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

LiDAR Surveys and Flood Mapping of Tambang River

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

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LIST OF ACRONYMS AND ABBREVIATIONS

AAC	Asian Aerospace Corporation
Ab	abutment
ADNU	Ateneo de Naga University
ALTM	Airborne LiDAR Terrain Mapper
ARG	automatic rain gauge
AWLS	Automated Water Level Sensor
BA	Bridge Approach
BM	benchmark
CAD	Computer-Aided Design
CN	Curve Number
CSRS	Chief Science Research Specialist
DA-BSWM	Department of Agriculture - Bureau of Soil and Water Management
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
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 TAMBANG RIVER

Enrico C. Paringit, Dr. Eng. and Ms. Joanaviva Plopenio

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) Grants-in-Aid (GiA) Program. The program was primarily aimed at acquiring a national elevation and resource dataset at sufficient resolution to produce information necessary to support the different phases of disaster management. Particularly, it targeted to operationalize the development of flood hazard models that would produce updated and detailed flood hazard maps for the major river systems in the country.

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

The implementing partner university for the Phil-LiDAR 1 Program is the 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 Tambang River Basin

Tambang River Basin is under the jurisdiction of Lagonoy, Goa and Tinambac towns in Camarines Sur. The first two (2) towns are second class municipalities while Tinambac is a first class municipality. The population of Lagonoy is 55,465, Goa, 63,308 and Tinambac, 67,572. The major stream of this river basin is actually known as Bocogan River and it empties out to the much larger Tambang River. The mouth of the Bocogan River is bordered to the north by a barangay with the same name and to the south with a stand of mangroves. The Tambang River Basin experiences maximum rainfall from November to January and has no dry season under the type II of the modified Corona classification of climate. The DENR River Basin Control Office identified the basin to have a drainage area of 164 km2 and an estimated 222 million cubic meter (MCM) annual run-off (RBCO, 2015).

The Tambang river, also known as Guinatagan river to the locals, is part of the 27 river systems in Bicol Region. According to the 2010 national census of NSO, a total of 6,147 people are residing within the immediate vicinity of the river which is distributed among Barangays Del Carmen and Olas in the Municipality of Lagonoy in Camarines Sur. Lagonoy is the primary municipality wherein the river is located and is the chief supplier of tiger grass to the prominent walis tambo makers of North Luzon and some parts of Central Luzon. (http://america.pink/lagonoy-camarines-sur_2524227.html, 2013) One of the flood events in the area was on November 2006 brought by Typhoon Reming. This caused destruction to a large percent of houses and buildings in the area (http://www.typhoon2000.ph/stormstats/12WorstPhilippineTyphoons.htm).

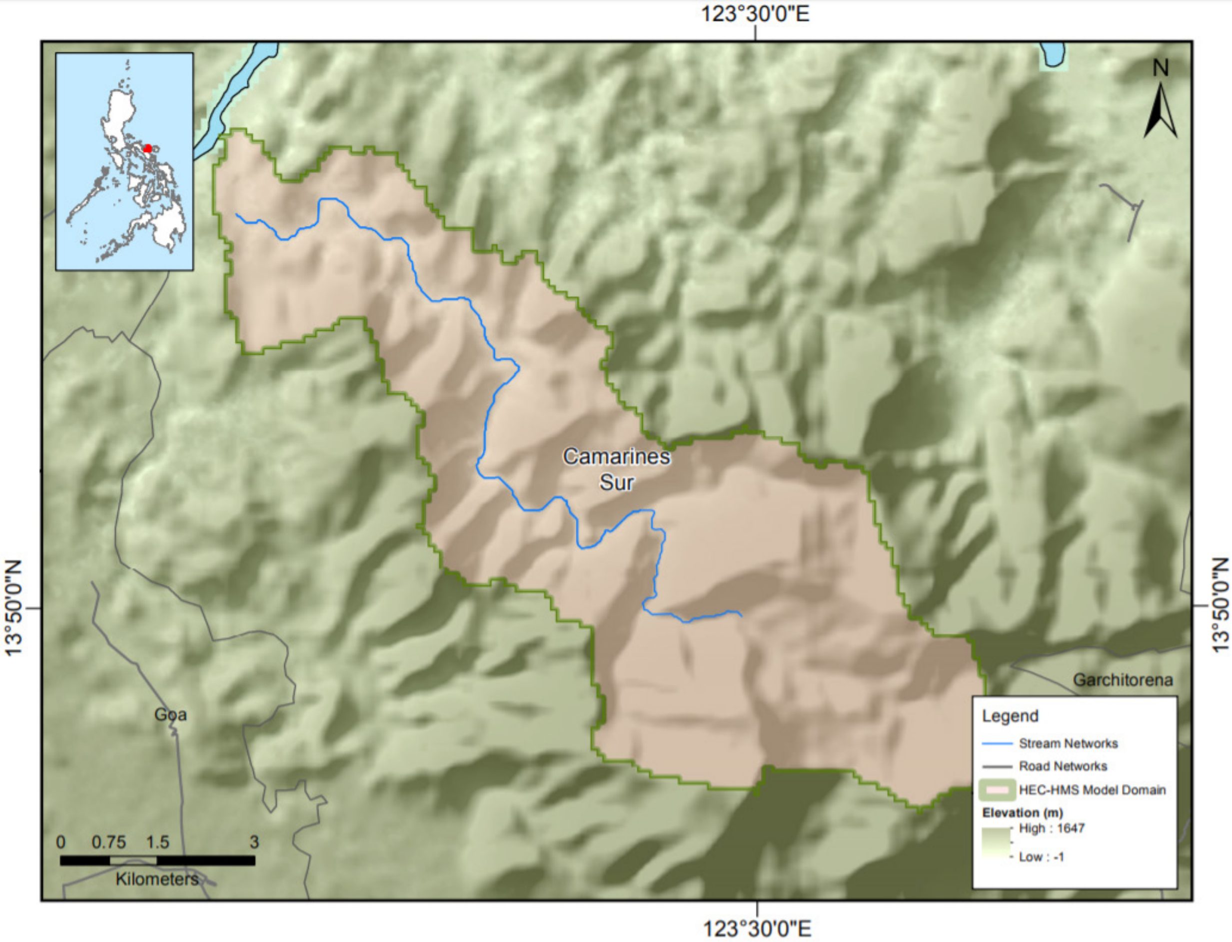

Figure 1. Map of Tambang River Basin (in brown)

Tambang River Basin is bordered to the east and southeast by the low hills and mountains of the Caramoan Peninsula and further south by Mt. Isarog Natural Park. The name Tambang or Tamban is believed to have come from a fish of the same name and known in English as herring or sardine. Some of the folks along the river usually dump their wastes by the riverbanks. The majority of the people by the river are dependent on corn, sugarcane, abaca, coconut, root crops and other fishery and agricultural products. Piggeries and fishponds are also found in the area, although these are just in and near barangay Bocogan which is part of the town of Lagonoy. Tambang Port is also an alternative point of origin for the other coastal towns nearby like Siruma, Garchitorena and Caramoan.

CHAPTER 2: LIDAR DATA ACQUISITION OF THE TAMBANG FLOODPLAIN

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

2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Tambang floodplain in Camarines Sur. These missions were planned for 16 lines that run for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameters for the LiDAR system used in the LiDAR system are found in Table 1. Figure 2 shows the flight plan for Tambang floodplain.

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

Block Name	Flying Height (m AGL)	Overlap (%)	Field of view (ø)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK24A	1000	30	50	200	30	130	5
BLK2B	1000	30	50	200	30	130	5
BLK24C	1000	30	50	200	30	130	5
BLK24E	1000	30	50	200	30	130	5
BLK24F	1000	30	50	200	30	130	5
BLK24G	1000	30	50	200	30	130	5

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

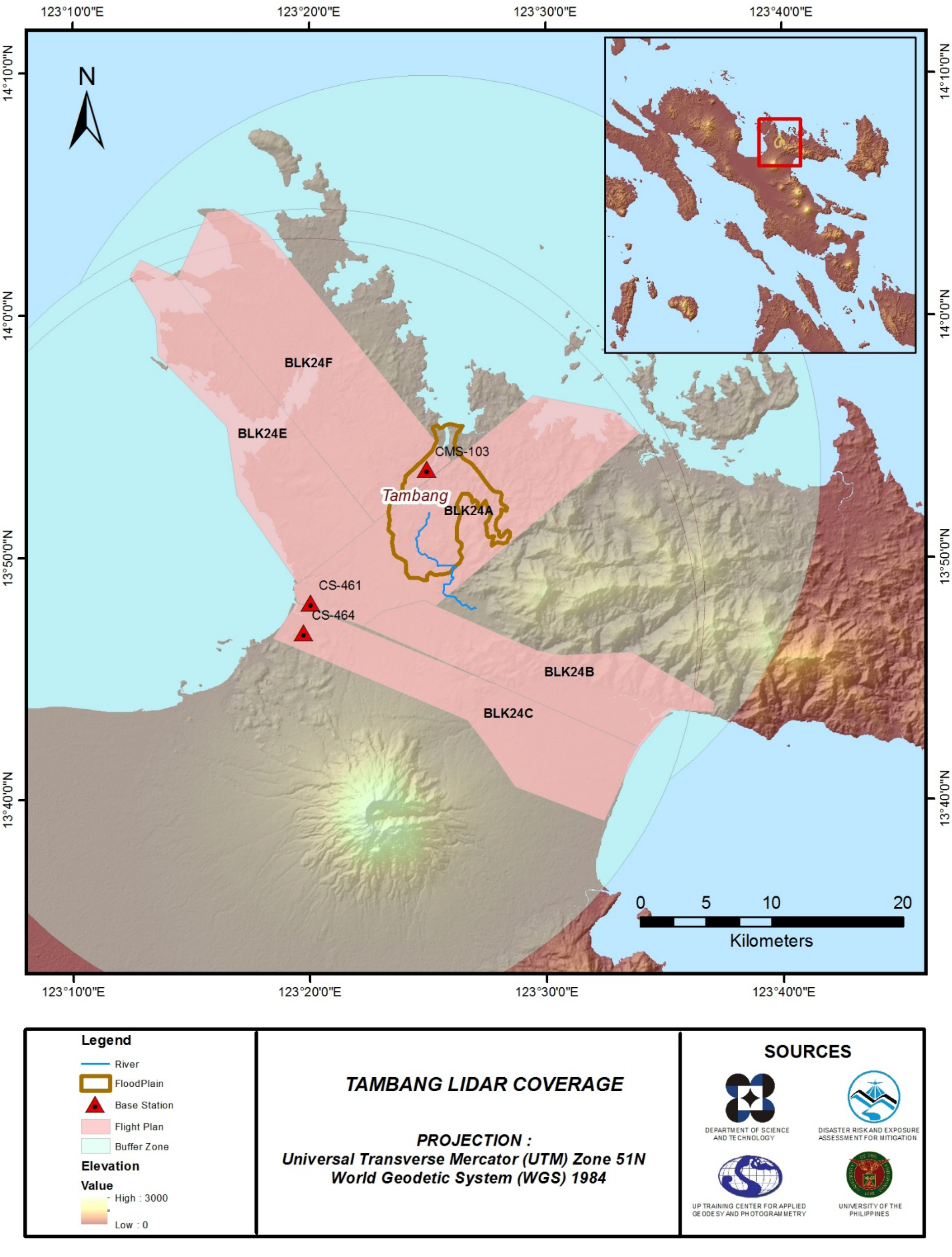
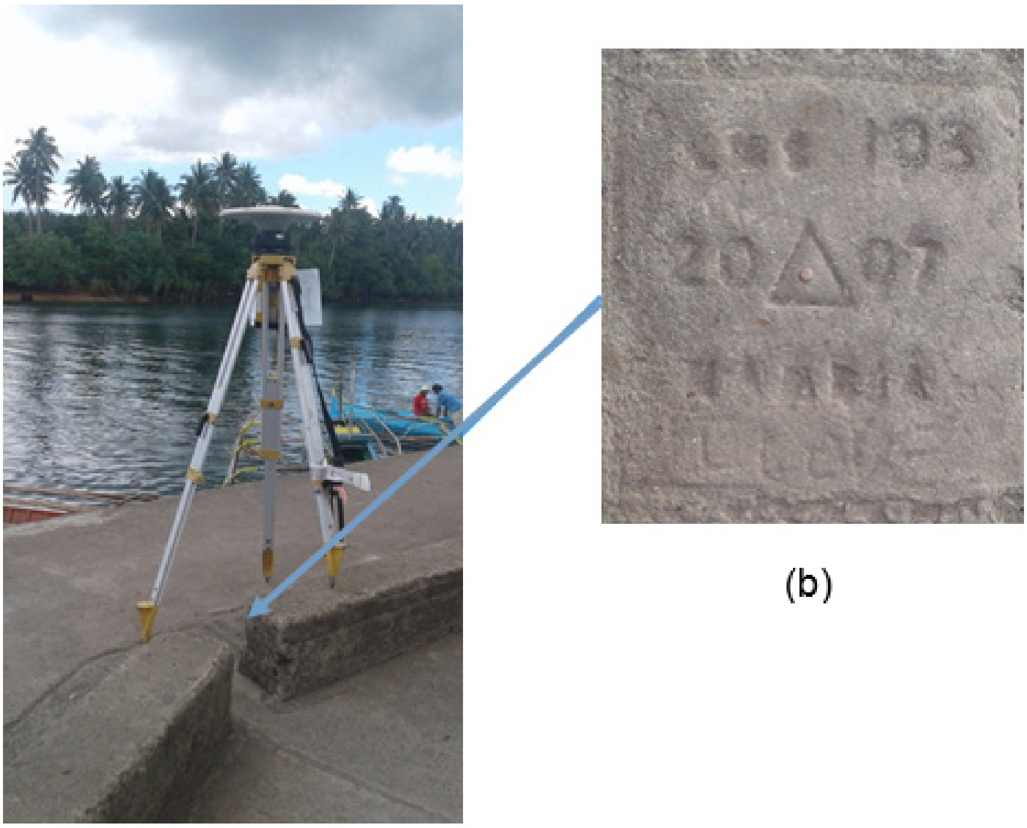


Figure 2. Flight Plan and base station used for the Tambang Floodplain survey.

2.2 Ground Base Stations

The project team was able to recover one (1) NAMRIA ground control point, CMS-103 which is of second (2nd) order accuracy, and two (2) NAMRIA benchmarks, CS-464 and CS-461, which are of first (1st) order accuracy. These benchmarks were used as vertical reference points and were also established as ground control points. The certifications for the NAMRIA reference points are found in Annex B while the baseline processing reports for the established GCPs are found in Annex C. These ground control points were used as base stations during flight operations for the entire duration of the survey (April 22 to May 3, 2016). Base stations were observed using dual frequency GPS receivers, Trimble SPS 852 and SPS 882. Flight plans and location of base stations used during the aerial LiDAR data acquisition in Tambang floodplain are shown in Figure 2.

Figure 3 to Figure 5 show the recovered NAMRIA control station within the area. In addition Table 2 to Table 4 show the details about the following NAMRIA control stations and established points, Table 5 shows the list of all ground control points occupied during the acquisition with the corresponding dates of utilization. The list of team members are found in Annex 4.



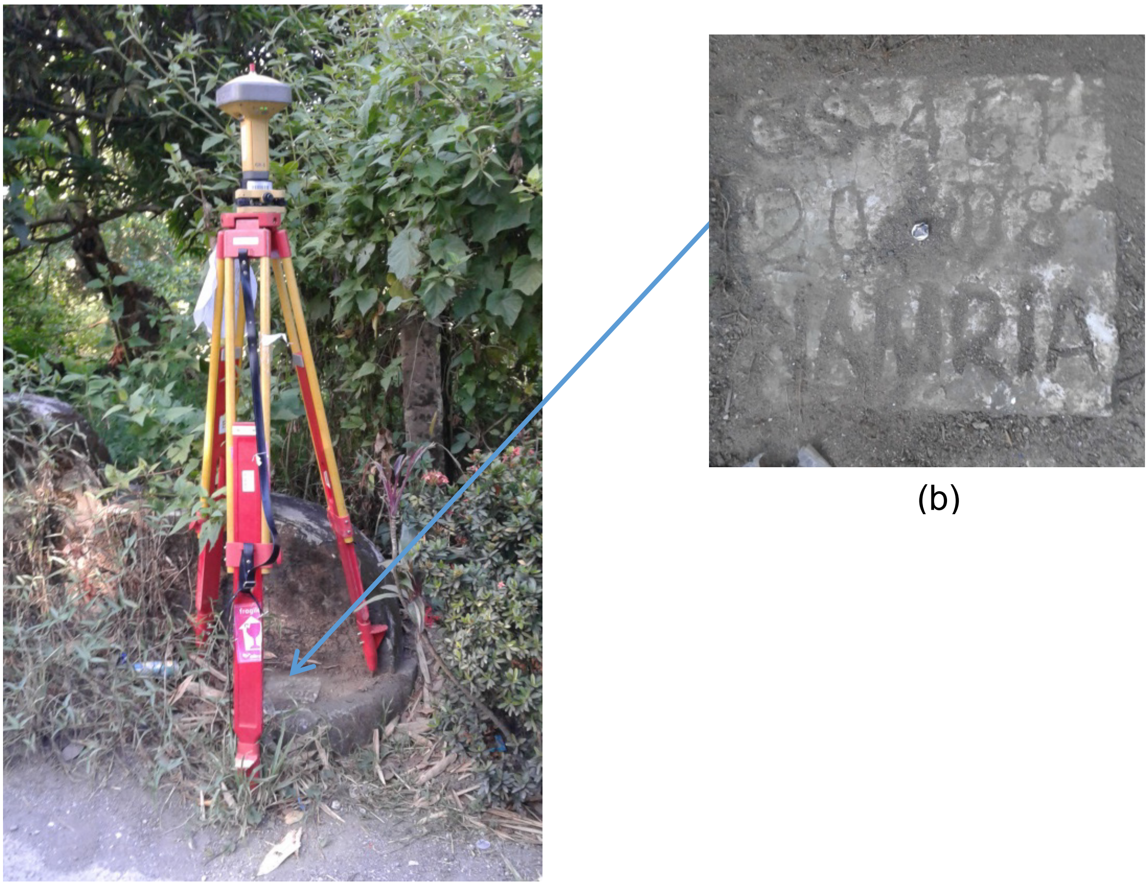
(b)

(a)

Figure 3. GPS set-up (a) over CMS-103 located at Tamban port area on top of the seawall, and NAMRIA reference point CMS-103 (b) as recovered by the field team.

Table 2. Details of the recovered NAMRIA horizontal control point CMS-103 used as base station for the LiDAR data acquisition.

Station Name	CMS-103	
Order of Accuracy	2rd	
Relative Error (Horizontal positioning)	1 : 50,000	
Geographic Coordinates, Philippine Reference 0f 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 53’ 44.46082” North 123° 24’ 52.41074” East 4.58100 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	544805.234 meters 1536671.409 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 53’ 39.40601” North 123° 24’ 557.34955” East 55.99300 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	544,789.55 meters 1,536,133.55 meters



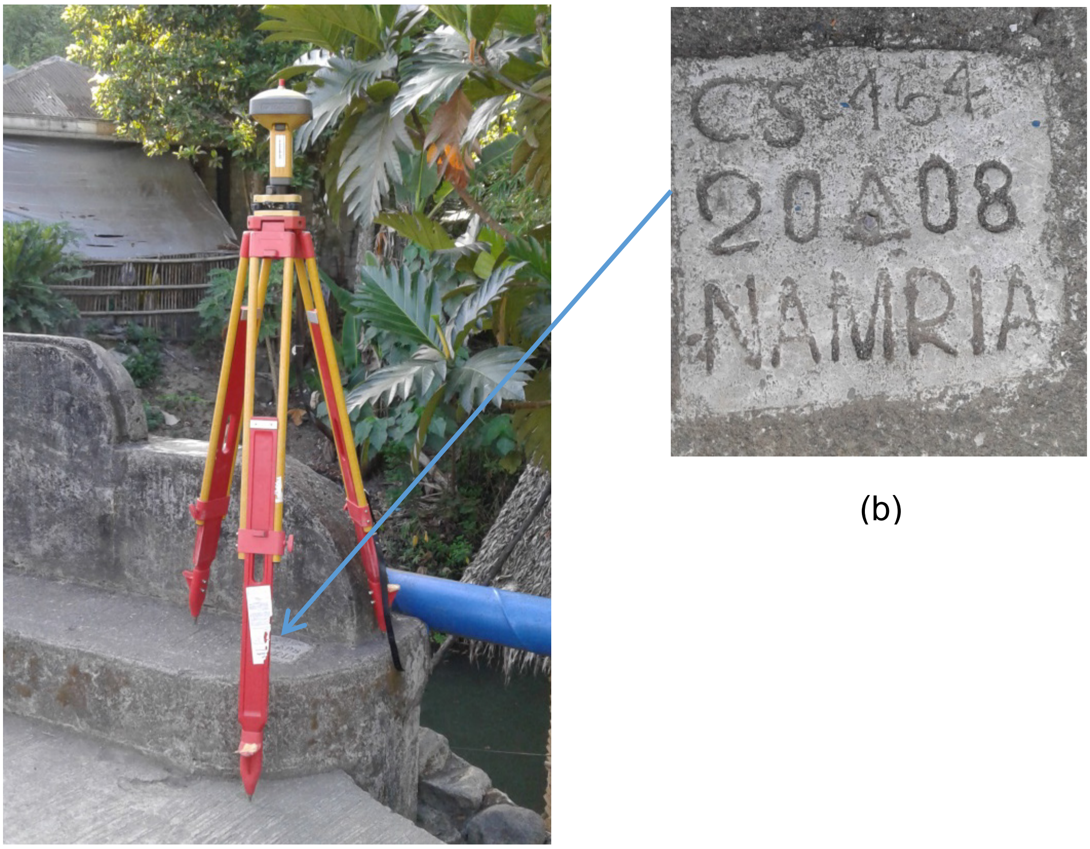
(b)

(a)

Figure 4. GPS set-up (a) over CS-461 located along Tinambac to Calabanga road in Barangay Bolaobalite, Municipality of Tinambac, Province of Camarines Sur, and NAMRIA reference point CS-461 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA vertical control point CS-461 used as base station for the LiDAR data acquisition with established coordinates.

Station Name	**CS-461**	
Order of Accuracy	**2rd**	
Relative Error (Horizontal positioning)	**1 : 50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 48’ 16.97629” North 123° 19’ 59.46340” East 8.314 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 48’ 11.93661” North 123° 20’ 04.41063” East 59.780 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	536011.654 meters 1526059.719 meters



(b)

(a)

Figure 5. GPS set-up (a) over CS-464 located in the Municipality of Mananao, Province of Camarines Sur, and NAMRIA benchmark CS-464 (b) as recovered by the field team.

Table 4. Details of the recovered NAMRIA vertical reference point CS-464 used as base station for the LiDAR data acquisition with established coordinates.

Station Name	CS-464	
Order of Accuracy	2rd	
Relative Error (horizontal positioning)	1 : 50,000	
Elevation	7.478 meters	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 47' 06.64679" North 123° 19' 53.49615" East 8.046 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 47' 01.61166" North 123° 19' 58.44508" East 59.563 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 52N PRS 1992)	Easting Northing	535835.478 meters 11523899.018 meters

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

Date Surveyed	Flight Number	Mission Name	Ground Control Points
22 April 2016	23276P	1BLK24FG113A	CMS-103 & CS-464
23 April 2016	23278P	1BLK24CAF114A	CMS-103 & CS-464
24 April 2016	23282P	1BLK24ASFS115A	CMS-103 & CS-464
26 April 2016	23290P	1BLK24CSE117A	CMS-103 & CS-464
29 April 2016	23302P	1BLK24BES120A	CMS-103 & CS-464
29 April 2016	23304P	1BLK24ESGS120B	CMS-103 & CS-464
2 May 2016	23314P	1BLK24ABCVOIDS123A	CMS-103 & CS-464
3 May 2016	23318P	1BLK24ACF124A	CMS-103 & CS-461

2.3 Flight Missions

Eight (8) missions were conducted to complete LiDAR data acquisition in Tambang floodplain, for a total of 34 hours and 46 minutes (34+46) of flying time for RP-C9122. All missions were acquired using the Pegasus LiDAR system. Table 6 shows the total area of actual coverage per mission with the corresponding flight duration, while Table 7 presents the actual parameters used during the LiDAR data acquisition.

Table 6. Flight missions for the LiDAR data acquisition in Tambang Floodplain.

Date Surveyed	Flight Number	Flight Plan Area (km2)	Surveyed Area (km2)	Area Surveyed within the Floodplain (km2)	Area Surveyed Outside the Floodplain (km2)	Flying Hours	
						Hr	Min
22-Apr-16	23276P	200.69	226.29	8.54	217.75	4	10
23-Apr-16	23278P	183.14	191.52	24.24	167.28	4	5
24-Apr-16	23282P	188.57	327.92	37.23	290.69	4	23
26-Apr-16	23290P	127.15	225.08	0	225.08	4	15
29-Apr-16	23302P	138.17	313.66	0.94	312.72	4	35
29-Apr-16	23304P	200.69	125.47	0	125.47	4	18
2-May-16	23314P	183.14	235.89	13.16	222.73	4	35
3-May-16	23318P	183.14	133.94	15.01	118.93	4	25
TOTAL		**937.19**	**1194.9**	**54.32**	**1140.58**	**3**	**46**

Table 7. Actual parameters used during the LiDAR data acquisition of the Tambang Floodplain.

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (khz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
23276P	700,1000	30	50	200	30	130	5
23278P	600, 1000	30	50	200	30	130	5
23282P	850, 1000	30	50	200	30	130	5
23290P	850, 1000	30	50	200	30	130	5
23302P	800, 1000	30	50	200	30	130	5
23304P	1000	30	50	200	30	130	5
23314P	600, 850	30	50	200	30	130	5
23318P	550, 600, 1000	30	50	200	30	130	5

2.4 Survey Coverage

Tambang floodplain is located in the province of Camarines Sur, with majority of the floodplain situated within the municipality of Lagonoy. The municipalities Siruma, Tinambac, and San Jose are mostly covered by the survey. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 8. The actual coverage of the LiDAR acquisition for Tambang floodplain is presented in Figure 6.

Table 8. List of municipalities and cities surveyed of the Tambang Floodplain LiDAR acquisition.

Province	Municipality/ City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Camarines Sur	Siruma	137.36	136.27	99.20%
	Tinambac	288.53	280.98	97.38%
	San Jose	44.63	43.17	96.73%
	Goa	220.76	164.22	74.38%
	Lagonoy	394.86	234.43	59.37%
	Calabanga	151.49	31.75	20.96%
	Bombon	40.64	3.63	8.94%
	Tigaon	79.34	2.61	3.29%
	Garchitorena	245.52	6.94	2.83%
	Presentacion	160.13	4.45	2.78%
Total		**1,763.26**	**908.45**	**51.52%**

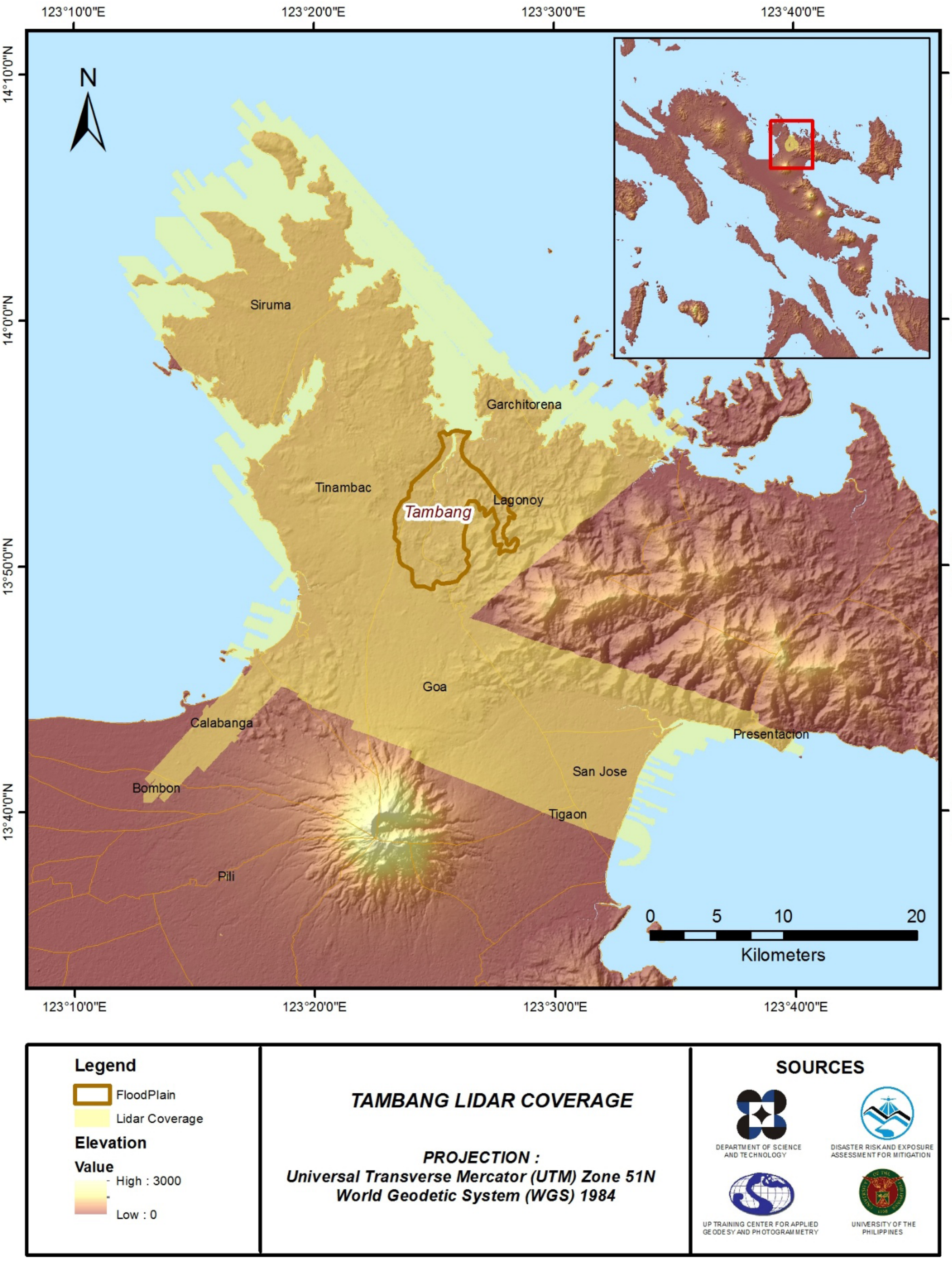


Figure 6. Actual LiDAR survey coverage of the Tambang Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE TAMBANG FLOODPLAIN

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

3.1 Overview of the LiDAR Data Pre-Processing

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

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

These processes are summarized in the flowchart shown in Figure 7.

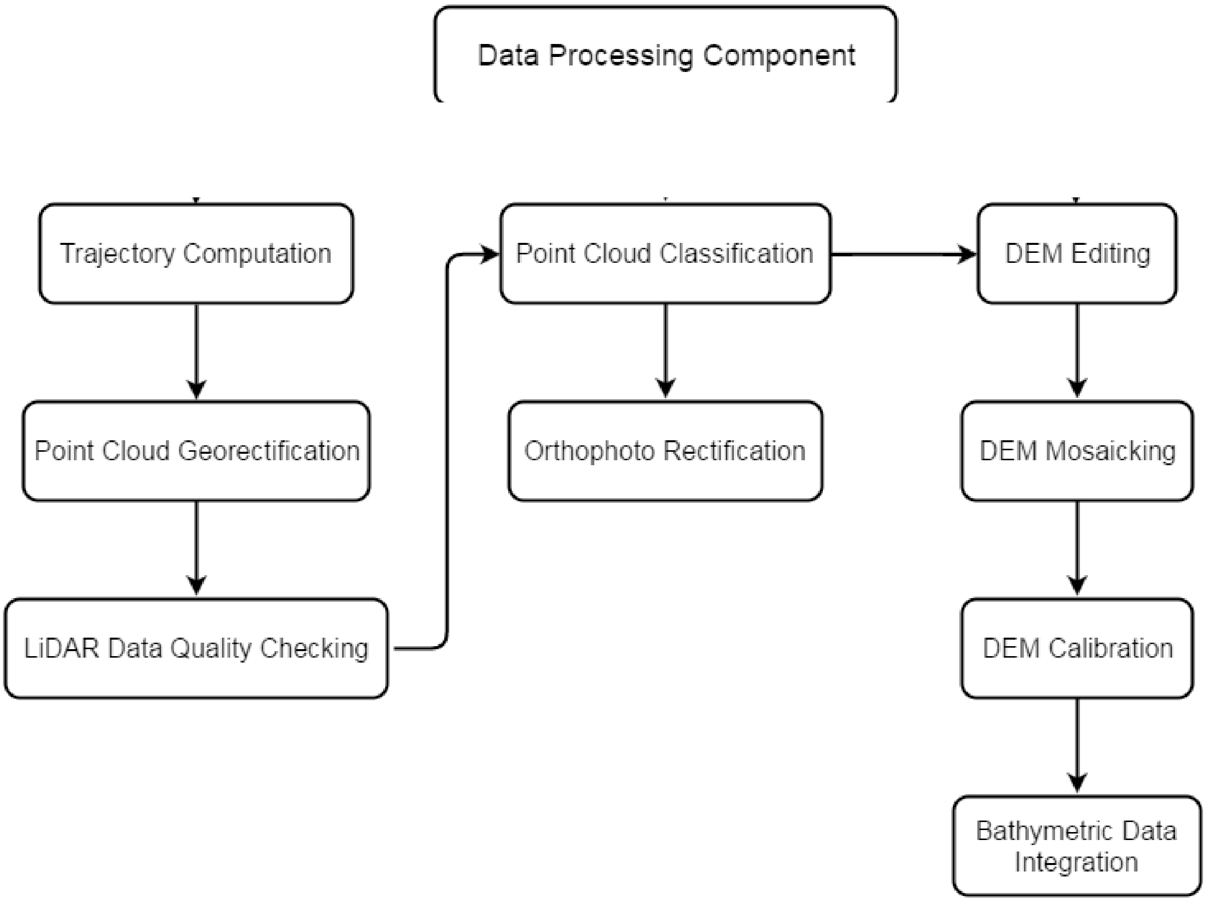

Figure 7. Schematic diagram for Data Pre-Processing Component.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Tambang floodplain can be found in Annex 5. Missions flown during the survey conducted on June 2016 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus system over Tinambac, Lagonoy, Goa, Camarines Sur.

The Data Acquisition Component (DAC) transferred a total of 175.98 Gigabytes of Range data, 2.02 Gigabytes of POS data, 812.9 Megabytes of GPS base station data, and no raw image data to the data server on June 10, 2016. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Tambang was fully transferred on June 10, 2016, as indicated on the Data Transfer Sheets for Tambang floodplain..

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 23278P, one of the Tambang 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 April 23, 2016 00:00AM. The y-axis is the RMSE value for that particular position.

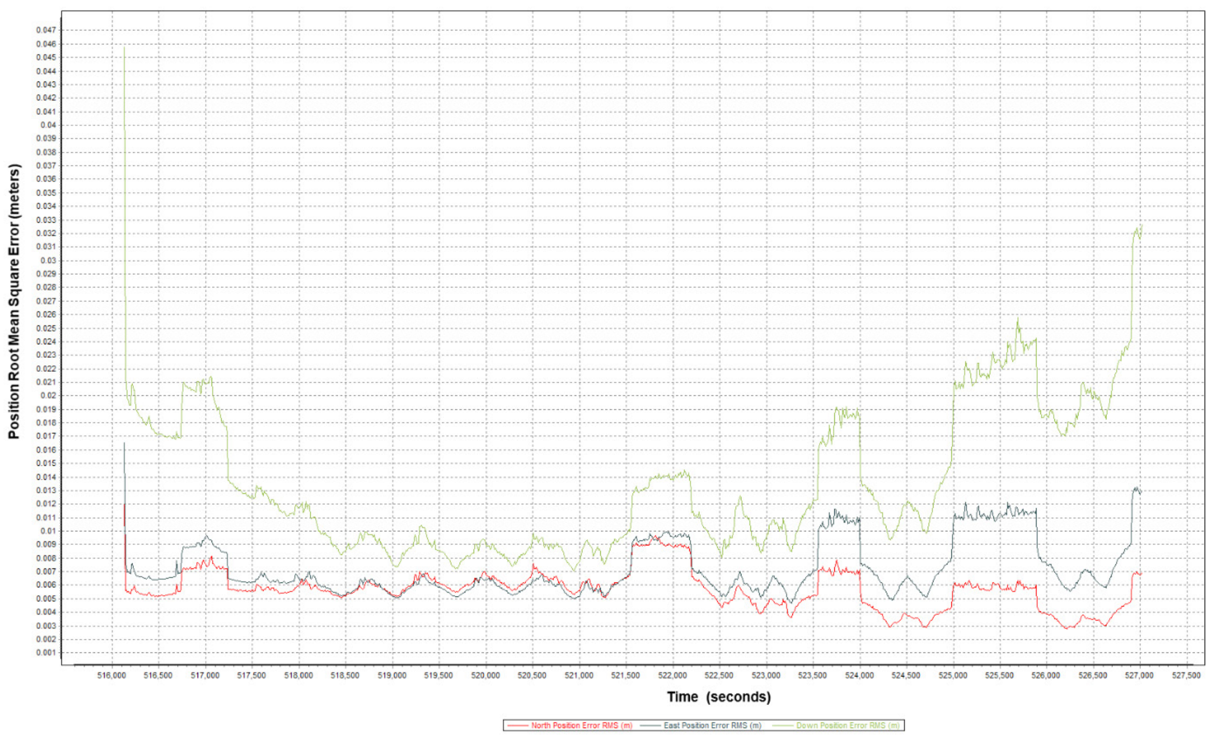

Figure 8. Smoothed Performance Metrics of Tambang Flight 23278P

The time of flight was from 516000 seconds to 527000 seconds, which corresponds to morning of April 23, 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 1.50 centimeters, the East position RMSE peaks at 1. 45 centimeters, and the Down position RMSE peaks at 4.47 centimeters, which are within the prescribed accuracies described in the methodology.

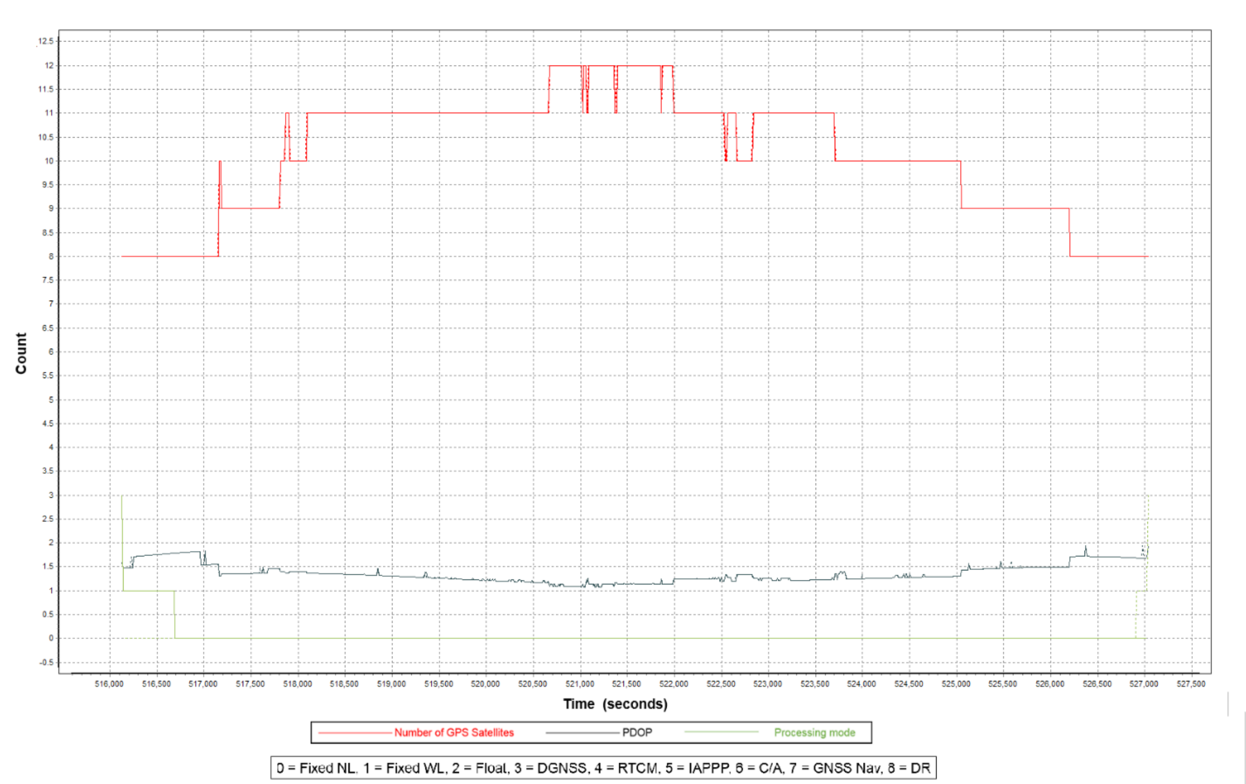

Figure 9. Solution Status Parameters of Tambang Flight 23278P.

The Solution Status parameters of flight 23278P, one of the Tambang 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 8. Majority of the time, the number of satellites tracked was between 8 and 12. The PDOP value also did not go above the value of 2, 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 Tambang flights is shown in Figure 10.

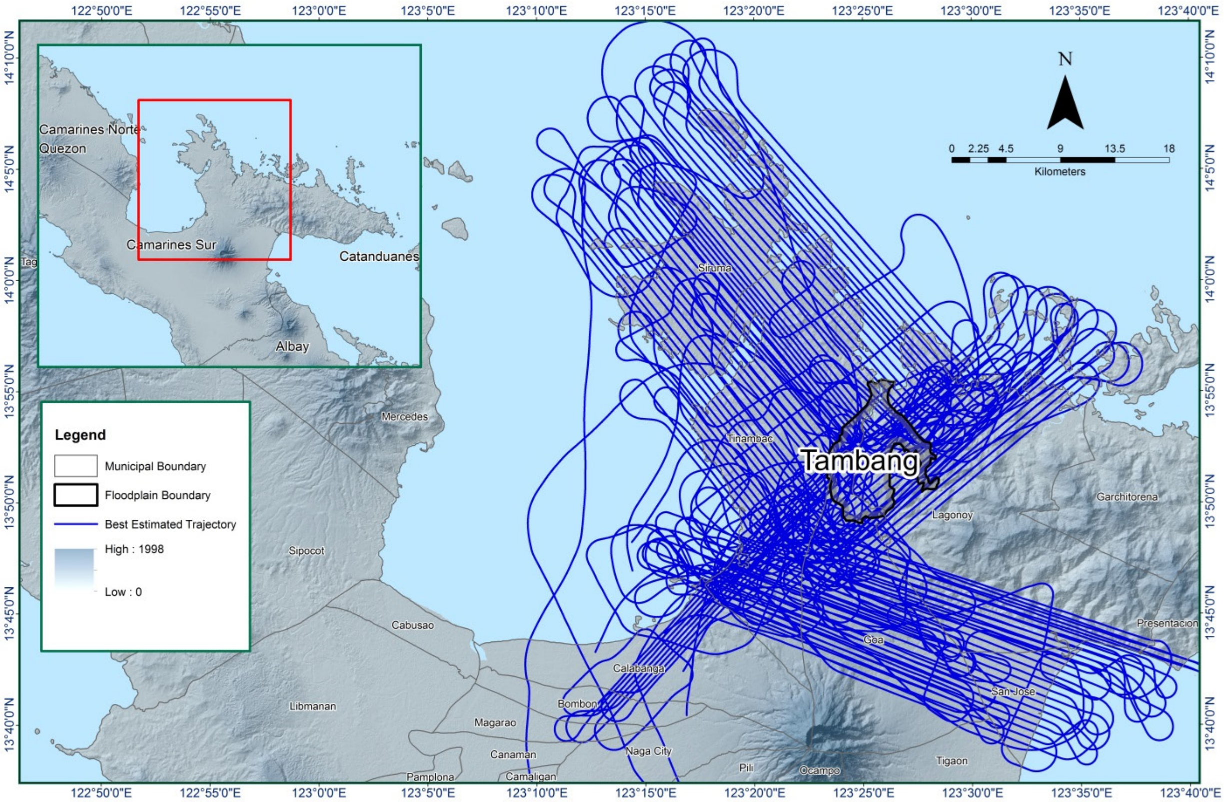

Figure 10. Best Estimated Trajectory of the LiDAR missions conducted over the Tambang Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 176 flight lines, with each flight line containing two channels, since the Pegasus System contains two channels. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Tambang floodplain are given in Table 9.

Table 9 Self-calibration Results values for Tambang flights.

Parameter	Acceptable Value	Computed Value
Boresight Correction stdev	<0.001degrees	0.000181
IMU Attitude Correction Roll and Pitch Correction stdev	<0.001degrees	0.000521
GPS Position Z-correction stdev	<0.01meters	0.0053

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

3.5 LiDAR Data Quality Checking

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

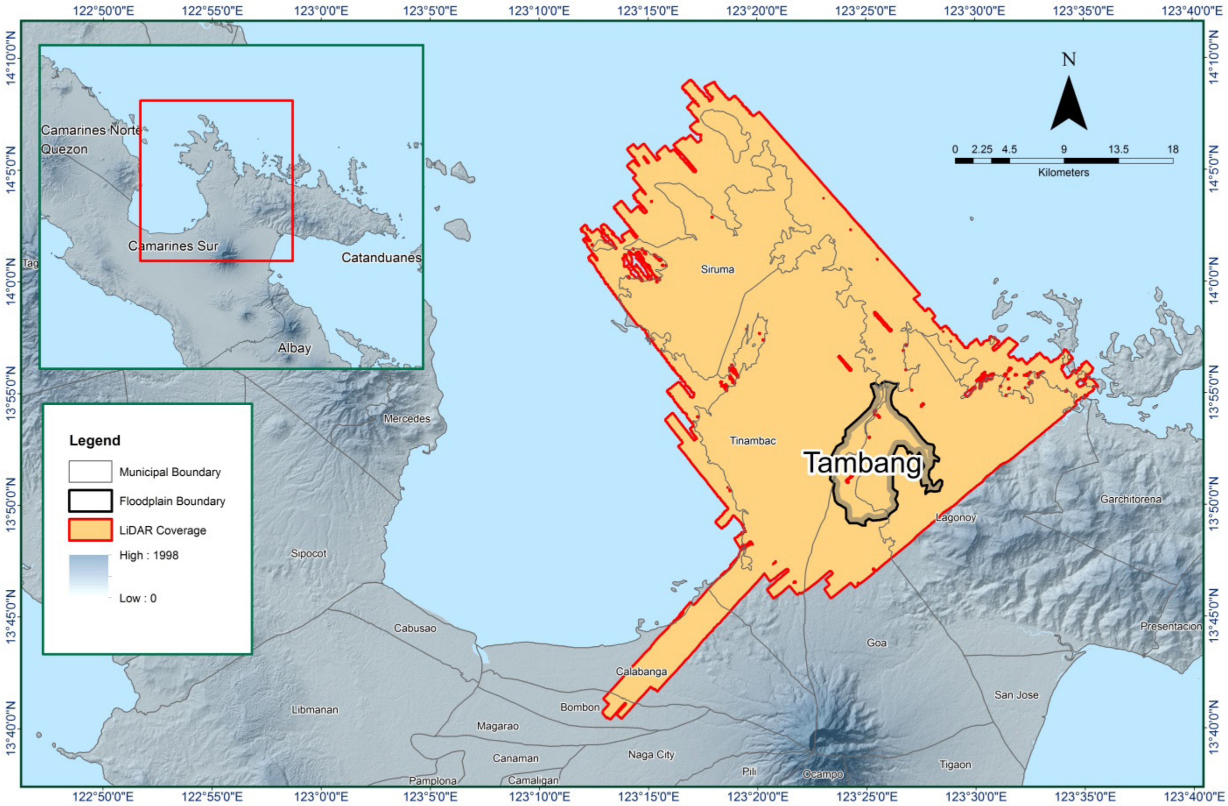

Figure 11. Boundary of the processed LiDAR data over Tambang Floodplain

The total area covered by the Tambang missions is 904.53 sq.km that is comprised of eight (8) flight acquisitions grouped and merged into seven (7) blocks as shown in Table 10.

Table 10. List of LiDAR blocks for Tambang Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Naga_Blk24F	23318P	184.40
	23278P	
Naga_Blk24E	23302P	133.54
Naga_Blk24E_additional	23290P	16.17
Naga_Blk24A_additional	23318P	26.95
Naga_Blk24A	23278P	263.59
	23282P	
	23302P	
	23314P	
	23318P	
Naga_Blk24G_additional	23304P	69.02
Naga_Blk24G	23276P	210.86
	23318P	
TOTAL		**904.53 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 Pegasus system employs two channels, we would expect an average value of 2 (blue) for areas where there is limited overlap, and a value of 3 (yellow) or more (red) for areas with three or more overlapping flight lines.

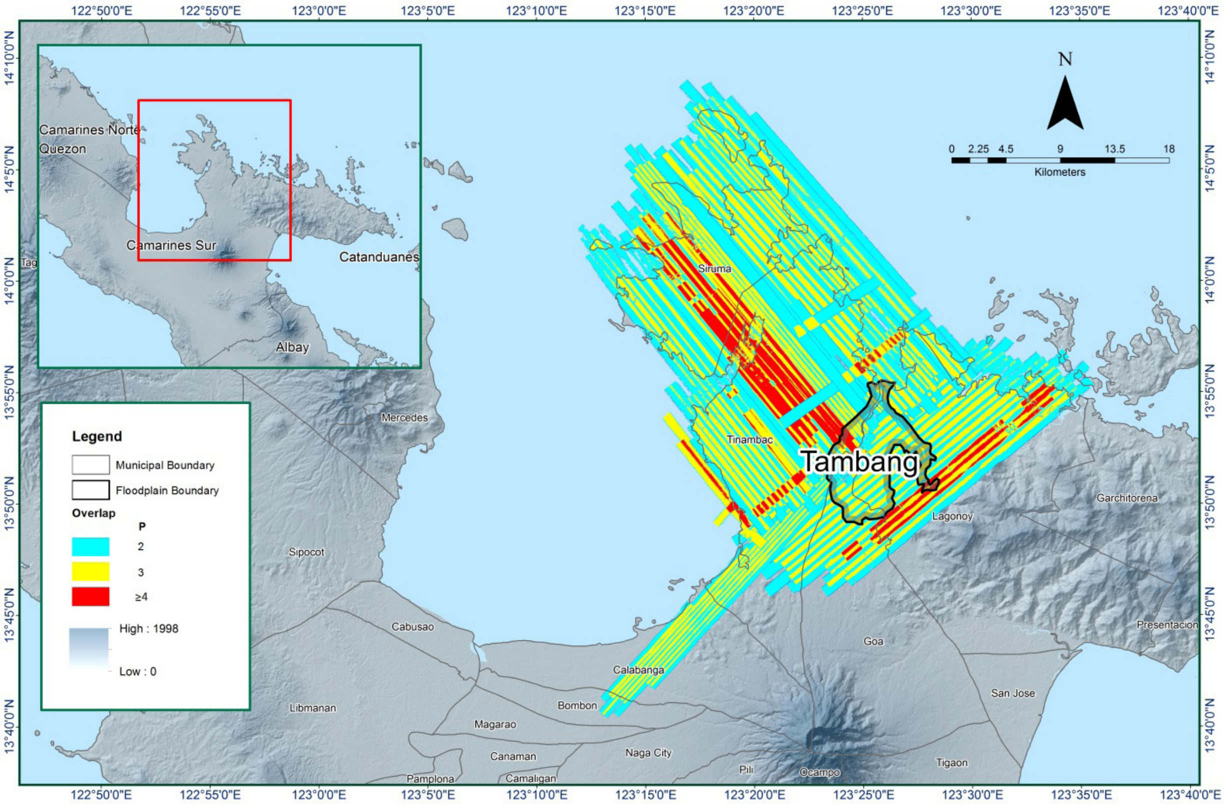

Figure 12. Image of data overlap for Tambang Floodplain.

The overlap statistics per block for the Tambang 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 4.07% and 92.48% respectively, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 13. It was determined that all LiDAR data for Tambang floodplain satisfy the point density requirement, and the average density for the entire survey area is 2.22 points per square meter.

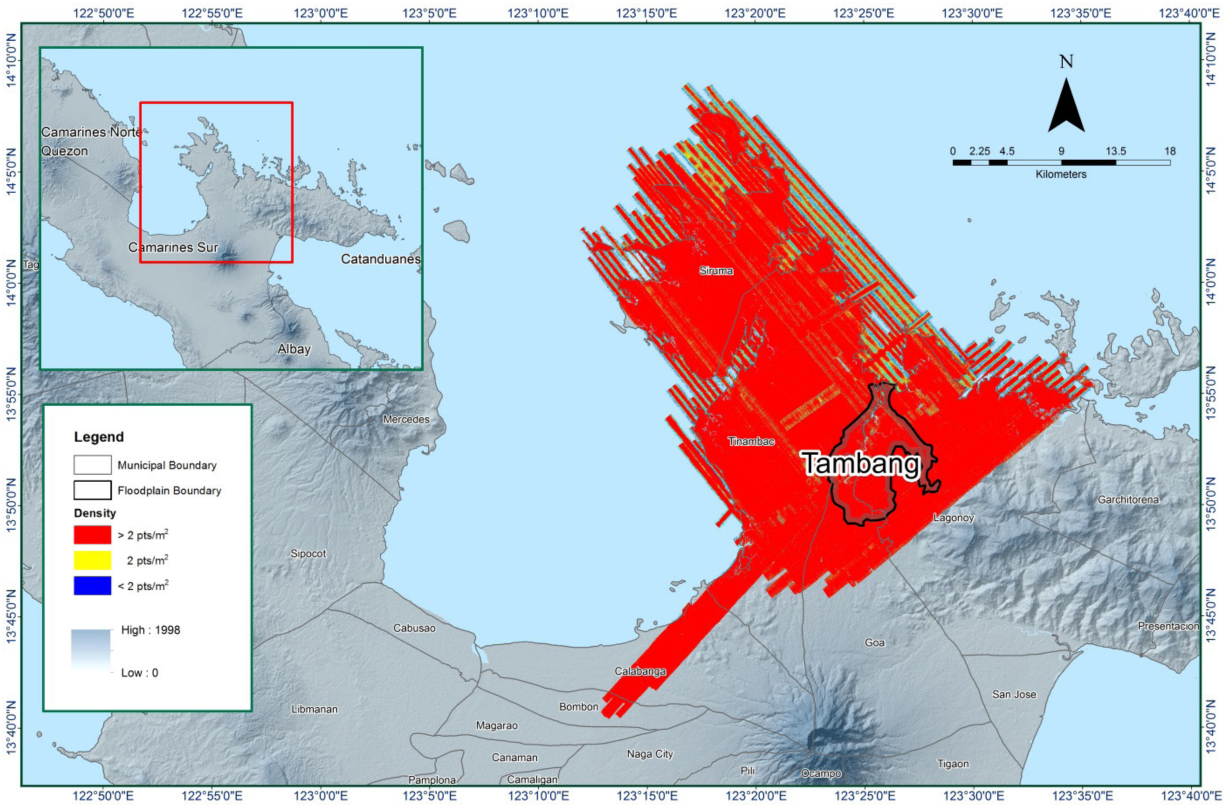

Figure 13. Pulse density map of merged LiDAR data for Tambang Floodplain.

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.

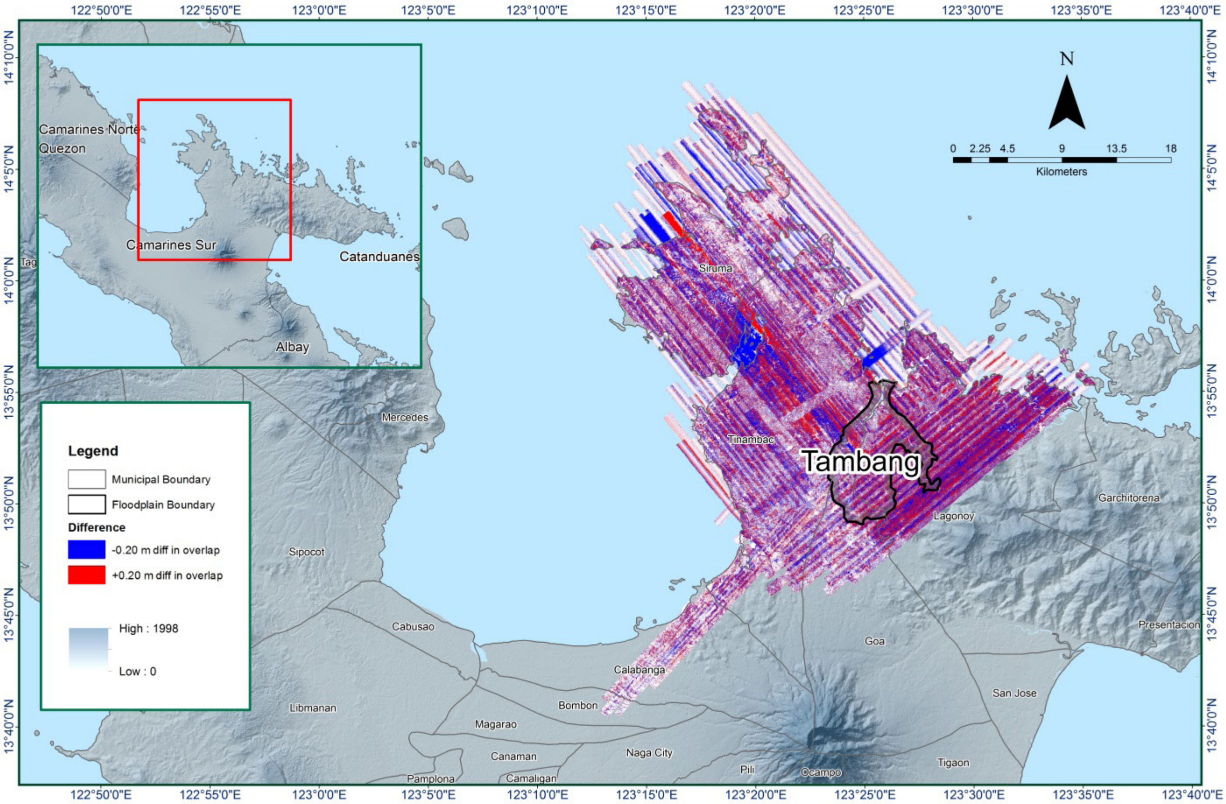

Figure 14. Elevation Difference Map between flight lines for Tambang Floodplain Survey.

A screen capture of the processed LAS data from a Tambang flight 23278P 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.

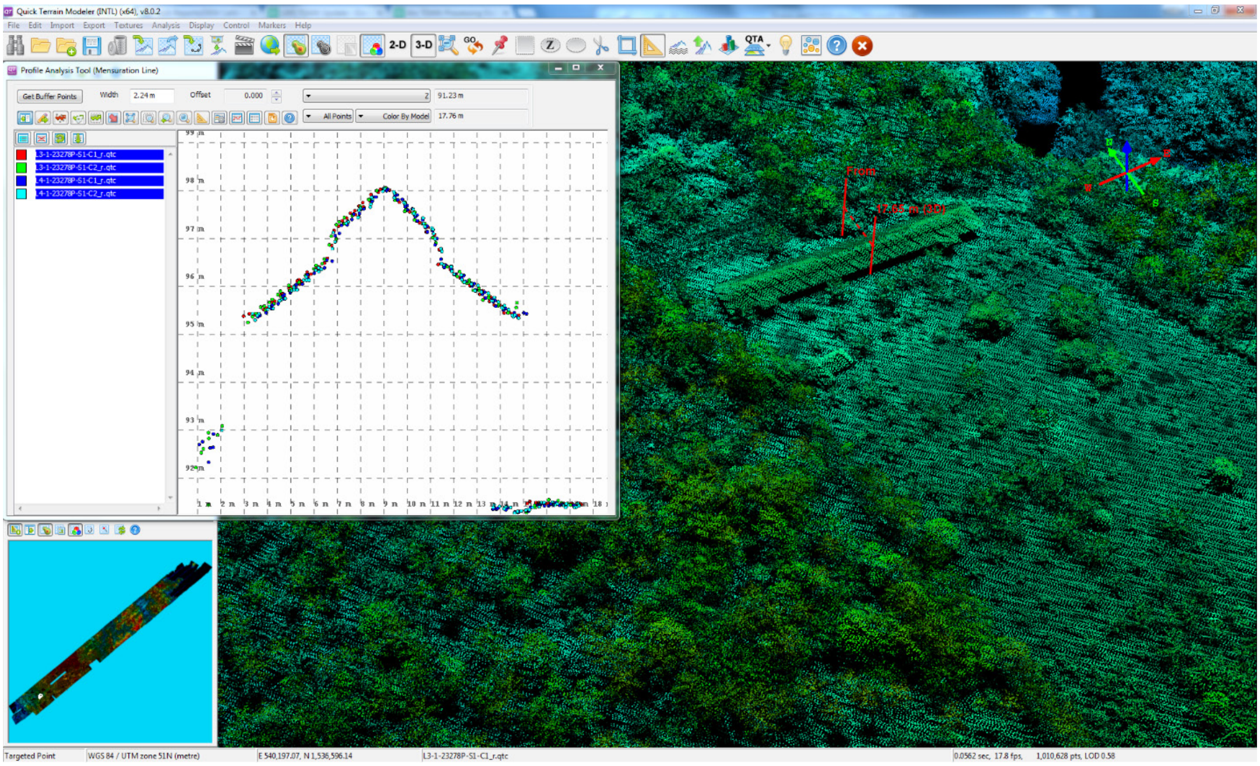

Figure 15. Quality checking for Tambang Flight 23278P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 11. Tambang classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	957,927,487
Low Vegetation	590,132,973
Medium Vegetation	1,347,270,652
High Vegetation	3,415,545,798
Building	49,575,213

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Tambang floodplain is shown in Figure 16. A total of 1,524 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 489.43 meters and 42.35 meters respectively.

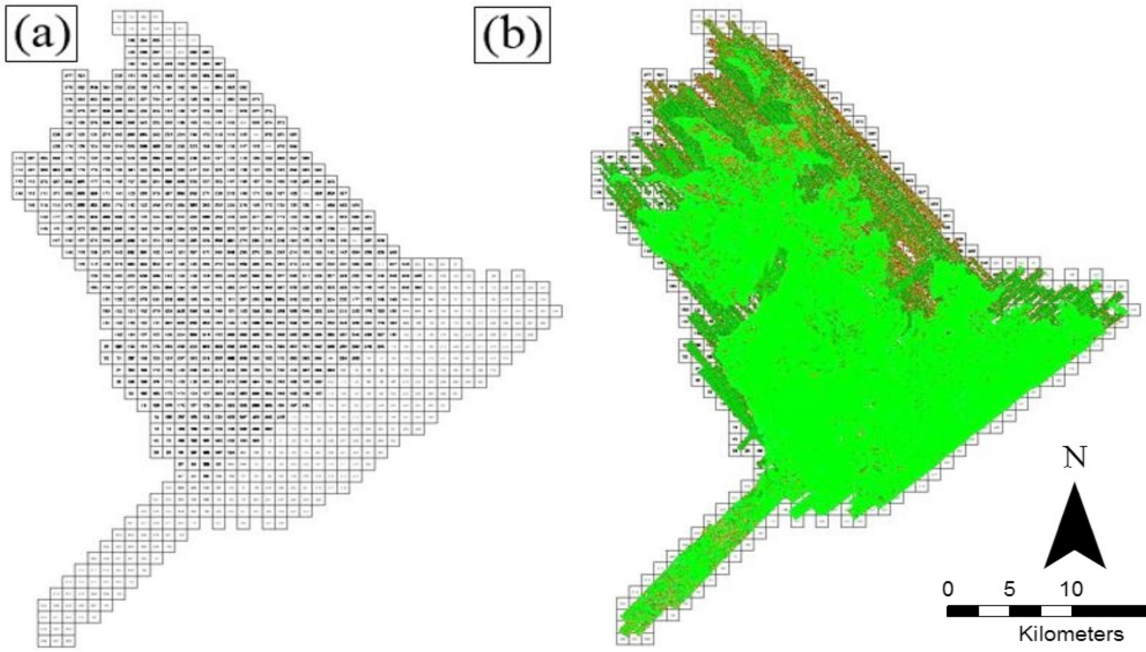

Figure 16. Tiles for Tambang Floodplain (a) and classification results (b) in TerraScan.

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.

