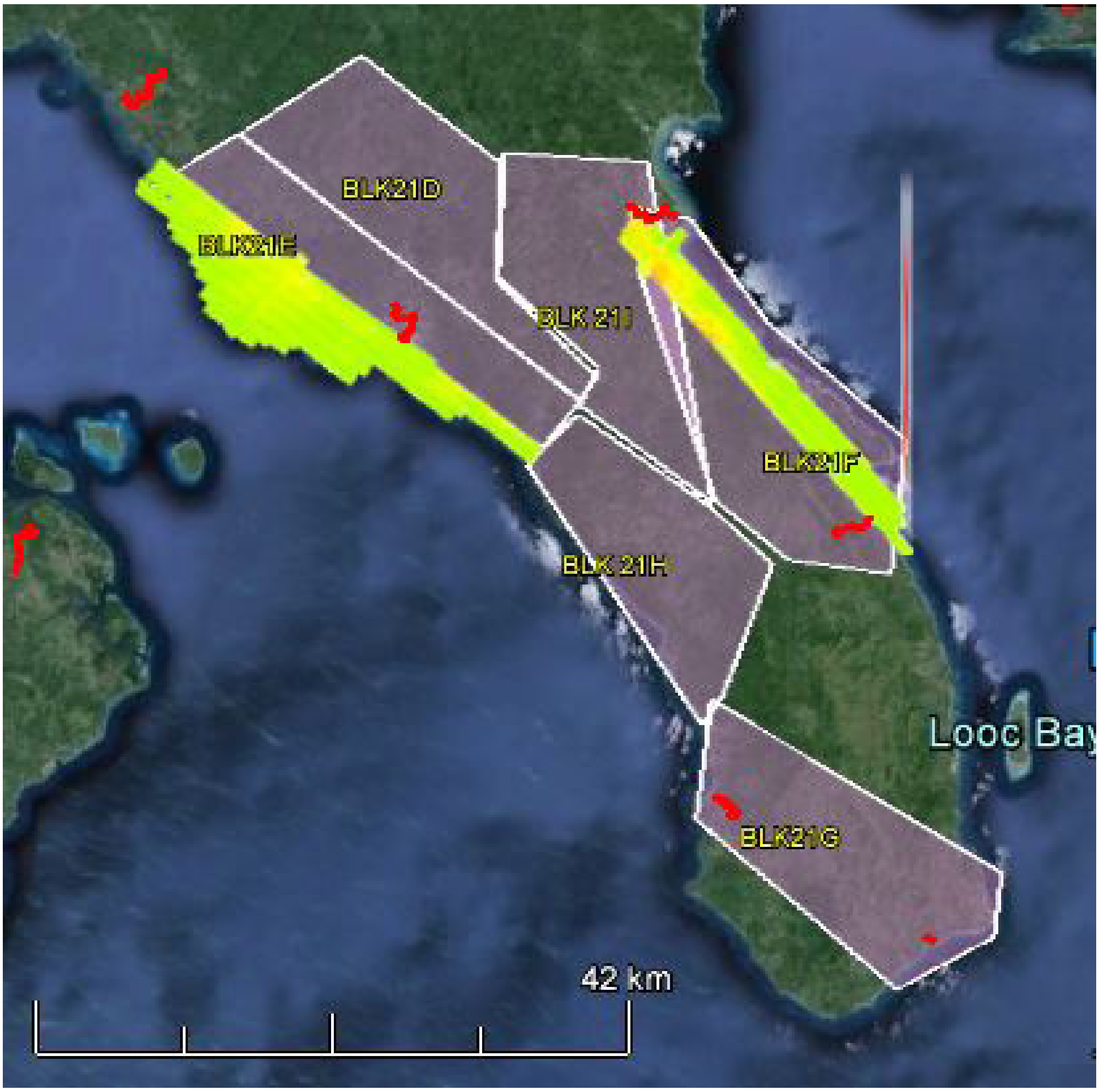


Figure A-7.2 Swath for Flight No. 23354P

FLIGHT NO.	23362P	
AREA:	Quezon (CATANAUAN FP)	
MISSION NAME:	1BLK21E128A	
ALT: 700-1000M	SCAN FREQ: 30	SCAN ANGLE: 50
SURVEYED AREA:	205 SQ KM	

