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

LiDAR Surveys and Flood Mapping of Pambukhan River

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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]
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
NAMRIA	National Mapping and Resource Information Authority
NSTC	Northern Subtropical Convergence
PAF	Philippine Air Force
PAGASA	Philippine Atmospheric Geophysical and Astronomical Services Administration
PDOP	Positional Dilution of Precision
PPK	Post-Processed Kinematic [technique]
PRF	Pulse Repetition Frequency
PTM	Philippine Transverse Mercator
QC	Quality Check
QT	Quick Terrain [Modeler]
RA	Research Associate
RIDF	Rainfall-Intensity-Duration-Frequency
RMSE	Root Mean Square Error
SAR	Synthetic Aperture Radar
SCS	Soil Conservation Service
SRTM	Shuttle Radar Topography Mission
SRS	Science Research Specialist
SSG	Special Service Group
TBC	Thermal Barrier Coatings
UP-TCAGP	University of the Philippines – Training Center for Applied Geodesy and Photogrammetry
UTM	Universal Transverse Mercator
VSU	Visayas State University
WGS	World Geodetic System

CHAPTER 1: OVERVIEW OF THE PROGRAM AND PAMBUKHAN RIVER

Engr. Florentino Morales Jr. and Enrico C. Paringit, Dr. Eng.

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

Also, the program was aimed at producing an up-to-date and detailed national elevation dataset suitable for 1:5,000 scale mapping, with 50 cm and 20 cm horizontal and vertical accuracies, respectively. These accuracies were achieved through the use of the state-of-the-art Light Detection and Ranging (LiDAR) airborne technology procured by the project through DOST. The methods applied in this report are thoroughly described in a separate publication entitled "FLOOD MAPPING OF RIVERS IN THE PHILIPPINES USING AIRBORNE LIDAR: METHODS (Paringit, et. al. 2017) available separately.

The implementing partner university for the Phil-LiDAR 1 Program is the Visayas State University (VSU). VSU 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 28 river basins in the Eastern Visayas Region. The university is located in Baybay City in the province of Leyte.

1.2 Overview of the Pambukhan River Basin

Pambukhan River Basin covers the majority of four (4) municipalities, and three (3) municipalities in Northern Samar. The DENR River Basin Control Office identified the basin to have a drainage area of 596 km^2 and an estimated 1,132 million cubic meter (MCM) annual run-off (RBCO, 2016).

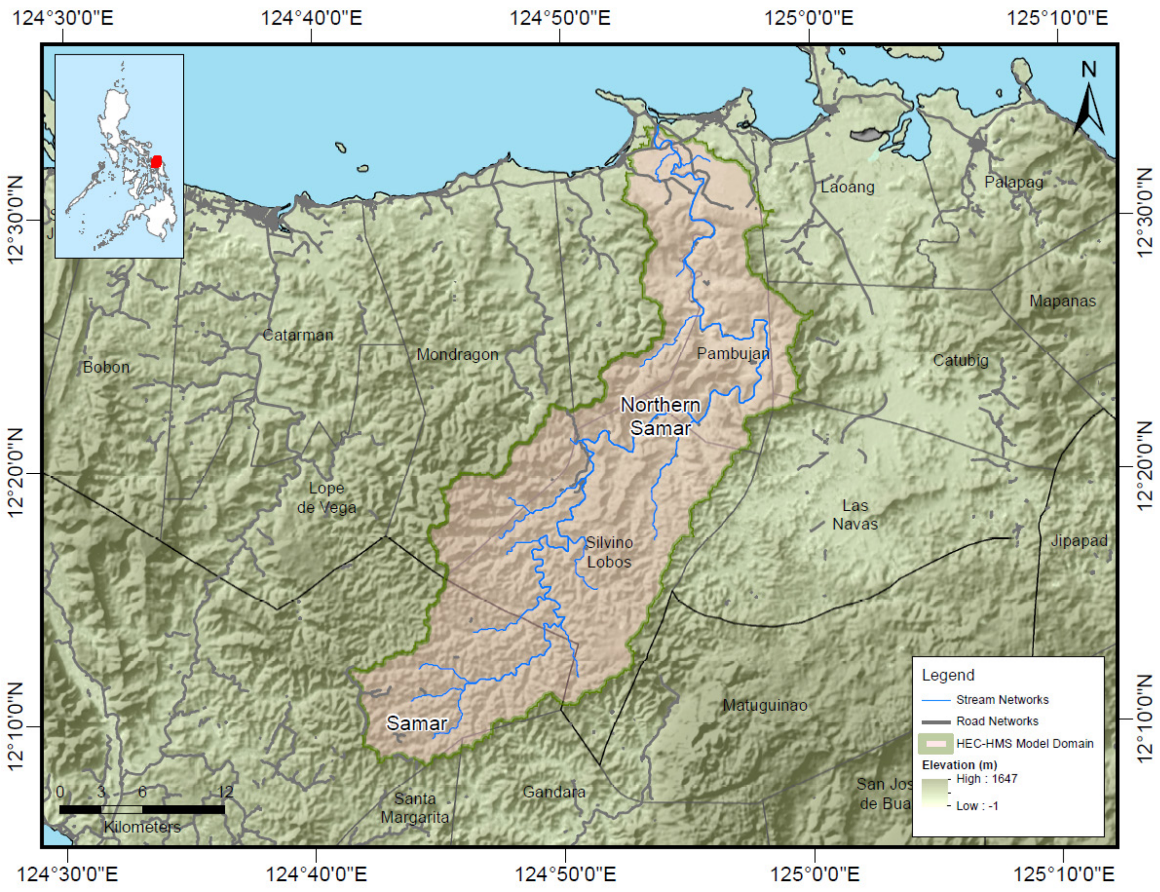

Figure 1.Map of Pambukhan River Basin (in brown).

Its main stem, Pambujan River, is part of the 19 river systems in Eastern Visayas Region. According to the 2015 national census of NSO, a total of 7,104 persons are residing within the immediate vicinity of the river which is distributed among seven (7) barangays in the Municipalities of San Roque and Pambujan (NSO, 2015). The source of livelihood of the residents living on the riverside depend mainly on copra, abaca, rice fields, root crops, and handicraft-making (Source: http://www.oocities.org/lppsec/pp/nsamar.htm). Last December 14, 2015, the province of Northern Samar was the most devastated province during the landfall of Typhoon Nona, internationally known as *Melor.* Almost ninety (90) percent of the province was ravaged. The Provincial Disaster Risk Reduction and Management Council reported that 117,788 families from twenty-four (24) municipalities were affected with infrastructure damages amounting to over P1.37 million (Source: http://www.philstar.com/region/2015/12/20/1534660/typhoon-nona-devastation-northern-samar-people-appealing-assistance).

CHAPTER 2: LIDAR DATA ACQUISITION OF THE PAMBUKHANFLOODPLAIN

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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).

2.1 Flight Plans

To initiate the LiDAR acquisition survey of the Pambukhan floodplain, the Data Acquisition Component (DAC) created flight plans within the delineated priority area for Pambukhan Floodplain in Northern Samar. These flight missions were planned for 21 lines and ran for at most four and a half hours (4.5) including take-off, landing and turning time. The flight planning parameters for the LiDAR system are outlined in Table 1 and Table 2. Figure 2 shows the flight plan for Pambukhanfloodplain survey.

Table 1.Flight planning parameters for Aquarius LiDAR system

Block Name	Flying Height (m AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
Block 331H	600	30	18	50	50	130	5
Block 331L	600	30	18	50	50	130	5
Block 331N	500	30	20	50	45	130	5
Block 331O	1000/600	30	18 / 25	125 / 50	40 / 50	130	5
Block 331P	600	30	20	50	45	130	5
Block 33D	600	30	18	50	45	130	5

Table 2.Flight planning parameters for Gemini LiDAR system

Block Name	Flying Height (m AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
Block 33E	800	25	25	125	40	130	5
Block 33G	800	25	25	125	40	130	5

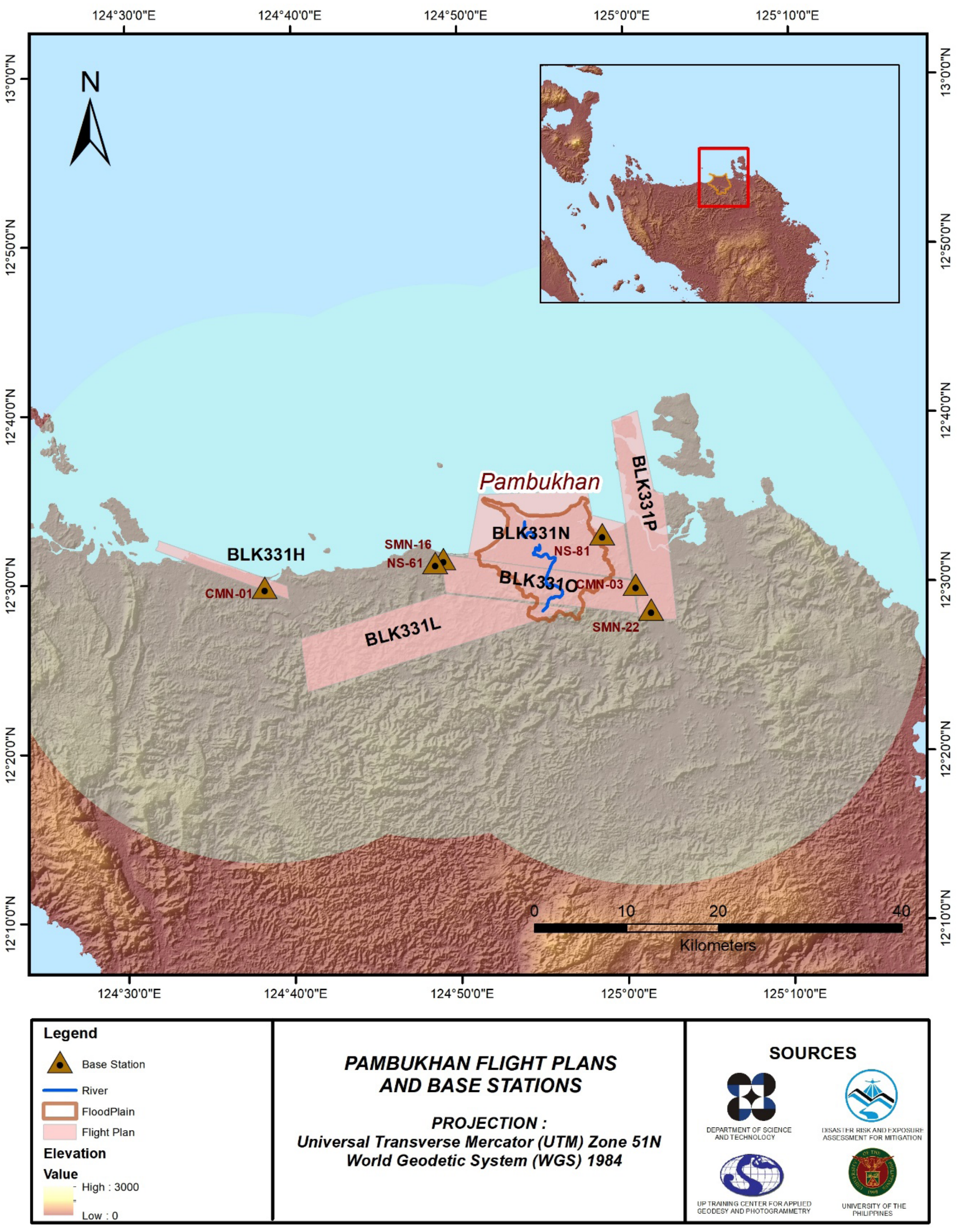

Figure 2.Flight plans and base stations used for Pambukhan floodplain.

2.2 Ground Base Stations

The project team was able to recover two (2) NAMRIA ground control points, SMN-16 and SMN-22, both of which are of second (2nd) order accuracy. The project team also established ground control points CMN-01 and CMN-03. Two (2) NAMRIA benchmarks were recovered: NS-61 and NS-81 which are both of first (1st) order accuracy. These benchmarks were used as vertical reference points and were also established as ground control points.

The certification for the NAMRIA reference points and benchmarks are found in Annex C while the baseline processing reports for the established control points are found in Annex D. These were used as base stations during flight operations for the entire duration of the survey (March 1-9, 2015, August 10-12, 2015 and April 9-11, 2016). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 985, TRIMBLE SPS 852 and TOPCON GR-5. Flight plans and location of base stations used during the aerial LiDAR acquisition in Pambukhan floodplain are shown in Figure 2.

The succeeding sections depict the sets of reference points, control stations and established points, and the ground control points for the entire Pambukahan Floodplain LiDAR Survey. Figure 3 to Figure 6 show the recovered NAMRIA reference points within the area of the floodplain, while Table 3 to Table 8 show the details about the following NAMRIA control stations and established points. Table 9, on the other hand, shows the list of all ground control points occupied during the acquisition together with the corresponding dates of utilization.

(b)

(a)

Figure 3. GPS set-up over SMN-16 situated in Brgy. Bagasbas, Municipality of Mondragon located inside the Basketball Court (a) and NAMRIA reference point SMN-16 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point SMN-16 used as base station for the LiDAR acquisition

Station Name	SMN-16	
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	12°31'32.33268" North 124° 48'56.69485"East 5.45500 m
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	479974.965 meters 1385085.603 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	12° 31' 27.72792" North 124° 49' 1.74020"East 63.99100 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 92)	Easting Northing	697302.11 meters 1385272.01 meters

(b)

(a)

Figure 4. GPS set-up over SMN-22 located in Barangay Simora Elementary School, Northern Samar, and NAMRIA reference point SMN-22 (b) as recovered by the field team.

Table 4.Details of the recovered NAMRIA horizontal control point SE-16 used as base station for the LiDAR acquisition.

Station Name	SMN-22	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	12°28’27.20633” North 125°1’25.36067” East -1.70407 m
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	502577.525m 1379390.508m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	12°28’22.63174” North 125°1’30.408661” East 57.47400 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 92)	Easting Northing	719951.32 meters 1379746.87 meters

(a)

(b)

Figure 5. NS-61 as situated in Muyaw Bridge, Mondragon Northern Samar (a) and NAMRIA reference point NS-61 (a) as recovered by the field team.

Table 5.Details of the recovered NAMRIA benchmark NS-61 used as base station for the LiDAR Acquisition

Station Name	NS-61	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1:50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	12°31’17.86801” North
	Longitude	124°48’26.40323” East
	Ellipsoidal Height	5.208 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	12°31’13.26354” North
	Longitude	124°48’31.44902” East
	Ellipsoidal Height	63.733 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting	696390.555 m
	Northing	1384821.249 m

(a) (b)

Figure 6. NS-81 at Burabod bridge in the Municipality of Laoang, Northern Samar (a) and NAMRIA reference point NS-61 (b) as recovered by the field team.

Table 6.Details of the recovered NAMRIA benchmark NS-81 used as base station for the LiDAR Acquisition.

Station Name	NS-81	
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	12° 32’ 56.09555” North 124° 58’ 29.89302” East -0.487 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	12° 32’ 51.49836” North 124° 58’ 34.93490” East 58.377 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	714590.119 meters 1387970.443 meters

Table 7. Details of the established horizontal control point CMN-01 used as base station for the LiDAR Acquisition.

Station Name	CMN-01	
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	12° 29' 53.60604" 124° 38' 11.46535" 12.573 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	12° 29' 48.99306" North 124° 38' 16.51471" East 70.742 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	677840.326 meters 1382111.129 meters

Table 8.Details of the established horizontal control point CMN-03 used as base station for the LiDAR Acquisition.

Station Name	CMN-03	
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	12° 29' 56.60389" 125° 00' 29.19031" -0.122 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	12° 29' 52.02635" North 125° 00' 34.23621" East 58.953 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	718234.013 meters 1382481.531 meters

Table 9. Ground control points used during the LiDAR data acquisition.

Date Surveyed	Flight Number	Mission Name	Ground Control Points
April 9, 2016	3917P	2BLK33EGS100A	NS-81 and SMN-22
March 1, 2015	7830AC	3BLK331HS060A	NS-61 and SMN-16
March 4, 2015	7836AC	3BLK331ON063A	NS-61 and SMN-16
March 9, 2015	7846AC	3BLK331L068A	NS-61 and SMN-16
August 10, 2015	8154AC	3BLK331NO222A	CMN-01 and SMN-16
August 11, 2015	8156AC	3BLK331LNS223A	CMN-01 and SMN-16
August 11, 2015	8157AC	3BLK331NS223B	CMN-01 and SMN-16
August 12, 2015	8159AC	3BLK331NSPS224B	SMN-22 and CMN-03
April 11, 2016	8431AC	3BLK33D102A	NS-81 and SMN-22

2.3 Flight Missions

A total of nine (9) missions were conducted to complete the LiDAR data acquisition in Pambukhan floodplain, for a total of thirty one hours and twenty six (31+26) minutes of flying time for RP-C9322 and RP-C9022 (See Annex 6). All missions were acquired using the Gemini and Aquarius LiDAR systems. As shown below, the total area of actual coverage per mission and the corresponding flying hours are depicted inTable 10, while the actual parameters used during the LiDAR data acquisition are presented in Table 11.

