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

LiDAR Surveys and Flood Mapping of Ragay River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

AAC	Asian Aerospace Corporation
Ab	abutment
ALTM	Airborne LiDAR Terrain Mapper
ARG	automatic rain gauge
AWLS	Automated Water Level Sensor
BA	Bridge Approach
BM	benchmark
CAD	Computer-Aided Design
CN	Curve Number
CSRS	Chief Science Research Specialist
DAC	Data Acquisition Component
DEM	Digital Elevation Model
DENR	Department of Environment and Natural Resources
DOST	Department of Science and Technology
DPPC	Data Pre-Processing Component
DREAM	Disaster Risk and Exposure Assessment for Mitigation [Program]
DRRM	Disaster Risk Reduction and Management
DSM	Digital Surface Model
DTM	Digital Terrain Model
DVBC	Data Validation and Bathymetry Component
FMC	Flood Modeling Component
FOV	Field of View
GiA	Grants-in-Aid
GCP	Ground Control Point
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center - River Analysis System
HC	High Chord
IDW	Inverse Distance Weighted [interpolation method]
ISU	Isabela State University
IMU	Inertial Measurement Unit
kts	knots
LAS	LiDAR Data Exchange File format
LC	Low Chord
LGU	local government unit
LiDAR	Light Detection and Ranging
LMS	LiDAR Mapping Suite
m AGL	meters Above Ground Level
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 RAGAY RIVER

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

1.1 Background of the Phil-LiDAR 1 Program

The University of the Philippines Training Center for Applied Geodesy and Photogrammetry (UP-TCAGP) launched a research program entitled "Nationwide Hazard Mapping using LiDAR" or Phil-LiDAR 1 in 2014, supported by the Department of Science and Technology (DOST) 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 Ragay River Basin

There are two (2) municipalities with jurisdiction over the Ragay River Basin: Ragay and Lupi, Camarines Sur. Ragay town is a first class municipality while Lupi is a third class municipality. Ragay has a total population of 58,214 distributed to 38 barangays, while Lupi has a population of 32,167 in its 38 barangays. These areas are covered with Type IV climate, meaning it has an evenly distributed rainfall all year round.

The Ragay River is bound by Mt. Labo to the north and by the Bicol Natural Park to the east. Ragay River is 90.83 km long with headwaters coming from Mt. Labo. Mt. Labo has an elevation of 1,544 mASL and is also a potentially active volcano. The Bicol Natural Park is a protected area covering 52.01 km2 being managed by two (2) protected area management boards (PAMB) for the areas covered by Camarines Norte and Camarines Sur. The Ragay coast is basically rolling and hilly. Lupi is also hilly in terms of topography. Both are agricultural municipalities. There are several cave systems in the hills facing Ragay Gulf. Ragragio (2012) reported of caves with skeletons and shards of potteries in Calabanig Point in Ragay. The Andaya Highway which is the main road going to Manila passes through both towns.

Ragay and Lupi are part of a large area that is also categorized as very high for both terrestrial and inland water areas of biological importance and terrestrial and inland waters conservation priority areas in the Philippine Biodiversity Conservation Priorities Report.

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

CHAPTER 2: LIDAR DATA ACQUISITION OF THE RAGAY 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

To initiate the LiDAR acquisition survey of the Ragay floodplain, the Data Acquisition Component (DAC) created flight plans within the delineated priority area for Ragay Floodplain in Surigao del Sur. These flight missions were planned for 19 lines and ran for at most four hours including take-off, landing and turning time. The flight planning parameters for the LiDAR system are outlined in Table 1. Table 1 shows the flight plan for Ragay floodplain survey.

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)
BLK20I	1100	30	50	200	30	130	5
BLK20J	1100	30	50	200	30	130	5
BLK20K	1100	30	50	200	30	130	5
BLK20L	1100	30	50	200	30	130	5
BLK20M	1100	30	50	200	30	130	5

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

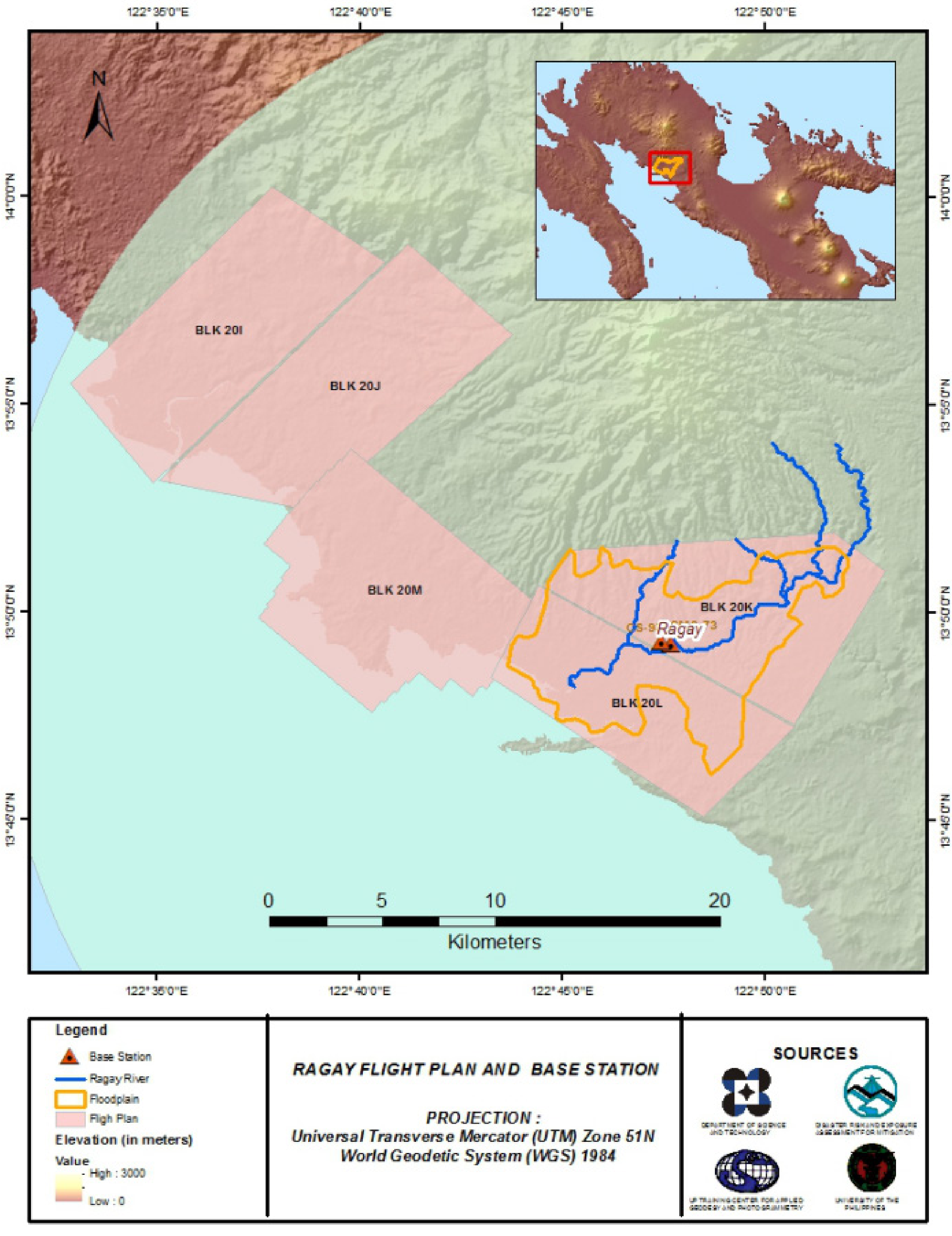

Figure 2. Flight Plan and base stations used for the Ragay Floodplain survey.

2.2 Ground Base Stations

The field team was able to recover one (1) NAMRIA ground control points: CMS-73 and one (1) NAMRIA benchmarks CS-98. The benchmark was used as vertical reference point and was also established as ground control point.

The certifications for the base stations are found in Annex 2 while the baseline processing reports for the established control points are found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey from March 13 to 16, 2016. Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 985 and TOPCON GR5. Flight plans and location of base stations used during the aerial LiDAR acquisition in Ragay floodplain are shown in Figure 2. The list of team members are found in Annex 4.

The succeeding sections depict the sets of reference points, control stations and established points, and the ground control points for the entire Ragay Floodplain LiDAR Survey. Figure 3. and Figure 4 show the recovered NAMRIA reference points and established point within the area of the floodplain, while Table 2 and Table 3 show the details about the following NAMRIA control stations and established points. Table 4, on the other hand, shows the list of all ground control points occupied during the acquisition together with the corresponding dates of utilization.

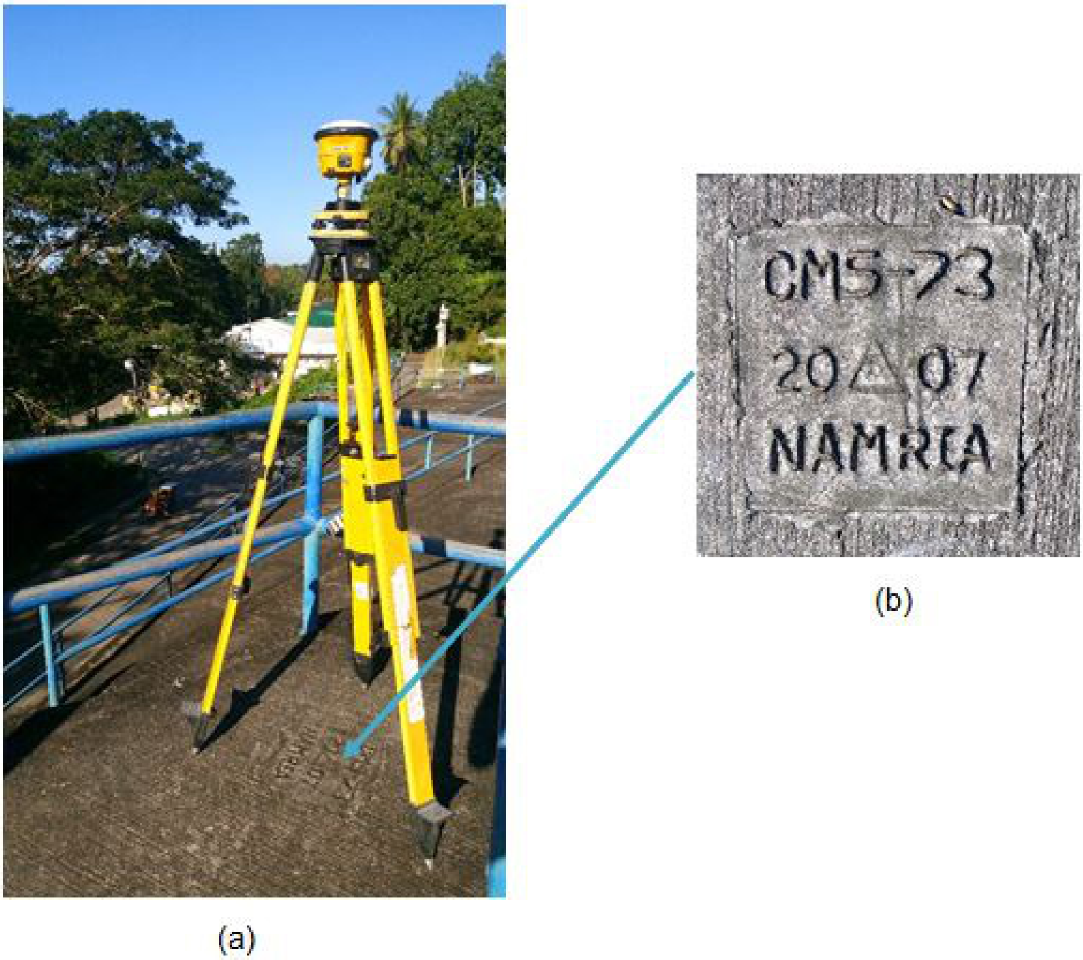

Figure 3. GPS set-up over CMS-73 (a) and NAMRIA reference point CMS-73 (b) as recovered by the field team.

Table 2. Details of the recovered NAMRIA horizontal control point CMS-73 used as base station for the LiDAR acquisition.

Station Name	CMS-73	
Order of Accuracy	2nd	
Relative Error (Horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference 0f 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 49' 23.30467" North 122° 47' 22.99347" East 29.10700 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	477,266.186 meters 1,528,617.256 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 49' 18.21600" North 122° 47' 27.94306" East 79.19600 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	477,274.14 meters 1,528,082.21 meters

(a) (b)

Figure 4. GPS set-up over CS-98 (a) and NAMRIA reference point CS-98 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point CS-98 used as base station for the LiDAR acquisition.

Station Name	CS-98	
Order of Accuracy	2nd	
Relative Error (Horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 49' 19.42547" North 122° 47' 36.54972" East 13.233 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 49' 14.33735" North 122° 47' 41.49939" East 63.335 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	477,681.010 meters 1,527,962.695 meters

Table 4. Ground control points that were used during the LiDAR data acquisition.

Date Surveyed	Flight Number	Mission Name	Ground Control Points
March 13, 2016	23186P	1BLK20K73A	CMS-73, CS-98
March 15, 2016	23194P	1BLK20JKL75A	CMS-73, CS-98
March 16, 2016	23198P	1BLK2ILM76A	CMS-73, CS-98

2.3 Flight Missions

A total of three (3) missions were conducted to complete the LiDAR data acquisition in Ragay floodplain, for a total of eleven hours and thirty five minutes (11+35) of flying time for[Check total flying hours] RP-C9122 (See Annex 6). All missions were acquired using the Pegasus system. As shown below, the total area of actual coverage per mission and the corresponding flying hours are depicted in Table 5, while the actual parameters used during the LiDAR data acquisition are presented in Table 5.

Table 5. Flight missions for the LiDAR data acquisition of the Ragay Floodplain.

Date Surveyed	Flight Number	Flight Plan Area (km2)	Surveyed Area (km2)	Area Surveyed within the Floodplain (km2)	Area Surveyed Outside the Floodplain (km2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
March 13, 2016	23186P	73.42	107.14	45.04	62.1	278	3	5
March 15, 2016	23194P	211.08	195.42	47.26	148.16	536	4	10
March 16, 2016	23198P	220.69	209.77	4.32	205.45	504	4	20
TOTAL		**505.19**	**512.13**	**96.62**	**415.71**	**1,318**	**11**	**35**

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

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (khz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
23186P	1100	30	50	200	30	125	5
23194P	1100	30	50	200	30	125	5
23198P	1100	30	50	200	30	125	5

2.4 Survey Coverage

This certain LiDAR acquisition survey covered the Ragay floodplain (See Annex 7). It is located in the province of Camarines Sur with majority of the floodplain situated within the municipality of Ragay. The list of municipalities and cities surveyed with at least one (1) square kilometer coverage is shown in Table 7. Figure 5, on the other hand, shows the actual coverage of the LiDAR acquisition for the Ragay floodplain.

Table 7. List of municipalities and cities surveyed in the Ragay Floodplain LiDAR acquisition.

Province	Municipality/ City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Camarines Sur	Ragay	296.26	198.17	67%
	Del Gallego	279.27	137.04	49%
	Lupi	230.62	26.14	11%
Quezon	Tagkawayan	551.73	35.00	6%
Total		**1357.88**	**396.35**	**29.19%**

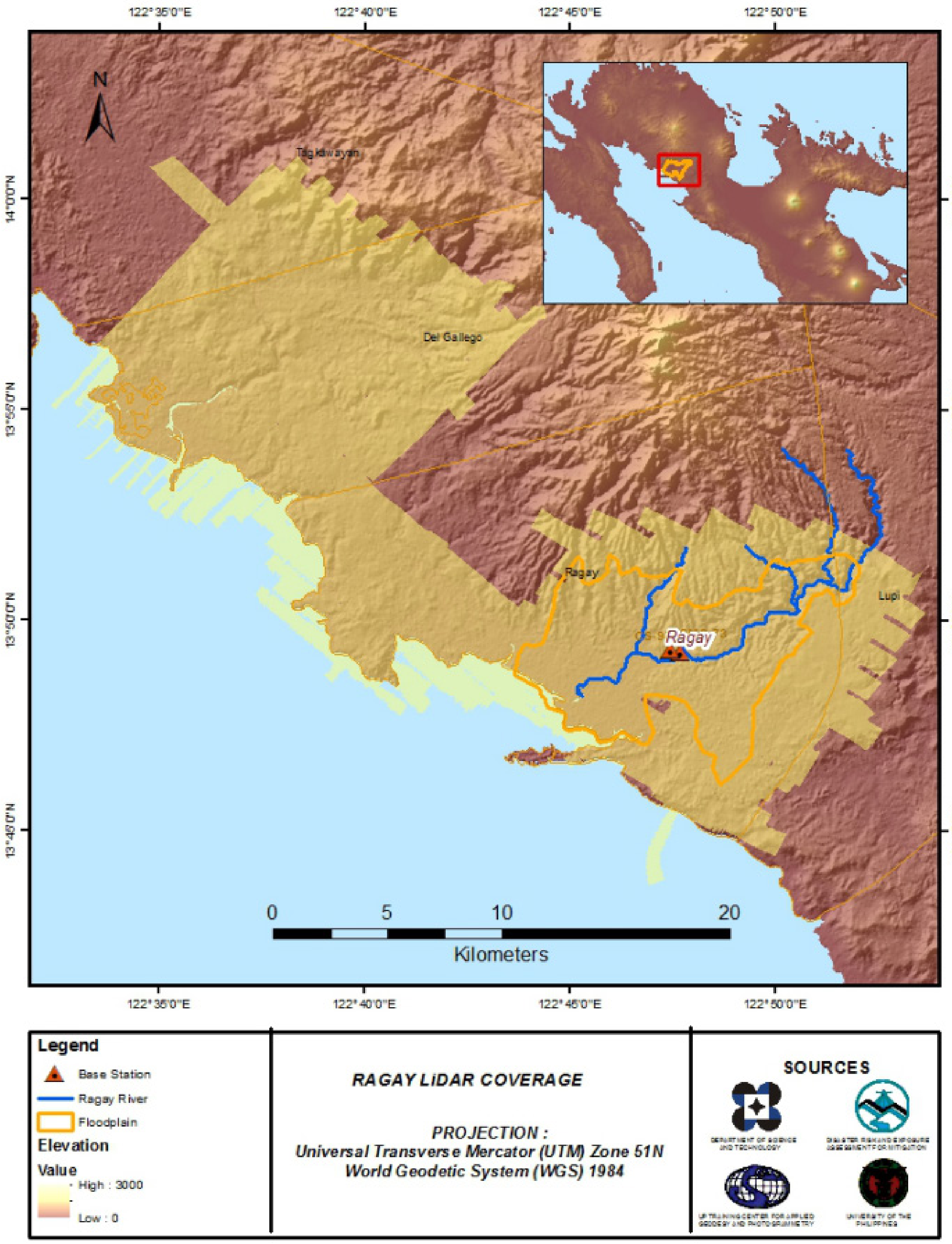

Figure 5. Actual LiDAR survey coverage of the Ragay Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE RAGAY 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 6.

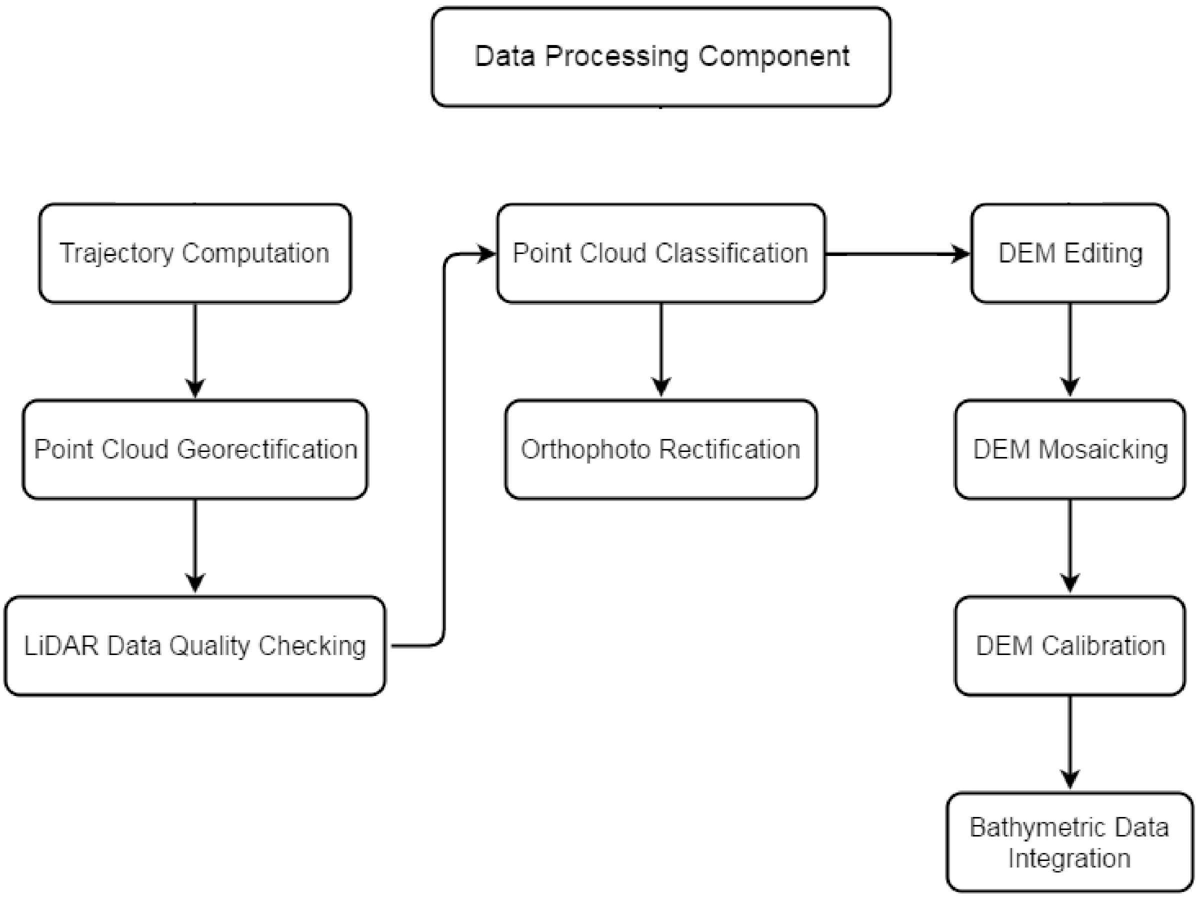


Figure 6. Schematic diagram for Data Pre-Processing Component.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions of the Ragay Floodplain can be found in Annex 5. The missions flown during the conduct of the first survey in March 2016 utilized the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus system over Bagasbas.

The Data Acquisition Component (DAC) transferred a total of 57.2 Gigabytes of Range data, 736 Megabytes of POS data, 167.4 Megabytes of GPS base station data, and 87.1 Gigabytes of raw image data to the data server on April 11, 2016 for the survey, which was verified for accuracy and completeness by the DPPC. The whole dataset for the Ragay Floodplain was fully transferred on April 11, 2016, as indicated on the Data Transfer Sheets for the Ragay floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for Flight 23186P, one of the Ragay flights, which is the North, East, and Down position RMSE values are shown in Figure 7. The x-axis corresponds to the time of the flight, which was measured by the number of seconds from the midnight of the start of the GPS week, which fell on the date and time of March 13, 2016, 00:00AM. The y-axis, on the other hand, represents the RMSE value for that particular position.

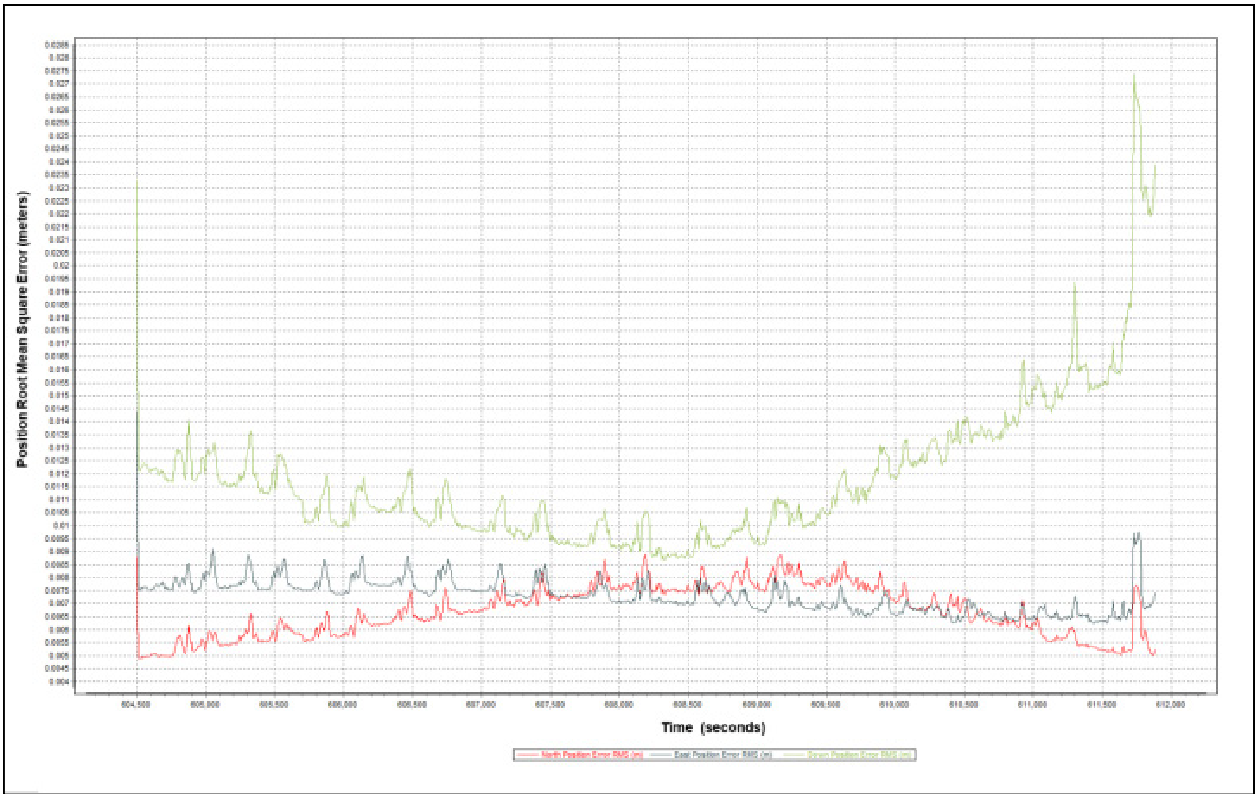


Figure 7. Smoothed Performance Metrics of Ragay Flight 23186P.

The time of flight was from 604,500 seconds to 612,000 seconds, which corresponds to morning of March 13, 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 minimize 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 7 shows that the North position RMSE peaks at 0.80 centimeters, the East position RMSE peaks at 0.90 centimeters, and the Down position RMSE peaks at 0.90 centimeters, which are within the prescribed accuracies described in the methodology.

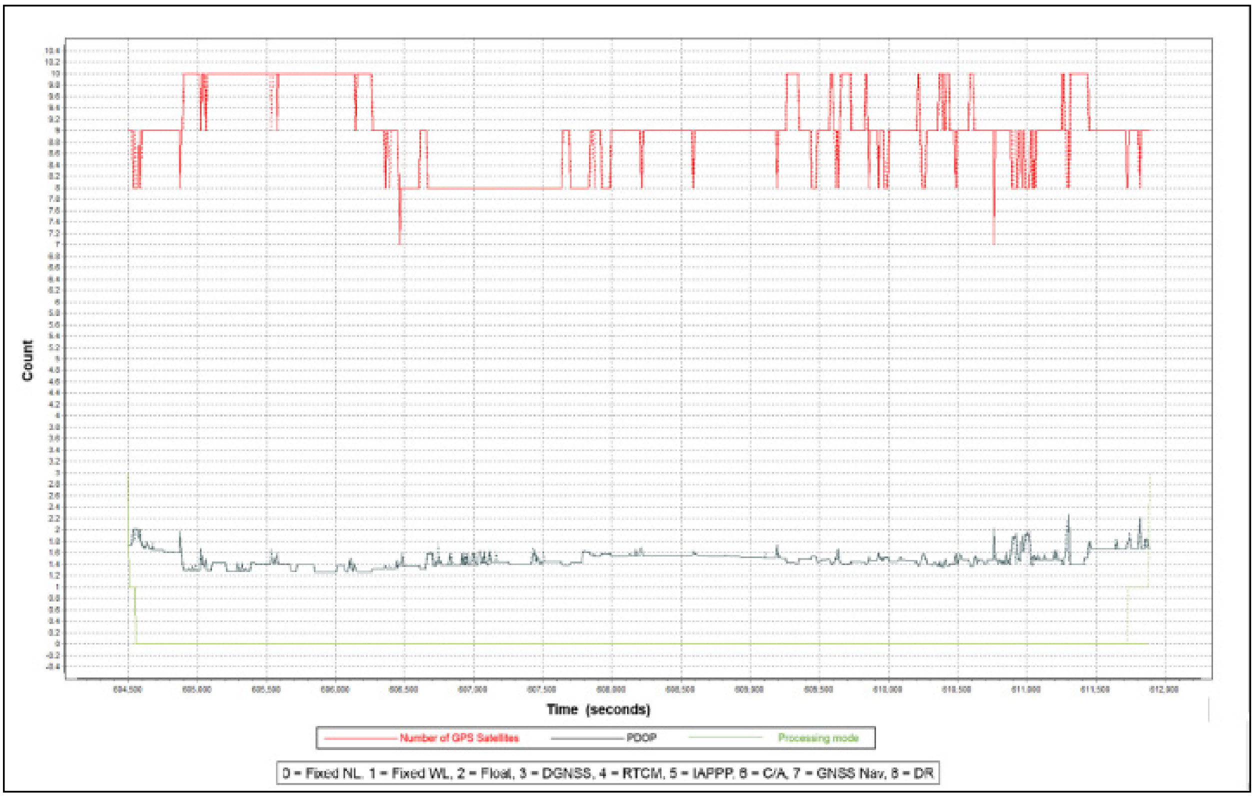


Figure 8. Solution Status Parameters of Ragay Flight 23186P.

The Solution Status parameters, which indicate the number of GPS satellites; Positional Dilution of Precision (PDOP); and the GPS processing mode used for Ragay Flight 23186P are shown in Figure 8. For the Solution Status parameters, the figure above signifies that the number of satellites utilized and tracked during the acquisition were between 7 and 10, not going lower than 7. Similarly, the PDOP value did not go above the value of 3, which indicates optimal GPS geometry. The processing mode also stayed at the value of 0 for the majority of the survey stayed at the value of 0 with some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane Mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for the POSPAC MMS. Fundamentally, all of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Ragay flights is shown in Figure 9.

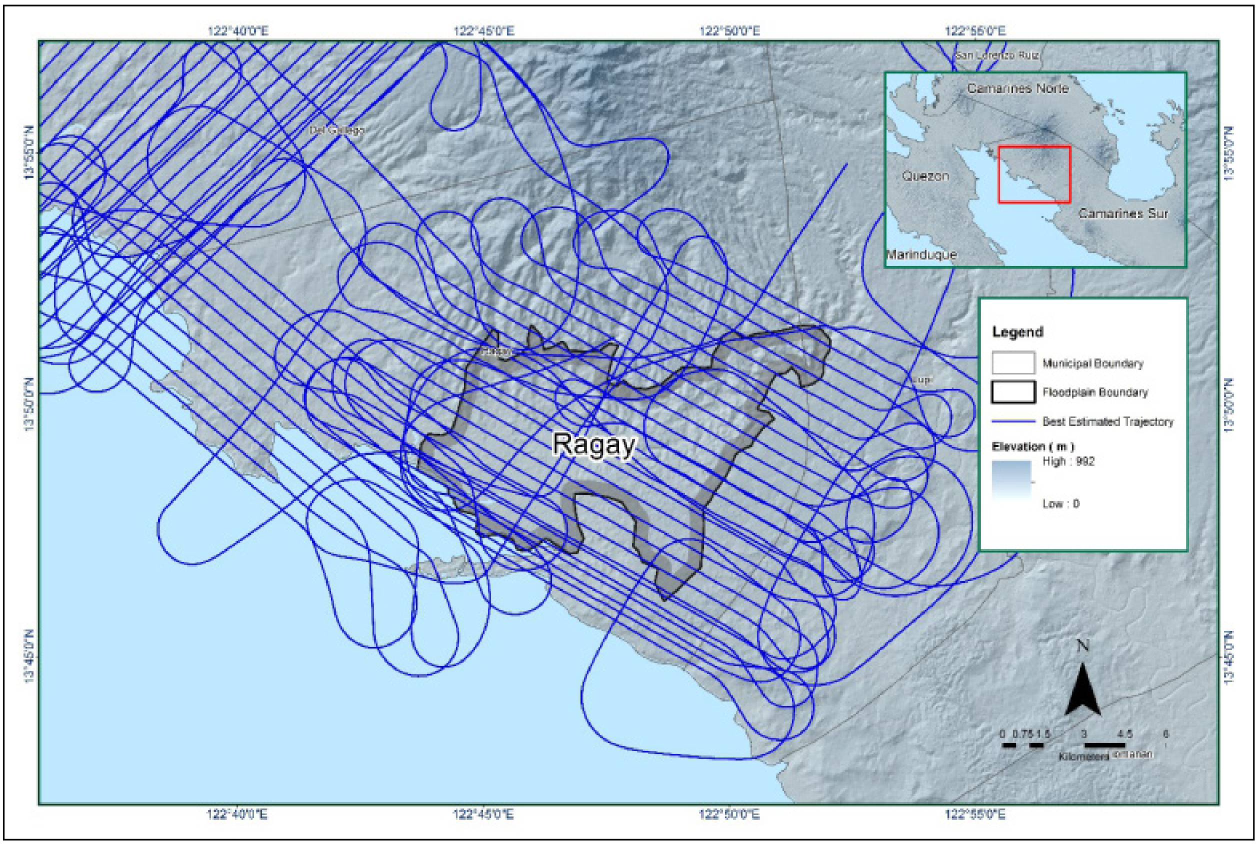


Figure 9. Best Estimated Trajectory of the LiDAR missions conducted over the Ragay Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS contains 48 flight lines, with each flight line contains two channel, since the Pegasus system contains two channel. The summary of the self-calibration results obtained from LiDAR processing in the LiDAR Mapping Suite (LMS) software for all flights over the Ragay floodplain are given in Table 8.

Table 8. Self-calibration Results values for Ragay flights.

Parameter	Acceptable Value	Computed Value
Boresight Correction stdev	<0.001degrees	0.000234
IMU Attitude Correction Roll and Pitch Correction stdev	<0.001degrees	0.000720
GPS Position Z-correction stdev	<0.01meters	0.0019

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

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data on top of the SAR Elevation Data over the Ragay Floodplain is shown in Figure 10. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

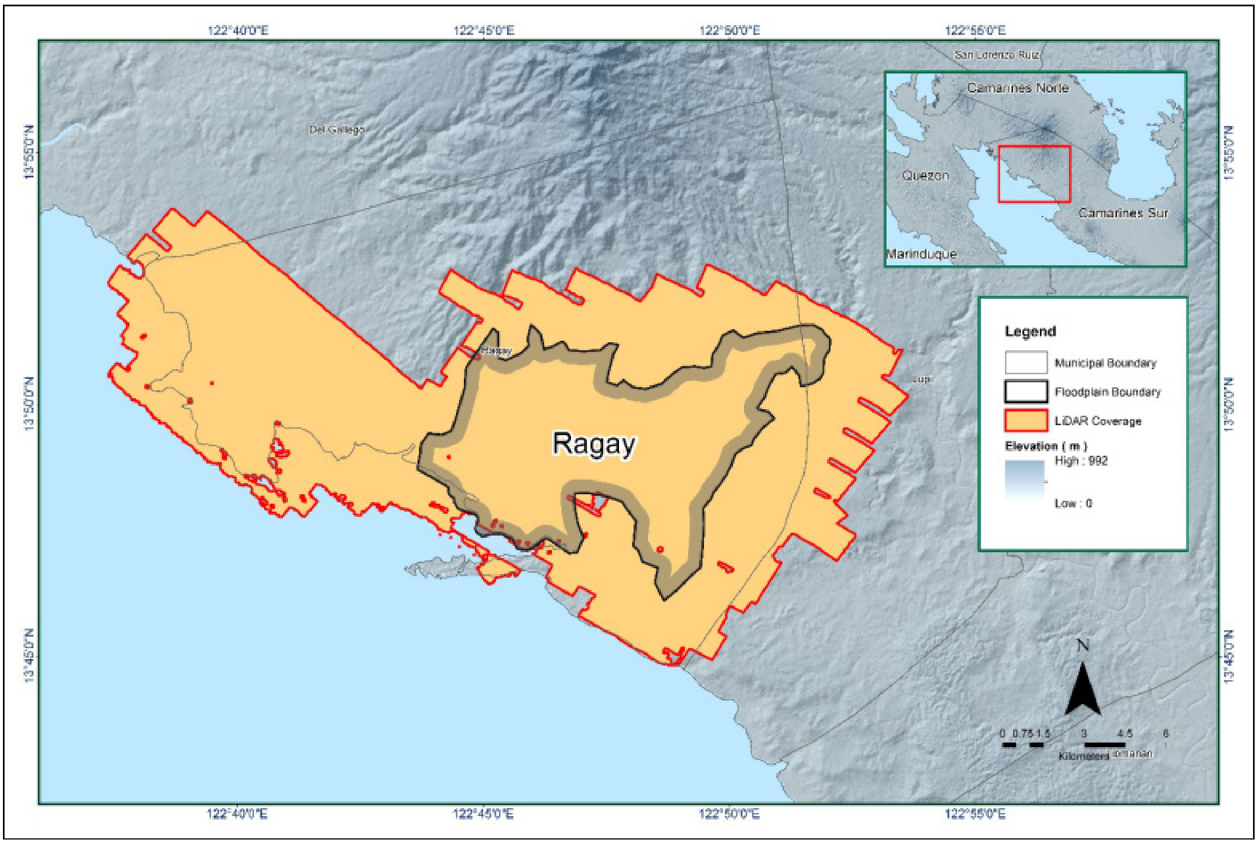


Figure 10. Boundary of the processed LiDAR data over the Ragay Floodplain

A total area of 244.06 square kilometers (sq. kms.) were covered by the Ragay flight missions as a result of three (3) flight acquisitions, which were grouped and merged into three (3) blocks accordingly, as portrayed in Table 9.

Table 9. List of LiDAR blocks for Ragay Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Bagasbas_Blk20K	23186P	93.13
Bagasbas_Blk20L	23194P	107.18
	23198P	
Bagasbas_Blk20M	23198P	43.75
TOTAL		**244.06 sq.km**

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 11. Since the Pegasus system employs one channel, 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.

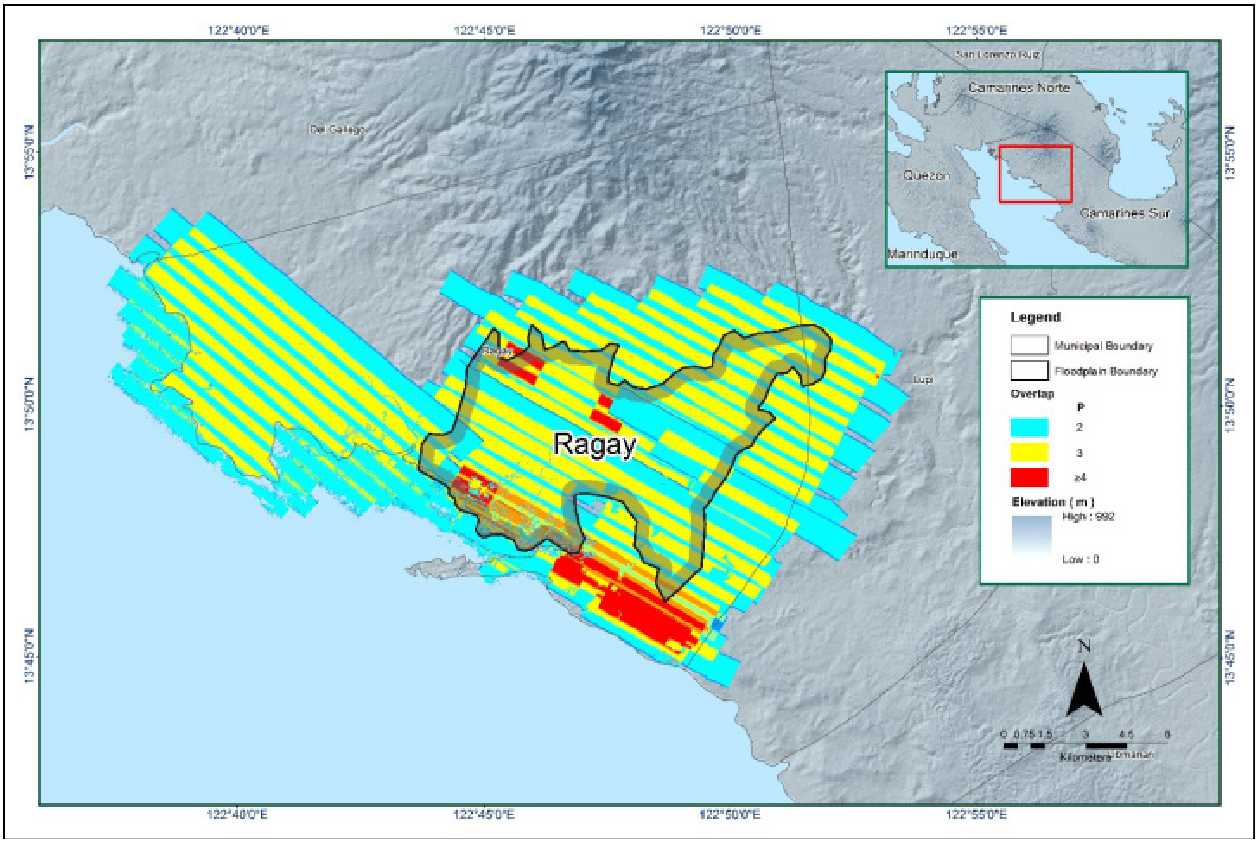


Figure 11. Image of data overlap for Ragay Floodplain.

The overlap statistics per block for the Ragay floodplain can be found in the Mission Summary Reports (Annex 8). One pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 44.13% and 56.23% respectively, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the two (2) points per square meter criterion is shown in Figure 12. As seen in the figure below, it was determined that all LiDAR data for the Ragay Floodplain Survey satisfy the point density requirement, as the average density for the entire survey area is 3.31 points per square meter.

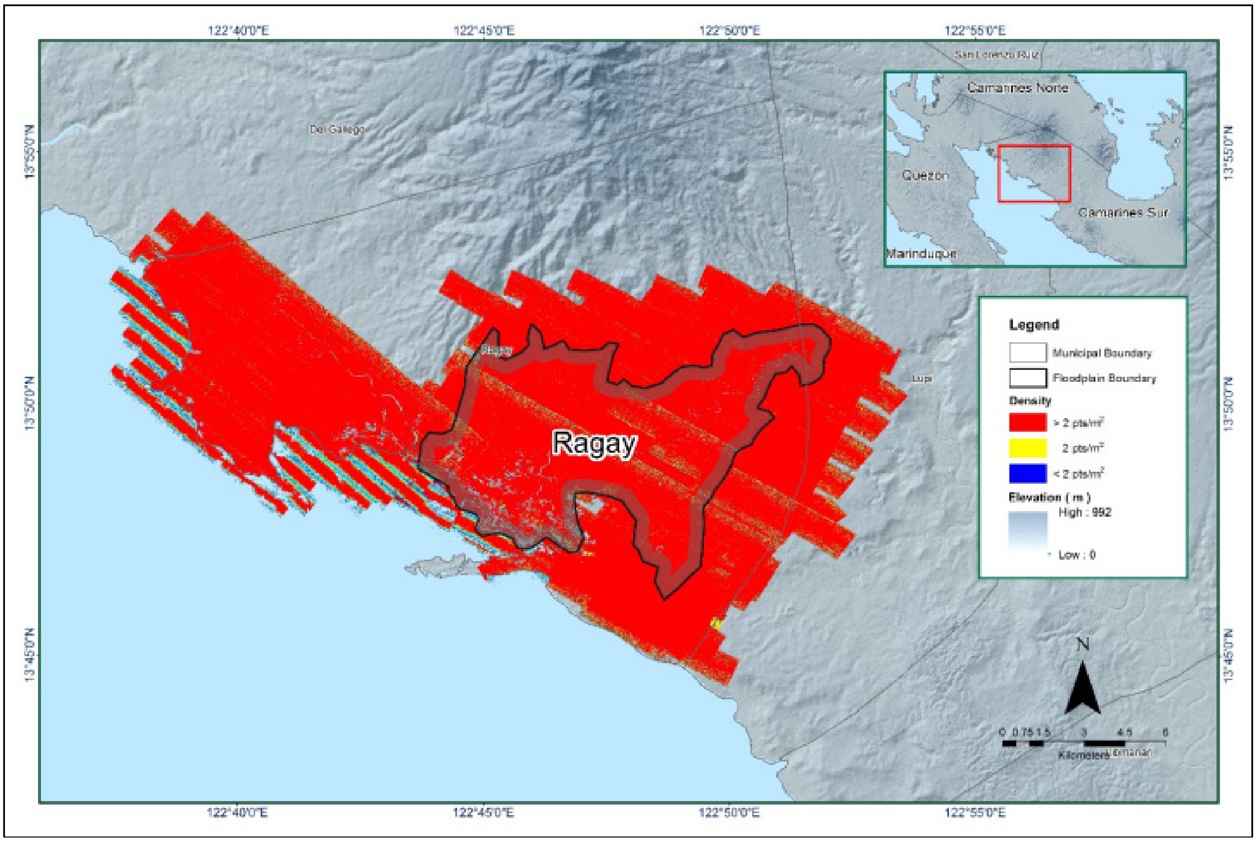


Figure 12. Pulse density map of merged LiDAR data for Ragay Floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 13. The default color range is blue to red, where bright blue areas correspond to portions where elevations of a previous flight line are higher by more than 0.20m, as identified by its acquisition time; which is relative to the elevations of its adjacent flight line. Similarly, bright red areas indicate portions where elevations of a previous flight line are lower by more than 0.20m, relative to the elevations of its adjacent flight line. Areas highlighted in bright red or bright blue necessitate further investigation using the Quick Terrain Modeler software.

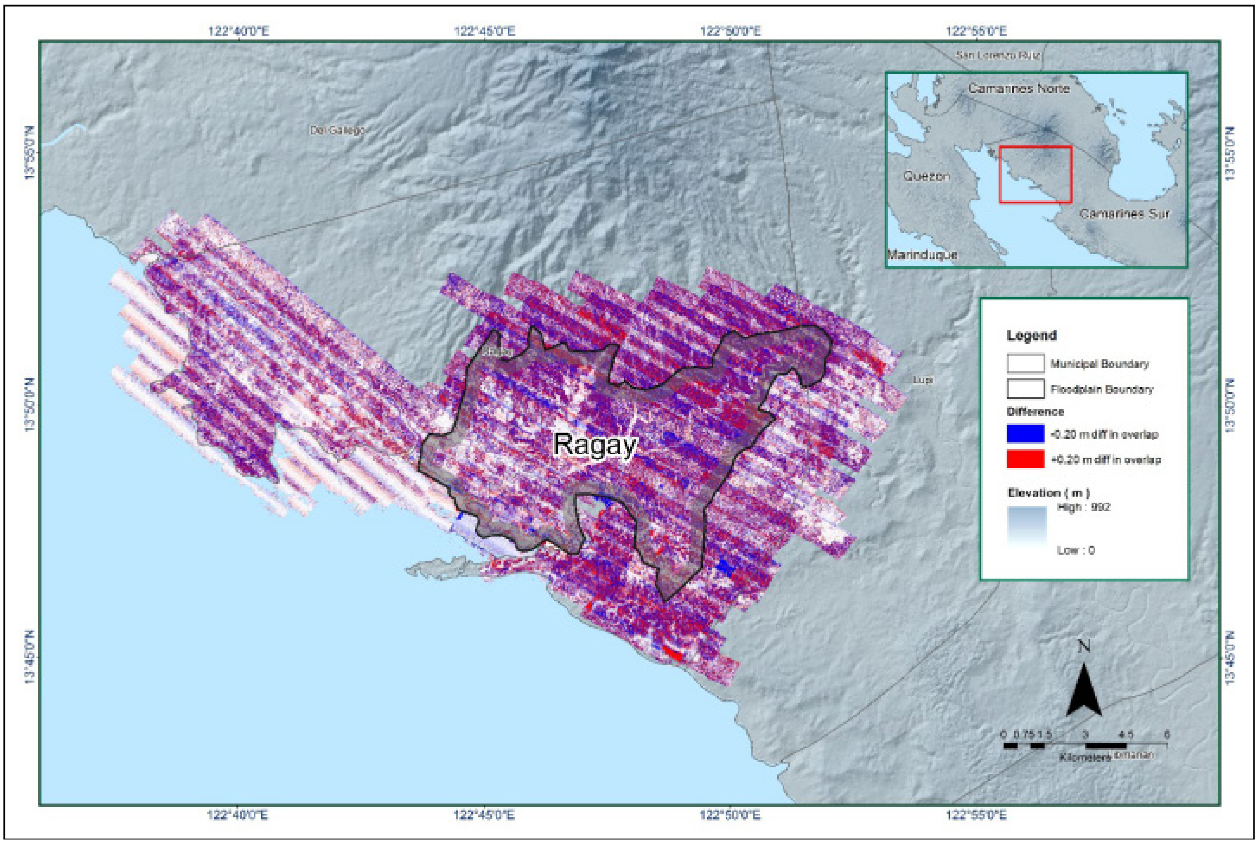


Figure 13. Elevation Difference Map between flight lines for Ragay Floodplain Survey.

A screen capture of the processed LAS data from Ragay flight 23186P loaded in QT Modeler is shown in Figure 14. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed red line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data generated satisfactory results. No reprocessing was done for this LiDAR dataset.

