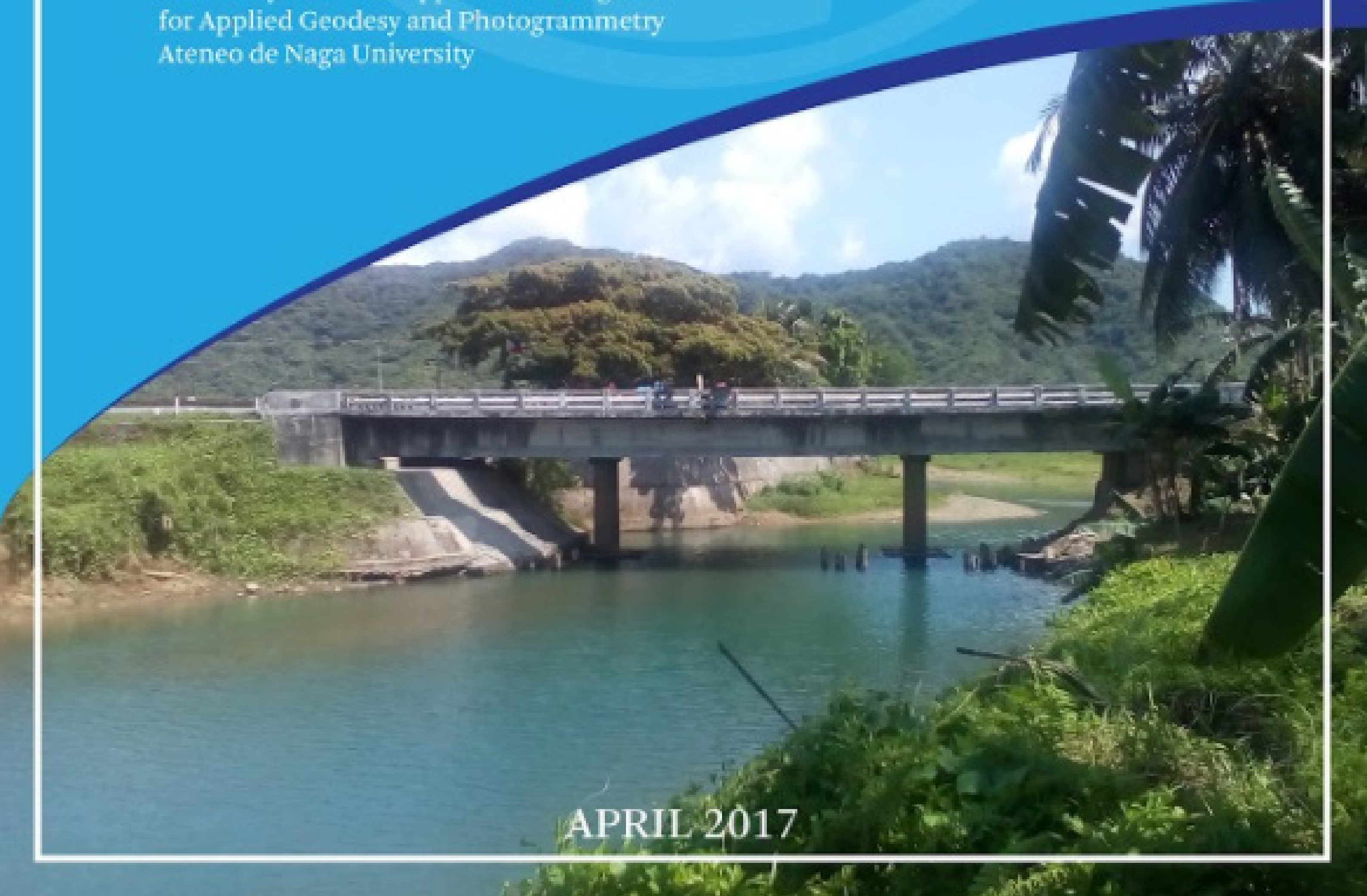
HAZARD MAPPING OF THE PHILIPPINES USING LIDAR (PHIL-LIDAR I)

LiDAR Surveys and Flood Mapping of Viga River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
Ateneo de Naga University



APRIL 2017

Published by the UP Training Center for Applied Geodesy and Photogrammetry (TCAGP)
College of Engineering
University of the Philippines – Diliman
Quezon City
1101 PHILIPPINES

This research project is supported by the Department of Science and Technology (DOST) as part of its Grants-in-Aid Program and is to be cited as:

E.C. Paringit and J.C. Plopenio (2017), LiDAR Surveys and Flood Mapping of Viga River, Quezon City: UP Training Center for Applied Geodesy and Photogrammetry-163pp

For questions/queries regarding this report, contact:

Ms. Joanaviva C. *Plopenio
Project Leader, Phil-LiDAR 1 Program
Ateneo de Naga University
Naga City, Philippines 4400
E-mail: inecar@gbox.adnu.edu.ph

Enrico C. Paringit, Dr. Eng.
Program Leader, Phil-LiDAR 1 Program
University of the Philippines Diliman
Quezon City, Philippines 1101
E-mail: ecparingit@up.edu.ph

National Library of the Philippines
ISBN: 978-971-9695-78-3

TABLE OF CONTENTS

LIST OF FIGURES v
LIST OF TABLES vii
LIST OF ACRONYMS AND ABBREVIATIONS viii
CHAPTER 1: OVERVIEW OF THE PROGRAM AND THE VIGA RIVER 1
1.1 Background of the Phil-LIDAR 1 Program 1
1.2 Overview of the Viga River Basin 2
CHAPTER 2: LIDAR ACQUISITION OF THE VIGA FLOODPLAIN 3
2.1 Flight Plans 3
2.2 Ground Base Station 4
2.3 Flight Missions 8
2.4 Survey Coverage 9
CHAPTER 3: LIDAR DATA PROCESSING OF THE VIGA FLOODPLAIN 11
3.1 Overview of LiDAR Data Pre-Processing 11
3.2 Transmittal of Acquired LiDAR Data 12
3.3 Trajectory Computation 12
3.4 LiDAR Point Cloud Computation 14
3.5 LiDAR Data Quality Checking 15
3.6 LiDAR Point Cloud Classification and Rasterization 19
3.7 LiDAR Image Processing and Orthophotograph Rectification 22
3.8 DEM Editing and Hydro-Correction 23
3.9 Mosaicking of Blocks 24
3.10 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model 26
3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model 30
3.12 Feature Extraction 31
3.12.1 Quality Checking (QC) of Digitized Features' Boundary 31
3.12.2 Height Extraction 31
3.12.3 Feature Attribution 32
3.12.4 Final Quality Checking of Extracted Features 33
CHAPTER 4: LIDAR VALIDATION SURVEY AND MEASUREMENTS OF THE VIGA RIVER BASIN 34
4.1 Summary of Activities 34
4.2 Control Survey 36
4.3 Baseline Processing 40
4.4 Network Adjustment 41
4.5 Cross Section and Bridge As-Built survey and Water Level Marking 44
4.6 Validation Points Acquisition Survey 48
4.7 River Bathymetric Survey 50
CHAPTER 5: FLOOD MODELING AND MAPPING 54
5.1 Data used for Hydrologic Modeling 54
5.1.1 Hydrometry and Rating Curves 54
5.1.2 Precipitation 54
5.1.3 Rating Curves and River Outflow 55
5.2 RIDF Station 56
5.3 HMS Model 58
5.4 Cross-section Data 63
5.5 Flo 2D Model 63
5.6 Results of HMS Calibration 65
5.7 Calculated outflow hydrographs and discharge values for different rainfall return periods 67
5.7.1 Hydrograph using the Rainfall Runoff Model 67
5.8 River Analysis Model Simulation 68
5.9 Flood Depth and Flood Hazard 68
5.10 Inventory of Areas Exposed to Flooding 75
5.11 Flood Validation 89
REFERENCES 90
ANNEXES 91
Annex 1. Optech Technical Specification of the Pegasus Sensor 91
Annex 2. NAMRIA Certificates of Reference Points Used 93
Annex 3. Baseline Processing Report of Reference Points Used 96

Annex 4.The LiDAR Survey Team Composition 97
Annex 5. Data Transfer Sheets for Viga Floodplain 98
Annex 6. Flight logs 99
Annex 7. Flight Status Report 102
Annex 8. Mission Summary Reports 106
Annex 9. Viga Model Basin Parameters 151
Annex 10. Viga Model Reach Parameters 152
Annex 11. Viga Field Validation Points 153
Annex 12. Educational Institutions Affected by Flooding in Viga Floodplain 153
Annex 13. Health Institutions Affected by Flooding in Viga Floodplain 154

LIST OF FIGURES

Figure 1. Map of Viga River Basin (in brown) 2
Figure 2. Flight plans and base stations used to cover Viga Floodplain.......... 4
Figure 3. 2GPS set-up over CNS-17 at Bagamanoc. (a) and NAMRIA reference point CNS-17 (b) as recovered by the field team. 5
Figure 4. GPS set-up over CNS-20 at Malmag Bridge, Barangay Pagsangahan, San Miguel along the Circumferential Road (a) and NAMRIA reference point CNS-20 (b) as recovered by the field team. 6
Figure 5. GPS set-up over CA-130 at Balatohan Bridge, barangay Balatohan, San Miguel (a) and NAMRIA reference point CA-130 (b) as recovered by the field team. 7
Figure 6. Actual LiDAR data acquisition for Viga floodplain.......... 10
Figure 7. Schematic Diagram for Data Pre-Processing Component.......... 11
Figure 8. Smoothed Performance Metric Parameters of a Viga Flight 3050P. 12
Figure 9. Solution Status Parameters of Viga Flight 3050P. 13
Figure 10. The best estimated trajectory of the lidar missions conducted over the Viga floodplain. 14
Figure 11. Boundary of the processed LiDAR data over Viga Floodplain.......... 15
Figure 12. Image of data overlap for Viga floodplain. 16
Figure 13. Density map of merged LiDAR data for Viga floodplain.......... 17
Figure 14. Elevation difference map between flight lines for Viga floodplain. 18
Figure 15. Quality checking for a Viga flight 3050P using the Profile Tool of QT Modeler.......... 19
Figure 16. Tiles for Viga floodplain (a) and classification results (b) in TerraScan. 20
Figure 17. Point cloud before (a) and after (b) classification. 20
Figure 18. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Viga floodplain. 21
Figure 19. Portions in the DTM of Viga floodplain – a Mountain Ridge before (a) and after (b) data retrieval; a triangulated waterway before (c) and after (d) manual editing 23
Figure 20. Map of Processed LiDAR Data for Viga Flood Plain.......... 25
Figure 21. Map of Viga Flood Plain with validation survey points in green. 27
Figure 22. Correlation plot between calibration survey points and LiDAR data. 28
Figure 23. Correlation plot between validation survey points and LiDAR data. 29
Figure 24. Map of Viga Flood Plain with bathymetric survey points shown in blue. 30
Figure 25. QC blocks for Viga building features. 31
Figure 26. Extracted features for Viga floodplain. 33
Figure 27. Survey extent for Viga River Basin 35
Figure 28. GNSS Network of Viga River field survey 36
Figure 29. GNSS base set up, Trimble® SPS 882, at CNS-21, located at the approach of Palta Bridge in Brgy. Palta Small, Municipalit of Virac, Catanduanes 37
Figure 31. GNSS base set up, Trimble® SPS 882, at CA-15, located at the approach of the left side of Kanparel Bridge in Brgy. Santa Maria, Municipality of Panganiban, Catanduanes 38
Figure 30. GNSS base set up, Trimble® SPS 882, at CA-130, located at the end of path walk in Brgy. Balatohan, Municipality of San Miguel, Catanduanes 38
Figure 32. GNSS base set up, Trimble® SPS 882, at CNS-3018, located at the approach of Pilot Bridge along Catanduanes Circumferential Road in Brgy. San Isidro, Municipality of Viga, Catanduanes 39
Figure 33. GNSS base set up, Trimble® SPS 852, at CNS-3028, located at the approach of Bato Bridge along Catanduanes Circumferential Road in Brgy. Tilis, Municipality of Bato, Catanduanes 39
Figure 34. GNSS base set up, Trimble® SPS 852, at CNS-3028, located at the approach of Bato Bridge along

Catanduanes Circumferential Road in Brgy. Tilis, Municipality of Bato, Catanduanes 40
Figure 35. Cross-Section Survey at Pilot Bridge 44
Figure 36. Pilot bridge cross-section location map.. 45
Figure 37. Viga River Cross-section Diagram 46
Figure 38. Pilot bridge as-built form 47
Figure 39. Validation points acquisition survey set up 48
Figure 40. Validation point acquisition survey for Viga River Basin.. 49
Figure 41. Bathymetry by boat set up for Viga River survey 50
Figure 42. Manual bathymetry set-up for Viga River survey 51
Figure 43. Extent of the bathymetric survey (in blue) in Viga River 52
Figure 44. Riverbed profile of Danao River... 53
Figure 45. The location map of Viga HEC-HMS model used for calibration 54
Figure 46. Cross-Section Plot of Danao Footbridge 55
Figure 47. The rating curve of Pilot Bridge in Viga, Catanduanes 55
Figure 48. Rainfall and outflow data of the Viga River Basin, which was used for modeling 56
Figure 49. The location of the Virac RIDF station relative to the Viga River Basin..................................... 57
Figure 50. The synthetic storm generated for a 24-hour period for various return periods 57
Figure 51. Soil map of Viga River Basin (Source: NAMRIA).. 58
Figure 52. Land cover map of the Danao River Basin 59
Figure 53. Slope map of Viga River Basin 60
Figure 54. Stream delineation map of Viga River Basin.. 61
Figure 55. The Viga River Basin model generated in HEC-HMS 62
Figure 56. River cross-section of Viga River generated through Arcmap HEC GeoRAS tool 63
Figure 57. Screenshot of subcatchment with the computational area to be modeled in FLO-2D Grid Developer System Pro (FLO-2D GDS Pro) 64
Figure 58. Outflow hydrograph of Viga River Basin produced by the HEC-HMS model compared with observed outflow 65
Figure 59. The outflow hydrograph at the Viga River Basin, generated using the simulated events for 24-hour period for Virac station 67
Figure 60. The sample output map of the Viga RAS Model.. 68
Figure 61. 100-year flood hazard map for the Viga flood plain overlaid on Google Earth imagery 69
Figure 62. 100-year flow depth map for the Viga flood plain overlaid on Google Earth imagery 70
Figure 63. 25-year flood hazard map for the Viga flood plain overlaid on Google Earth imagery.............. 71
Figure 64. 25-year flow depth map for the Viga flood plain overlaid on Google Earth imagery 72
Figure 65. 5-year flood hazard map for the Viga flood plain overlaid on Google Earth imagery................ 73
Figure 66. 5-year flow depth map for the Viga flood plain overlaid on Google Earth imagery 74
Figure 67. Affected Barangays in Panganiban, Catanduanes during the 5-Year Rainfall Return Period...... 75
Figure 68. Affected Barangays in Panganiban, Catanduanes during the 5-Year Rainfall Return Period...... 76
Figure 69. Affected Barangays in Viga, Catanduanes during the 5-Year Rainfall Return Period 78
Figure 70. Affected Barangays in Viga, Catanduanes during the 5-Year Rainfall Return Period 78
Figure 71. Affected Barangays in Panganiban, Catanduanes during the 25-Year Rainfall Return Period.... 80
Figure 72. Affected Barangays in Panganiban, Catanduanes during the 5-Year Rainfall Return Period...... 80
Figure 73. Affected Barangays in Viga, Catanduanes during the 5-Year Rainfall Return Period 82
Figure 74. Affected Barangays in Viga, Catanduanes during the 25-Year Rainfall Return Period 82
Figure 75. Affected Barangays in Panganiban, Catanduanes during the 100-Year Rainfall Return Period.. 84
Figure 76. Affected Barangays in Panganiban, Catanduanes during the 100-Year Rainfall Return Period. 84
Figure 77. Affected Barangays in Viga, Catanduanes during the 100-Year Rainfall Return Period 86
Figure 78. Affected Barangays in Viga, Catanduanes during the 100-Year Rainfall Return Period............. 86

LIST OF TABLES

Table 1. Flight planning parameters for Pegasus LiDAR system 3
Table 2. Details of the recovered NAMRIA horizontal control point CNS-17 used as base station for the LiDAR Acquisition. 5
Table 3. Details of the recovered NAMRIA horizontal control point CNS-20 used as base station for the LiDAR Acquisition. 6
Table 4. Details of the recovered NAMRIA vertical control point CA-130 used as base station for the LiDAR Acquisition. 7
Table 5. Ground control points used during LiDAR Data Acquisition 8
Table 6. Flight missions for LiDAR data acquisition in Viga floodplain. 8
Table 7. Actual parameters used during LiDAR data acquisition 9
Table 8. List of Municipalities/Cities Surveyed in Negros Occidental 9
Table 9. Self-Calibration Results values for Viga flights. 14
Table 10. List of LiDAR blocks for Viga Floodplain 15
Table 11. Viga classification results in TerraScan. 19
Table 12. LiDAR blocks with its corresponding area. 23
Table 13. Shift Values of each LiDAR Block of Viga floodplain. 24
Table 14. Calibration Statistical Measures 28
Table 15. Validation Statistical Measures. 29
Table 16. Quality Checking Ratings for Viga Building Features. 31
Table 17. Building Features Extracted for Viga Floodplain. 32
Table 18. Total Length of Extracted Roads for Viga Floodplain. 33
Table 19. Number of Extracted Water Bodies for Viga Floodplain. 33
Table 20. List of reference and control points occupied for Viga River Survey (Source: NAMRIA, UP-TCAGP) 37
Table 21. Baseline Processing Report for Viga River Basin Static Survey 40
Table 22. Control Point Constraints 41
Table 23. Adjusted Grid Coordinates 41
Table 24. Adjusted Geodetic Coordinates 42
Table 25. Reference and control points used and its location (Source: NAMRIA, UP-TCAGP) 43
Table 26. RIDF values for Virac Rain Gauge computed by PAG-ASA 56
Table 27. Range of calibrated values for the Viga River Basin 65
Table 28. Summary of the Efficiency Test of Viga HMS Model 66
Table 29. Outlines the peak values of the Viga HEC-HMS Model outflow using the Virac RIDF 24-hour values. 67
Table 30. Municipalities affected in Viga floodplain 68
Table 31. Affected Areas in Panganiban Catanduanes during 5-Year Rainfall Return Period 77
Table 32. Affected Areas in Viga, Catanduanes during 5-Year Rainfall Return Period 79
Table 33. Affected Areas in Panganiban Catanduanes during 25-Year Rainfall Return Period 81
Table 34. Affected Areas in Viga, Catanduanes during 25-Year Rainfall Return Period 83
Table 35. Affected Areas in Panganiban Catanduanes during 100-Year Rainfall Return Period 85
Table 36. Affected Areas in Viga, Catanduanes during 100-Year Rainfall Return Period 87
Table 37. Area covered by each warning level with respect to the rainfall scenario 88

LIST OF ACRONYMS AND ABBREVIATIONS

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

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

CHAPTER 1: OVERVIEW OF THE PROGRAM AND THE VIGA RIVER

Enrico C. Paringit, Dr. Eng., Ms. Joanaviva C. Plopenio, and Engr. Ferdinand Bien

1.1 Background of the Phil-LIDAR 1 Program

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

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

The implementing partner university for the Phil-LiDAR 1 Program is the Ateneo de Naga University (ADNU). ADNU 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 24 river basins in the Bicol Region. The university is located in Naga City in the province of Camarines Sur.

1.2 Overview of the Viga River Basin

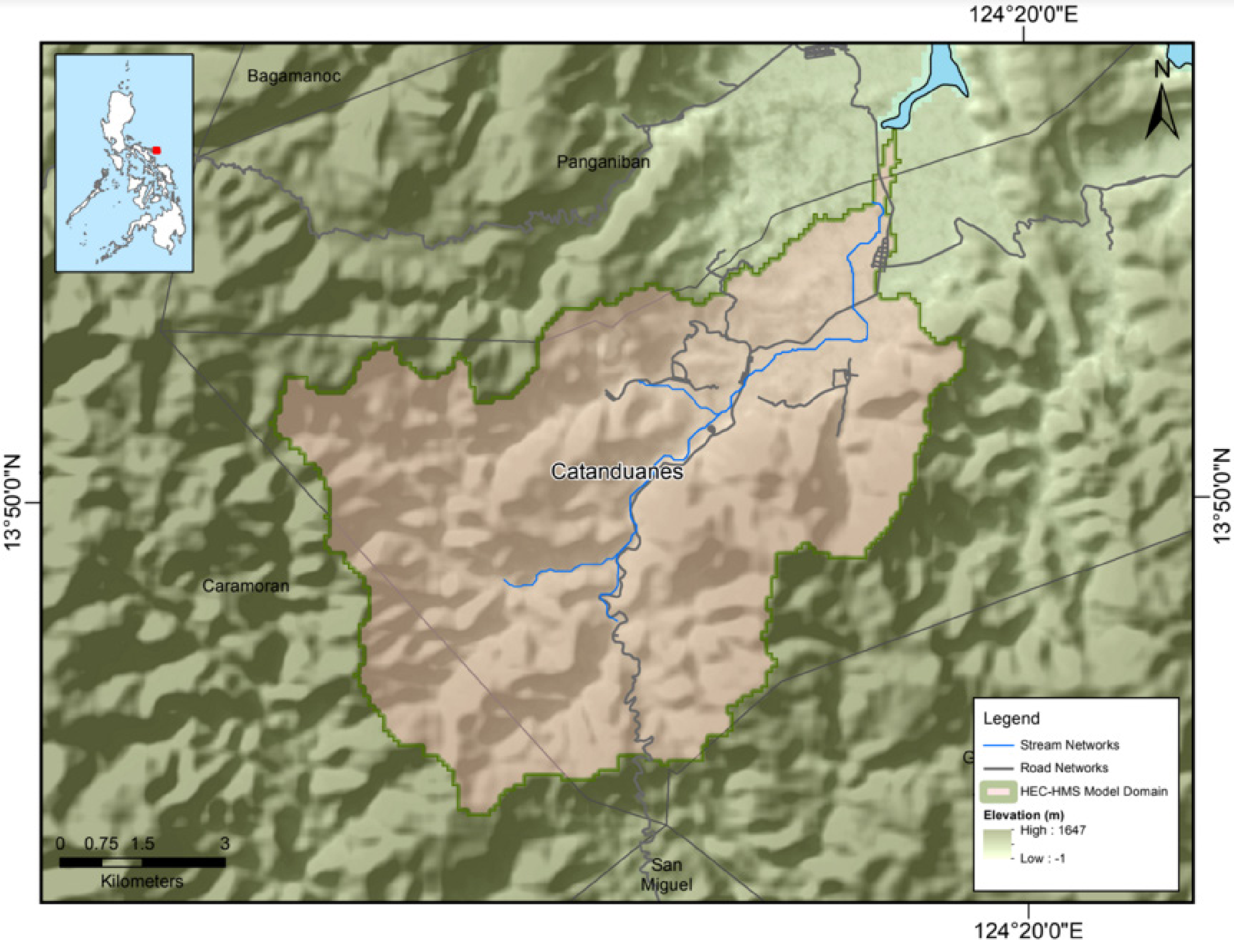


Figure 1. Map of Viga River Basin (in brown)

Viga river basin is more extensive compared to Cabuyan 1 but with just three (3) municipalities covering the area: Caramoran, Viga and Panganiban which are classified as third, fourth and fifth class municipalities, respectively. Among the three (3), Caramoran is the town with the largest population with 30, 056, followed by Viga with 21,624 and Panganiban at 9,287.

The major stream in Viga river basin is about 81 km long. This also empties out to the Pacific Ocean. This river basin is bound to the east and west by low-lying hills of not more than 400 mASL. Precipitation is distributed all throughout the year and becomes wetter during November and the succeeding months even up to April. There is no dry season in the area which is governed by Type II climate in the modified Corona classification of climate of the Philippines.

The area is highly agricultural with rice as main product along with corn, vegetables, legumes, coconut and abaca. Fishing is limited to local consumption. The area is also with the largest cover of nipa and mangrove in the province.

CHAPTER 2: LIDAR ACQUISITION OF THE VIGA FLOODPLAIN

Engr. Louie P. Balicanta, Engr. Christopher Cruz, Lovely Gracia Acuña, Engr. Gerome Hipolito, Engr. Iro Niel D. Roxas, and Engr. Frank Nicolas H. Ilejay

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 Viga Floodplain in Catanduanes. These missions were planned for 14 lines and ran 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 plans and base stations for Viga Floodplain.

Table 1. Flight planning parameters for Pegasus LiDAR system

Block Name	Flying Height (AGL)	Overlap (%)	Field of View	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency	Average Speed	Average Turn Time (Minutes)
BLK25D	1000	20	50	200	30	130	5
BLK25E	1000	20	50	200	30	130	5
BLK25F	1000	20	50	200	30	130	5
BLK25G	1000	20	50	200	30	130	5

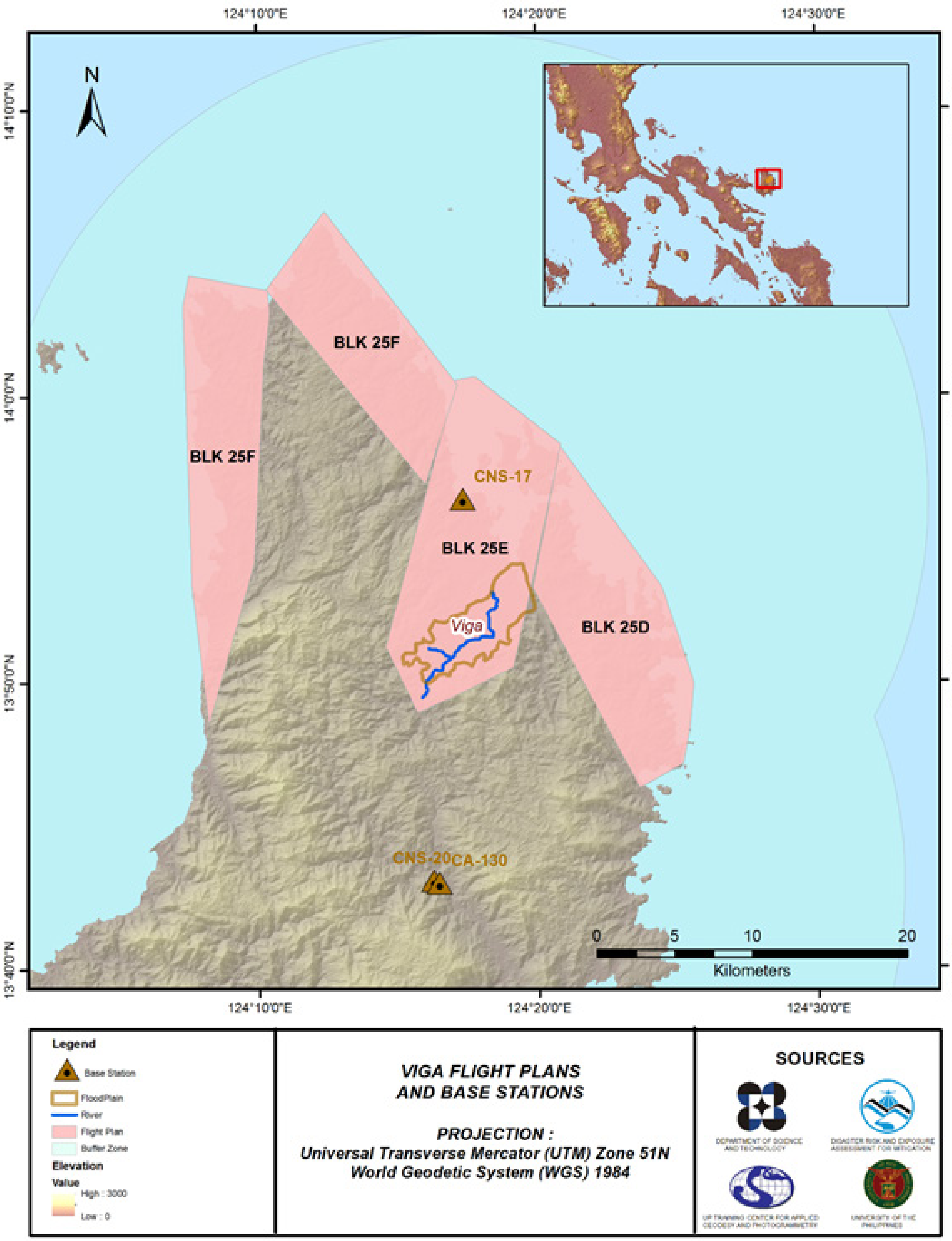


Figure 2. Flight plans and base stations used to cover Viga Floodplain

2.2 Ground Base Station

The project team was able to recover two (2) NAMRIA ground control points: CNS-17 and CNS-20 which are of second (2nd) order accuracy. One (1) NAMRIA benchmark was recovered: CA-130.This benchmark was used as vertical reference point and was also established as ground control point. The certifications for the NAMRIA reference points and benchmark are found in Annex 2, while the processing report for the NAMRIA benchmark is found in Annex 3. These were used as base stations during the flight operation for the entire duration of the survey (January 20 – February 4, 2016). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 985 and TOPCON GR5. Flight plans and location of base stations used during the aerial LiDAR acquisition in Viga floodplain are shown in Figure 1.

Figure 3 to Figure 5 show the recovered NAMRIA reference points within the area. In addition, Table 2 to Table 4 show the details about the following NAMRIA control points and established control points while Table 5 shows the list of all ground control points occupied during the acquisition together with corresponding dates of utilization.

Figure 3. 2GPS set-up over CNS-17 at Bagamanoc. (a) and NAMRIA reference point CNS-17 (b) as recovered by the field team.

Table 2. Details of the recovered NAMRIA horizontal control point CNS-17 used as base station for the LiDAR Acquisition.

Station Name	CNS-17	
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° 56' 28.40127" North 124° 17' 15.04693" East 3.511 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 4 PRS 92)	Easting Northing	639,087 meters 1,542,046.993 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 56' 23.40703" North 124° 17' 19.97478" East 56.921 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	639,087.04 meters 1,541,507.25 meters

Figure 4. GPS set-up over CNS-20 at Malmag Bridge, Barangay Pagsangahan, San Miguel along the Circumferential Road (a) and NAMRIA reference point CNS-20 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point CNS-20 used as base station for the LiDAR Acquisition.

Station Name	CNS-20	
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° 43' 8.77572" North 124° 16' 9.57152" East 43.752 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 4 PRS 92)	Easting Northing	637,300.168 meters 1,517,459.029 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 43' 3.83355" North 124° 16' 14.51857" East 97.736 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	637,252.11 meters 1,516,927.89 meters

(a)

(b)

Figure 5. GPS set-up over CA-130 at Balatohan Bridge, barangay Balatohan, San Miguel (a) and NAMRIA reference point CA-130 (b) as recovered by the field team.

Table 4. Details of the recovered NAMRIA vertical control point CA-130 used as base station for the LiDAR Acquisition.

Station Name	**CA-130**	
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° 43’ 8.77572” North 124° 16’ 9.57152” East 43.752 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 43’ 3.83355” North 124° 16’ 14.51857” East 97.736 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	637,252.11 meters 1,516,927.89 meters

Table 5. Ground control points used during LiDAR Data Acquisition

Date Surveyed	Flight Number	Mission Name	Ground Control Points
January 28, 2016	3032P	1BLK25E028A	CNS-17, CNS-20
February 1, 2016	3048P	1BLK25F032A	CNS-20, CA-130
February 1, 2016	3050P	1BLK25E032B	CNS-20, CA-130

2.3 Flight Missions

Three (3) missions were conducted to complete the LiDAR Data Acquisition in Viga Floodplain, for a total of seven hours and thirty-three (7+33) minutes of flying time for RP-C9122. All missions were acquired using the Pegasus LiDAR system. Table 6 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 7 presents the actual parameters used during the LiDAR data acquisition.

Table 6. Flight missions for LiDAR data acquisition in Viga 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
January 28, 2016	3032P	197.38	3	0	3	NA	3	23
February 1, 2016	3048P	462.53	49.63	0	49.63	NA	0	59
February 1, 2016	3050P	265.15	112.29	19.30	92.99	NA	3	11
TOTAL		925.06	164.92	19.30	145.62	NA	7	33

Table 7. 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
3032P	1000	20	50	200	30	110-130	5
3048P	1000	20	50	200	30	110-130	5
3050P	800	20	50	200	30	110-130	5

2.4 Survey Coverage

Viga floodplain is located in the province of Catanduanes covering parts of Bagamanoc, Viga and Pandan. The list of municipalities/cities surveyed in these provinces during the LiDAR acquisition is shown in Table 8. The actual coverage of the LiDAR acquisition for Viga floodplain is presented in Figure 6.

Table 8. List of Municipalities/Cities Surveyed in Negros Occidental

Province	Municipality/City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Catanduanes	Panganiban	85.59	52.00	61%
	Bagamanoc	82.85	26.66	32%
	Pandan	117.38	32.93	28%
	Viga	158.74	22.40	14%

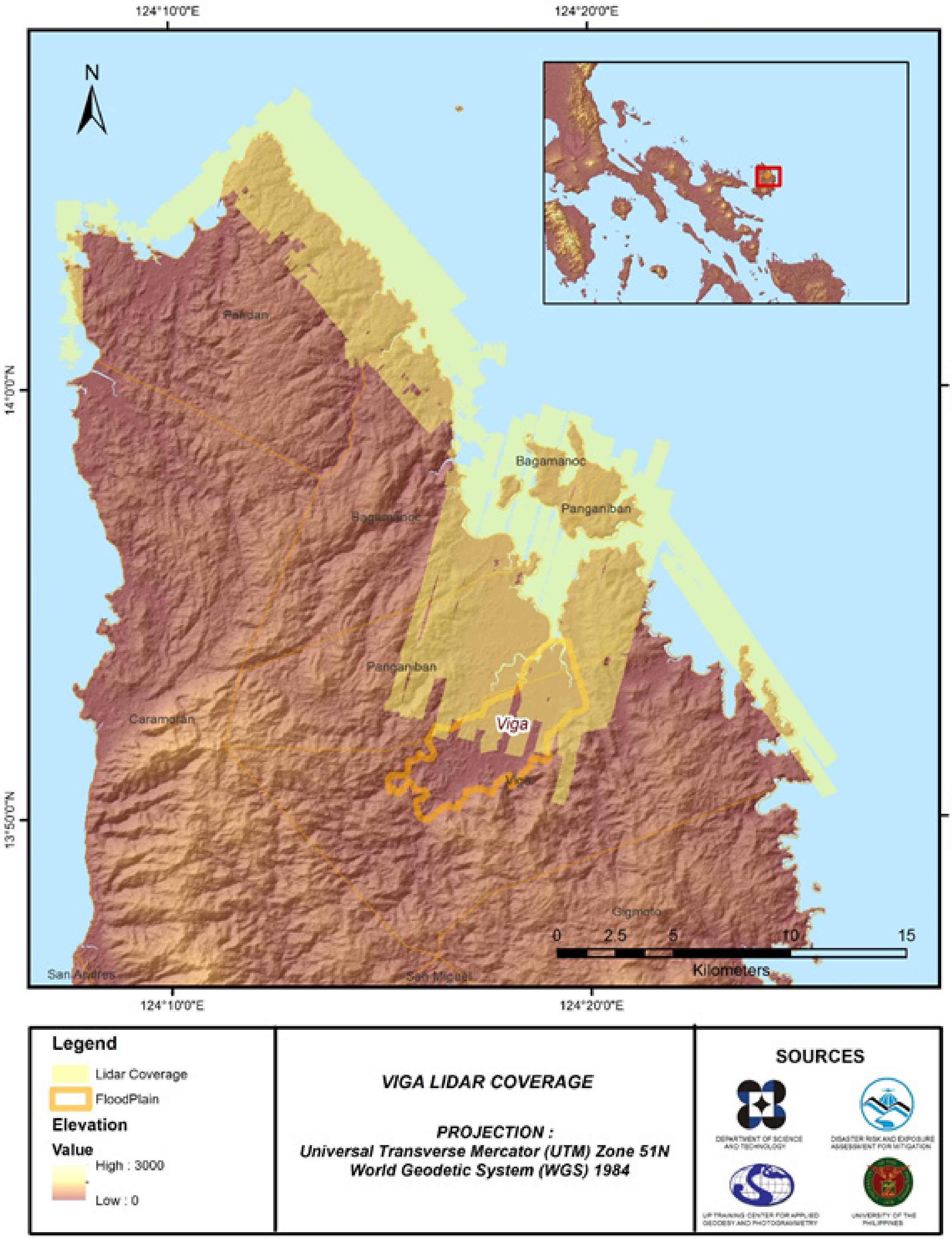


Figure 6. Actual LiDAR data acquisition for Viga floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE VIGA FLOODPLAIN

Engr. Ma. Rosario Concepcion O. Ang, Engr. John Louie D. Fabila, Engr. Sarah Jane D. Samalburo , Engr. Gladys Mae Apat , Engr. Harmond F. Santos , Engr. Ma. Ailyn L. Olanda, Engr. Erica Erin E. Elazegui, Engr. Christy T. Lubiano , Jerry P. Ballori, Jaylyn L. Paterno, Engr. Ferdinand E. Bien, Engr. Francis Patray P. Bolaños, Carlota M. Davocol, Arnulfo G. Enciso, Jr., Engr. Jan Karl T. Ilarde, Engr. Kevin Kristian L. Peñaserada, Richmund P. Saldo, Engr. Jayrik T. San Buenaventura, and Engr. Jess Andre S. Soller

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 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 7.

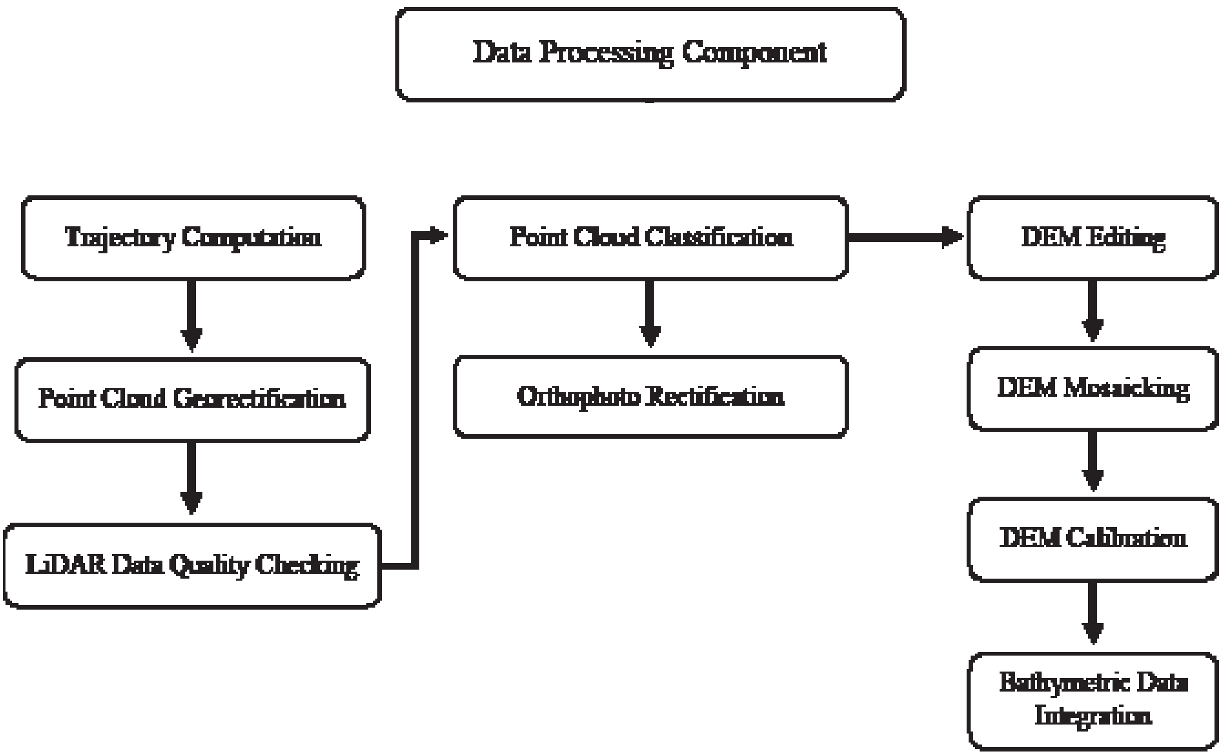


Figure 7. Schematic Diagram for Data Pre-Processing Component

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Viga floodplain can be found in Annex 5. Missions flown during the first survey conducted on May 2014 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus system over Viga, Catanduanes. The Data Acquisition Component (DAC) transferred a total of 42.3 Gigabytes of Range data, 558 Gigabytes of POS data, 265.40 Megabytes of GPS base station data, and 0 Gigabytes of raw image data to the data server on January 2016 for the first survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Viga was fully transferred on February 12, 2016, as indicated on the Data Transfer Sheets for Viga floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 3050P, one of the Viga flights, which is the North, East, and Down position RMSE values are shown in Figure 8. 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 February 10, 2016 00:00AM. The y-axis is the RMSE value for that particular position.

Figure 8. Smoothed Performance Metrics of a Viga Flight 3050P.

The time of flight was from 104,800 seconds to 114,800 seconds, which corresponds to afternoon of February 10, 2016. 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 8 shows that the North position RMSE peaks at 1.20 centimeters, the East position RMSE peaks at 1.20 centimeters, and the Down position RMSE peaks at 2.80 centimeters, which are within the prescribed accuracies described in the methodology.

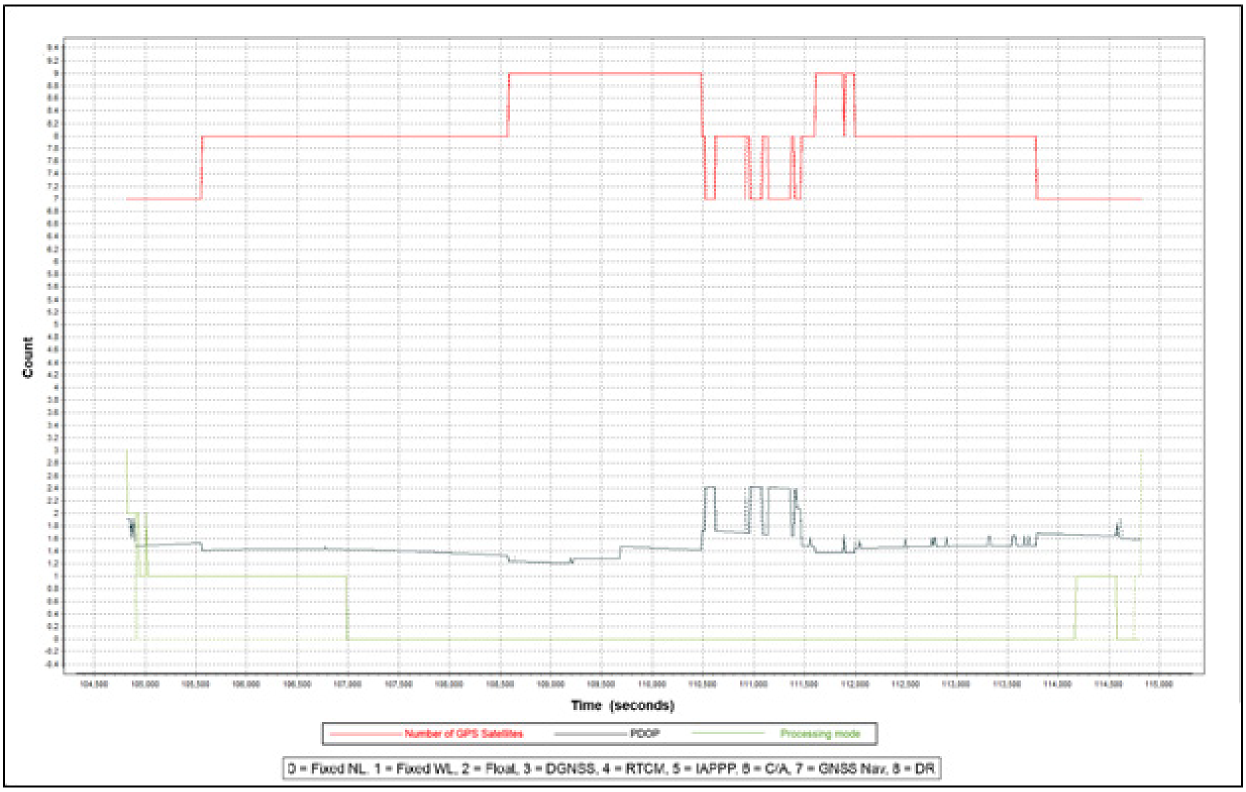


Figure 9. Solution Status Parameters of Viga Flight 3050P.

The Solution Status parameters of flight 3050P, one of the Viga flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 9. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Majority 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 stayed at the value of 0 for majority of the survey with some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for 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 Viga flights is shown in Figure 10.

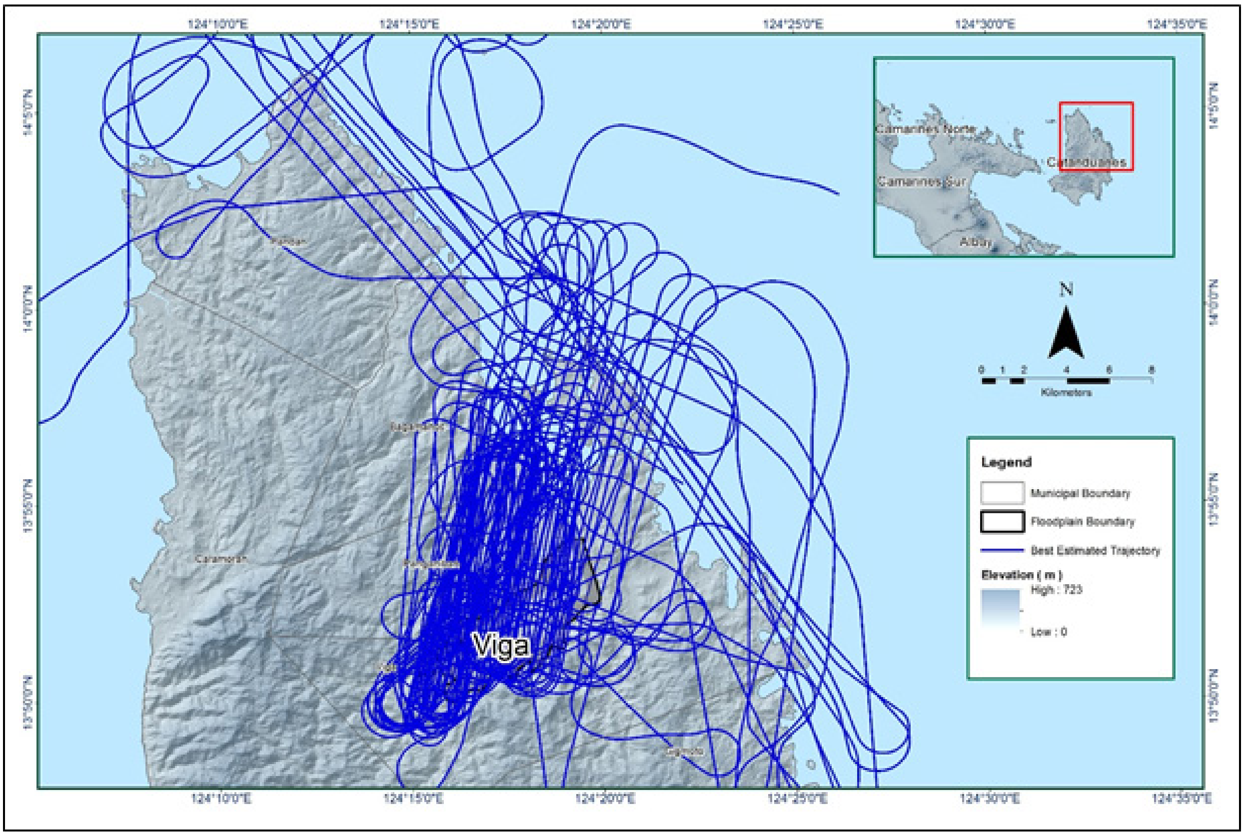


Figure 10. The best estimated trajectory of the lidar missions conducted over the Viga floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 23 flight lines, the flight lines from Aquarius system contain one channel, while the flight lines from the Pegasus system contain two channels. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Viga floodplain are given in Table 9.

Table 9. Self-Calibration Results values for Viga flights.

Parameter	Acceptable Value	Value
Boresight Correction stdev	(<0.001degrees)	0.000241
IMU Attitude Correction Roll and Pitch Corrections stdev	(<0.001degrees)	0.00003
GPS Position Z-correction stdev	(<0.01meters)	0.008

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

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Viga Floodplain is shown in Figure 11. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

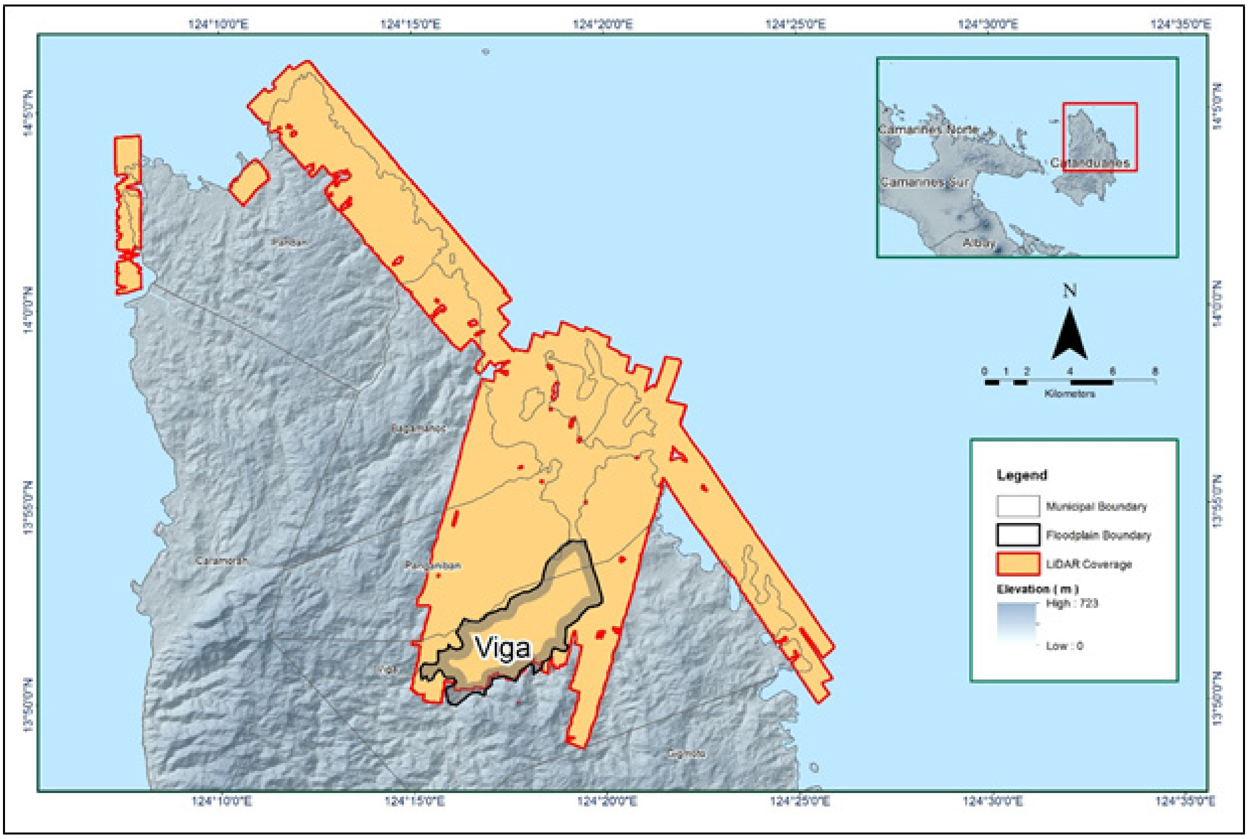


Figure 11. Boundary of the processed LiDAR data over Viga Floodplain

The total area covered by the Viga missions is 243.31 sq.km that is comprised of nine (9) flight acquisitions grouped and merged into nine (9) blocks as shown in Table 10.

Table 10. List of LiDAR Blocks for Viga Floodplain

LiDAR Blocks	Flight Numbers	Area (sq. km)
Catanduanes_Blk25D	3048P	37.19
Catanduanes_Blk25D_additional	3016P	16.90
	3048P	
Catanduanes_Blk25E	3050P	114.60
Catanduanes_reflights_Blk25A	8537AC	10.32
Catanduanes_reflights_Blk25B	8529AC	14.79
Catanduanes_reflights_Blk25B_supplement	8535AC	11.38
Catanduanes_reflights_Blk25C	8527AC	7.84
Catanduanes_reflights_Blk25C_supplement	8531AC	10.97
Catanduanes_reflights_Blk25D	8533AC	10.32
TOTAL		**243.31 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 12. Since the Gemini system employs one channel, we would expect an average value of 1 (blue) for areas where there is limited overlap, and a value of 2 (yellow) or more (red) for areas with three or more overlapping flight lines. While for the Pegasus system which 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.

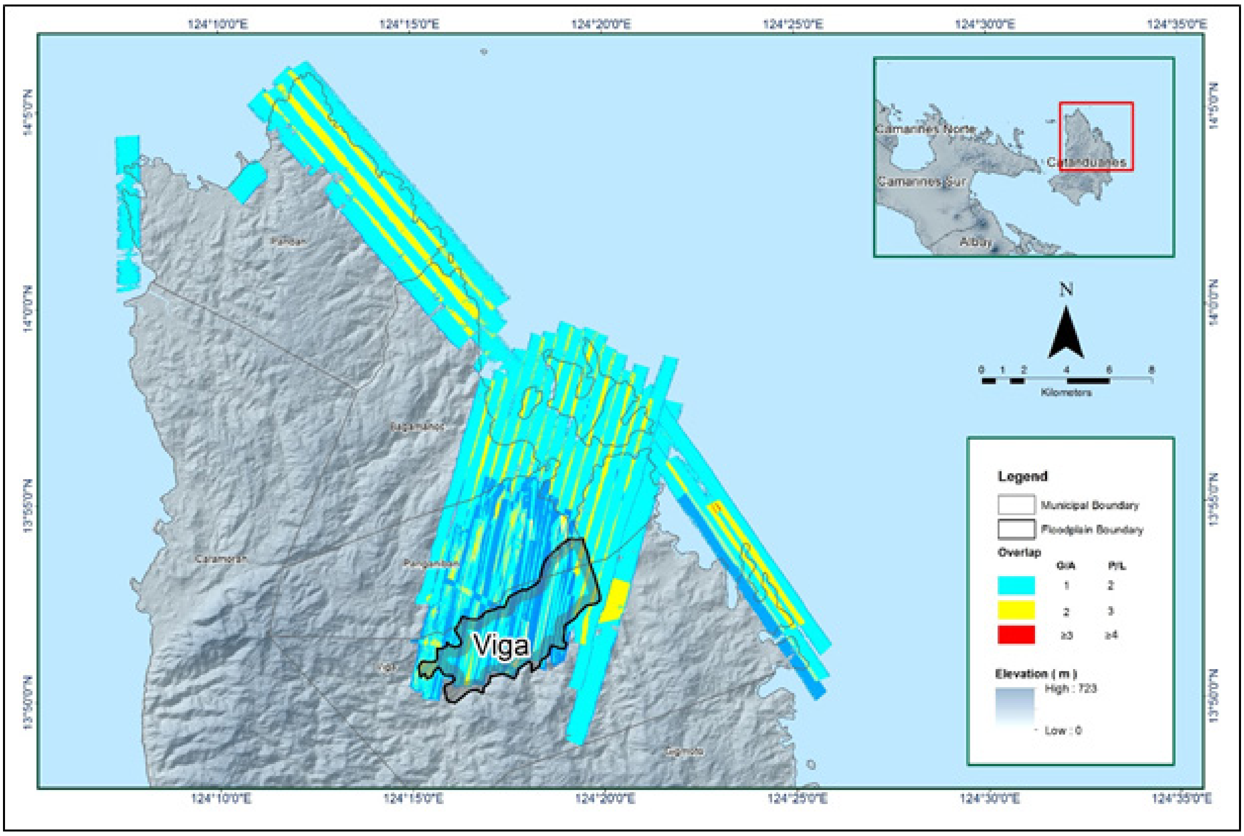


Figure 12. Image of data overlap for Viga floodplain.

The overlap statistics per block for the Viga floodplain can be found in Annex 8. One pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 19.91% and 20.87% respectively.

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 13. It was determined that all LiDAR data for Viga floodplain satisfy the point density requirement, and the average density for the entire survey area is 2.91 points per square meter.

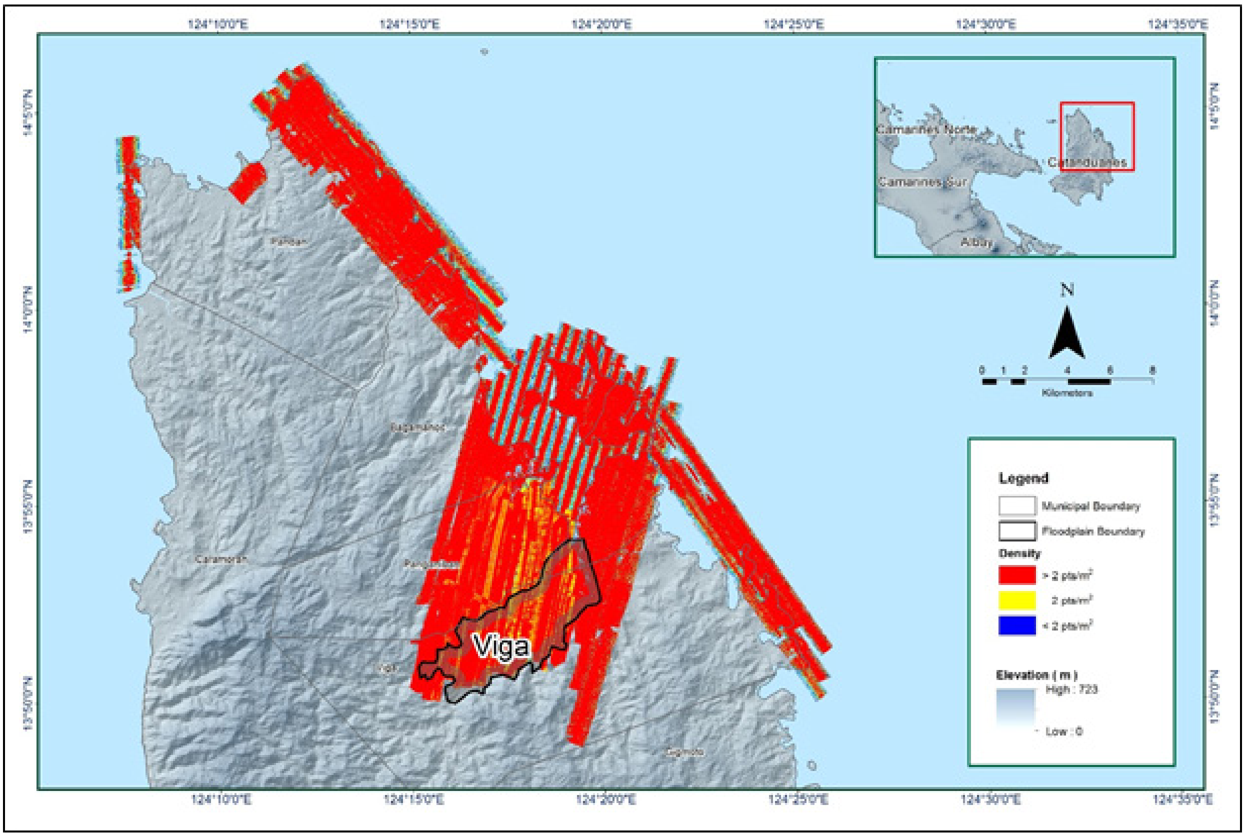


Figure 13. Pulse density map of merged LiDAR data for Viga floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 14. 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.

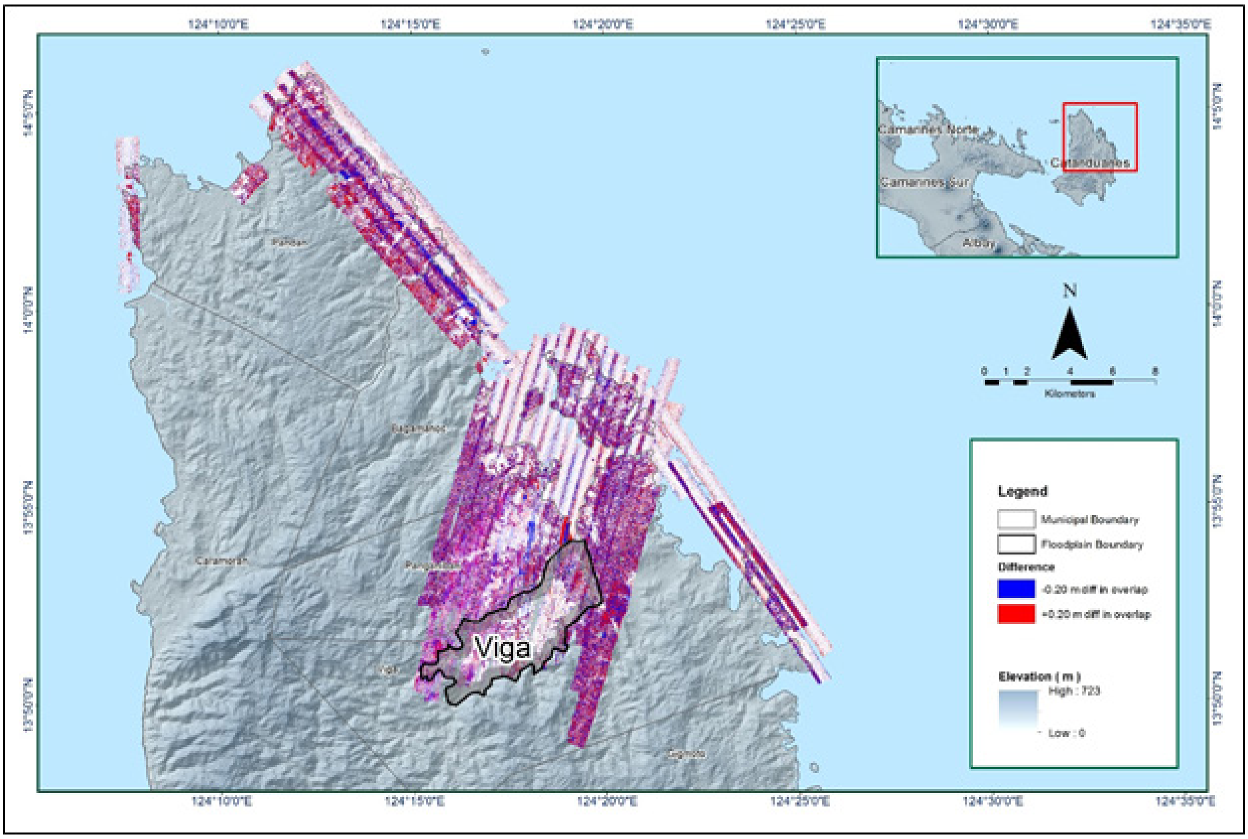


Figure 14. Elevation difference map between flight lines for Viga floodplain.

A screen capture of the processed LAS data from a Viga flight 3050P loaded in QT Modeler is shown in Figure 15. 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.

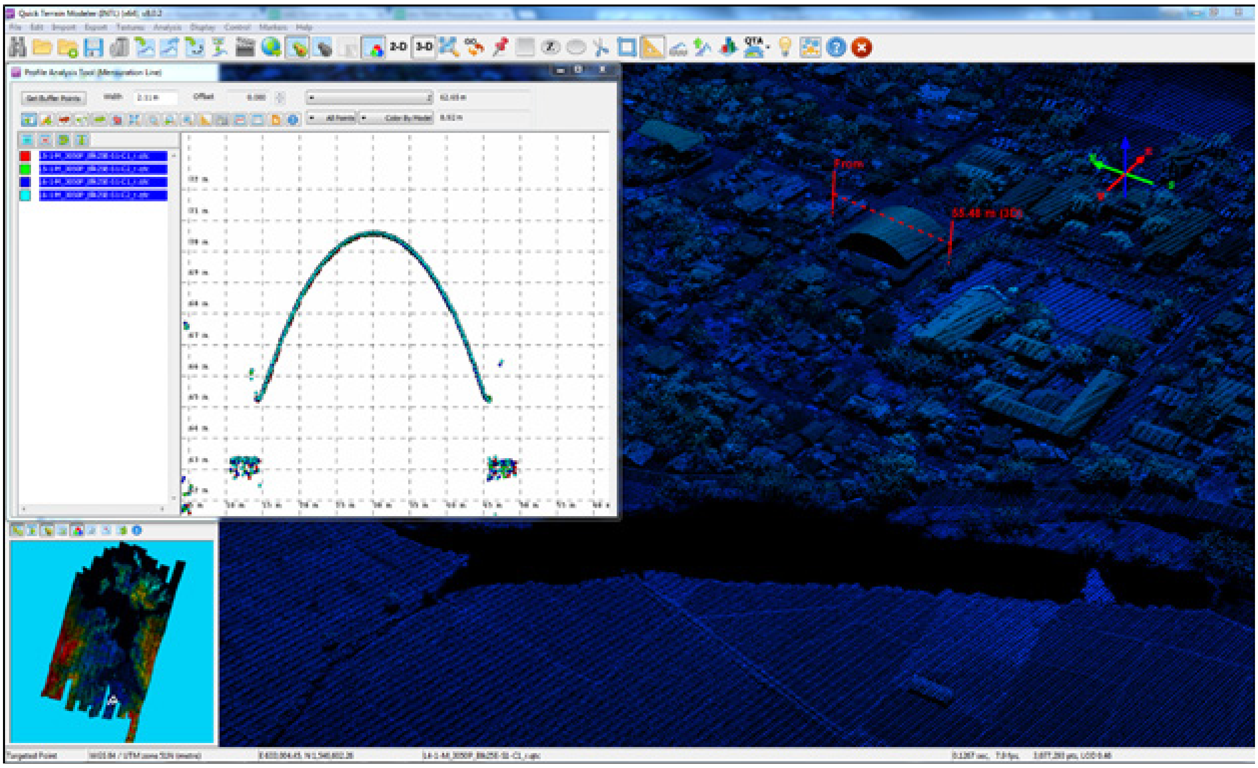


Figure 15. Quality checking for a Viga flight 3050P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 11. Viga classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	250,017,146
Low Vegetation	133,973,174
Medium Vegetation	197,744,565
High Vegetation	657,103,407
Building	13,454,517

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Viga floodplain is shown in Figure 16. A total of 374 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 11. The point cloud has a maximum and minimum height of 394.46 meters and 44.27 meters respectively.