Table 10. Flight missions for LiDAR data acquisition in Pambukhan floodplain.

Date Surveyed	Flight Number	Flight Plan Area (km^2)	Surveyed Area (km^2)	Area Surveyed within the Floodplain (km^2)	Area Surveyed Outside the Floodplain (km^2)	Flying Hours	
						Hr	**Min**
March 1, 2015	7830AC	97.15	87.12	17.06	70.06	3	59
March 4, 2015	7836AC	79.02	43.37	43.37	0.00	2	43
March 9, 2015	7846AC	136.73	127.71	6.42	121.28	3	48
August 10, 2015	8154AC	206.81	79.16	44.77	34.39	3	23
August 11, 2015	8156AC	264.52	89.92	28.00	61.92	3	41
August 11, 2015	8157AC	127.79	67.86	33.66	34.20	2	47
August 12, 2015	8159AC	214.74	38.19	3.76	34.43	2	29
April 9, 2016	3917P	50.95	127.79	6.90	120.89	4	23
April 11, 2016	8431AC	63.26	86.68	0.00	86.68	4	13
TOTAL		1240.96	747.80	183.94	563.86	31	26

Table 11.Actual parameters used during LiDAR data acquisition.

Date Surveyed	Flight Number	Flying Height (AGL) (m)	Overlap (%)	Field of View	PRF (kHz)	Scan Frequency (Hz)	Speed of Plane (Kts)
April 9, 2016	3917G	900	25	50	200	50	130
March 1, 2015	7830AC	600	30	36	50	50	130
March 4, 2015	7836AC	600	30	36	50	50	130
March 9, 2015	7846AC	600	30	36	50	50	130
August 10, 2015	8154AC	600	30	40	50	45	130
August 11, 2015	8156AC	600	30	40	50	45	130
August 11, 2015	8157AC	600	30	40	50	45	130
August 12, 2015	8159AC	600	30	40	50	45	130
April 11, 2016	8431AC	600	30	36	50	45	130

2.4 Survey Coverage

This certain LiDAR acquisition survey covered the Pambukhan floodplain (See Annex 7). It is located in the province of Northern Samar with majority of the floodplain situated within the municipality of San Roque and Pambukhanambukhan. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 12. Figure 7, on the other hand, shows the actual coverage of the LiDAR acquisition for thePambukhan floodplain.

Table 12.List of municipalities and cities surveyed during Pambukhan floodplain LiDAR survey.

Province	Municipality/City	Area of Municipality (km²)	Total Area Surveyed (km²)	Percentage of Area Surveyed (%)
Northern Samar	San Roque	166.51	99.20	60%
	Pambukjan	150.63	79.15	53%
	Catubig	217.59	95.38	44%
	Laoang	207.60	86.12	41%
	Mondragon	322.75	90.08	28%
	Palapag	153.46	36.62	24%
	Catarman	255.77	45.53	18%
	Las Navas	267.47	10.33	4%
	Mapanas	143.56	5.05	4%
	Lope de Vega	186.62	5.77	3%
	Bobon	198.53	2.88	1%
Eastern Samar	Jipapad	173.29	5.35	3%
Total		**2443.78**	**561.46**	**4%**

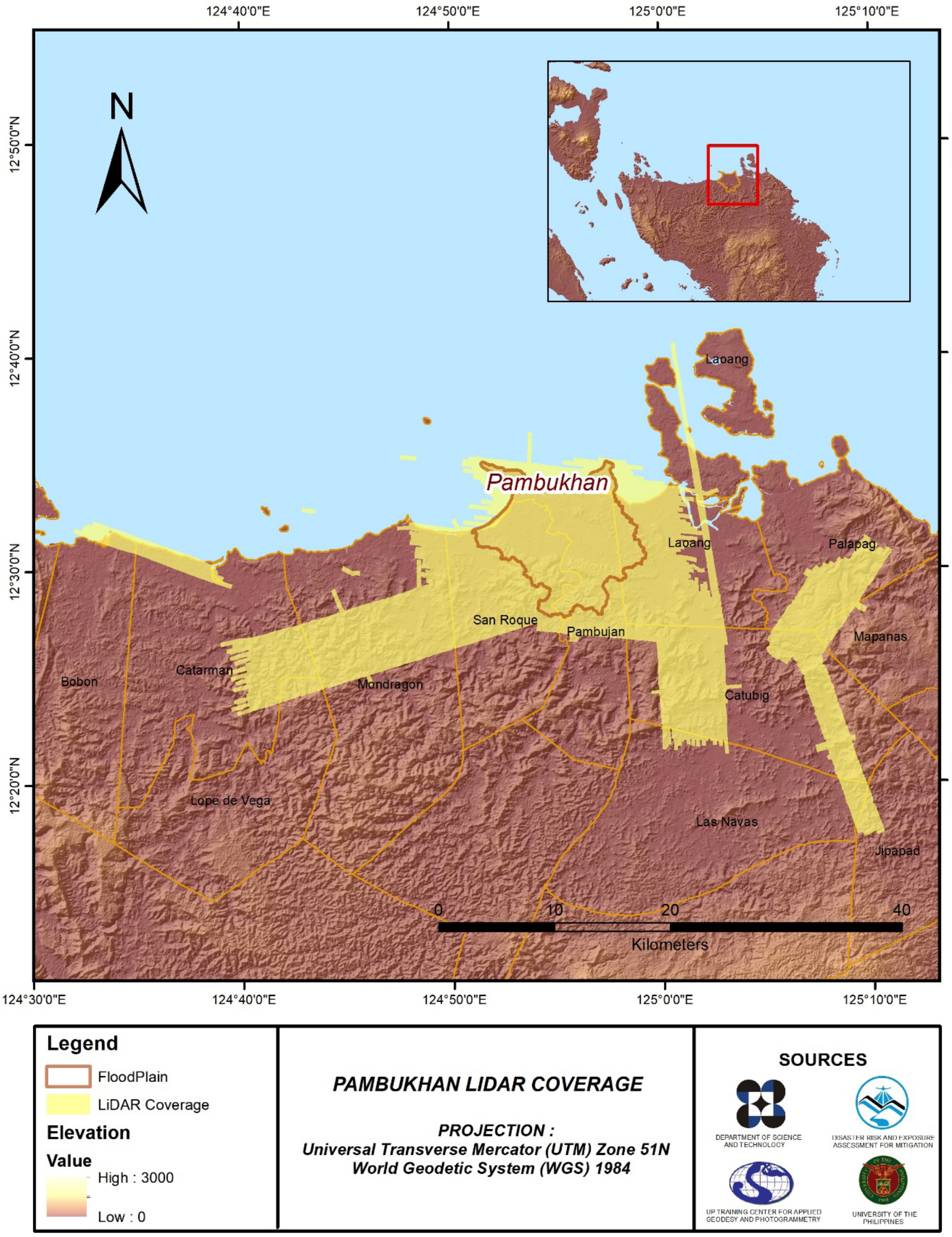

Figure 7.Actual LiDAR survey coverage for Pambukhan floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE PAMBUKHAN FLOODPLAIN

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

3.1 Overview of the LIDAR Data Pre-Processing

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

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

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

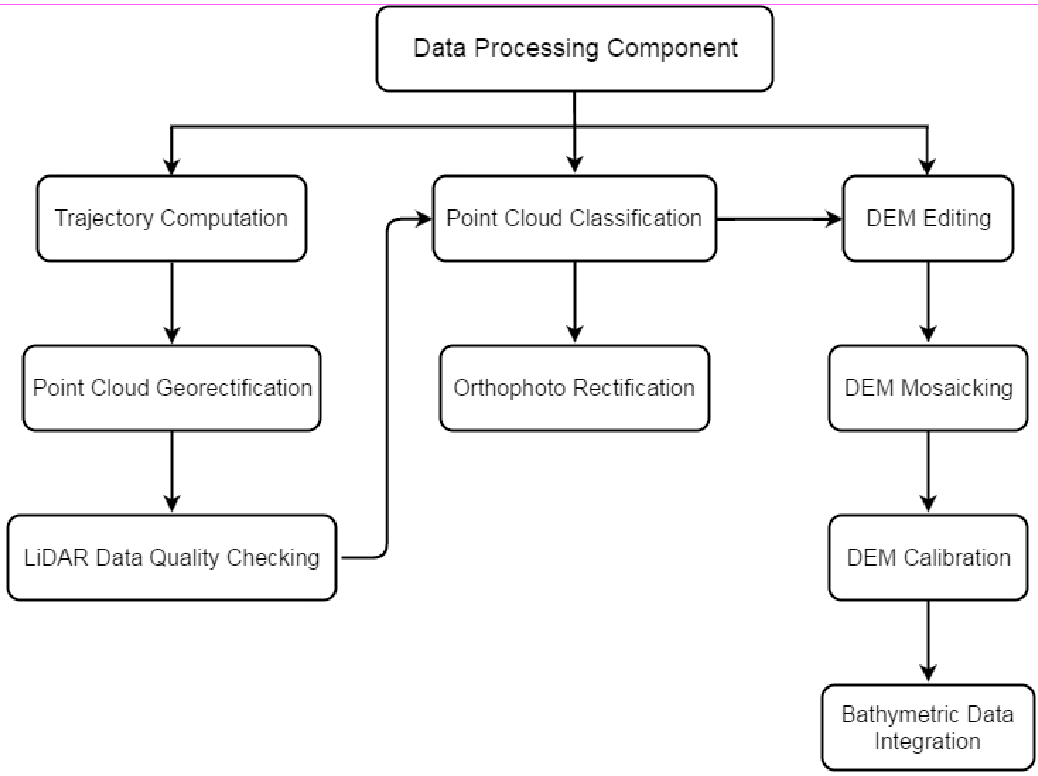

Figure 8. Schematic diagram for the data pre-processing.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Pambukhan floodplain can be found in Annex A-5. Missions flown during the first survey conducted on February 2015 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Aquarius system while missions acquired during the second survey on April 2016 were flown using the Gemini system over Pambujan, Northern Samar.

The Data Acquisition Component (DAC) transferred a total of 96.92 Gigabytes of Range data, 1.49 Gigabytes of POS data, 468.15 Megabytes of GPS base station data, and 106.2 Gigabytes of raw image data to the data server on June 25, 2015 for the first survey and May 5, 2016 for the second survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Pambukhan was fully transferred on May 11, 2016, as indicated on the Data Transfer Sheets for Pambukhan floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 8154AC, one of the Pambukhanflights, which is the North, East, and Down position RMSE values are shown in Figure 9. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on August 10, 2014 00:00AM. The y-axis is the RMSE value for that particular position.

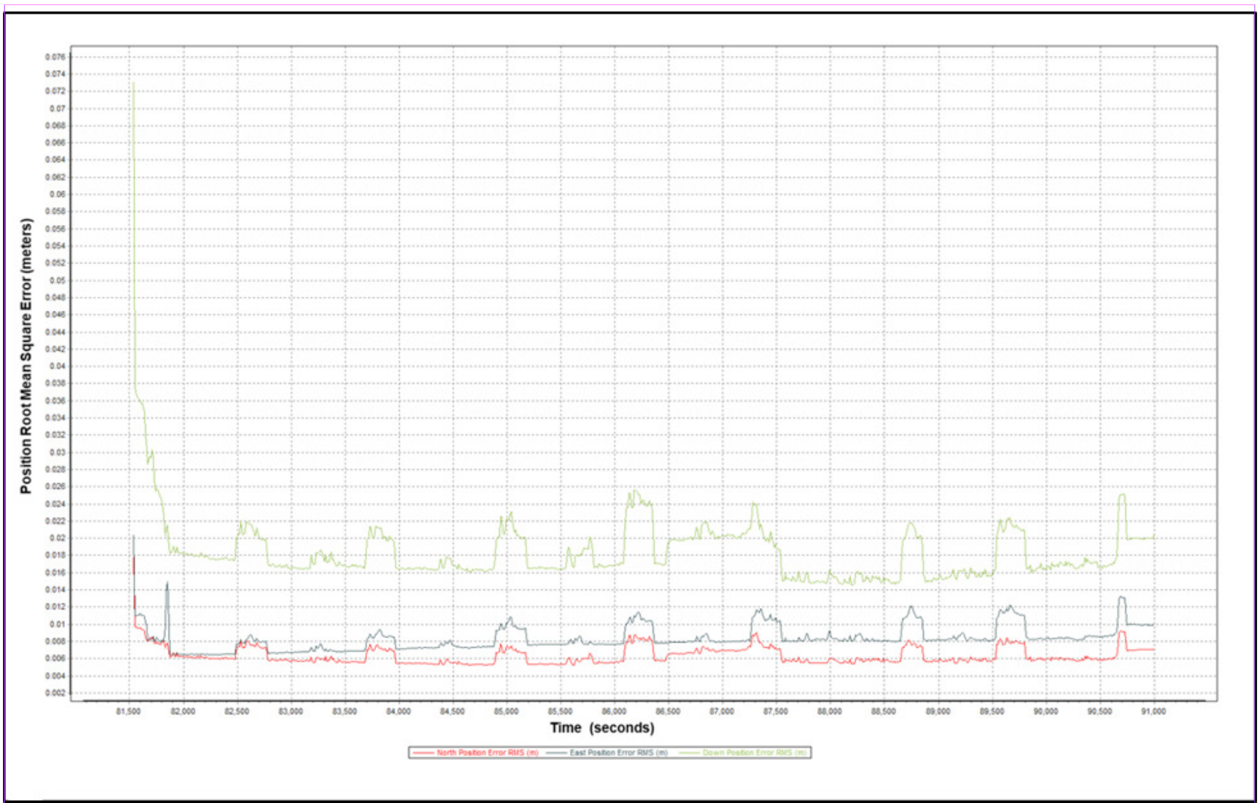

Figure 9. Smoothed Performance Metrics of a Pambukhan Flight 8154A.

The time of flight was from 81500 seconds to 91000 seconds, which corresponds to morning of August 10, 2016. The initial spike that is seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the POS system starts computing for the position and orientation of the aircraft.

Redundant measurements from the POS system quickly minimized the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values correspond to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 9 shows that the North position RMSE peaks at 1.0 centimeters, the East position RMSE peaks at 1.60 centimeters, and the Down position RMSE peaks at 2.60 centimeters, which are within the prescribed accuracies described in the methodology

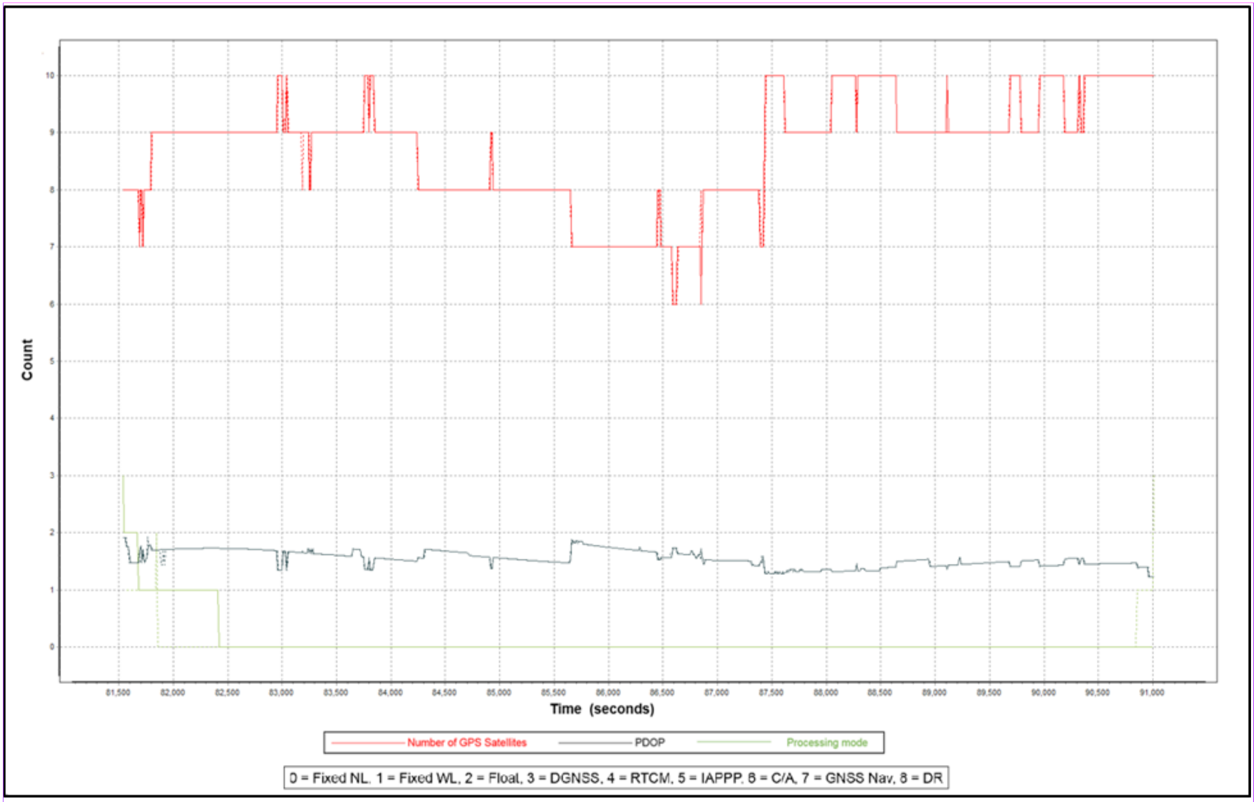

Figure 10. Solution Status Parameters of Pambukhan Flight 8154A.