LAS

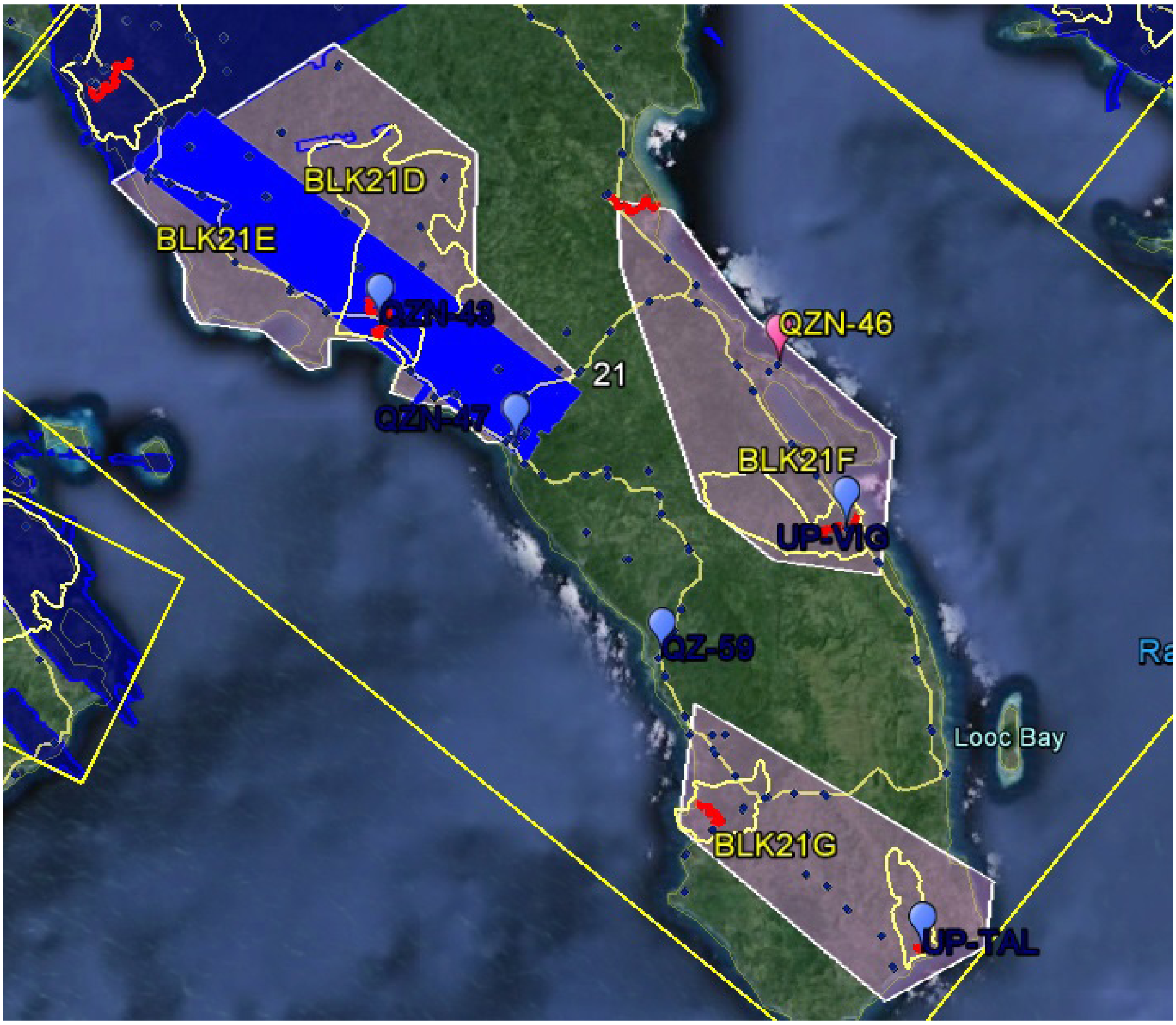


Figure A-7.3 Swath for Flight No. 23362P

Annex 8. Mission Summary Report

Table A-8.1 Mission Summary Report of Mission Bagasbas_Blk21F

Flight Area	Bagasbas
Mission Name	**Bagasbasa_Blk21F**
Inclusive Flights	23324P
Range data size	26.5 GB
POS data size	240 MB
Base data size	55.5 MB
Image	n/a
Transfer date	September 6, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	No
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.4
RMSE for East Position (<4.0 cm)	1.9
RMSE for Down Position (<8.0 cm)	4.1
Boresight correction stdev (<0.001deg)	0.000149
IMU attitude correction stdev (<0.001deg)	0.002577
GPS position stdev (<0.01m)	0.0023
Minimum % overlap (>25)	46.95%
Ave point cloud density per sq.m. (>2.0)	3.45
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	366
Maximum Height	400.57
Minimum Height	9.92
Classification (# of points)	
Ground	439161917
Low vegetation	216086525
Medium vegetation	417004507
High vegetation	925276667
Building	4896578
Orthophoto	Yes
Processed by:	Engr. Sheila-Maye Santillan, Engr. Edgardo Gubatanga, Jr., Maria Tamsyn Malabanan