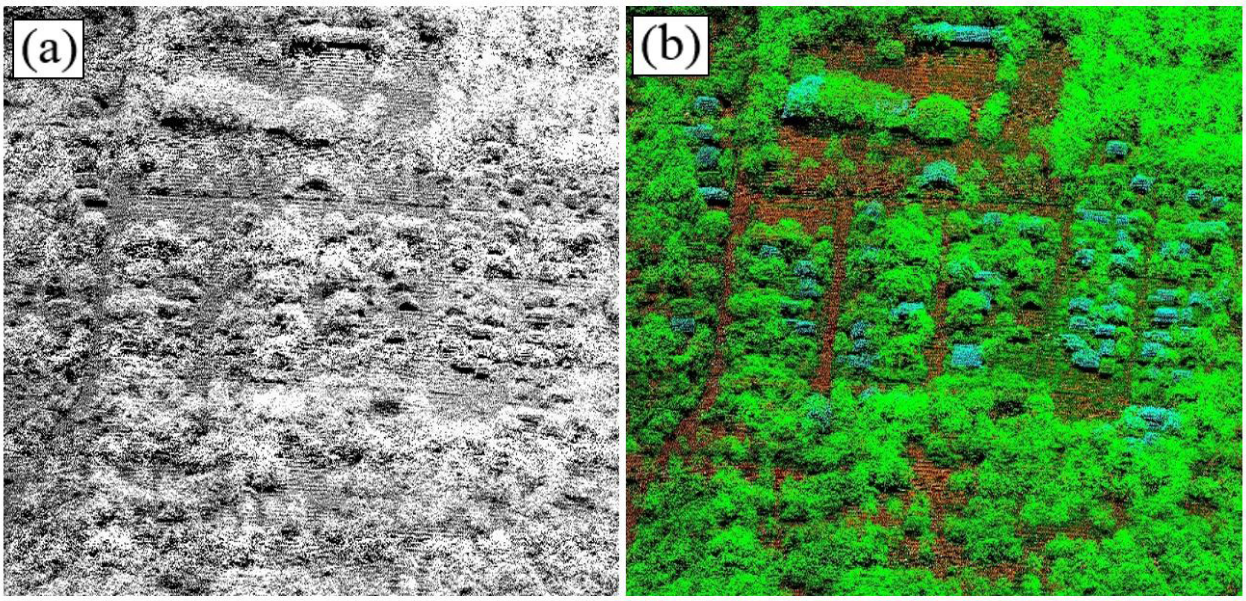

Figure 17. Point cloud before (a) and after (b) classification

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.

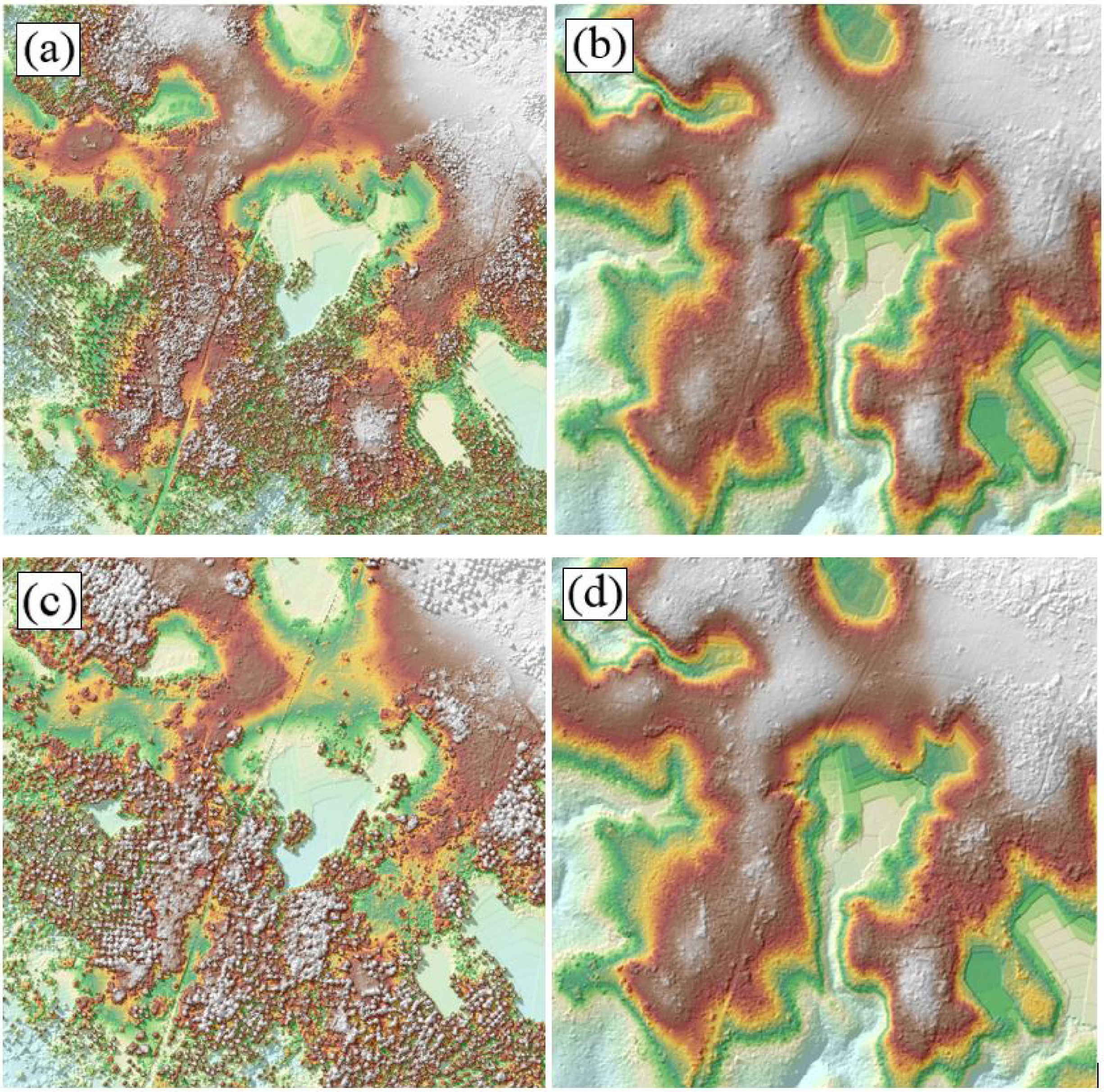

Figure 18. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Tambang Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

There are no available orthophotographs for the Tambang floodplain.

3.8 DEM Editing and Hydro-Correction

Seven (7) mission blocks were processed for Tambang flood plain. These blocks are composed of Naga blocks with a total area of 904.53 square kilometers. Table 12 shows the name and corresponding area of each block in square kilometers.

Table 12. LiDAR blocks with its corresponding areas.

LiDAR Blocks	Area (sq.km)
Naga_Blk24F	184.40
Naga_Blk24E	133.54
Naga_Blk24E_additional	16.17
Naga_Blk24A_additional	26.95
Naga_Blk24A	263.59
Naga_Blk24G_additional	69.02
Naga_Blk24G	210.86
TOTAL	**904.53 sq.km**

Portions of DTM before and after manual editing are shown in Figure 19. It shows that 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 riverbank (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.

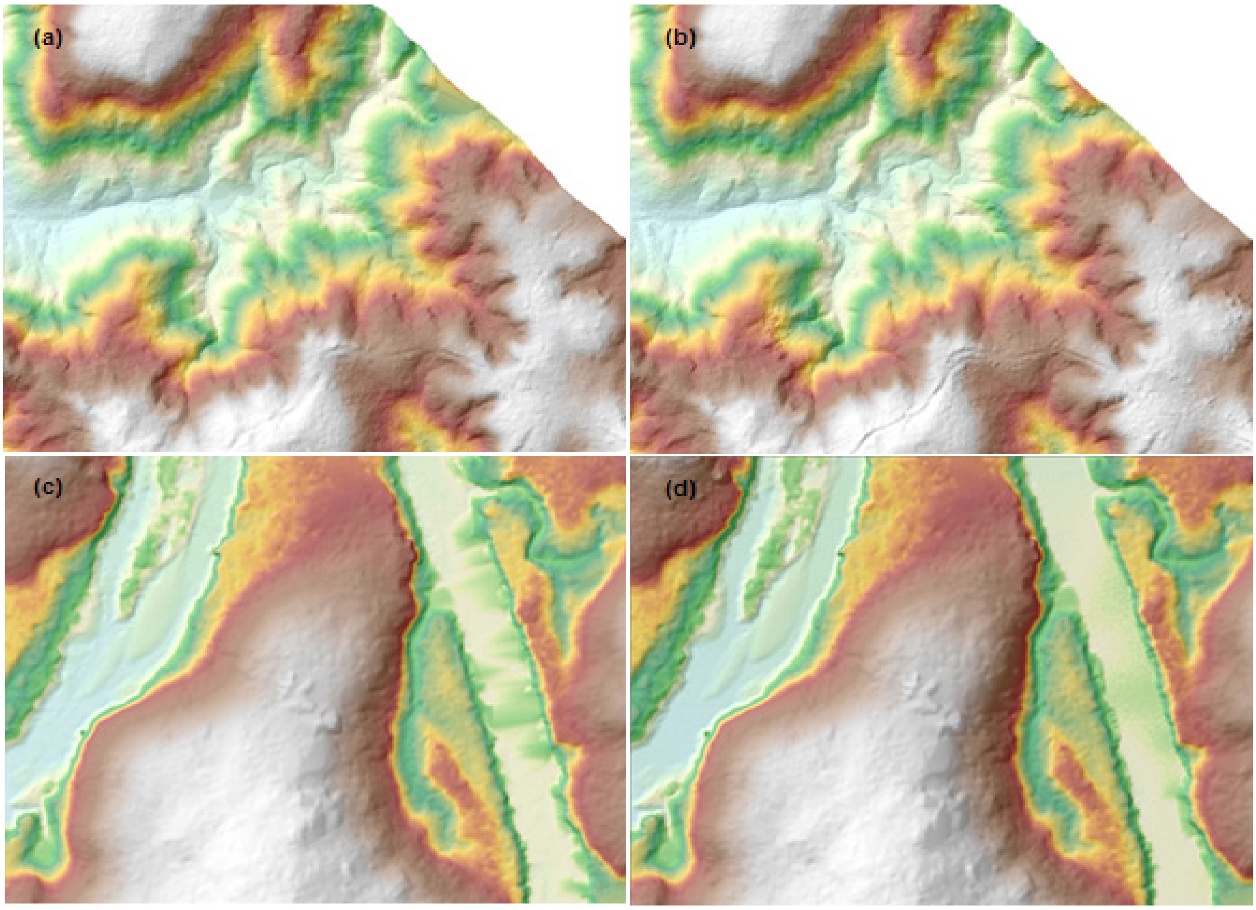

Figure 19. Portions in the DTM of Tambang Floodplain –a mountain ridge before (a) and after (b) data retrieval; a triangulated riverbank before (c) and after (d) manual editing

3.9 Mosaicking of Blocks

Naga_Blk24A was used as the reference block at the start of mosaicking because it is located near the ocean. Table 13 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Tambang floodplain is shown in Figure 20. It can be seen that the entire Tambang floodplain is 99.80% covered by LiDAR data while portions with no LiDAR data were patched with the available IFSAR data.

Table 13. Shift values of each LiDAR block of Tambang Floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
Naga_Blk24F	0.00	0.00	0.08
Naga_Blk24E	1.00	0.00	0.09
Naga_Blk24E_additional	0.00	0.00	-0.09
Naga _Blk24A_additional	0.00	0.00	0.18
Naga_Blk24A	Reference Block		
Naga Blk24G_additional	0.00	0.00	0.25
Naga Blk24G	0.00	0.00	0.08

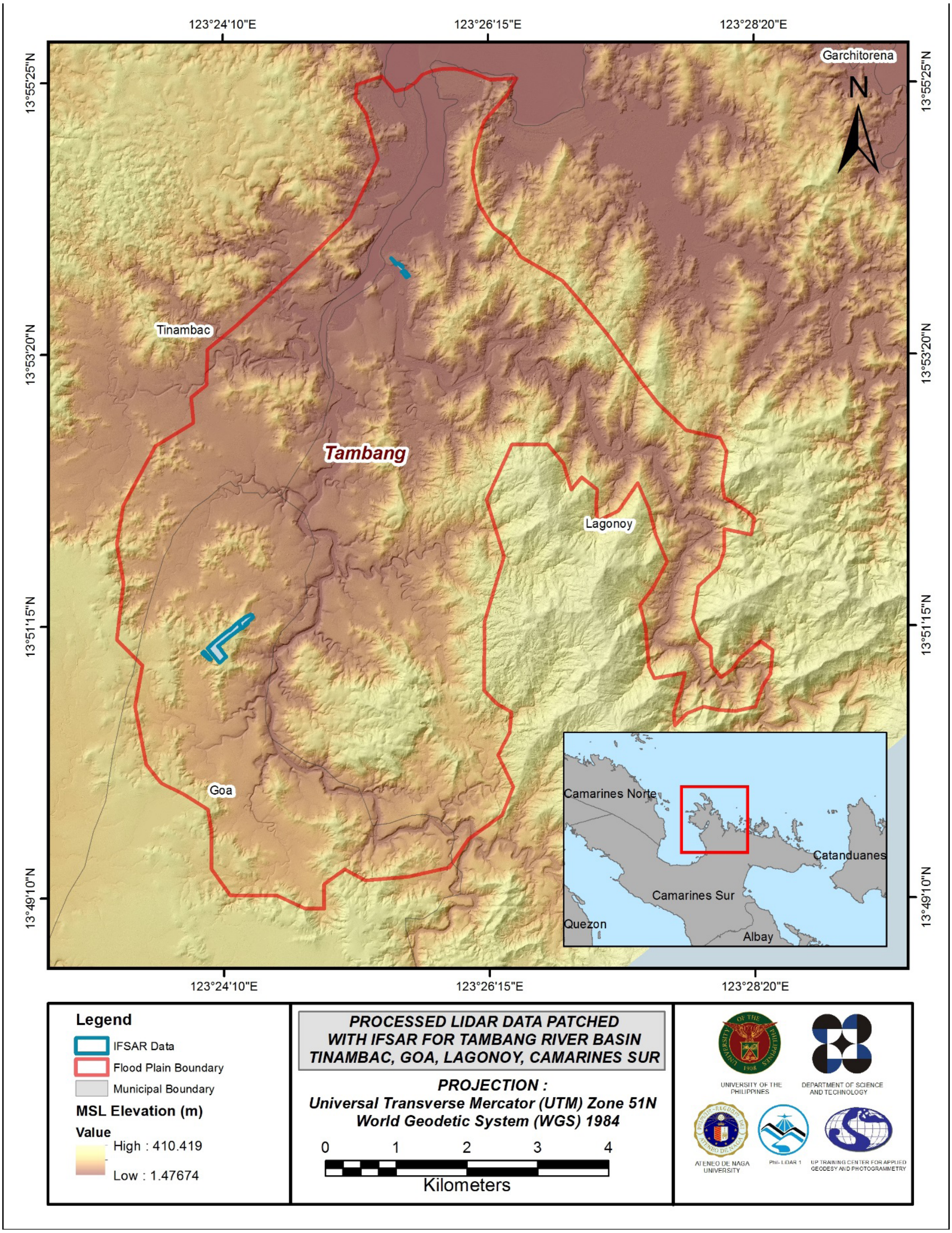

Figure 20. Map of Processed LiDAR Data for Tambang Floodplain

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

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Tambang to collect points with which the LiDAR dataset is validated is shown in Figure 21. A total of 4789 survey points were used for calibration and validation of Tambang LiDAR data. Random selection of 80% of the survey points, resulting to 4310 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 2.67 meters with a standard deviation of 0.09 meters. Calibration of Tambang LiDAR data was done by subtracting the height difference value, 2.67 meters, to Tambang mosaicked LiDAR data. Table 14 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

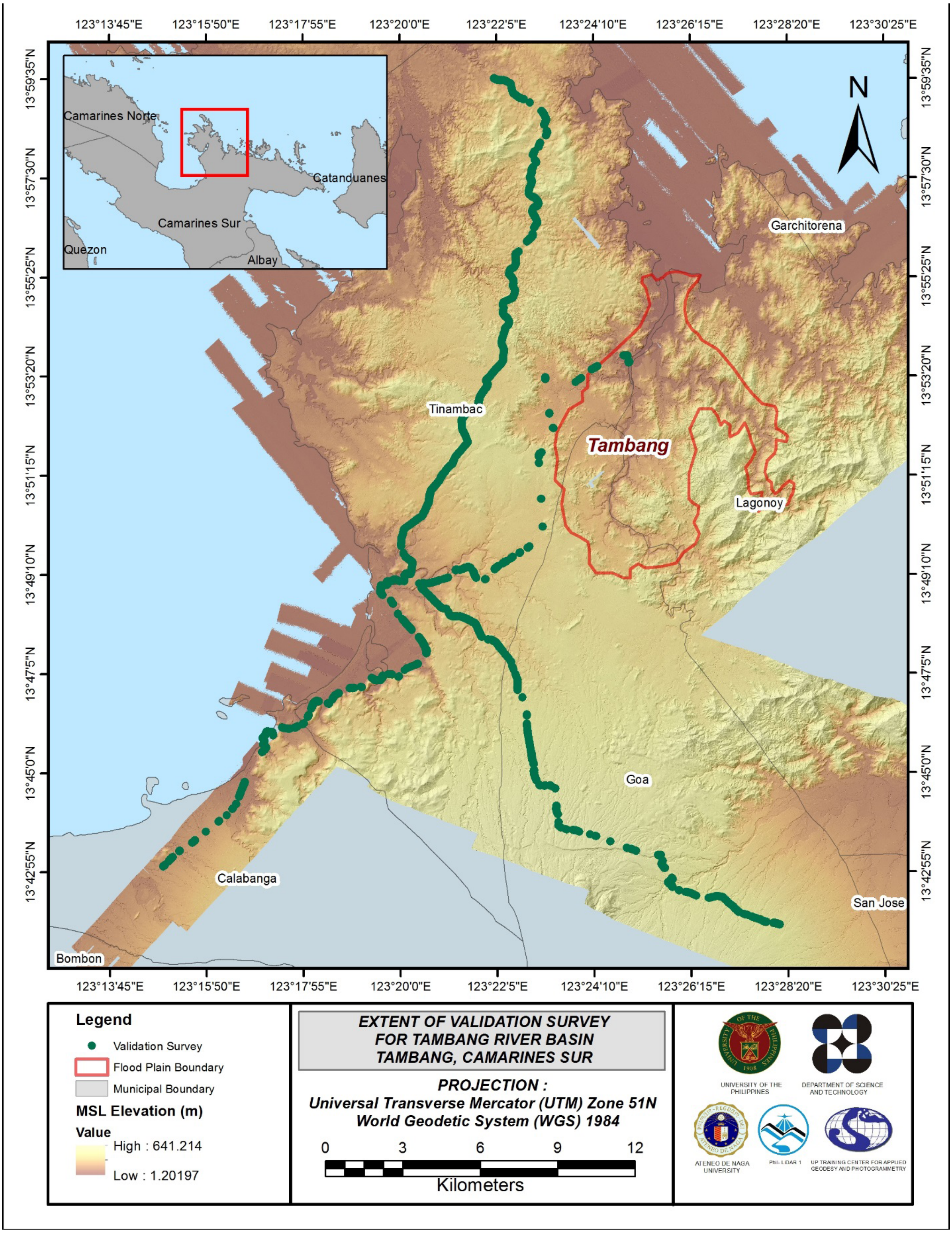

Figure 21. Map of Tambang Floodplain with validation survey points in green.

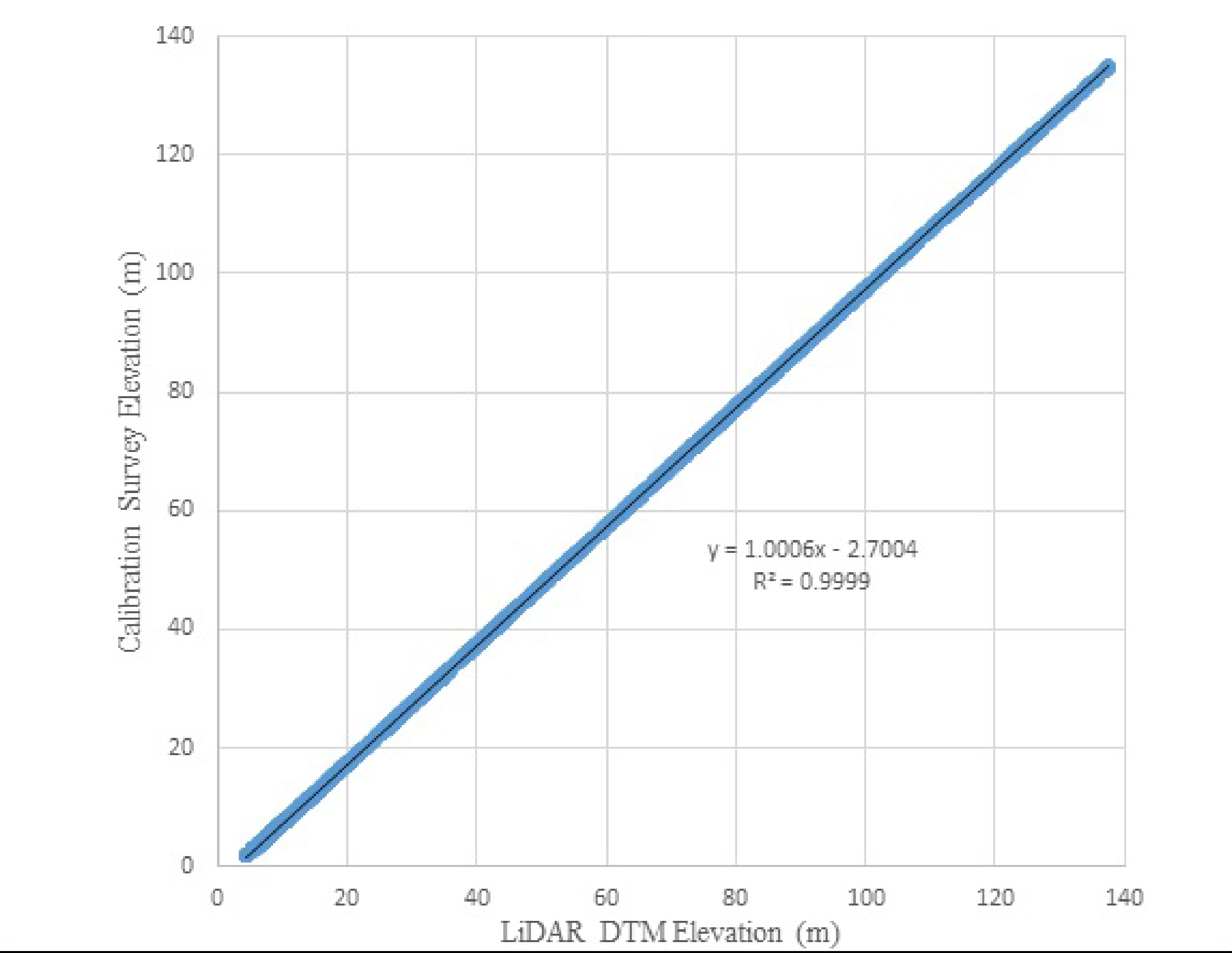

Figure 22. Correlation plot between calibration survey points and LiDAR data.

Table 14. Calibration Statistical Measures

Calibration Statistical Measures	Value (meters)
Height Difference	2.67
Standard Deviation	0.09
Average	-2.66
Minimum	-2.84
Maximum	-2.49

The remaining 20% of the total survey points, resulting to 22 points, were used for the validation of calibrated Tambang 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 0.10 meters with a standard deviation of 0.07 meters, as shown in Table 15.

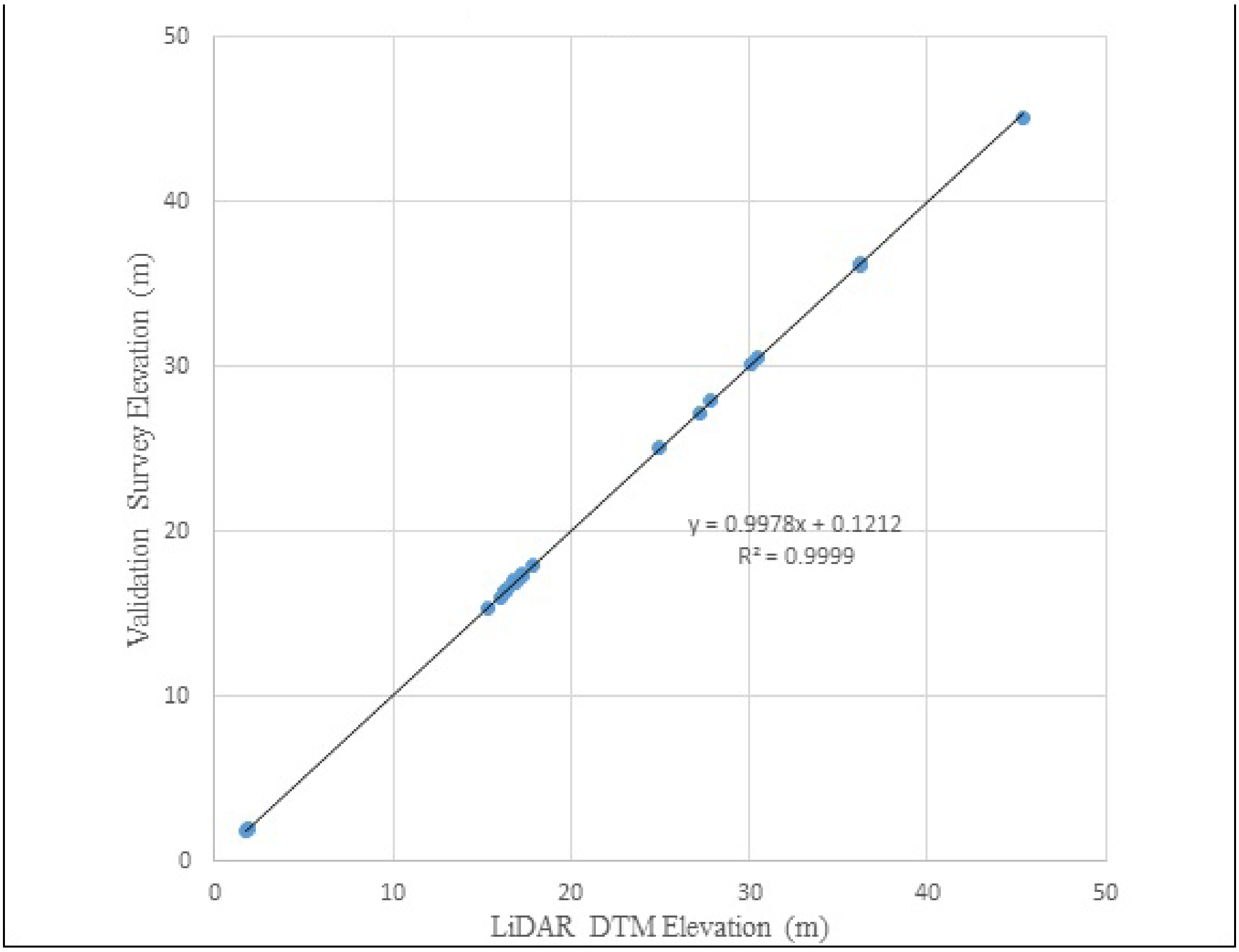

Figure 23. Correlation plot between validation survey points and LiDAR data.

Table 15. Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.10
Standard Deviation	0.07
Average	0.07
Minimum	-0.07
Maximum	0.22

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and zigzag data was available for Tambang with 14,257 bathymetric survey points. The resulting raster surface produced was done by Inverse Distance Weighted (IDW) interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.02 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Tambang integrated with the processed LiDAR DEM is shown in Figure 24.

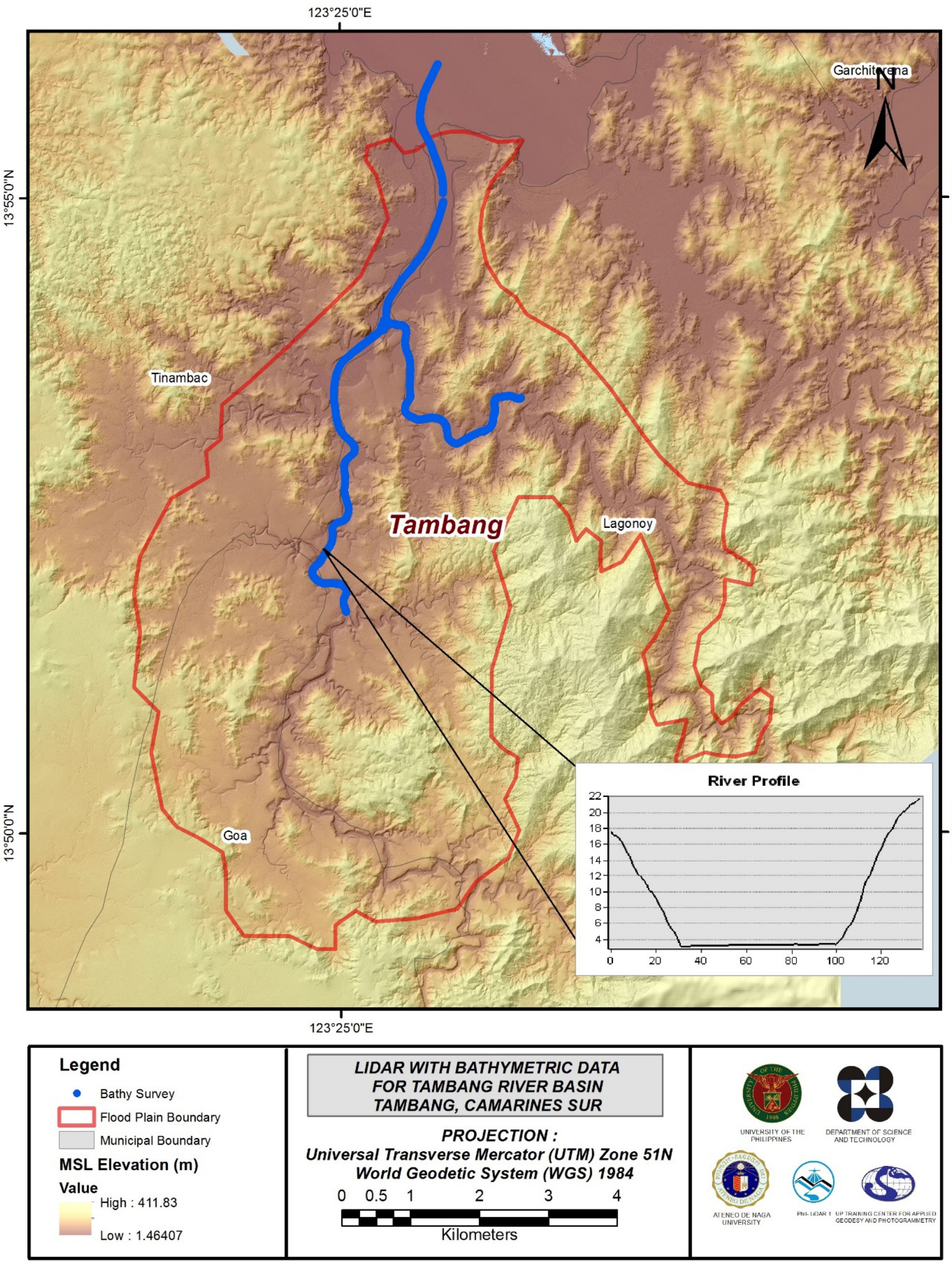

Figure 24. Map of Tambang Floodplain with bathymetric survey points shown in blue.

3.12 Feature Extraction

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

3.12.1 Quality Checking of Digitized Features' Boundary

Tambang floodplain, including its 200 m buffer, has a total area of 63.96 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 481 building features, are considered for QC. Figure 25 shows the QC blocks for Tambang floodplain.

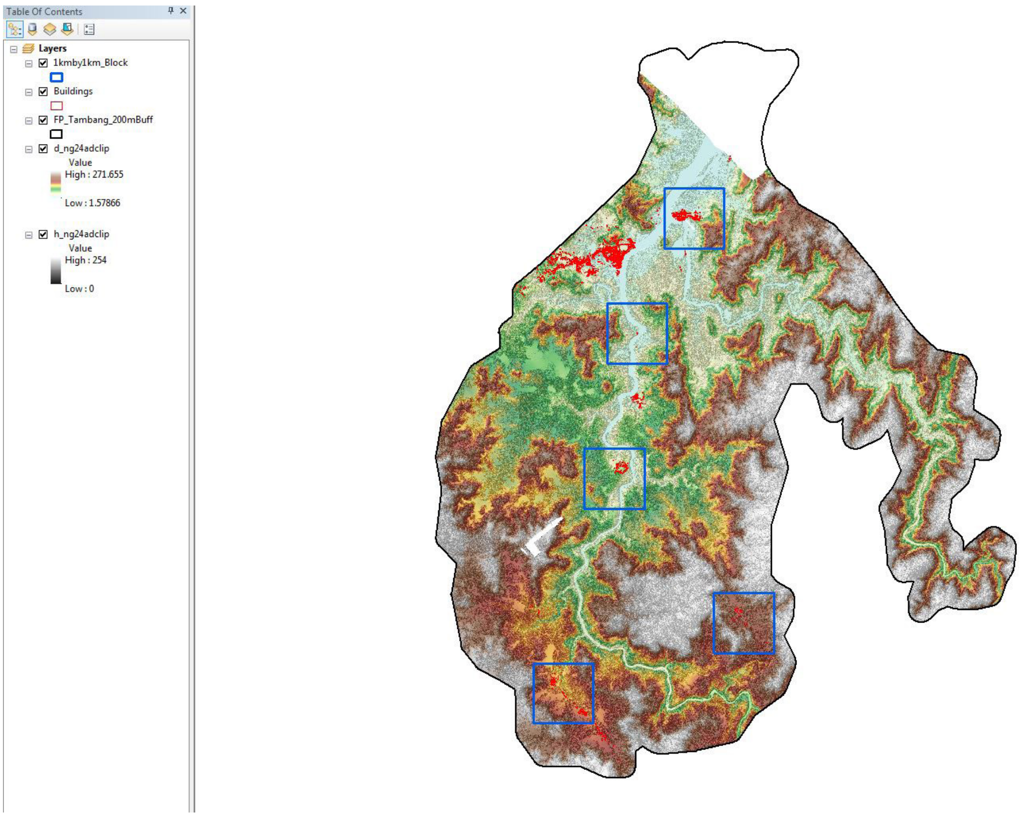

Figure 25. Blocks (in blue) of Tambang building features subjected to QC

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

Table 16. Quality Checking Ratings for Tambang Building Features

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Tambang	97.76	100	82.95	PASSED

3.12.2 Height Extraction

Height extraction was done for 2,014 building features in Tambang floodplain. Of these building features, 9 was filtered out after height extraction, resulting to 2,005 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 9.06 m.

3.12.3 Feature Attribution

Feature Attribution was done for 2,005 building features in Tambang 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] 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 Tambang Floodplain.

Facility Type	No. of Features
Residential	1917
School	12
Market	36
Agricultural/Agro-Industrial Facili-ties	0
Medical Institutions	4
Barangay Hall	3
Military Institution	0
Sports Cen-ter/Gymnasium/Covered Court	0
Telecommunication Facilities	0
Transport Terminal	4
Warehouse	5
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	0
Water Supply/Sewerage	0
Religious Institutions	10
Bank	0
Factory	0
Gas Station	0
Fire Station	0
Other Government Offices	1
Other Commercial Establishments	12
Demolished Building	0
New Building	1
Total	**2005**

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

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Tambang	11.1	0	6.95	0	0	18.04579

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

Floodplain	Water Body Type					Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Tambang	1	5	0	0	0	6

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

3.12.4 Final Quality Checking of Extracted Features

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

Figure 26 shows the Digital Surface Model (DSM) of Tambang floodplain overlaid with its ground features.

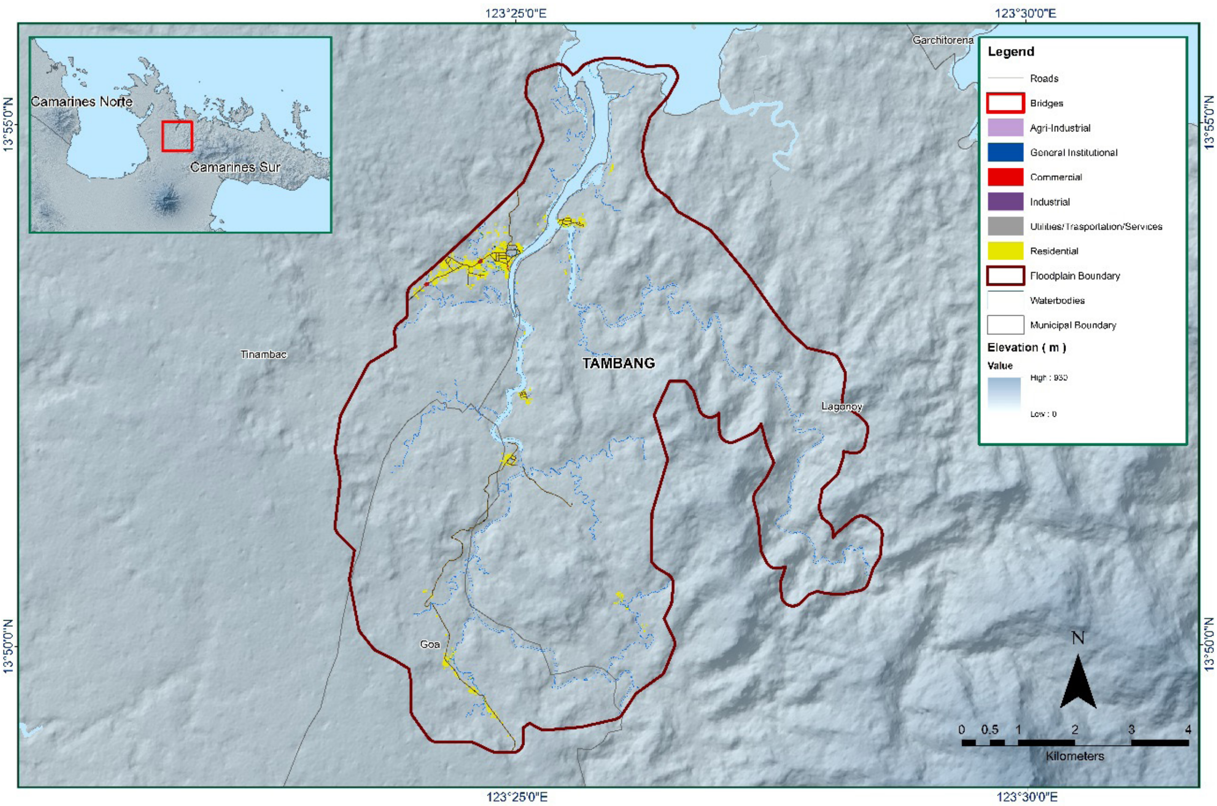

Figure 26. Extracted features for Tambang Floodplain.

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

Engr. Louie P. Balicanta, Engr. Joemarie Caballero, Patrizcia Mae. P. dela Cruz, Engr. Kristine Ailene B. Borromeo, For. Dona Rina Patricia C. Tajora, Elaine Bennet Salvador, and For. Rodel C. Alberto

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

4.1 Summary of Activities

The Data Validation and Bathymetry Component (DVBC) conducted a field survey in Tambang River on June 22 – July 6, 2016 with the following scope of work: reconnaissance; control survey; cross-section at the deployment site in Brgy. Del Carmen, Municipality of Lagonoy; validation points acquisition of about 77 km covering the Guinatagan River Basin area; and bathymetric survey from its upstream in Brgy. Olas to the mouth of the river located in Brgy. Del Carmen, both in the Municipality of Lagonoy, with an approximate length of 4.189 km using Ohmex™ single beam echo sounder and Trimble® SPS 882 GNSS PPK survey technique (Figure 27).

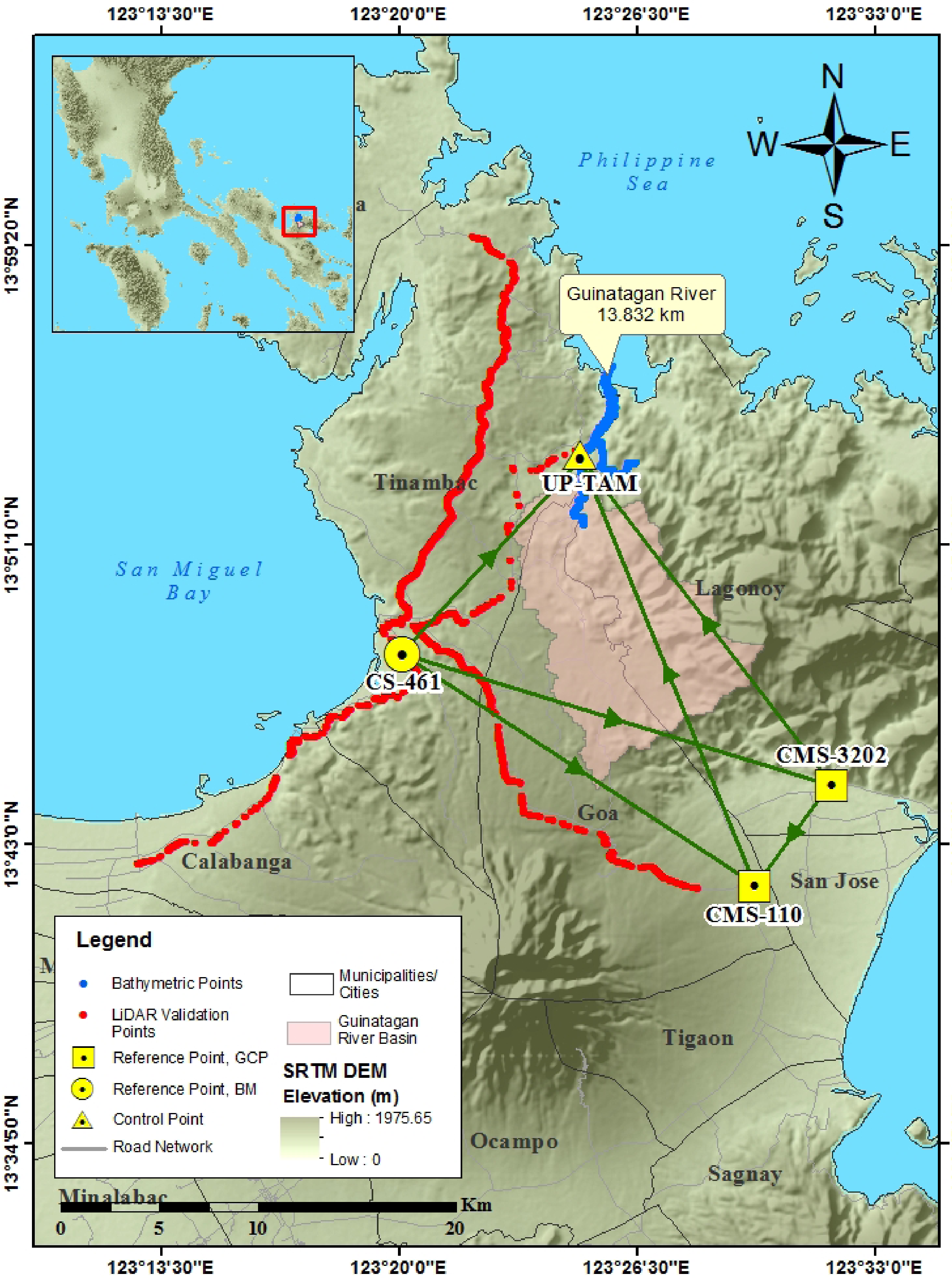

Figure 27. Extent of the bathymetric survey (in blue line) in Tambang River and the LiDAR data validation survey (in red).

4.2 Control Survey

The GNSS network used for Tambang River Basin is composed of four (4) loops established on June 27, 2016 occupying the following reference points: CMS-110, a second-order GCP in Brgy. Taytay, Municipality of Goa; and CS-461, a first order BM, in Brgy. Balaobalite, Municipality of Timambac.

A control point was established namely UP-TAM, located at Tamban Port in Brgy. Tamban, Municipality of Tinambac. A NAMRIA established control point, CMS-3202 in Brgy. Ginotangan, Municipality of Lagonoy, was also occupied to use as marker.

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

Table 20. List of Reference and Control Points occupied for Tambang 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
CMS-110	2nd order, GCP	13°41'52.12609"N	123°29'44.20763"E	104.205	-	2007
CS-461	1st order, BM	-	-	57.480	5.428	2009
CMS-3202	Used as Marker	-	-	-	-	2-26-16
UP-TAM	UP Established	-	-	-	-	2-27-16

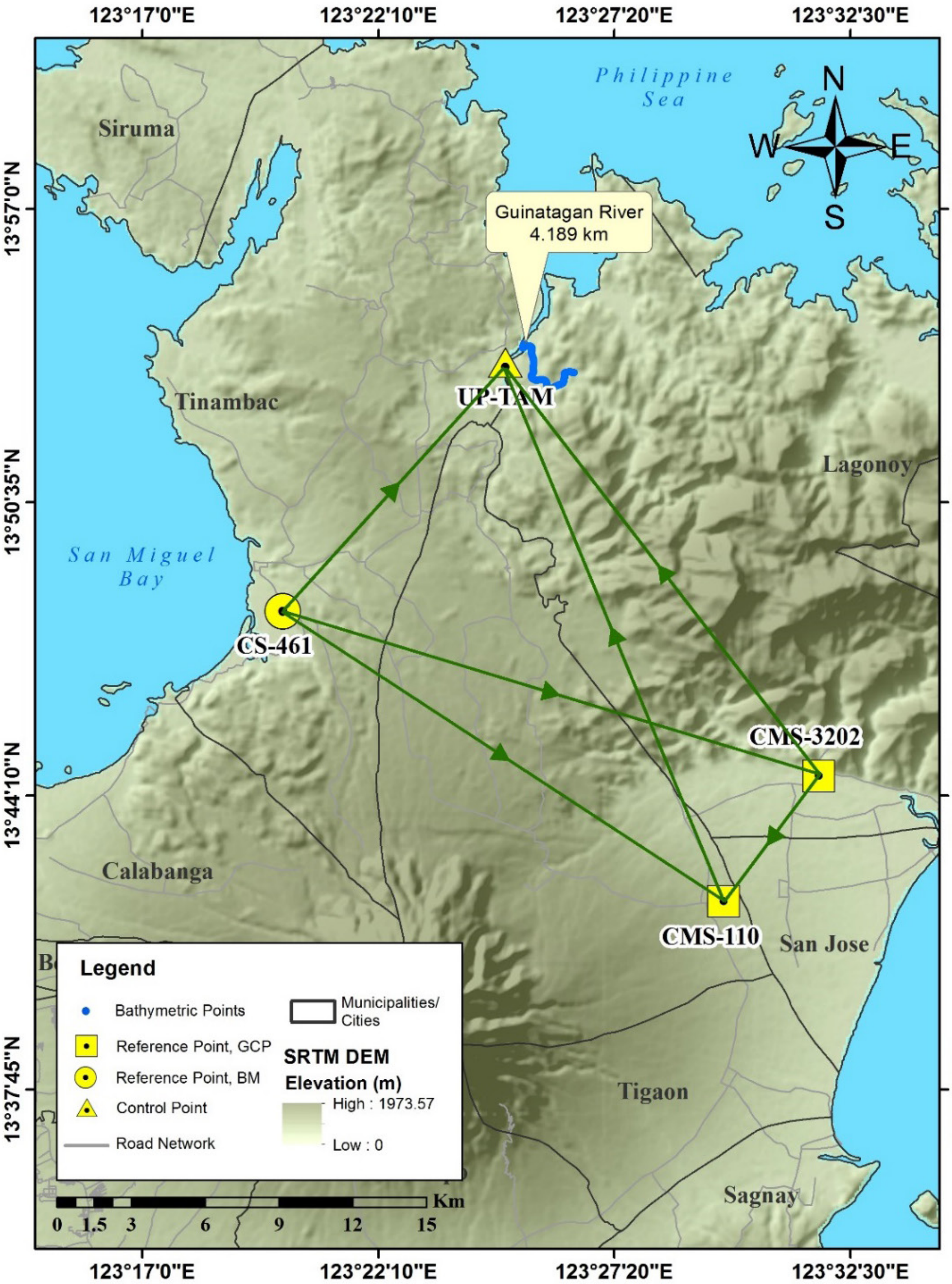

Figure 28. The GNSS Network established in the Tambang River Survey.

The GNSS set-ups on recovered reference points and established control points in Guinatagan River are shown in Figure 29 to Figure 32.

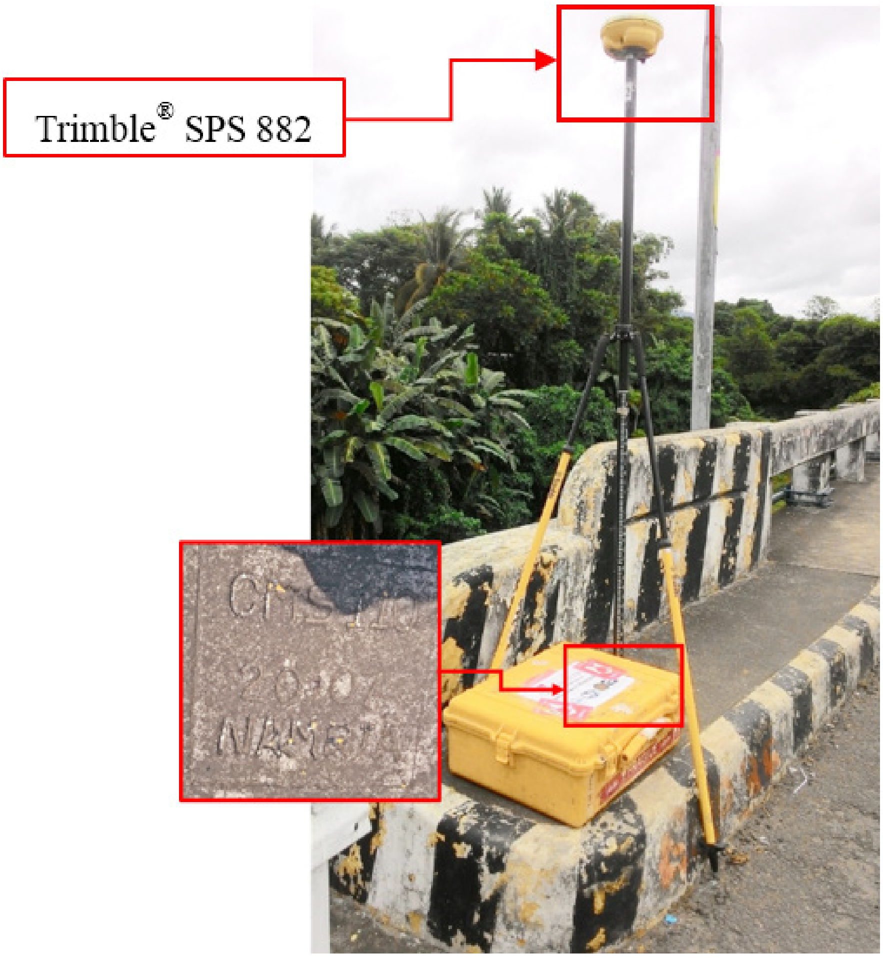

Figure 29. GNSS base set up, Trimble® SPS 882, at CMS-110, situated at the approach of Culasi Bridge in Brgy. Taytay, Municipality of Goa, Camarines Sur

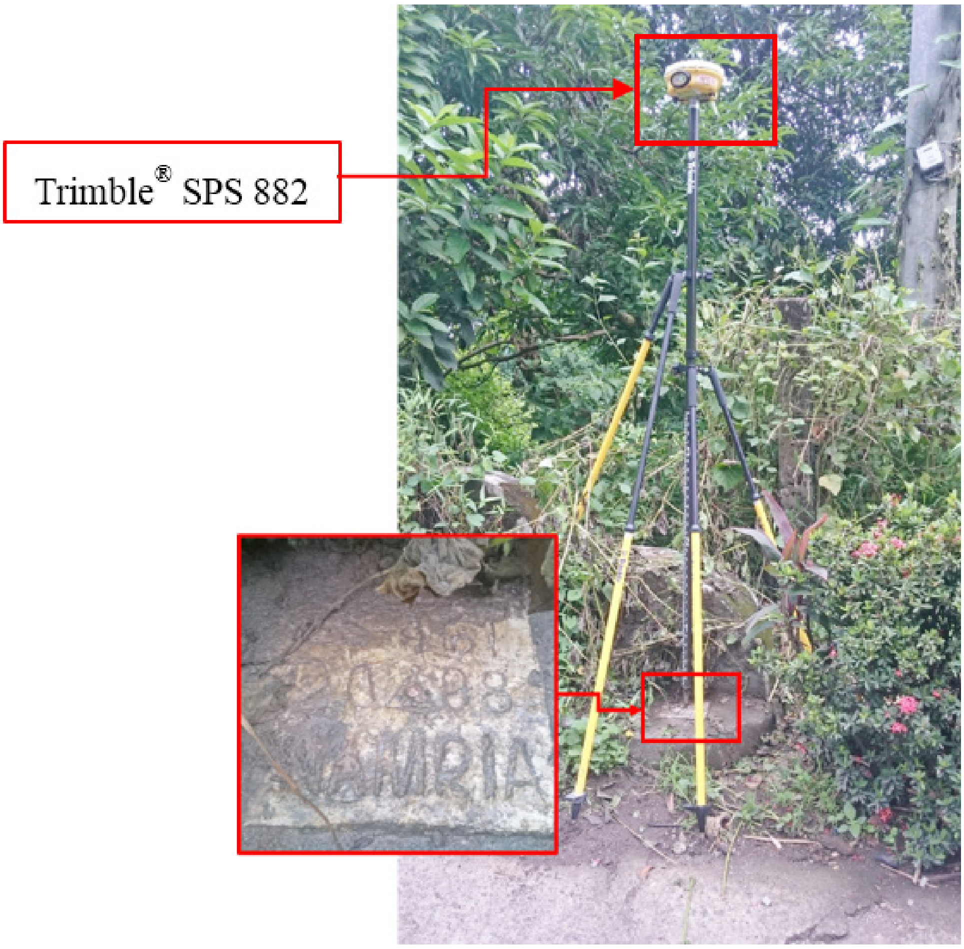

Figure 30. GNSS receiver setup, Trimble® SPS 882, at CS-461, located at the approach of a bridge in Brgy. Balaobalite, Municipality of Tinambac, Camarines Sur

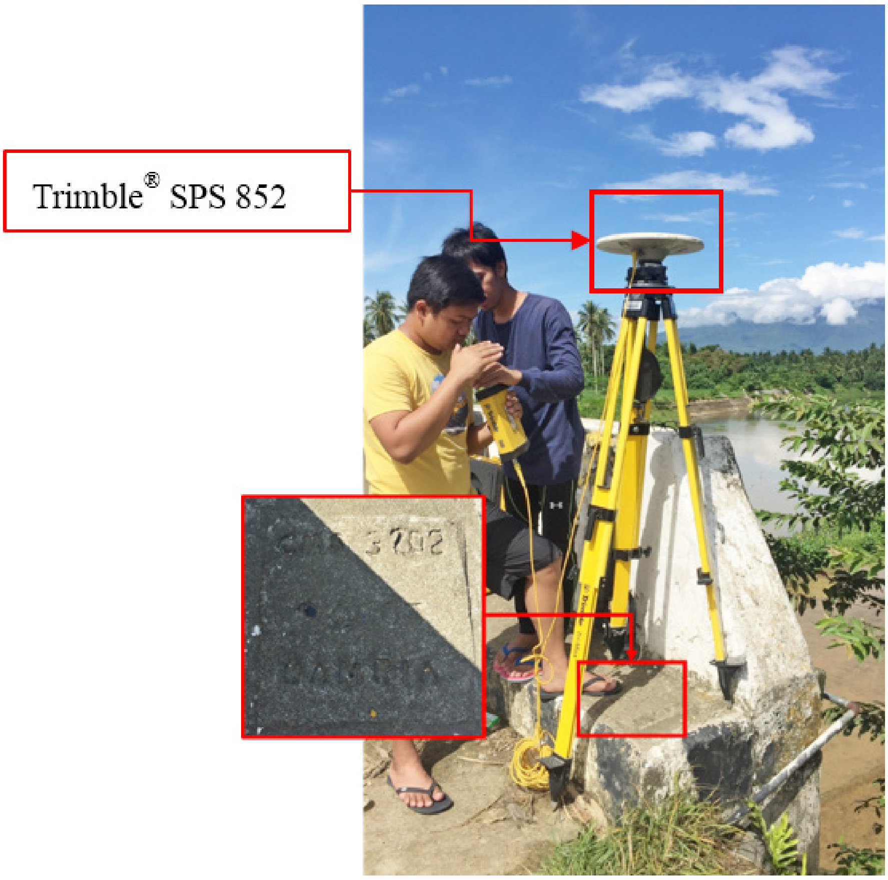

Figure 31. GNSS receiver setup, Trimble® SPS 852, at CMS-3202, located at the approach of Lagonoy Bridge in Brgy. Ginorangan, Municipality of Lagonoy, Camarines Sur

Figure 32. GNSS receiver setup, Trimble® SPS 822, at UP-TAM, located at Tamban Port, Brgy. Tamban, Municipality of Tinambac, Camarines Sur

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

Table 21. Baseline Processing Summary Report for Tambang River Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
CS-461 --- UP-TAM	06-27-16	Fixed	0.006	0.026	41°09'23"	13328.475	-3.608
CS-461 --- UP-TAM	06-27-16	Fixed	0.005	0.042	41°09'22"	13328.449	-3.540
CS-461 --- CMS-3202	06-27-16	Fixed	0.003	0.019	107°21'48"	22178.246	4.270
CS-461 --- CMS-110	06-27-16	Fixed	0.003	0.019	123°48'32"	20967.545	46.722
CMS-3202 --- UP-TAM	06-27-16	Fixed	0.004	0.017	323°23'08"	20760.844	-7.812
CMS-3202 --- UP-TAM	06-27-16	Fixed	0.004	0.023	323°23'07"	20760.831	-7.801
CMS-3202 --- CMS-110	06-27-16	Fixed	0.003	0.011	216°37'18"	6285.971	42.467
CMS-110 --- UP-TAM	06-27-16	Fixed	0.005	0.021	338°18'24"	23362.491	-50.291
CMS-110 --- UP-TAM	06-27-16	Fixed	0.004	0.023	338°18'24"	23362.483	-50.264

As shown in Table 21, a total of nine (9) baselines were processed with reference points CMS-110 and CS-461 held fixed for coordinate and elevation values. 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 C-of the TBC generated Network Adjustment Report, it is observed that the square root of the sum of the squares of x and y must be less than 20 cm and z less than 10 cm or in equation form:

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

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 22 to Table 25 for complete details.

The four (4) control points, CMS-110, CS-461, CMS-3202 and UP-TAM were occupied and observed simultaneously to form a GNSS loop. Coordinates of CMS-110; and elevation values of CS-461 were held fixed during the processing of the control points as presented in Table 22. Through these reference points, the coordinates and elevation of the unknown control points will be computed.

Table 22. Constraints applied to the adjustment of the control points.

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
CMS-110	Global	Fixed	Fixed		
CS-461	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 CMS-110 has no values for grid errors while CS-461 has no value for elevation errors.

Table 23. Adjusted grid coordinates for the control points used in the Tambang River Floodplain survey.

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
CMS-110	553591.452	?	1514361.204	?	51.938	0.056	LL
CS-461	536159.891	0.008	1525999.493	0.007	5.428	?	e
CMS-3202	557328.793	0.007	1519412.663	0.006	9.384	0.055	
UP-TAM	544914.191	0.007	1536043.176	0.006	1.819	0.059	

With the mentioned equation, $\sqrt{((x_e)^2 + (y_e)^2)}$ <20cm and $z_e < 10\ cm$ for horizontal and $z_e < 10\ cm$ for the vertical;

the computation for the accuracy are as follows:

a. CMS-110
horizontal accuracy = Fixed
vertical accuracy = 5.6 cm < 10 cm

b. CS-461
horizontal accuracy = $\sqrt{((0.8)^2 + (0.7)^2}$
= $\sqrt{(0.64 + 0.49)}$
= 1.06 < 20 cm
vertical accuracy = Fixed

c. CMS-3202
horizontal accuracy = $\sqrt{((0.7)^2 + (0.6)^2}$
= $\sqrt{(0.49 + 0.36)}$
= 0.92 < 20 cm
vertical accuracy = 5.5 cm < 10 cm

d. UP-TAM
horizontal accuracy = $\sqrt{((0.7)^2 + (0.6)^2}$
= $\sqrt{(0.49 + 0.36)}$
= 0.92 < 20 cm
vertical accuracy = 5.9 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 for control points used in the Tambang River Floodplain validation.

Point ID	Latitude	Longitude	Ellipsoidal Height (Meter)	Height Error (Meter)	Constraint
CMS-110	N13°41'52.12609"	E123°29'44.20763"	104.205	0.056	LL
CS-461	N13°48'11.94074"	E123°20'04.40925"	57.480	?	e
CMS-3202	N13°44'36.29589"	E123°31'48.99957"	61.737	0.055	
UP-TAM	N13°53'38.42492"	E123°24'56.57247"	53.908	0.059	

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 condition is satisfied; hence, the required accuracy for the program was met.

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

Table 25. Reference and control points utilized in the Tambang River Static Survey, with their corresponding locations (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N			
		Latitude	Longitude	Ellipsoidal Height (m)	Northing (m)	Easting (m)	EGM Ortho (m)	BM Ortho (m)
CMS-110	2nd order, GCP	13°41'52.12609"N	123°29'44.20763"E	104.205	1514361.204	553591.452	51.938	287.844
CS-461	1st order, BM	13°48'11.94074"N	123°20'04.40925"E	57.480	1525999.493	536159.891	5.428	58.767
CMS-3202	Used as Marker	13°44'36.29589"N	123°31'48.99957"E	61.737	1519412.663	557328.793	9.384	3.317
UP-TAM	UP Established	13°53'38.42492"N	123°24'56.57247"E	53.908	1536043.176	544914.191	1.819	4.332
UP_QUI-1	Established	7°05'25.95862"N	126°27'58.08622"E	70.854	784522.58	220097.24	6.305	13.001

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

Cross-section survey was conducted on June 29, 2016 in Brgy. Del Carmen, Municipality of Lagonoy, Camarines Sur. This is the site is where ADNU deploys depth gauge and gather flow measurements as shown in Figure 33. A survey grade GNSS receiver Trimble® SPS 882 in PPK survey technique was utilized for this survey.

Figure 33. Deployment site of depth gauge and flow meter showing the obstructions (circled in red) during cross-section survey

The cross-sectional line of the deployment site is about 55.850 m with fifty-four (54) cross-sectional points using the control point UP-TAM as the GNSS base station. The banks of the river were not accessible due to the Bakawan species. The cross-section diagram and its location map are shown in Figure 34 and Figure 35.