The Solution Statusparameters of flight 8154A one of the Pambukhanflights, which indicate the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 10. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Most of the time, the number of satellites tracked was between 6 and 10. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode remained at 0 for majority of the survey with some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Pambukhan flights is shown inFigure 11.

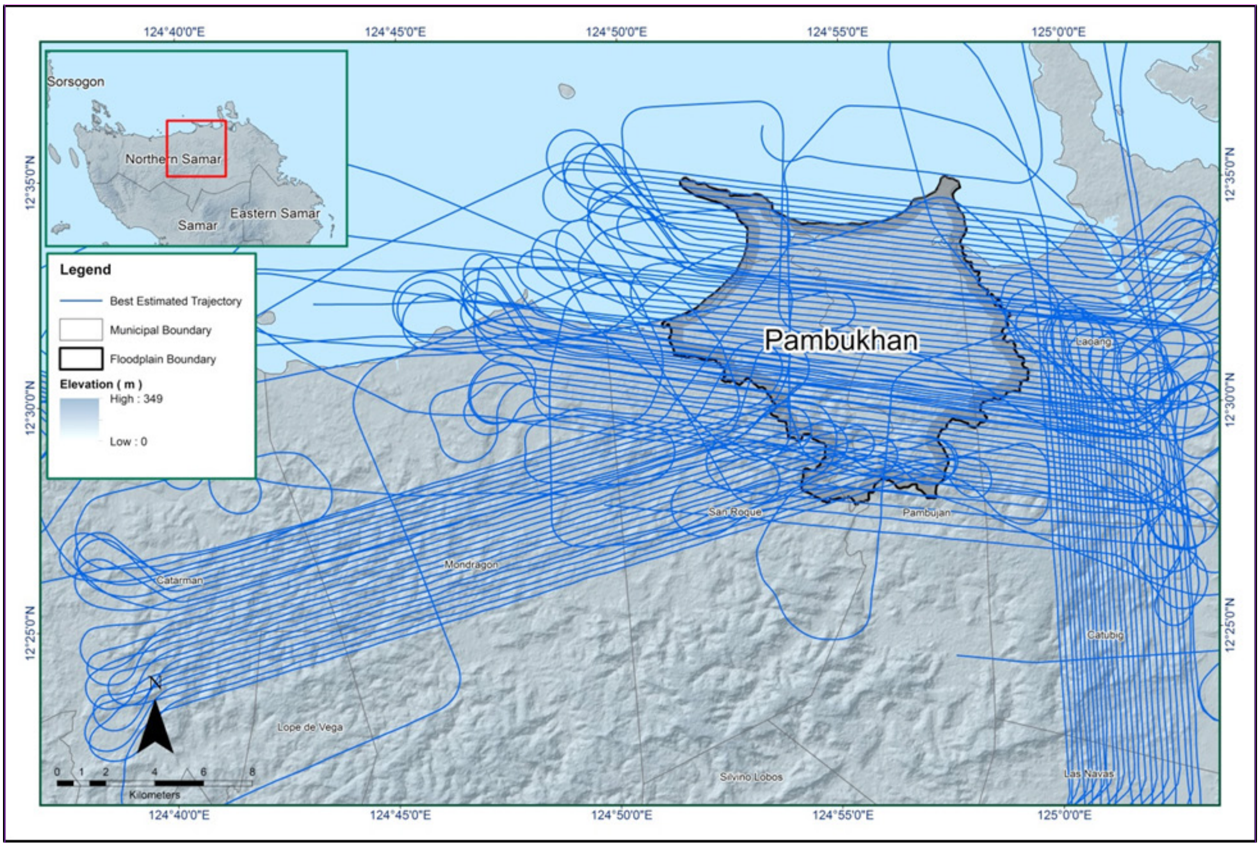

Figure 11. Best estimated trajectory of the LiDAR missions conducted over the Pambukhan Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS contains 107 flight lines, with each flight line contains one channel, since the Gemini and Aquarius systems both contain only one channel. The summary of the self-calibration results obtained from LiDAR processing in the LiDAR Mapping Suite (LMS) software for all flights over the Pambukhan floodplain are given inTable 13.

Table 13. Self-calibration Results values for Pambukhan flights.

Parameter	Acceptable Value	Computed Value
Boresight Correction stdev)	<0.001degrees	0.001941
IMU Attitude Correction Roll and Pitch Corrections stdev)	<0.001degrees	0.001425
GPS Position Z-correction stdev)	<0.01meters	0.0034

The optimum accuracy values for all Pambukhan 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 (Annex8).

3.5 LiDAR Quality Checking

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

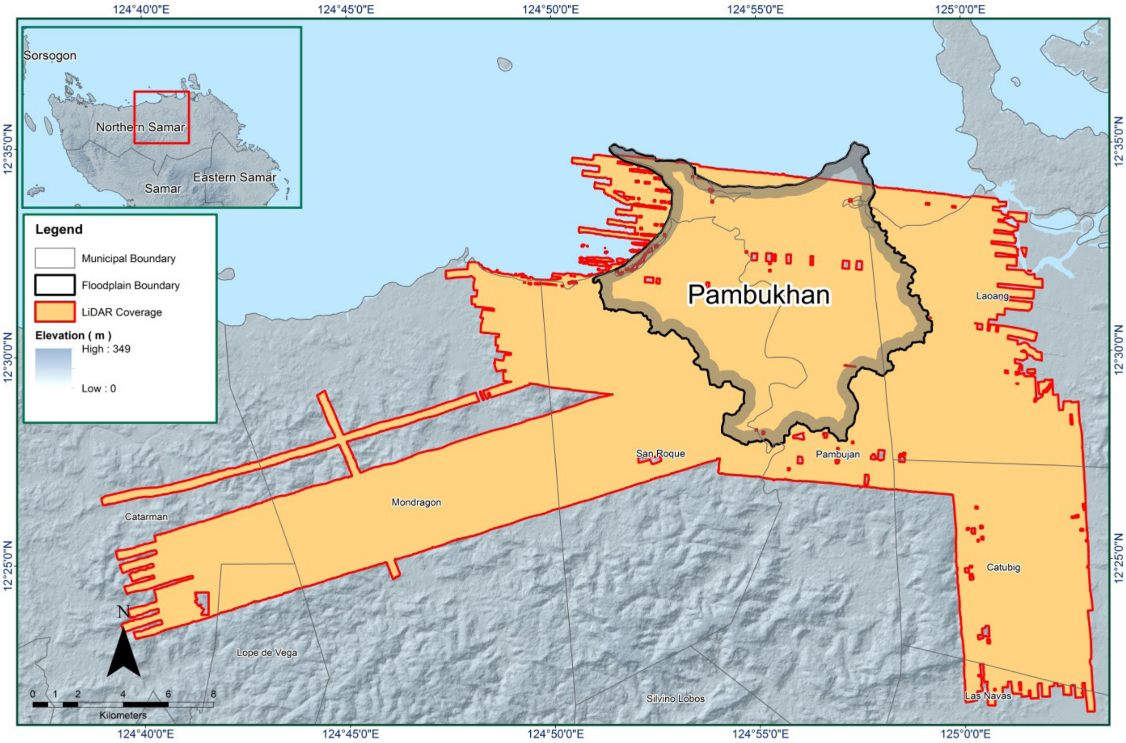

Figure 12. Boundary of the processed LiDAR data on top of the SAR Elevation Data over the Pambukhan Floodplain.

A total area of 501.6 square kilometers (sq. kms.) were covered by the Pambukhan flight missions as a result of seven (7) flight acquisitions, which were grouped and merged into six (6) blocks accordingly, as portrayed inTable 14.

Table 14. List of LiDAR blocks for the Pambukhan floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Catarman_Blk331L	7846AC	126.39
Catarman_Blk331N	8154AC	93.71
	8156AC	
	8157AC	
	8159AC	
Catarman_Blk331O	8159AC	102.39
	7836AC	
Catarman_Blk331O_supplement	7830AC	60.20
Catarman_reflights_Blk331O	8159AC	34.91
Catarman_reflights_Blk331P	8154AC	84.07
	TOTAL	**501.67 sq.km**

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 13. Since the Gemini and Aquarius systems both employ one channel, we would expect an average value of 1 (blue) for areas where there is limited overlap, and a value of 2 (yellow) or more (red) for areas with three or more overlapping flight lines.

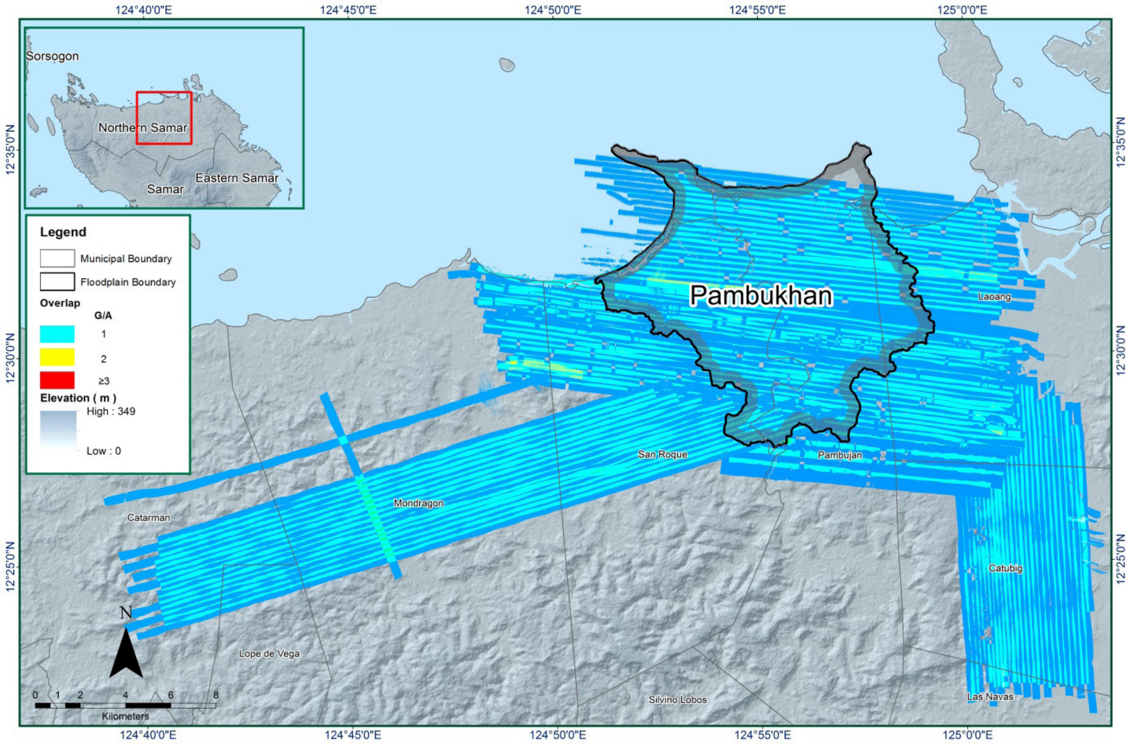

Figure 13.Image of data overlap for Pambukhan floodplain.

The overlap statistics per block for the Pambukhan 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 percent overlaps are35.78% and 40.05%, 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 inFigure 14. As seen in the figure below, it was determined that all LiDAR data for the Pambukhan Floodplain Survey satisfy the point density requirement, as the average density for the entire survey area is 3.30 points per square meter.

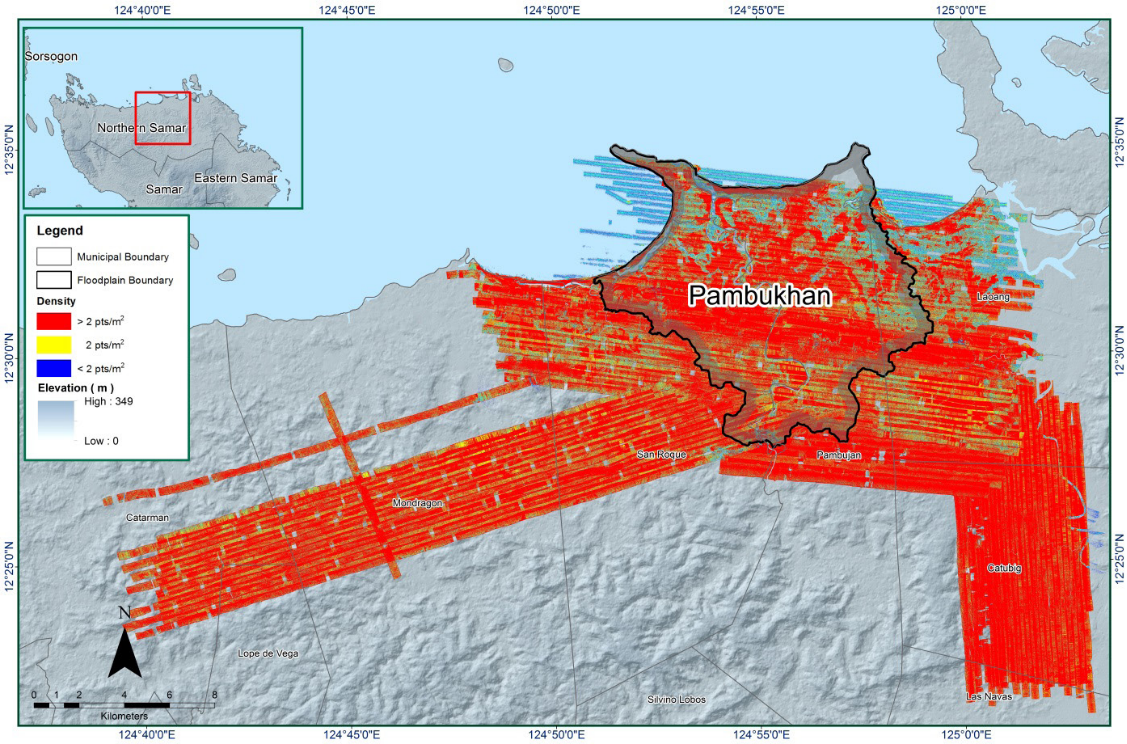

Figure 14. Pulse density map of the merged LiDAR data for Pambukhan floodplain.