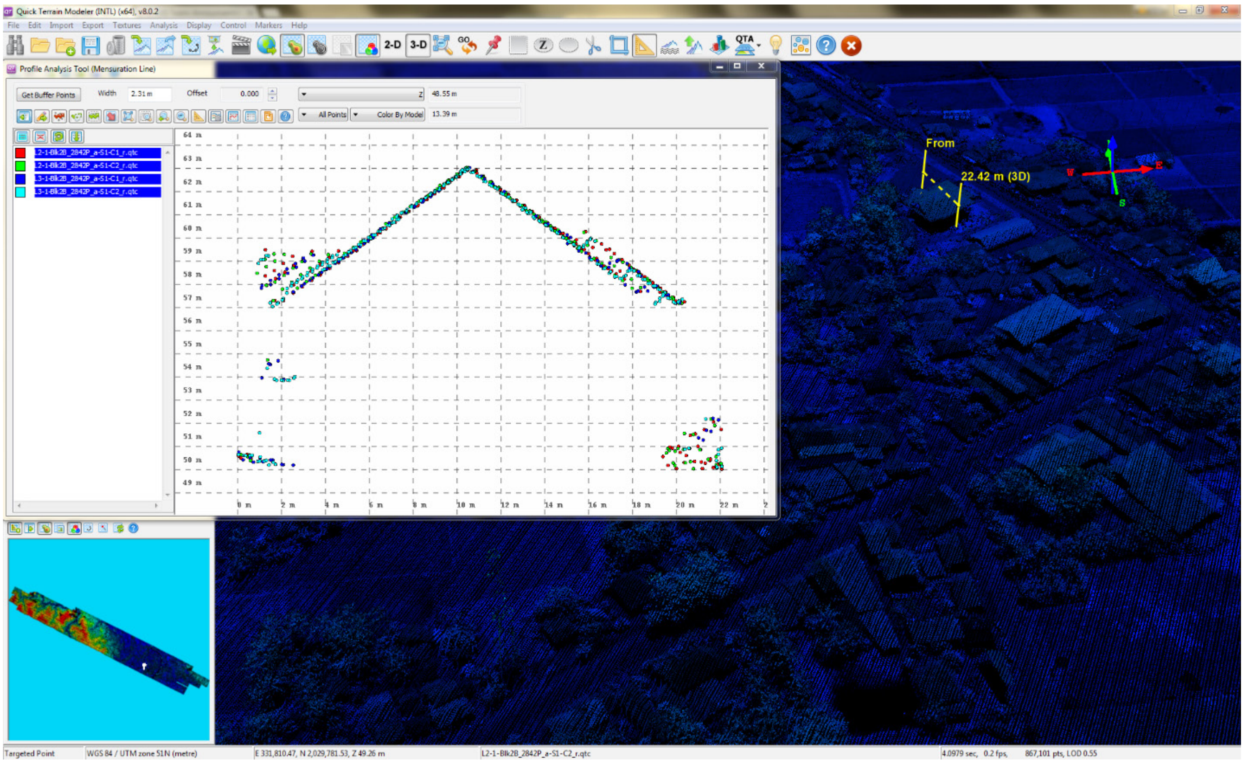


Figure 14. Quality checking for a Ragay flight 2842P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 10. Ragay classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	265,167,876
Low Vegetation	165,129,326
Medium Vegetation	348,133,205
High Vegetation	923,468,952
Building	9,377,994

The tile system that TerraScan employed for the LiDAR data as well as the final classification image for a block of the Ragay floodplain is shown in Figure 15. A total of 389 tiles with 1 km. X 1 km. (one kilometer by one kilometer) size were produced. Correspondingly, Table 10 summarizes the number of points classified to the pertinent categories. The point cloud has a maximum and minimum height of 493.57 meters and 51.35 meters respectively.

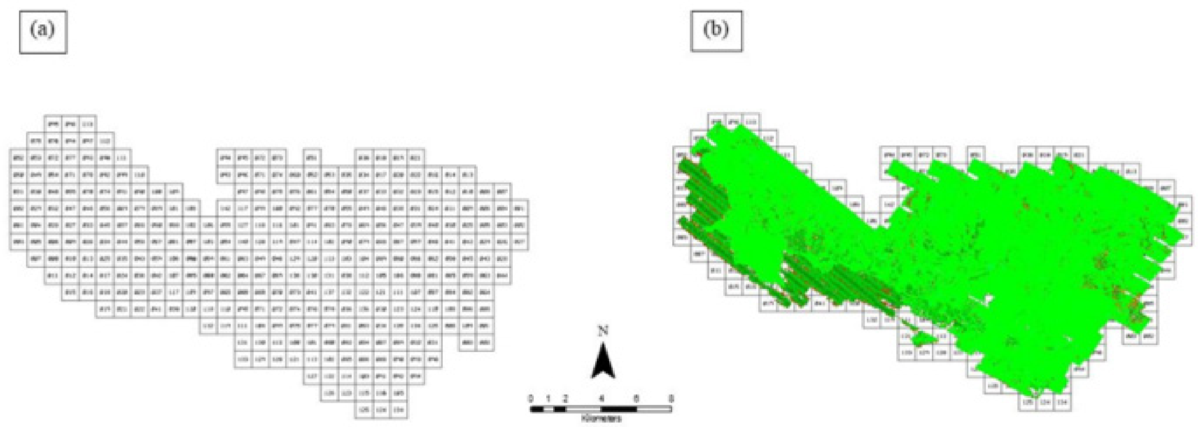


Figure 15. Tiles for Ragay Floodplain (a) and classification results (b) in TerraScan.

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

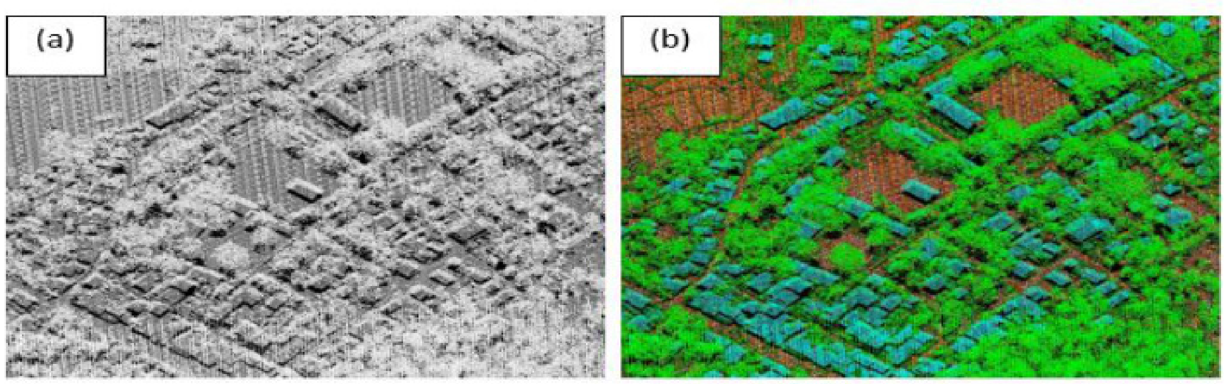


Figure 16. Point cloud before (a) and after (b) classification

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.

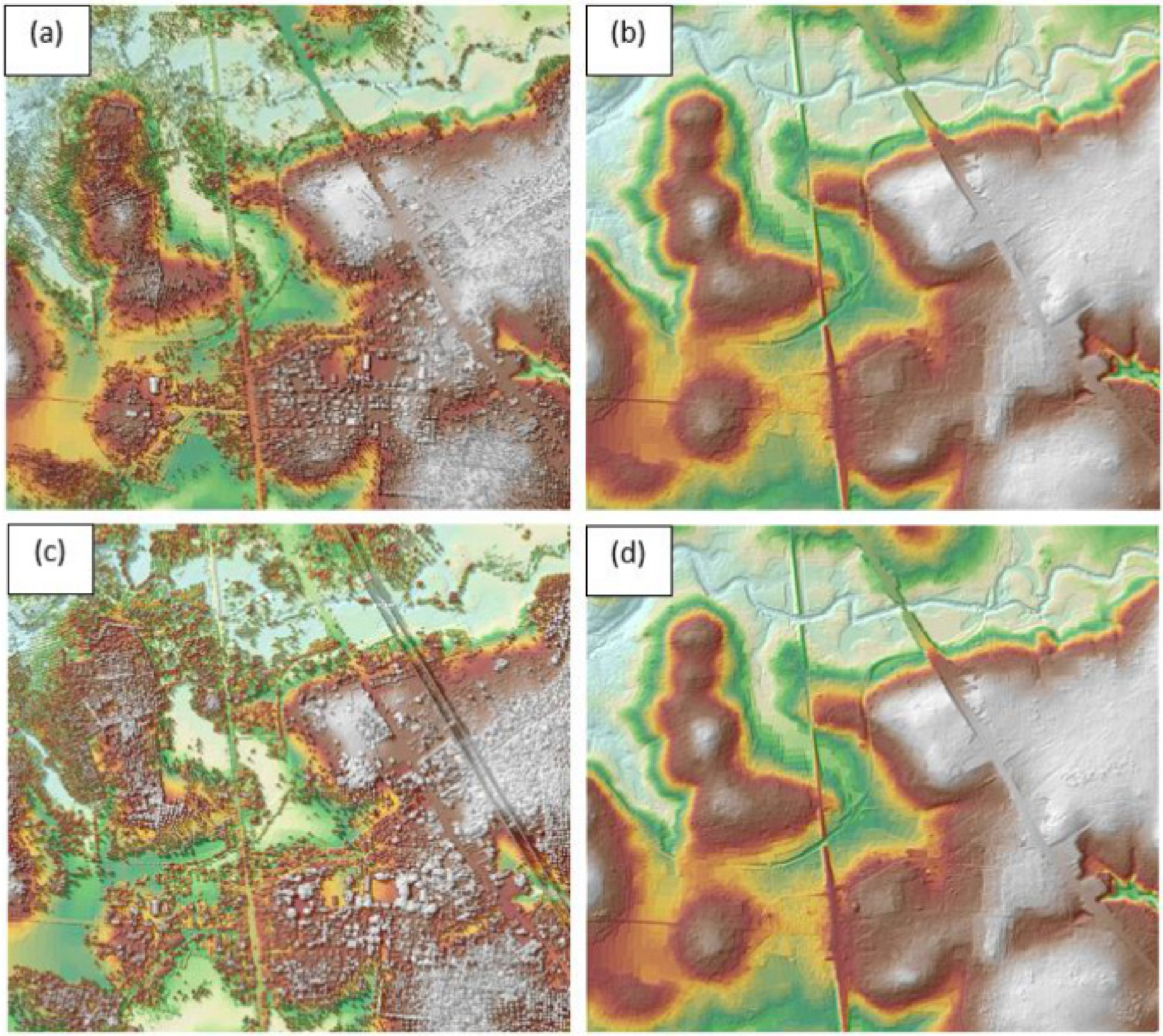


Figure 17. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Ragay floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 491 1km by 1km tiles area covered by the Ragay floodplain is shown in Figure 18. After the tie point selection to fix photo misalignments, color points were added to smooth out visual inconsistencies along the seam lines where photos overlap. The Ragay floodplain attained a total of 250.82 sq. kms. in orthophotograph coverage comprised of 673 images. A zoomed-in version of sample orthophotographs named in reference to its tile number is shown in Figure 19.

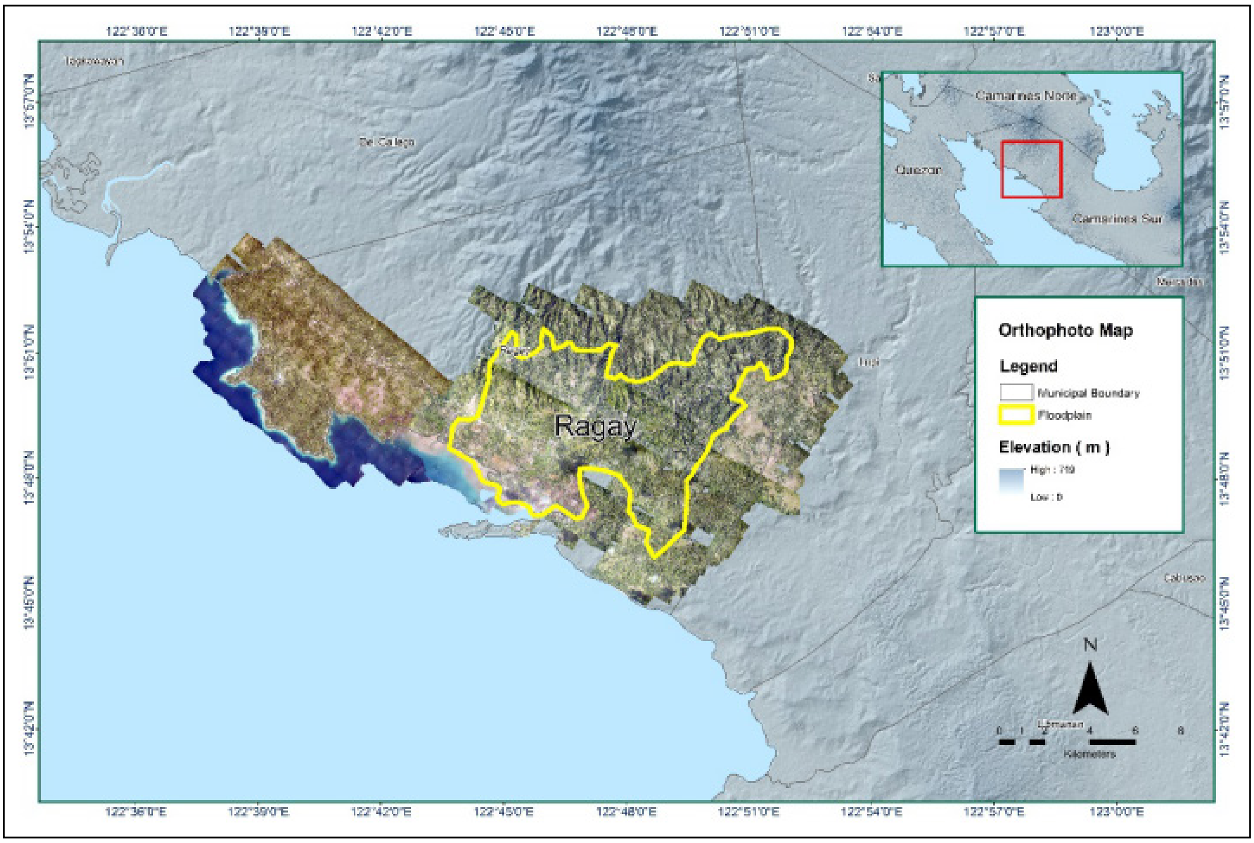


Figure 18. Ragay Floodplain with available orthophotographs.

Figure 19. Sample orthophotograph tiles for Ragay Floodplain.

3.8 DEM Editing and Hydro-Correction

Three (3) mission blocks were processed for the Ragay Floodplain Survey. These blocks are composed of Bagasbas blocks with a total area of 244.06 square kilometers. Table 11 shows the name and corresponding area of each block in square kilometers.

Table 11. LiDAR blocks with its corresponding areas.

LiDAR Blocks	Area (sq.km)
Bagasbas_Blk20L	93.13
Bagasbas_Blk20K	107.18
Bagasbas_Blk20M	43.75
TOTAL	244.06 sq.km

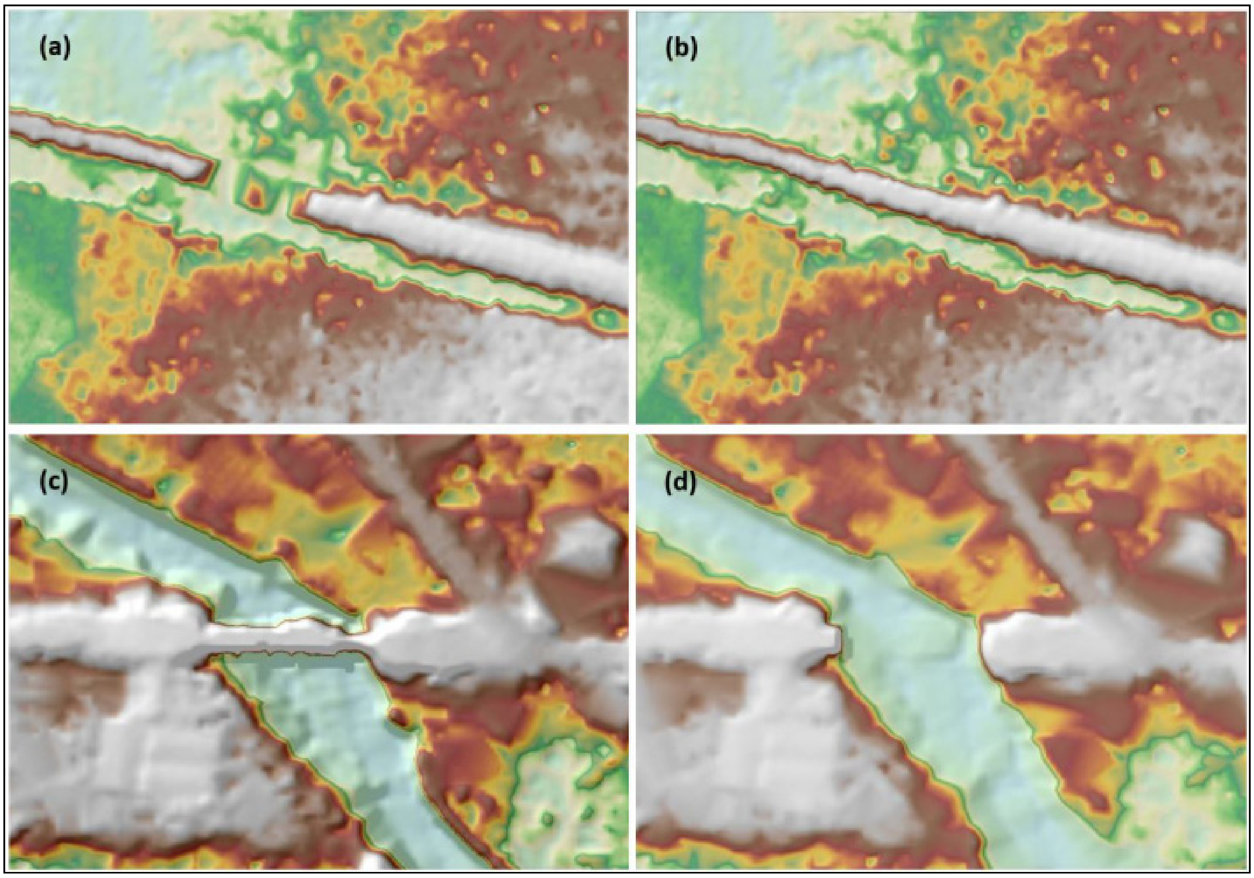


Figure 20. Portions in the DTM of the Ragay Floodplain – a road before (a) and after (b) data retrieval; and a bridge before (c) and after (d) manual editing.

Bagasbas Blk20L was used as the reference block at the start of mosaicking because this block contained national highway in which the validation surveys passed through this road. Table 12 shows the shift values applied to each LiDAR block during mosaicking.

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

3.9 Mosaicking of Blocks

Bagasbas Blk20L was used as the reference block at the start of mosaicking because this block contained national highway in which the validation surveys passed through this road. Table 12 shows the shift values applied to each LiDAR block during mosaicking.

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

Table 12. Shift values of each LiDAR block of Ragay Floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
Bagasbas Blk20L	0.00	0.00	-2.00
Bagasbas Blk20K	0.00	0.00	-2.10
Bagasbas Blk20M	0.00	0.00	-4.12

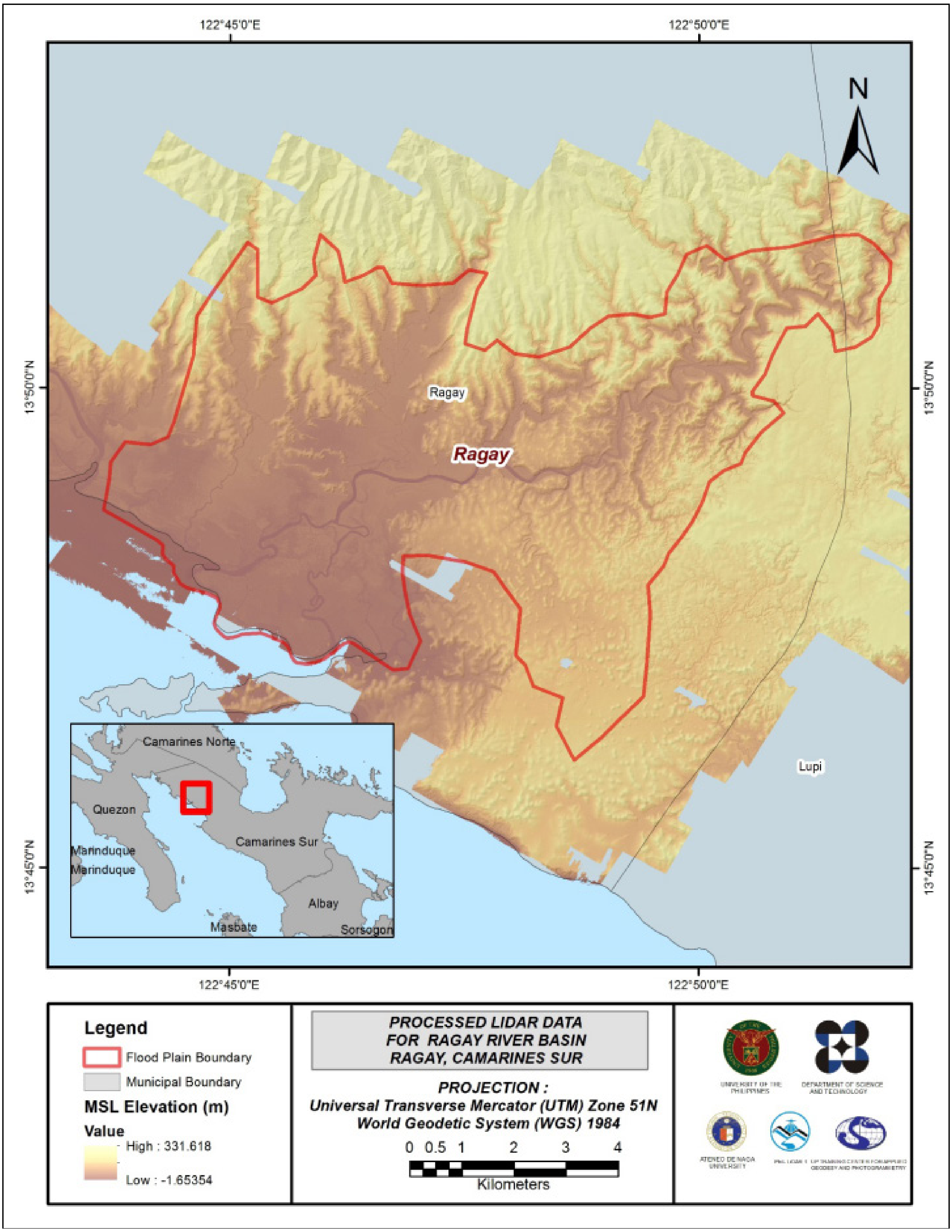


Figure 21 . Map of Processed LiDAR Data for Ragay Floodplain.

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 Ragay to collect points with which the LiDAR dataset is validated is shown in Figure 22. A total of 15,500 survey points were gathered for all the flood plains within the provinces of Quezon and Camarines Sur wherein the Ragay floodplain is located. Random selection of 80% of the survey points, resulting to 12400 points, was used for calibration.

A good correlation between the uncalibrated mosaicked LiDAR DTM and ground survey elevation values is shown in Figure 23. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration points is 3.08 meters with a standard deviation of 0.17 meters. Calibration of the LiDAR data was done by subtracting the height difference value, 3.08 meters, to the mosaicked LiDAR data. Table 13 shows the statistical values of the compared elevation values between the LiDAR data and calibration data.

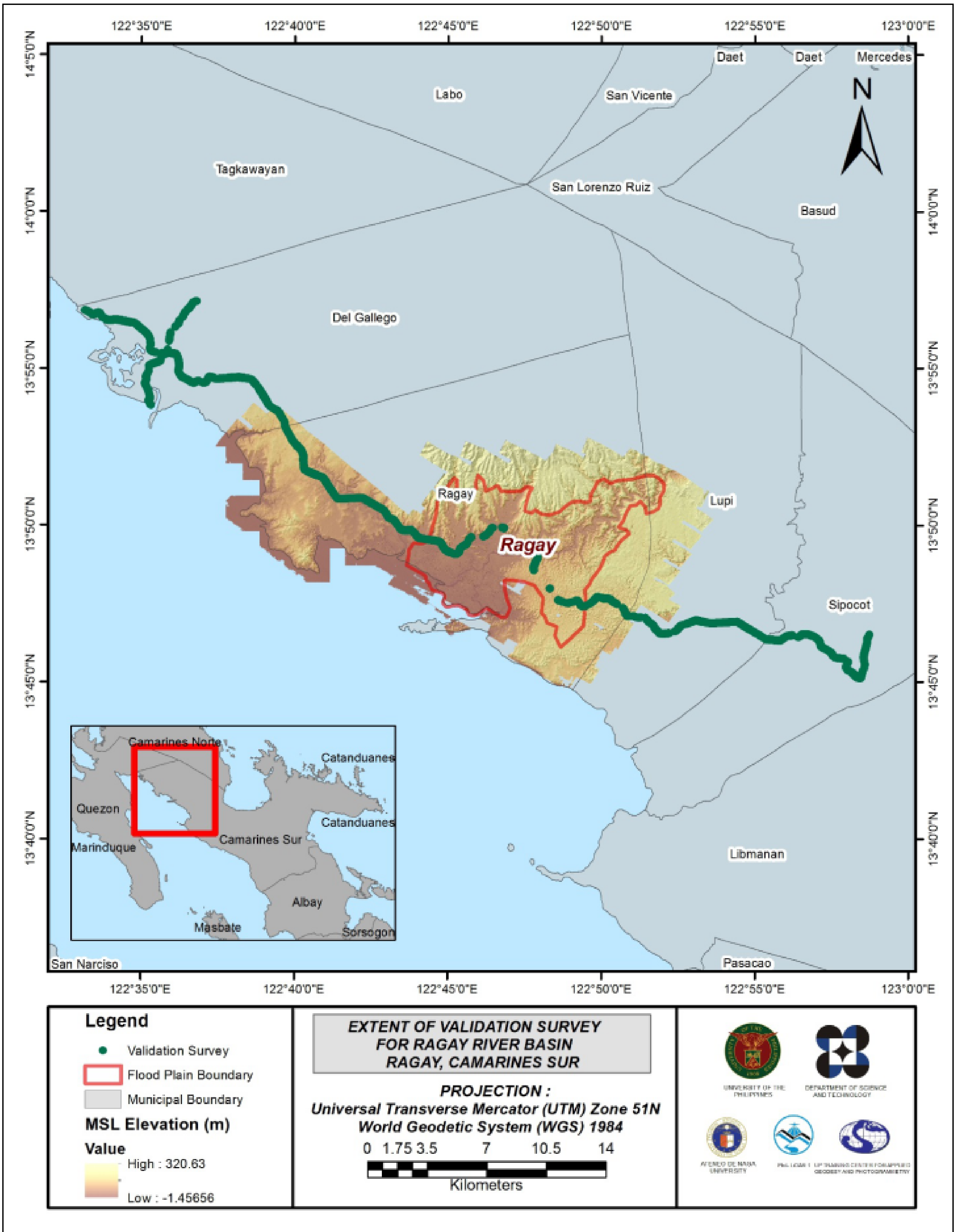


Figure 22. Map of Ragay Floodplain with validation survey points in green.

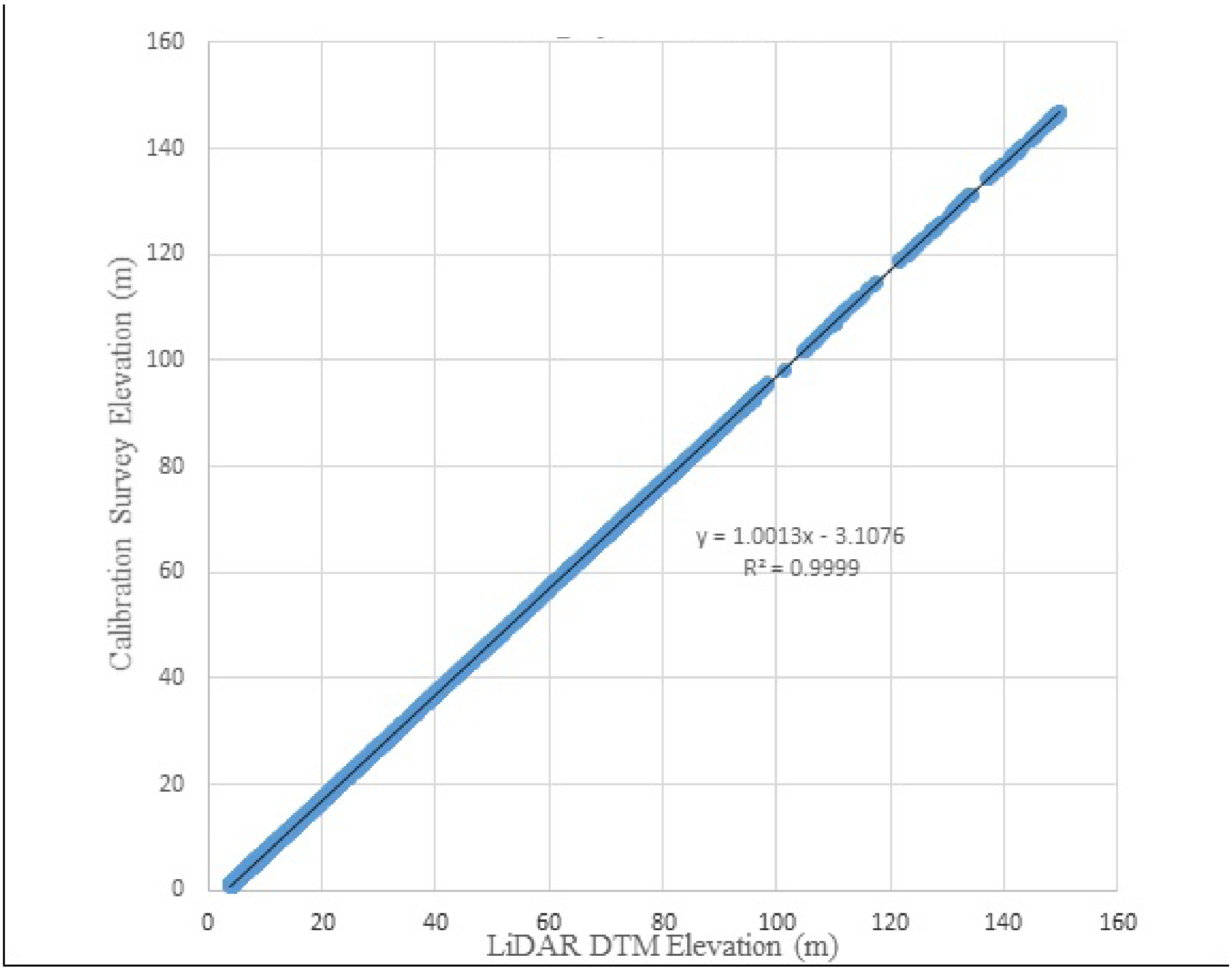


Figure 23. Correlation plot between calibration survey points and LiDAR data.

Table 13. Calibration Statistical Measures

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

The remaining 20% of the total survey points were intersected to the floodplain, resulting to 224 points were used for the validation of calibrated Ragay DTM. A good correlation between the calibrated mosaicked LiDAR elevation values and the ground survey elevation, which reflects the quality of the LiDAR DTM, is shown in Figure 24. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.10 meters with a standard deviation of 0.10 meters, as shown in Table 14.

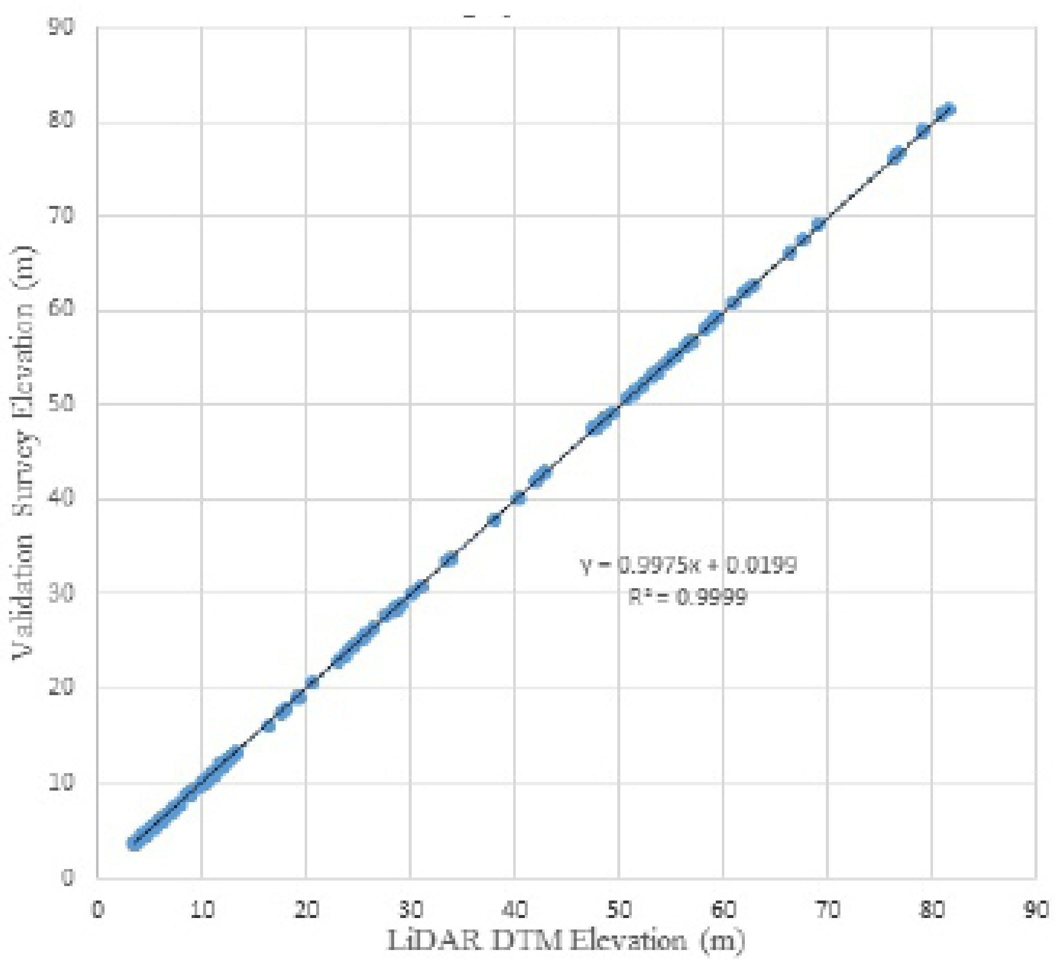


Figure 24. Correlation plot between validation survey points and LiDAR data.

Table 14. Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.10
Standard Deviation	0.10
Average	-0.04
Minimum	-0.27
Maximum	0.25

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and zigzag data were available for Ragay with a total of 18,289 bathymetric survey points. The resulting raster surface produced was done by Kernel interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.07 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Ragay integrated with the processed LiDAR DEM is shown in Figure 25.

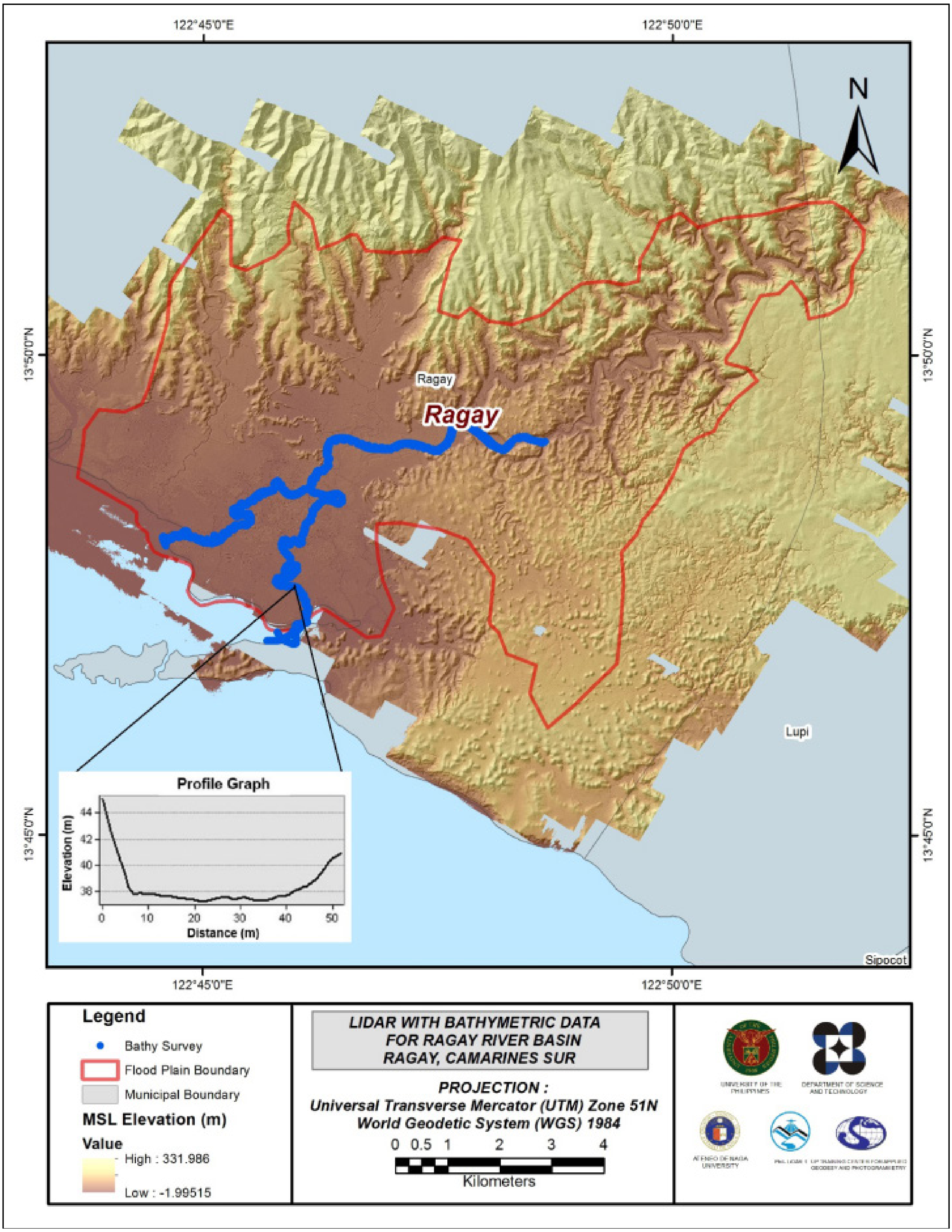


Figure 25. Map of Ragay Floodplain with bathymetric survey points shown in blue.

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

3.12.1 Quality Checking of Digitized Features' Boundary

Ragay floodplain, including its 200-m buffer, has a total area of 86.84 sq km. For this area, a total of 5.0 sq. km., corresponding to a total of 501 building features, were considered for QC. Figure 26 shows the QC blocks for the Ragay floodplain.

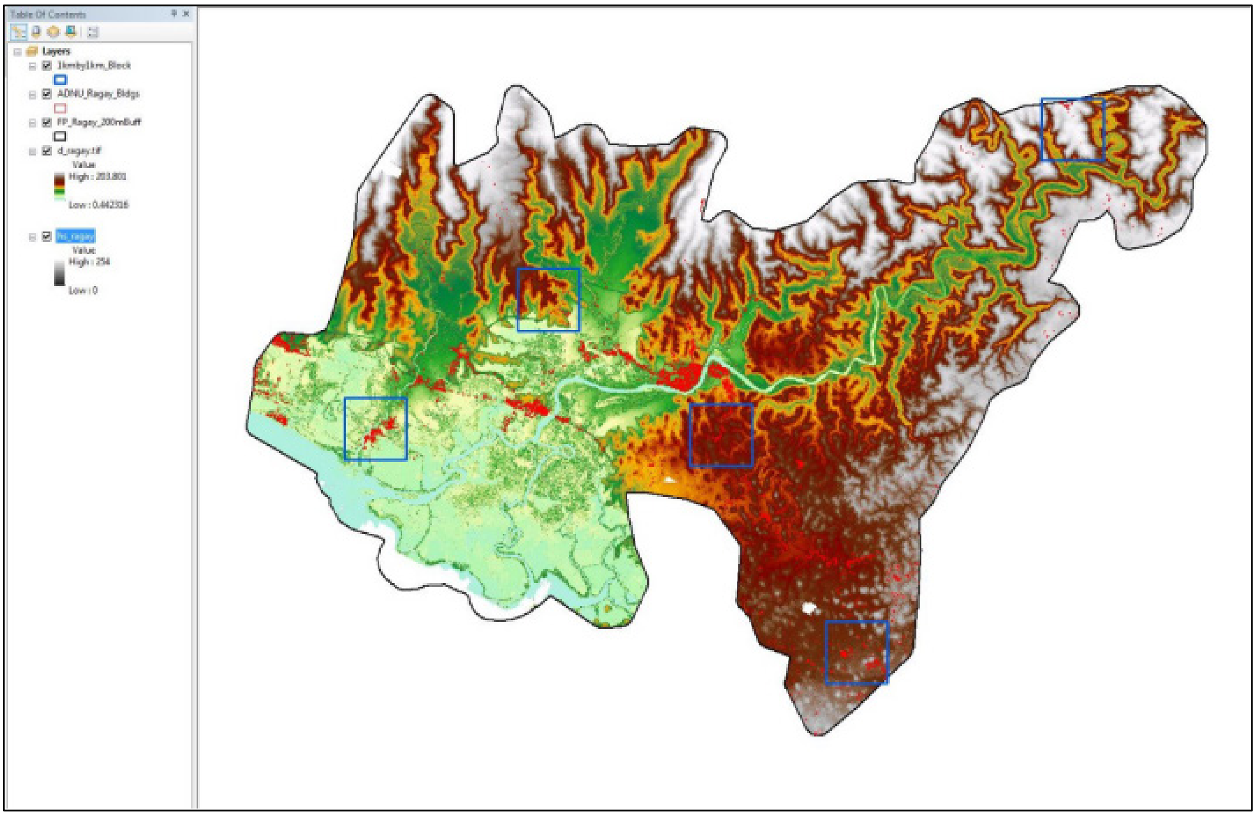


Figure 26. Blocks (in blue) of Ragay building features that were subjected to QC

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

Table 15. Quality Checking Ratings for Ragay Building Features

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Ragay	98.24	100.00	91.22	PASSED

3.12.2 Height Extraction

Height extraction was done for 4,423 building features in Ragay floodplain. Of these building features, 7 buildings were filtered out after height extraction, resulting to 4,416 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 6.16 meters.

3.12.3 Feature Attribution

Field surveys, familiarity with the area, and free online web maps such as Wikimapia (http://wikimapia.org/) and Google Map (https://www.google.com/maps) were used to gather information such as name and type of the features within the river basin.

Table 16 summarizes the number of building features per type, while Table 17 shows the total length of each road type.

Table 18, on the other hand, shows the number of water features extracted per type.

Table 16. Building Features Extracted for Ragay Floodplain.

Facility Type	No. of Features
Residential	4119
School	153
Market	13
Agricultural/Agro-Industrial Facilities	3
Medical Institutions	10
Barangay Hall	11
Military Institution	0
Sports Center/Gymnasium/Covered Court	2
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	3
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	2
Water Supply/Sewerage	0
Religious Institutions	25
Bank	1
Factory	0
Gas Station	2
Fire Station	0
Other Government Offices	14
Other Commercial Establishments	57
Total	**4416**

Table 17. Total Length of Extracted Roads for Ragay Floodplain.

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Ragay	78.75	4.09	0	13.94	0.00	**96.78**

Table 18. Number of Extracted Water Bodies for Ragay Floodplain.

Floodplain	Water Body Type					Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Ragay	1	330	0	0	0	**331**

A total of 16 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 given the complete required attributes. Respectively, all these output features comprise the flood hazard exposure database for the floodplain. The final quality checking completes the feature extraction phase of the project.

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

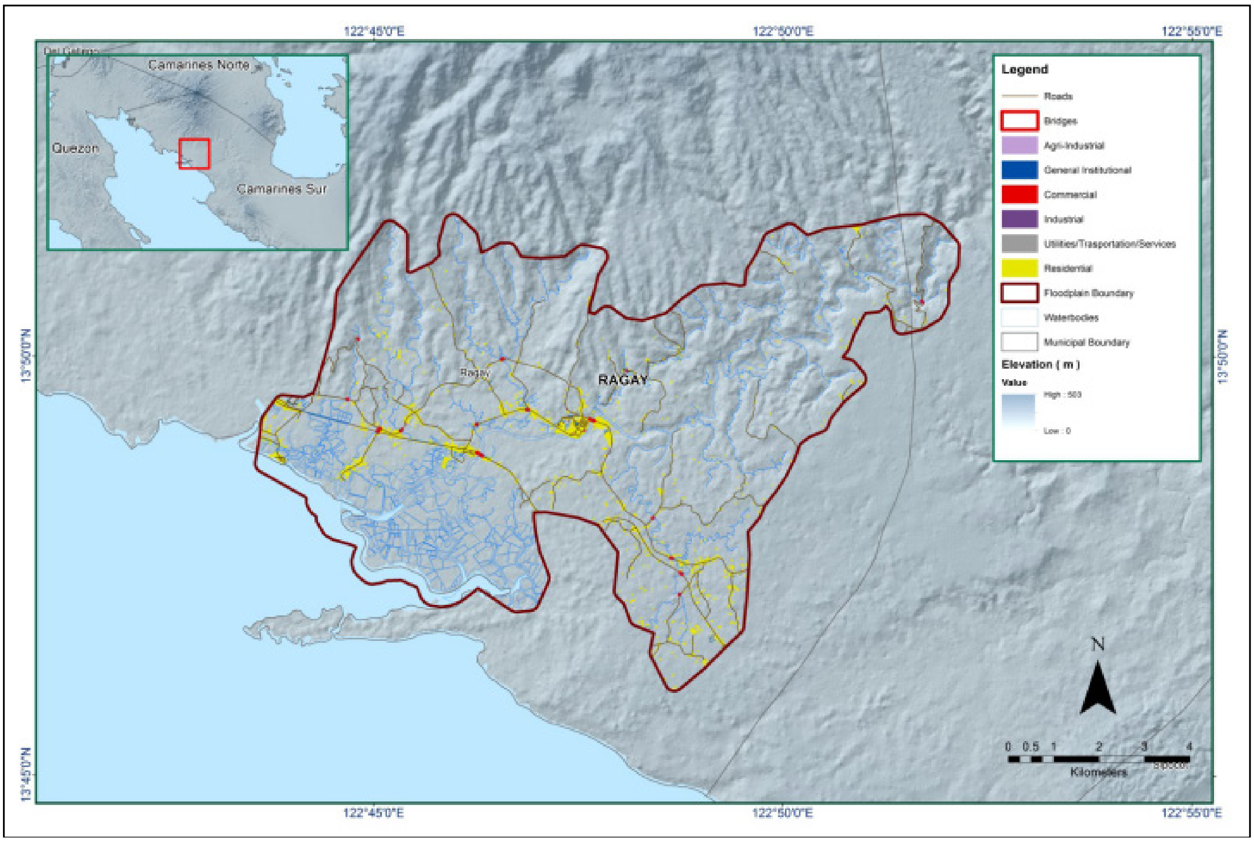


Figure 27. Extracted features for Ragay Floodplain.

CHAPTER 4: LIDAR VALIDATION SURVEY AND MEASUREMENTS OF THE RAGAY 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 Ragay River on June 28, 2016 – July 12, 2016 with the following scope of work: reconnaissance; control survey; cross-section and as-built survey at Ragay Bridge in Brgy. Pangitayan, Municipality of Ragay; validation points acquisition of about 69 km covering the Ragay River Basin area; and bathymetric survey of about 16.496 km from its upstream in Brgy. Lower Santa Cruz down to two mouths of the river located in Brgy. Buenasuerte and Brgy. Binahan Proper, all of which in Municipality of Ragay, with an approximate length of 16.496 km using Ohmex™ single beam echo sounder and Trimble® SPS 882 GNSS PPK survey technique (Figure 28).