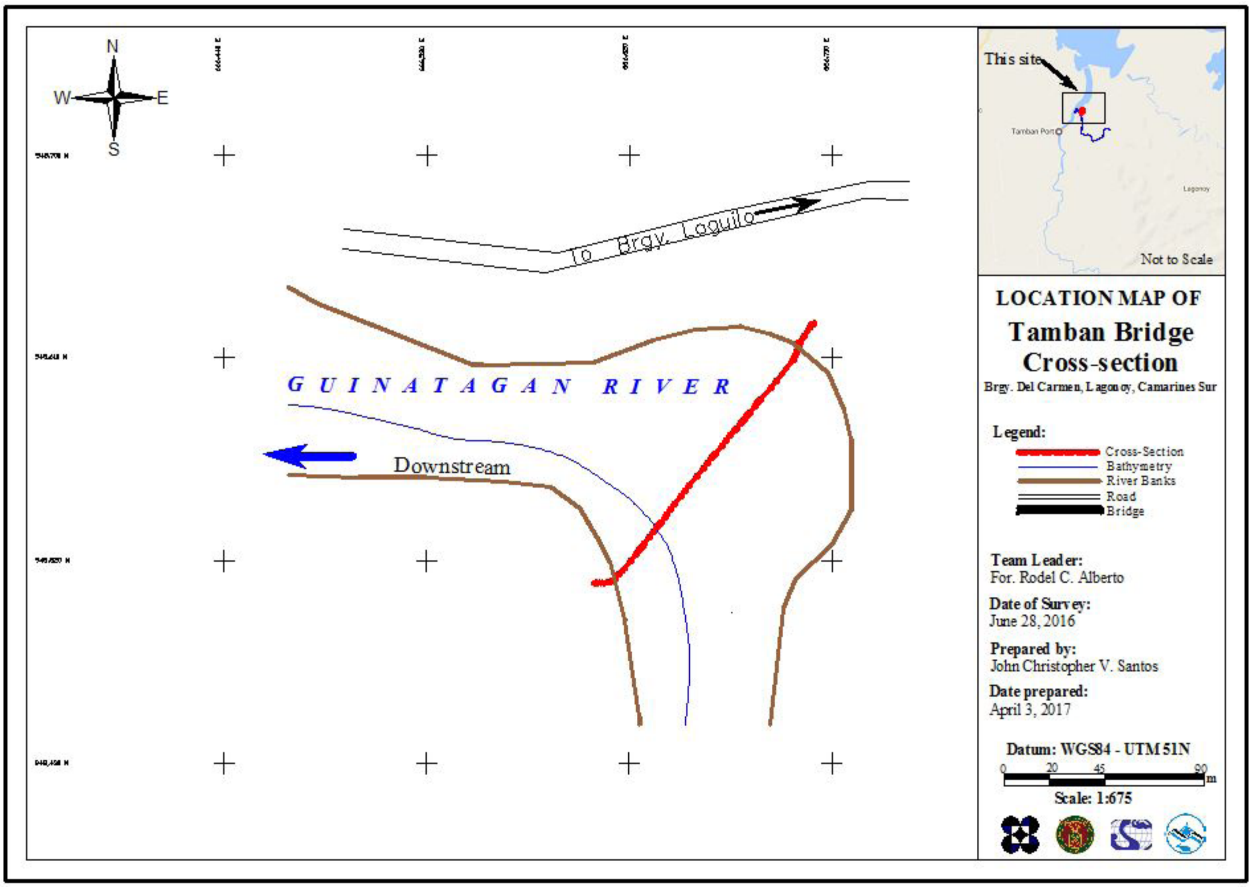

Figure 34. Location map of Tambang (also known as Guinatagan) River cross-section survey

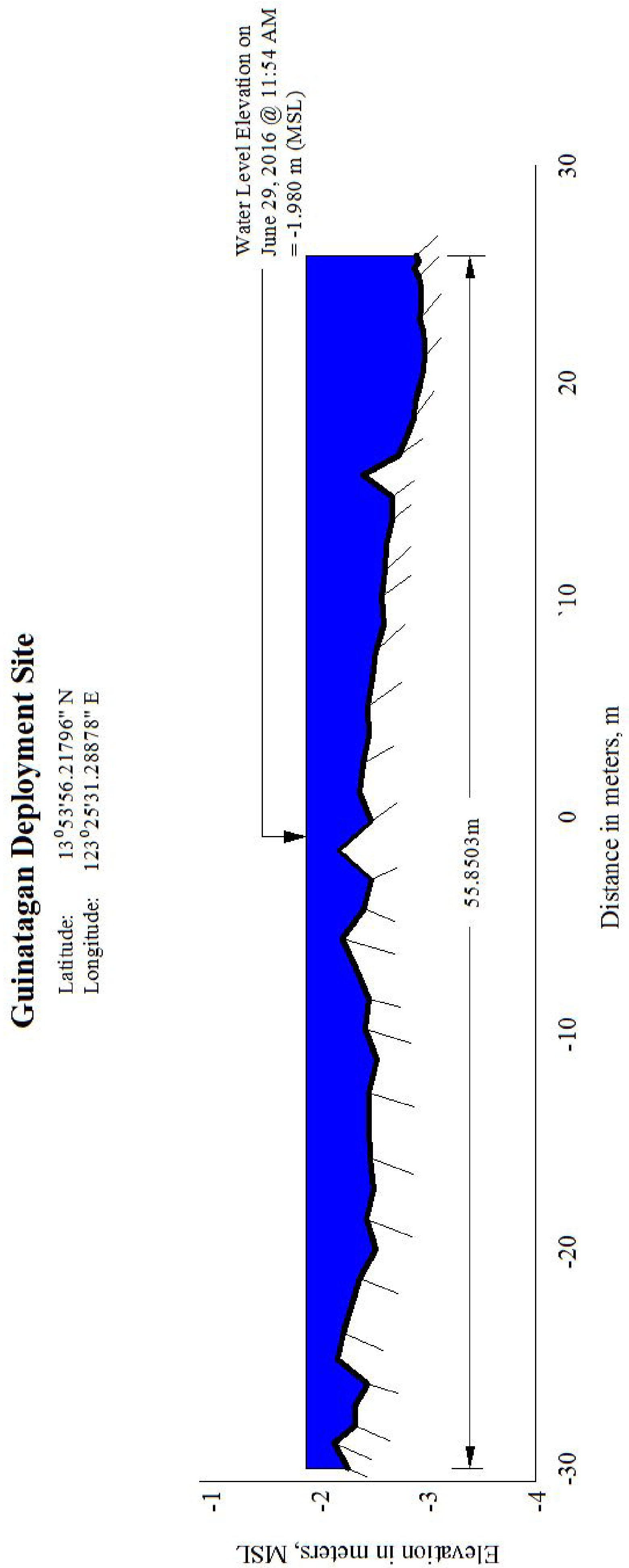

Figure 35. Tambang (also known as Guinatagan) Deployment site cross-section diagram

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on June 26 and 28, 2016 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted in front of a vehicle as shown in Figure 36. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The antenna height was 2.30 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 CMS-3202 occupied as the GNSS base stations in the conduct of the survey.

Figure 36. Validation points acquisition survey set up along Tambang River Basin

The survey was composed of two strips: one which started from Brgy. Magsaysay, in the Municipality of Tinambac, going south covering twety-four (24) barangays of Municipalities of Calabanga and Tinambac which ended in Brgy. Del Carmen, Municipality of Calabanga; and second which started from Tamban Port also going south covering thirteen (13) more barangays in Municipalities of Goa and Tinambac, and ended in Tagongtong, Municipality of Goa. The survey gathered a total of 7,540 points with approximate length of 77 km using CMS-3202 as GNSS base station for the entire extent validation points acquisition survey as illustrated in the map in Figure 37.

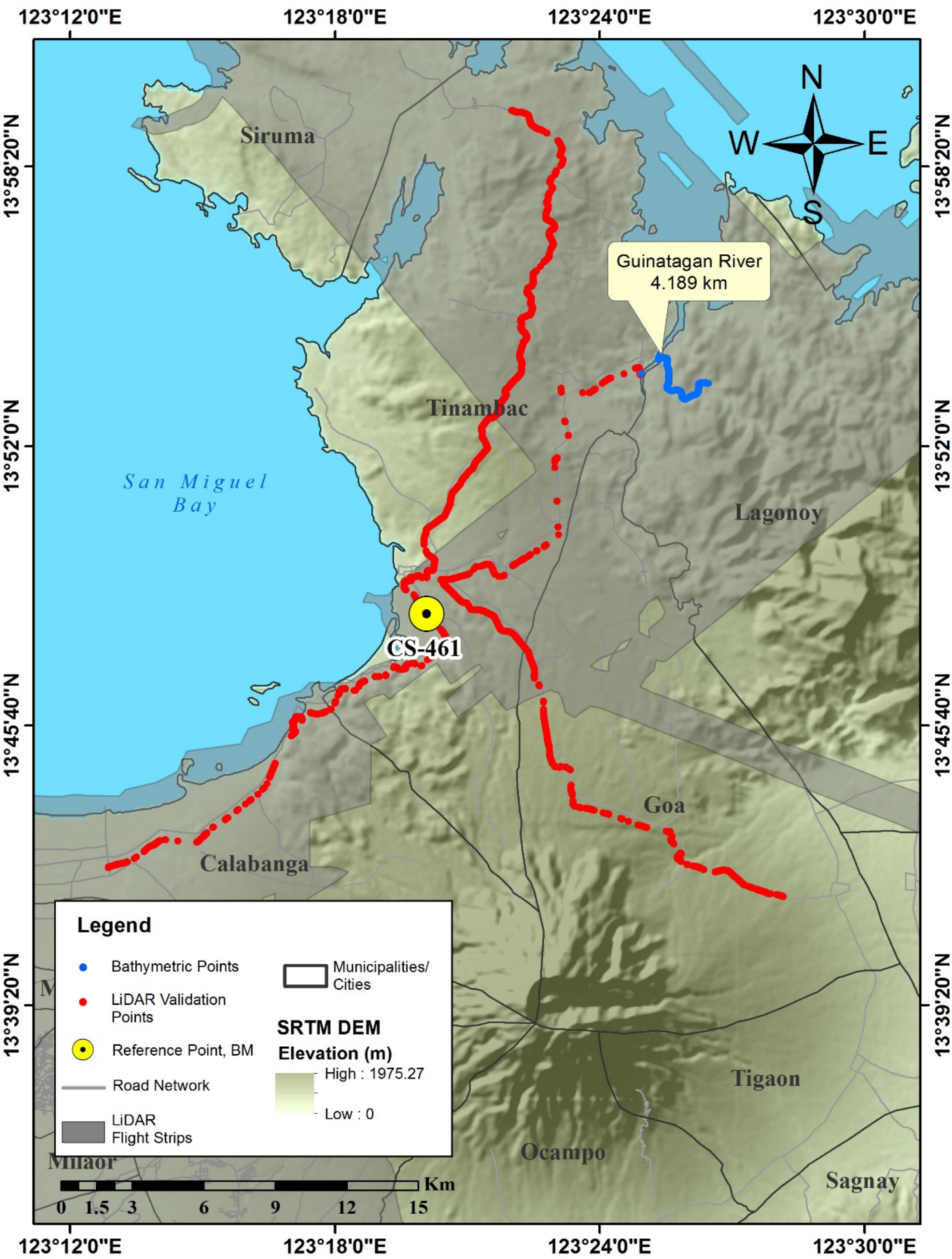

Figure 37. Validation point acquisition survey of Tambang River basin

4.7 River Bathymetric Survey

Bathymetric survey was executed on June 29, 2016 using an Ohmex™ single beam echo sounder and Trimble® SPS 882 in GNSS PPK survey technique in continuous topo mode as illustrated in Figure 38. The survey started in Brgy. Olas, Municipality of Lagonoy, with coordinates 13°44'18.28661"N, 123°32'59.30757"E, and ended at the mouth of the river in Brgy. Del Caren, also in Municipality of Lagonoy with coordinates 13°43'24.89932"N, 123°35'48.11928"E. The control point UP-TAM was used as the GNSS base station all throughout the entire survey.

Figure 38. Bathymetric survey using Ohmex™ single beam echo sounder in Tambang River

The bathymetric survey coverage for Tambang river is illustrated in Figure 39. The bathymetric survey for Guinatagan River gathered a total of 5,280 points covering 4.189 km of the river traversing two (2) barangays in Municipality of Lagonoy namely: Olas and Del Carmenn. A CAD drawing was also produced to illustrate the riverbed profile of Guinatagan River. As shown in Figure 40, the highest and lowest elevation has a 6-m difference. The highest elevation observed was -0.155 m below MSL located at the downstream portion of the river in Brgy. Del Carmen, Municipality of Lagonoy, while the lowest was -6.933 m below MSL located at the upstream portion of the river also in Brgy. Del Carmen

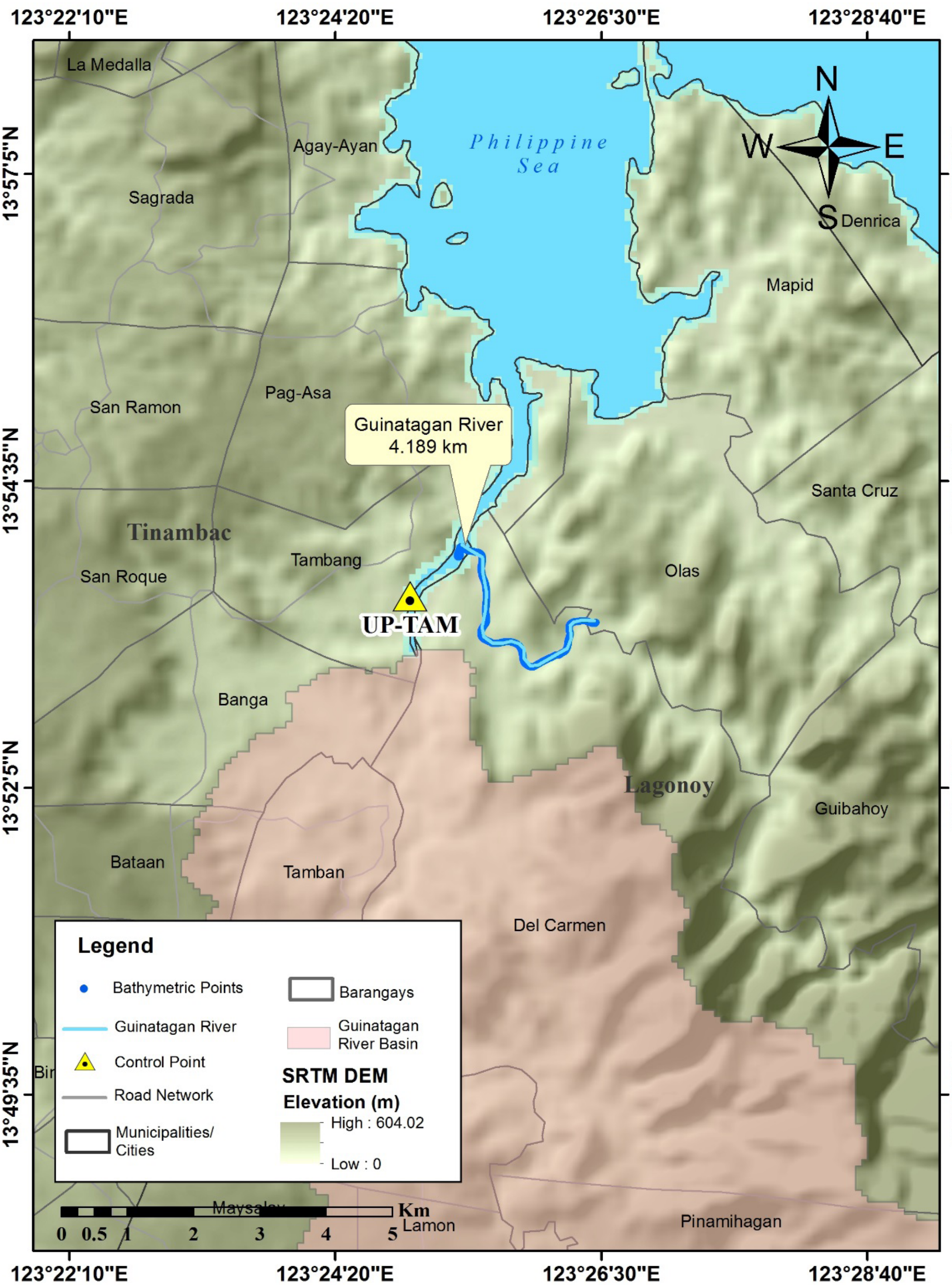

Figure 39. Bathymetric survey of Tambang (also known as Guinatagan) River

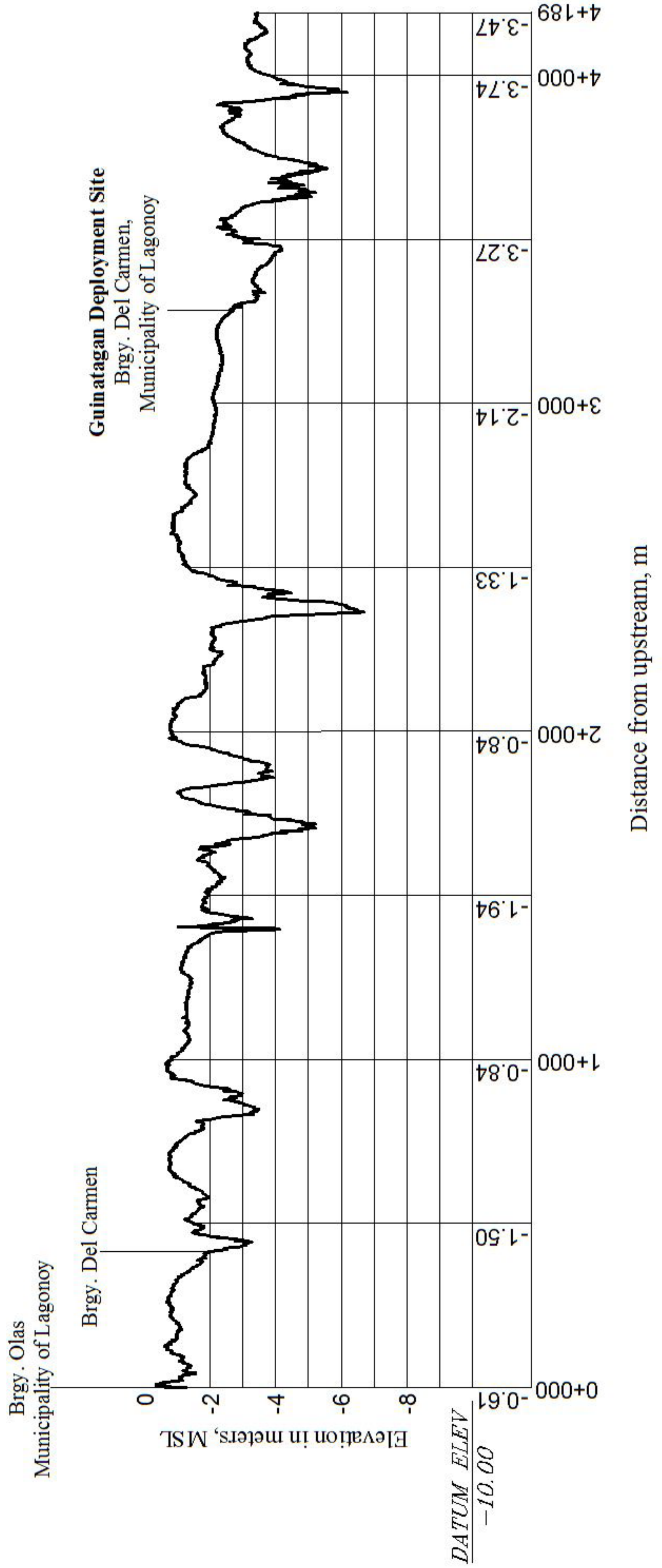

Figure 40. Tambang (also known as Guinatagan) riverbed profile.

CHAPTER 5: FLOOD MODELING AND MAPPING

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

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

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

5.1.2 Precipitation

Precipitation data was taken from one automatic rain gauge (ARGs) installed by the Department of Science and Technology – Adv¬anced Science and Technology Institute (DOST-ASTI). The rain gauge was installed at PSHS Bicol ARG (Figure 1). The precipitation data collection started from December 25, 2016 at 4:30 PM to December 26, 2016 at 6:30 AM with a 15-minute recording interval. The location of the rain gages used in calibration in the watershed in presented in Figure 41.

The total precipitation for this event in PSHS Bicol ARG is 557.4mm. It has a peak rainfall of 48.4mm on December 25, 2016 at 10:00 PM. The lag time between the peak rainfall and discharge is 2 hours and 40 minutes.

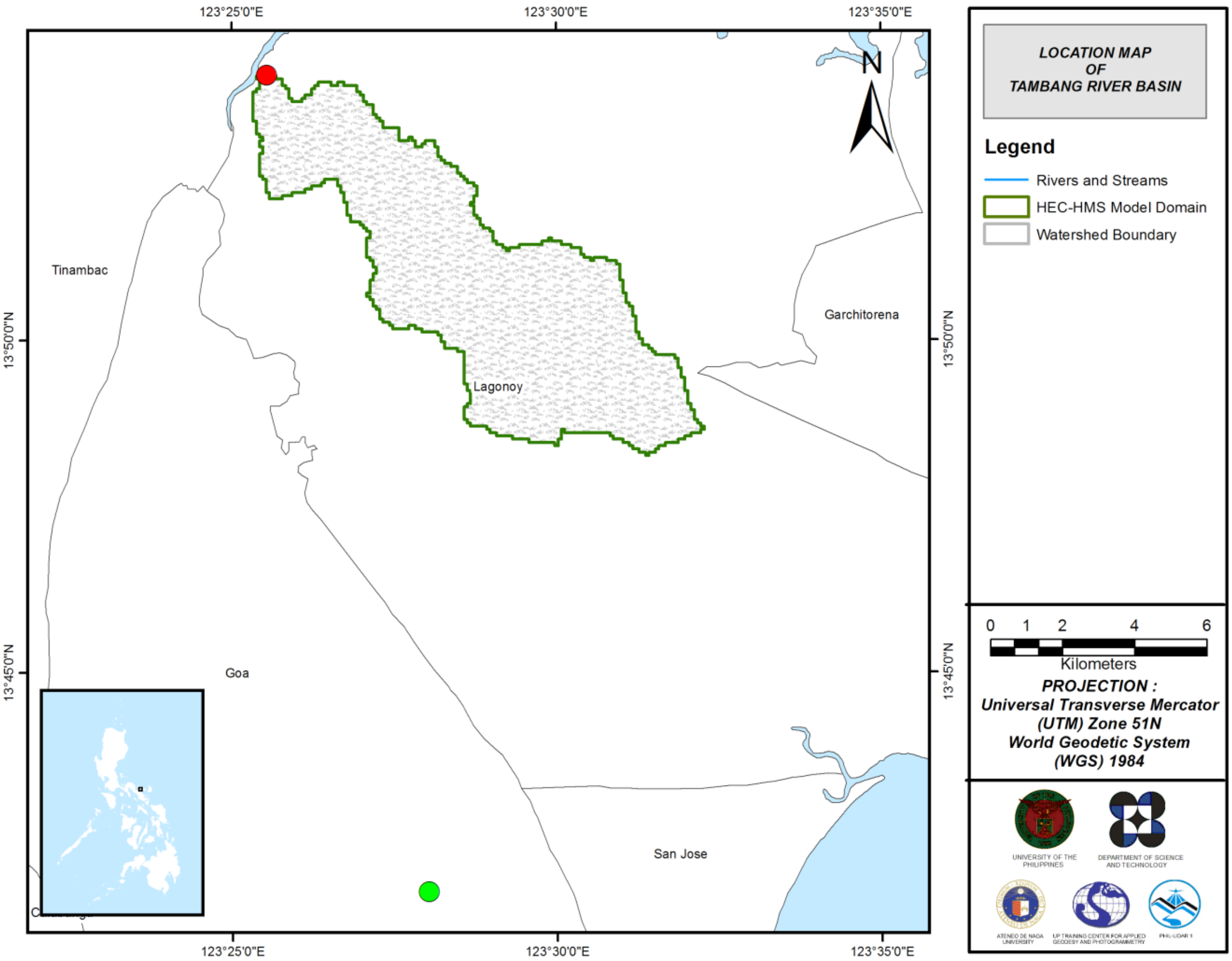

Figure 41. Location map of the Tambang HEC-HMS model used for calibration.

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Brgy. Bocogan, Lagonoy, Camarines Sur (13°53’59.2”N, 123°25’32.13”E). It gives the relationship between the observed water levels at Brgy. Bocogan and outflow of the watershed at this location.

Figure 42. Cross-section plot of Tambang Bridge

For Brgy. Bocogan, the rating curve is expressed as Q = 195.97e0.483h as shown in Figure 43.

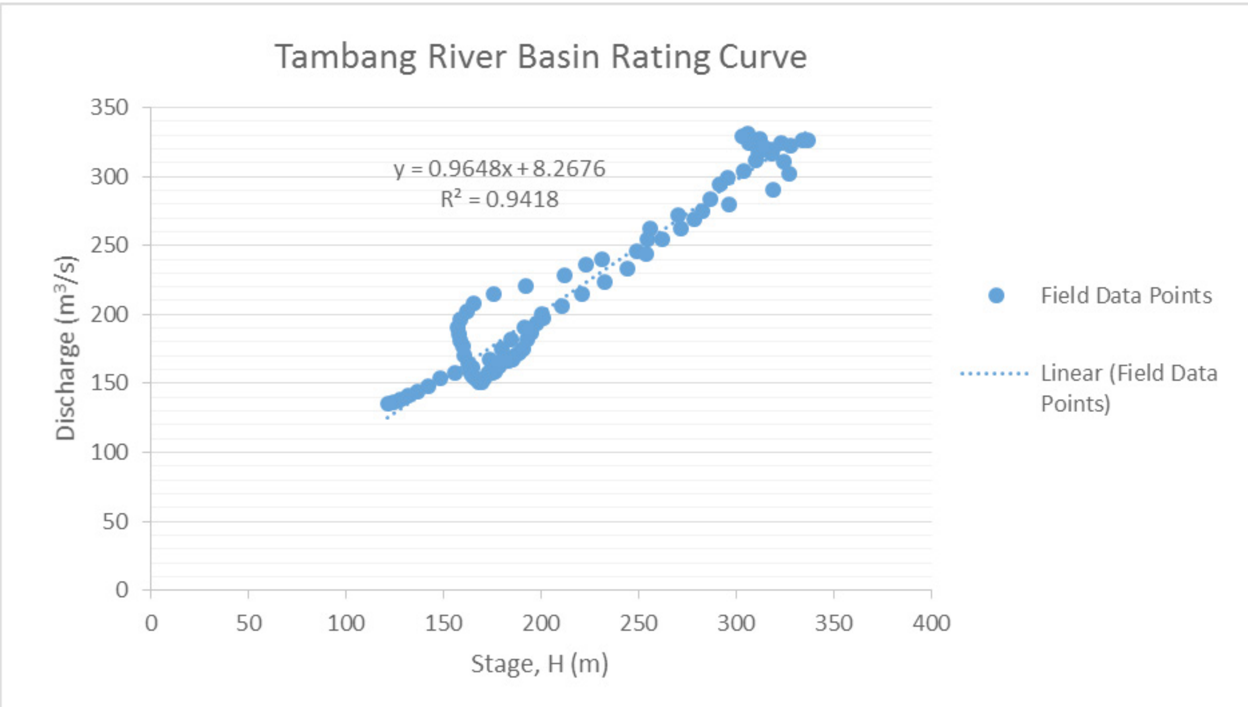

Figure 43. Rating curve of Brgy. Bocogan in Lagonoy, Camarines Sur

The rating curve equation was used to compute the river outflow at Brgy. Bocogan for the calibration of the HEC-HMS model shown in Figure 44. The total rainfall for this event is 557.4mm and the peak discharge is 331.286m3/s at 12:40 AM, December 26, 2016.

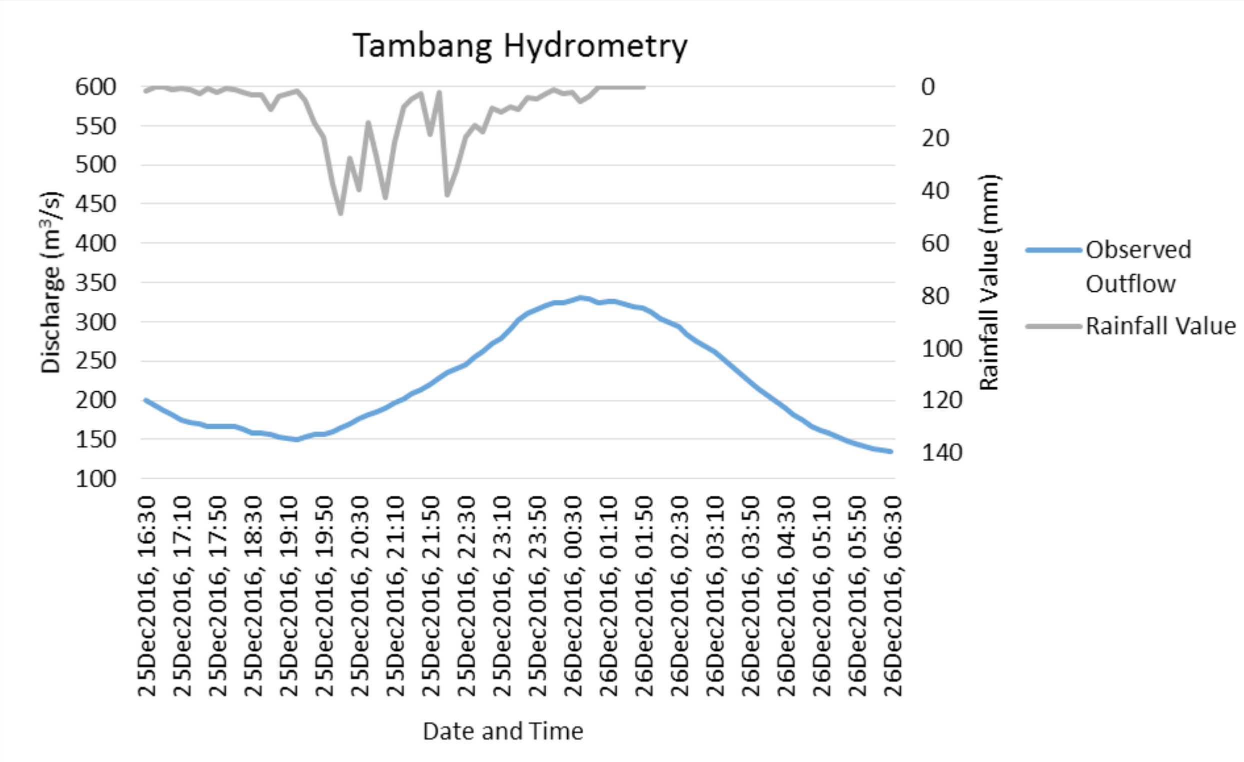

Figure 44. Rainfall and outflow data of the Tambang River Basin used for modeling

5.2 RIDF Station

The Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Daet 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 Tambang watershed. The extreme values for this watershed were computed based on a 26-year record, with the computed extreme values shown in Table 26.

Table 26. RIDF values for Tambang Rain Gauge computed by PAGASA

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

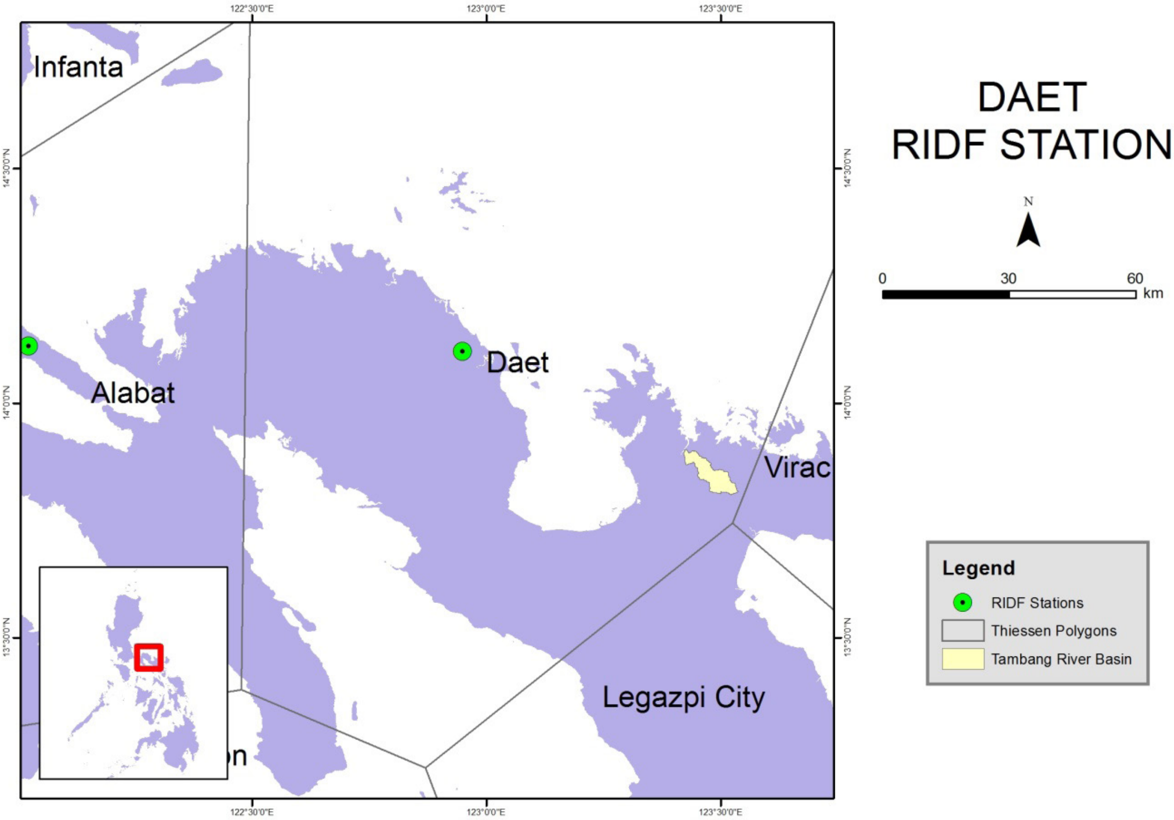

Figure 45. Location of Daet RIDF Station relative to Tambang River Basin

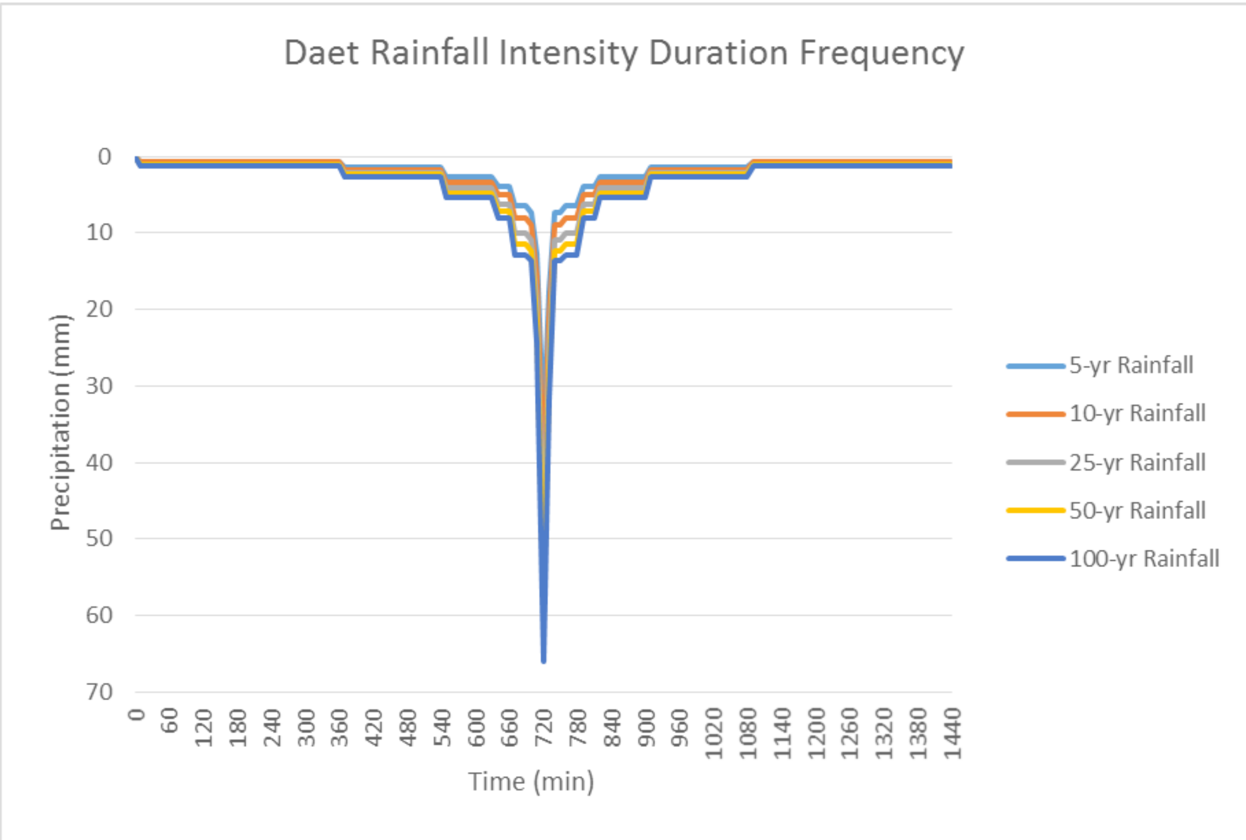

Figure 46. Synthetic storm generated for a 24-hr period rainfall for various return periods.

5.3 HMS Model

The soil dataset was generated before 2004 by the Bureau of Soils and Water Management under the Department of Agriculture (DA - BSWM). The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Tambang River Basin are shown in Figure 47 and Figure 48, respectively.

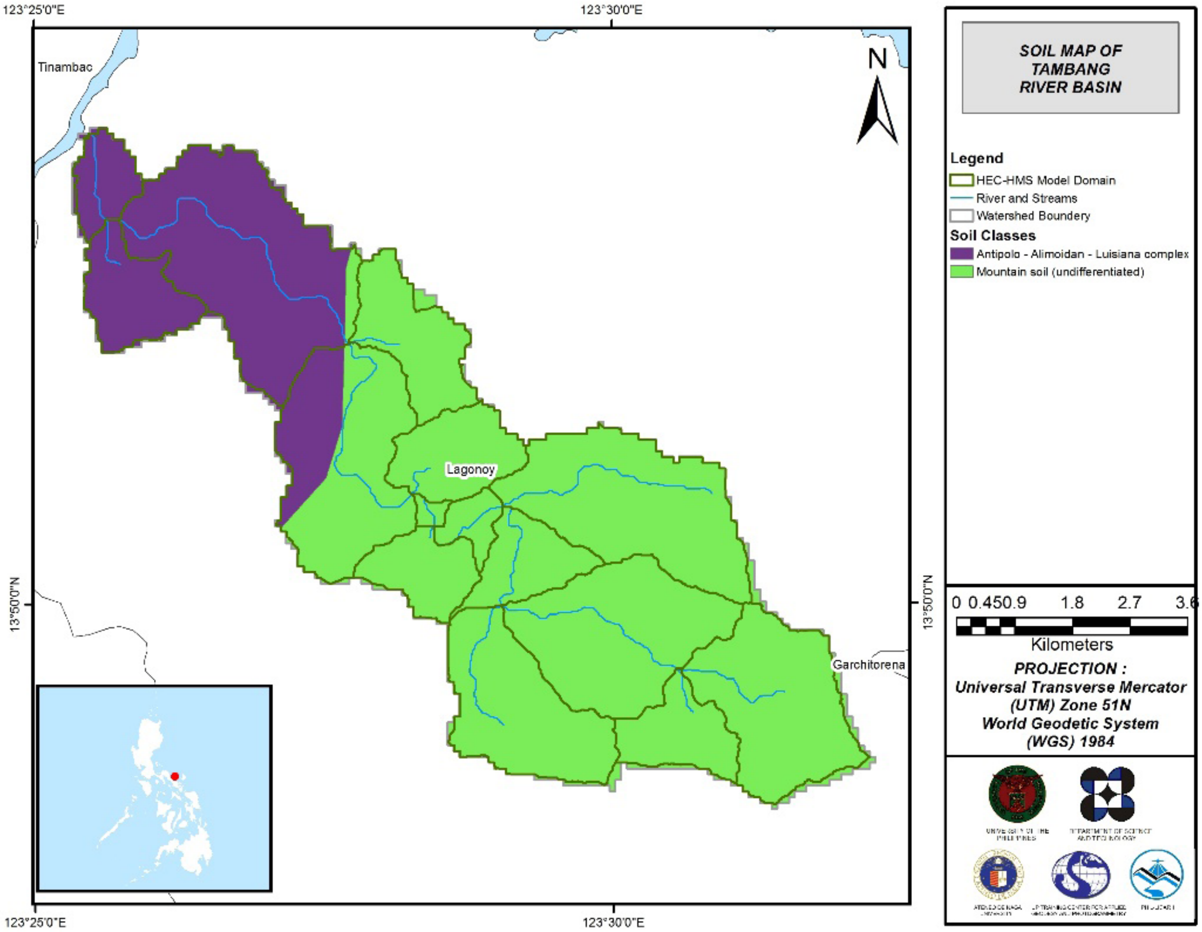

Figure 47. Soil Map of Tambang River Basin used for the estimation of the CN parameter.

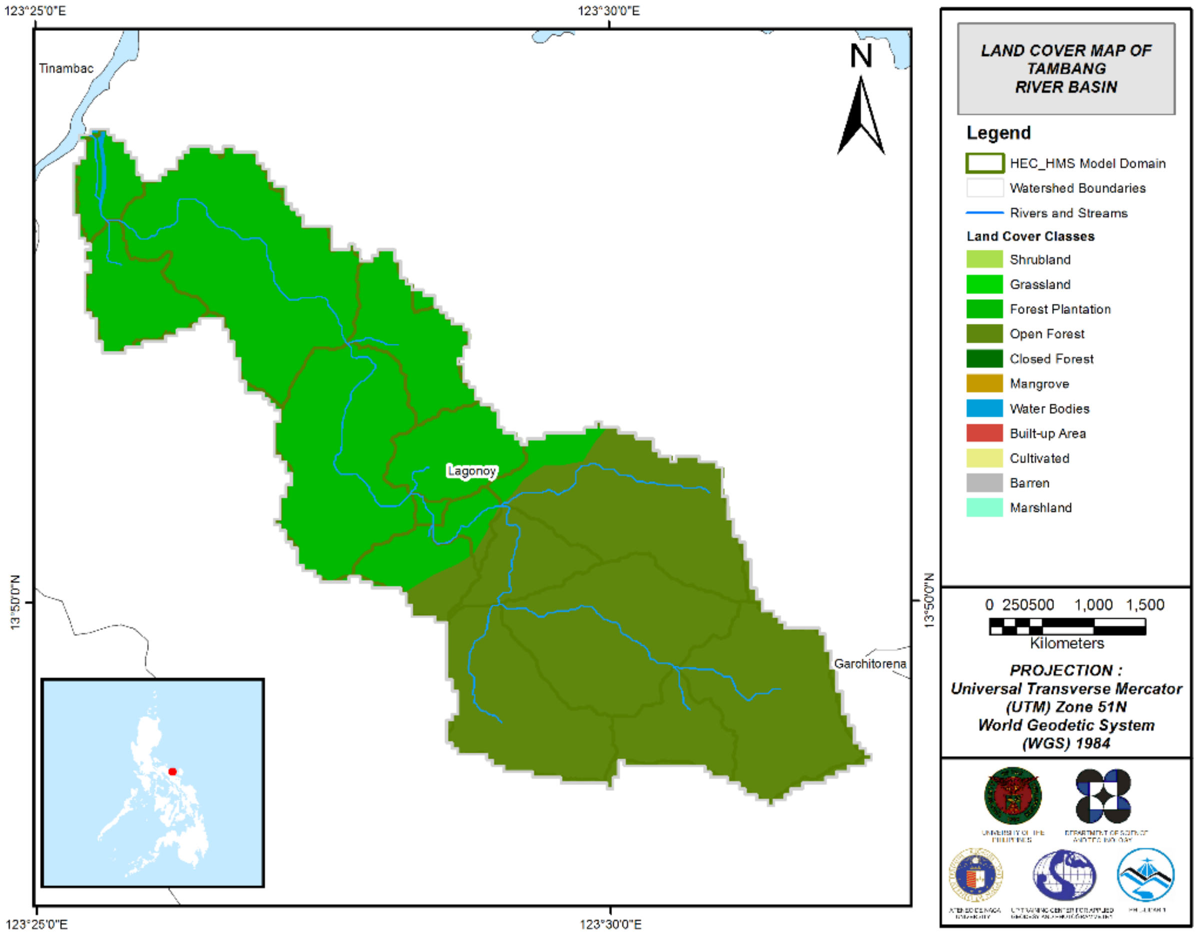

Figure 48. Land Cover Map of Tambang River Basin used for the estimation of the Curve Number (CN) and the watershed lag parameters of the rainfall-runoff model.

For Tambang, two soil classes were identified. These are Antipolo-Alimodian-Luisiana complex and undifferentiated mountain soil. Moreover, two land cover classes were identified. These are forest plantation and open forest.

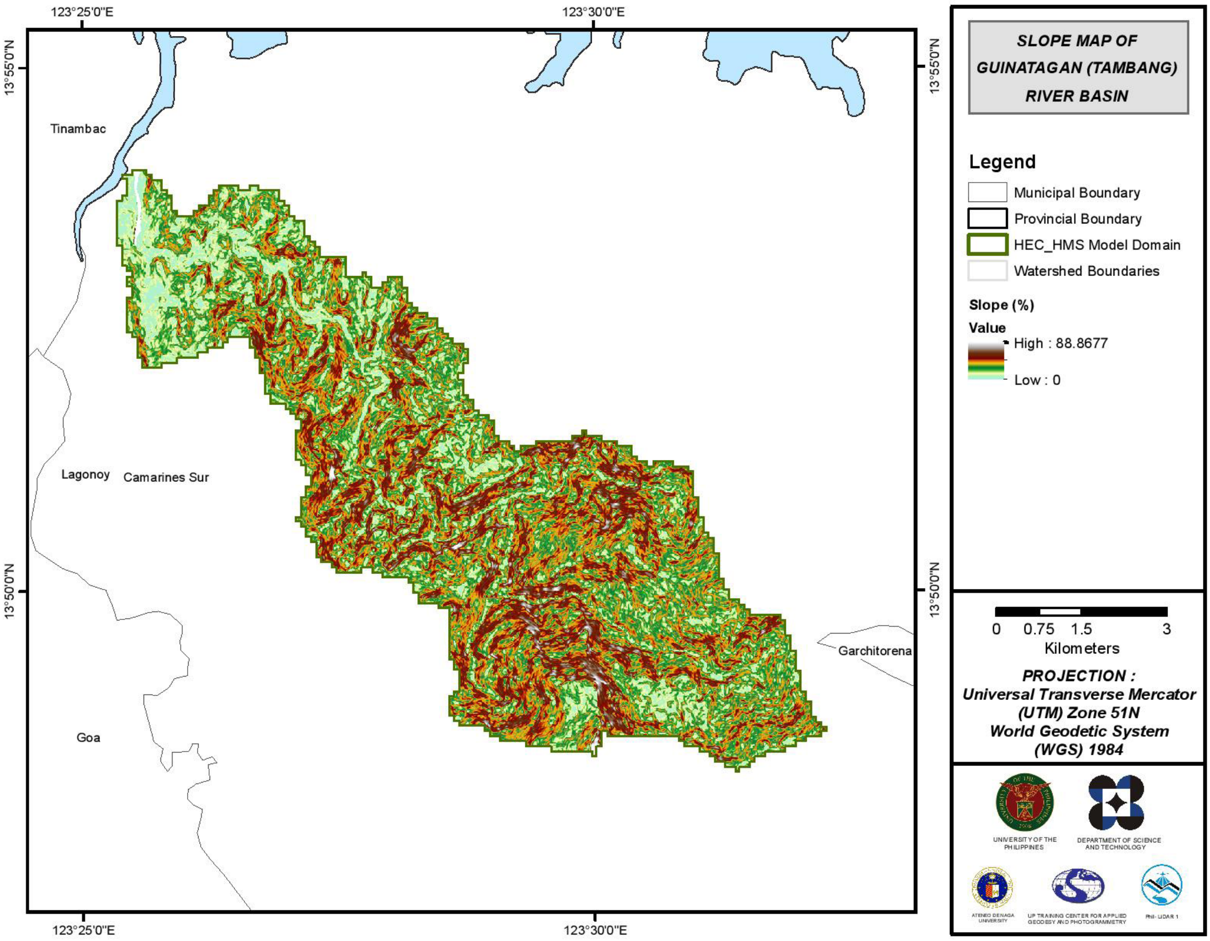

Figure 49. Slope Map of Tambang River Basin

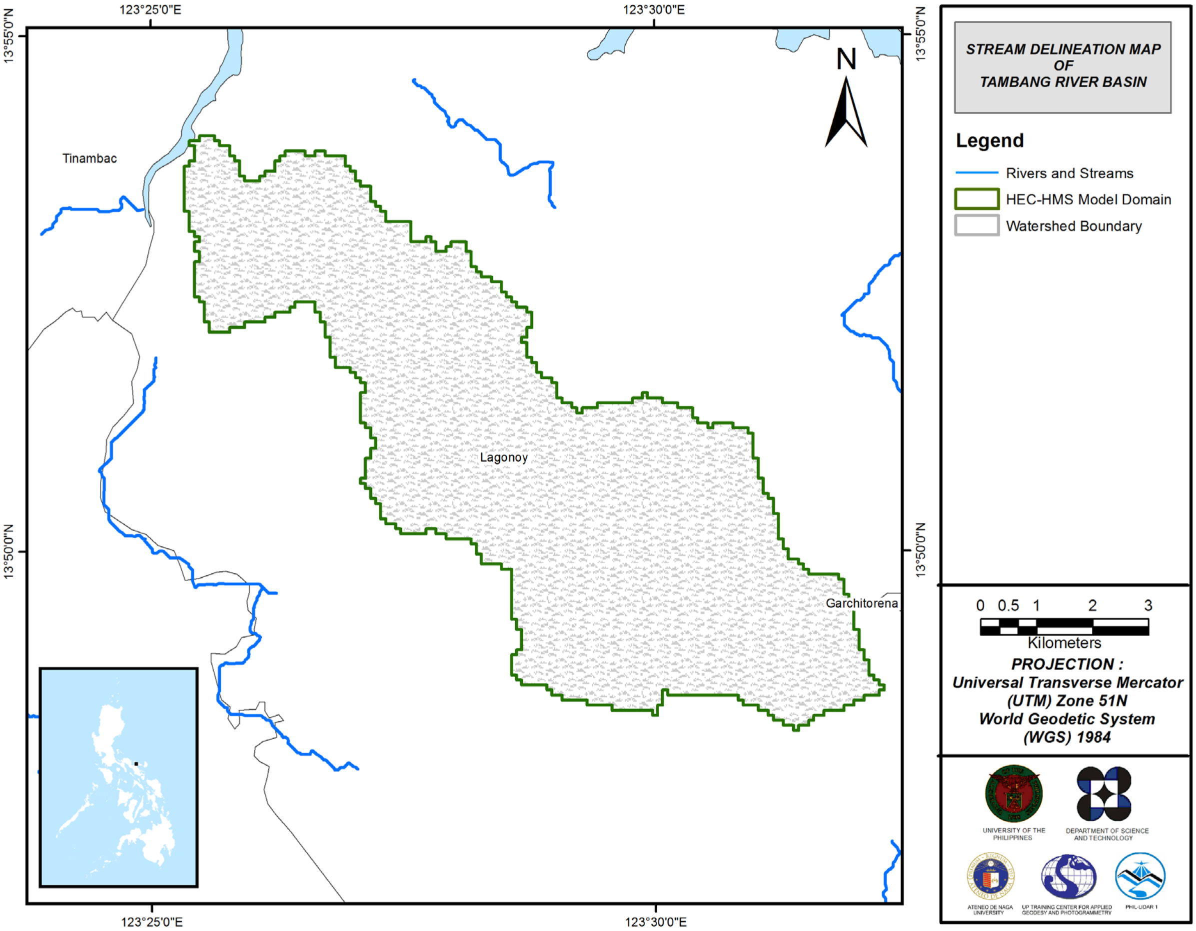

Figure 50. Stream Delineation Map of Tambang River Basin

Using the SAR-based DEM, the Tambang basin was delineated and further divided into subbasins. The model consists of 21 sub basins, 10 reaches, and 10 junctions, as shown in Figure 51. The main outlet is Brgy. Bocogan.

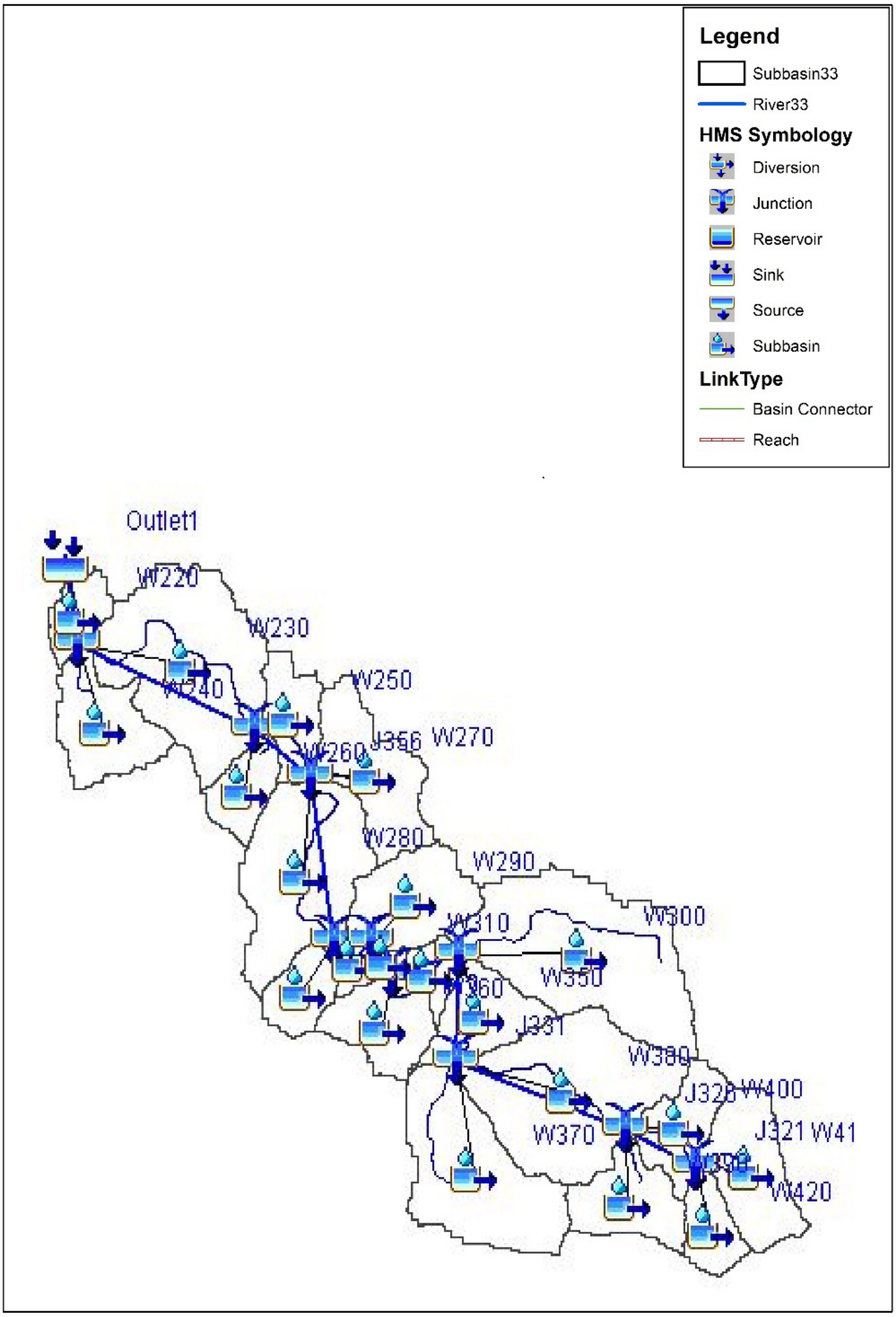

Figure 51. Tambang River Basin model generated in HEC-HMS

5.4 Cross-section Data

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

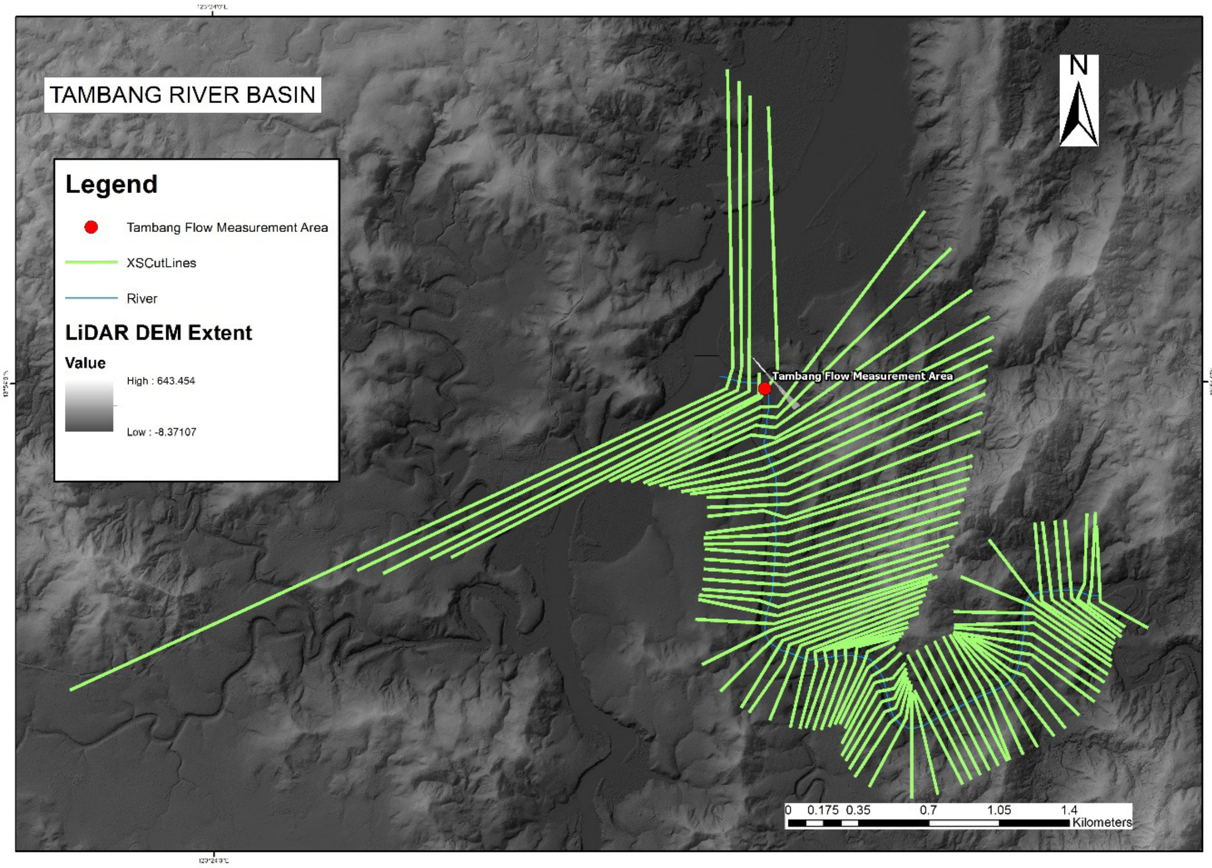

Figure 52. River cross-section of Tambang River generated through Arcmap HEC GeoRAS tool

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 south of the model to the north, following the main channel. As such, boundary elements in those particular regions of the model are assigned as inflow and outflow elements respectively.

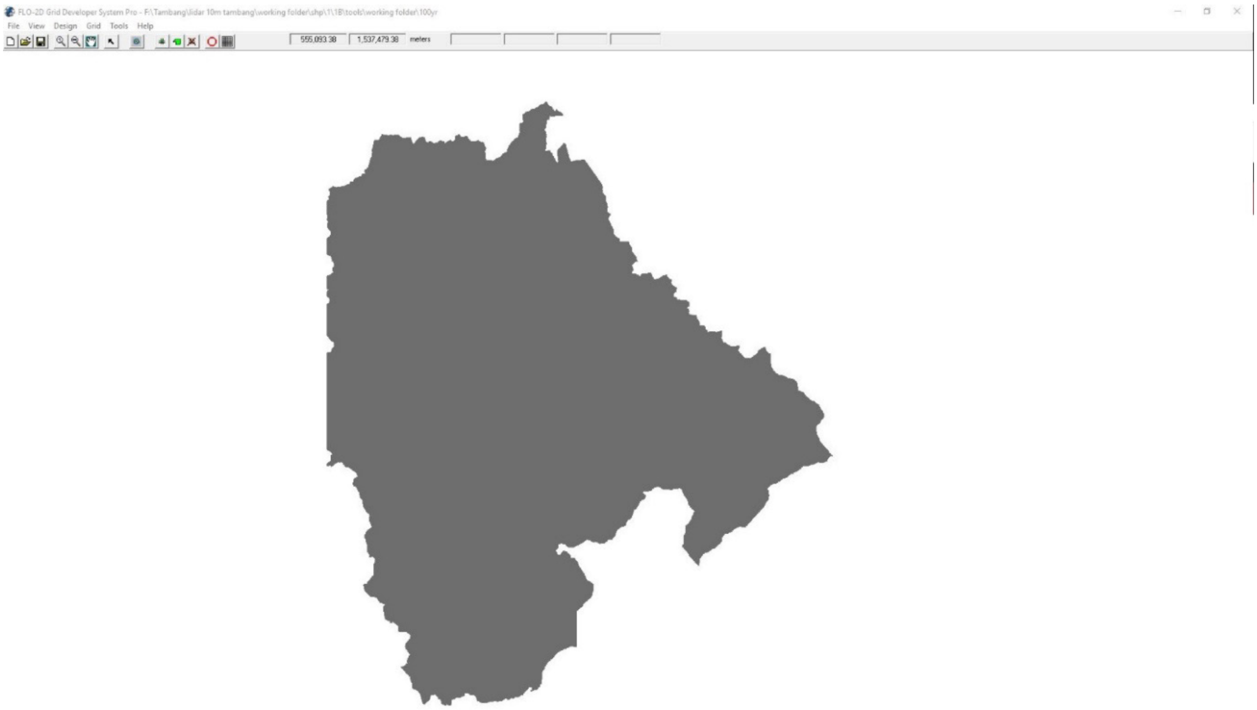

Figure 53. Screenshot of the river sub-catchment with the computational area to be modeled in FLO-2D Grid Developer System Pro (FLO-2D GDS Pro)

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 220.37793 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m2/s. The generated hazard maps for Tambang are in Figure 57, Figure 59, and Figure 61.

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 82,537,440.00 m2. The generated flood depth maps for Tambang are in Figure 58, Figure 60, and Figure 62.

There is a total of 68,348,674.31 m3 of water entering the model. Of this amount, 37,011,348.95 m3 is due to rainfall while 31,337,325.36 m3 is inflow from other areas outside the model. 44,867,551.64 m3 of this water is lost to infiltration and interception, while 8,313,813.00 m3 is stored by the flood plain. The rest, amounting up to 44,867,551.64 m3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Tambang HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 14 shows the comparison between the two discharge data.

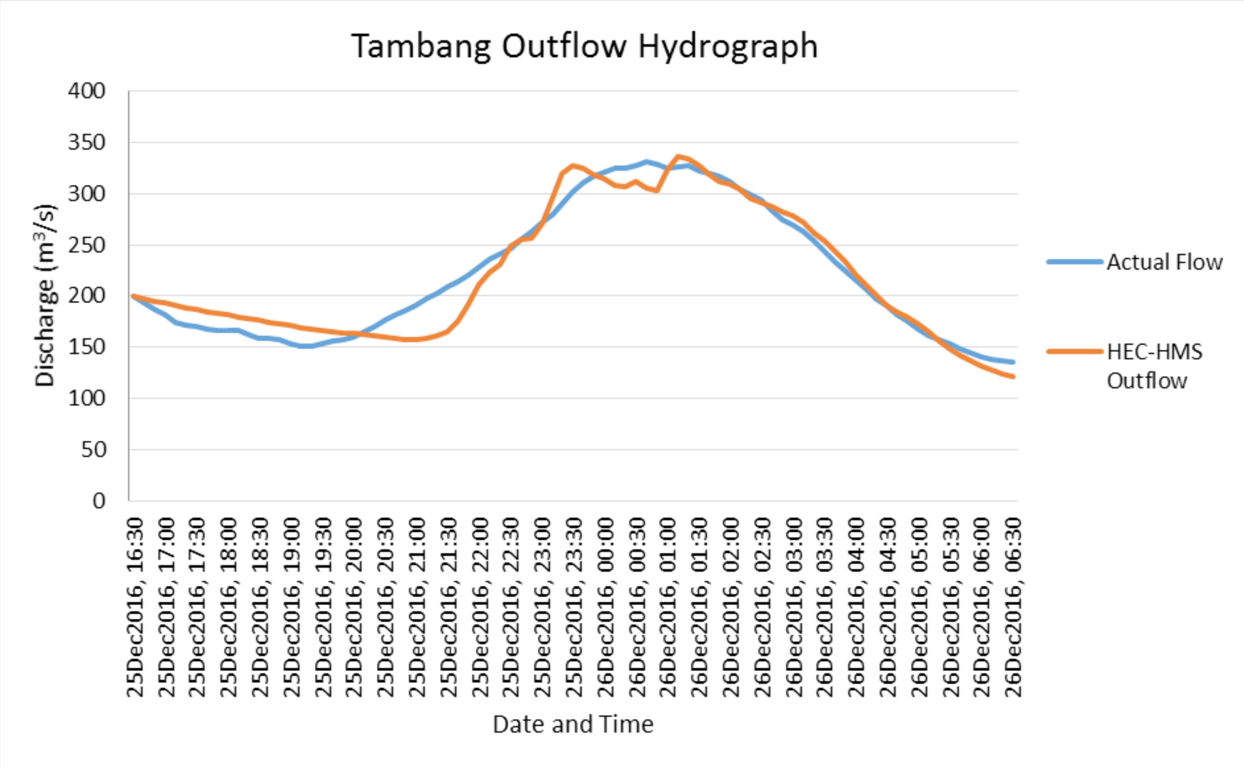

Figure 54. Outflow hydrograph of Tambang produced by the HEC-HMS model compared with observed outflow

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

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

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	0.001 – 25
			Curve Number	35 – 89
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.02 – 144
			Storage Coefficient (hr)	0.02 – 7
	Baseflow	Recession	Recession Constant	0.00001
			Ratio to Peak	0.0008 – 1
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.0004 – 0.05

Initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as initial abstraction decreases. The range of values from 0.001mm to 25mm means that there is minimal to average 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 89 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 Tambang, the basin mostly consists of forest plantation and the soil consists of Antipolo-Alimodian-Luisiana complex 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 0.02 hours to 144 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 Tambang, it will take at least 3 hours from the peak discharge to go back to the initial discharge.

Manning's roughness coefficient of 0.00001 corresponds to the common roughness in Tambang watershed, which is determined to have a smooth surface (Brunner, 2010).

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

Accuracy measure	Value
RMSE	15.614
r2	0.942
NSE	0.94
PBIAS	0.224
RSR	0.244

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 15.614 (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 0.942.

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 0.94.

A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate bias towards over-prediction. Again, the optimal value is 0. In the model, the PBIAS is 0.224.

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 0.244.

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 55) shows the Tambang outflow using the synthetic storm events using the Daet Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (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 142.5m3/s in a 5-year return period to 260.9m3/s in a 100-year return period.