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

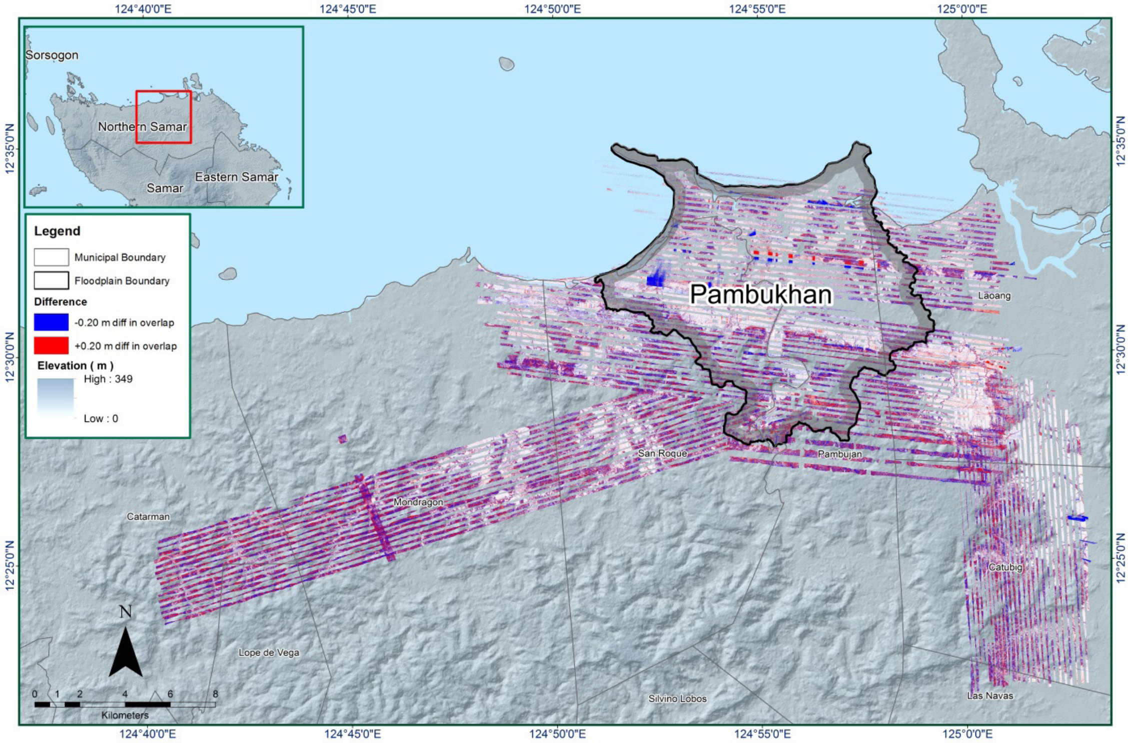

Figure 15.Elevation difference Map between flight lines for the Pambukhan Floodplain Survey

A screen capture of the processed LAS data from a Pambukhan flight 8154AC loaded in QT Modeler is shown in Figure 16. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed red line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the researcher was satisfied with the quality of the LiDAR data. No reprocessing was done for this LiDAR dataset

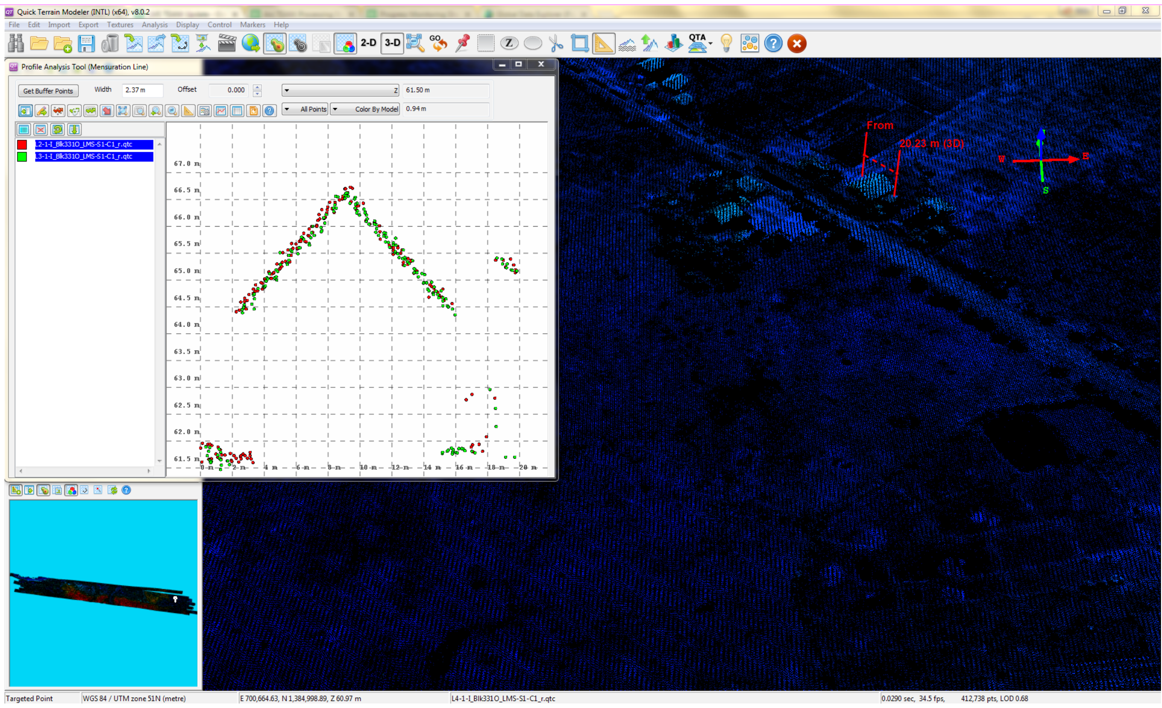

Figure 16.Quality checking for aPambukhan flight 8154A using the Profile Tool of QT Modeler

3.6 LiDAR Point Cloud Classification and Rasterization

Table 15.Pambukhan classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	286,037,005
Low Vegetation	150,090,543
Medium Vegetation	270,671,319
High Vegetation	331,236,282
Building	3,298,633

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Pambukhan floodplain is shown in Figure 17. A total of 807 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 15. The point cloud has a maximum and minimum height of 531.87 meters and 40.62 meters respectively.

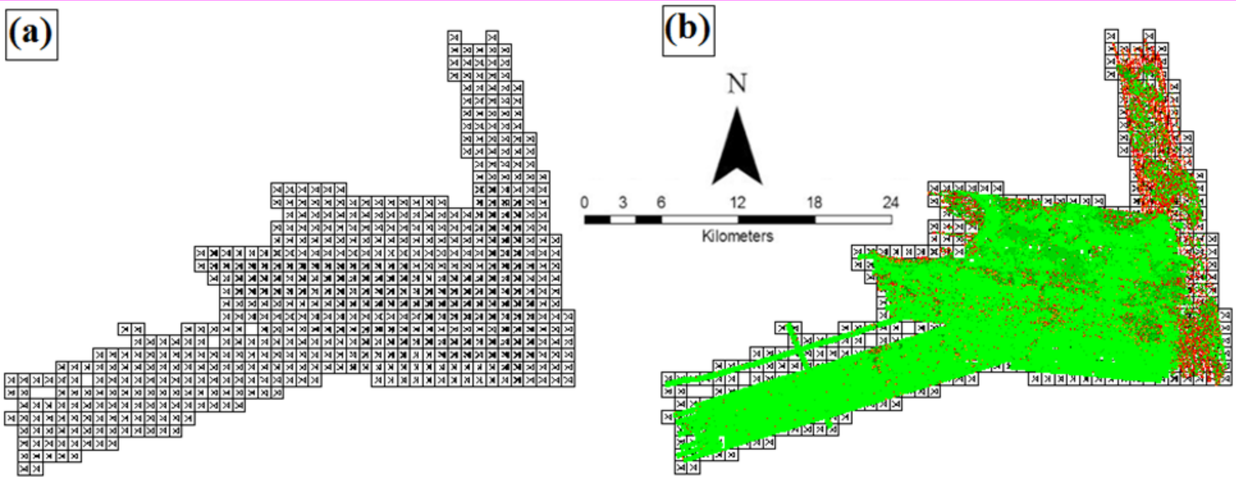

Figure 17.Tiles for Pambukhanfloodplain (a) and classification results (b) in TerraScan.

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

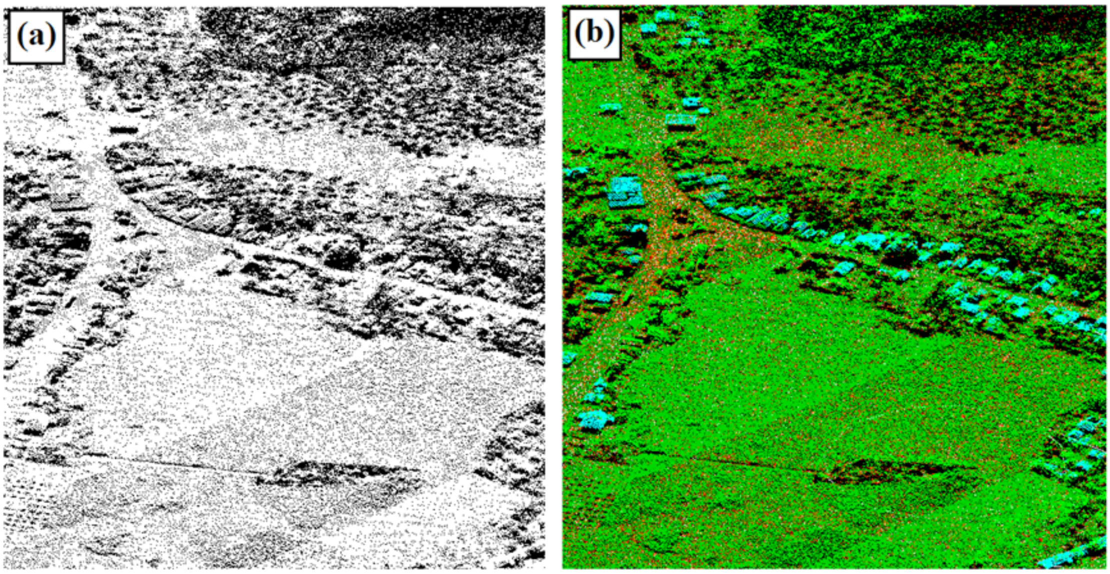

Figure 18. Point cloud before (a) and after (b) classification.

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

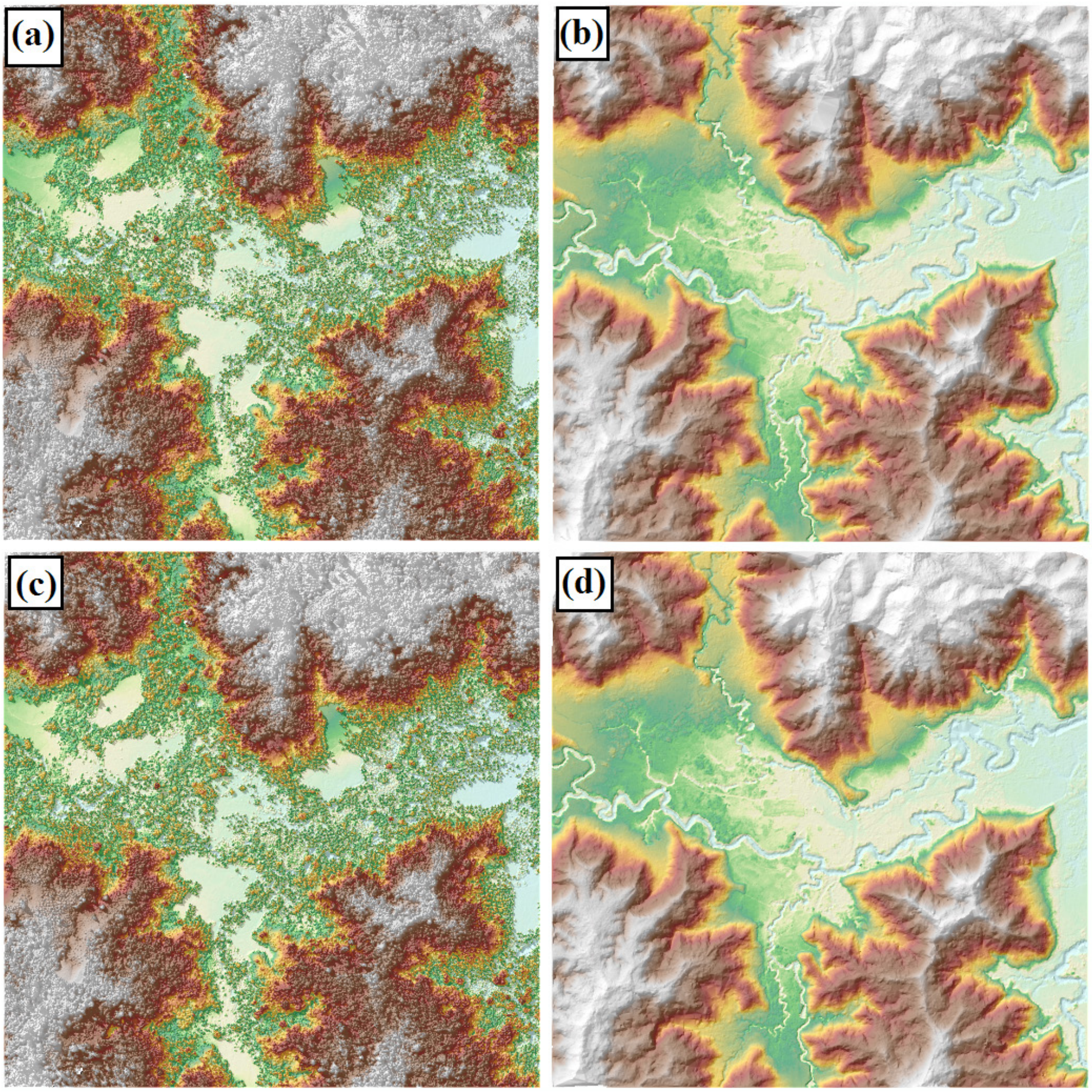

Figure 19.The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Pambukhan floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

There are no available orthophotographs for the Pambukhan floodplain

3.8 DEM Editing and Hydro-Correction

Six (6) mission blocks were processed for Pambukhan flood plain. These blocks are composed of Catarman blocks with a total area of 501.67 square kilometers. Table B-4 shows the name and corresponding area of each block in square kilometers.

Table 16. LiDAR blocks with its corresponding areas.

LiDAR Blocks	Area (sq. km.)
Catarman_Blk331L	126.39
Catarman_Blk331N	93.71
Catarman_Blk331O	102.39
Catarman_Blk331O_supplement	60.20
Catarman_reflights_Blk331O	34.91
Catarman_reflights_Blk33P	84.07
TOTAL	501.67 sq.km

Figure 20 shows portions of a DTM before and after manual editing. As evident in the figure, the bridge (Figure 20a) has obstructed the flow of water along the river. To correct the river hydrologically, the bridge was removed through manual editing (Figure 20b). The paddy field (Figure 20c) has been misclassified and removed during classification process and has to be retrieved to complete the surface (Figure 20d) to allow the correct flow of water.

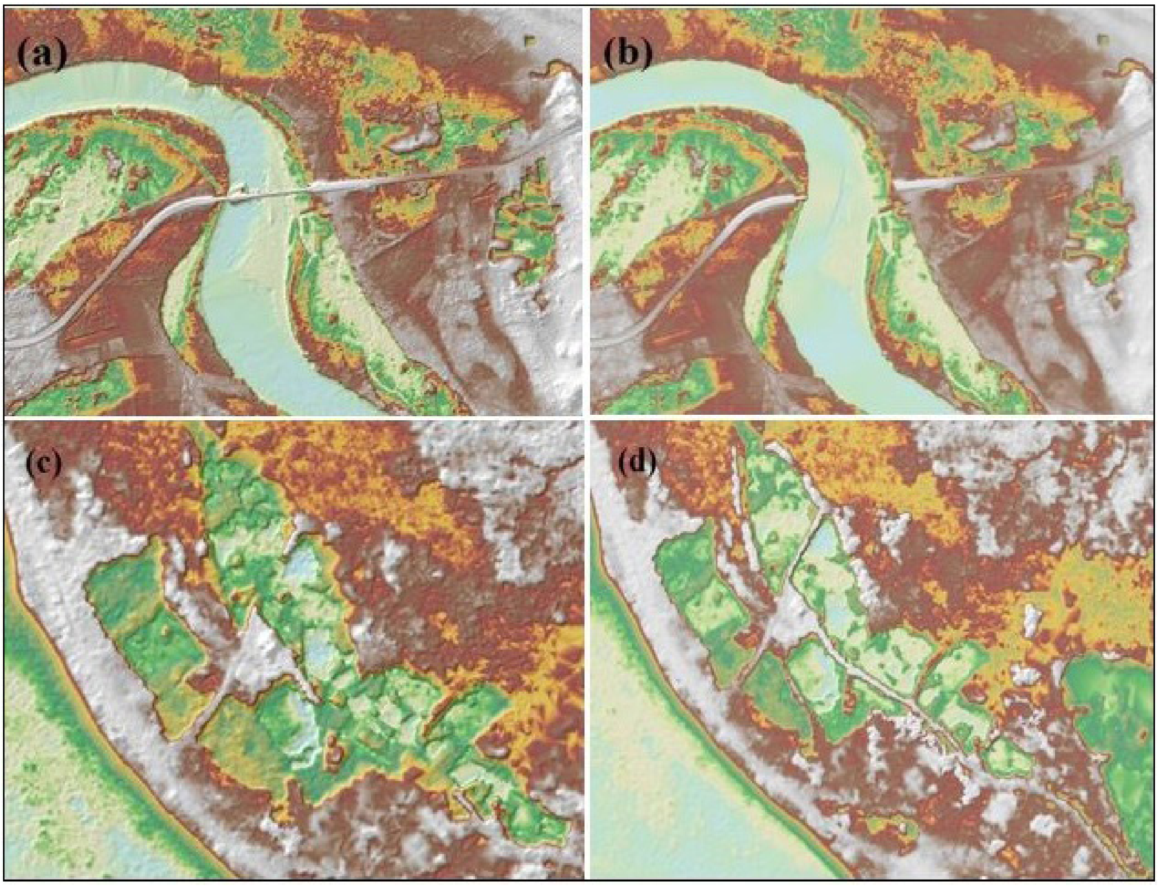

Figure 20.Portions in the DTM of the Pambukhan Floodplain –a bridge before (a) and after (b) manual editing; a paddy field before (c) and after (d) data retrieval.

3.9 Mosaicking of Blocks

Catarman_Blk331H was used as the reference block at the start of mosaicking because this block was made available for editing and mosaicking before the other blocks. Table B-5 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Pambukhan floodplain is shown in Figure 21. It can be seen that the entire Pambukhan floodplain is 96.45% covered by LiDAR data while portions with no LiDAR data were patched with the available IFSAR data.