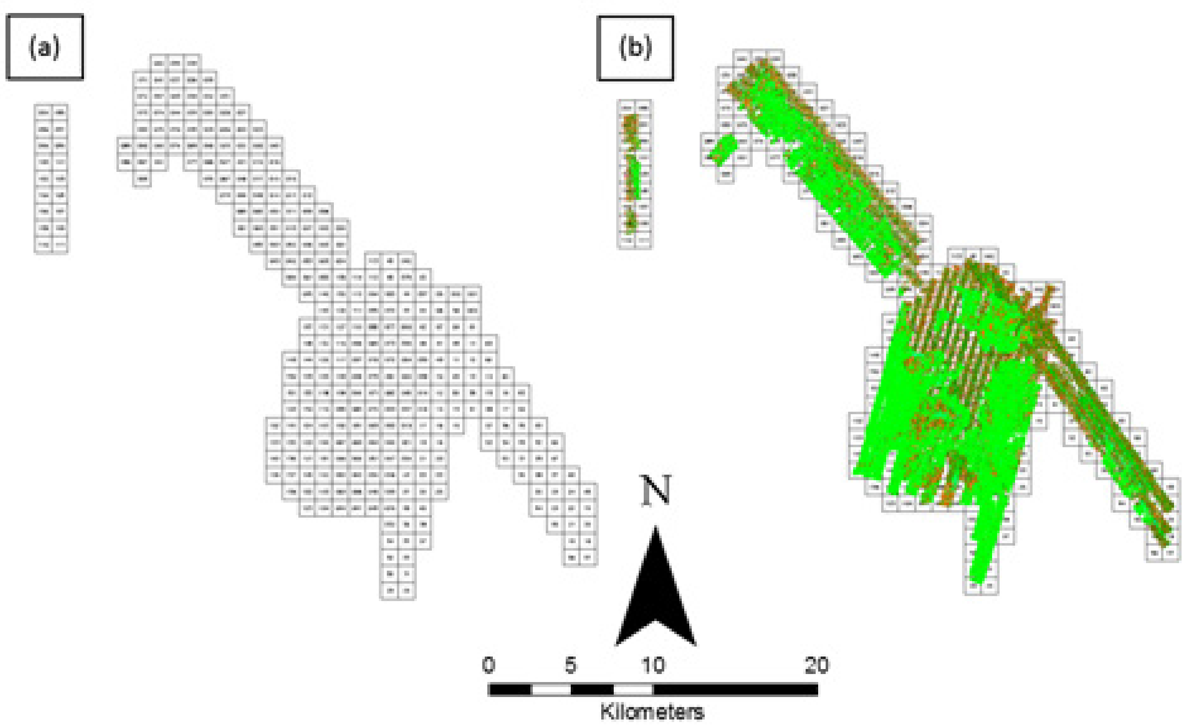


Figure 16. Tiles for Viga floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 17. 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.

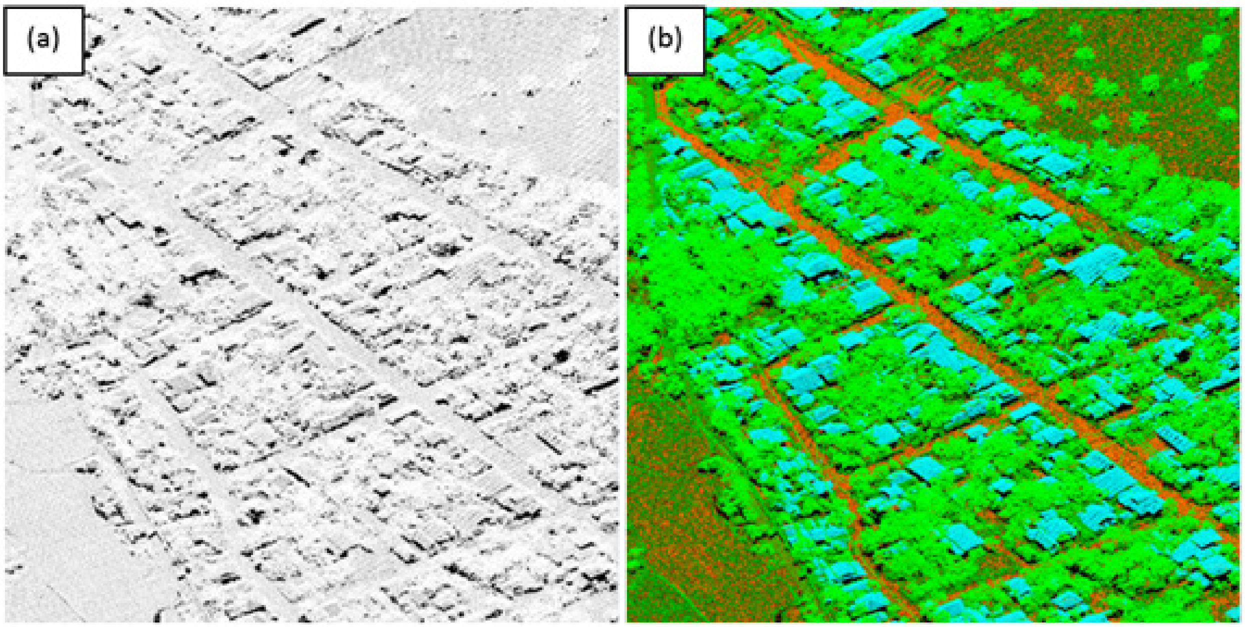


Figure 17. Point cloud before (a) and after (b) classification.

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

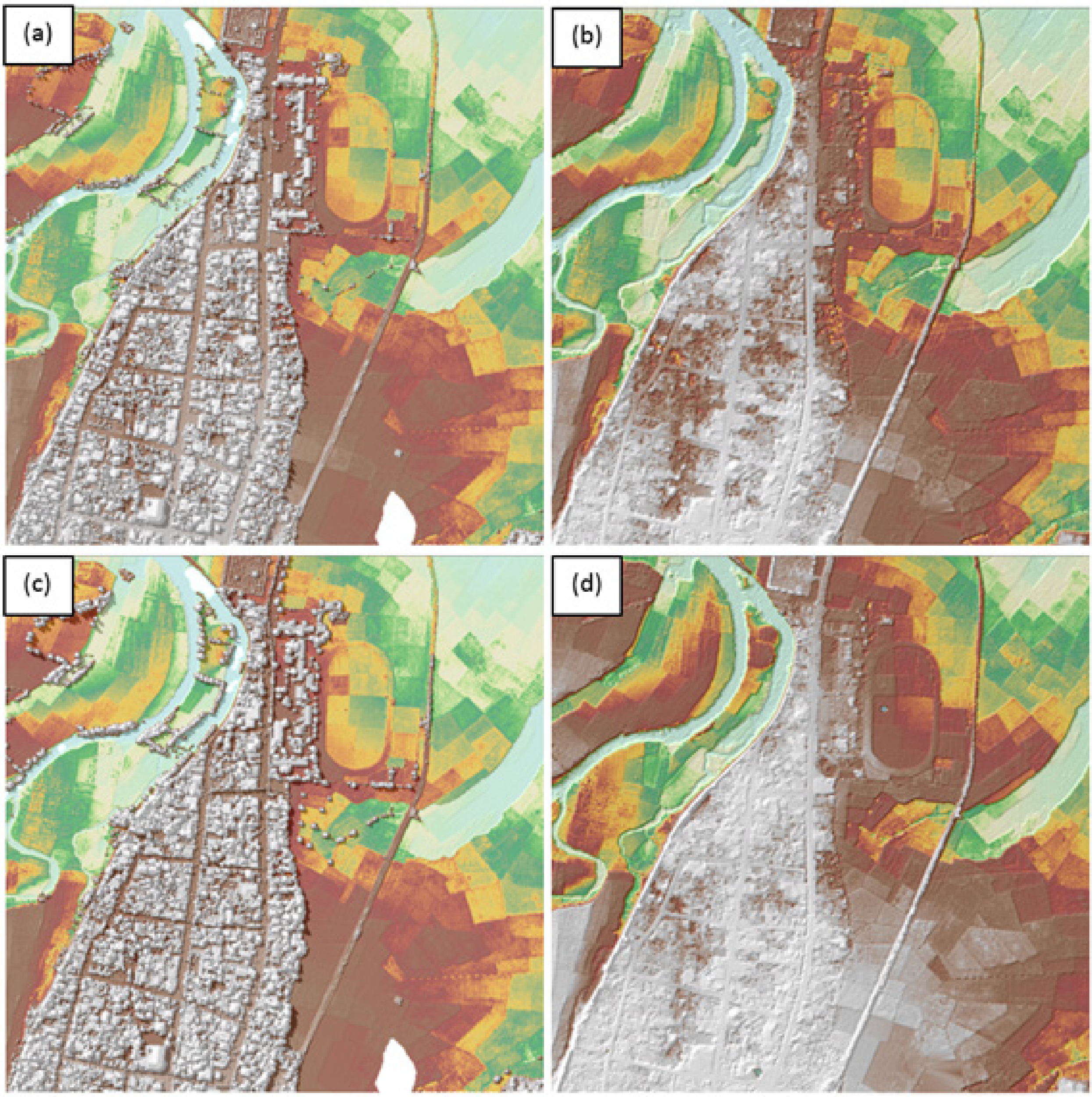


Figure 18. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Viga floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

There are no available orthophotographs for the Viga floodplain.

3.8 DEM Editing and Hydro-Correction

Nine (9) mission blocks were processed for Viga flood plain. These blocks are composed of Catanduanes and Catanduanes reflights with a total area of 243.31 square kilometers. Table 12 shows the name and corresponding area of each block in square kilometers.

Table 12. LiDAR blocks with its corresponding area.

LiDAR Blocks	Area (sq.km)
Catanduanes_Blk25D	37.19
Catanduanes_Blk25D_additional	16.90
Catanduanes_Blk25E	114.60
Catanduanes_reflights_Blk25A	10.32
Catanduanes_reflights_Blk25B	14.79
Catanduanes_reflights_Blk25B_supplement	11.38
Catanduanes_reflights_Blk25C	7.84
Catanduanes_reflights_Blk25C_supplement	10.97
Catanduanes_reflights_Blk25D	10.32
TOTAL	**234.31 sq.km**

Portions of DTM before and after manual editing are shown in Figure 19. The mountain ridge (Figure 19a) has been misclassified and removed during classification process and has to be retrieved to complete the surface (Figure 19b) to allow the correct flow of water. The triangulated waterway (Figure 19c) is also considered to be an impedance to the flow of water along the river and has to be removed (Figure 19d) in order to hydrologically correct the river.

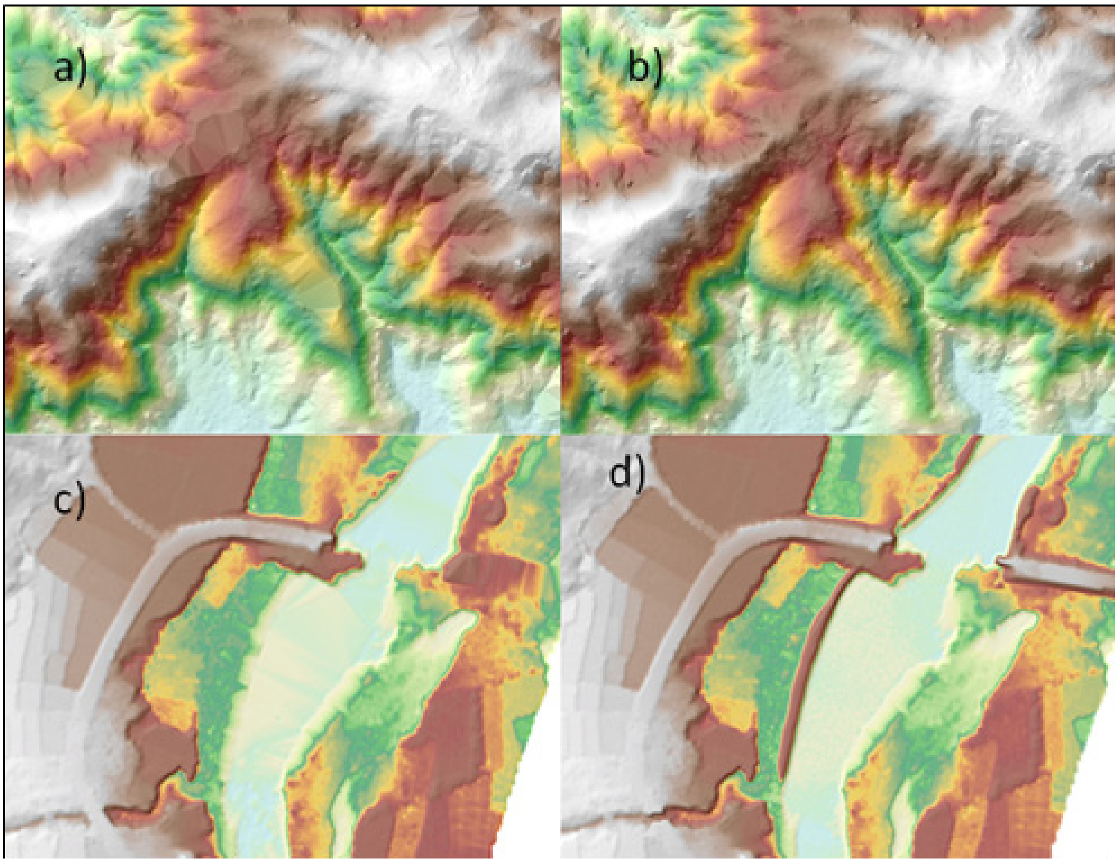


Figure 19. Portions in the DTM of Viga floodplain – a Mountain Ridge before (a) and after (b) data retrieval; a triangulated waterway before (c) and after (d) manual editing

3.9 Mosaicking of Blocks

No assumed reference block was used in mosaicking because the identified reference for shifting was an existing calibrated Catanduanes DEM overlapping with the blocks to be mosaicked. Table 13 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Viga floodplain is shown in Figure 20. It can be seen that the entire Viga floodplain is 95.30% covered by LiDAR data.

Table 13. Shift Values of each LiDAR Block of Viga floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
Catanduanes_Blk25D	0.00	0.00	-1.30
Catanduanes_Blk25E	0.00	0.00	-1.15
Catanduanes_Blk25D_additional	-0.50	1.50	-1.16
Catanduanes_reflights_Blk25A	0.00	-1.00	-0.23
Catanduanes_reflights_Blk25B	0.00	0.00	-0.39
Catanduanes_reflights_Blk25B_supplement	0.00	-1.00	-0.47
Catanduanes_reflights_Blk25C	0.00	0.00	-0.59
Catanduanes_reflights_Blk25C_supplement	-1.00	0.00	-0.65
Catanduanes_reflights_Blk25D	0.00	-1.00	-0.26

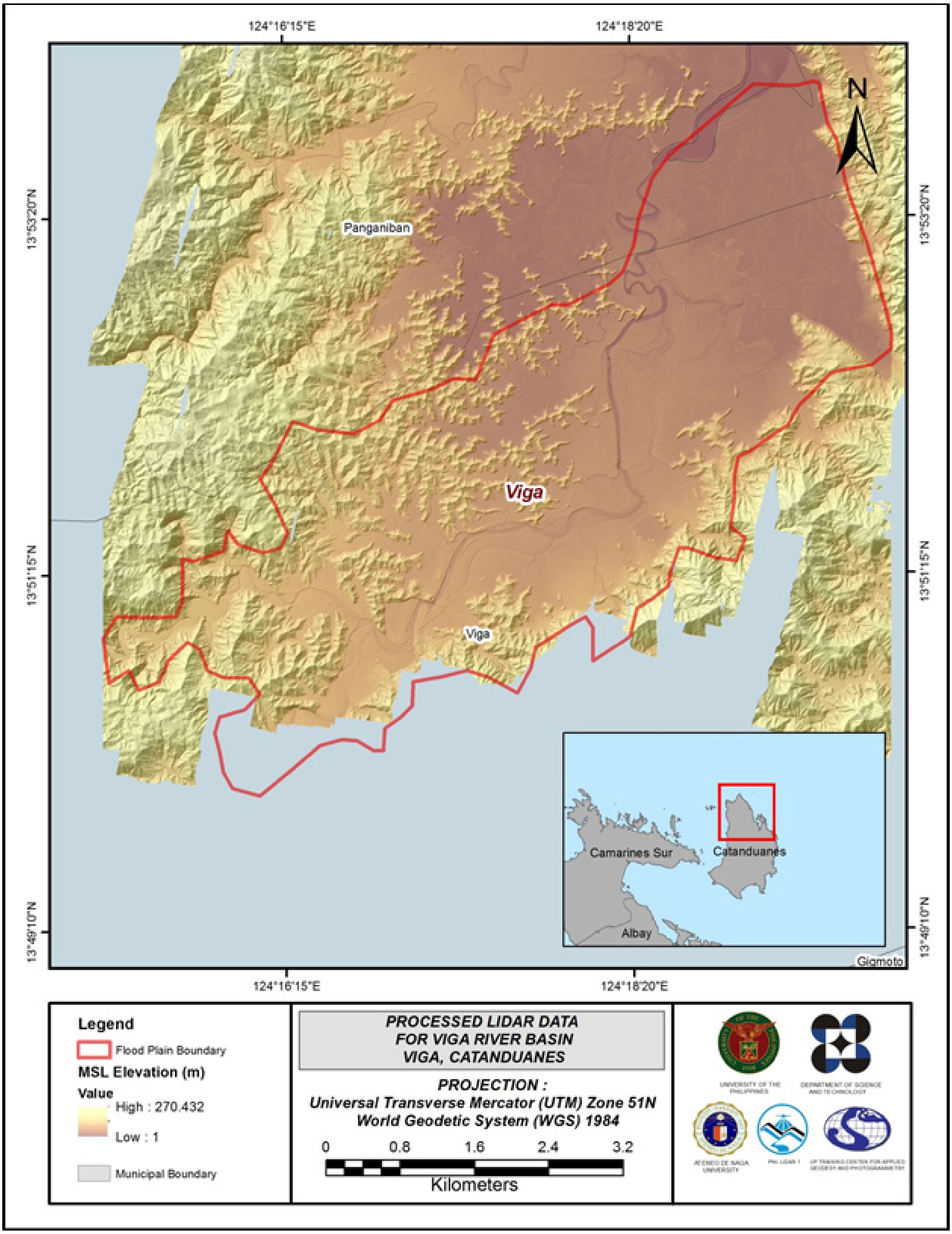


Figure 20. Map of Processed LiDAR Data for Viga Flood Plain.

3.10 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) to collect points in the whole of Catanduanes with which the LiDAR dataset is validated is shown in Figure 21. A total of 7,208 survey points were used for calibration and validation of Viga LiDAR data. Random selection of 80% of the survey points, resulting to 4,782 points, were used for calibration.

A good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values is shown in Figure 22. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration elevation values is 1.42 meters with a standard deviation of 0.10 meters. Calibration of Viga LiDAR data was done by subtracting the height difference value, 1.42 meters, to Viga mosaicked LiDAR data. Table 14 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

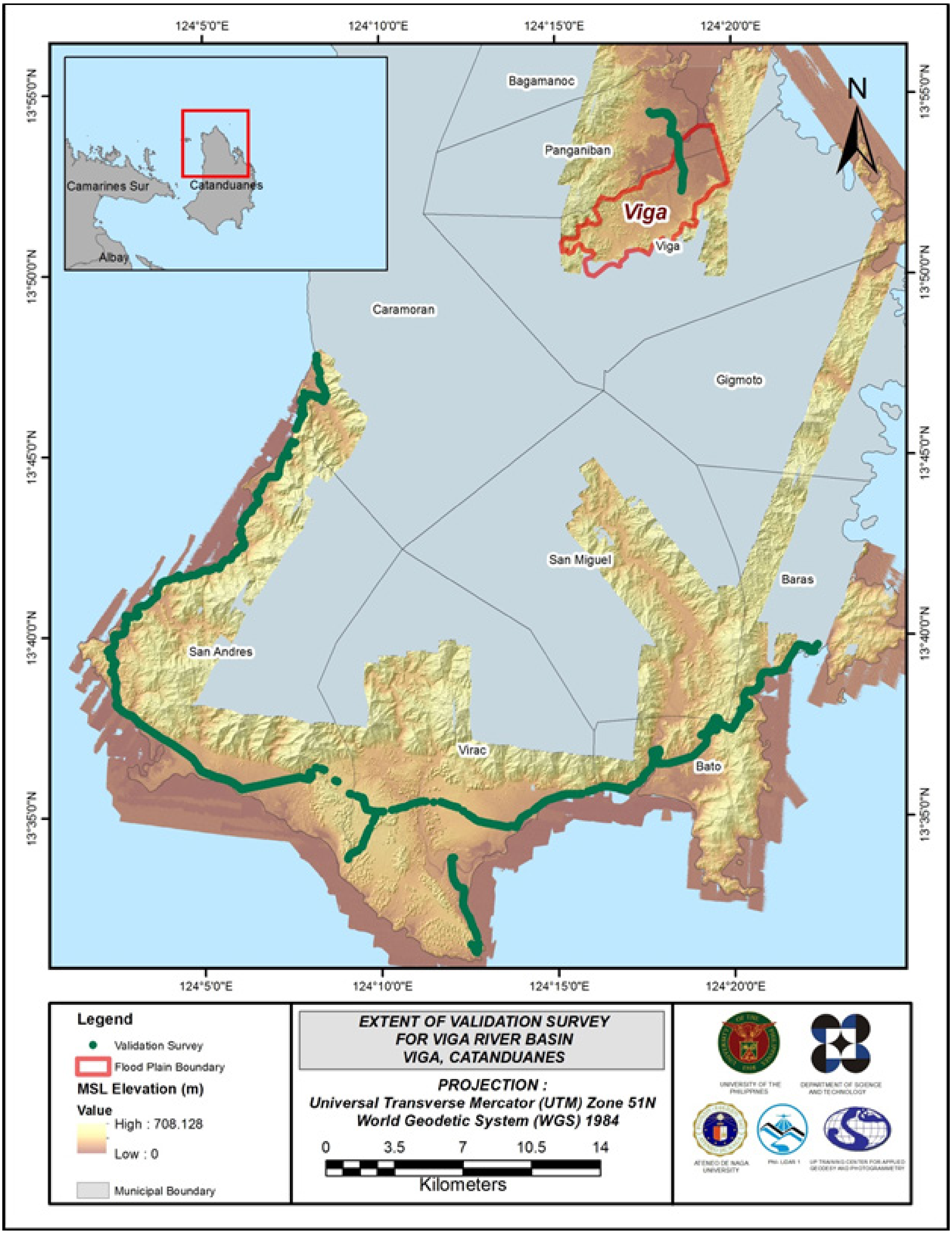


Figure 21. Map of Viga Floodplain with validation survey points in green.

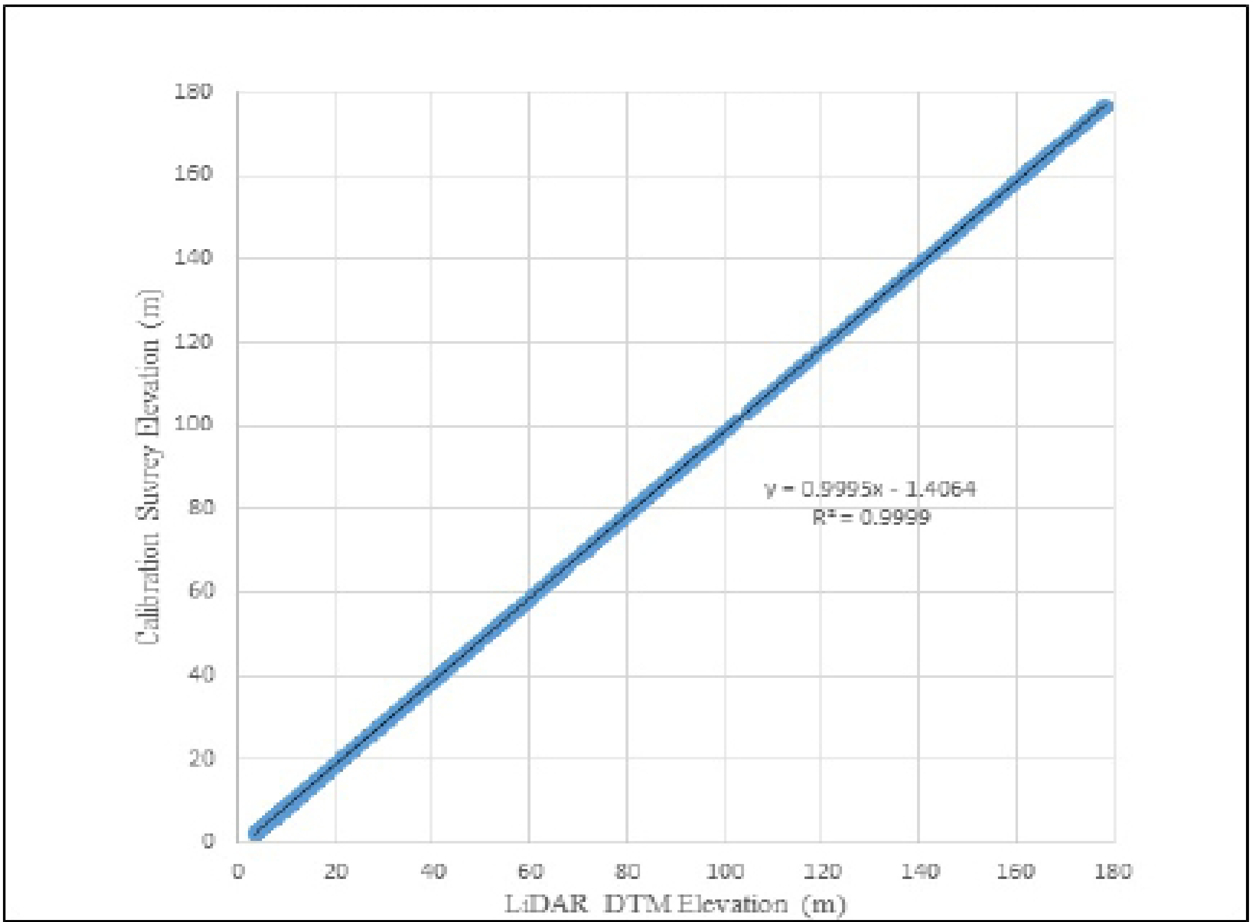


Figure 22. Correlation plot between calibration survey points and LiDAR data.

Table 14. Calibration Statistical Measures

Calibration Statistical Measures	Value (meters)
Height Difference	1.42
Standard Deviation	0.10
Average	-1.42
Minimum	-1.63
Maximum	-1.21

A total of 1,888 survey points lie within Viga flood plain and were used for the validation of the calibrated Viga 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 23. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.15 meters with a standard deviation of 0.14 meters, as shown in Table 15.

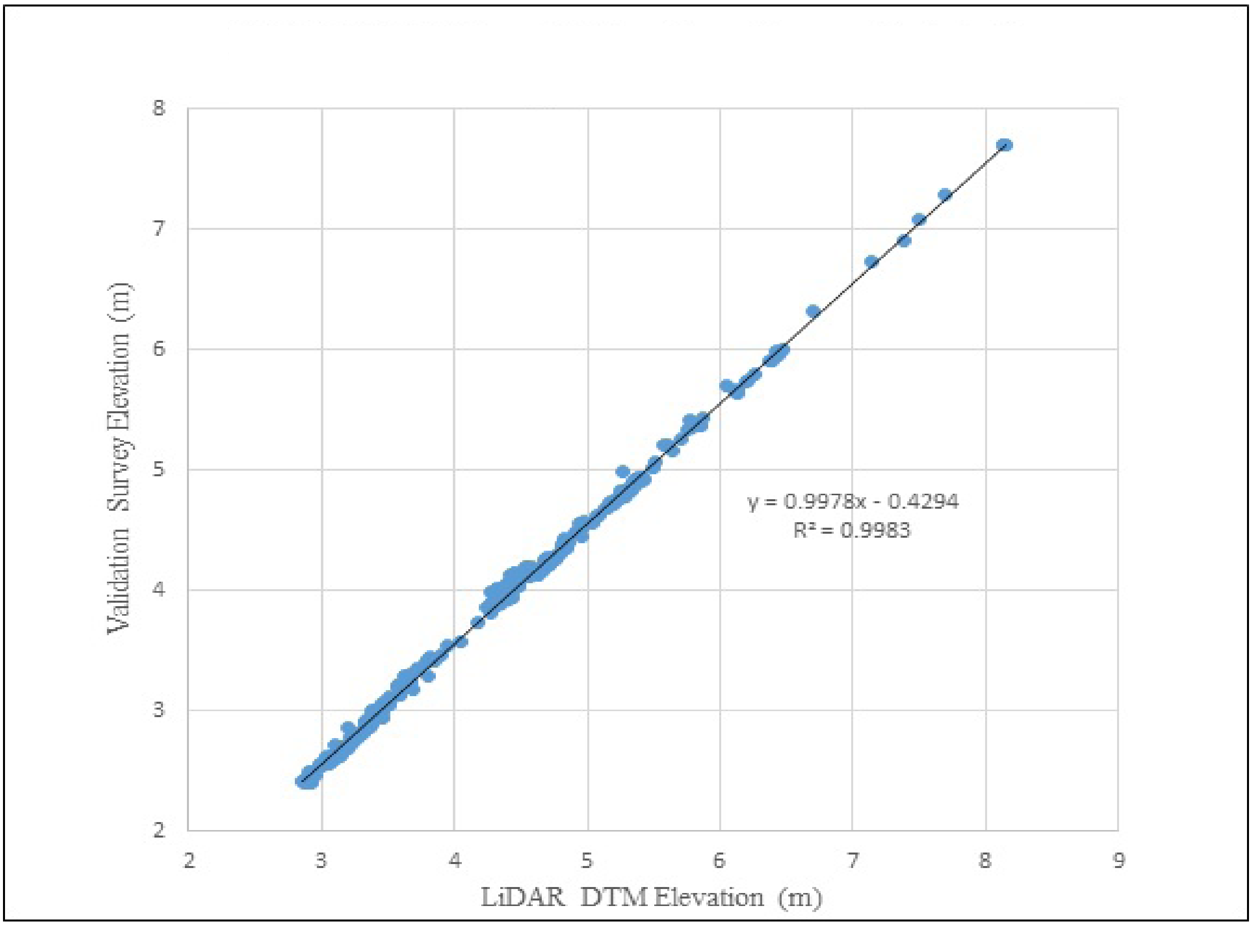


Figure 23. Correlation plot between validation survey points and LiDAR data.

Table 15. Validation Statistical Measures.

Validation Statistical Measures	Value (meters)
RMSE	0.15
Standard Deviation	0.14
Average	-0.04
Minimum	-0.45
Maximum	0.33

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and zigzag data were available for Viga with 7,128 bathymetric survey points. The resulting raster surface produced was done Kernel interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.64 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Viga integrated with the processed LiDAR DEM is shown in Figure 24.

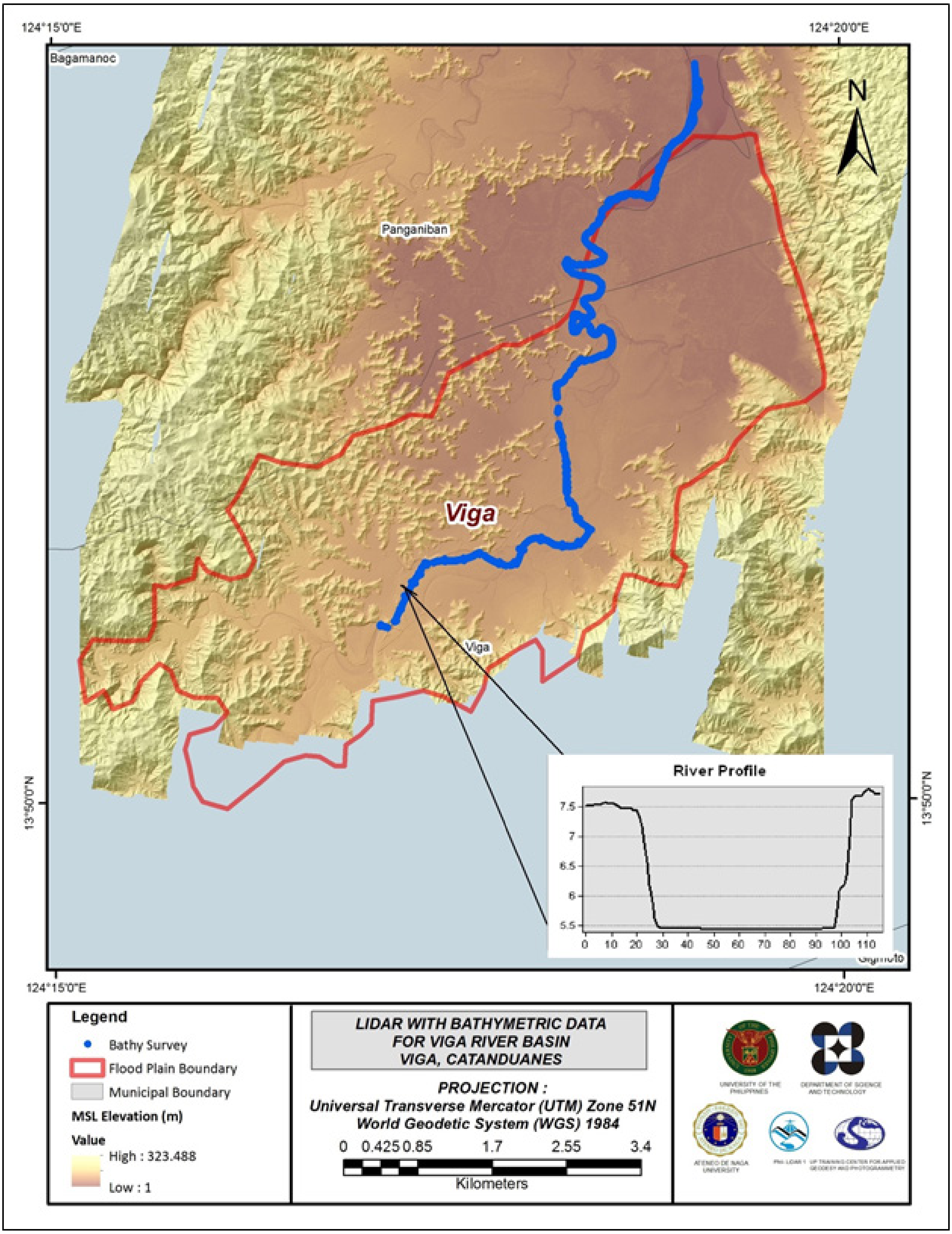


Figure 24. Map of Viga Floodplain with bathymetric survey points shown in blue.

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 (QC) of Digitized Features' Boundary

Viga floodplain, including its 200 m buffer, has a total area of 31.80 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 428 building features, are considered for QC. Figure 25 shows the QC blocks for Viga floodplain.

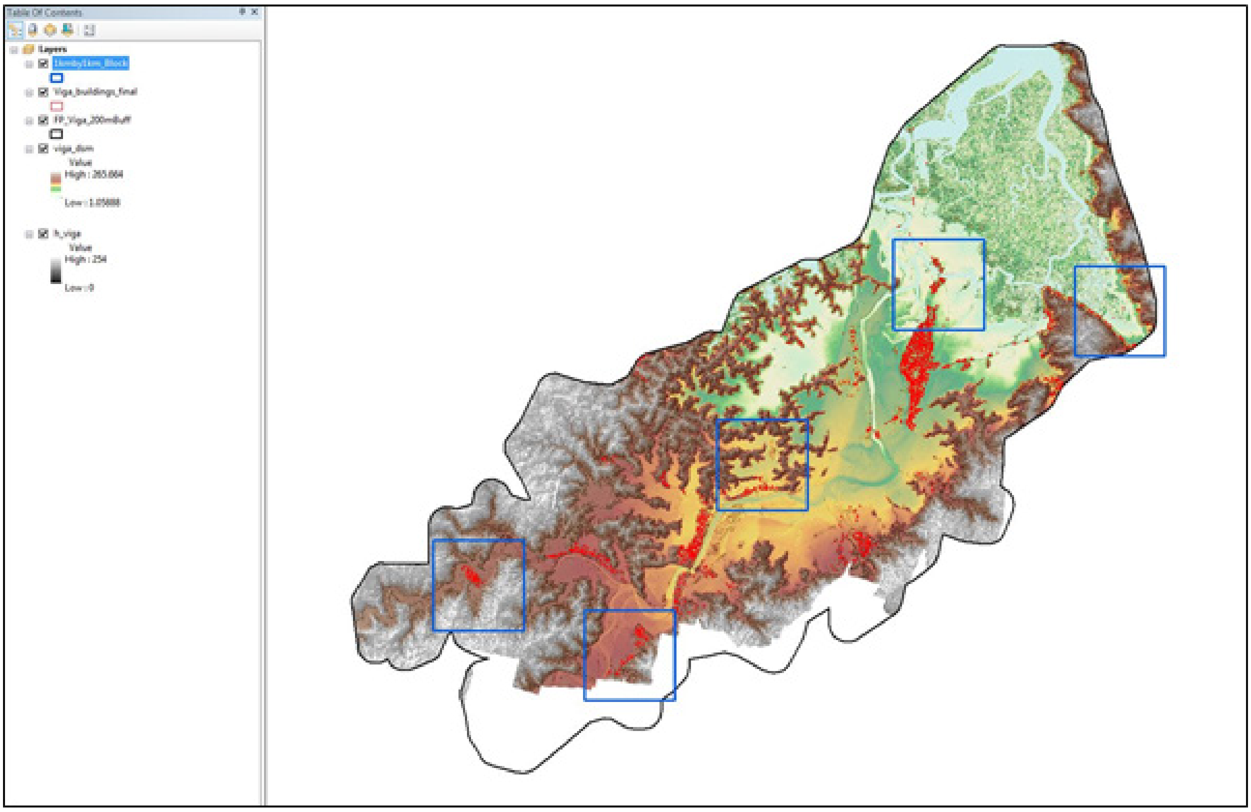


Figure 25. QC blocks for Viga building features.

Quality checking of Viga building features resulted in the ratings shown in Table 16.

Table 16. Quality Checking Ratings for Viga Building Features.

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Viga	100.00	100.00	98.02	PASSED

3.12.2 Height Extraction

Height extraction was done for 2,662 building features in Viga floodplain. Of these building features, 648 was filtered out after height extraction, resulting to 2,014 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 18.68 m.

3.12.3 Feature Attribution

Feature Attribution was done for 2,014 building features in Viga Floodplain with the use of participatory mapping and innovations. The approach used in participatory mapping undergoes the creation of feature extracted maps in the area and presenting spatial knowledge to the community with the premise that the local community in the area are considered experts in determining the correct attributes of the building features in the area.

The innovation used in this process is the creation of an android application called reGIS. The Resource Extraction for Geographic Information System (reGIS)[1][1] app was developed to supplement and increase the field gathering procedures being done by the AdNU Phil-LiDAR 1. The Android application allows the user to automate some procedures in data gathering and feature attribution to further improve and accelerate the geotagging process. The app lets the user record the current GPS location together with its corresponding exposure features, code, timestamp, accuracy and additional remarks. This is all done by a few swipes with the help of the device's pre-defined list of exposure features. This effectively allows unified and standardized sets of data.

Table 17 summarizes the number of building features per type. On the other hand, Table 18 shows the total length of each road type, while Table 19 shows the number of water features extracted per type.

Table 17. Building Features Extracted for Viga Floodplain.

Facility Type	No. of Features
Residential	1,853
School	69
Market	6
Agricultural/Agro-Industrial Facilities	0
Medical Institutions	4
Barangay Hall	15
Military Institution	0
Sports Center/Gymnasium/Covered Court	0
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	2
Power Plant/Substation	0
NGO/CSO Offices	2
Police Station	0
Water Supply/Sewerage	0
Religious Institutions	26
Bank	0
Factory	0
Gas Station	1
Fire Station	0
Other Government Offices	11
Other Commercial Establishments	25
Total	**2,014**

1 Resource Extraction for Geographic Information System (reGIS), 17 March 2015

Table 18. Total Length of Extracted Roads for Viga Floodplain.

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Viga	22.96	0	25.39	0	0	48.35

Table 19. Number of Extracted Water Bodies for Viga Floodplain.

Floodplain	Water Body Type					Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Viga	1	19	0	0	0	20

A total of 10 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 26 shows the Digital Surface Model (DSM) of Viga floodplain overlaid with its ground features.

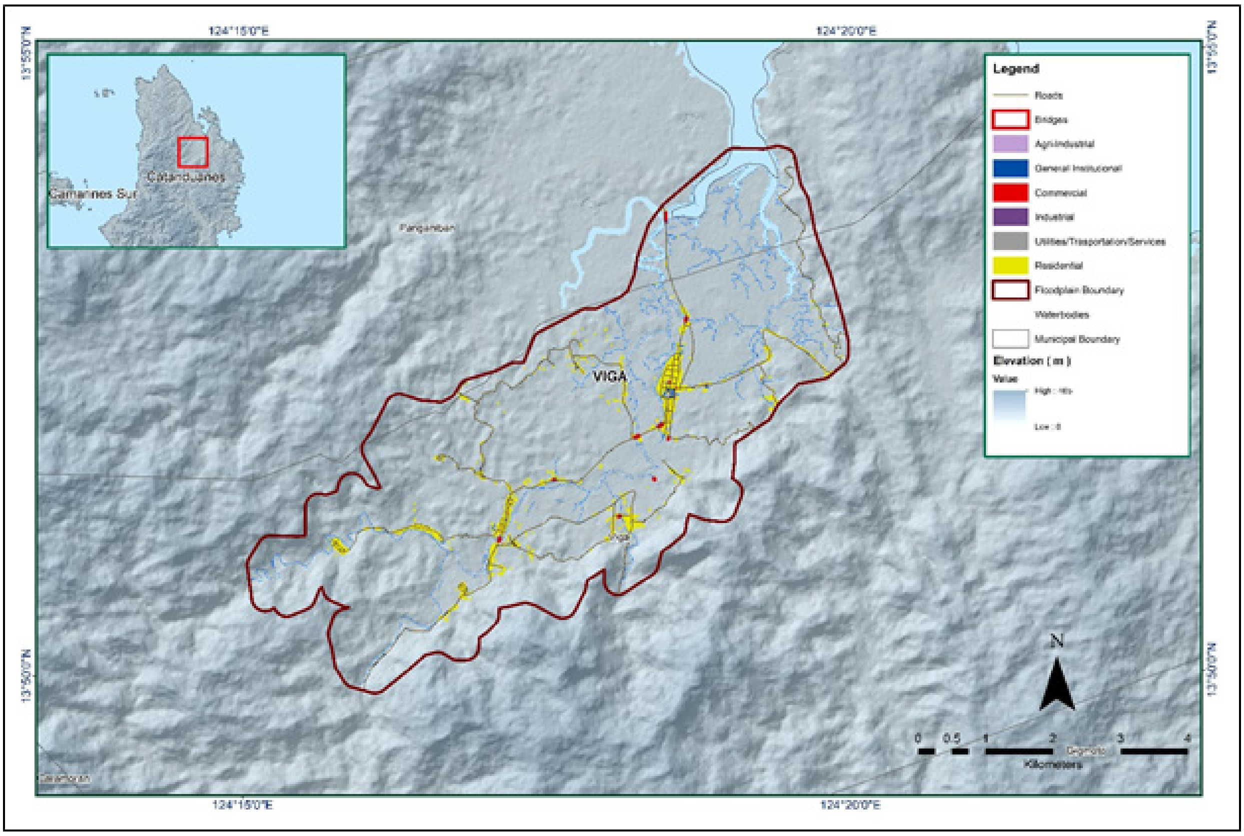


Figure 26. Extracted features for Viga floodplain.

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

Engr. Louie P. Balicanta, Engr. Joemarie S. Caballero, Ms. Patrizcia Mae. P. dela Cruz, Engr. Kristine Ailene B. Borromeo, For. Dona Rina Patricia C. Tajora, Elaine Bennet Salvador, For. Rodel C. Alberto, Cybil Claire Atacador, Engr. Lorenz R. Taguse

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 Viga River Basin covers three (3) municipalities in Catanduanes namely: Viga, Caramoran, and part of Panganiban. According to DENR -River Basin Control Office, it has a drainage area of 103 km2 and an estimated 196 million cubic meter (MCM) annual run-off of (RCBO, 2015).

Its main stem, Viga River, is part of the 24 river systems in the Bicol Region. According to the 2010 national census of NSO, a total of 4,595 locals are residing in the immediate vicinity of the river which are distributed among eight (8) barangays in Municipality of Viga. The income-generating industries in the province are service, agriculture, tourism, cottage industry, and manufacturing. (Philippine Statistics Authority Bicol Region, 2014). Last May 2015, the Catanduanes province experienced Tropical Storm Noul, locally known as “Dodong”, which brought with it strong winds reaching 160 kph, and heavy rains which placed the province under Public Storm Warning Signal Number 2 (Sunstar, 2015).

In line with this, DVBC conducted a field survey in Viga River on April 8 to 22, 2016 with the following scope of work: reconnaissance; control survey; cross-section survey and as-built survey at Pilot Bridge; validation points acquisition of about 87.267 km covering the Municipalities of Caramoran, San Andres, Virac, Bato, Baras, Panganiban and Viga; and bathymetric survey from its upstream in Brgy. San Jose Oco, Municipality of Viga down to the mouth of the river in Brgy. San Joaquin, Municipality of Panganiban, with an approximate length of 9.117 km using Ohmex™ single beam echo sounder and Trimble® SPS 882 GNSS PPK survey technique as shown Figure 27.

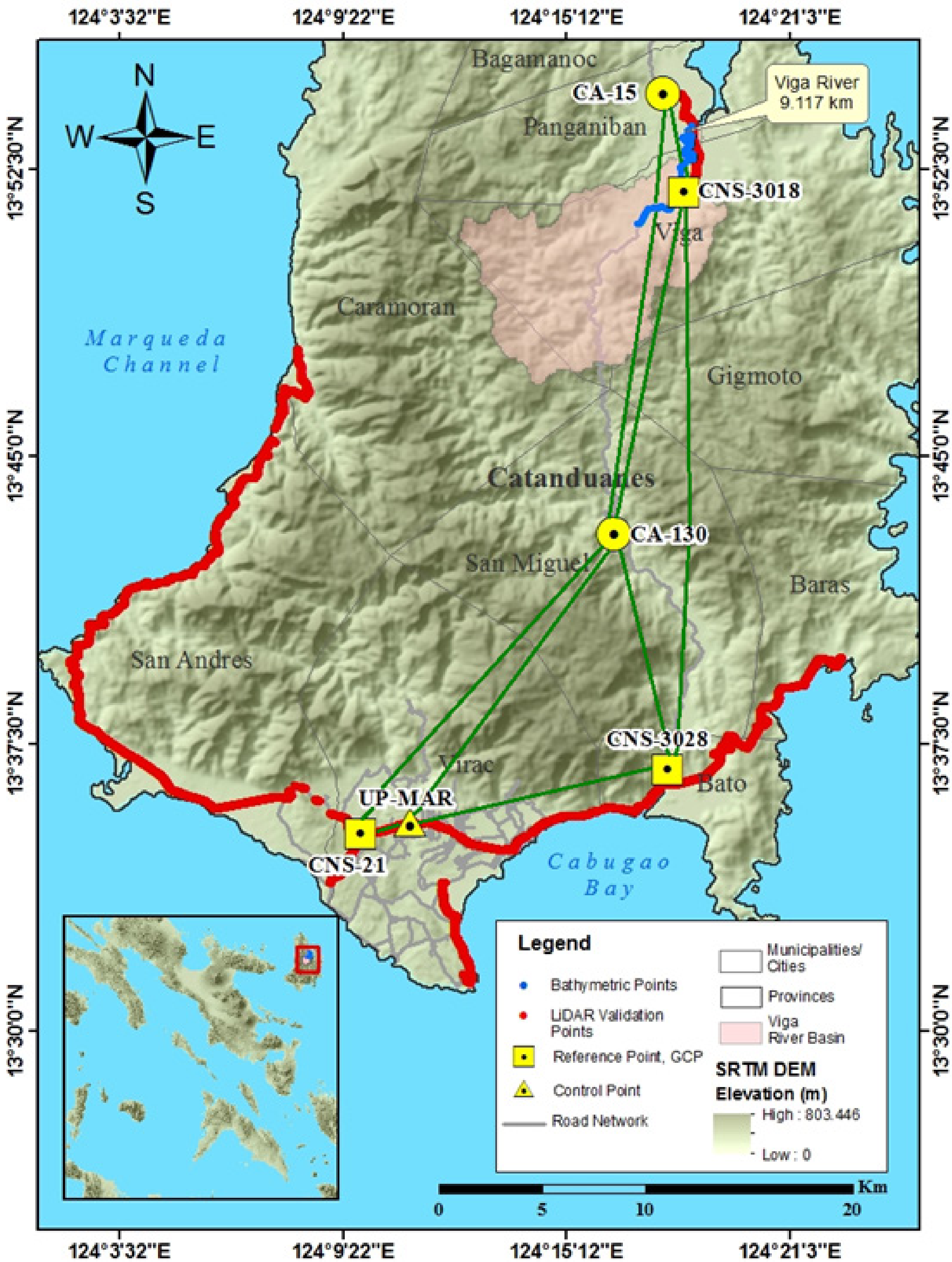


Figure 27. Survey extent for Viga River Basin

4.2 Control Survey

The GNSS network used for Viga River Basin is composed of four (4) loops established on April 9 and 10, 2016 occupying the following reference points: CNS-21, a second-order GCP, in Brgy. Palta Small, Municipality of Virac; and, CA-130, a first-order BM, in Brgy. Balatohan, Municipality of San Miguel.

The UP established control point UP-MAR located at the approach of Marcos Bridge in Brgy. Bigaa, Municipality of Virac; and NAMRIA established control points, namely CA-15 in Brgy. Sta. Maria, Municipality of Panganiban, CNS-3018 in Brgy. San Isidro, Muncipality of Viga, and CNS-3028 in Brgy. Tilis, in Municipality of Bato; were also occupied and used as marker for the network.

The summary of reference and control points and its location is summarized in Table 20. while GNSS network established is illustrated in Figure 28.

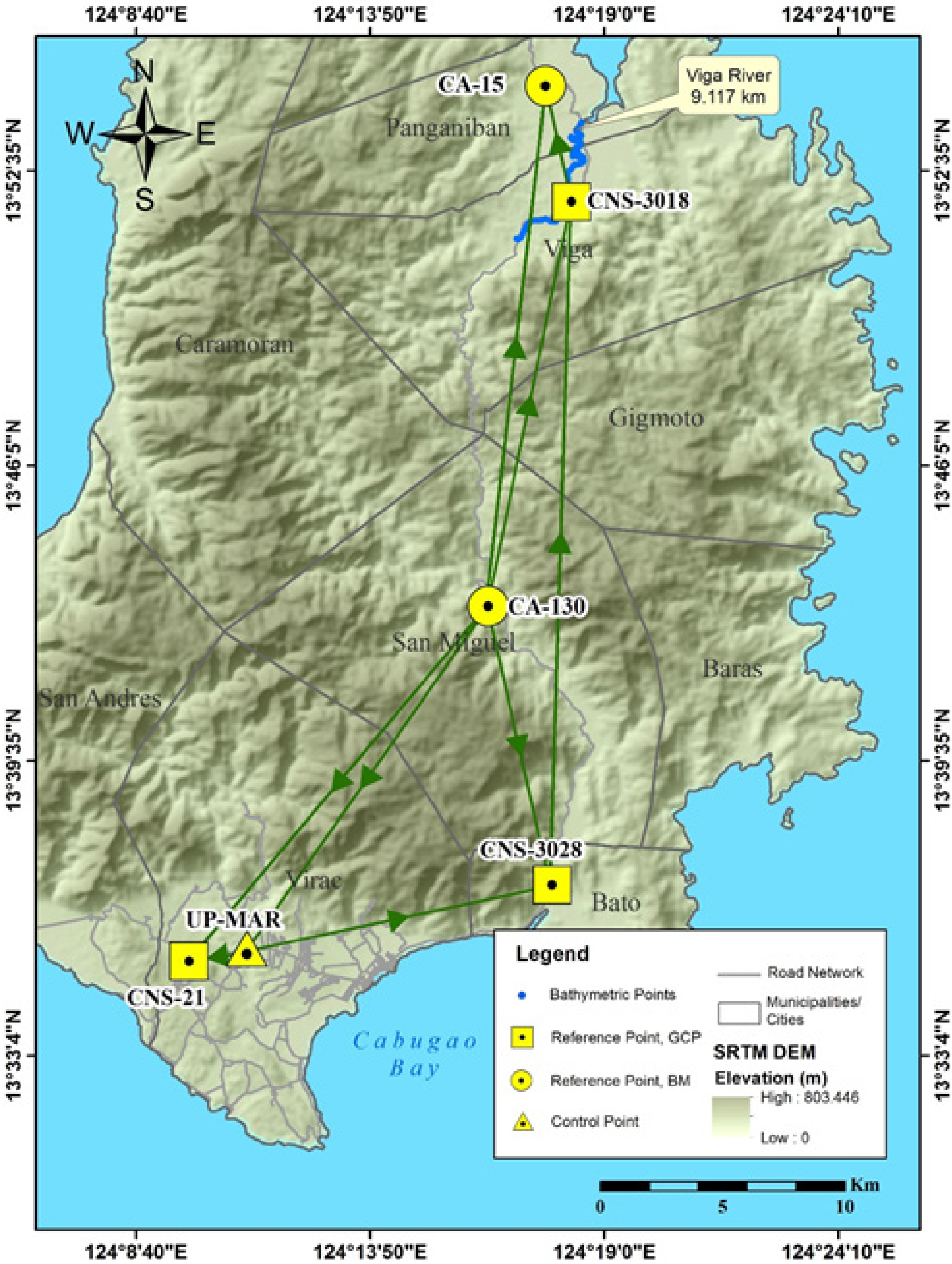


Figure 28. GNSS Network of Viga River field survey

Table 20. List of reference and control points occupied for Viga 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
CNS-21	2nd Order, GCP	13°35'09.45275" N	124°09'50.36457"	136.082	-	2007
CA-130	1st order Order, BM	-	-	90.506	37.6703	2008
CA-15	Used as Marker	-	-	-	-	2008
CNS-3018	Used as Marker	-	-	-	-	2007
CNS-3028	Used as Marker	-	-	-	-	2007
UP-MAR	UP Established	-	-	-	-	04-09-06

The GNSS set-ups on recovered reference points and established control points in Viga River are shown in Figure 29 to Figure 34.

Figure 29. GNSS base set up, Trimble® SPS 882, at CNS-21, located at the approach of Palta Bridge in Brgy. Palta Small, Municipalit of Virac, Catanduanes

Figure 30. GNSS base set up, Trimble® SPS 882, at CA-130, located at the end of path walk in Brgy. Balatohan, Municipality of San Miguel, Catanduanes

Figure 31. GNSS base set up, Trimble® SPS 882, at CA-15, located at the approach of the left side of Kanparel Bridge in Brgy. Santa Maria, Municipality of Panganiban, Catanduanes

Figure 32. GNSS base set up, Trimble® SPS 882, at CNS-3018, located at the approach of Pilot Bridge along Catanduanes Circumferential Road in Brgy. San Isidro, Municipality of Viga, Catanduanes

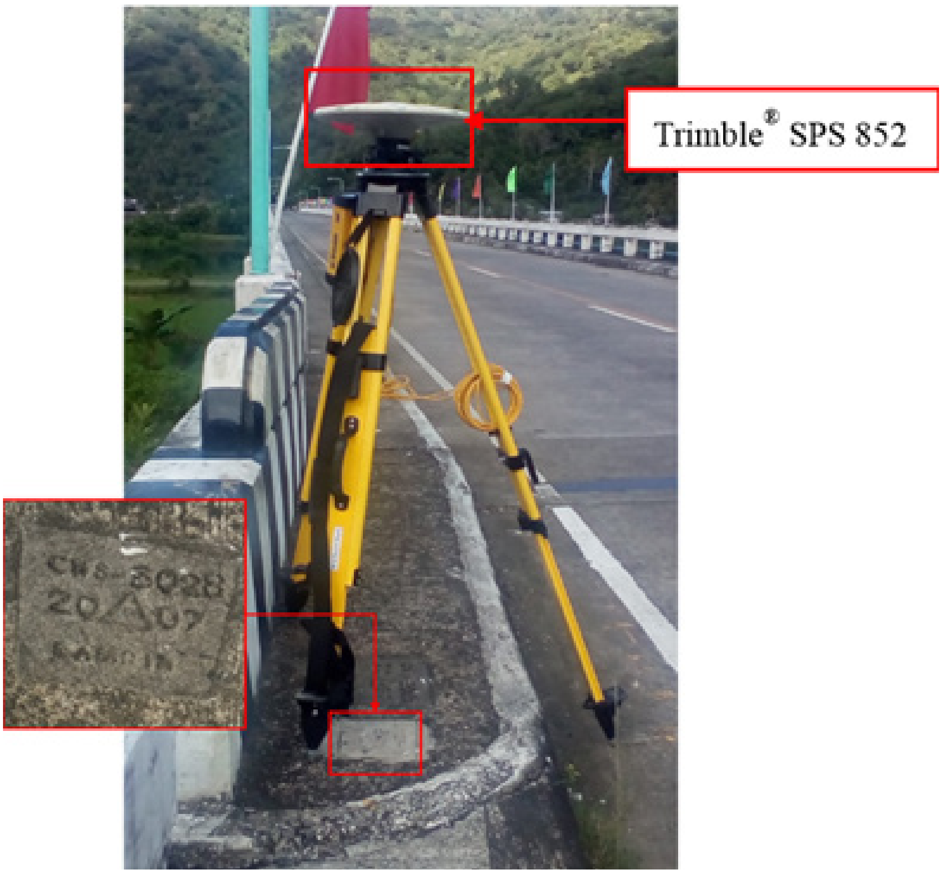


Figure 33. GNSS base set up, Trimble® SPS 852, at CNS-3028, located at the approach of Bato Bridge along Catanduanes Circumferential Road in Brgy. Tilis, Municipality of Bato, Catanduanes

Figure 34. GNSS base set up, Trimble® SPS 852, at CNS-3028, located at the approach of Bato Bridge along Catanduanes Circumferential Road in Brgy. Tilis, Municipality of Bato, Catanduanes

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 Viga River Basin is summarized in Table 21. generated by TBC software.

Table 21. Baseline Processing Report for Viga River Basin Static Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)
CNS-3018--- CA-15	04-10-16	Fixed	0.003	0.016	347°50'15"	4831.606
CNS-3028--- CNS-3018	04-10-16	Fixed	0.002	0.014	1°35'28"	27798.226
CA-130 --- CNS-3028	04-09-16	Fixed	0.004	0.024	167°24'47"	11614.119
CNS-3028--- CA-130	04-09-16	Fixed	0.003	0.012	167°24'48"	11614.112
CA-130 --- CNS-21	04-09-16	Fixed	0.003	0.016	219°31'42"	18701.297
CA-130 --- CA-15	04-10-16	Fixed	0.003	0.006	6°08'58"	21298.173
CA-130 --- CNS-3018	04-10-16	Fixed	0.003	0.015	11°20'31"	16780.283
CA-130 --- CNS-3018	04-10-16	Fixed	0.003	0.014	11°20'31"	16780.296
UP-MAR --- CNS-3028	04-09-16	Fixed	0.004	0.023	78°00'02"	12411.353
UP-MAR --- CA-130	04-09-16	Fixed	0.003	0.011	34°37'02"	16907.625
UP-MAR --- CNS-21	04-09-16	Fixed	0.002	0.009	77°20'46"	2349.293

As shown in Table 20 a total of eleven (11) baselines were processed with reference points CNS-21 fixed for grid values; and CA-130 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 22 of the TBC generated Network Adjustment Report, it is observed that the square root of the sum of the squares of x and y must be less than 20 cm and z less than 10 cm or in equation form:

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

Where:

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

for each control point. See the Network Adjustment Report shown in Table 21 to Table 23 for the complete details.

The six (6) control points, CNS-21, CA-130, CA-15, CNS-3018, CNS-3028 and UP-MAR were occupied and observed simultaneously to form a GNSS loop. Elevation value of CA-130 and coordinates of point CNS-21 were held fixed during the processing of the control points as presented in Table 21. Through these reference points, the coordinates and elevation of the unknown control points will be computed.

Table 22. Control Point Constraints

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
CNS-21	Local	Fixed	Fixed		
CA-130	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 23. The fixed control point CNS-21 has no values for grid error; while CA-130 has no values for elevation errors.

Table 23. Adjusted Grid Coordinates

Point ID	Easting	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
CNS-21	625929.746	?	1502236.721	?	83.792	0.087	LL
CA-130	637754.301	0.014	1516720.821	0.012	37.670	?	e
CA-15	639923.023	0.020	1537904.832	0.017	9.219	0.048	
CNS-3018	640966.615	0.017	1533188.045	0.014	9.300	0.067	
CNS-3028	640344.326	0.018	1505401.099	0.014	12.262	0.073	
UP-MAR	628219.036	0.012	1502762.192	0.010	20.754	0.074	

The network is fixed at reference point CNS-21 with known coordinates; and CA-130 with known elevation. As shown in Table C-4, the standard errors (xe and ye) of CA-130 are 1.40 cm and 1.2 cm; CA-15 are 2.0 cm and 1.7 cm; CNS-3018 are 1.7 cm and 1.40 cm; CNS-3028 are 1.80 cm and 1.40cm; and UP-MAR are 1.20 cm and 1 cm. With the mentioned equation, $\sqrt{((x_e)^2 + (y_e)^2)}$ <20cm and $z_e < 10\ cm$, <20cm for horizontal and z_e<10 cm for the vertical; the computation for the accuracy are as follows:

a. CNS-21

horizontal accuracy	=	Fixed
vertical accuracy	=	8.7 cm< 10 cm

b. CA-130

horizontal accuracy	=	√((1.4)² + (1.2)²
	=	√ (1.96 + 1.44)
	=	1.84 cm < 20 cm
vertical accuracy	=	Fixed

c. CA-15

horizontal accuracy	=	√((2.0)² + (1.7)²
	=	√ (4 + 2.89)
	=	2.62 cm < 20 cm
vertical accuracy	=	4.8 cm < 20 cm

d. CNS-3018

horizontal accuracy	=	√((1.7)² + (1.4)²
	=	√ (2.89+ 1.96)
	=	2.20 cm < 20 cm
vertical accuracy	=	6.7 cm < 10 cm

e. CNS-3028

horizontal accuracy	=	√((1.8)² + (1.4)²
	=	√ (3.24+ 1.96)
	=	2.28 cm < 20 cm
vertical accuracy	=	7.3 cm < 10 cm

f. UP-MAR

horizontal accuracy	=	√((1.2)² + (1.0)²
	=	√ (1.44+ 1)
	=	1.56 cm < 20 cm
vertical accuracy	=	7.4 cm < 10 cm

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

Table 24. Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
CNS-21	N13°35'09.45275"	E124°09'50.36457"	136.082	0.087	LL
CA-130	N13°42'58.90071"	E124°16'26.29487"	90.506	?	e
CA-15	N13°54'27.92390"	E124°17'42.29172"	61.912	0.048	
CNS-3018	N13°51'54.24025"	E124°18'16.19947"	62.000	0.067	
CNS-3028	N13°36'50.06664"	E124°17'50.49382"	64.549	0.073	
UP-MAR	N13°35'26.19548"	E124°11'06.61522"	73.091	0.074	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 24. Based on the result of the computation, the accuracy conditions are satisfied; hence, the required accuracy for the program was met.

The summary of reference and control points used is indicated in Table 25.

Table 25. Reference and control points used and its location (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing	Easting	BM Ortho (m)
CNS-21	2nd order, GCP	13°35'09.45275"	124°09'50.36457"	136.082	1502236.721	625929.746	83.792
CA-130	1st Order, BM	13°42'58.90071"	124°16'26.29487"	90.506	1516720.821	637754.301	37.67
CA-15	Used as Marker	13°54'27.92390"	124°17'42.29172"	61.912	1537904.832	639923.023	9.219
CNS-3018	Used as Marker	13°51'54.24025"	124°18'16.19947"	62.000	1533188.045	640966.615	9.300
CNS-3028	Used as Marker	13°36'50.06664"	124°17'50.49382"	64.549	1505401.099	640344.326	12.262
UP-MAR	Used as Marker	13°35'26.19548"	124°11'06.61522"	73.091	1502762.192	628219.036	20.754

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

Cross-section survey was conducted on April 18, 2016 at the downstream part of Pilot Bridge in Brgy. San Isidro, Municipality of Viga, Catanduanes, using a GNSS receiver, Trimble® SPS 882, in PPK survey technique, as shown in Figure 35.

Figure 35. Cross-Section Survey at Pilot Bridge

The cross-sectional line length of the deployment site is about 142.247 m with 19 cross-sectional points acquired using CNS-3018 as the GNSS base station. The location map, cross-section diagram, and bridge as-built form are illustrated in Figure 36 to Figure 37, respectively.

Water surface elevation in MSL of Viga River was determined using Trimble® SPS 882 in PPK mode technique on April 18, 2016 at 9:59 AM with a value of 2.571 m in MSL. The value was translated onto one of the piers of Pilot Bridge which will serve as reference for flow data gathering and depth gauge deployment.