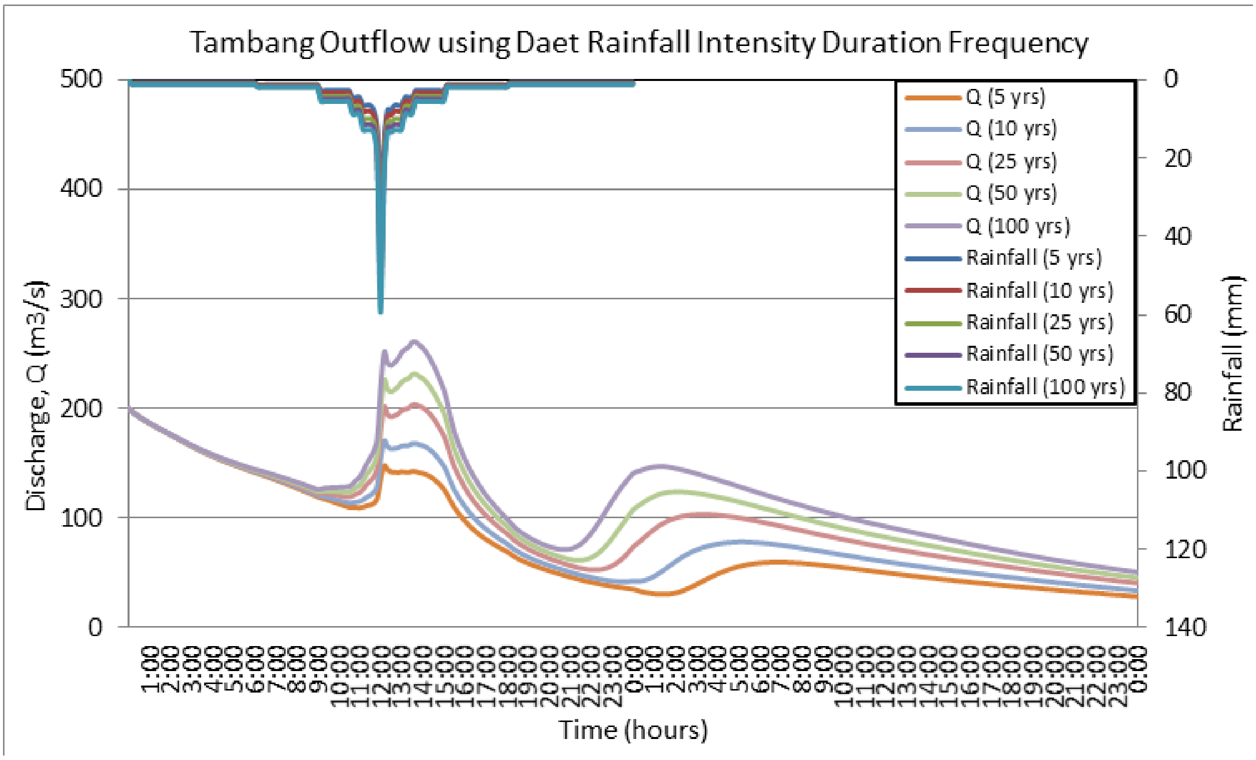

Figure 55. Outflow hydrograph at the Tambang Basin generated using the simulated rain events for 24-hour period for Daet station

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

Table 29. Peak values of the Tambang HEC-HMS Model outflow using the Daet RIDF 24-hour values.

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	278.70	31.80	142.5	1 hour, 40 minutes
10-Year	337.20	38.50	168.2	1 hour, 40 minutes
25-Year	411.10	46.90	203.76	1 hour, 40 minutes
50-Year	465.90	53.20	231.5	1 hour, 40 minutes
100-Year	520.30	59.40	260.9	1 hour, 40 minutes

5.8 River Analysis (RAS) Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model 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. Figure 56 shows a generated sample map of the Tambang River using the calibrated HMS base flow.

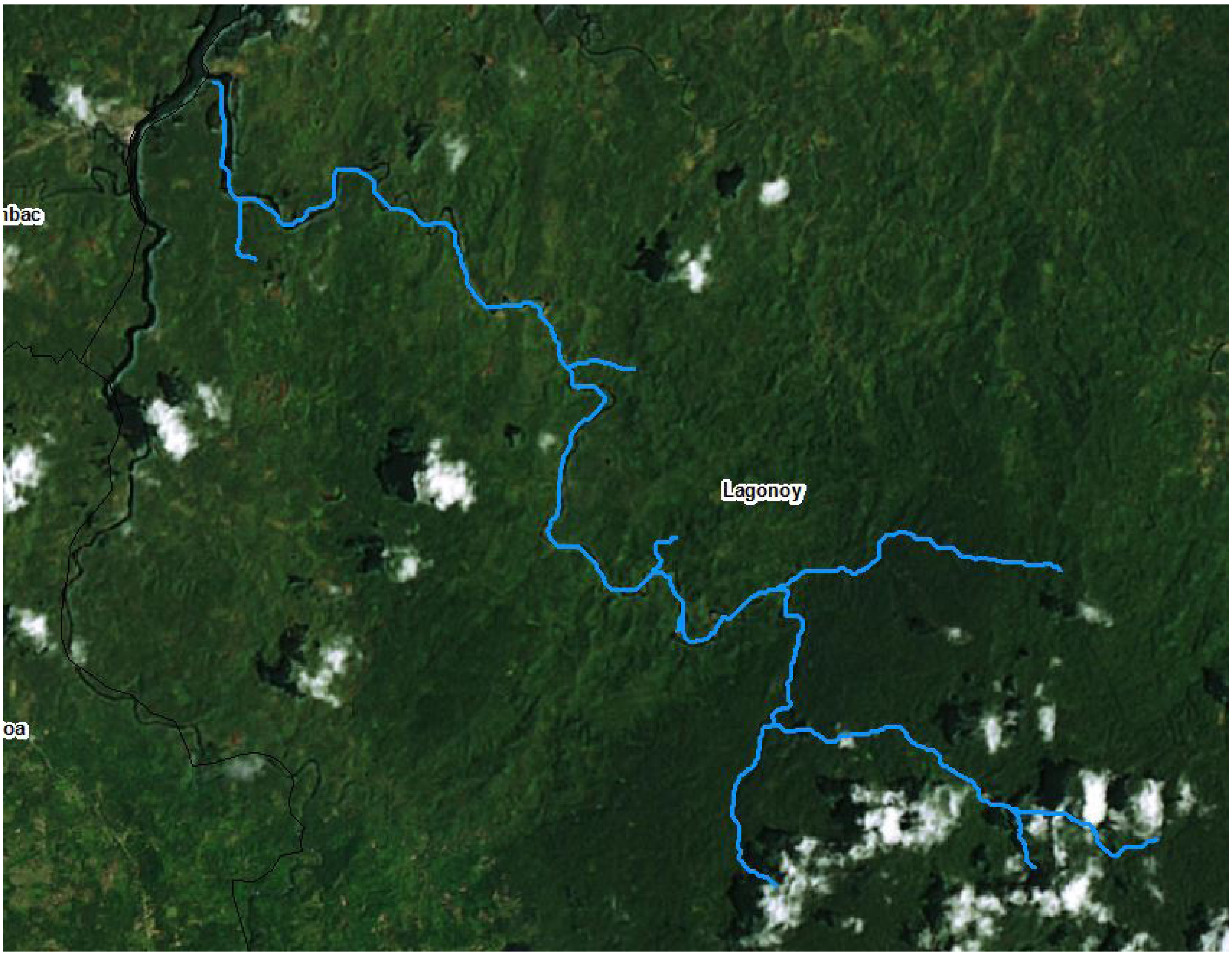

Figure 56. Sample output map of Gahub RAS Model

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. The generated flood hazard maps for the Tambang Floodplain were used to assess the vulnerability of the educational and medical institutions in the floodplain. Using the flood depth units of PAGASA for hazard maps - “Low”, “Medium”, and “High” - the affected institutions were given their individual assessment for each Flood Hazard Scenario (5 yr, 25 yr, and 100 yr). Figure 57 to Figure 62 shows the 5-, 25-, and 100-year rain return scenarios of the Tambang floodplain. The flood plain, with an area of 127.4km2, covers three (3) municipalities, namely Goa, Lagonoy, and Tinambac. Table 30 shows the percentage of area affected by flooding per municipality.

Table 30. Municipalities affected in Tambang Floodplain

Municipality	Total Area	Area Flooded	% Flooded
Goa	220.76	9.85	4.46
Lagonoy	394.86	83.43	21.13
Tinambac	288.53	33.28	11.54

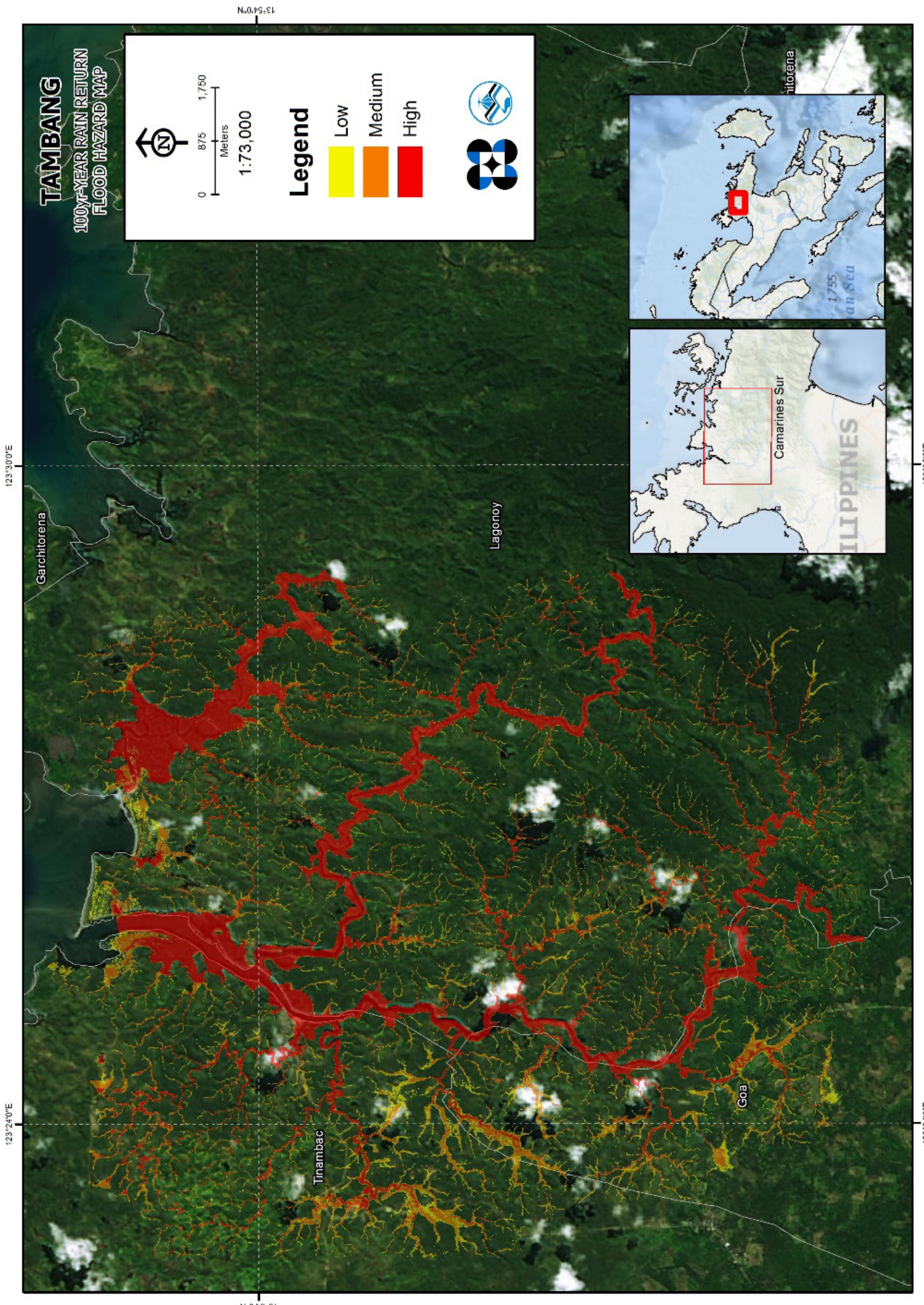

Figure 57. 100-year Flood Hazard Map for Tambang Floodplain overlaid on Google Earth imagery

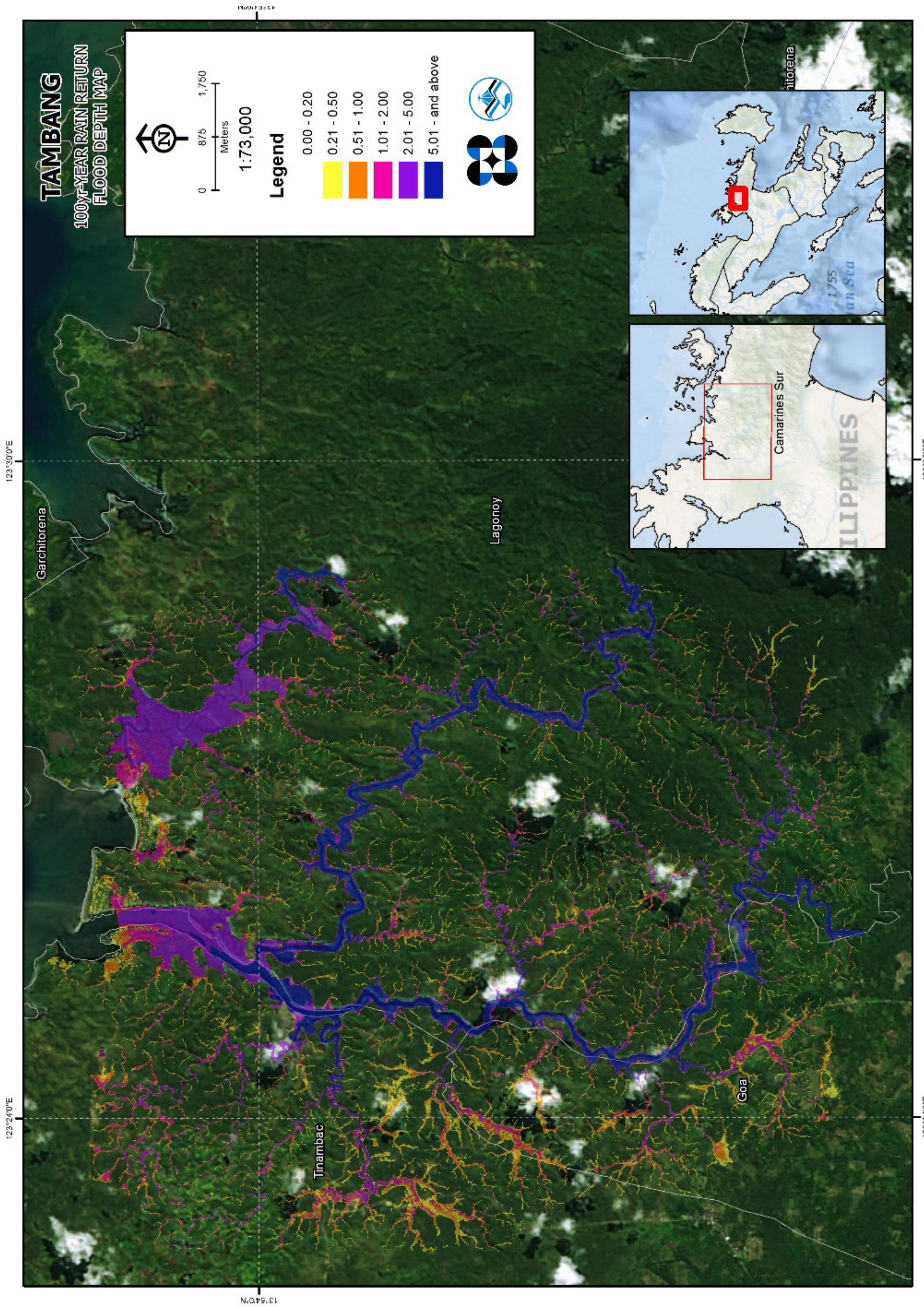

Figure 58. 100-year Flow Depth Map for Tambang Floodplain overlaid on Google Earth imagery

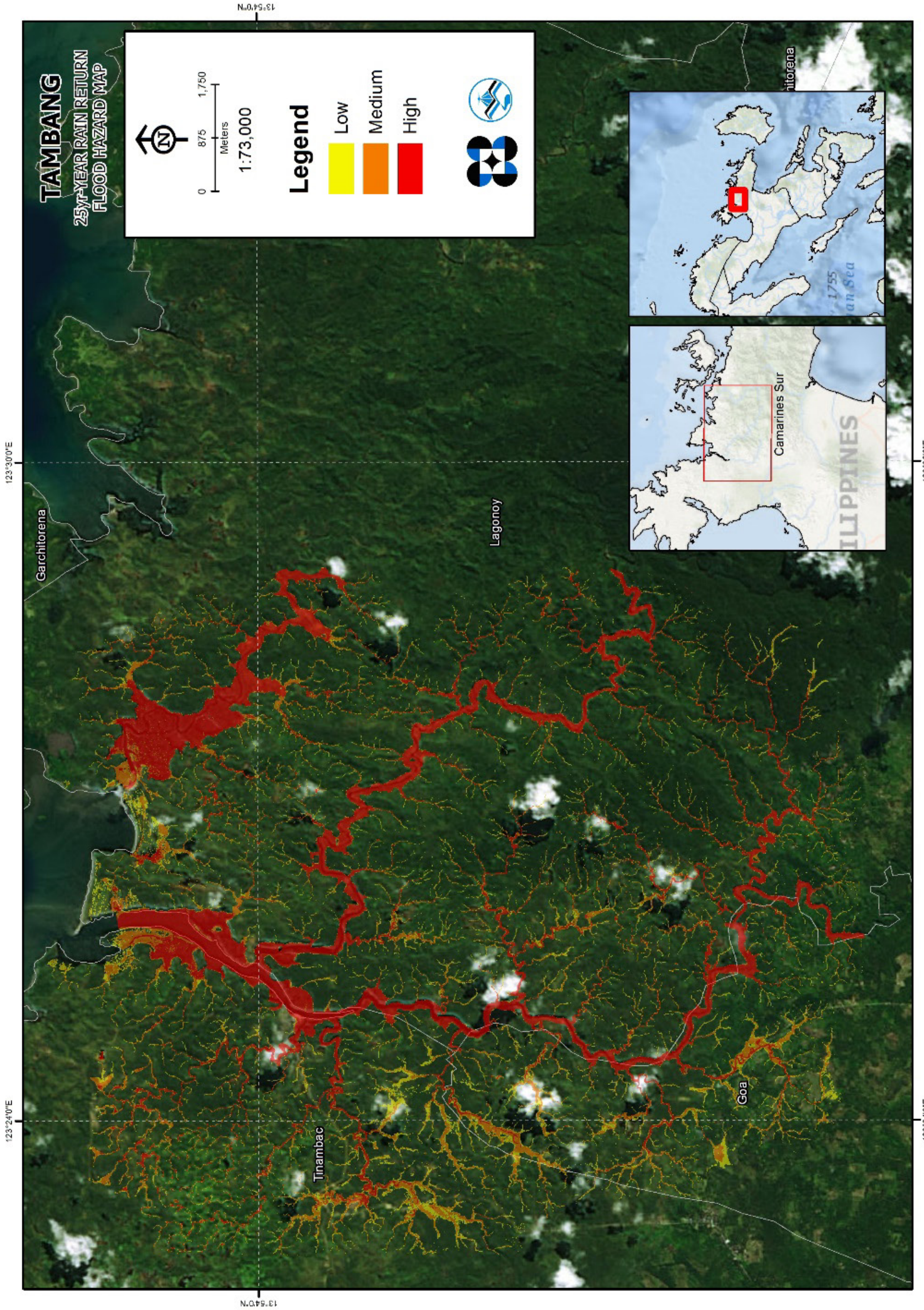

Figure 59. 25-year Flood Hazard Map for Tambang Floodplain overlaid on Google Earth imagery

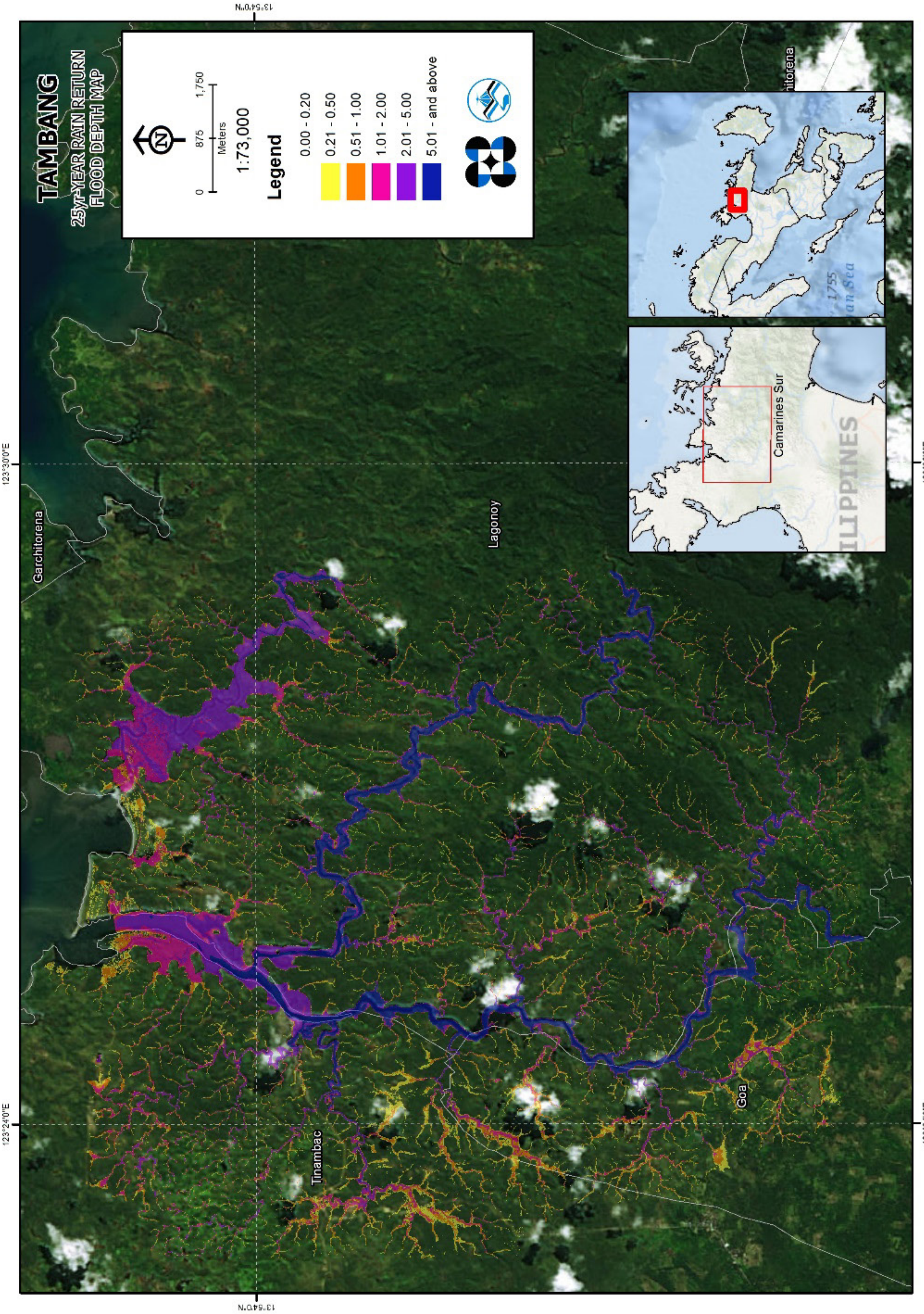

Figure 60. 25-year Flow Depth Map for Tambang Floodplain overlaid on Google Earth imagery

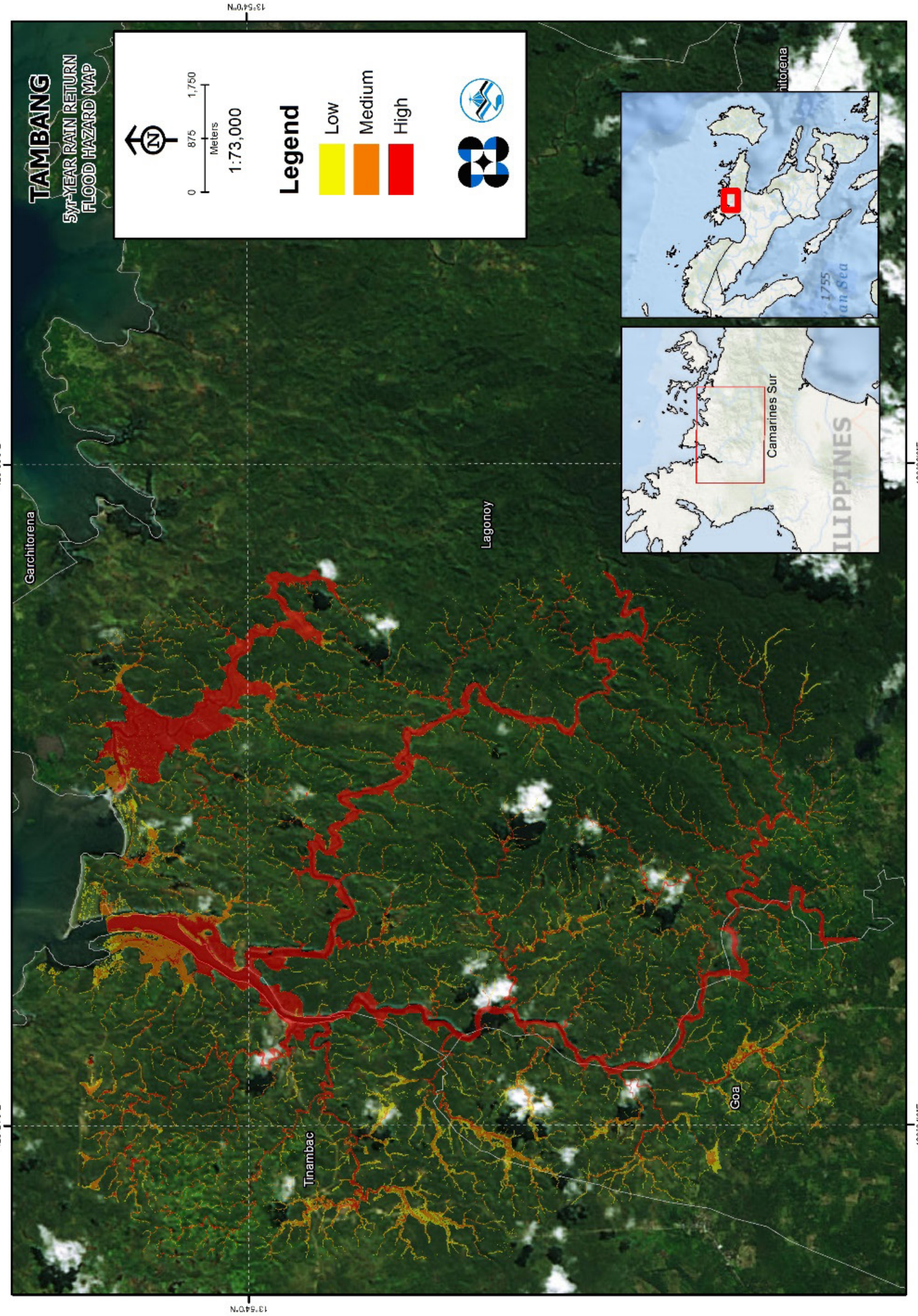

Figure 61. 5-year Flood Hazard Map for Tambang Floodplain overlaid on Google Earth imagery

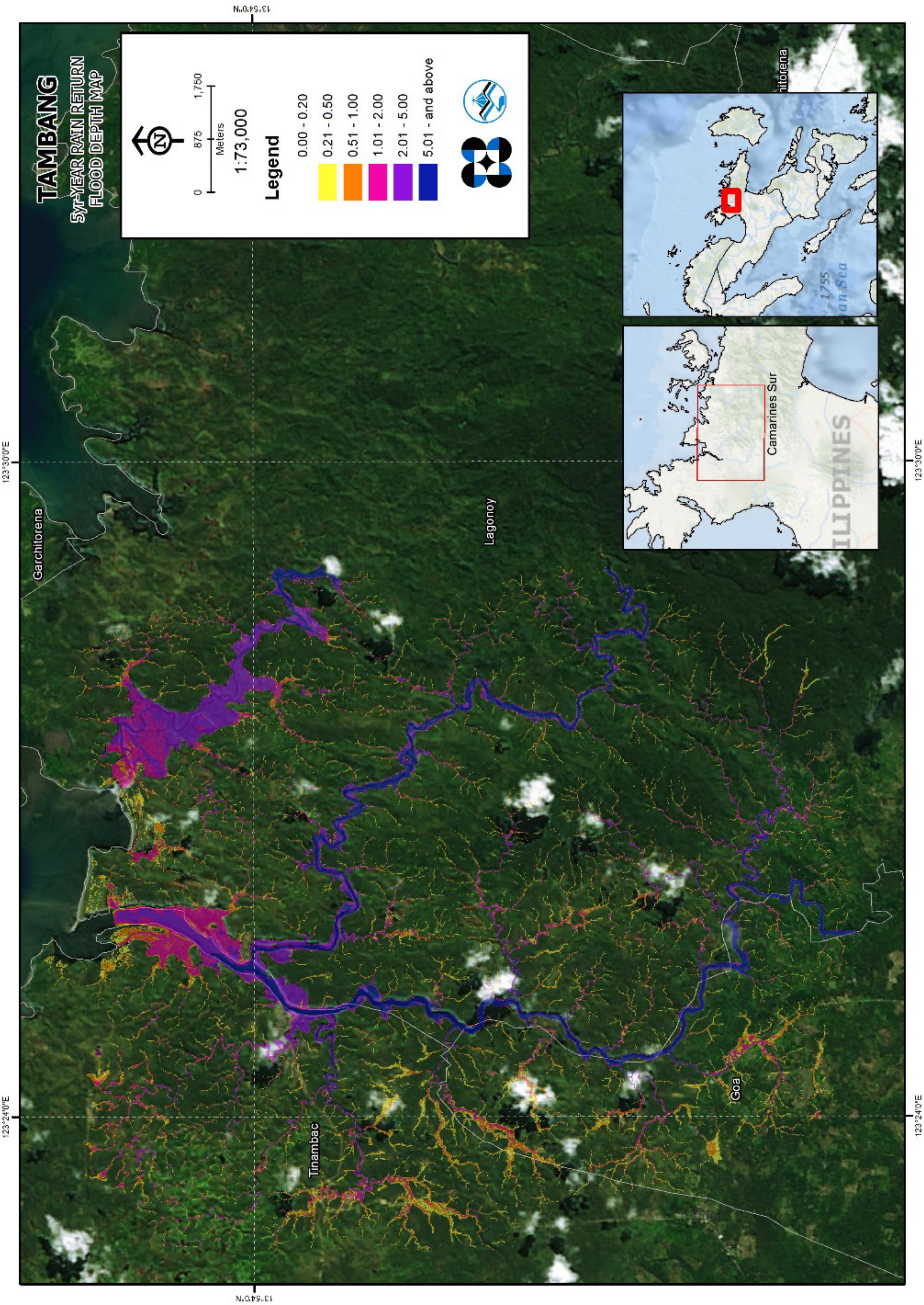

Figure 62. 5-year Flood Depth Map for Tambang Floodplain overlaid on Google Earth imagery

5.10 Inventory of Areas Exposed to Flooding

Listed below are the barangays affected by the Tambang River Basin, grouped accordingly by municipality. For the said basin, three (3) municipalities consisting of 18 barangays are expected to experience flooding when subjected to the three rainfall return period scenarios.

For the 5-year rainfall return period, 0.03% of the municipality of Goa with an area of 220.76 sq. km. will experience flood levels of less than 0.20 meters. 0.24% of the area will experience flood levels of 0.21 to 0.50 meters, while 1.42%, 1.16%, 0.79%, and 0.82% 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. Listed in Table 31 and shown in Figure 63 are the affected areas in Goa in square kilometres by flood depth per barangay.

Table 31. Affected areas in Goa, Camarines Sur during a 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Goa (in sq. km.)			
	Lamon	Maysalay	Scout Fuentebella	Tamban
0.03-0.20	0.061	0.00088	0.0001	0.000086
0.21-0.50	0.3	0.13	0.046	0.059
0.51-1.00	0.097	0.17	0.27	2.6
1.01-2.00	0.0086	0.043	2.44	0.068
2.01-5.00	1.62	0	0.082	0.045
> 5.00	1.69	0	0.071	0.056

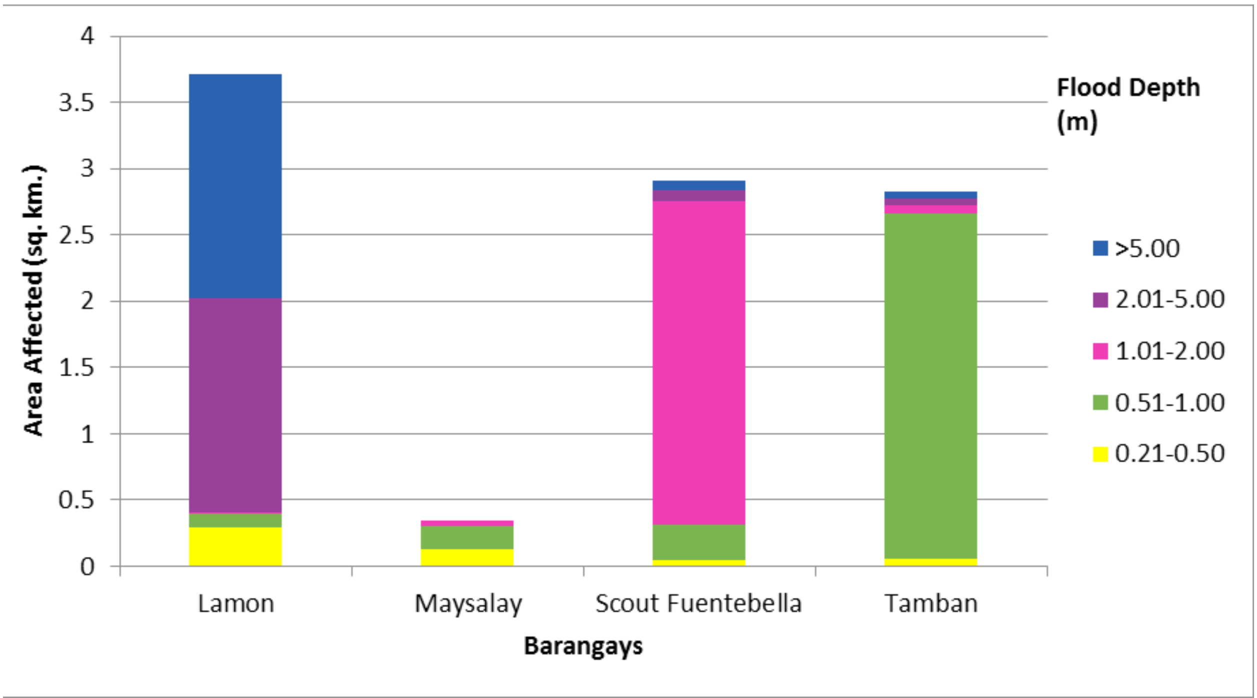

Figure 63. Affected Areas in Goa, Camarines Sur during 5-Year Rainfall Return Period

For the municipality of Lagonoy with an area of 394.86 sq. km., 2.37% will experience flood levels of less than 0.20 meters. 11.18% of the area will experience flood levels of 0.21 to 0.50 meters, while 3.88%, 0.17%, 1.82%, and 1.71% 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. Listed in Table 32 and shown in Figure 64 are the affected areas in square kilometres by flood depth per barangay.

Table 32. Affected areas in Lagonoy, Camarines Sur during a 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Lagonoy (in sq. km.)						
	Bocogan	Del Carmen	Guibahoy	Mapid	Olas	Pinamihagan	Santa Cruz
0.03-0.20	0.0002	0.0011	0.085	0.0076	0.0012	0.000077	9.26
0.21-0.50	0.96	0.086	0.081	0.28	0.014	41.53	1.2
0.51-1.00	0.083	0.081	0.19	0.32	13.7	0.49	0.45
1.01-2.00	0.056	0.057	0.26	0.098	0.19	0.0057	0.0025
2.01-5.00	0.0079	0.0004	6.26	0.33	0.29	0.22	0.084
> 5.00	0	0.041	0.033	0	0.0005	6.44	0.24

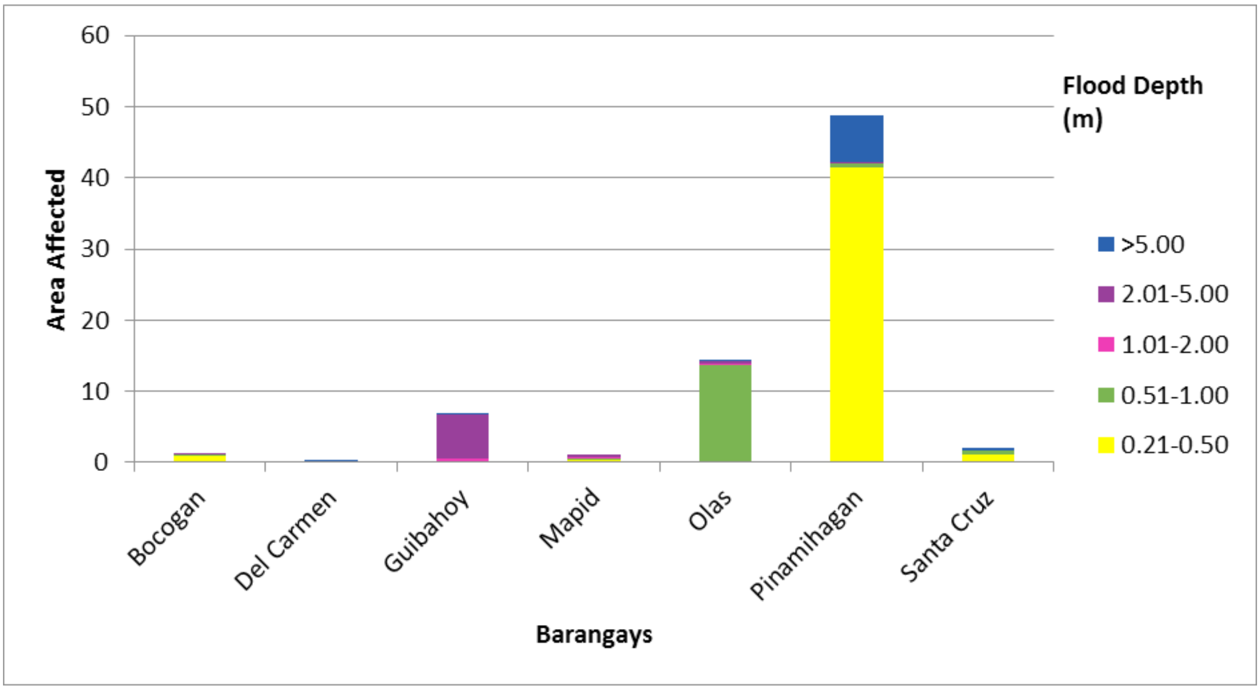

Figure 64. Affected Areas in Lagonoy, Camarines Sur during 5-Year Rainfall Return Period

For the municipality of Tinambac with an area of 288.53 sq. km., 2.43% will experience flood levels of less than 0.20 meters. 3.92% of the area will experience flood levels of 0.21 to 0.50 meters, while 1.28%, 2.9%, 0.55%, and 0.45% 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. Listed in Table 33 and shown in Figure 65 are the areas affected in Tinambac in square kilometers by flood depth per barangay.

Table 33. Affected areas in Tinambac, Camarines Sur during a 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Tinambac (in sq. km.)						
	Antipolo	Banga	Bataan	Pag-Asa	San Ramon	San Roque	Tambang
0.03-0.20	0.51	0.35	0.18	0.13	0.27	5.2	0.38
0.21-0.50	0.75	0.76	1.41	1.54	6.62	0.14	0.09
0.51-1.00	0.89	1.4	0.31	1.05	0.032	0.011	0.0066
1.01-2.00	0.0004	6.98	0.67	0.42	0.18	0.086	0.022
2.01-5.00	0	0.0001	1.41	0.054	0.051	0.055	0.015
> 5.00	0	0.28	0	0.5	0	0.44	0.083

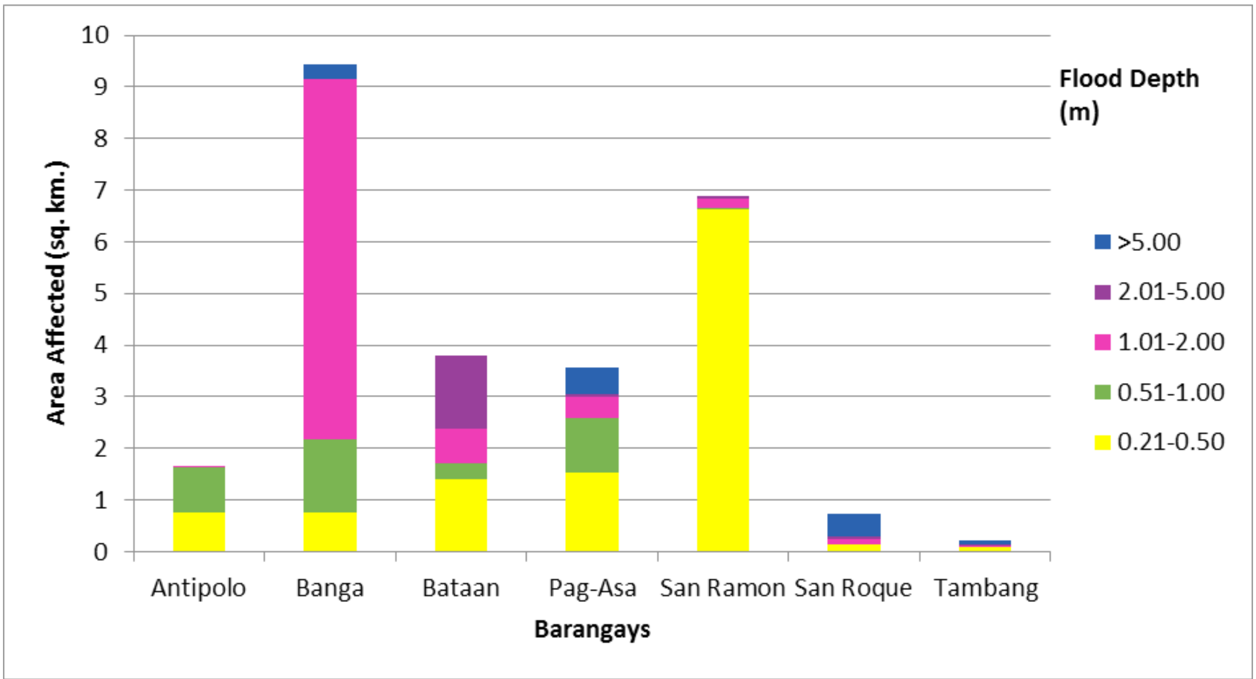

Figure 65. Affected Areas in Tinambac, Camarines Surl during 5-Year Rainfall Return Period

For the 25-year rainfall return period, 6.42% of the municipality of Goa with an area of 220.76 sq. km. will experience flood levels of less than 0.20 meters. 0.44% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.35%, 0.19%, 0.1%, 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. Listed in Table 34 and shown in Figure 66 are the affected areas in square kilometres by flood depth per barangay.

Table 34. Affected areas in Goa, Camarines Sur during a 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Goa (in sq. km.)			
	Lamon	Maysalay	Scout Fuentebella	Tamban
0.03-0.20	0.06	0.077	8.99	5.05
0.21-0.50	0.0012	0.016	0.55	0.4
0.51-1.00	0.0001	0.0016	0.42	0.35
1.01-2.00	0	0.00014	0.23	0.18
2.01-5.00	0.00042	0	0.17	0.058
> 5.00	0.0014	0	0.35	0.074

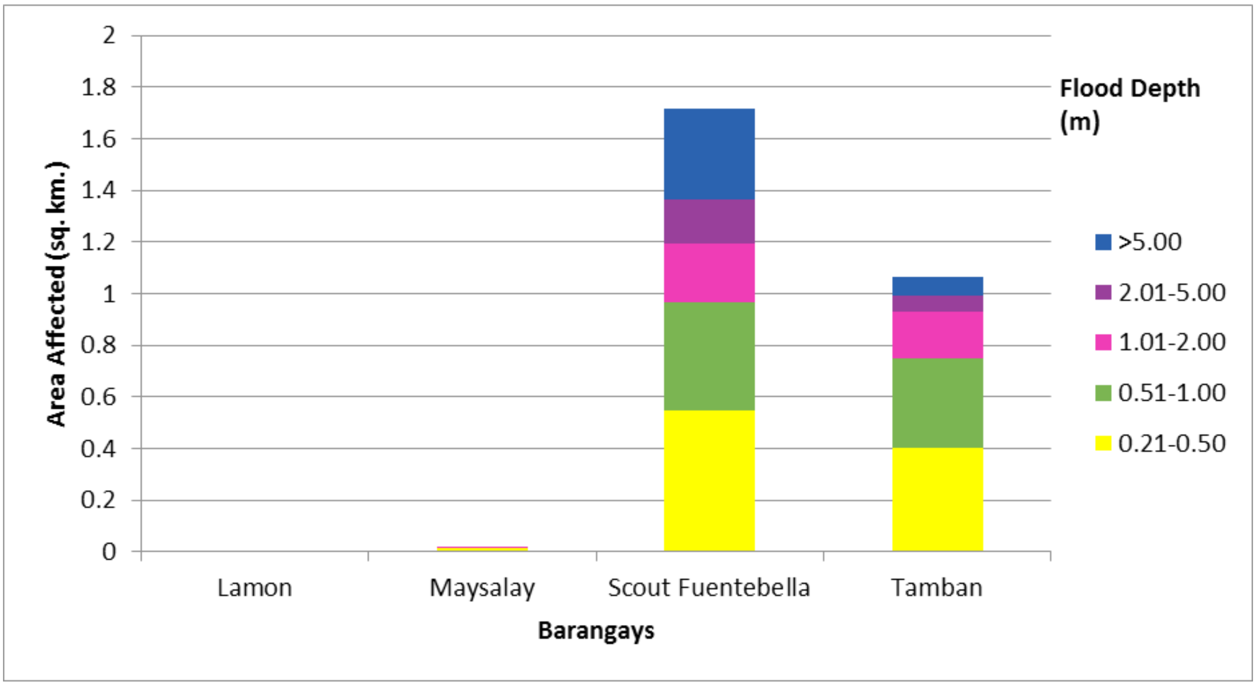

Figure 66. Affected Areas in Goa, Camarines Sur during 25-Year Rainfall Return Period

For the municipality of Lagonoy with an area of 394.86 sq. km., 17.17% will experience flood levels of less than 0.20 meters. 0.58% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.41%, 0.57%, 0.99%, and 0.7% 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. Listed in Table 35 and shown in Figure 67 are the affected areas in square kilometres by flood depth per barangay.

Table 35. Affected areas in Lagonoy, Camarines Sur during a 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Lagonoy (in sq. km.)						
	Bocogan	Del Carmen	Guibahoy	Mapid	Olas	Pinamihagan	Santa Cruz
0.03-0.20	0.92	40.79	6.53	2.58	13.52	1.03	2.43
0.21-0.50	0.098	1.32	0.15	0.086	0.52	0.034	0.073
0.51-1.00	0.059	0.84	0.099	0.076	0.48	0.014	0.061
1.01-2.00	0.14	0.77	0.1	0.21	0.96	0.0076	0.062
2.01-5.00	0.21	1.46	0.19	0.32	1.41	0.0088	0.3
> 5.00	0	2.02	0.3	0	0.36	0.056	0.048

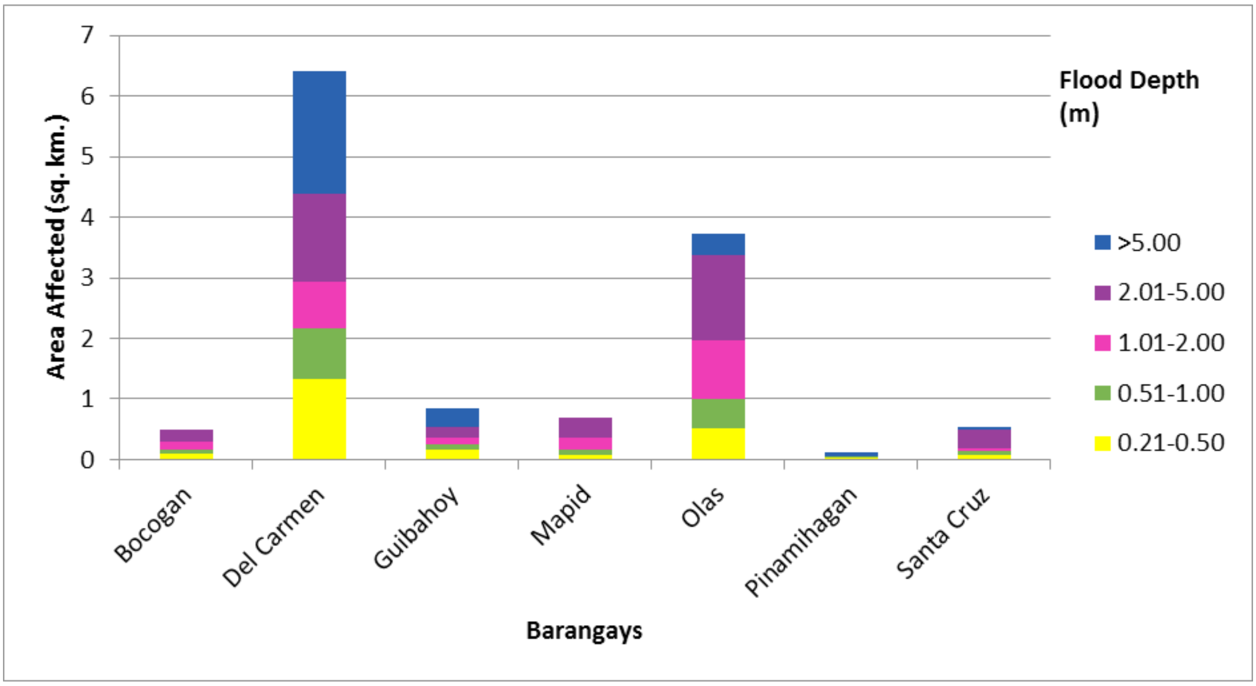

Figure 67. Affected Areas in Lagonoy, Camarines Sur during 25-Year Rainfall Return Period

For the municipality of Tinambac with an area of 288.53 sq. km., 8.32% will experience flood levels of less than 0.20 meters. 0.53% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.42%, 0.41%, 0.27%, and 0.08% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Listed in Table 36 and shown in Figure 68 are the areas affected in Tinambac in square kilometers by flood depth per barangay.

Table 36. Affected areas in Tinambac, Camarines Sur during a 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Tinambac (in sq. km.)						
	Antipolo	Banga	Bataan	Pag-Asa	San Ramon	San Roque	Tambang
0.03-0.20	0.19	6.74	1.59	6.14	1.39	1.67	6.29
0.21-0.50	0.0065	0.74	0.085	0.32	0.055	0.072	0.25
0.51-1.00	0.003	0.5	0.057	0.33	0.053	0.063	0.2
1.01-2.00	0.0006	0.24	0.013	0.27	0.064	0.048	0.55
2.01-5.00	0	0.11	0.0005	0.12	0.021	0.04	0.47
> 5.00	0	0.033	0	0.0005	0	0.0014	0.21

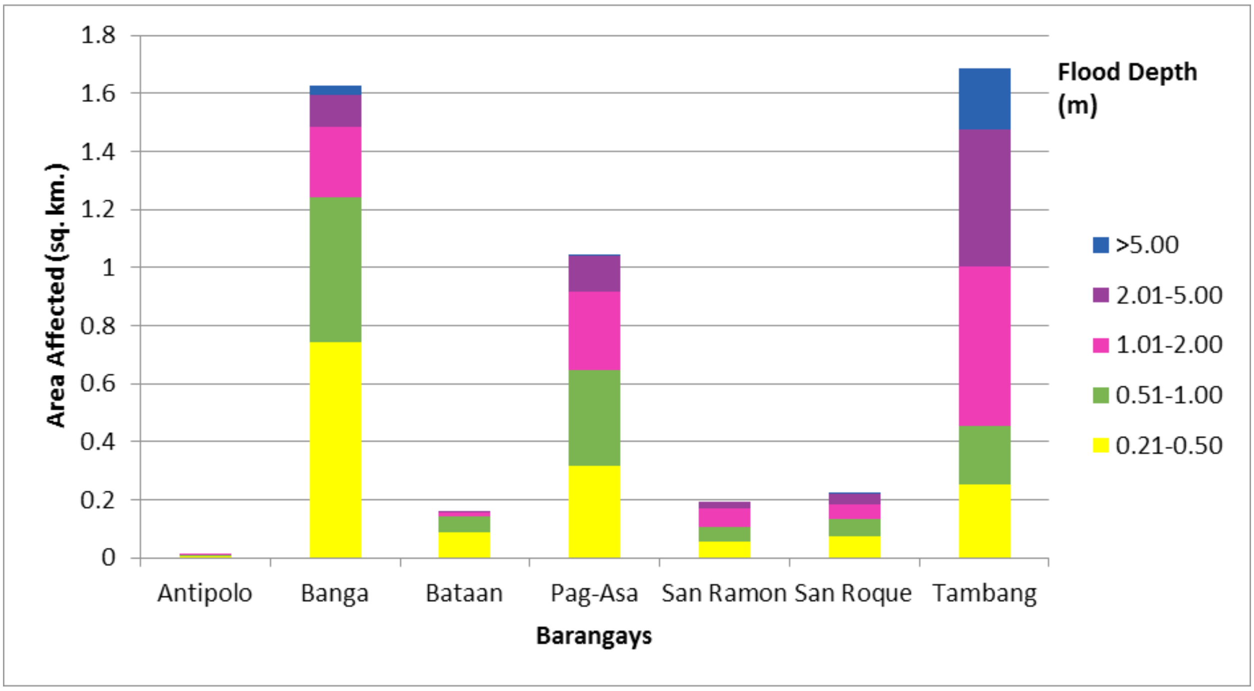

Figure 68. Affected Areas in Tinambac, Camarines Surl during 25-Year Rainfall Return Period

For the 100-year rainfall return period, 6.22% of the municipality of Goa with an area of 220.76 sq. km. will experience flood levels of less than 0.20 meters. 0.46% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.39%, 0.24%, 0.13%, and 0.25% 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. Listed in Table 37 and shown in Figure 69 are the affected areas in Goa in square kilometres by flood depth per barangay.

Table 37. Affected areas in Goa, Camarines Sur during a 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Goa (in sq. km.)			
	Lamon	Maysalay	Scout Fuentebella	Tamban
0.03-0.20	0.06	0.069	8.69	4.91
0.21-0.50	0.0012	0.023	0.57	0.42
0.51-1.00	0	0.0015	0.47	0.39
1.01-2.00	0.0004	0.00035	0.29	0.23
2.01-5.00	0.00014	0	0.22	0.076
> 5.00	0.0018	0	0.45	0.09

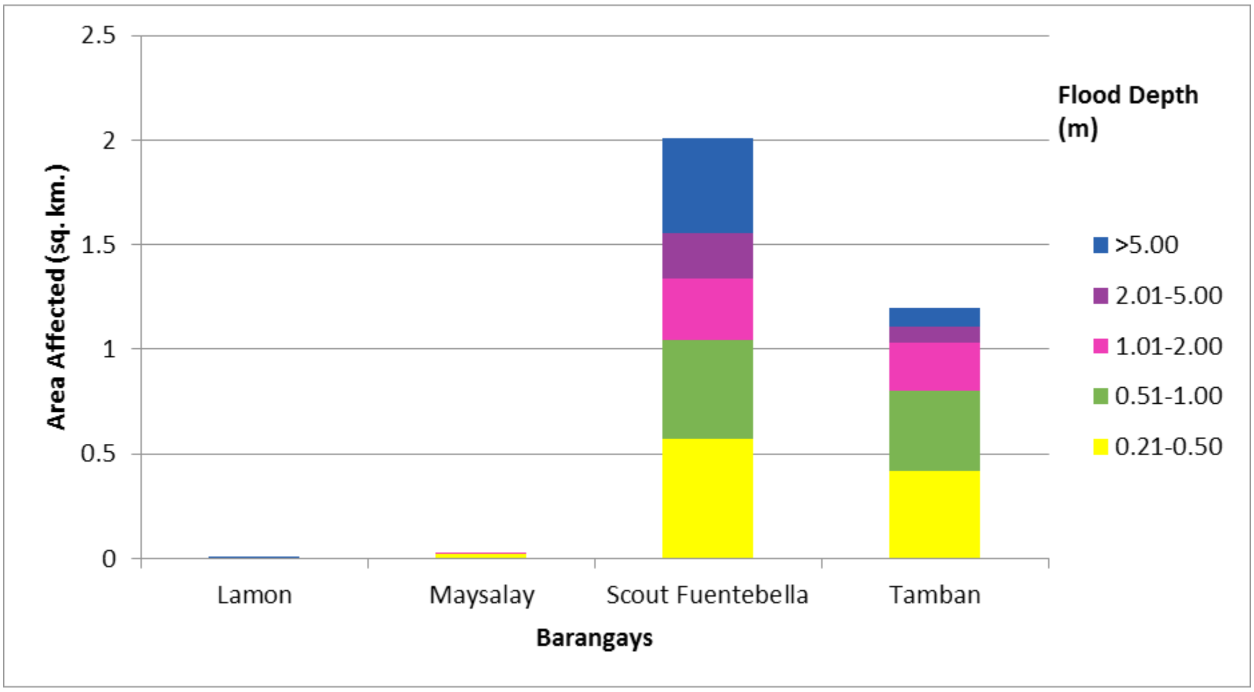

Figure 69. Affected Areas in Goa, Camarines Sur during 100-Year Rainfall Return Period

For the municipality of Lagonoy with an area of 394.86 sq. km., 16.86% will experience flood levels of less than 0.20 meters. 0.62% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.43%, 0.5%, 1.08%, and 0.94% 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. Listed in Table 38 and shown in Figure 70 are the affected areas in Lagonoy in square kilometres by flood depth per barangay.

Table 38. Affected areas in Lagonoy, Camarines Sur during a 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Lagonoy (in sq. km.)						
	Bocogan	Del Carmen	Guibahoy	Mapid	Olas	Pinamihagan	Santa Cruz
0.03-0.20	0.89	39.98	6.42	2.56	13.3	1.02	2.39
0.21-0.50	0.11	1.44	0.17	0.086	0.54	0.038	0.076
0.51-1.00	0.059	0.92	0.099	0.075	0.46	0.017	0.06
1.01-2.00	0.079	0.86	0.1	0.12	0.75	0.0085	0.066
2.01-5.00	0.29	1.35	0.19	0.43	1.73	0.01	0.27
> 5.00	0	2.64	0.41	0	0.48	0.063	0.11

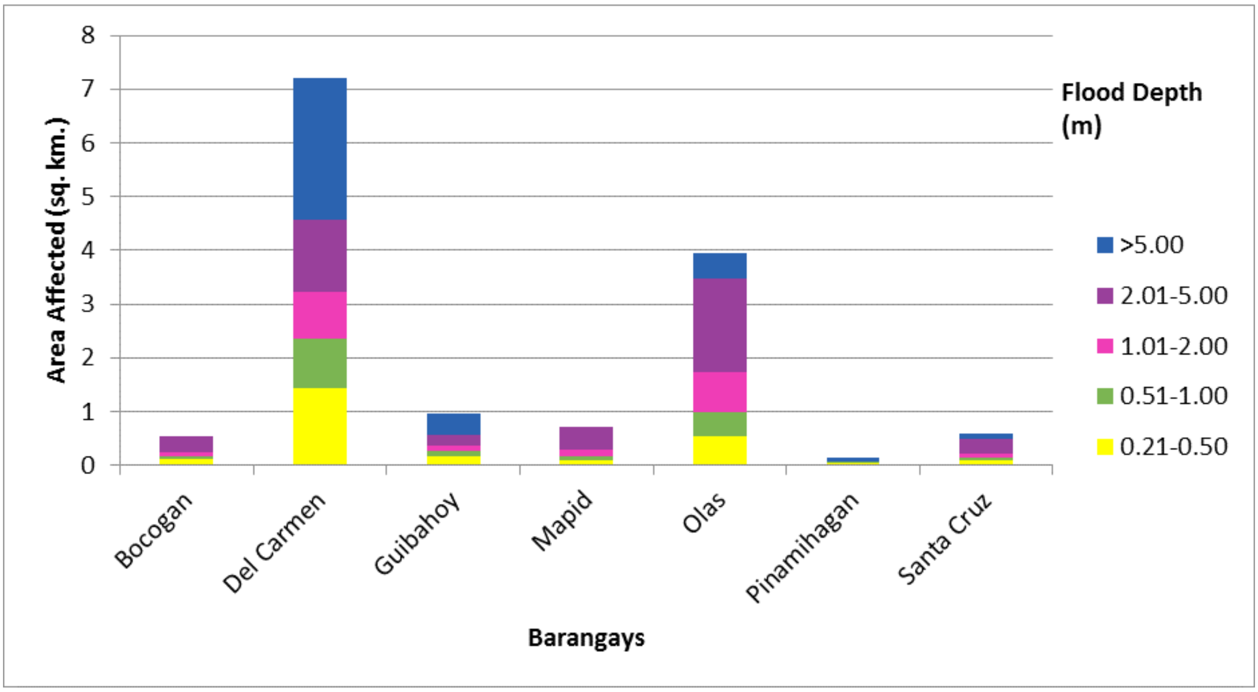

Figure 70. Affected Areas in Lagonoy, Camarines Sur during 100-Year Rainfall Return Period

For the municipality of Tinambac with an area of 288.53 sq. km., 8.13% will experience flood levels of less than 0.20 meters. 0.55% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.46%, 0.39%, 0.38%, and 0.12% 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. Listed in Table 39 and shown in Figure 71 are the areas affected in Tinambac in square kilometers by flood depth per barangay.

Table 39. Affected areas in Tinambac, Camarines Sur during a 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Tinambac (in sq. km.)						
	Antipolo	Banga	Bataan	Pag-Asa	San Ramon	San Roque	Tambang
0.03-0.20	0.18	6.51	1.57	6.02	1.37	1.64	6.16
0.21-0.50	0.0071	0.78	0.094	0.32	0.052	0.075	0.26
0.51-1.00	0.0035	0.58	0.063	0.34	0.061	0.067	0.2
1.01-2.00	0.0008	0.31	0.02	0.32	0.071	0.055	0.35
2.01-5.00	0	0.14	0.0005	0.17	0.029	0.049	0.7
> 5.00	0	0.043	0	0.0036	0.0001	0.0031	0.31

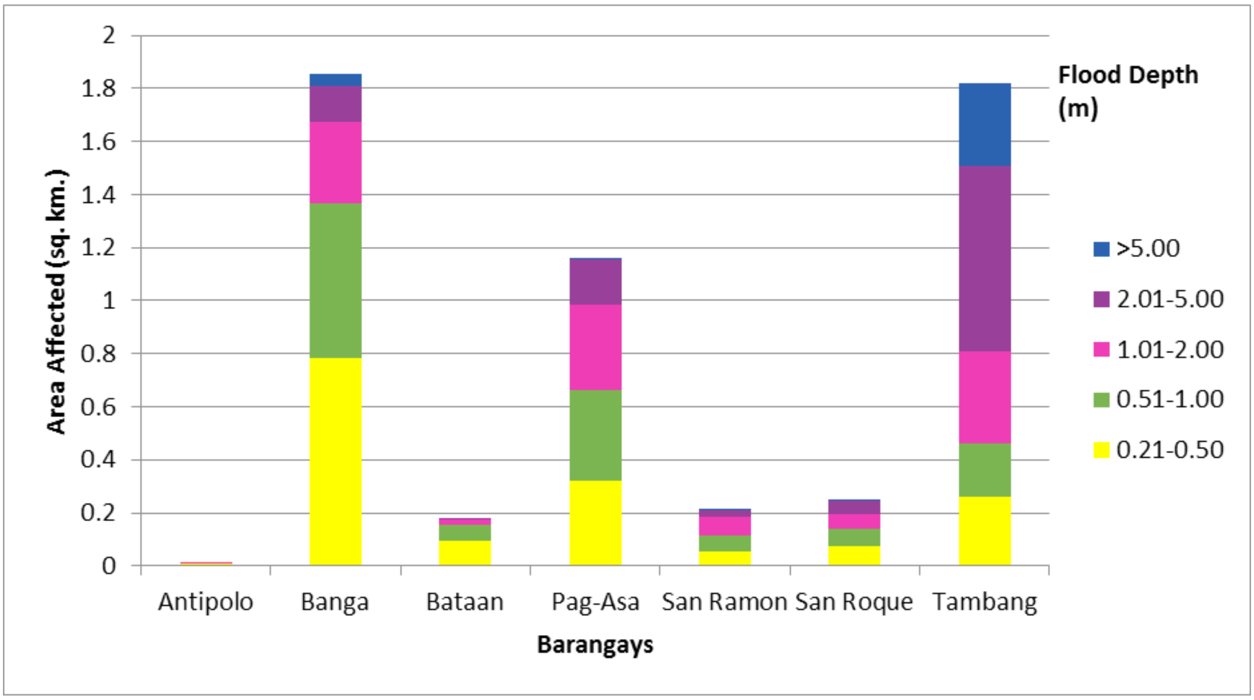

Figure 71. Affected Areas in Tinambac, Camarines Surl during 100-Year Rainfall Return Period

Among the barangays in the municipality of Goa, Lamon is projected to have the highest percentage of area that will experience flood levels at 1.71%. Meanwhile, Scout Fuentebella posted the second highest percentage of area that may be affected by flood depths at 1.32%.

Among the barangays in the municipality of Lagonoy, Pinamihagan is projected to have the highest percentage of area that will experience flood levels at 12.33%. Meanwhile, Olas posted the second highest percentage of area that may be affected by flood depths at 3.59%.

Among the barangays in the municipality of Tinambac, Banga is projected to have the highest percentage of area that will experience flood levels at 3.39%. Meanwhile, San Ramon posted the second highest percentage of area that may be affected by flood depths at 2.48%.