Table 17. Shift values of each LiDAR block of Pambukhan Floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
Catarman_Blk331L	0.00	0.00	0.00
Catarman_Blk331N	0.00	0.00	0.05
Catarman_Blk331O	0.00	0.00	0.00
Catarman_Blk331O_supplement	0.00	0.00	0.15
Catarman_reflights_Blk33P	-14.00	-17.00	4.33
Catarman_reflights_Blk331O	-14.00	-17.00	3.57
Catarman_Blk331L	0.00	0.00	0.00

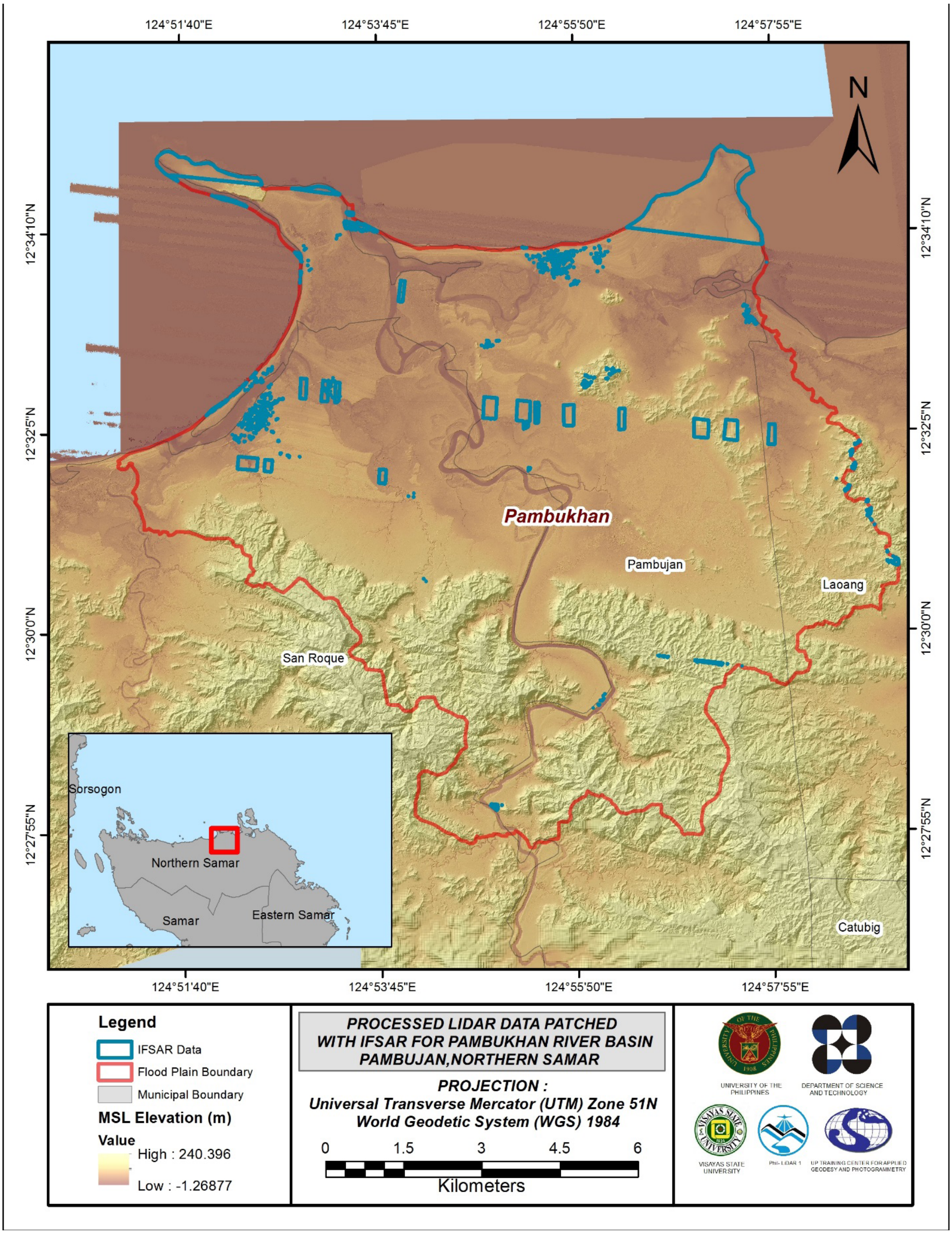

Figure 21.Map of processed LiDAR data for the Pambukhan Floodplain.

3.10 Calibration and Validation of Mosaicked LiDAR DEM

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Northern Samar to collect points with which the LiDAR dataset is validated is shown in Figure 22. A total of 14,268 survey points were gathered for all the flood plains within Northern Samar wherein the Pambukhan is located. Random selection of 80% of the survey points, resulting to 11,415 points, were used for calibration.

A good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values is shown in Figure 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 elevation values is 2.79 meters with a standard deviation of 0.18 meters. Calibration of Pambukhan LiDAR data was done by subtracting the height difference value, 2.79 meters, to Pambukhan mosaicked LiDAR data. Table 18 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

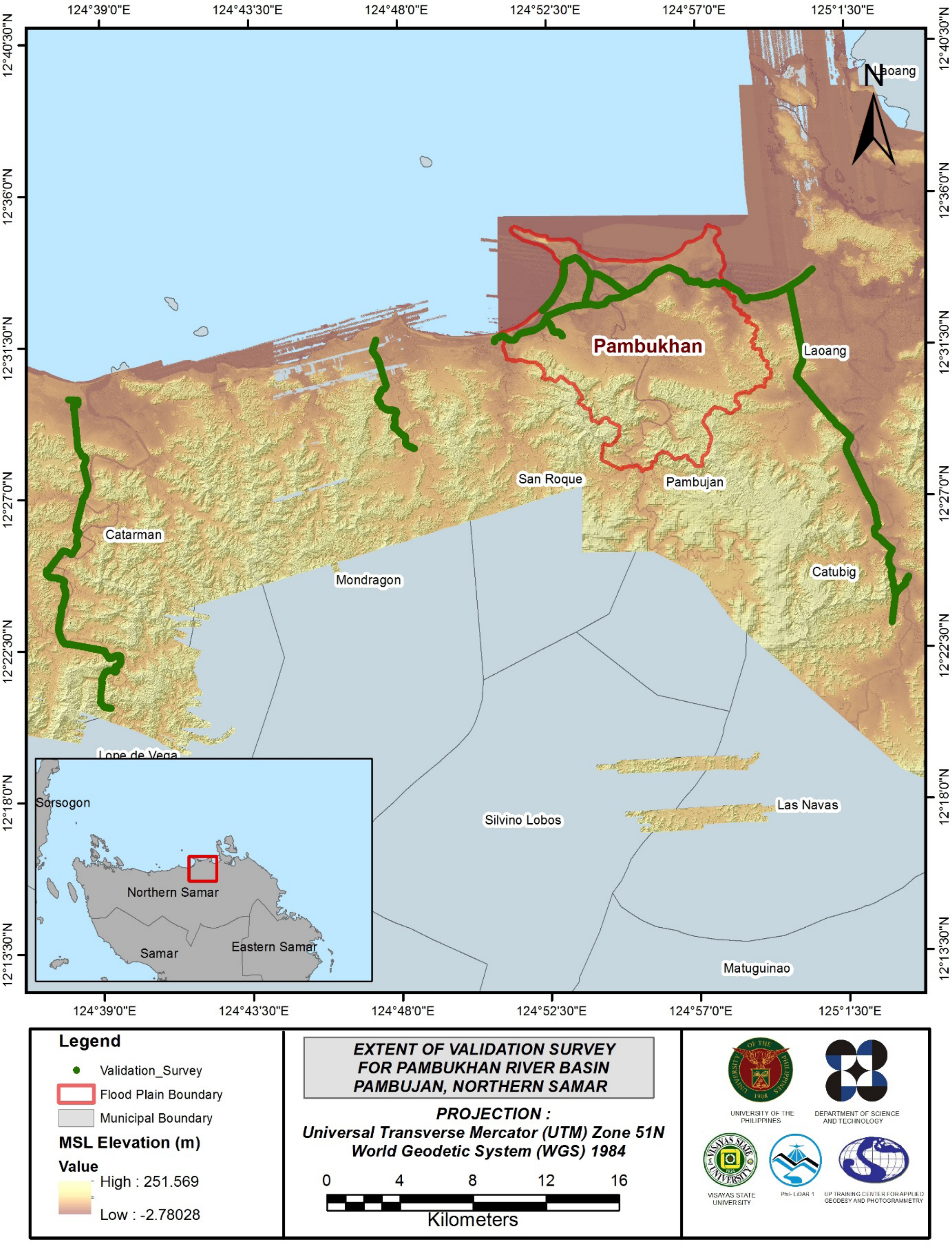

Figure 22.Map of Pambukhan Floodplain with validation survey points in green.

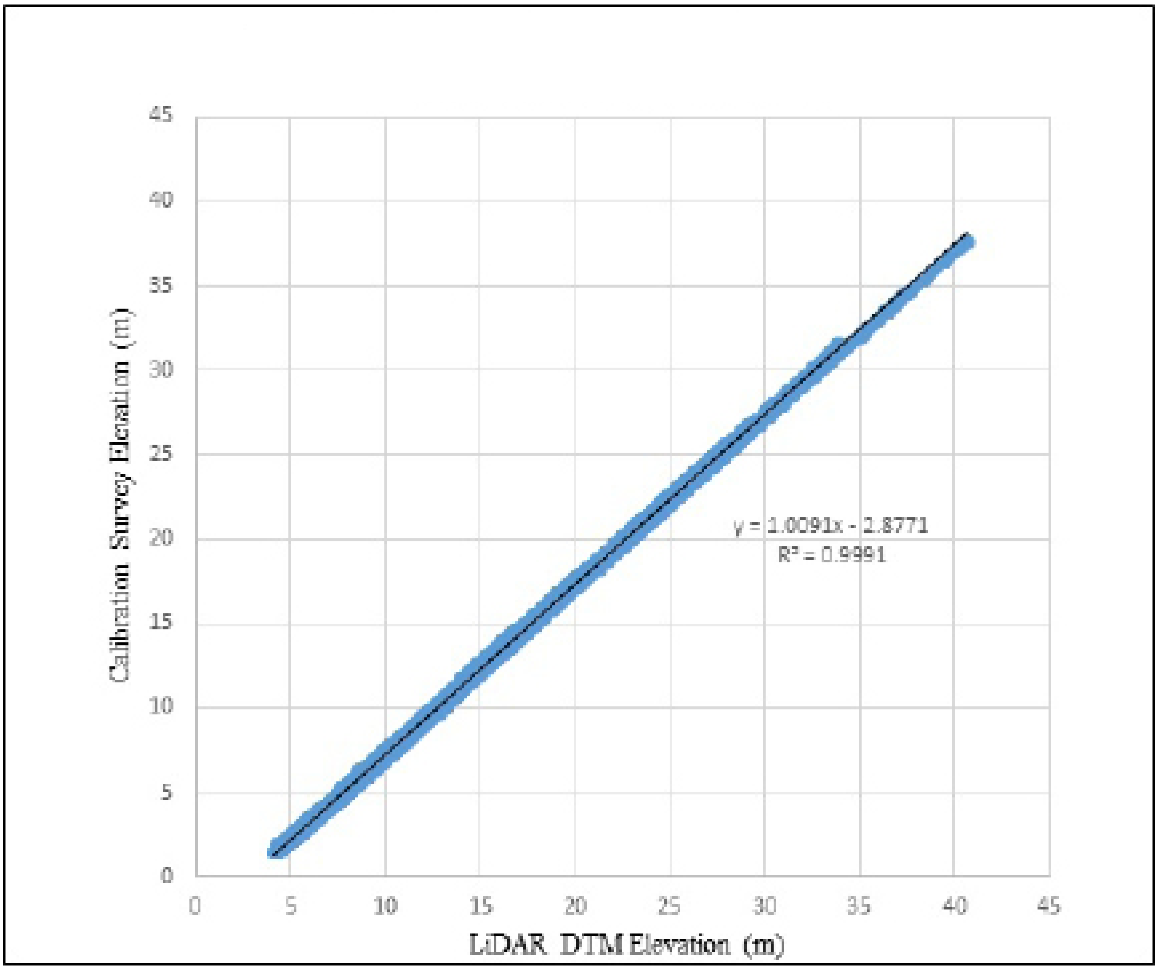

Figure 23.Correlation plot between calibration survey points and LiDAR data.

Table 18. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	2.79
Standard Deviation	0.18
Average	-2.79
Minimum	-3.20
Maximum	-2.20

Only 963 points that lie within the Pambukhan floodplain, derived from the 20% of the total survey points, were used for the validation of calibrated Pambukhan 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 0.06 meters with a standard deviation of 0.06 meters, as shown in Table 19.

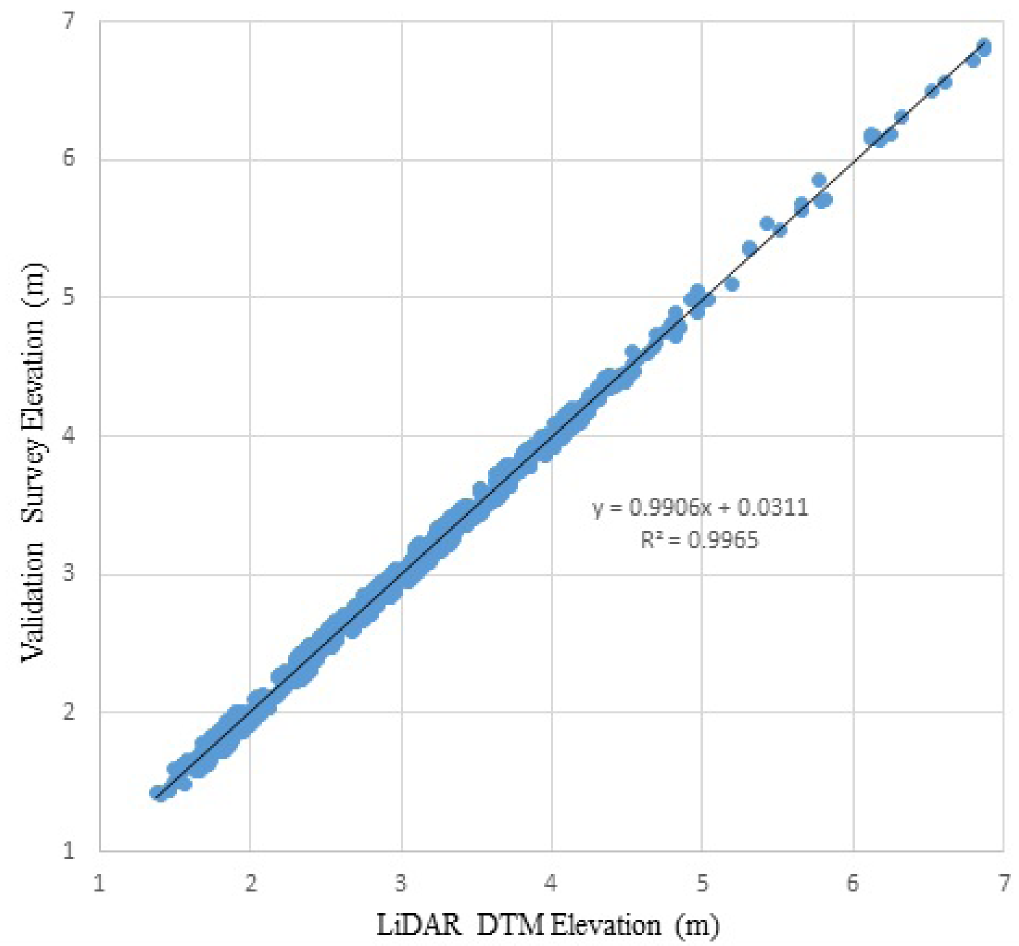

Figure 24. Correlation plot between the validation survey points and the LiDAR data.

Table 19. Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.06
Standard Deviation	0.06
Average	0.002
Minimum	-0.10
Maximum	0.11

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and zigzag data were available for Pambukhan with 14,741 bathymetric survey points. The resulting raster surface produced was done by Kernel Interpolation with Barriers method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.46 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Pambukhan integrated with the processed LiDAR DEM is shown in Figure 25.