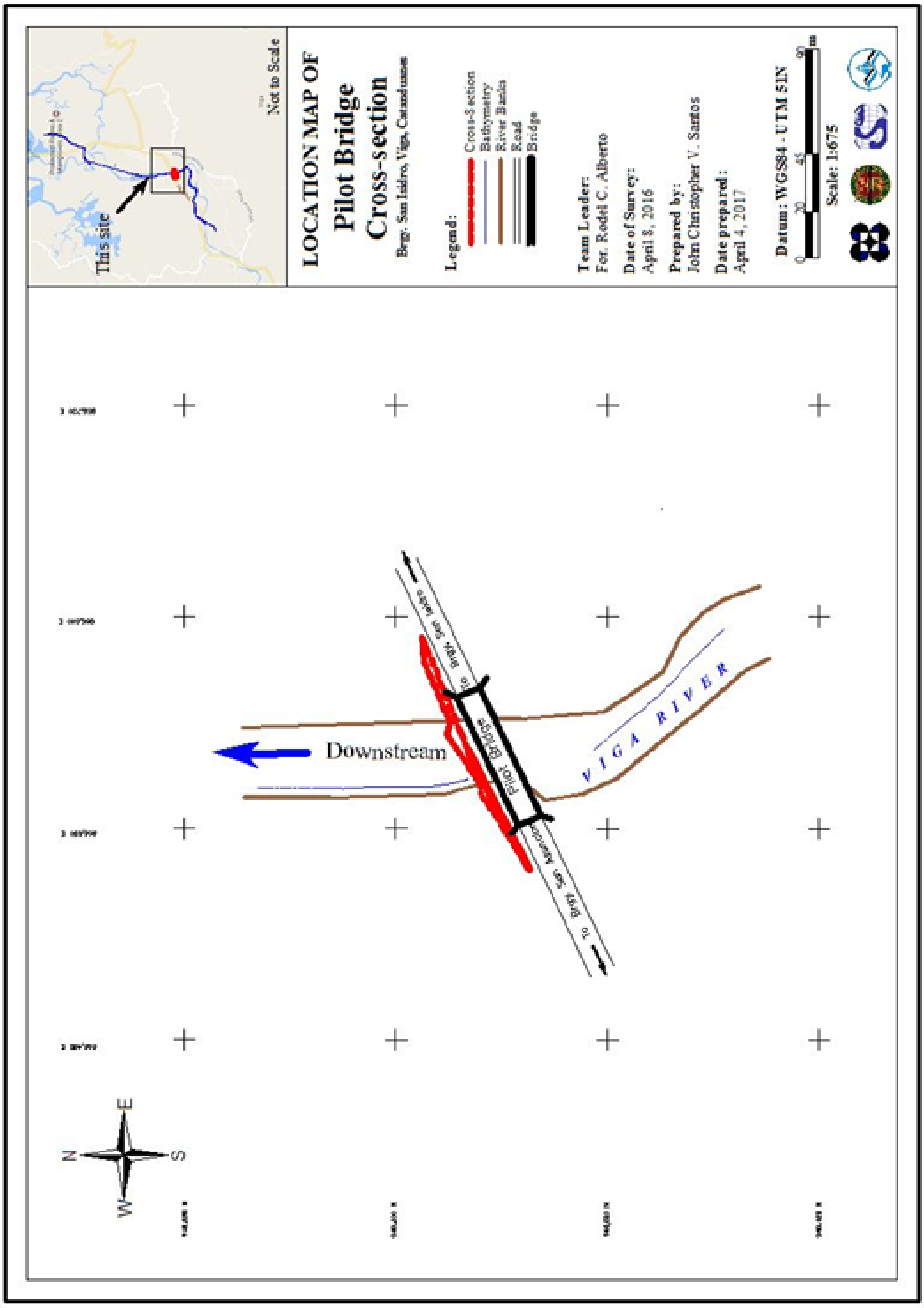


Figure 36. Pilot bridge cross-section location map

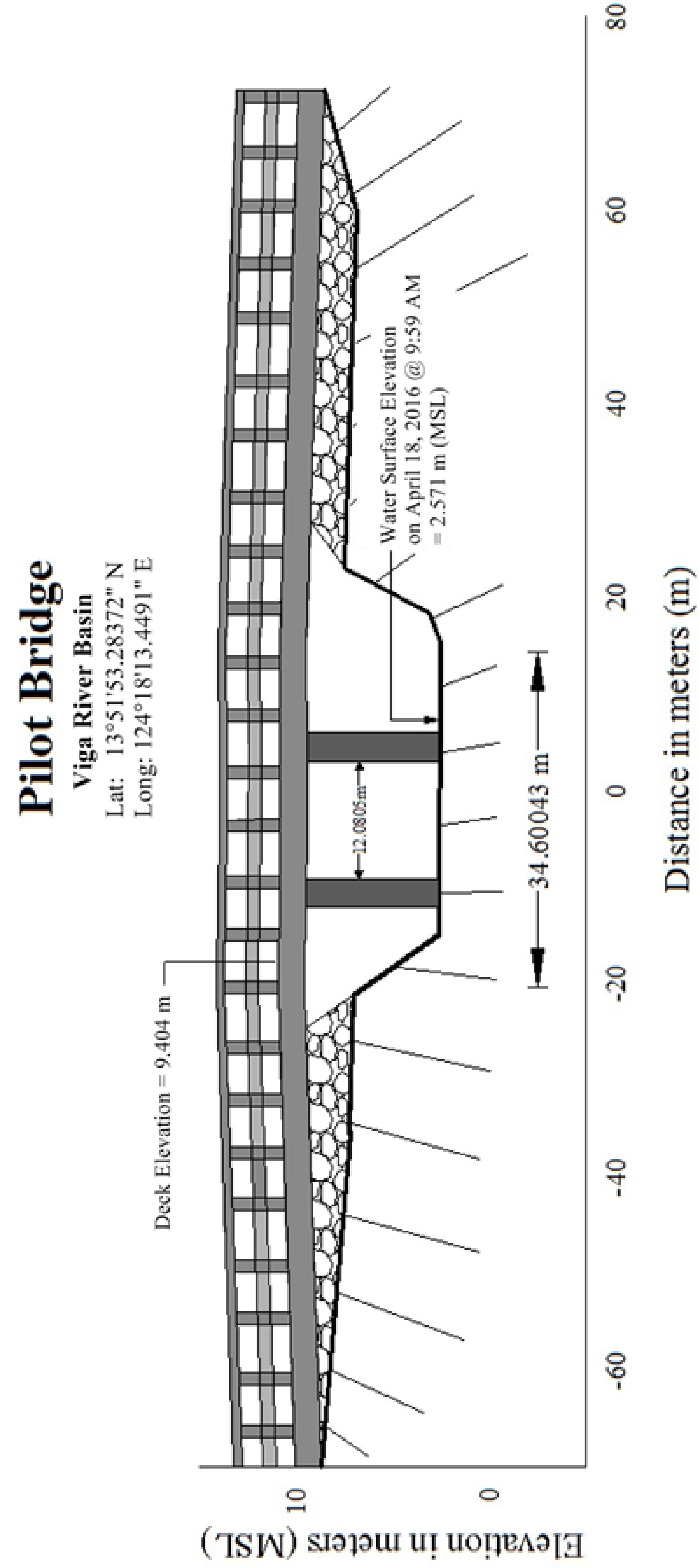


Figure 37. Viga River Cross-section Diagram

Bridge Data Form

Bridge Name: Pilot Bridge — **Date:** April 18, 2016

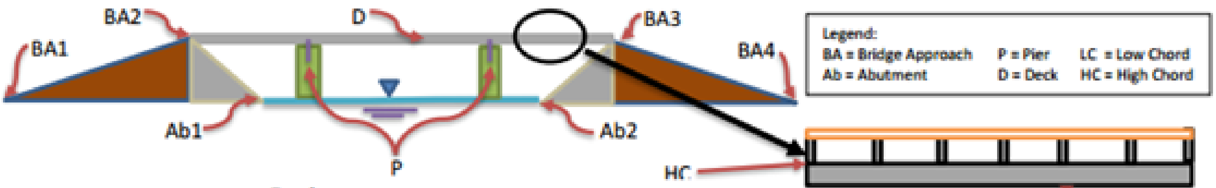
River Name: Viga River — **Time:** 09:48 AM

Location (Brgy, City,Region): Brgy. San Isidro, Municipality of Viga, Catanduanes

Survey Team: Mark Rojas, Marla Morris, Lorenz Taguse

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

Latitude: 13°51'53.28372" N — **Longitude:** 124°18'13.44991" E



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

Elevation: 9.404 m — **Width:** 6.3 m — **Span (BA3-BA2):** 34.60 m

	Station	High Chord Elevation	Low Chord Elevation
1	49.60609 m	9.539 m	7.399 m
2	59.24861 m	9.440 m	7.300 m
3	65.20736 m	9.404 m	7.264 m
4	74.31162 m	9.400 m	7.260 m
5	84.20653 m	9.446 m	7.306 m
6	142.2471 m	8.547 m	6.357 m

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	8.614 m	BA3	84.207 m	9.446 m
BA2	49.606 m	9.539 m	BA4	142.2472 m	8.497 m

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

	Station (Distance from BA1)	Elevation
Ab1	85.139 m	2.468 m
Ab2	55.010 m	2.571 m

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

Shape: Cylindrical — Number of Piers: 2 — Height of column footing: N/A

	Station (Distance from BA1)	Elevation	Pier Width
Pier 1	59.249 m	9.440 m	1.0 m
Pier 2	74.312 m	9.400 m	1.0 m

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

Figure 38. Pilot bridge as-built form

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on April 9, 10, 11, and 12, 2016 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted on a roof of a vehicle as shown in Figure 39. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The antenna height was 1.935 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 CNS-3018, CNS-30-28, and UP-MAR occupied as the GNSS base stations in the conduct of the survey.

Figure 39. Validation points acquisition survey set up

The survey started from Brgy. Inalmasinan in the Municipality of Caramoan, going south towards the municipalities of San Andres, Virac, Bato, and ended in Brgy. Bagong Sirang, Municipality of Baras. This route aims to cut flight strips perpendicularly. The survey gathered 10,379 points with approximate length of 87.267 km using UP-MAR, CNS-3028, and CNS-3018 as GNSS base stations for the entire extent validation points acquisition survey, as illustrated in the map in Figure 40.

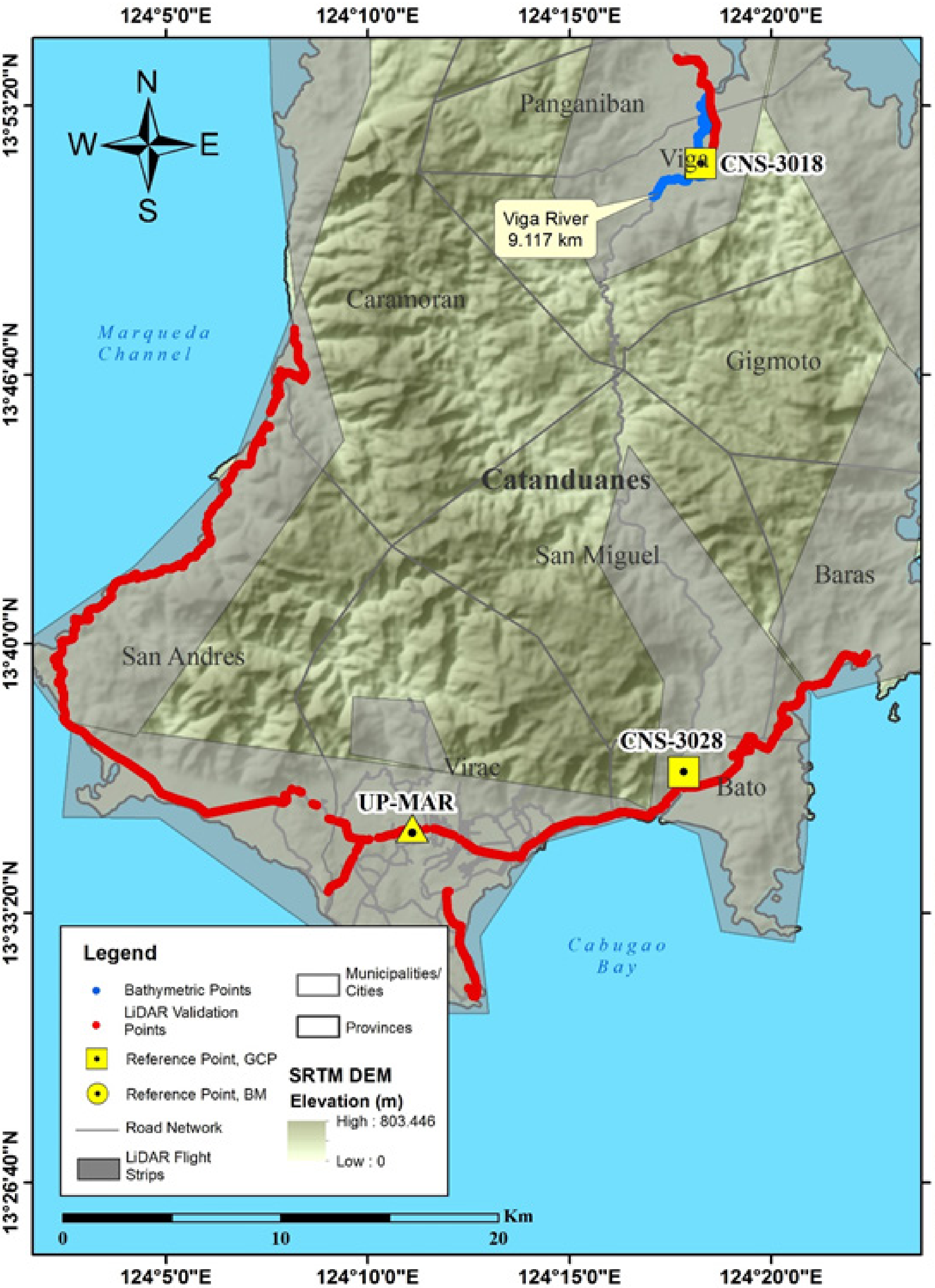


Figure 40. Validation point acquisition survey for Viga River Basin

4.7 River Bathymetric Survey

Bathymetric survey was executed on April 15 and 16, 2016 using a Trimble® SPS 882 in GNSS PPK survey technique and Ohmex™ single beam echo sounder, as illustrated in Figure 41. The extent of the survey using the Ohmex™ single beam echo sounder is, from mid portion of the river, in Brgy. San Isidro, Municipality of Viga with coordinates 13°51'54.37481"N, 124°18'15.43947"E, down to the mouth of the river in the same Brgy. San Joaquin, Municipality of Panganiban with coordinates 13°53'39.46662"N, 124°18'30.02101"E.

Manual bathymetric survey was done on April 16 using a Trimble® SPS 882 GNSS PPK survey technique as shown in Figure 41. The survey began from the upstream portion of the river in Brgy. San Jose Oco, in the Municipality of Viga with coordinates 13°51'06.72643"N, 124°17'09.73688"E; traversed down by foot and ended at the starting point of bathymetric survey using a boat in the same barangay. The control points CA-15 and CNS-3018, were occupied as the GNSS base stations all throughout the surveys. The survey did not cover 1.5 km from the planned bathymetry line because the areas are unaffected by flooding as determined by the partner HEI, Ateneo de Naga University.

Figure 41. Bathymetry by boat set up for Viga River survey

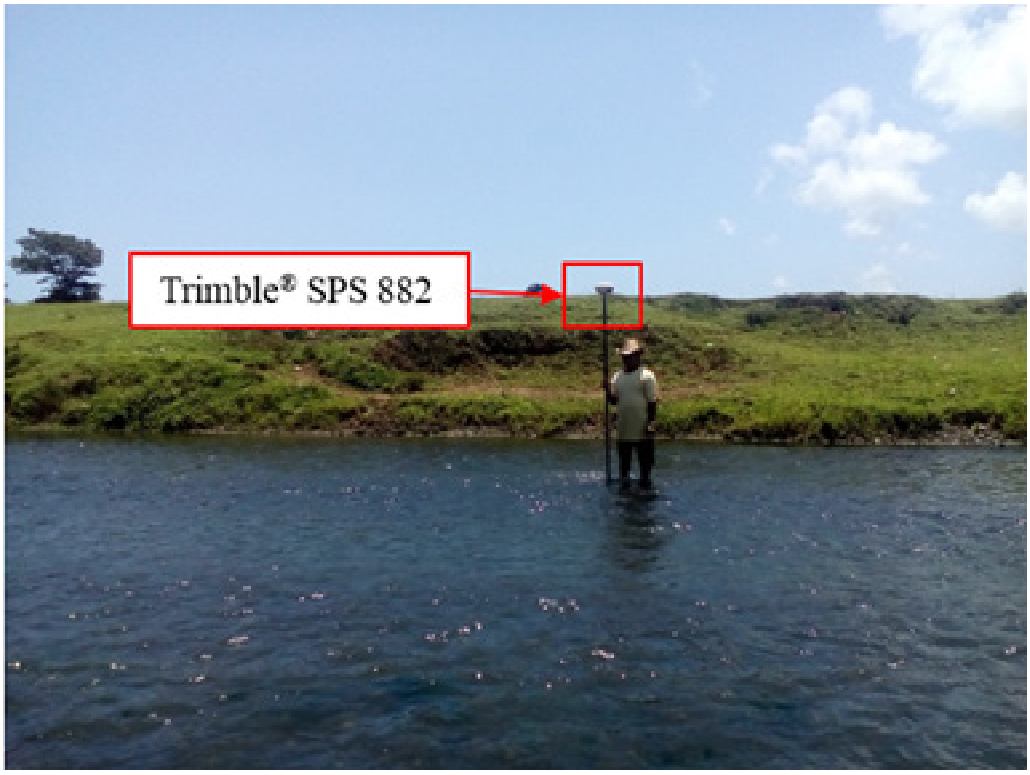


Figure 42. Manual bathymetry set-up for Viga River survey

A CAD drawing was also produced to illustrate the riverbed profile of Viga River. As shown in Figure 44, the highest and lowest elevation has a 14.8-meter difference. The highest elevation observed was 8.665 m above MSL located at the mid upstream portion of the river in Brgy. San Jose Oco while the lowest was -6.131 m below MSL located at the mid downstream portion of the river in Brgy. San Joaquin, Municipality of Panganiban. The bathymetric survey gathered a total of 5,689 points covering 9.117 km of the river traversing eight barangays in the Municipalities of Viga and Panganiban.

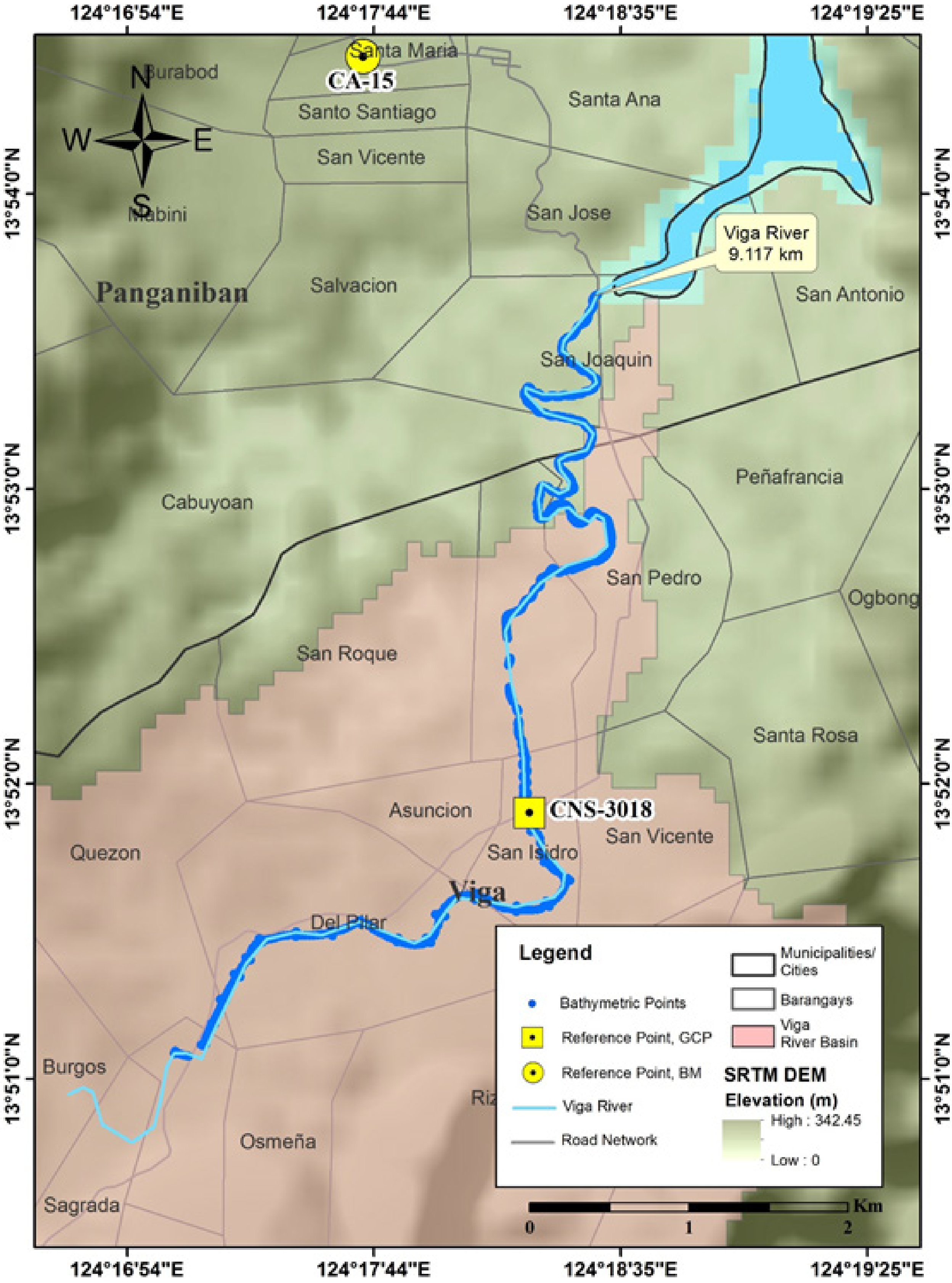


Figure 43. Extent of the bathymetric survey (in blue) in Viga River

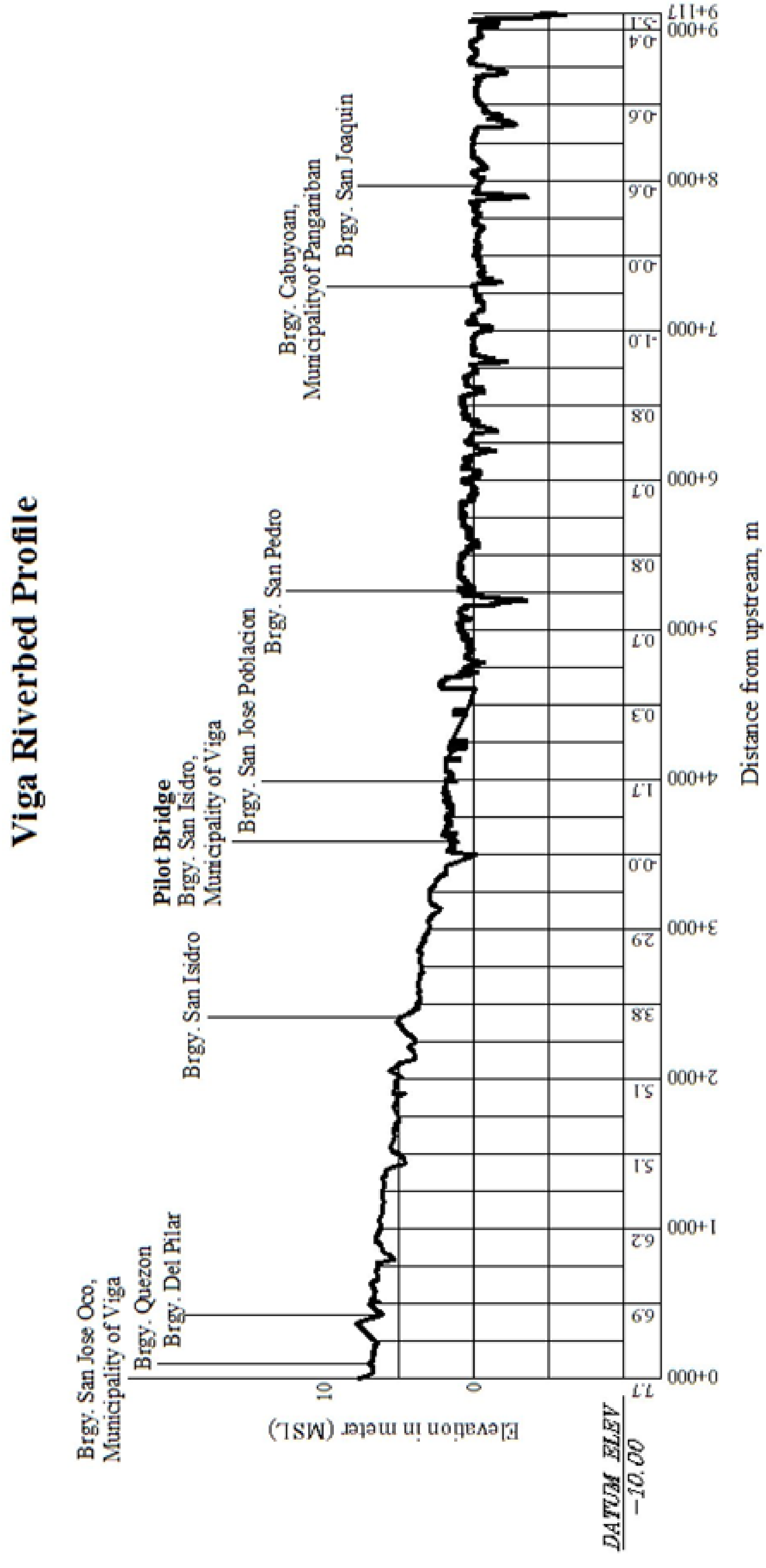


Figure 44. Riverbed profile of Danao River

CHAPTER 5: FLOOD MODELING AND MAPPING

Dr. Alfredo Mahar Lagmay, Christopher Uichanco, Sylvia Sueno, Marc Moises, Hale Ines, Miguel del Rosario, Kenneth Punay, Neil Tingin, Gianni Sumajit, Adbalagao, Maria Jemelita B.
Christian Javier B. Arroyo, Engr. Ferdinand E. Bien, Shane B. Bimeda, Juvylin B. Bismonte, Mary Ruth A. Bongon, Mark D. Delloro, Sarah Mae F. Fulleros, Berlin Phil V. Garciano, Ruth R. Lumbera, Engr. Herminio A. Magpantay, Engr. Julius Hector S. Manchete, John Paul B. Obina, Jan Carlo C. Plopenio, Ernesto F. Razal, Jr., Rox Harvey DP. Rosales, Aaron P. San Andres, and Engr. Lech Fidel C. Pante

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 Hydologic Modeling

5.1.1 Hydrometry and Rating Curves

Components and data that affect the hydrologic cycle of the river basin was monitored, collected, and analyzed. Rainfall, water level, and flow in a certain period of time, which may affect the hydrologic cycle of the Viga river were monitored, collected and analyzed.

5.1.2 Precipitation

Precipitation data was taken from one automatic rain gauge (ARGs) deployed by the ADNU-FMC. The rain gauge was installed at Brgy. San Isidro (Figure 45). The precipitation data collection started from October 14, 2016 at 11:30 PM to October 15, 2016 at 3:30 PM with a 10-minute recording interval.

The total precipitation for this event in Brgy. San Isidro ARG is 437mm. It has a peak rainfall of 20mm on October 14, 2016, at 11:30 PM. The lag time between the peak rainfall and discharge is 16 hours.

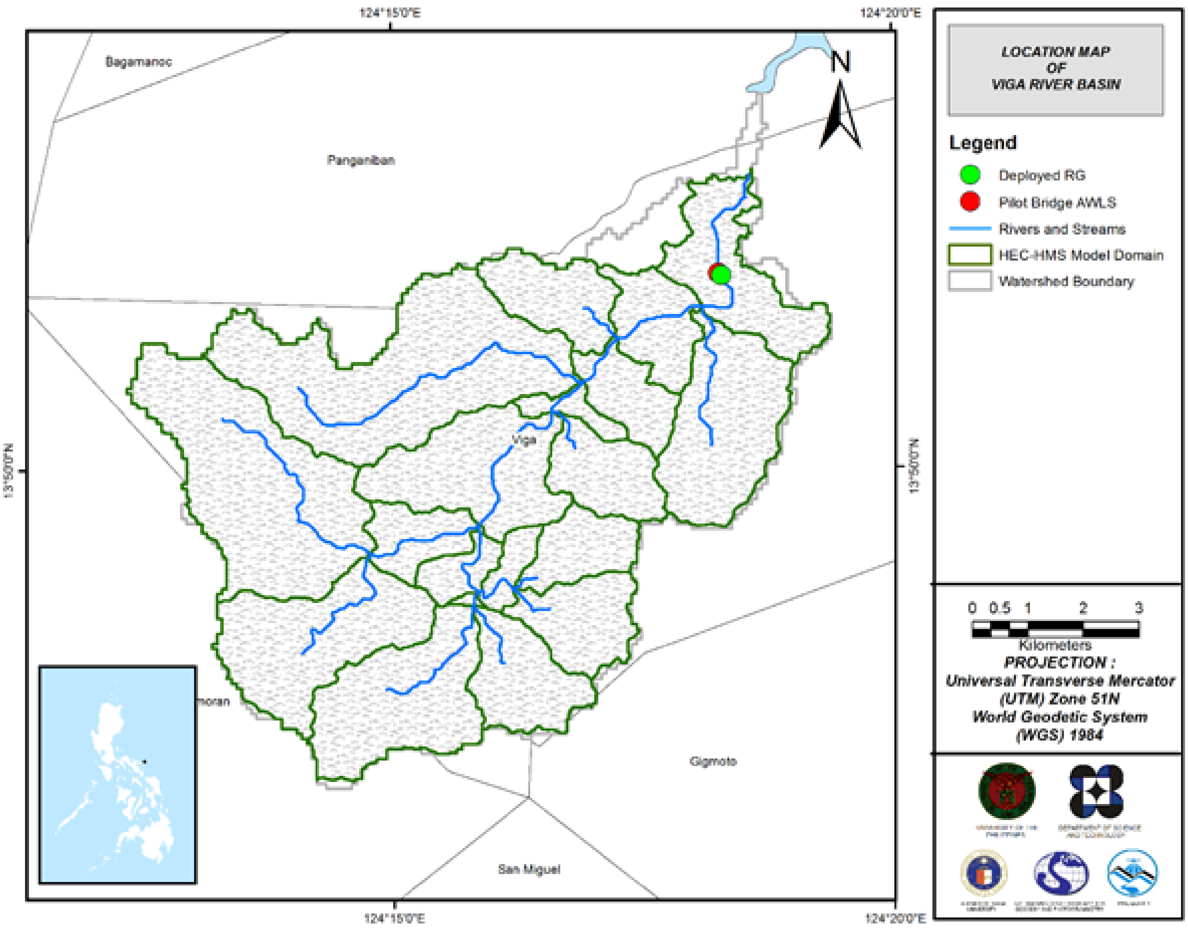


Figure 45. The location map of Viga HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Pilot Bridge, Viga, Catanduanes (13°51'54.13"N, 124°18'15.64"E). It gives the relationship between the observed water levels at Pilot Bridge and outflow of the watershed at this location.

For Pilot Bridge, the rating curve is expressed as Q=0.2574e0.9061h as shown in Figure 47.

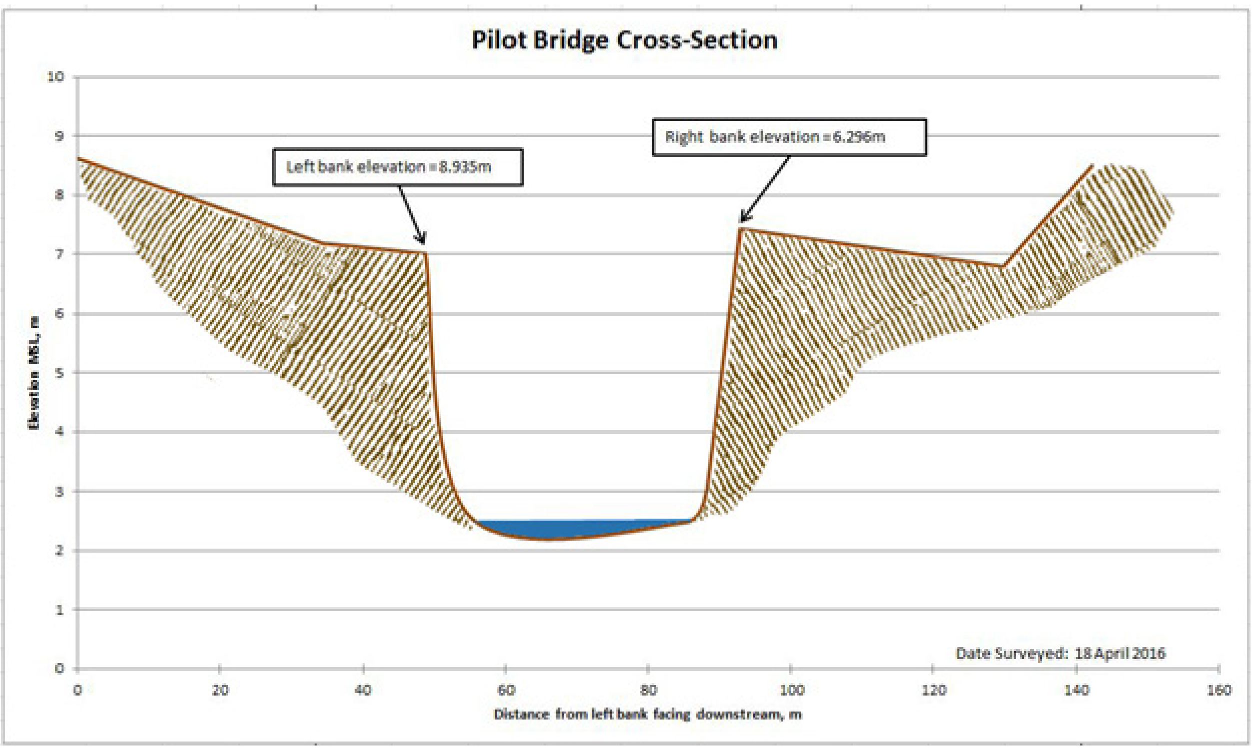


Figure 46. Cross-Section Plot of Viga Footbridge

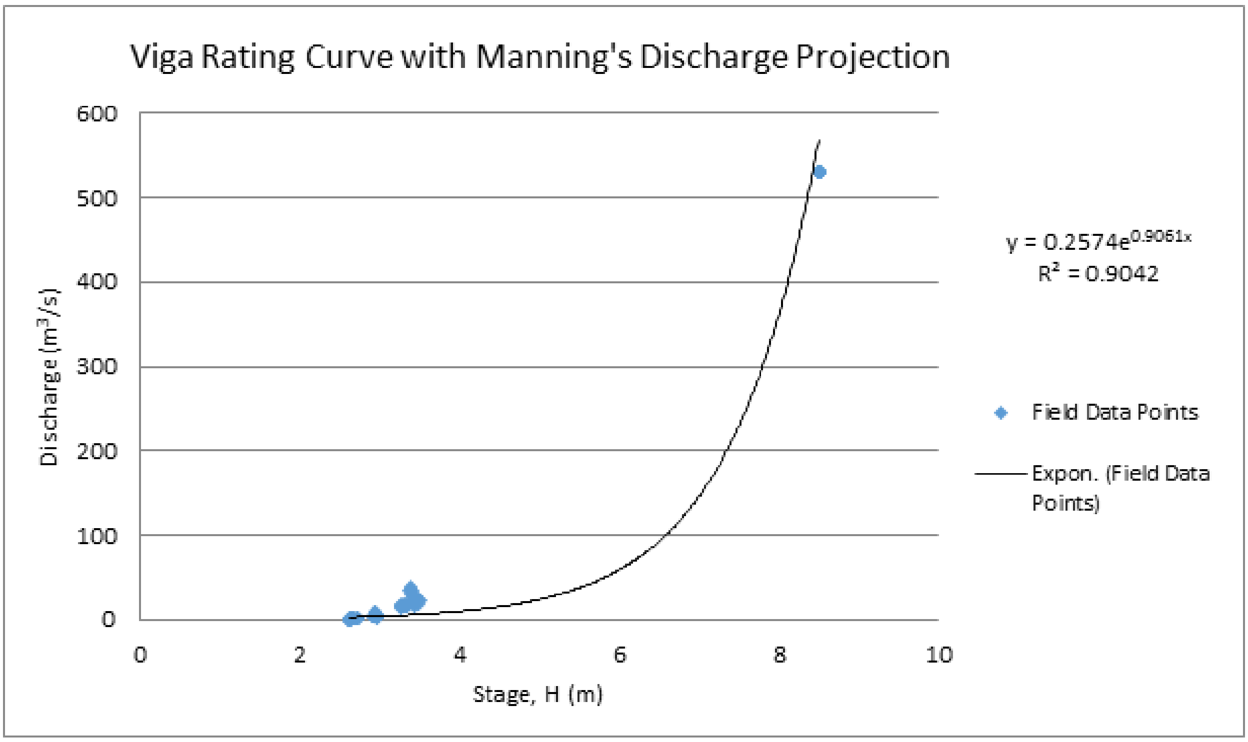


Figure 47. The rating curve of Pilot Bridge in Viga, Catanduanes

This rating curve equation was used to compute the river outflow at Pilot Bridge for the calibration of the HEC-HMS model shown in Figure 48. The total rainfall for this event is 437mm and the peak discharge is 27.8m3/s at 3:30 PM, October 15, 2016.

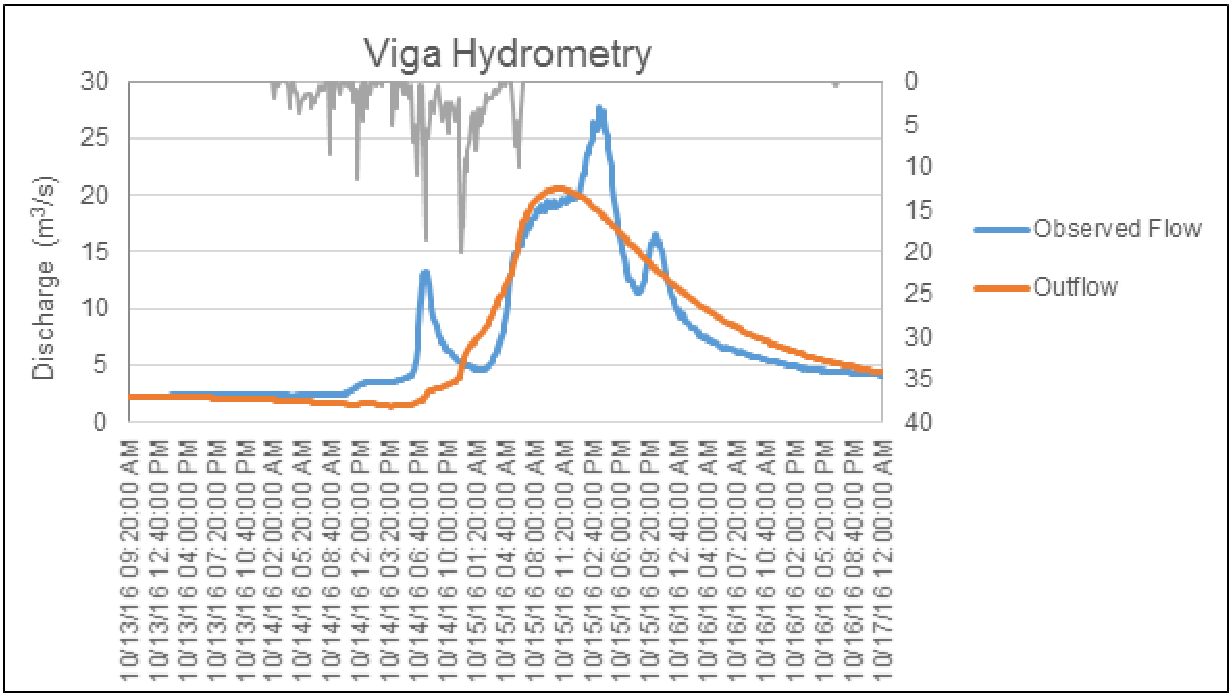


Figure 48. Rainfall and outflow data of the Viga River Basin, which was used for modeling

5.2 RIDF Station

The Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Virac RIDF. The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the value in such a way certain peak value will be attained at a certain time. This station was chosen based on its proximity to the Viga watershed. The extreme values for this watershed were computed based on a 26-year record.

Table 26. RIDF values for Virac Rain Gauge computed by PAG-ASA

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	24	36.2	44.9	60	85.1	100.5	133.3	167.2	195.6
5	35.2	52.7	65.5	87.6	126.6	150.8	200.7	251.3	297
10	42.7	63.6	79.2	105.9	154.1	184.1	245.3	307.1	364.1
15	46.8	69.7	86.9	116.2	169.6	202.8	270.5	338.5	402
20	49.8	74	92.3	123.4	180.4	216	288.1	360.5	428.6
25	52	77.3	96.4	129	188.8	226.1	301.7	377.4	449
50	59	87.5	109.2	146.1	214.6	257.4	343	429.7	511.9
100	65.9	97.7	122	163.1	240.1	288.3	385	481.5	574.4

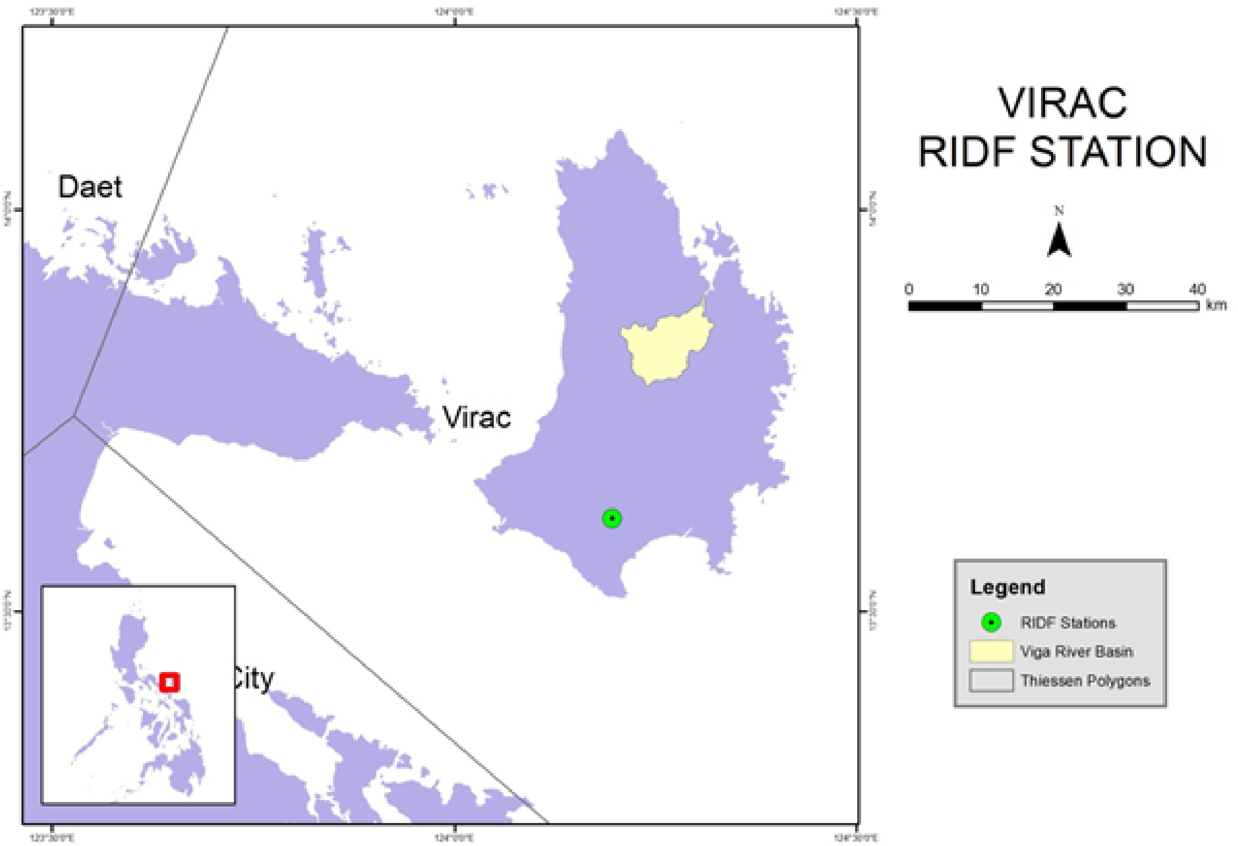


Figure 49. The location of the Virac RIDF station relative to the Viga River Basin

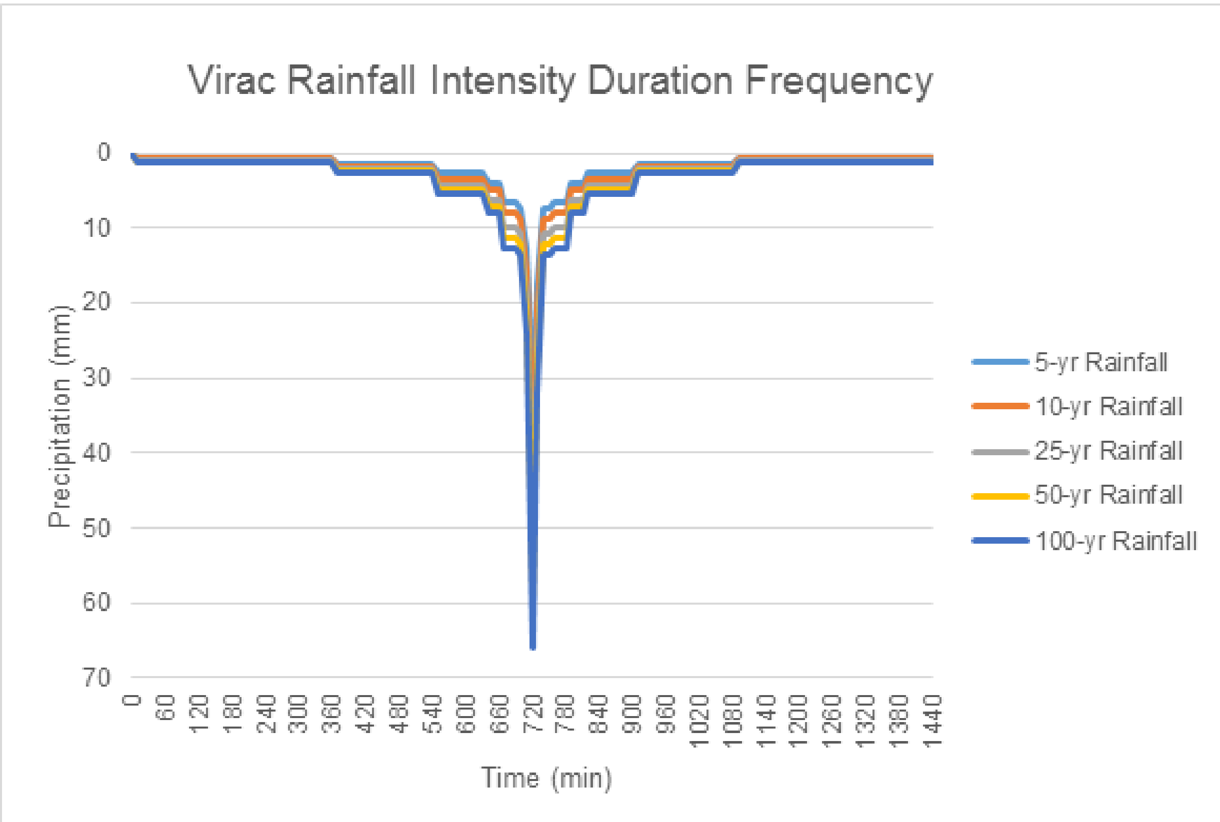


Figure 50. The synthetic storm generated for a 24-hour period for various return periods

5.3 HMS Model

The soil dataset was taken before 2004 by the Bureau of Soils and Water Management (BSWM), under the Department of Agriculture (DA). The land cover dataset file is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Viga River Basin are shown in Figures 51 and 52, respectively.

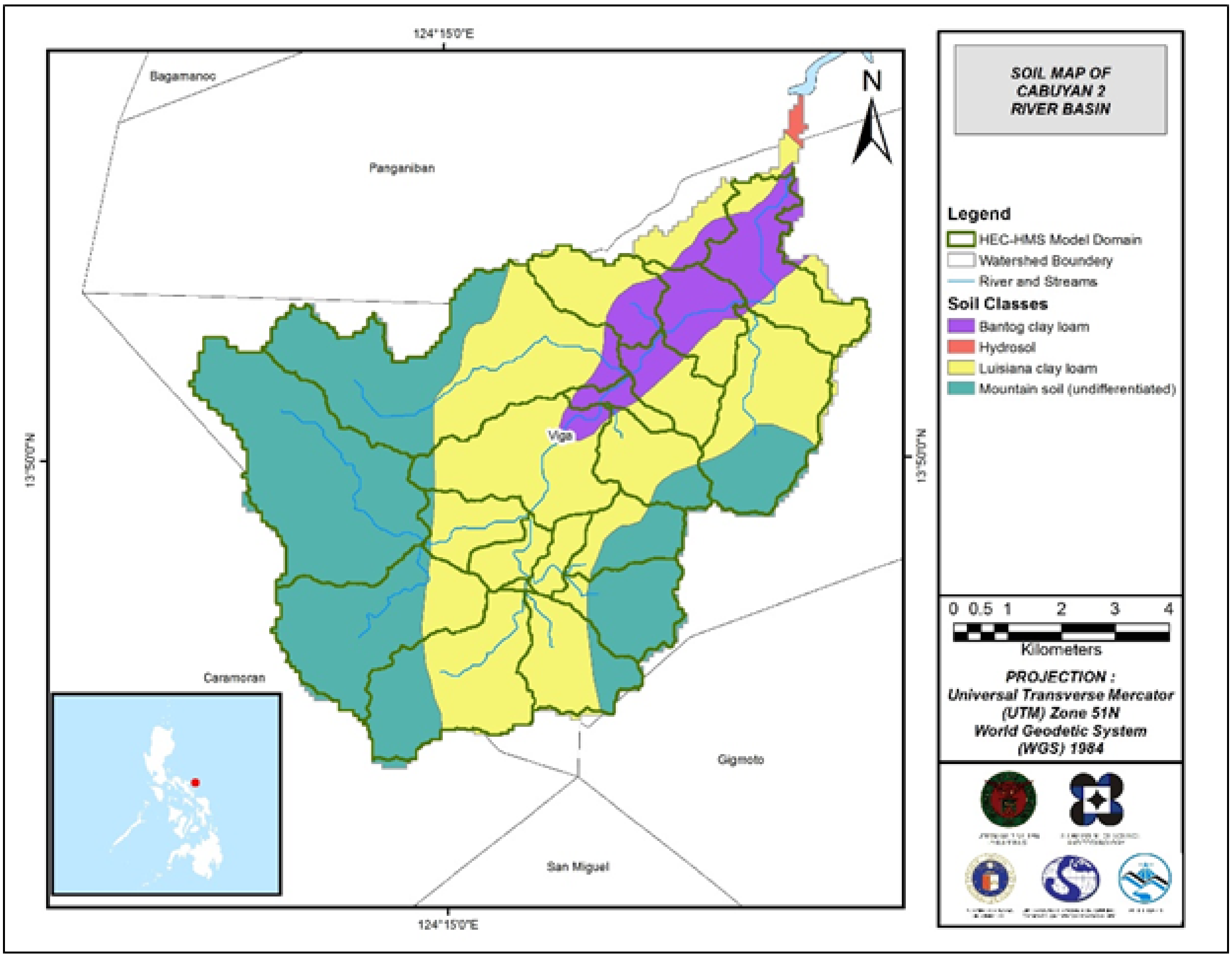


Figure 51. Soil map of Viga River Basin (Source: NAMRIA)

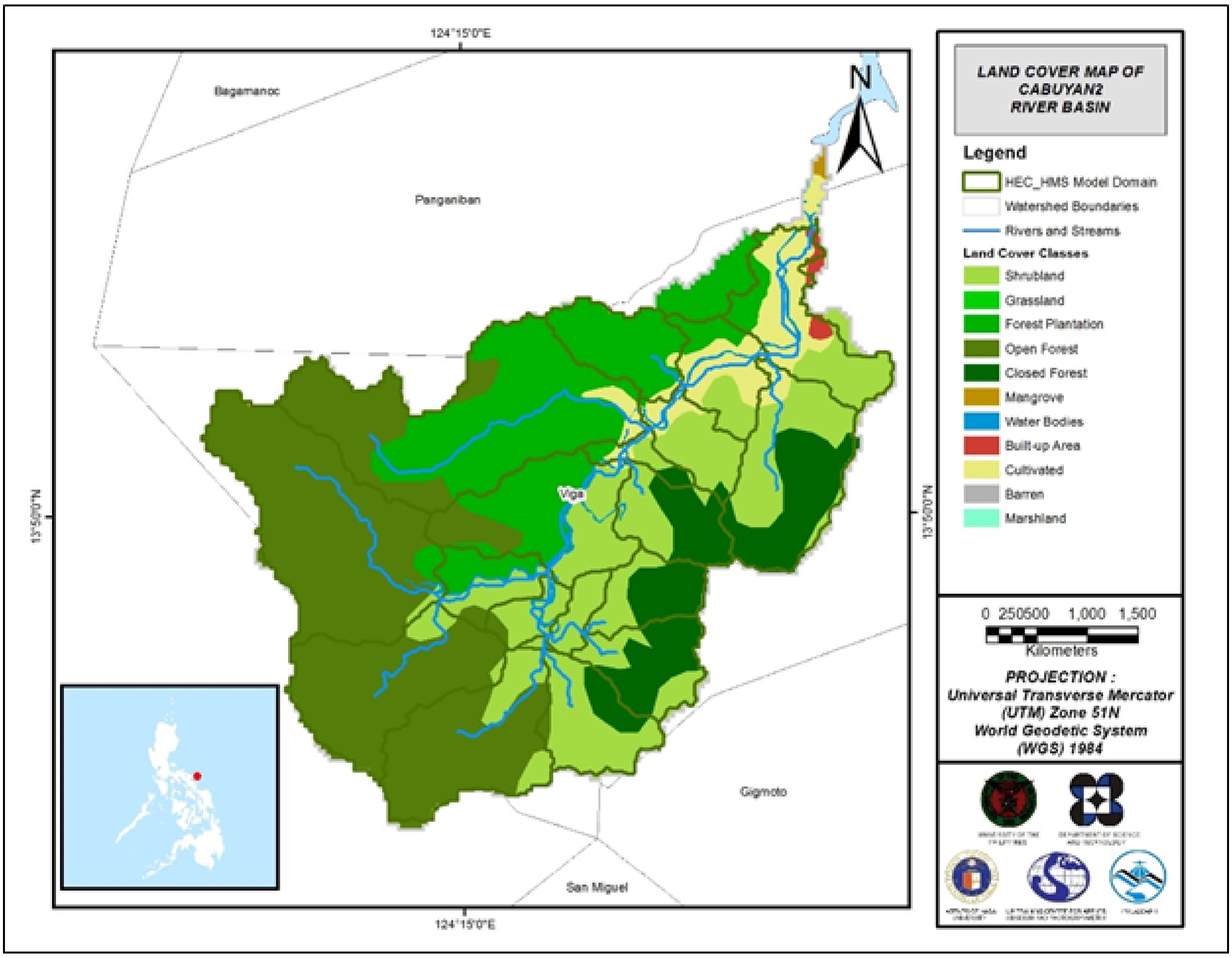


Figure 52. Land cover map of the Viga River Basin

For Viga, four soil classes were identified. These are Bantog clay loam, Luisiana clay loam, hydrosol, and undifferentiated mountain soil. Moreover, seven land cover classes were identified. These are open and closed forests, shrubland, grassland, mangrove, cultivated, and built-up areas.

For Bago, three soil classes were identified. These are loam, clay, and undifferentiated soil. Moreover, two land cover classes were identified. These are cultivated areas and forest plantations.

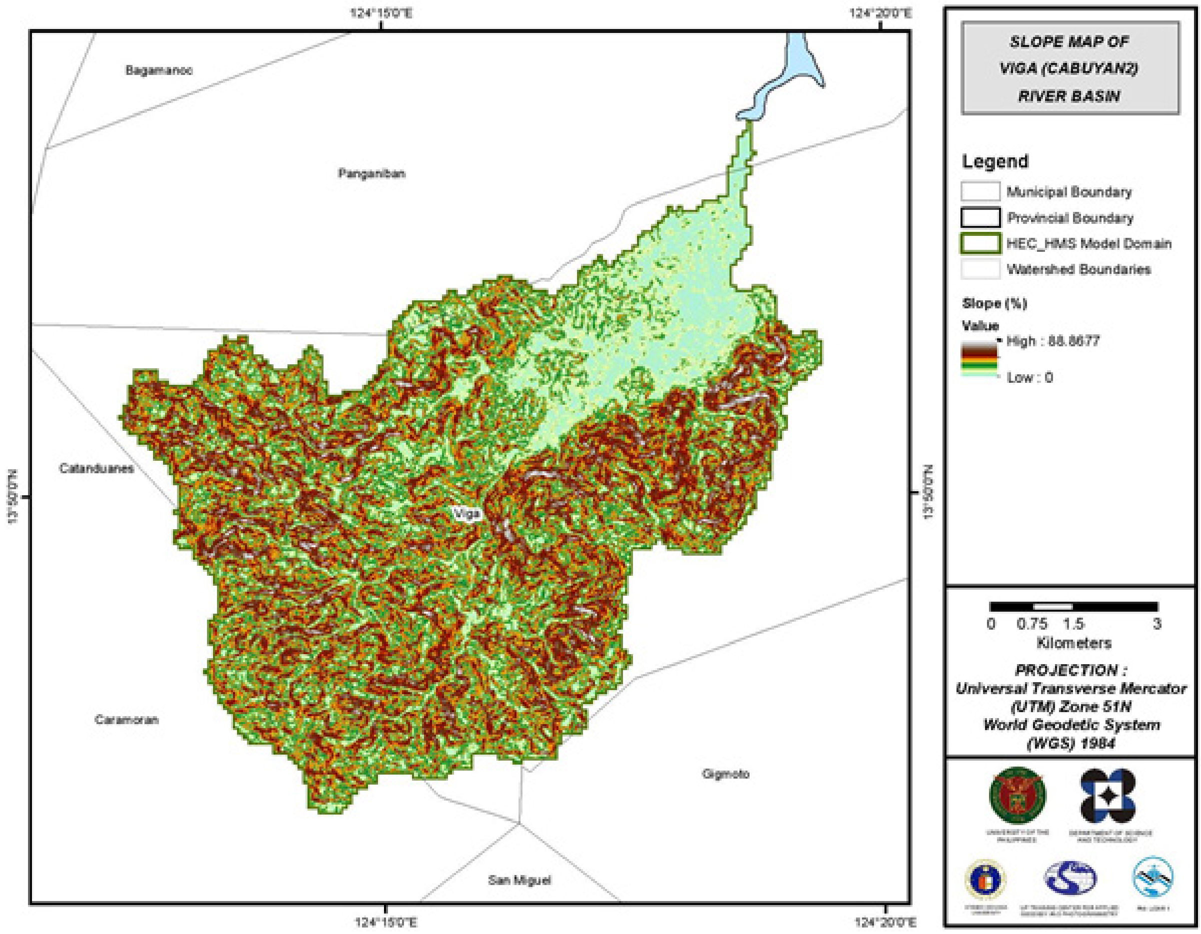


Figure 53. Slope map of Viga River Basin

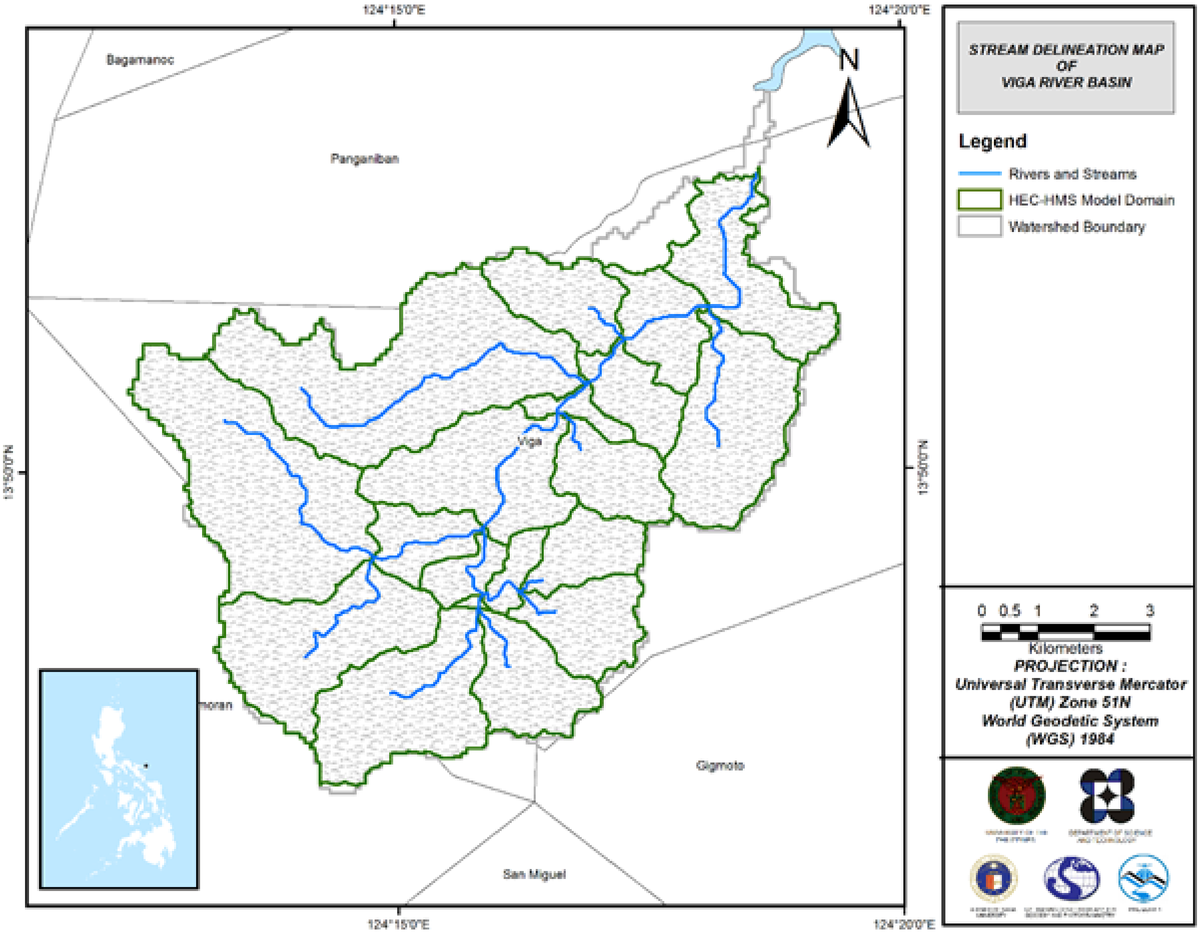


Figure 54. Stream delineation map of Viga River Basin

Using the SAR-based DEM, the Viga basin was delineated and further divided into subbasins. The model consists of 19 sub basins, 9 reaches, and 9 junctions, as shown in Figure 55. The main outlet is Pilot Bridge.

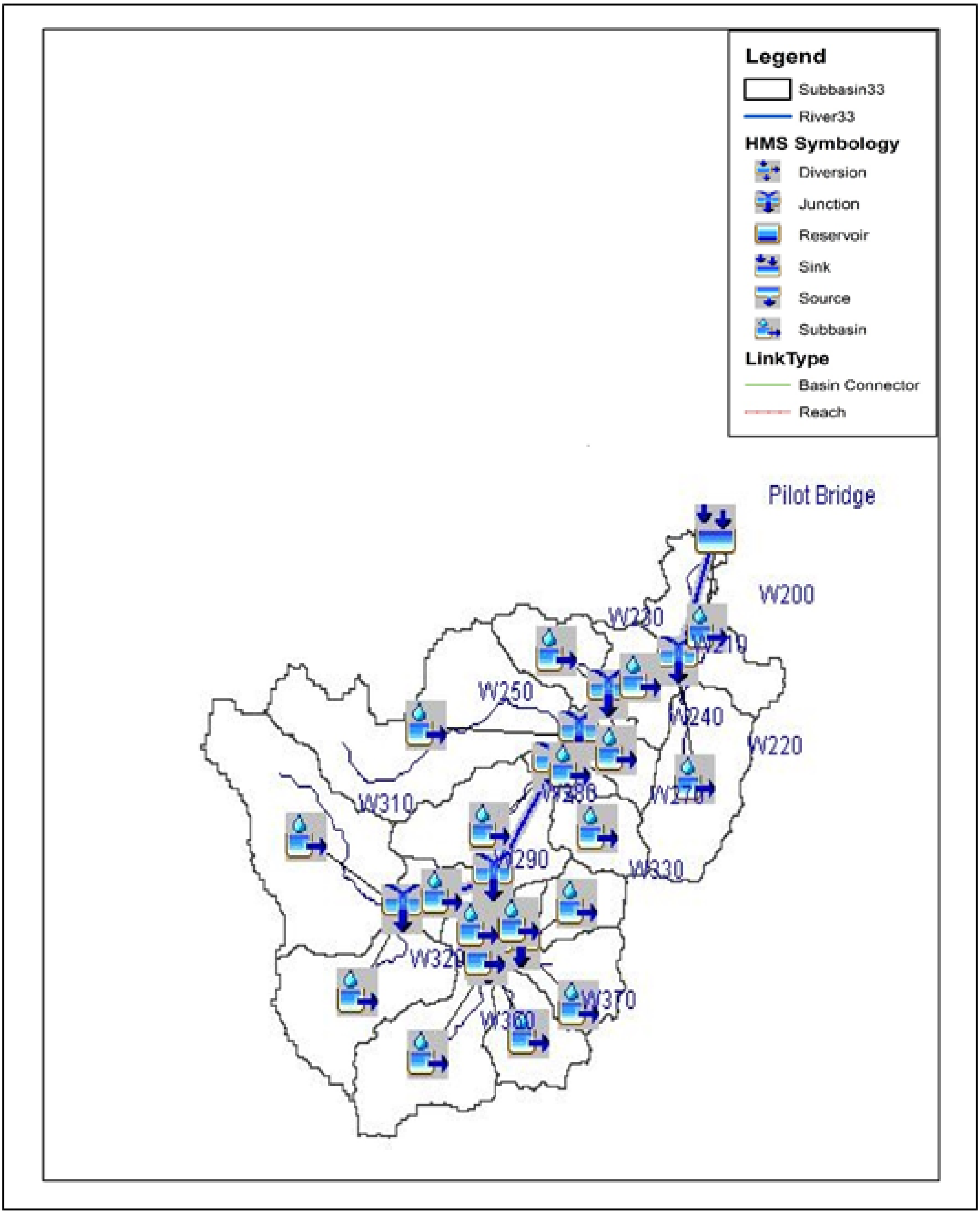


Figure 55. Viga River Basin model generated in HEC-HMS

5.4 Cross-section Data

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

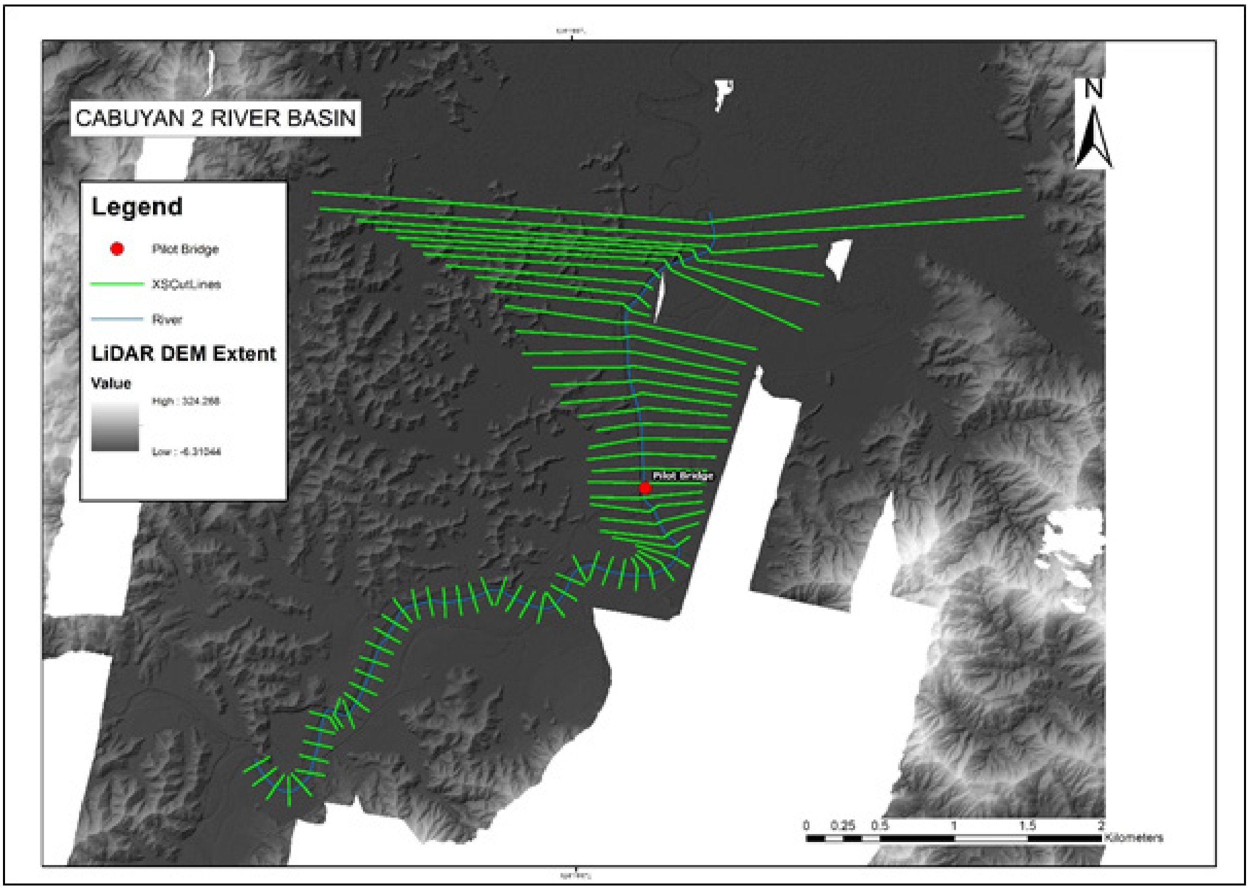


Figure 56. River cross-section of Viga River generated through Arcmap HEC GeoRAS tool

5.5 Flo 2D Model

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

Based on the elevation and flow direction, it is seen that the water will generally flow from the southwest of the model to the northeast, following the main channel. As such, boundary elements northwest of the model are assigned as outflow elements.