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

Table 40. Areas covered by each warning level with respect to the rainfall scenarios

Warning Level	Area Covered in sq. km.		
	5 year	25 year	100 year
Low	4.46	4.77	5.04
Medium	5.23	5.53	5.82
High	9.81	11.32	13.01
TOTAL	**19.5**	**21.62**	**23.87**

Of the 6 identified Educational Institutions in Tambang floodplain, none was assessed to be exposed to any level of flooding in all the rainfall scenarios. The educational institutions exposed to flooding are shown in Annex 12.

Of the 4 identified Medical or Health Institutions in Tambang floodplain, none was assessed to be exposed to any level of flooding in the 5-year scenario. In the 25-year scenario, none was assessed to be exposed to any level of flooding. In the 100-year scenario, none was assessed to be exposed to both low and high, while 1 was assessed to be exposed to medium level flooding. The medical institutions exposed to flooding are found in Annex 13.

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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

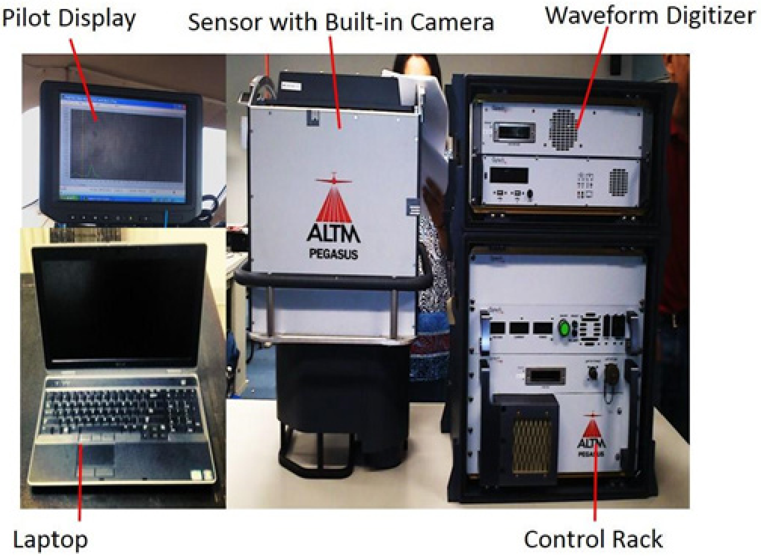


Figure A-1.1. Parameters and Specification of the Pegasus Sensor

Table A-1.1. Parameters and Specification 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 dis-tance	<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
Relative humidity	0-95% no-condensing

1 Target reflectivity ≥20%
2 Dependent on selected operational parameters using nominal FOV of up to 40° in standard atmospheric conditions with 24-km visibility
3 Angle of incidence ≤20˚
4 Target size ≥ laser footprint5 Dependent on system configuration

Annex 2. NAMRIA Certification of Reference Points Used in the LIDAR Survey

1. CMS-103

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

May 02, 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: **CAMARINES SUR**			
		Station Name: **CMS-103**			
		Order: **2nd**			
Island:	**LUZON**	Barangay:	**POBLACION**		
Municipality:	**TAMBAN**	MSL Elevation:			
		PRS92 Coordinates			
Latitude:	**13° 53' 44.46082"**	Longitude:	**123° 24' 52.41074"**	Ellipsoidal Hgt:	**4.58100 m.**
		WGS84 Coordinates			
Latitude:	**13° 53' 39.40601"**	Longitude:	**123° 24' 57.34955"**	Ellipsoidal Hgt:	**55.99300 m.**
		PTM / PRS92 Coordinates			
Northing:	**1536671.409 m.**	Easting:	**544805.234 m.**	Zone:	**4**
		UTM / PRS92 Coordinates			
Northing:	**1,536,133.55**	Easting:	**544,789.55**	Zone:	**51**

Location Description

CMS-103

Station is located at Tamban port area, it was established at the top edge of seawall. Mark is the head of a 4 in. copper nail centered on a drilled hole with cement putty, embedded at concrete pavement, with inscriptions, "CMS-103, 2007, NAMRIA".

Requesting Party: **Merlin Fernando**
Purpose: **Reference**
OR Number: **3943035 I**
T.N.: **2016-1021**

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

9905022016121208

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. CMS-103

2. CS-461

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

June 28, 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: **CAMARINES SUR**
Station Name: **CS-461**

Island: **Luzon**	Municipality: **TINAMBAC**	Barangay: **BOLAOBALITE**
Elevation: **5.4281 +/- 0.0618 m.**	Accuracy Class at 95% C.L: **5 CM**	Datum: **Mean Sea Level**
Latitude:	Longitude:	

The accuracy standards reported herein (FGDC-STD-007-1998) supersedes and replace the previous accuracy standards found in FGCC 1984 and FGCC 1988. Classified control points are verified as being consistent w/ all other points in the network, not merely those within that particular survey.

Location Description

CS-461 is in the Province of Camarines Sur, Municipality of Tinambac, Brgy. Balaobalite, along the Tinambac to Calabanga road. The station i sloctaec on a bridge.

A copper nail is embedded and cemented in the middle of a 6 in. x 6 in cement putty with inscription "CS-461, 2008 NAMRIA".

Requesting Party: **PHIL-LIDAR 1**
Purpose: **Reference**
OR Number: **8094859 I**
T.N.: **2016-1311**

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

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. CS-461

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

1. CS-461

Table A-3.1. CS-461

Vector Components (Mark to Mark)

From:	CMS-103				
Grid		Local		Global	
Easting	544789.551 m	Latitude	N13°53'44.46082"	Latitude	N13°53'39.40601"
Northing	1536133.547 m	Longitude	E123°24'52.41074"	Longitude	E123°24'57.34955"
Elevation	3.904 m	Height	4.581 m	Height	55.993 m

To:	CS-461				
Grid		Local		Global	
Easting	536011.654 m	Latitude	N13°48'16.97629"	Latitude	N13°48'11.93661"
Northing	1526059.719 m	Longitude	E123°19'59.46340"	Longitude	E123°20'04.41063"
Elevation	7.728 m	Height	8.314 m	Height	59.780 m

Vector					
ΔEasting	-8777.897 m	NS Fwd Azimuth	221°10'00"	ΔX	6018.784 m
ΔNorthing	-10073.828 m	Ellipsoid Dist.	13366.718 m	ΔY	6854.008 m
ΔElevation	3.824 m	ΔHeight	3.732 m	ΔZ	-9770.665 m

Standard Errors

Vector errors:					
σ ΔEasting	0.001 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.006 m
σ ΔNorthing	0.001 m	σ Ellipsoid Dist.	0.001 m	σ ΔY	0.009 m
σ ΔElevation	0.011 m	σ ΔHeight	0.011 m	σ ΔZ	0.003 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000320941		
Y	-0.0000473036	0.0000756414	
Z	-0.0000144523	0.0000223329	0.0000079814

Occupations

	From	To
Point ID:	CMS-103	CS-461
Data file:	C:\Users\Windows User\Documents \Business Center - HCE\Unnamed(3)\CMS-103 (Modular) 1.552M [05-03-16].T02	C:\Users\Windows User\Documents \Business Center - HCE\Unnamed (3)\RINEX CS-461 1.490M [05-03-16].16D
Receiver type:	SPS852	Unknown
Receiver serial number:	5203K81512	U1K7M3544CO
Antenna type:	Zephyr Geodetic	CR.G5
Antenna serial number:	--------	-Unknown-
Antenna height (measured):	1.552 m	1.490 m
Antenna method:	Bottom of notch	Bottom of antenna mount

Tracking Summary

2. CS-464

Table A-3.2. DVE-3118

Vector Components (Mark to Mark)

From:	CMS-103				
Grid		Local		Global	
Easting	544789.551 m	Latitude	N13°53'44.46082"	Latitude	N13°53'39.40601"
Northing	1536133.547 m	Longitude	E123°24'52.41074"	Longitude	E123°24'57.34955"
Elevation	3.904 m	Height	4.581 m	Height	55.993 m

To:	CS-464				
Grid		Local		Global	
Easting	535835.478 m	Latitude	N13°47'06.64679"	Latitude	N13°47'01.61166"
Northing	1523899.018 m	Longitude	E123°19'53.49615"	Longitude	E123°19'58.44508"
Elevation	7.478 m	Height	8.046 m	Height	59.563 m

Vector					
ΔEasting	-8954.073 m	NS Fwd Azimuth	216°17'54"	ΔX	5885.438 m
ΔNorthing	-12234.530 m	Ellipsoid Dist.	15166.867 m	ΔY	7382.824 m
ΔElevation	3.574 m	ΔHeight	3.465 m	ΔZ	-11869.678 m

Standard Errors

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

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000186593		
Y	-0.0000199574	0.0000353943	
Z	-0.0000064437	0.0000096572	0.0000033881

Annex 4. The LIDAR Survey Team Composition

Table A-4.1. The LiDAR Survey Team Composition

Data Acquisition Component Sub-Team	Designation	Name	Agency/ Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, DR.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
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUÑA	UP-TCAGP
			UP-TCAGP

FIELD TEAM

LiDAR Operation	Supervising Science Research Specialist (SSRS)	LOVELYN ASUNCION	UP-TCAGP
	Research Associate (RA)	MARY CATHERINE ELIZA-BETH BALIGUAS	UP-TCAGP
	RA	ENGR. GEF SORIANO	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	JASMIN DOMINGO	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. BENJIE CAR-BOLLEDO	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. KAHLIL CHI	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. DEXTER CABUDOL	AAC

Annex 5. Data Transfer Sheet for Tambang Floodplain

DATA TRANSFER SHEET
5/5/2014(Bacolod ~~Pend(S)~~) Ready

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS	POS	RAW IMAGES	MISSION LOG FILE	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
Apr 21, 2014	1371P	1BLK45DE110A	PEGASUS	1.83GB	300KB	7.87MB	165MB	43.7GB	336KB	16.9GB	N/A	14.8MB	103B	0B	53.3KB/48.8KB/ 39.9KB/53.3KB/	1.67KB	Z:\Airborne_Raw\1371P
Apr 21, 2014	1373P	1BLK45B110B	PEGASUS	1.93GB	1.42MB	7.76MB	149MB	23.2GB	221KB	17.2GB	N/A	14.8MB	103B	230B	39.9KB	1.67KB	Z:\Airborne_Raw\1373P
Apr 22, 2014	1375P	1BLK45B111A	PEGASUS	3.72GB	1.65MB	13.9MB	264MB	46.0GB	366KB	34.9GB	N/A	13.6MB	103B	527B	28.3KB/37.8KB/ 41.0KB	1.67KB	Z:\Airborne_Raw\1375P
Apr 22, 2014	1377P	1BLK45C111B	PEGASUS	1.73GB	1.06MB	7.10MB	154MB	17.5GB	4.19KB/ 164KB	15.6GB	N/A	13.6MB	103B	250B	3.44KB/49.6KB	1.67KB	Z:\Airborne_Raw\1377P
Apr 25, 2014	1387P	1BLK45AC114A	PEGASUS	2.59GB	672KB	13.2MB	275MB	44.2GB	350KB	27.3GB	N/A	7.15MB	103B	457B	73.5KB/62.3KB/ 57.8KB	1.67KB	Z:\Airborne_Raw\1387P
Apr 26, 2014	1391P	1BLK44CB115A	PEGASUS	3.40GB	1.51MB	12.6MB	257MB	52.0GB	159KB/ 168KB	30.7GB	N/A	12.3MB	152B	460B	51KB/48.8KB/7. 25KB/63.8KB/3.	2.01KB	Z:\Airborne_Raw\1391P
Apr 27, 2014	1393P	1BLK44AB115B	PEGASUS	2.92GB	2.91MB	13.3MB	264MB	45.0GB	356KB	30.6GB	N/A	12.3MB	152B	666B	51.3KB/49.1KB	2.01KB	Z:\Airborne_Raw\1393P

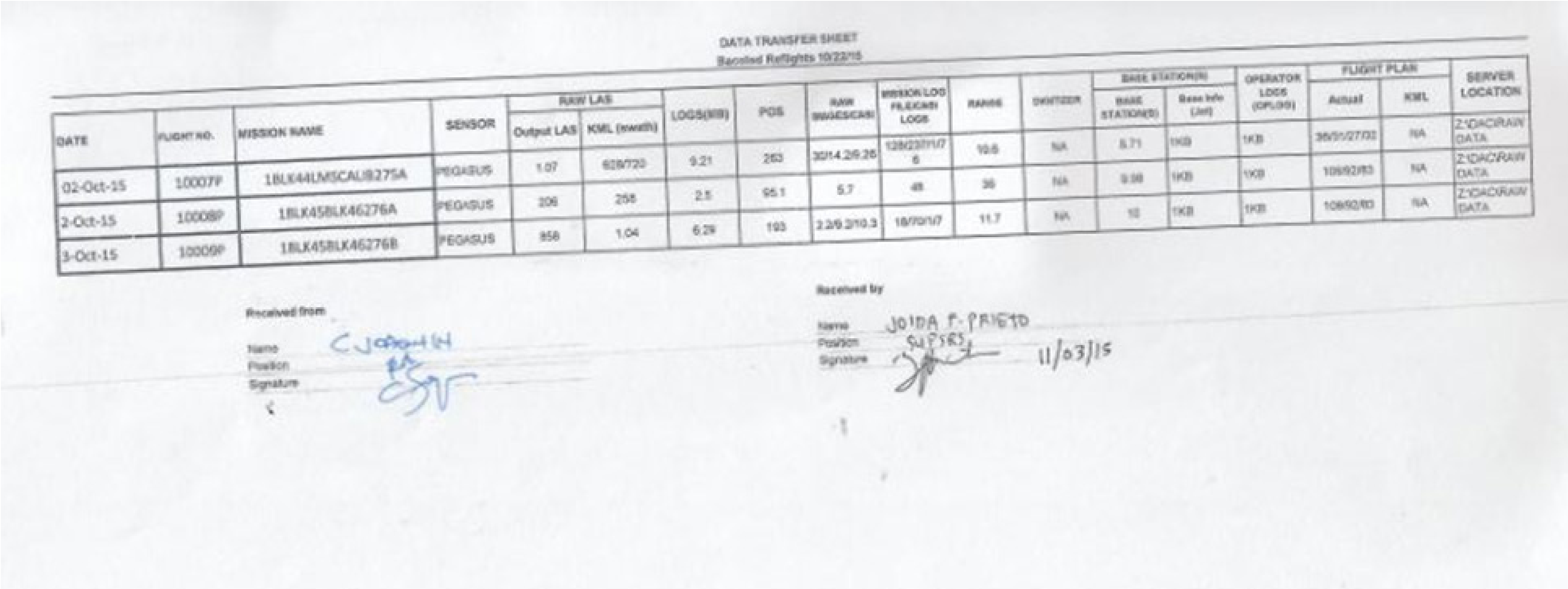
Received from

Name GRACE B. SINADJAN
Position RA
Signature

Received by

Name Benjamin Magallon
Position
Signature
5/26/2014

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



DATA TRANSFER SHEET
Bacolod Reflights 10/22/15

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	
02-Oct-15	10007P	1BLK44LMSCALIB275A	PEGASUS	1.07	628/720	9.21	263	30/14.2/9.26	128/237/1/7 6	10.6	NA	8.71	1KB	1KB	36/51/27/32	NA	Z:\DAC\RAW DATA
2-Oct-15	10008P	1BLK45BLK46276A	PEGASUS	206	258	2.5	95.1	5.7	48	36	NA	9.98	1KB	1KB	109/92/83	NA	Z:\DAC\RAW DATA
3-Oct-15	10009P	1BLK45BLK46276B	PEGASUS	856	1.04	6.29	193	2.2/9.2/10.3	18/70/1/7	11.7	NA	10	1KB	1KB	108/92/80	NA	Z:\DAC\RAW DATA

Received from

Name C JOSON H
Position RA
Signature

Received by

Name JOIDA F. PRIETO
Position SUPSRS
Signature 11/03/15

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

Annex 6. Flight Logs for the Flight Missions

1. Flight Log for Mission 23276P

DREAM Program's Data Acquisition Flight Log

Flight Log No.: 23276P

1 LiDAR Operator: BALICUAS / SORIANO	2 ALTM Model: PEGASUS	3 Mission Name: 1BLK24F6113A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9122
7 Pilot: S. ALFONSO	8 Co-Pilot: K.A. CHI	9 Route:			
10 Date: 4/22/16	12 Airport of Departure (Airport, City/Province): NAIA		12 Airport of Arrival (Airport, City/Province): NAIA		
13 Engine On: 0815	14 Engine Off: 1225	15 Total Engine Time: 4+10	16 Take off: 0820	17 Landing: 1220	18 Total Flight Time: 4+00
19 Weather: cloudy					

20 Flight Classification

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

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

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

21 Remarks

Surveyed BLK24F & BLK24G

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/ Technician
LOVELY ACUNA	BENJIE CAMBOLLEDO	C. A. ALFONSO III	MCE BALICUAS	
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 23276P

2. Flight Log for 23278P Mission

DREAM Program's Data Acquisition Flight Log

Flight Log No.: 23278P

1 LiDAR Operator: Soriano	2 ALTM Model: Pegasus	3 Mission Name: 1BLK14CFMA	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP-9122
7 Pilot: S. Alfonso	8 Co-Pilot: K. Chi	9 Route:			
10 Date: 09/27/16	12 Airport of Departure (Airport, City/Province): NAGA		12 Airport of Arrival (Airport, City/Province): NAGA		
13 Engine On: 0647	14 Engine Off: 1054	15 Total Engine Time: 4+05	16 Take off: 0652	17 Landing: 1047	18 Total Flight Time: 3+55
19 Weather					

20 Flight Classification

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

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

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

21 Remarks

Surveyed 2 lines in BLK C, 4 lines in BLK A and 6 lines in BLK F.

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/ Technician
Lovelyn Asuncion	Bendie Cardolledo	C. Alfonso III	Gef Soriano	
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 23278P

3. Flight Log for 23282P Mission

DREAM Program's Data Acquisition Flight Log

Flight Log No.: 23282P

1 LiDAR Operator: BALIGUAS	2 ALTM Model: PEGASUS	3 Mission Name: 1BLK24ASFS*SA	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RP-9122
7 Pilot: S. Alfonso	8 Co-Pilot: K. Chi	9 Route:			
10 Date: 04/24/16	12 Airport of Departure (Airport, City/Province): NAGA		12 Airport of Arrival (Airport, City/Province): NAGA		
13 Engine On: 0628	14 Engine Off: 1651	15 Total Engine Time: 4+23	16 Take off: 0633	17 Landing: 1046	18 Total Flight Time: 4+18
19 Weather					

20 Flight Classification

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

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

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

21 Remarks

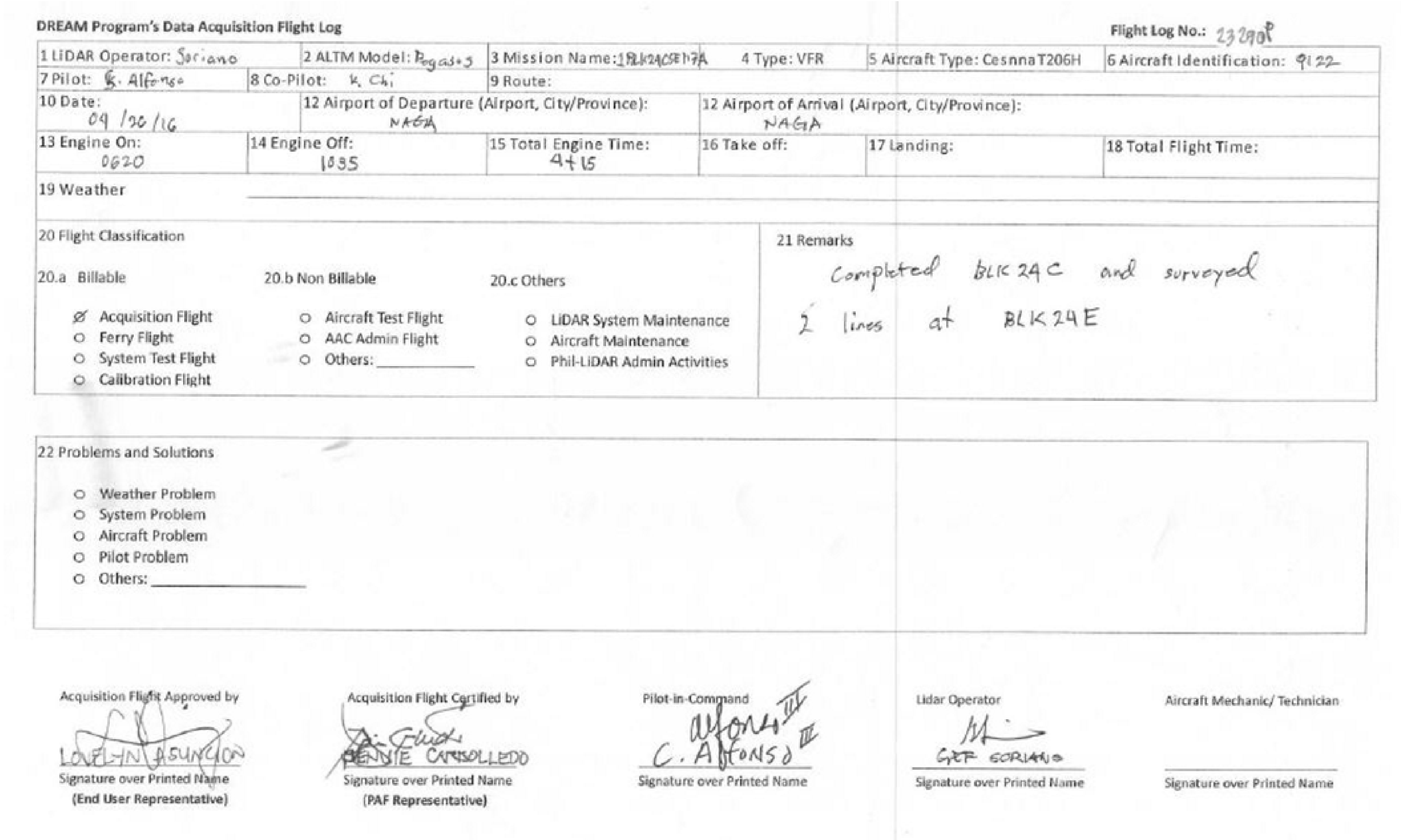
Completed BLK 24a and BLK 24f

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/ Technician
LOVELYN ASUNCION	MENDIE CARBOLLEDO	C. ALFONSO III	MCE BALIGUAS	
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 23282P

4. Flight Log for 23290P Mission



DREAM Program's Data Acquisition Flight Log

Flight Log No.: 23290P

1 LiDAR Operator: Soriano	2 ALTM Model: Pegasus	3 Mission Name: 1BLK24CSE17A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9122
7 Pilot: G. Alfonso	8 Co-Pilot: K. Chi	9 Route:			
10 Date: 04/26/16	12 Airport of Departure (Airport, City/Province): NAGA		12 Airport of Arrival (Airport, City/Province): NAGA		
13 Engine On: 0620	14 Engine Off: 1035	15 Total Engine Time: 4+15	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather					

20 Flight Classification

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

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

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

21 Remarks

Completed BLK 24C and surveyed 2 lines at BLK 24E

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/ Technician
LOVELYN ASUNCION	BENNIE CATSOLLEDO	C. ALFONSO III	GEF SORIANO	
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-6.4. Flight Log for Mission 23290P

5. Flight Log for 23302P Mission

DREAM Program's Data Acquisition Flight Log

Flight Log No.: 23302P

1 LiDAR Operator: MCE Baligons	2 ALTM Model: Pegasus	3 Mission Name: 2BLK29BES140A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9122
7 Pilot: S Alfonso	8 Co-Pilot: K Chi	9 Route:			
10 Date: 09/29/16	12 Airport of Departure (Airport, City/Province): Naga		12 Airport of Arrival (Airport, City/Province): Naga		
13 Engine On: 0600	14 Engine Off: 1035	15 Total Engine Time: 4+35	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather					

20 Flight Classification

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

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

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

21 Remarks

Completed BLK 29B and 24E

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/ Technician
LOVELYN ASUNCION	BESSIE CARBOLLEDO	C. ALFONSO III	MCE BALIGUAS	
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-6.5. Flight Log for Mission 23302P

6. Flight Log for 23304P Mission

DREAM Program's Data Acquisition Flight Log — **Flight Log No.:** 23304P

1 LiDAR Operator: G. SORIANO	2 ALTM Model: Pegasus	3 Mission Name: [illegible]	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9122
7 Pilot: S. Alfonso	8 Co-Pilot: K. Chi	9 Route:			
10 Date: 04/29/16	12 Airport of Departure (Airport, City/Province): Naga		12 Airport of Arrival (Airport, City/Province): Naga		
13 Engine On: 1192	14 Engine Off: 1400	15 Total Engine Time: 2+08	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather					

20 Flight Classification

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

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

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

21 Remarks

Completed BLK 2A G

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/ Technician
LOVELYN ASUNCION	CAMBOLLEDO	C. ALFONSO III	GEF SORIANO	
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-6.6. Flight Log for Mission 23304P

7. Flight Log for 23314P Mission

DREAM Program's Data Acquisition Flight Log — **Flight Log No.:** 23314P

1 LIDAR Operator: MCE BALIGUAS	2 ALTM Model: PEGASUS	3 Mission Name: 1BLK24ABC123A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9122
7 Pilot: C. ALFONSO III	8 Co-Pilot: D. CHI	9 Route:			
10 Date: MAY 2, 2016	12 Airport of Departure (Airport, City/Province):		12 Airport of Arrival (Airport, City/Province):		
13 Engine On: 0645	14 Engine Off: 1120	15 Total Engine Time: 4+35	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather					

20 Flight Classification

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

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

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

21 Remarks

Covered voids over BLK24A, B, C

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/ Technician
LOVELYN ASUNCION	BENJIE CAMPOLLEDO	C. ALFONSO III	MCE BALIGUAS	
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-6.7. Flight Log for Mission 23314P

8. Flight Log for 23318P Mission

DREAM Program's Data Acquisition Flight Log — Flight Log No.: 23318P

1 LiDAR Operator: G. SORIANO	2 ALTM Model: PEGASUS	3 Mission Name: 1BLK24ABC	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9122
7 Pilot: S. Alfonso	8 Co-Pilot: K. Chi	9 Route:			
10 Date: May 8, 2016	12 Airport of Departure (Airport, City/Province): Naga		12 Airport of Arrival (Airport, City/Province): Naga		
13 Engine On: 0622	14 Engine Off: 1047	15 Total Engine Time: 4+25	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: cloudy					

20 Flight Classification

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

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

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

21 Remarks

Surveyed voids in BLK24A, B, C

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/ Technician
LOVELYN ASUNCION	[illegible] CASTILLEJO	C. ALFONSO III	GEF SORIANO	G. ANTONIO
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-6.8. Flight Log for Mission 23318P

Annex 7. Flight Status Report

NAGA A (PEGASUS SENSOR WITHOUT CAMERA & DIGITIZER)
April 20 - May 4, 2016

Table A-7.1. Flight Status Report

FLIGHT NO.	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
23276	202.44	1BLK24FG113A	MCE BALIGUAS & G SO-RIANO	22 APRIL 16	Surveyed 14 lines over BLK24FG. Varying alti-tude due to clouds. Laser shut off at cloudy part. Camera not triggering while laser is on.
23278	169.14	1BLK24CAF114A	G SO-RIANO	23 APRIL 16	Surveyed 2 lines over BLK24C, 4 lines over BLK24A and 6 lines over BLK24F. Laser shut off due to clouds.
23282	291.79	1BLK24ASFS115A	MCE BALIGUAS	24 APRIL 16	Completed BLK24 & F with voids due to clouds. Surveyed 11 lines at BLK24A and 8 lines at BLK24 F.
23290	202.07	1BLK24CSE117A	G SO-RIANO	26 APRIL 16	Surveyed 11 lines over BLK24C and 2 lines at BLK24E.
23302	283.94	1BLK24BES120A	MCE BALIGUAS	29 APRIL 16	Surveyed 7 lines over BLK24B, 2 lines at A and 12 lines at E. Surveyed at different altitudes due to clouds.
23304	108.44	1BLK24ESGS120B	G SO-RIANO	29 APRIL 16	Surveyed 4 lines each for BLKs24 G and E
23314	208.44	1BLK24ABCVOIDS123A	MCE BALIGUAS	02 MAY 16	Covered voids over BLKs 24 A, B and C at different altitudes because of high terrain and heavy buildup of clouds.
23318	120.98	1BLK24ACFVOIDS124A	G SO-RIANO	03 MAY 16	Covered voids over BLKs24 A, C,F. Cloudy most of the area.

SWATH BOUNDARIES PER MISSION FLIGHT

Flight No. : 23276P
Area: BLK24 F & G
Mission Name: 1BLK24FG113A
Parameters: Altitude: 700 and 1000m PRF: 200
Total Area Surveyed: 202.44 sq km

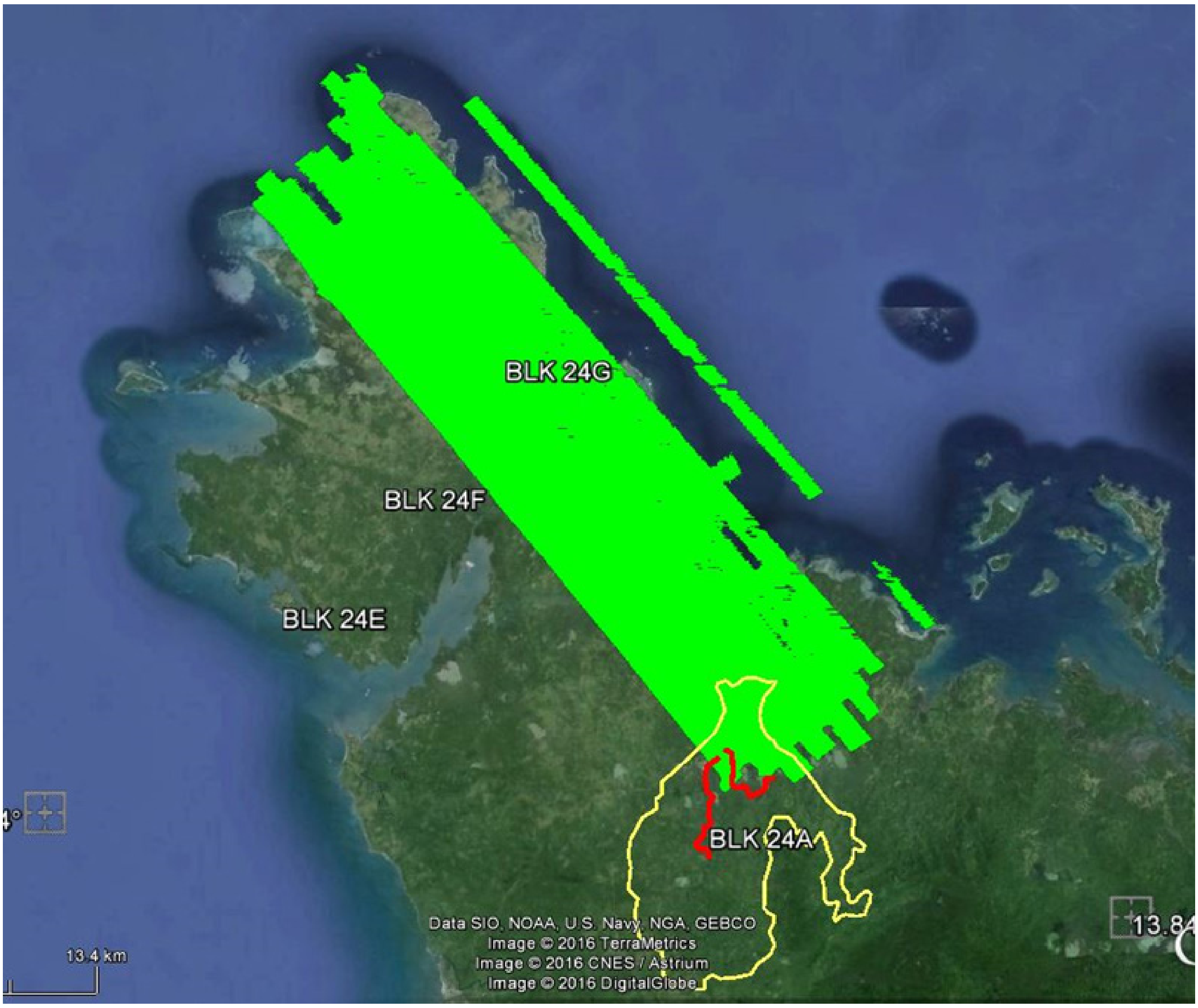


Figure A-7.1. Swath for Flight No. 23276P

Flight No. : 23278
Area: BLK24 C, A & F
Mission Name: 1BLK24CAF114A
Parameters: Altitude: 600 and 1000m PRF: 150 & 200
Total Area Surveyed: 169.14 sq km

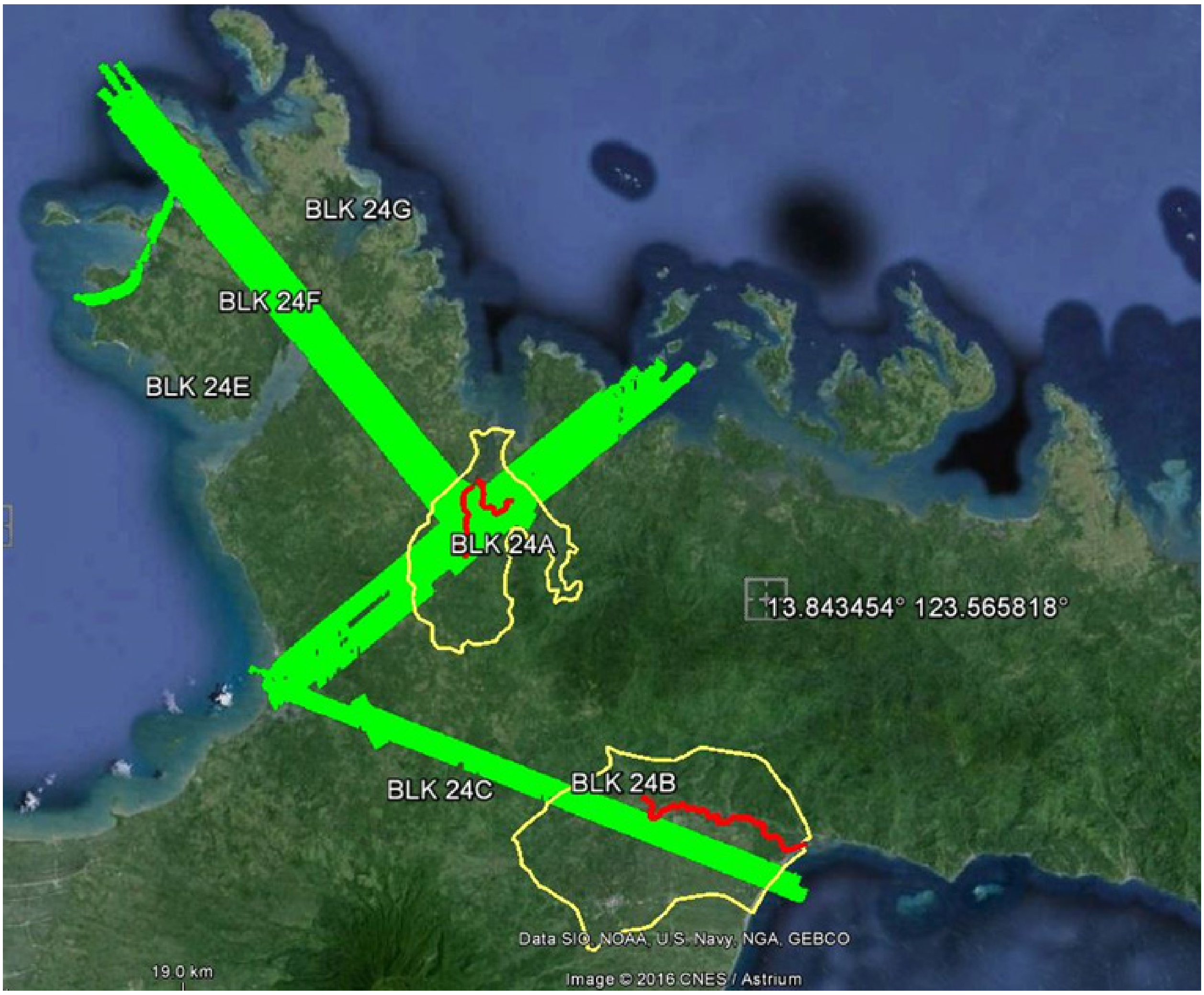


Figure A-7.2. Swath for Flight No. 23278

Flight No. : 23282P
Area: BLk24 A and F
Mission Name: 1BLK24ASFS115A
Parameters: Altitude: 850 and 1000m PRF: 200
Total Area Surveyed: 291.79 sq km

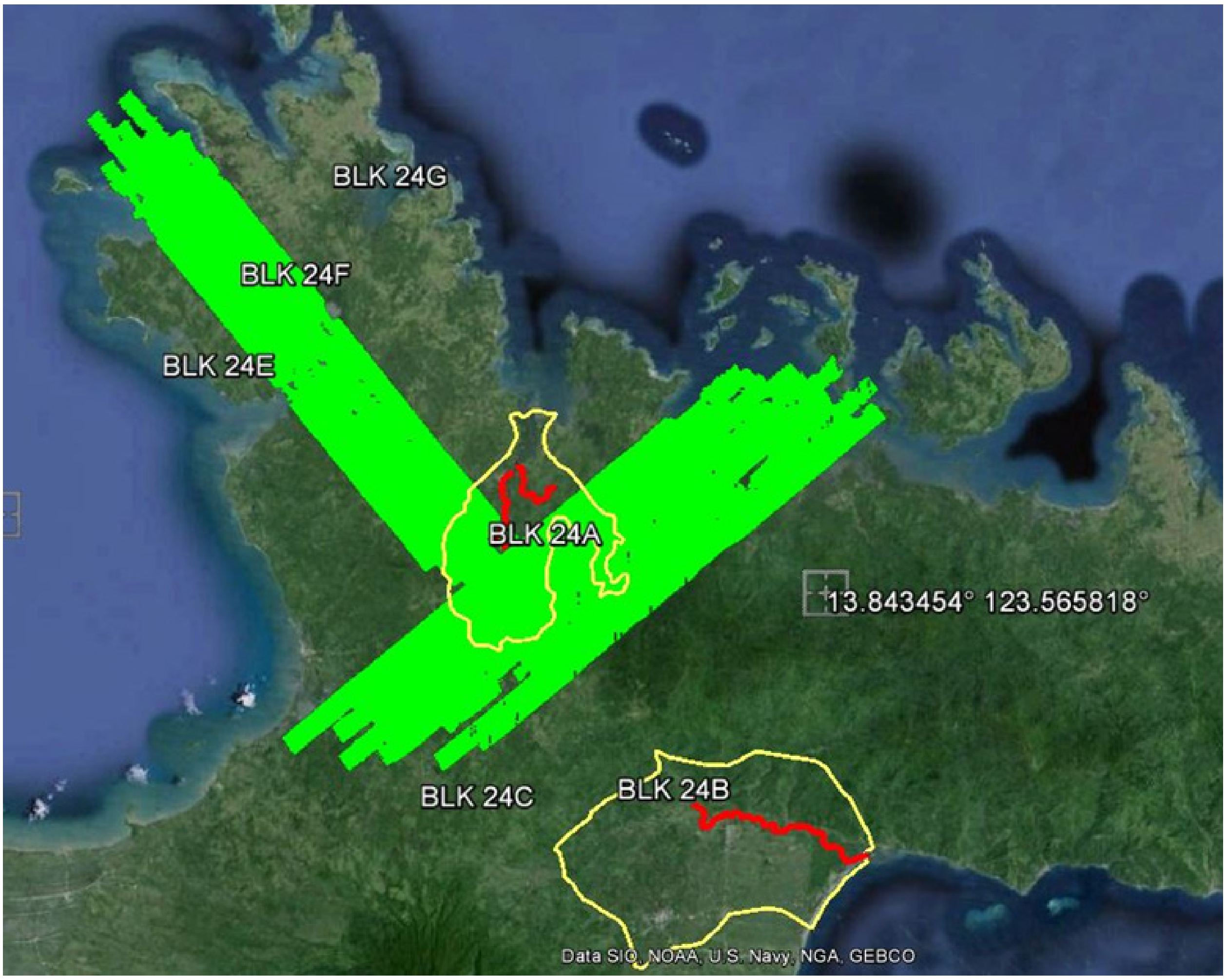


Figure A-7.3. Swath for Flight No. 23282P

Flight No. : 23290P
Area: BLK24 C and E
Mission Name: 1BLK24CSE117A
Parameters: Altitude: 850 and 1000m PRF: 200
Total Area Surveyed: 202.07 sq km

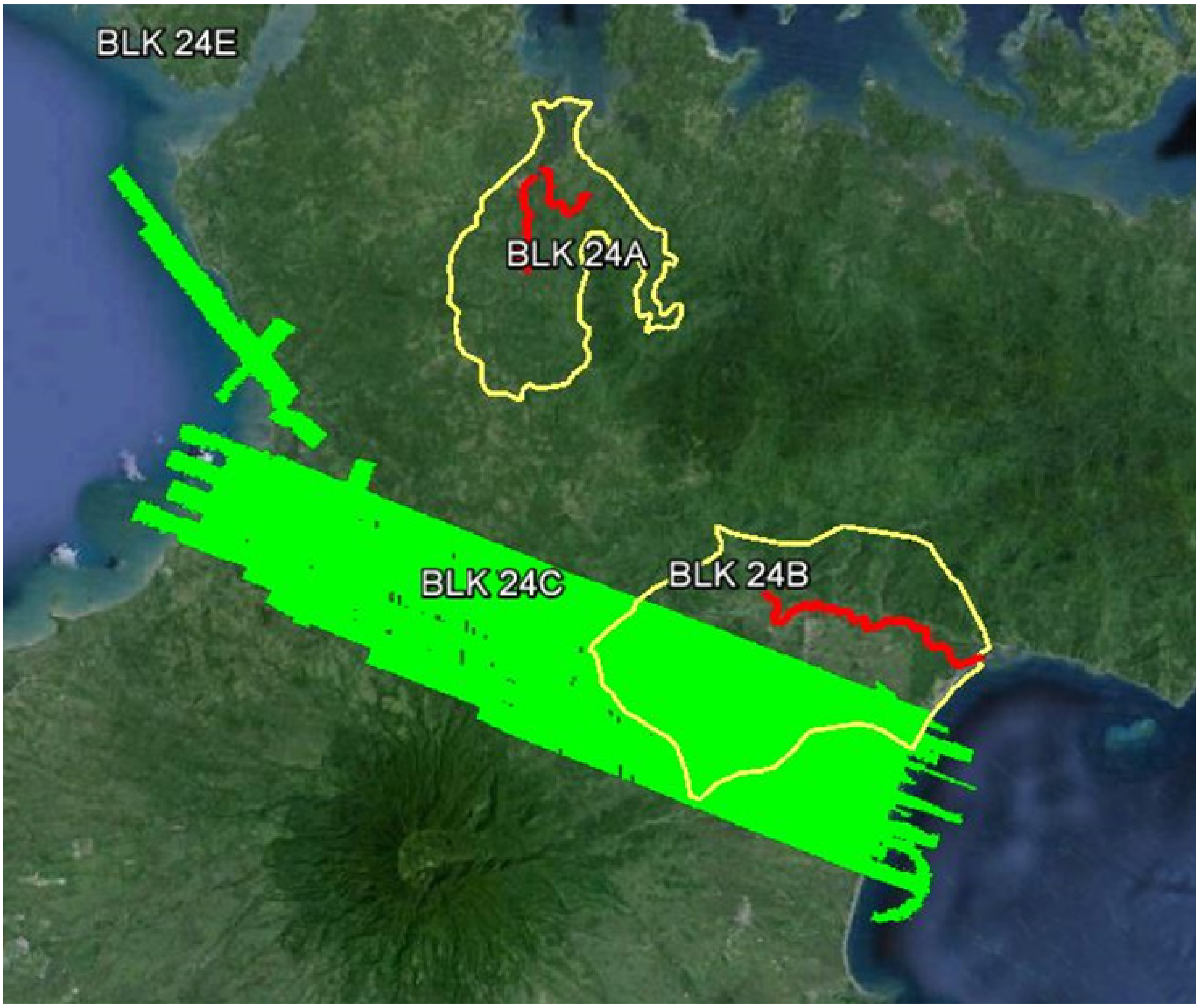


Figure A-7.4. Swath for Flight No. 23290P

Flight No. : 23302P
Area: BLK24B, A and E
Mission Name: 1BLK24BES120A
Parameters: Altitude: 800 and 1000m PRF: 200
Total Area Surveyed: 283.94 sq km

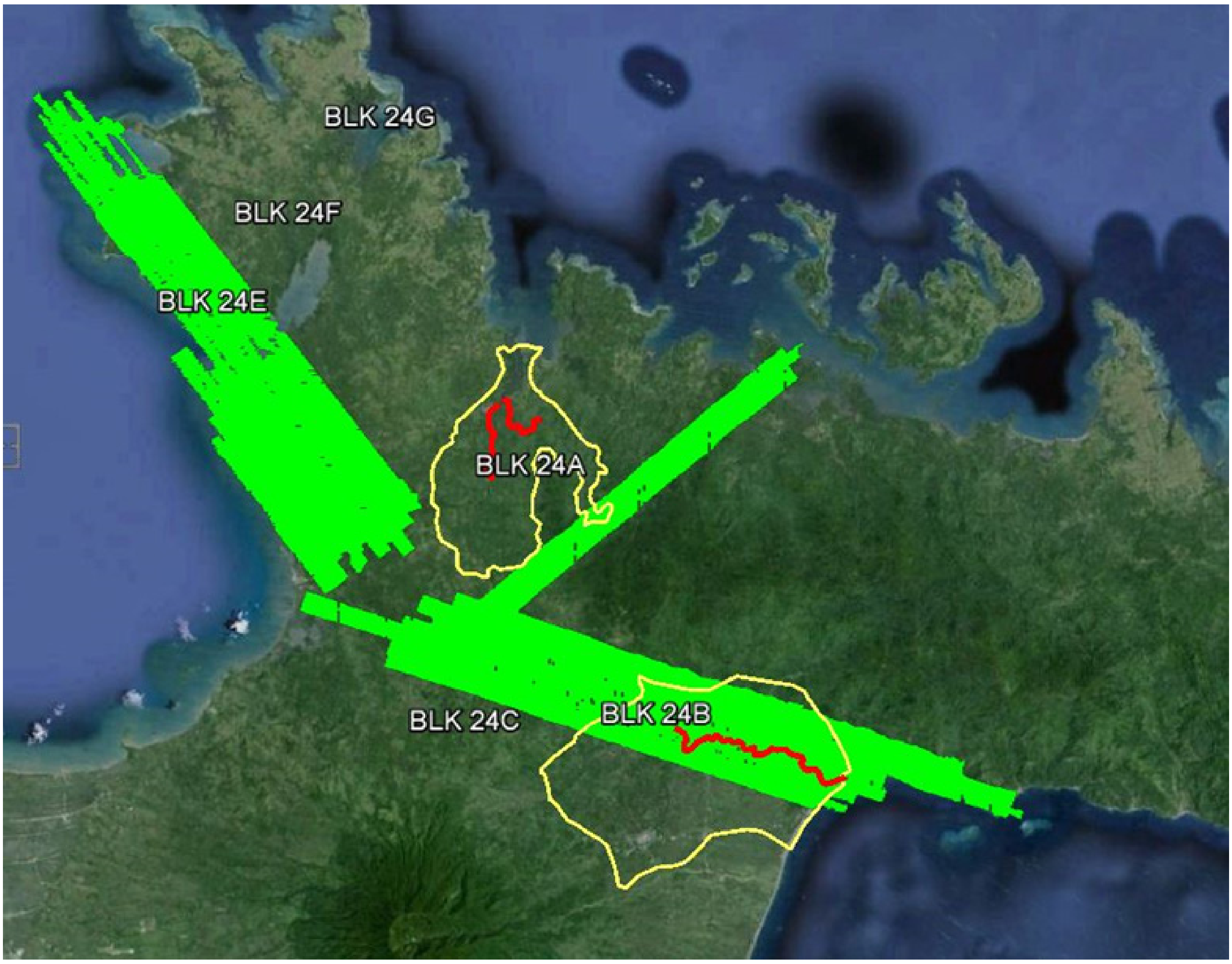


Figure A-7.5. Swath for Flight No. 23302P

Flight No. : 23304P
Area: BLK24 G and E
Mission Name: 1BLK24ESGS120B
Parameters: Altitude: 1000m PRF: 200
Total Area Surveyed: 108.44 sq km

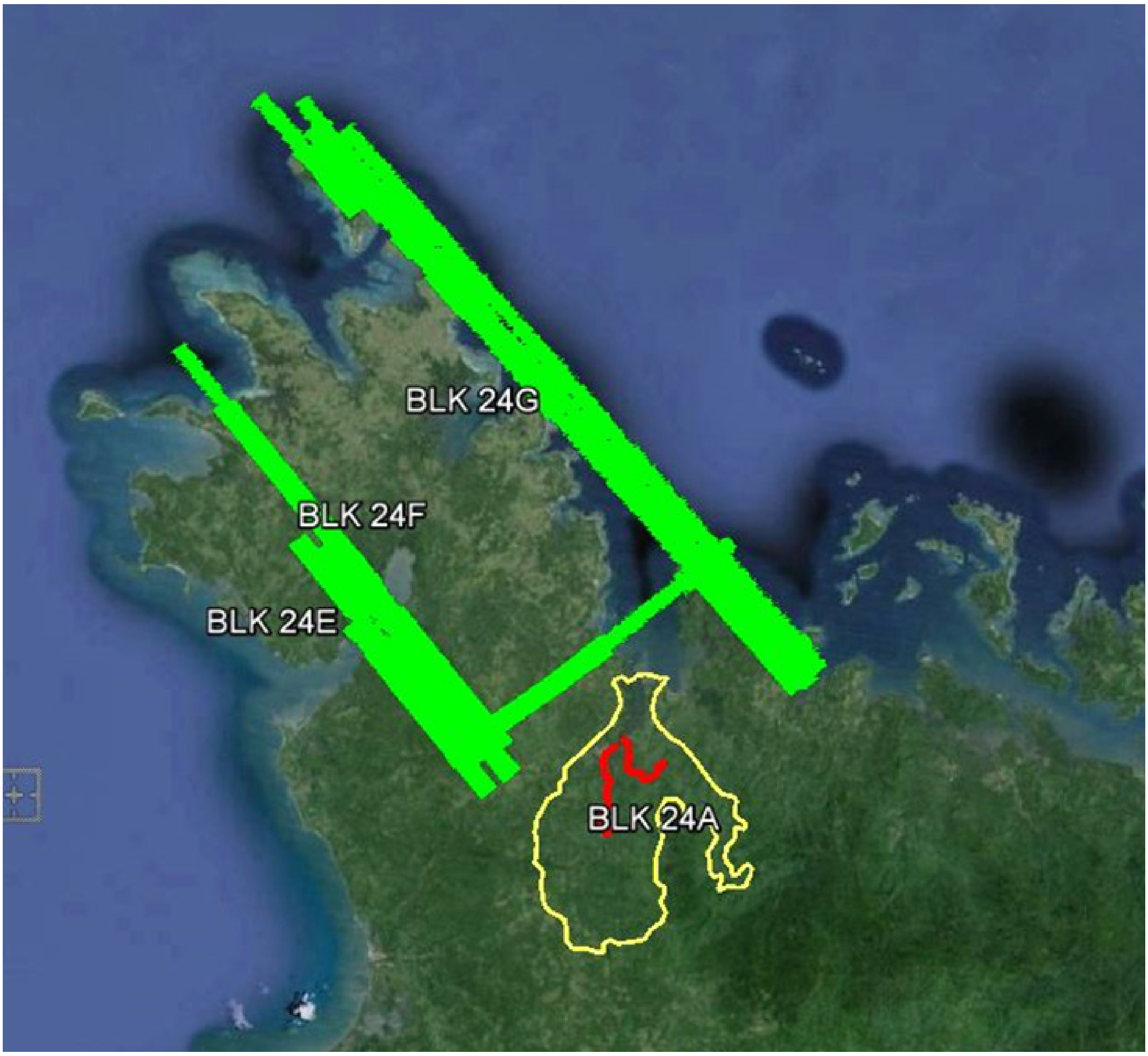


Figure A-7.6. Swath for Flight No. 23304P

Flight No. : 23306P
Area: BLK24 G and E
Mission Name: 1BLK24ABCVOIDS123A
Parameters: Altitude: 600-850m PRF: 150
Total Area Surveyed: 208.44 sq km

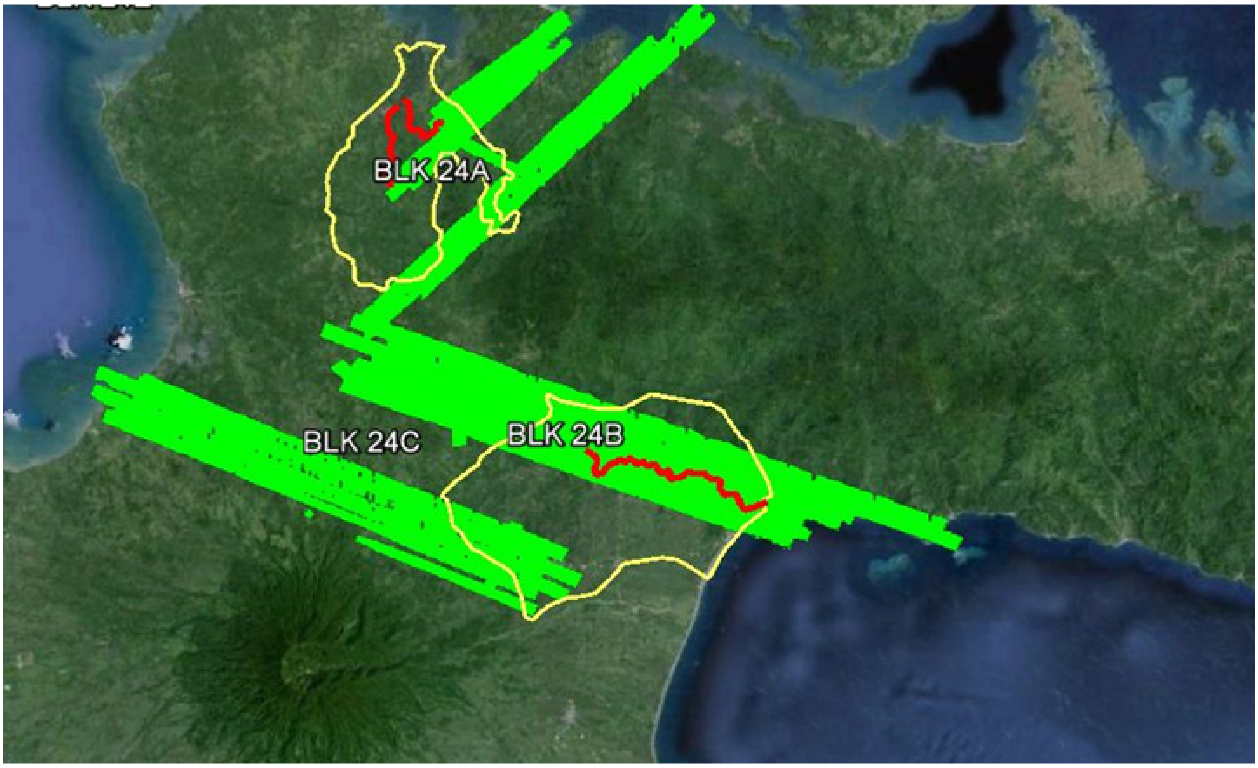


Figure A-7.7. Swath for Flight No. 23306P

Flight No: 23308P
Area: BLK24 A, C and F
Mission Name: 1BLK24ACFVOIDS124A
Parameters: Altitude: 550 to 600 and 1000m PRF: 150 and 200
Total Area Surveyed: 120.98 sq km

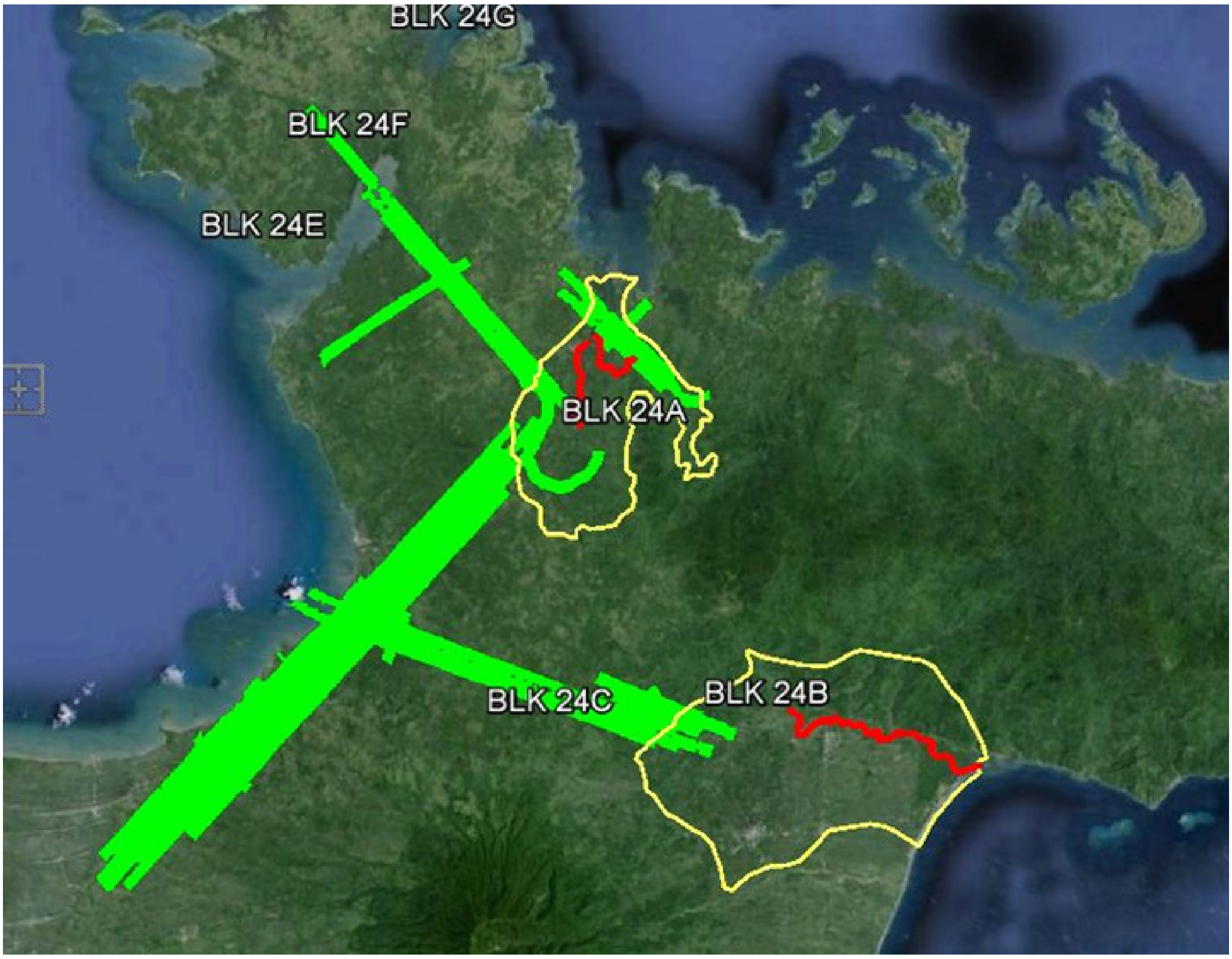


Figure A-7.8. Swath for Flight No. 23308P

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Blk 24F

Flight Area	Naga
Mission Name	Blk 24F
Inclusive Flights	23278P, 23282P, 23304P, 23318P
Range data size	89.24 GB
POS data size	937 MB
Base data size	378.4 MB
Image	NA
Transfer date	June 10, 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)	1.537
RMSE for East Position (<4.0 cm)	1.445
RMSE for Down Position (<8.0 cm)	4.470
Boresight correction stdev (<0.001deg)	0.000181
IMU attitude correction stdev (<0.001deg)	0.000521
GPS position stdev (<0.01m)	0.0053
Minimum % overlap (>25)	68.26%
Ave point cloud density per sq.m. (>2.0)	4.22
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	241
Maximum Height	232.13
Minimum Height	42.35
Classification (# of points)	
Ground	213,197,454
Low vegetation	127,100,752
Medium vegetation	402,295,919
High vegetation	930,677,714
Building	13,353,068
Orthophoto	No
Processed by	Engr. Jennifer B. Saguran, Engr. Irish Cortez, Engr. Kenneth Soli-dum, Engr. Regis Guhiting, Engr. Edgardo Gubatanga Jr., Engr. Elainne Lopez