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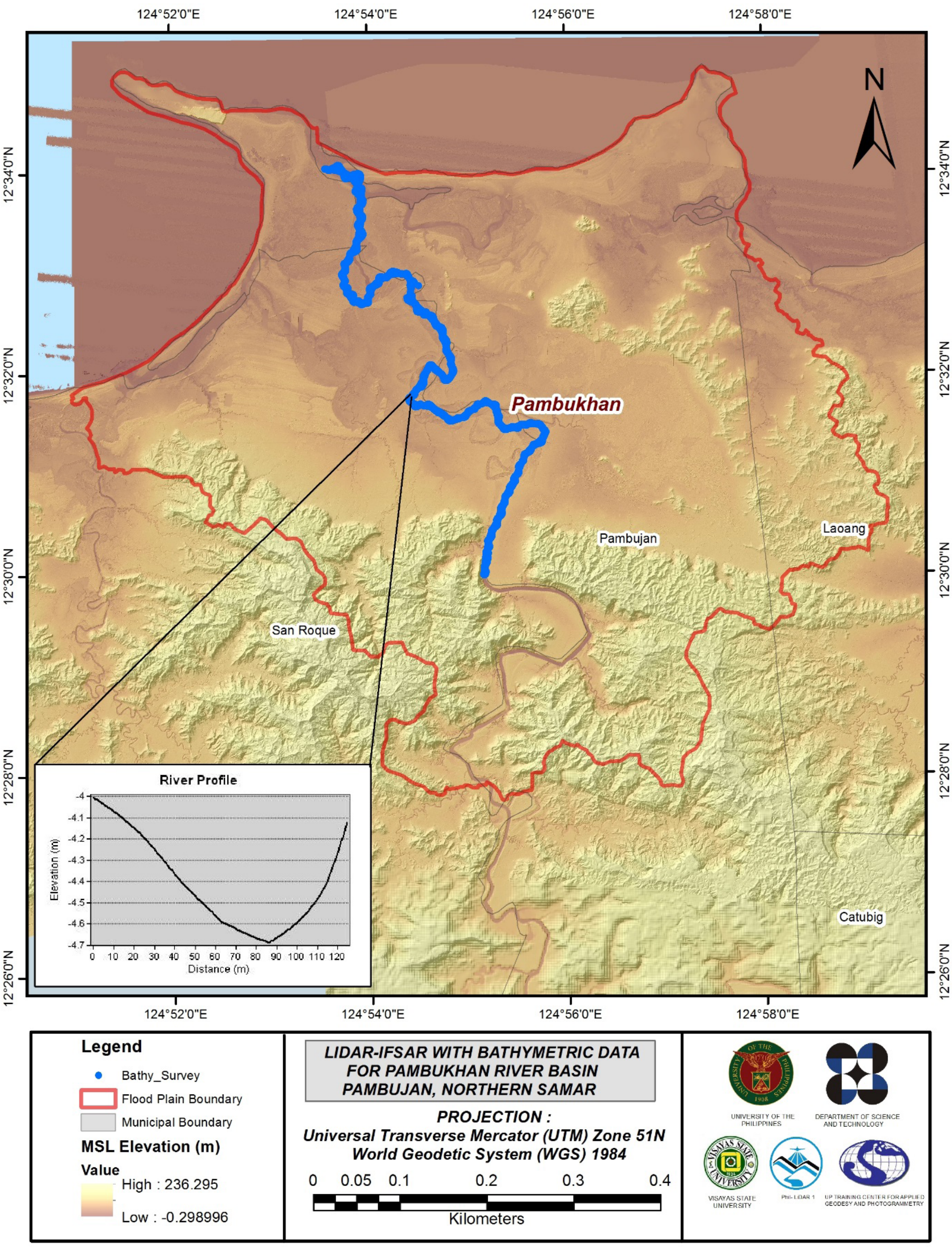


Figure 25. Map of Pambukhan floodplain with bathymetric survey points in blue.

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 (QC) of Digitized Features' Boundary

Pambukhan floodplain, including its 200 m buffer, has a total area of 125.05 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 1008 building features, are considered for QC. Figure 26 shows the QC blocks for Pambukhan floodplain.

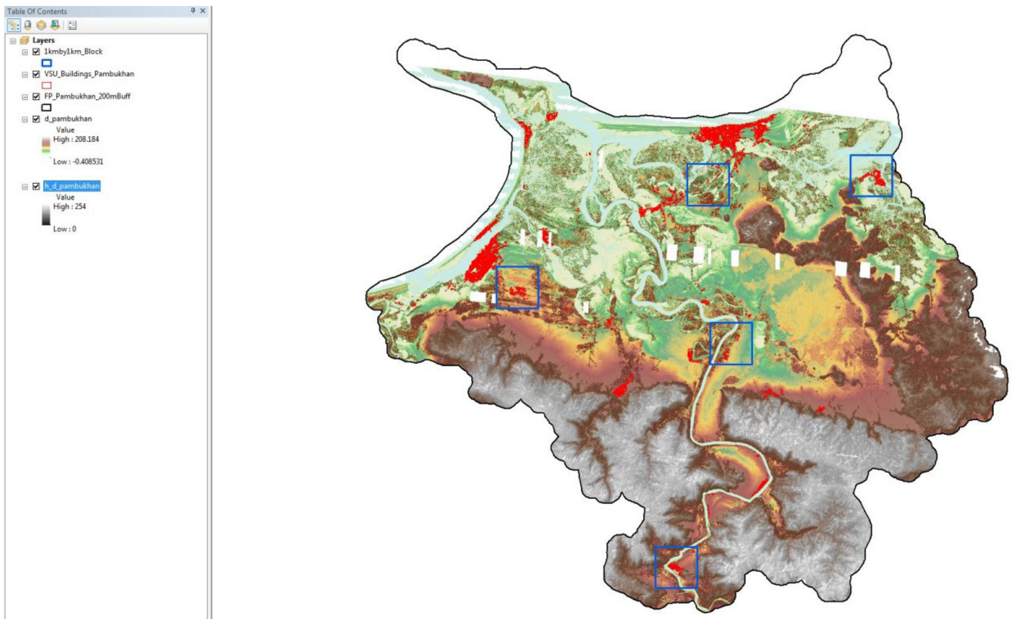


Figure 26. Block (in blue) of Pambukhan building features that was subjected to QC.

Quality checking of Pambukhan building features resulted in the ratings shown in Table 20.

Table 20. Details of the quality checking ratings for the building features extracted for the Pambukhan River Basin

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Pambukhan	99.90	100.00	94.28	PASSED

3.12.2 Height Extraction

Height extraction was done for 9004 building features in Pambukhan floodplain. Of these building features, 81 were filtered out after height extraction, resulting to 8,923 buildings with height attributes. The lowest building height is at 2.00 meters, while the highest building is at 10.61 meters.

3.12.3 Feature Attribution

The digitized features were marked and coded in the field using handheld GPS receivers. The attributes of non-residential buildings were first identified; all other buildings were then coded as residential. A DSM was generated using the LiDAR DEMs to extract the heights of the buildings. A minimum height of 2 meters was used to filter out the terrain features that were digitized as buildings. Buildings that were not yet constructed during the time of LiDAR acquisition were noted as new buildings in the attribute table.

Table 21 summarizes the number of building features per type, while Table 22 shows the total length of each road type. Table 23, on the other hand, shows the number of water features extracted per type.

Table 21. Building features extracted for Pambukhan Floodplain.

Facility Type	No. of Features
Residential	8382
School	213
Market	23
Agricultural/Agro-Industrial Facilities	9
Medical Institutions	13
Barangay Hall	25
Military Institution	0
Sports Center/Gymnasium/Covered Court	6
Telecommunication Facilities	2
Transport Terminal	0
Warehouse	11
Power Plant/Substation	0
NGO/CSO Offices	2
Police Station	2
Water Supply/Sewerage	0
Religious Institutions	16
Bank	0
Factory	3
Gas Station	6
Fire Station	1
Other Government Offices	27
Other Commercial Establishments	60
Abandoned	1
Monument	1
Cemetery	120
Total	**8923**

Table 22. Total length of extracted roads for Pambukhan Floodplain.

Floodplain	**Road Network Length (km)**					**Total**
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Pambukhan	47.87	23.72	14.81	0.00	0.00	**86.40**

Table 23. Number of extracted water bodies for Pambukhan Floodplain.

Floodplain	**Water Body Type**					**Total**
	Rivers/ Streams	Lakes/ Ponds	Sea	Dam	Fish Pen	
Pambukhan	49	0	0	0	16	**65**

A total of 18 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 Pambukhan floodplain overlaid with its ground features.

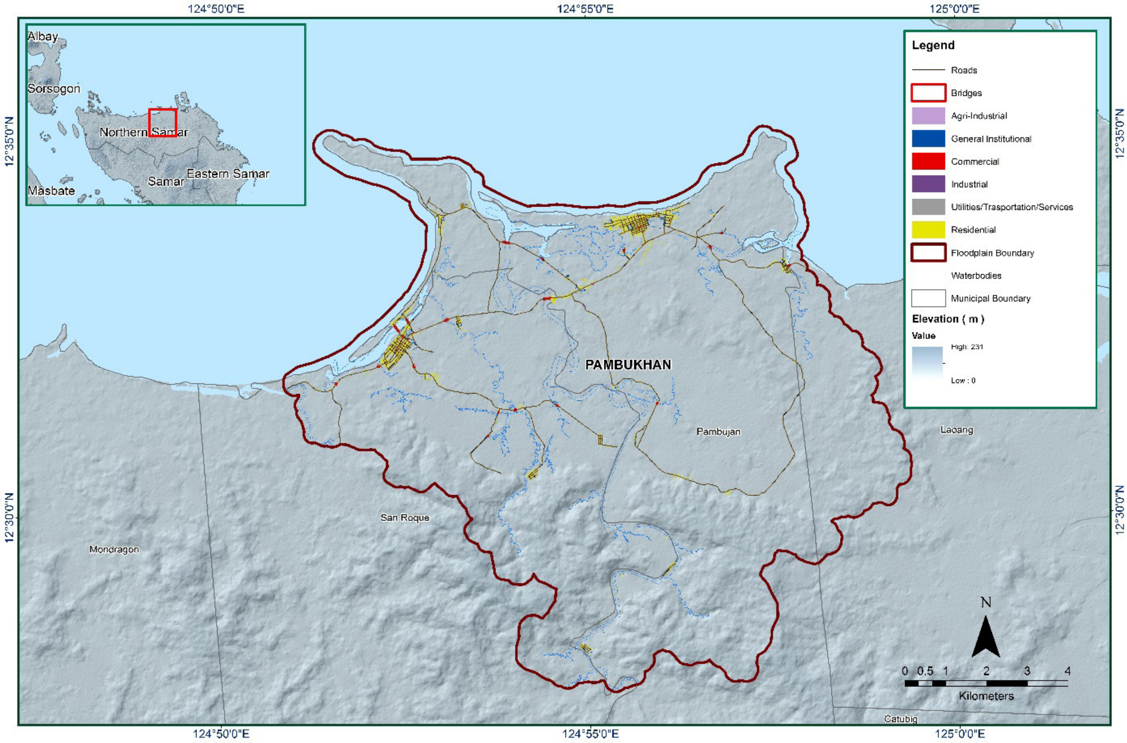


Figure 27. Extracted features of the Pambukhan Floodplain.

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

Engr. Louie P. Balicanta, Engr. Joemarie S. Caballero, Ms. Patrizcia Mae. P. dela Cruz, Engr. Dexter T. Lozano Engr. Bernard Paul D. Maramot, Engr. Precious Annie C. Lopez, Mr. Jann Russell J. Manzano, Mr. Kim Patrick A. Tort

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).

4.1 Summary of Activities

The Data Validation and Bathymetry Component (DVBC) conducted a field survey in Pambujan River on August 28 to September 5, and October 17 to 26, 2016 for reconnaissance; control survey; cross section and as-built survey at Pambujan Bridge in Brgy. Dale, Municipality of San Roque, Northern Samar; validation points acquisition of about 79.364 km covering seven (7) municipalities in Northern Samar; and bathymetric survey from its upstream in Brgy. Balnasan, Municipality of San Roque, down to the downstream end of the river located in Brgy. Doña Anecita, Municipality of Pambujan, with an approximate total length of 13.513 km using Ohmex™ single beam echo sounder and Trimble® SPS 882 GNSS PPK survey technique. The entire survey extent is illustrated in Figure 28.

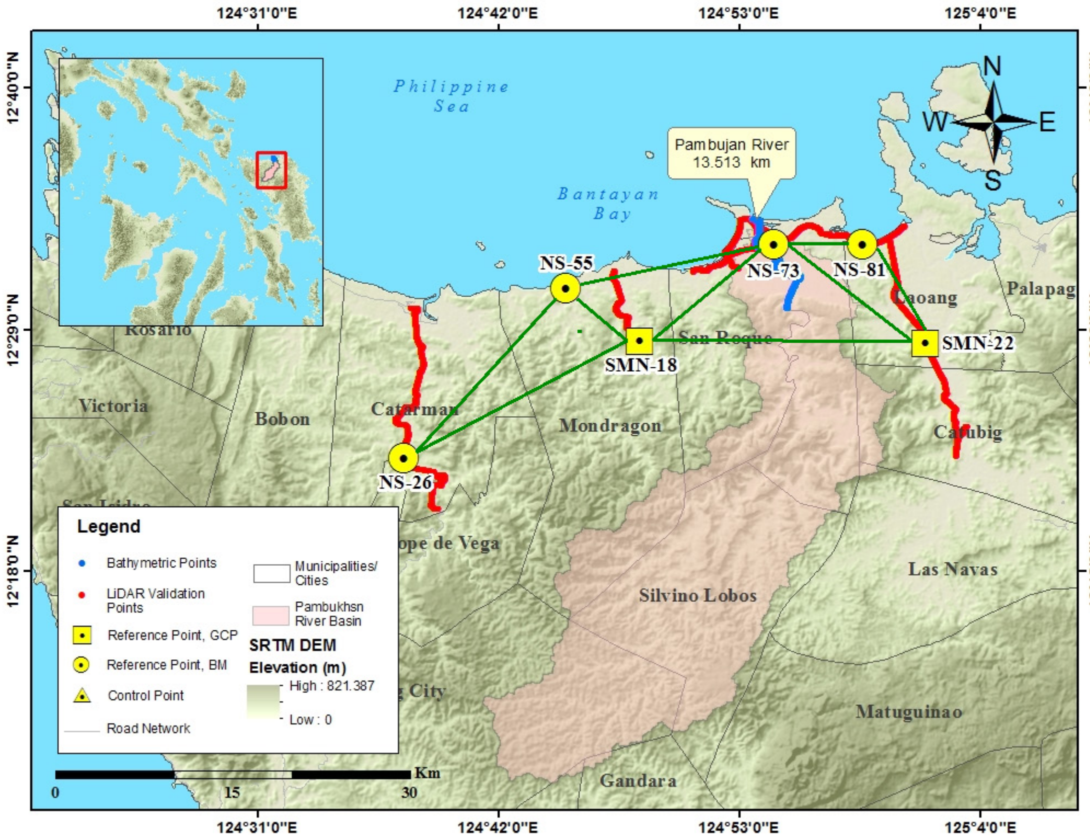


Figure 28.Pambukhan River Survey Extent

4.2 Control Survey

The GNSS network used for Pambukhan River Basin is composed of four loopsestablished on September 2, 2016 occupying the following control points:SMN-18, a 2nd order GCP in SMN-18, a 2nd order GCP in Brgy. Nenita, Municipality of Mondragon, Northern Samar; NS-26, a 1st order BM in Brgy.Polangi, Municipality of Catarman; NS-55, a 1st order BM in Brgy.Eco Poblacion, Municipality of Mondragon; NS-73, a 1st order BM in Brgy. Dale, Municipality of San Roque; and NS-81, a 1st order BM located in Brgy. Burabud, Municipality of Laoang, all in Northern Samar.

A NAMRIA established control point namely SMN-22 located in Brgy. Simora, Municipality of Laoang, was also used as a marker.

Table 24 depicts the summary of reference and control points utilized, with their corresponding locations, while Figure 29shows the GNSS network established in the Pambukhan River Survey.

Table 24. List of reference and control points used during the survey in Pambukhan River (Source: NAMRIA, UP-TCAGP).