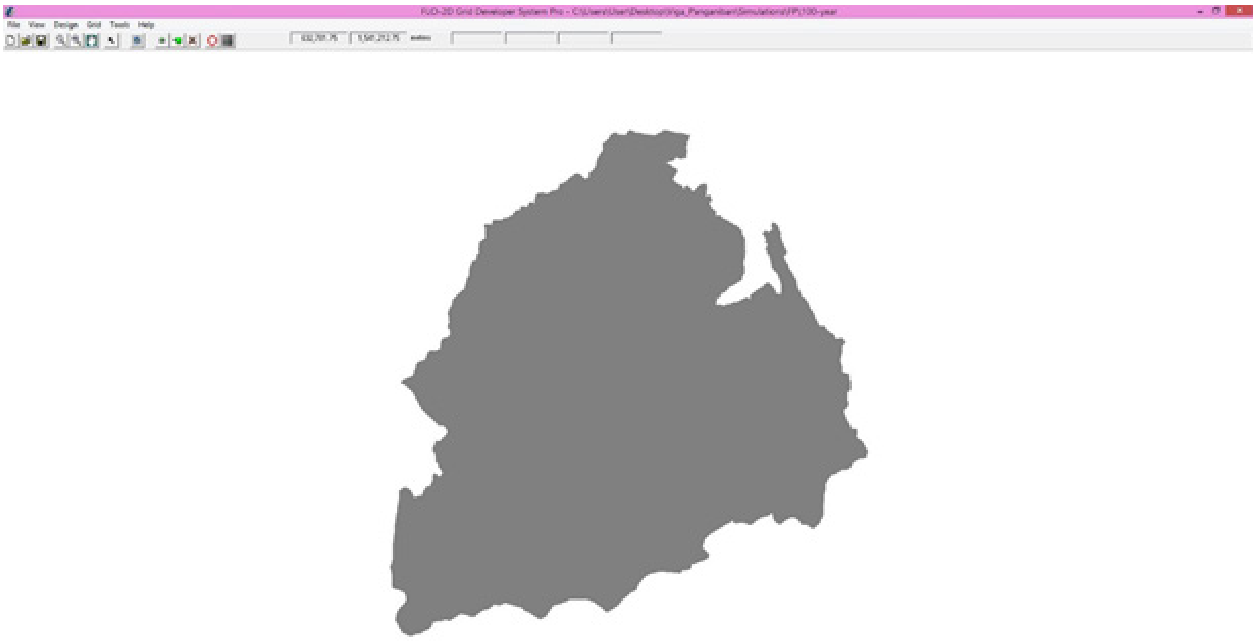


Figure 57. Screenshot of subcatchment with the computational area to be modeled in FLO-2D Grid Developer System Pro (FLO-2D GDS Pro)

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 108.3 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 0m2/s. The generated hazard maps for Viga are in Figures 61, 63, and 65.

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 56,777,700.00 m2. The generated flood depth maps for Viga are in Figures 62, 64, and 66.

There is a total of 69,798,322.71m3 of water entering the model, of which 31,370,986.66m3 is due to rainfall and 38,427,336.05 m3 is inflow from basins upstream. 8,671,795.00 m3 of this water is lost to infiltration and interception, while 14,656,207.03m3 is stored by the flood plain. The rest, amounting up 46,470,344.48m3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Viga HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 60 shows the comparison between the two discharge data.

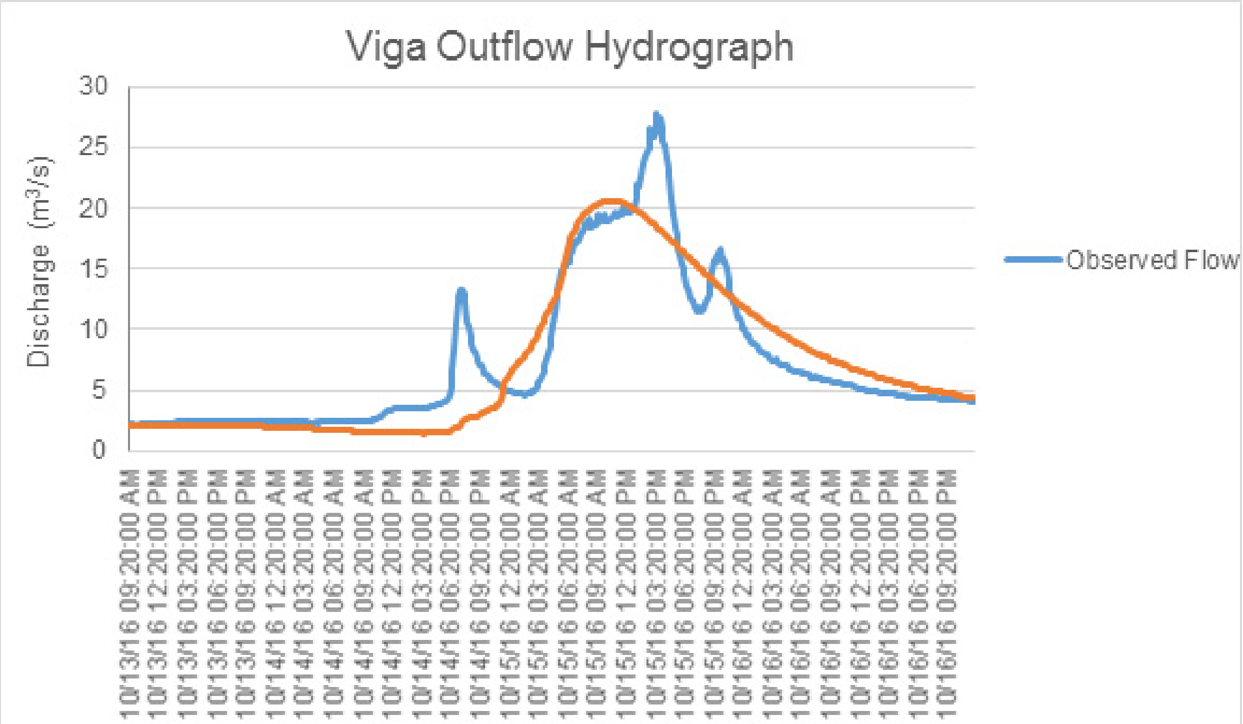


Figure 58. Outflow hydrograph of Viga River Basin produced by the HEC-HMS model compared with observed outflow

Enumerated in Table 27 are the adjusted range of values of the parameters used in calibrating the model.

Table 27. Range of calibrated values for the Viga River Basin

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	39 - 500
			Curve Number	35 - 53
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.14 - 354
			Storage Coefficient (hr)	0.06 - 708
	Baseflow	Recession	Recession Constant	0.00001 - 1
			Ratio to Peak	0.0002 – 0.2
Reach	Routing	Muskingum-Cunge	Slope	0.0009 – 0.03
			Manning's Coefficient	0.0001 – 0.8

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 39mm to 500mm means that there is average to high amount of infiltration or rainfall interception by vegetation.

The curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 35 to 53 for curve number is wider than the advisable for Philippine watersheds (70-80), depending on the soil and land cover of the area (M. Horritt, personal communication, 2012). For Viga, the basin mostly consists of open forest and the soil consists of Bantog clay loam, Luisiana clay loam, and undifferentiated mountain soil.

The time of concentration and storage coefficient are the travel time and index of temporary storage of runoff in a watershed. The range of calibrated values from 0.14 hours to 354 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. For Viga, it will take at least 37 hours from the peak discharge to go back to the initial discharge.

Manning's roughness coefficient of 0.0001 corresponds to the common roughness in Viga watershed, which is determined to be a mangrove forest with trees with heavy stand that flow into branches (Brunner, 2010).

Table 28. Summary of the Efficiency Test of Viga HMS Model

ACCURACY MEASURE	VALUE
RMS Error	2.524
r2	0.841
NSE	0.836
RSR	2.098
PBIAS	0.405

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 2.524 (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 0.841.

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 0.836.

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 2.098.

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 0.405.

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 59) shows the Viga outflow using the synthetic storm events using the Virac Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAG-ASA) data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods from 9.3m3/s in a 5-year return period to 37.4m3/s in a 100-year return period.

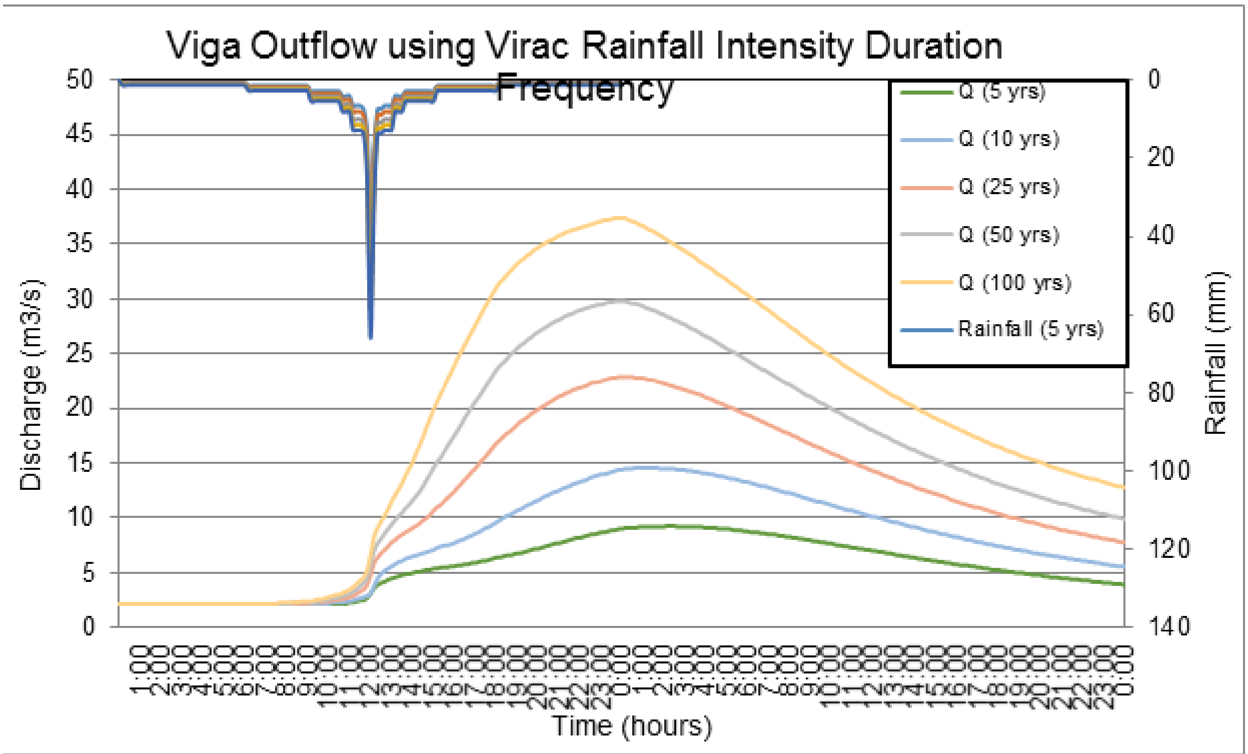


Figure 59. The outflow hydrograph at the Viga River Basin, generated using the simulated events for 24-hour period for Virac station

A summary of the total precipitation, peak rainfall, peak outflow, and time to peak of the Viga discharge using the Virac Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 29.

Table 29. Outlines the peak values of the Viga HEC-HMS Model outflow using the Virac RIDF 24-hour values.

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	297	35.2	9.3	14 hours, 10 minutes
10-Year	364.1	42.7	14.6	12 hours, 40 minutes
25-Year	449	52	22.9	11 hours, 50 minutes
50-Year	511.9	59	29.8	11 hours, 40 minutes
100-Year	574.4	65.9	37.4	11 hours, 40 minutes

5.8 River Analysis Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. For this publication, only a sample output map river was to be shown, since only the ADNU-DVC base flow was calibrated. The sample generated map of Viga River using the calibrated HMS base flow is shown in Figure 60.

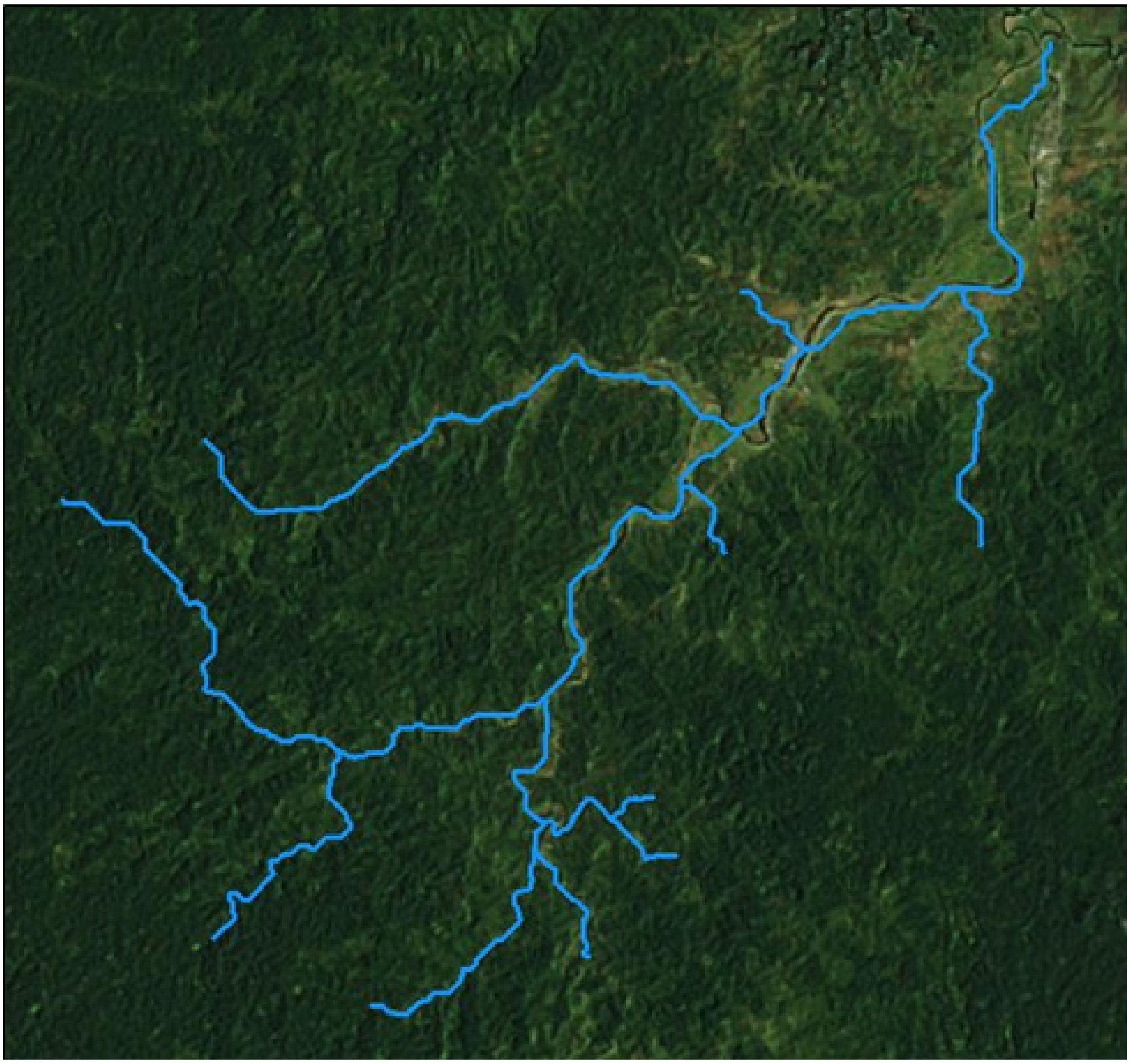


Figure 60. The sample output map of the Viga RAS Model

5.9 Flood Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. Figures 61 to 66 show the 5-, 25-, and 100-year rain return scenarios of the Viga flood plain. The flood plain, with an area of 56.78km^2, covers three (3) municipalities, namely Bagamanoc, Panganiban, and Viga. Table 30 shows the percentage of area affected by flooding per municipality.

Table 30. Municipalities affected in Viga floodplain

City / Municipality	Total Area	Area Flooded	% Flooded
Bagamanoc	82.85	0.006	0.008
Panganiban	85.59	28.95	33.83
Viga	158.74	27.71	17.46

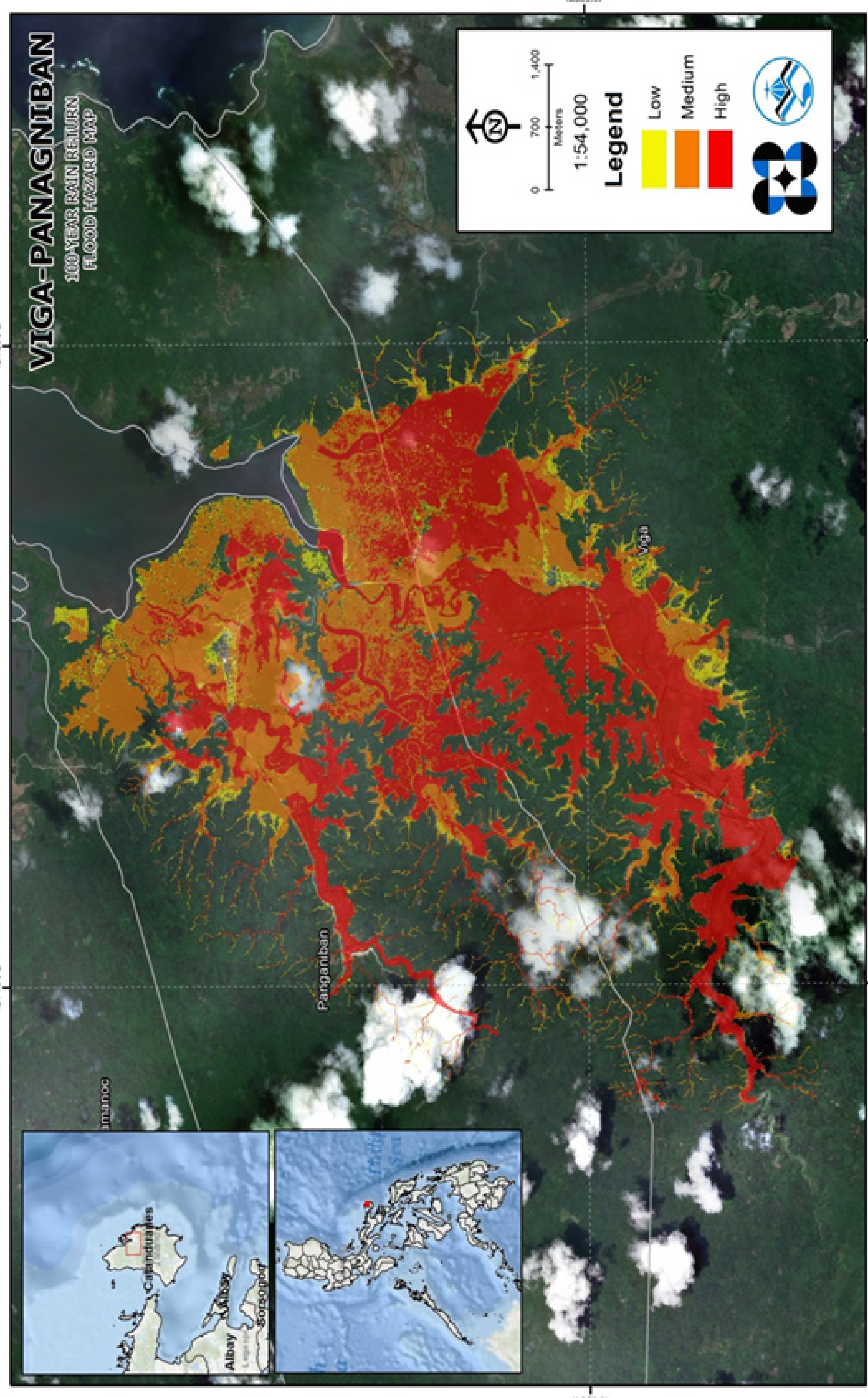


Figure 61. 100-year flood hazard map for the Viga flood plain overlaid on Google Earth imagery

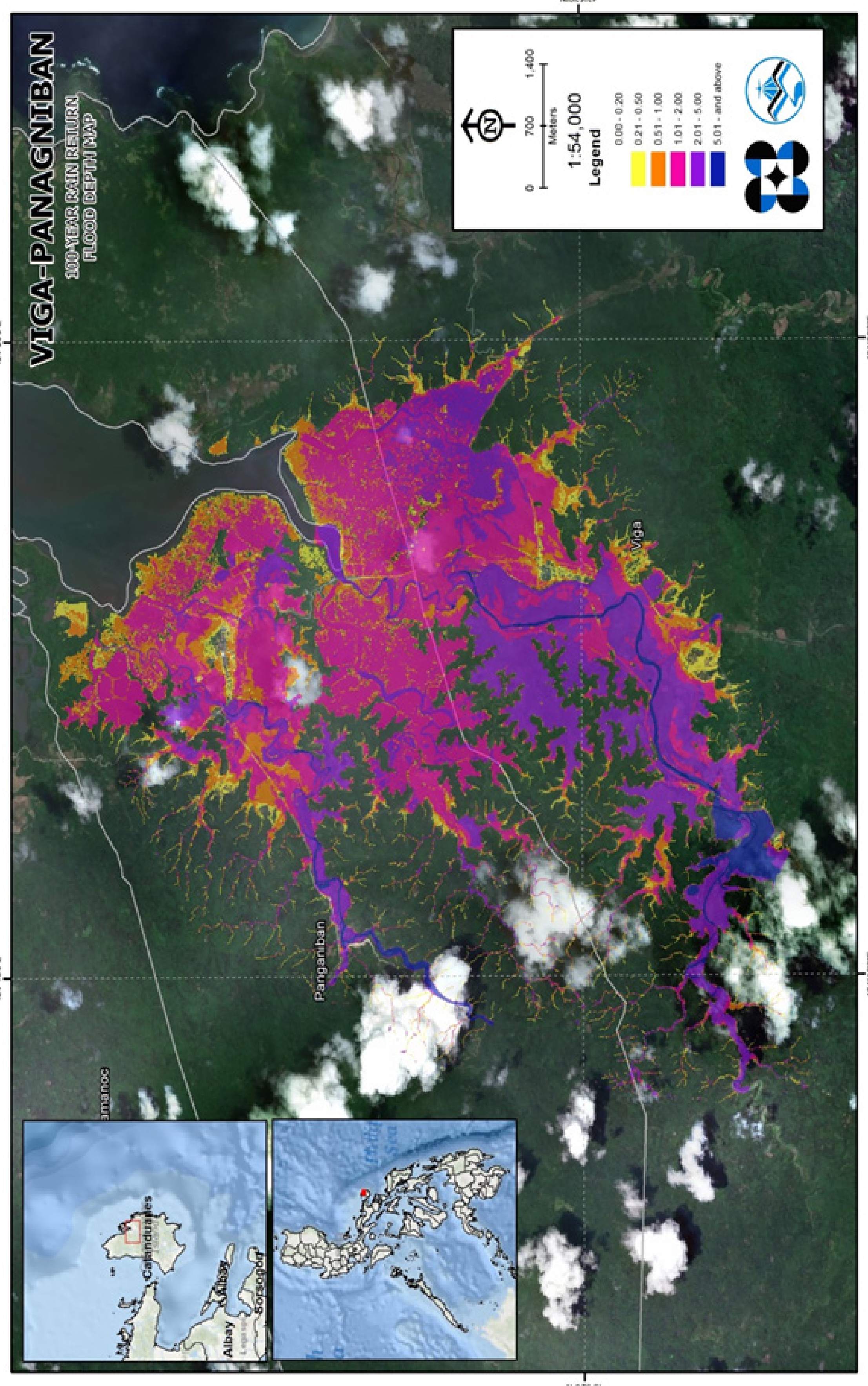


Figure 62. 100-year flow depth map for the Viga flood plain overlaid on Google Earth imagery

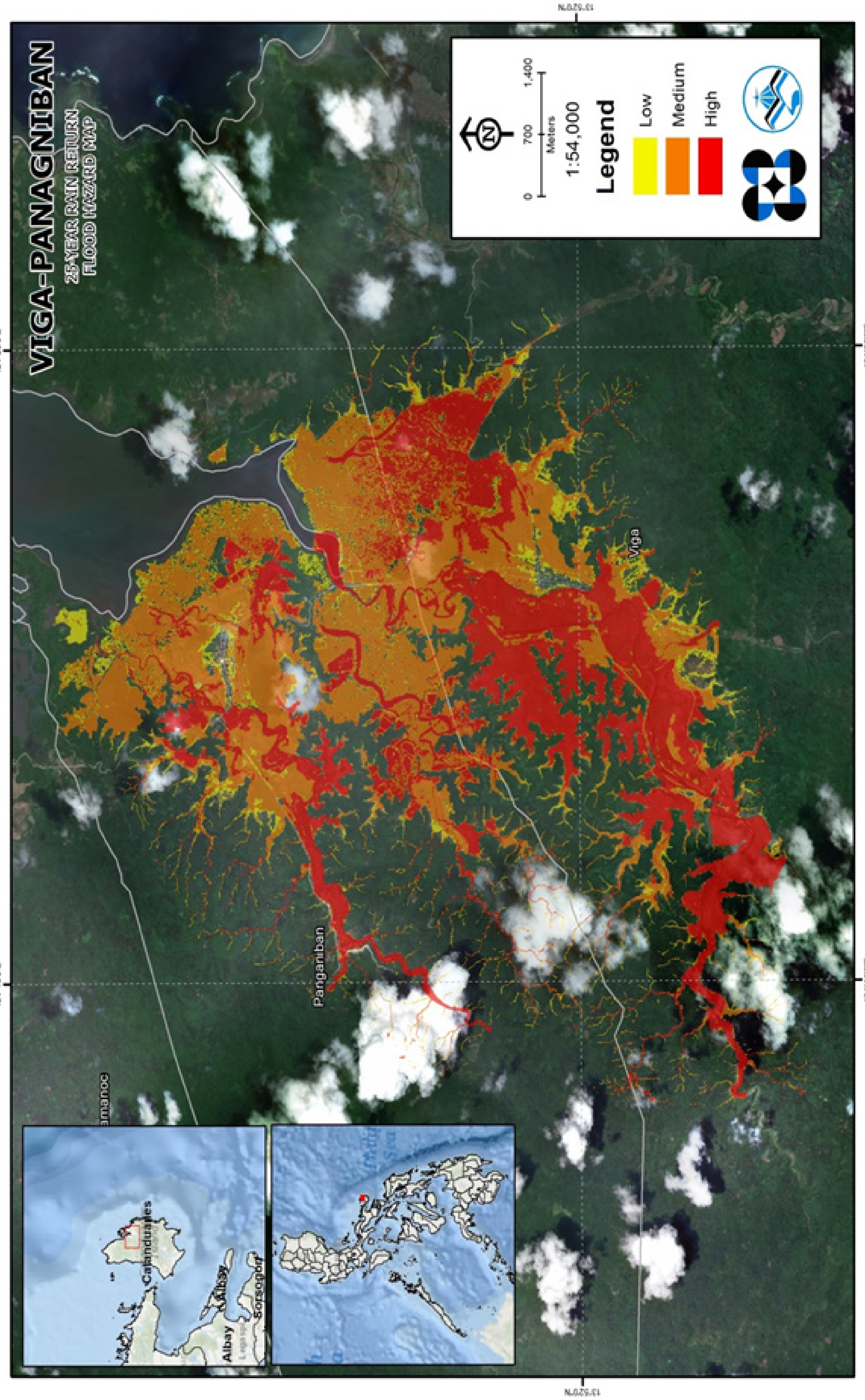


Figure 63. 25-year flood hazard map for the Viga flood plain overlaid on Google Earth imagery

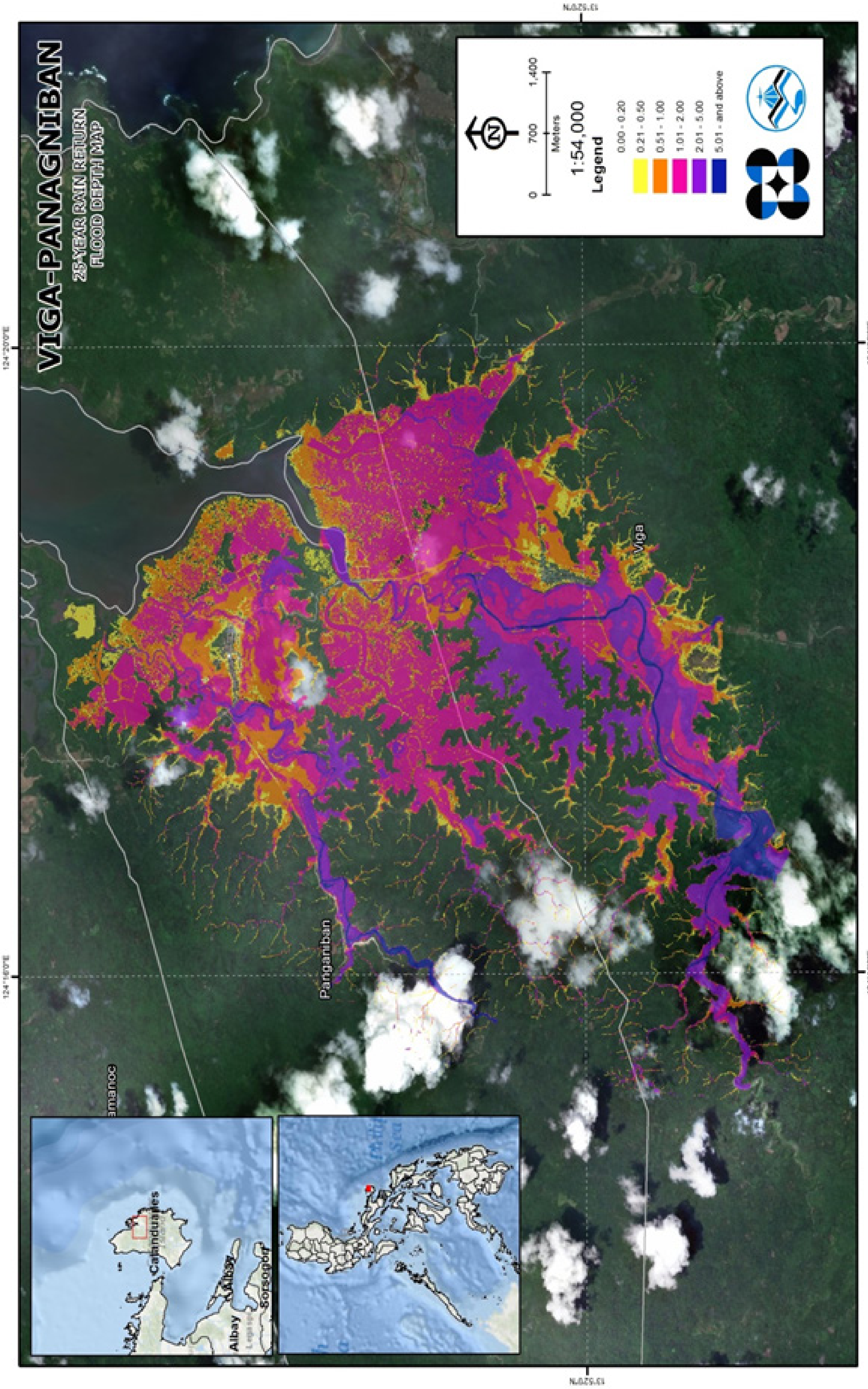


Figure 64. 25-year flow depth map for the Viga flood plain overlaid on Google Earth imagery

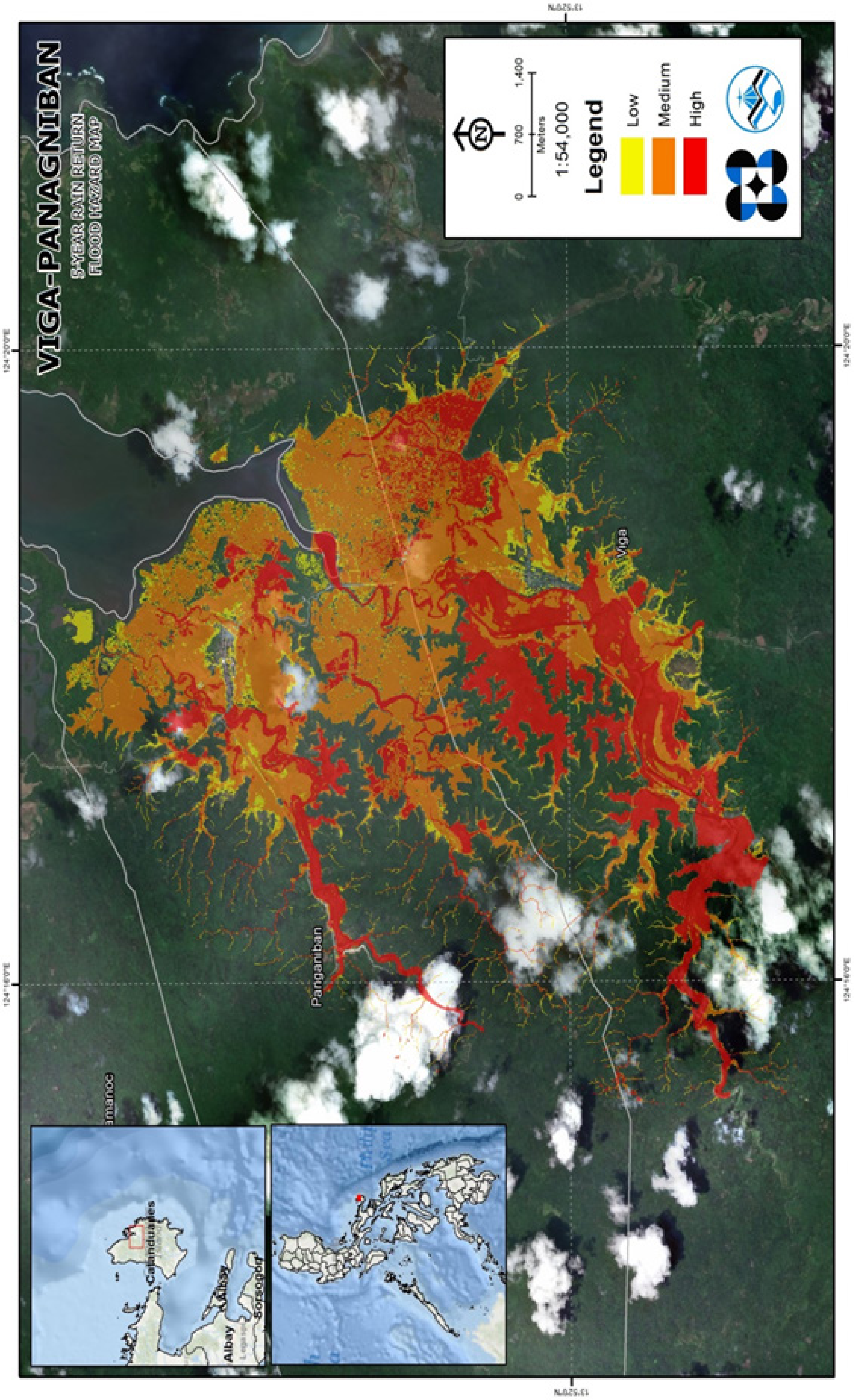


Figure 65. 5-year flood hazard map for the Viga flood plain overlaid on Google Earth imagery

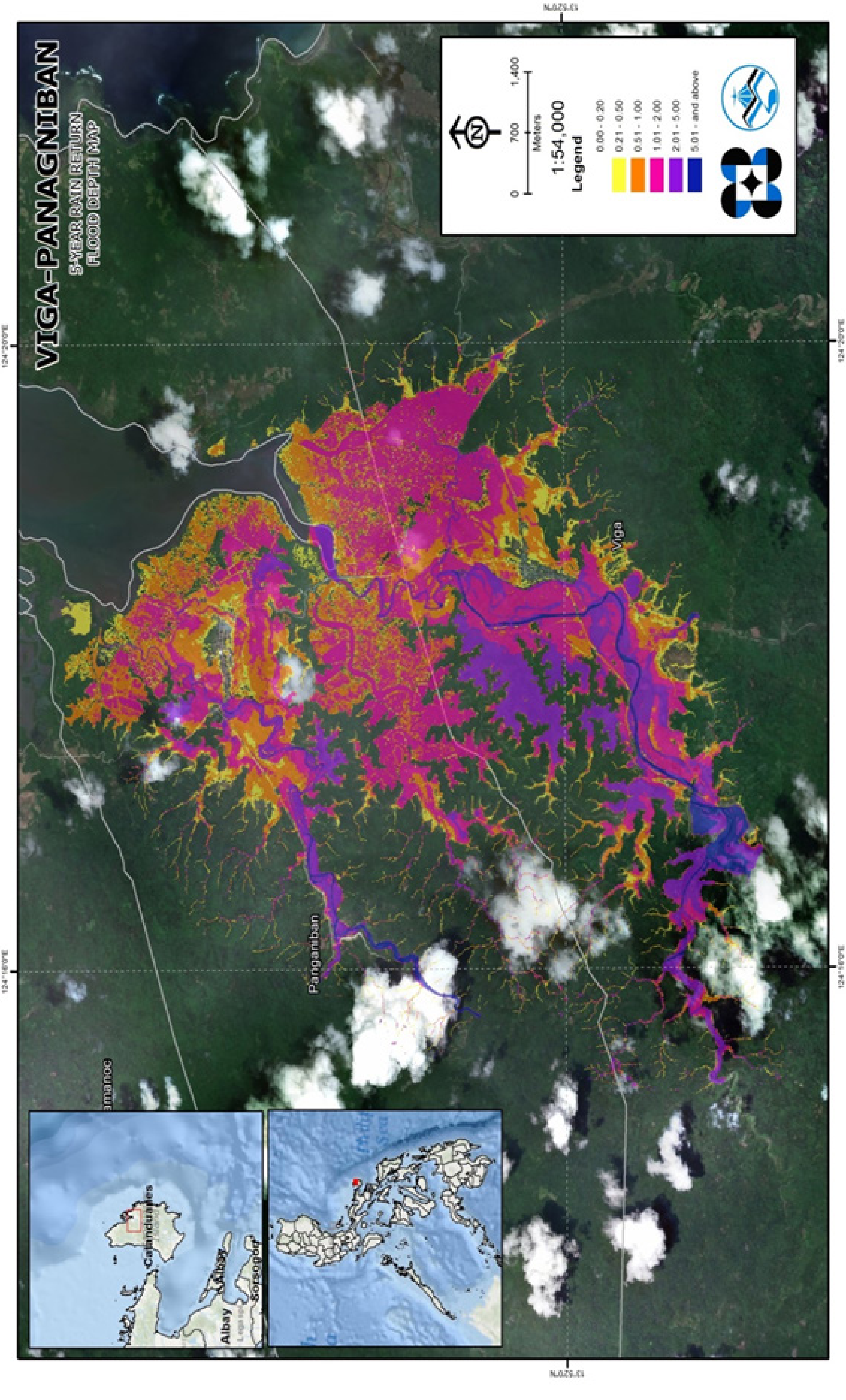


Figure 66. 5-year flow depth map for the Viga flood plain overlaid on Google Earth imagery

5.10 Inventory of Areas Exposed to Flooding

Listed below are the barangays affected by the Viga River Basin, grouped accordingly by municipality. For the said basin, three (3) municipalities consisting of 50 barangays are expected to experience flooding when subjected to the three rainfall return period scenarios.

For the 5-year rainfall return period, 0.008% of the municipality of Bagamanoc with an area of 82.85 sq. km. will experience flood levels of less than 0.20 meters.

For the municipality of Panganiban with an area of 85.59 sq. km., 18.94% will experience flood levels of less than 0.20 meters. 2.23% of the area will experience flood levels of 0.21 to 0.50 meters, while 5.37%, 5.83%, 1.25%, and 0.19% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 31 depicts the areas affected in Panganiban in square kilometers by flood depth per barangay. Educational institutions and health institutions exposed to flooding can be found at Annex 12 and Annex 13 respectively.

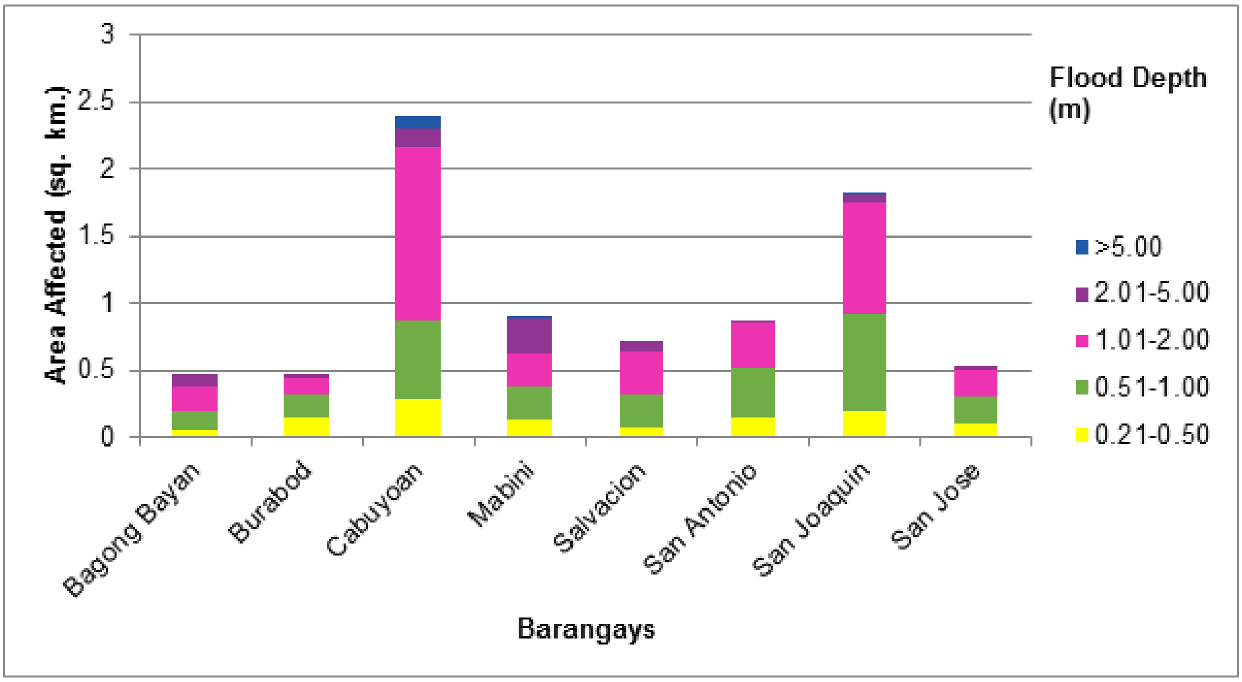


Figure 67. Affected Barangays in Panganiban, Catanduanes during the 5-Year Rainfall Return Period

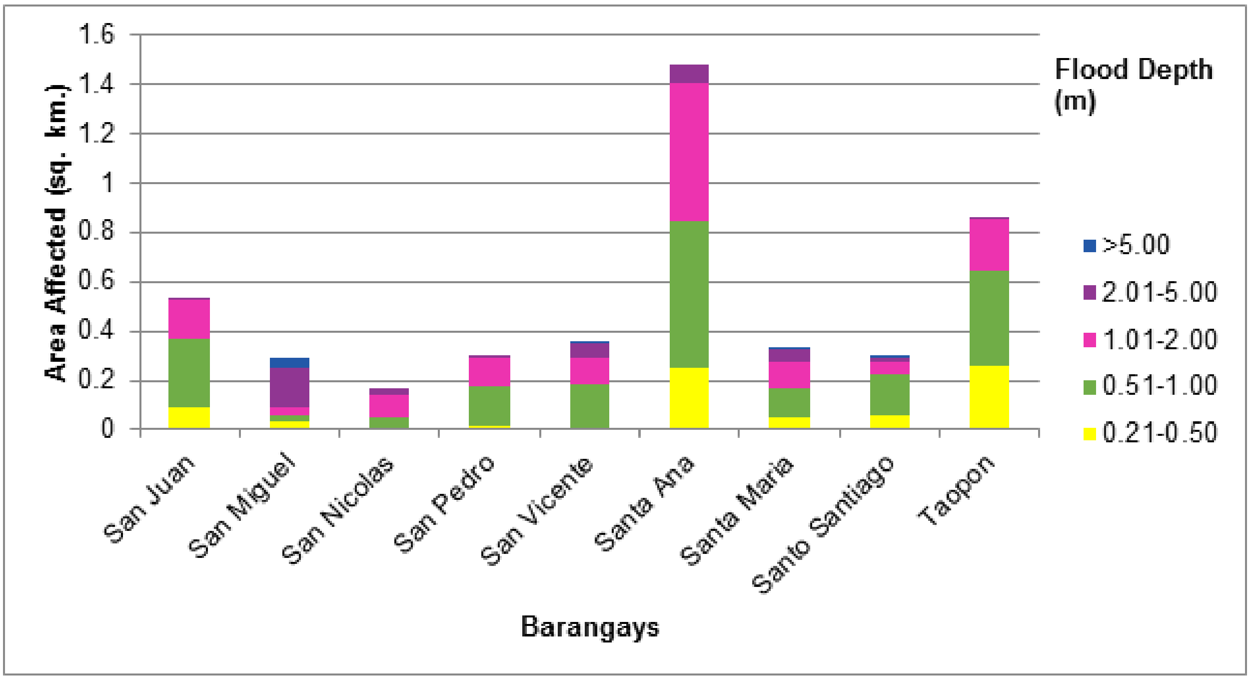


Figure 68. Affected Barangays in Panganiban, Catanduanes during the 5-Year Rainfall Return Period

Table 31. .Affected Areas in Panganiban, Catanduanes during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Panganiban									
	Bagong Bayan	Burabod	Cabuyoan	Mabini	Salvacion	San Antonio	San Joaquin	San Jose	San Juan	San Miguel
0.03-0.20	0.17	1.8	7.25	1.95	0.81	0.77	0.17	0.44	0.094	0.97
0.21-0.50	0.055	0.15	0.29	0.13	0.068	0.14	0.2	0.11	0.089	0.034
0.51-1.00	0.15	0.16	0.57	0.25	0.25	0.37	0.71	0.19	0.28	0.022
1.01-2.00	0.18	0.13	1.3	0.25	0.32	0.34	0.84	0.21	0.16	0.036
2.01-5.00	0.084	0.026	0.13	0.25	0.082	0.00087	0.056	0.024	0.0086	0.16
>5.00	0	0	0.099	0.019	0	0	0.001	0	0	0.042

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Panganiban						
	San Nicolas	San Pedro	San Vicente	Santa Ana	Santa Maria	Santo Santiago	Taopon
0.03-0.20	0.047	0.013	0.015	0.39	0.11	0.011	1.19
0.21-0.50	0.008	0.015	0.0057	0.25	0.05	0.057	0.26
0.51-1.00	0.042	0.16	0.18	0.6	0.12	0.17	0.39
1.01-2.00	0.089	0.12	0.11	0.55	0.11	0.052	0.21
2.01-5.00	0.029	0.0018	0.061	0.077	0.05	0.02	0.0062
>5.00	0	0	0.0003	0	0.0021	0.0008	0

For the municipality of Viga with an area of 158.74 sq. km., 9.63% will experience flood levels of less than 0.20 meters. 0.84% of the area will experience flood levels of 0.21 to 0.50 meters, while 1.46%, 3.27%, 1.95%, and 0.32% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 32 depicts the areas affected in Viga in square kilometers by flood depth per barangay.

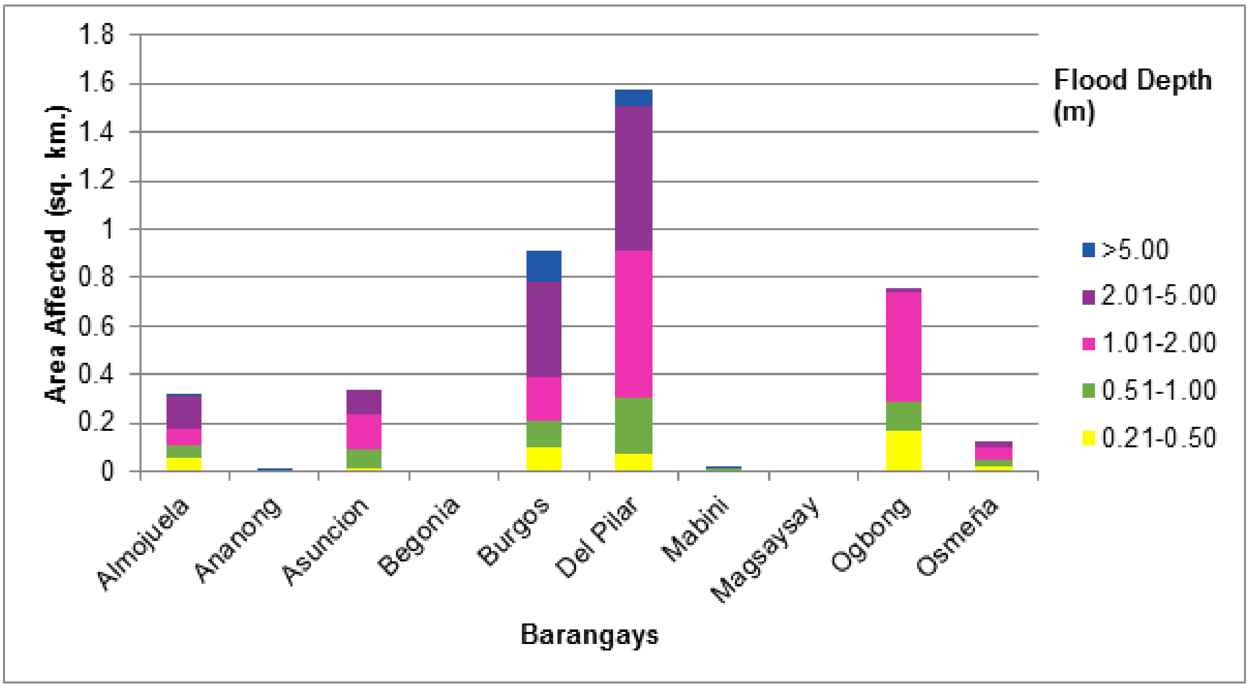


Figure 69. Affected Barangays in Viga, Catanduanes during the 5-Year Rainfall Return Period

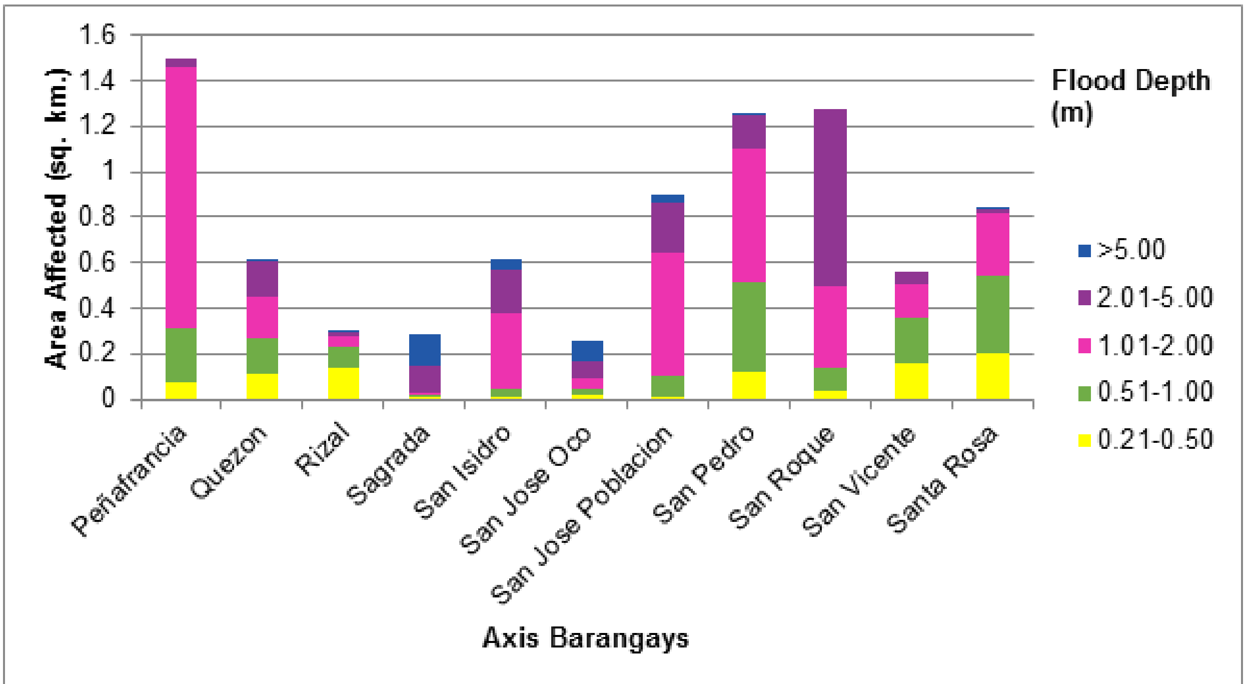


Figure 70. Affected Barangays in Viga, Catanduanes during the 5-Year Rainfall Return Period

Table 32. Affected Areas in Viga, Catanduanes during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Viga											
	Almojuela	Ananong	Asuncion	Begonia	Burgos	Del Pilar	Mabini	Magsaysay	Ogbong	Osmeña	Peñafrancia	Quezon
0.03-0.20	1.87	0.096	0.18	0.001	2.77	0.67	0.4	0.035	2.68	0.43	0.18	1.9
0.21-0.50	0.054	0.0026	0.013	0	0.1	0.078	0.0099	0	0.17	0.021	0.074	0.11
0.51-1.00	0.052	0.0007	0.075	0	0.11	0.23	0.0032	0	0.12	0.027	0.24	0.16
1.01-2.00	0.073	0.0004	0.15	0	0.17	0.6	0.0024	0	0.45	0.056	1.15	0.18
2.01-5.00	0.13	0.00061	0.1	0	0.4	0.6	0.00085	0	0.014	0.022	0.041	0.16
>5.00	0.0009	0.0007	0	0	0.13	0.063	0.0001	0	0	0	0	0.0058

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Viga								
	Rizal	Sagrada	San Isidro	San Jose Oco	San Jose Poblacion	San Pedro	San Roque	San Vicente	Santa Rosa
0.03-0.20	0.83	0.051	0.018	0.15	0.13	0.16	1.08	0.63	1.04
0.21-0.50	0.14	0.012	0.012	0.017	0.0097	0.12	0.038	0.16	0.21
0.51-1.00	0.092	0.0085	0.04	0.027	0.095	0.39	0.1	0.2	0.34
1.01-2.00	0.046	0.0093	0.33	0.05	0.54	0.59	0.36	0.15	0.27
2.01-5.00	0.019	0.12	0.19	0.075	0.22	0.14	0.78	0.059	0.017
>5.00	0.0061	0.13	0.041	0.09	0.032	0.0054	0	0	0.0001

For the 25-year rainfall return period, 0.008% of the municipality of Bagamanoc with an area of 82.85 sq. km. will experience flood levels of less than 0.20 meters.

For the municipality of Panganiban with an area of 85.59 sq. km., 18.45% will experience flood levels of less than 0.20 meters. 1.93% of the area will experience flood levels of 0.21 to 0.50 meters, while 4.38%, 7.38%, 1.47%, and 0.22% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 33 depicts the areas affected in Panganiban in square kilometers by flood depth per barangay.

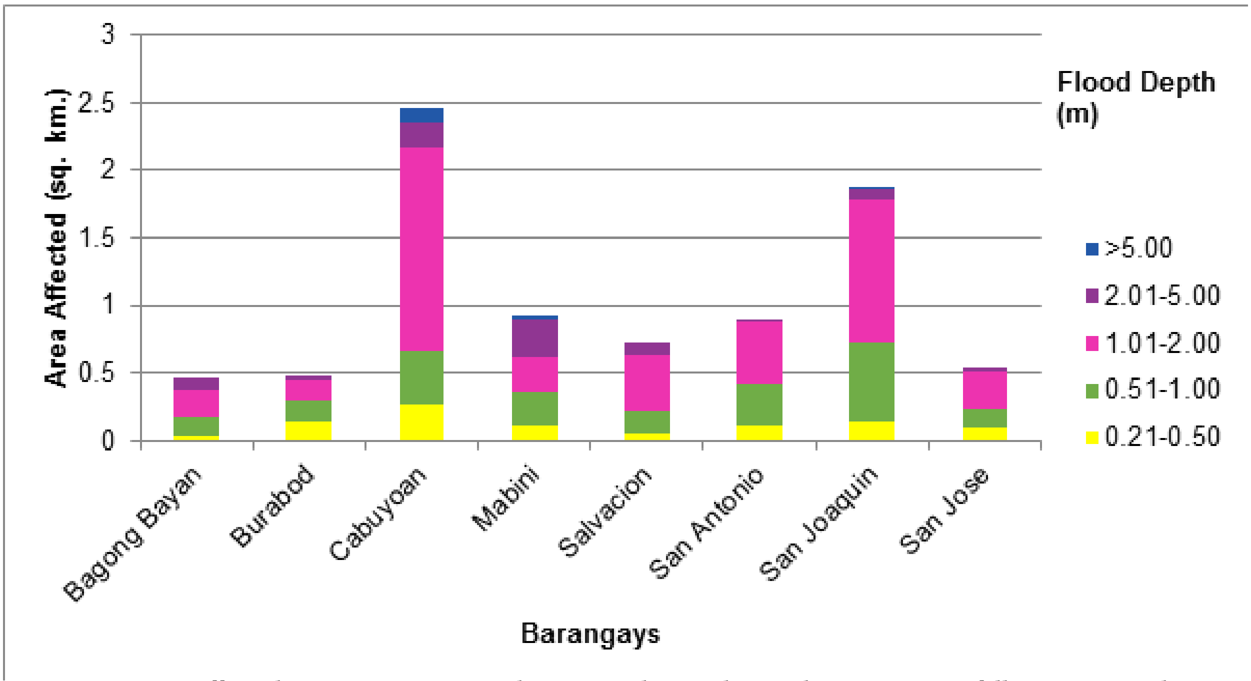


Figure 71. Affected Barangays in Panganiban, Catanduanes during the 25-Year Rainfall Return Period

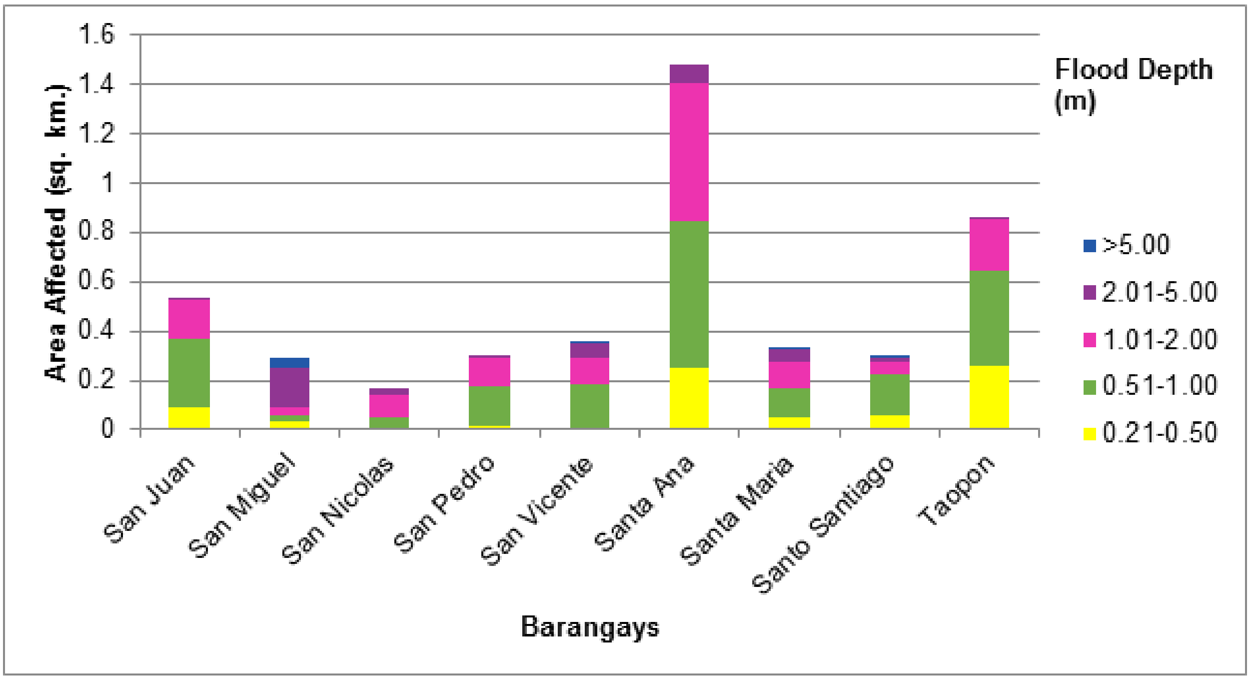


Figure 72. Affected Barangays in Panganiban, Catanduanes during the 25-Year Rainfall Return Period

Table 33. Affected Areas in Panganiban, Catanduanes during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Panganiban									
	Bagong Bayan	Burabod	Cabuyoan	Mabini	Salvacion	San Antonio	San Joaquin	San Jose	San Juan	San Miguel
0.03-0.20	0.16	1.78	7.19	1.93	0.8	0.74	0.12	0.42	0.075	0.96
0.21-0.50	0.046	0.14	0.27	0.11	0.052	0.11	0.15	0.098	0.071	0.035
0.51-1.00	0.14	0.16	0.4	0.24	0.18	0.3	0.58	0.15	0.26	0.022
1.01-2.00	0.2	0.15	1.5	0.27	0.41	0.47	1.06	0.26	0.21	0.028
2.01-5.00	0.092	0.035	0.18	0.27	0.098	0.0012	0.069	0.037	0.016	0.17
>5.00	0	0	0.11	0.024	0	0	0.0014	0	0	0.048

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Panganiban						
	San Nicolas	San Pedro	San Vicente	Santa Ana	Santa Maria	Santo Santiago	Taopon
0.03-0.20	0.045	0.011	0.014	0.31	0.092	0.0045	1.14
0.21-0.50	0.0069	0.013	0.0033	0.2	0.05	0.025	0.26
0.51-1.00	0.038	0.12	0.11	0.55	0.11	0.15	0.24
1.01-2.00	0.093	0.15	0.18	0.7	0.13	0.099	0.4
2.01-5.00	0.032	0.0024	0.062	0.1	0.058	0.022	0.0074
>5.00	0	0	0.0014	0	0.0027	0.0026	0

For the municipality of Viga with an area of 158.74 sq. km., 9.63% will experience flood levels of less than 0.20 meters. 0.84% of the area will experience flood levels of 0.21 to 0.50 meters, while 1.46%, 3.27%, 1.95%, and 0.32% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 34 depicts the areas affected in Viga in square kilometers by flood depth per barangay.

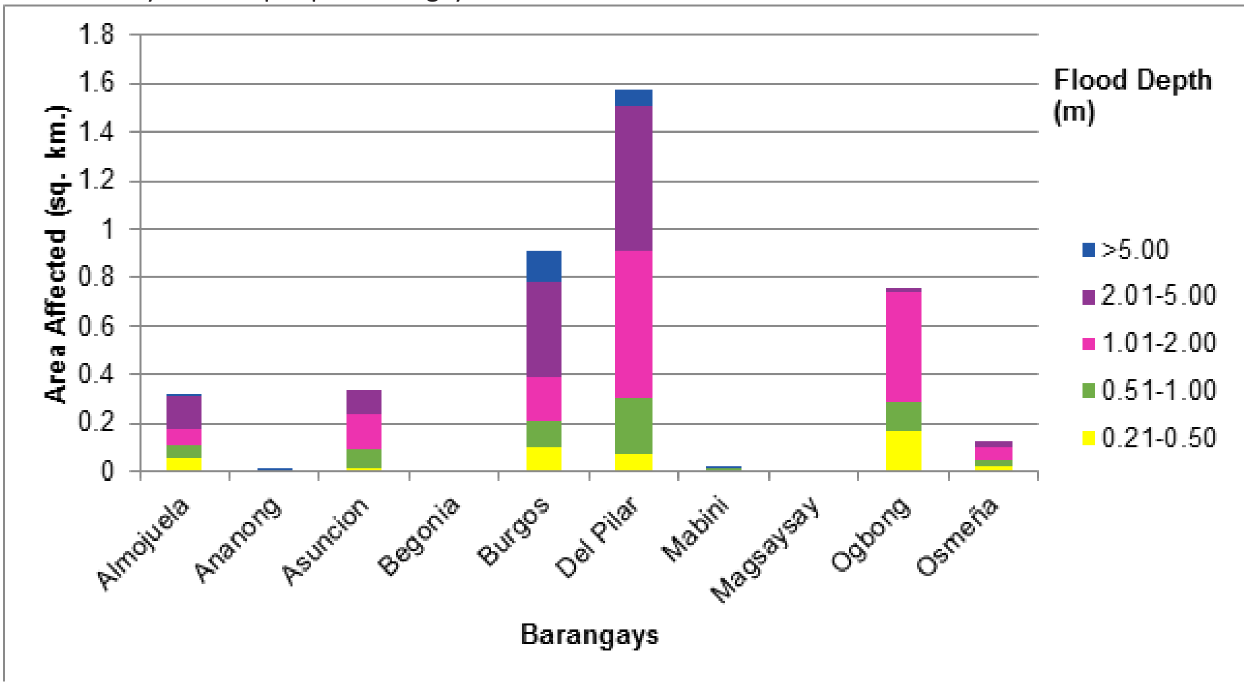


Figure 73. Affected Barangays in Viga, Catanduanes during the 25-Year Rainfall Return Period

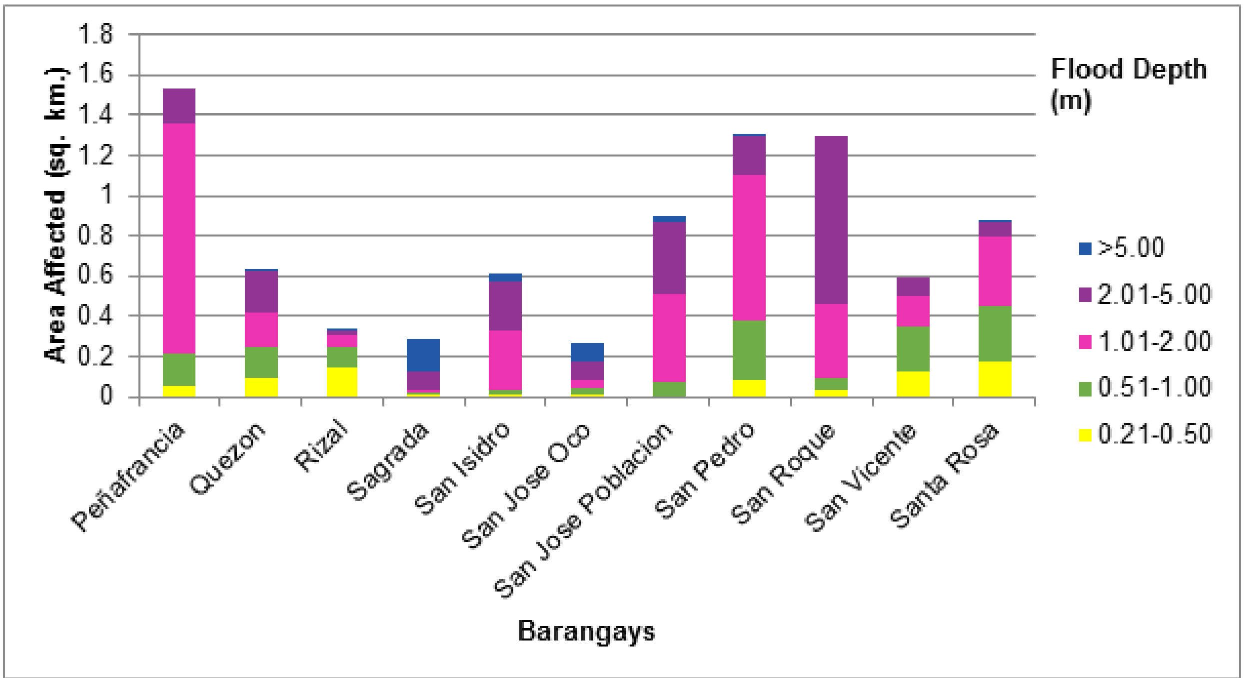


Figure 74. Affected Barangays in Viga, Catanduanes during the 25-Year Rainfall Return Period

Table 34. Affected Areas in Viga, Catanduanes during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Viga											
	Almojuela	Ananong	Asuncion	Begonia	Burgos	Del Pilar	Mabini	Magsaysay	Ogbong	Osmeña	Peñafrancia	Quezon
0.03-0.20	1.86	0.095	0.18	0.001	2.74	0.64	0.4	0.035	2.64	0.42	0.15	1.88
0.21-0.50	0.057	0.0031	0.0081	0	0.1	0.06	0.011	0	0.17	0.019	0.052	0.093
0.51-1.00	0.05	0.0007	0.042	0	0.1	0.16	0.0034	0	0.11	0.026	0.17	0.16
1.01-2.00	0.065	0.0005	0.16	0	0.14	0.52	0.0026	0	0.4	0.048	1.14	0.17
2.01-5.00	0.15	0.00061	0.13	0	0.42	0.79	0.0013	0	0.11	0.038	0.18	0.21
>5.00	0.0026	0.0007	0	0	0.17	0.072	0.0001	0	0	0.0001	0	0.0072

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Viga								
	Rizal	Sagrada	San Isidro	San Jose Oco	San Jose Poblacion	San Pedro	San Roque	San Vicente	Santa Rosa
0.03-0.20	0.79	0.048	0.015	0.15	0.12	0.1	1.06	0.6	1.01
0.21-0.50	0.14	0.011	0.0076	0.015	0.0057	0.08	0.033	0.13	0.17
0.51-1.00	0.11	0.009	0.027	0.022	0.069	0.29	0.064	0.22	0.28
1.01-2.00	0.065	0.0076	0.3	0.044	0.43	0.73	0.36	0.16	0.35
2.01-5.00	0.02	0.091	0.24	0.091	0.36	0.2	0.84	0.083	0.066
>5.00	0.0065	0.17	0.044	0.093	0.034	0.0083	0	0	0.0001

For the 100-year rainfall return period, 0.008% of the municipality of Bagamanoc with an area of 82.85 sq. km. will experience flood levels of less than 0.20 meters.