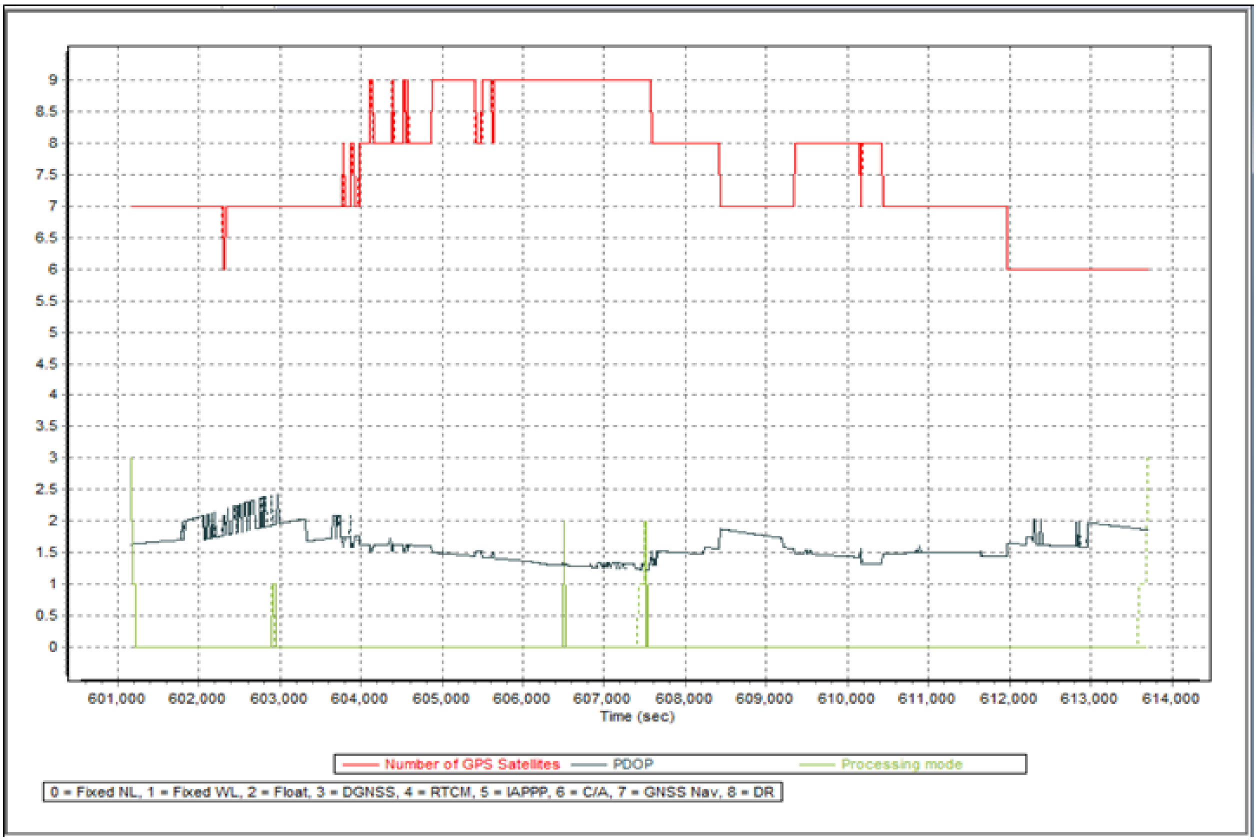


Figure A-8.1. Solution Status

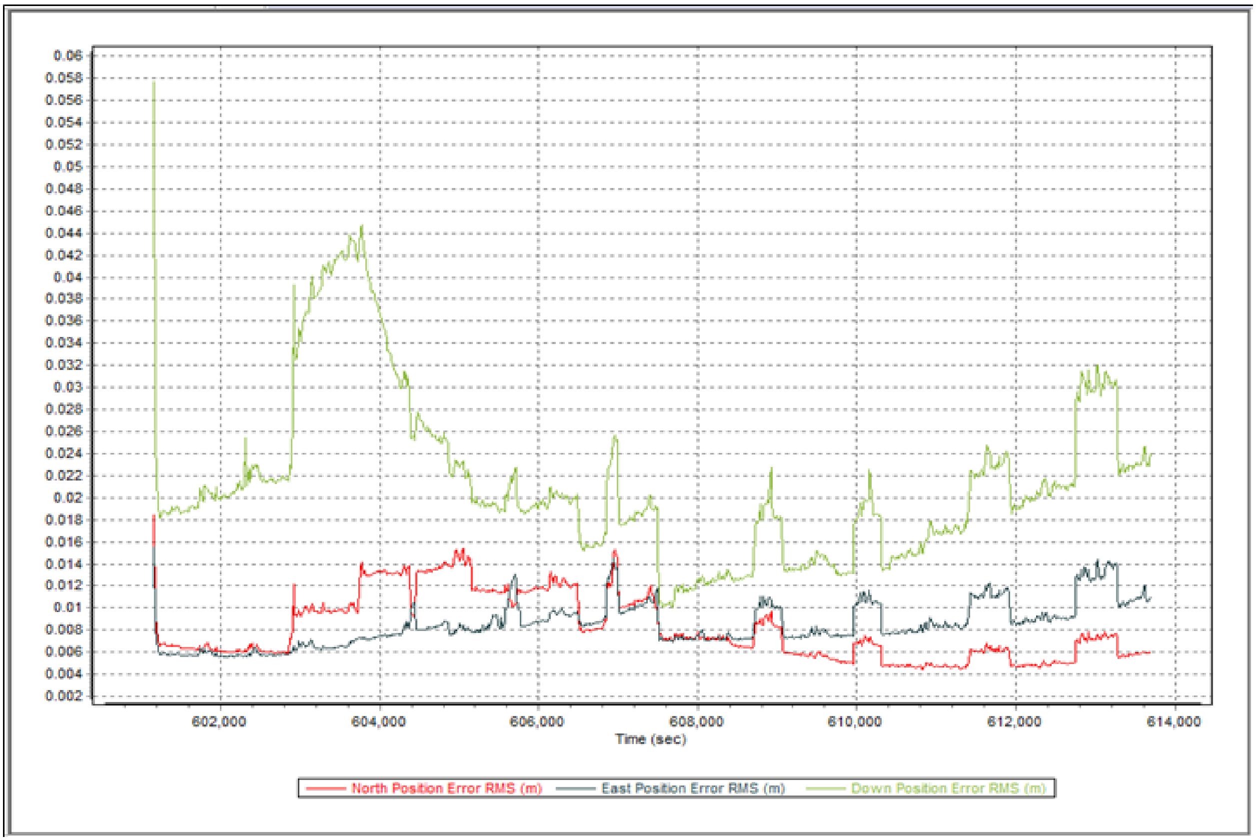


Figure A-8.2. Smoothed Performance Metrics Parameters

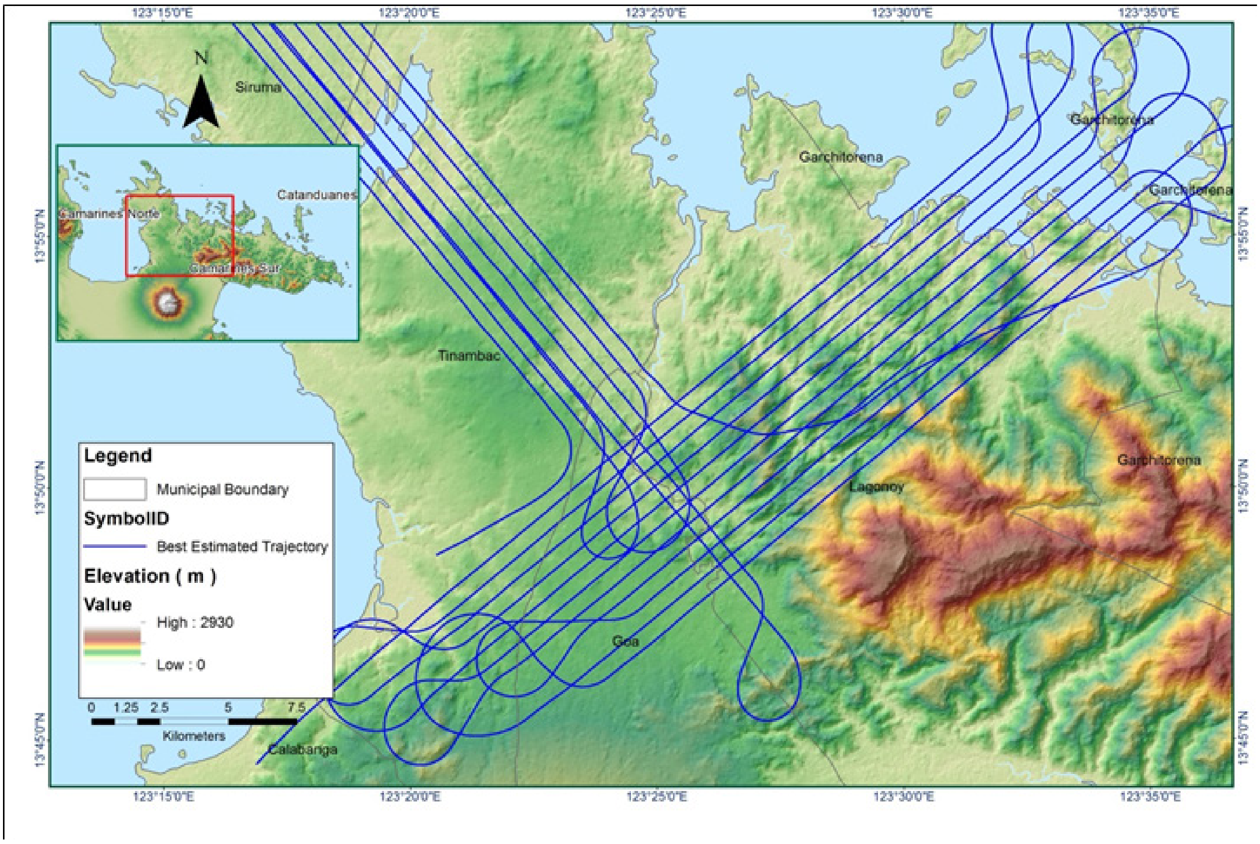


Figure A-8.3. Best Estimated Trajectory

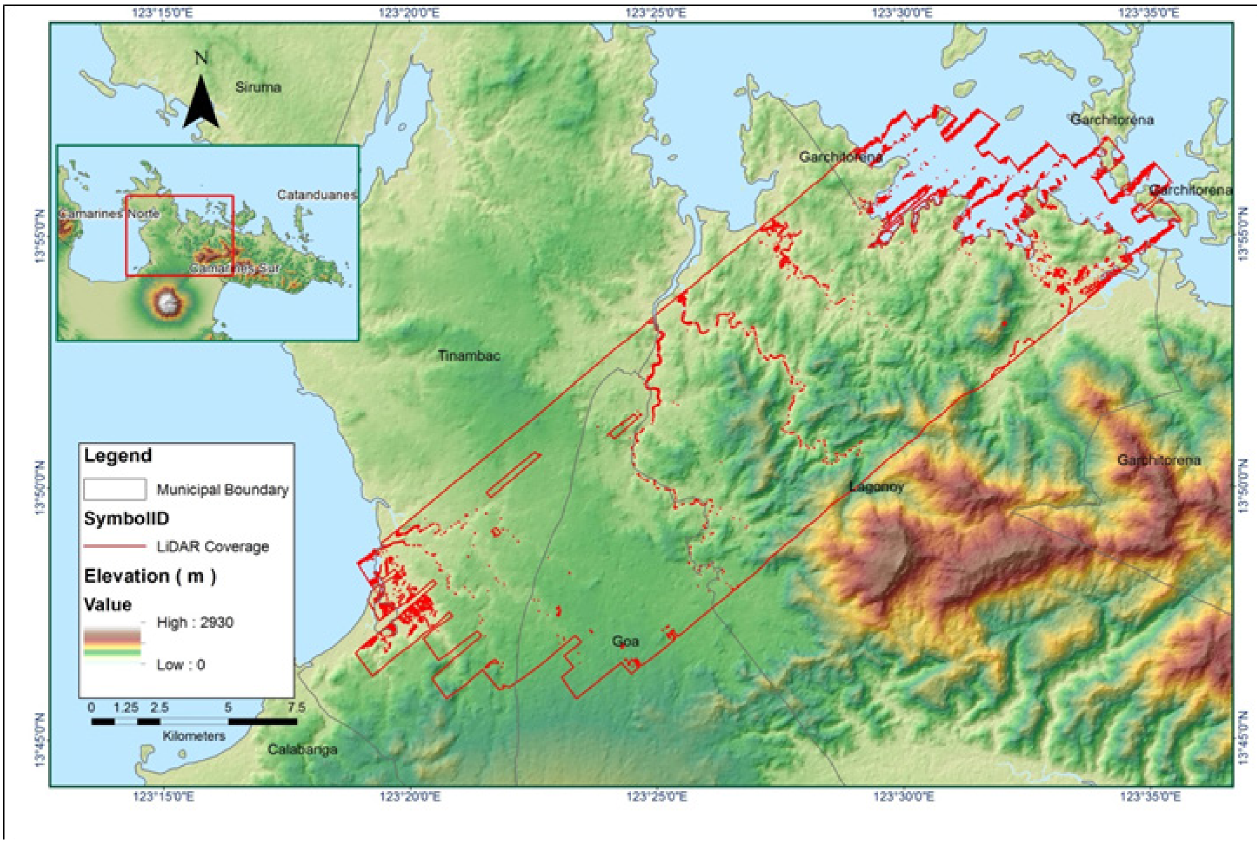


Figure A-8.4. Coverage of LiDAR data

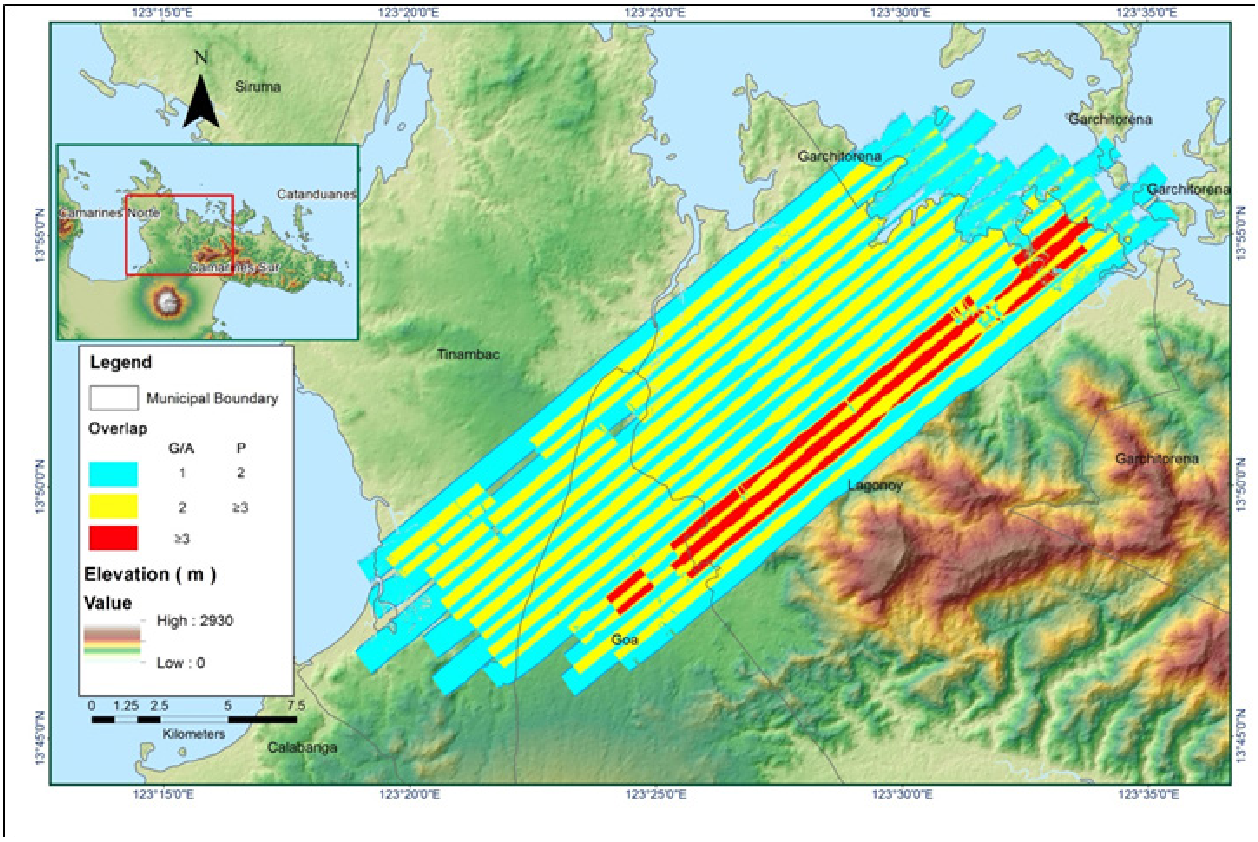


Figure A-8.5. Image of Data Overlap

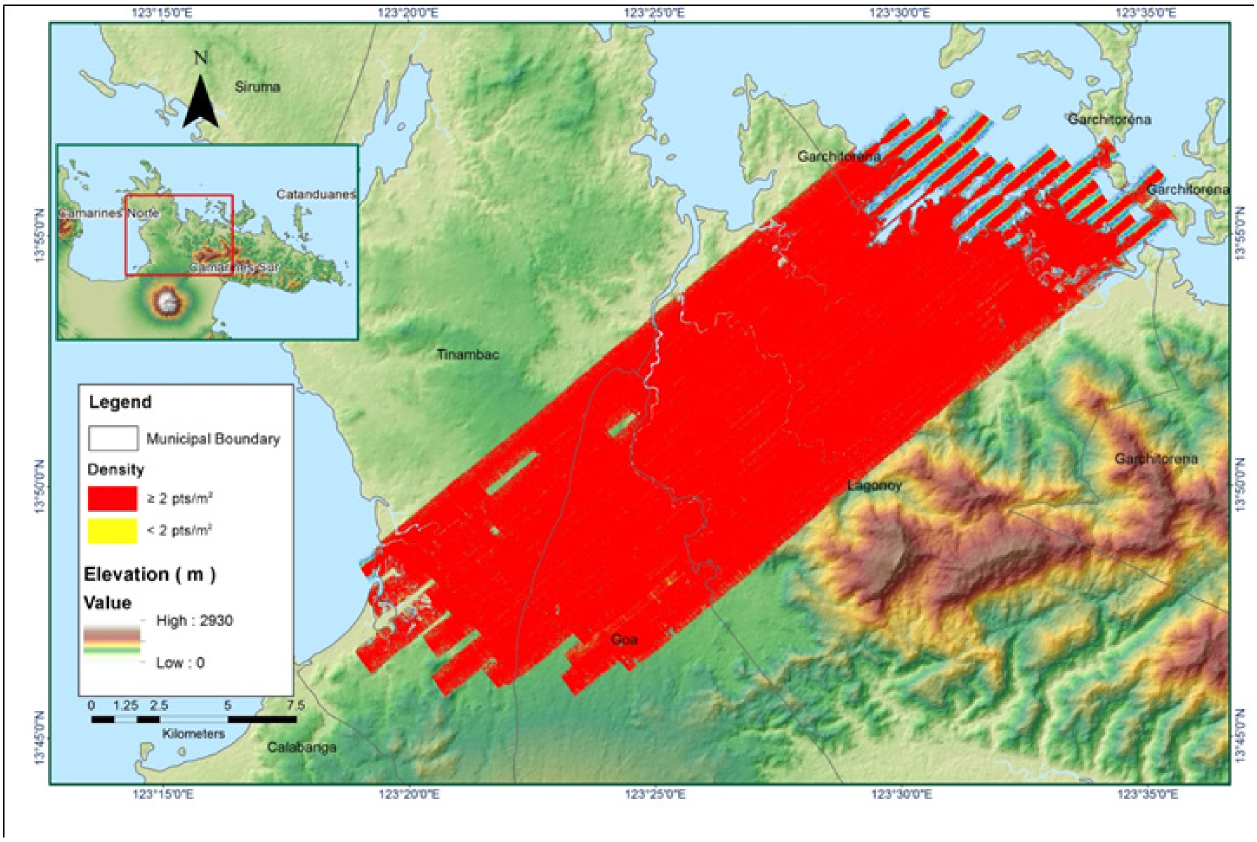


Figure A-8.6. Density map of merged LiDAR data

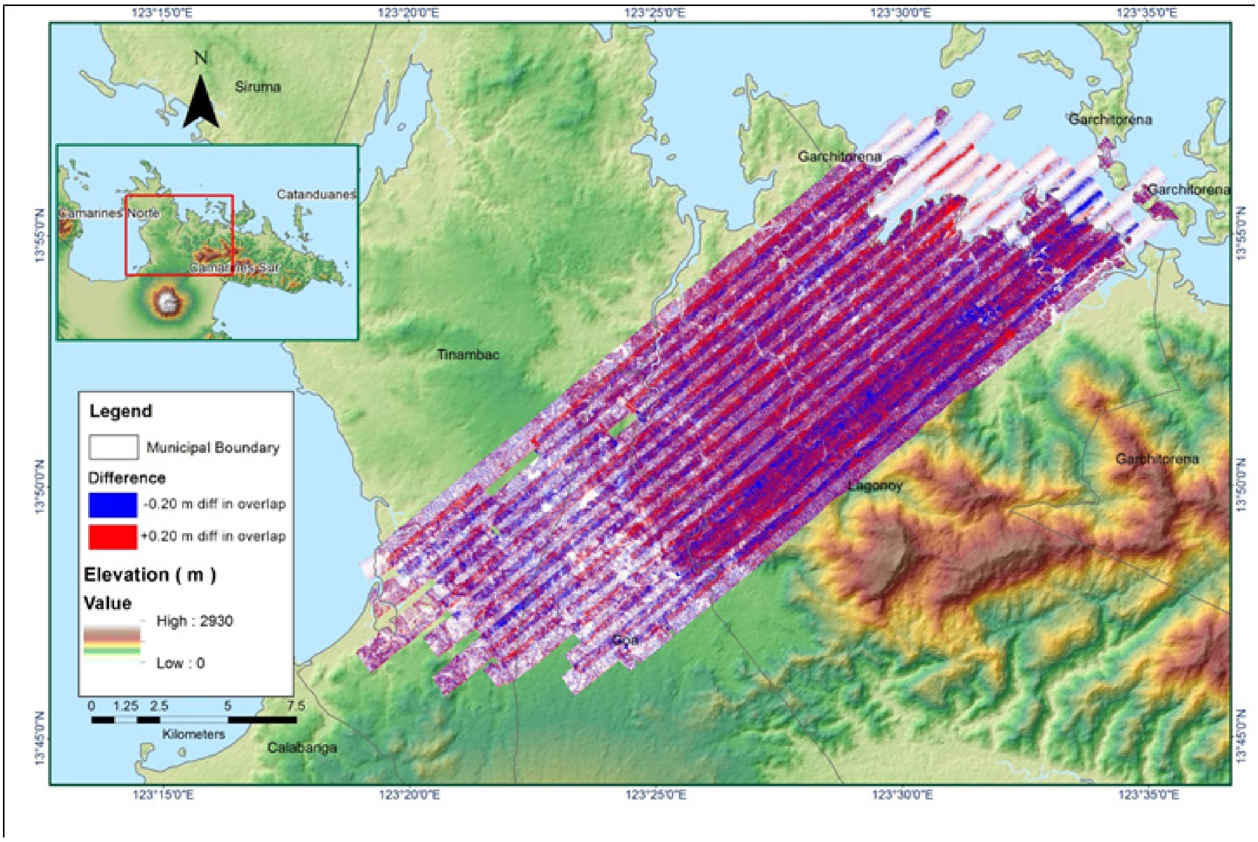


Figure A-8.7. Elevation difference between flight lines

Table A-8.2. Mission Summary Report for Mission Blk 24E

Flight Area	Naga
Mission Name	Blk 24E
Inclusive Flights	23302P
Range data size	29.5 GB
POS data size	293 MB
Base data size	113 MB
Image	NA
Transfer date	June 10, 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)	1.534
RMSE for East Position (<4.0 cm)	1.666
RMSE for Down Position (<8.0 cm)	3.158
Boresight correction stdev (<0.001deg)	0.000175
IMU attitude correction stdev (<0.001deg)	0.000409
GPS position stdev (<0.01m)	0.0010
Minimum % overlap (>25)	43.09%
Ave point cloud density per sq.m. (>2.0)	3.47
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	198
Maximum Height	244.82 m
Minimum Height	52.62 m
Classification (# of points)	
Ground	104,143,487
Low vegetation	71,414,844
Medium vegetation	178,708,674
High vegetation	528,446,260
Building	7,464,973
Orthophoto	No
Processed by	Engr. Don Matthew Banatin, Aljon Rei Araneta, Maria Tamsyn Mala-banan

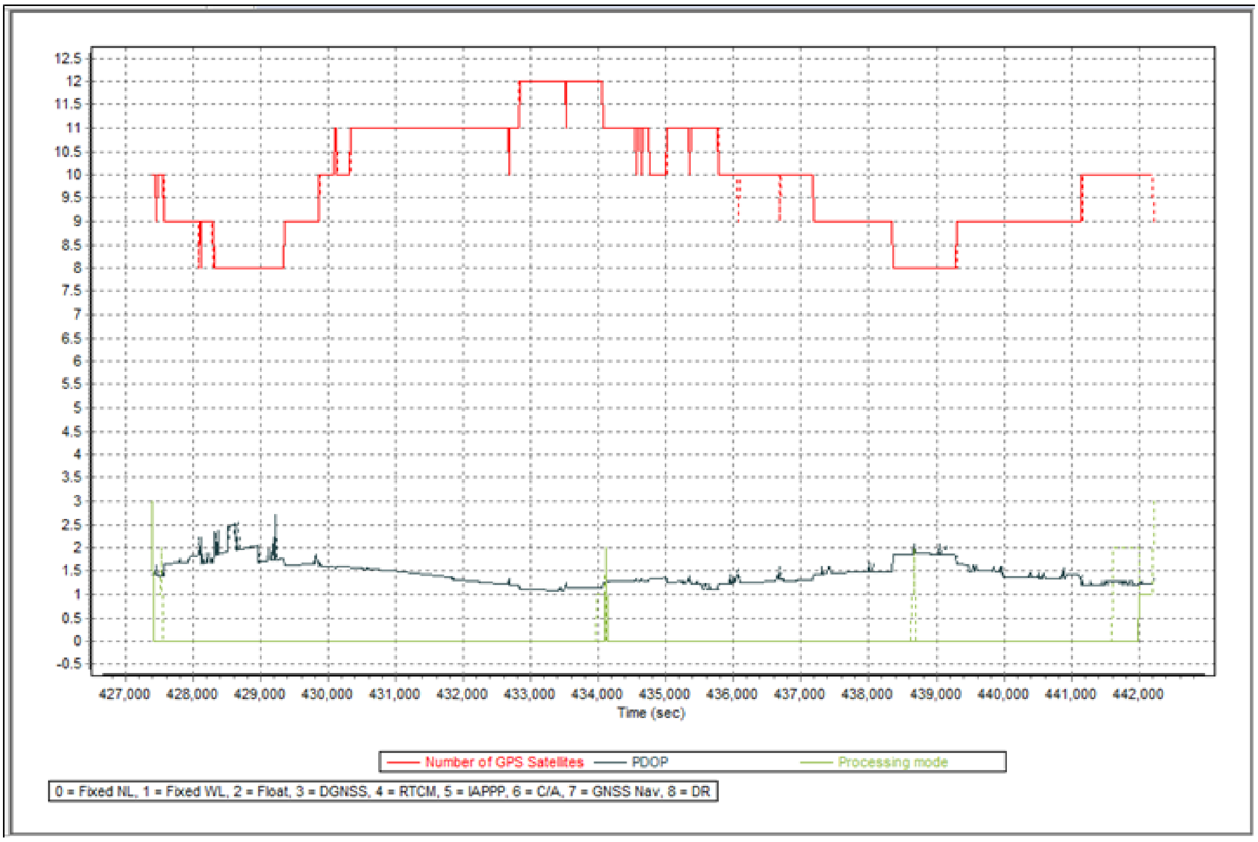


Figure A-8.8. Solution Status Parameters

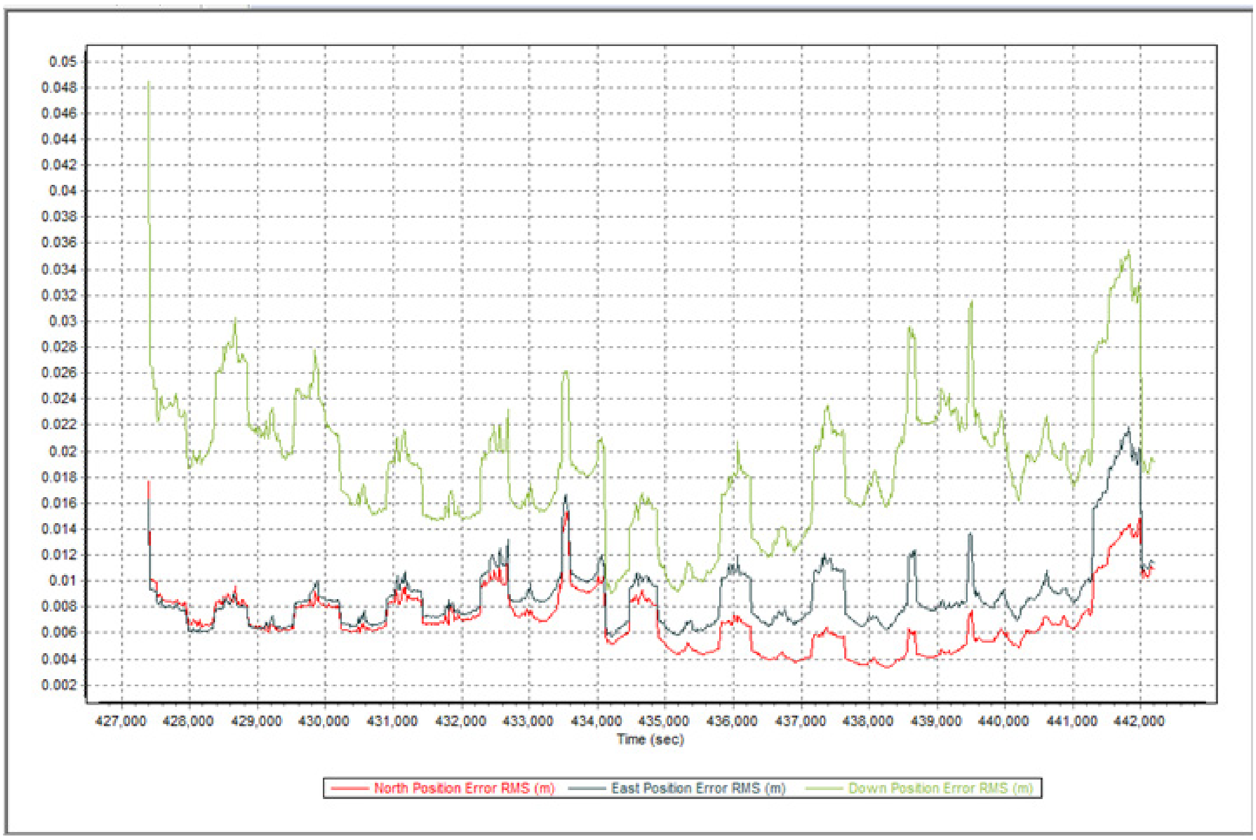


Figure A-8.9. Smoothed Performance Metrics Parameters

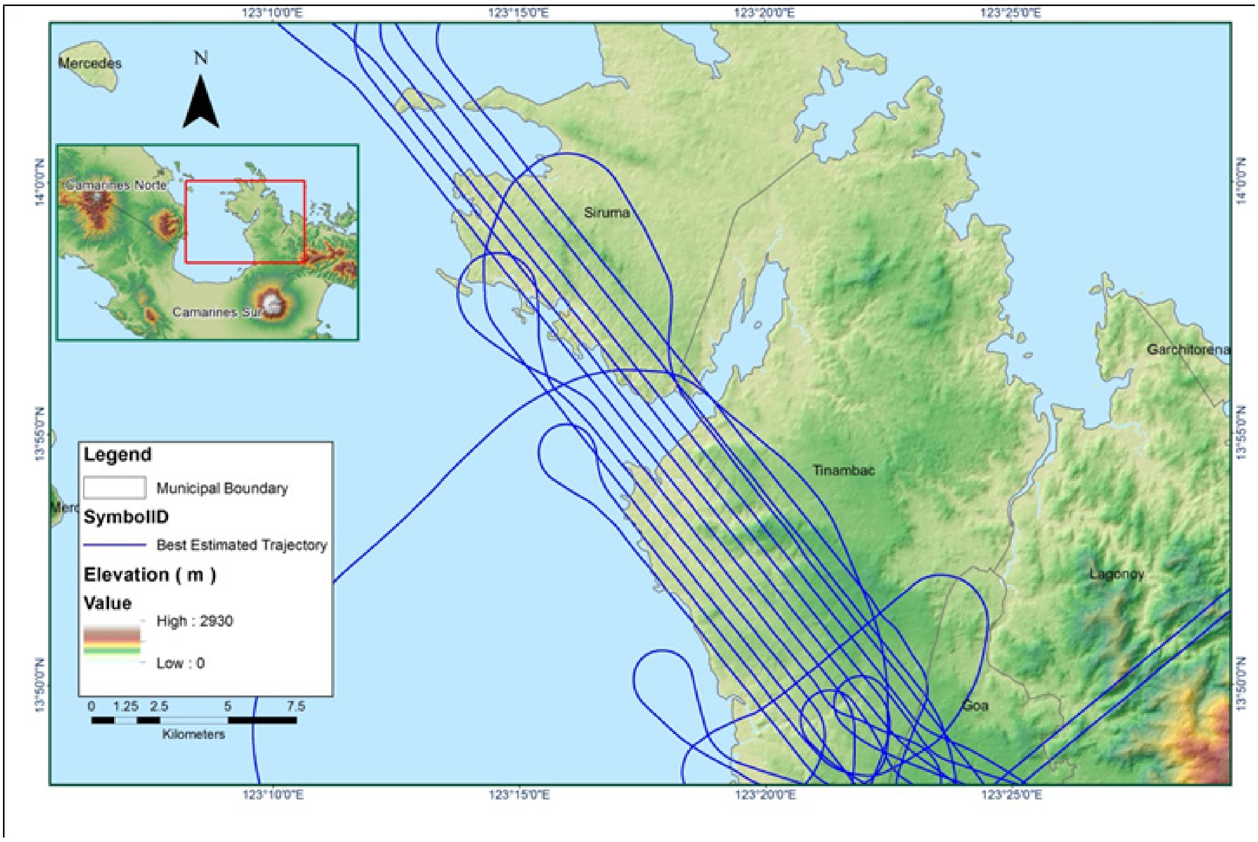


Figure A-8.10. Best Estimated Trajectory

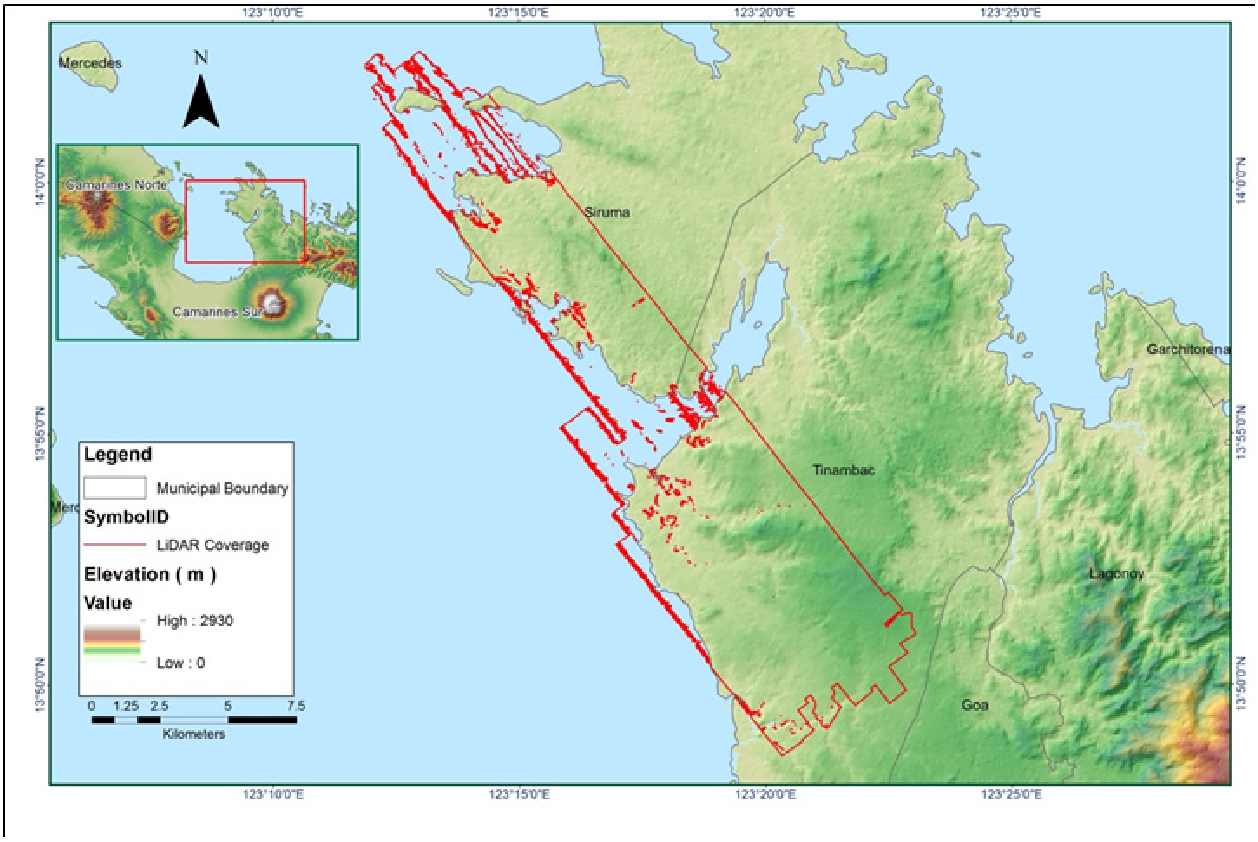


Figure A-8.11. Coverage of LiDAR data

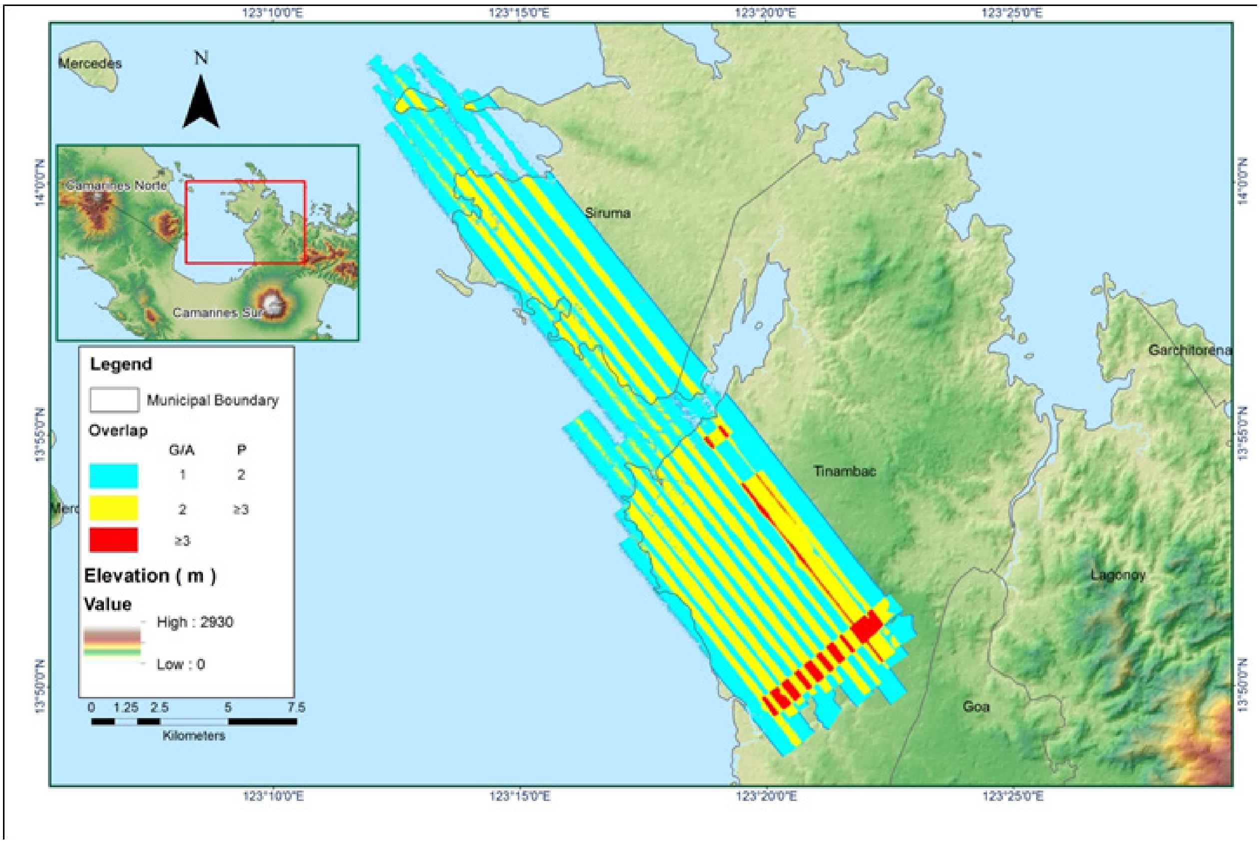


Figure A-8.12. Image of Data Overlap

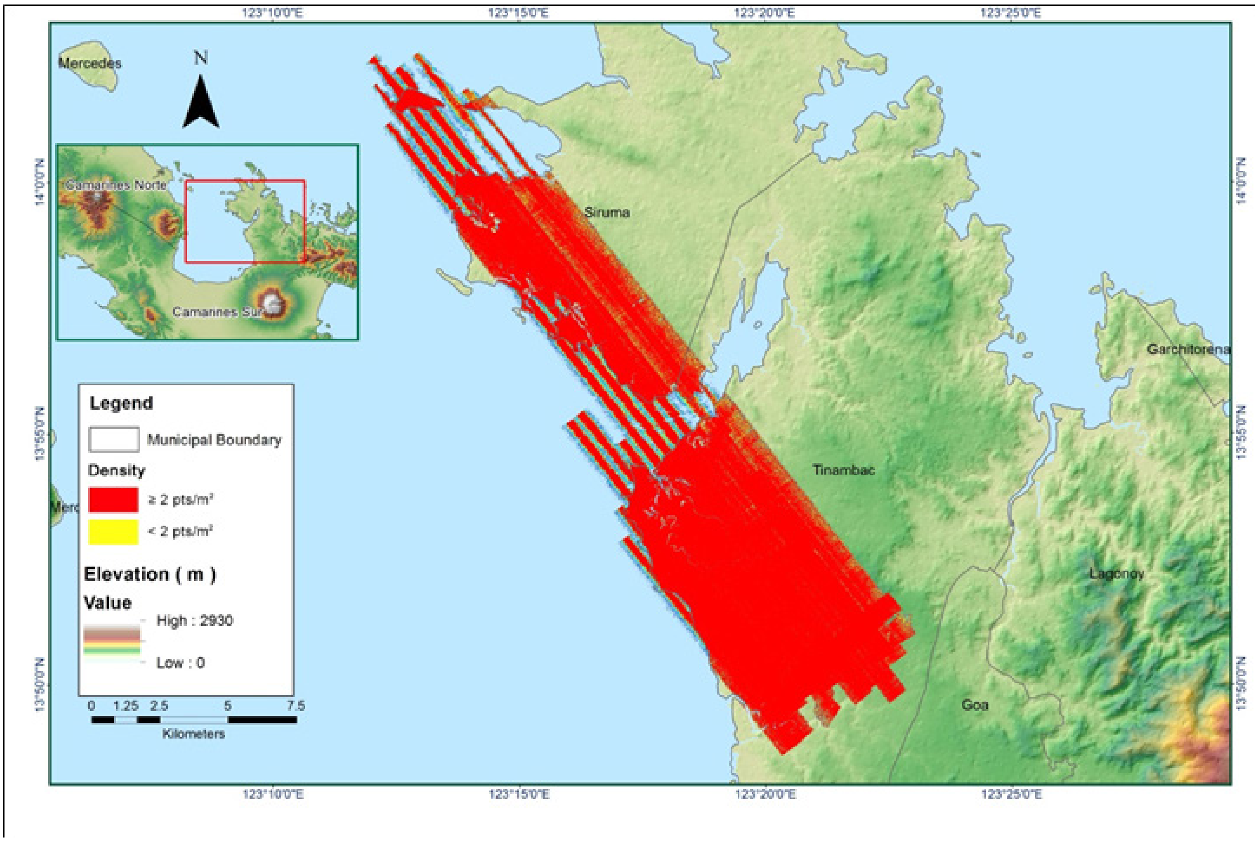


Figure A-8.13. Density map of merged LiDAR data

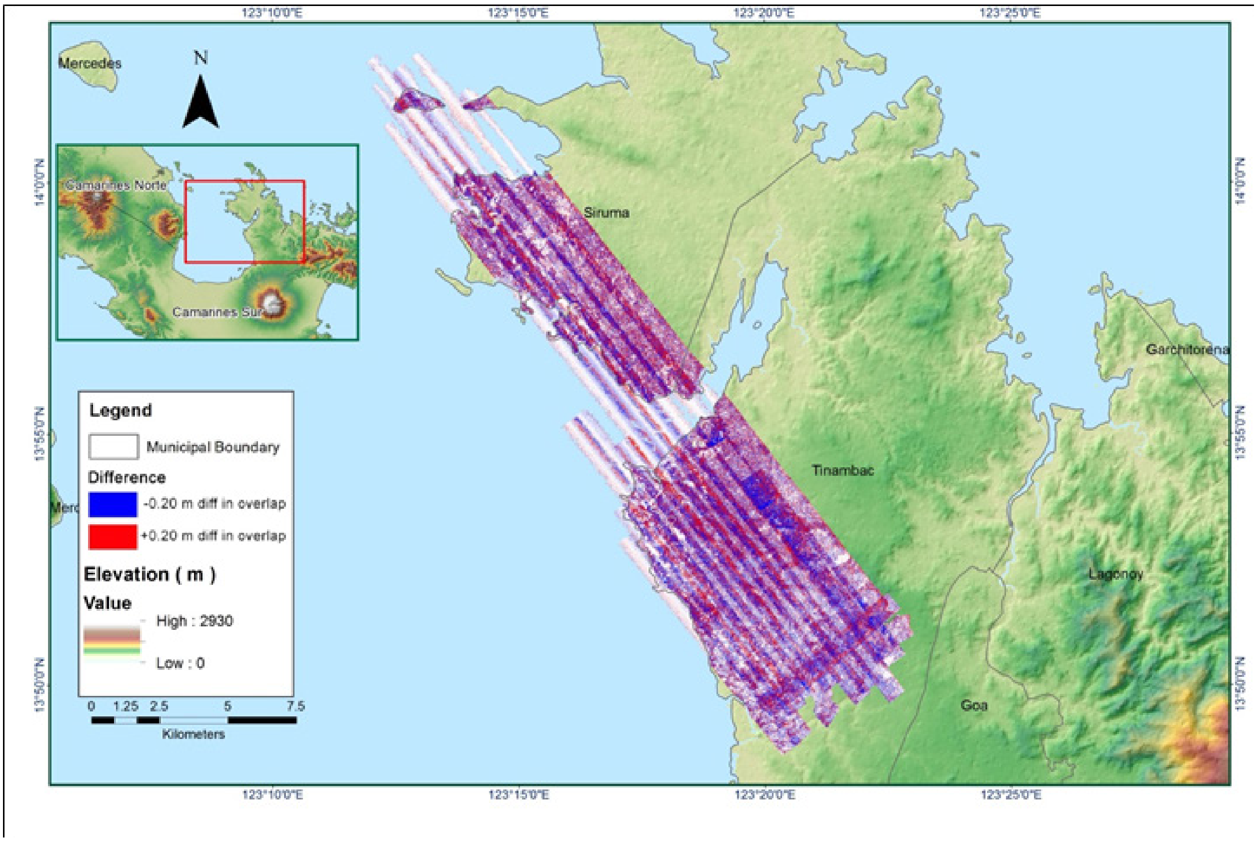


Figure A-8.14. Elevation difference between flight lines

Table A-8.3. Mission Summary Report for Mission Naga_Blk24E_Additional

Flight Area	Naga
Mission Name	Naga_Blk24E_Additional
Inclusive Flights	23290P
Range data size	19.8 GB
POS data size	244 MB
Base data size	84.5 MB
Image	n/a
Transfer date	June 6, 2016
Solution Status	
Number of Satellites (>6)	No
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.0
RMSE for East Position (<4.0 cm)	1.1
RMSE for Down Position (<8.0 cm)	2.3
Boresight correction stdev (<0.001deg)	0.000846
IMU attitude correction stdev (<0.001deg)	0.000405
GPS position stdev (<0.01m)	0.0014
Minimum % overlap (>25)	92.48%
Ave point cloud density per sq.m. (>2.0)	3.64
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	41
Maximum Height	138.57 m
Minimum Height	54.00 m
Classification (# of points)	
Ground	18,353,237
Low vegetation	32,167,927
Medium vegetation	22,113,692
High vegetation	27,290,109
Building	4,258,729
Orthophoto	No
Processed by	Engr. Don Matthew Banatin, Aljon Rei Araneta, Engr. Monalyne Rabino

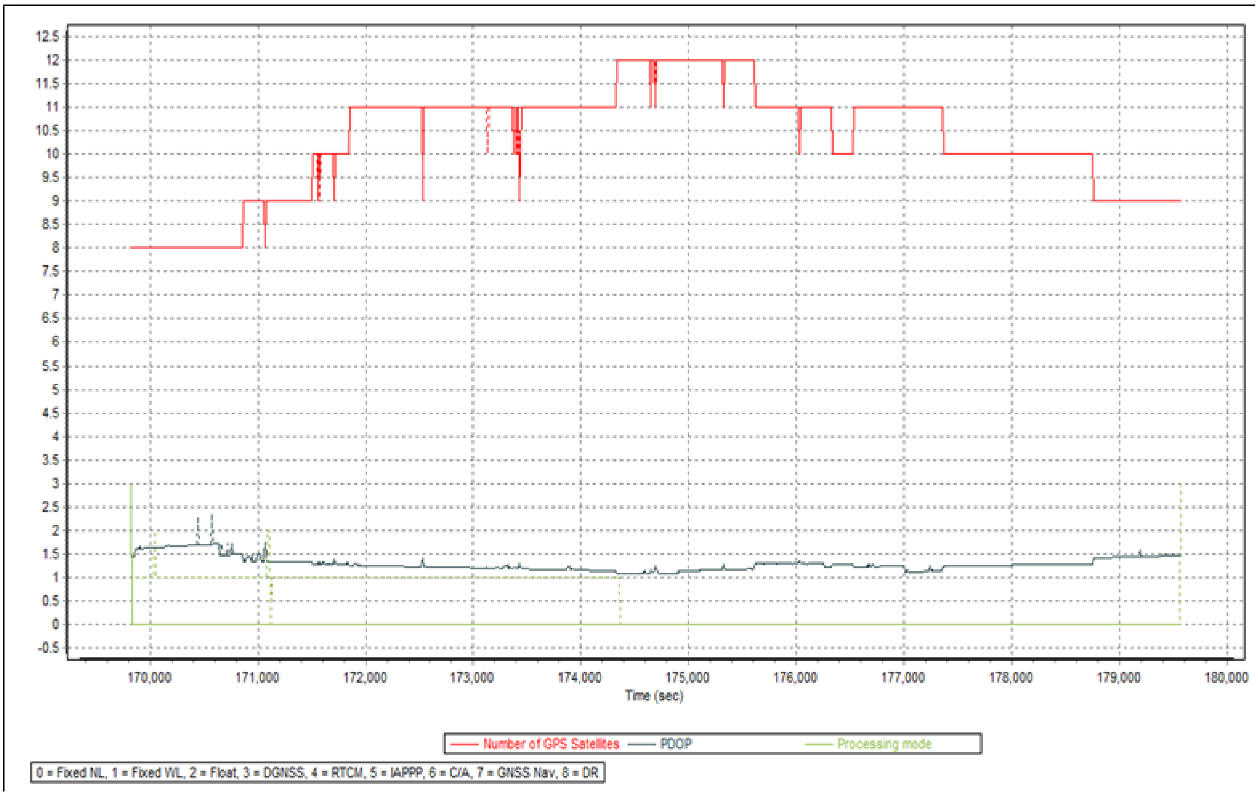


Figure A-8.15. Solution Status

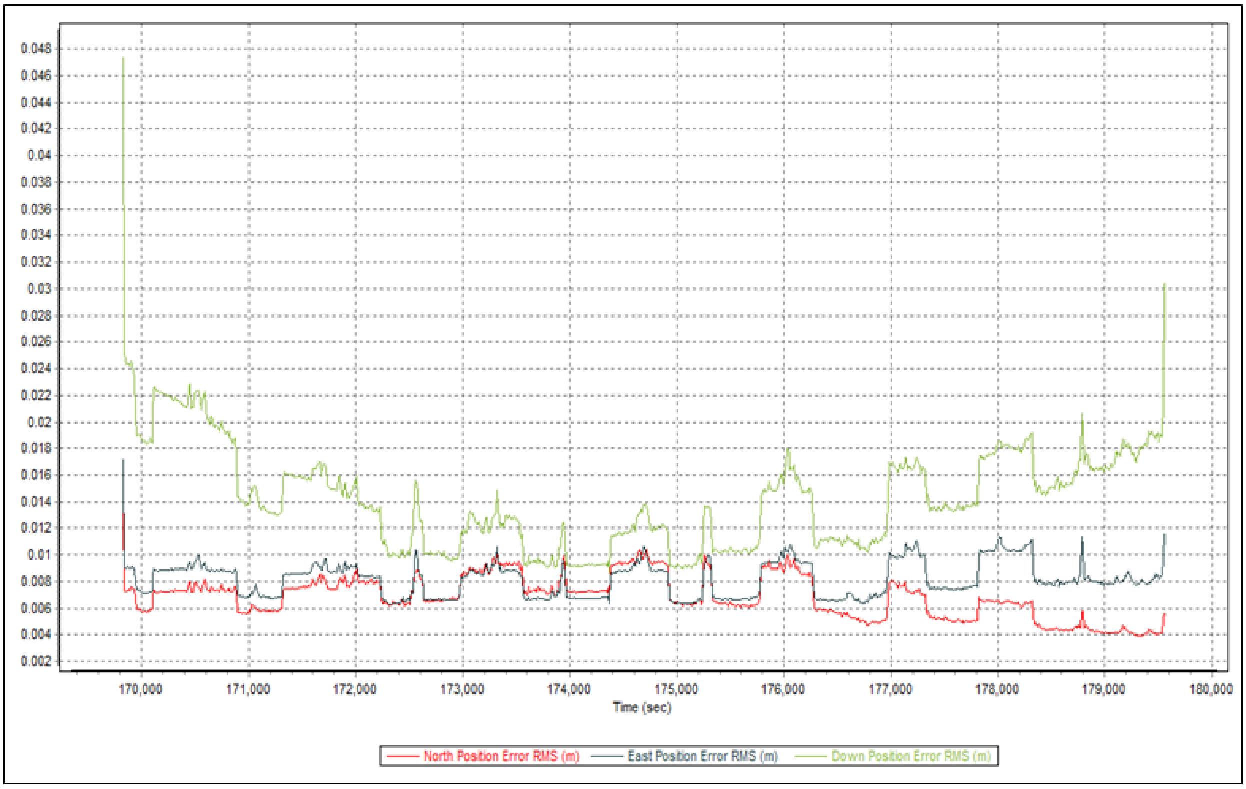


Figure A-8.16. Smoothed Performance Metric Parameters

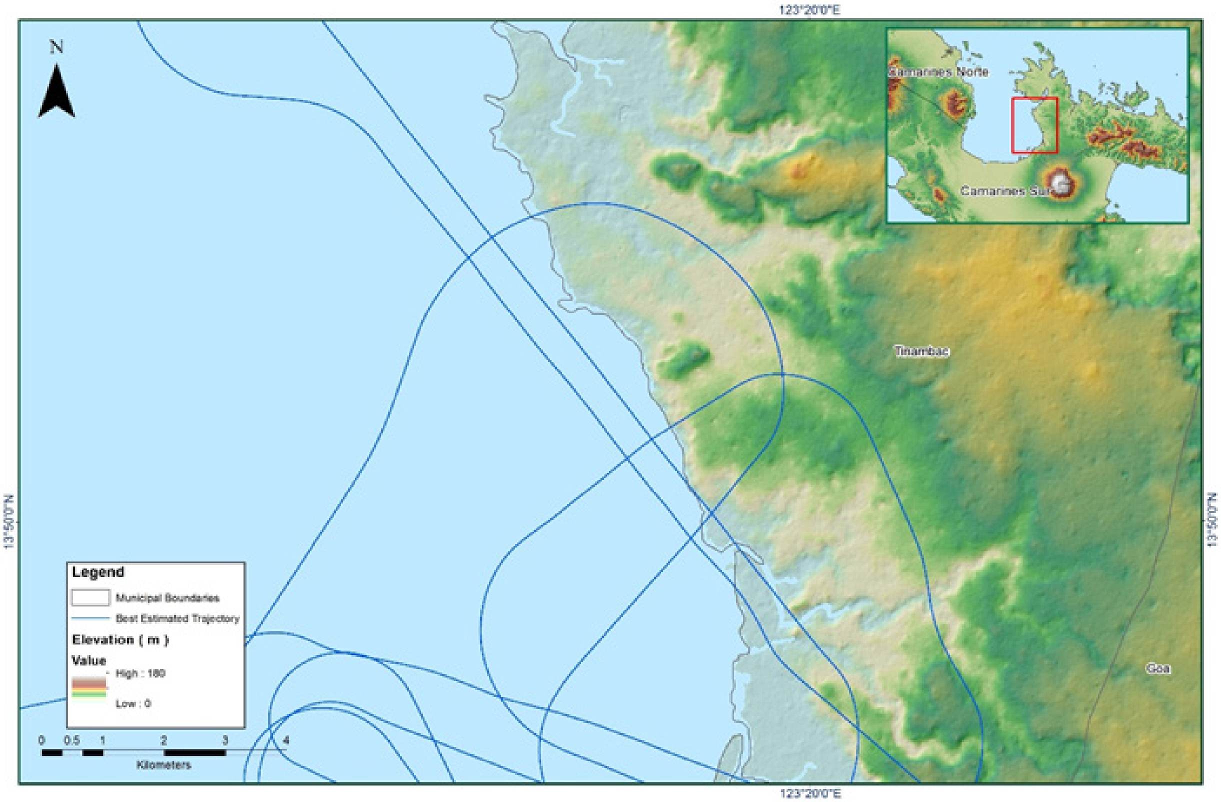


Figure A-8.17. Best Estimated Trajectory

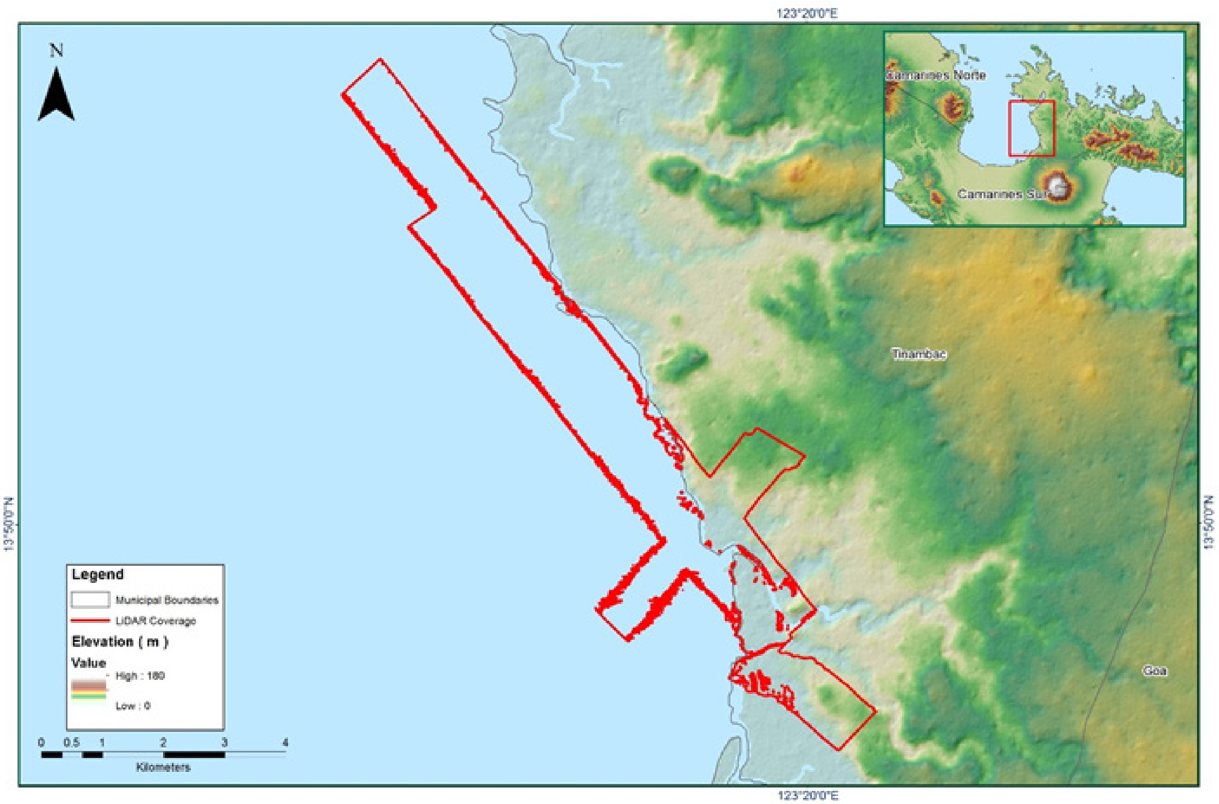


Figure A-8.18. Coverage of LiDAR data

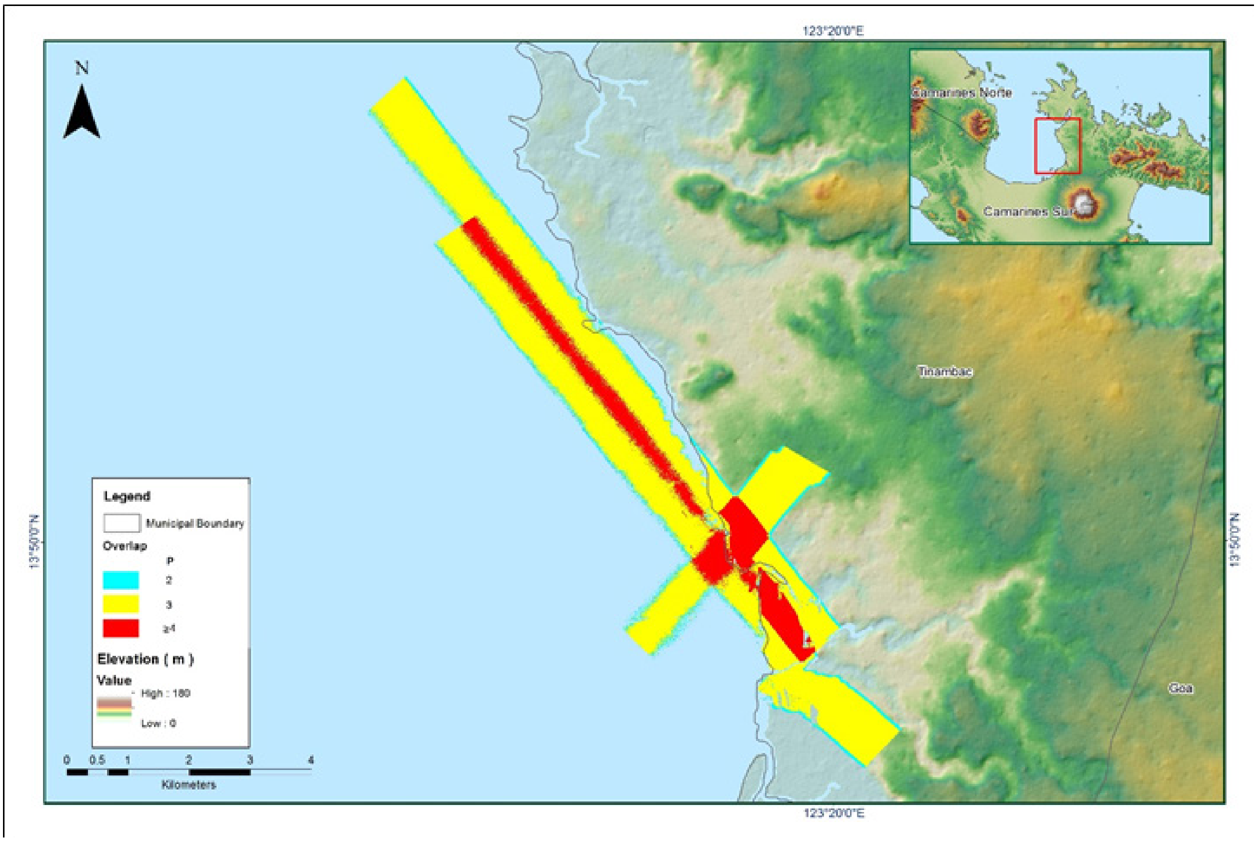


Figure A-8.19. Image of Data Overlap

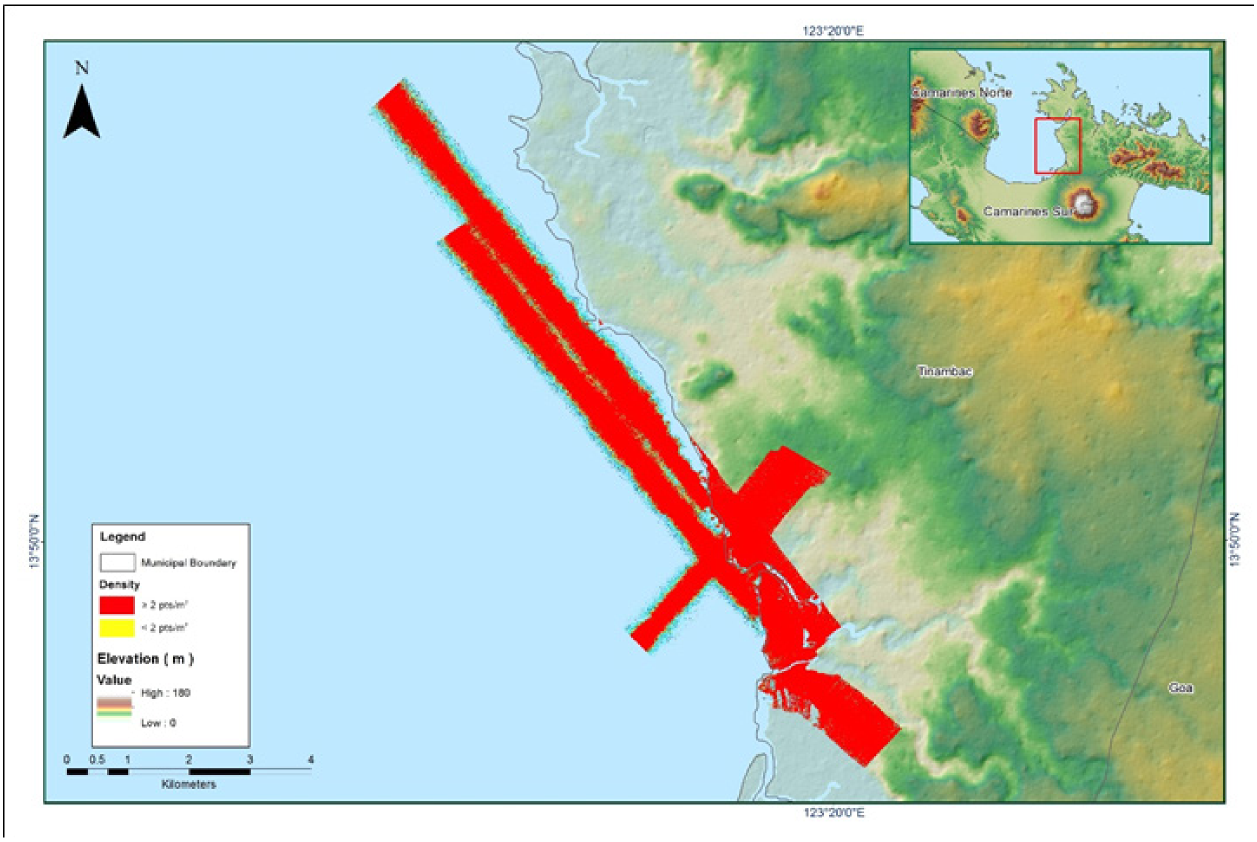


Figure A-8.20. Density map of merged LiDAR data

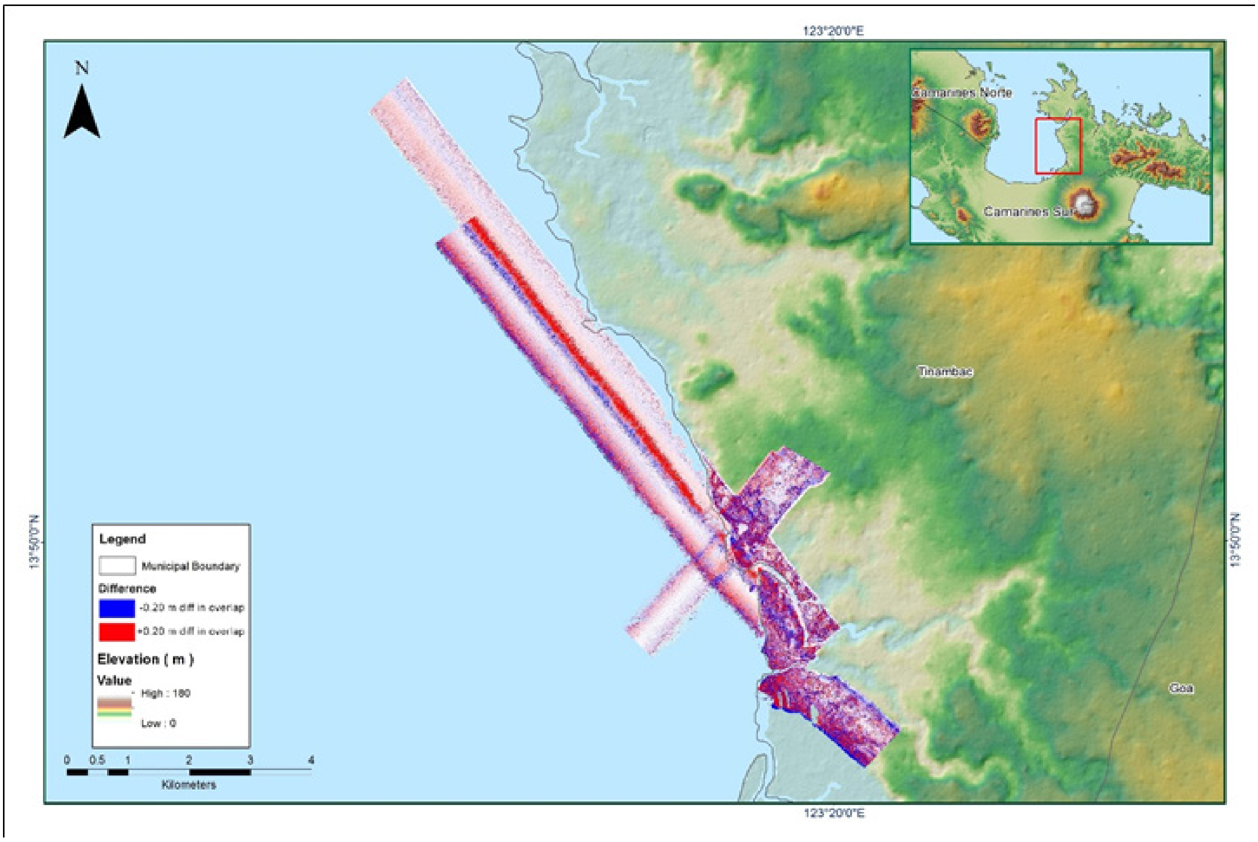


Figure A-8.21. Elevation difference between flight lines

Table A-8.4. Mission Summary Report for Mission Blk 24A_additional

Flight Area	Naga
Mission Name	Blk 24A_additional
Inclusive Flights	23318P
Range data size	19.5 GB
POS data size	261 MB
Base data size	101 MB
Image	NA
Transfer date	June 10, 2016
Solution Status	
Number of Satellites (>6)	No
PDOP (<3)	No
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.453
RMSE for East Position (<4.0 cm)	2.882
RMSE for Down Position (<8.0 cm)	7.629
Boresight correction stdev (<0.001deg)	0.001288
IMU attitude correction stdev (<0.001deg)	0.005345
GPS position stdev (<0.01m)	0.0018
Minimum % overlap (>25)	25.74%
Ave point cloud density per sq.m. (>2.0)	3.78
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	68
Maximum Height	338.13 m
Minimum Height	51.81 m
Classification (# of points)	
Ground	17,406,728
Low vegetation	10,904,027
Medium vegetation	53,319,574
High vegetation	113,771,943
Building	953,655
Orthophoto	No
Processed by	Engr. Regis Guhiting, Engr. Jovelle Anjeanette Canlas, Engr. Melissa Fernandez