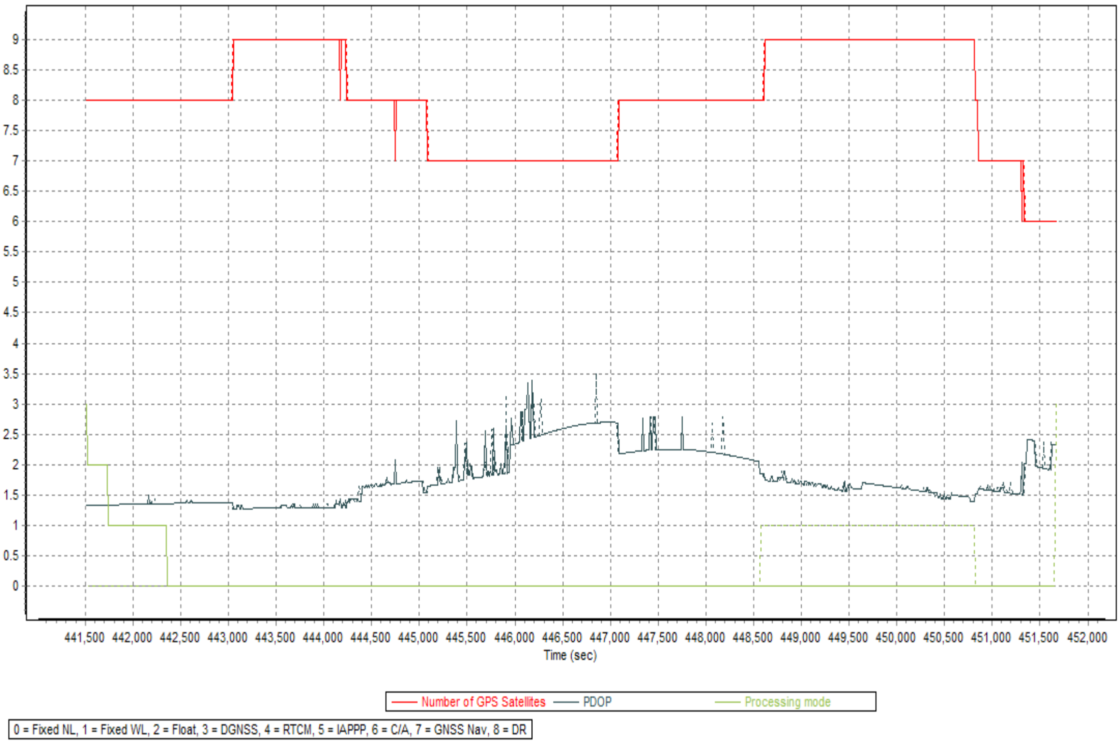


Figure A-8.1 Solution Status

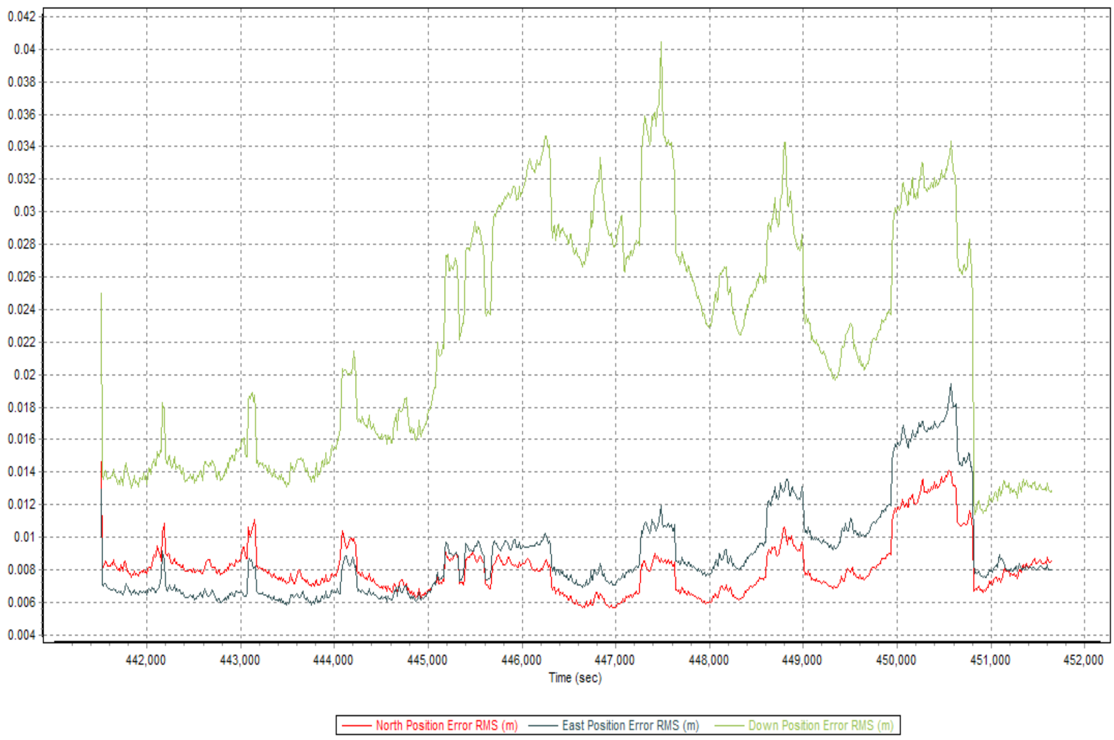


Figure A-8.2. Smoothed Performance Metrics Parameters

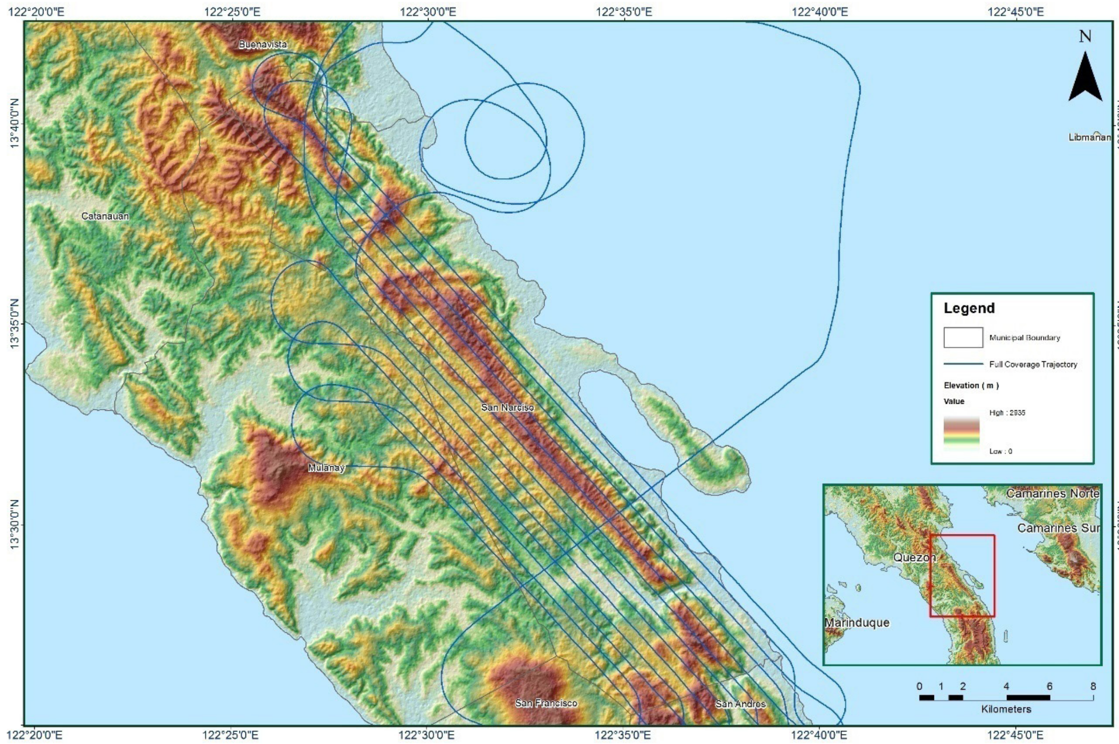


Figure A-8.3. Best Estimated Trajectory

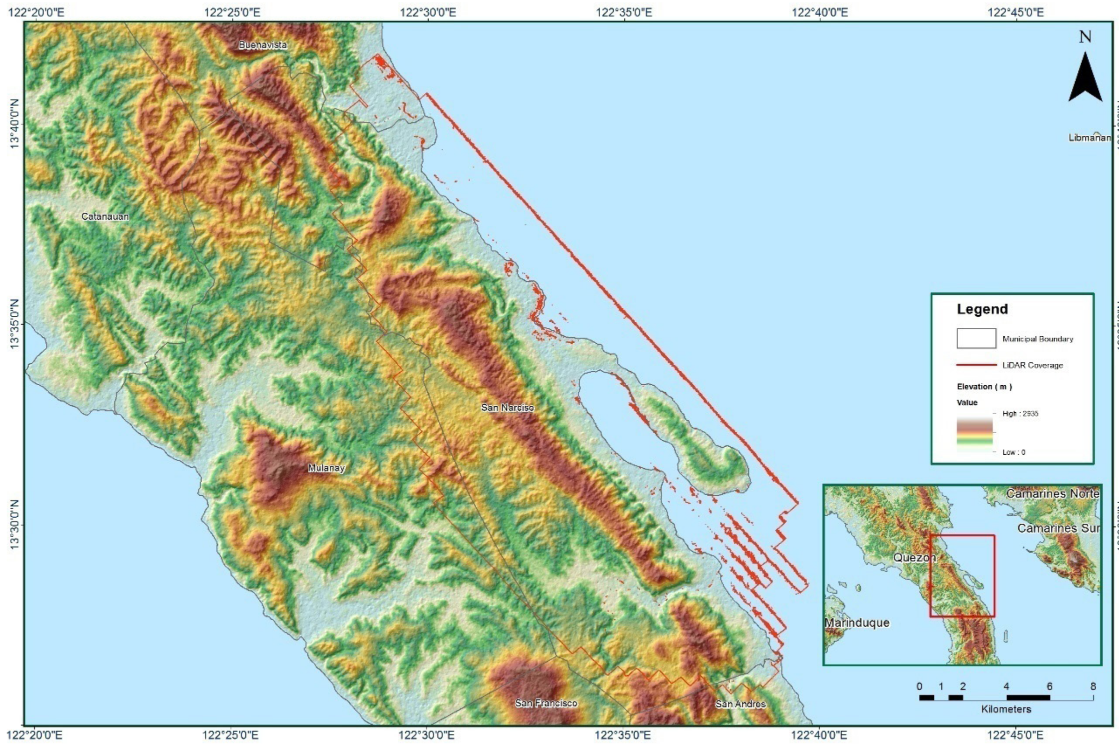


Figure A-8.4. Coverage of LiDAR data

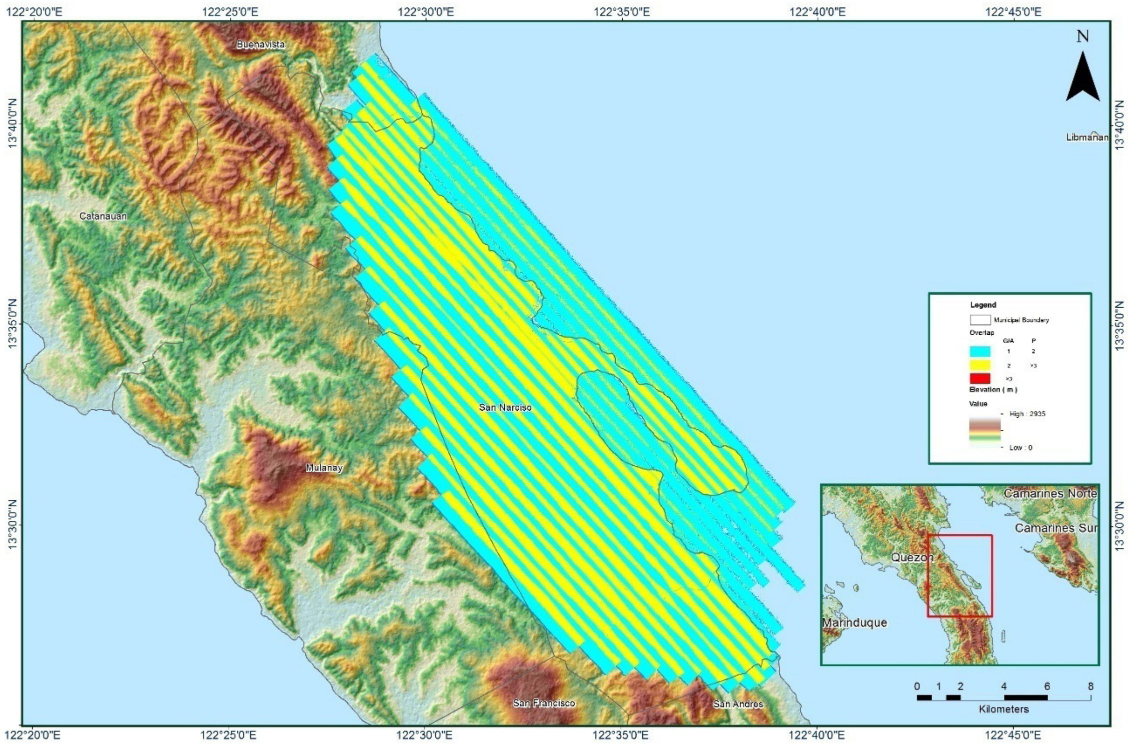


Figure A-8.5. Image of data overlap

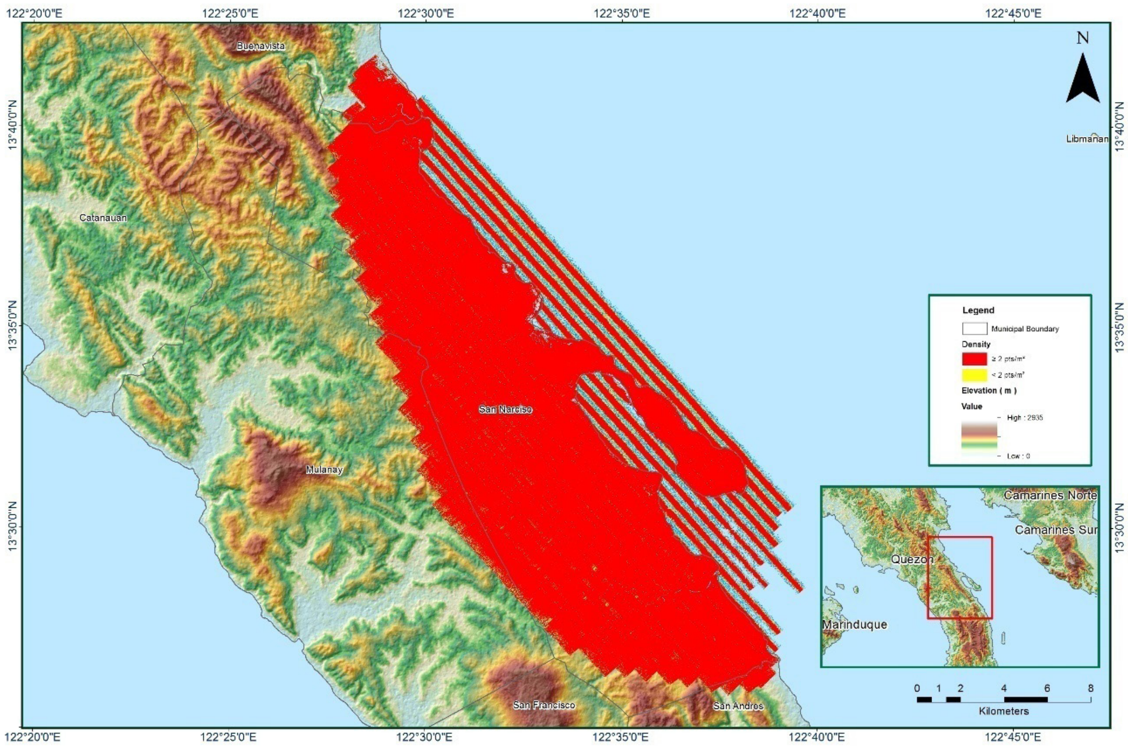


Figure A-8.6. Density map of merged LiDAR data

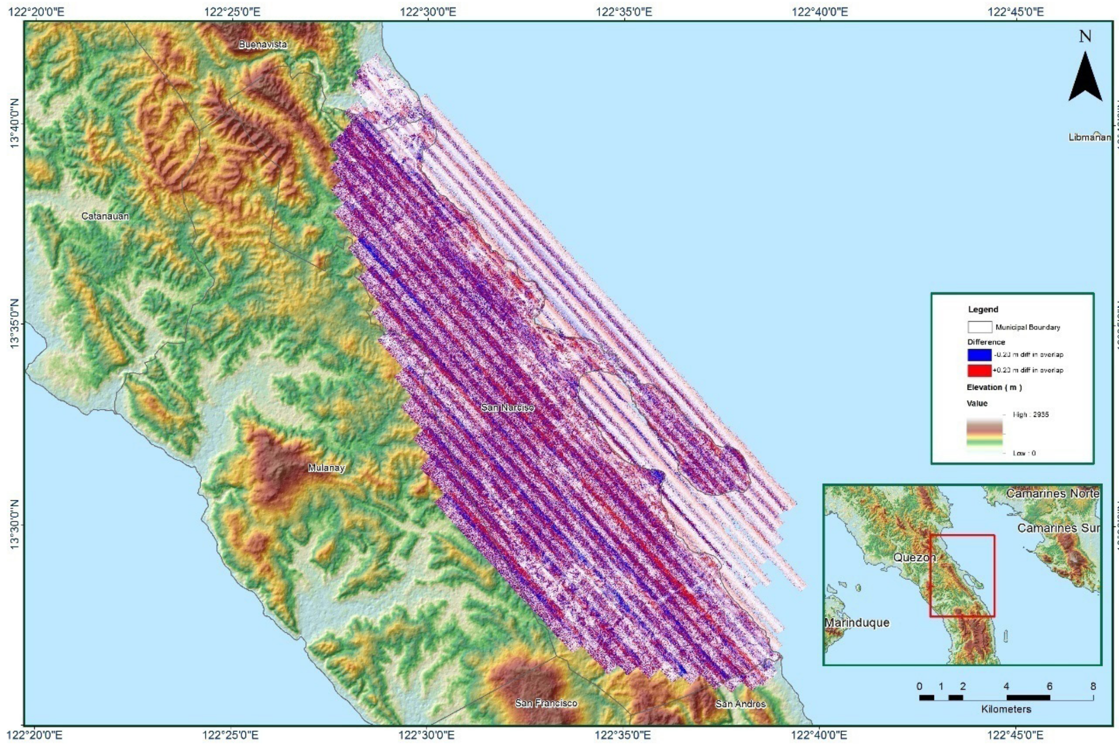


Figure A-8.7. Elevation difference between flight lines

Annex 9. Vigo Model Basin Parameters

Table A-9.1 Vigo Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concen-tration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
W480	0.33646	58.046	0	0.17718	1.8609	Discharge	0.03853	2.70E-05	Ratio to Peak	0.16505
W490	0.71586	56.319	0	2.8666	2.9407	Discharge	0.0444	1.84E-05	Ratio to Peak	0.33333
W500	0.07031	99	0	0.01667	0.10759	Discharge	0.00315	1.00E-05	Ratio to Peak	0.35052
W510	0.472	53.856	0	1.8925	1.1419	Discharge	0.03393	5.33E-05	Ratio to Peak	0.1449
W520	0.84158	65.276	0	3.6047	7.4942	Discharge	0.06394	2.01E-05	Ratio to Peak	0.5
W530	1.5253	38.628	0	2.7039	2.716	Discharge	0.0433	1.84E-05	Ratio to Peak	0.32013
W540	3.6602	38.643	0	1.6824	0.31596	Discharge	0.07424	0.00023	Ratio to Peak	0.21118
W550	1.2107	38.535	0	2.5848	1.5279	Discharge	0.02325	2.04E-05	Ratio to Peak	0.22222
W560	2.5176	58.373	0	0.15637	2.9727	Discharge	0.00024	2.01E-05	Ratio to Peak	0.14519
W570	1.731	35.184	0	0.87432	1.8072	Discharge	0.09711	1.79E-05	Ratio to Peak	0.33417