For the municipality of Panganiban with an area of 85.59 sq. km., 17.89% will experience flood levels of less than 0.20 meters. 1.6% of the area will experience flood levels of 0.21 to 0.50 meters, while 3.33%, 8.68%, 2.07%, and 0.26% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 35 depicts the areas affected in Panganiban in square kilometers by flood depth per barangay.

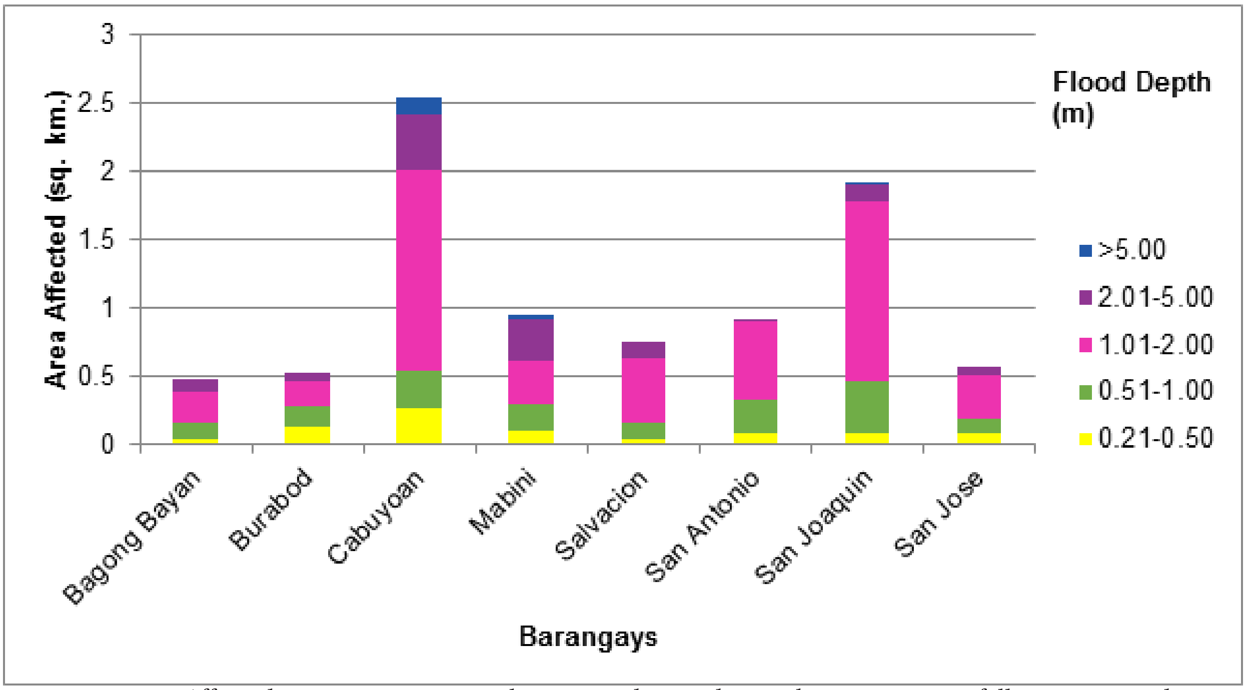


Figure 75. Affected Barangays in Panganiban, Catanduanes during the 100-Year Rainfall Return Period

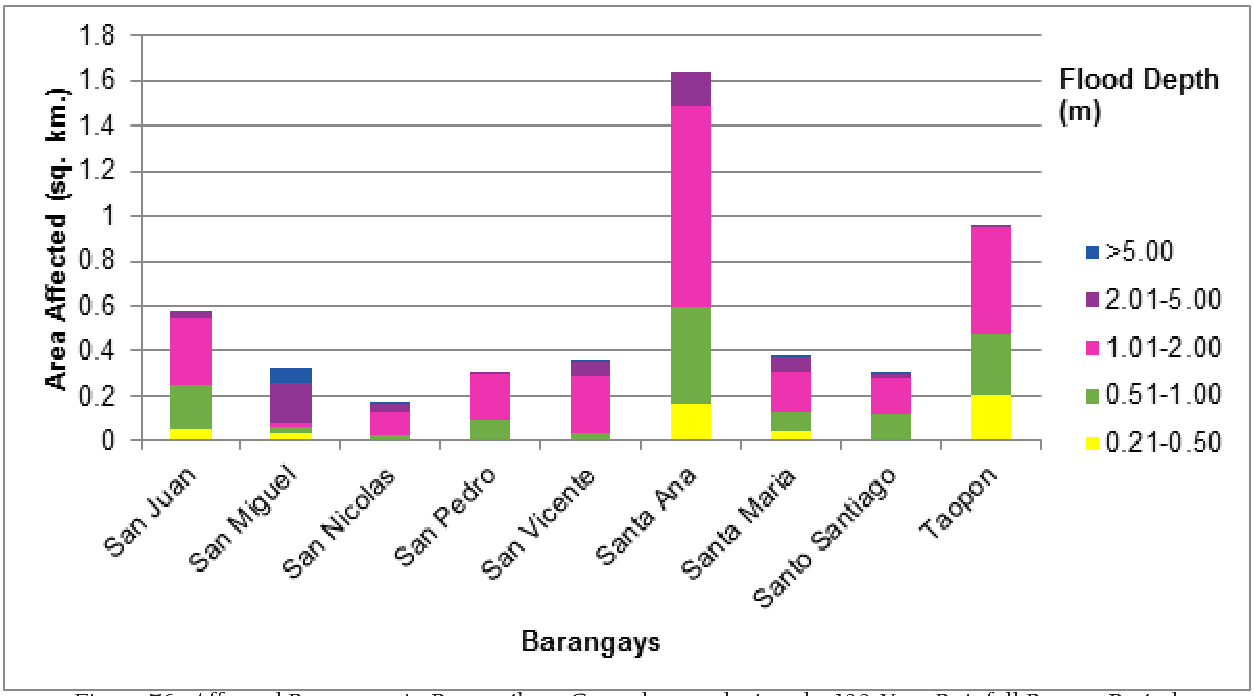


Figure 76. Affected Barangays in Panganiban, Catanduanes during the 100-Year Rainfall Return Period

Table 35. Affected Areas in Panganiban, Catanduanes during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Panganiban									
	Bagong Bayan	Burabod	Cabuyoan	Mabini	Salvacion	San Antonio	San Joaquin	San Jose	San Juan	San Miguel
0.03-0.20	0.15	1.75	7.11	1.9	0.77	0.72	0.068	0.4	0.054	0.94
0.21-0.50	0.037	0.13	0.26	0.098	0.04	0.087	0.089	0.09	0.06	0.04
0.51-1.00	0.12	0.15	0.28	0.2	0.12	0.24	0.38	0.1	0.2	0.021
1.01-2.00	0.22	0.18	1.46	0.31	0.47	0.57	1.32	0.32	0.3	0.027
2.01-5.00	0.1	0.055	0.42	0.31	0.13	0.011	0.12	0.059	0.026	0.17
>5.00	0	0	0.12	0.03	0	0	0.0035	0	0	0.063

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Panganiban						
	San Nicolas	San Pedro	San Vicente	Santa Ana	Santa Maria	Santo Santiago	Taopon
0.03-0.20	0.043	0.0077	0.013	0.23	0.063	0.0019	1.09
0.21-0.50	0.0051	0.0098	0.002	0.16	0.051	0.0063	0.21
0.51-1.00	0.021	0.08	0.034	0.43	0.083	0.11	0.27
1.01-2.00	0.1	0.2	0.25	0.89	0.17	0.16	0.48
2.01-5.00	0.041	0.0029	0.065	0.15	0.069	0.024	0.011
>5.00	0.0001	0	0.0034	0	0.0035	0.0047	0

For the municipality of Viga with an area of 158.74 sq. km., 9.12% will experience flood levels of less than 0.20 meters. 0.66% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.9%, 2.77%, 3.54%, 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 greater than 5 meters, respectively. Table 36 depicts the areas affected in Viga in square kilometers by flood depth per barangay.

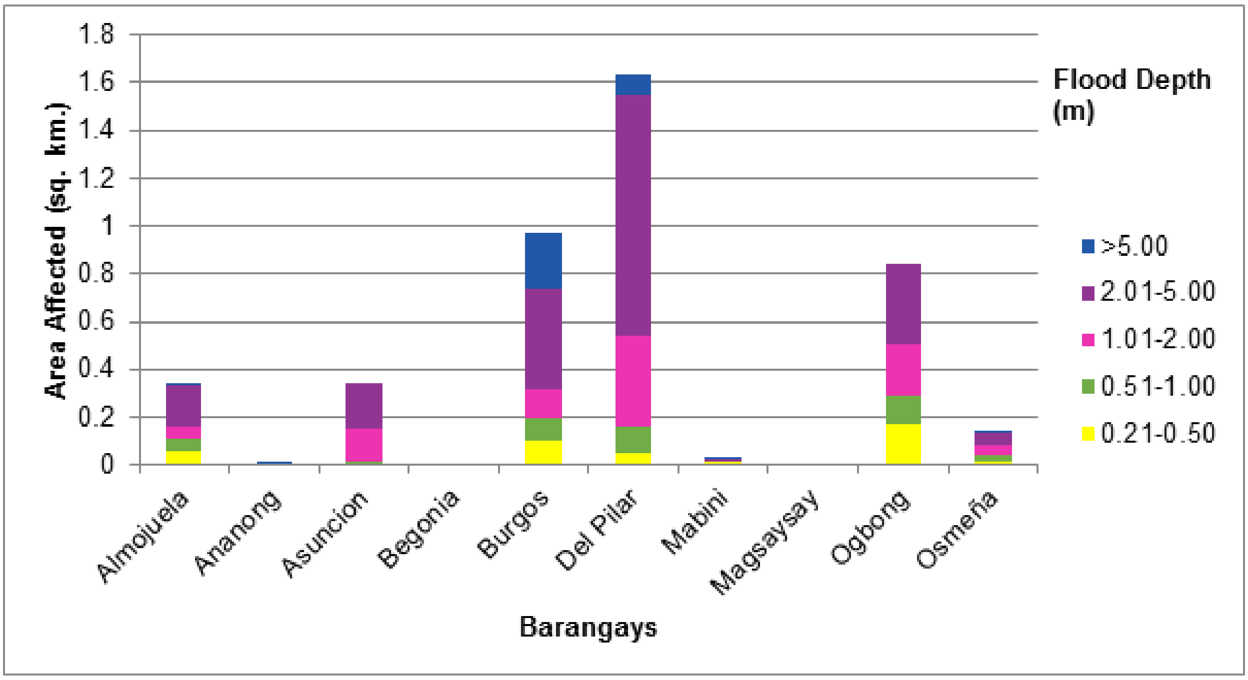


Figure 77. Affected Barangays in Viga, Catanduanes during the 100-Year Rainfall Return Period

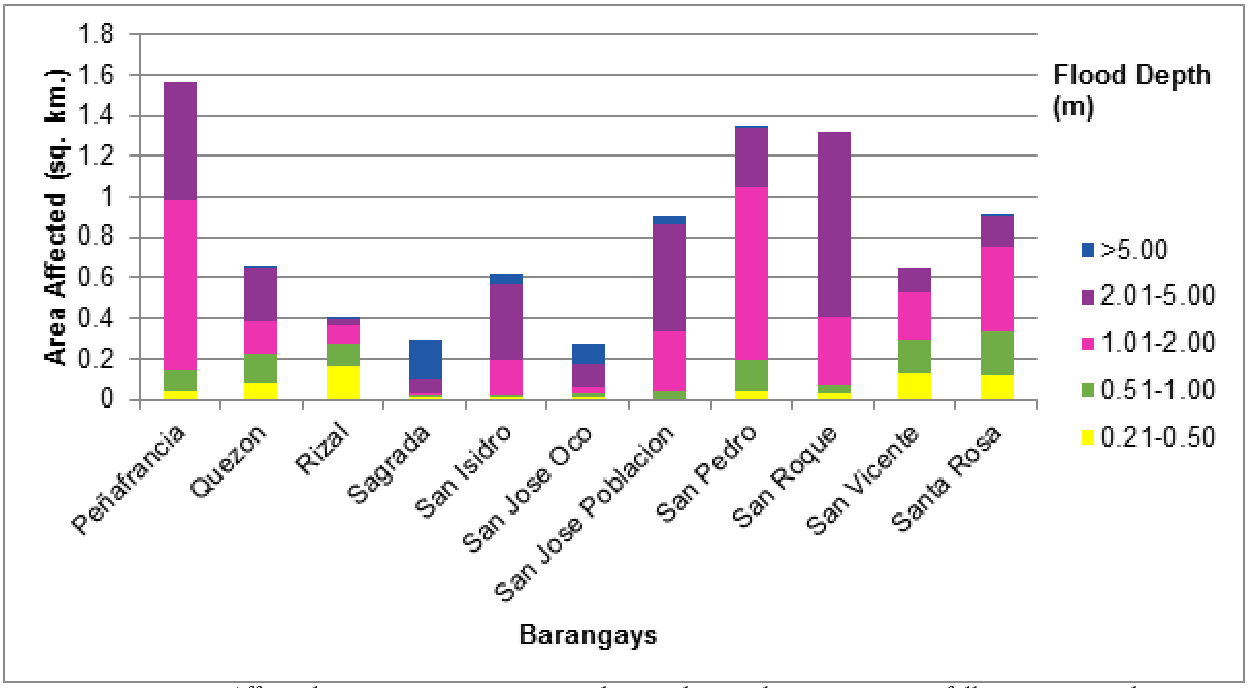


Figure 78. Affected Barangays in Viga, Catanduanes during the 100-Year Rainfall Return Period

Table 36. Affected Areas in Viga, Catanduanes during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Viga											
	Almojuela	Ananong	Asuncion	Begonia	Burgos	Del Pilar	Mabini	Magsaysay	Ogbong	Osmeña	Peñafrancia	Quezon
0.03-0.20	1.84	0.094	0.17	0.001	2.71	0.61	0.39	0.035	2.59	0.42	0.12	1.85
0.21-0.50	0.061	0.0038	0.0037	0	0.098	0.045	0.012	0	0.17	0.018	0.037	0.08
0.51-1.00	0.047	0.0007	0.012	0	0.097	0.12	0.0046	0	0.12	0.023	0.1	0.14
1.01-2.00	0.052	0.0007	0.14	0	0.12	0.38	0.0021	0	0.22	0.039	0.85	0.17
2.01-5.00	0.17	0.00061	0.19	0	0.42	1.01	0.0019	0	0.33	0.056	0.58	0.26
>5.00	0.014	0.0007	0	0	0.23	0.088	0.0002	0	0	0.0003	0	0.0092

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Viga								
	Rizal	Sagrada	San Isidro	San Jose Oco	San Jose Poblacion	San Pedro	San Roque	San Vicente	Santa Rosa
0.03-0.20	0.72	0.042	0.013	0.14	0.12	0.06	1.04	0.54	0.97
0.21-0.50	0.16	0.013	0.0063	0.013	0.0052	0.042	0.028	0.13	0.13
0.51-1.00	0.11	0.0089	0.014	0.016	0.039	0.16	0.047	0.17	0.21
1.01-2.00	0.095	0.0077	0.18	0.037	0.29	0.84	0.34	0.23	0.41
2.01-5.00	0.033	0.071	0.37	0.11	0.53	0.3	0.91	0.12	0.15
>5.00	0.0069	0.19	0.047	0.096	0.037	0.013	0	0	0.0003

The only barangay in the municipality of Bagamanoc that will experience flood levels at 0.008% is Santa Mesa.

Among the barangays in the municipality of Panganiban, Cabuyoan is projected to have the highest percentage of area that will experience flood levels at 11.27%. Meanwhile, Mabini posted the second highest percentage of area that may be affected by flood depths at 3.33%.

Among the barangays in the municipality of Viga, Burgos is projected to have the highest percentage of area that will experience flood levels of at 2.32%. Meanwhile, Ogbong posted the second highest percentage of area that may be affected by flood depths at 2.16%.

Moreover, the generated flood hazard maps for the Viga Floodplain were used to assess the vulnerability of the educational and medical institutions in the floodplain. Using the flood depth units of PAG-ASA for hazard maps - “Low”, “Medium”, and “High” - the affected institutions were given their individual assessment for each Flood Hazard Scenario (5 yr, 25 yr, and 100 yr). The educational and health institutions exposed to flooding in Viga Floodplain are found in Annex 12 and Annex 13, respectively.

Table 37. Area covered by each warning level with respect to the rainfall scenario

Warning Level	Area Covered in sq. km.		
	5 year	25 year	100 year
Low	3.17	2.74	2.35
Medium	13.42	12.5	10.47
High	8.78	10.9	14.25
TOTAL	**25.37**	**26.14**	**27.07**

5.11 Flood Validation

This river basin has no flood validation data.

REFERENCES

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

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

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

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

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

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

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

ANNEXES

Annex 1. Optech Technical Specification of the Pegasus Sensor

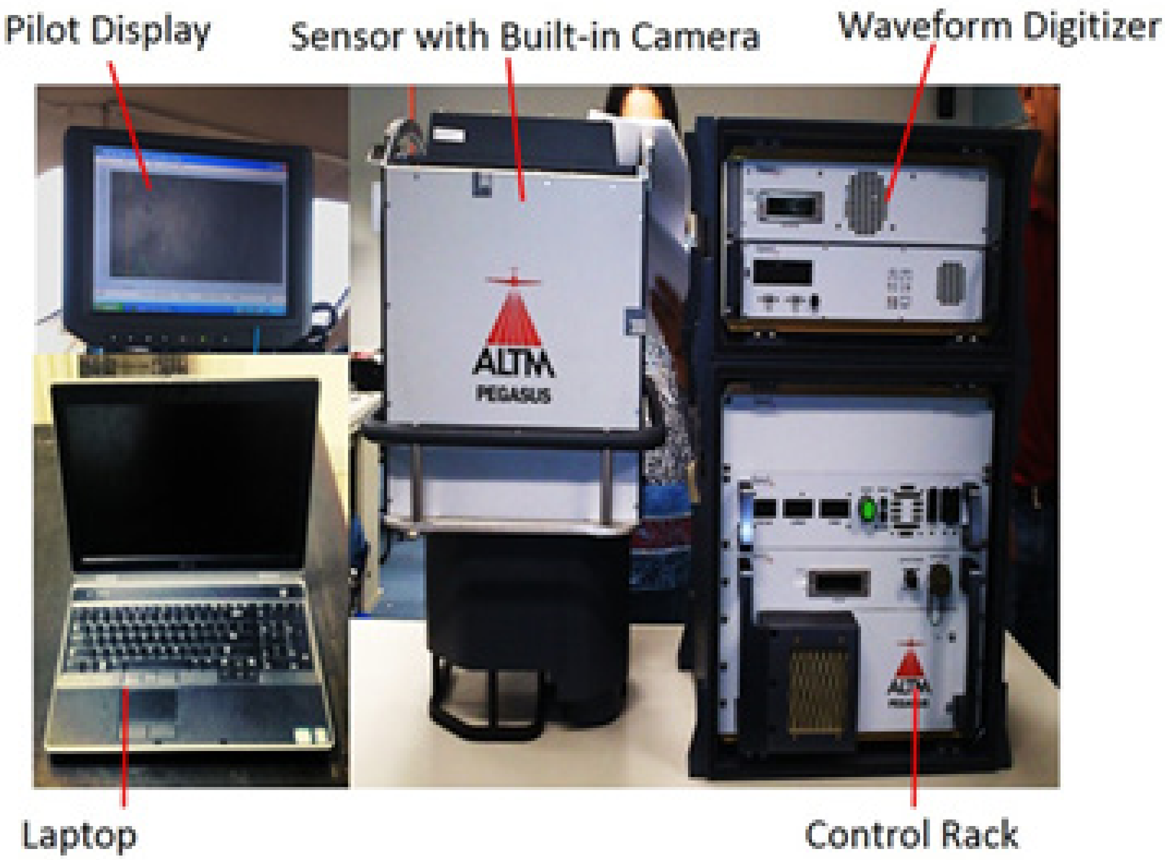


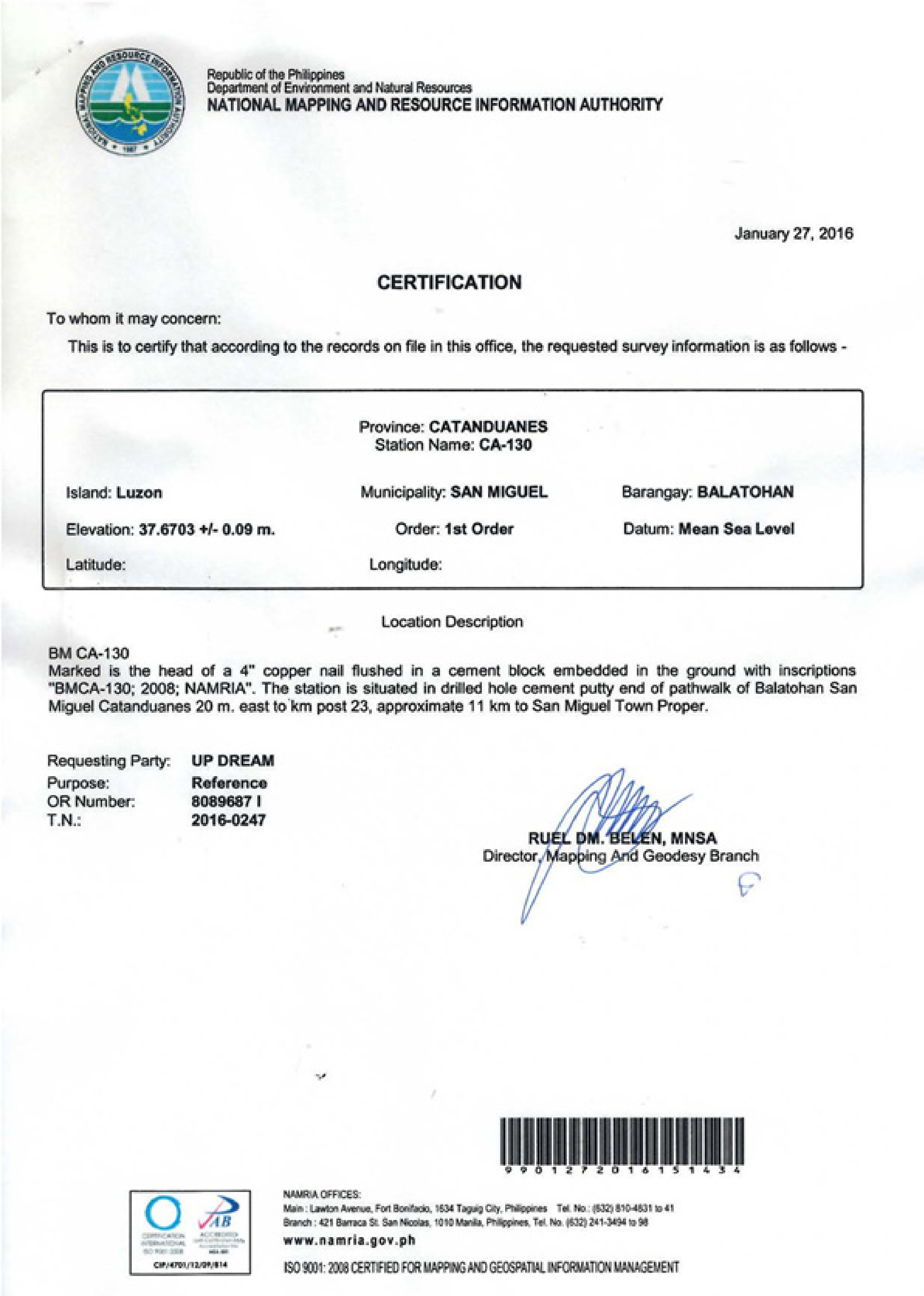
Figure A-1.1 Pegasus Sensor

Table A-1.1 Parameters and Specifications of the Pegasus Sensor

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

Annex 2. NAMRIA Certificates of Reference Points Used

1. CA-130



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

January 27, 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: **CATANDUANES** Station Name: **CA-130**	
Island: **Luzon**	Municipality: **SAN MIGUEL**	Barangay: **BALATOHAN**
Elevation: **37.6703 +/- 0.09 m.**	Order: **1st Order**	Datum: **Mean Sea Level**
Latitude:	Longitude:	

Location Description

BM CA-130
Marked is the head of a 4" copper nail flushed in a cement block embedded in the ground with inscriptions "BMCA-130; 2008; NAMRIA". The station is situated in drilled hole cement putty end of pathwalk of Balatohan San Miguel Catanduanes 20 m. east to km post 23, approximate 11 km to San Miguel Town Proper.

Requesting Party: **UP DREAM**
Purpose: **Reference**
OR Number: **8089687 I**
T.N.: **2016-0247**

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

9 9 0 1 2 7 2 0 1 6 1 5 1 4 3 4

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.1 CA-130

2. CNS-17

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

January 27, 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: **CATANDUANES**	
	Station Name: **CNS-17**	
	Order: **2nd**	
Island: **LUZON**	Barangay: **POBLACION**	
Municipality: **BAGAMANOC**	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **13° 56' 28.40127"**	Longitude: **124° 17' 15.04693"**	Ellipsoidal Hgt: **3.51100 m.**
	WGS84 Coordinates	
Latitude: **13° 56' 23.40703"**	Longitude: **124° 17' 19.97478"**	Ellipsoidal Hgt: **56.92100 m.**
	PTM / PRS92 Coordinates	
Northing: **1542046.993 m.**	Easting: **639135.732 m.**	Zone: **4**
	UTM / PRS92 Coordinates	
Northing: **1,541,507.25**	Easting: **639,087.04**	Zone: **51**

Location Description

CNS-17

From Mun. of Panganiban, travel N along Circumferential Road for about 5 Km. up to Mun. of Bagamanoc. Station is located at the top end of riprap and concrete box culvert along the Nat'l Road. Mark is the head of a 4 in. copper nail centered on a drilled hole with cement putty, embedded at concrete riprap with inscriptions, "CNS-17, 2007, NAMRIA".

Requesting Party: **UP DREAM**
Purpose: **Reference**
OR Number: **8089687 I**
T.N.: **2016-0246**

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

9 9 0 1 2 7 2 0 1 6 1 5 1 4 1 7

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.2 CNS-17

3. CNS-20

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

January 27, 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: **CATANDUANES**	
	Station Name: **CNS-20**	
	Order: **2nd**	
Island: **LUZON**	Barangay: **PAGSANGAHAN**	
Municipality: **SAN MIGUEL**	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **13° 43' 8.77572"**	Longitude: **124° 16' 9.57152"**	Ellipsoidal Hgt: **43.75200 m.**
	WGS84 Coordinates	
Latitude: **13° 43' 3.83355"**	Longitude: **124° 16' 14.51857"**	Ellipsoidal Hgt: **97.73600 m.**
	PTM / PRS92 Coordinates	
Northing: **1517459.029 m.**	Easting: **637300.168 m.**	Zone: **4**
	UTM / PRS92 Coordinates	
Northing: **1,516,927.89**	Easting: **637,252.11**	Zone: **51**

Location Description

CNS-20

From Virac Town Proper, travel N passing through Mun. of San Miguel for about 25 Km. Station is located at NW wing of Malmag bridge along Circumferential Road going to Mun. of Viga. Mark is the head of a 4 in. copper nail centered on a drilled hole with cement putty, embedded at concrete bridge with inscriptions, "CNS-20, 2007, NAMRIA".

Requesting Party: **UP DREAM**
Purpose: **Reference**
OR Number: **8089687 I**
T.N.: **2016-0244**

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

9 9 0 1 2 7 2 0 1 6 1 5 1 3 3 5

NAMRIA OFFICES:
Main : Lawton Avenue, Fort Bonifacio, 1634 Taguig City, Philippines Tel. No.: (632) 810-4831 to 41
Branch : 421 Barraca St. San Nicolas, 1010 Manila, Philippines, Tel. No. (632) 241-3494 to 98
www.namria.gov.ph
ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.3 CNS-20

Annex 3. Baseline Processing Report of Reference Points Used

1. CA-130

Vector Components (Mark to Mark)

From:	CNS-20 2016-1-27 TOPCON_GR5_ECQW				
Grid		Local		Global	
Easting	637252.110 m	Latitude	N13°43'08.77572"	Latitude	N13°43'03.83355"
Northing	1516927.891 m	Longitude	E124°16'09.57152"	Longitude	E124°16'14.51857"
Elevation	44.886 m	Height	43.752 m	Height	97.736 m

To:	CA-130				
Grid		Local		Global	
Easting	637606.660 m	Latitude	N13°43'03.83963"	Latitude	N13°42'58.89826"
Northing	1516778.097 m	Longitude	E124°16'21.34732"	Longitude	E124°16'26.29446"
Elevation	38.672 m	Height	37.511 m	Height	91.507 m

Vector					
ΔEasting	354.550 m	NS Fwd Azimuth	113°12'17"	ΔX	-309.234 m
ΔNorthing	-149.795 m	Ellipsoid Dist.	384.959 m	ΔY	-174.525 m
ΔElevation	-6.214 m	ΔHeight	-6.240 m	ΔZ	-148.827 m

Standard Errors

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

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000019397		
Y	-0.0000007127	0.0000032012	
Z	-0.0000005242	0.0000008142	0.0000005724

Figure A-3.1 Baseline Processing Report - A

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 BALICANTA	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP

FIELD TEAM

LiDAR Operation, Ground Survey, Data Download and Transfer	Senior Science Research Specialist (SSRS)	JASMINE ALVIAR	UP-TCAGP
	Research Associate (RA)	KENNETH QUISADO	UP-TCAGP
		KRISTINE JOY ANDAYA	
		NICOLAS ILEJAY	
LiDAR Operation	Airborne Security	SSG. LEE JAY PUNZALAN	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. SHERWIN ALFONSO III	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. JERICHO JECIEL	

Annex 5. Data Transfer Sheet for Viga Floodplain

DATA TRANSFER SHEET
2/10/16 (Catanduanes)

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	
3-Feb	10081AC	3AQUACALIB034A	Aquarius	NA	47	143	110	12.7	29.1/31.8/31.1/24	2.44	na	4.32	1KB	1KB	4KB	30KB	Z:\DAC\RAW DATA
27-Jan	3026P	1BLK25F027A	Pegasus	303	617KB/91KB	6.04	135	NA	NA	4.78	NA	64.5	1KB	1KB	NA	617KB/91KB	Z:\DAC\RAW DATA
28-Jan	3032P	1BLK25E028B	Pegasus	3.34	47KB	4.53	149	NA	NA	3.27	na	95.9	1KB	NA	312KB/283KB/303KB	47KB	Z:\DAC\RAW DATA
1-Feb	3048P	1BLK25F032A	Pegasus	983	557KB/231KB	7.84	195	NA	NA	12.9	na	91.5	1KB	NA	NA	557KB/231KB	Z:\DAC\RAW DATA
1-Feb	3050P	1BLK25E032B	Pegasus	1.29	2801KB/291KB	8.5	196	NA	NA	14.8	na	91.5	1KB	NA	312KB/283KB/303KB	2801KB/291KB	Z:\DAC\RAW DATA

Received from

Name Jonalyn Gonzales
Position RA
Signature

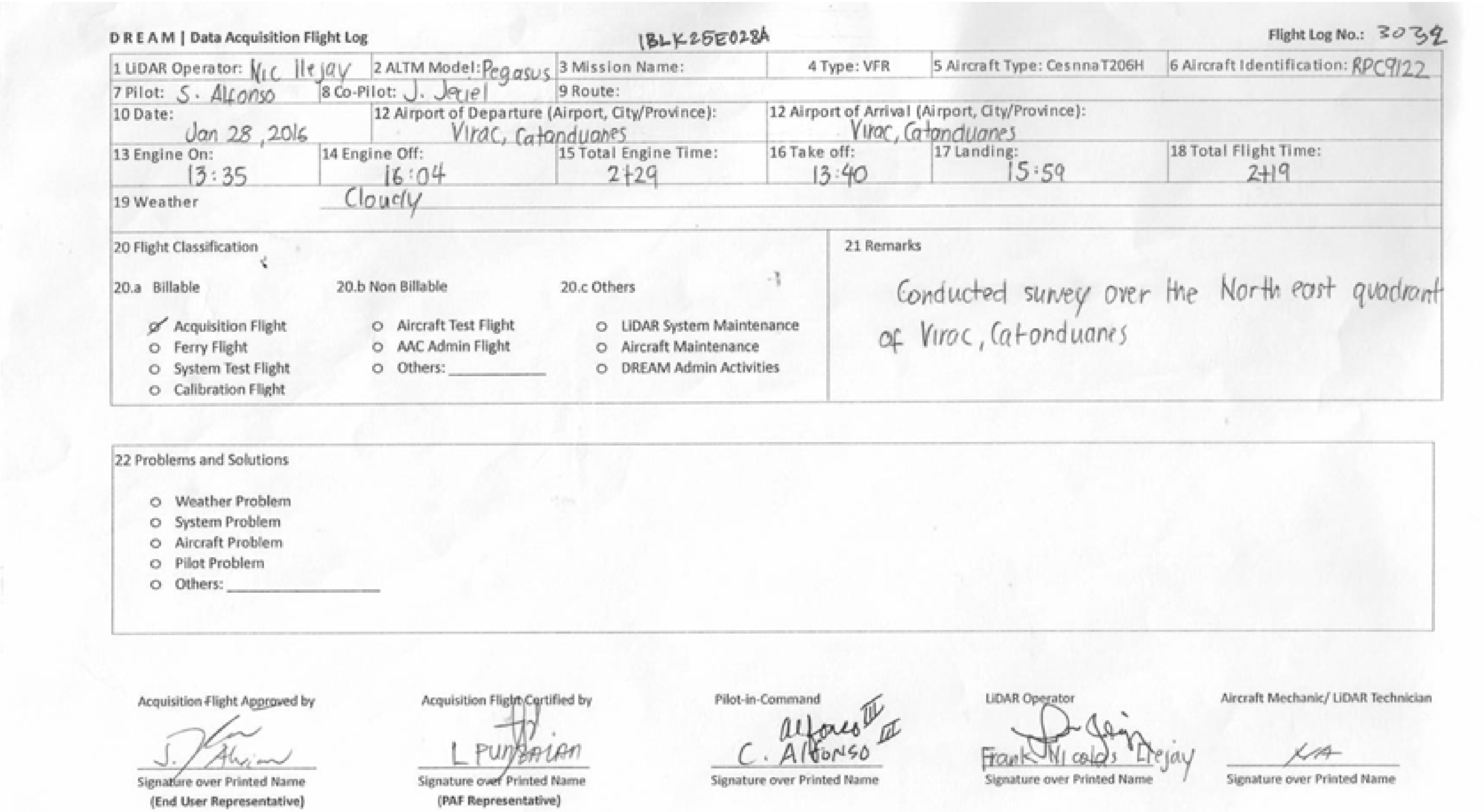
Received by

Name AC Bongat 2/12/16
Position SSRS
Signature

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

Annex 6. Flight logs

1. Flight Log for 3032P Mission



DREAM | Data Acquisition Flight Log — 1BLK25E028A — Flight Log No.: 3032

1 LiDAR Operator: Nic Ilejay	2 ALTM Model: Pegasus	3 Mission Name:	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RPC9122
7 Pilot: S. Alfonso	8 Co-Pilot: J. Jeciel	9 Route:			
10 Date: Jan 28, 2016	12 Airport of Departure (Airport, City/Province): Virac, Catanduanes		12 Airport of Arrival (Airport, City/Province): Virac, Catanduanes		
13 Engine On: 13:35	14 Engine Off: 16:04	15 Total Engine Time: 2+29	16 Take off: 13:40	17 Landing: 15:59	18 Total Flight Time: 2+19
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
- ○ DREAM Admin Activities

21 Remarks

Conducted survey over the North east quadrant of Virac, Catanduanes

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	LiDAR Operator	Aircraft Mechanic/ LiDAR Technician
J. Alviar	L Punzalan	C. Alfonso III	Frank Nicolas Ilejay	
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

Figure A-6.1 Flight log for Mission 3032P

2. Flight Log for 3048P Mission

Flight Log No.: 3048

D R E A M | Data Acquisition Flight Log

1 LiDAR Operator: Kenneth Quisado	2 ALTM Model: Pegasus	3 Mission Name: 1BLK25P132A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP C9122
7 Pilot: S. Alfonso	8 Co-Pilot: J. Jeciel	9 Route: RPUV - Local Area			
10 Date: Feb 1, 2016	12 Airport of Departure (Airport, City/Province): Virac, Catanduanes		12 Airport of Arrival (Airport, City/Province): Virac, Catanduanes		
13 Engine On: 8:05	14 Engine Off: 11:28	15 Total Engine Time: 3+23	16 Take off: 8:10	17 Landing: 11:23	18 Total Flight Time: 3+13
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
- ○ DREAM Admin Activities

21 Remarks

Surveyed area over the Northeast quadrant of Virac, Catanduanes

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	LiDAR Operator	Aircraft Mechanic/ LiDAR Technician
J. [signature]	L. Pumarian	C. Alfonso III	Kenneth Quisado	[signature]
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

Figure A-6.2 Flight log for Mission 3048P

3. Flight Log for 3050P Mission

DREAM | Data Acquisition Flight Log

Flight Log No.: 3050

1 LiDAR Operator: Kristine Andaya	2 ALTM Model: Pegasus	3 Mission Name: 1BLK25E032B	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RPC9122
7 Pilot: S. Alfonso	8 Co-Pilot: J. Jeciel	9 Route: RPUV-Local Area			
10 Date: Feb 1, 2016	12 Airport of Departure (Airport, City/Province): Viroc, Catanduanes		12 Airport of Arrival (Airport, City/Province): Viroc, Catanduanes		
13 Engine On: 13:00	14 Engine Off: 16:11	15 Total Engine Time: 3H11	16 Take off: 13:05	17 Landing: 16:06	18 Total Flight Time: 3H01
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 DREAM Admin Activities

21 Remarks

Surveyed area over the North quadrant of Viroc, Catanduanes

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	LiDAR Operator	Aircraft Mechanic/ LiDAR Technician
J. Alviar	L. Pumalan	C. Alfonso III	Kristine Joy Andaya	
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

Figure A-6.3 Flight log for Mission 3050P

Annex 7. Flight Status Report

FLIGHT STATUS REPORT
CATANDUANES
(January 20 – February 4, 2016)

Table A-7.1 Flight Status Report

FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
3032P	BLK 25F	1BLK25E028A	KA QUISADO	JAN 28	SURVEYEED BLK 25F; NO LAS OUTPUT 25.44 SQ.KM
3048P	BLK 25E,D,F	1BLK25F032A	KA QUISADO	FEB 1	SURVEYED BLK 25ED 134.438 SQ.KM
3050P	BLK 25E CABUYAN AND CABUYAN 2 FPS	1BLK25E032B	KJ ANDAYA	FEB 1	SURVEYED BLK 25E: CABUYAN AND CABUYAN 2 FPS 120.79 SQ.KM

LAS BOUNDARIES PER FLIGHT

Flight No. :	3032P			
Area:	BLK 25F			
Mission Name:	1BLK25E028A			
Parameters:	Altitude:	1000m;	Scan Frequency: 30Hz;	
	Scan Angle:	25deg;	Overlap: 20%	

LAS

Figure A-7.1 Swath of Flight No. 3032P

Flight No. :	3048P			
Area:	BLK 25EDF			
Mission Name:	1BLK25EF032A			
Parameters:	Altitude:	1000m;	Scan Frequency: 30Hz;	
	Scan Angle:	25deg;	Overlap: 20%	

LAS

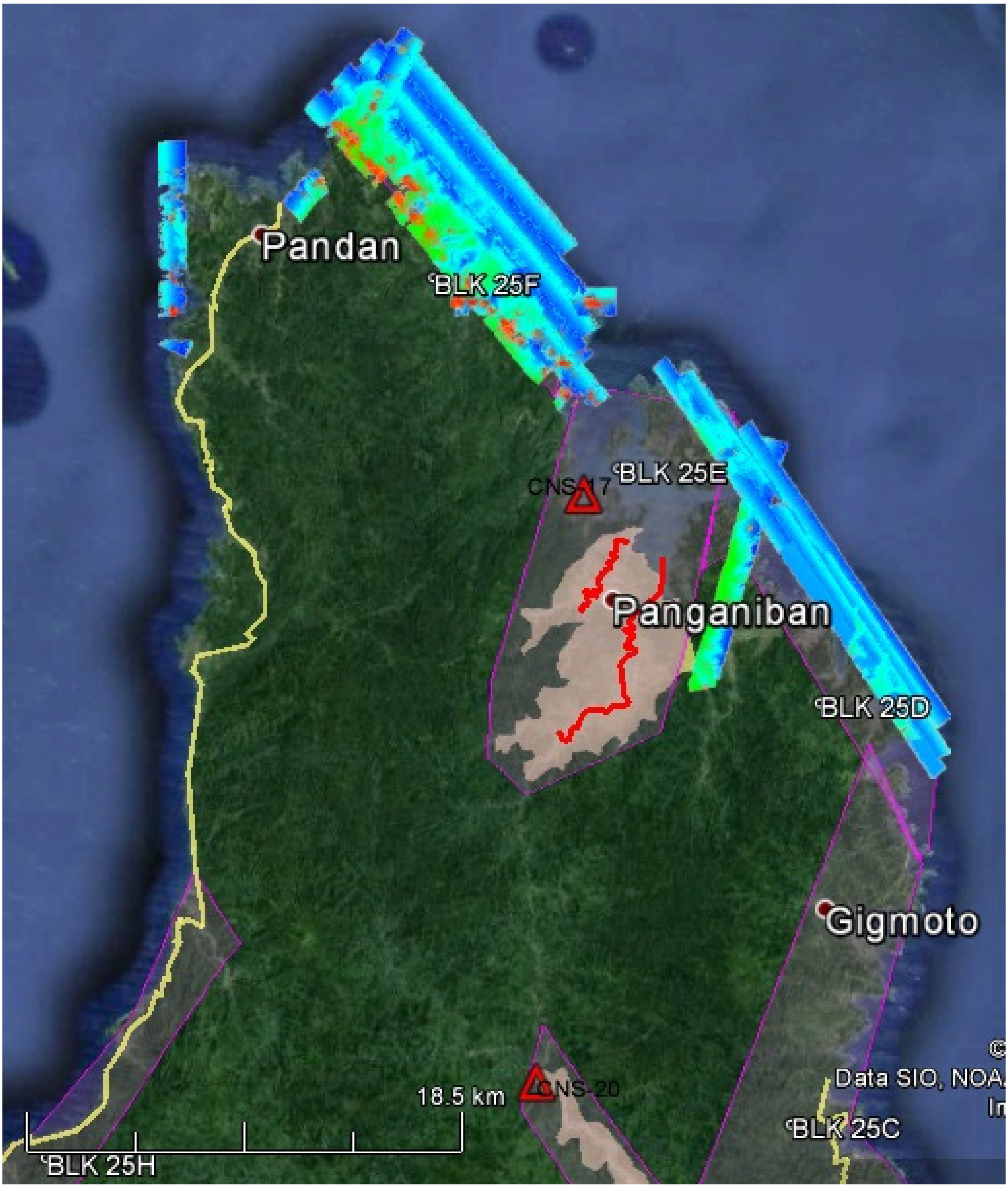


Figure A-7.2 Swath of Flight No. 3048P

Flight No. :	3050P			
Area:	BLK 25E			
Mission Name:	1BLK25E032B			
Parameters:	Altitude:	800m;	Scan Frequency: 30Hz;	
	Scan Angle:	25deg;	Overlap: 20%	

LAS

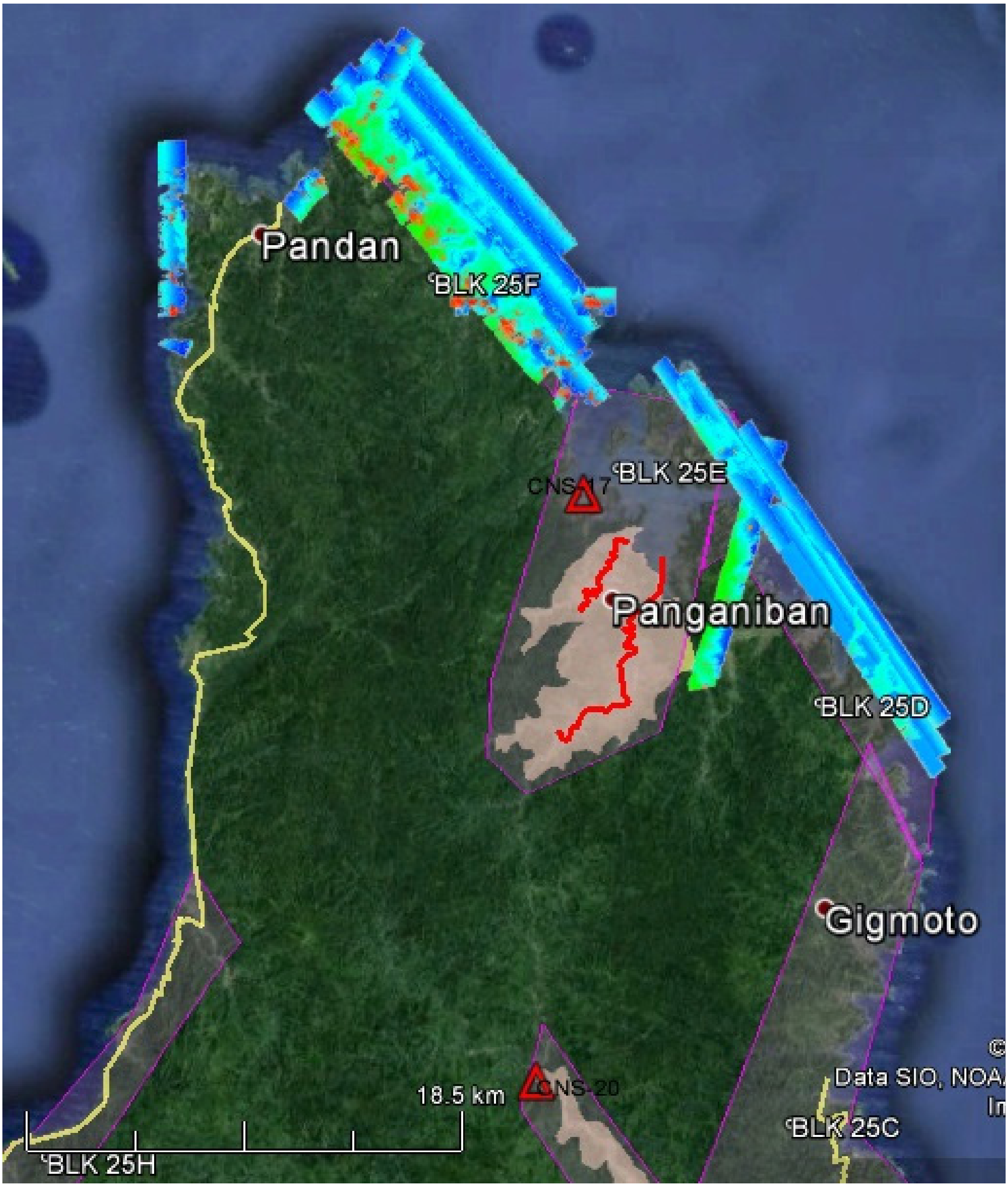


Figure A-7.3 Swath of Flight No. 3050P

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report of Mission Blk25E

FLIGHT AREA	CATANDUANES
Mission Name	Blk25E
Inclusive Flights	3050P
Range data size	14.8 GB
POS	196 MB
Image	NA
Base Station	91.5 MB
Transfer date	February 12, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	2.4
RMSE for East Position (<4.0 cm)	2.2
RMSE for Down Position (<8.0 cm)	5.0
Boresight correction stdev (<0.001deg)	0.000226
IMU attitude correction stdev (<0.001deg)	NA
GPS position stdev (<0.01m)	0.0008
Minimum % overlap (>25)	20.87
Ave point cloud density per sq.m. (>2.0)	3.63
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	153
Maximum Height	394.46 m
Minimum Height	44.27 m
Classification (# of points)	
Ground	145,694,380
Low vegetation	62,990,506
Medium vegetation	116,153,296
High vegetation	446,464,799
Building	8,055,412
Orthophoto	No
Processed by	Engr. Don Matthew Banatin, Engr. Edgardo Gubatanga Jr., Maria Tamsyn Malabanan

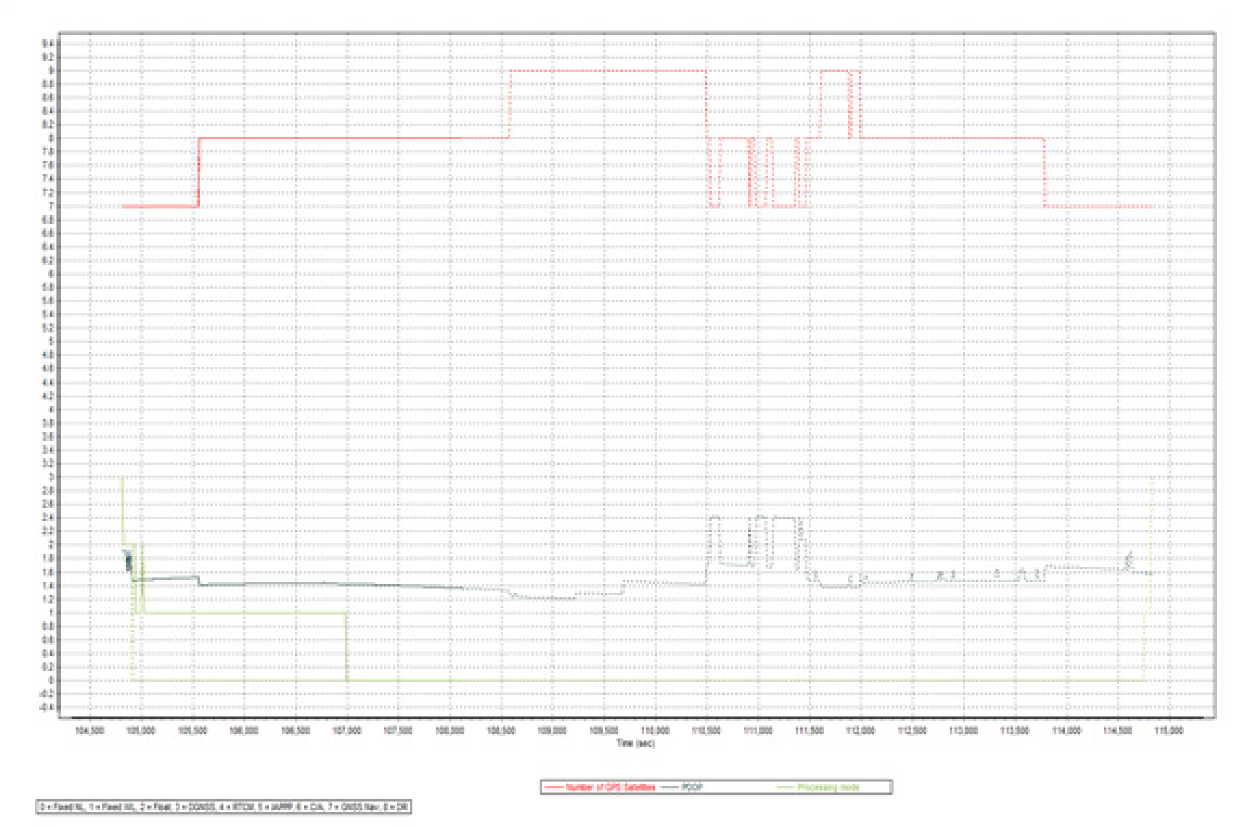


Figure A-8.1. Solution Status

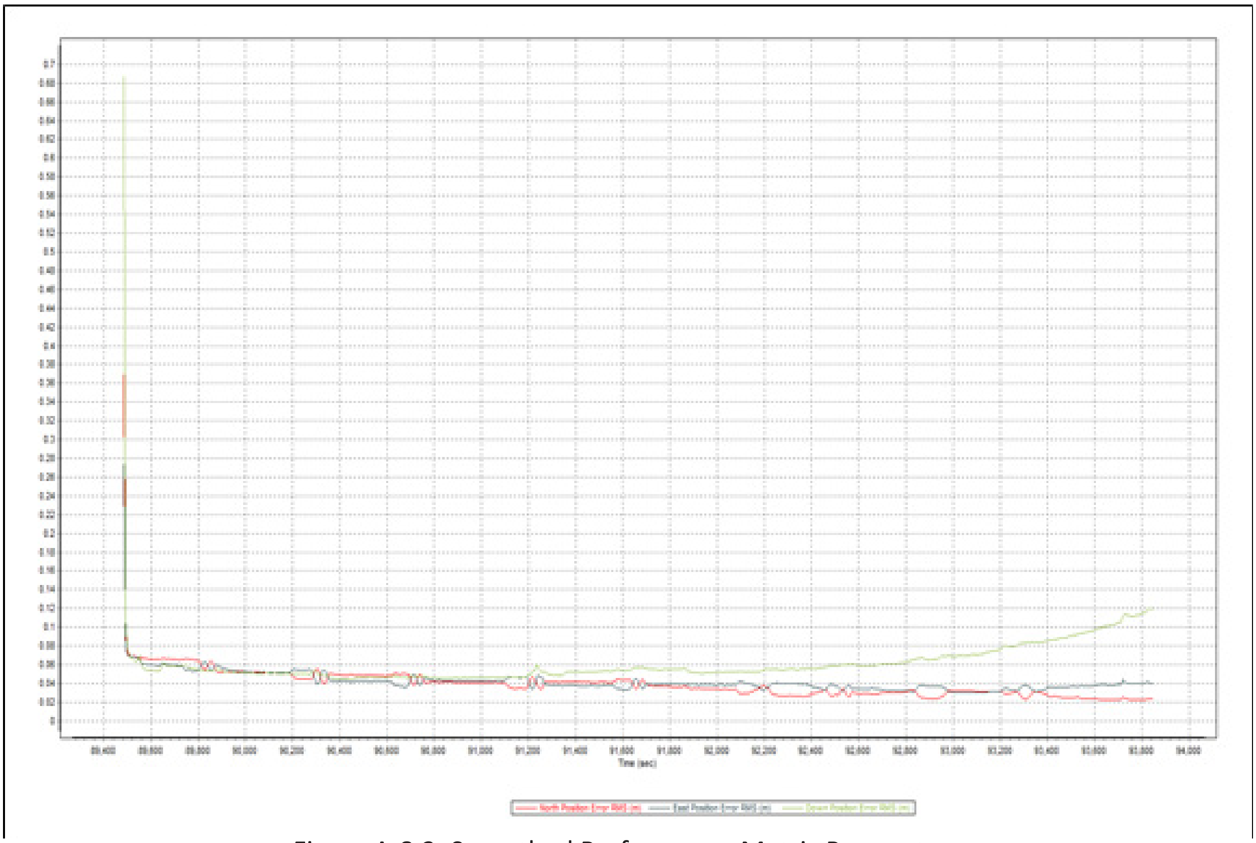


Figure A-8.2. Smoothed Performance Metric Parameters

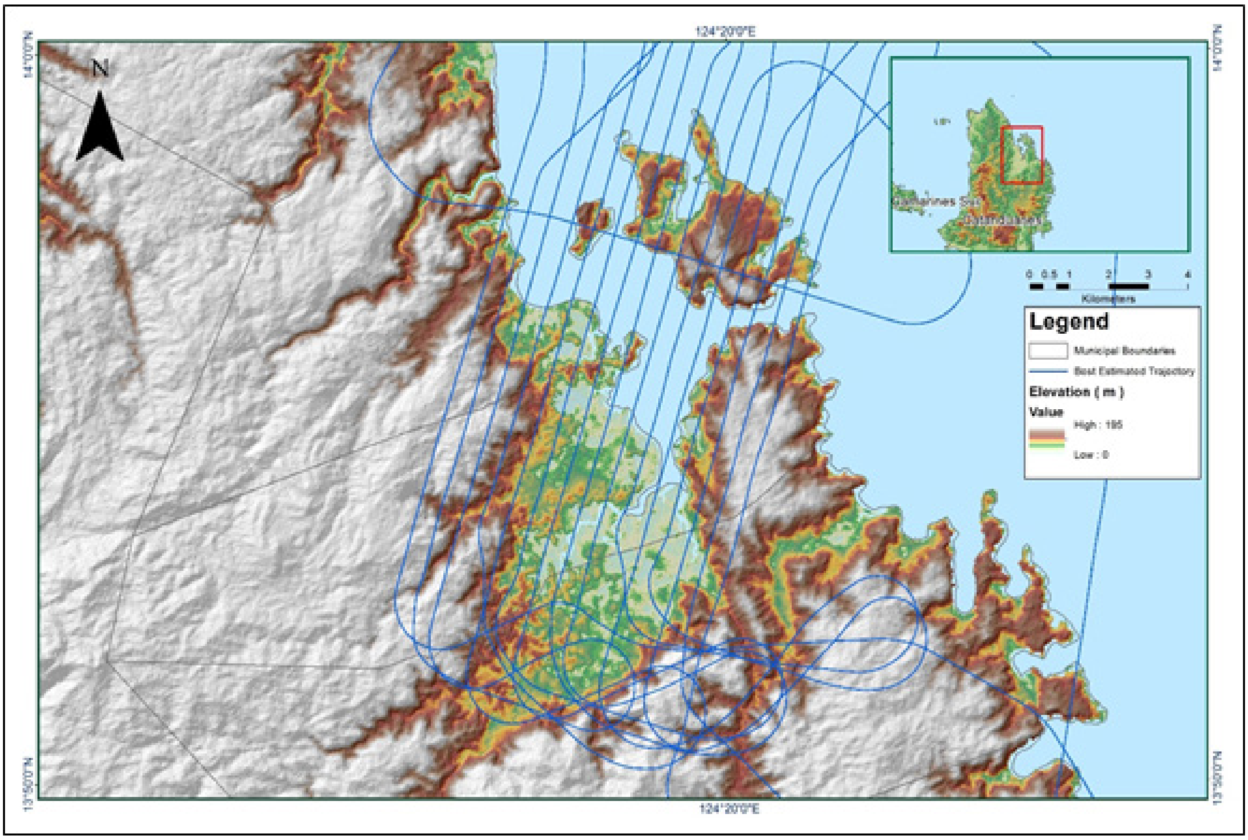


Figure A-8.3. Best Estimate Trajectory

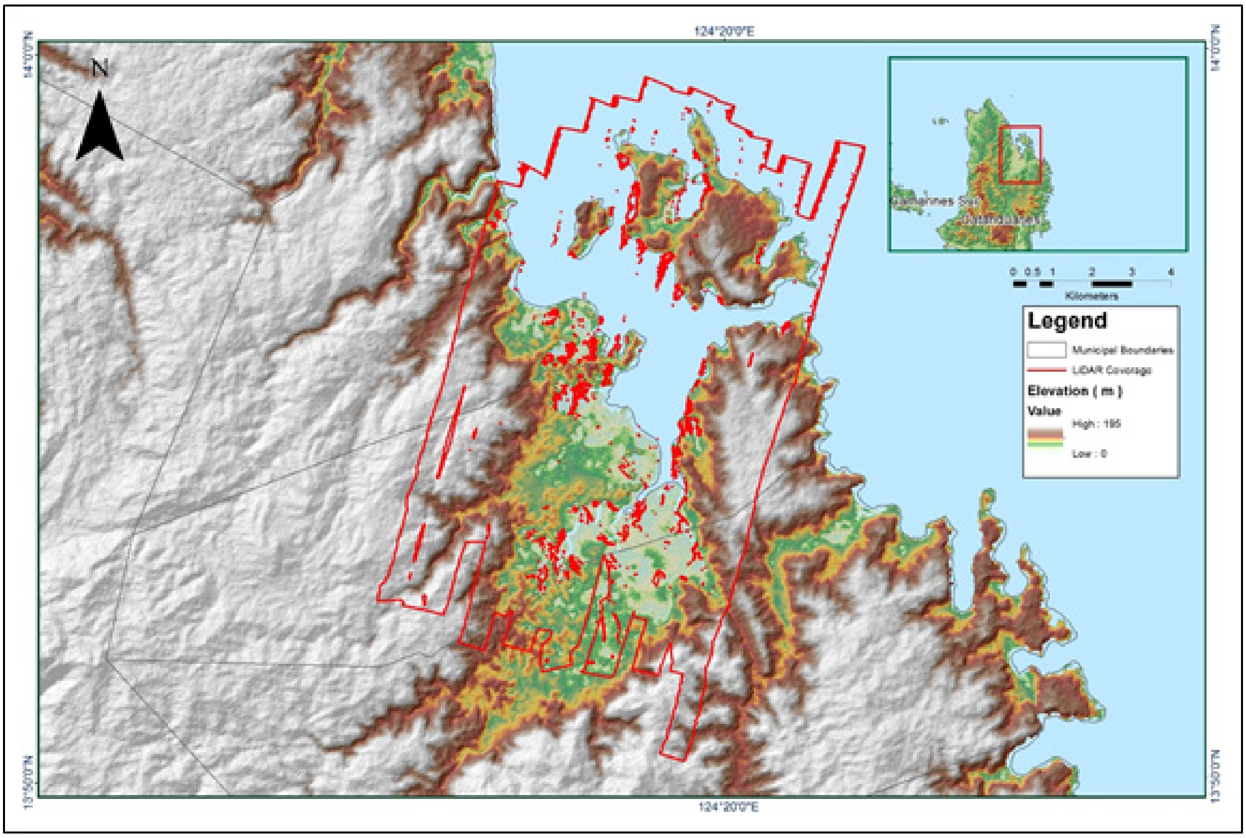


Figure A-8.4. Coverage of LiDAR data

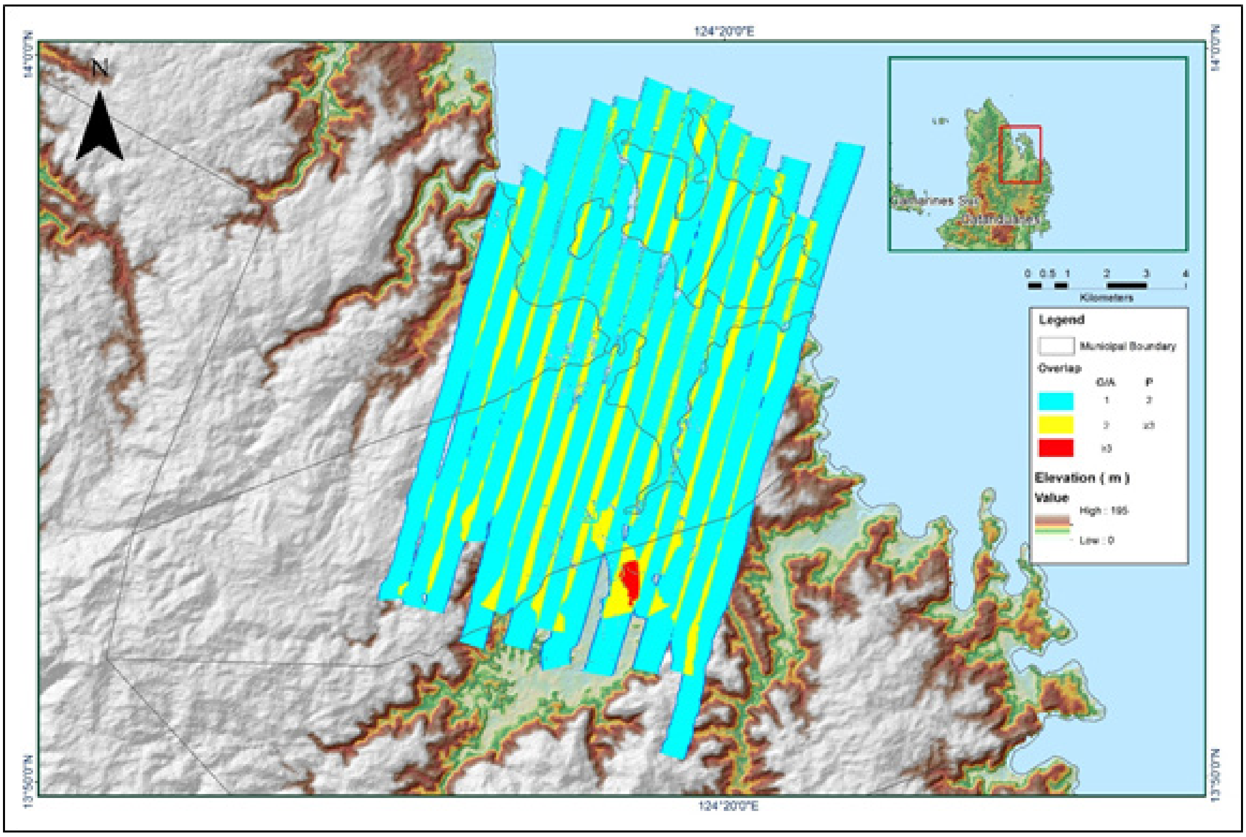


Figure A-8.5. Image of data overlap

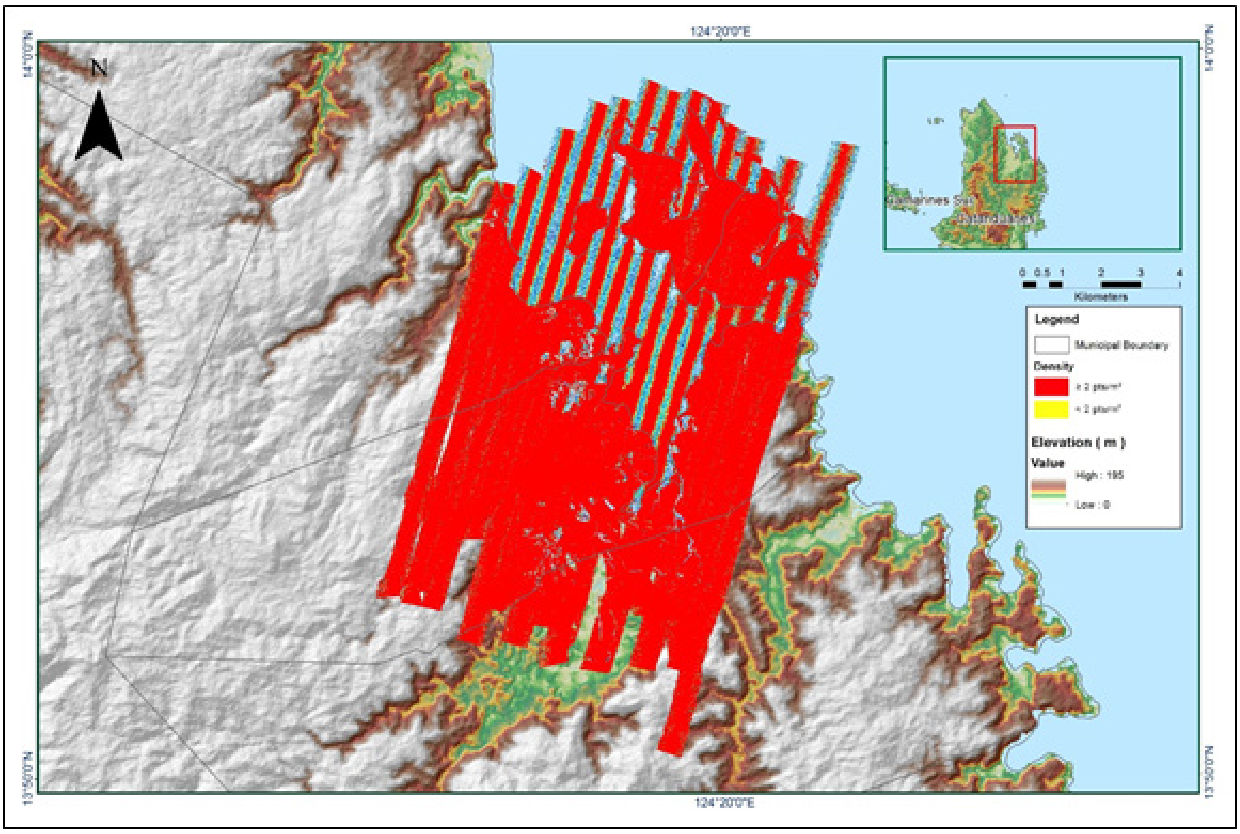


Figure A-8.6. Density Map of merged LiDAR data

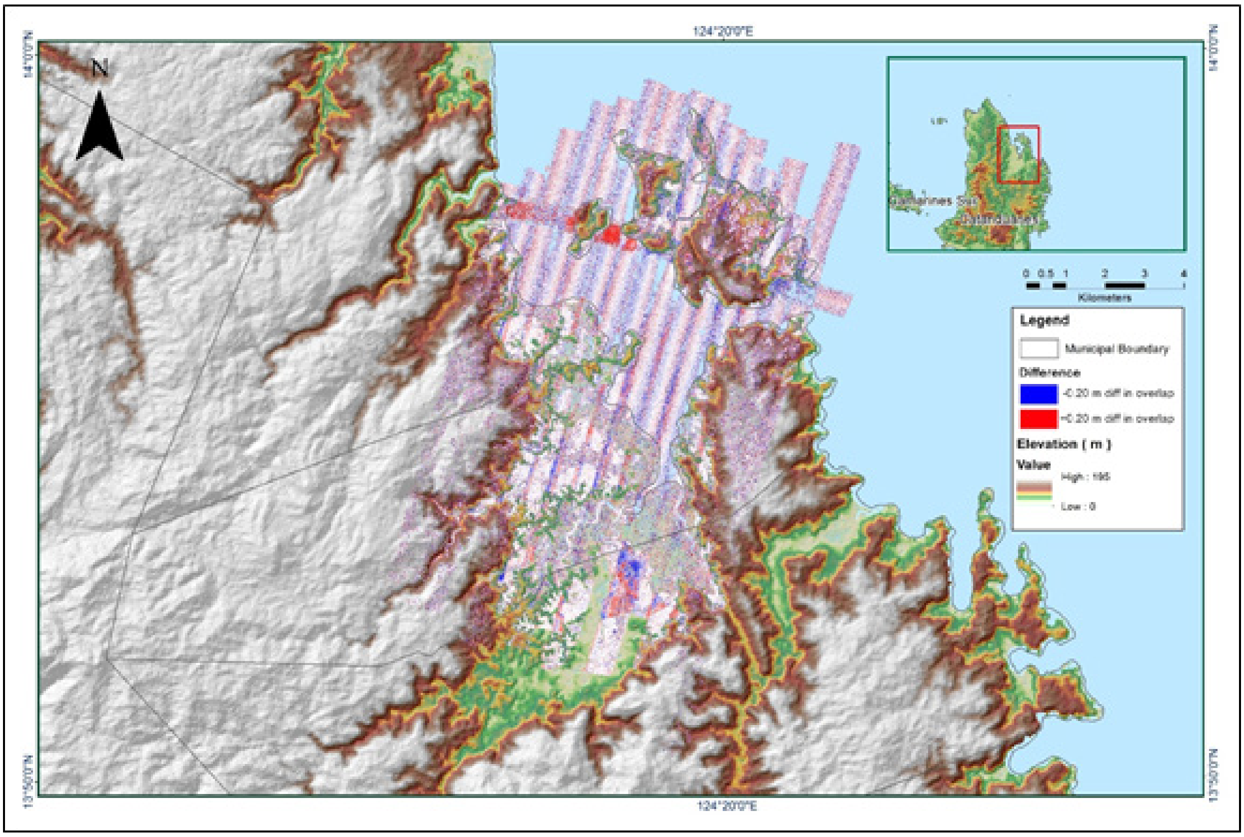


Figure A-8.7. Elevation Difference Between flight lines

Table A-8.2. Mission Summary Report of Mission Blk25D

FLIGHT AREA	CATANDUANES
Mission Name	Blk25D
Inclusive Flights	3048P
Range data size	12.9 GB
POS	195 MB
Image	NA
Base Station	91.5 MB
Transfer date	February 12, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	3.0
RMSE for East Position (<4.0 cm)	3.2
RMSE for Down Position (<8.0 cm)	8.5
Boresight correction stdev (<0.001deg)	0.000287
IMU attitude correction stdev (<0.001deg)	NA
GPS position stdev (<0.01m)	0.0013
Minimum % overlap (>25)	19.91
Ave point cloud density per sq.m. (>2.0)	2.20
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	70
Maximum Height	168.47 m
Minimum Height	49.78 m
Classification (# of points)	
Ground	52,050,815
Low vegetation	41,787,198
Medium vegetation	29,147,460
High vegetation	30,154,460
Building	2,482,762
Orthophoto	No
Processed by	Engr. Don Matthew Banatin, Engr. Mark Joshua Salvacion, Maria Tamsyn Malabanan