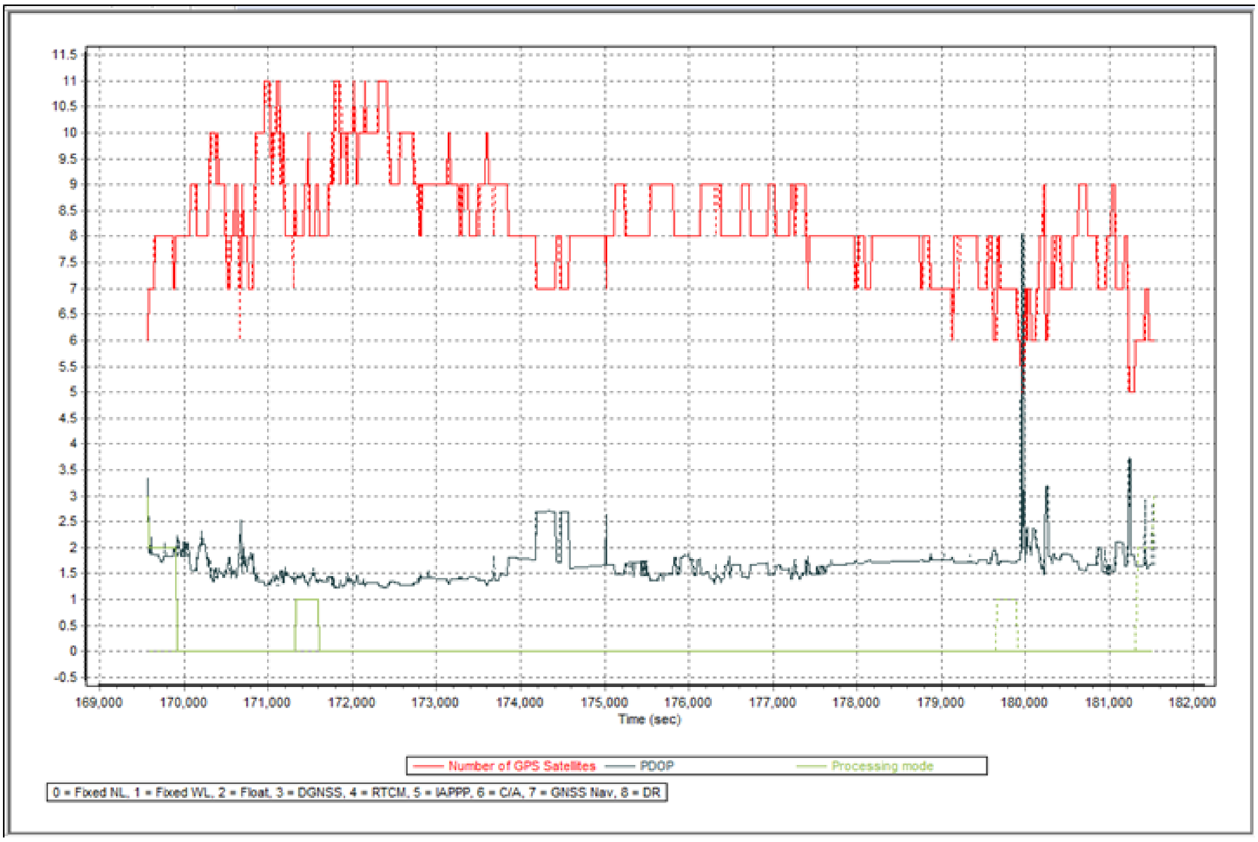


Figure A-8.22. Solution Status

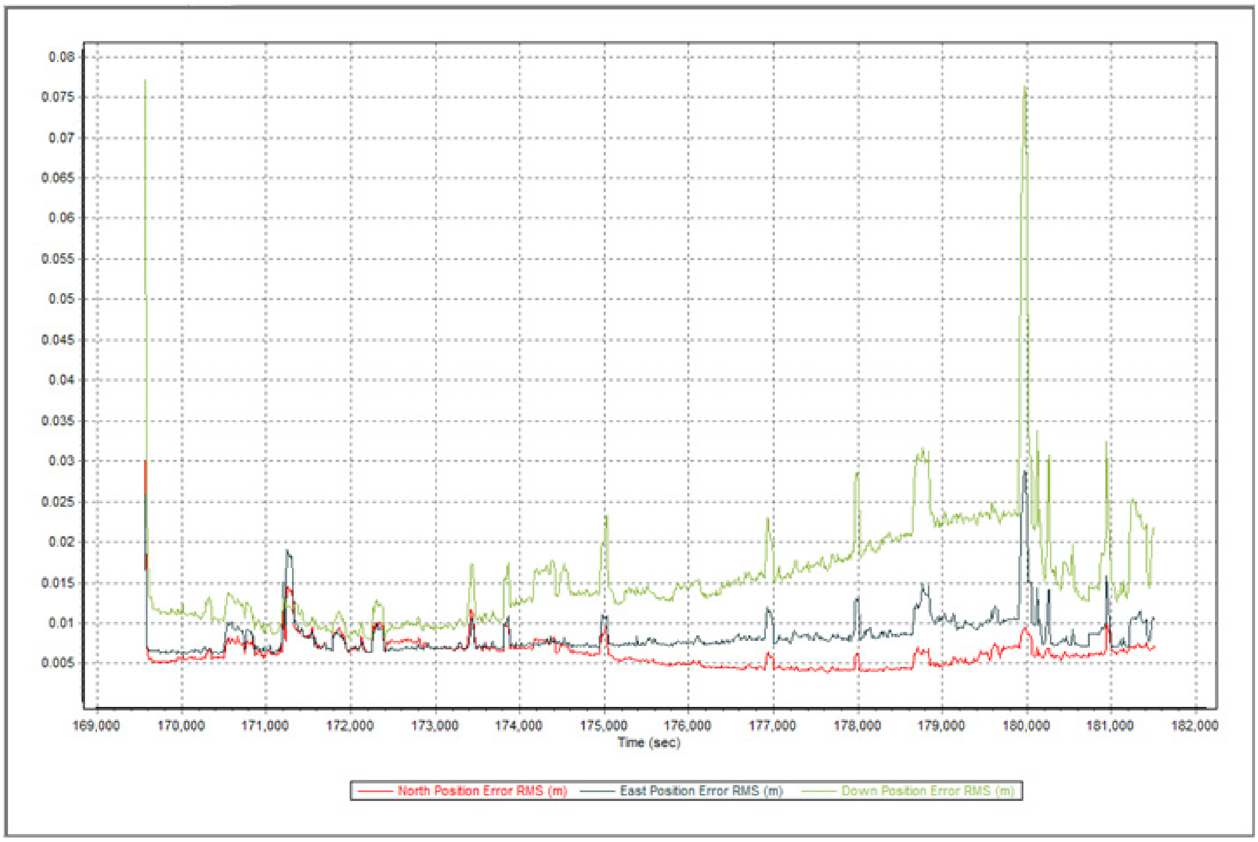


Figure A-8.23. Smoothed Performance Metric Parameters

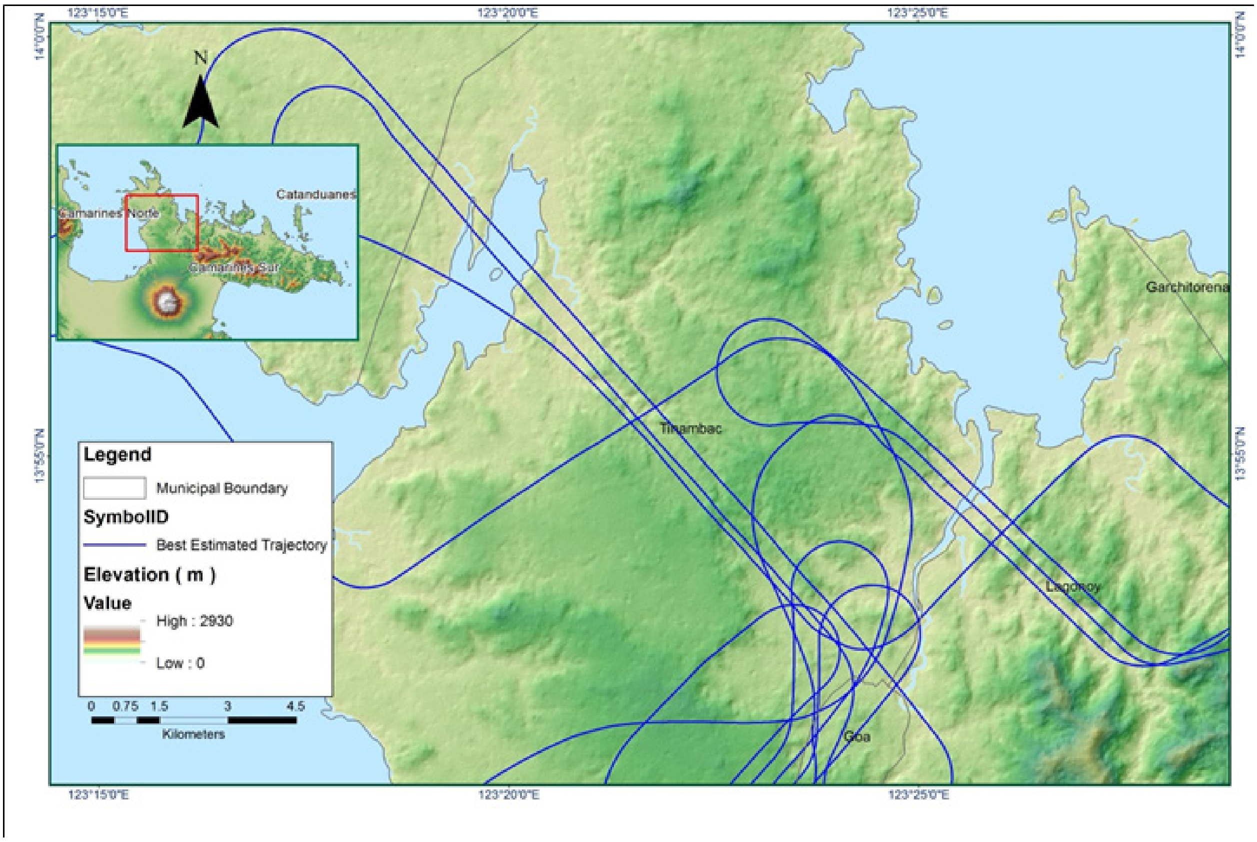


Figure A-8.24. Best Estimated Trajectory

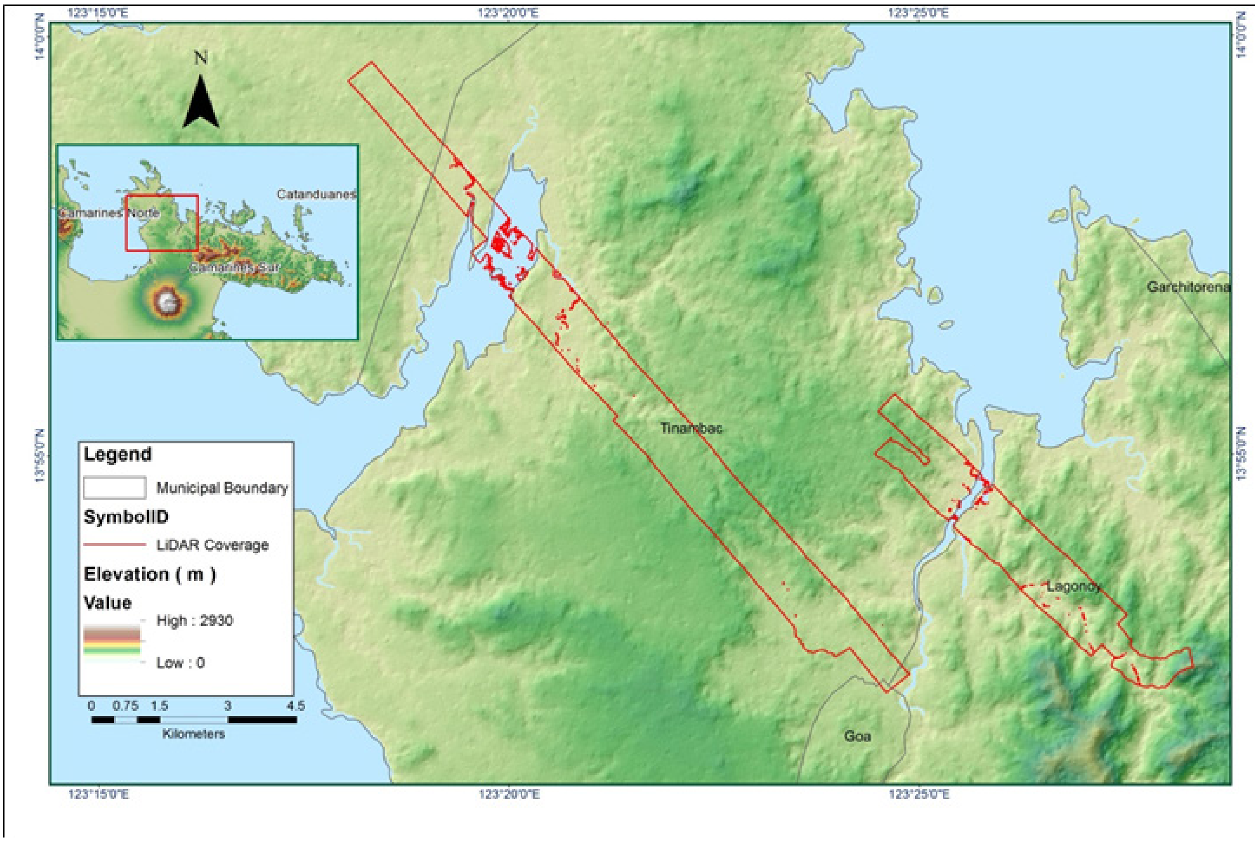


Figure A-8.25. Coverage of LiDAR data

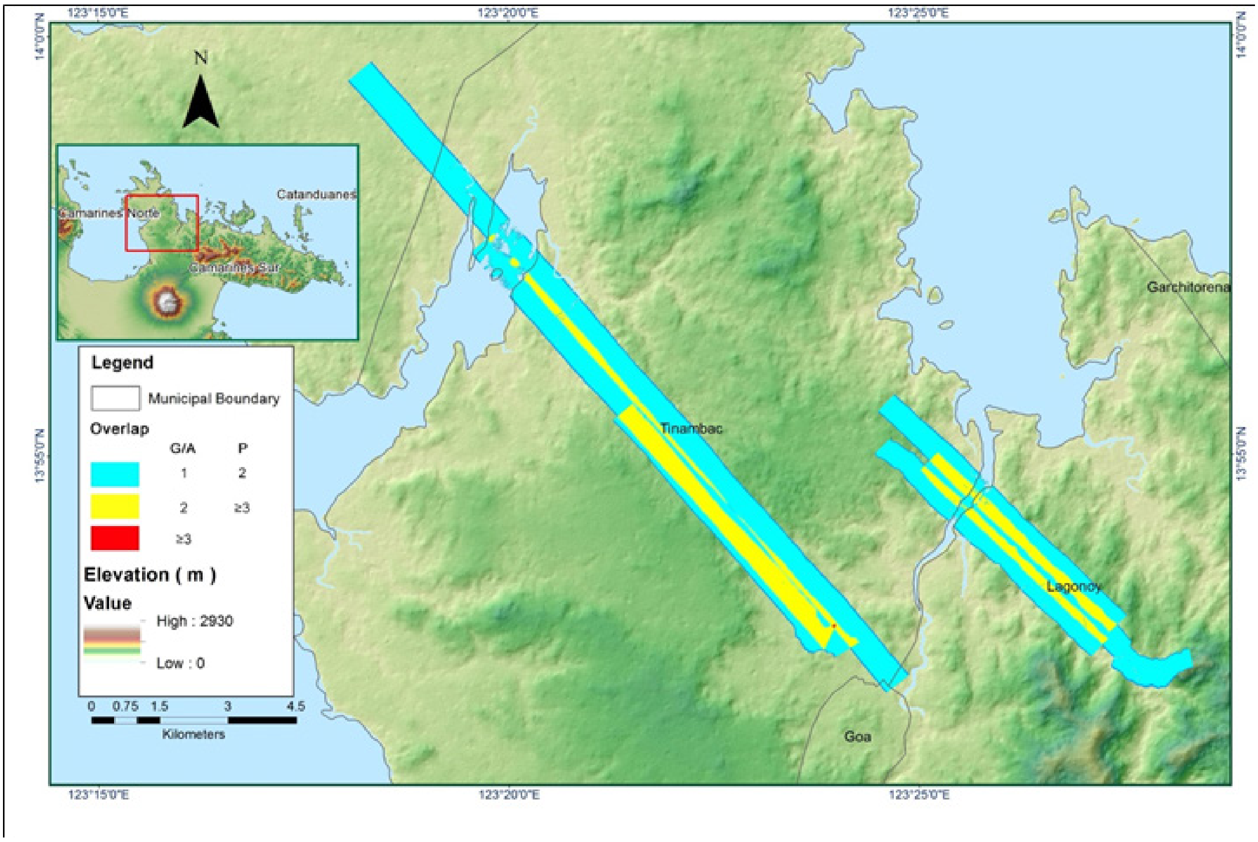


Figure A-8.26. Image of Data Overlap

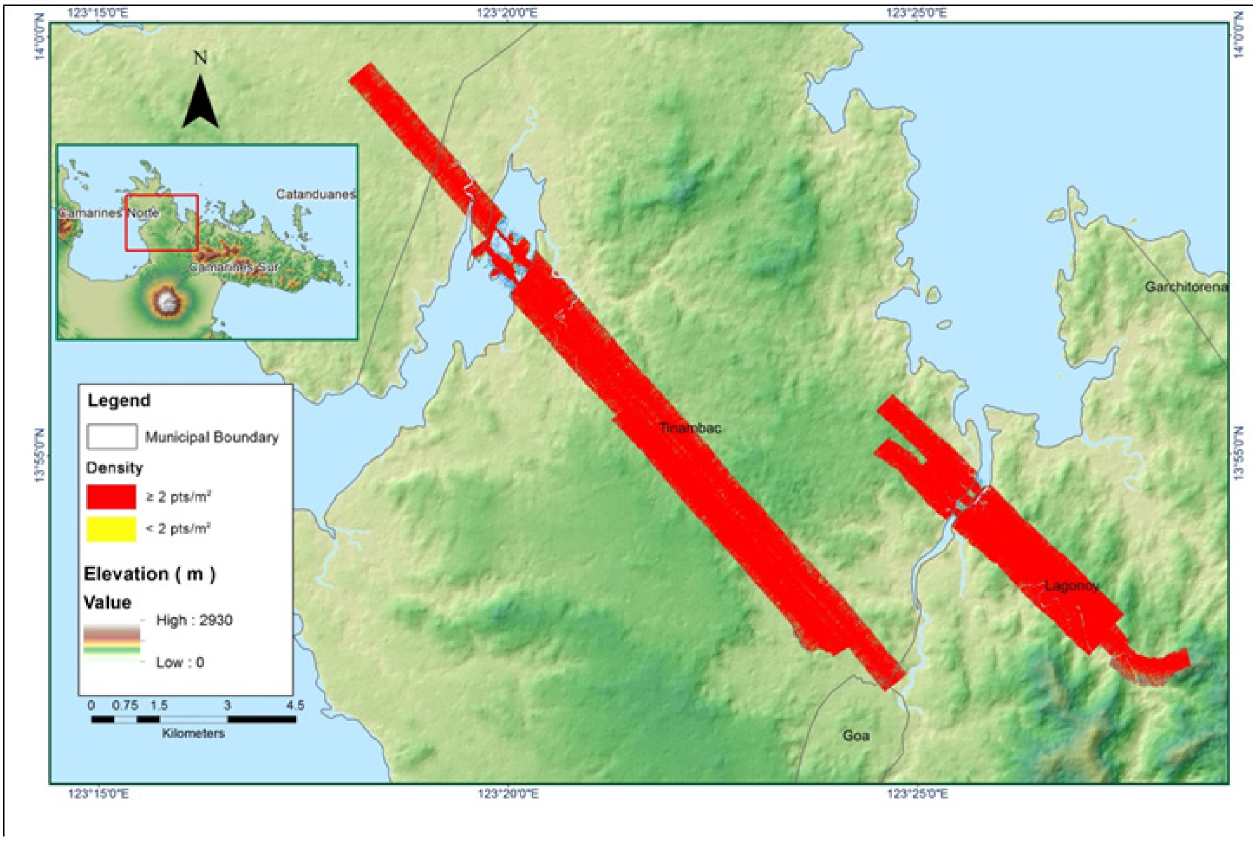


Figure A-8.27. Density map of merged LiDAR data

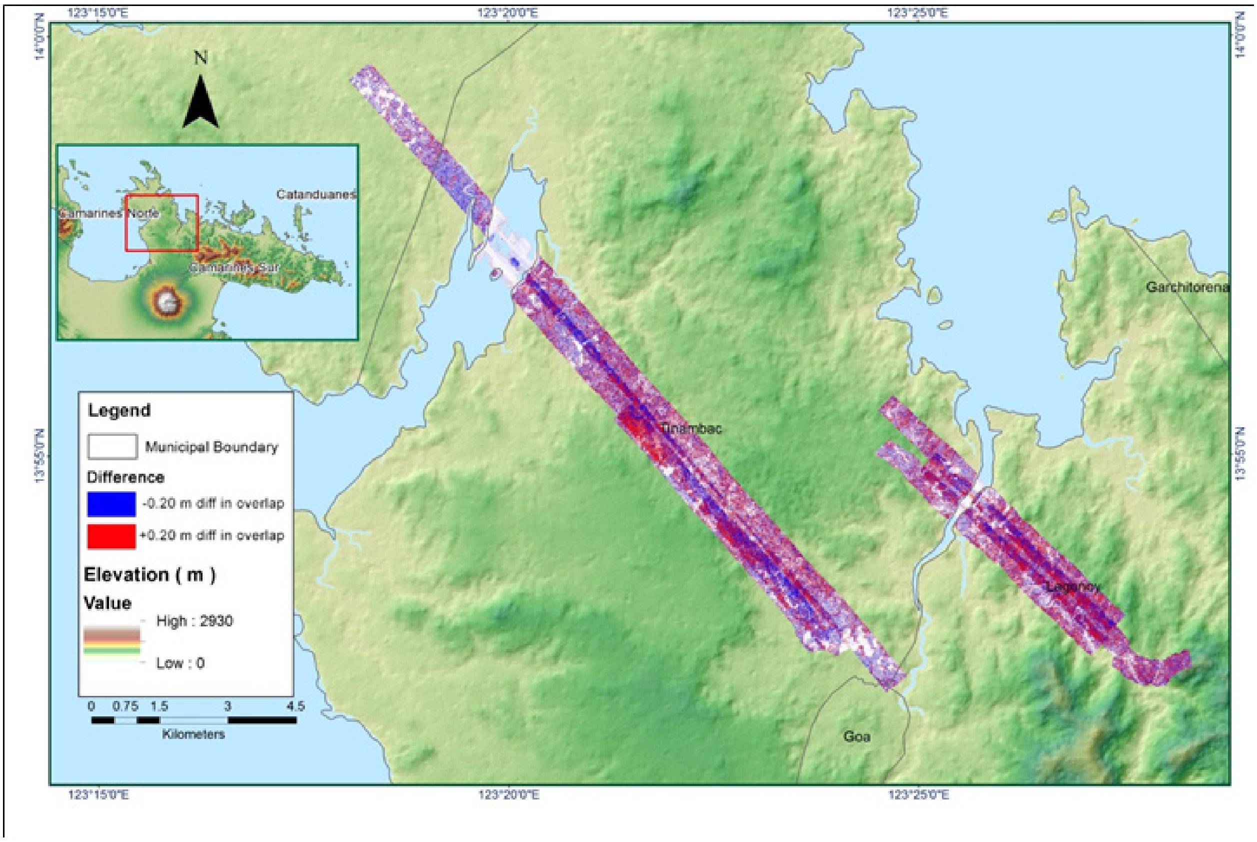


Figure A-8.28. Elevation difference between flight lines

Table A-8.5. Mission Summary Report for Mission Blk 24A

Flight Area	Naga
Mission Name	Blk 24A
Inclusive Flights	23278P, 23282P, 23302P, 23314P, 23318P
Range data size	139.1 GB
POS data size	1422 MB
Base data size	488.4 MB
Image	NA
Transfer date	June 10, 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)	1.537
RMSE for East Position (<4.0 cm)	1.445
RMSE for Down Position (<8.0 cm)	4.470
Boresight correction stdev (<0.001deg)	0.000270
IMU attitude correction stdev (<0.001deg)	0.001293
GPS position stdev (<0.01m)	0.0011
Minimum % overlap (>25)	48.58%
Ave point cloud density per sq.m. (>2.0)	3.87
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	313
Maximum Height	489.43 m
Minimum Height	53.46 m
Classification (# of points)	
Ground	173,715,934
Low vegetation	109,850,164
Medium vegetation	353,108,413
High vegetation	1,228,570,622
Building	16,008,099
Orthophoto	No
Processed by	Engr. Jennifer Saguran, Engr. Kenneth Solidum, Engr. Don Matthew Banatin, Engr. Sheila Maye Santillan, Engr. Regis Guhiting, Engr. Jovelle Anjeannette Can-las, Engr. Vincent Louise Azucena

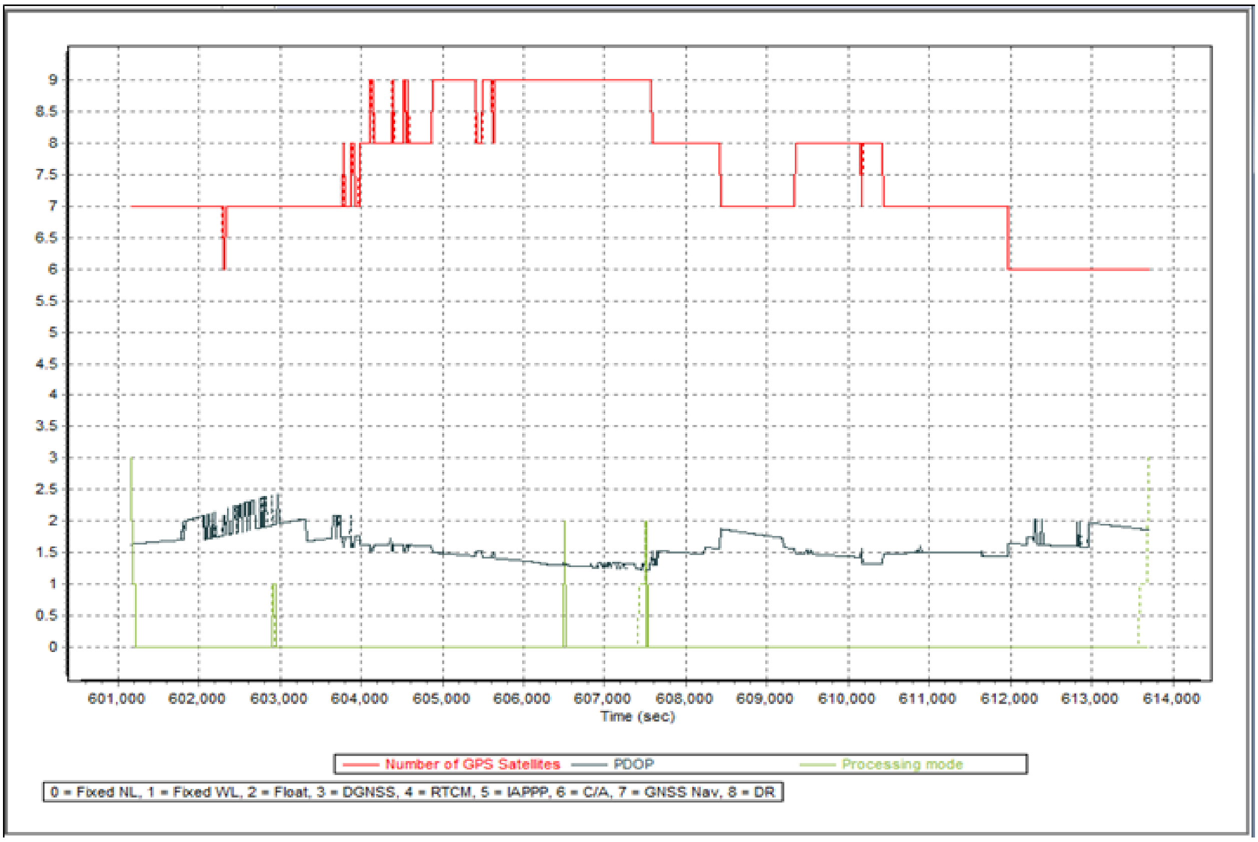


Figure A-8.29. Solution Status

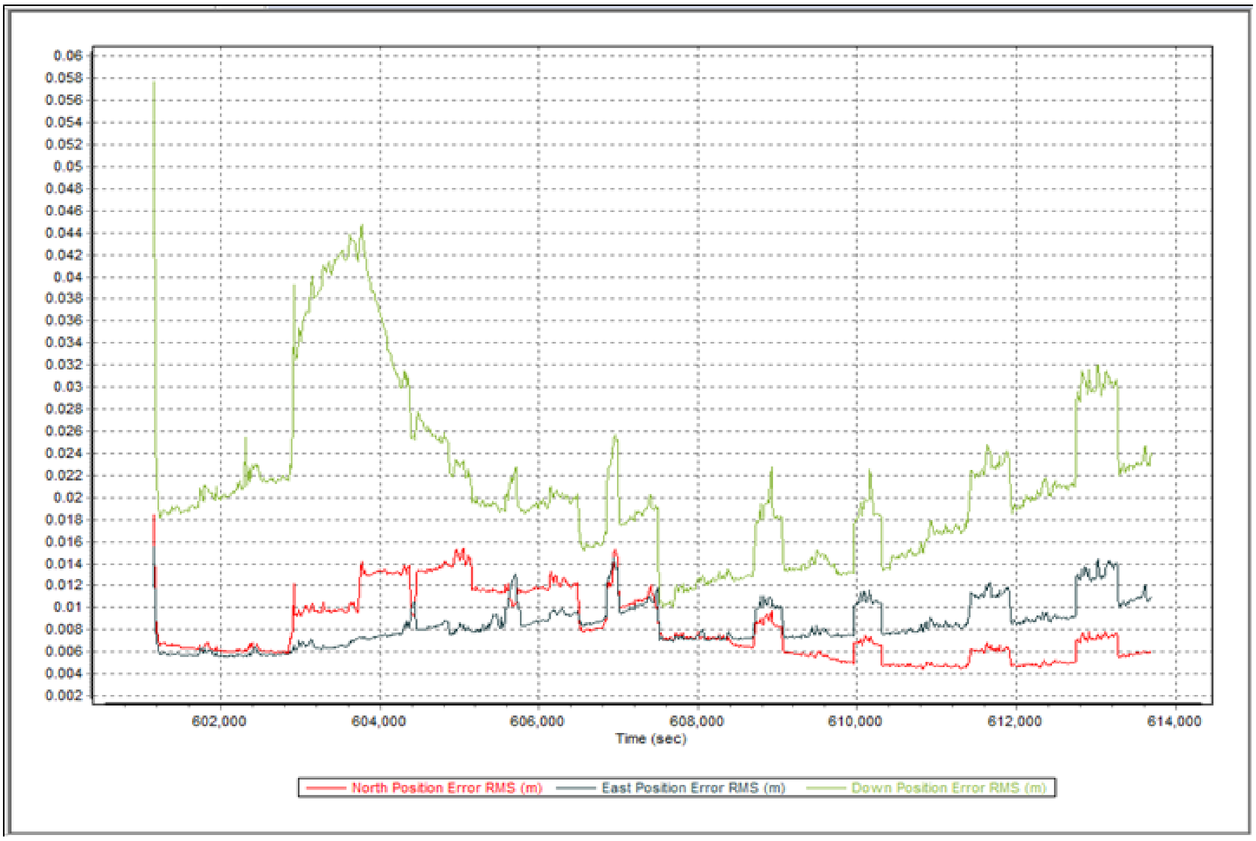


Figure A-8.30. Smoothed Performance Metric Parameters

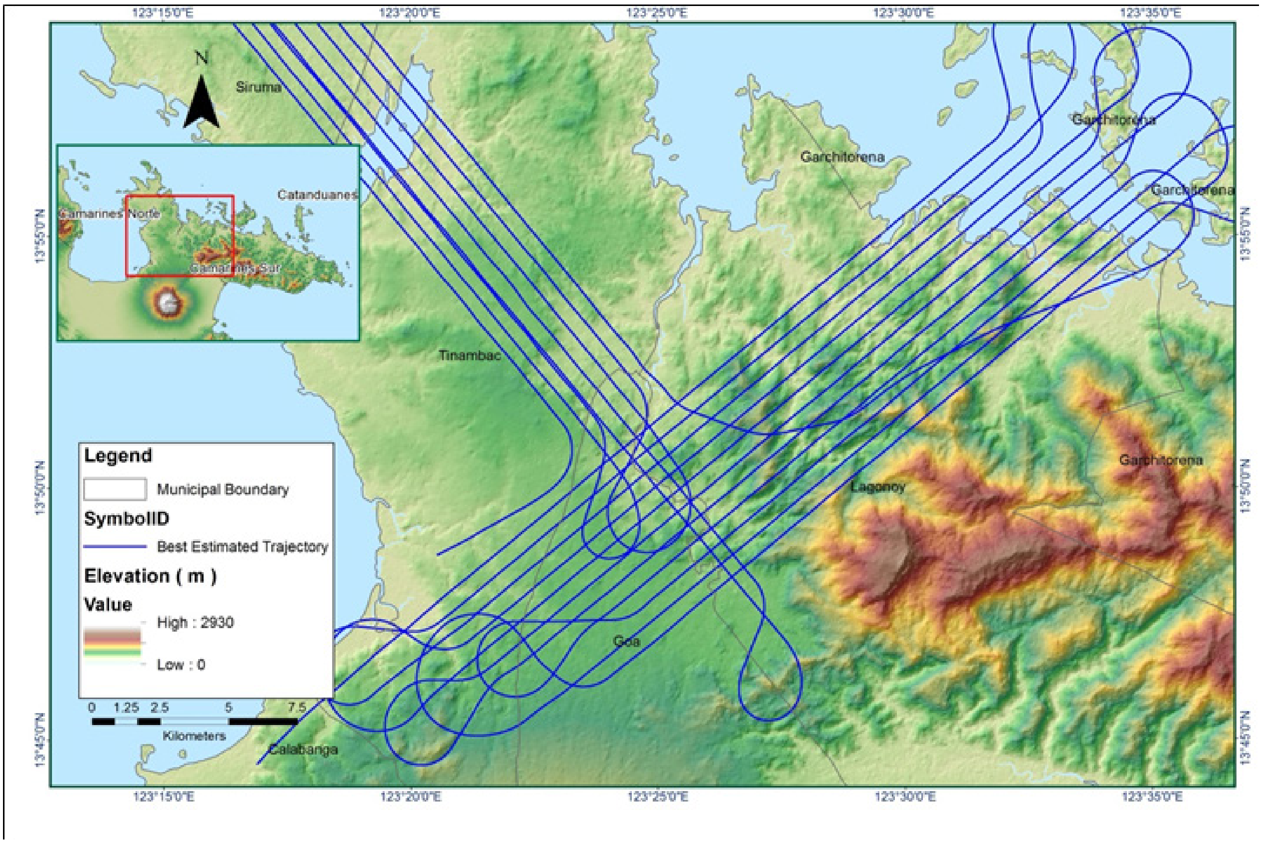


Figure A-8.31. Best Estimated Trajectory

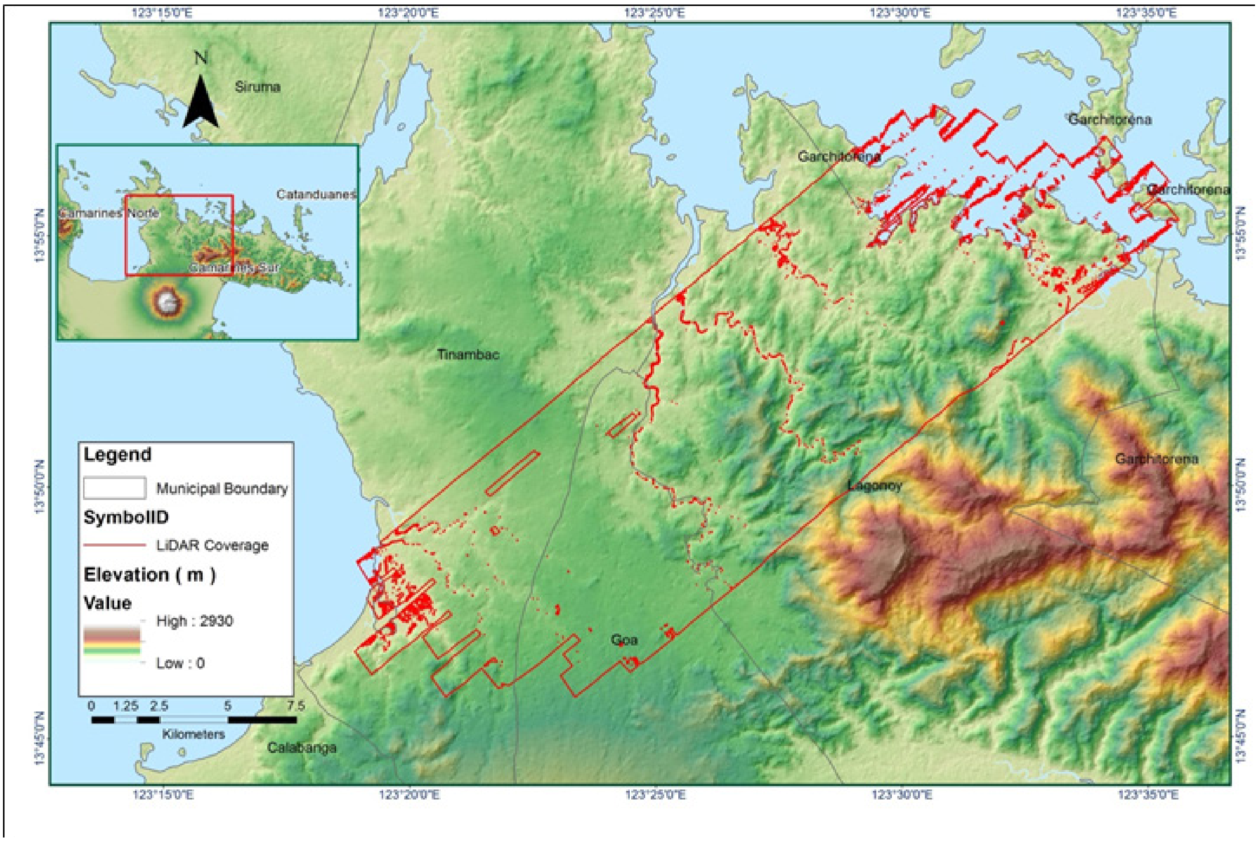


Figure A-8.32. Coverage of LiDAR data

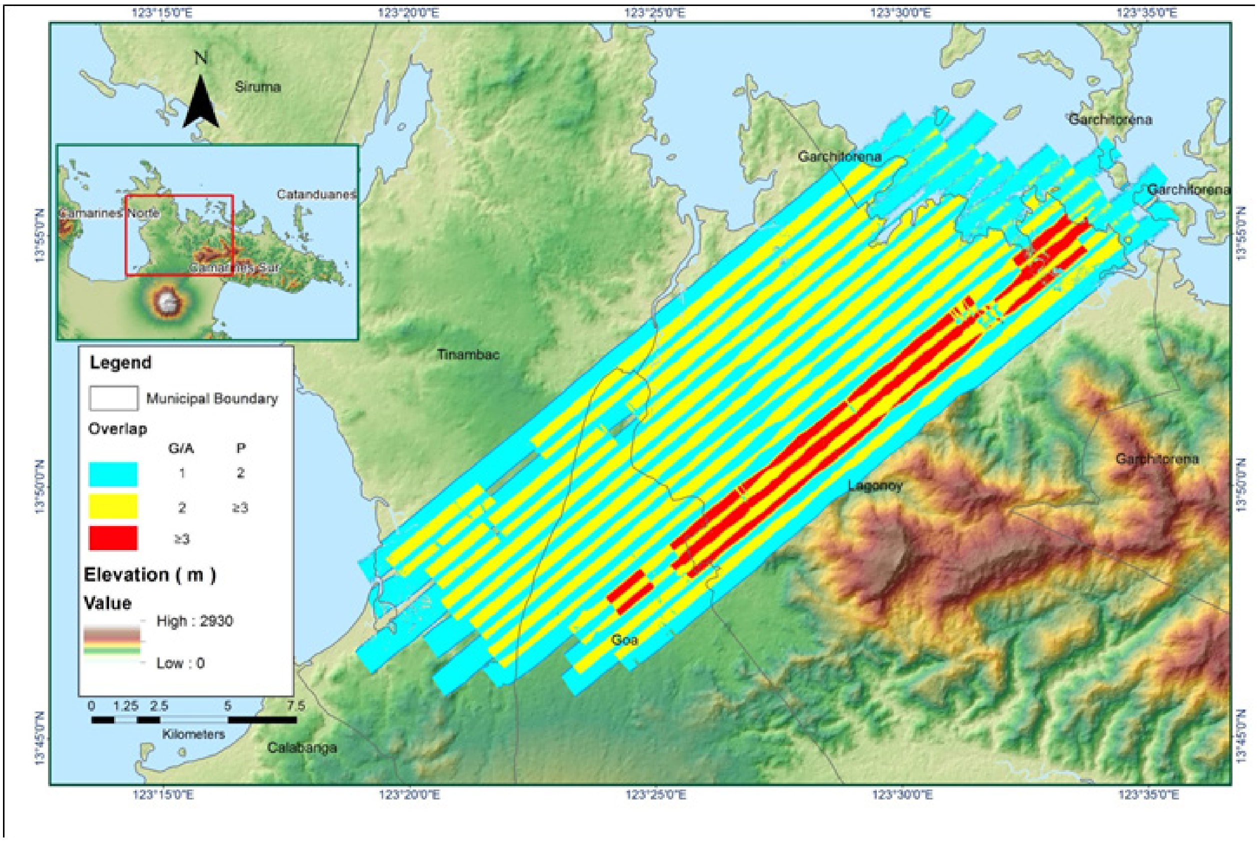


Figure A-8.33. Image of Data Overlap

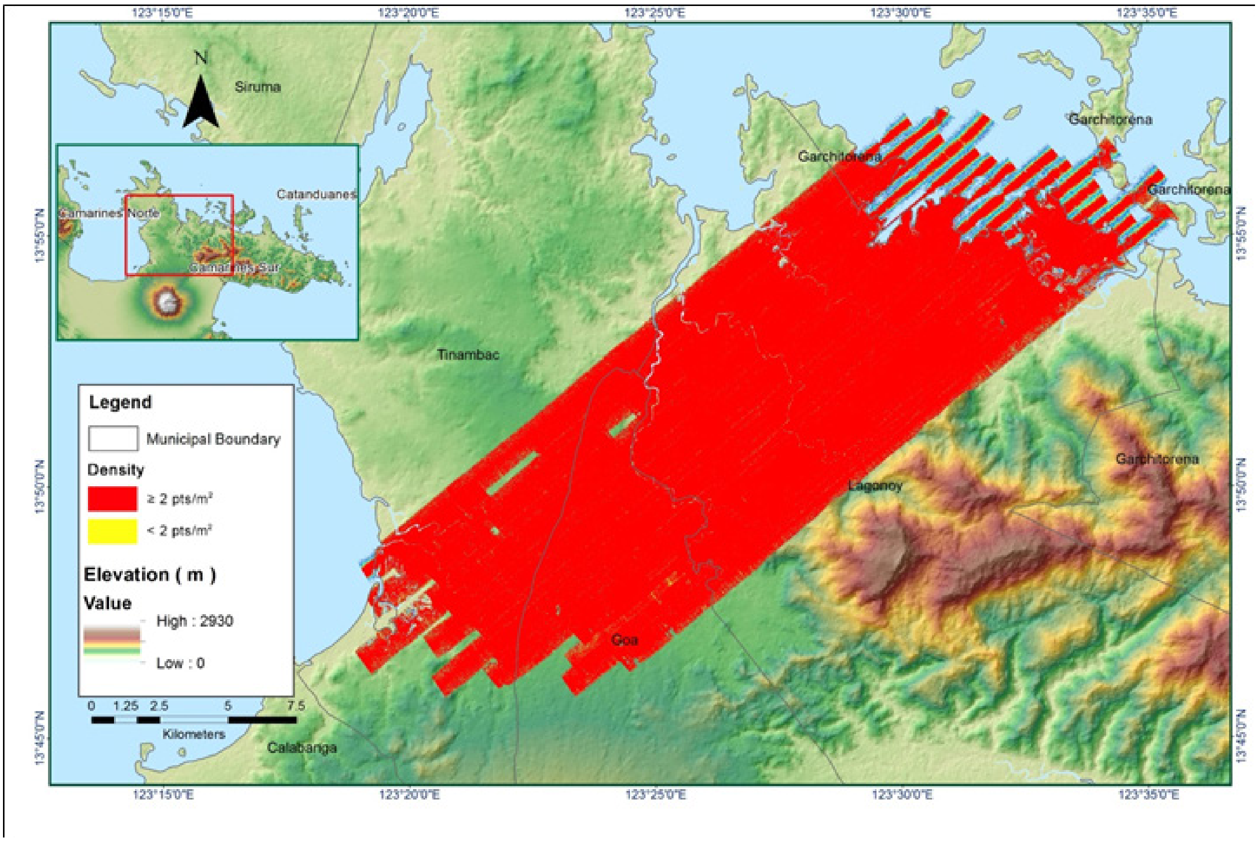


Figure A-8.34. Density map of merged LiDAR data

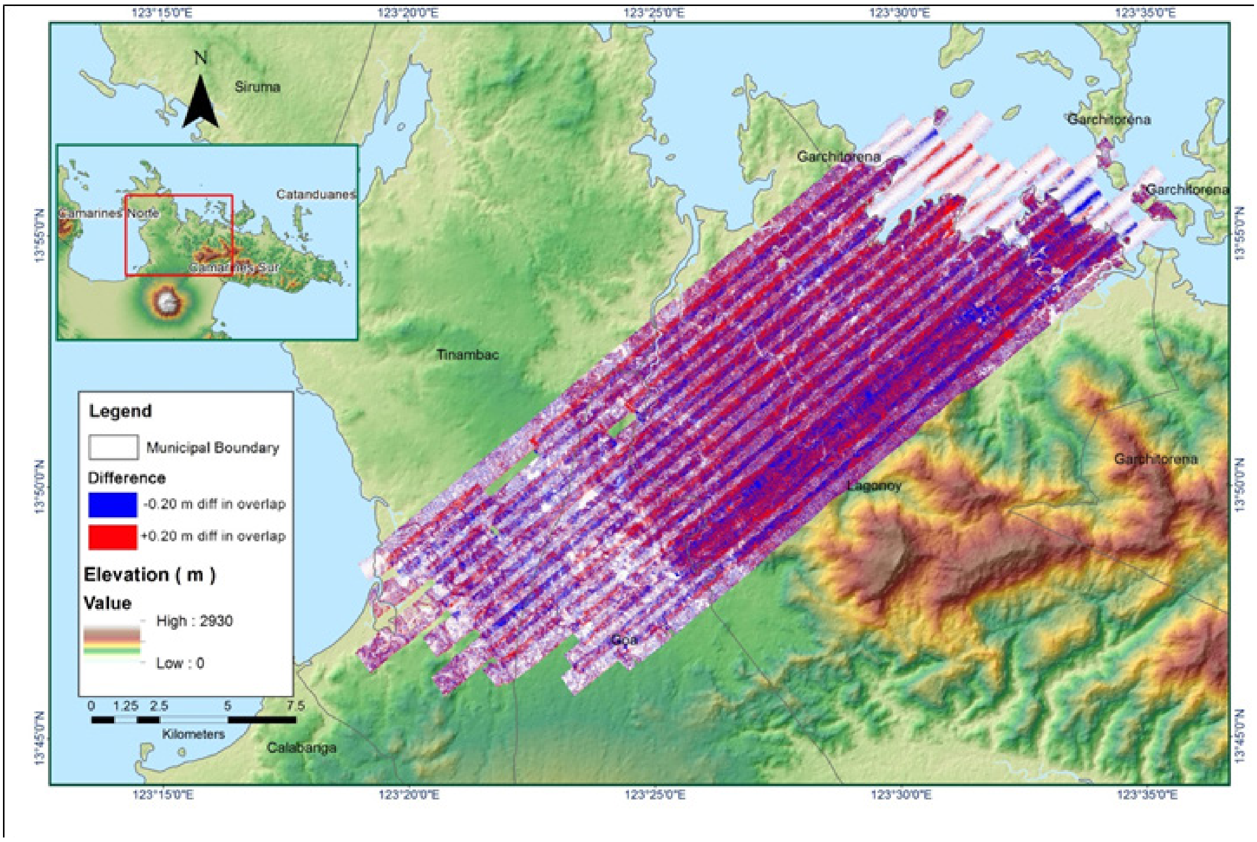


Figure A-8.35. Elevation difference between flight lines

Table A-8.6. Mission Summary Report for Mission Blk 24G

Flight Area	Naga
Mission Name	Blk 24G
Inclusive Flights	23276P, 23304P
Range data size	31.74 GB
POS data size	358 MB
Base data size	240 MB
Image	NA
Transfer date	June 19, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	1.027
RMSE for North Position (<4.0 cm)	1.748
RMSE for East Position (<4.0 cm)	3.339
RMSE for Down Position (<8.0 cm)	
Boresight correction stdev (<0.001deg)	0.000124
IMU attitude correction stdev (<0.001deg)	0.000333
GPS position stdev (<0.01m)	0.0009
Minimum % overlap (>25)	41.51%
Ave point cloud density per sq.m. (>2.0)	2.27
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	322
Maximum Height	265.70 m
Minimum Height	44.14 m
Classification (# of points)	
Ground	245,799,624
Low vegetation	112,184,158
Medium vegetation	166,355,964
High vegetation	374,734,176
Building	4,248,566
Orthophoto	No
Processed by	Engr. Don Matthew Banatin, Engr. Edgardo Gubatanga Jr., Engr. Monalyne Rabino