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (m)	MSL Elevation (m)	Date of Establishment
Control Survey on December 10, 2016						
SMN-18	2nd Order, GCP	12°28’28.14643”	124°48’26.98399”	64.624	8.910	09-07-16
NS-26	Acc. Class at 95%CL: 4cm	12°23’08.14503”	124°37’40.19430”	70.990	13.480	09-01-16
NS-55	Acc. Class at 95%CL: 4cm	12°30’53.61856”	124°45’01.76667”	61.077	5.710	05-02-16
NS-73	Acc. Class at 95%CL: 6cm	12°32’52.45862”	124°54’30.80700”	60.314	5.945	09-01-16
NS-81	Acc. Class at 95%CL: 6cm	12°32’50.94301”	124°58’34.46636”	59.293	5.105	04-14-16
SMN-22	Used as Marker	-	-	-	-	09-04-15

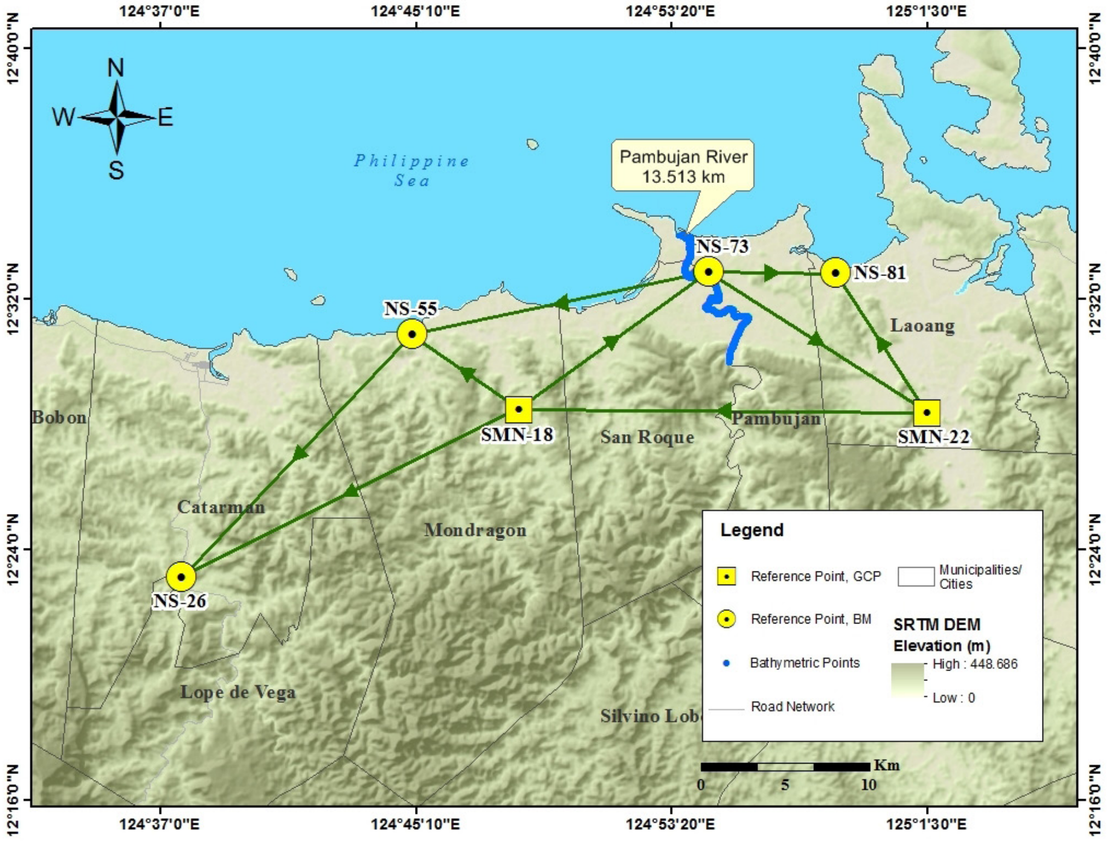


Figure 29.Pambukhan River Basin Control Survey Extent.

Figure 30 to Figure 35 depict the setup of the GNSS on recovered reference points and established control points in the Pambukhan River.

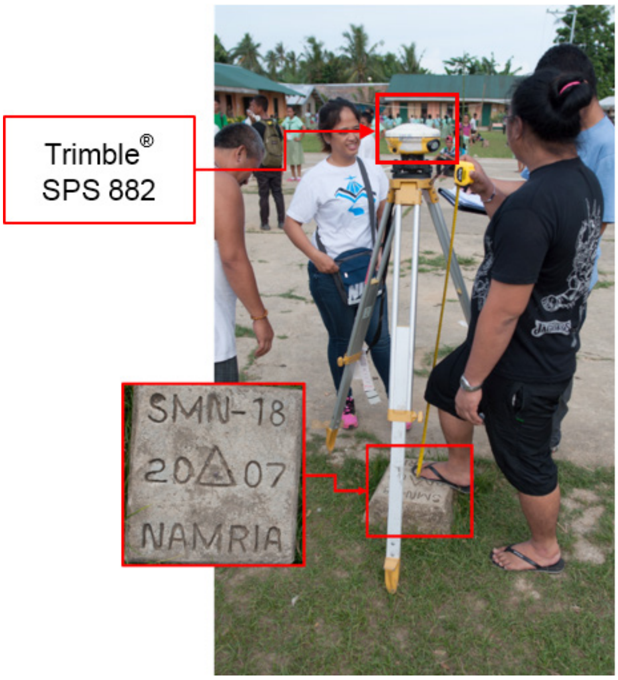


Figure 30. GNSS receiver setup, Trimble® SPS 882, at SMN-18, located inside Nenita Elementary School in Brgy. Nenita, Municipality of Mondragon, Northern Samar.

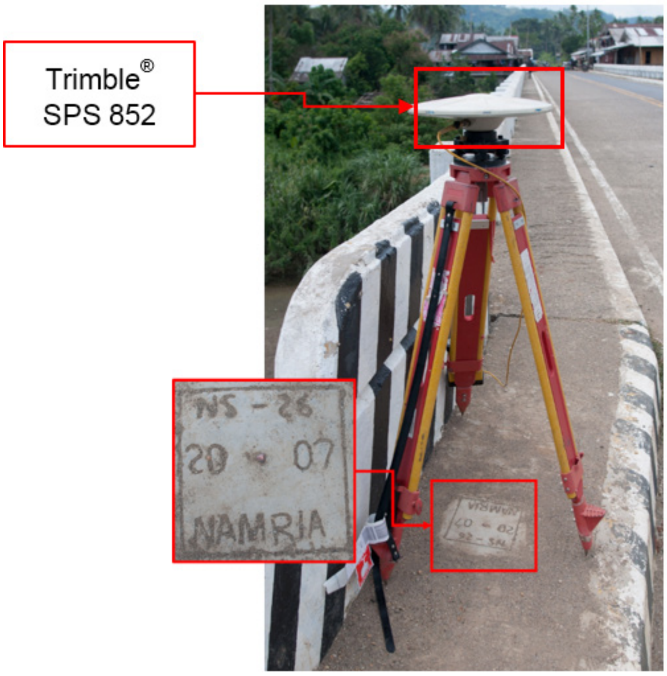


Figure 31. GNSS base set up, Trimble® SPS 852, at NS-26, located near the approach of Paticua Bridge in Brgy. Polangi, Municipality of Catarman, Northern Samar

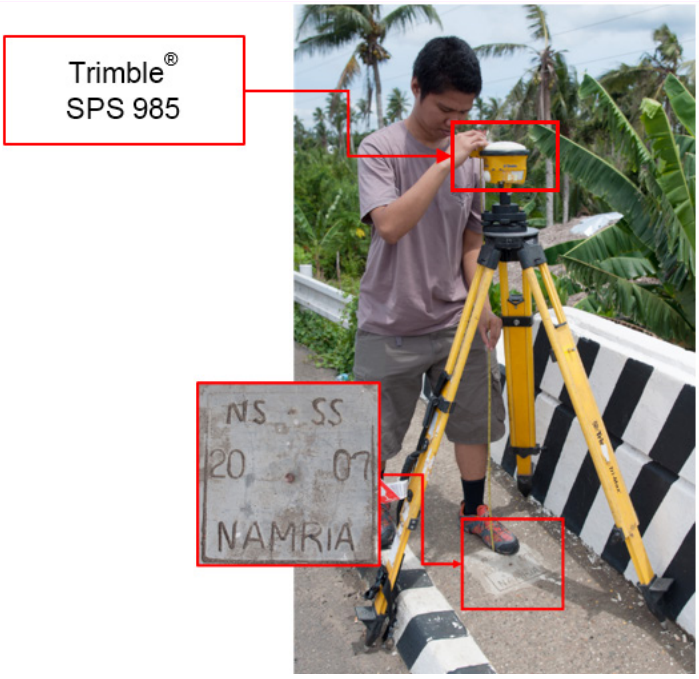


Figure 32.GNSS receiver setup, Trimble® SPS 985 at NS-55, located at the approach of Mondragon Bridge in Brgy. Eco Poblacion, Municipality of Mondragon, Northern Samar

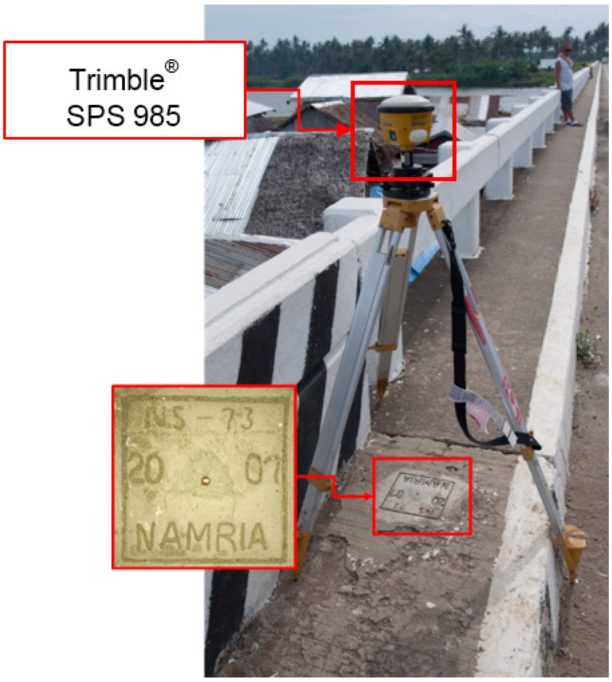


Figure 33.GNSS receiver setup, Trimble® SPS 985, at NS-73, located at the approach of Pambujan Bridge, in Brgy. Dale, Municipality of San Roque, Northern Samar

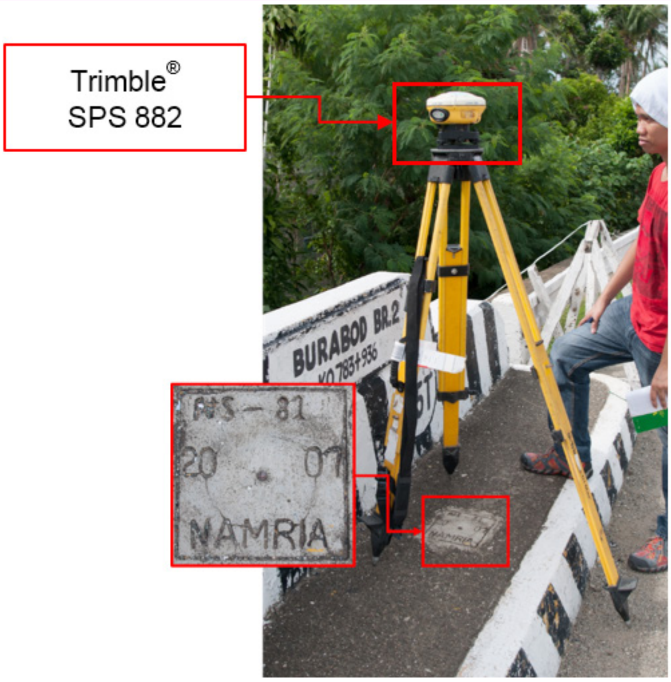


Figure 34.GNSS receiver setup, Trimble® SPS 882, at NS-81, located at the approach of Burabod Bridge in Brgy. Burabud, Municipality of Laoang, Northern Samar

Figure 35.GNSS receiver setup, Trimble® SPS 852, at SMN-22, located at Simora Elementary School in Brgy. Simora, Municipality ofLaoang, Northern Samar

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 25 presents the baseline processing results of control points in the Pambukhan River Basin, as generated by the TBC software.

Table 25.The Baseline processing report for the Pambujan River GNSS static observation survey.

Observation	Date of Observation	Solution Type	H.Prec (Meter)	V.Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	Height (Meter)
NS-73 --- SMN-18 (B2)	09-02-16	Fixed	0.007	0.019	53°30’34”	13661.419	-4.222
NS-26 --- SMN-18 (B5)	09-02-16	Fixed	0.003	0.015	243°17’56”	21869.739	6.334
NS-55 --- NS-26 (B7)	09-02-16	Fixed	0.003	0.014	223°00’23”	19555.744	9.752
NS-73 --- NS-55 (B8)	09-02-16	Fixed	0.005	0.013	258°00’58”	17563.299	0.841
NS-55 --- SMN-18 (B9)	09-02-16	Fixed	0.004	0.015	305°48’50”	7640.620	-3.409
NS-73 --- NS-81 (B11)	09-02-16	Fixed	0.003	0.013	90°21’20”	7355.805	-1.057
NS-73 --- SMN-22 (B18)	09-02-16	Fixed	0.009	0.017	123°16’30”	15138.600	-2.047
SMN-22 --- SMN-18 (B19)	09-02-16	Fixed	0.004	0.015	270°28’32”	23643.589	6.262
SMN-22 --- NS-81 (B20)	09-02-16	Fixed	0.004	0.016	327°20’08”	9814.890	0.918
NS-73 --- SMN-22 (B21)	09-02-16	Fixed	0.004	0.014	123°16’30”	15138.605	-1.963

As shown in Table 25, a total of ten(10) baselines were processed with values of all reference points except SMN-22, held fixed for coordinate and elevation values. All of them 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:

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

where:

x_e is the Easting Error,

y_e is the Northing Error, and

z_e is the Elevation Error

For complete details, see the Network Adjustment Report shown inTable 26to Table 29.

The six (6) control points, NS-26, NS-55, NS-73, NS-81, SMN-18 and SMN-22 were occupied and observed simultaneously to form a GNSS loop. Coordinates of SMN-18 and elevation values of all benchmarks were held fixed during the processing of the control points as presented in Table 26. Through these reference points, the coordinates and elevation of the unknown control points will be computed.

Table 26.Constraints applied to the adjustment of the control points.

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
SMN-18	Global	Fixed	Fixed		
NS-26	Grid				
NS-55	Grid				
NS-73	Grid				
NS-81	Grid				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 inTable 27.

Table 27. Adjusted grid coordinates for the control points used in the Pambukhan River flood plain survey.

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
SMN-18	696441.22698	?	1379691.63306	?	8.9098	0.031	LL
NS-26	676970.19397	0.007	1369731.98493	0.006	13.4801	?	e
NS-55	690214.51511	0.008	1384120.46061	0.006	5.7095	?	e
NS-73	707369.75759	0.009	1387891.68118	0.006	5.9447	?	e
NS-81	714726.67255	0.011	1387899.30448	0.008	5.1053	?	e
SMN-22	720088.05329	0.009	1379675.96886	0.006	3.45269	0.067	

The results of the computation for accuracy are as follows:

a. **SMN-18**
horizontal accuracy = Fixed
vertical accuracy = 3.1 cm < 10 cm

b. **NS-26**
horizontal accuracy = $\sqrt{((0.7)^2 + (0.6)^2}$
= $\sqrt{(0.49 + 0.36)}$
= 0.92< 20 cm
vertical accuracy = Fixed

c. **NS-55**
horizontal accuracy = $\sqrt{((0.8)^2 + (0.6)^2}$
= $\sqrt{(0.64 + 0.36)}$
= 1.00 < 20 cm
vertical accuracy = Fixed

d. **NS-73**
horizontal accuracy = $\sqrt{((0.9)^2 + (0.6)^2}$
= $\sqrt{(0.81 + 0.36)}$
= 1.08< 20 cm
vertical accuracy = Fixed

e. **NS-81**
horizontal accuracy = $\sqrt{((1.1)^2 + (0.8)^2}$
= $\sqrt{(1.21 + 0.64)}$
= 1.36 cm < 20 cm
vertical accuracy = Fixed

f. **SMN-22**
horizontal accuracy = $\sqrt{((0.9)^2 + (0.6)^2}$
= $\sqrt{(0.81 + 0.36)}$
= 1.08 cm < 20 cm
vertical accuracy = 6.7 cm < 10 cm

Following the given formula, the horizontal and vertical accuracy result of the two (2) occupied control points are within the required precision.

Table 28.Adjusted geodetic coordinates for control points used in the Pambukhan River Flood Plain validation.

Point ID	Latitude	Longitude	Ellipsoid Height (Meter)	Height Error (Meter)	Constraint
SMN-18	N12°28’28.14643”	E124°48’26.98399”	64.6235	0.031	LL
NS-26	N12°23’08.14503”	E124°37’40.1943”	70.99005	?	e
NS-55	N12°30’53.61856”	E124°45’01.76667”	61.0772	?	e
NS-73	N12°32’52.45862”	E124°54’30.807”	60.31401	?	e
NS-81	N12°32’50.94301”	E124°58’34.46636”	59.29264	?	e
SMN-22	N12°28’22.07678”	E125°01’29.94039”	58.56371	0.067	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 28. 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 Pambukhan River GNSS Static Survey are seen in Table 29.