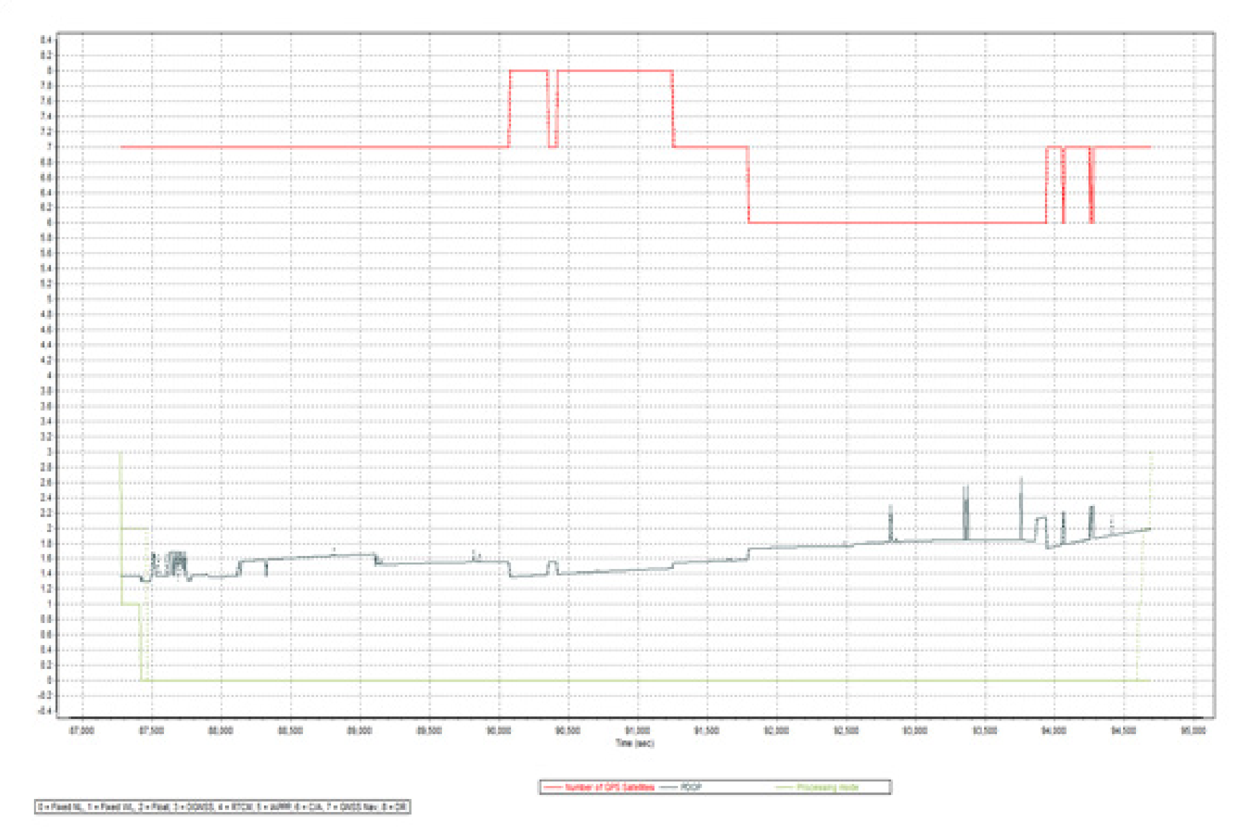


Figure A-8.8. Solution Status

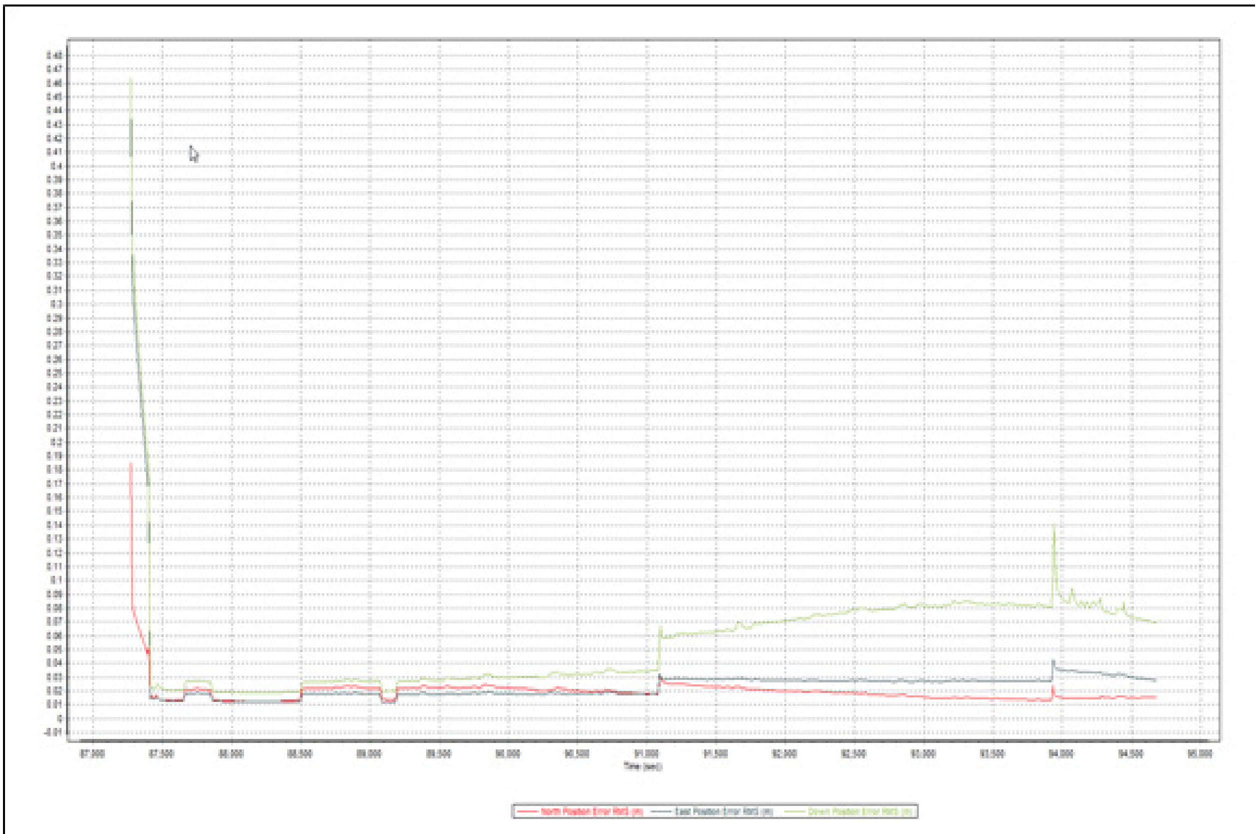


Figure A-8.9. Smoothed Performance Metric Parameters

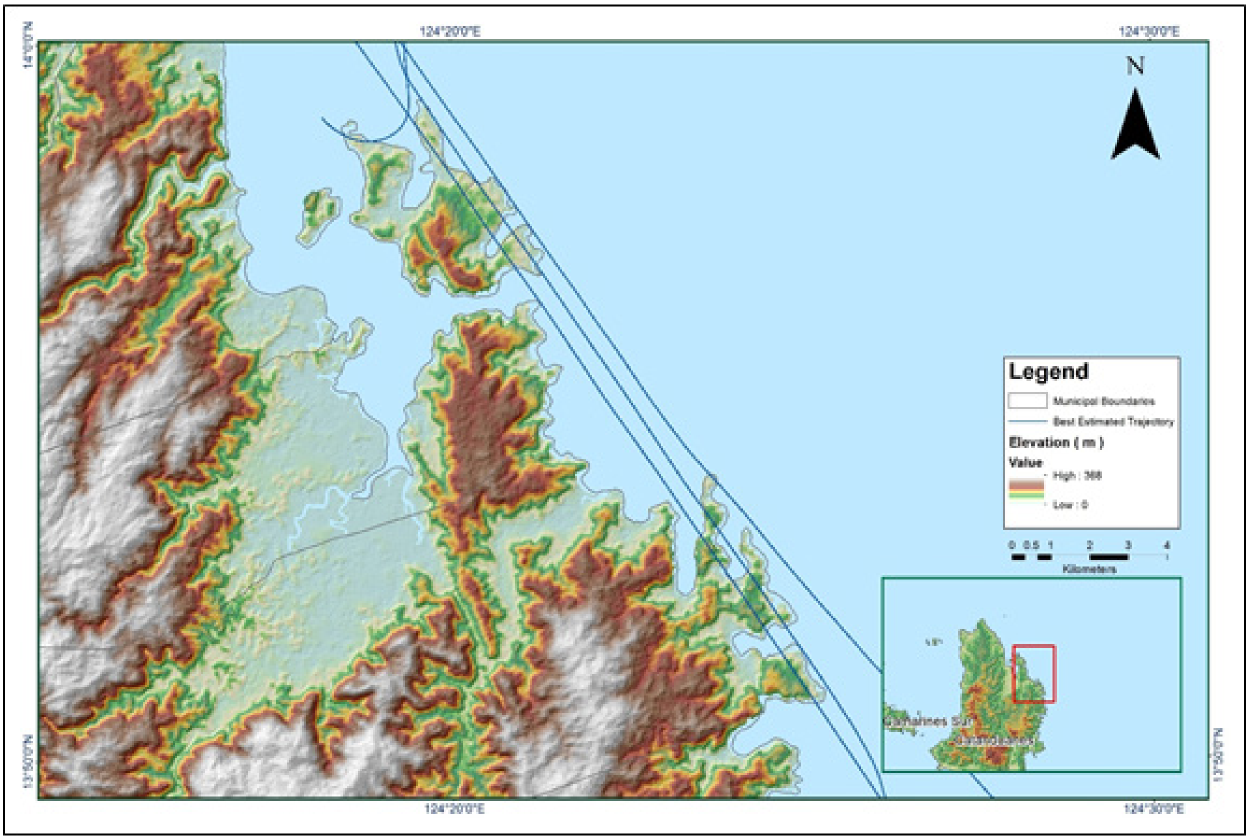


Figure A-8.10. Best Estimate Trajectory

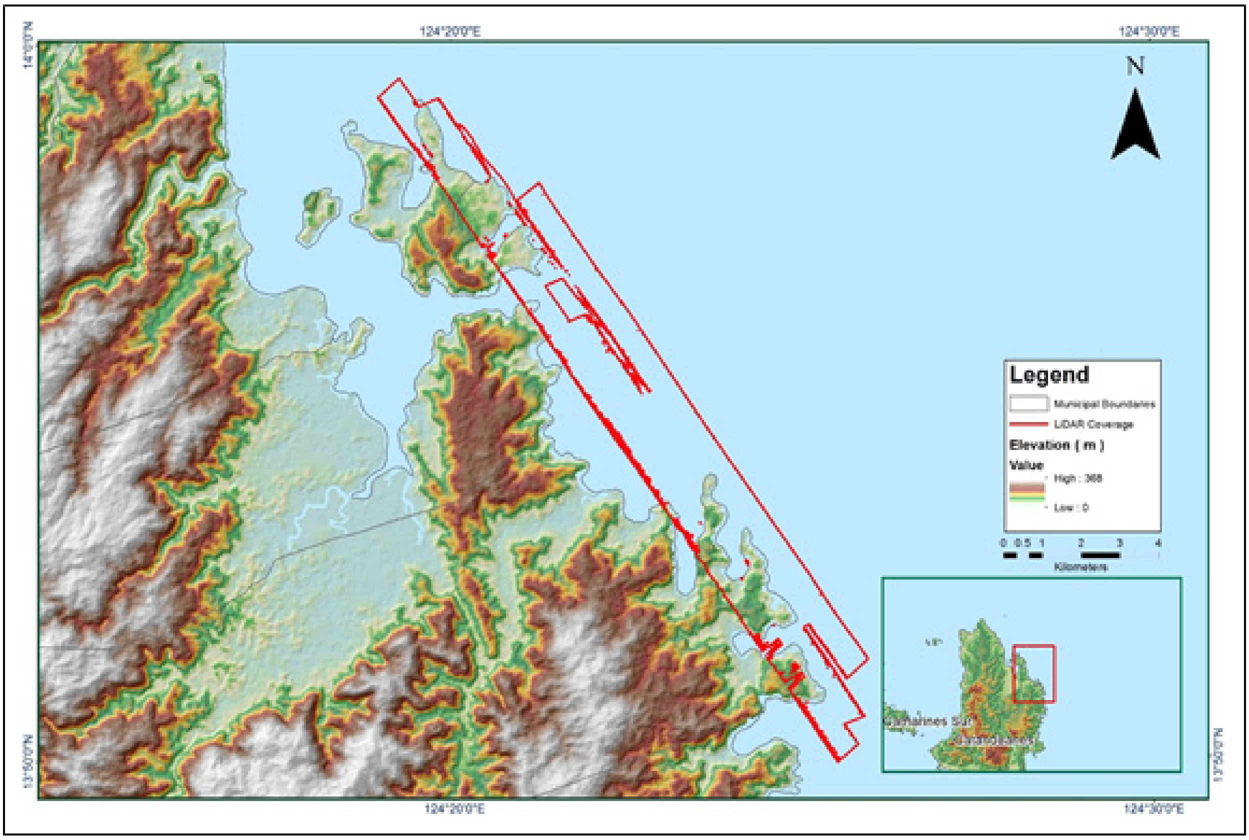


Figure A-8.11. Coverage of LiDAR data

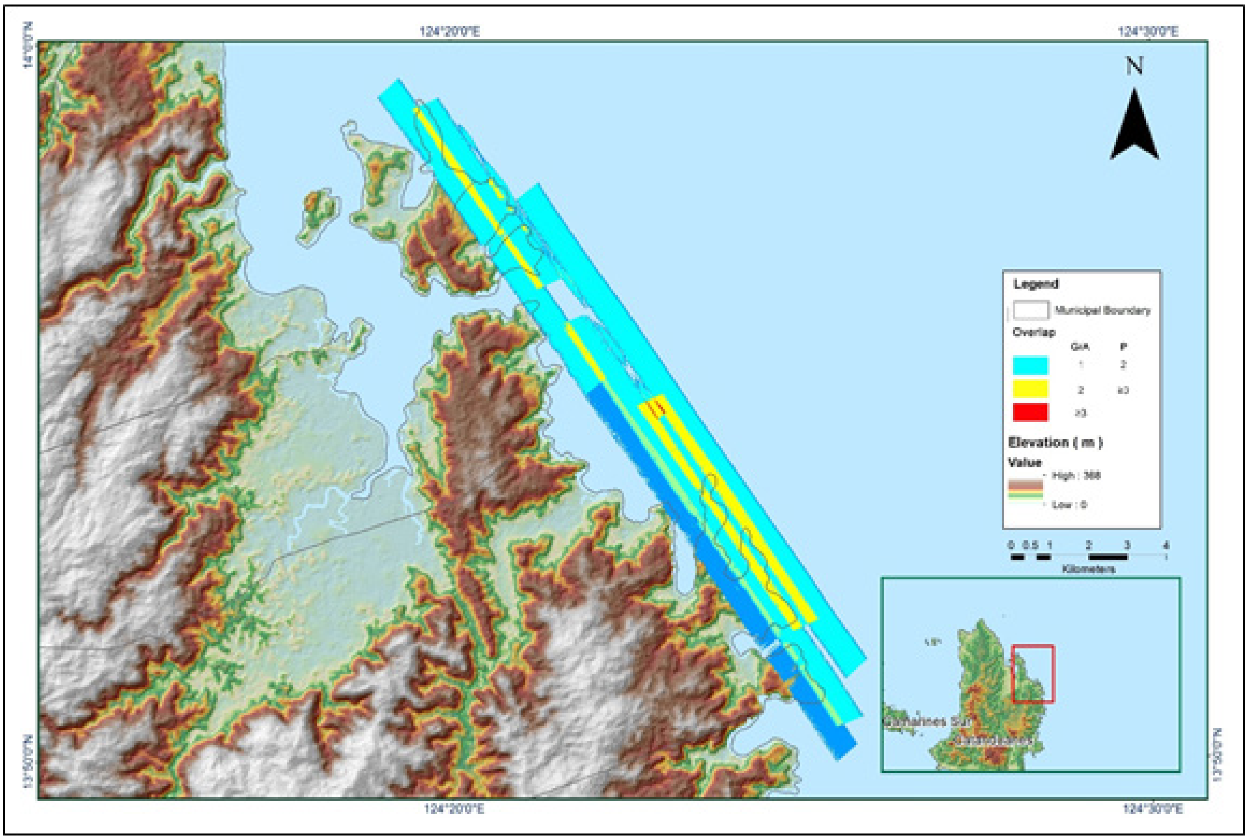


Figure A-8.12. Image of data overlap

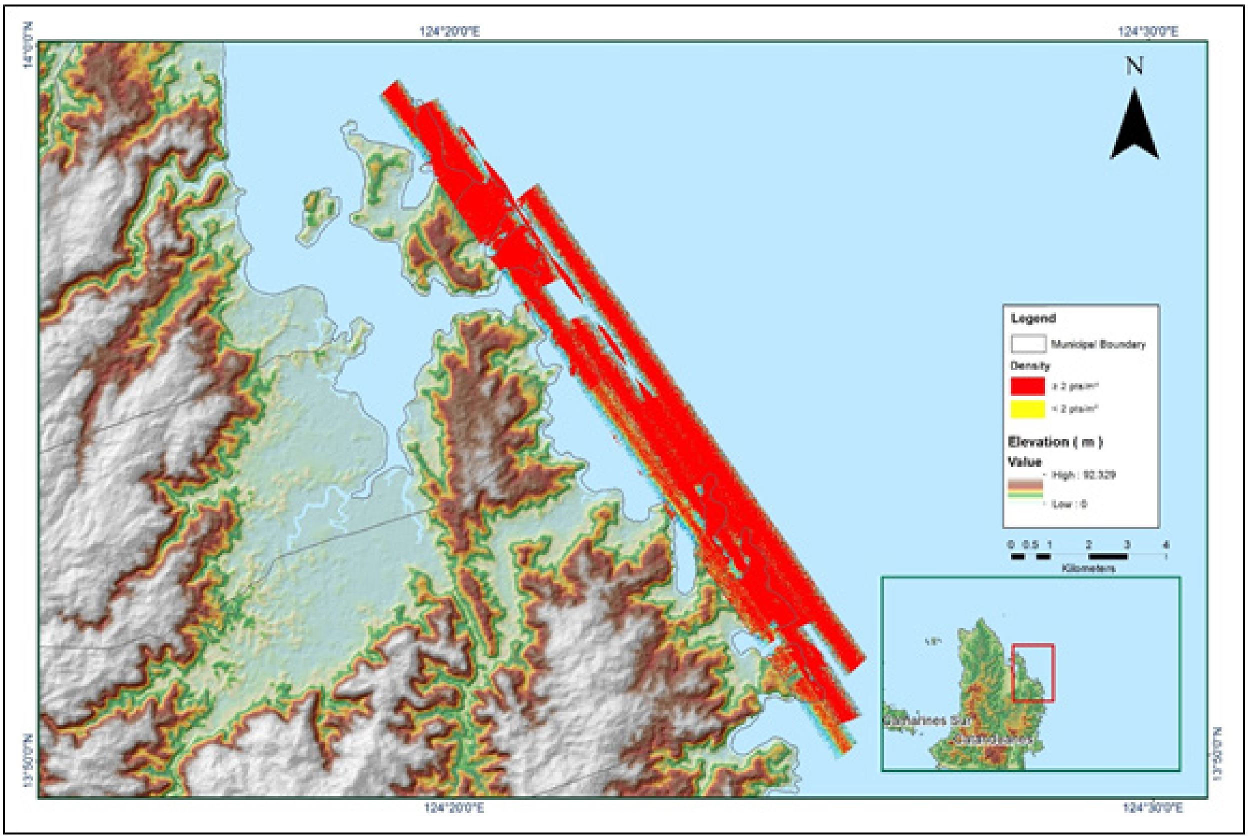


Figure A-8.13. Density Map of merged LiDAR data

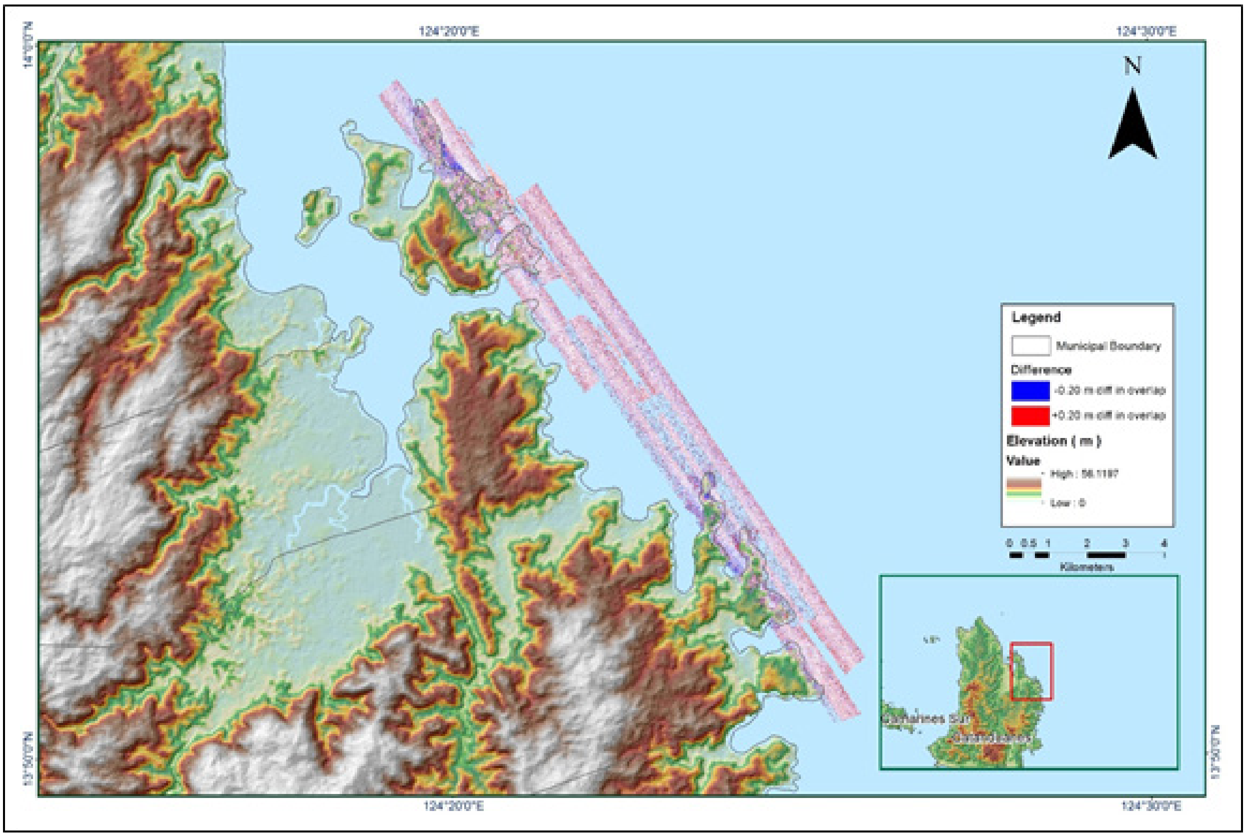


Figure A-8.14. Elevation Difference Between flight lines

Table A-8.3. Mission Summary Report of Mission Blk25D_additional

FLIGHT AREA	CATANDUANES
Mission Name	Blk25D_additional
Inclusive Flights	3016P, 3048P
Range data size	27.5 GB
POS	362 MB
Image	NA
Base Station	173.9 MB
Transfer date	February 12, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.31
RMSE for East Position (<4.0 cm)	1.11
RMSE for Down Position (<8.0 cm)	3.51
Boresight correction stdev (<0.001deg)	0.003866
IMU attitude correction stdev (<0.001deg)	0.001426
GPS position stdev (<0.01m)	0.0017
Minimum % overlap (>25)	11.78
Ave point cloud density per sq.m. (>2.0)	2.95
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	40
Maximum Height	361.10 m
Minimum Height	52.75 m
Classification (# of points)	
Ground	9,118,770
Low vegetation	3,234,646
Medium vegetation	9,325,788
High vegetation	66,974,665
Building	121,955
Orthophoto	No
Processed by	Engr. Don Matthew Banatin, Engr. Mark Joshua Salvacion, Engr. Gladys Mae Apat

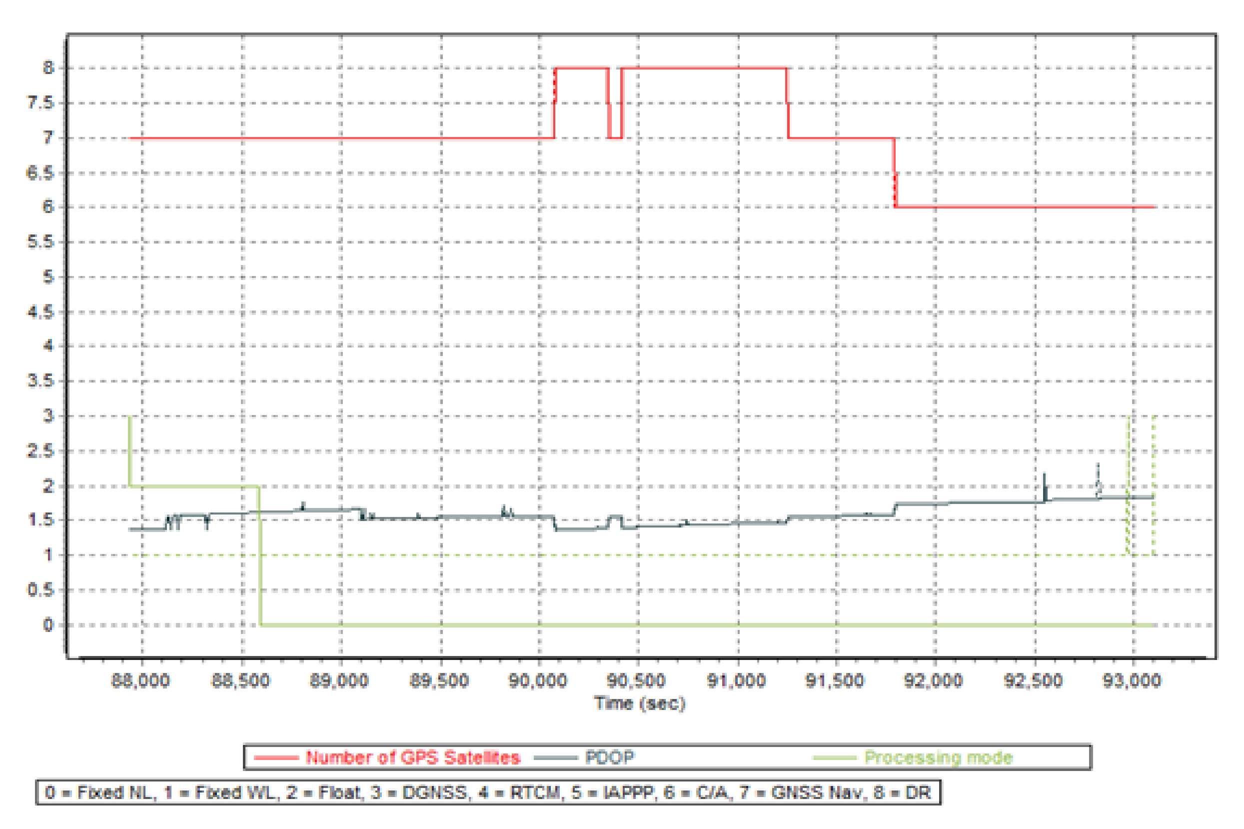


Figure A-8.15. Solution Status

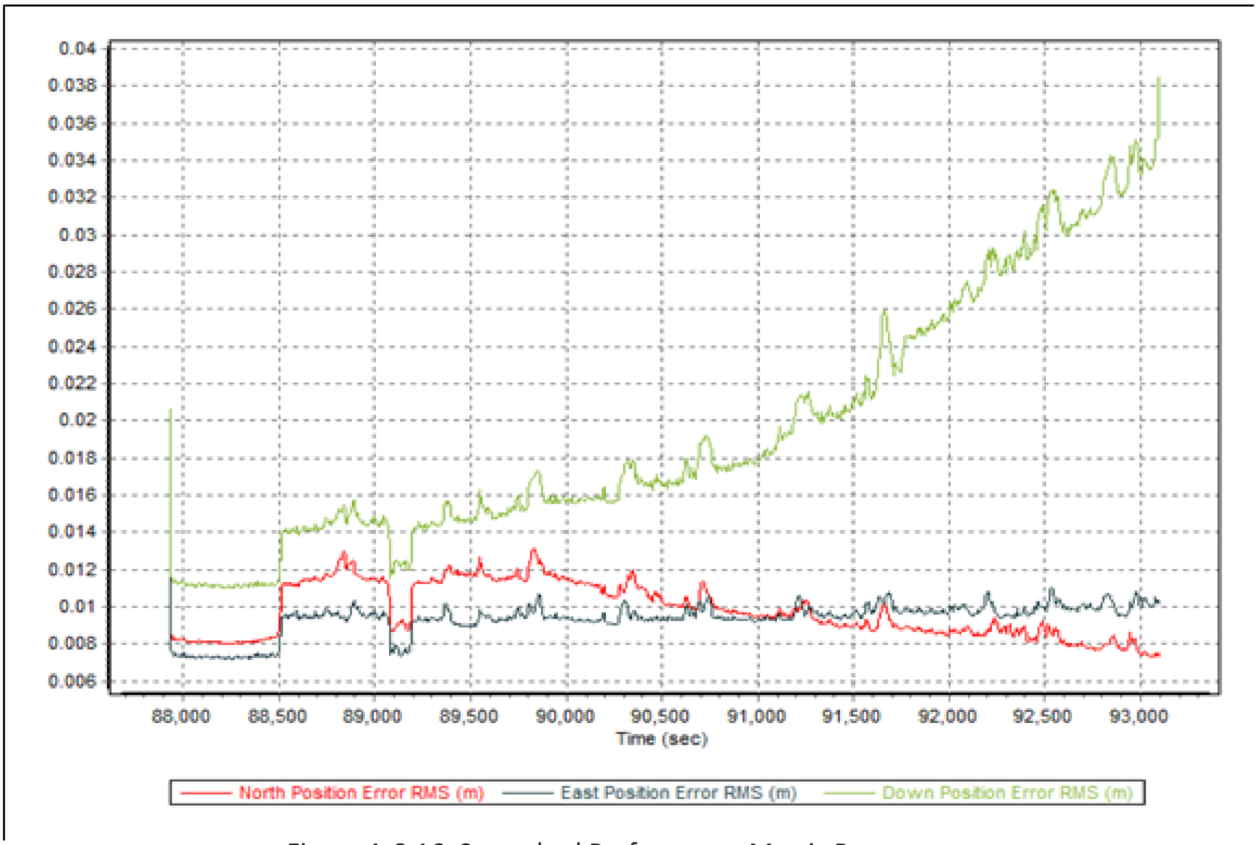


Figure A-8.16. Smoothed Performance Metric Parameters

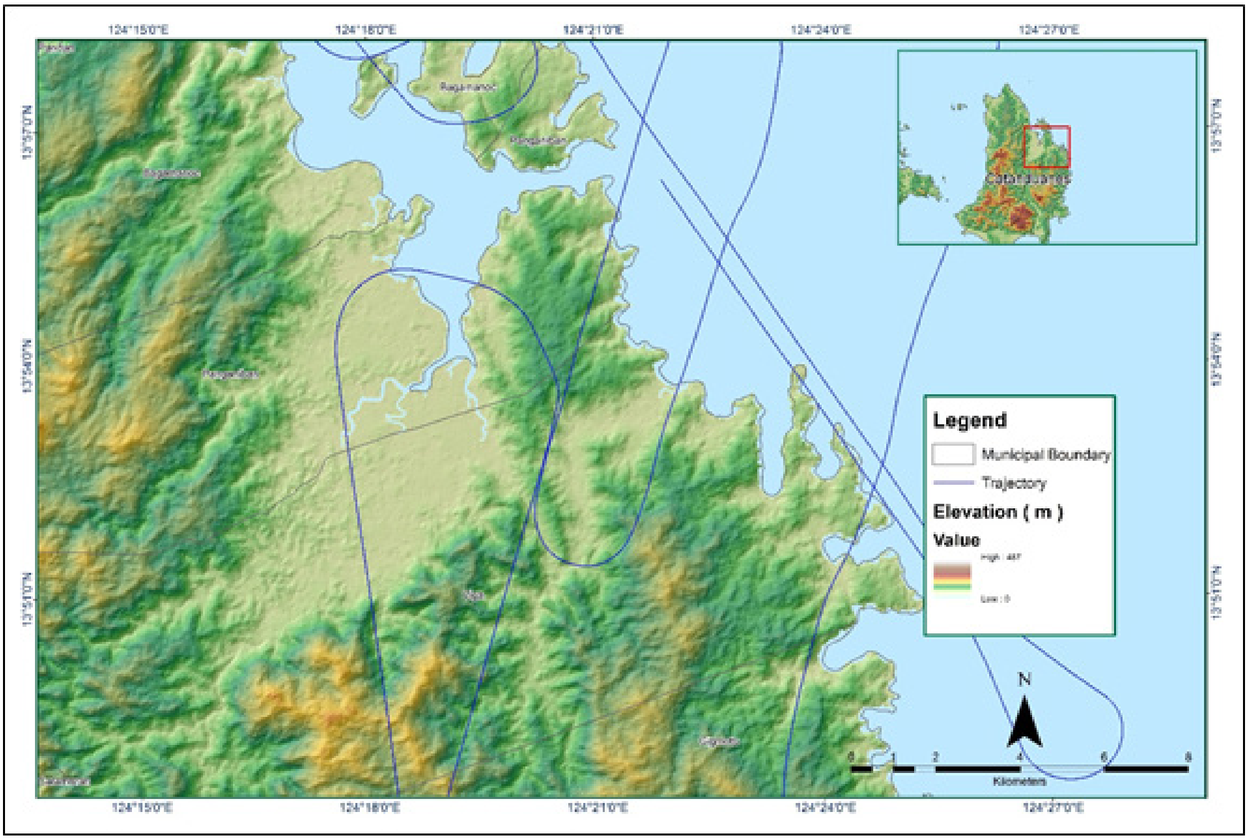


Figure A-8.17. Best Estimated Trajectory

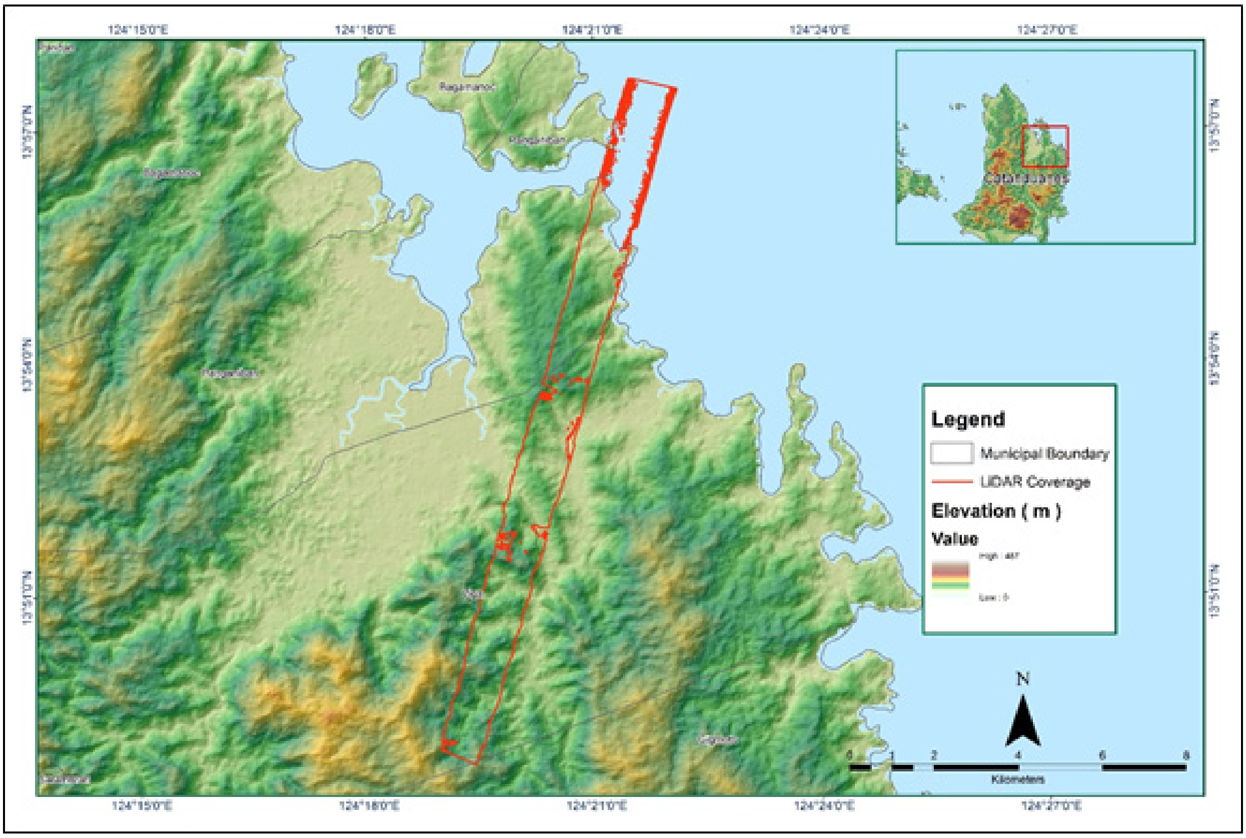


Figure A-8.18. Coverage of LiDAR data

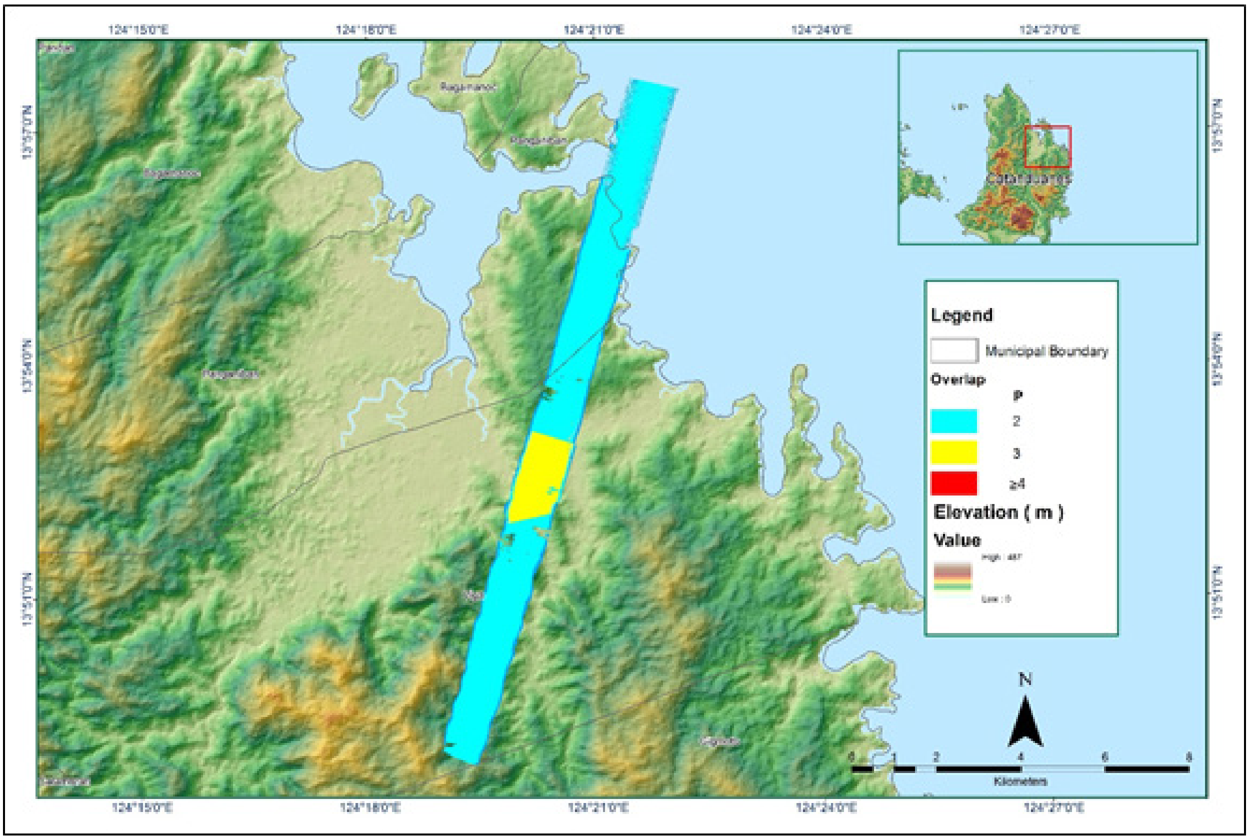


Figure A-8.19. Image of data overlap

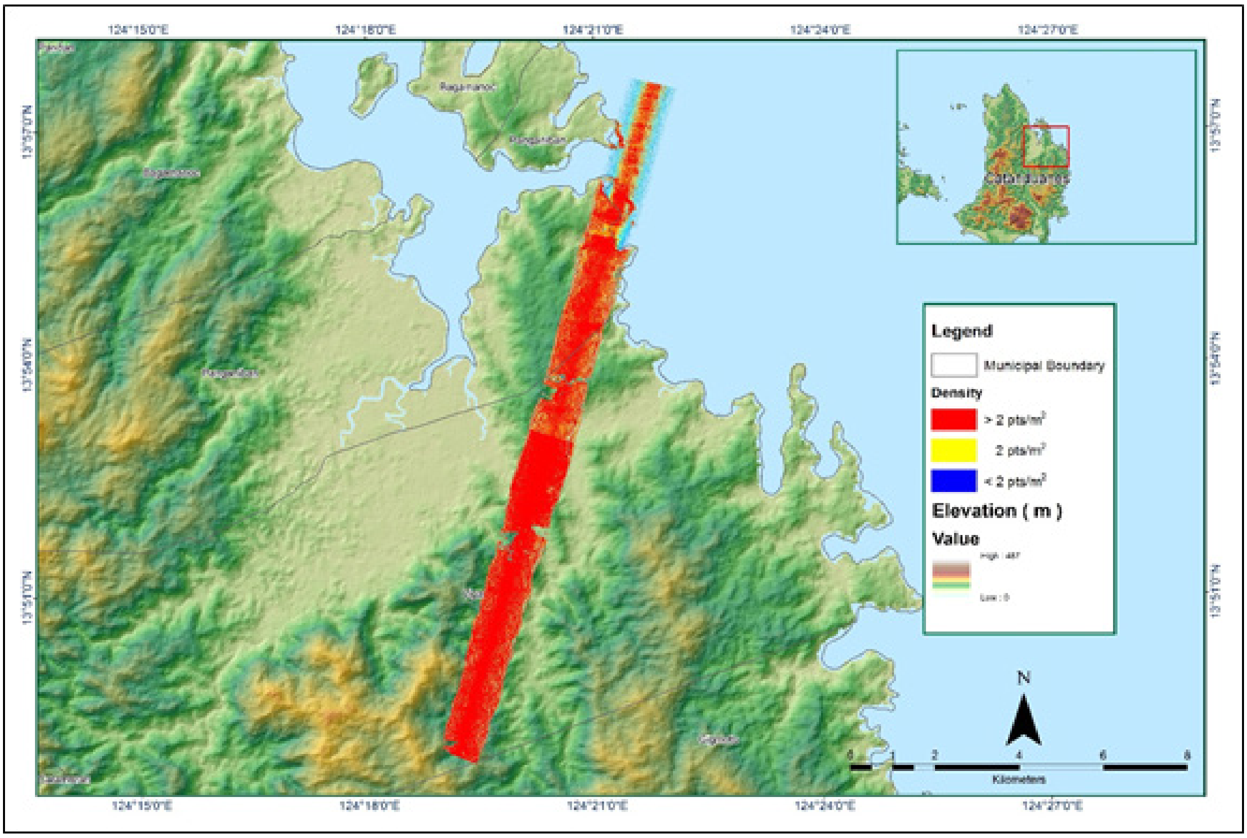


Figure A-8.20. Density Map of merged LiDAR data

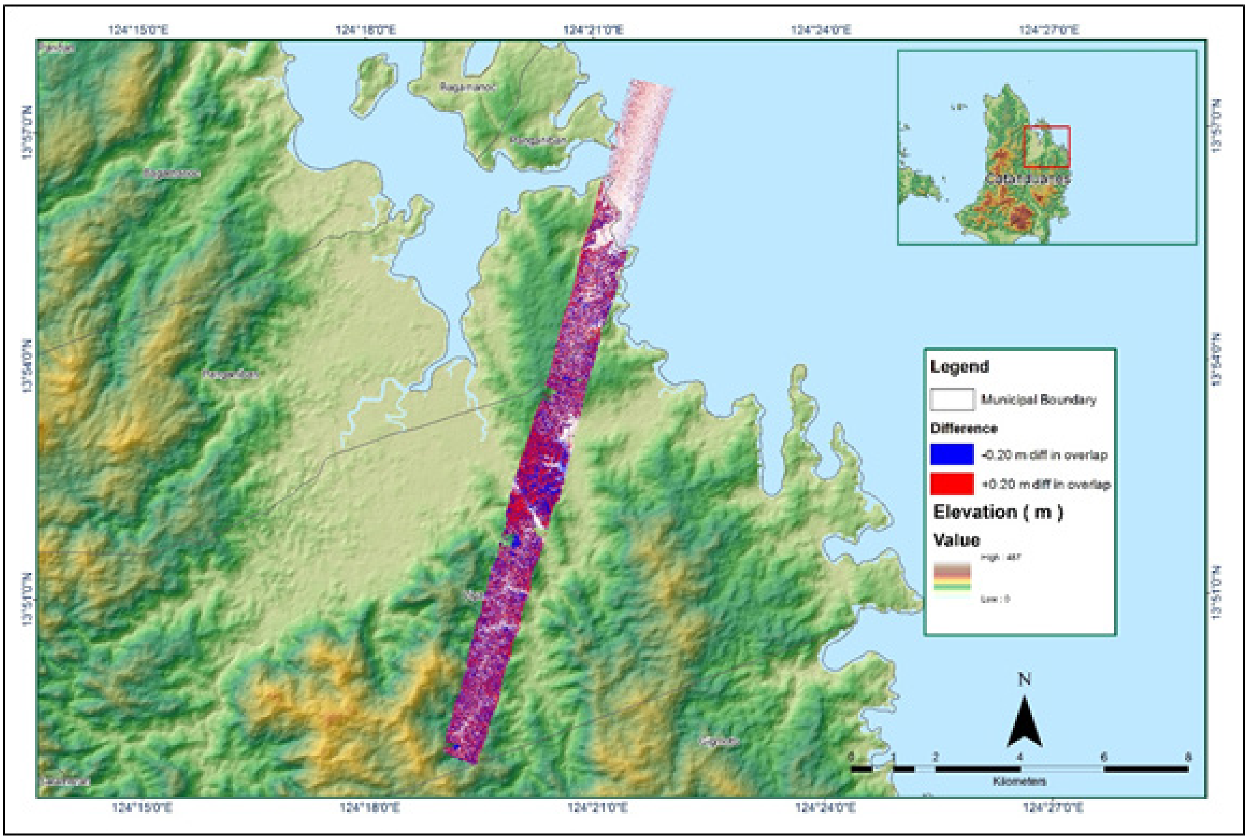


Figure A-8.21. Elevation Difference Between flight lines

Table A-8.4. Mission Summary Report of Mission Blk25A

FLIGHT AREA	CATANDUANES
Mission Name	Blk25A
Inclusive Flights	8537AC
Range data size	2.94 GB
Base data size	22.7 MB
POS	141 MB
Image	NA
Transfer date	February 21, 2017
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	3.72
RMSE for East Position (<4.0 cm)	3.50
RMSE for Down Position (<8.0 cm)	9.20
Boresight correction stdev (<0.001deg)	NA
IMU attitude correction stdev (<0.001deg)	0.003590
GPS position stdev (<0.01m)	0.0022
Minimum % overlap (>25)	61.95
Ave point cloud density per sq.m. (>2.0)	9.12
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	26
Maximum Height	373.13 m
Minimum Height	67.20 m
Classification (# of points)	
Ground	10,537,033
Low vegetation	5,838,452
Medium vegetation	17,842,937
High vegetation	57,198,062
Building	879,739
Ortophoto	No
Processed by	Engr. Regis Guhiting, Engr. Harmond Santos, Engr. Gladys Mae Apat