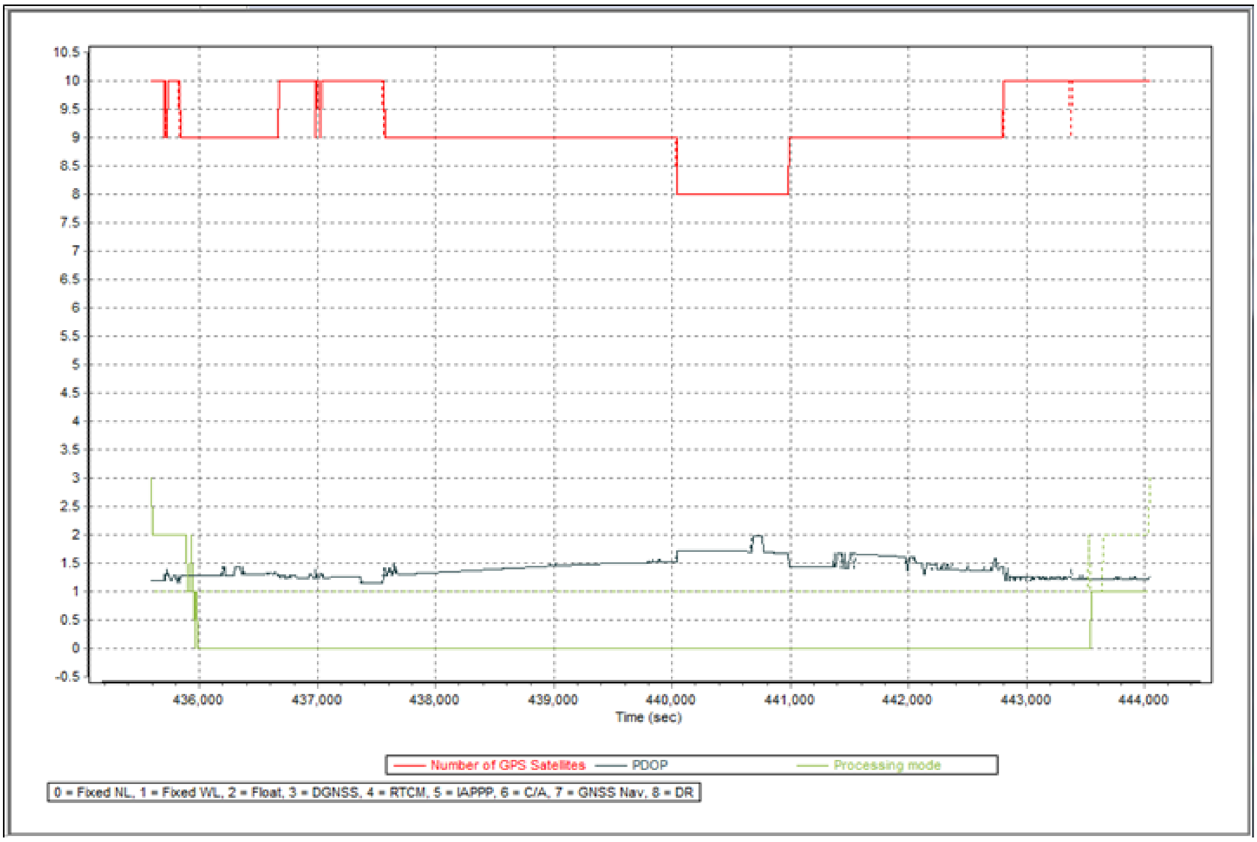


Figure A-8.36. Solution Status

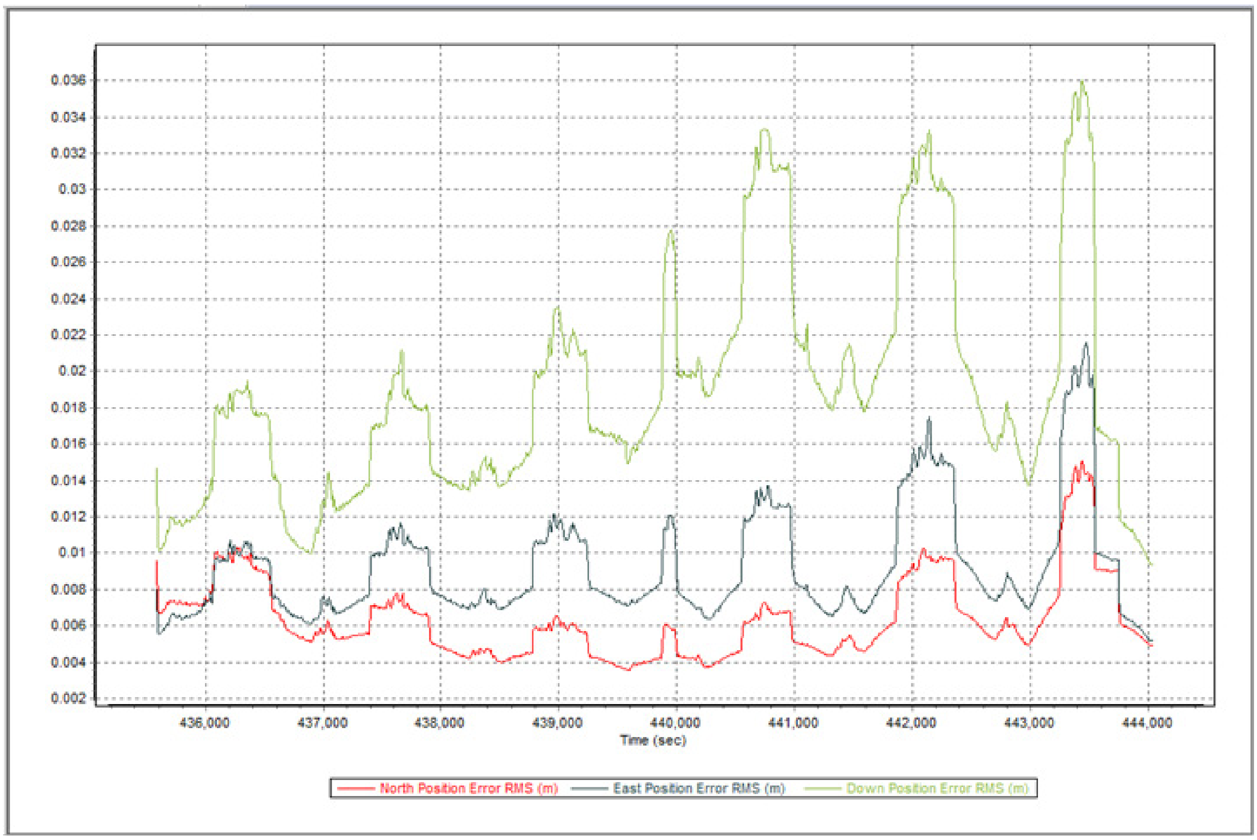


Figure A-8.37. Smoothed Performance Metric Parameters

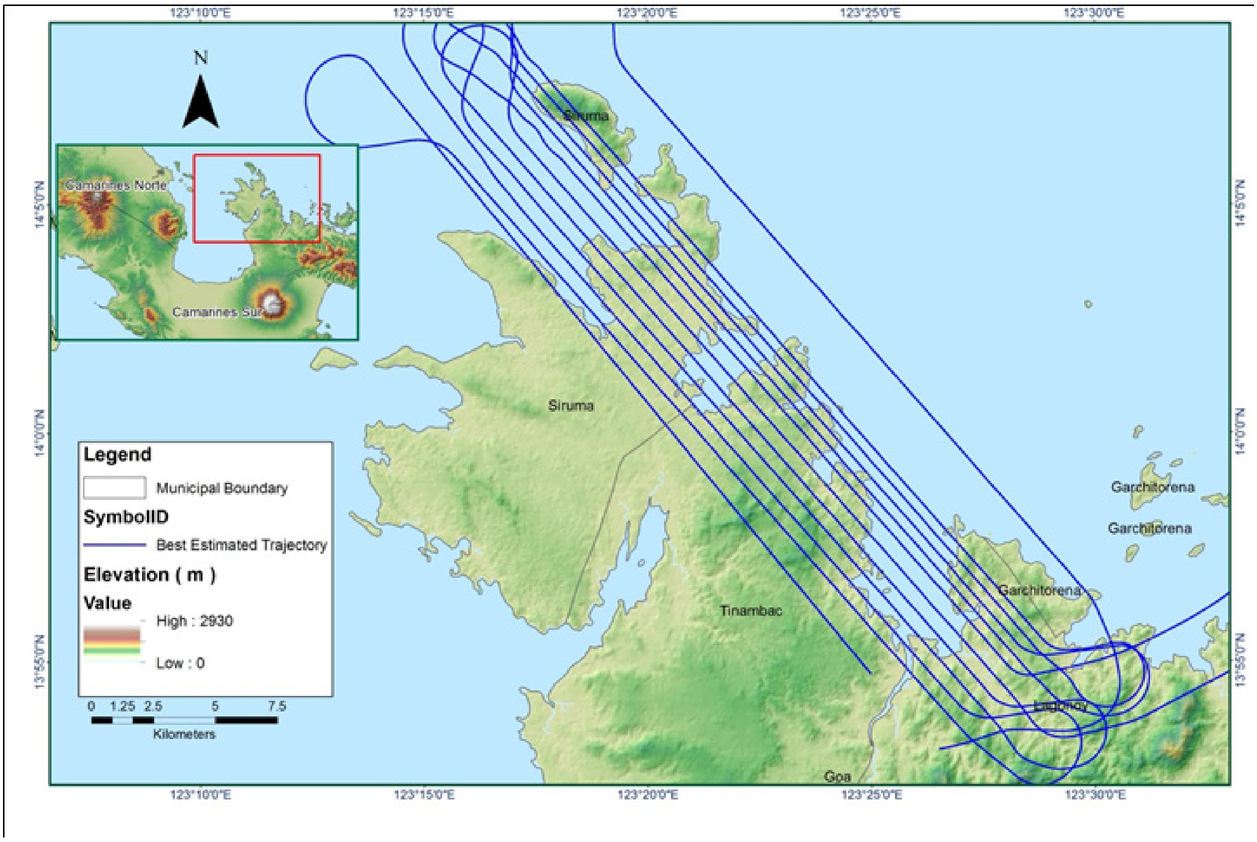


Figure A-8.38. Best Estimated Trajectory

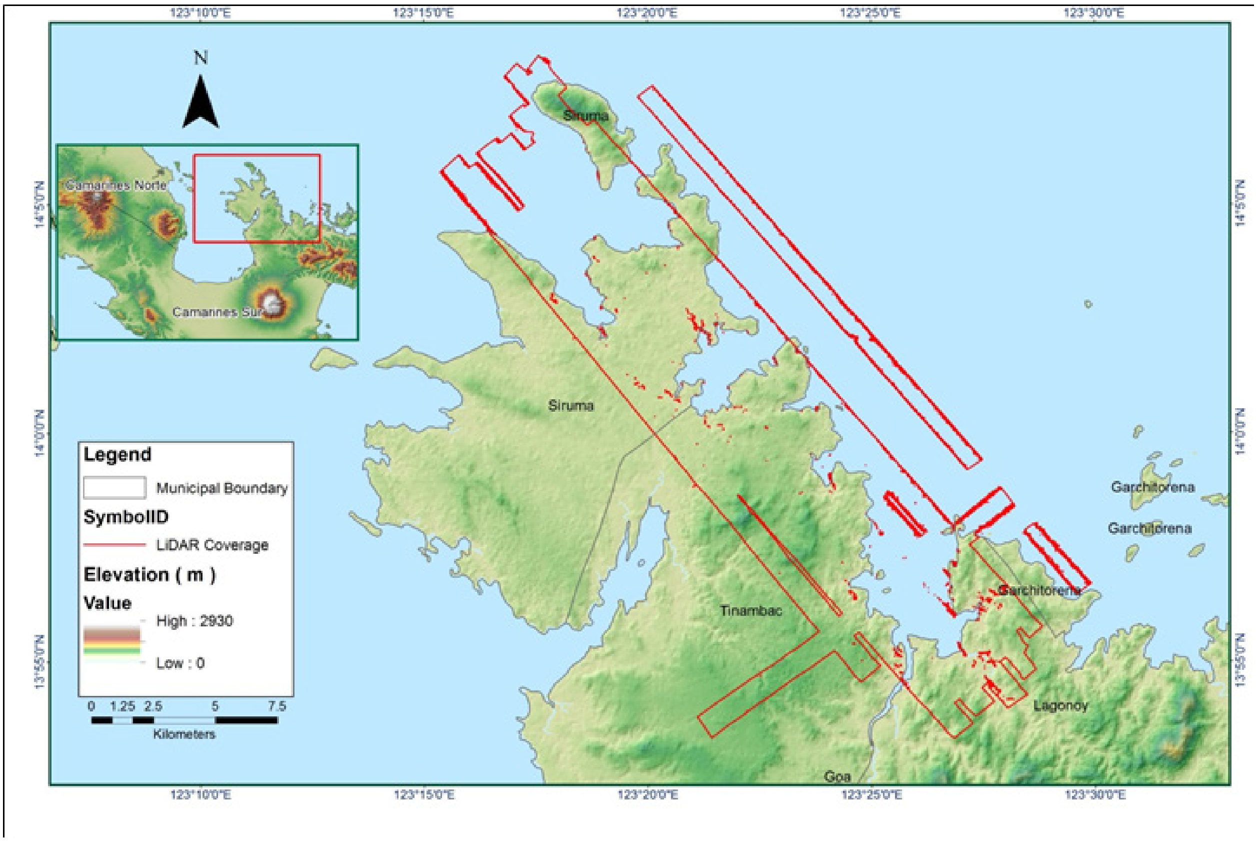


Figure A-8.39. Coverage of LiDAR data

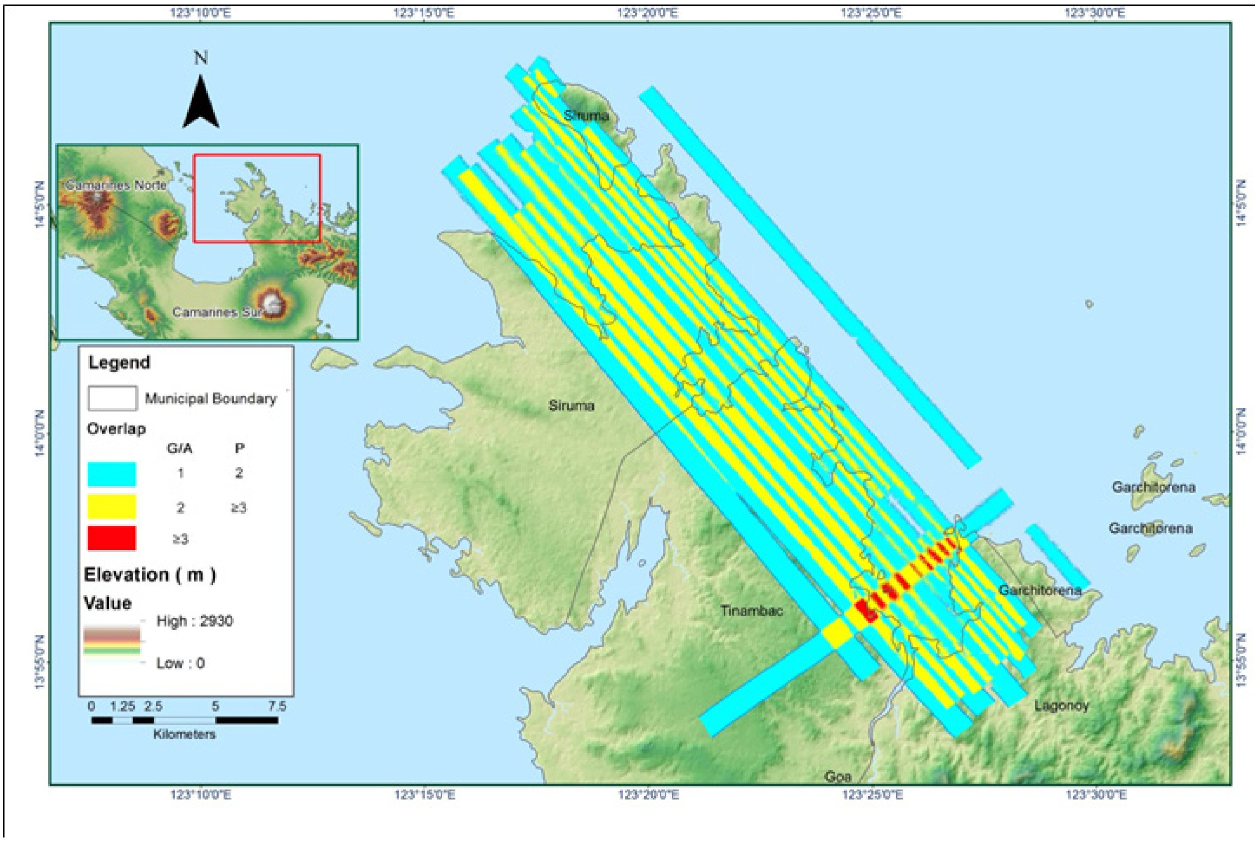


Figure A-8.40. Image of Data Overlap

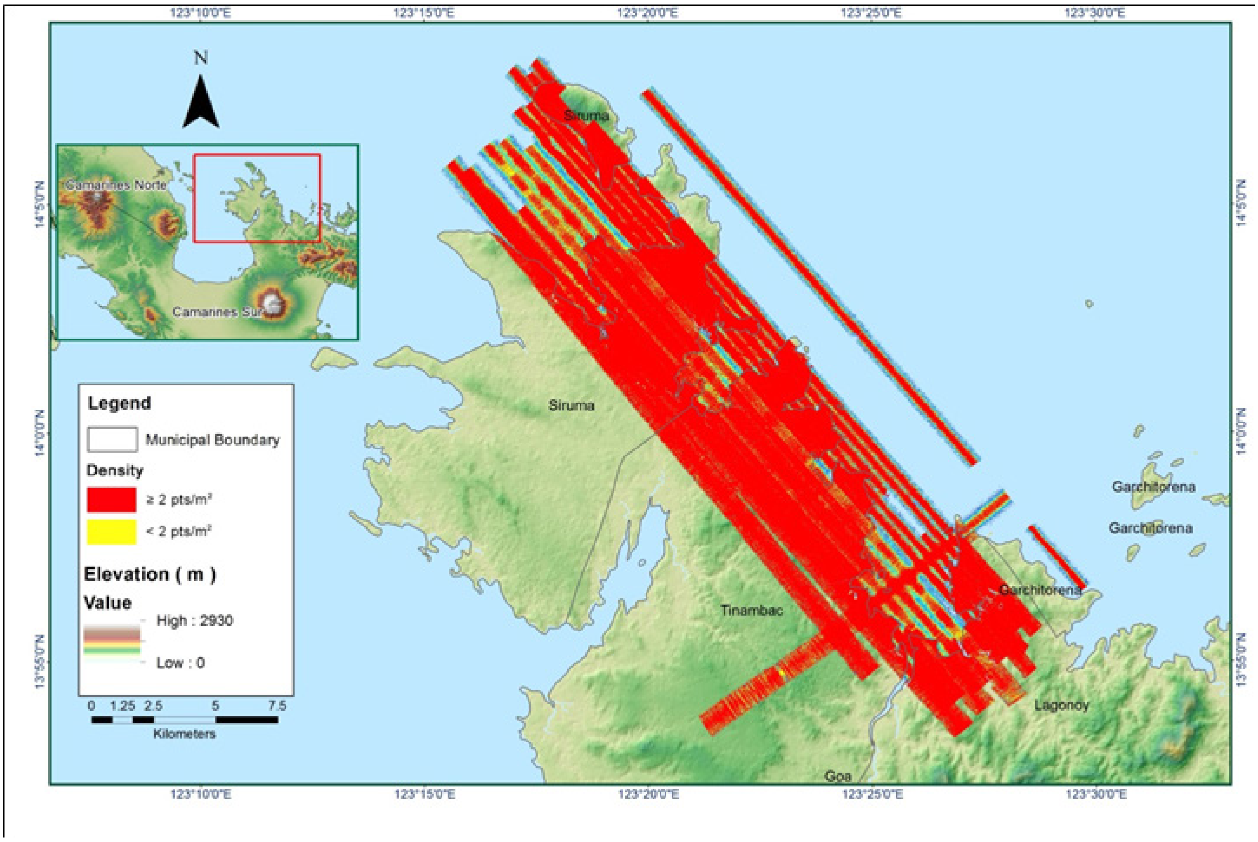


Figure A-8.41. Density map of merged LiDAR data

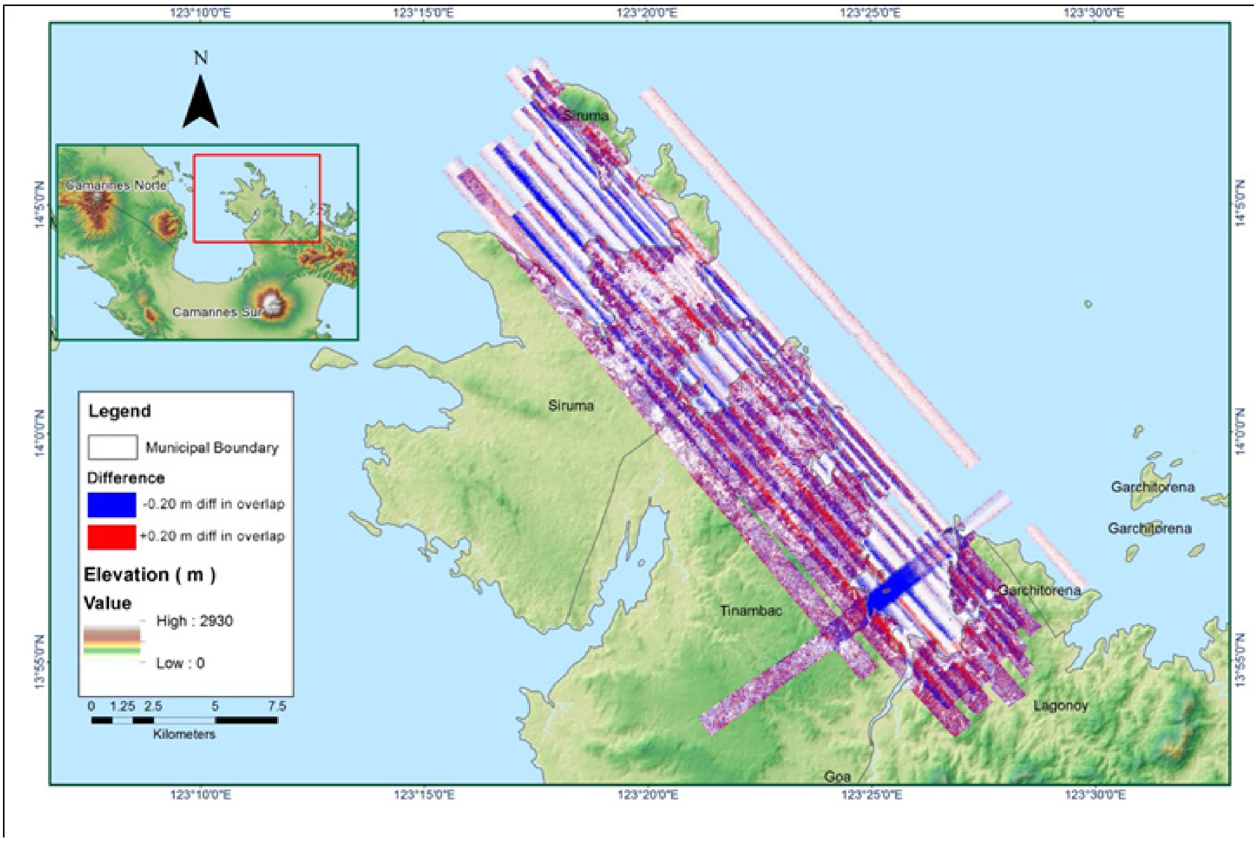


Figure A-8.42. Elevation difference between flight lines

Table A-8.7. Mission Summary Report for Mission Naga_Blk24G_Supplement

Flight Area	Naga
Mission Name	Naga_Blk24G_Supplement
Inclusive Flights	23276P
Range data size	23.2 GB
POS data size	233 MB
Base data size	127 MB
Image	n/a
Transfer date	June 6, 2016
Solution Status	
Number of Satellites (>6)	No
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.1
RMSE for East Position (<4.0 cm)	0.8
RMSE for Down Position (<8.0 cm)	1.7
Boresight correction stdev (<0.001deg)	0.000527
IMU attitude correction stdev (<0.001deg)	0.000260
GPS position stdev (<0.01m)	0.0016
Minimum % overlap (>25)	4.07%
Ave point cloud density per sq.m. (>2.0)	2.17
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	96
Maximum Height	307.74 m
Minimum Height	51.90 m
Classification (# of points)	
Ground	25,508,895
Low vegetation	16,732,584
Medium vegetation	34,992,302
High vegetation	84,104,668
Building	543,426
Orthophoto	No
Processed by	Engr. Don Matthew Banatin, Engr. Mark Joshua Salvacion, Jovy Narisma

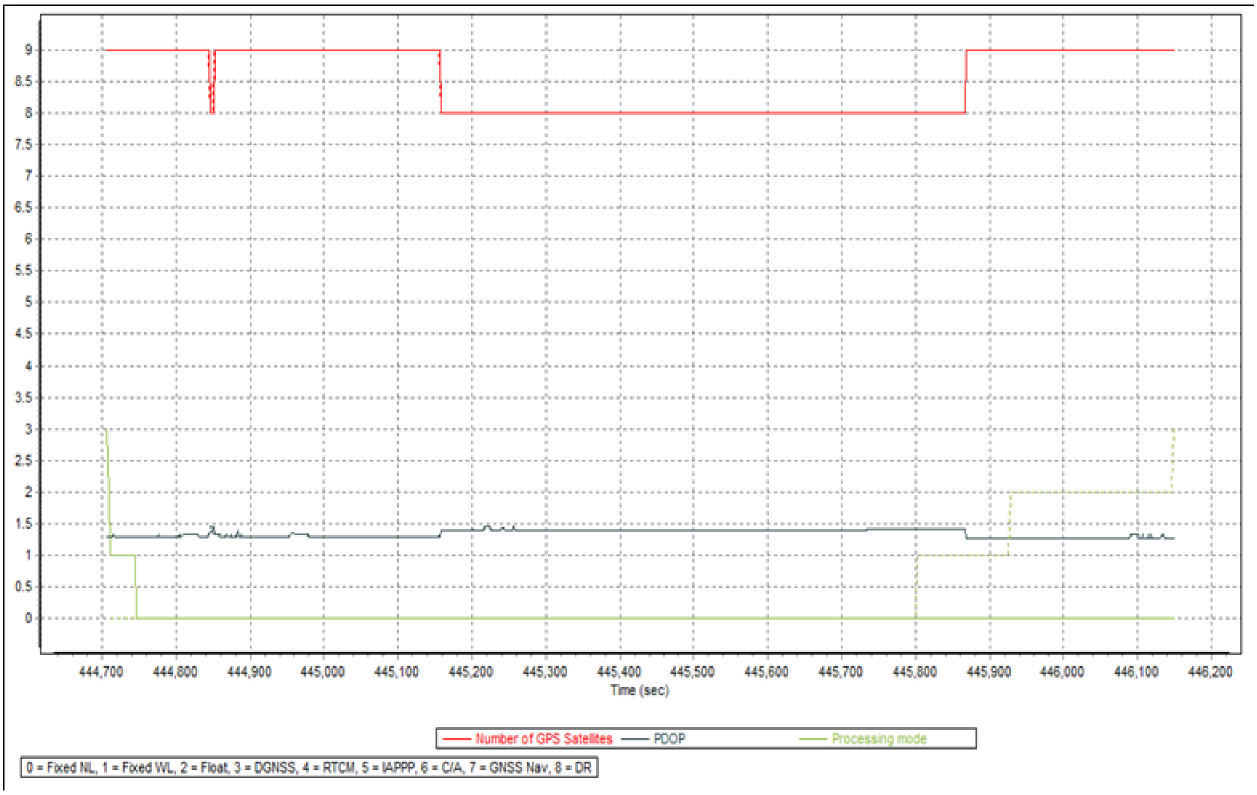


Figure A-8.43. Solution Status

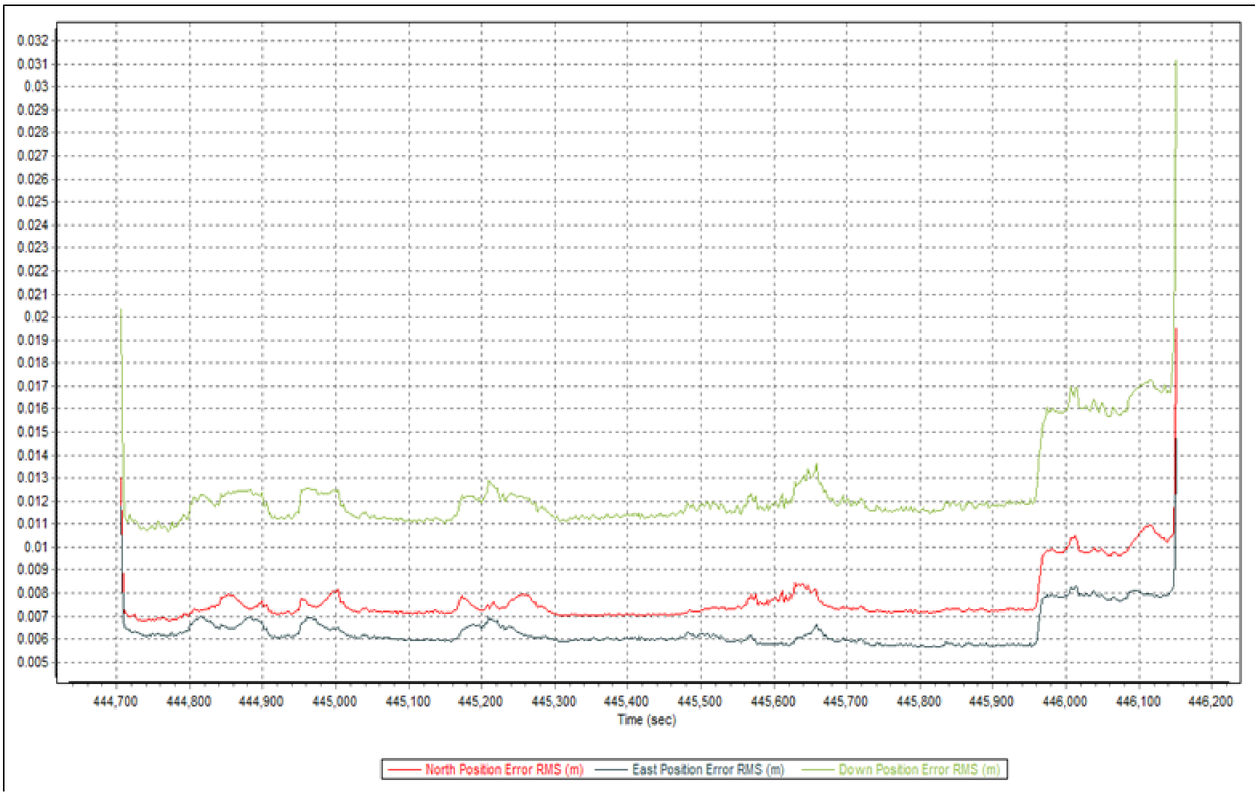


Figure A-8.44. Smoothed Performance Metric Parameters

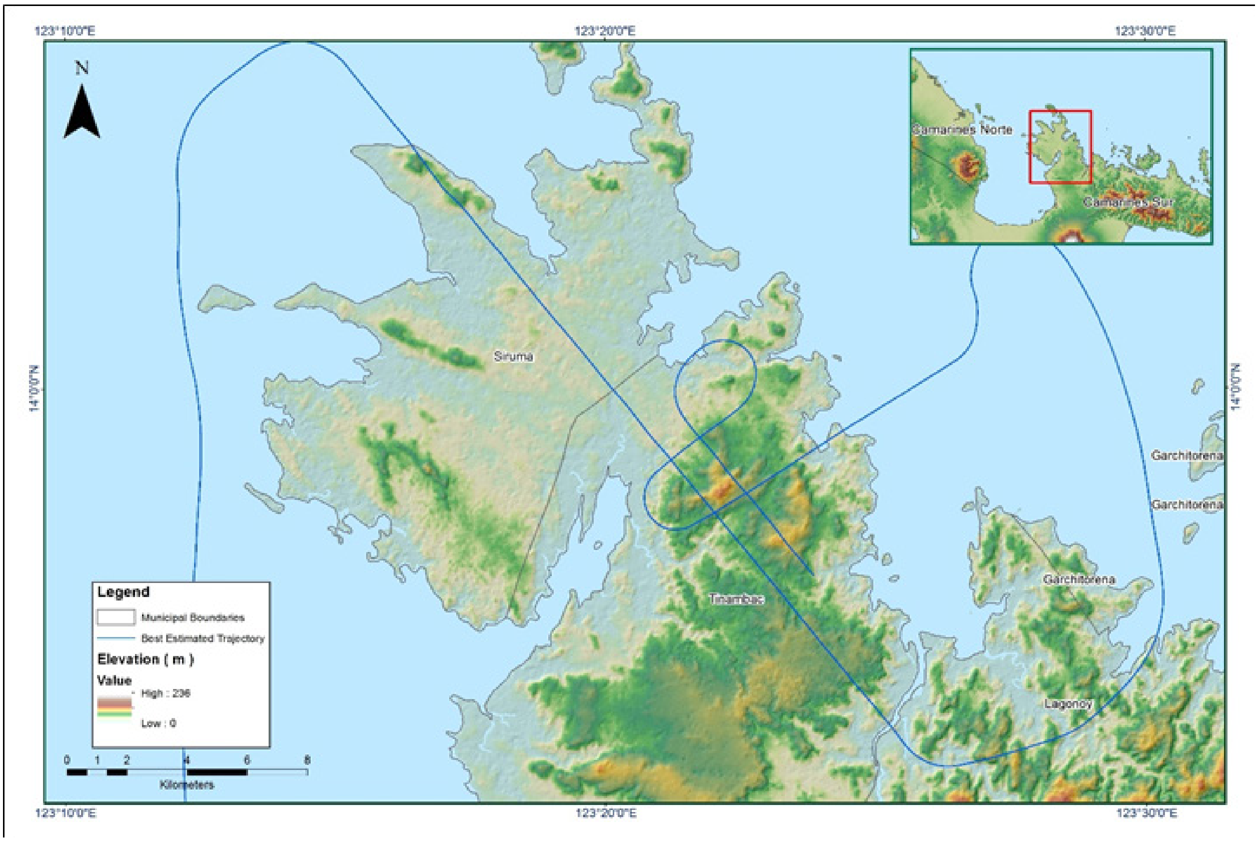


Figure A-8.45. Best Estimated Trajectory

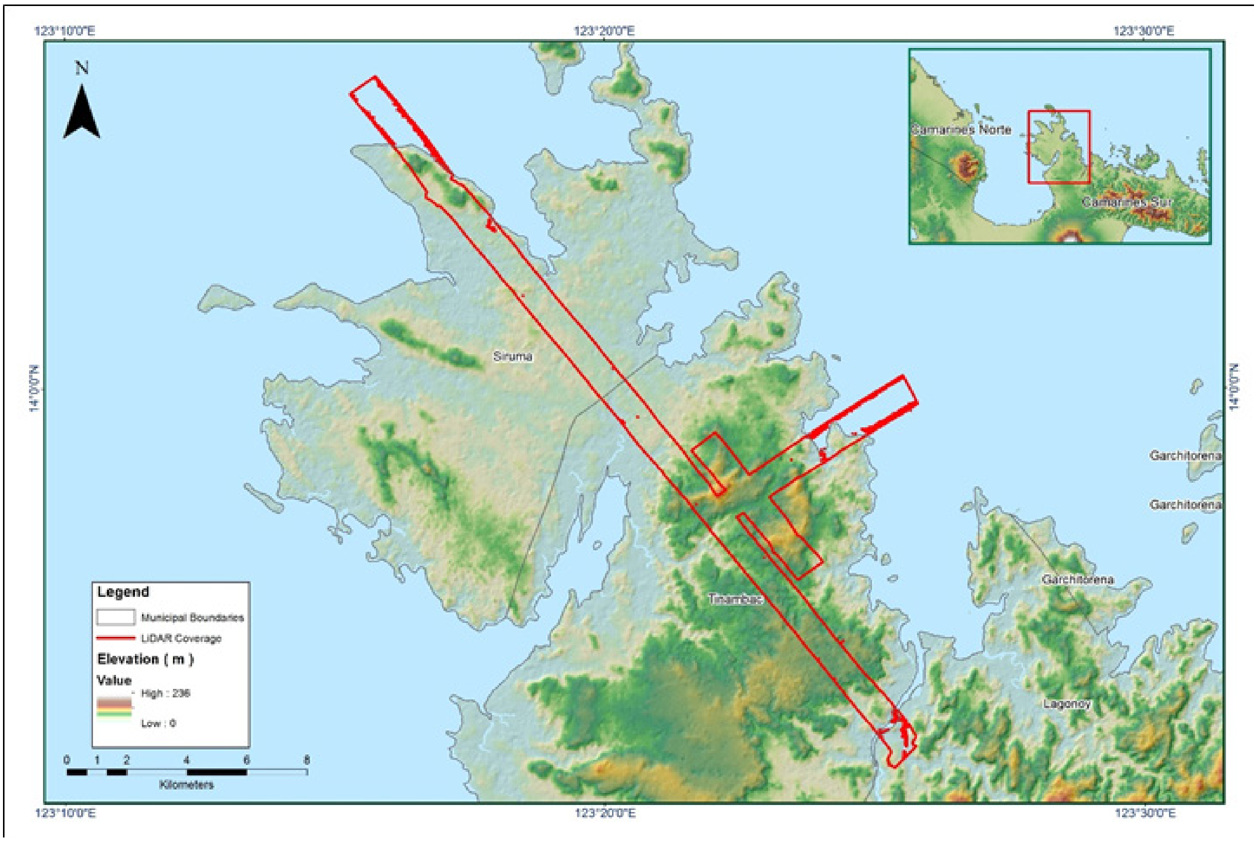


Figure A-8.46. Coverage of LiDAR data

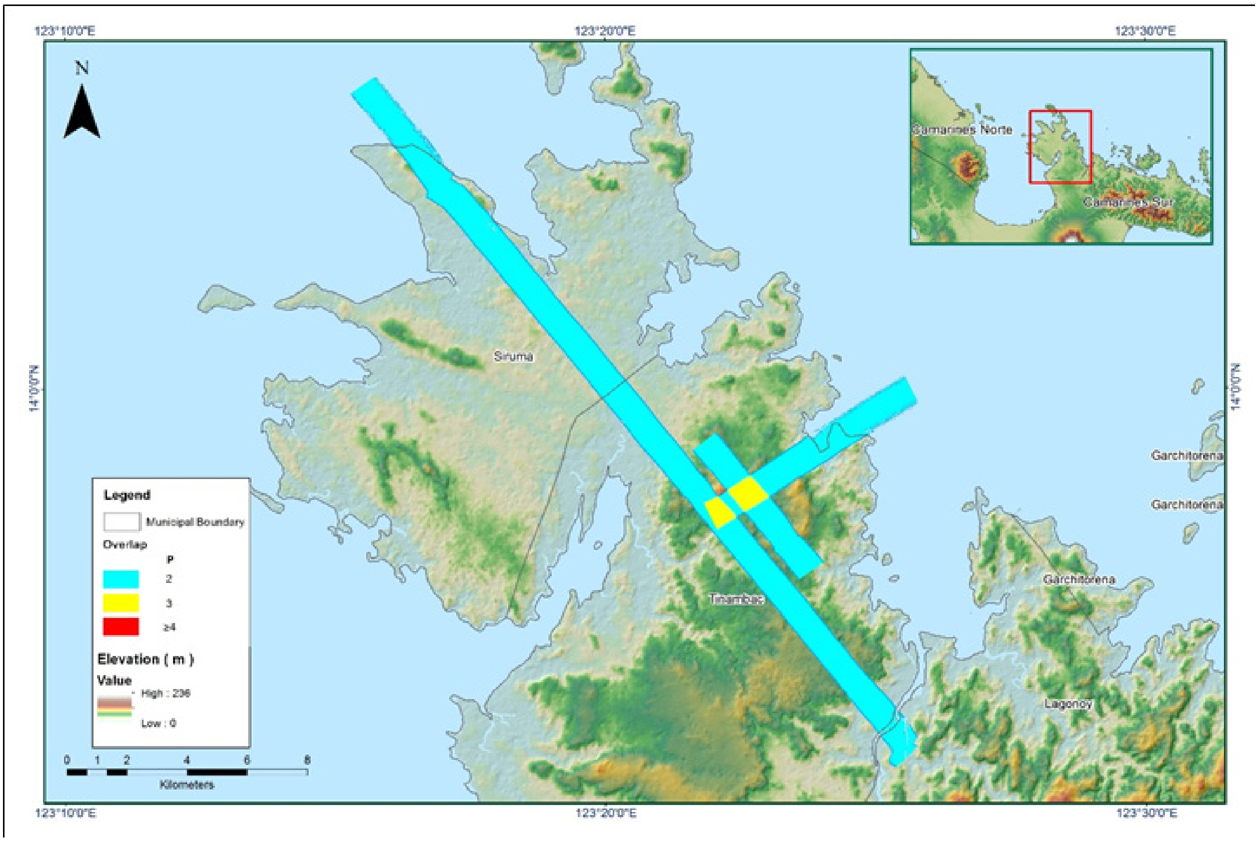


Figure A-8.47. Image of Data Overlap

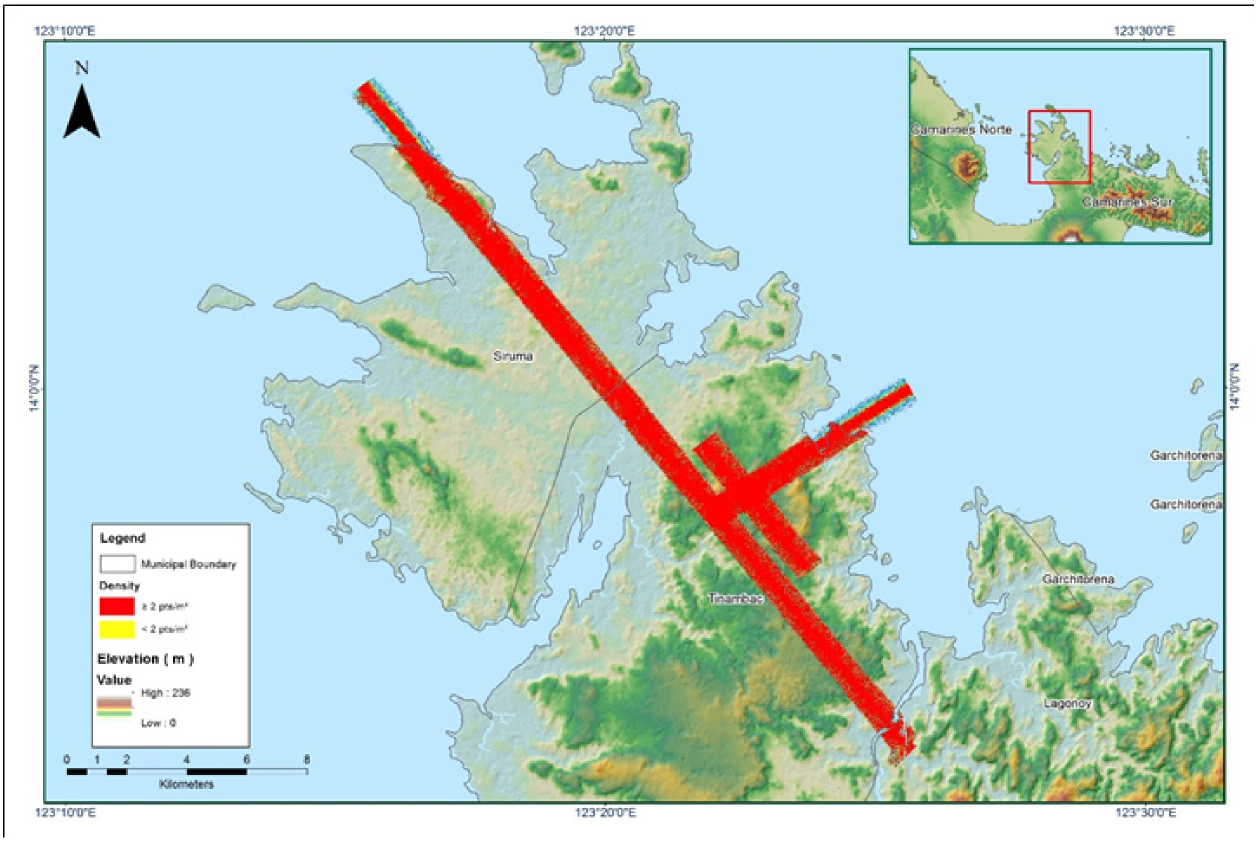


Figure A-8.48. Density map of merged LiDAR data

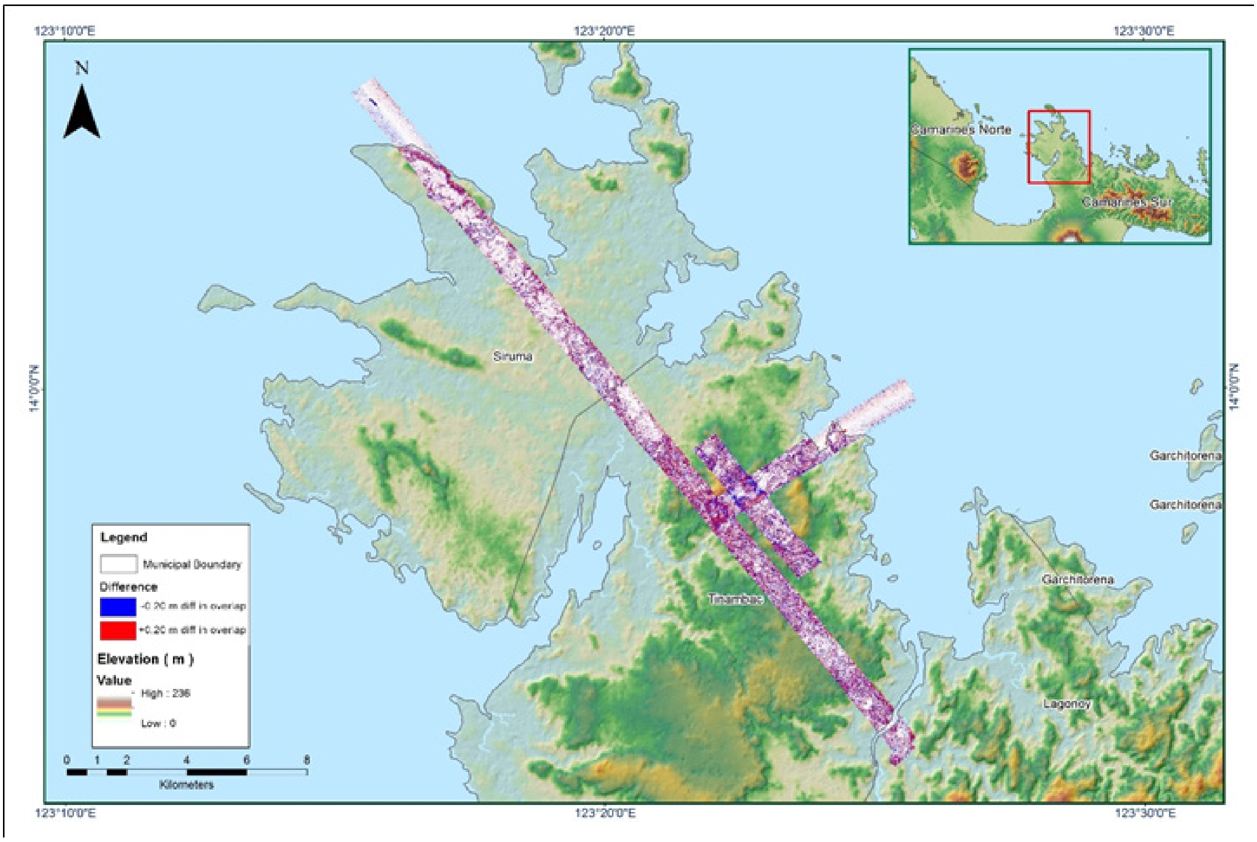


Figure A-8.49. Elevation difference between flight lines

Table A-8.8. Mission Summary Report for Mission Naga_Blk24D

Flight Area	Naga
Mission Name	Naga_Blk24D
Inclusive Flights	23318P
Range data size	19.5 GB
POS data size	261 MB
Base data size	101 MB
Image	n/a
Transfer date	June 6, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	No
Baseline Length (<30km)	Yes
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.4
RMSE for East Position (<4.0 cm)	1.9
RMSE for Down Position (<8.0 cm)	7.6
Boresight correction stdev (<0.001deg)	0.000191
IMU attitude correction stdev (<0.001deg)	0.000411
GPS position stdev (<0.01m)	0.0008
Minimum % overlap (>25)	46.51%
Ave point cloud density per sq.m. (>2.0)	4.68
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	112
Maximum Height	253.36 m
Minimum Height	45.39 m
Classification (# of points)	
Ground	113,254,148
Low vegetation	75,223,098
Medium vegetation	112,610,876
High vegetation	83,013,207
Building	2,234,116
Orthophoto	No
Processed by	Engr. Regis Guhiting, Engr. Erica Erin Elazegui, Engr. Monalyne Rabino

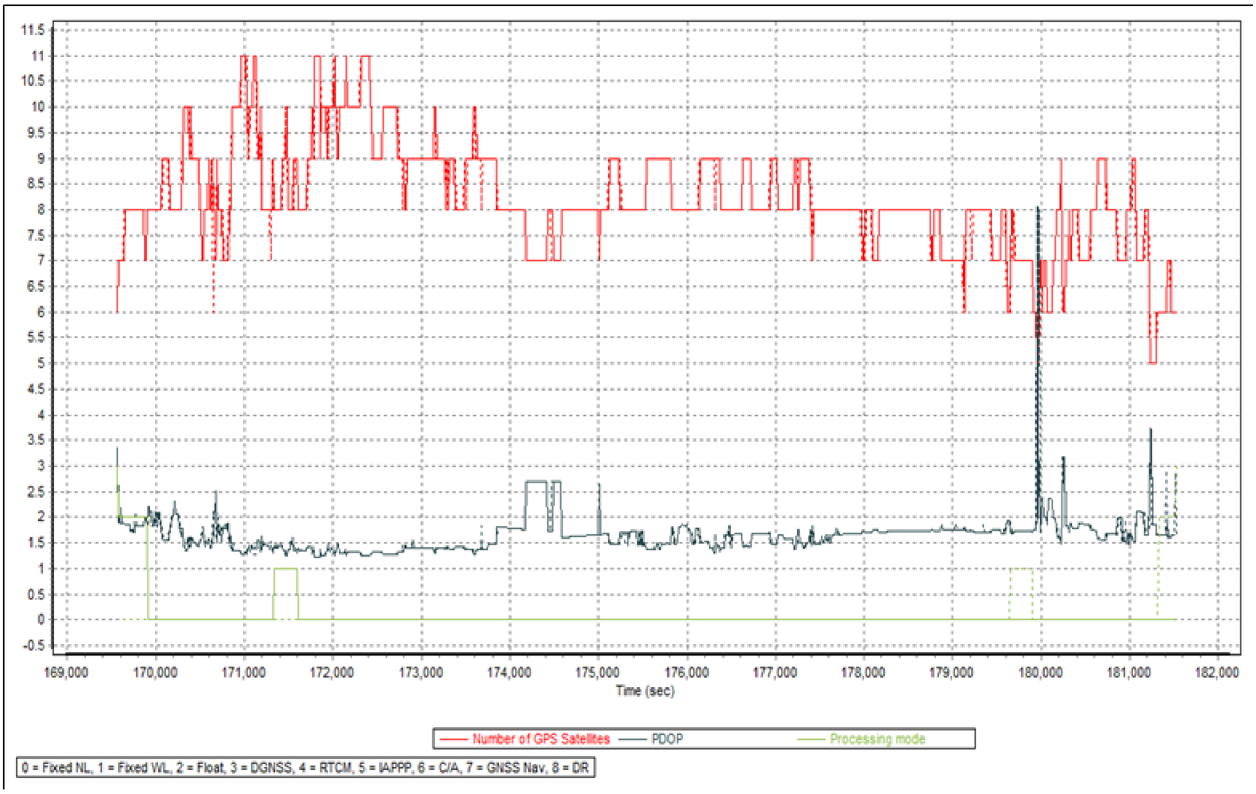


Figure A-8.50. Solution Status

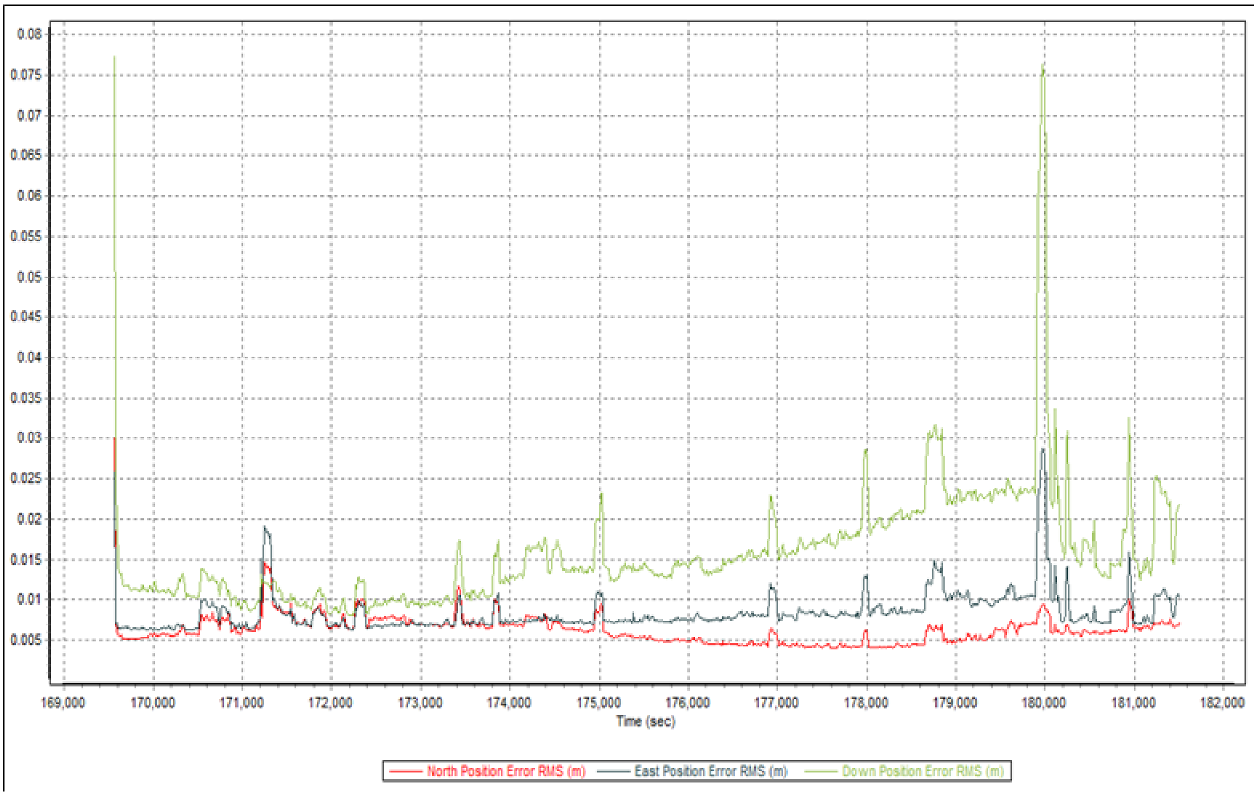


Figure A-8.51. Smoothed Performance Metric Parameters

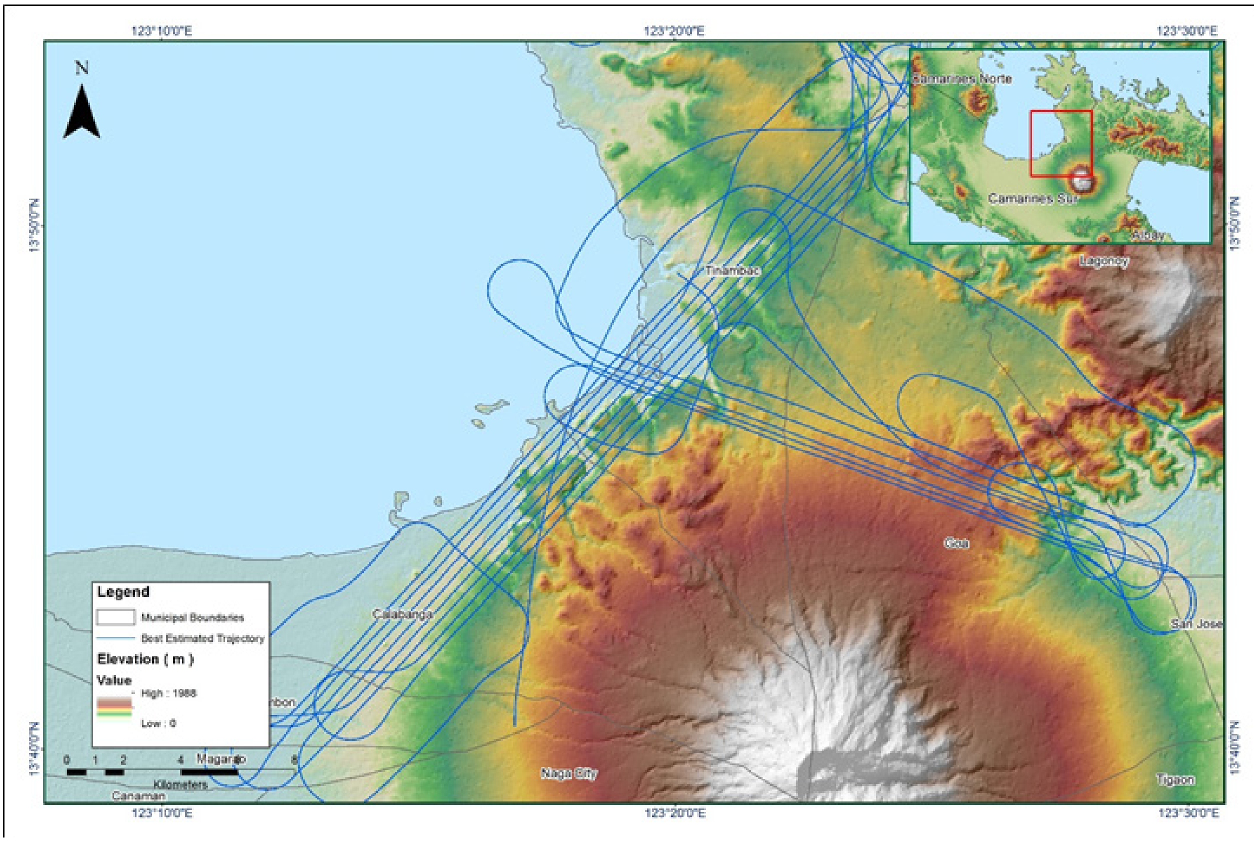


Figure A-8.52. Best Estimated Trajectory

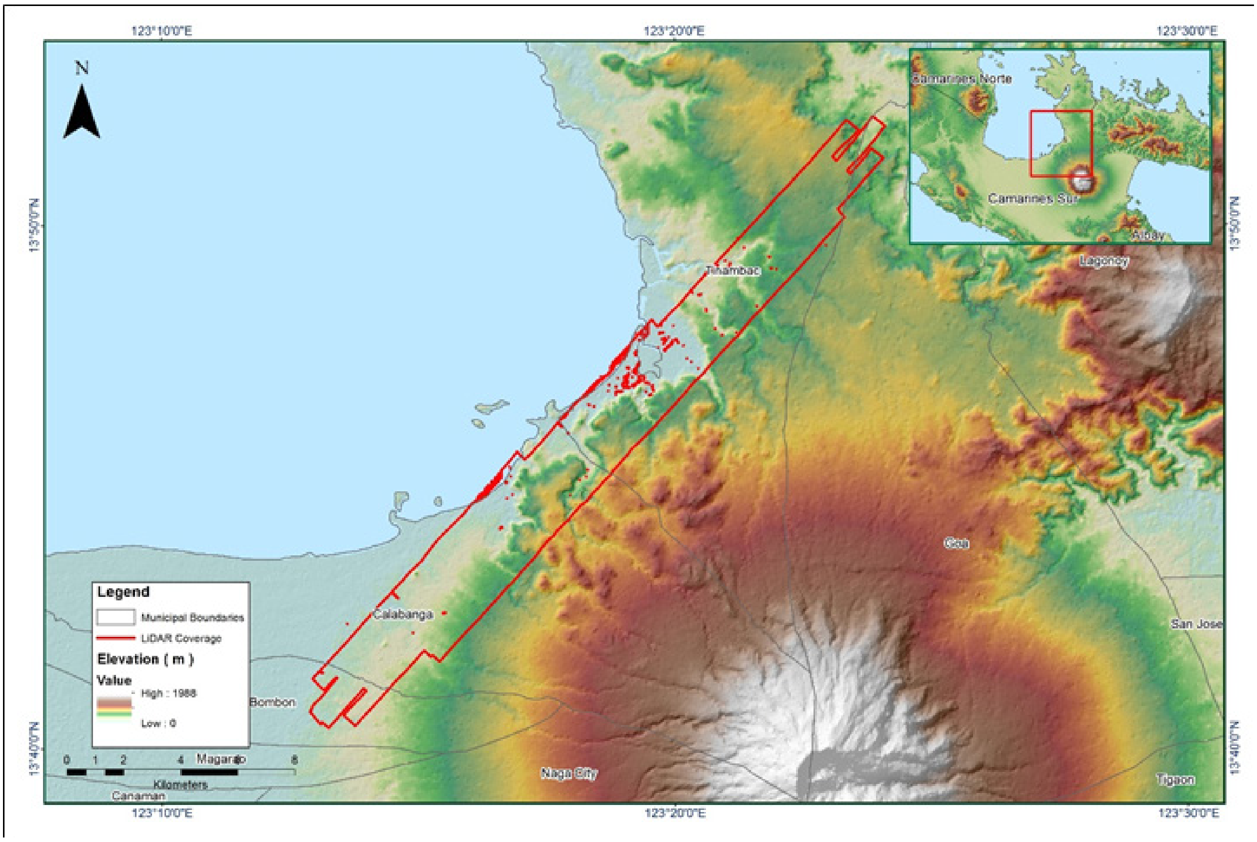


Figure A-8.53. Coverage of LiDAR data

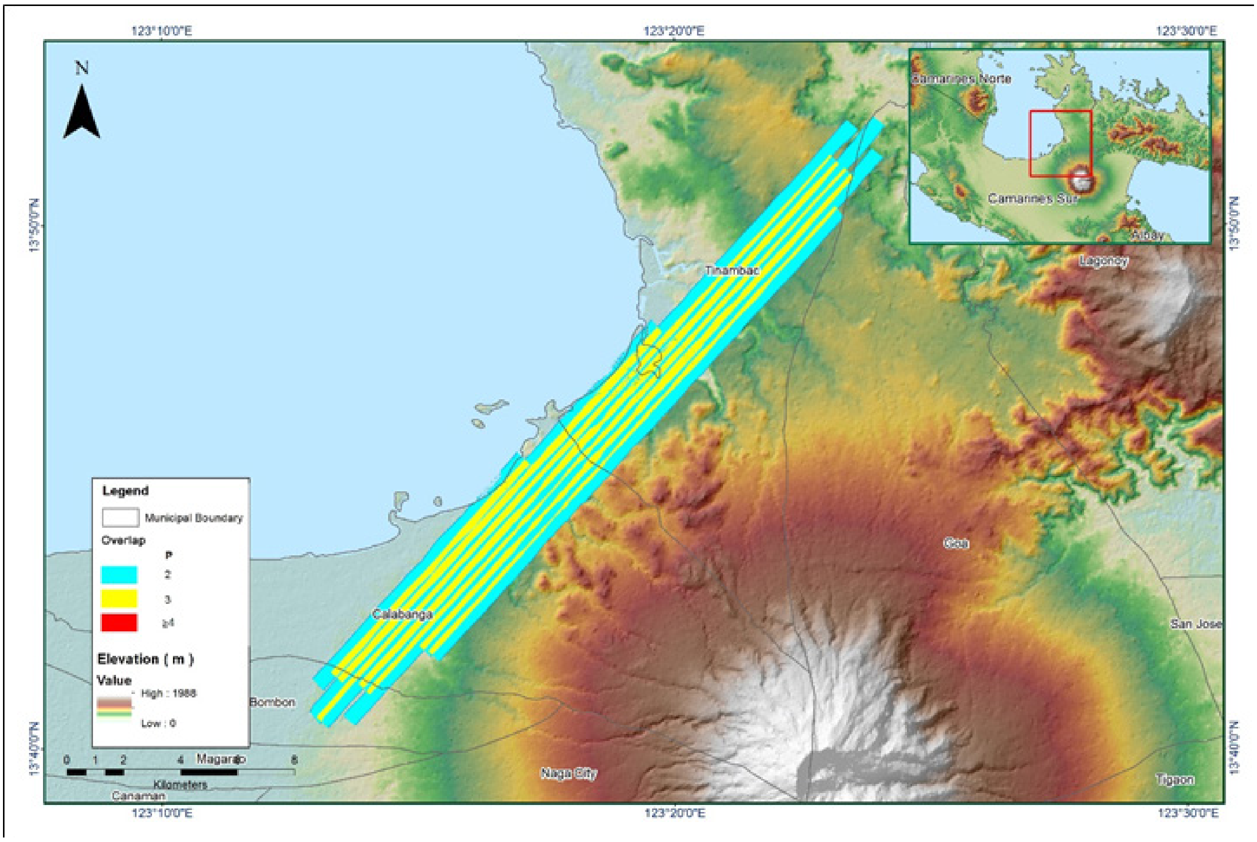


Figure A-8.54. Image of Data Overlap

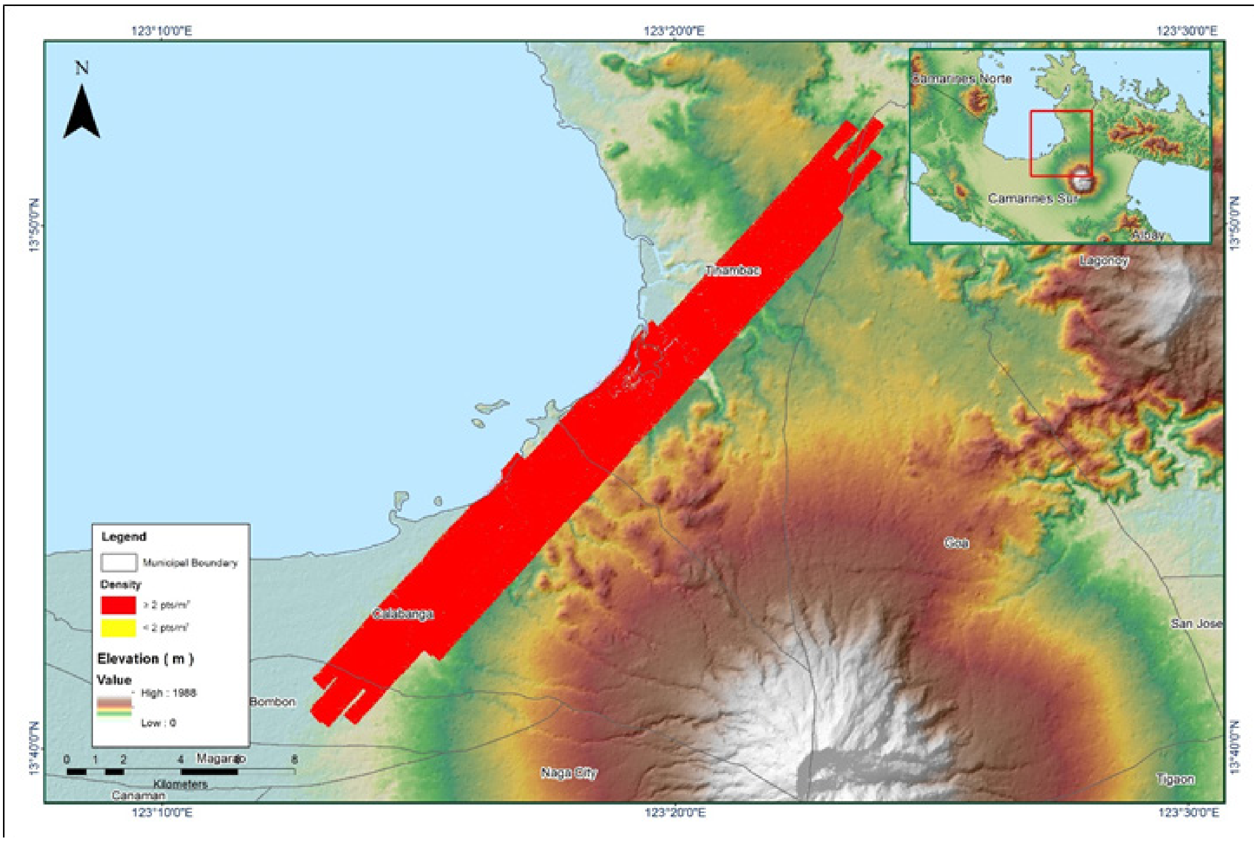


Figure A-8.55. Density map of merged LiDAR data

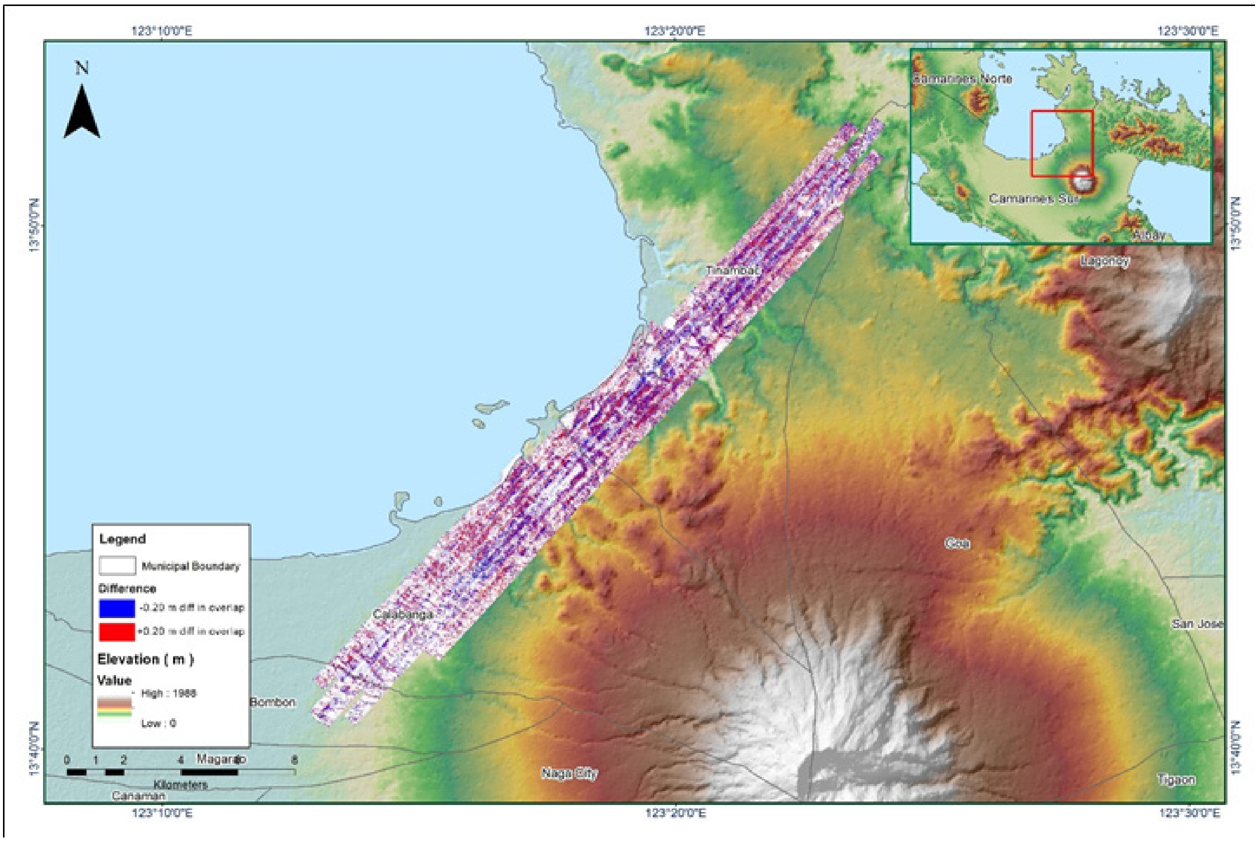


Figure A-8.56. Elevation difference between flight lines

Annex 9. Tambang Model Basin Parameters

Table A-9.1. Tambang 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	2.035	99.000	0	14.391	7.07470	Discharge	11.2800	0.83080	Ratio to Peak	0.61468
W210	3.830	99.000	0	16.993	3.40960	Discharge	2.0475	1.00000	Ratio to Peak	1.00000
W220	4.397	96.634	0	6.011	10.18100	Discharge	7.2599	1.00000	Ratio to Peak	1.00000
W230	4.424	93.625	0	0.167	3.19730	Discharge	1.8025	1.00000	Ratio to Peak	1.00000
W240	4.143	98.887	0	0.143	3.40000	Discharge	0.9872	1.00000	Ratio to Peak	1.00000
W250	4.411	98.940	0	0.017	8.52310	Discharge	1.6786	1.00000	Ratio to Peak	1.00000
W260	35.312	99.000	0	0.126	0.22431	Discharge	0.0018	0.66051	Ratio to Peak	1.00000
W270	3.951	92.808	0	0.165	2.32820	Discharge	0.4412	0.65398	Ratio to Peak	1.00000
W280	4.458	69.169	0	0.146	6.51440	Discharge	1.6715	1.00000	Ratio to Peak	0.46488
W290	3.949	76.424	0	0.146	5.70260	Discharge	1.9126	0.66643	Ratio to Peak	0.96600
W300	4.048	94.064	0	0.147	9.57070	Discharge	1.7442	0.64027	Ratio to Peak	0.66667
W310	2.756	86.762	0	0.017	3.97860	Discharge	0.4529	0.65863	Ratio to Peak	1.00000
W320	4.324	64.251	0	0.017	7.40240	Discharge	2.0103	1.00000	Ratio to Peak	1.00000
W330	1.322	99.000	0	0.155	5.71030	Discharge	0.1502	1.00000	Ratio to Peak	0.32014
W340	4.108	72.742	0	0.149	4.78960	Discharge	2.6756	1.00000	Ratio to Peak	1.00000
W350	5.988	71.903	0	0.017	4.49550	Discharge	1.9141	0.67898	Ratio to Peak	0.96504
W360	4.022	75.111	0	0.165	5.70840	Discharge	2.5278	0.95976	Ratio to Peak	1.00000
W370	3.622	76.628	0	0.166	7.80920	Discharge	5.6395	1.00000	Ratio to Peak	1.00000
W380	4.784	92.138	0	0.888	0.06637	Discharge	0.2029	0.68042	Ratio to Peak	0.43045

Annex 10. Tambang Model Reach Parameters

Table A-10.1. Tambang Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R30	Automatic Fixed Inter-val	2335.6	0.43297	1.00000	Trapezoid	35.961	1
R60	Automatic Fixed Inter-val	1910.5	0.21088	0.48358	Trapezoid	35.961	1
R70	Automatic Fixed Inter-val	38.3	0.05785	0.04033	Trapezoid	35.961	1
R100	Automatic Fixed Inter-val	2067.2	0.10355	0.25088	Trapezoid	35.961	1
R120	Automatic Fixed Inter-val	747.7	0.30433	0.47604	Trapezoid	35.961	1
R130	Automatic Fixed Inter-val	1044.0	0.00010	0.00010	Trapezoid	35.961	1
R150	Automatic Fixed Inter-val	3946.9	0.050017	0.0793342	Trapezoid	35.961	1
R180	Automatic Fixed Inter-val	6420.7	0.0015498	0.0023624	Trapezoid	35.961	1
R190	Automatic Fixed Inter-val	560.62	0.10352	0.24468	Trapezoid	35.961	1

Annex 11. Educational Institutions affected by flooding in Tambang Floodplain

Table A-11.1. Educational Institutions in Lagonoy, Camarines Sur affected by flooding in Tambang Floodplain

Camarines Sur				
Lagonoy				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Brgy. Tamban goa day care center	Del Carmen			
Del carmen elementary school	Del Carmen			
Tamban goa elem. school	Del Carmen			

Table A-11.2. Educational Institutions in Tinambac, Camarines Sur affected by flooding in Tambang Floodplain

Camarines Sur				
Tinambac				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
CC and tamban daycare	Tambang			
Tamban central school	Tambang			
CC and tamban daycare	Tambang			

Annex 12. Health Institutions affected by flooding in Tambang Floodplain

Table A-12.1. Health Institutions in Lagonoy, Camarines Sur affected by flooding in Tambang Floodplain

Camarines Sur				
Lagonoy				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Brgy. tamban goa health center	Del Carmen			

Table A-12.2. Health Institutions in Tinambac, Camarines Sur affected by flooding in Tambang Floodplain

Camarines Sur				
Tinambac				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Mother Teresa x-ray and ultrasound clinic	Tambang			
Rhu tamban birthing clinic	Tambang			
Socorro sevilla Cabral foundation lying in clinic	Tambang			Medium