W580	0.8234	60.661	0	1.9565	0.21821	Discharge	0.02799	0.00079	Ratio to Peak	0.14776
W590	1.1213	35.342	0	1.7293	12.049	Discharge	0.058	1.00E-05	Ratio to Peak	0.33333
W600	1.0455	61.956	0	2.3326	0.18991	Discharge	0.0178	0.00051	Ratio to Peak	0.14354
W610	1.1503	35.275	0	2.2761	6.5294	Discharge	0.04067	1.00E-05	Ratio to Peak	0.32667
W620	0.70207	59.165	0	2.2706	0.32401	Discharge	0.00141	0.00022	Ratio to Peak	0.10072
W630	1.0216	36.806	0	1.9411	0.4253	Discharge	0.03385	4.45E-05	Ratio to Peak	0.15028
W640	0.60751	38.349	0	1.2185	0.42969	Discharge	0.02249	1.22E-05	Ratio to Peak	0.00279
W650	0.66641	35.244	0	1.4448	0.48139	Discharge	0.0258	2.00E-05	Ratio to Peak	0.1007
W660	0.73837	35.221	0	2.087	0.58665	Discharge	0.01367	1.00E-05	Ratio to Peak	0.10069

W670	0.73844	35.221	0	2.3506	16.068	Discharge	0.01665	1.00E-05	Ratio to Peak	0.32667
W680	0.7384	35.221	0	2.1482	10.16	Discharge	0.05734	1.00E-05	Ratio to Peak	0.49
W690	1.6869	35.221	0	0.31836	1.3989	Discharge	0.00055	6.71E-05	Ratio to Peak	0.14802
W700	0.7384	35.221	0	1.3684	19.943	Discharge	0.01578	1.22E-05	Ratio to Peak	0.33333
W710	0.73842	35.181	0	2.0267	10.46	Discharge	0.03754	1.00E-05	Ratio to Peak	0.33333
W720	1.3799	35.274	0	0.16483	11.037	Discharge	0.04518	1.00E-05	Ratio to Peak	0.14519
W730	1.3144	35.227	0	0.80975	5.742	Discharge	0.03669	1.00E-05	Ratio to Peak	0.14519
W740	1.7331	40.484	0	0.25939	8.1994	Discharge	0.00881	2.06E-05	Ratio to Peak	0.09877
W750	1.2073	35.316	0	2.7343	0.58829	Discharge	0.02605	0.0001	Ratio to Peak	0.19474