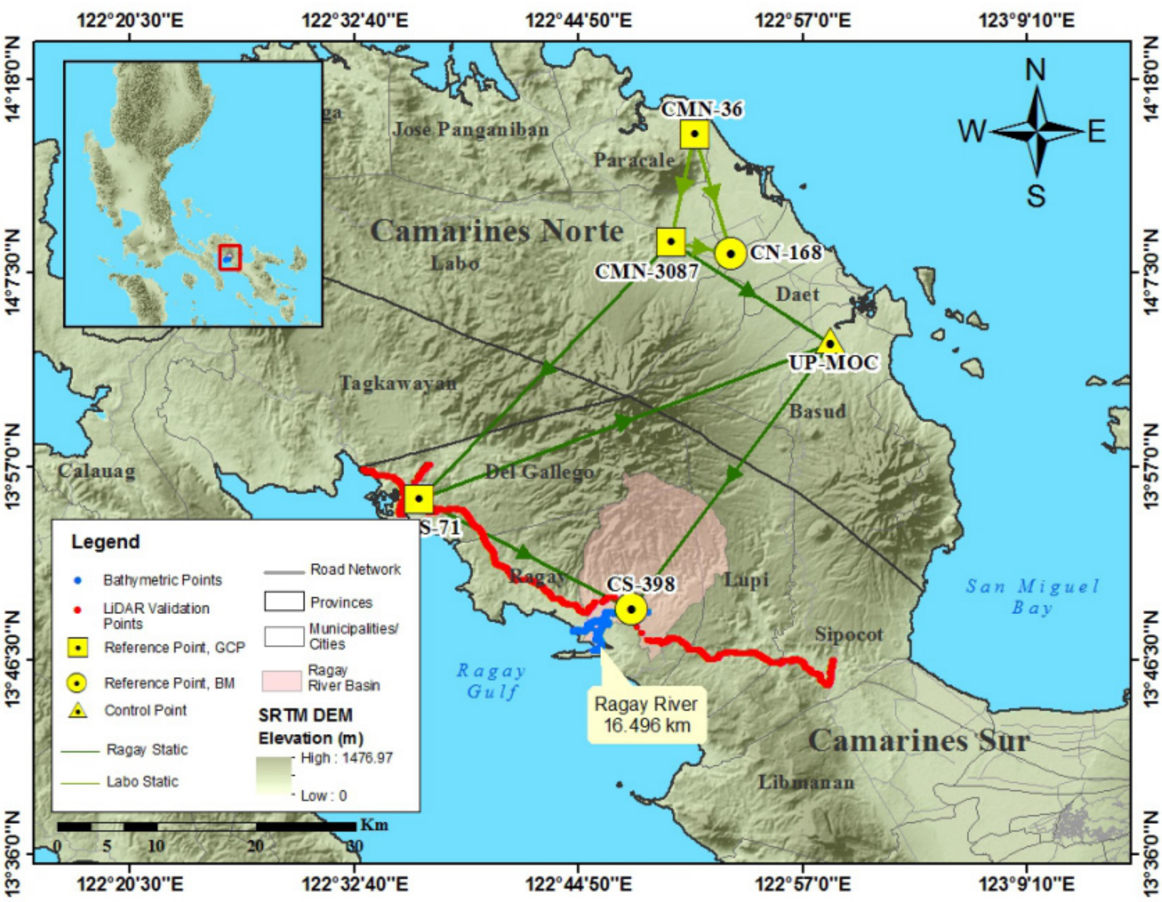


Figure 28. Extent of the bathymetric survey (in blue line) in Ragay River and the LiDAR data validation survey (in red).

4.2 Control Survey

The GNSS network used for Ragay River Basin is composed of two (2) loops established on June 30, 2016 occupying the following reference points: CMS-71, a second-order GCP in Brgy. Cabasag, Municipality of Del Gallego; CS-398, a first order BM, in Brgy. Pangitayan, Municipality of Ragay; and CMN-3087, a fixed point from Labo Survey, located in Brgy. Bakiad, Municipality of Labo.

A control point was established along the approach of Mocong Bridge namely: UP-MOC, located in Brgy. Mocong, Municipality of Basud, Camarines Norte.

Table 19 depicts the summary of reference and control points utilized, with their corresponding locations, while Figure 29 shows the GNSS network established in the Ragay River Survey.

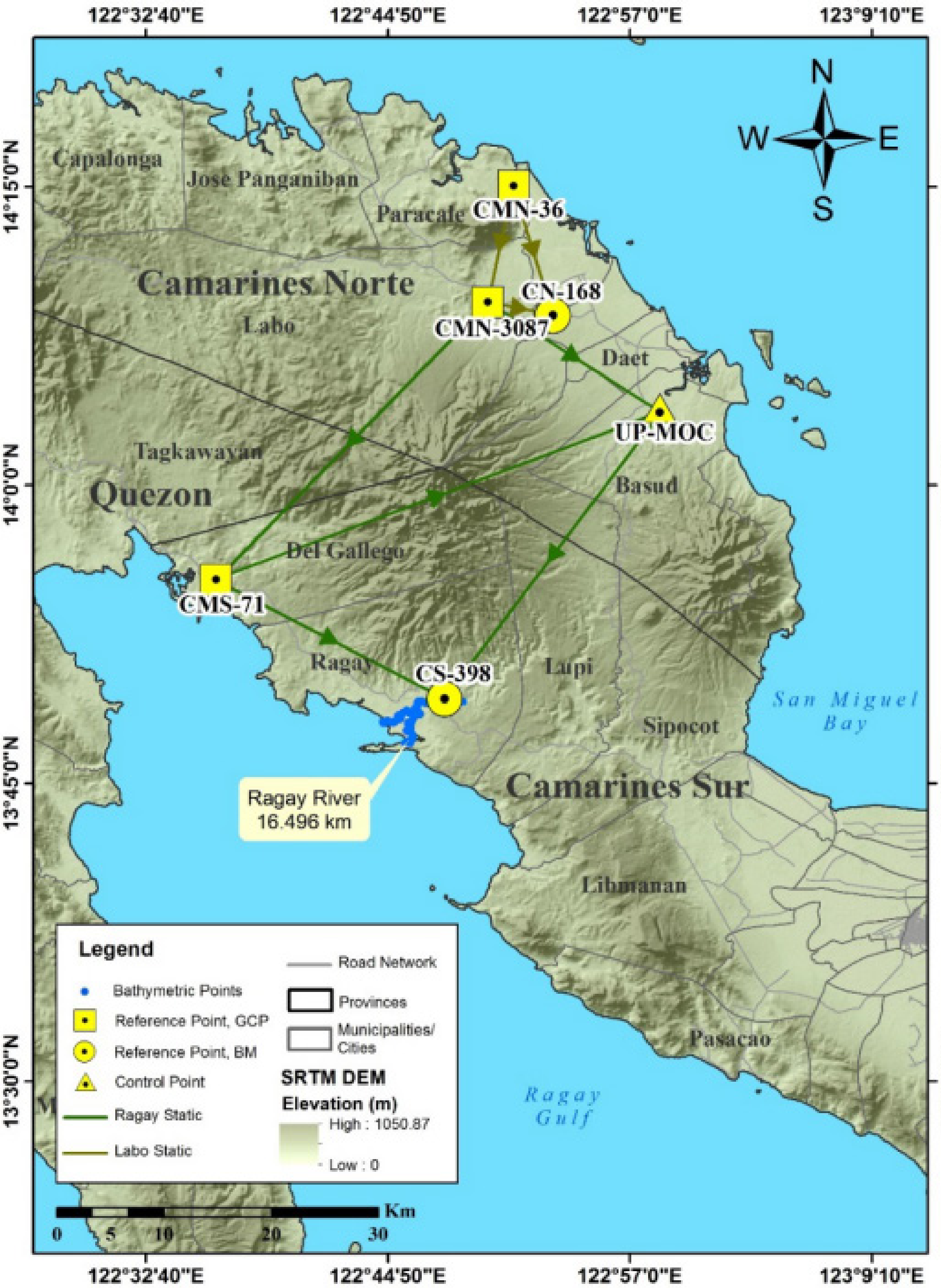


Figure 29. The GNSS Network established in the Ragay River Survey.

Table 19. List of Reference and Control Points occupied for Ragay 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
Control Survey on June 30, 2016						
CMN-36	2nd Order GCP	14°15'02.89999"N	122°51'10.48832"E	54.569	5.129	2007
CN-168	1st Order BM	14°08'31.19463"N	122°53'08.49490"E	62.569	12.721	2007
CMN-3087	Used as Marker	14°09'12.36125"N	122°49'52.53365"E	64.661	14.905	2007
Control Survey on June 28, 2016						
CMS-71	2nd order, GCP	13°55'14.18695"N	122°36'12.89833"E	59.636	-	2007
CS-398	1st order, BM	-	-	60.994	10.576	2008
CMN-3087	Fixed Control	14°09'12.36125"N	122°49'52.53365"E	64.661	14.905	2007
UP-MOC	UP Established	-	-	-	-	06-28-16

Figure 30 to Figure 33 depict the setup of the GNSS on recovered reference points and established control points in the Ragay River.

Figure 30. GNSS base set up, Trimble® SPS 985, at CMS-71, situated at the approach of Kilbay Bridge in Brgy. Cabasag, Municipality of Del Gallego, Camarines Sur.

Figure 31. GNSS receiver setup, Trimble® SPS 882, at CS-398, located at the approach of Ragay Bridge in Brgy. Pangitayan, Municipality of Ragay, Camarines Sur.

Figure 32. GNSS receiver setup, Trimble® SPS 852, at CMN-3087, located at the approach of Labo Bridge in Brgy. Bakiad, Municipality of Labo, Camarines Norte.

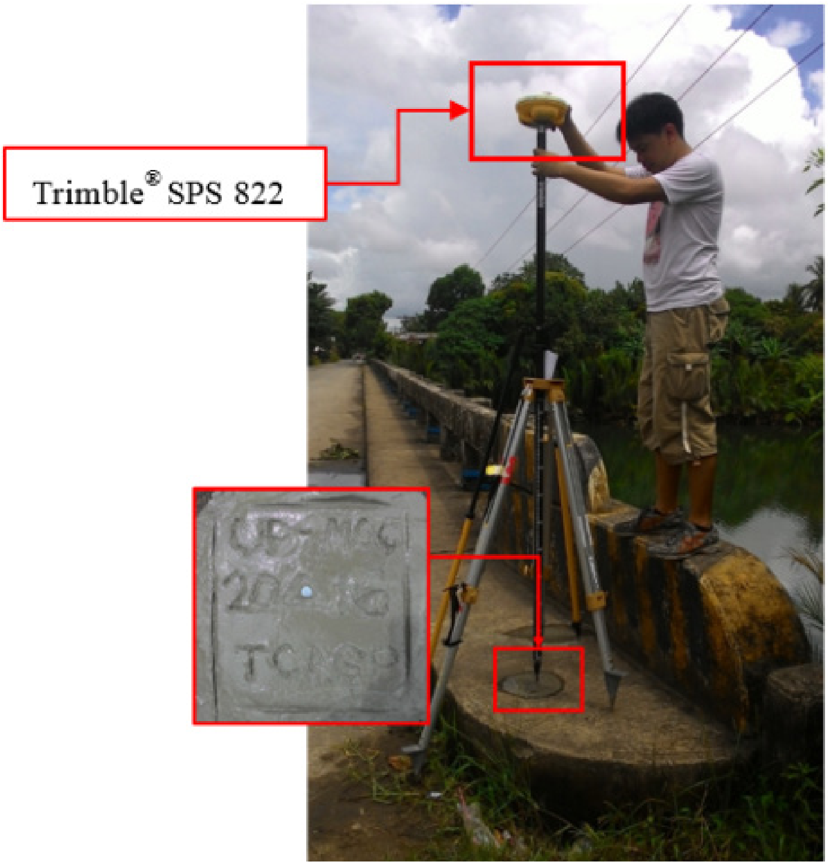


Figure 33. GNSS receiver setup, Trimble® SPS 822, at UP-MOC, located at the approach of Mocong Bridge in Brgy. Mocong, Municipality of Basud, Camarines Norte.

4.3 Baseline Processing

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

Table 20. Baseline Processing Summary Report for Ragay River Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
CMS-71 -- CS-398	06-30-16	Fixed	0.003	0.014	118°07'06"	23448.013	1.313
CMS-71 -- UP-MOC	06-30-16	Fixed	0.004	0.014	68°18'41"	43178.316	-4.130
UP-MOC -- CS-398	06-30-16	Fixed	0.004	0.015	215°50'13"	33277.281	5.437
CMN-3087 -- UP-MOC	06-30-16	Fixed	0.003	0.015	122°19'44"	18380.742	-9.211
CMN-308 -- CMS-71	06-30-16	Fixed	0.003	0.017	223°41'59"	35614.428	-5.115

As shown in Table 20, a total of three (3) baselines were processed with the coordinates of NGW-50, and the elevation value of reference points NW-100 held fixed; it is apparent that all baselines passed the required accuracy.

4.4 Network Adjustment

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

<20cm and

where:

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

For complete details, see the Network Adjustment Report shown in Table 21 to Table 23.

The four (4) control points, CMS-71, CS-398, CMS-3087 and UP-MOC were occupied and observed simultaneously to form a GNSS loop. Coordinates of CMS-71 and CMN-3087; and elevation values of CS-398 and CMN-3087 were held fixed during the processing of the control points as presented in Table 21. Through these reference points, the coordinates and elevation of the unknown control points were computed.

Table 21. 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-71	Local	Fixed	Fixed		
CS-398	Grid				Fixed
CMN-3087	Local	Fixed	Fixed	Fixed	
Fixed = 0.000001 (Meter)					

Likewise, the list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 22. The fixed control CMS-71 has no values for grid error and CS-398 has no value for elevation error, while CS-398 has no value for both grid error and elevation error.

Table 22. Adjusted grid coordinates for the control points used in the Ragay River Floodplain survey.

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
CMS-71	457175.646	?	1538981.558	?	10.059	0.046	LL
CS-398	477829.729	0.011	1527900.590	0.010	10.576	?	e
CMN-3087	481789.697	?	1564701.975	?	14.905	?	LLh
UP-MOC	497307.927	0.011	1554865.116	0.010	5.214	0.046	

The results of the computation for accuracy are as follows:

a. CMS-71

horizontal accuracy	=	Fixed
vertical accuracy	=	4.6 cm < 10 cm

b. CS-398

horizontal accuracy	=	$\sqrt{((1.1)^2 + (1.0)^2}$
	=	$\sqrt{(1.21 + 1.0)}$
	=	1.49 < 20 cm
vertical accuracy	=	Fixed

c.CMN-3087

horizontal accuracy	=	Fixed
vertical accuracy	=	Fixed

d.UP-MOC

horizontal accuracy	=	$\sqrt{((1.1)^2 + (1.0)^2}$
	=	$\sqrt{(1.21 + 1.0)}$
	=	1.49 < 20 cm
vertical accuracy	=	4.6 cm < 10 cm

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

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

Table 23. Adjusted geodetic coordinates for control points used in the Ragay River Floodplain validation.

Point ID	Latitude	Longitude	Ellipsoid	Height	Constraint
CMS-71	N13°55'14.18695"	E122°36'12.89833"	59.636	0.046	LL
CS-398	N13°49'14.33596"	E122°47'41.49841"	60.994	?	e
CMN-3087	N14°09'12.36125"	E122°49'52.53365"	64.661	?	LLh
UP-MOC	N14°03'52.37147"	E122°58'30.23146"	55.501	0.046	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 23. Based on the results of the computation, the accuracy conditions are satisfied; hence, the required accuracy for the program was met. The computed coordinates of the reference and control points utilized in the Ragay River GNSS Static Survey are seen in Table 24.

Table 24. The reference and control points utilized in the Ragay River Static Survey, with their corresponding locations (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
CMS-71	2nd order, GCP	13°55'14.18695"	122°36'12.89833"	59.636	1538981.558	457175.646	10.059
CS-398	1st order, BM	13°49'14.33596"	122°47'41.49841"	60.994	1527900.59	477829.729	10.576
CMN-3087	Fixed Control	14°09'12.36125"	122°49'52.53365"	64.661	1564701.975	481789.697	14.905
UP-MOC	UP Established	14°03'52.37147"	122°58'30.23146"	55.501	1554865.116	497307.927	5.214

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

The bridge cross-section and as-built surveys were conducted on July 5, 2016 and July 7, 2016 at the downstream side of Ragay Bridge in Brgy. Pangitayan, Municipality of Ragay, Camarines Norte as shown in Figure 34. A total station through open traverse method and Trimble® SPS 882 GNSS PPK survey technique.

Figure 34. Ragay Bridge facing upstream

The cross-sectional line of Ragay Bridge is about 174 meters with eighty-five (85) points acquired using the control point CS-398 as GNSS base station. The cross-section diagram, location map, and bridge as-built from are shown in Figure 35, Figure 36, and Figure 37, respectively.

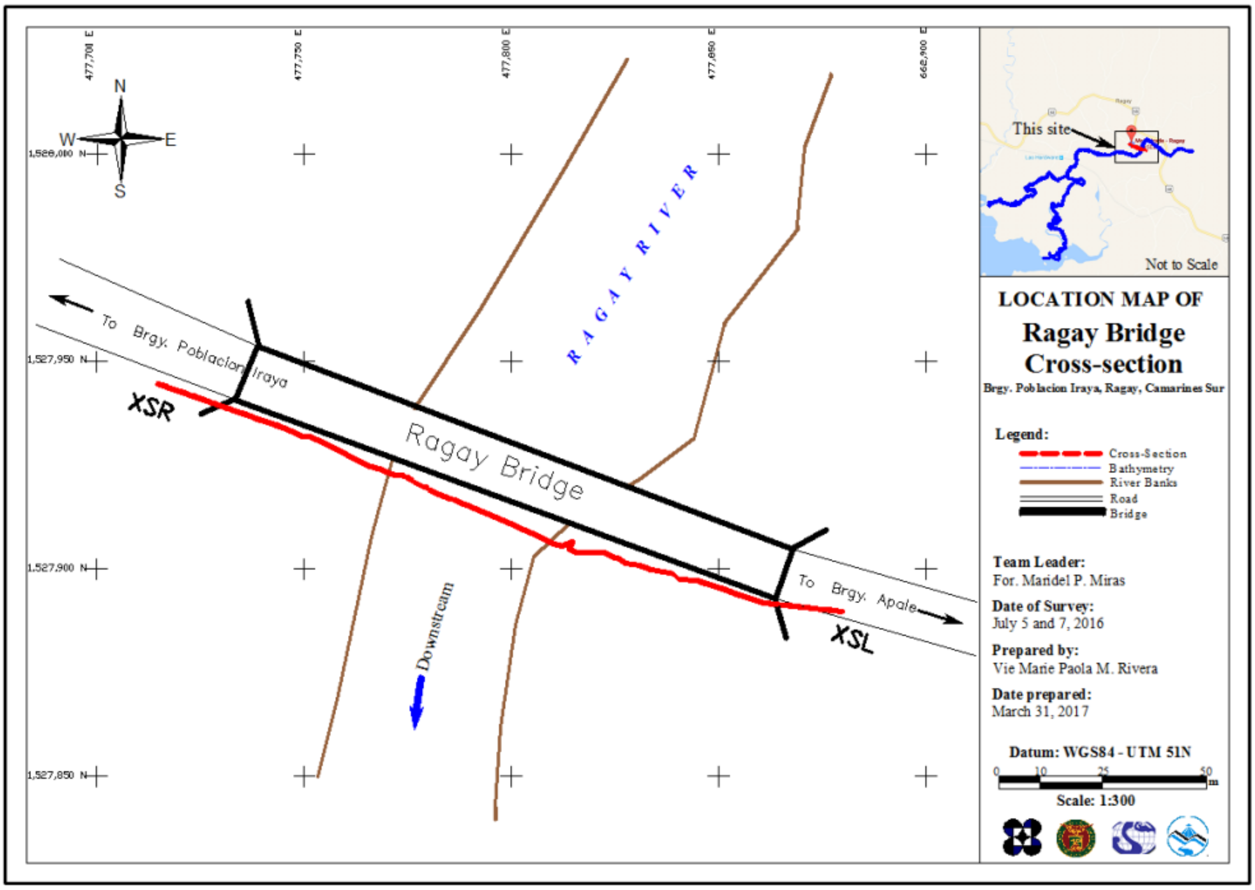


Figure 35. Location map of the Ragay bridge cross-section survey

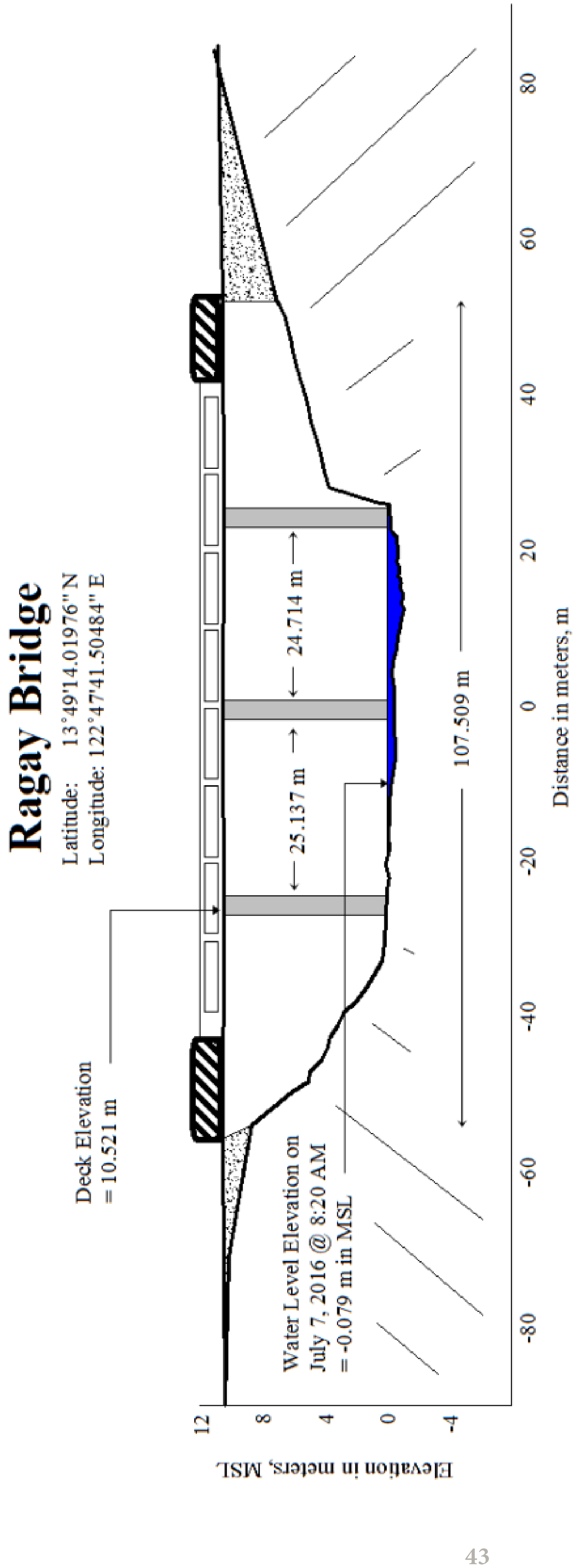


Figure 36. Ragay Bridge cross-section diagram

Bridge Data Form

Bridge Name: **Ragay Bridge** | **Date:** **July 5 and 7, 2016**

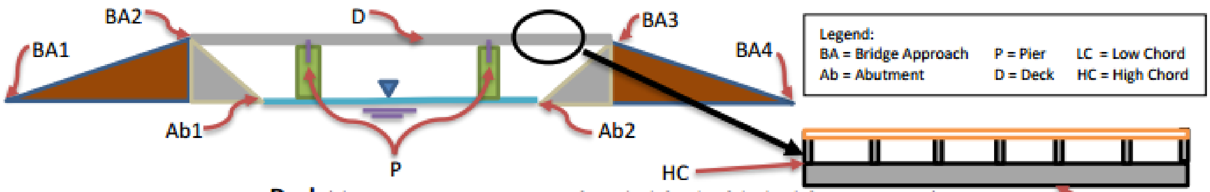
River Name: **Basud River** | **Time:** **8:20 AM**

Location (Brgy, City,Region): **Brgy. Poblacion Iraya, Municipality of Ragay, Camarines Sur**

Survey Team: **Maridel Miras, Caren Ordoña**

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

Latitude: **13°49'14.01976" N** | **Longitude:** **122°47'41.50484" E**



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

Elevation: **10.521 m** **Width:** **9 m** **Span (BA3-BA2):** **107.509 m**

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

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

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	0	10.419 m	BA3	141.756 m	10.548 m
BA2	34.247 m	10.521 m	BA4	174.733 m	10.880 m

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

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

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

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

	Station (Distance from BA1)	Elevation	Pier Diameter
Pier 1	62.978 m	10.489 m	6 m
Pier 2	88.115 m	10.532 m	6 m
Pier 3	112.830 m	10.492 m	6 m

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

Figure 37. Bridge as-built form of Ragay Bridge

4.6 Validation Points Acquisition Survey

The validation points acquisition survey was conducted on July 5, July 8, and July 8, 2016 using a survey GNSS rover receiver Trimble® SPS 882 mounted on a pole, which was attached in front of the vehicle as shown in Figure 38. It was secured with a steel rod and tied with cable ties to ensure that it was horizontally and vertically balanced. Points were gathered along concrete roads of national highway so that data to be acquired will have a relatively minimal change in elevation and observing vehicle speed of 10 to 20 kph. Cutting across the flight strips of the Data Acquisition Component (DAC) with the aid of available topographic maps and Google Earth™ images. Gathered data were processed using Trimble® Business Center Software.

Figure 38. Validation points acquisition survey set up along Ragay River Basin

The GNSS base station was set-up over CS-398 gathered validation points from Brgy. Pasay, Municipality of Del Gallego, going south east traversing the Municipalities of Del Gallego, Ragay, Lupi and Sipocot in Camarines Sur. The survey ended in Brgy. Impig, Municipality of Sipocot. The ground validation line is approximately 69 km in length with 9,762 points.

Figure 39. Extent of the LiDAR ground validation survey (in red) for Ragay River Basin.

4.7 River Bathymetric Survey

Bathymetric survey was conducted on July 5-6, 2016 using an Ohmex™ single beam echo sounder and Trimble® SPS 882 in GNSS PPK survey technique in continuous topo mode as shown in Figure 40. The survey started in Brgy. Lower Sata Cruz, Municipality of Ragay, with coordinates 13°49’06.17235”N, 122°48’38.67983”E, and ended at two mouths of the river: one in Brgy. Buenasuerte with coordinates 13°47’01.48002”N, 122°45’41.23893”E; and one in Brgy. Binahan Proper with coordinates 13°48’00.90927”N, 122°44’36.21354”E.

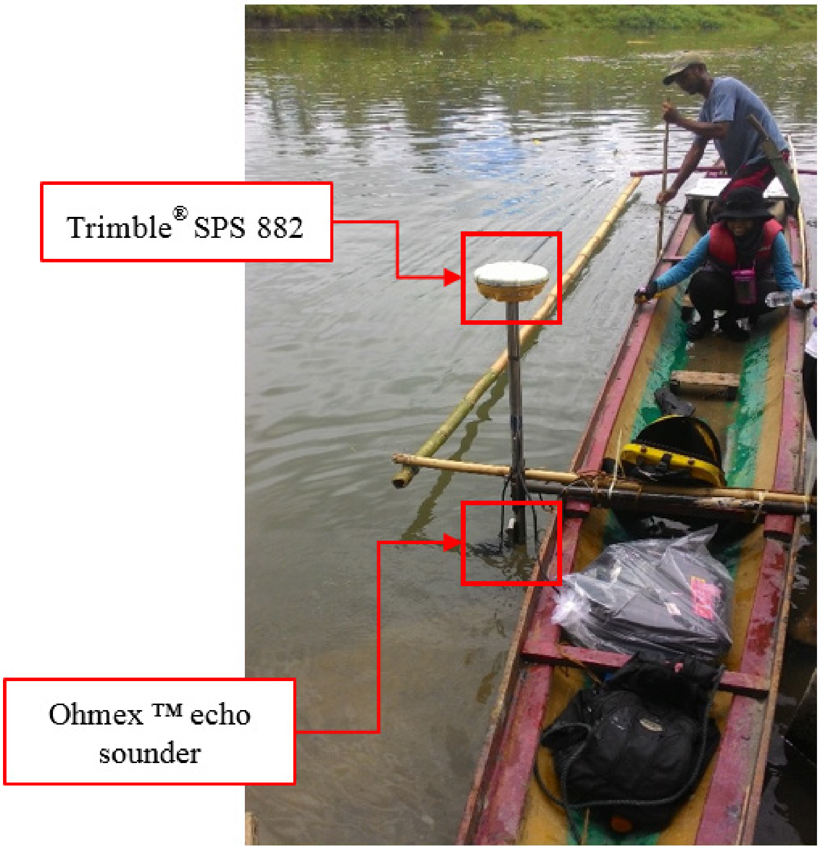


Figure 40. Bathymetric survey using Ohmex™ single beam echo sounder in Ragay River

The entire bathymetric data coverage for Ragay River is illustrated in the map in Figure 41. The bathymetric line is approximately 16.496 km in length with 16,496 bathymetric points acquired using CS-398 as GNSS base station traversing ten (10) barangays in Municipalities of Ragay. A CAD diagram was also produced to illustrate the Ragay riverbed profile as shown in Figure 42 and Figure 43. The lowest elevation was recorded at -5.298 m (below MSL) in Brgy. Apad, while the highest elevation observed was 0.957 m in MSL located at Brgy. Lower Sata Cruz, both in Municipality of Ragay. A 6-km additional bathymetric survey was added to include the other exit point or mouth of the river.

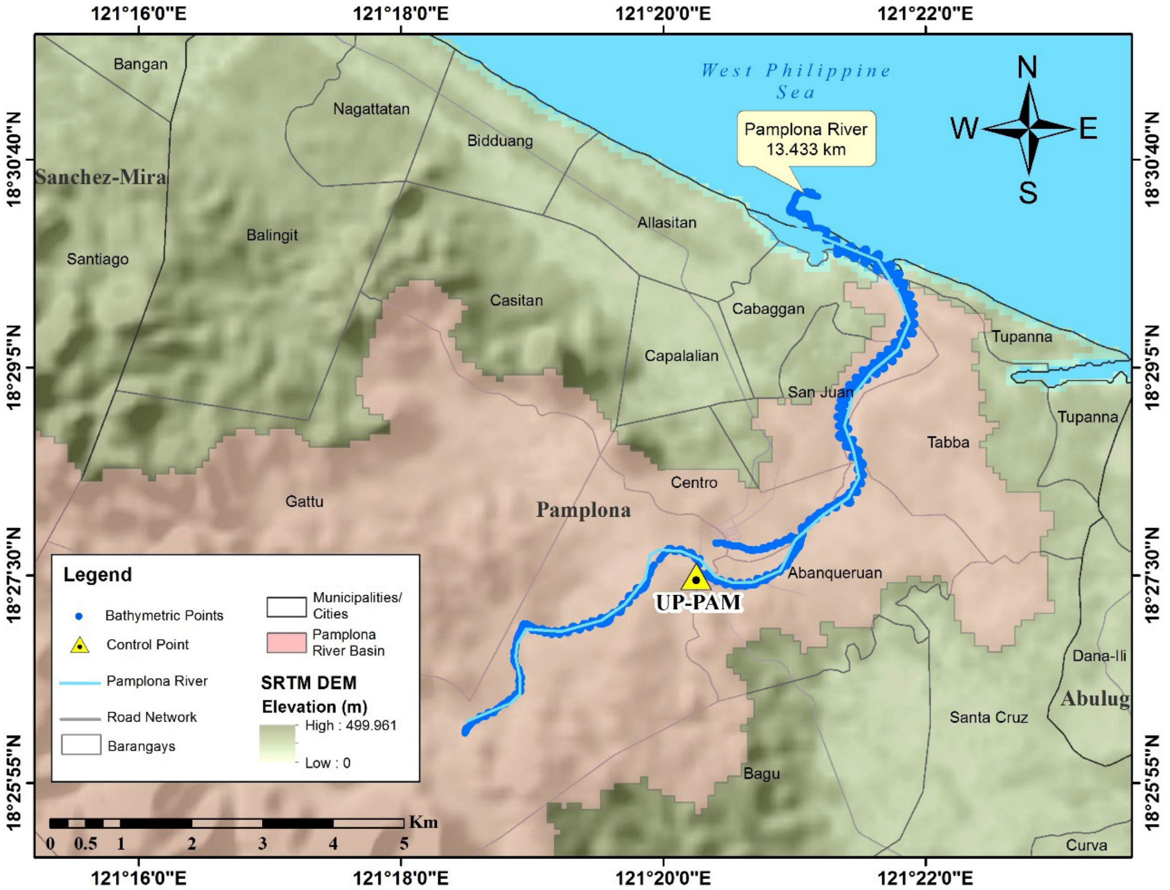


Figure 41. Extent of the Ragay River Bathymetry Survey

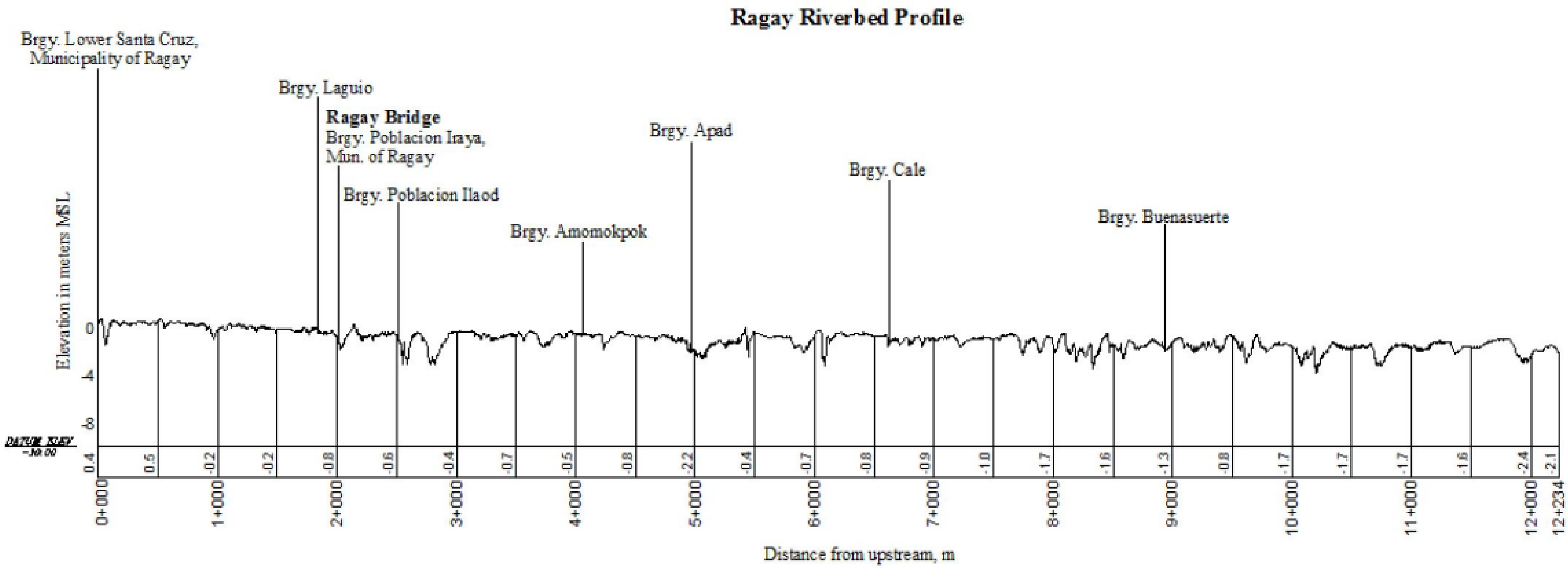


Figure 42. Ragay riverbed profile, left mouth.

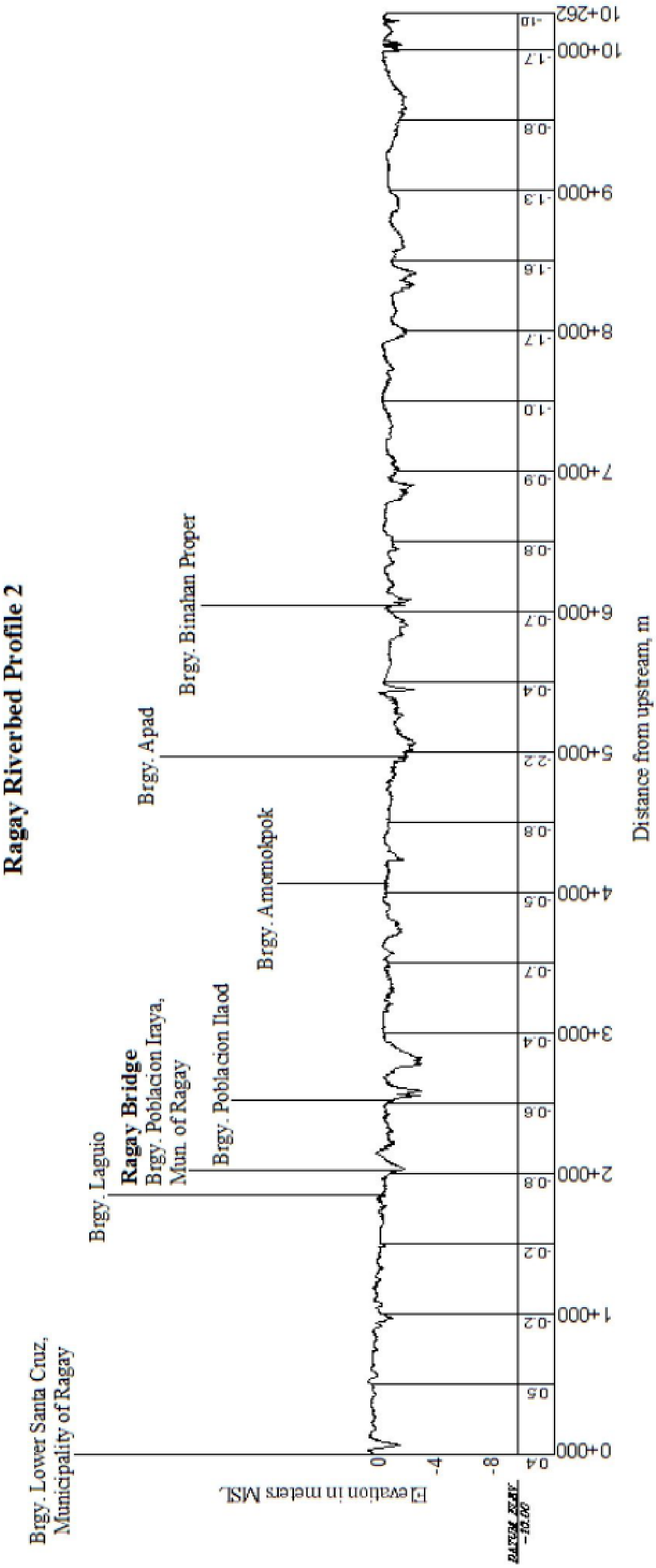


Figure 43. Ragay riverbed profile, right mouth.

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 Ragay 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 Ragay River Basin were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from an automatic rain gauge (ARG) installed by the Department of Science and Technology – Advanced Science and Technology Institute as illustrated in Figure 44. The precipitation data collection started from December 25, 2016 at 06:15 PM to December 26, 2016 at 07:00 PM.

The total precipitation for this event in Ragay, Camarines Sur ARG was 27.8 mm. It has a peak rainfall of 2.4 mm. on December 26, 2015 at 2:00 in the morning. The lag time between the peak rainfall and discharge is 30 minutes.

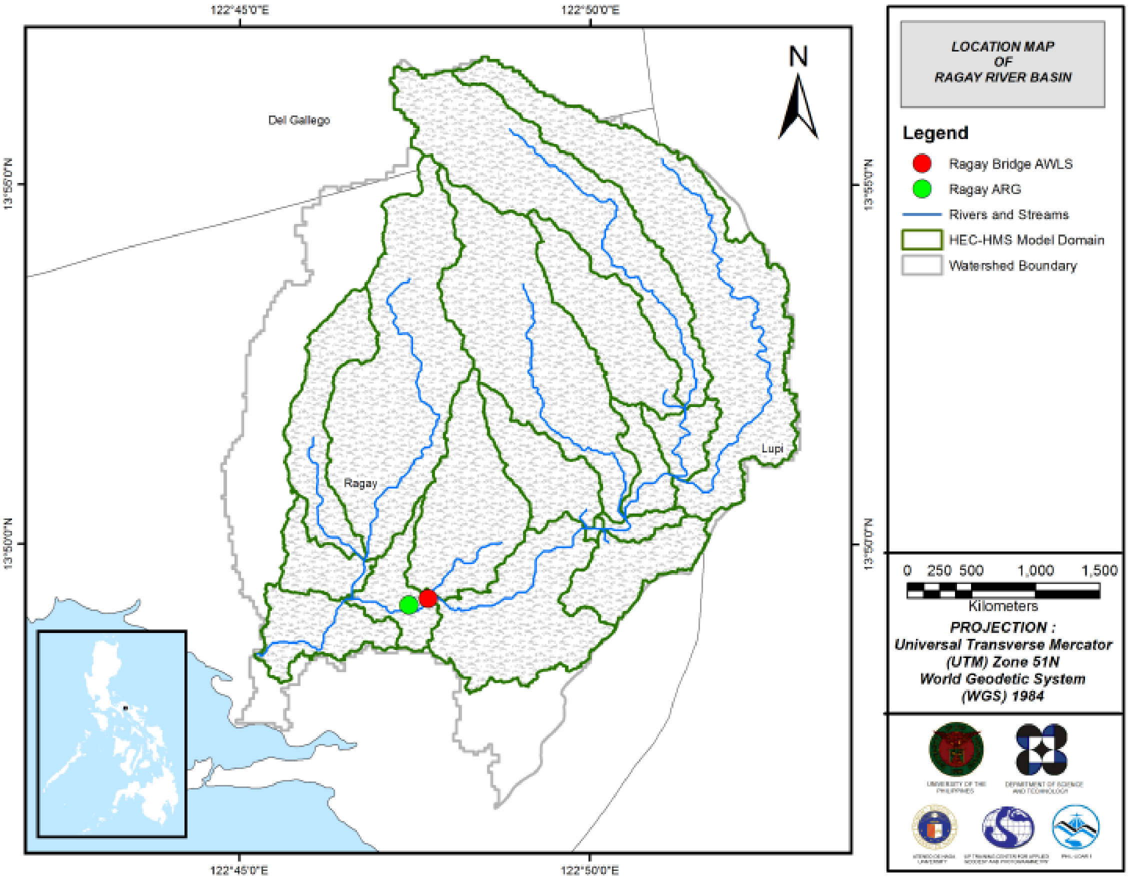

Figure 44. Location map of the Ragay HEC-HMS model used for calibration.

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Ragay Bridge, Ragay, Camarines Sur (13°49’14.6”N, 122°47’41.3”E) to establish the relationship between the observed water levels (H) at Ragay Bridge and outflow (Q) of the watershed at this location.

For Ragay Bridge, the rating curve is expressed as Q = 18.27e0.3135h as shown in Figure 45.

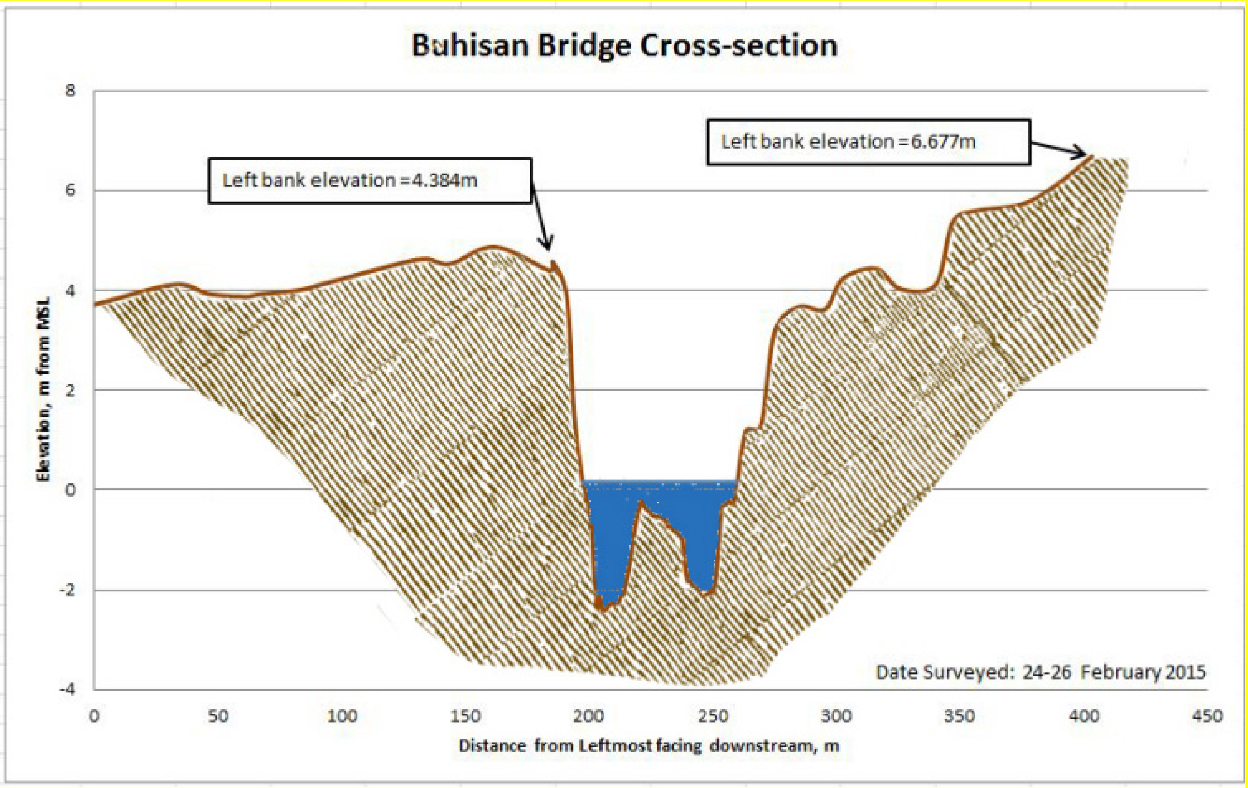

Figure 45. Cross-section plot of Ragay Bridge (also known as Buhisan Bridge)

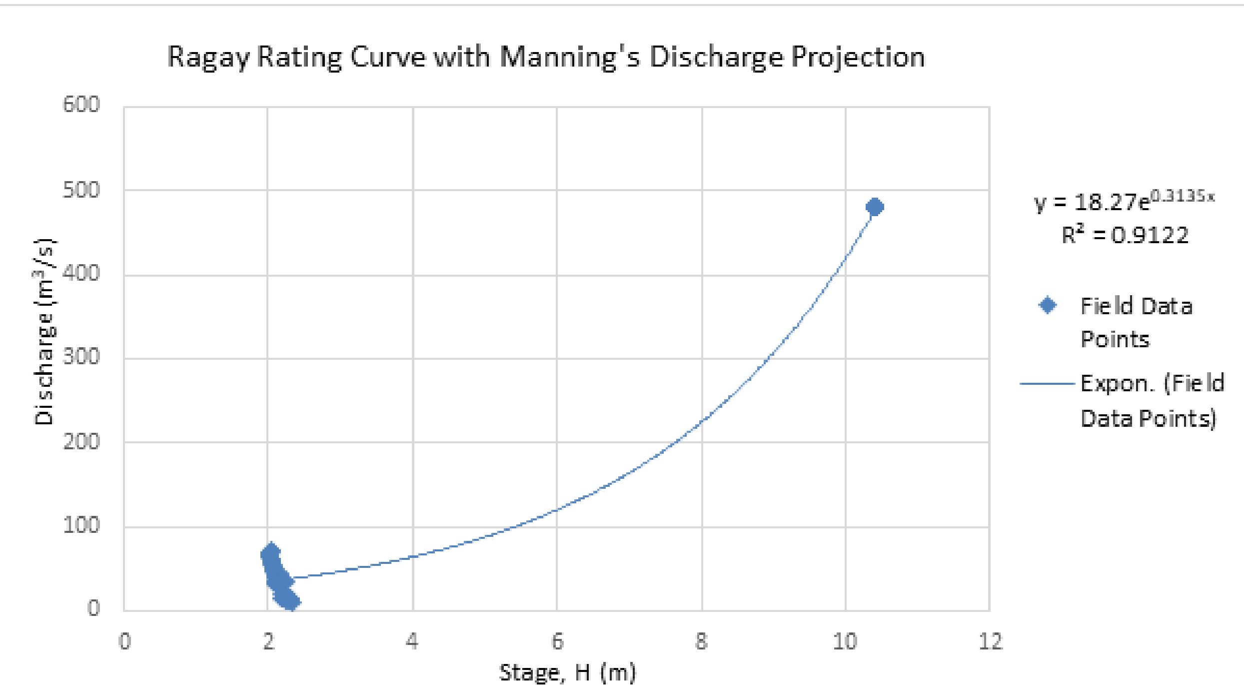

Figure 46. Rating curve of Ragay Bridge in Ragay, Camarines Sur

This rating curve equation was used to compute the river outflow at Ragay Bridge for the calibration of the HEC-HMS model shown in Figure 46. The total rainfall for this event is 27.8mm and the peak discharge is 51.2 m3/s at 2:30 AM, December 26, 2016.

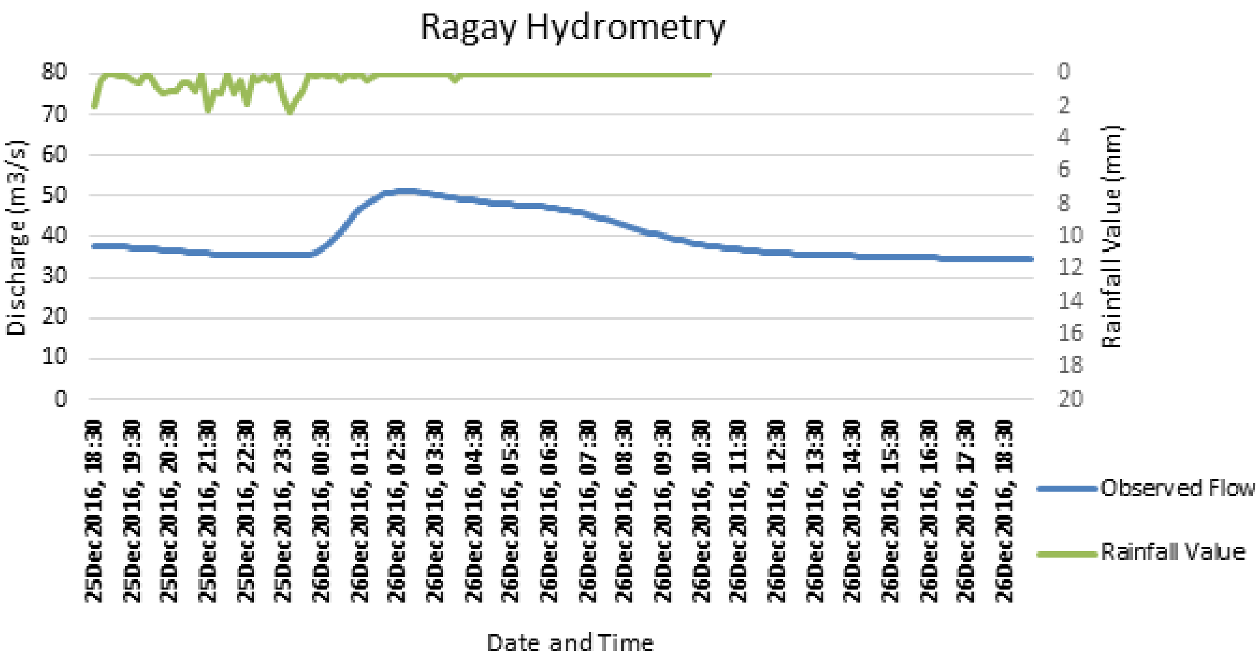

Figure 47. Rainfall and outflow data at the Ragay Bridge of the Ragay River Basin used for modeling.