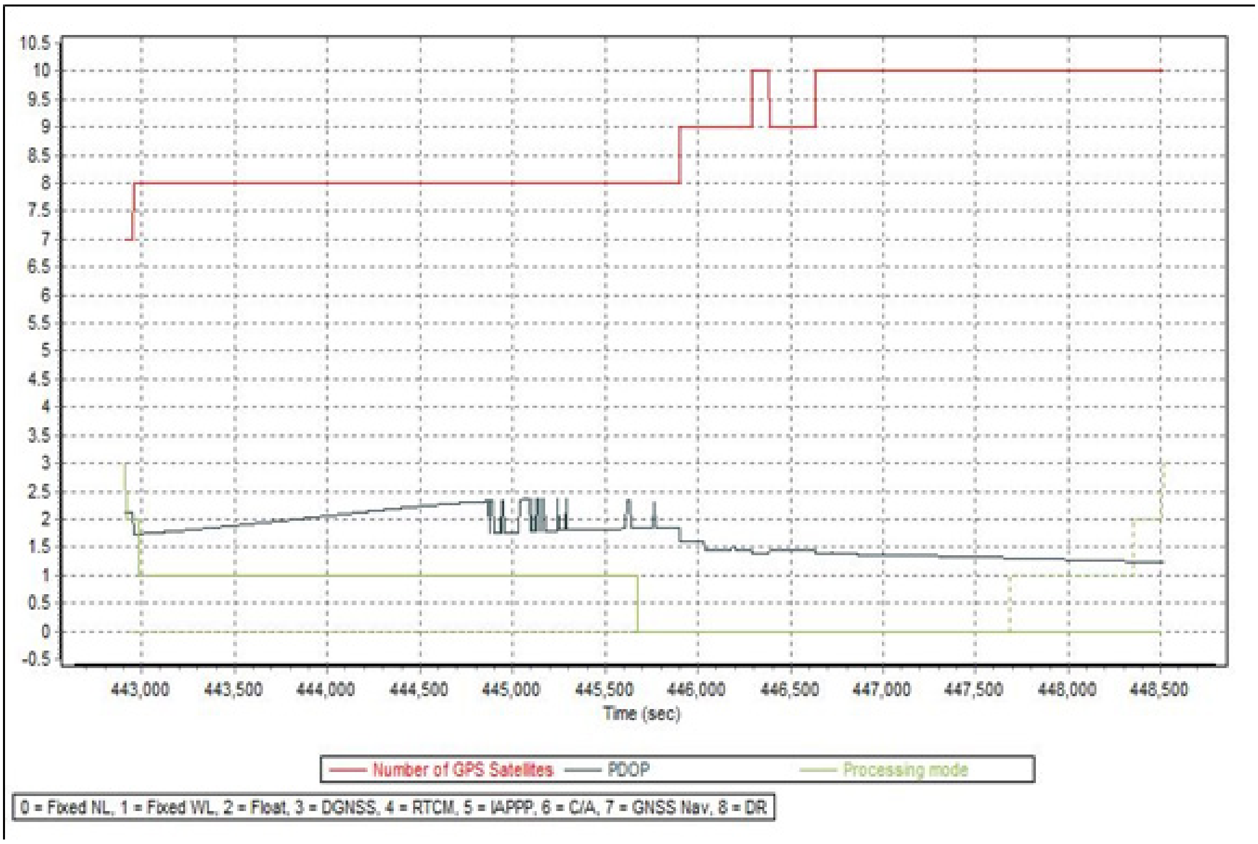


Figure A-8.22. Solution Status

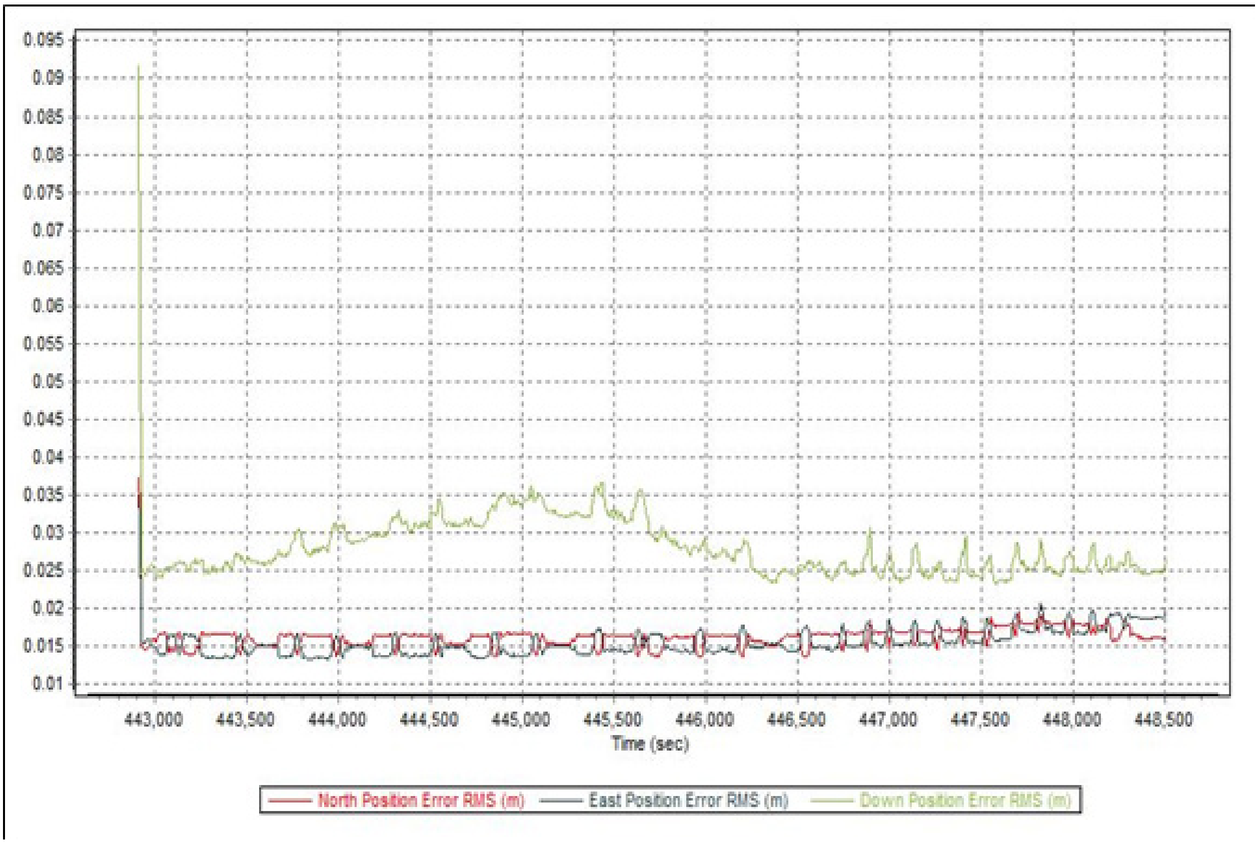


Figure A-8.23. Smoothed Performance Metric Parameters

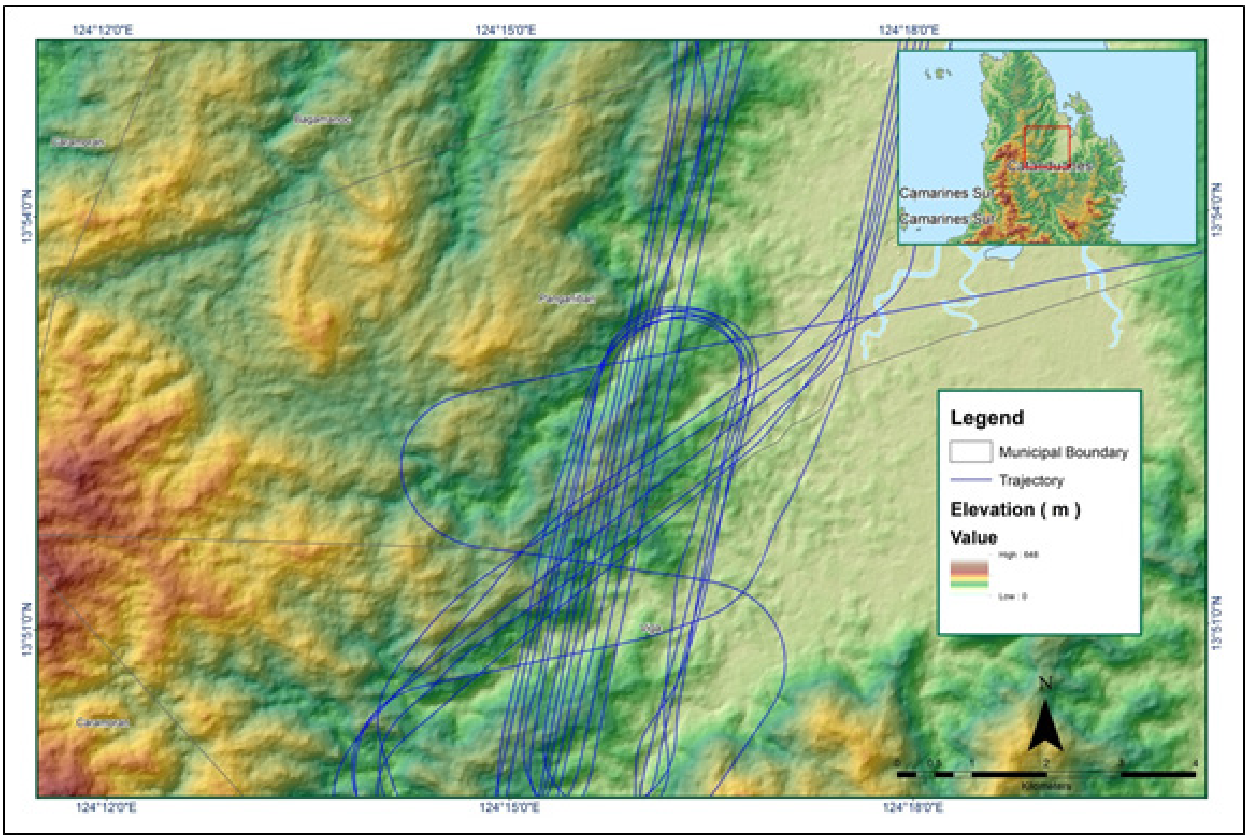


Figure A-8.24 Best Estimated Trajectory

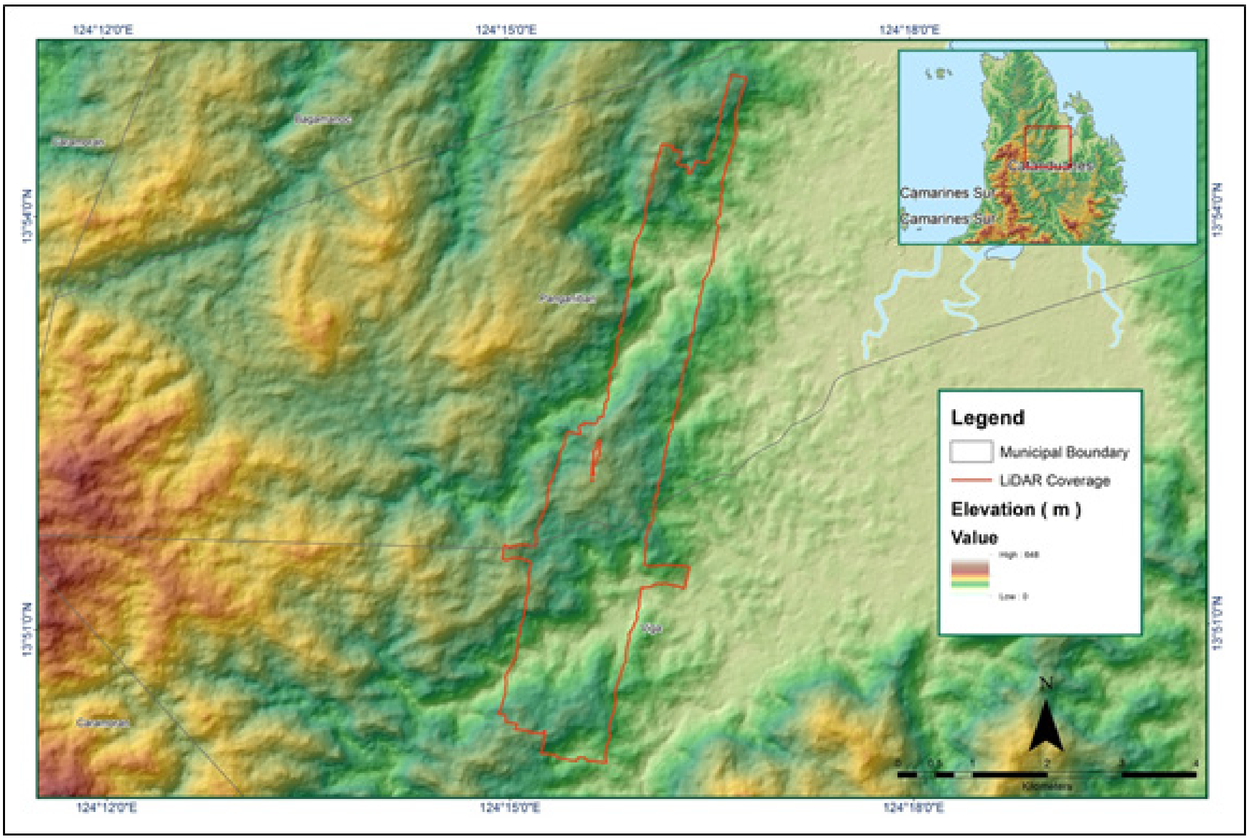


Figure A-8.25 Coverage of LiDAR data

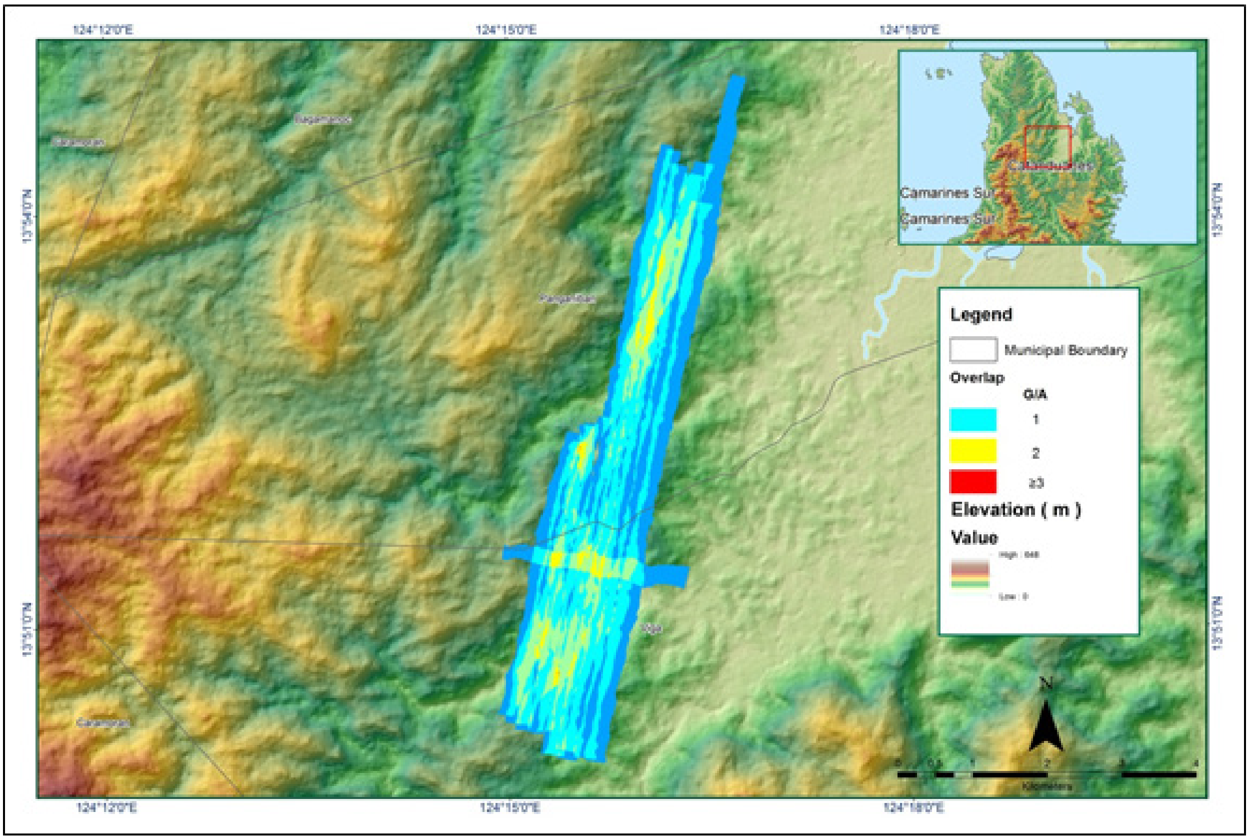


Figure A-8.26 Image of data overlap

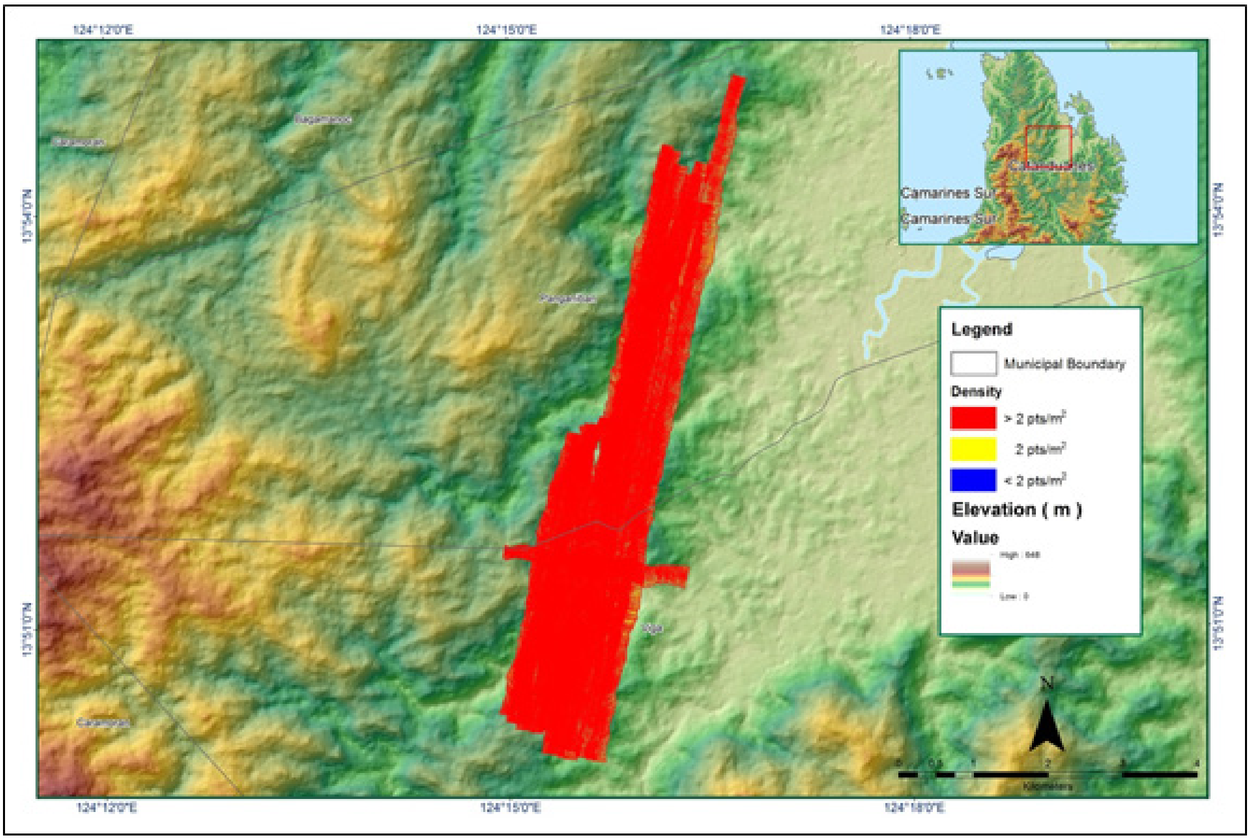


Figure A-8.27 Density Map of merged LiDAR data

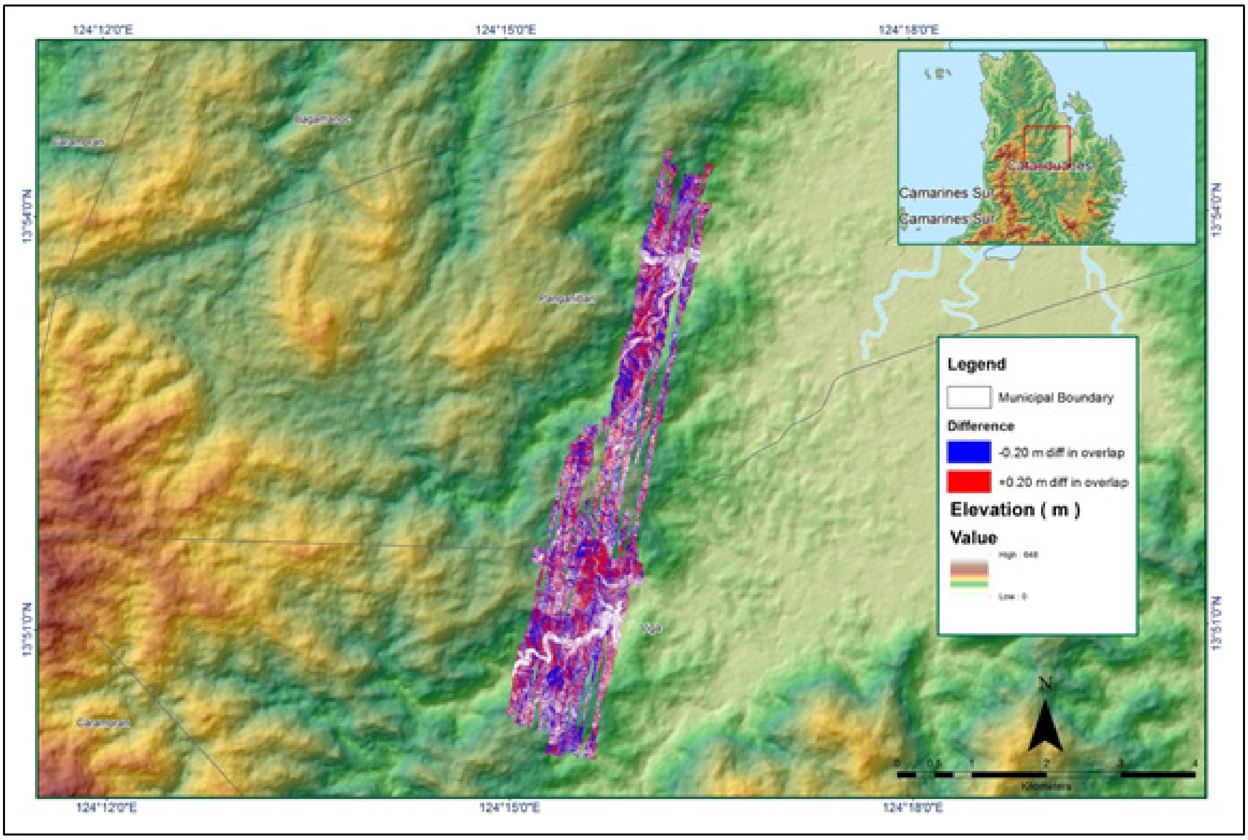


Figure A-8.28 Elevation Difference Between flight lines

Table A-8.5. Mission Summary Report of Mission Blk25B

FLIGHT AREA	CATANDUANES
Mission Name	Blk25B
Inclusive Flights	8529AC
Range data size	3.52 GB
Base data size	14.9 MB
POS	153 MB
Image	NA
Transfer date	February 21, 2017
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.44
RMSE for East Position (<4.0 cm)	1.42
RMSE for Down Position (<8.0 cm)	3.54
Boresight correction stdev (<0.001deg)	NA
IMU attitude correction stdev (<0.001deg)	0.000700
GPS position stdev (<0.01m)	0.0012
Minimum % overlap (>25)	70.50
Ave point cloud density per sq.m. (>2.0)	5.46
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	30
Maximum Height	222.98 m
Minimum Height	53.21 m
Classification (# of points)	
Ground	19,505,987
Low vegetation	10,933,175
Medium vegetation	14,003,649
High vegetation	31,919,047
Building	494,480
Ortophoto	No
Processed by	Engr. Sheila Maye Santillan, Engr. Harmond Santos, Engr. Gladys Mae Apat

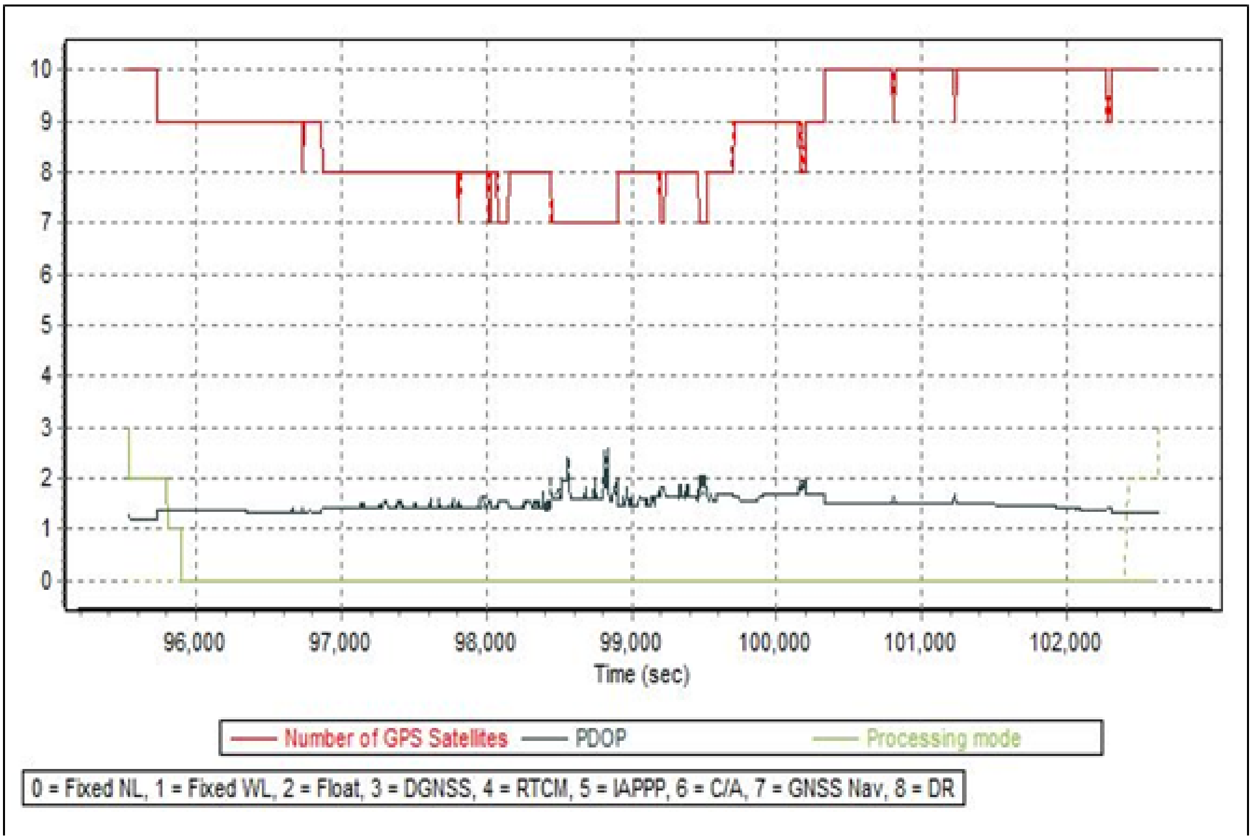


Figure A-8.29. Solution Status

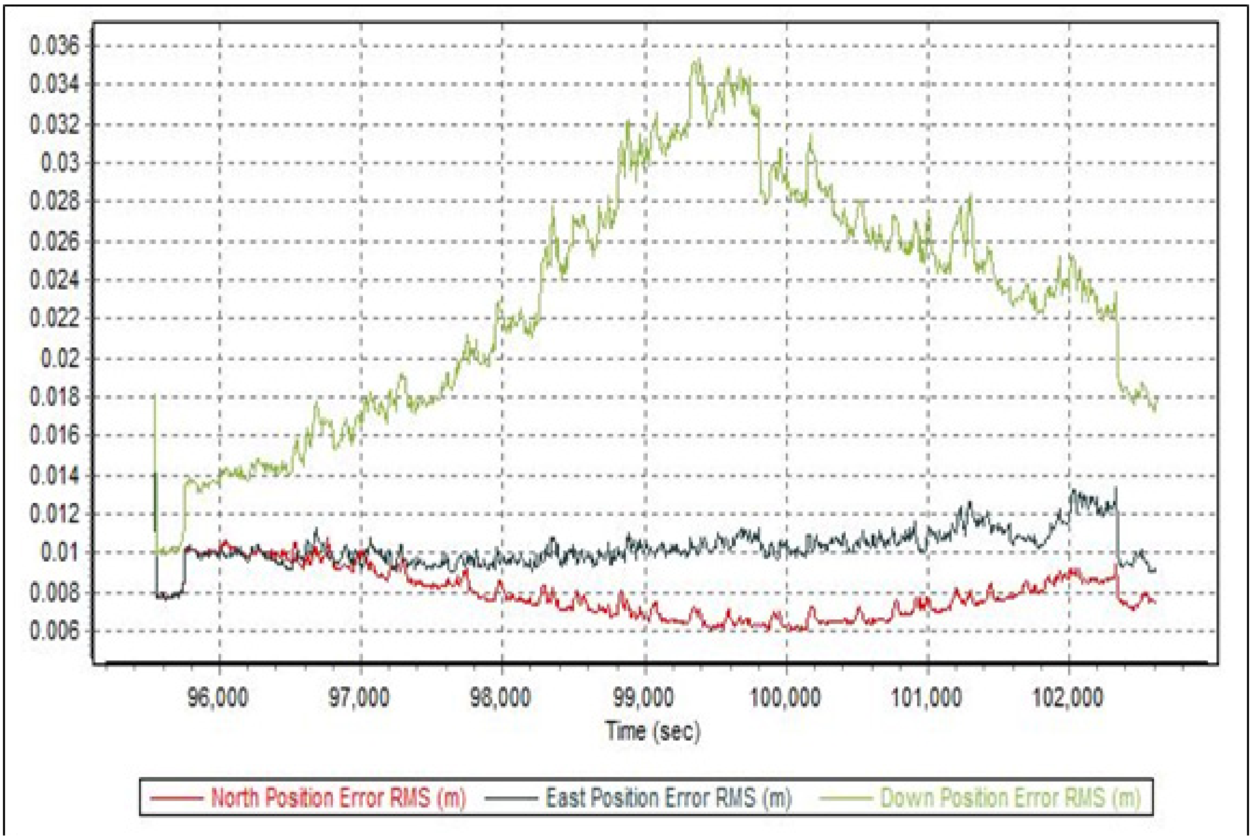


Figure A-8.30. Smoothed Performance Metric Parameters

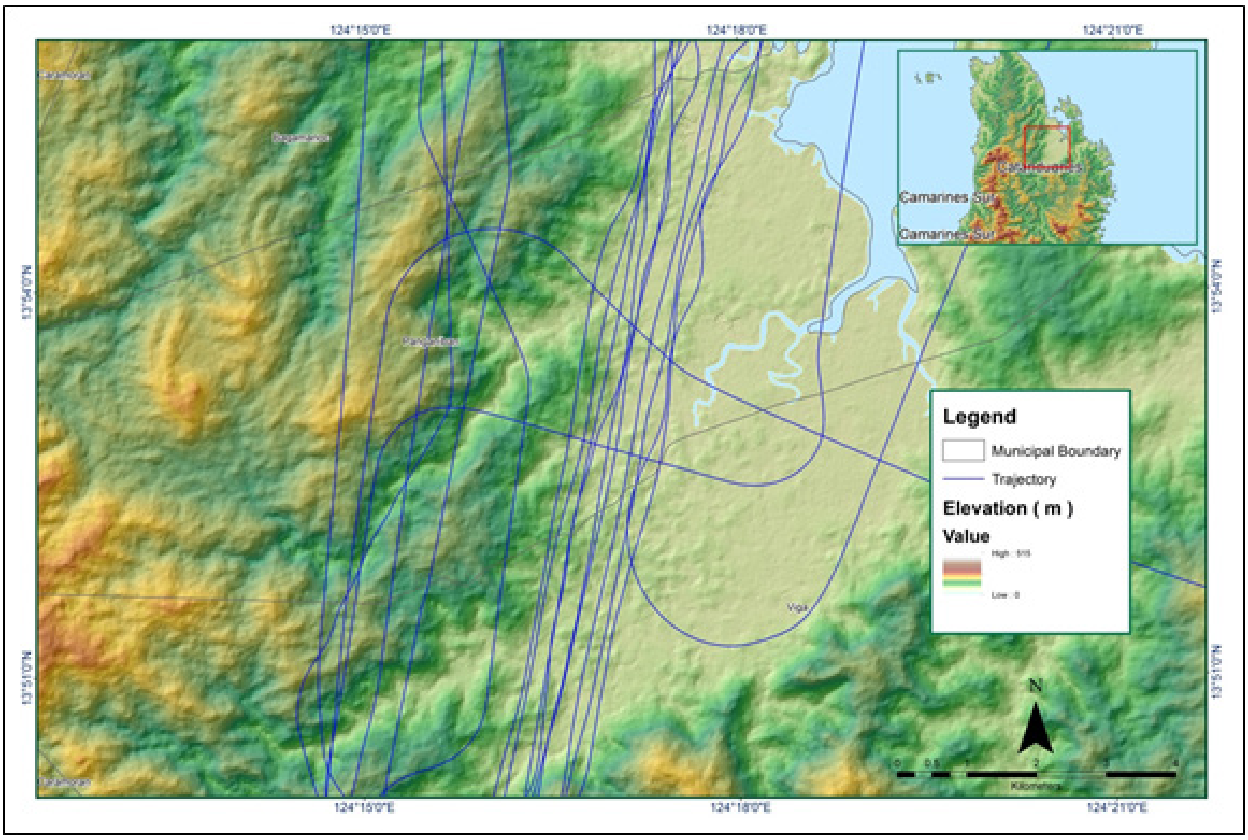


Figure A-8.31 Best Estimated Trajectory

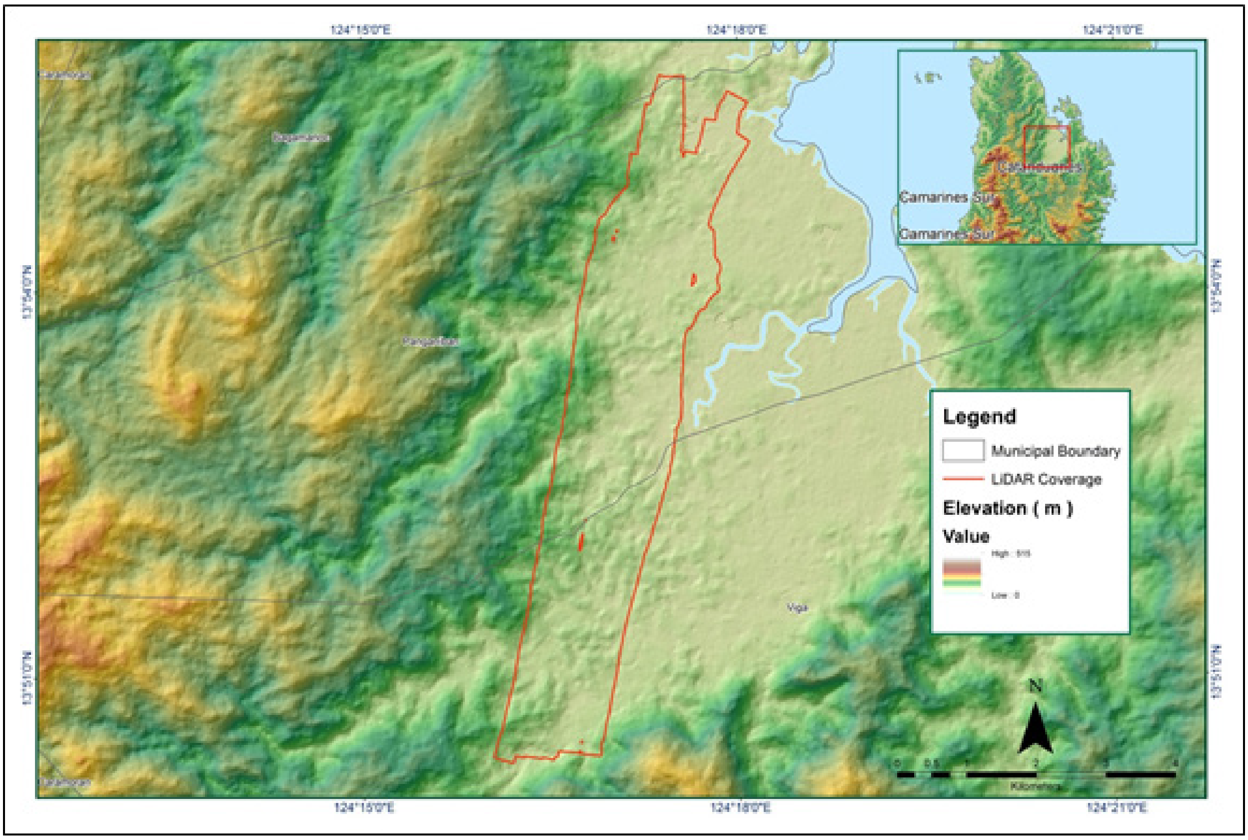


Figure A-8.32 Coverage of LiDAR data

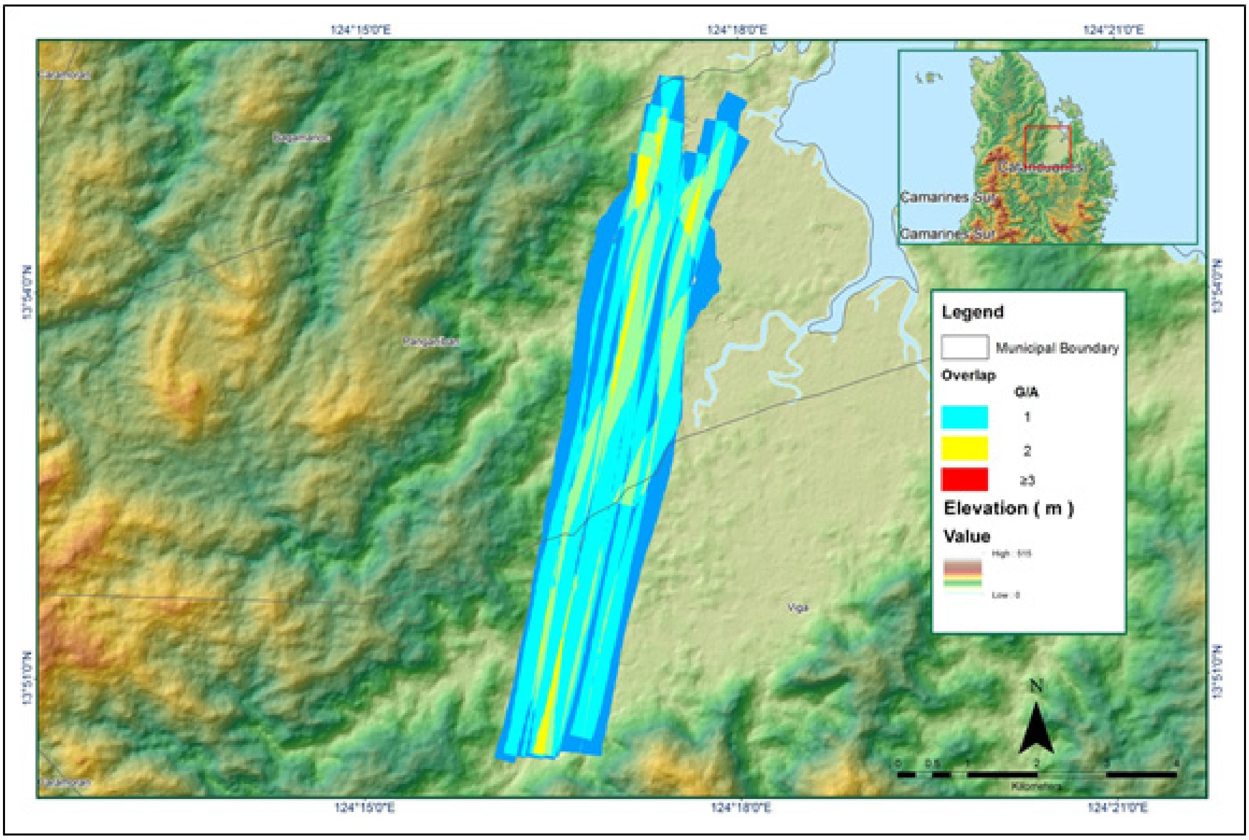


Figure A-8.33. Image of data overlap

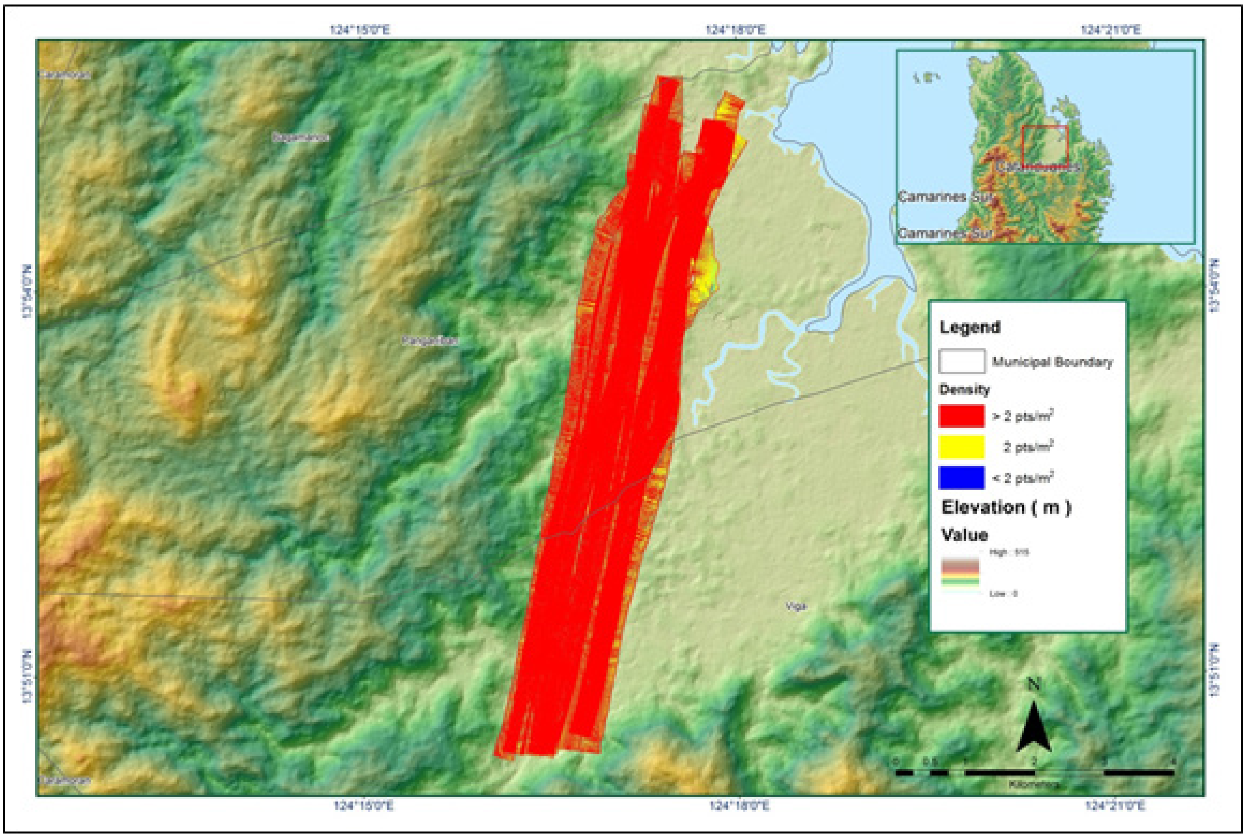


Figure A-8.34. Density Map of merged LiDAR data

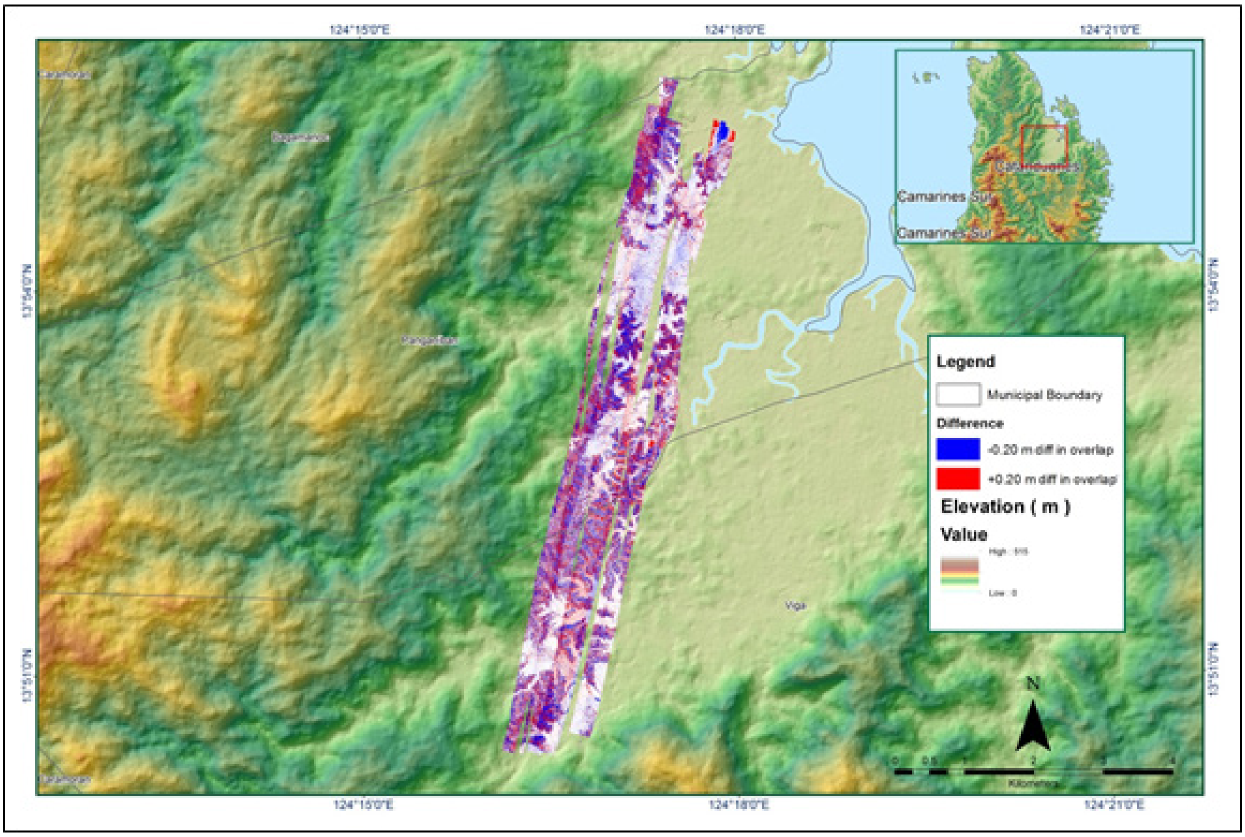


Figure A-8.35. Elevation Difference Between flight lines

Table A-8.6. Mission Summary Report of Mission Blk25B_supplement

FLIGHT AREA	CATANDUANES
Mission Name	Blk25B_supplement
Inclusive Flights	8535AC
Range data size	2.65 GB
Base data size	36.6 MB
POS	134 MB
Image	NA
Transfer date	February 21, 2017
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.64
RMSE for East Position (<4.0 cm)	1.82
RMSE for Down Position (<8.0 cm)	4.56
Boresight correction stdev (<0.001deg)	NA
IMU attitude correction stdev (<0.001deg)	0.001672
GPS position stdev (<0.01m)	0.0139
Minimum % overlap (>25)	38.65
Ave point cloud density per sq.m. (>2.0)	6.11
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	33
Maximum Height	299.13 m
Minimum Height	54.41 m
Classification (# of points)	
Ground	11,017,141
Low vegetation	4,356,990
Medium vegetation	10,746,979
High vegetation	40,761,877
Building	762,334
Ortophoto	No
Processed by	Engr. James Kevin Dimaculangan, Engr. Harmond Santos, Engr. Gladys Mae Apat

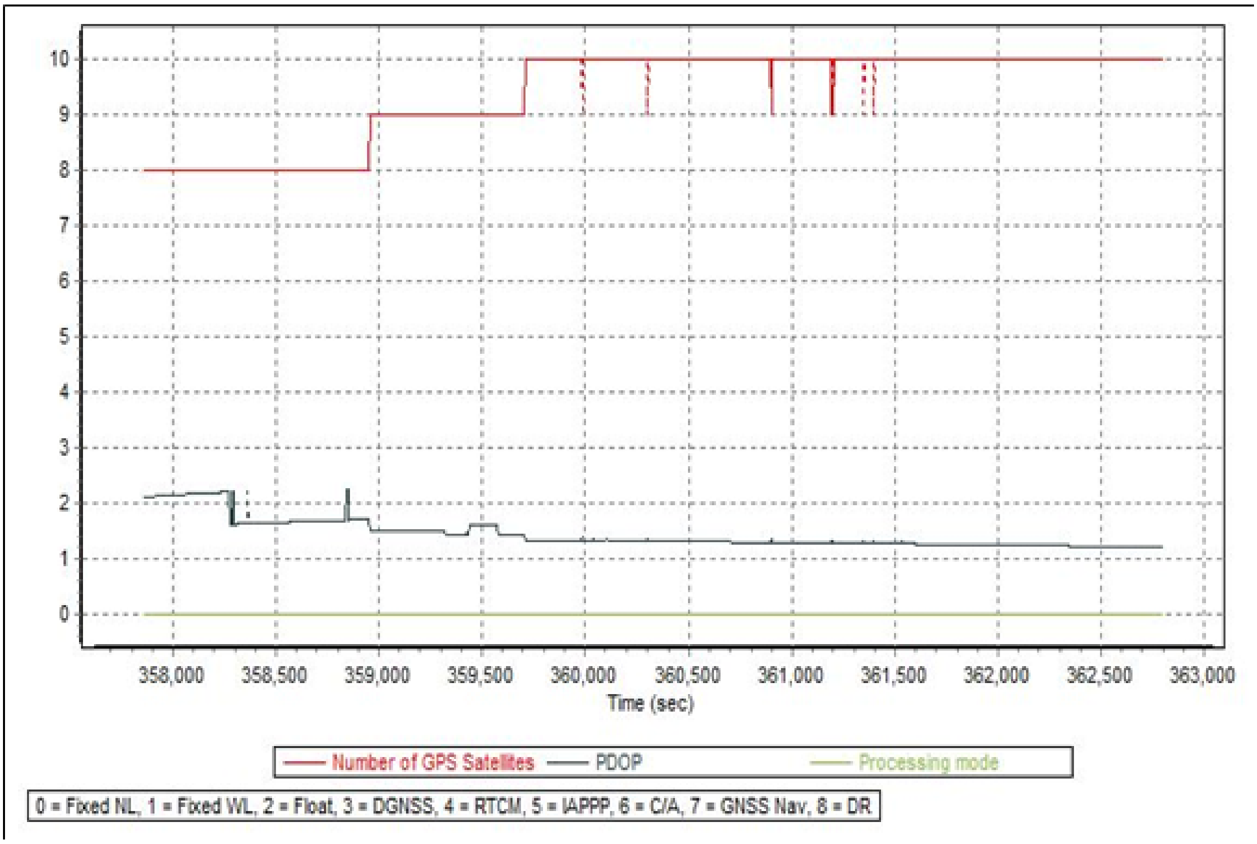


Figure A-8.36. Solution Status

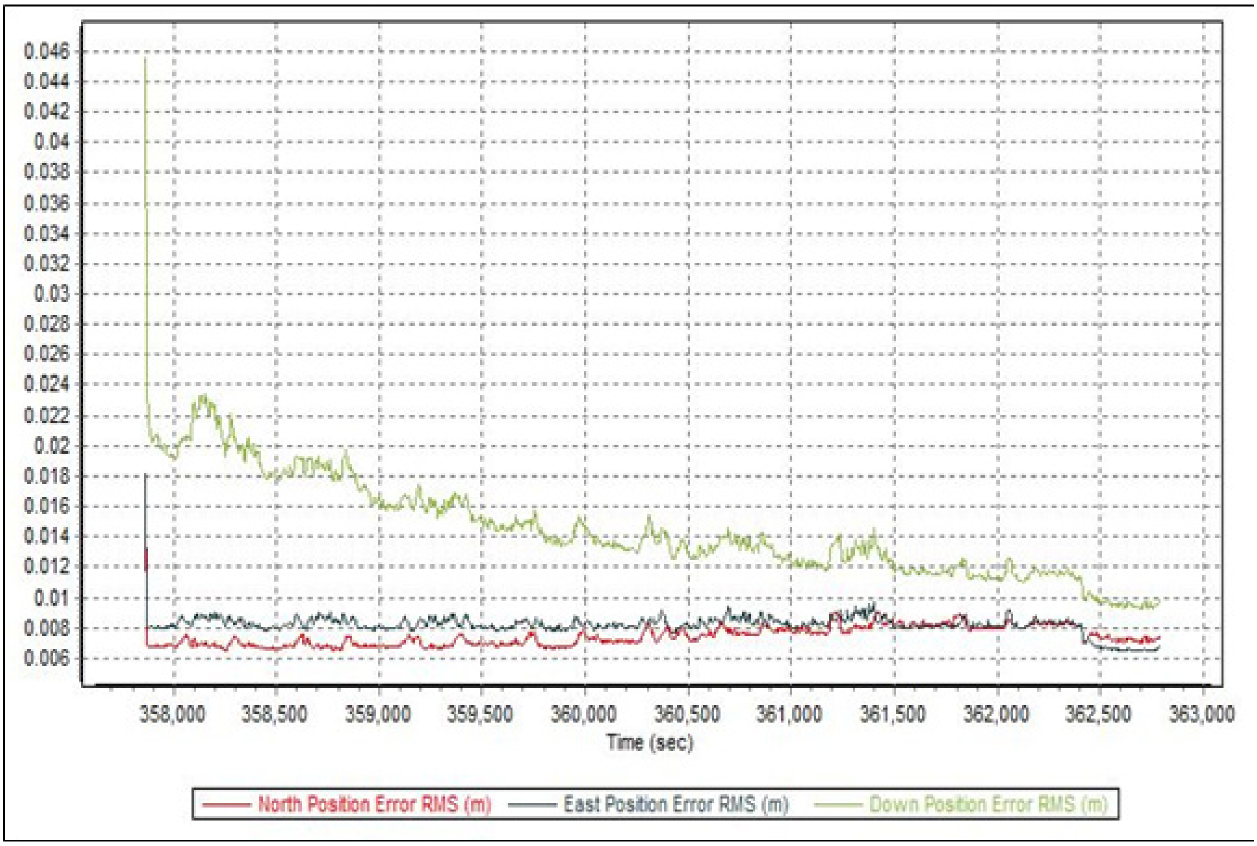


Figure A-8.37. Smoothed Performance Metric Parameters

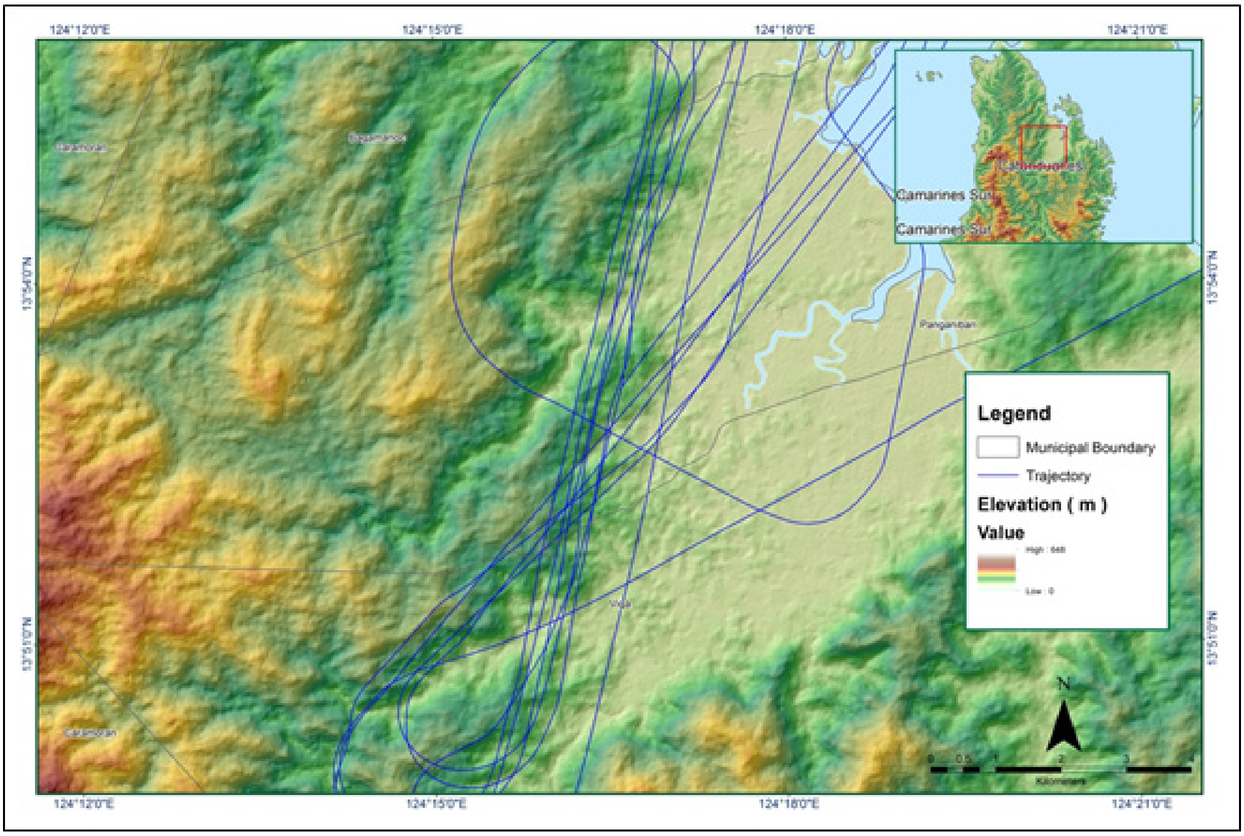


Figure A-8.38 Best Estimated Trajectory

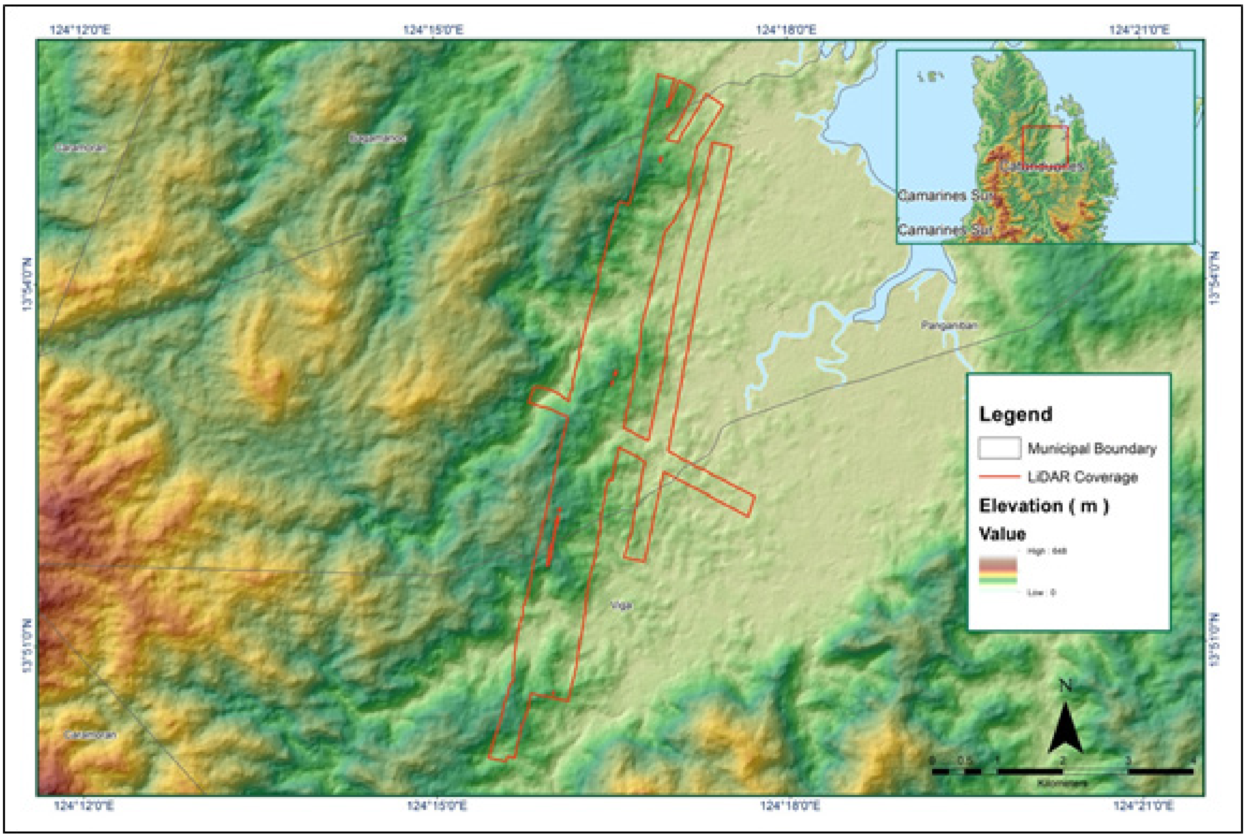


Figure A-8.39 Coverage of LiDAR data

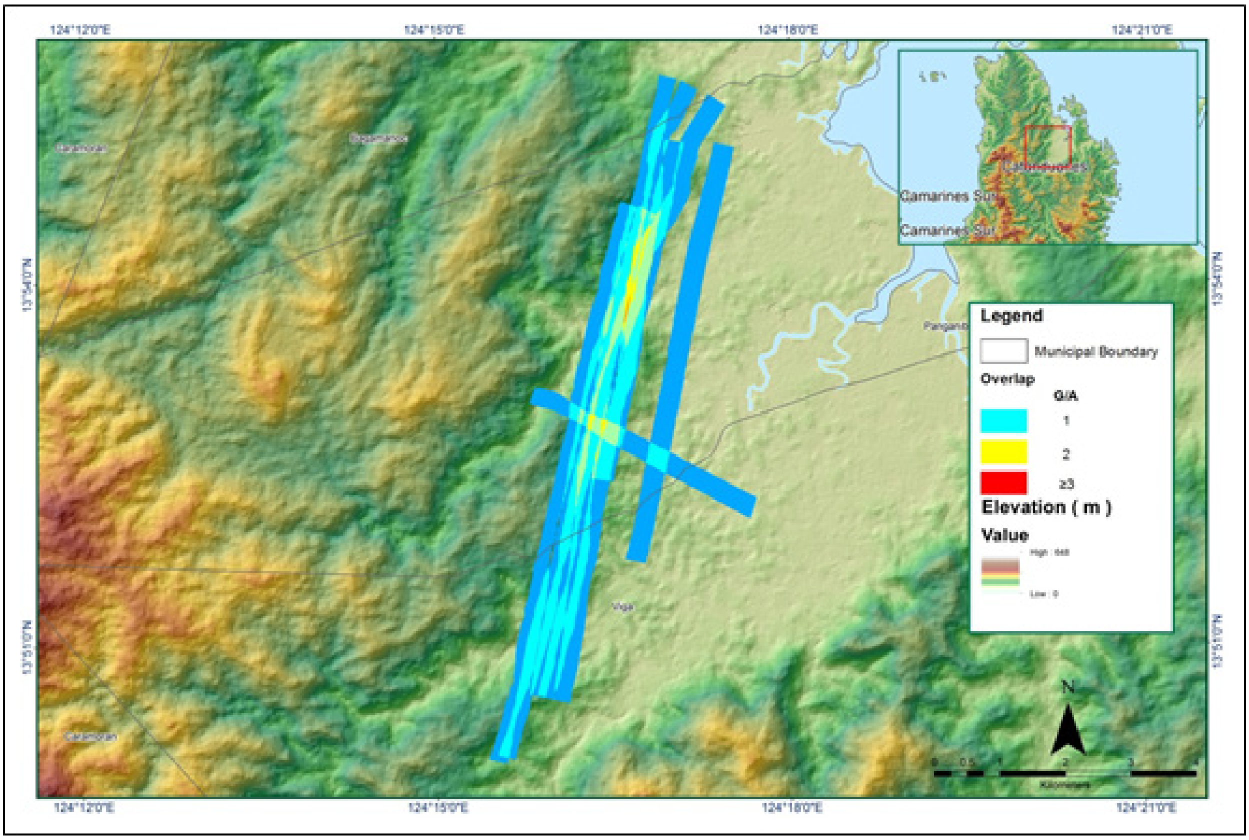


Figure A-8.40. Image of data overlap

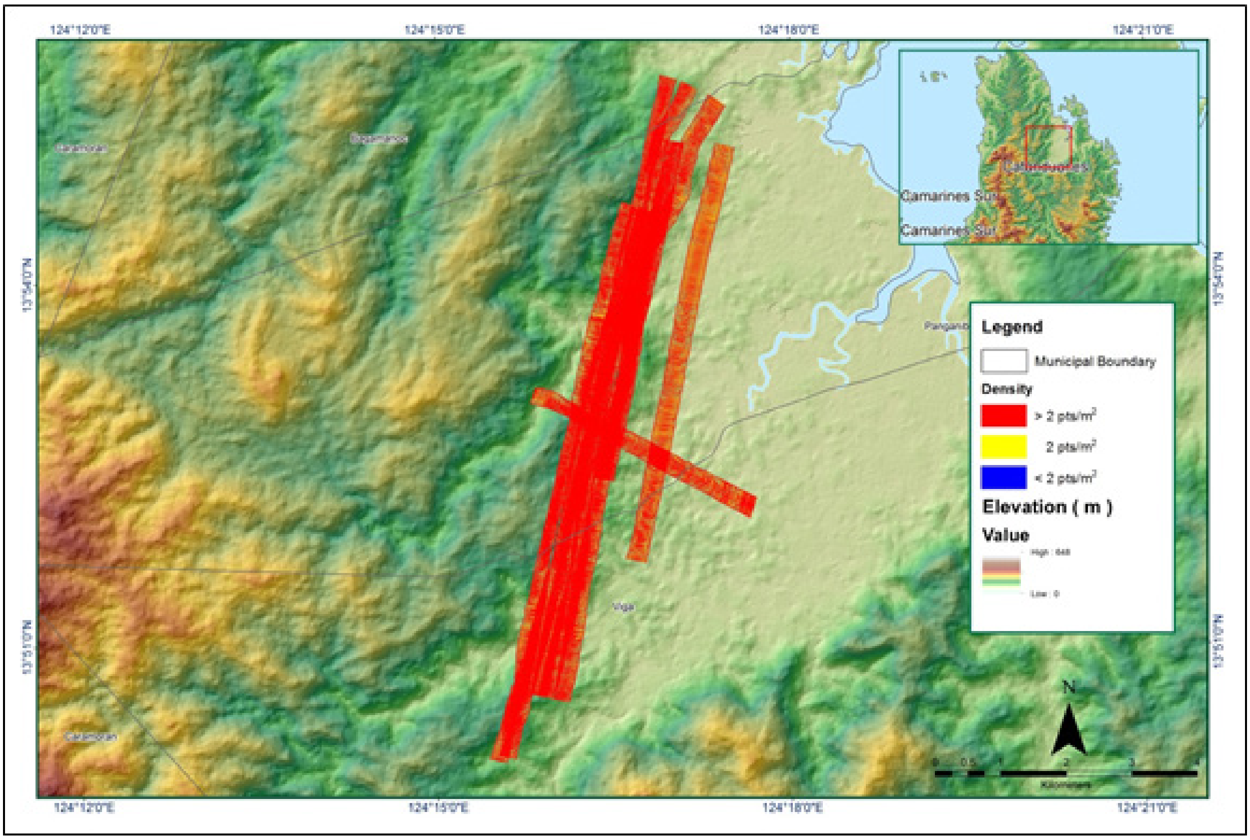


Figure A-8.41. Density Map of merged LiDAR data

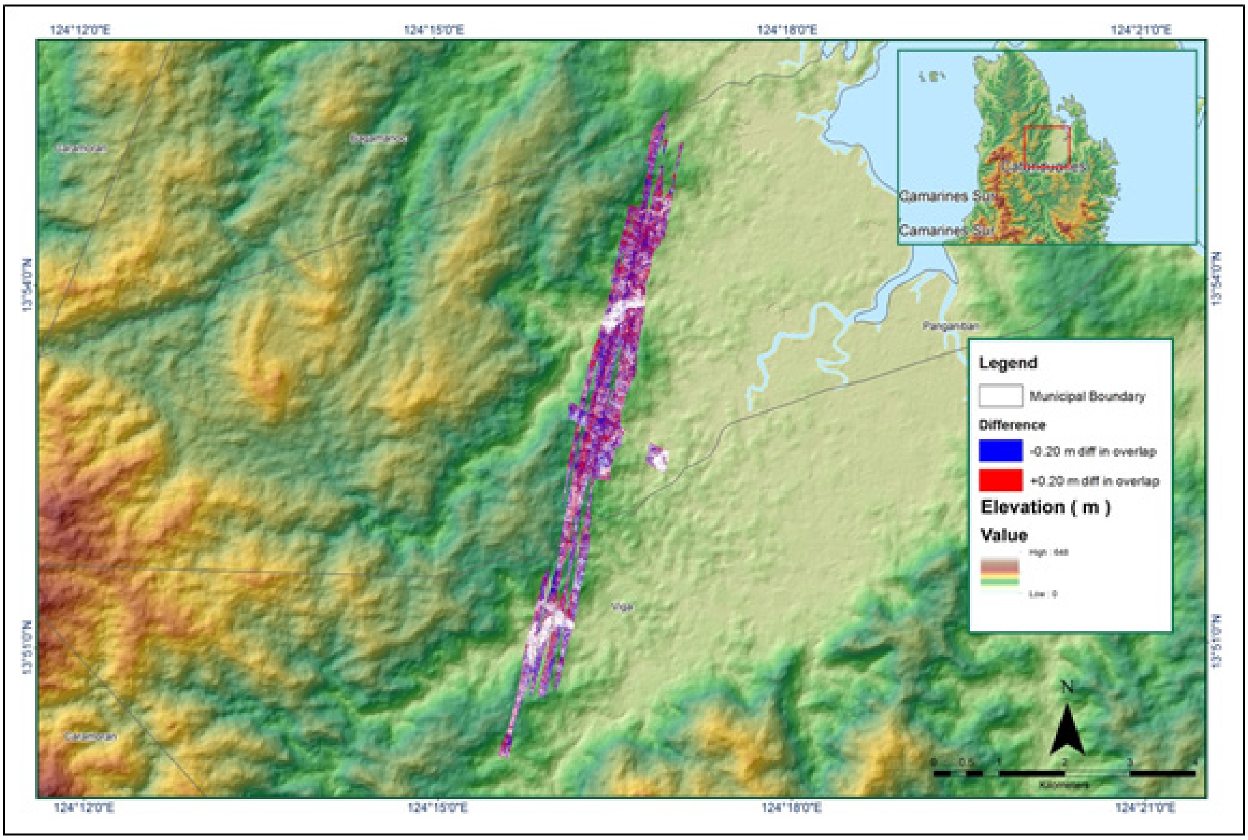


Figure A-8.42 Elevation Difference Between flight lines

Table A-8.7. Mission Summary Report of Mission Blk25C

FLIGHT AREA	CATANDUANES
Mission Name	Blk25C
Inclusive Flights	8527AC
Range data size	1.85 GB
Base data size	7.36 MB
POS	105 MB
Image	NA
Transfer date	February 21, 2017
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.55
RMSE for East Position (<4.0 cm)	1.41
RMSE for Down Position (<8.0 cm)	3.30
Boresight correction stdev (<0.001deg)	NA
IMU attitude correction stdev (<0.001deg)	0.001316
GPS position stdev (<0.01m)	0.0132
Minimum % overlap (>25)	44.30
Ave point cloud density per sq.m. (>2.0)	3.28
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	22
Maximum Height	703.57 m
Minimum Height	53.23 m
Classification (# of points)	
Ground	7,458,173
Low vegetation	3,352,392
Medium vegetation	4,980,210
High vegetation	6,529,541
Building	303,915
Ortophoto	No
Processed by	Engr. Kenneth Solidum, Engr. Harmond Santos, Engr. Gladys Mae Apat