W760	2.151	40.23	0	2.768	0.55196	Discharge	0.04776	9.50E-05	Ratio to Peak	0.15164
W770	1.0745	42.727	0	1.795	0.49293	Discharge	0.01772	2.04E-05	Ratio to Peak	0.14077
W780	0.7384	35.22	0	1.6785	4.2359	Discharge	0.03021	1.22E-05	Ratio to Peak	0.32013
W790	0.70203	36.47	0	1.6714	0.40499	Discharge	0.01257	0.00021	Ratio to Peak	0.14377
W800	1.3048	37.859	0	1.9461	0.29564	Discharge	0.01618	0.00046	Ratio to Peak	0.15172
W810	0.66672	44.076	0	2.0705	0.25733	Discharge	0.01556	0.00054	Ratio to Peak	0.24171
W820	0.73471	35.244	0	0.91579	16.883	Discharge	0.02293	3.63E-05	Ratio to Peak	0.4706
W830	0.51814	56.45	0	1.3207	0.29888	Discharge	0.01013	0.00042	Ratio to Peak	0.1468
W840	0.66661	36.979	0	1.5785	0.40789	Discharge	0.02259	0.00077	Ratio to Peak	0.20915
W850	0.6508	35.244	0	1.2563	0.74718	Discharge	0.01601	2.69E-05	Ratio to Peak	0.22095
W860	0.54679	38.882	0	1.4844	0.28369	Discharge	0.03969	8.88E-05	Ratio to Peak	0.14908
W870	1.6363	35.22	0	1.3732	8.9944	Discharge	0.03453	4.11E-05	Ratio to Peak	0.21778
W880	1.6038	35.221	0	0.10678	0.83564	Discharge	0.00034	3.66E-05	Ratio to Peak	0.10065
W890	0.52693	39.143	0	1.7221	0.29281	Discharge	0.00455	0.00069	Ratio to Peak	0.21691
W900	1.5422	36.591	0	1.6063	0.4226	Discharge	0.06699	0.00014	Ratio to Peak	0.42538
W910	0.94067	35.21	0	1.2008	1.1505	Discharge	0.02448	0.00014	Ratio to Peak	0.32404
W920	0.94801	37.747	0	0.78353	0.3937	Discharge	0.03056	0.00041	Ratio to Peak	0.12518
W930	0.61012	38.76	0	0.75461	0.40749	Discharge	0.04988	0.00021	Ratio to Peak	0.1441
W940	1.7497	35.096	0	0.99925	11.714	Discharge	0.16681	0.00012	Ratio to Peak	0.33333