5.2 RIDF Station

PAGASA computed the Rainfall Intensity Duration Frequency (RIDF) values for the Daet Gauge (Table 25). The RIDF rainfall amount for 24 hours was converted into a synthetic storm by interpolating and re-arranging the values in such a way that certain peak values will be attained at a certain time (Figure 48). This station was selected based on its proximity to the Ragay watershed. The extreme values for this watershed were computed based on a 26-year record.

Table 25. RIDF values for the Ragay River Basin based on average RIDF data of Daet station, as computed by PAGASA

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	**10 mins**	**20 mins**	**30 mins**	**1 hr**	**2 hrs**	**3 hrs**	**6 hrs**	**12 hrs**	**24 hrs**
2	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	271.9	271.9	370.4	438.3	520.3

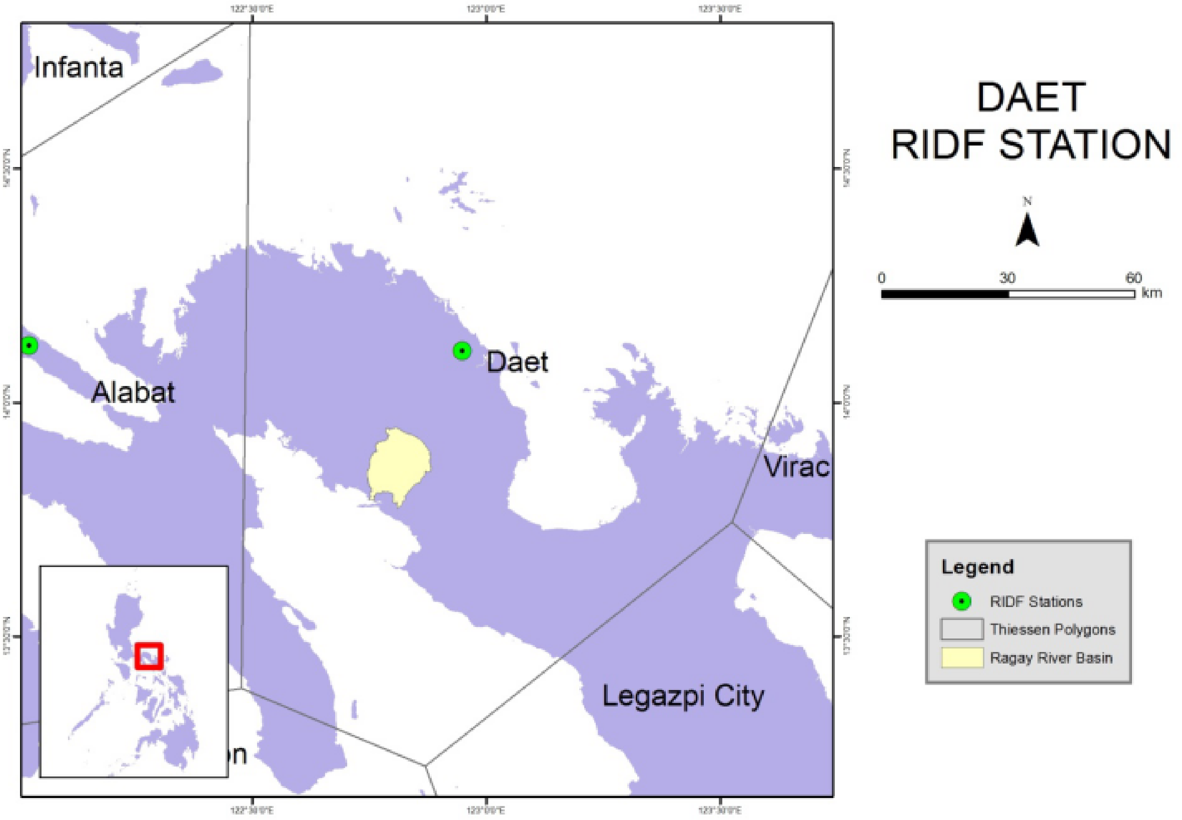

Figure 48. Location of Daet RIDF Station relative to Ragay River Basin

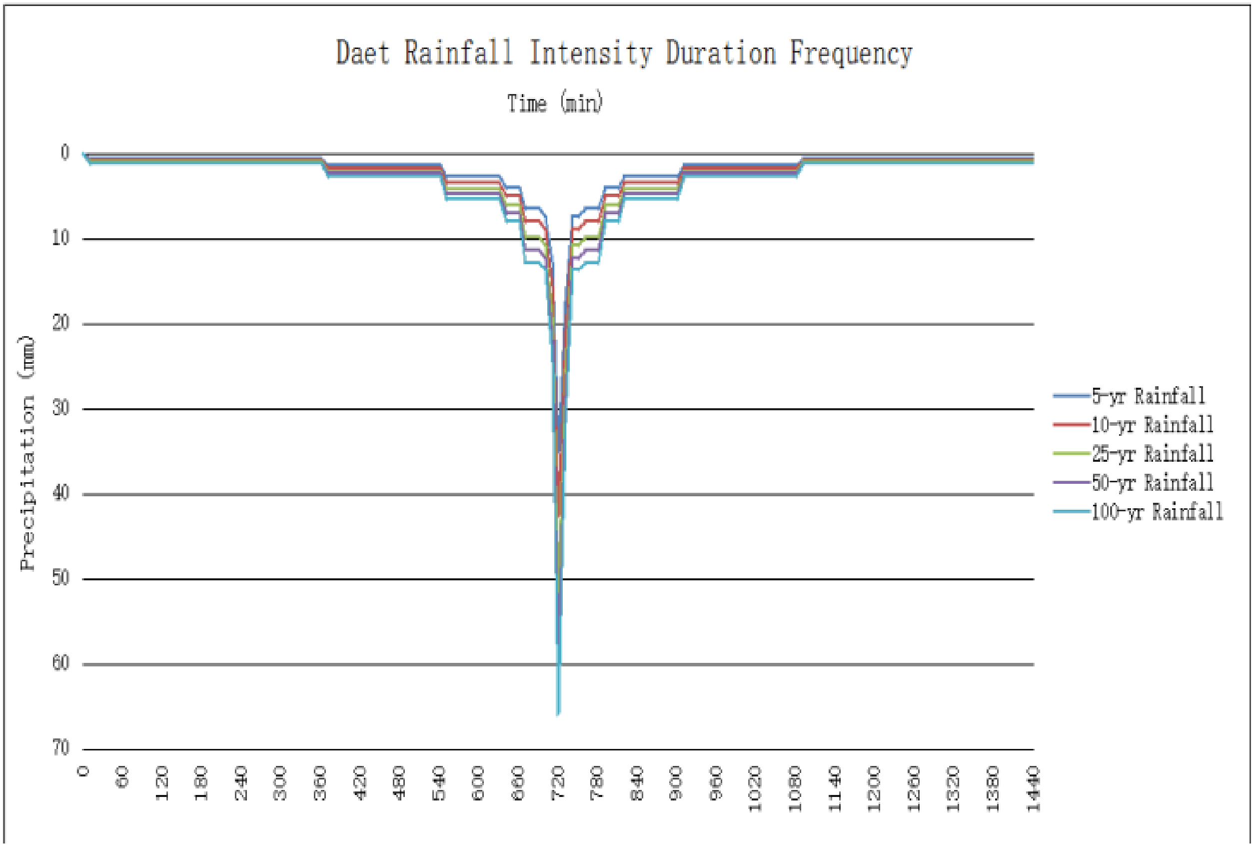

Figure 49. Synthetic storm generated for a 24-hr period rainfall for various return periods.

5.3 HMS Model

The soil dataset was taken before 2004 from the Bureau of Soils under the Department of Agriculture. The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Pamplona River Basin are shown in Figure 50 and Figure 51, respectively.

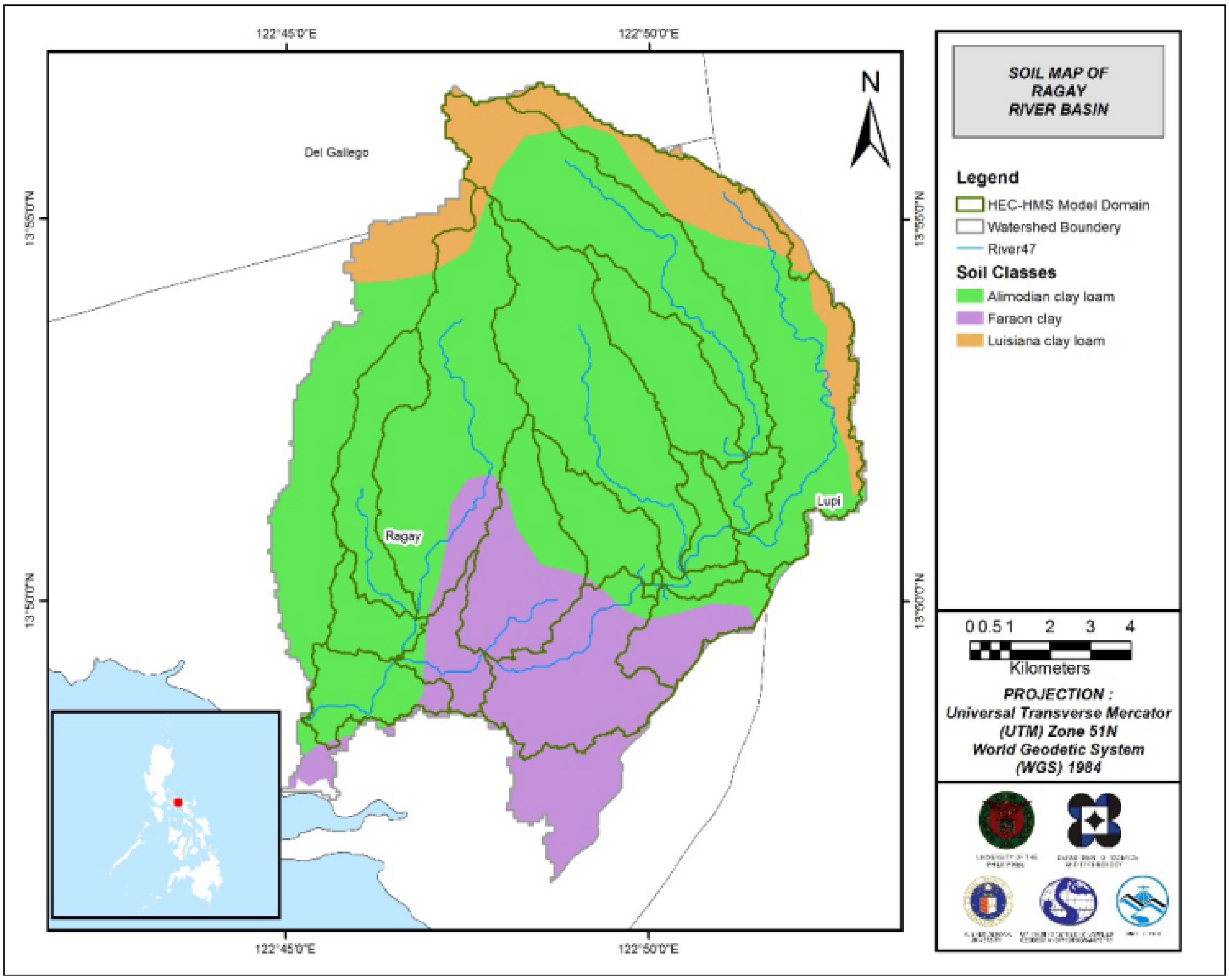

Figure 50. Soil Map of Ragay River Basin

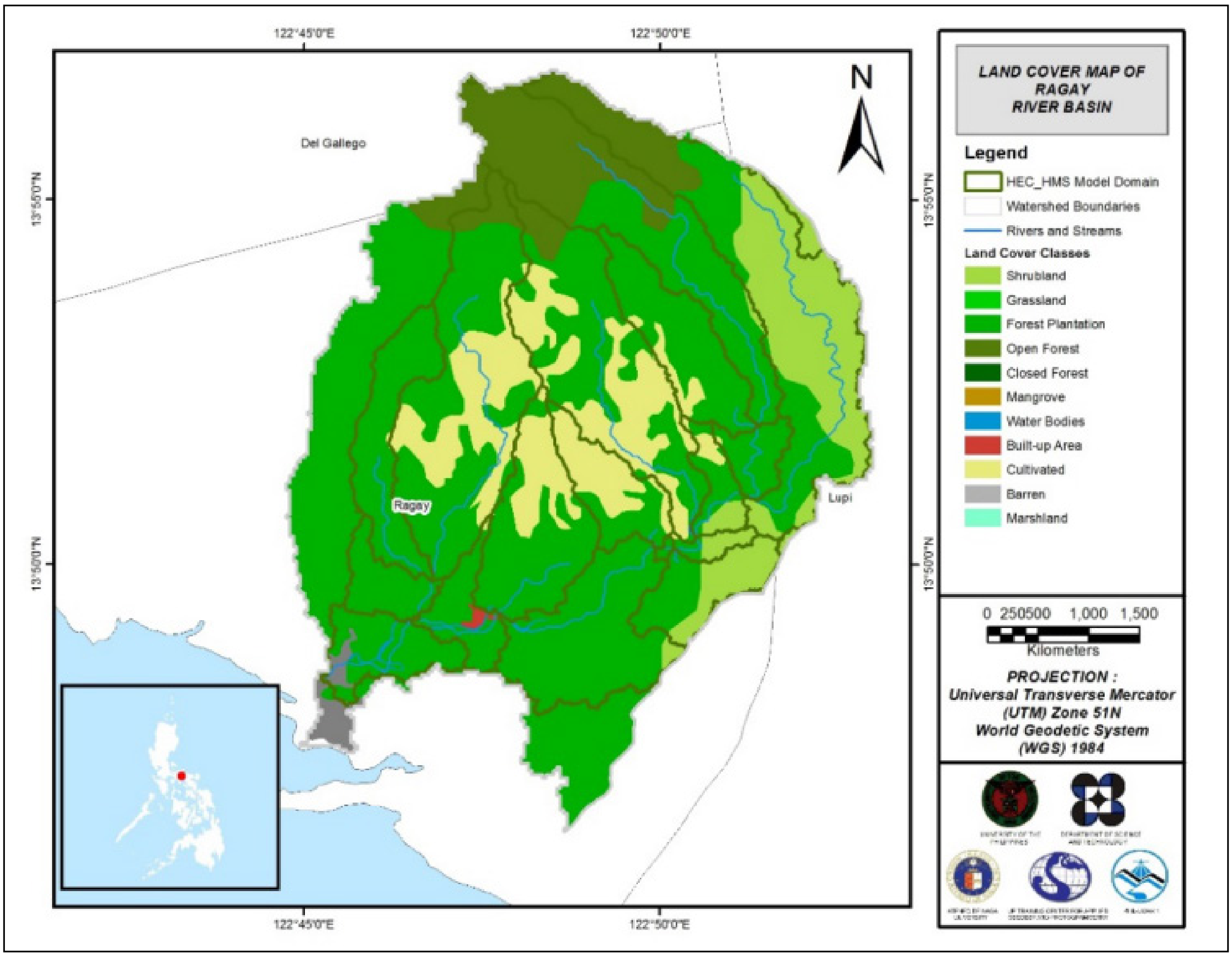

Figure 51. Land Cover Map of Ragay River Basin

For Ragay, three soil classes were identified. These are Alimodian clay loam, Faraon clay, and Luisiana clay loam. Moreover, six land cover classes were identified. These are grassland, shrubland, open forest, built-up, and barren areas.

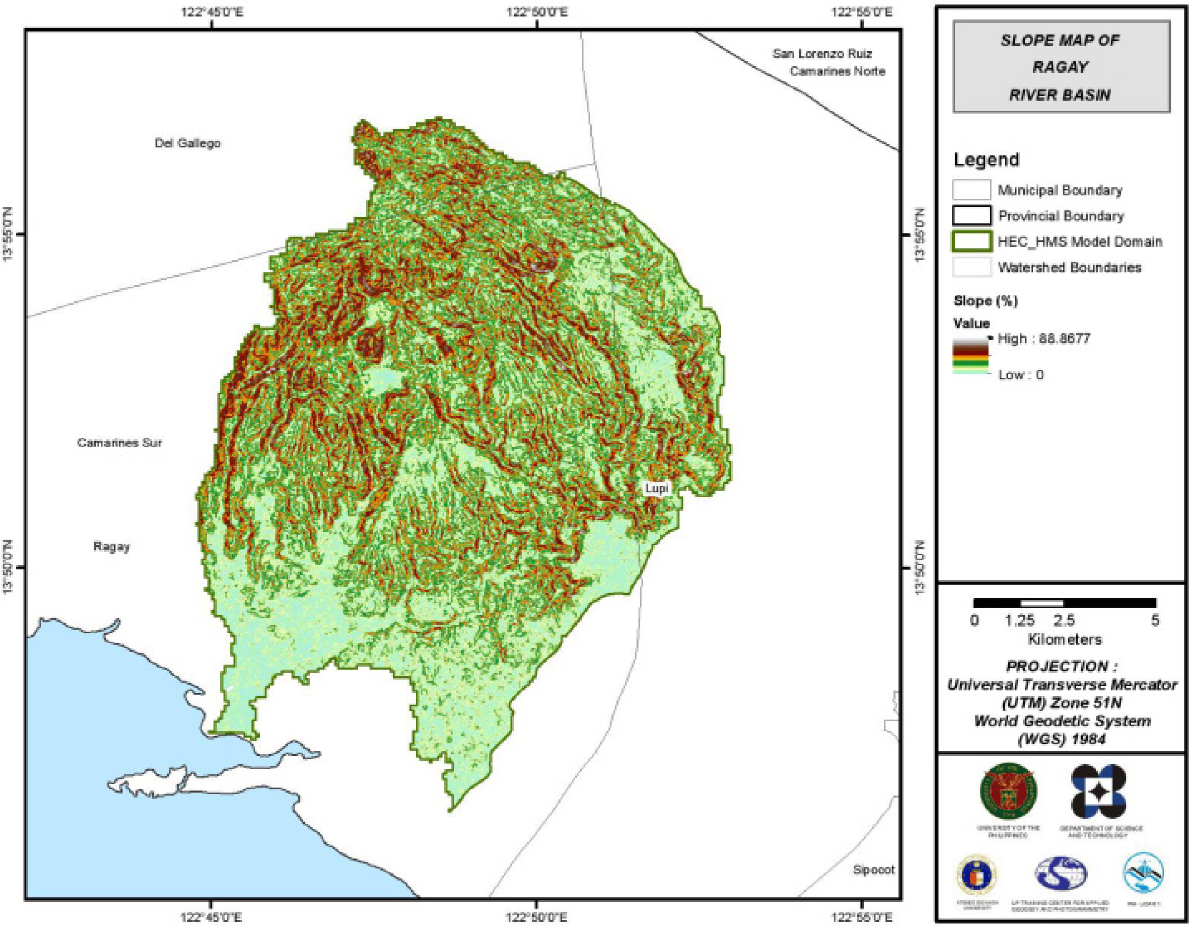

Figure 52. Slope Map of Ragay River Basin

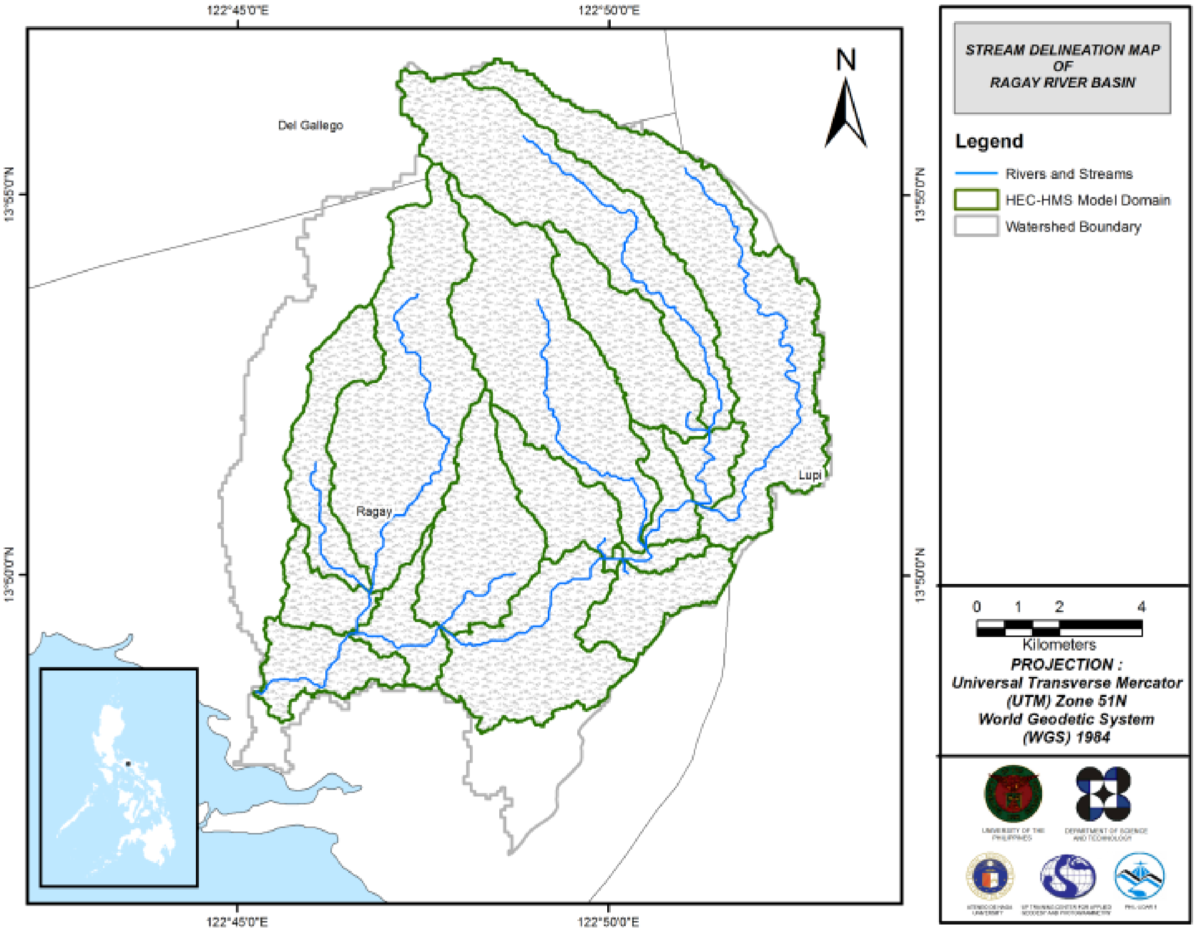

Figure 53. Stream Delineation Map of Ragay River Basin

Using the SAR-based DEM, the Ragay basin was delineated and further subdivided into subbasins. The model consists of 17 sub-basins, 8 reaches, and 8 junctions as shown in Figure 54. The main outlet is at Ragay Bridge.

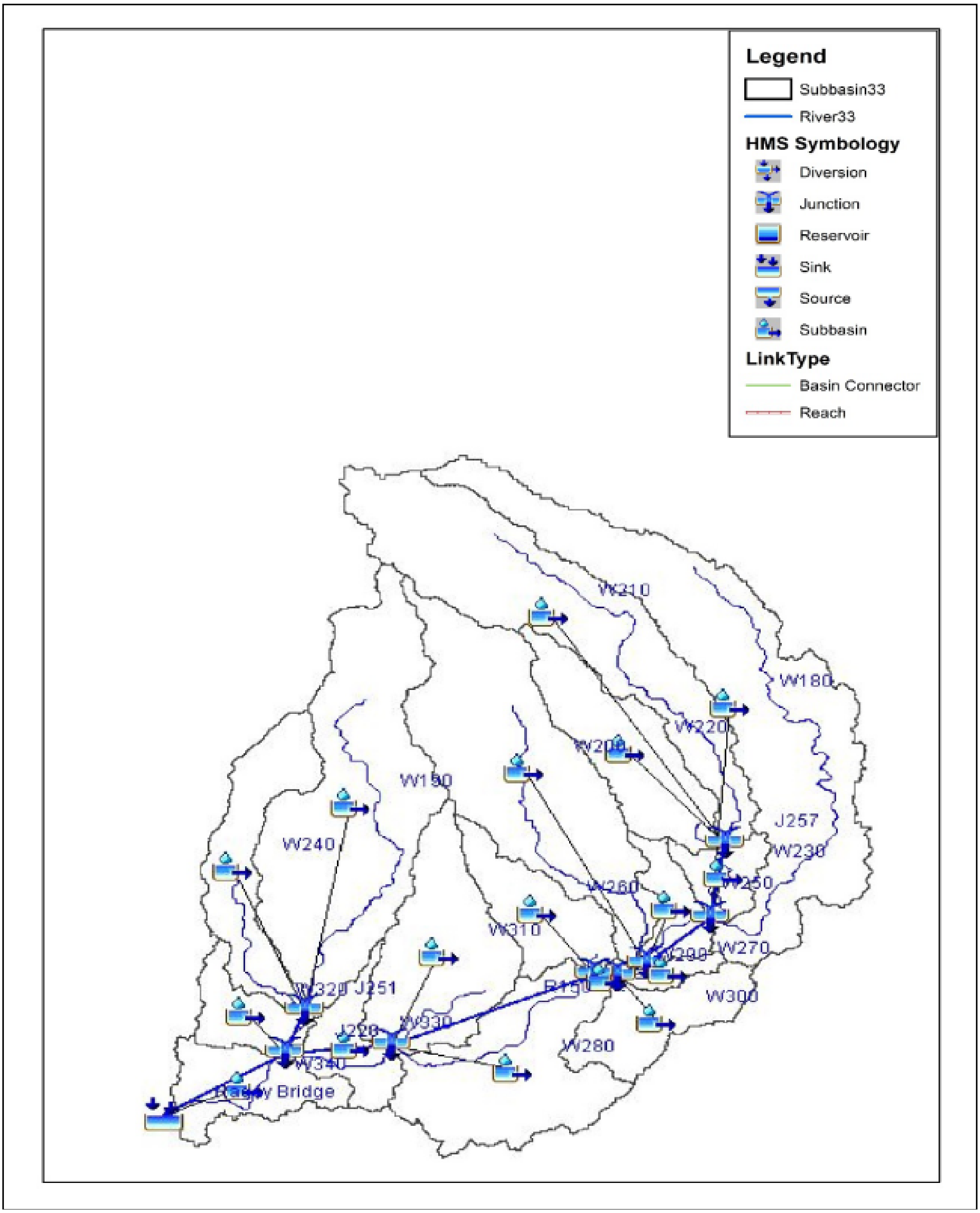

Figure 54. Ragay River Basin model generated in HEC-HMS

5.4 Cross-section Data

The riverbed cross-sections of the watershed were necessary in the HEC-RAS model setup. The cross-section data for the HEC-RAS model was derived from the LiDAR DEM data, which was defined using the Arc GeoRAS tool and was post-processed in ArcGIS (Figure 55).

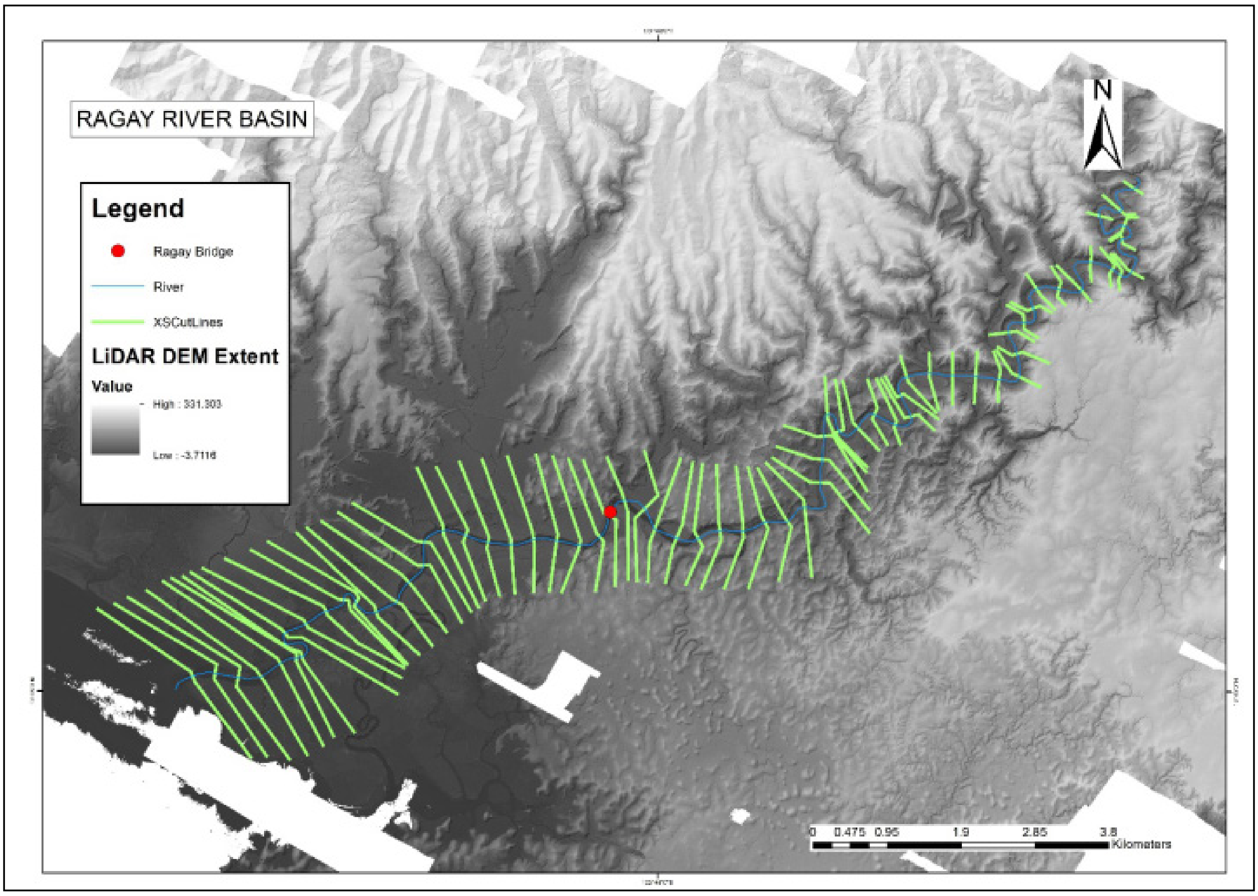

Figure 55. River cross-section of the Ragay River through the ArcMap HEC GeoRas tool.

5.5 Flo 2D Model

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

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

Figure 56. 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 42.76562 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 Ragay are in Figure 64, Figure 66, and Figure 68.

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 24,263,500.00 m2. The generated flood depth maps for Ragay are in Figure 65, Figure 67, and Figure 69.

There is a total of 32,111,961.70 m3 of water entering the model. Of this amount, 10 150,925.15 m3 is due to rainfall while 21,961,036.55 m3 is inflow from other areas outside the model. 2,609,145.50 m3 of this water is lost to infiltration and interception, while 8,591,367.90m3 is stored by the flood plain. The rest, amounting up to 20,911,450.34 m3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Ragay HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 57 shows the comparison between the two discharge data.

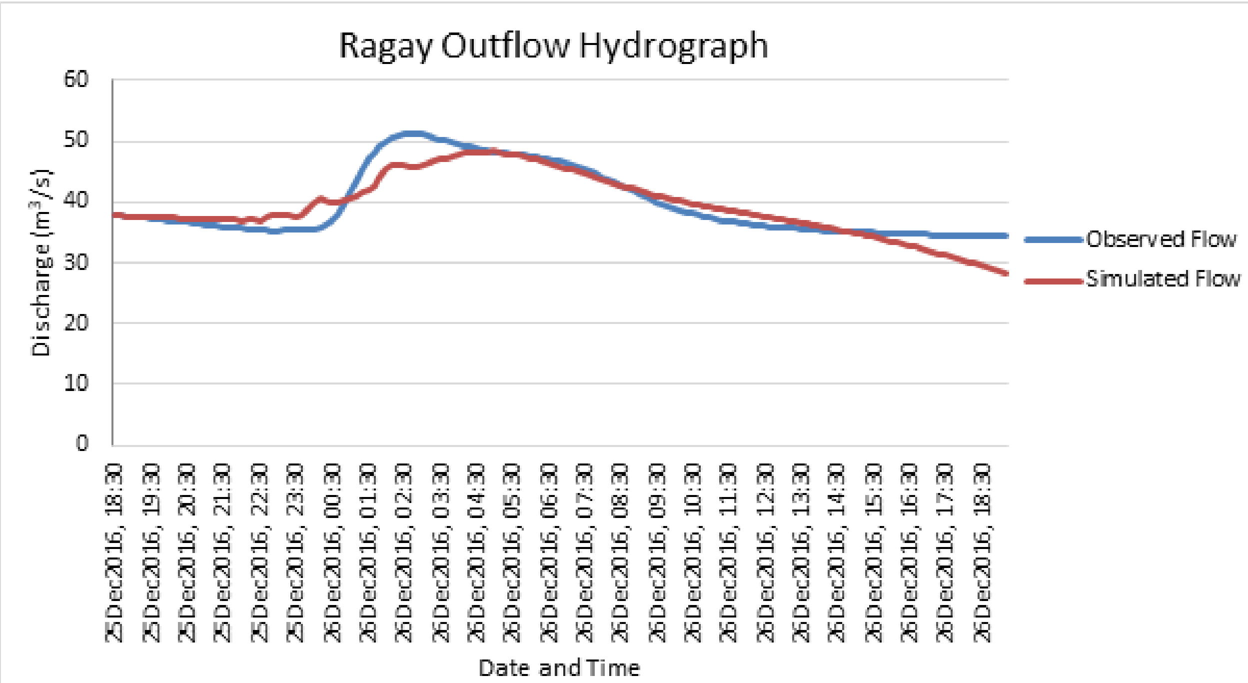

Figure 57. Outflow hydrograph of Ragay produced by the HEC-HMS model compared with observed outflow

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

Table 26. Range of calibrated values for the Ragay River Basin.

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	0.001-2
			Curve Number	53-99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.02-0.5
			Storage Coefficient (hr)	0.02-8
	Baseflow	Recession	Recession Constant	0.0004-0.02
			Ratio to Peak	0.01-0.7
			Slope	0.0002-0.008
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.004-1

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 0.0001mm to 2mm means that there is minimal to average amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 53 to 99 for curve number is advisable for Philippine watersheds depending on the soil and land cover of the area (M. Horritt, personal communication, 2012). For Ragay, the basin mostly consists of grassland and the soil consists of Alimodian clay loam, Luisiana clay loam, and Faraon clay.

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 8 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 Ragay, it will take at least 6 hours from the peak discharge to go back to the initial discharge.

Manning's roughness coefficient of 1 corresponds to the common roughness in Ragay watershed, which is determined to be mangrove forest with trees with heavy stand that flow into branches (Brunner, 2010).

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

Accuracy measure	Value
RMSE	2.39
r2	0.82
NSE	0.82
PBIAS	1.05
RSR	0.42

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 2.39 (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 0.82.

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 0.82.

A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate bias towards over-prediction. Again, the optimal value is 0. In the model, the PBIAS is 1.05.

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 0.42.

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

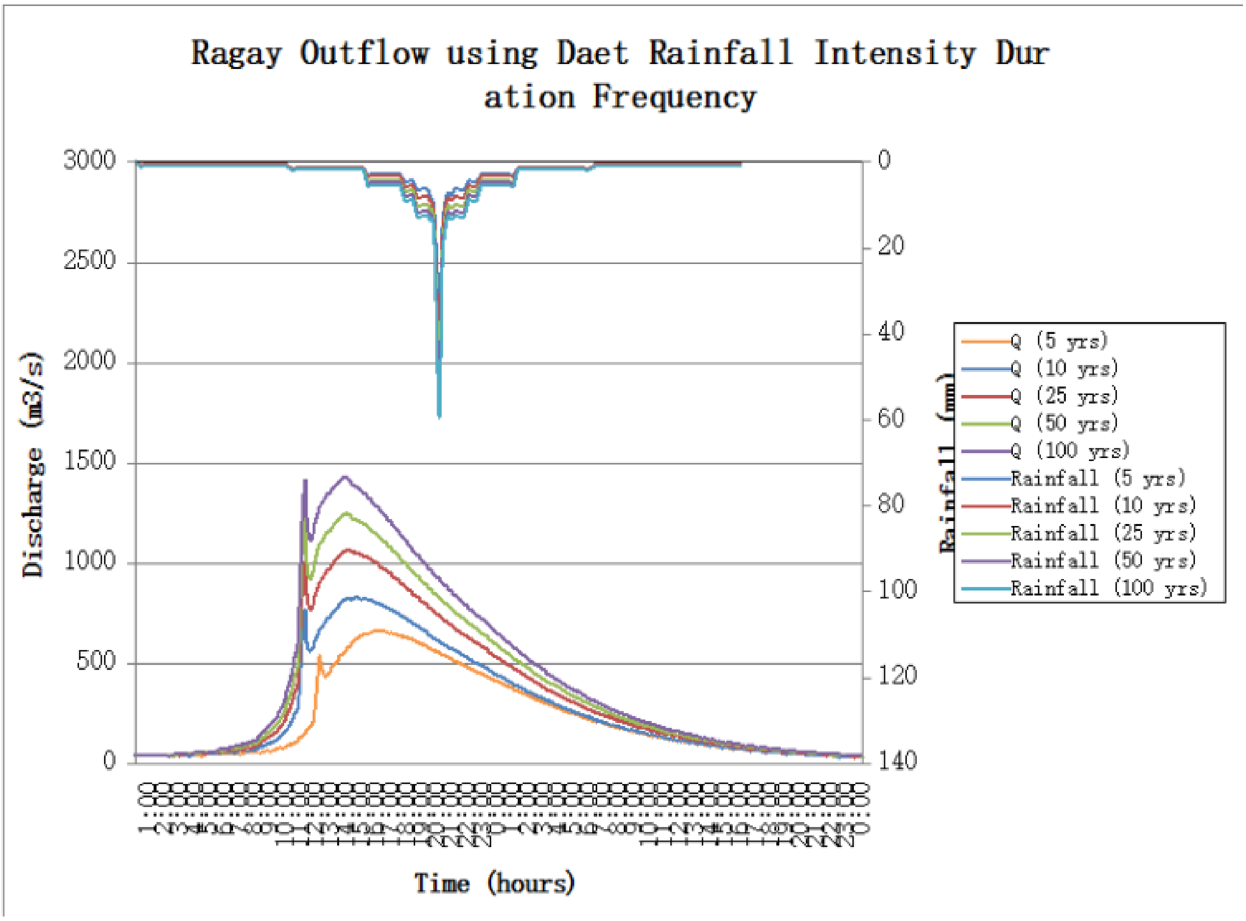

Figure 58. The Outflow hydrograph at the Ragay Station generated using Daet RIDF simulated in HEC-HMS

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

Table 28. Peak values of the Ragay 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	277.54	31.8	657.2	4 hours
10-Year	335.77	38.5	828.3	2 hours
25-Year	409.33	46.9	1070.9	2 hours
50-Year	463.87	53.2	1270.2	2 hours
100-Year	518.02	59.4	1429	1 hour and 50 minutes

5.7.2. Discharge data using Dr. Horritts's recommended hydrologic method

The river discharges for the three rivers entering the floodplain are shown in Figure59 to Figure 62, and the peak values are summarized in Table 29 to Table 33.

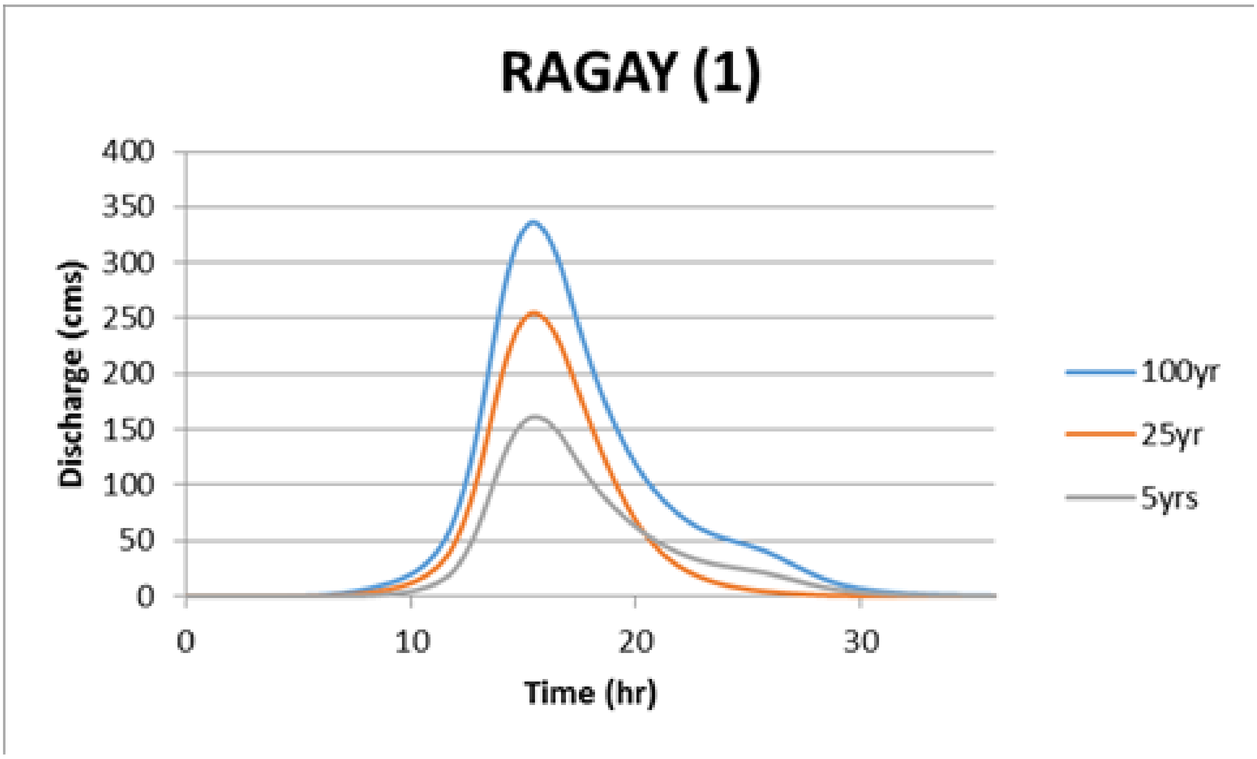

Figure 59. Ragay river (1) generated discharge using 5-, 25-, and 100-year Daet rainfall intensity-duration-frequency (RIDF) in HEC-HMS

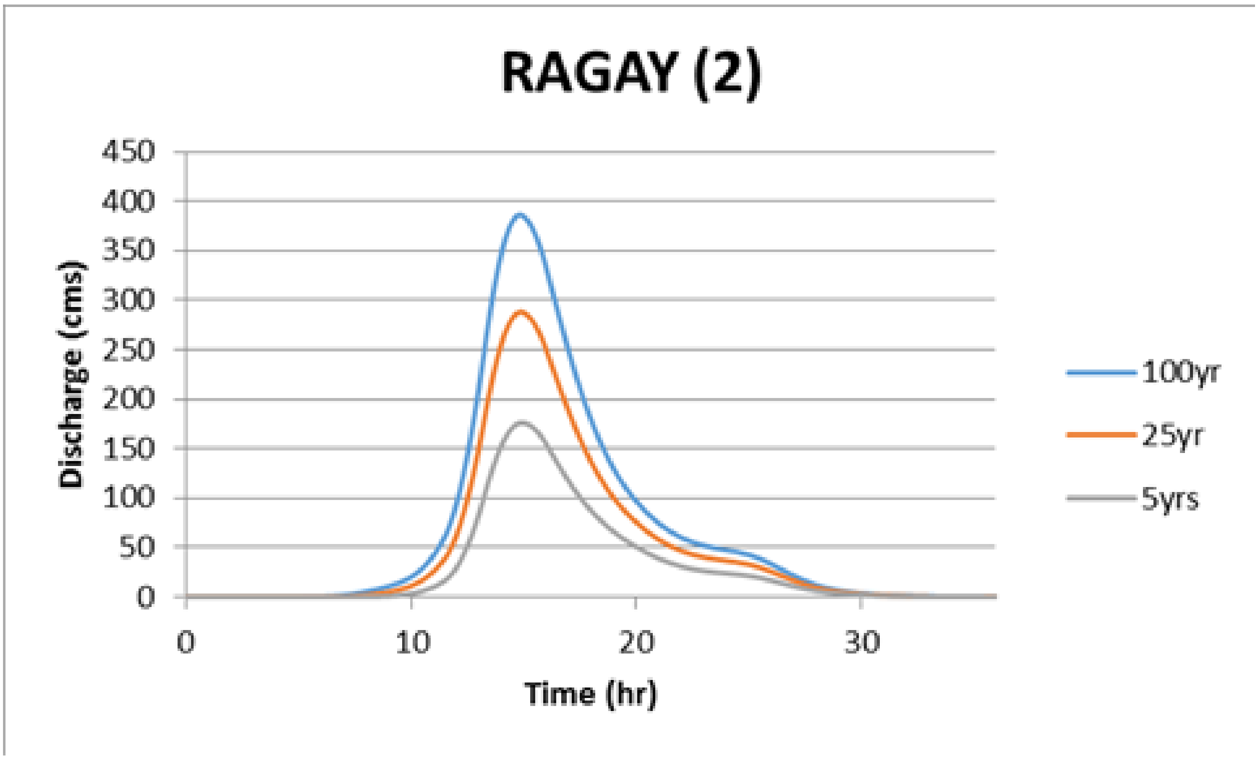

Figure 60. Ragay river (2) generated discharge using 5-, 25-, and 100-year Daet rainfall intensity-duration-frequency (RIDF) in HEC-HMS

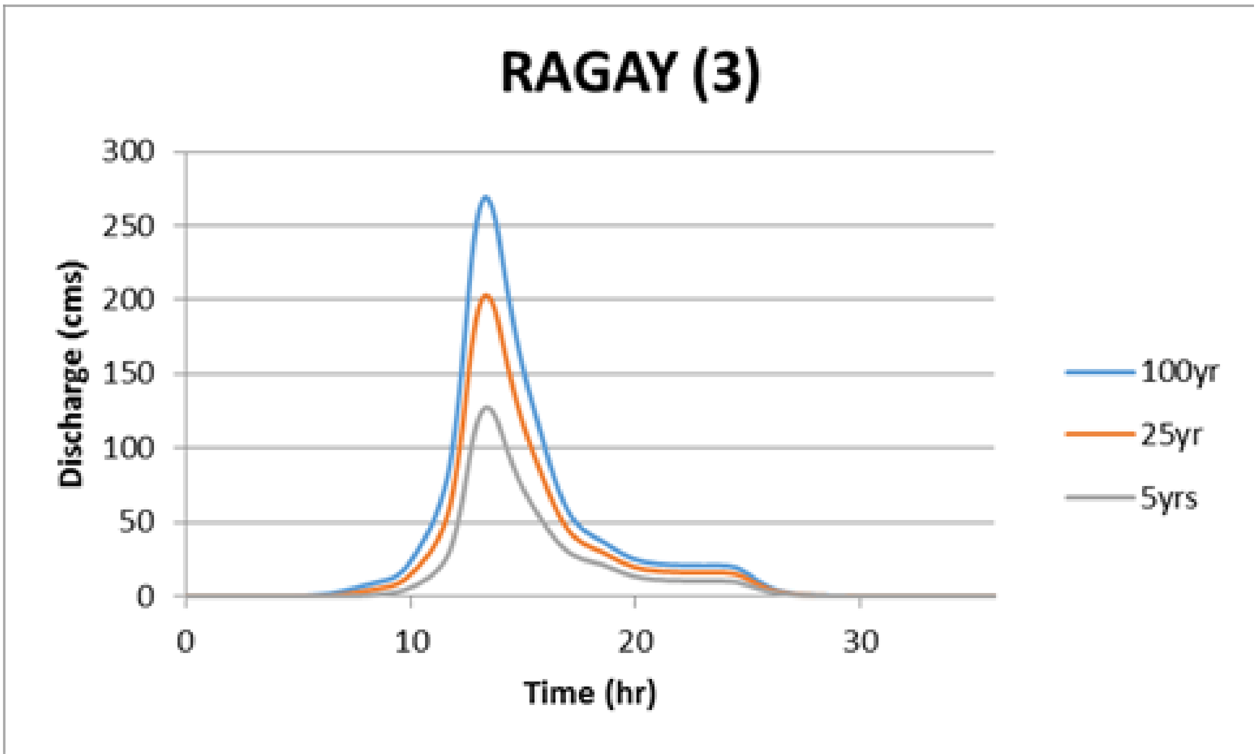

Figure 61. Ragay river (3) generated discharge using 5-, 25-, and 100-year Daet rainfall intensity-duration-frequency (RIDF) in HEC-HMS

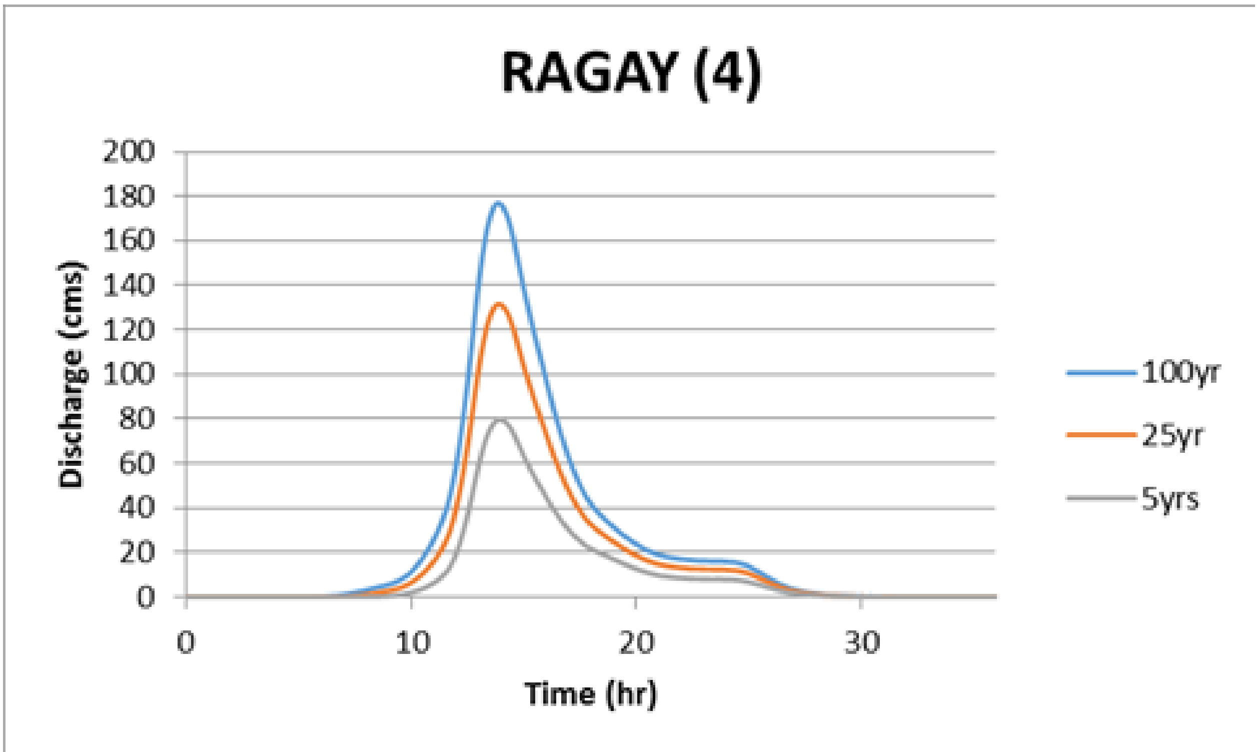

Figure 62. Ragay river (4) generated discharge using 5-, 25-, and 100-year Daet rainfall intensity-duration-frequency (RIDF) in HEC-HMS

Table 29. Summary of Ragay river (1) discharge generated in HEC-HMS

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	336.2	15 hours, 30 minutes
25-Year	254.7	15 hours, 30 minutes
5-Year	161.4	15 hours, 30 minutes

Table 30. Summary of Ragay river (2) discharge generated in HEC-HMS

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	386.3	14 hours, 50 minutes
25-Year	288.1	14 hours, 50 minutes
5-Year	176.1	15 hours

Table 31. Summary of Ragay river (3) discharge generated in HEC-HMS

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	269.2	13 hours, 20 minutes
25-Year	203	13 hours, 20 minutes
5-Year	127.1	13 hours, 20 minutes

Table 32. Summary of Ragay river (4) discharge generated in HEC-HMS

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	176.9	13 hours, 50 minutes
25-Year	131.4	13 hours, 50 minutes
5-Year	79.7	14 hours

The comparison of the discharge results using Dr. Horritt's recommended hydrological method against the bankful and specific discharge estimates is shown in Table 33.