Figure A-8.43. Solution Status

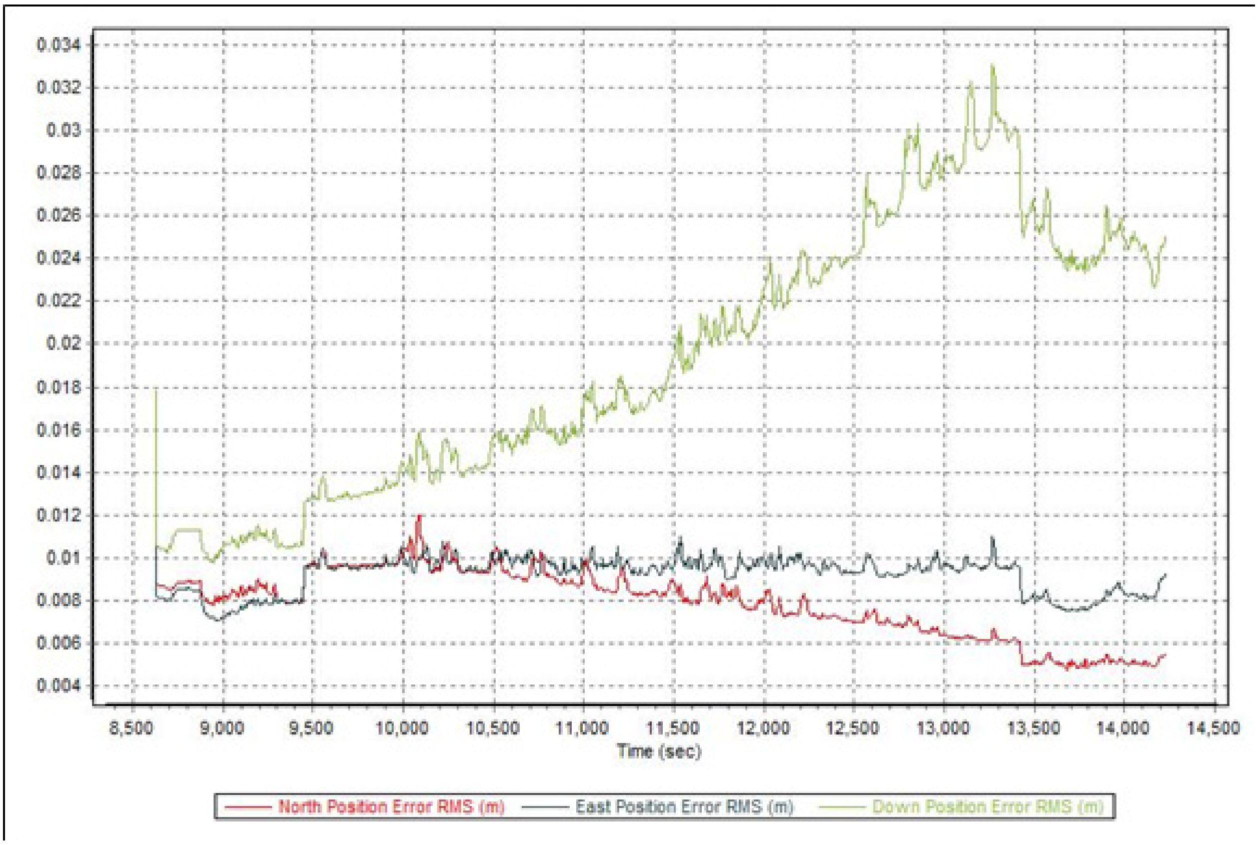


Figure A-8.44. Smoothed Performance Metric Parameters

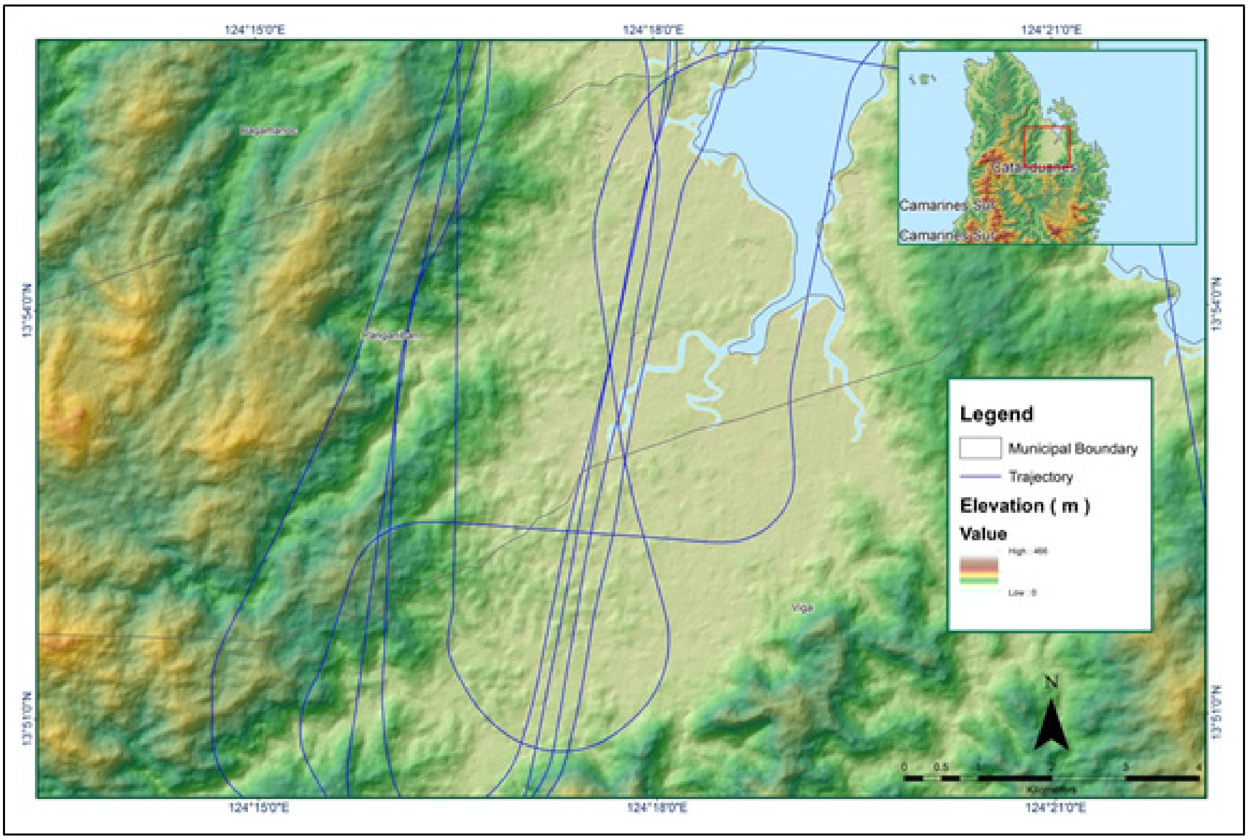


Figure A-8.45. Best Estimated Trajectory

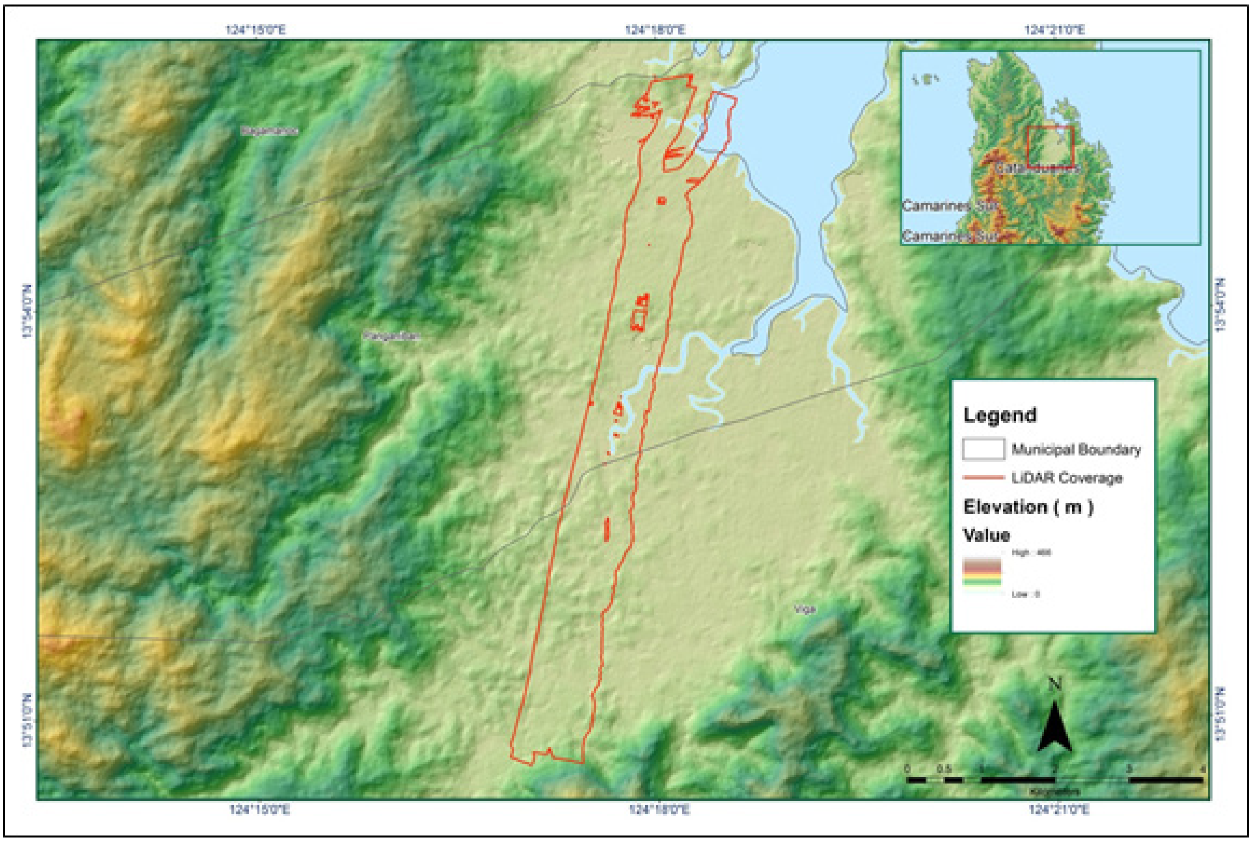


Figure A-8.46. Coverage of LiDAR data

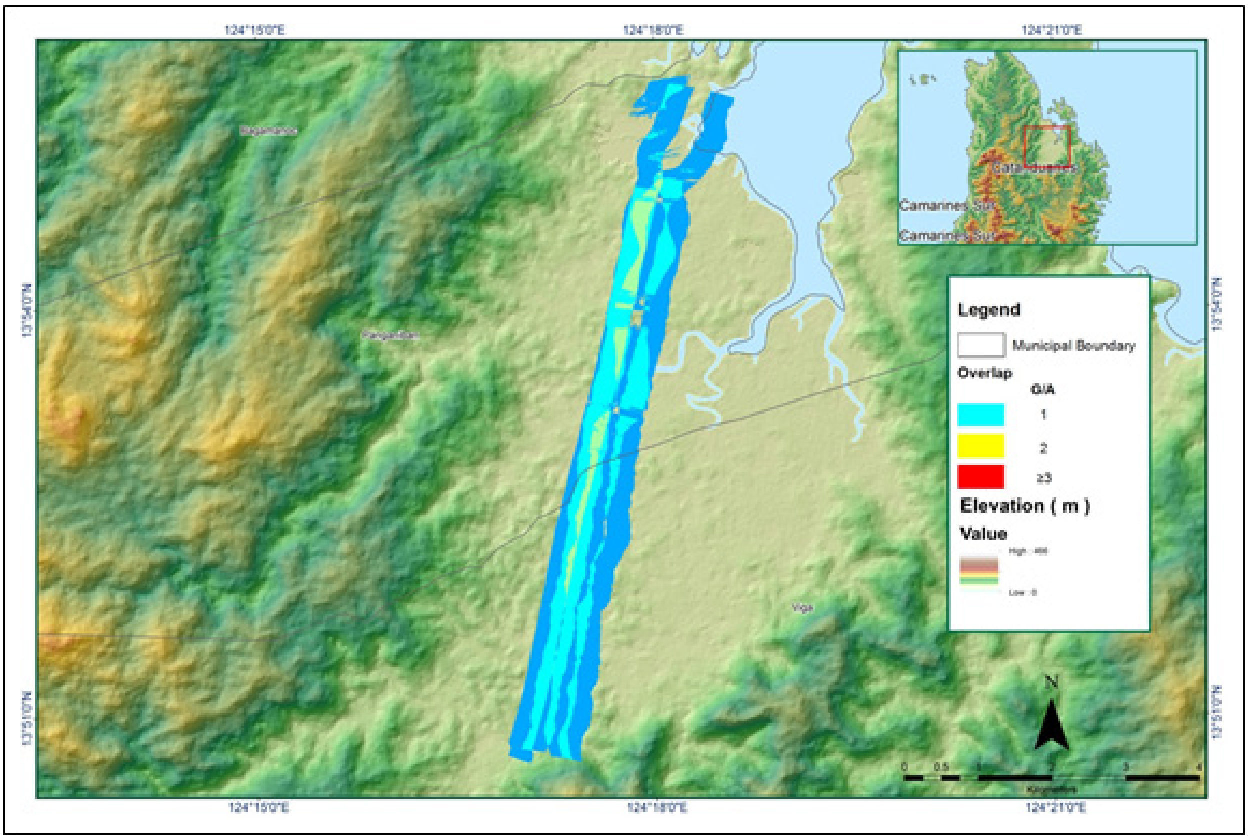


Figure A-8.47. Image of data overlap

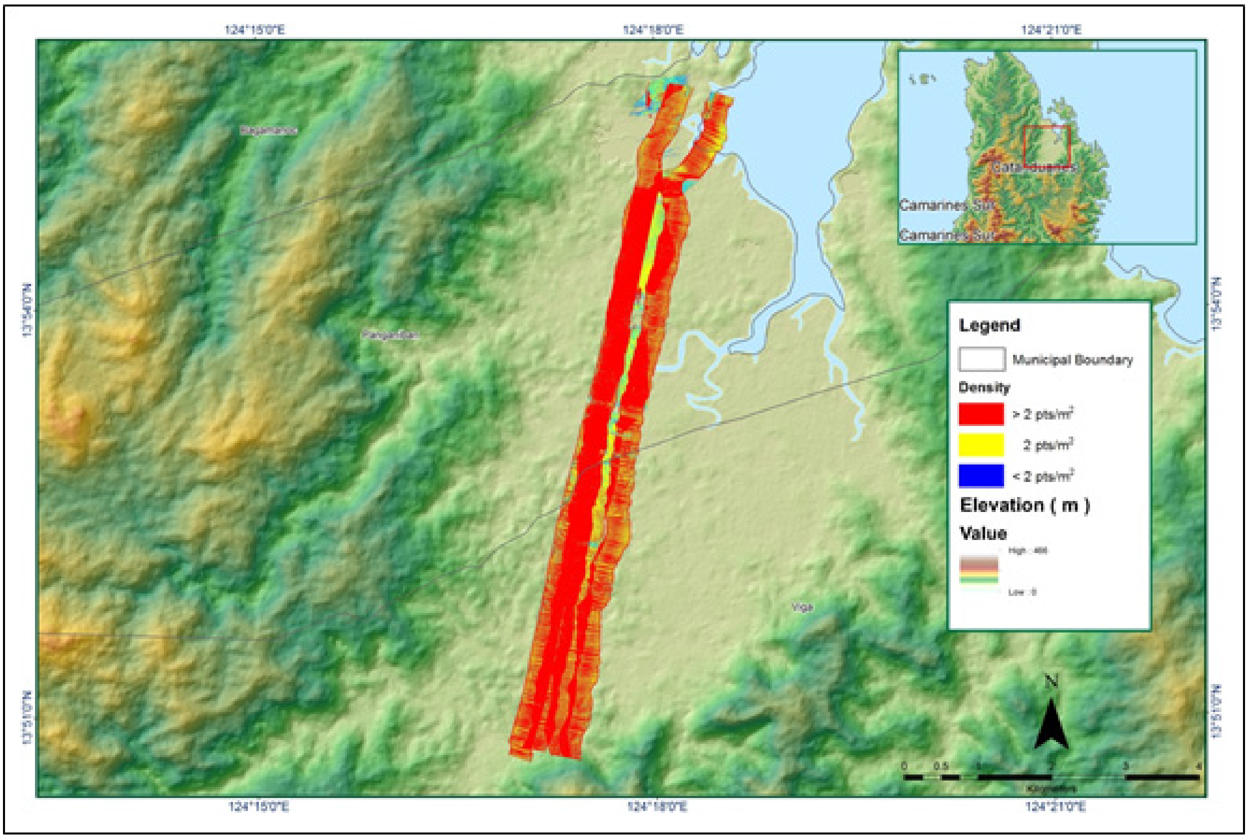


Figure A-8.48. Density Map of merged LiDAR data

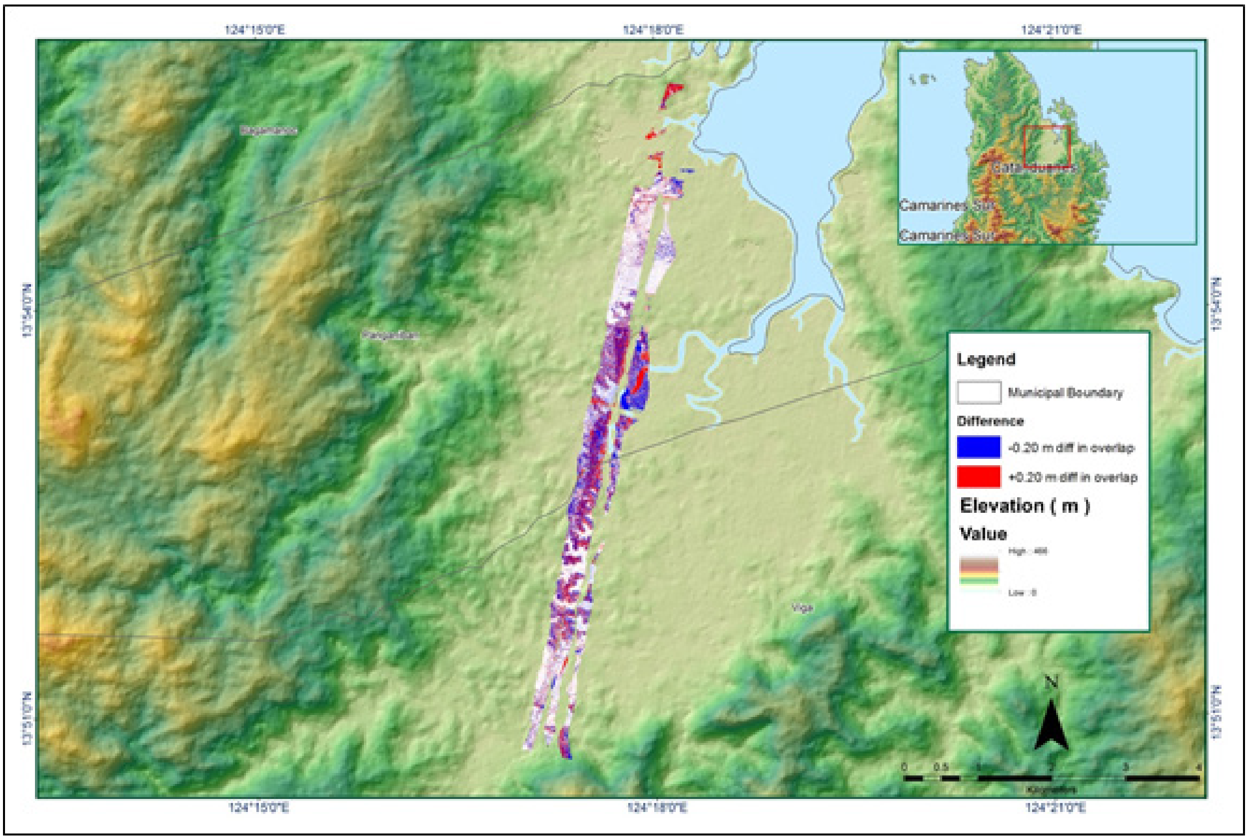


Figure A-8.49 Elevation Difference Between flight lines

Table A-8.8. Mission Summary Report of Mission Blk25C_supplement

FLIGHT AREA	CATANDUANES
Mission Name	Blk25C_supplement
Inclusive Flights	8531AC
Range data size	2.59 GB
Base data size	27.2 MB
POS	132 MB
Image	NA
Transfer date	February 21, 2017
Solution Status	
Number of Satellites (>6)	No
PDOP (<3)	No
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	4.17
RMSE for East Position (<4.0 cm)	1.79
RMSE for Down Position (<8.0 cm)	67.4
Boresight correction stdev (<0.001deg)	NA
IMU attitude correction stdev (<0.001deg)	0.000964
GPS position stdev (<0.01m)	0.0011
Minimum % overlap (>25)	34.58
Ave point cloud density per sq.m. (>2.0)	3.09
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	22
Maximum Height	364.19 m
Minimum Height	53.26 m
Classification (# of points)	
Ground	9,709,130
Low vegetation	5,150,278
Medium vegetation	8,181,648
High vegetation	8,711,413
Building	201,086
Orthophoto	No
Processed by	Engr. Don Matthew Banatin, Engr. Harmond Santos, Engr. Gladys Mae Apat

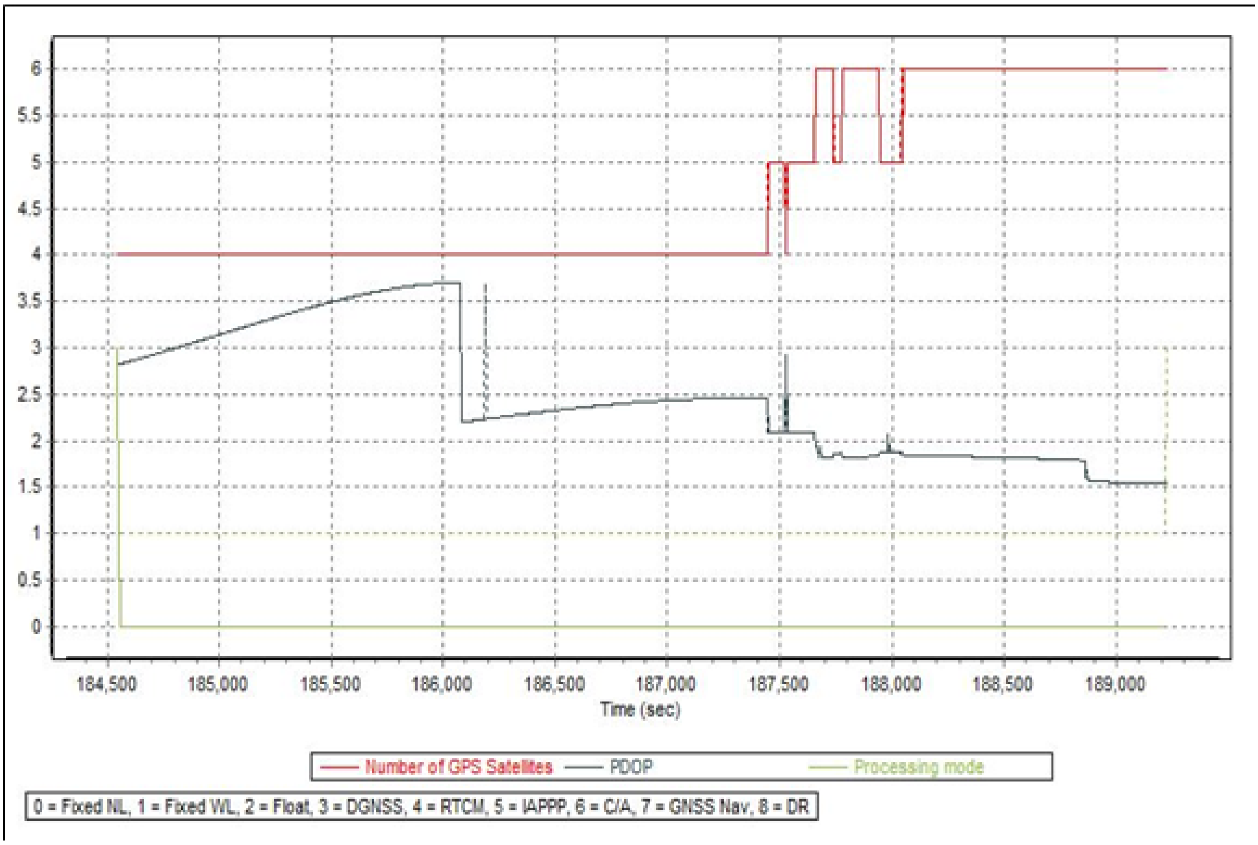


Figure A-8.50. Solution Status

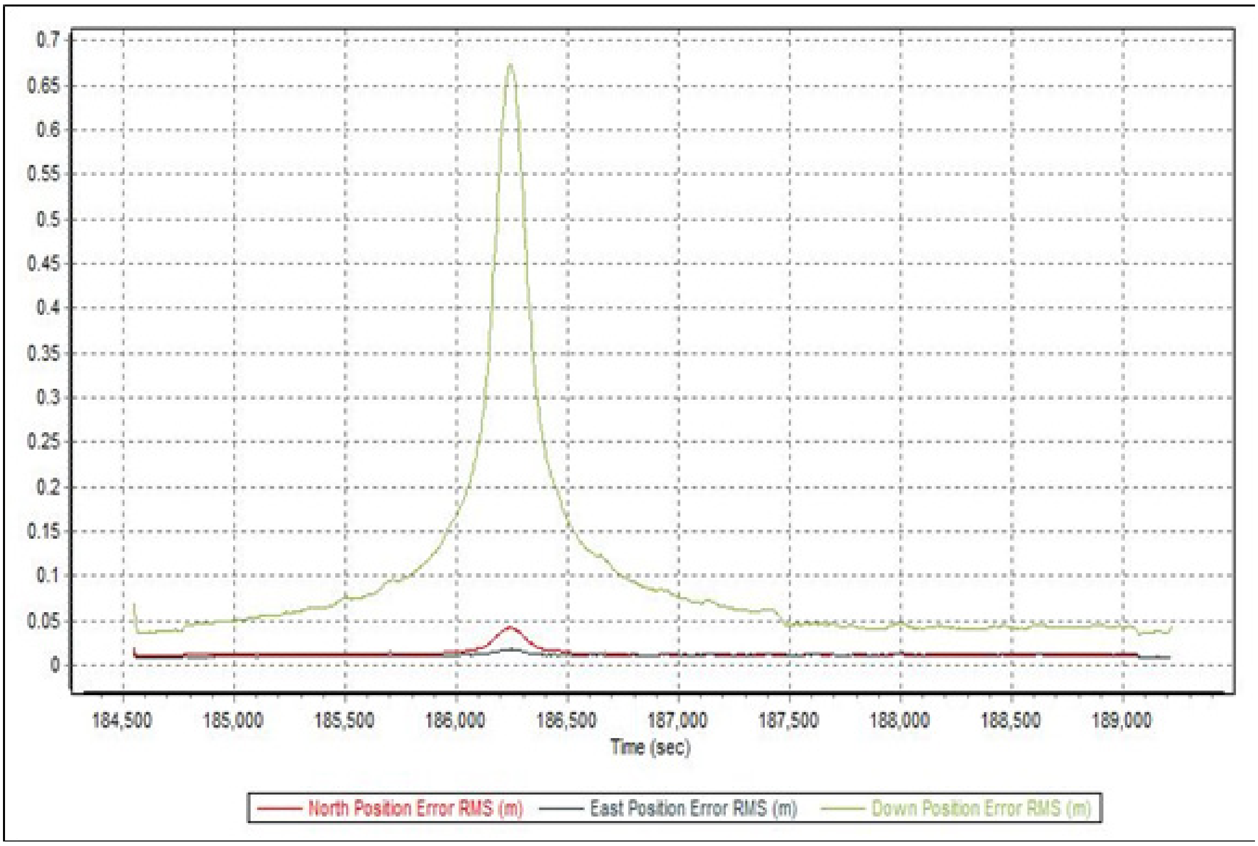


Figure A-8.51. Smoothed Performance Metric Parameters

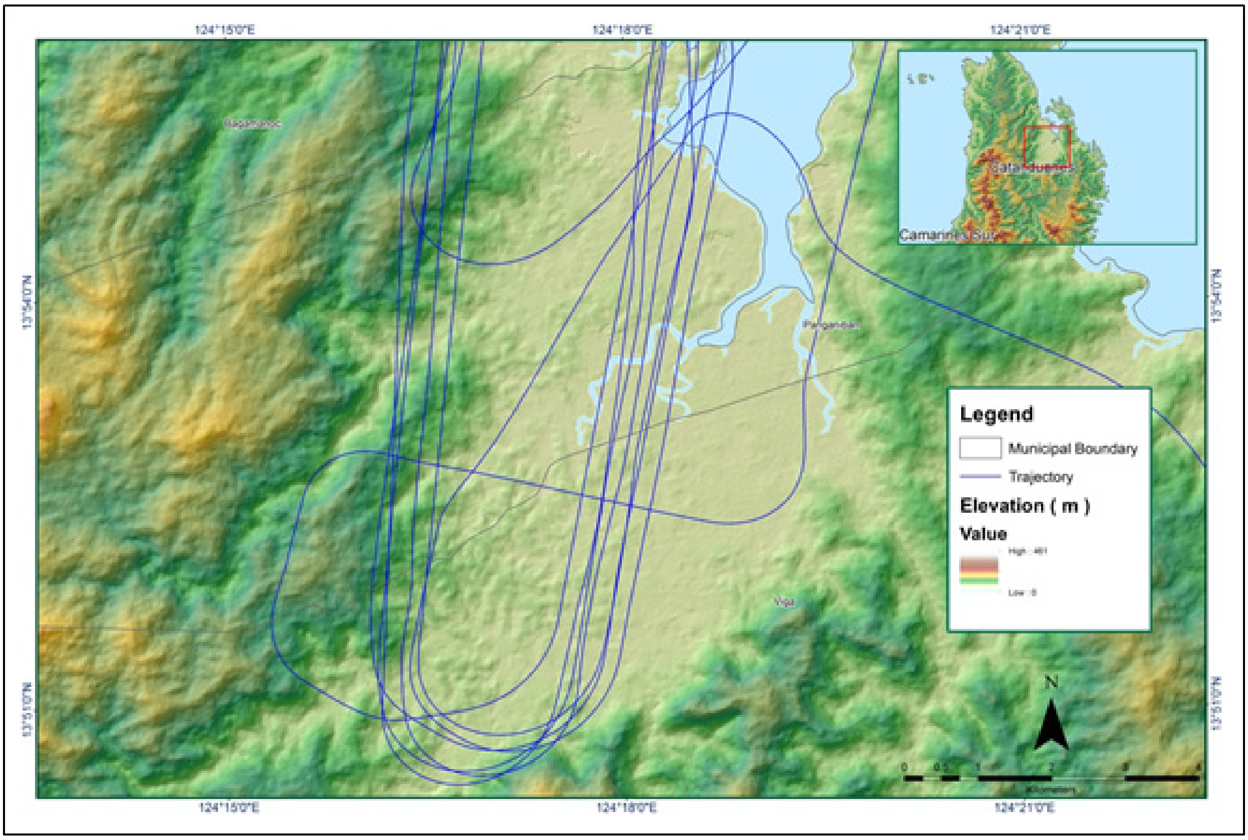


Figure A-8.52. Best Estimated Trajectory

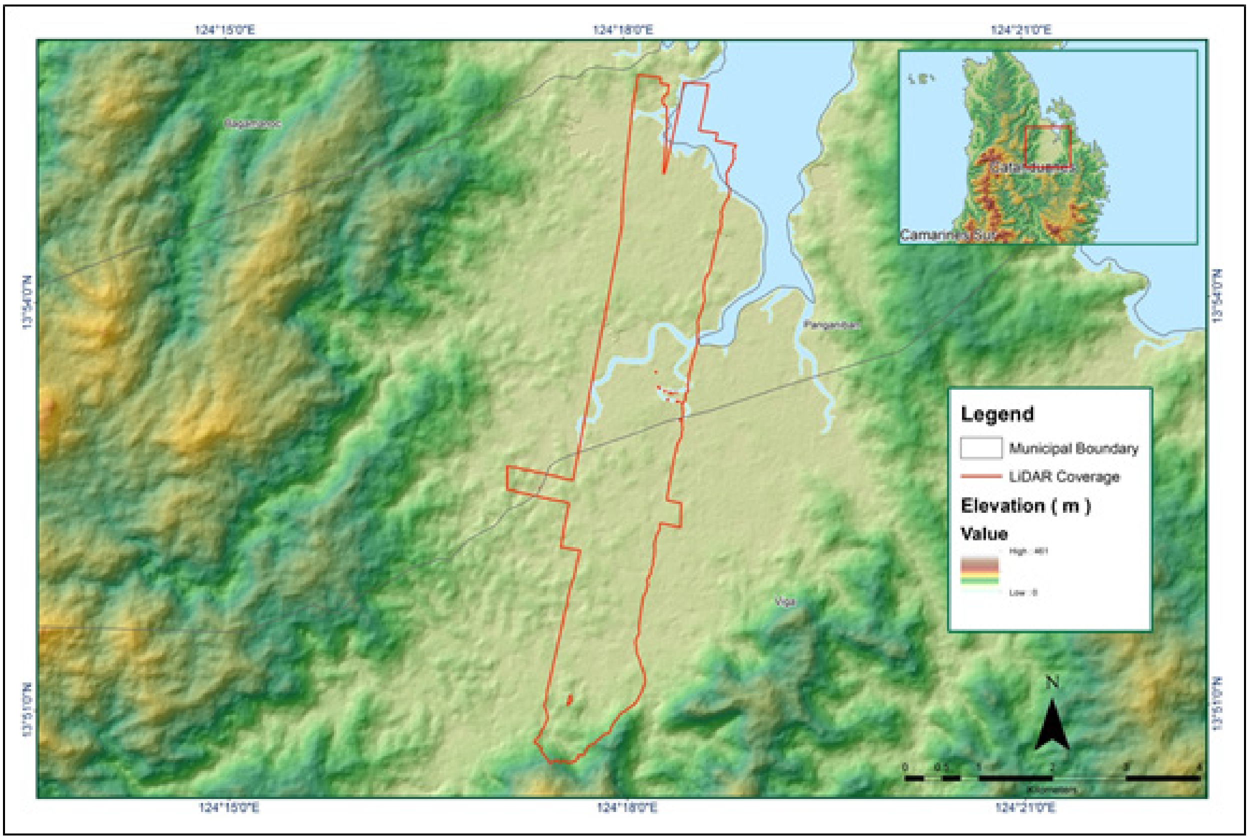


Figure A-8.53. Coverage of LiDAR data

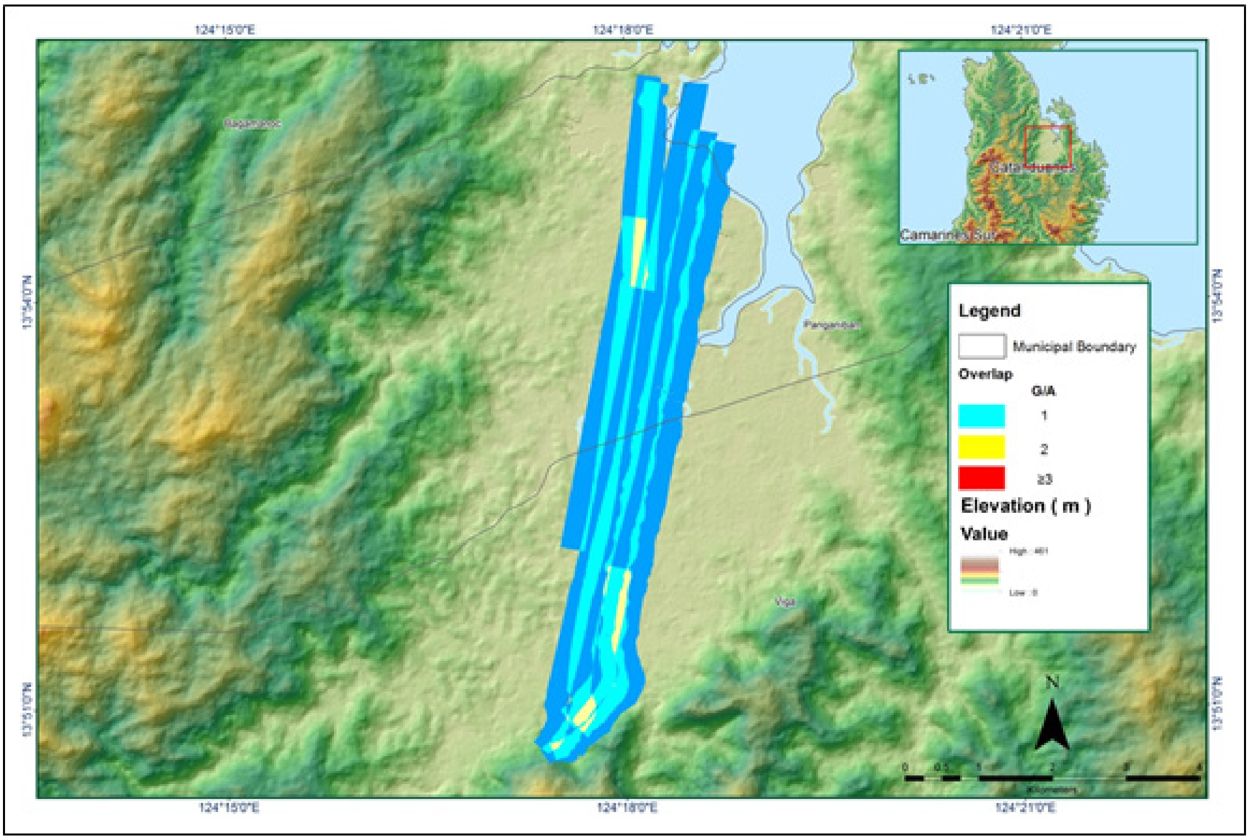


Figure A-8.54. Image of data overlap

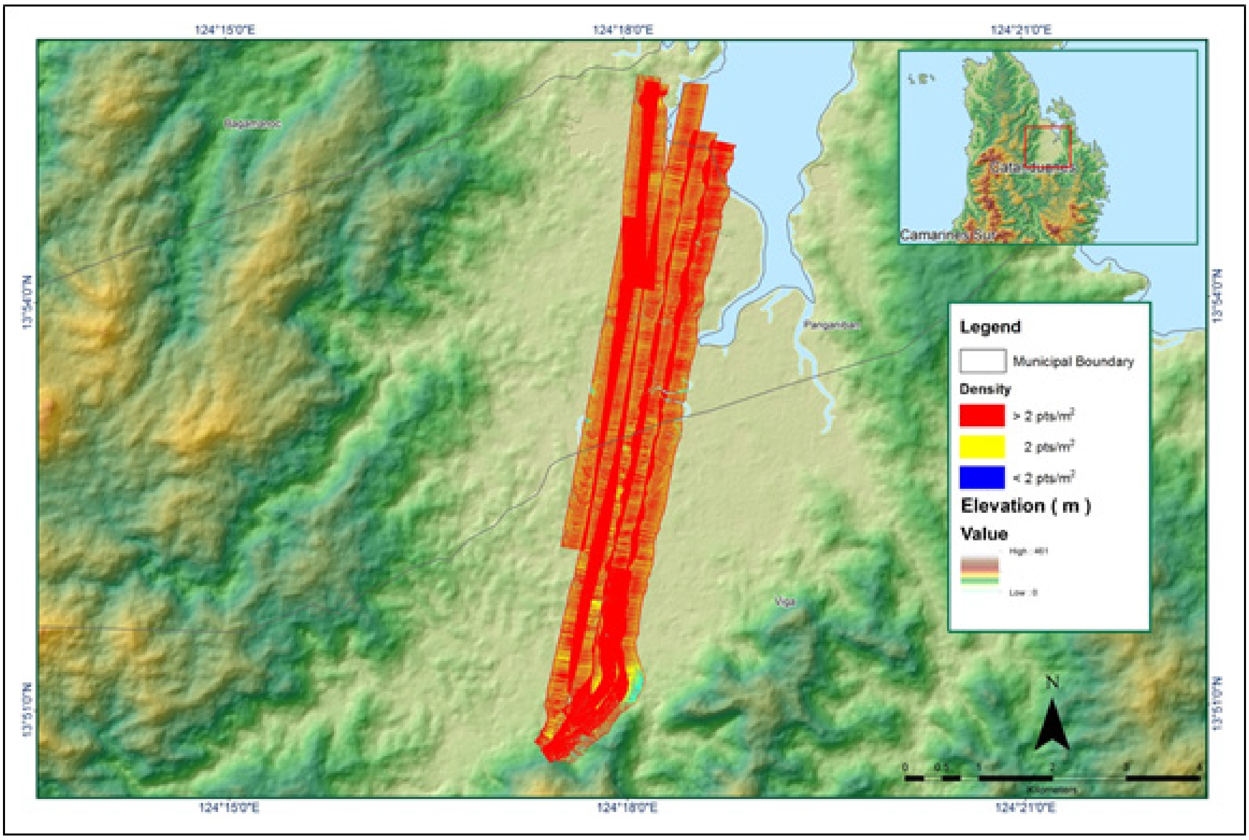


Figure A-8.55 Density Map of merged LiDAR data

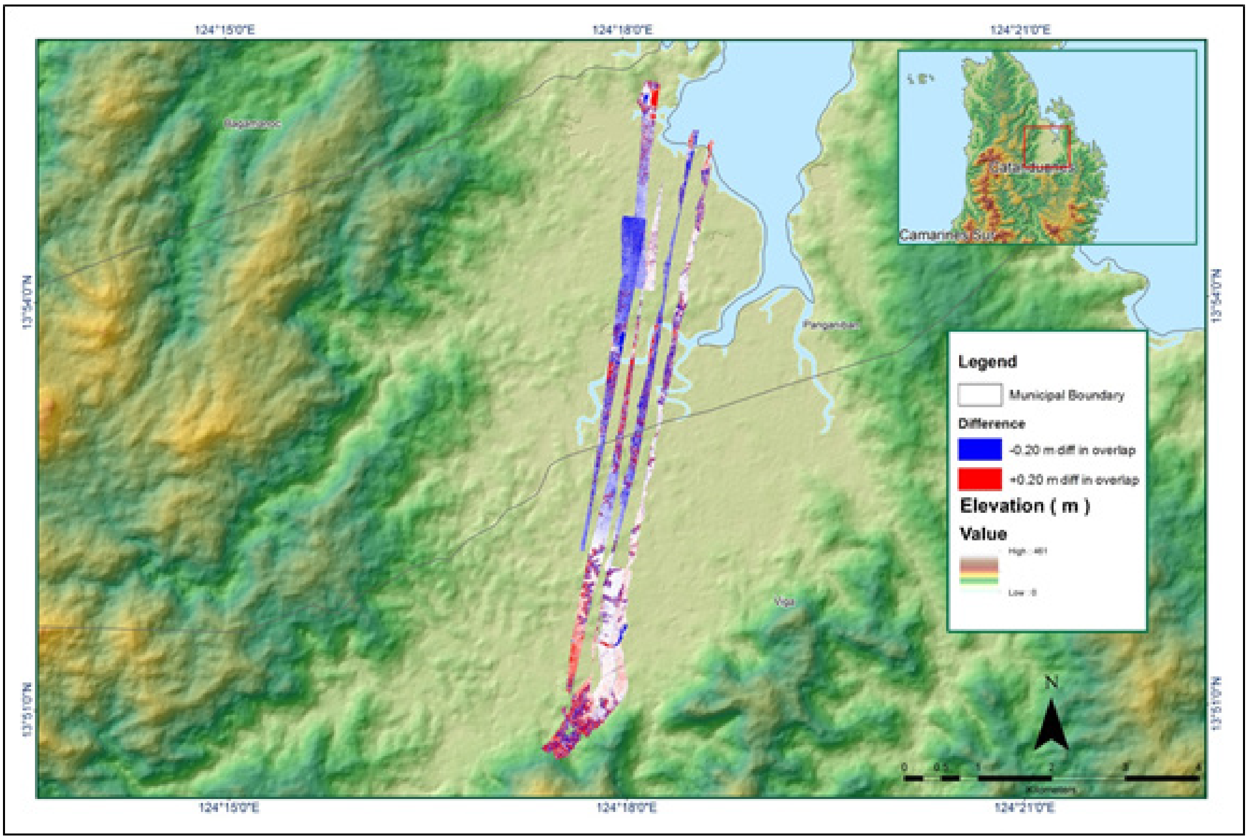


Figure A-8.56 Elevation Difference Between flight lines

Table A-8.9. Mission Summary Report of Mission Blk25D

FLIGHT AREA	CATANDUANES
Mission Name	Blk25D
Inclusive Flights	8533AC
Range data size	2.39 GB
Base data size	26.9 MB
POS	145 MB
Image	NA
Transfer date	February 21, 2017
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.55
RMSE for East Position (<4.0 cm)	1.41
RMSE for Down Position (<8.0 cm)	3.30
Boresight correction stdev (<0.001deg)	NA
IMU attitude correction stdev (<0.001deg)	0.451529
GPS position stdev (<0.01m)	0.0024
Minimum % overlap (>25)	55.72
Ave point cloud density per sq.m. (>2.0)	3.77
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	20
Maximum Height	353.63 m
Minimum Height	52.63 m
Classification (# of points)	
Ground	9,563,484
Low vegetation	5,581,676
Medium vegetation	8,640,654
High vegetation	11,898,946
Building	422,343
Orthophoto	No
Processed by	Engr. Ben Joseph Harder, Engr. Harmond Santos, Engr. Gladys Mae Apat

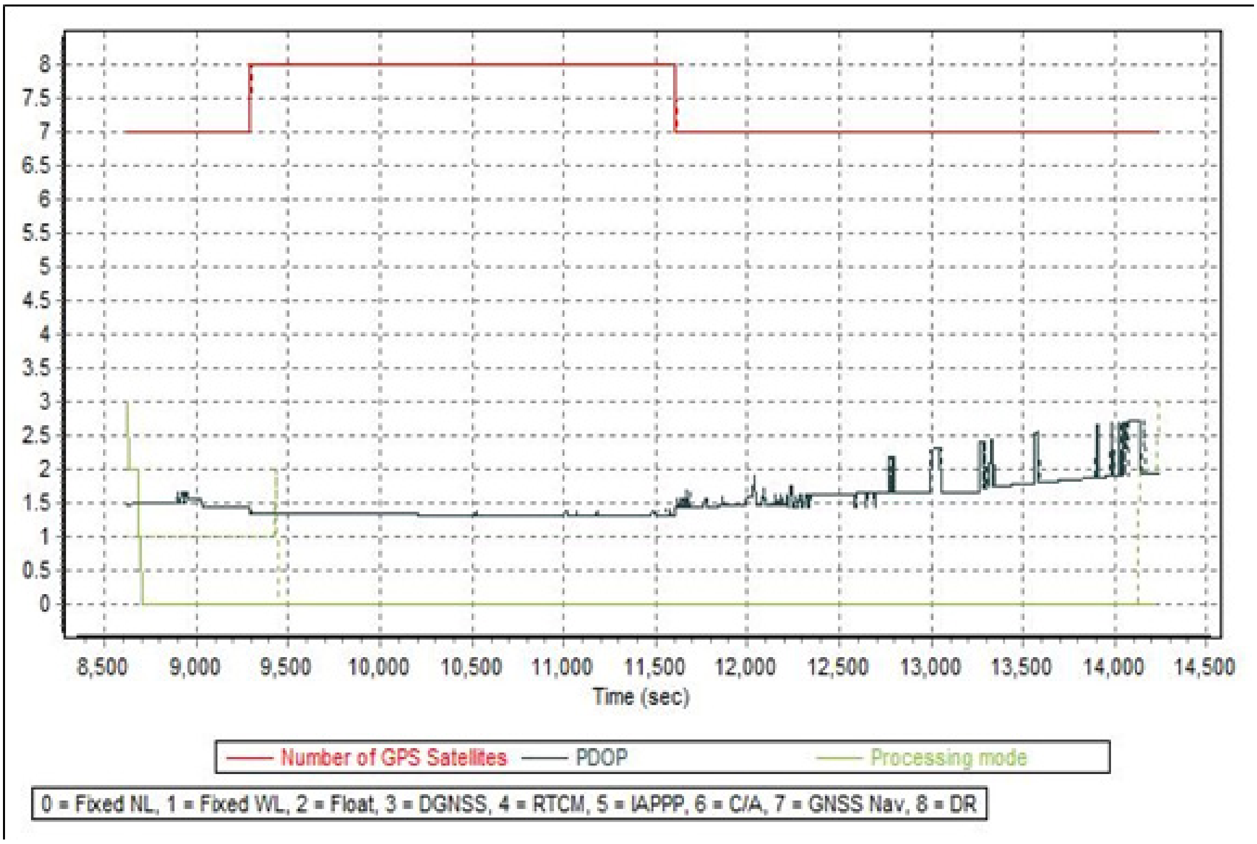


Figure A-8.57. Solution Status

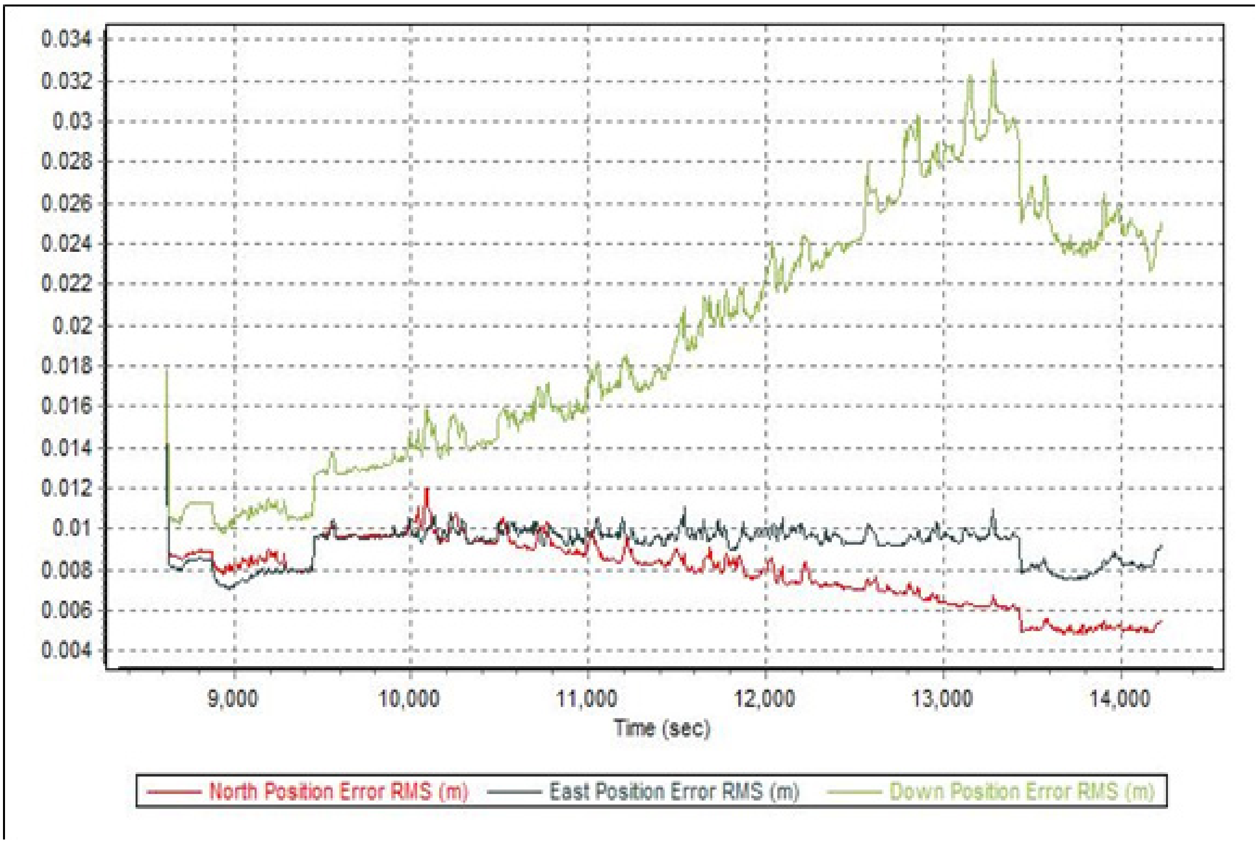


Figure A-8.58. Smoothed Performance Metric Parameters

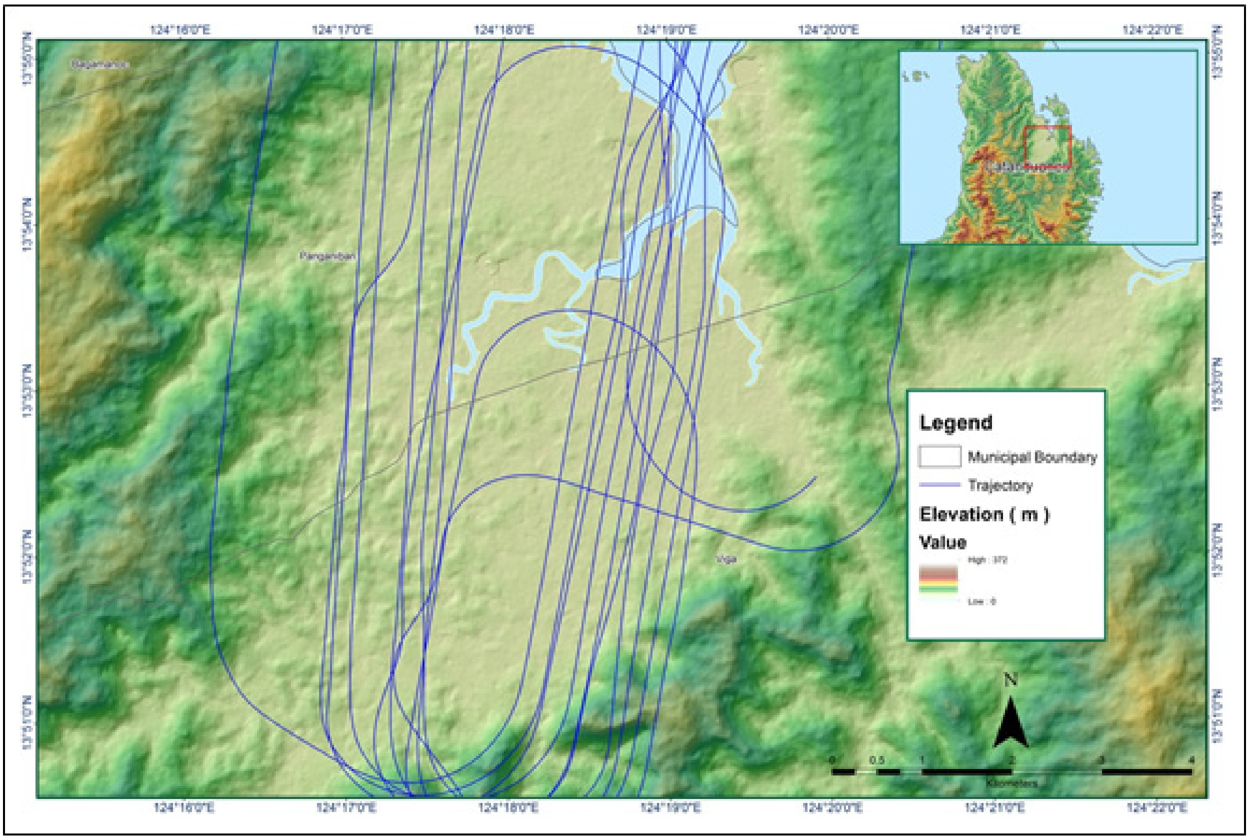


Figure A-8.59. Best Estimated Trajectory

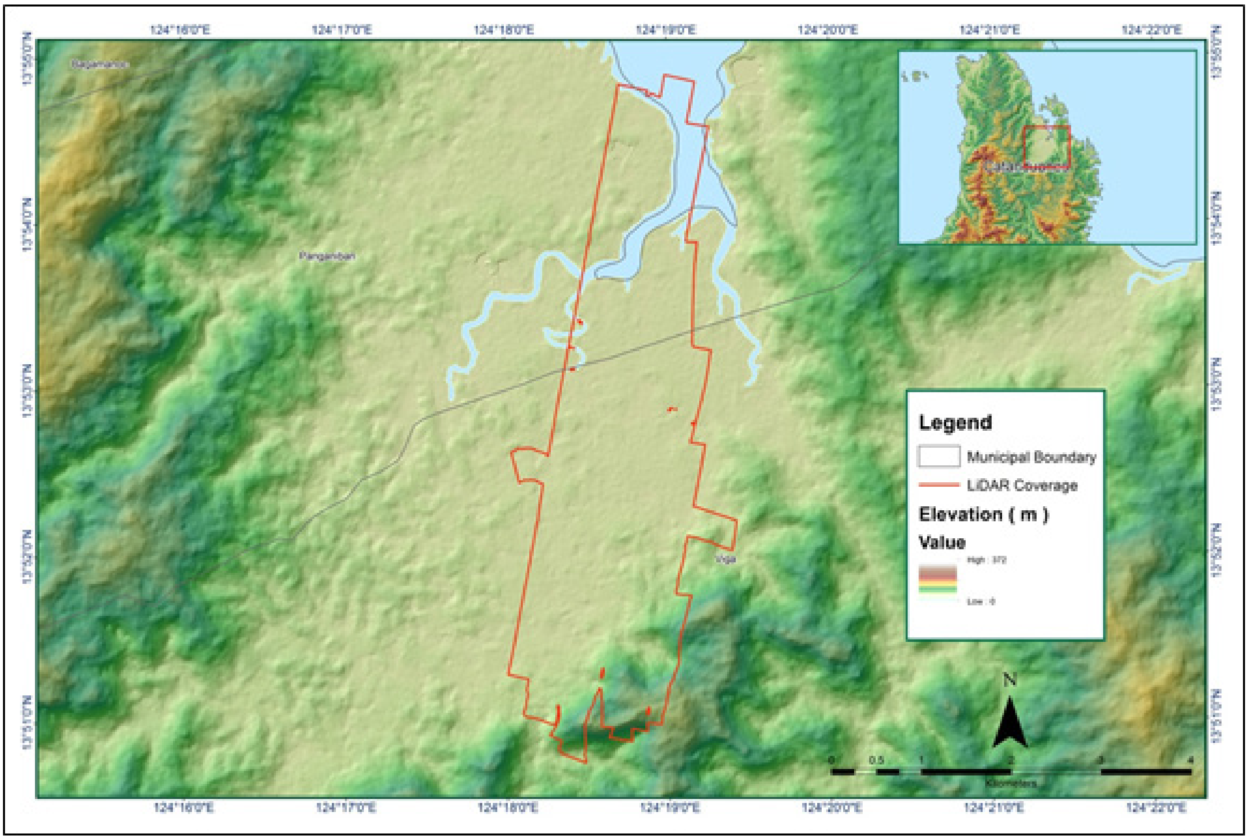


Figure A-8.60 Coverage of LiDAR data

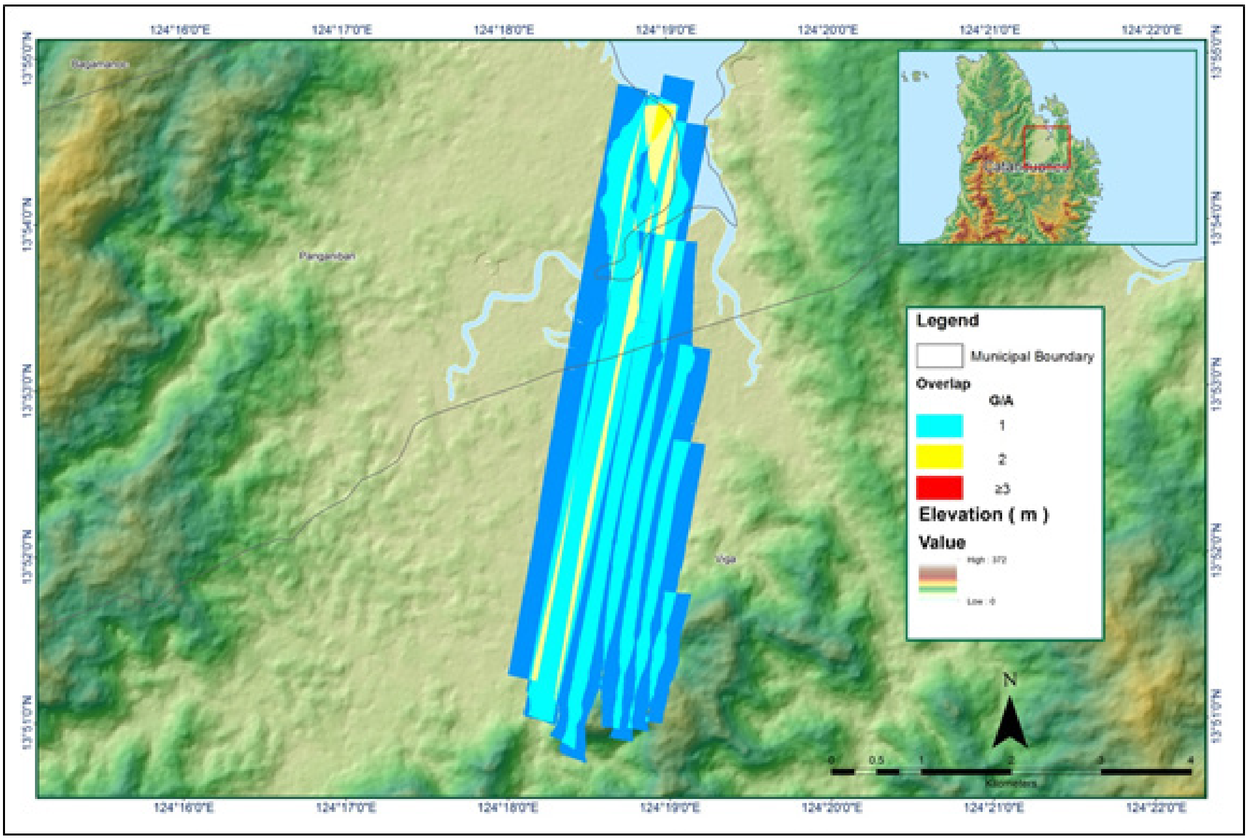


Figure A-8.61. Image of data overlap

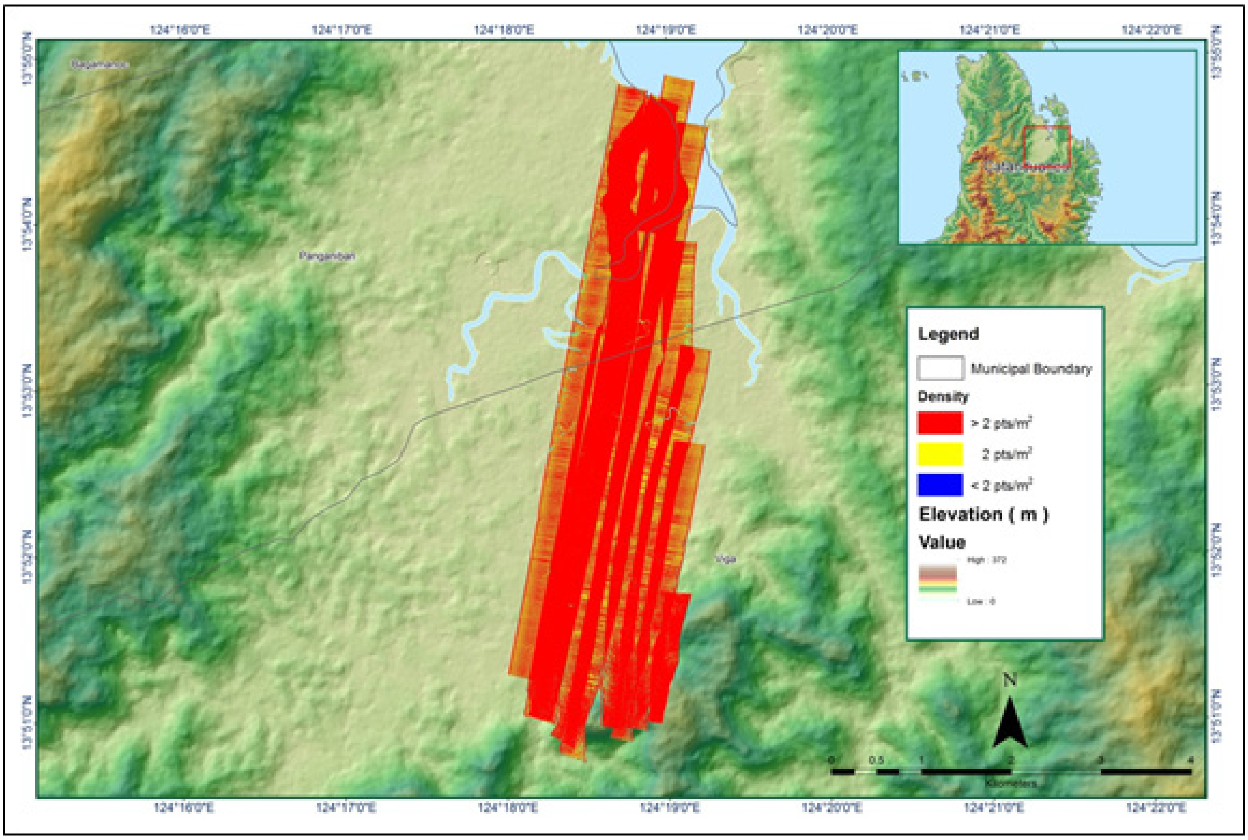


Figure A-8.62. Density Map of merged LiDAR data

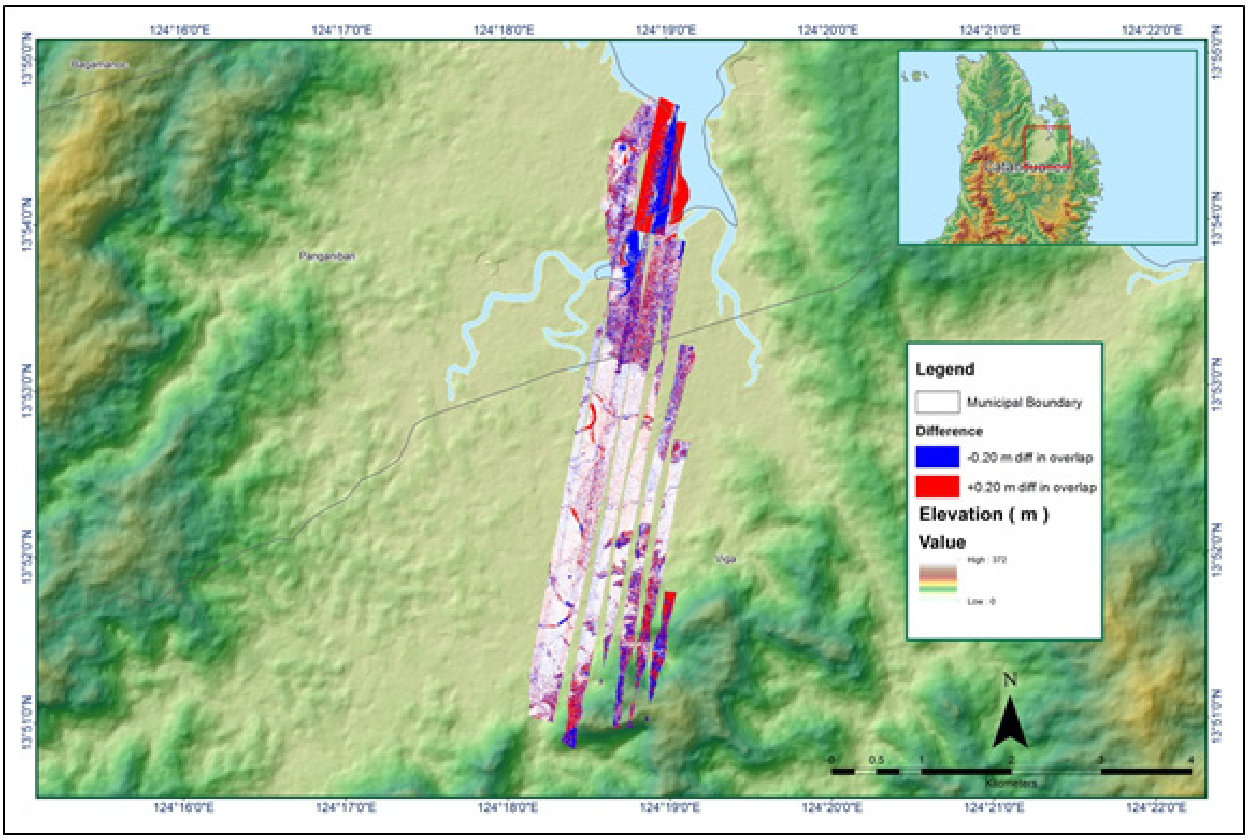


Figure A-8.63. Elevation Difference Between flight lines

Annex 9. Viga Model Basin Parameters

Table A-9.1. Viga Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
W200	47.604	38.191	0	0.14451	21.695	Discharge	0.12812	1	Ratio to Peak	0.092314
W210	143.36	41.266	0	0.14748	6.3733	Discharge	0.077009	0.49969	Ratio to Peak	0.001406
W220	39.418	35.103	0	0.14342	142.67	Discharge	0.17742	0.35125	Ratio to Peak	0.011814
W230	85.054	46.012	0	0.14711	10.648	Discharge	0.085089	0.00001	Ratio to Peak	0.05861
W240	298.83	35.209	0	2.3803	0.057089	Discharge	0.062358	0.001775	Ratio to Peak	0.00049
W250	437.07	52.839	0	0.16508	139.94	Discharge	0.35273	0.36755	Ratio to Peak	0.1192
W260	145.15	35.107	0	0.14939	0.060684	Discharge	0.023232	2.08E-05	Ratio to Peak	0.000613
W270	223.97	35.202	0	116.16	44.807	Discharge	0.079283	0.16444	Ratio to Peak	0.20185
W280	205.93	35.206	3	0.14781	205.57	Discharge	0.16684	0.22012	Ratio to Peak	0.092449
W290	500	52.849	0	48.79	26.068	Discharge	0.056833	0.000552	Ratio to Peak	0.027678
W300	478.04	53.012	0	0.14747	0.066065	Discharge	0.032883	1.28E-05	Ratio to Peak	0.000222
W310	434.32	35.284	0	354.25	168.1	Discharge	0.31468	0.00001	Ratio to Peak	0.18618
W320	434.4	35.1	0	0.15877	707.88	Discharge	0.19164	0.002779	Ratio to Peak	0.012808
W330	500	52.635	0	145.09	1.9173	Discharge	0.064019	0.000991	Ratio to Peak	0.038293
W340	278.26	35.226	0	86.053	435.19	Discharge	0.026004	0.000054	Ratio to Peak	0.12164
W350	362.57	35.285	0	265	121.67	Discharge	0.003003	0.002698	Ratio to Peak	0.093408
W360	500	52.618	0	0.41338	126.03	Discharge	0.17986	0.001399	Ratio to Peak	0.14297
W370	500	52.878	0	108.62	370.36	Discharge	0.094013	1.64E-05	Ratio to Peak	0.063544
W380	500	52.865	0	5.4417	123.37	Discharge	0.084987	0.001758	Ratio to Peak	0.097255

Annex 10. Viga Model Reach Parameters

Table A-10.1. Viga Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing							
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope	
1	R10	Automatic Fixed Interval	3474.7	0.00089	0.66135	Trapezoid	44.2	1
2	R30	Automatic Fixed Interval	1790.2	0.00569	0.0001	Trapezoid	44.2	1
3	R40	Automatic Fixed Interval	1085.4	0.0045	0.0001	Trapezoid	44.2	1
4	R50	Automatic Fixed Interval	844.68	0.0045	0.26108	Trapezoid	44.2	1
5	R90	Automatic Fixed Interval	2979.5	0.00574	0.27342	Trapezoid	44.2	1
6	R110	Automatic Fixed Interval	2282.7	0.01272	0.31313	Trapezoid	44.2	1
7	R130	Automatic Fixed Interval	1604	0.0106	0.23019	Trapezoid	44.2	1
8	R140	Automatic Fixed Interval	1024.7	0.018709	0.042344	Trapezoid	44.2	1
9	R150	Automatic Fixed Interval	287.28	0.025507	0.75833	Trapezoid	44.2	1

Annex 11. Viga Field Validation Points

This river basin has no field validation data.

Annex 12. Educational Institutions Affected by Flooding in Viga Floodplain

Table A-12.1. Educational institutions in Catanduanes affected by flooding in Viga Floodplain

CATANDUANES				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Almojuela Elementary School	Almojuela	High	High	High
Burgos Elementary School	Burgos	High	High	High
Quezon Elementary School	Quezon			
San Jose Elementary School	Quezon			
San Jose National High School	Quezon	Medium	Medium	High
Day Care	Rizal	Medium	Medium	Medium
Rizal Elementary School	Rizal	Medium	Medium	Medium
Sagrada Day Care Center	Sagrada	Low	Low	Low
Osmeña Day Care Center	San Jose Oco	Medium	High	High
Osmeña Primary School	San Jose Oco	High	High	High
Roxas Elementary School	San Jose Oco			
San Jose Elementary School	San Jose Oco	Medium	Medium	Medium
San Jose National High School	San Jose Oco	Medium	Medium	Medium
Day Care	San Pedro	Medium	Medium	Medium
Day Care Center	San Pedro	Medium	Medium	Medium
Elementary School	San Pedro	Low	Medium	Medium
Sweet Child Learning Center	San Pedro	Medium	Medium	Medium
Viga Central Elementray School	San Pedro	Medium	Medium	Medium
Viga Rural Development	San Pedro	Low	Low	Low
San Vicente Elementary School	San Vicente			
Brgy. Sta. Rosa	Santa Rosa	Medium	Medium	High
Sta. Rosa Elementary School	Santa Rosa			

Annex 13. Health Institutions Affected by Flooding in Viga Floodplain

Table A-12.1. Health institutions in Catanduanes affected by flooding in Viga Floodplain

CATANDUANES				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Dental Clinic	San Pedro	Medium	Medium	Medium
Health Center	San Vicente			Low
San Vicente Viga District Hospital	Santa Rosa		Low	Medium