Annex 10. Vigo Model Reach Parameters

Table A-10.1 Vigo Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R110	Automatic Fixed Interval	1287.8	0.00625	0.034	Trapezoid	41	1
R120	Automatic Fixed Interval	303.85	0.0155	0.10314	Trapezoid	41	1
R140	Automatic Fixed Interval	4072.3	0.0061	0.1982	Trapezoid	41	1
R160	Automatic Fixed Interval	1310.5	0.00462	0.06473	Trapezoid	41	1
R170	Automatic Fixed Interval	264.14	0.01187	0.03646	Trapezoid	41	1
R190	Automatic Fixed Interval	1259.1	0.00415	0.05196	Trapezoid	41	1
R200	Automatic Fixed Interval	1433.8	0.00245	0.03417	Trapezoid	41	1
R210	Automatic Fixed Interval	707.4	0.00427	0.05767	Trapezoid	41	1
R230	Automatic Fixed Interval	2176.8	0.00116	0.0213	Trapezoid	41	1
R240	Automatic Fixed Interval	2146.7	0.00419	0.0561	Trapezoid	41	1
R250	Automatic Fixed Interval	341.42	0.00691	0.20105	Trapezoid	41	1
R270	Automatic Fixed Interval	3418.1	0.01206	0.04425	Trapezoid	41	1
R310	Automatic Fixed Interval	1556.8	0.01397	0.04409	Trapezoid	41	1
R330	Automatic Fixed Interval	1192	0.00179	0.01723	Trapezoid	41	1
R340	Automatic Fixed Interval	1434	0.02778	0.12651	Trapezoid	41	1
R350	Automatic Fixed Interval	666.98	0.01367	0.00045	Trapezoid	41	1
R390	Automatic Fixed Interval	1637.8	0.00855	0.05967	Trapezoid	41	1
R40	Automatic Fixed Interval	528.7	0.00909	0.02658	Trapezoid	41	1
R410	Automatic Fixed Interval	113.14	0.09133	0.11935	Trapezoid	41	1
R420	Automatic Fixed Interval	420.12	0.01934	0.45985	Trapezoid	41	1
R440	Automatic Fixed Interval	1877.7	0.00603	0.03812	Trapezoid	41	1
R70	Automatic Fixed Interval	2624.2	0.01033	0.04796	Trapezoid	41	1
R80	Automatic Fixed Interval	62.426	0.01824	0.76131	Trapezoid	41	1

Annex 11. Vigo Flood Validation Data

Table A-11.1 Vigo Flood Validation Data

Point No	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
1	13.47617	122.6172	1.59	0.6	-0.99	Rosing/November 2,1995	5 -Year
2	13.48005	122.5828	0.42	0.2	-0.22	Rosing/November 2,1995	5 -Year
3	13.47975	122.5835	0.03	0.2	0.17	Rosing/November 2,1995	5 -Year
4	13.47517	122.6155	1.33	0.3	-1.03	Rosing/November 2,1995	5 -Year
5	13.4755	122.6156	1.04	0.3	-0.74	Rosing/November 2,1995	5 -Year
6	13.47486	122.6155	0.92	0.3	-0.62	Rosing/November 2,1995	5 -Year
7	13.47445	122.6156	0.09	0.5	0.41	Rosing/November 2,1995	5 -Year
8	13.48617	122.6166	0.14	0.5	0.36	Rosing/November 2,1995	5 -Year
9	13.47774	122.5861	0.03	0.5	0.47	Rosing/November 2,1995	5 -Year
10	13.46795	122.6256	0.33	0.5	0.17	Rosing/November 2,1995	5 -Year
11	13.469	122.626	0.41	0.5	0.09	Rosing/November 2,1995	5 -Year
12	13.46895	122.626	0.45	0.5	0.05	Rosing/November 2,1995	5 -Year

13	13.47806	122.5858	0.03	0.5	0.47	Rosing/November 2,1995	5 -Year
14	13.47925	122.5848	0.03	0.5	0.47	Rosing/November 2,1995	5 -Year
15	13.47956	122.5846	0.06	0.5	0.44	Rosing/November 2,1995	5 -Year
16	13.47691	122.5865	0.03	0.5	0.47	Rosing/November 2,1995	5 -Year
17	13.47626	122.6181	1.2	0.6	-0.6	Rosing/November 2,1995	5 -Year
18	13.47606	122.6169	1.29	0.6	-0.69	Rosing/November 2,1995	5 -Year
19	13.47605	122.6166	1.19	0.6	-0.59	Rosing/November 2,1995	5 -Year
20	13.47608	122.6162	0.89	0.6	-0.29	Rosing/November 2,1995	5 -Year
21	13.47574	122.6143	0.14	0.6	0.46	Rosing/November 2,1995	5 -Year
22	13.47629	122.6183	1.28	0.7	-0.58	Rosing/November 2,1995	5 -Year
23	13.47633	122.6185	1.27	0.7	-0.57	Rosing/November 2,1995	5 -Year
24	13.47626	122.618	1.4	0.7	-0.7	Rosing/November 2,1995	5 -Year
25	13.47625	122.6177	1.61	0.7	-0.91	Rosing/November 2,1995	5 -Year
26	13.47627	122.6182	1.27	0.7	-0.57	Rosing/November 2,1995	5 -Year
27	13.48262	122.5729	0.03	0	-0.03	Rosing/November 2,1995	5 -Year

28	13.48481	122.568	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
29	13.48583	122.5677	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
30	13.48781	122.5669	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
31	13.48713	122.5672	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
32	13.4775	122.5681	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
33	13.47676	122.5689	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
34	13.47325	122.567	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
35	13.47309	122.5669	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
36	13.47285	122.5667	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
37	13.48128	122.5809	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
38	13.47132	122.5653	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
39	13.47014	122.5649	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
40	13.46825	122.5643	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
41	13.45284	122.5637	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
42	13.48268	122.5727	0.03	0	-0.03	Rosing/November 2,1995	5 -Year

43	13.48369	122.6141	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
44	13.48162	122.5804	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
45	13.4729	122.6158	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
46	13.46949	122.6194	0.04	0	-0.04	Rosing/November 2,1995	5 -Year
47	13.48214	122.5792	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
48	13.48253	122.5784	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
49	13.48288	122.5774	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
50	13.48252	122.577	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
51	13.4822	122.5767	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
52	13.48241	122.5737	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
53	13.48073	122.5817	0.03	0	-0.03	Rosing/November 2,1995	5 -Year
54	13.47426	122.6146	0.97	1.1	0.13	Rosing/November 2,1995	5 -Year
55	13.47443	122.6152	1.13	1.1	-0.03	Rosing/November 2,1995	5 -Year
56	13.47476	122.6156	1.18	1.1	-0.08	Rosing/November 2,1995	5 -Year
57	13.4764	122.6187	1.08	1.1	0.02	Rosing/November 2,1995	5 -Year