Table 33. Validation of river discharge estimates

Discharge Point	QMED(SCS), cms	QBANKFUL, cms	QMED(SPEC), cms	VALIDATION	
				Bankful Discharge	Specific Discharge
Ragay (1)	173.184	141.379	117.873	Pass	Pass
Ragay (2)	235.136	174.190	182.976	Pass	Pass
Ragay (3)	83.424	95.243	45.300	Pass	Fail
Ragay (4)	24.464	23.684	12.765	Pass	Fail

Three from the HEC-HMS river discharge estimates were able to satisfy the conditions for validation using the bankful and specific discharge methods. One passed the conditions for validation only using the specific discharge method while it failed the bankful discharge method. The passing values are based on theory but are supported using other discharge computation methods so they were good to use flood modeling. These values will need further investigation for the purpose of validation. It is therefore recommended to obtain actual values of the river discharges for higher-accuracy modeling.

5.8 River Analysis (RAS) Model Simulation

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

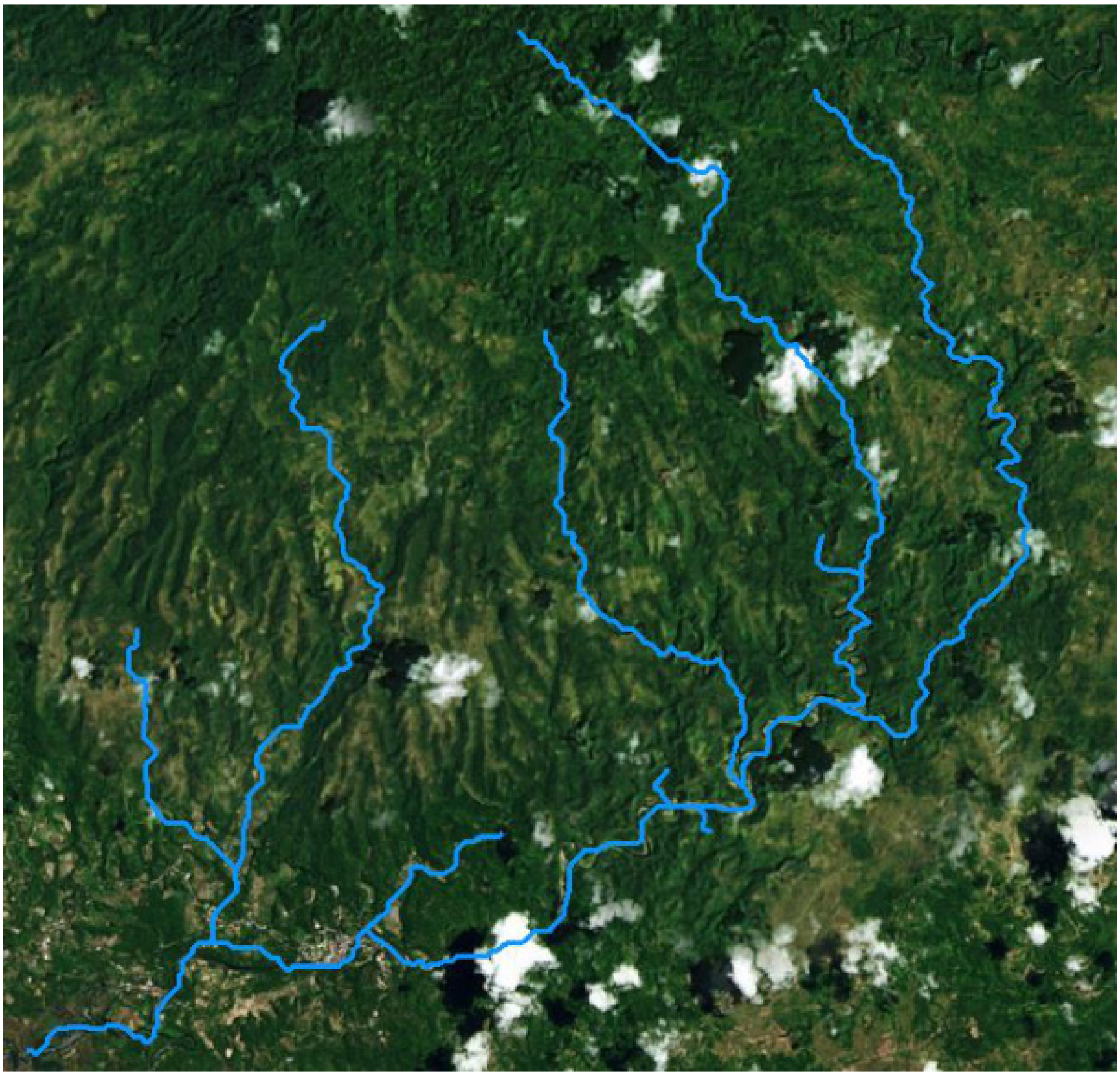

Figure 63. Sample output map of Ragay RAS Model

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. Figure 64 to Figure 69 show the 5-, 25-, and 100-year rain return scenarios of the Ragay flood plain. The flood plain, with an area of 111.35km2, covers two (2) municipalities, namely Lupi and Ragay. Table 34 shows the percentage of area affected by flooding per municipality.

Table 34. Municipalities affected in Ragay Floodplain

Municipality	Total Area	Area Flooded	% Flooded
Lupi	230.62	14.41	6.25%
Ragay	296.26	96.65	32.62%

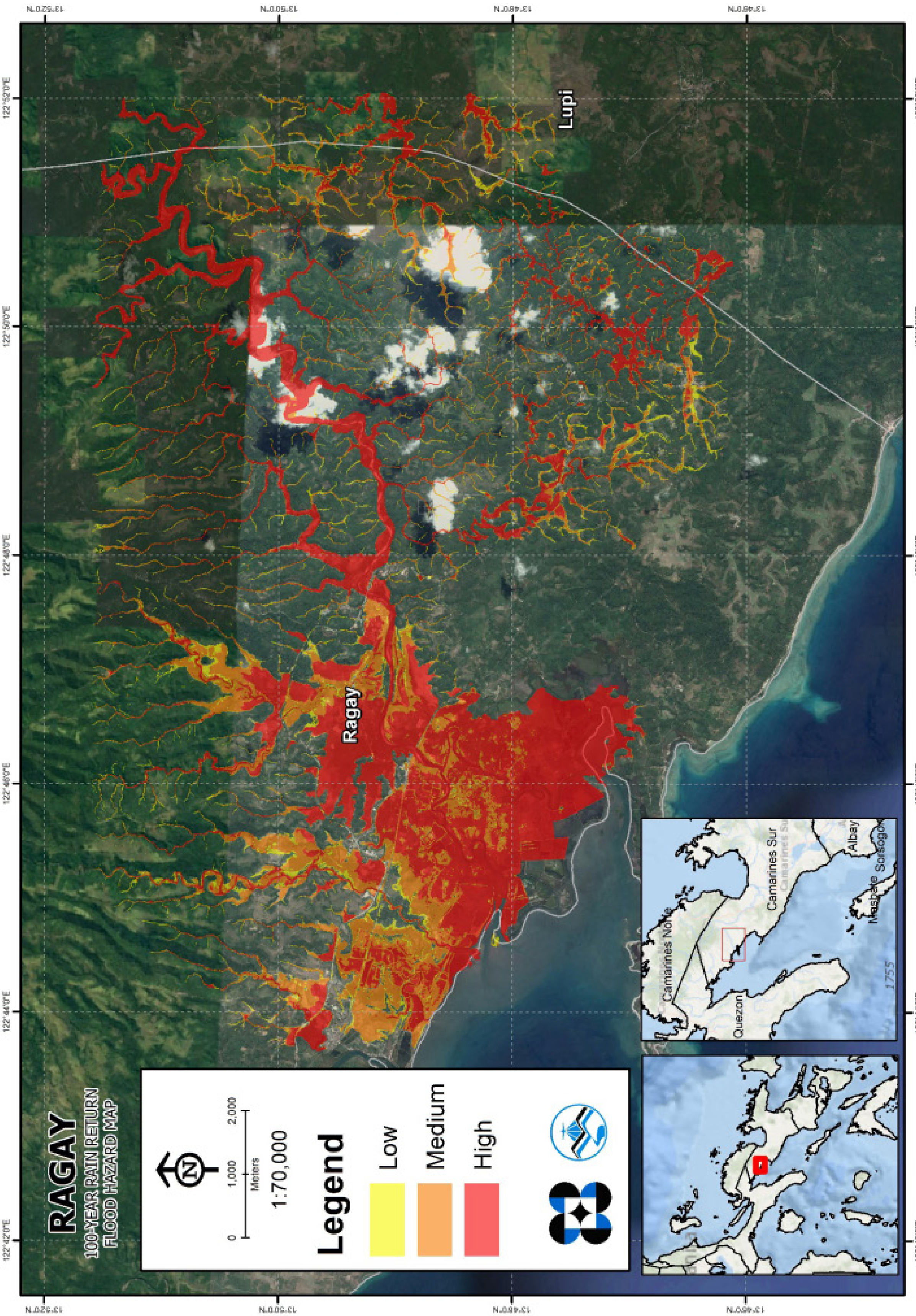

Figure 64. A 100-year flood hazard map for Ragay Floodplain

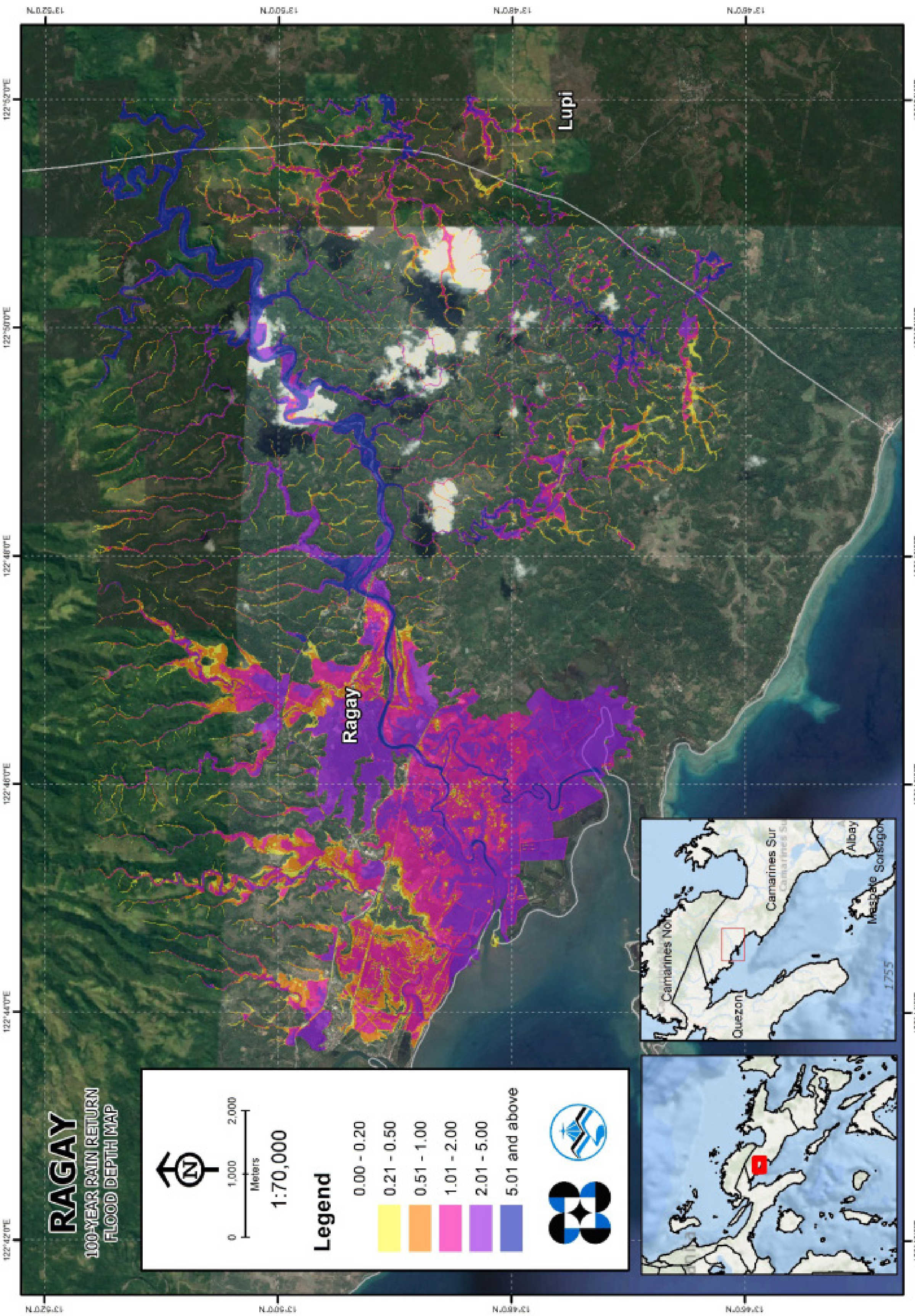

Figure 65. A 100-year Flow Depth Map for Ragay Floodplain

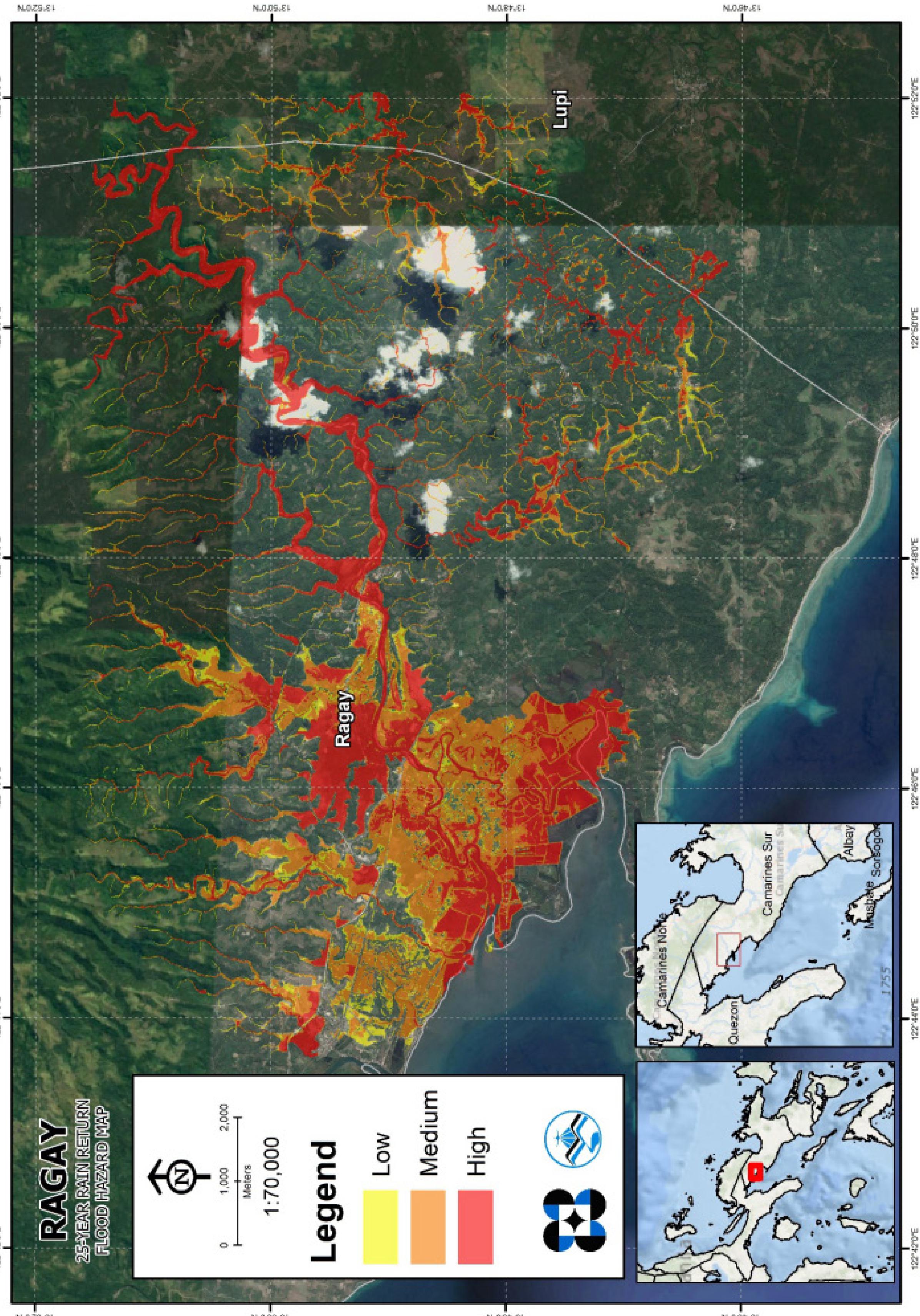

Figure 66. A 25-year Flood Hazard Map for Ragay Floodplain

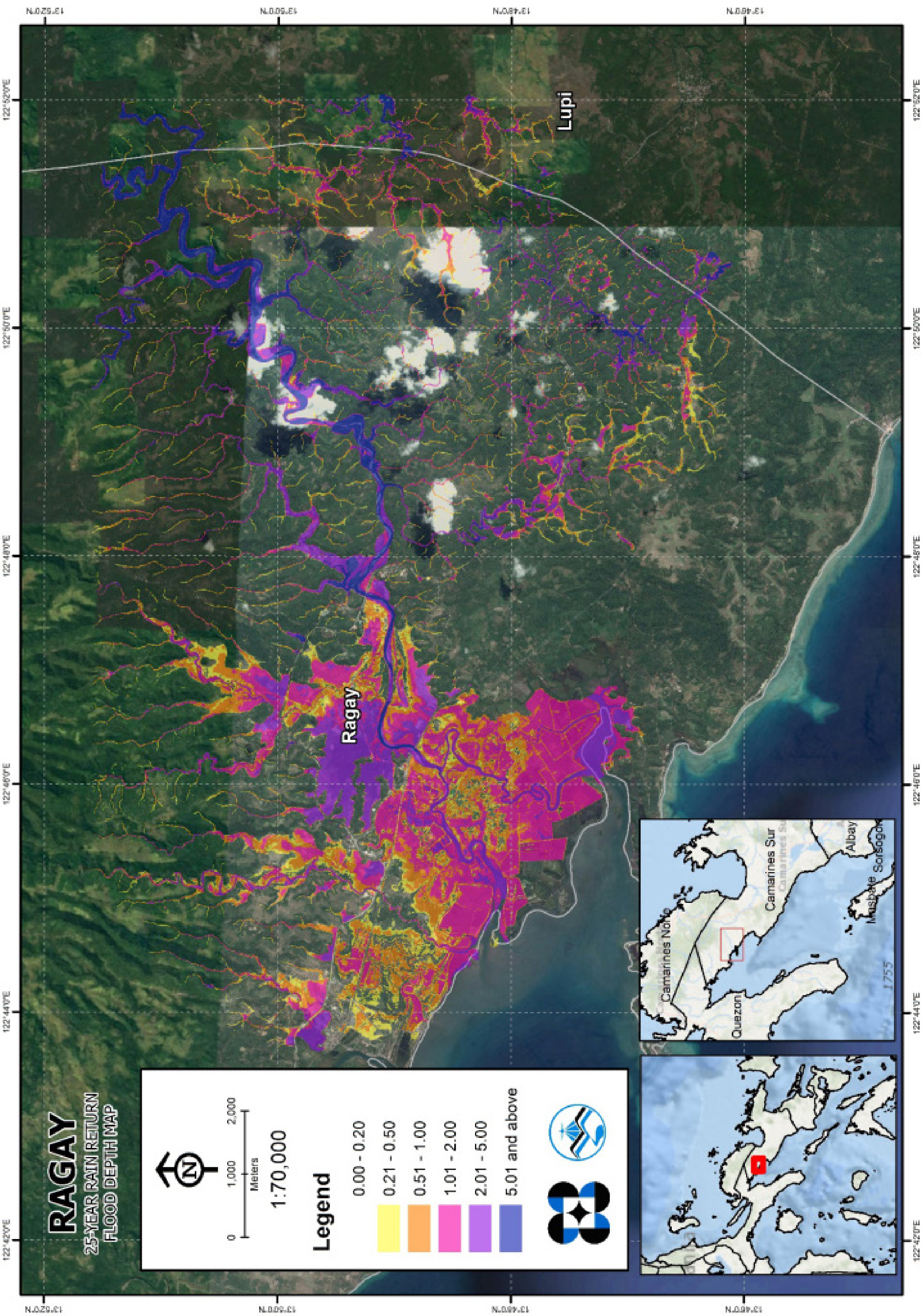

Figure 67. A 25-year Flow Depth Map for Ragay Floodplain

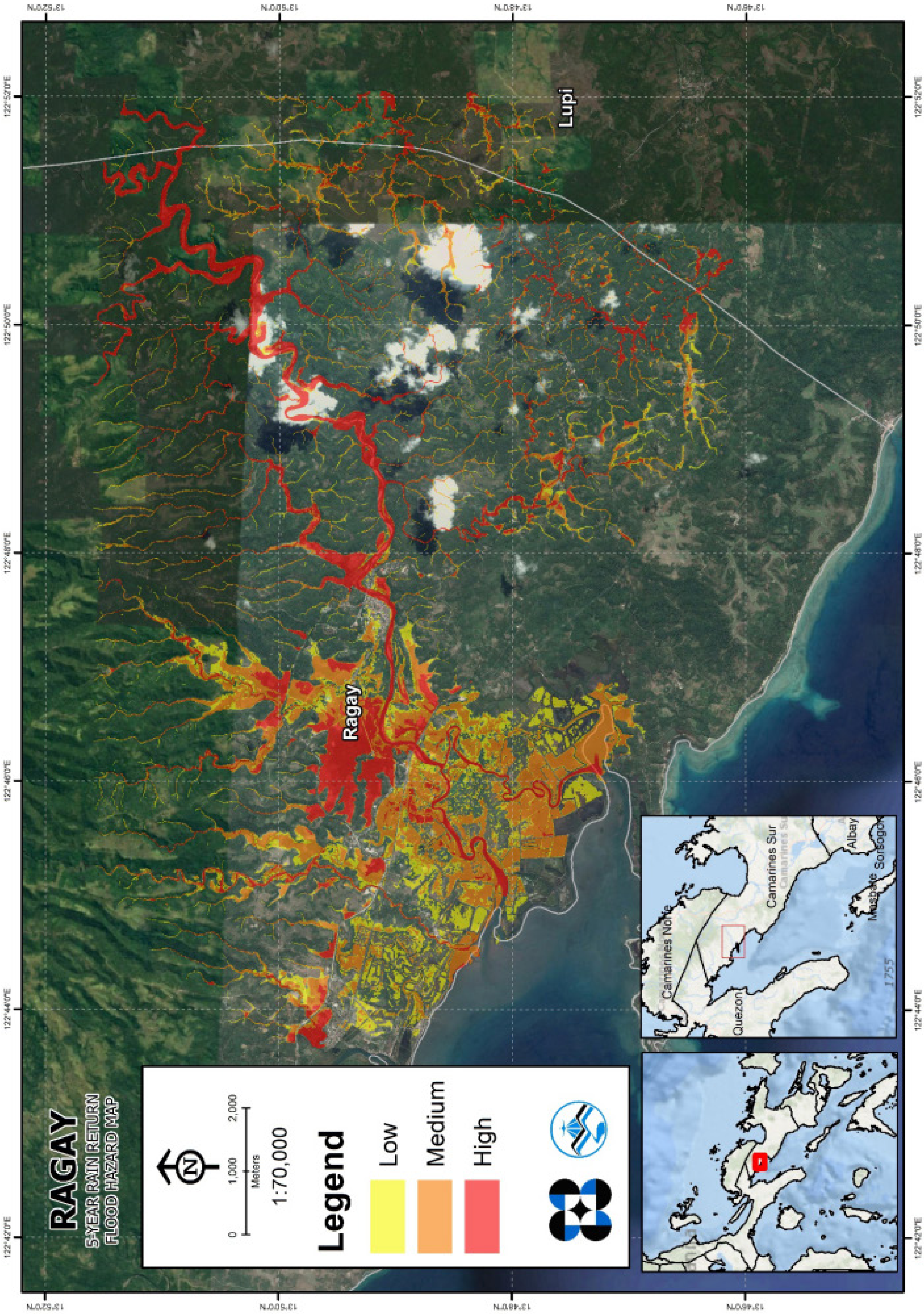

Figure 68. A 5-year Flood Hazard Map for Ragay Floodplain

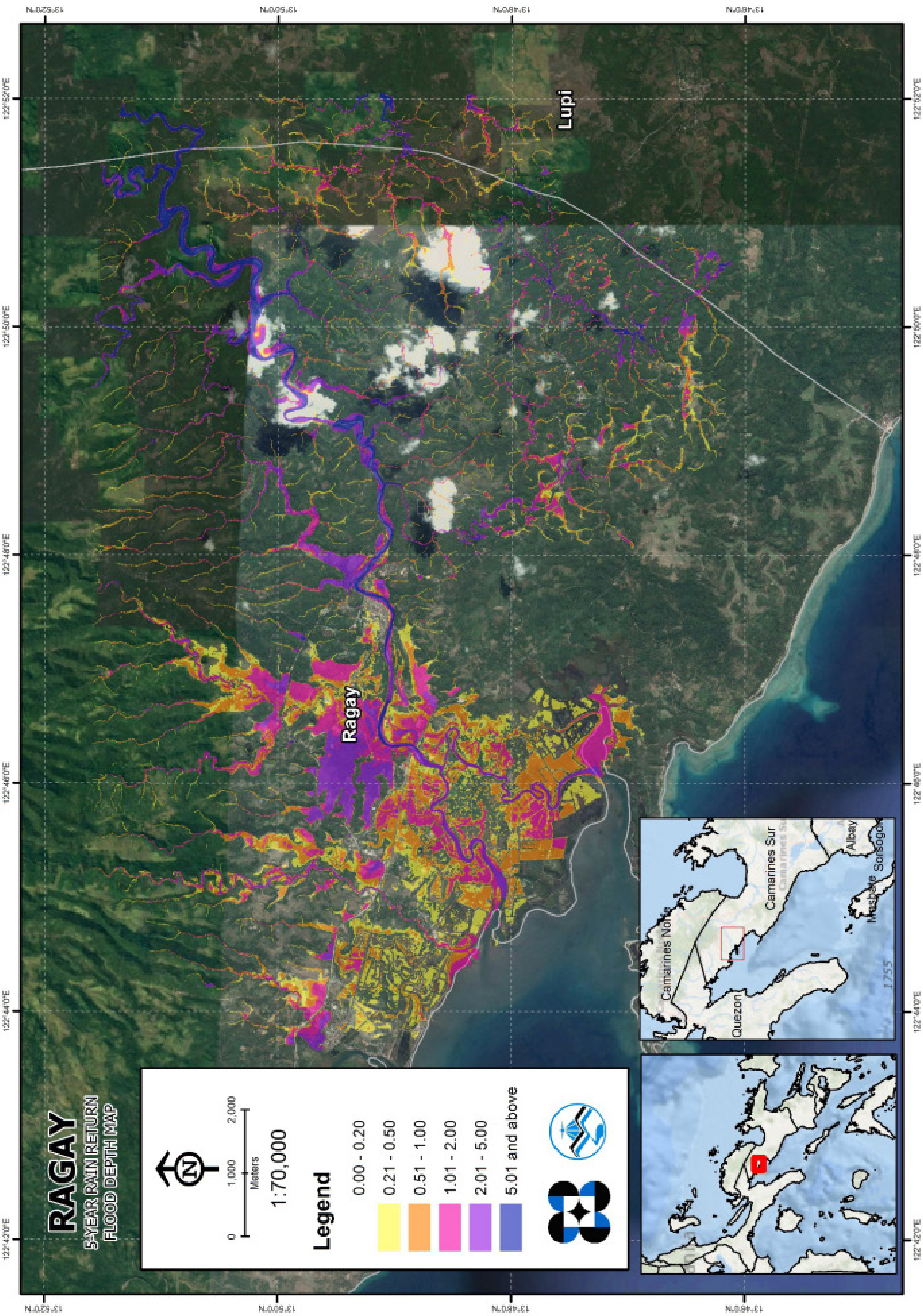

Figure 69. A 5-year Flow depth map for Ragay Floodplain.

5.10 Inventory of Areas Exposed to Flooding

Listed below are the affected barangays in the Ragay River Basin, grouped accordingly by municipality. For the said basin, two municipalities consisting of 31 barangays are expected to experience flooding when subjected to 5-yr rainfall return period.

For the 5-year rainfall return period, 0.84% of the municipality of Lupi with an area of 230.62 sq. km. will experience flood levels of less than 0.20 meters. 0.39% of the area will experience flood levels of 0.21 to 0.50 meters, while 1.52%, 1.35%, 1.83%, and 0.31% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 35 depicts the areas affected in Lupi in square kilometers by flood depth per barangay.

Table 35. Affected areas in Lupi, Camarines Sur during a 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Lupi (in sq. km.)						
	Alleomar	Bangon	Casay	Haguimit	Lourdes	Salvacion	Tanawan
0.03-0.20	1.61	0.068	0.065	0.061	0.048	0.034	0.056
0.21-0.50	0.003	0.0046	0.0044	0.0001	0.83	0.024	0.025
0.51-1.00	0.59	0.39	0.015	2.28	0.087	0.067	0.083
1.01-2.00	0.25	0.0001	1.29	0.63	0.65	0.22	0.063
2.01-5.00	0.29	0.3	0.32	0.31	2.13	0.58	0.29
> 5.00	0.034	0.059	0.031	0.47	0	0.071	0.049

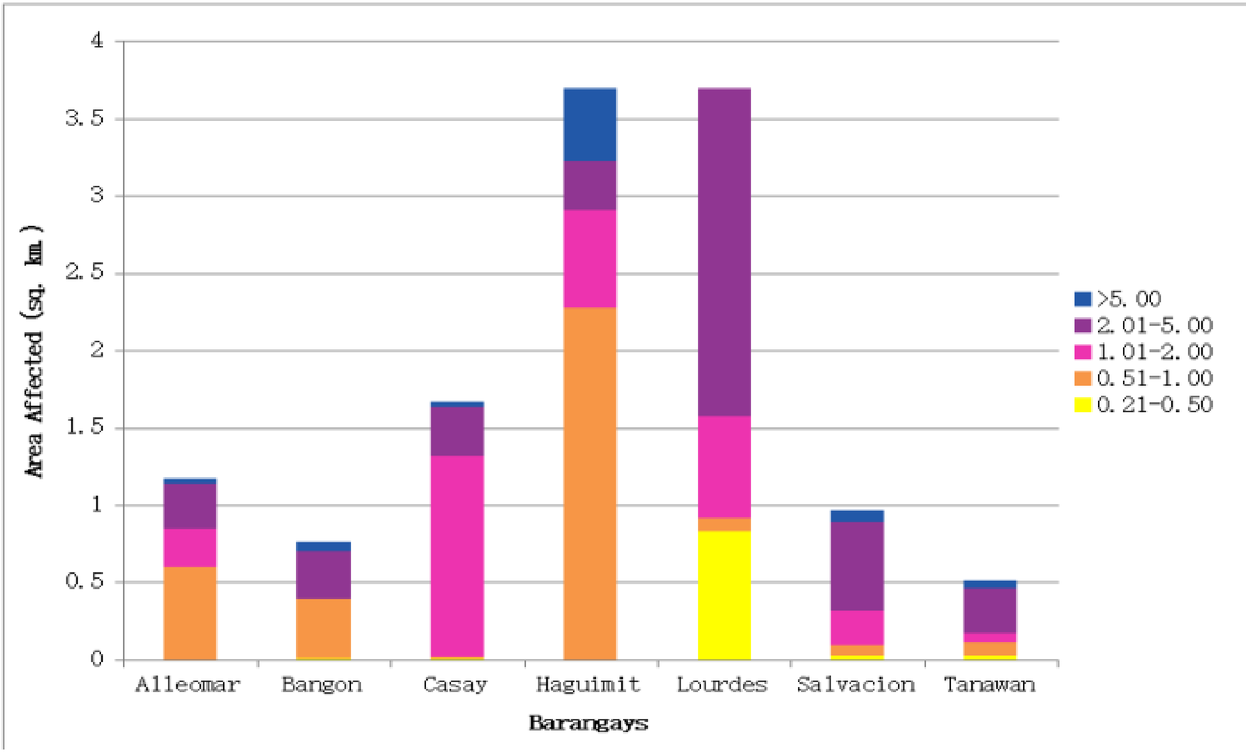

Figure 70 Affected Areas in Lupi, Camarines Sur during 5-Year Rainfall Return Period

For the municipality of Ragay with an area of 296.26 sq. km., 1.47% will experience flood levels of less than 0.20 meters. 5.7% of the area will experience flood levels of 0.21 to 0.50 meters, while 7.06%, 5.7%, 7.25%, and 5.43% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 36 and Table 37 depict the areas affected in Ragay in square kilometers by flood depth per barangay.

Table 36. Affected Areas in Ragay, Camarines Sur during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Ragay (in sq. km.)											
	Agao-Ao	Agrupacion	Amomokpok	Apad	Apale	Banga Caves	Baya	Binahan Proper	Binahan Upper	Buenasuerte	Cabinitan	Caditaan
0.03-0.20	0.0009	0.0013	0.00066	0.0031	0.0016	1.61	0.059	0.051	0.044	0.049	0.048	1.38
0.21-0.50	0.038	0.075	0.0072	3.75	0.081	0.05	0.067	0.26	0.5	1.61	0.12	0.1
0.51-1.00	0.086	0.015	3.44	0.19	0.16	0.13	0.13	0.042	3.48	0.098	0.078	0.042
1.01-2.00	3.3	0.22	0.16	0.15	0.056	1.46	0.039	0.047	0.024	0.0054	0.0002	0.75
2.01-5.00	0.26	0.13	6.22	0.21	0.16	0.26	0.42	0.25	5.03	0.47	0.58	0.55
> 5.00	0.069	0.014	0.023	3.78	0.078	0.081	0.059	0.016	0.0023	0	0	0.13

Table 37. Affected Areas in Ragay, Camarines Sur during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Ragay (in sq. km.)											
	Cale	Laguio	Lanipga-Cawayan	Liboro	Lower Santa Cruz	Panaytayan	Patalunan	Poblacion Ilaod	Poblacion Iraya	Salvacion	San Rafael	Upper Santa Cruz
0.03-0.20	0.023	0.012	0.0089	0.023	0.095	0.75	0.037	0.025	0.017	0.013	0.1	0.0045
0.21-0.50	0.11	0.055	0.0003	4.84	0.31	0.36	0.67	0.78	0.036	1.32	0.76	1
0.51-1.00	0.005	0.0007	2.7	1.13	0.91	0.68	0.19	0.0001	6.19	0.4	0.5	0.32
1.01-2.00	0.29	0.34	0.29	0.057	1.56	0.03	0.034	0.075	0.19	0.021	7.51	0.29
2.01-5.00	0.13	0.0047	5.79	0.11	0.081	0.11	0.2	0.1	0.32	0.048	0	0.046
> 5.00	0	0.052	0.025	0	0.004	10.5	0.42	0.35	0.3	0.17	0	0.018

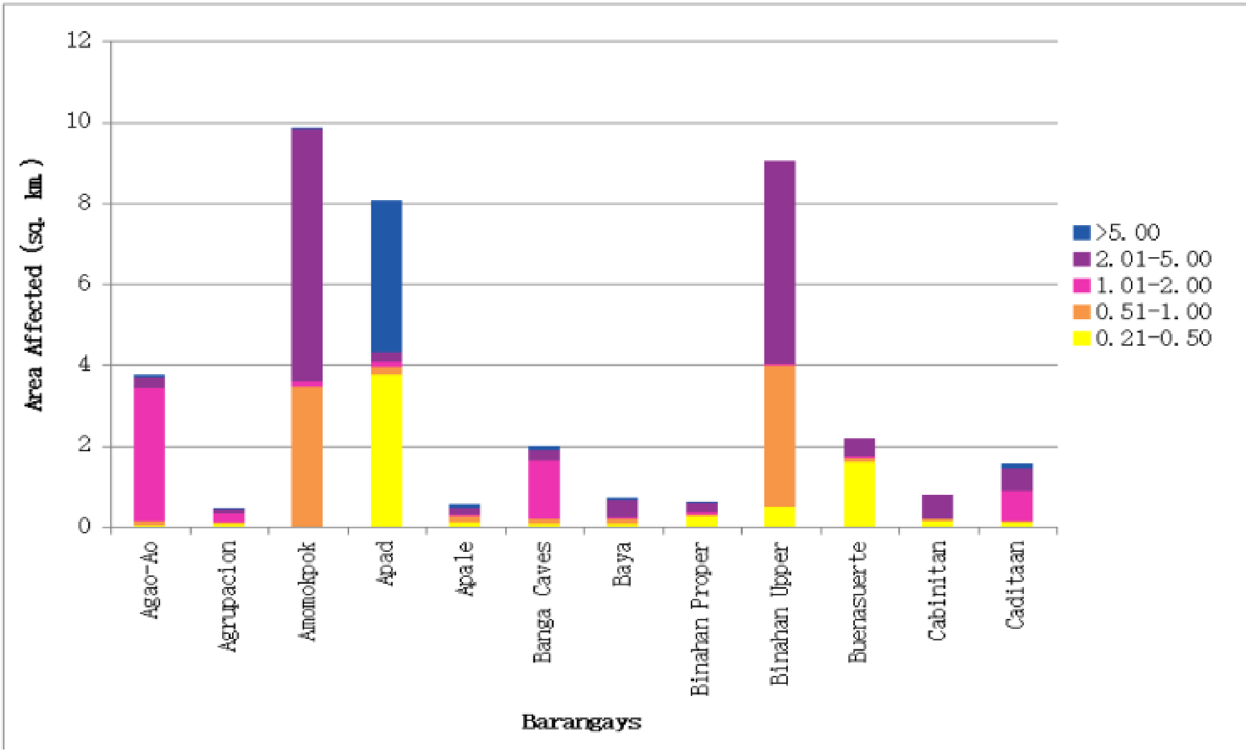

Figure 71. Affected Areas in Ragay, Camarines Sur during 5-Year Rainfall Return Period

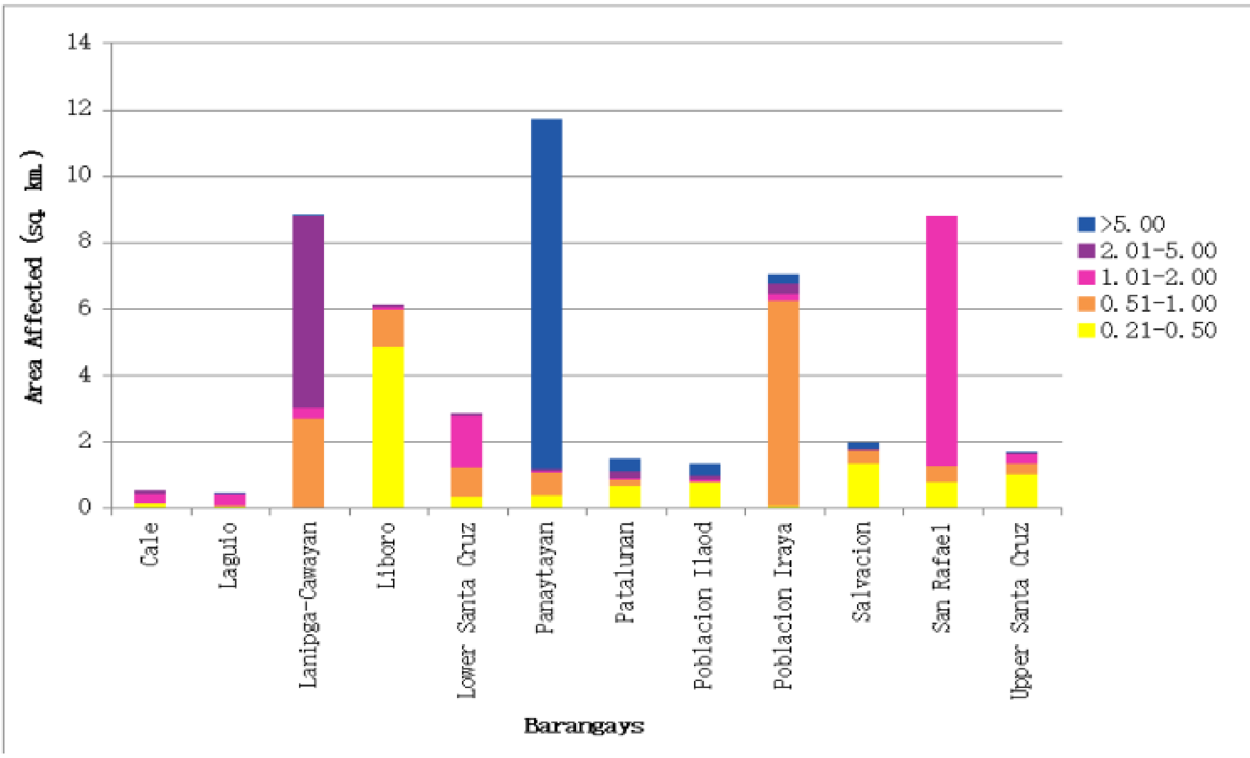

Figure 72. Affected Areas in Ragay, Camarines Sur during 5-Year Rainfall Return Period

For the 25-year rainfall return period, 2.65% of the municipality of Lupi with an area of 230.62 sq. km. will experience flood levels of less than 0.20 meters. 0.1% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.09%, 0.09%, 0.11%, and 0.13% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 38 depicts the areas affected in Lupi in square kilometers by flood depth per barangay.

Table 38. Affected areas in Lupi, Camarines Sur during a 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Lupi (in sq. km.)						
	Alleomar	Bangon	Casay	Haguimit	Lourdes	Salvacion	Tanawan
0.03-0.20	1.55	0.053	1.55	1.35	0.73	0.098	0.79
0.21-0.50	0.071	0.00054	0.066	0.026	0.038	0.0067	0.026
0.51-1.00	0.07	0.0012	0.054	0.016	0.031	0.0041	0.028
1.01-2.00	0.079	0.0014	0.057	0.0087	0.021	0.0056	0.039
2.01-5.00	0.071	0.0026	0.061	0.021	0.017	0.0065	0.081
> 5.00	0.051	0.0043	0.077	0.13	0.0022	0.00021	0.04

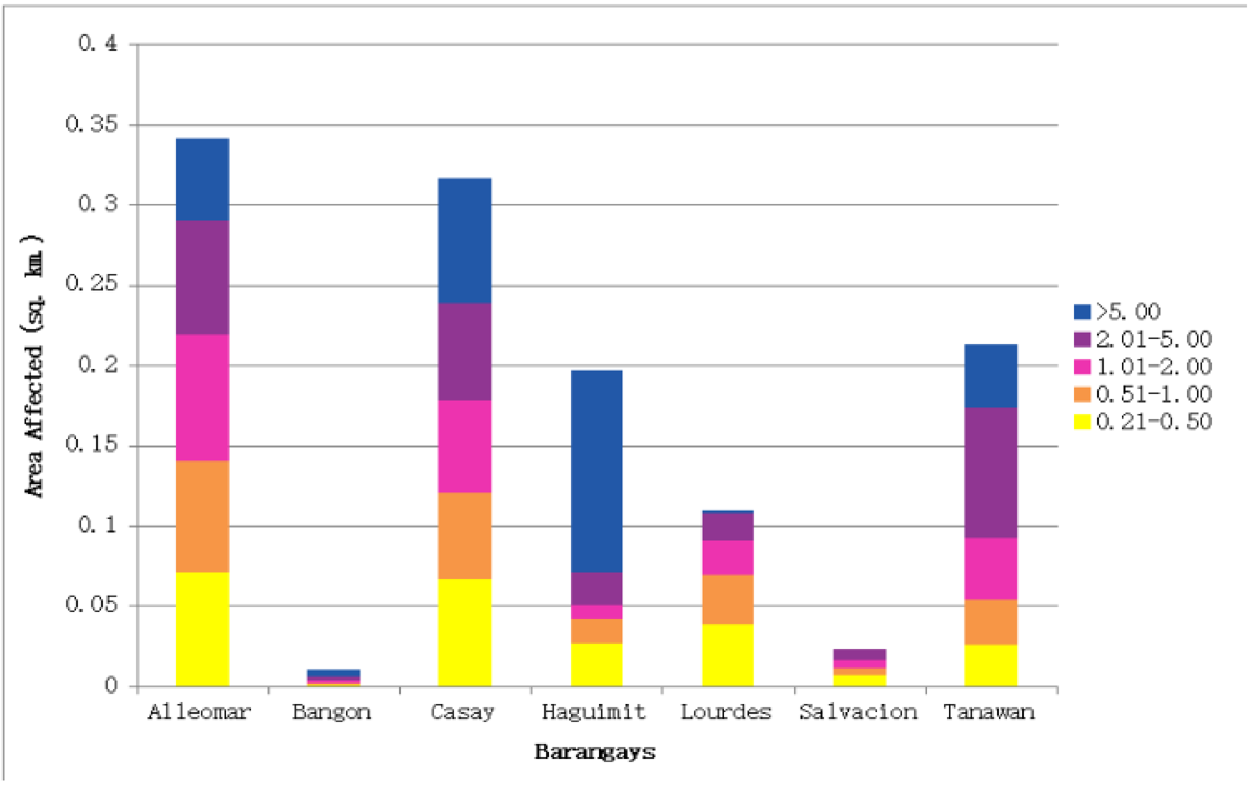

Figure 73. Affected Areas in Lupi, Camarines Sur during 25-Year Rainfall Return Period

For the municipality of Ragay with an area of 296.26 sq. km., 24.95% will experience flood levels of less than 0.20 meters. 1.6% of the area will experience flood levels of 0.21 to 0.50 meters, while 2.19%, 3.28%, 1.92%, and 0.72% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 39 and Table 40 depict the areas affected in Ragay in square kilometers by flood depth per barangay.

Table 39. Affected Areas in Ragay, Camarines Sur during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Ragay (in sq. km.)											
	Agao-Ao	Agrupacion	Amomokpok	Apad	Apale	Banga Caves	Baya	Binahan Proper	Binahan Upper	Buenasuerte	Cabinitan	Caditaan
0.03-0.20	3.64	1.51	4.66	0.41	2.2	3.28	3.44	1.54	5.96	0.32	3.18	1.45
0.21-0.50	0.087	0.098	0.23	0.28	0.078	0.21	0.1	0.62	0.37	0.073	0.25	0.036
0.51-1.00	0.053	0.12	0.32	0.85	0.071	0.17	0.084	1.2	0.56	0.48	0.18	0.046
1.01-2.00	0.045	0.15	0.57	1.93	0.082	0.17	0.058	1.8	0.46	1.68	0.17	0.04
2.01-5.00	0.18	0.11	1.17	0.58	0.16	0.18	0.014	0.46	0.32	0.31	0.1	0.0073
> 5.00	0.71	0.0029	0.043	0.025	0.027	0.077	0.001	0.0003	0.0013	0.0001	0.0001	0.0005

Table 40. Affected Areas in Ragay, Camarines Sur during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Ragay (in sq. km.)											
	Cale	Laguio	Lanipga-Cawayan	Liboro	Lower Santa Cruz	Panaytayan	Patalunan	Poblacion Ilaod	Poblacion Iraya	Salvacion	San Rafael	Upper Santa Cruz
0.03-0.20	0.51	1.52	7.26	1.84	6.06	4.86	5.69	0.17	0.32	3.75	0.089	10.27
0.21-0.50	0.14	0.032	0.29	0.46	0.21	0.39	0.12	0.057	0.067	0.079	0.029	0.45
0.51-1.00	0.33	0.023	0.29	0.51	0.15	0.61	0.085	0.11	0.1	0.083	0.043	0
1.01-2.00	0.5	0.042	0.34	0.36	0.2	0.65	0.1	0.089	0.14	0.073	0.048	0
2.01-5.00	0.24	0.21	0.39	0.22	0.47	0.23	0.2	0.068	0.042	0.027	0.0002	0
> 5.00	0	0.078	0.46	0	0.44	0.01	0.2	0.049	0.026	0.0041	0	0

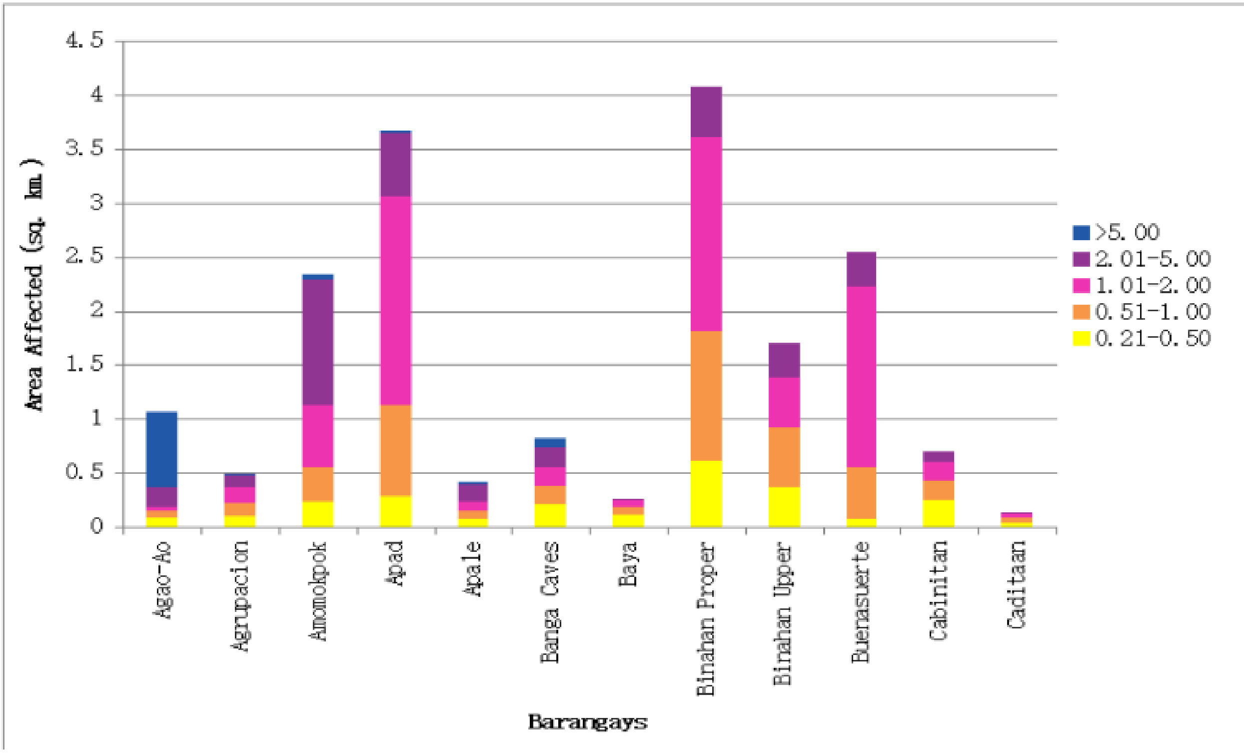

Figure 74. Affected Areas Ragay, Camarines Sur during 25-Year Rainfall Return Period

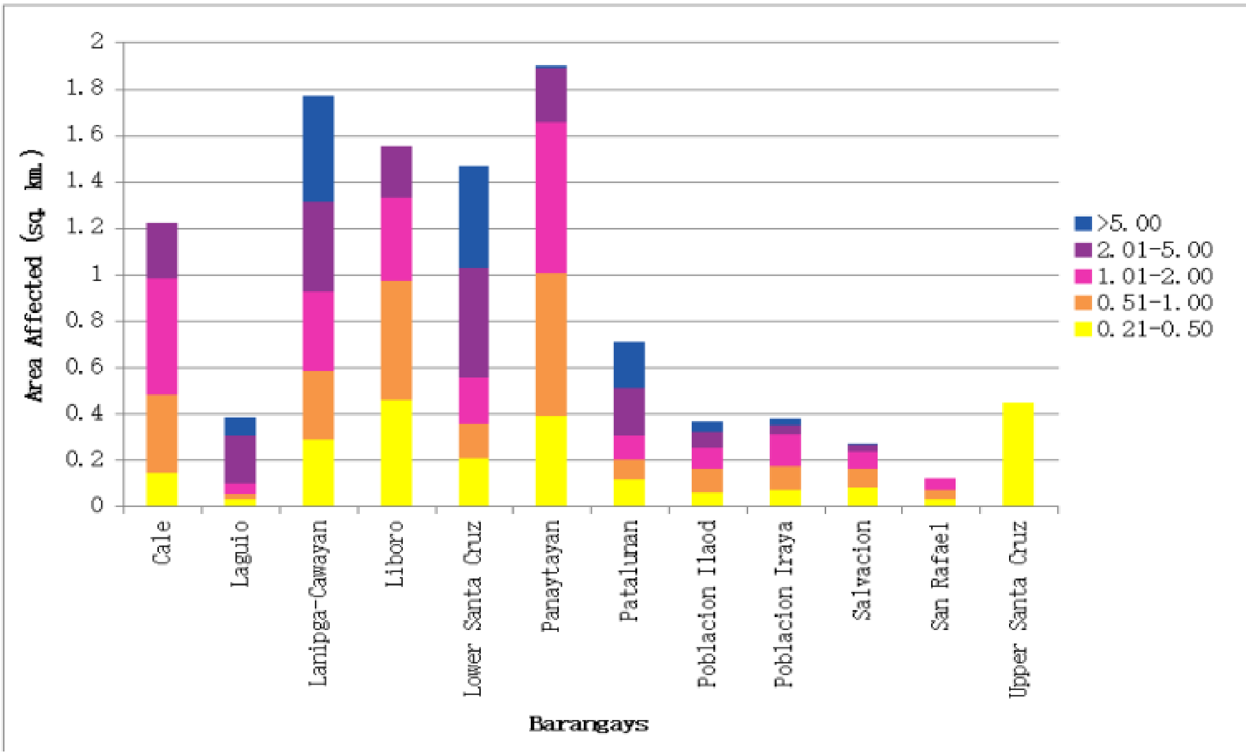

Figure 75. Affected Areas Ragay, Camarines Sur during 25-Year Rainfall Return Period

For the 100-year rainfall return period, 2.56% of the municipality of Lupi with an area of 230.62 sq. km. will experience flood levels of less than 0.20 meters. 0.11% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.09%, 0.11%, 0.14%, and 0.17% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 41 depicts the areas affected in Lupi in square kilometers by flood depth per barangay.

Table 41. Affected Areas in Lupi, Camarines Sur during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Lupi (in sq. km.)						
	Alleomar	Bangon	Casay	Haguimit	Lourdes	Salvacion	Tanawan
0.03-0.20	1.49	0.05	1.48	1.32	0.71	0.094	0.74
0.21-0.50	0.074	0.0011	0.072	0.028	0.043	0.0082	0.026
0.51-1.00	0.073	0.00095	0.057	0.017	0.038	0.0049	0.027
1.01-2.00	0.095	0.0021	0.067	0.0095	0.023	0.0055	0.043
2.01-5.00	0.096	0.0032	0.076	0.021	0.019	0.0075	0.095
> 5.00	0.057	0.0057	0.1	0.15	0.0047	0.00018	0.063

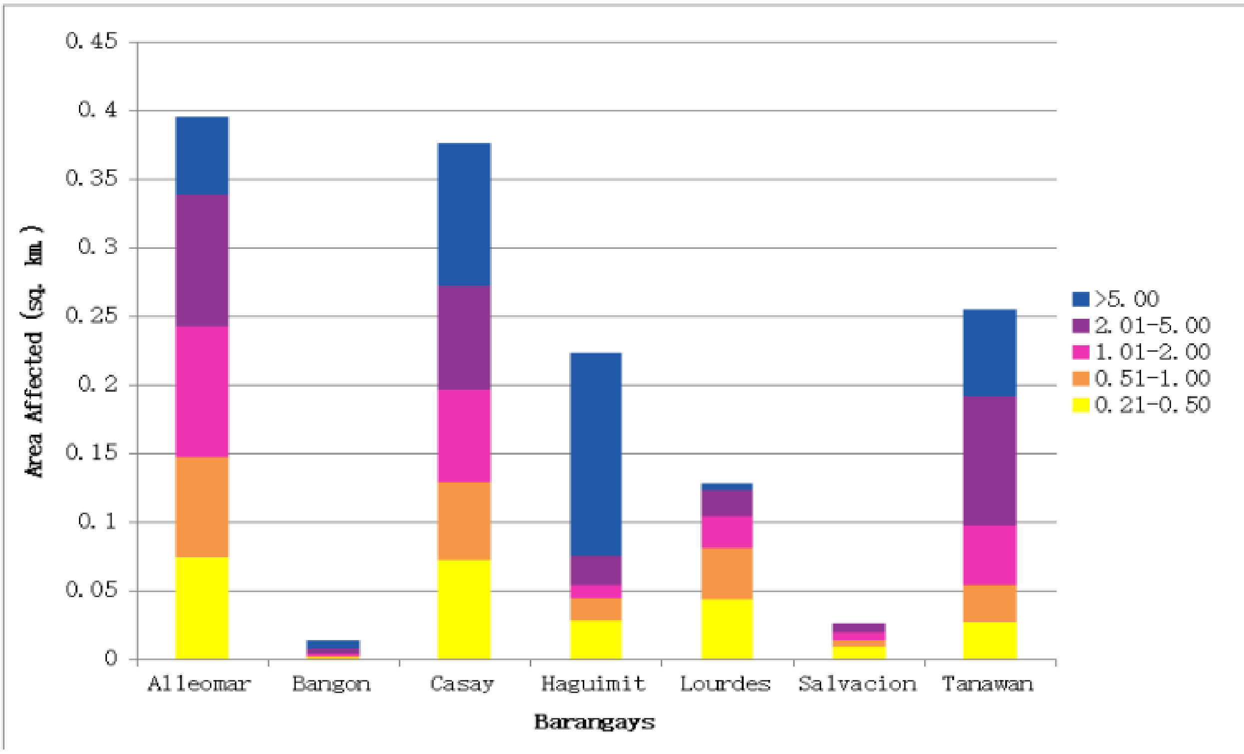

Figure 76. Affected Areas Lupi, Camarines Sur during 100-Year Rainfall Return Period

For the municipality of Ragay with an area of 296.26 sq. km., 23.98% will experience flood levels of less than 0.20 meters. 1.22% of the area will experience flood levels of 0.21 to 0.50 meters, while 1.72%, 3.28%, 3.8%, and 0.86% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 42 and Table 43 depict the areas affected in Ragay in square kilometers by flood depth per barangay.

Table 42. Affected Areas in Ragay, Camarines Sur during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Ragay (in sq. km.)											
	Agao-Ao	Agrupacion	Amomokpok	Apad	Apale	Banga Caves	Baya	Binahan Proper	Binahan Upper	Buenasuerte	Cabinitan	Caditaan
0.03-0.20	3.55	1.45	4.58	0.18	2.16	3.08	3.42	0.99	5.83	0.27	3.09	1.43
0.21-0.50	0.091	0.097	0.2	0.044	0.083	0.21	0.11	0.28	0.34	0.0079	0.27	0.037
0.51-1.00	0.06	0.1	0.25	0.2	0.063	0.17	0.089	0.74	0.57	0.022	0.2	0.041
1.01-2.00	0.051	0.17	0.48	1.47	0.082	0.22	0.066	2.04	0.56	0.59	0.18	0.054
2.01-5.00	0.12	0.17	1.43	2.09	0.18	0.26	0.023	1.55	0.36	1.93	0.14	0.011
> 5.00	0.84	0.011	0.051	0.11	0.045	0.14	0.0011	0.016	0.0018	0.037	0.0002	0.0005

Table 43. Affected Areas in Ragay, Camarines Sur during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Ragay (in sq. km.)											
	Cale	Laguio	Lanipga-Cawayan	Liboro	Lower Santa Cruz	Panaytayan	Patalunan	Poblacion Ilaod	Poblacion Iraya	Salvacion	San Rafael	Upper Santa Cruz
0.03-0.20	0.43	1.51	7.11	1.42	5.95	4.76	5.62	0.11	0.29	3.73	0.02	10.07
0.21-0.50	0.046	0.035	0.29	0.21	0.22	0.3	0.11	0.04	0.029	0.077	0.016	0.47
0.51-1.00	0.11	0.021	0.3	0.6	0.16	0.58	0.095	0.085	0.082	0.083	0.058	0.41
1.01-2.00	0.57	0.039	0.35	0.84	0.16	0.76	0.11	0.17	0.16	0.084	0.093	0.42
2.01-5.00	0.58	0.16	0.4	0.31	0.45	0.35	0.2	0.077	0.11	0.038	0.022	0.31
> 5.00	0.0016	0.15	0.58	0.0016	0.58	0	0	0	0	0	0	0

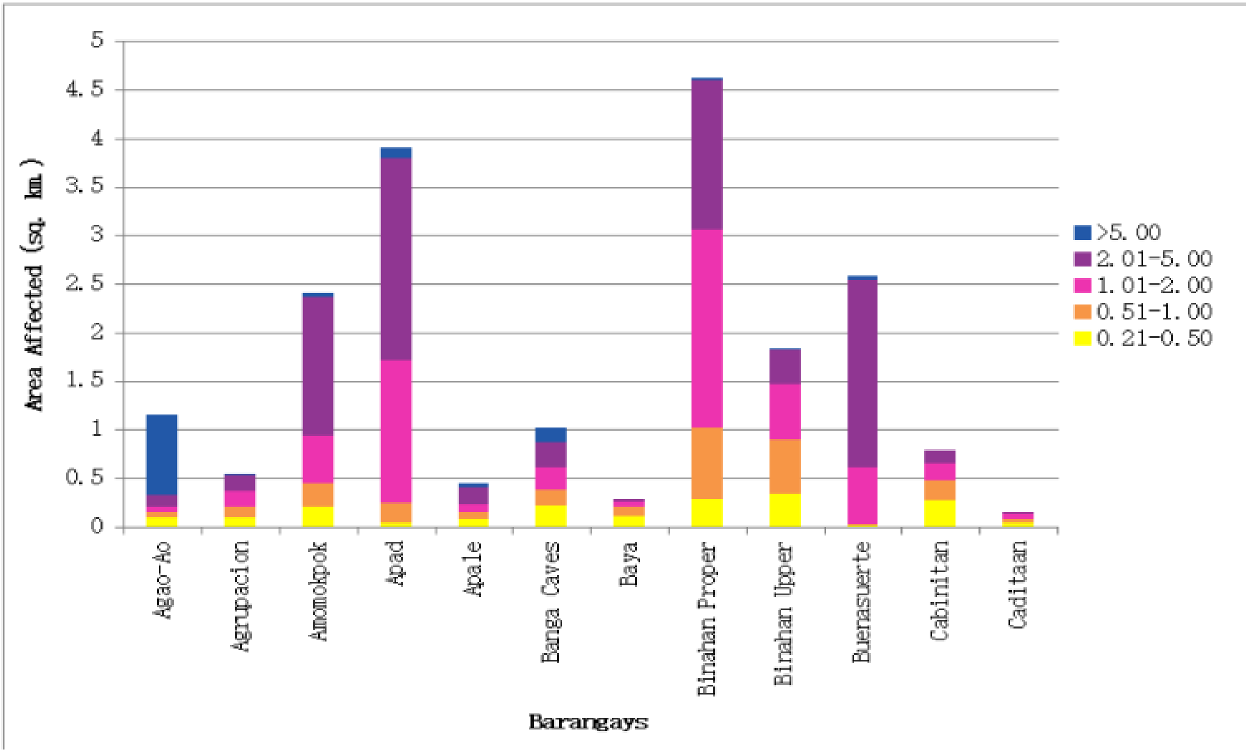

Figure 77. Affected Areas Camarines Sur during 100-Year Rainfall Return Period

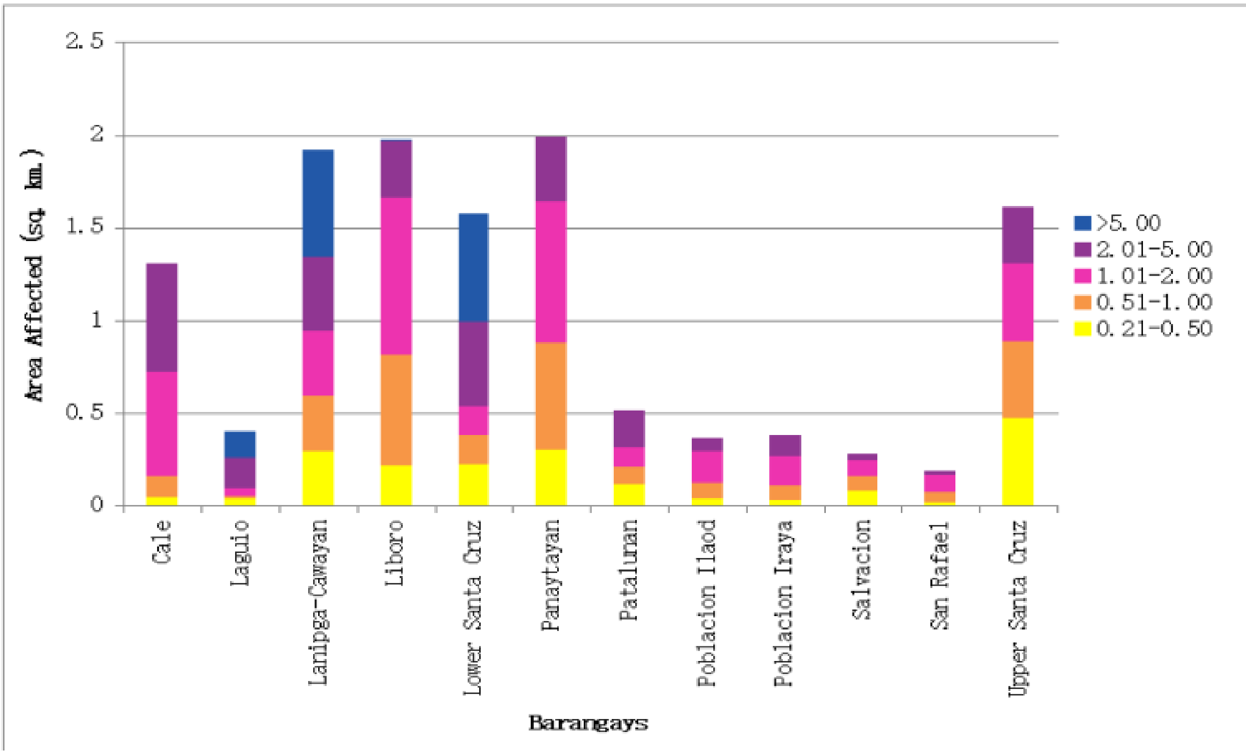

Figure 78. Affected Areas Camarines Sur during 100-Year Rainfall Return Period

Among the barangays in the municipality of Lupi, Haguimit is projected to have the highest percentage of area that will experience flood levels at 1.63%. Meanwhile, Lourdes posted the second highest percentage of area that may be affected by flood depths at 1.62%.

Among the barangays in the municipality of Ragay, Panaytayan is projected to have the highest percentage of area that will experience flood levels at 4.2%. Meanwhile, Amomokpok posted the second highest percentage of area that may be affected by flood depths at 3.33%.

Moreover, the generated flood hazard maps for the Ragay flood plain were used to assess the vulnerability of the educational and medical institutions in the flood plain. 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 44. 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	7.01	4.98	3.88
Medium	10.41	12.34	10.1
High	8.07	14.21	20.58
TOTAL	**25.49**	**31.53**	**34.56**

Of the 29 identified educational institutions in Ragay floodplain, 4 were assessed to be exposed to low, 4 to medium, and none to high level flooding during the 5-year scenario. In the 25-year scenario, 3 were assessed to be exposed to low, 10 to medium, and 2 to high level flooding. In the 100-year scenario, 1 was assessed to be exposed to low, 9 to medium, and 7 to high level flooding. The educational institutions exposed to flooding are shown in Annex 12.

Of the 8 identified medical or health institutions in Ragay flood plain, none was assessed to be exposed to low and high, while 2 were assessed to be exposed to medium level flooding in the 5-year scenario. In the 25-year scenario, 2 were assessed to be exposed to low, 1 to medium, and 2 to high level flooding. In the 100-year scenario, none was assessed to be exposed to low, 3 to medium, and 2 to high level flooding. The health institutions exposed to flooding are found in Annex 13.

5.11 Flood Validation

In order to check and validate the extent of flooding in different river systems, there is a need to perform validation survey work. Field personnel gathered secondary data regarding flood occurrence in the area within the major river system in the Philippines.

From the flood depth maps produced by Phil-LiDAR 1 Program, multiple points representing the different flood depths for different scenarios we identified for validation.

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

After which, the actual data from the field were compared to the simulated data to assess the accuracy of the Flood Depth Maps produced and to improve on the results of the flood map. The points in the flood map versus its corresponding validation depths are shown in Figure 80.

The flood validation consists of 169 points randomly selected all over the Ragay flood plain (Figure 79). Comparing it with the flood depth map of the nearest storm event, the map has an RMSE value of 1.230087071m. Table 45 shows a contingency matrix of the comparison. The validation points are found in Annex 11.

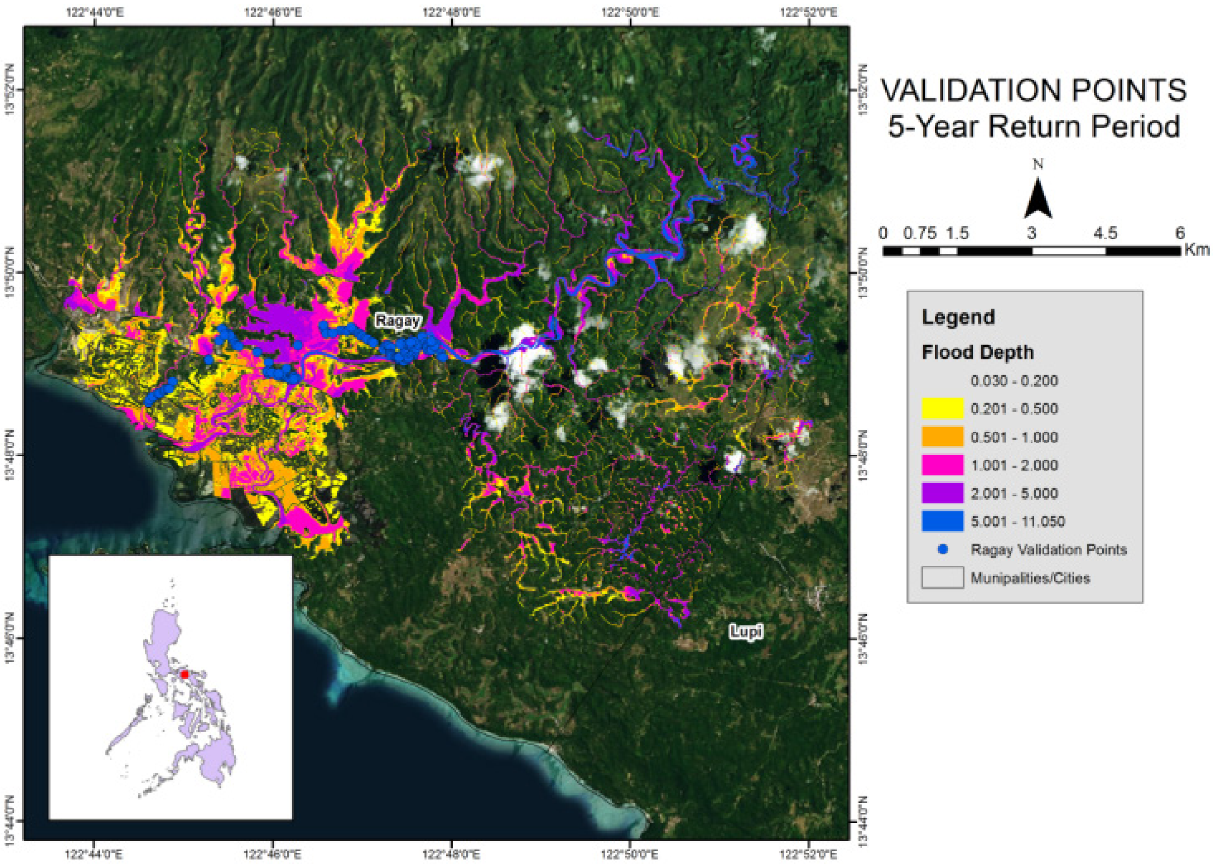

Figure 79. Ragay Flood Validation Points

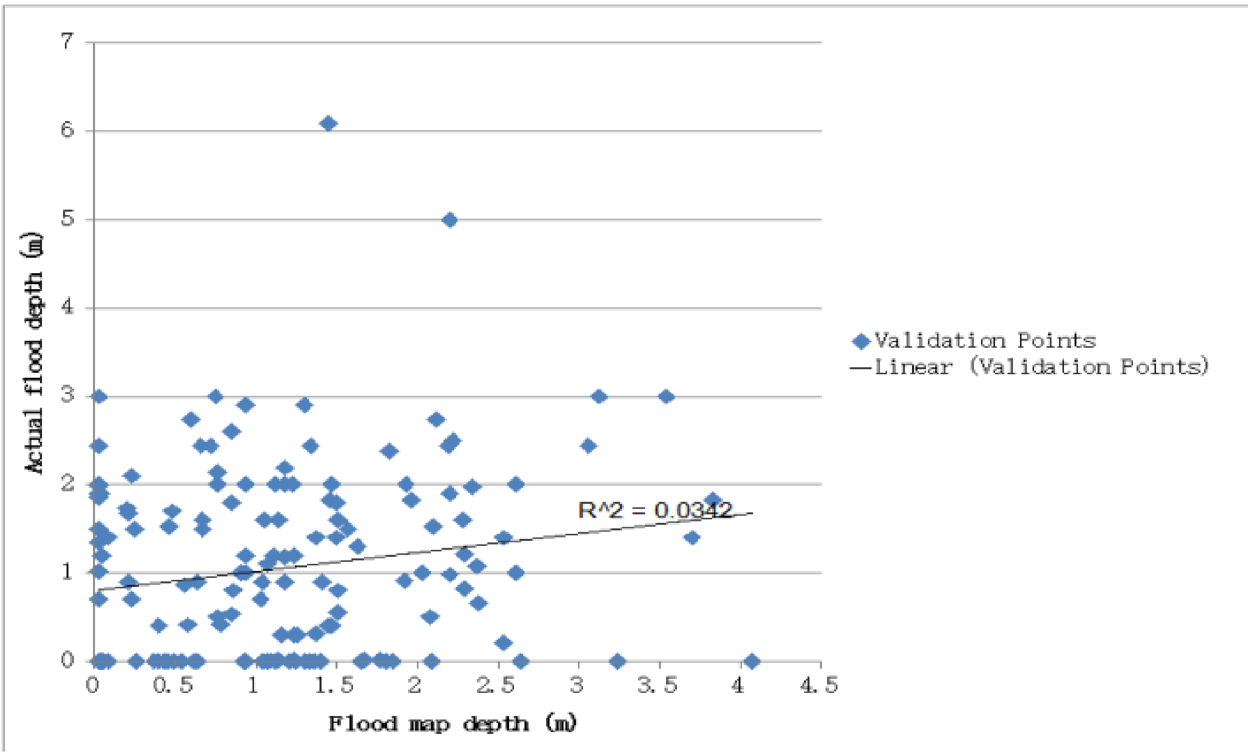

Figure 80. Flood map depth vs. actual flood depth

Table 45. Actual flood vs simulated flood depth at different levels in the Ragay River Basin.

Actual Flood Depth (m)	Modeled Flood Depth (m)						
	0-0.20	0.21-0.50	0.51-1.00	1.01-2.00	2.01-5.00	> 5.00	Total
0-0.20	20	6	6	23	4	0	59
0.21-0.50	0	1	3	6	2	0	12
0.51-1.00	1	2	8	9	5	0	25
1.01-2.00	12	4	6	19	10	0	51
2.01-5.00	2	1	7	4	7	0	21
> 5.00	0	0	0	1	0	0	1
Total	35	14	30	62	28	0	169

On the whole, the overall accuracy generated by the flood model is estimated at 32.54%, with 55 points correctly matching the actual flood depths. In addition, there were 40 points estimated one level above and below the correct flood depths, 30 points estimated two levels above and below, and 44 points estimated three or more levels above and below the correct flood depths. A total of 74 points were overestimated while a total of 40 points were underestimated in the modelled flood depths of Ragay. Table 46 depicts the summary of the accuracy assessment in the Ragay River Basin survey.

Table 46. The summary of the Accuracy Assessment in the Ragay River Basin Survey

	No. of Points	%
Correct	55	32.54
Overestimated	74	43.79
Underestimated	40	23.67
Total	169	100

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ANNEXES

Annex 1. Optech Technical Specifications of the Pegasus Sensor used in the Ragay Floodplain survey

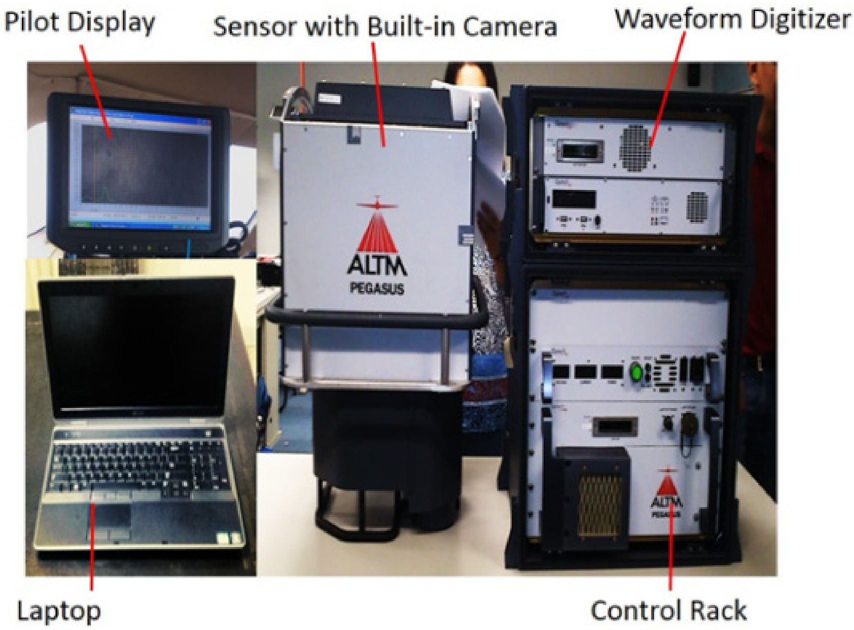


Figure A-1.1. Pegasus Sensor

Table A-1.1. Parameters and Specification of Pegasus Sensor

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

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

1. CMS-73

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

March 16, 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-73**	
	Order: **2nd**	
Island: **LUZON**	Barangay: **F. SIMEON (PUGOD)**	
Municipality: **RAGAY**	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **13° 49' 23.30467"**	Longitude: **122° 47' 22.99347"**	Ellipsoidal Hgt: **29.10700 m.**
	WGS84 Coordinates	
Latitude: **13° 49' 18.21600"**	Longitude: **122° 47' 27.94306"**	Ellipsoidal Hgt: **79.19600 m.**
	PTM / PRS92 Coordinates	
Northing: **1528617.256 m.**	Easting: **477266.186 m.**	Zone: **4**
	UTM / PRS92 Coordinates	
Northing: **1,528,082.21**	Easting: **477,274.14**	Zone: **51**

Location Description

CMS-73

From Sipocot travel W to Ragay along Quirino Highway for about 20 Km. Station is located at the park along the highway and the road intersection leading to Ragay Mun. Hall, about 10 m. from highway centerline, about 6 m from the E kiosk at the park. 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-73, 2007, NAMRIA".

Requesting Party: **UP-Lidar 1**
Purpose: **Reference**
OR Number: **8090044 I**
T.N.: **2016-0645**

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-2.1. CMS-73

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

1. CS-98

Table A-3.1. CS-98 Part 1

Project Information		**Coordinate System**	
Name:	F:\Doc\DAC\2016\Fieldwork\2016-3 Bagasbas\mas 15\CS-98 vs CMS-73.vce	Name: Datum:	UTM PRS 92
Size	169 KB	Zone:	51 North (123E)
Modified	4/19/2016 11:00:42 AM (UTC-8)	Geoid:	egmPH
Time zone:	Taipei Standard Time	Vertical datum:	
Reference number:			
Description:			

Baseline Processing Reports

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	Change in Height (Meter)
CS-98 - CMS-73 (B1)	CMS-73	CS-98	Fixed	0.001	0.002	106°19’12”	424.225	-15.873

Acceptance Summary

Processed	Passed	Flag	Fail
1	1	0	0

Table A-3.2. CS-98 Part 2

CS-98 - CMS-73 (7:17:13 AM-11:37:02 AM (S1)	
Baseline observation:	CS-98 - CMS-73 (B1)
Processed:	4/19/2016 11:04:39 AM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.001 m
Vertical precision:	0.002 m
RMS:	0.000 m
Maximum PDOP:	6.629
Ephemeris used:	Broadcast
Antenna model:	No phase table corrections applied.
Processing start time:	3/15/2016 7:17:21 AM (Local: UTC+8hr)
Processing stop time:	3/15/2016 11:37:02 AM (Local: UTC+8hr)
Processing duration:	04:19:41
Processing interval:	1 second

Vector Components (Mark to Mark)

From:	CMS-73				
Grid		Local		Global	
Easting	477274.143 m	Latitude	N13°49'23.30467"	Latitude	N13°49'18.21600"
Northing	1528082.214 m	Longitude	E122°47'22.99347"	Longitude	E122°47'22.99347"
Elevation	28.789 m	Height	29.107 m	Height	29.107 m

To:	CS-98				
Grid		Local		Global	
Easting	477681.010 m	Latitude	N13°49'19.42547"	Latitude	N13°49'14.33735"
Northing	1527962.695 m	Longitude	E122°47'36.54972"	Longitude	E122°47'41.49939"
Elevation	12.917 m	Height	13.233 m	Height	63.335 m

Vector					
Change in Easting	406.867 m	NS Fwd Azimuth	106°19'12"	Change in X	-349.332 m
Change in Northing	-119.518 m	Ellipsoid Dist.	424.225 m	Change in Y	-209.515 m
Change in Elevation	-15.872 m	Change in Height	-15.873 m	Change in Z	-119.540 m

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
		LOVELYN ASUNCION	UP-TCAGP

FIELD TEAM

LiDAR Operation	Senior Science Research Specialist (SSRS)	PAULINE JOANNE ARCEO	UP-TCAGP
	Research Associate (RA)	MILLIE SHANE REYES	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	JONATHAN ALMALVEZ	UP-TCAGP
LiDAR Operation	Airborne Security	SSG JAYCO MANZANO	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. MARK TANGONAN	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. RANDY LAGCO	AAC

Annex 5. Data Transfer Sheet for Ragay Floodplain

DATA TRANSFER SHEET
01/04/2016 BAGASBAS

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
3/9/2016	23170P	1BLK20DE69A	PEGASUS	1.77	1245	11.5	253	40.6	309	18.2	NA	171	1KB	1KB	1.41	NA	Z:\DAC\RAWDATA
3/9/2016	23172P	1BLK20A69B	PEGASUS	815	552	6.27	149	14.9	123	8.3	NA	171	1KB	1KB	5.05	NA	Z:\DAC\RAWDATA
3/10/2016	23174P	1BLK20ASC70A	PEGASUS	2.12	1484	12.5	266	41.4	NA	22.5	NA	186	1KB	1KB	7.17	NA	Z:\DAC\RAWDATA
3/10/2016	23176P	1BLK20B70B	PEGASUS	903	490	5.53	159	15.7	NA	8.7	NA	186	1KB	1KB	NA	NA	Z:\DAC\RAWDATA
3/12/2016	23182P	1BLK20ABCE72A	PEGASUS	1.04	686	8.96	265	20.8	NA	10.8	NA	3.82	1KB	1KB	NA	NA	Z:\DAC\RAWDATA
3/13/2016	23186P	1BLK20K73A	PEGASUS	1.26	630	6.63	190	17.7	NA	12.8	NA	1.9	1KB	1KB	377	NA	Z:\DAC\RAWDATA
3/14/2016	23190P	1BLK20BS74A	PEGASUS	1.66	869	9.89	254	1.52	NA	17.4	NA	69.3	1KB	1KB	448	NA	Z:\DAC\RAWDATA
3/15/2016	23194P	1BLK20JKL75A	PEGASUS	2.15	1241	10.8	267	35.6	263	22.4	NA	81.5	1KB	1KB	103	NA	Z:\DAC\RAWDATA
3/16/2016	23198P	1BLK20IM76A	PEGASUS	1.96	1241	11	279	33.8	NA	22	NA	84	1KB	1KB	1.52	NA	Z:\DAC\RAWDATA
3/17/2016	23202P	1BLK20N77A	PEGASUS	2.29	1664	12.5	287	50.5	NA	25.9	NA	131	1KB	1KB	60.6	NA	Z:\DAC\RAWDATA

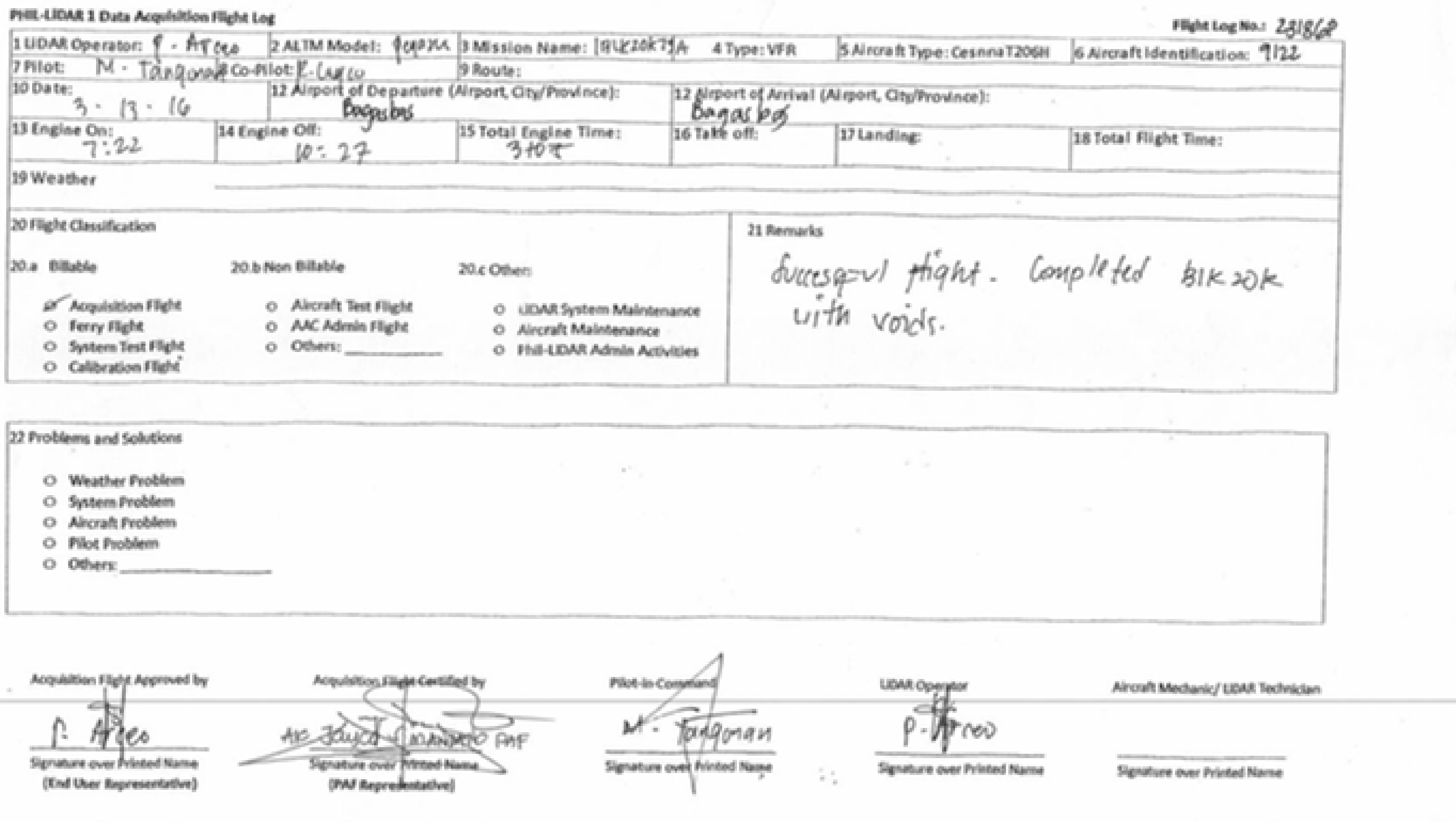
Name KJ ANDAYA
Position RA
Signature

Name Irish Cortez 4/11/16
Position RA
Signature

Figure A-5.1. Transfer Sheet for Ragay Floodplain

Annex 6. Flight Logs for the Flight Missions

1. Flight Log for Mission 23186P



PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 23186P

1 LIDAR Operator: P. Arceo	2 ALTM Model: Pegasus	3 Mission Name: 1BLK20K73A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9122
7 Pilot: M. Tangonan	8 Co-Pilot: F. Lugcu	9 Route:			
10 Date: 3-13-16	12 Airport of Departure (Airport, City/Province): Bagasbas		12 Airport of Arrival (Airport, City/Province): Bagasbas		
13 Engine On: 7:22	14 Engine Off: 10:27	15 Total Engine Time: 3+05	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

Successful flight. Completed BLK 20K with voids.

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

Acquisition Flight Approved by: P. Arceo — Signature over Printed Name (End User Representative)

Acquisition Flight Certified by: [illegible] PAF — Signature over Printed Name (PAF Representative)

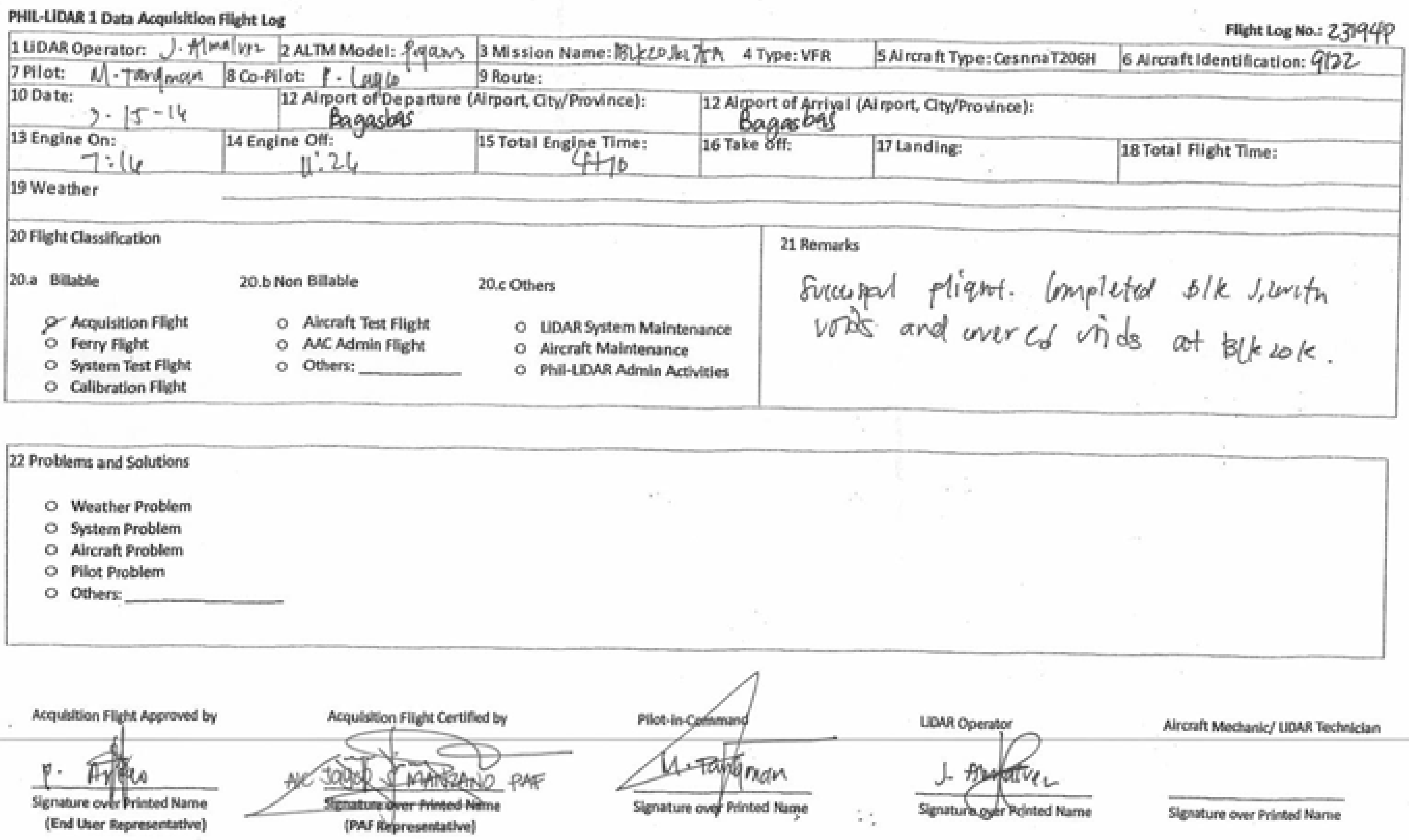
Pilot-in-Command: M. Tangonan — Signature over Printed Name

LIDAR Operator: P. Arceo — Signature over Printed Name

Aircraft Mechanic/ LIDAR Technician: Signature over Printed Name

Figure A-6.1. Flight Log for Mission 23186P

2. Flight Log for 23194P Mission



PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 23194P

1 LiDAR Operator: J. Almalvez	2 ALTM Model: Pegasus	3 Mission Name: 3BLK20J&K 7A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9122
7 Pilot: M. Tangonan	8 Co-Pilot: F. Lugto	9 Route:			
10 Date: 9-15-14	12 Airport of Departure (Airport, City/Province): Bagasbas		12 Airport of Arrival (Airport, City/Province): Bagasbas		
13 Engine On: 7:16	14 Engine Off: 11:26	15 Total Engine Time: 4+10	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

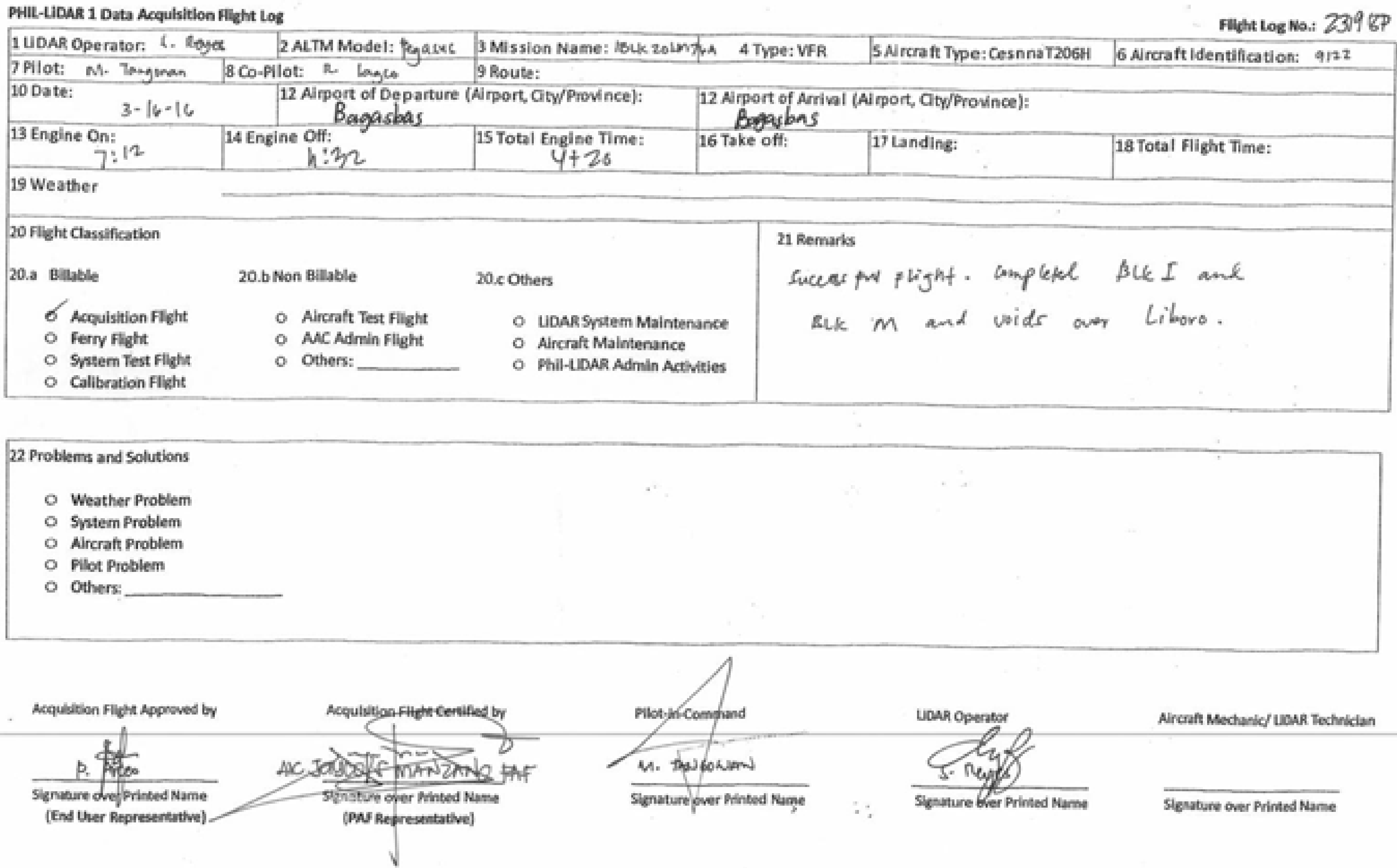
Successful flight. Completed blk J, with voids and covered voids at Blk 20K.