58	13.47567	122.6138	0.14	1.1	0.96	Rosing/November 2,1995	5 -Year
59	13.47424	122.6141	1.08	1.5	0.42	Rosing/November 2,1995	5 -Year
60	13.4832	122.5684	0.04	1.5	1.46	Rosing/November 2,1995	5 -Year
61	13.4829	122.5686	0.03	1.5	1.47	Rosing/November 2,1995	5 -Year
62	13.48314	122.5709	1.29	1.5	0.21	Rosing/November 2,1995	5 -Year
63	13.48647	122.6169	0.11	1.5	1.39	Rosing/November 2,1995	5 -Year
64	13.47414	122.6158	0.9	1.5	0.6	Rosing/November 2,1995	5 -Year
65	13.47457	122.6154	1.07	1.5	0.43	Rosing/November 2,1995	5 -Year
66	13.47481	122.6153	1.54	1.5	-0.04	Rosing/November 2,1995	5 -Year
67	13.47426	122.6138	1.18	1.5	0.32	Rosing/November 2,1995	5 -Year
68	13.48347	122.5683	0.07	1.5	1.43	Rosing/November 2,1995	5 -Year
69	13.47717	122.5867	0.03	1	0.97	Rosing/November 2,1995	5 -Year
70	13.4775	122.5863	0.03	1	0.97	Rosing/November 2,1995	5 -Year
71	13.48391	122.5685	0.03	1	0.97	Rosing/November 2,1995	5 -Year
72	13.48405	122.5694	0.03	1	0.97	Rosing/November 2,1995	5 -Year

73	13.48386	122.5698	0.03	1	0.97	Rosing/November 2,1995	5 -Year
74	13.48359	122.5702	0.28	1	0.72	Rosing/November 2,1995	5 -Year
75	13.47708	122.5866	0.05	1	0.95	Rosing/November 2,1995	5 -Year
76	13.48698	122.6193	0.12	2	1.88	Rosing/November 2,1995	5 -Year
77	13.47394	122.6158	0.95	2	1.05	Rosing/November 2,1995	5 -Year
78	13.48361	122.5702	0.08	2	1.92	Rosing/November 2,1995	5 -Year
79	13.47388	122.6159	1.34	3	1.66	Rosing/November 2,1995	5 -Year
80	13.46952	122.5997	5.73	4.5	-1.23	Rosing/November 2,1995	5 -Year
81	13.47022	122.6011	5.59	4.5	-1.09	Rosing/November 2,1995	5 -Year
82	13.47012	122.6008	5.83	4.5	-1.33	Rosing/November 2,1995	5 -Year
83	13.46995	122.6004	6.06	4.5	-1.56	Rosing/November 2,1995	5 -Year
84	13.46972	122.6	5.77	4.6	-1.17	Rosing/November 2,1995	5 -Year
85	13.46923	122.5994	4.88	4.7	-0.18	Rosing/November 2,1995	5 -Year
86	13.47069	122.5997	5.35	4.9	-0.45	Rosing/November 2,1995	5 -Year
87	13.47067	122.5995	5.35	4.9	-0.45	Rosing/November 2,1995	5 -Year

88	13.47342	122.605	3.63	4	0.37	Rosing/November 2,1995	5 -Year
89	13.46836	122.5969	4.07	4	-0.07	Rosing/November 2,1995	5 -Year
90	13.46991	122.5986	3.9	4	0.1	Rosing/November 2,1995	5 -Year
91	13.47072	122.5994	5.18	4	-1.18	Rosing/November 2,1995	5 -Year
92	13.47065	122.5993	5.18	4	-1.18	Rosing/November 2,1995	5 -Year
93	13.4706	122.5992	5.13	4	-1.13	Rosing/November 2,1995	5 -Year
94	13.47024	122.5985	4.14	4	-0.14	Rosing/November 2,1995	5 -Year
95	13.46957	122.5988	3.81	4	0.19	Rosing/November 2,1995	5 -Year
96	13.46892	122.5984	4.41	4	-0.41	Rosing/November 2,1995	5 -Year
97	13.46933	122.5958	5.37	4	-1.37	Rosing/November 2,1995	5 -Year
98	13.46934	122.5963	5.29	4	-1.29	Rosing/November 2,1995	5 -Year
99	13.47079	122.5994	4.97	4	-0.97	Rosing/November 2,1995	5 -Year
100	13.47108	122.6003	6.27	5.1	-1.17	Rosing/November 2,1995	5 -Year
101	13.47069	122.5992	4.8	5.1	0.3	Rosing/November 2,1995	5 -Year
102	13.47054	122.5991	5.06	5.1	0.04	Rosing/November 2,1995	5 -Year

103	13.47037	122.5988	4.46	5.1	0.64	Rosing/November 2,1995	5 -Year
104	13.47023	122.5985	3.66	5.1	1.44	Rosing/November 2,1995	5 -Year
105	13.47055	122.5998	5.09	5.1	0.01	Rosing/November 2,1995	5 -Year
106	13.47092	122.6001	5.84	5.1	-0.74	Rosing/November 2,1995	5 -Year
107	13.47375	122.6157	3.8	5.1	1.3	Rosing/November 2,1995	5 -Year
108	13.47082	122.5999	5.63	5.2	-0.43	Rosing/November 2,1995	5 -Year
109	13.46923	122.5987	3.94	5	1.06	Rosing/November 2,1995	5 -Year
110	13.47065	122.5997	5.29	5	-0.29	Rosing/November 2,1995	5 -Year
111	13.46907	122.5995	5.23	5	-0.23	Rosing/November 2,1995	5 -Year
112	13.469	122.5994	4.87	5	0.13	Rosing/November 2,1995	5 -Year
113	13.46902	122.5993	4.52	5	0.48	Rosing/November 2,1995	5 -Year
114	13.46884	122.5988	4.47	5	0.53	Rosing/November 2,1995	5 -Year
115	13.46872	122.5983	4.38	5	0.62	Rosing/November 2,1995	5 -Year
116	13.46863	122.5981	4.2	5	0.8	Rosing/November 2,1995	5 -Year
117	13.46835	122.5978	4.28	5	0.72	Rosing/November 2,1995	5 -Year