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	LiDAR Operator	Aircraft Mechanic/ LiDAR Technician
F. Aviles	A1C Jobert Manzano PAF	M. Tangonan	J. Almalver	
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 23194P

3. Flight Log for 23198P Mission



PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 23198P

1 LIDAR Operator: L. Reyes	2 ALTM Model: Pegasus	3 Mission Name: 1BLK 20LM76A	4 Type: VFR	5 Aircraft Type: CesnnaT206H / 6 Aircraft Identification: 9122
7 Pilot: M. Tangonan	8 Co-Pilot: R. Loyola	9 Route:		
10 Date: 3-16-16	12 Airport of Departure (Airport, City/Province): Bagasbas		12 Airport of Arrival (Airport, City/Province): Bagasbas	
13 Engine On: 7:12	14 Engine Off: 11:32	15 Total Engine Time: 4+20	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

Successful flight. Completed BLK I and BLK M and voids over Libon.

22 Problems and Solutions

- ○ Weather Problem
- ○ System Problem
- ○ Aircraft Problem
- ○ Pilot Problem
- ○ Others: ________________

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	LIDAR Operator	Aircraft Mechanic/ LIDAR Technician
D. Arceo	A1C Joseph Manzano PAF	M. Tangonan	L. Reyes	
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 23198P

Annex 7. Flight Status Reports

Surigao del Sur Mission
July 3 to August 1, 2014

Table A-7.1. Flight Status Report

FLIGHT NO.	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
23186P	BAGASBAS	1BLK20K73A	P. ARCEO	Mar .13, 2016	COMPLETED BLK 20K WITH VOIDS
23194P	BAGASBAS	1BLK20JKL75A	J. ALMALVEZ	Mar. 15, 2016	COMPLETED BLK20J WITH VOIDS AND COVERED VOIDS AT BLK 20K
23189P	BAGASBAS	1BLK20IM76A	M.S. REYES	Mar. 16, 2016	COMPLETED BLK20I AND BLK20M WITH VOIDS OVER LIBORO

SWATH PER FLIGHT MISSION

FLIGHT NO.:	23186P		
AREA:	Bagasbas		
MISSION NAME:	1BLK20K73A		
ALT:	600-1100 m	SCAN FREQ: 30	SCAN ANGLE: 50
SURVEYED AREA:	101.02		

Figure A-7.1. Swath for Flight No. 23186P

FLIGHT NO.:	23194P
AREA:	Bagasbas
MISSION NAME:	1BLK20JKL75A
ALT:	600-1100 m SCAN FREQ: 30 SCAN ANGLE: 50
SURVEYED AREA:	172.32

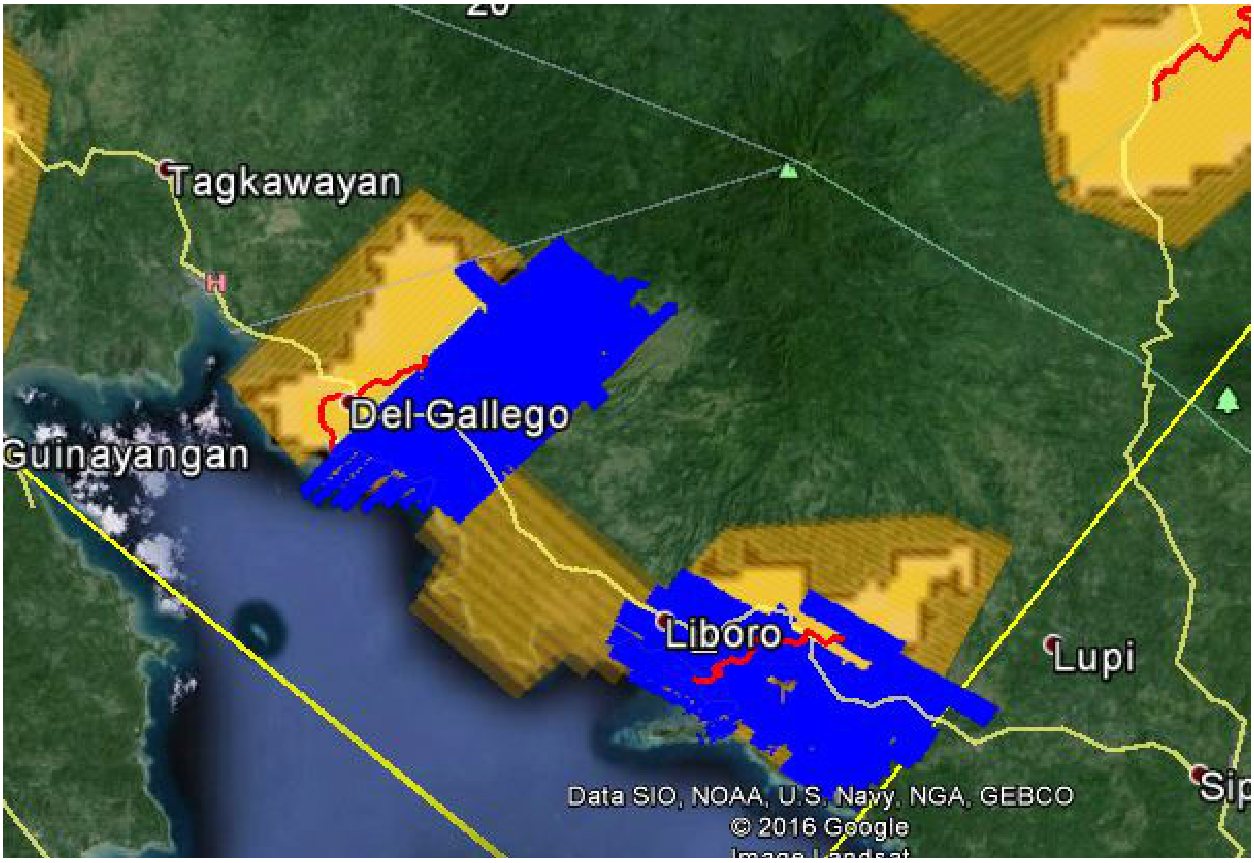


Figure A-7.2. Swath for Flight No. 23194P

FLIGHT NO.:	23198P		
AREA:	Bagasbas		
MISSION NAME:	1BLK20IM76A		
ALT:	600-1100 m	SCAN FREQ: 30	SCAN ANGLE: 50
SURVEYED AREA:	188.99		

Figure A-7.3. Swath for Flight No. 23198P

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Bagasbas Block 20K

Flight Area	Bagasbas
Mission Name	Bagasbas Block 20K
Inclusive Flights	23186P
Range data size	12.8GB
Base data size	190MB
POS	1.9 MB
Image	n/a
Transfer date	April 11,2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	0.8
RMSE for East Position (<4.0 cm)	0.9
RMSE for Down Position (<8.0 cm)	2.7
Boresight correction stdev (<0.001deg)	0.000193
IMU attitude correction stdev (<0.001deg)	-
GPS position stdev (<0.01m)	0.0011
Minimum % overlap (>25)	56.23%
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	142
Maximum Height	493.57
Minimum Height	52.69
Classification (# of points)	
Ground	111263454
Low vegetation	50864387
Medium vegetation	154454926
High vegetation	481317934
Building	4054110
Orthophoto	Yes
Processed by	Engr. Don Matthew Banatin, Engr. Edgardo Gubatanga Jr., Marie Denise Bueno

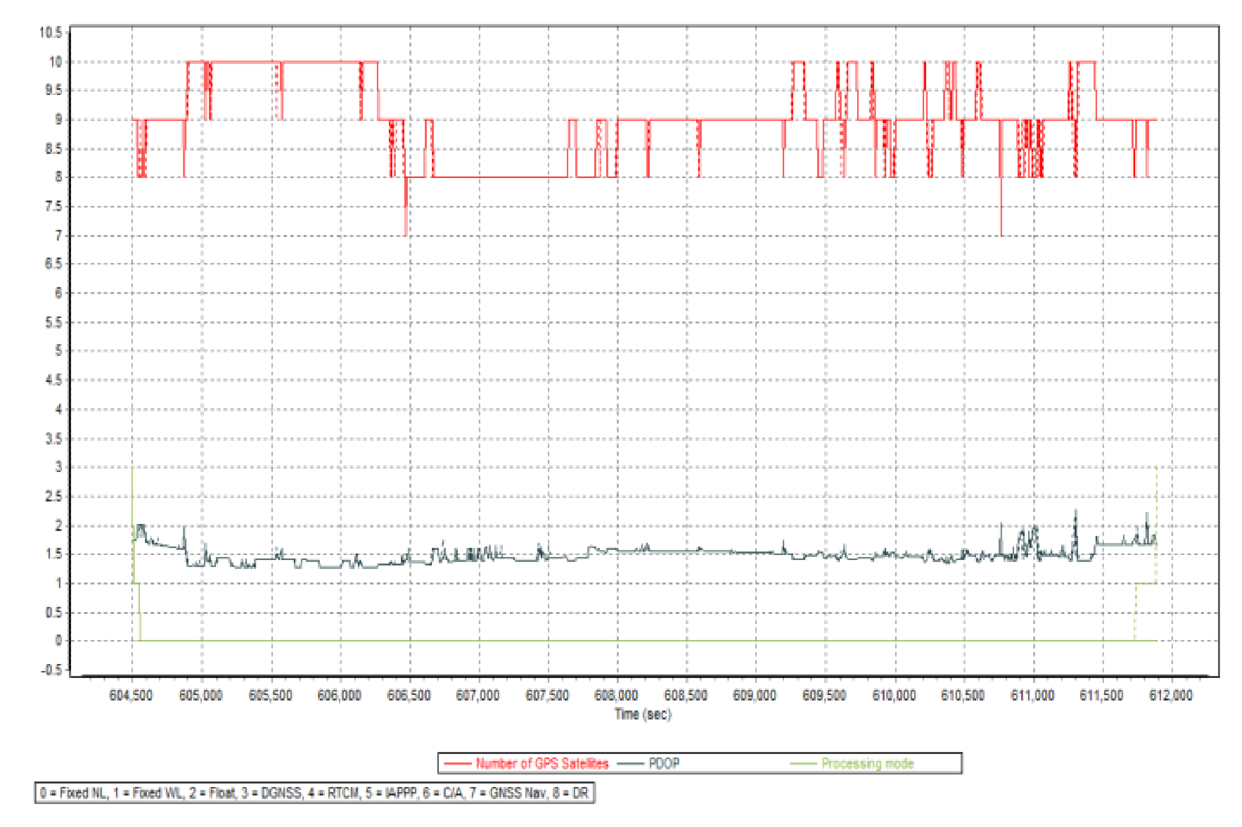


Figure A-8.1. Solution Status

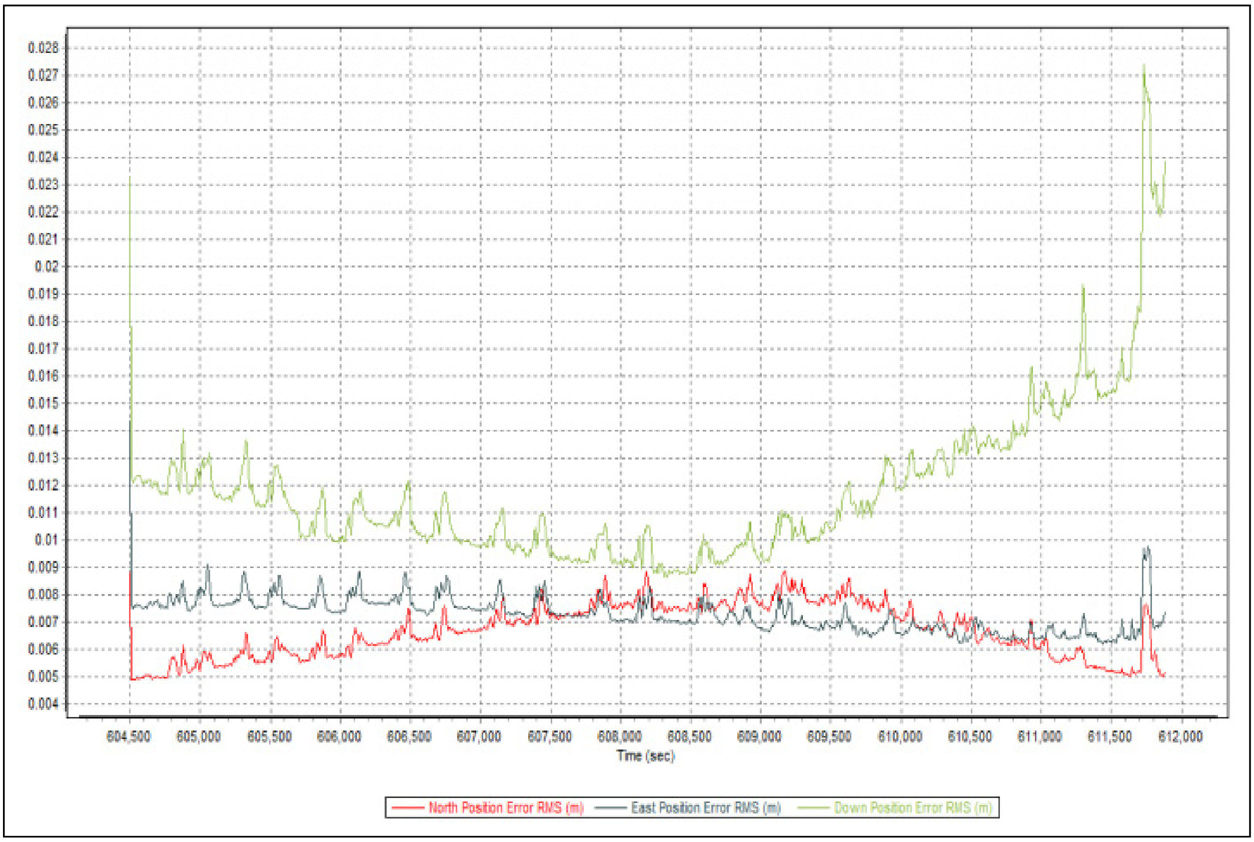


Figure A-8.2. Smoothed Performance Metrics Parameters

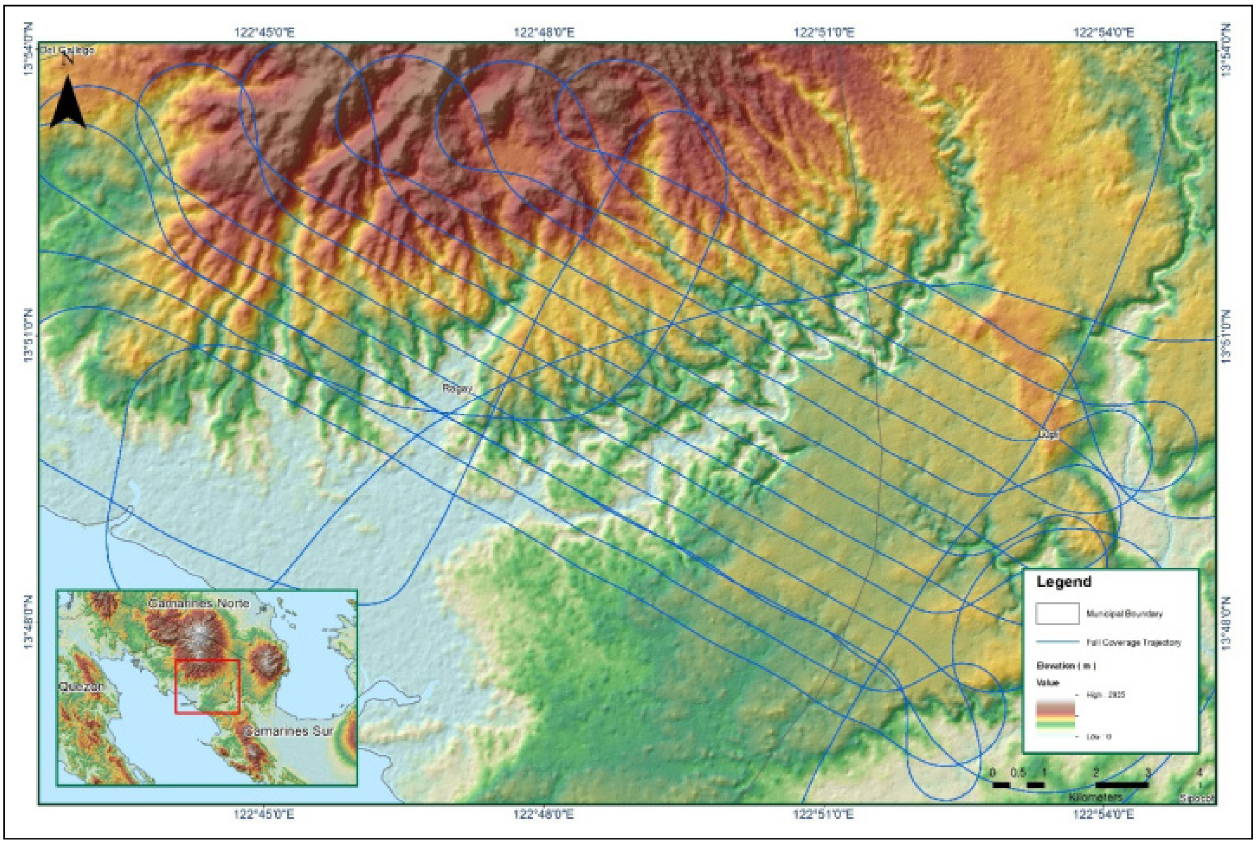


Figure A-8.3. Best Estimated Trajectory

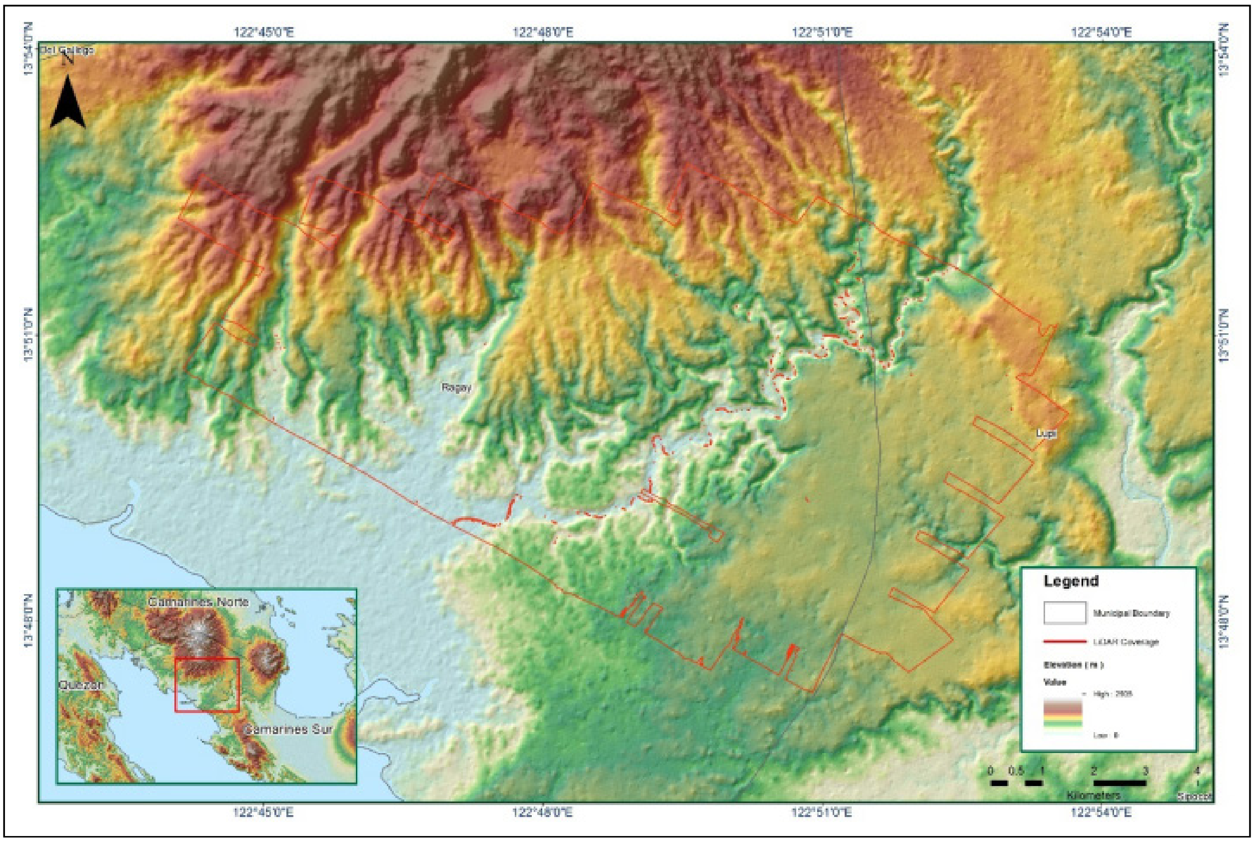


Figure A-8.4. Coverage of LiDAR data

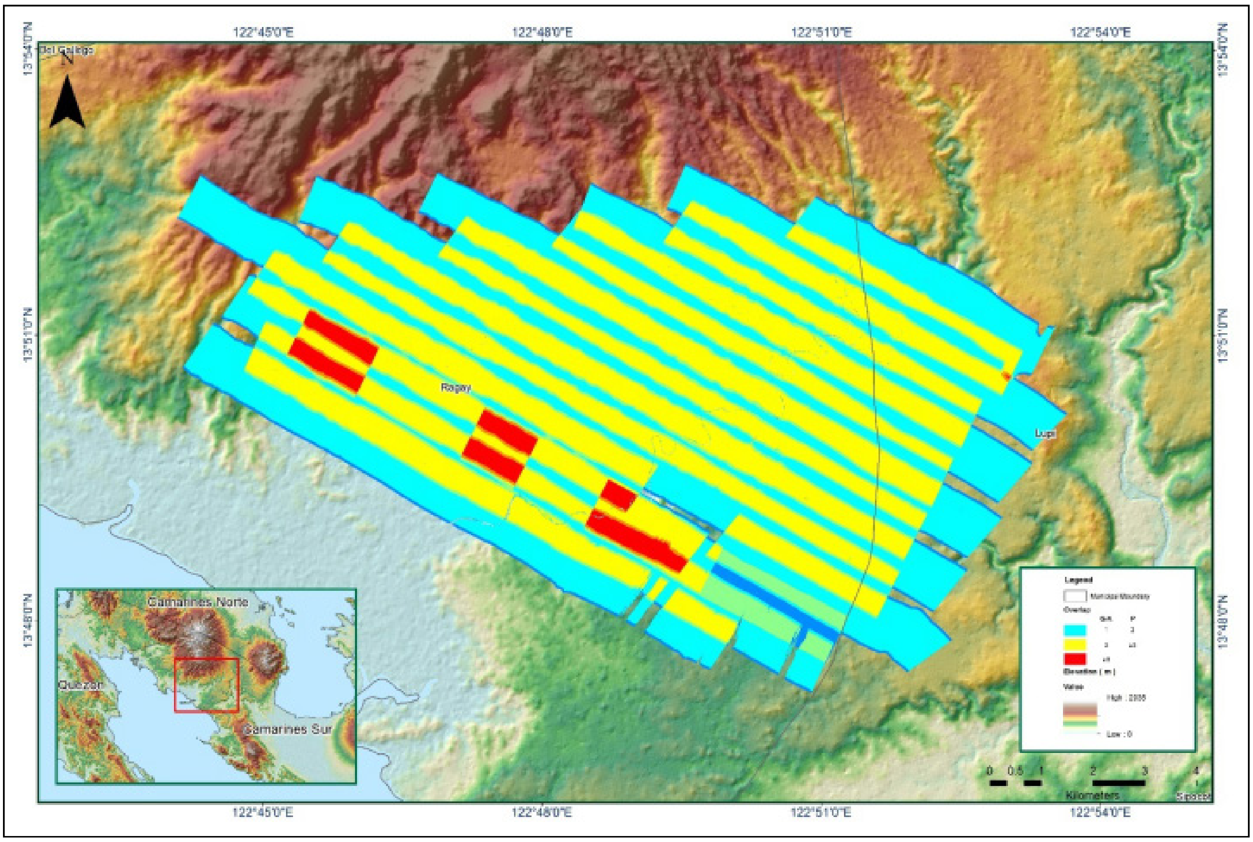


Figure A-8.5. Image of Data Overlap

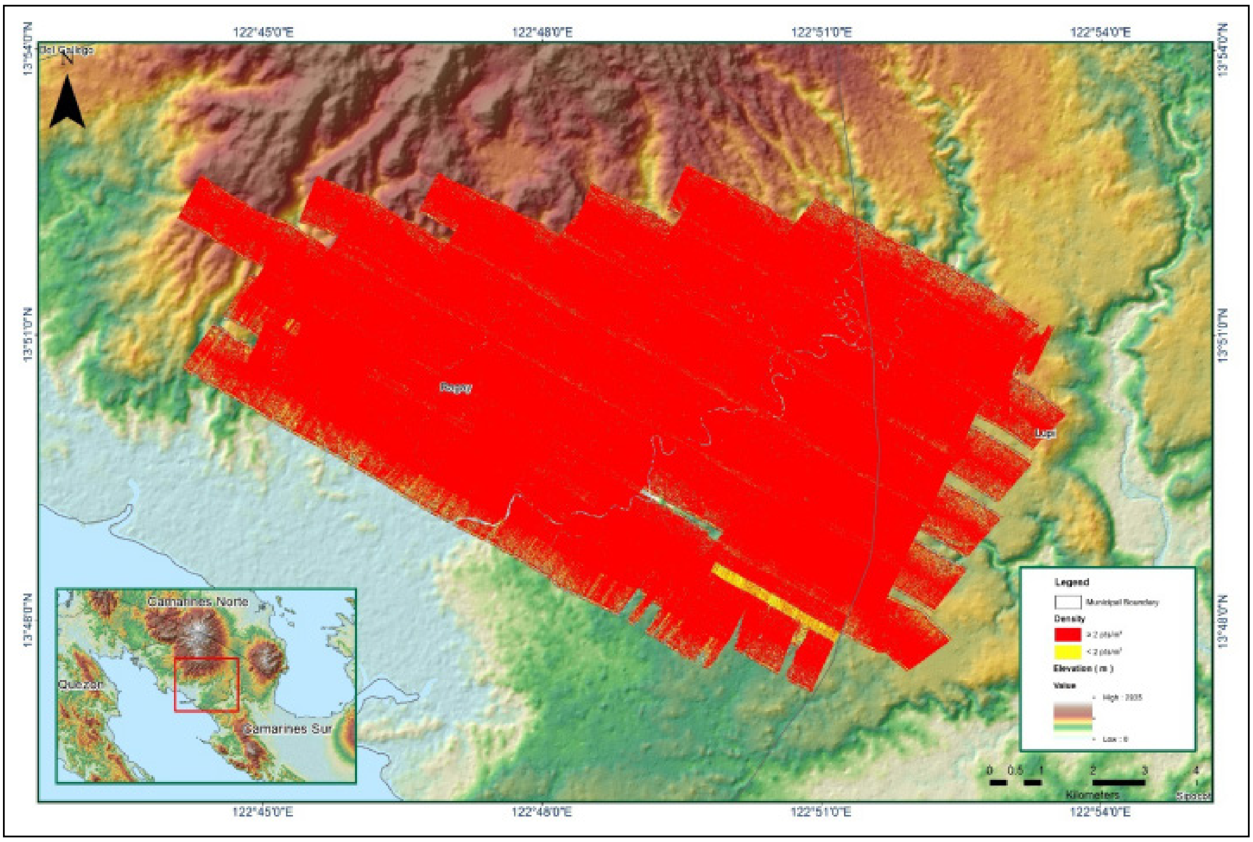


Figure A-8.6. Density map of merged LiDAR data

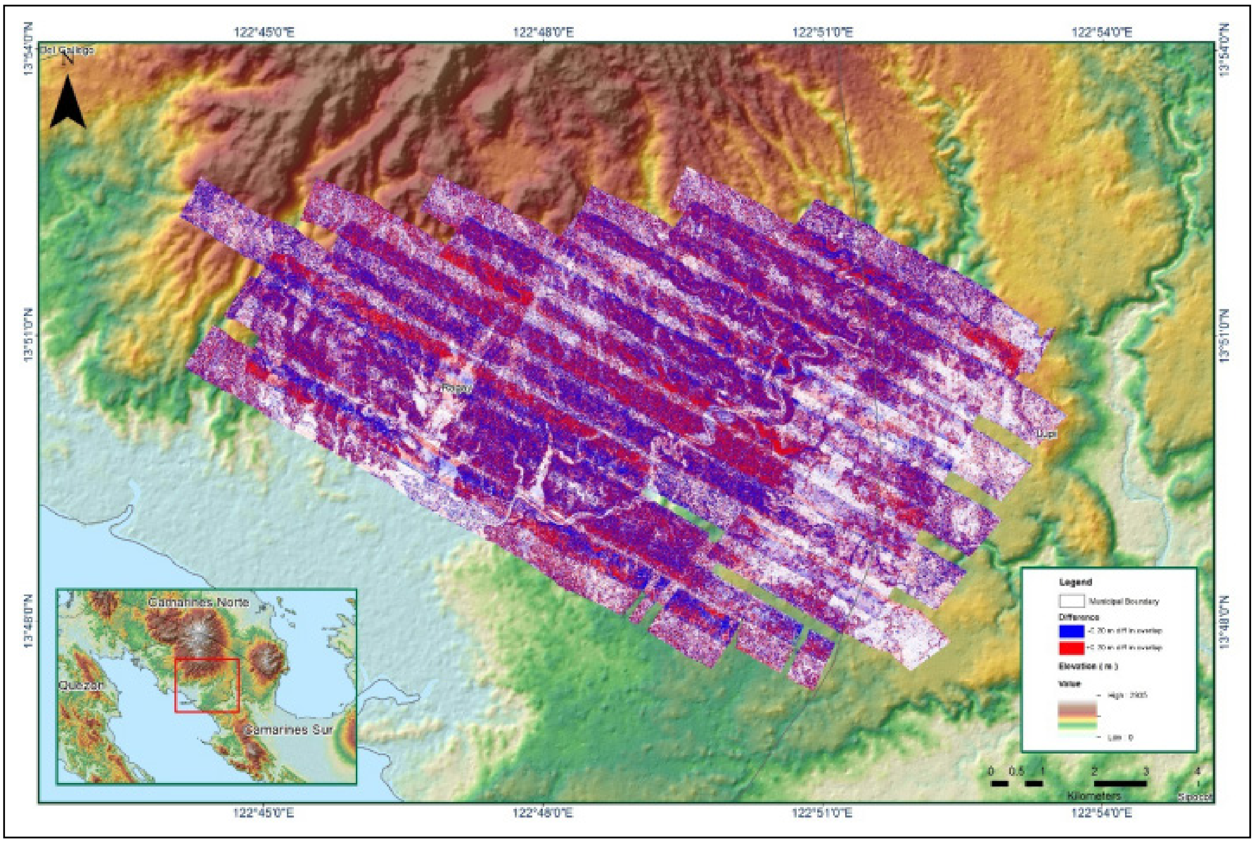


Figure A-8.7. Elevation difference between flight lines

Table A-8.2. Mission Summary Report for Mission Bagasbas Block 20L

Flight Area	Bagasbas
Mission Name	Bagasbas Block 20L
Inclusive Flights	23194P
Range data size	22.4 GB
Base data size	267 MB
POS	81.5 MB
Image	n/a
Transfer date	April 11,2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.0
RMSE for East Position (<4.0 cm)	1.4
RMSE for Down Position (<8.0 cm)	3.0
Boresight correction stdev (<0.001deg)	0.000300
IMU attitude correction stdev (<0.001deg)	-
GPS position stdev (<0.01m)	0.0026
Minimum % overlap (>25)	54.52%
Ave point cloud density per sq.m. (>2.0)	3.56
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	134
Maximum Height	229.85
Minimum Height	51.35
Classification (# of points)	
Ground	73162362
Low vegetation	54622805
Medium vegetation	113855998
High vegetation	294409517
Building	3421396
Orthophoto	Yes
Processed by	Engr. Irish Cortez, Engr. Merven Matthew Natino , Marie Denise Bueno

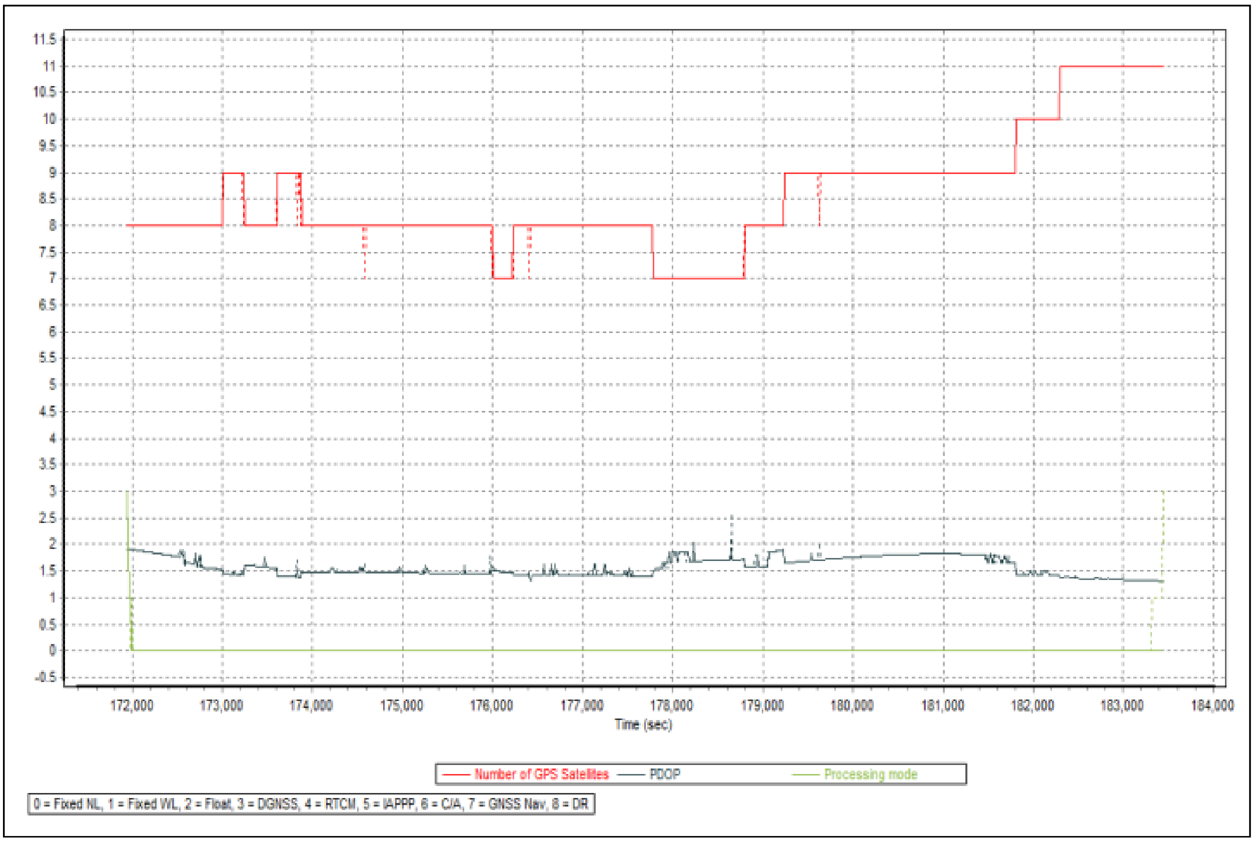


Figure A-8.8. Solution Status Parameters

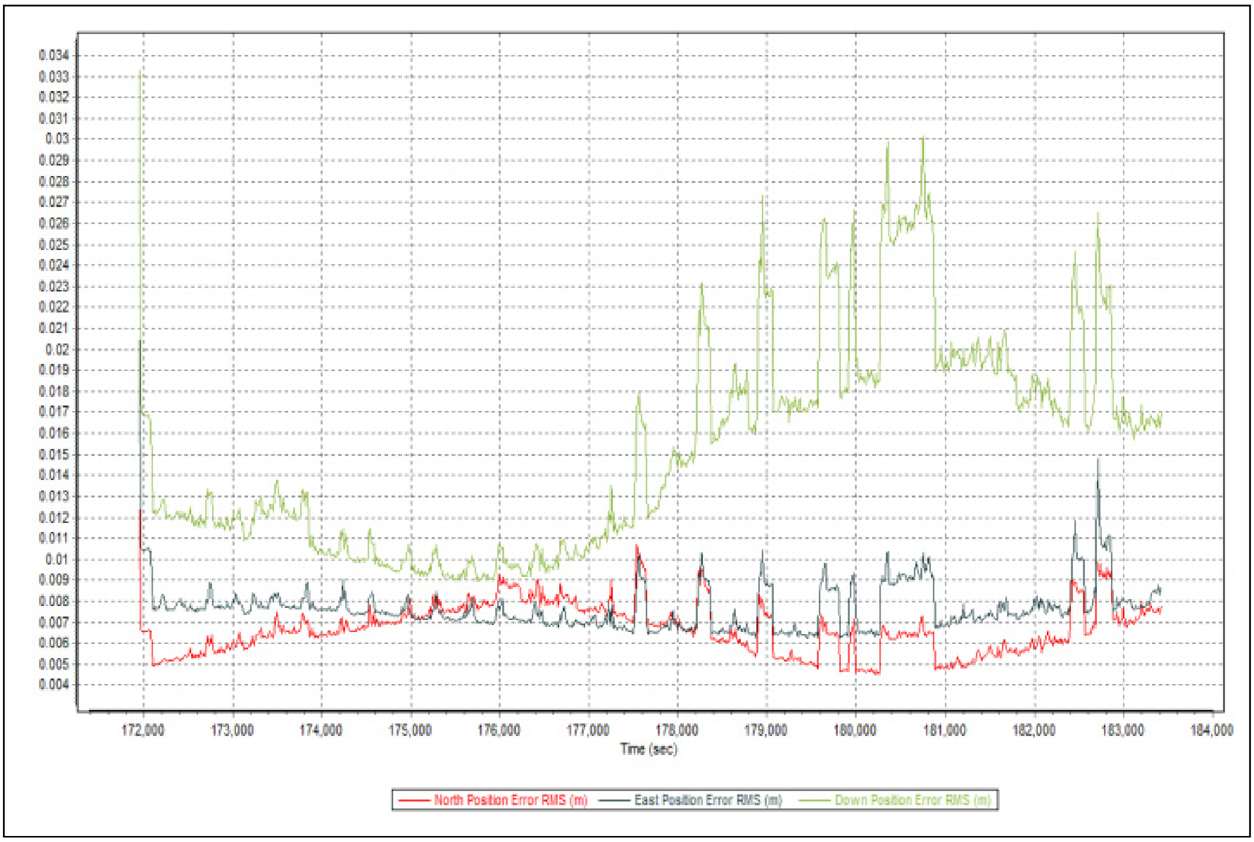


Figure A-8.9. Smoothed Performance Metrics Parameters

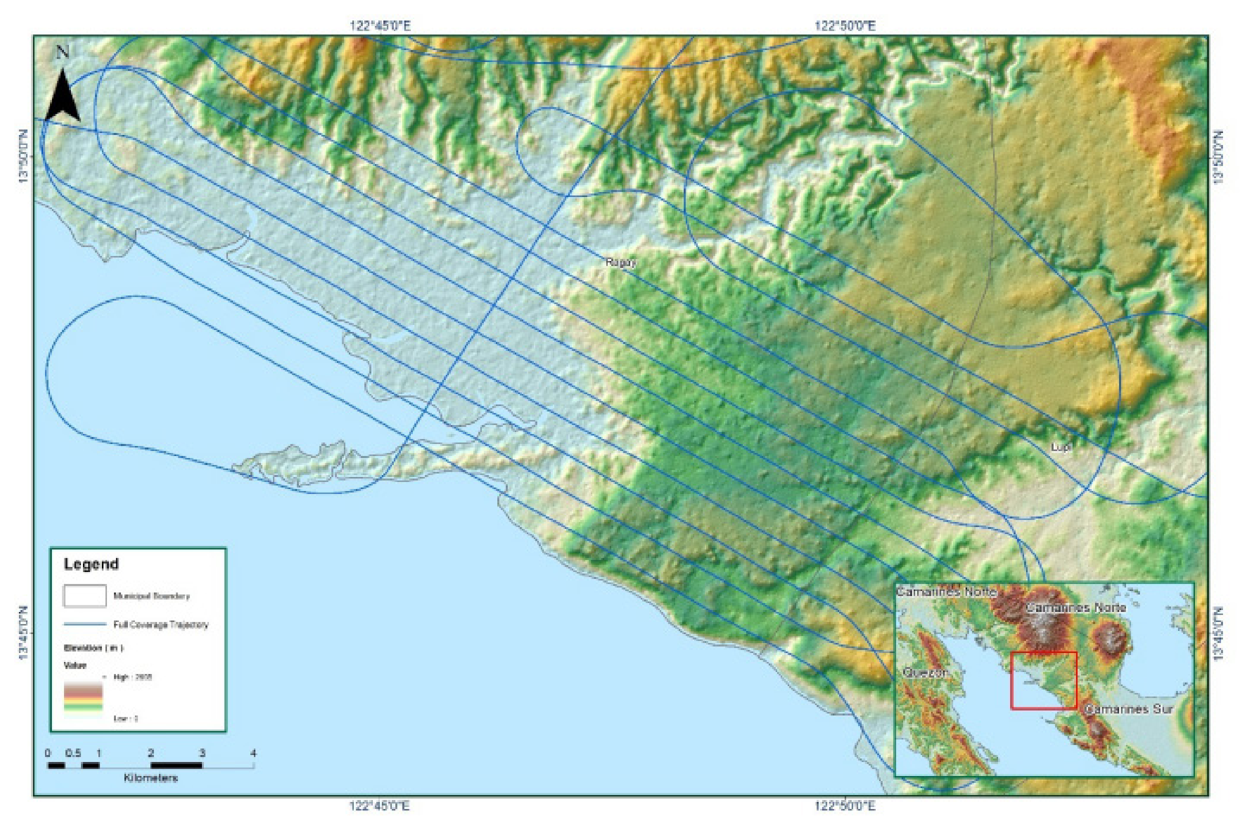


Figure A-8.10. Best Estimated Trajectory

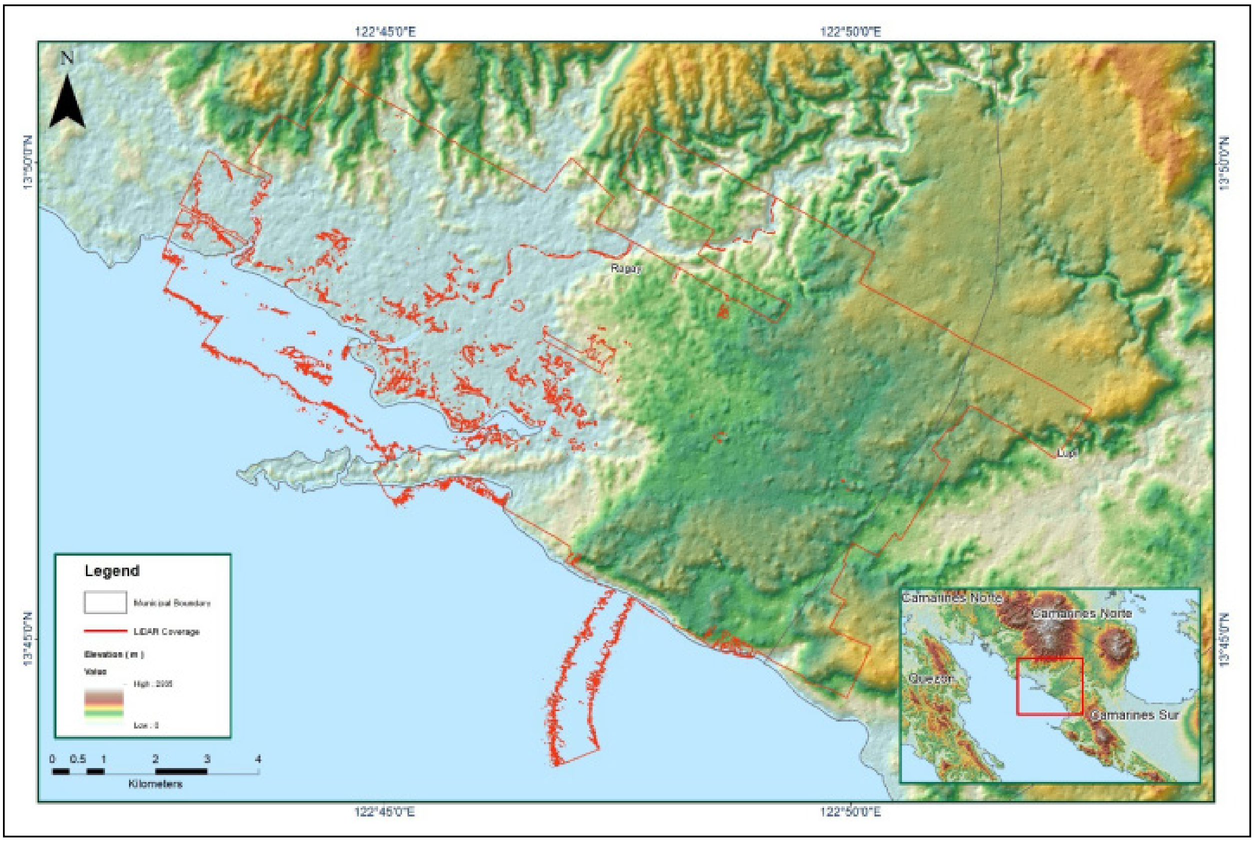


Figure A-8.11. Coverage of LiDAR data

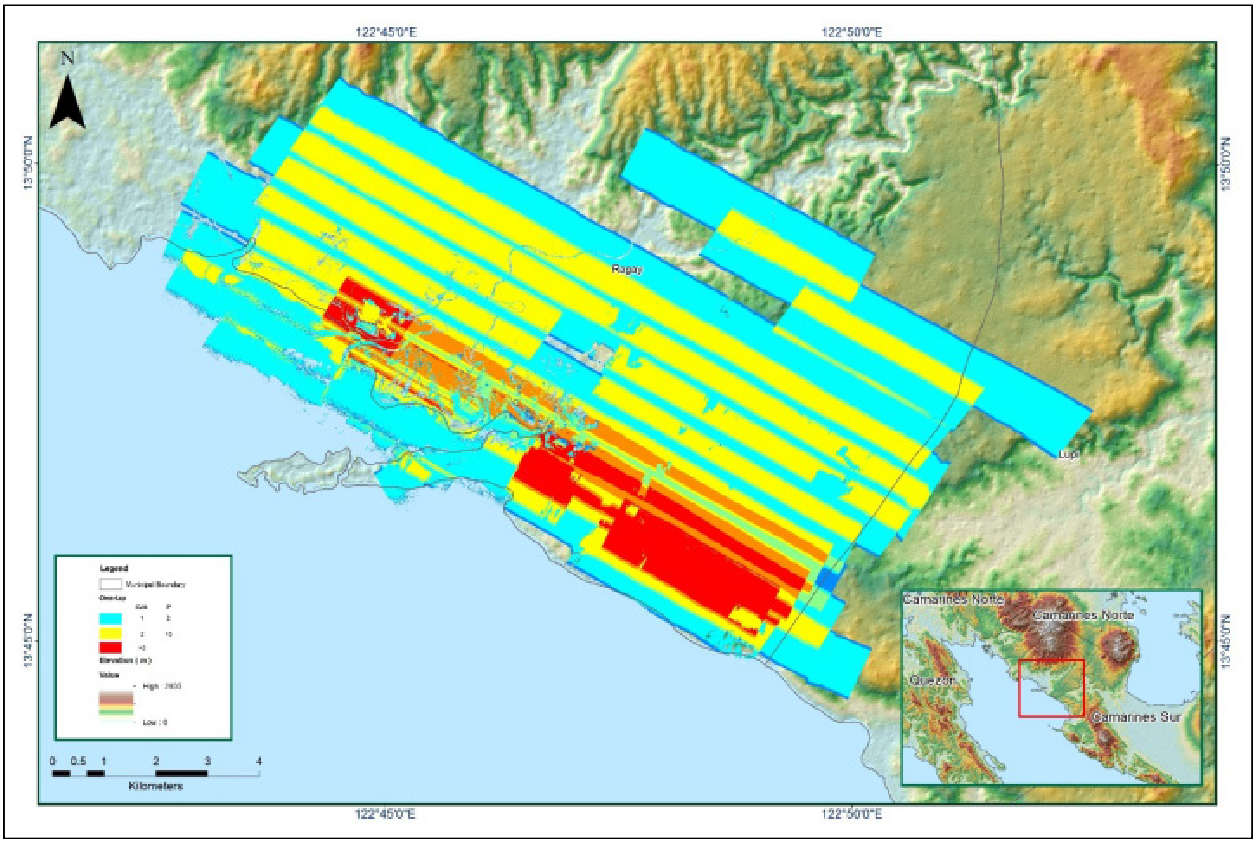


Figure A-8.12. Image of Data Overlap

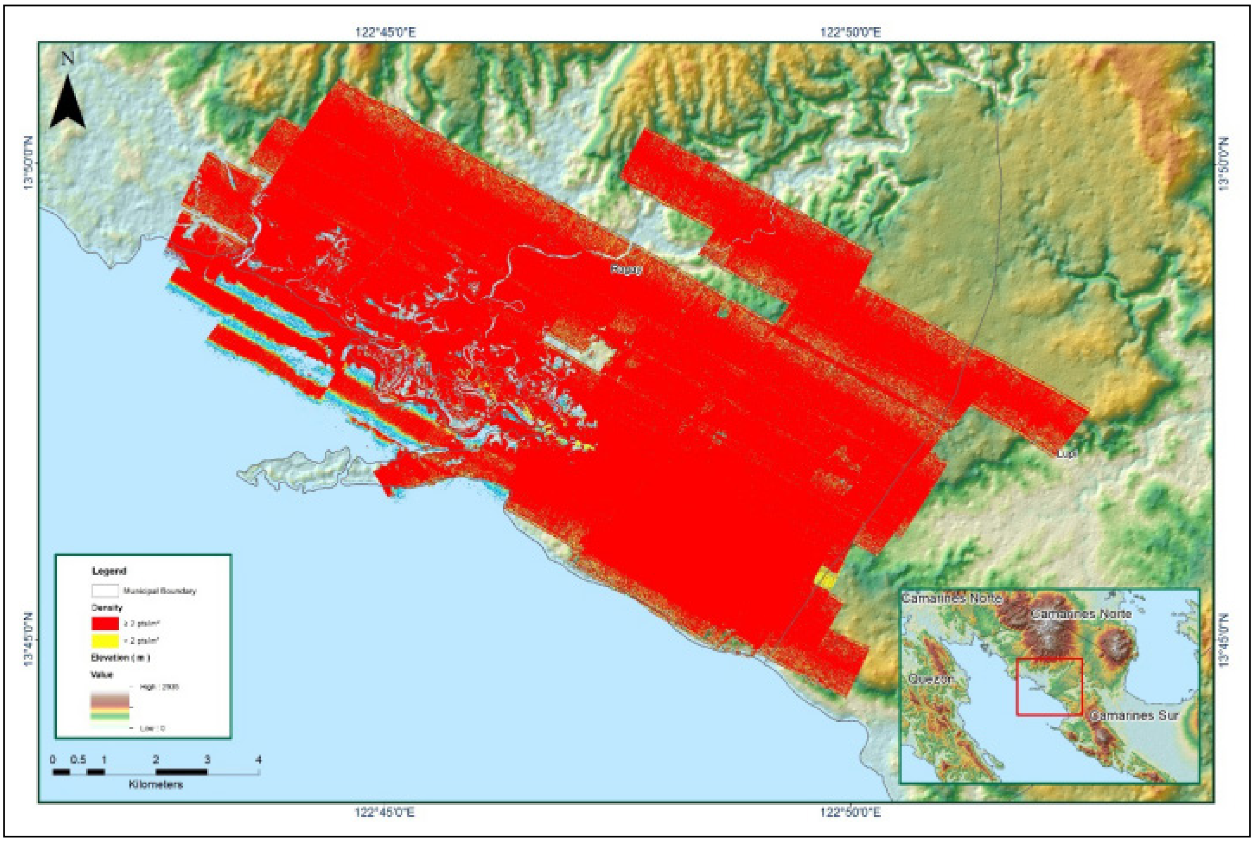


Figure A-8.13. Density map of merged LiDAR data

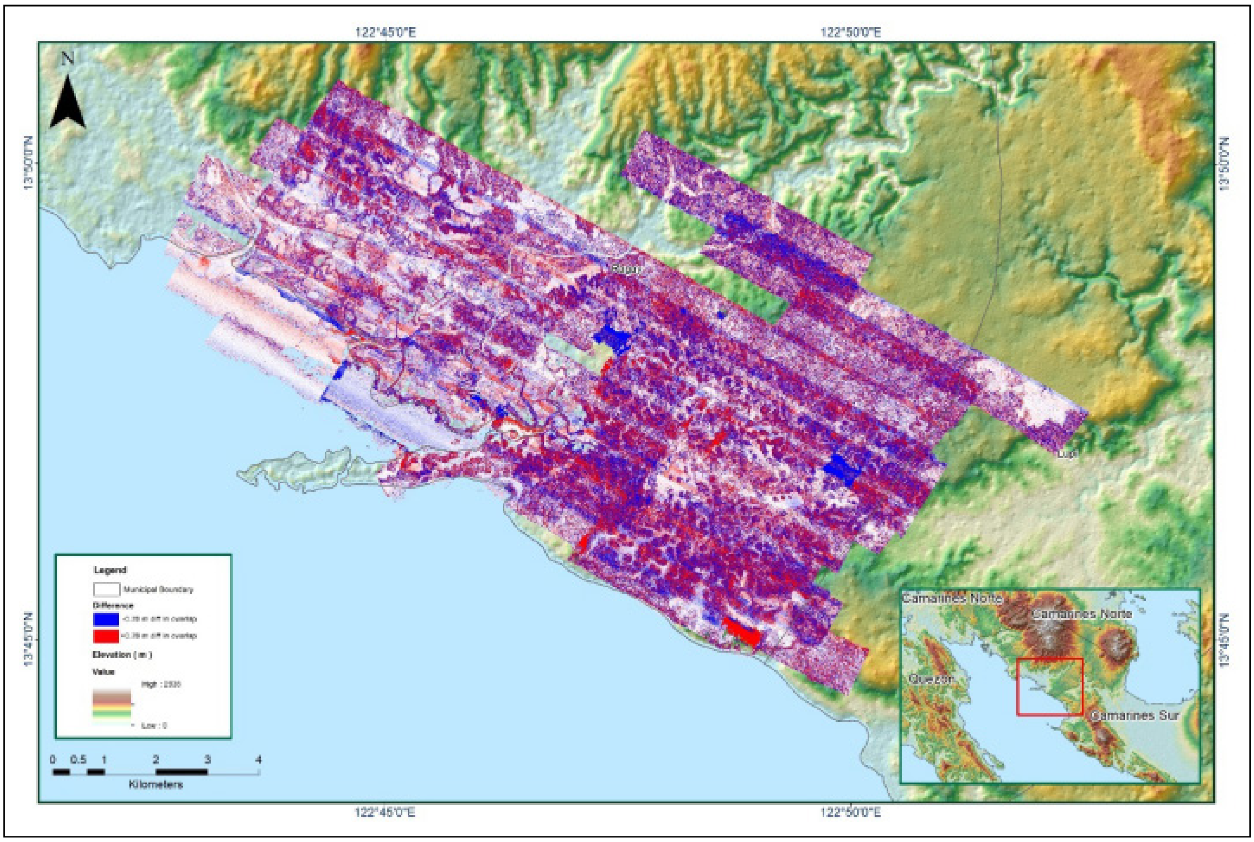


Figure A-8.14. Elevation difference between flight lines

Table A-8.3. Mission Summary Report for Mission Bagasbas Block 20M

Flight Area	Bagasbas
Mission Name	Bagasbas Block 20M
Inclusive Flights	23194P
Range data size	22.4 GB
Base data size	267 MB
POS	81.5 MB
Image	n/a
Transfer date	April 11,2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.0
RMSE for East Position (<4.0 cm)	1.4
RMSE for Down Position (<8.0 cm)	3.0
Boresight correction stdev (<0.001deg)	0.000234
IMU attitude correction stdev (<0.001deg)	0.000720
GPS position stdev (<0.01m)	0.0019
Minimum % overlap (>25)	44.13%
Ave point cloud density per sq.m. (>2.0)	2.50
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	113
Maximum Height	200.64
Minimum Height	51.63
Classification (# of points)	
Ground	
Low vegetation	59642134
Medium vegetation	79822281
High vegetation	147741501
Building	1902488
Orthophoto	Yes
Processed by	Engr. Irish Cortez, Aljon Rie Araneta, Engr. Elainne Lopez

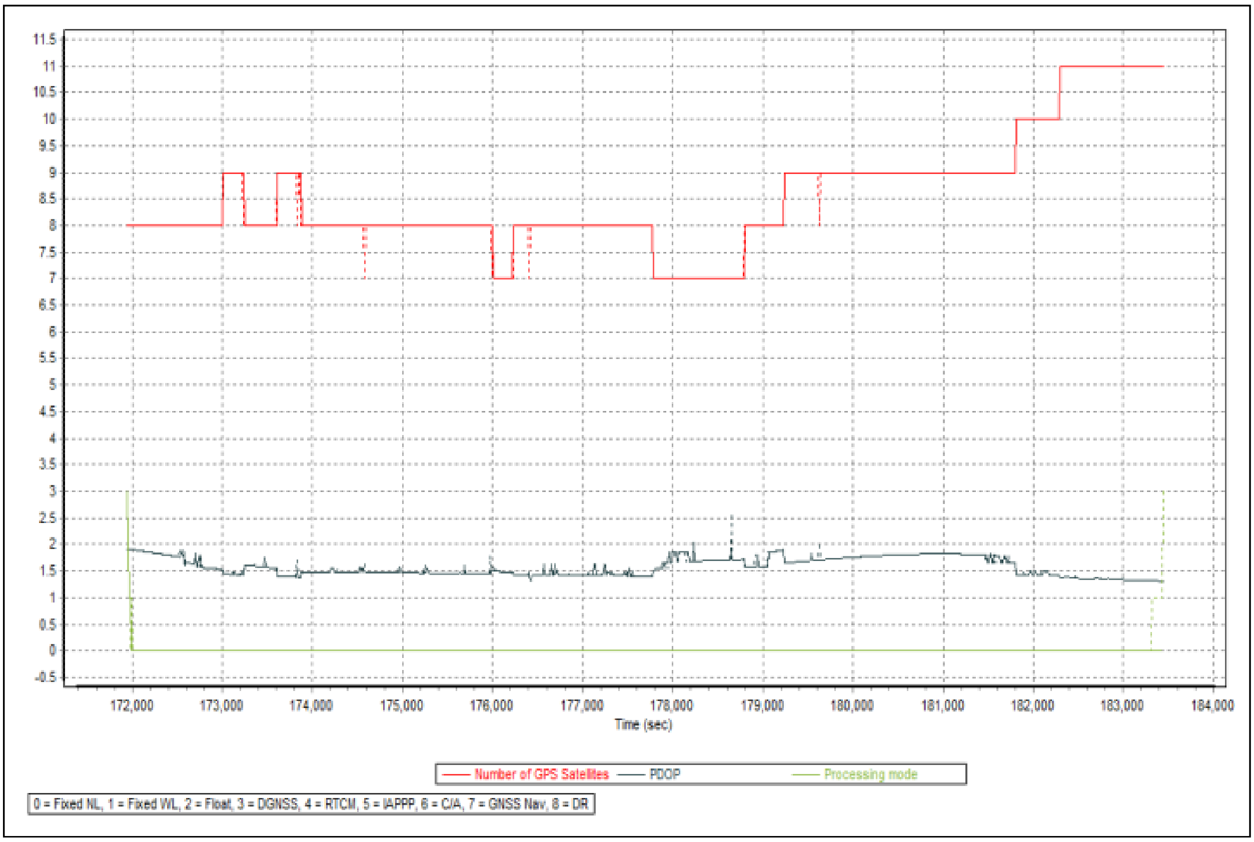


Figure A-8.15. Solution Status

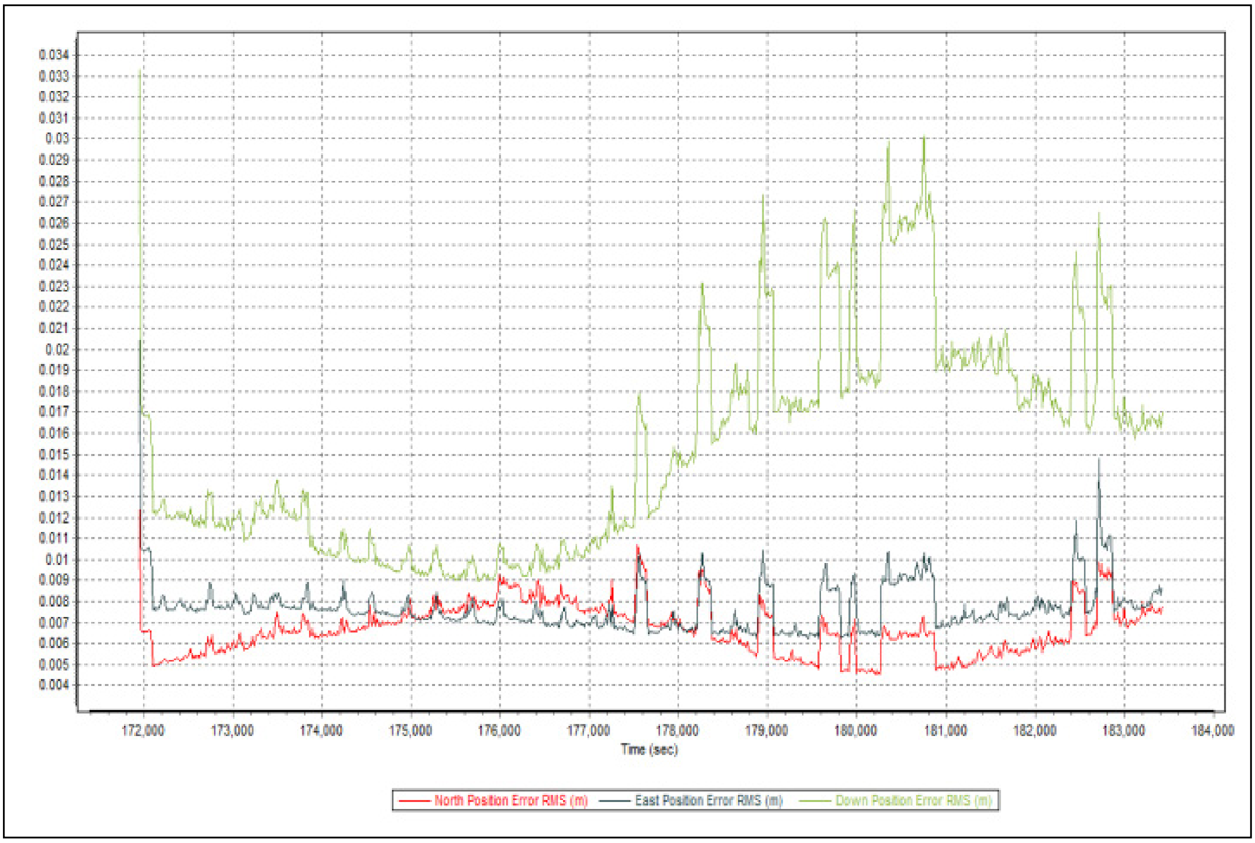


Figure A-8.16. Smoothed Performance Metric Parameters

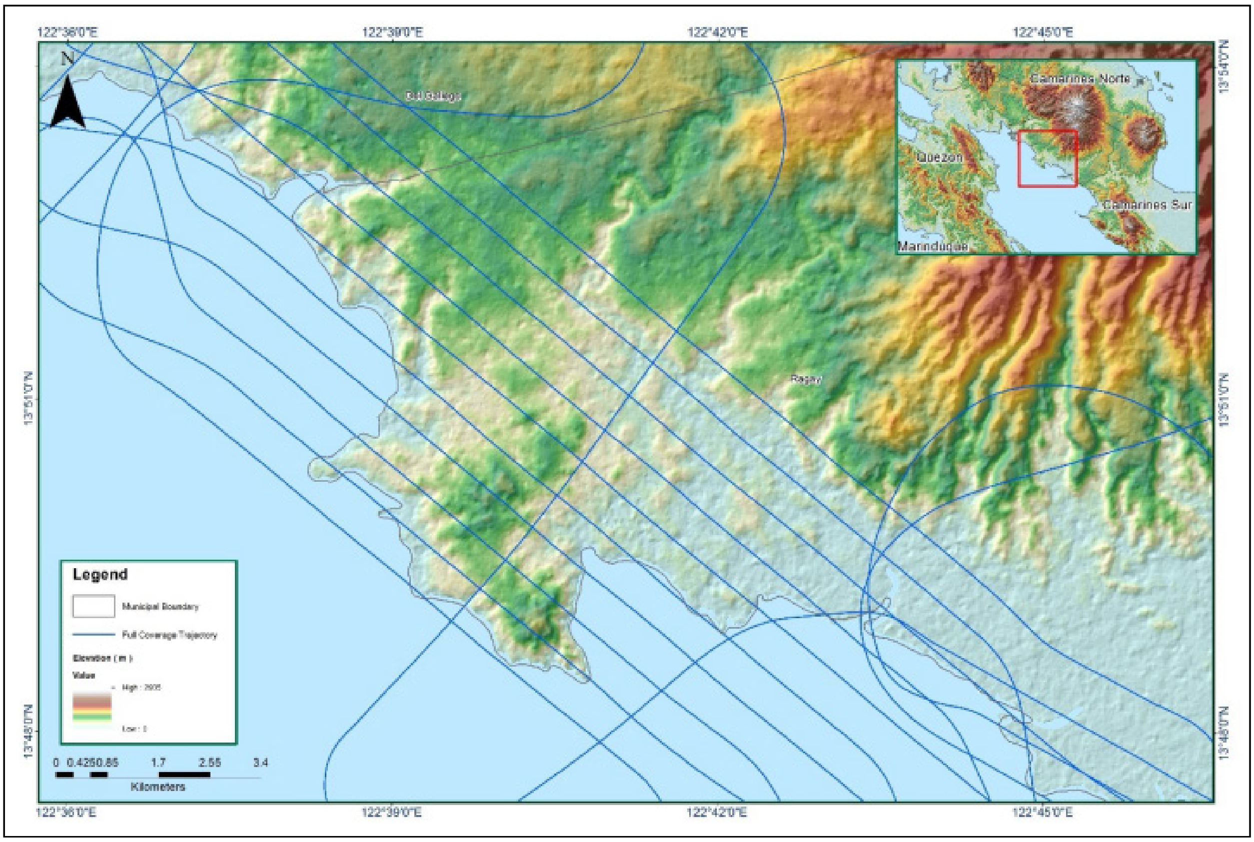


Figure A-8.17. Best Estimated Trajectory

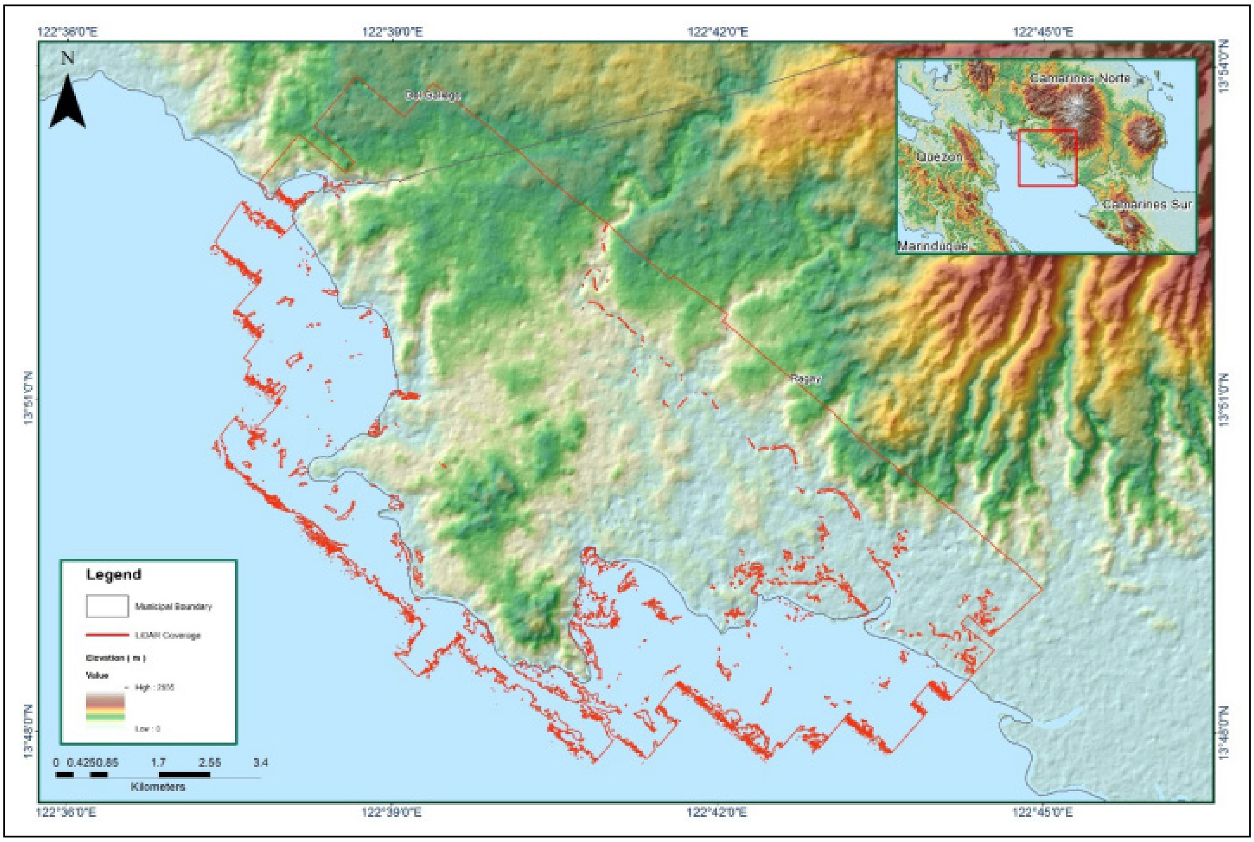


Figure A-8.18. Coverage of LiDAR data

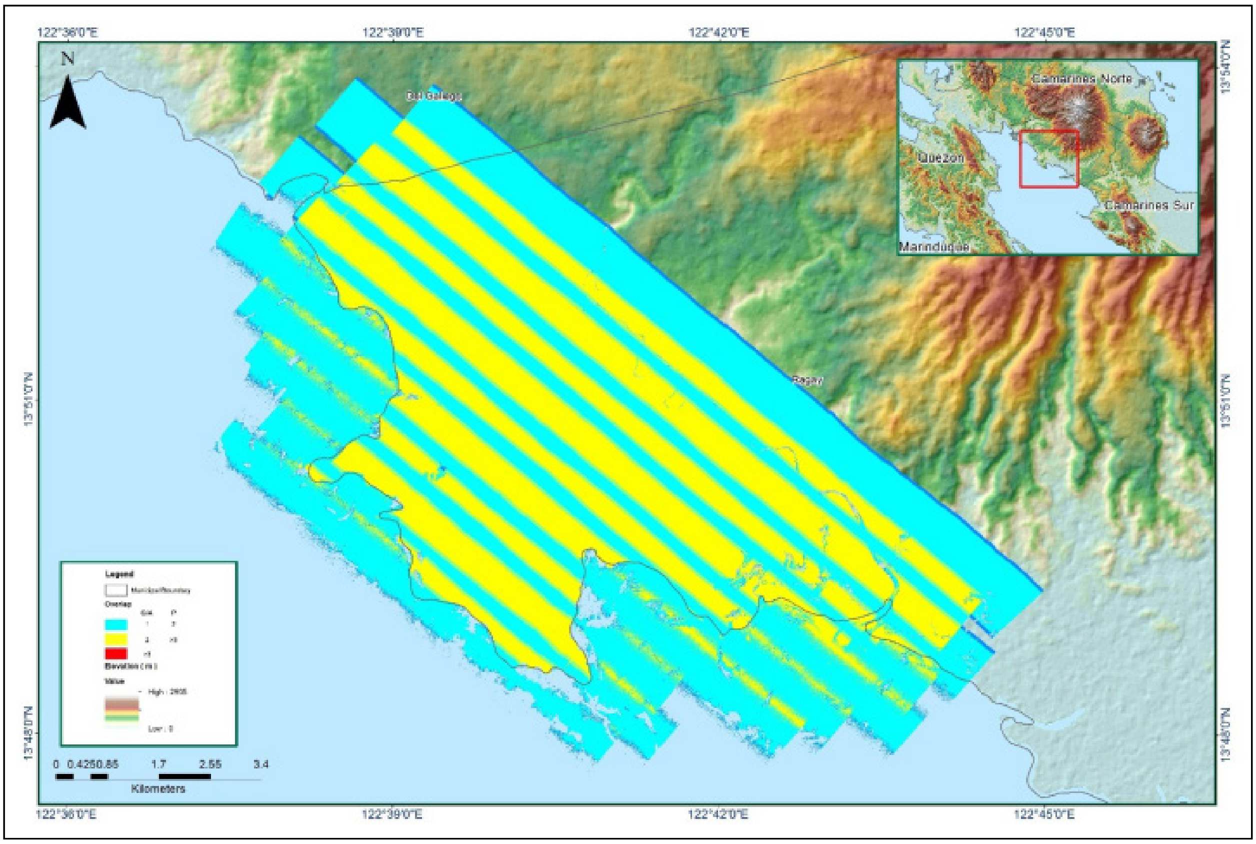


Figure A-8.19. Image of Data Overlap

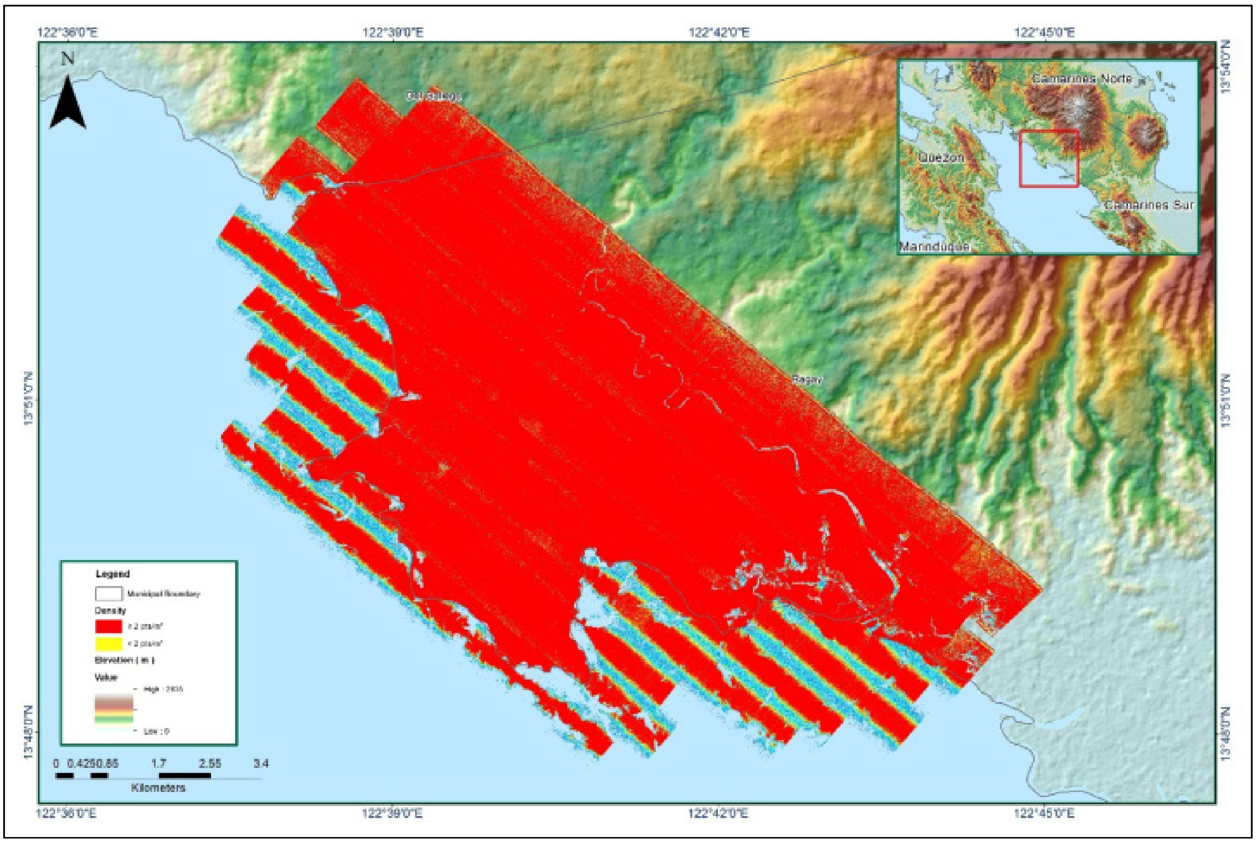


Figure A-8.20. Density map of merged LiDAR data

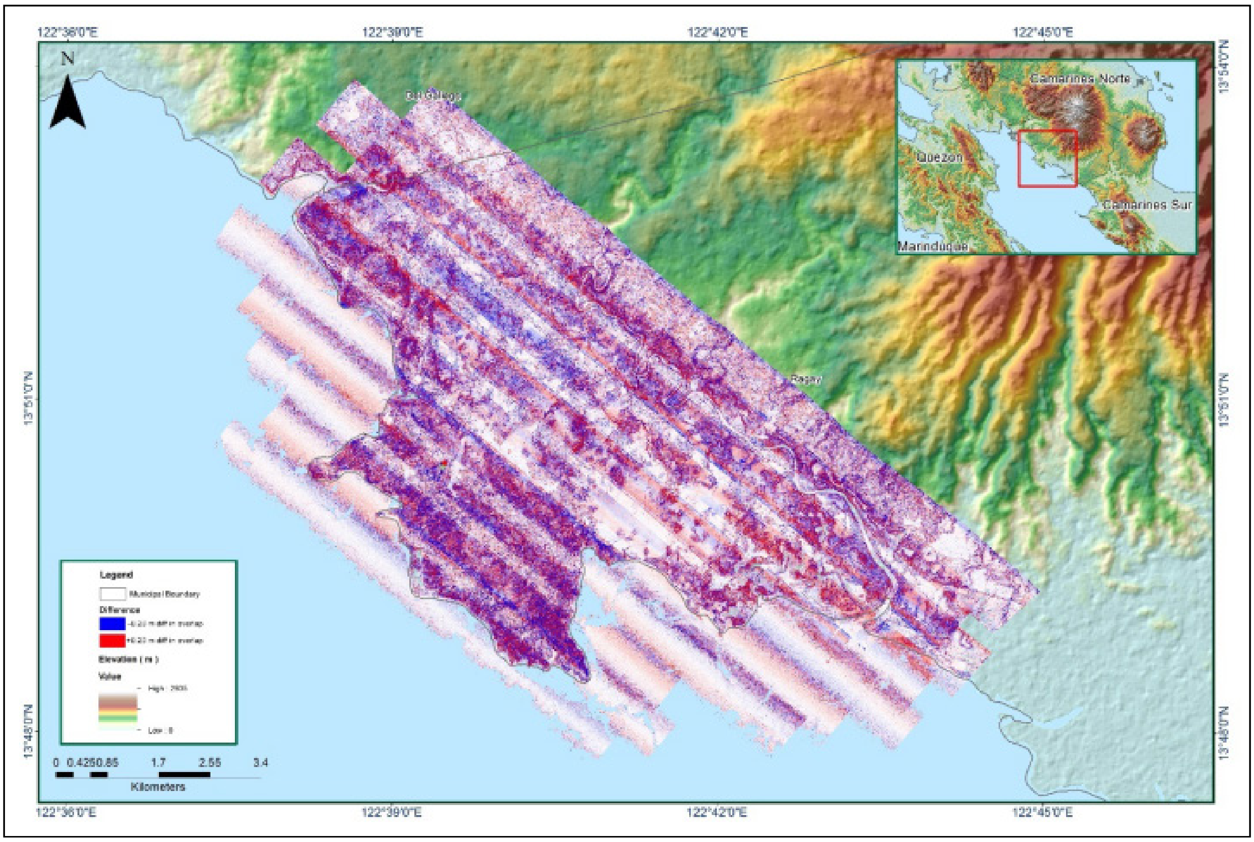


Figure A-8.21. Elevation difference between flight lines

Annex 9. Ragay Model Basin Parameters

Table A-9.1. Ragay 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
W180	0.016	83.583	0	0.017	0.60325	Discharge	6.3543	0.00827	Ratio to Peak	0.02471
W190	1.825	77.583	0	0.017	6.82630	Discharge	5.4141	0.00269	Ratio to Peak	0.68206
W200	0.001	97.059	0	0.017	6.86000	Discharge	4.7059	0.00126	Ratio to Peak	0.08055
W210	0.295	92.216	0	0.020	0.01667	Discharge	4.6709	0.00268	Ratio to Peak	0.17986
W220	0.873	98.617	0	0.020	0.08284	Discharge	2.0310	0.00127	Ratio to Peak	0.16416
W230	1.256	60.248	0	0.020	0.62778	Discharge	0.6158	0.00039	Ratio to Peak	0.01112
W240	35.312	99.000	0	0.020	0.50000	Discharge	1.8277	0.00086	Ratio to Peak	0.20000
W250	2.119	99.000	0	0.144	3.07800	Discharge	0.6470	0.00058	Ratio to Peak	0.05915
W260	0.010	69.486	0	0.130	7.63270	Discharge	1.3368	0.00276	Ratio to Peak	0.10406
W270	0.160	60.485	0	0.497	3.90890	Discharge	0.2713	0.00250	Ratio to Peak	0.12716
W280	0.084	97.072	0	0.133	0.06667	Discharge	2.9998	0.00086	Ratio to Peak	0.08462
W290	0.057	99.000	0	0.020	0.06667	Discharge	0.0451	0.00038	Ratio to Peak	0.06767
W300	0.036	53.177	0	0.020	0.05926	Discharge	1.2920	0.00312	Ratio to Peak	0.10000
W310	0.084	99.000	0	0.128	0.05926	Discharge	2.6148	0.00203	Ratio to Peak	0.08463
W320	1.110	96.803	0	0.017	0.06916	Discharge	0.8094	0.00222	Ratio to Peak	0.06084
W330	0.123	97.729	0	0.017	0.06453	Discharge	0.9090	0.00149	Ratio to Peak	0.05994
W340	0.850	66.320	0	0.020	0.14347	Discharge	1.2550	0.02216	Ratio to Peak	0.35655

Annex 10. Ragay Model Reach Parameters

Table A-10.1. Ragay 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 Interval	2719.0	0.00385	0.43764	Trapezoid	60.9	1
R60	Automatic Fixed Interval	2093.2	0.00694	1.00000	Trapezoid	60.9	1
R80	Automatic Fixed Interval	446.0	0.00847	1.00000	Trapezoid	60.9	1
R90	Automatic Fixed Interval	1081.5	0.00626	1.00000	Trapezoid	60.9	1
R140	Automatic Fixed Interval	1175.3	0.00096	0.00421	Trapezoid	60.9	1
R150	Automatic Fixed Interval	5616.9	0.00021	0.07840	Trapezoid	60.9	1
R160	Automatic Fixed Interval	2677.7	0.00071	0.29037	Trapezoid	60.9	1
R170	Automatic Fixed Interval	3635.8	0.00217	0.65762	Trapezoid	60.9	1

Annex 11. Ragay Field Validation Points

Table A-11.1. Ragay Field Validation Points

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Lat	Long					
1	13.8223	122.7582	0.04	0	0.04		5-Year
2	13.82089	122.7567	0.04	0	0.04		5-Year
3	13.8222	122.7583	0.09	0	0.09		5-Year
4	13.8219	122.7587	0.05	0	0.05		5-Year
5	13.82152	122.7589	1.3	0	1.3		5-Year
6	13.82127	122.7591	1.65	0	1.65		5-Year
7	13.81884	122.7637	1.47	2	-0.53		5-Year
8	13.81699	122.7659	1.12	0	1.12		5-Year
9	13.81494	122.7659	0.94	0	0.94		5-Year
10	13.82006	122.7713	3.12	3	0.12		5-Year
11	13.81869	122.793	0.64	0	0.64		5-Year
12	13.82061	122.7908	1.24	0.004	1.236		5-Year
13	13.82051	122.7905	1.24	0.009	1.231		5-Year
14	13.82009	122.7926	1.21	0.002	1.208		5-Year
15	13.8203	122.7938	1.09	0.006	1.084		5-Year
16	13.82097	122.7927	1.14	0.0085	1.1315		5-Year
17	13.82293	122.7574	1.04	0	1.04		5-Year
18	13.82311	122.7571	0.26	0	0.26		5-Year
19	13.8096	122.7435	1.07	0.0012	1.0688		5-Year
20	13.8096	122.7435	1.07	0.0039	1.0661		5-Year
21	13.81032	122.744	1.71	0	1.71		5-Year
22	13.81053	122.7442	1.6	0	1.6		5-Year
23	13.811	122.7449	1.67	0.0193	1.6507		5-Year
24	13.81132	122.7457	1.67	0.006	1.664		5-Year
25	13.81248	122.7475	1.77	0.008	1.762		5-Year
26	13.8135	122.748	1.77	0.018	1.752		5-Year
27	13.8135	122.748	1.5	1.8	-0.3		5-Year
28	13.82206	122.7585	1.37	0.31	1.06		5-Year
29	13.82183	122.7587	1.37	1.4	-0.03		5-Year
30	13.81456	122.7681	1.36	0	1.36		5-Year
31	13.81434	122.7685	0.03	1.02	-0.99		5-Year
32	13.81434	122.7689	0.03	1.99	-1.96		5-Year
33	13.81434	122.7689	0.03	1.35	-1.32		5-Year
34	13.81428	122.7691	1.51	1.6	-0.09		5-Year
35	13.81428	122.7691	1.51	0.55	0.96		5-Year
36	13.81422	122.7693	1.18	2.19	-1.01		5-Year
37	13.81407	122.7698	1.18	0.9	0.28		5-Year
38	13.81407	122.7698	0.23	2.1	-1.87		5-Year
39	13.81388	122.7702	0.03	1.85	-1.82		5-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Lat	Long					
40	13.81446	122.7705	0.03	1.99	-1.96		5-Year
41	13.81446	122.7705	0.03	1.35	-1.32		5-Year
42	13.81447	122.7706	1.51	1.6	-0.09		5-Year
43	13.82283	122.7763	1.51	0.55	0.96		5-Year
44	13.82283	122.7763	1.18	2.19	-1.01		5-Year
45	13.82358	122.7761	1.18	0.9	0.28		5-Year
46	13.82358	122.7761	0.23	2.1	-1.87		5-Year
47	13.8228	122.7818	0.03	1.85	-1.82		5-Year
48	13.8228	122.7818	1.12	0	1.12		5-Year
49	13.82276	122.7819	0.2	1.73	-1.53		5-Year
50	13.82227	122.7826	0.21	1.67	-1.46		5-Year
51	13.82221	122.7827	0.21	0.9	-0.69		5-Year
52	13.82221	122.7827	0.85	1.8	-0.95		5-Year
53	13.82171	122.7831	0.85	2.6	-1.75		5-Year
54	13.82171	122.7831	0.76	0.5	0.26		5-Year
55	13.82167	122.7836	0.76	2.14	-1.38		5-Year
56	13.82167	122.7836	1.83	2.38	-0.55		5-Year
57	13.81941	122.7873	2.37	1.08	1.29		5-Year
58	13.82004	122.7877	2.29	0.82	1.47		5-Year
59	13.82017	122.7881	2.29	1.21	1.08		5-Year
60	13.82017	122.7881	2.38	0.66	1.72		5-Year
61	13.82006	122.7883	2.2	0.98	1.22		5-Year
62	13.81972	122.7887	2.2	1.9	0.3		5-Year
63	13.81972	122.7887	1.26	0.3	0.96		5-Year
64	13.81861	122.7886	1.33	0	1.33		5-Year
65	13.81853	122.7887	1.18	1.18	0		5-Year
66	13.81833	122.789	0.64	0.9	-0.26		5-Year
67	13.81814	122.7888	0.58	0.41	0.17		5-Year
68	13.81807	122.7894	0.56	0.86	-0.3		5-Year
69	13.81789	122.7897	0.64	0.9	-0.26		5-Year
70	13.81788	122.7898	0.48	1.7	-1.22		5-Year
71	13.81798	122.7901	1.16	0.3	0.86		5-Year
72	13.81789	122.7901	2.28	1.6	0.68		5-Year
73	13.81761	122.7904	2.53	1.4	1.13		5-Year
74	13.81746	122.7903	2.53	0.21	2.32		5-Year
75	13.81736	122.7905	2.22	2.5	-0.28		5-Year
76	13.81736	122.7905	2.34	1.97	0.37		5-Year
77	13.81729	122.791					
78	13.81724	122.7911	0.85	0.53	0.32		5-Year
79	13.81785	122.7914	1.34	2.44	-1.1		5-Year
80	13.81785	122.7914	1.24	0.3	0.94		5-Year
81	13.81863	122.7915	0.78	0.41	0.37		5-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Lat	Long					
82	13.8187	122.7913	0.54	0	0.54		5-Year
83	13.81822	122.7907	0.45	0	0.45		5-Year
84	13.81803	122.7905	1.4	0	1.4		5-Year
85	13.81794	122.7903	1.51	0.8	0.71		5-Year
86	13.82196	122.7576	1.07	1.1	-0.03		5-Year
87	13.80968	122.7435	1.04	0.9	0.14		5-Year
88	13.81016	122.7437	0.91	1	-0.09		5-Year
89	13.81074	122.7443	1.03	0.7	0.33		5-Year
90	13.81129	122.7453	0.4	0.4	0		5-Year
91	13.81129	122.7455	2.08	0.5	1.58		5-Year
92	13.81175	122.7464	2.03	1	1.03		5-Year
93	13.81214	122.7471	1.57	1.5	0.07		5-Year
94	13.81744	122.7547	1.47	0.4	1.07		5-Year
95	13.81741	122.7548	0.03	0	0.03		5-Year
96	13.81525	122.7687	0.05	1.2	-1.15		5-Year
97	13.81495	122.7683	0.09	1.4	-1.31		5-Year
98	13.81467	122.7682	1.18	2	-0.82		5-Year
99	13.81443	122.7677	0.04	1.9	-1.86		5-Year
100	13.81462	122.7675	0.03	1.5	-1.47		5-Year
101	13.81494	122.7658	0.25	1.5	-1.25		5-Year
102	13.81533	122.7655	1.85	0	1.85		5-Year
103	13.81531	122.7658	1.12	2	-0.88		5-Year
104	13.81517	122.7665	3.54	3	0.54		5-Year
105	13.81498	122.7677	1.93	2	-0.07		5-Year
106	13.81587	122.7692	2.61	2	0.61		5-Year
107	13.82309	122.7762	0.94	2.9	-1.96		5-Year
108	13.8228	122.7793	1.3	2.9	-1.6		5-Year
109	13.82279	122.78	0.86	0.8	0.06		5-Year
110	13.8226	122.7805	1.03	0.7	0.33		5-Year
111	13.82285	122.7809	1.24	1.2	0.04		5-Year
112	13.82312	122.7815	1.23	2	-0.77		5-Year
113	13.82337	122.7813	3.7	1.4	2.3		5-Year
114	13.81961	122.7927	0.76	2	-1.24		5-Year
115	13.81935	122.7931	0.94	1	-0.06		5-Year
116	13.81935	122.793	0.94	2	-1.06		5-Year
117	13.81847	122.7928	1.14	1.6	-0.46		5-Year
118	13.81835	122.793	1.45	0.4	1.05		5-Year
119	13.81872	122.7931	1.18	0.9	0.28		5-Year
120	13.81845	122.7923	1.34	2.44	-1.1		5-Year
121	13.81783	122.7921	1.24	0.3	0.94		5-Year
122	13.81788	122.792	0.78	0.41	0.37		5-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Lat	Long					
123	13.81884	122.792	1.41	0.9	0.51		5-Year
124	13.81885	122.7913	0.94	1.2	-0.26		5-Year
125	13.81941	122.7912	1.11	1.2	-0.09		5-Year
126	13.81937	122.7912	0.93	0	0.93		5-Year
127	13.82003	122.7909	0.03	0.7	-0.67		5-Year
128	13.8206	122.7908	0.03	1.9	-1.87		5-Year
129	13.82033	122.7904	1.5	1.4	0.1		5-Year
130	13.82027	122.7919	1.63	1.3	0.33		5-Year
131	13.82023	122.7923	1.05	1.6	-0.55		5-Year
132	13.82007	122.7926	0.67	1.6	-0.93		5-Year
133	13.81953	122.7935	0.37	0	0.37		5-Year
134	13.82027	122.7936	0.49	0	0.49		5-Year
135	13.82079	122.793	0.4	0	0.4		5-Year
136	13.82062	122.7924	0.43	0	0.43		5-Year
137	13.81197	122.7468	0.03	0	0.03		5-Year
138	13.81204	122.7466	0.03	0	0.03		5-Year
139	13.81215	122.7471	0.03	0	0.03		5-Year
140	13.81208	122.7473	1.92	0.9144	1.0056		5-Year
141	13.82047	122.7596	0.03	1.5	-1.47		5-Year
142	13.82004	122.7599	0.25	1.5	-1.25		5-Year
143	13.81987	122.7603	1.85	0	1.85		5-Year
144	13.81415	122.771	1.12	2	-0.88		5-Year
145	13.8139	122.7706	3.54	3	0.54		5-Year
146	13.82223	122.7766	1.93	2	-0.07		5-Year
147	13.8238	122.7761	2.61	2	0.61		5-Year
148	13.82229	122.7778	0.94	2.9	-1.96		5-Year
149	13.82176	122.7835	1.3	2.9	-1.6		5-Year
150	13.82142	122.784	0.86	0.8	0.06		5-Year
151	13.82118	122.7844	1.03	0.7	0.33		5-Year
152	13.82056	122.7854	1.24	1.2	0.04		5-Year
153	13.82169	122.7945	1.23	2	-0.77		5-Year
154	13.82057	122.7951	3.7	1.4	2.3		5-Year
155	13.82012	122.7954	0.76	2	-1.24		5-Year
156	13.8198	122.7954	0.94	1	-0.06		5-Year
157	13.81942	122.7954	0.94	2	-1.06		5-Year
158	13.81918	122.796	1.14	1.6	-0.46		5-Year
159	13.81949	122.7963	1.45	0.4	1.05		5-Year
160	13.81926	122.7963	1.18	0.9	0.28		5-Year
161	13.81865	122.7981	1.34	2.44	-1.1		5-Year
162	13.81788	122.7984	1.24	0.3	0.94		5-Year

Annex 12. Educational Institutions affected by flooding in Ragay Floodplain

Table A-12.1. Educational Institutions in Ragay City, Camarines Sur affected by flooding in Ragay Floodplain

Camarines Sur				
Ragay				
Barangay	**Building Name**	**Rainfall Scenario**		
		5-year	**25-year**	**100-year**
Agrupacion	Agrupacion Elementary School			
Amomokpok	Amomokpok National High School	Medium	Medium	High
Amomokpok	Brgy Amomokpok Day Care Center			Medium
Apad	Apad Elem School/11 Rooms	Medium	Medium	High
Apad	Apad National High School	Medium	Medium	High
Apale	Casifmas Ragay Campus			
Apale	PUP Ragay Campus			
Banga Caves	Don M. Gonzales Memorial High School			
Baya	Little Dreamer Day Care Center			
Binahan Proper	Binahan Elementary School		Medium	Medium
Binahan Proper	Binahan Proper Day Care Center			Medium
Binahan Proper	Upper Binahan Elem School			
Binahan Upper	Upper Binahan Elem School			
Cabinitan	Cabinitan Day Care Center			
Cabinitan	Cabinitan Primary School			
Cabinitan	Don M. Gonzales Memorial High School			
Laguio	Laguio Day Care Center and Warehouse	Medium	High	High
Laguio	Laguio Elementary School			
Liboro	Paaralang Elementarya ng Liboro			
Liboro	Ragay Agricultural and Fisheries School	Low	Low	Low
Panaytayan	Panaytayan Elem School	Low	Medium	Medium
Poblacion Ilaod	CASIFMAS Ragay College		Medium	High
Poblacion Iraya	CASIFMAS Ragay College		Medium	High
Poblacion Iraya	Holy Trinity Learning Center		Low	Medium
Poblacion Iraya	Iraya Day Care Center		Low	Medium
Poblacion Iraya	Mother Immaculate Learning Center		Medium	Medium
Poblacion Iraya	Poblacion Iraya Daycare Center		Medium	Medium
Poblacion Iraya	Quezon Camarines High School	Low	High	High
Poblacion Iraya	Ragay Covered Court	Low	Medium	Medium

Annex 13. Health Institutions affected by flooding in Ragay Floodplain

Table A-13.1. Health Institutions in Ragay City, Camarines Sur affected by flooding in Ragay Floodplain

Camarines Sur				
Ragay				
Barangay	Building Name	Rainfall Scenario		
		5-year	25-year	100-year
Amomokpok	Brgy Amomokpok Health Center		Low	Medium
Apad	Apad Health Center			
Apale	Health Center Lower Sta Cruz	Medium	High	High
Binahan Proper	Binahan Health Center		Low	Medium
Binahan Proper	Health Center			
Laguio	Laguio Health Center	Medium	High	High
Poblacion Iraya	Abogado Clinic		Medium	Medium
Poblacion Iraya	Ragay District Hospital			