118	13.46838	122.5976	6	5	-1	Rosing/November 2,1995	5 -Year
119	13.4689	122.598	4.31	5	0.69	Rosing/November 2,1995	5 -Year
120	13.46909	122.5987	4.13	5	0.87	Rosing/November 2,1995	5 -Year
121	13.46862	122.597	6.95	5	-1.95	Rosing/November 2,1995	5 -Year
122	13.48006	122.5682	5	5	0	Rosing/November 2,1995	5 -Year
123	13.46896	122.5979	4.26	5	0.74	Rosing/November 2,1995	5 -Year
124	13.46892	122.5982	4.37	5	0.63	Rosing/November 2,1995	5 -Year
125	13.46874	122.5975	3.39	5	1.61	Rosing/November 2,1995	5 -Year
126	13.47423	122.6156	0.03	0.5	0.47	Milenyo/September 27,2006	5 -Year
127	13.47683	122.6196	0.82	1.5	0.68	Milenyo/September 27,2006	5 -Year
128	13.47725	122.6201	0.82	1.5	0.68	Milenyo/September 27,2006	5 -Year
129	13.47773	122.6204	0.7	1.5	0.8	Milenyo/September 27,2006	5 -Year
130	13.4782	122.6209	0.71	1.5	0.79	Milenyo/September 27,2006	5 -Year
131	13.47457	122.6171	1.96	1.5	-0.46	Milenyo/September 27,2006	5 -Year
132	13.4747	122.617	0.43	1.5	1.07	Milenyo/September 27,2006	5 -Year

133	13.47484	122.6167	0.56	1.5	0.94	Milenyo/September 27,2006	5 -Year
134	13.47496	122.6163	0.88	1.5	0.62	Milenyo/September 27,2006	5 -Year
135	13.47515	122.6161	2.02	1.5	-0.52	Milenyo/September 27,2006	5 -Year
136	13.47635	122.6186	1.31	1.5	0.19	Milenyo/September 27,2006	5 -Year
137	13.47657	122.6191	1.2	1.5	0.3	Milenyo/September 27,2006	5 -Year
138	13.4743	122.6163	1.55	1.5	-0.05	Milenyo/September 27,2006	5 -Year
139	13.47425	122.6166	1.5	1.5	0	Milenyo/September 27,2006	5 -Year
140	13.47435	122.6169	1.25	1.5	0.25	Milenyo/September 27,2006	5 -Year
141	13.4744	122.6174	1.16	1.5	0.34	Milenyo/September 27,2006	5 -Year
142	13.4746	122.6178	1.12	1.5	0.38	Milenyo/September 27,2006	5 -Year
143	13.47472	122.6182	1.98	1.5	-0.48	Milenyo/September 27,2006	5 -Year
144	13.47457	122.6172	1.44	1.5	0.06	Milenyo/September 27,2006	5 -Year
145	13.47435	122.616	0.6	1.5	0.9	Milenyo/September 27,2006	5 -Year
146	13.47621	122.6205	4.44	2.5	-1.94	Milenyo/September 27,2006	5 -Year
147	13.4764	122.6206	4.42	2.5	-1.92	Milenyo/September 27,2006	5 -Year

148	13.47792	122.6213	3.68	2.5	-1.18	Milenyo/September 27,2006	5 -Year
149	13.47816	122.6214	3.52	2.5	-1.02	Milenyo/September 27,2006	5 -Year
150	13.47841	122.6215	3.37	2.5	-0.87	Milenyo/September 27,2006	5 -Year
151	13.47865	122.6216	3.28	2.5	-0.78	Milenyo/September 27,2006	5 -Year
152	13.47575	122.6202	3.25	2.5	-0.75	Milenyo/September 27,2006	5 -Year
153	13.47384	122.6172	5.32	3.5	-1.82	Milenyo/September 27,2006	5 -Year
154	13.4771	122.621	4.16	3.5	-0.66	Milenyo/September 27,2006	5 -Year
155	13.47512	122.6197	4.58	3	-1.58	Milenyo/September 27,2006	5 -Year
156	13.47563	122.6201	4.6	3	-1.6	Milenyo/September 27,2006	5 -Year
157	13.47661	122.6208	4.39	3	-1.39	Milenyo/September 27,2006	5 -Year
158	13.47683	122.6208	4.3	3	-1.3	Milenyo/September 27,2006	5 -Year
159	13.47731	122.6211	4.05	3	-1.05	Milenyo/September 27,2006	5 -Year
160	13.4777	122.6212	3.77	3	-0.77	Milenyo/September 27,2006	5 -Year
161	13.47881	122.6216	3.21	3	-0.21	Milenyo/September 27,2006	5 -Year
162	13.47896	122.6217	3.19	3	-0.19	Milenyo/September 27,2006	5 -Year

163	13.47441	122.6191	4.86	3	-1.86	Milenyo/September 27,2006	5 -Year
164	13.4745	122.6192	4.82	3	-1.82	Milenyo/September 27,2006	5 -Year
165	13.47467	122.6194	4.76	3	-1.76	Milenyo/September 27,2006	5 -Year
166	13.47492	122.6195	4.54	3	-1.54	Milenyo/September 27,2006	5 -Year
167	13.47503	122.6196	4.53	3	-1.53	Milenyo/September 27,2006	5 -Year
168	13.47958	122.622	2.9	4	1.1	Milenyo/September 27,2006	5 -Year
169	13.47974	122.6221	2.86	4	1.14	Milenyo/September 27,2006	5 -Year
170	13.47407	122.6183	4.96	4	-0.96	Milenyo/September 27,2006	5 -Year
171	13.47414	122.6185	4.86	4	-0.86	Milenyo/September 27,2006	5 -Year
172	13.47422	122.6187	4.82	4	-0.82	Milenyo/September 27,2006	5 -Year
173	13.47432	122.6189	4.84	4	-0.84	Milenyo/September 27,2006	5 -Year
174	13.47524	122.6198	4.67	4	-0.67	Milenyo/September 27,2006	5 -Year
175	13.47752	122.6212	3.84	4	0.16	Milenyo/September 27,2006	5 -Year
176	13.47918	122.6218	3.03	4	0.97	Milenyo/September 27,2006	5 -Year
177	13.47933	122.6219	2.97	4	1.03	Milenyo/September 27,2006	5 -Year

178	13.474	122.6181	5.1	4	-1.1	Milenyo/September 27,2006	5 -Year
179	13.47549	122.62	4.57	5	0.43	Milenyo/September 27,2006	5 -Year
180	13.47537	122.6199	4.67	5	0.33	Milenyo/September 27,2006	5 -Year

RMSE: 0.847827

Annex 12. Educational Institutions Affected in Vigo Floodplain

Table A-12.1 Educational Institutions in San Narciso, Quezon affected by flooding in Vigo Floodplain

Quezon				
San Narciso				
Building	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Day Care Center	Binay	None	None	None
Busok Busukan Day Care Center	Binay	High	High	High
San Vicente Day Care Center	San Vicente	None	None	None
Vigo Central Day Care Center	Vigo Central	Low	Low	Medium
San Vicente Elem. School	San Vicente	None	None	None
Busok Busukan Elementary School	Binay	High	High	High
Vigo Central Elem. School	Vigo Central	Low	Low	Low

Annex 13. Health Institutions Affected in Vigo Floodplain

Table A-13.1 Health Institutions in San Narciso, Quezon affected by flooding in Vigo Floodplain

Quezon				
San Narciso				
Building	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Busok Busukan Health Center	San Vicente	None	None	None
Health Center	San Vicente	None	None	None