Table 29. The reference and control points utilized in the Pambukhan 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	Ellip-soidal Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
SMN-18	2nd Order, GCP	12°28’28.14643”	124°48’26.98399”	64.624	1379691.633	696441.227	8.910
NS-26	Acc. Class at 95%CL: 4cm	12°23’08.14503”	124°37’40.19430”	70.990	1369731.985	676970.194	13.480
NS-55	Acc. Class at 95%CL: 4cm	12°30’53.61856”	124°45’01.76667”	61.077	1384120.461	690214.515	5.710
NS-73	Acc. Class at 95%CL: 6cm	12°32’52.45862”	124°54’30.80700”	60.314	1387891.681	707369.758	5.945
NS-81	Acc. Class at 95%CL: 6cm	12°32’50.94301”	124°58’34.46636”	59.293	1387899.304	714726.673	5.105
SMN-22	Used as Marker	12°28’22.07678”	125°01’29.94039”	58.564	1379675.969	720088.053	3.453

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

The bridge cross-section and as-built surveys were conducted on September 1, 2016 at the upstream side of Pambujan Bridge in Brgy. Dale, Municipality of San Roque, Northern Samar. GNSS receiver Trimble® SPS 882 in PPK survey technique was utilized for this survey (Figure 36 and Figure 37).

Figure 36.Pambujan Bridge facing upstream.

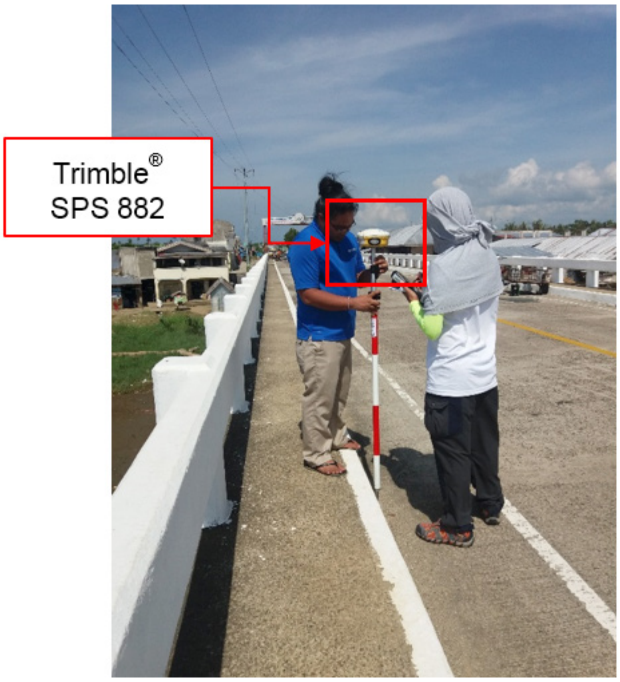


Figure 37. As-built survey conducted at Pambujan Bridge.

The length of the cross-sectional line surveyed atPambujan Bridge is about 386 m. (Figure 36) with one hundred and sixty-two (162) cross-sectional pointsacquired using the control point SMN-22 as the GNSS base station. Thelocation map, cross-section diagram and the accomplished bridge data formare shown in Figure 38, Figure 38 and Figure 40.

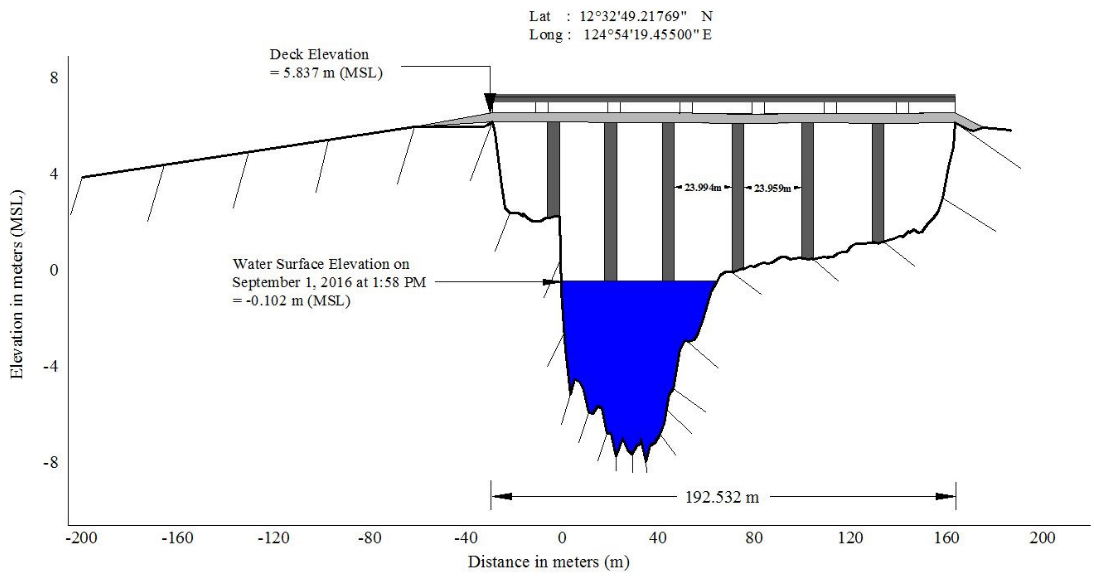


Figure 38. Location map of the Pambujan Bridge Cross Section

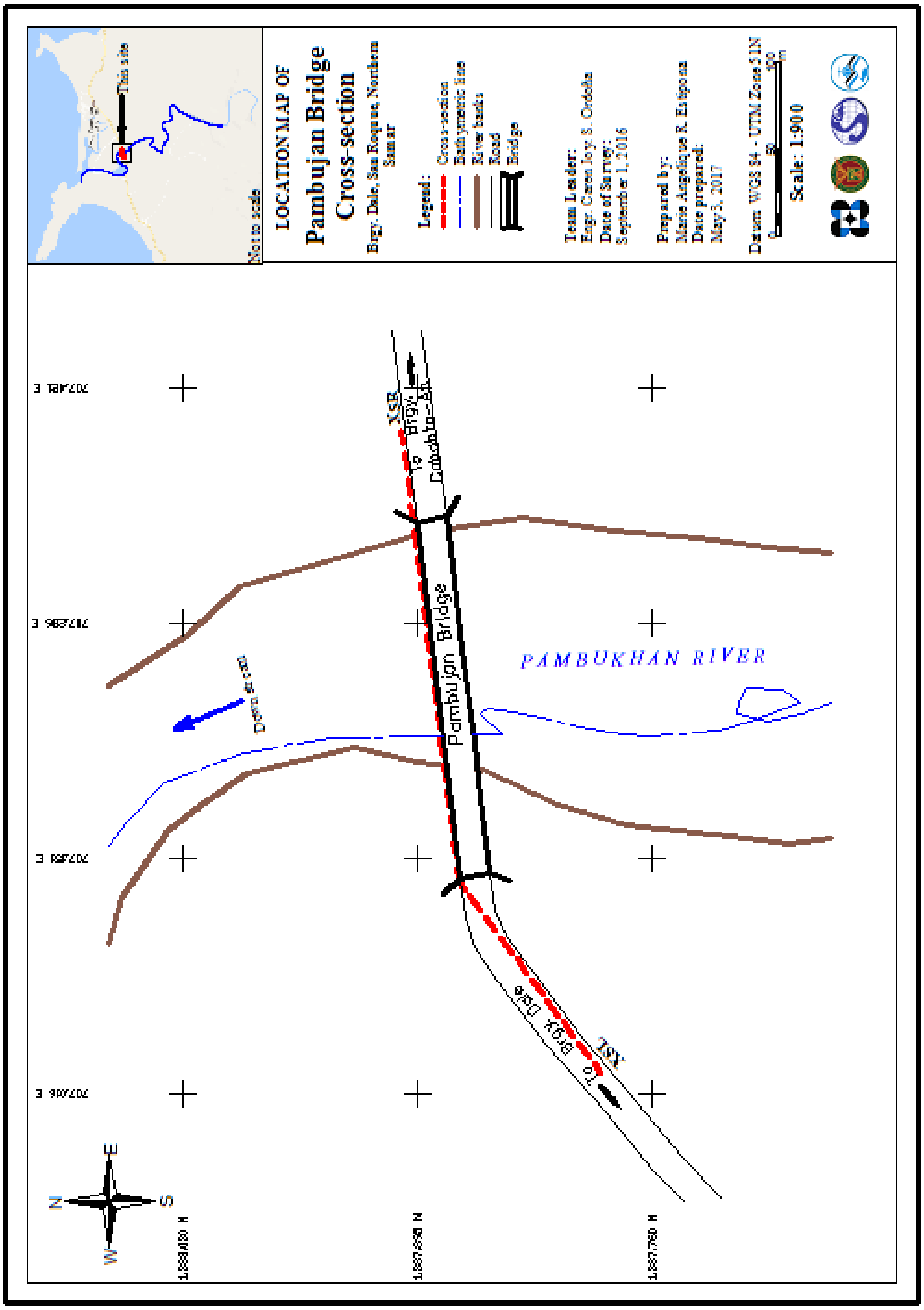
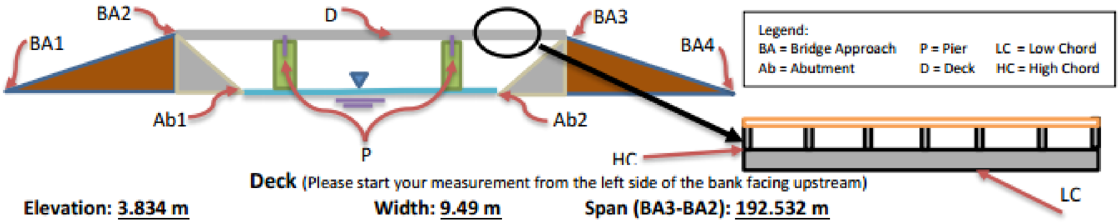


Figure 39.The PambujanBridge cross-section diagram.

Bridge Data Form

Bridge Name: Pambujan Bridge — **Date:** September 1, 2016
River Name: Pambukhan River — **Time:** 11:26 AM
Location (Brgy, City,Region): Brgy. Dale, Municipality of San Roque, Northern Samar
Survey Team: Caren Ordoña, Iro Niel Roxas, Merli Fernando, Frank Nicolas Ilejay
Flow condition: normal — **Weather Condition:** fair
Latitude: 12°32'49.21769" N — **Longitude:** 124°54'19.45500" E



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

Elevation: 3.834 m **Width:** 9.49 m **Span (BA3-BA2):** 192.532 m

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

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

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	0	3.834 m	BA3	363.006 m	6.107 m
BA2	170.474 m	6.120 m	BA4	370.677 m	5.753 m

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

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

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

Shape: Circular Number of Piers: 6 Height of column footing: Not available

	Station (Distance from BA1)	Elevation	Pier Diameter
Pier 1	198.435 m	6.113 m	1.20 m
Pier 2	222.213 m	6.111 m	1.20 m
Pier 3	246.201 m	6.092 m	1.20 m
Pier 4	275.195 m	6.046 m	1.20 m
Pier 5	304.154 m	6.089 m	1.20 m
Pier 6	333.434 m	6.066 m	1.20 m

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

Figure 40.The Pambujan Bridge as-built survey data.

The water surface elevation of Pambujan River was determined by a survey grade GNSS receiver Trimble® SPS 882 in PPK survey technique on September 1, 2016 at 1:58 PM with a value of -0.102 m in MSL as shown in Figure 39. This was translated into marking on the bridge's deck as shown in Figure 41. It now serves as the reference for flow data gathering and depth gauge deployment of the Visayas State University, the partner HEI responsible for the monitoring of the Pambujan River.

Figure 41.Water-level markings onPambujan Bridge.

4.6 Validation Points Acquisition Survey

The validation points acquisition survey was conducted on on August 31, September 2 and 3, 2016 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted in front of a vehicle as shown in Figure 42. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The antenna height was 1.907 m and measured from the ground up to the bottom of notch of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with NS-26, SMN-18 and SMN-22 occupied as the GNSS base stations in the conduct of the survey.

Figure 42.GNSS Receiver Trimble® SPS 882 installed on a vehicle for Ground Validation Survey.

The survey had three routes. The first route started in Brgy. Molave going south covering thirteen (13) barangays in Catarman and ended in Brgy. Cervantes, Municipality of Catarman. The second route started in Brgy. Bugko going south and ended in Brgy. Nenita, Municipality of Mondragon. The third route started in Brgy. Bantayan, Municipality of San Roque going east covering twelve (12) barangays of Laoang, Pambujan and San Roque and ended in Brgy. Rawis, Municipality of Laoang; and going south covering eighteen (18) more barangays and ended in Brgy. Sagudsuron, Municipality of Catubig. The survey gathered a total of 13,816 points with approximate length of 79 km using NS-26, SMN-18 and SMN-22 as GNSS base stations for the entire extent validation points acquisition survey as illustrated in the map in Figure 43.

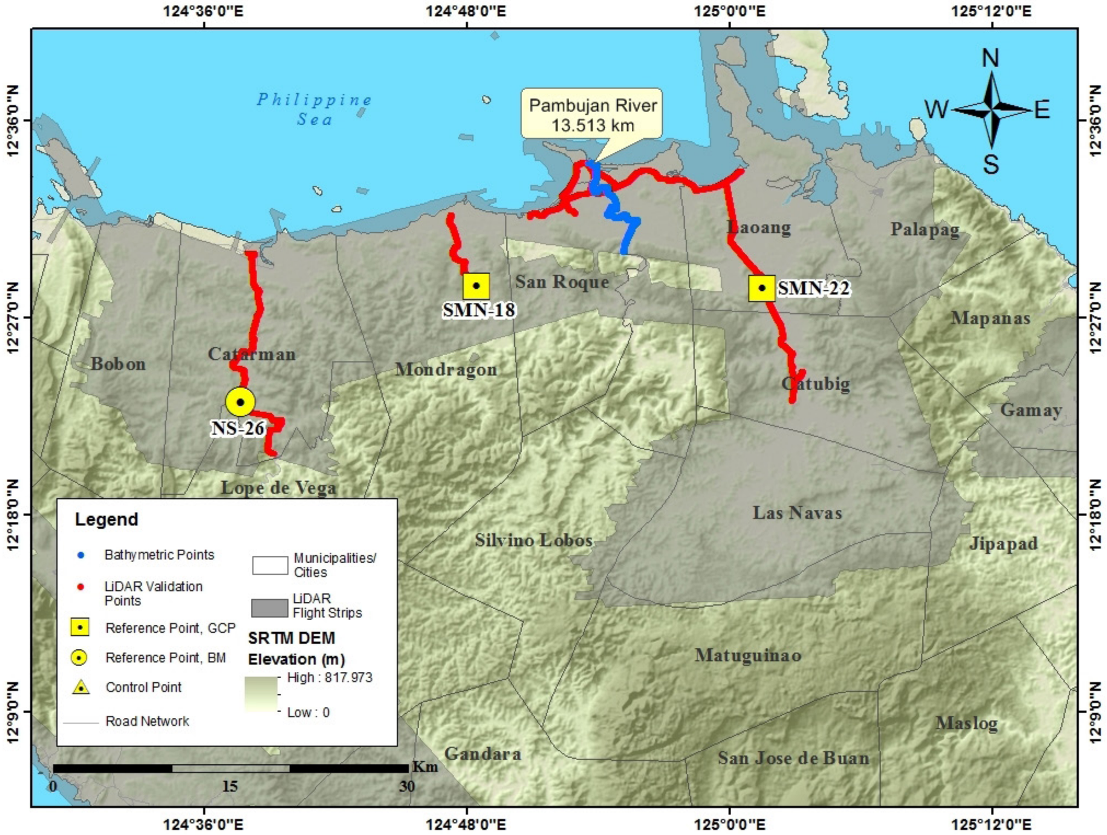


Figure 43.The extent of the LiDAR ground validation survey (in red) for Pambukhan River Basin.

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4.7 River Bathymetric Survey

A bathymetric survey was performedon October 19 and 20, 2016 using a Trimble® SPS 882 in GNSS PPK survey technique in continuous topographic modeas shown in Figure 44.

Figure 44.Set up of the bathymetric survey at Pambujan River using Trimble® SPS 882 in GNSS PPK survey technique.

The survey started in Brgy. Balnasan, Municipality of San Roque with coordinates 12°29'59.7747"N, 124°55'10.17770"E, and ended at the mouth of the river in Brgy. Doña Anecita, Municipality of Pambujan, with coordinates 12°34'02.52499"N, 124°53'34.86500"E. The control point NS-73 was used as the GNSS base station all throughout the entire survey.

Overall, the bathymetric survey for Pambujan River gathered a total of 16,461 points covering 13.513 km of the river traversing Barangays Cababto-An, Cabari-An, Canjumadal and Doña Anecita in Municipality of Pambujan; and barangays Balnasan, Balud and Dale in Municipality of San Roque, Northern Samar.A CAD drawing was also produced to illustrate the riverbed profile of PambujanRiverwas produced. As seen in Figure 46, the the highest and lowest elevation has an 8-m difference. The highest elevation observed was 0.274 m above MSL located in Brgy. Dale, Municipality of San Roque, while the lowest was -8.867 m below MSL located in Brgy. Cababto-An, Municipality of Pambujan.

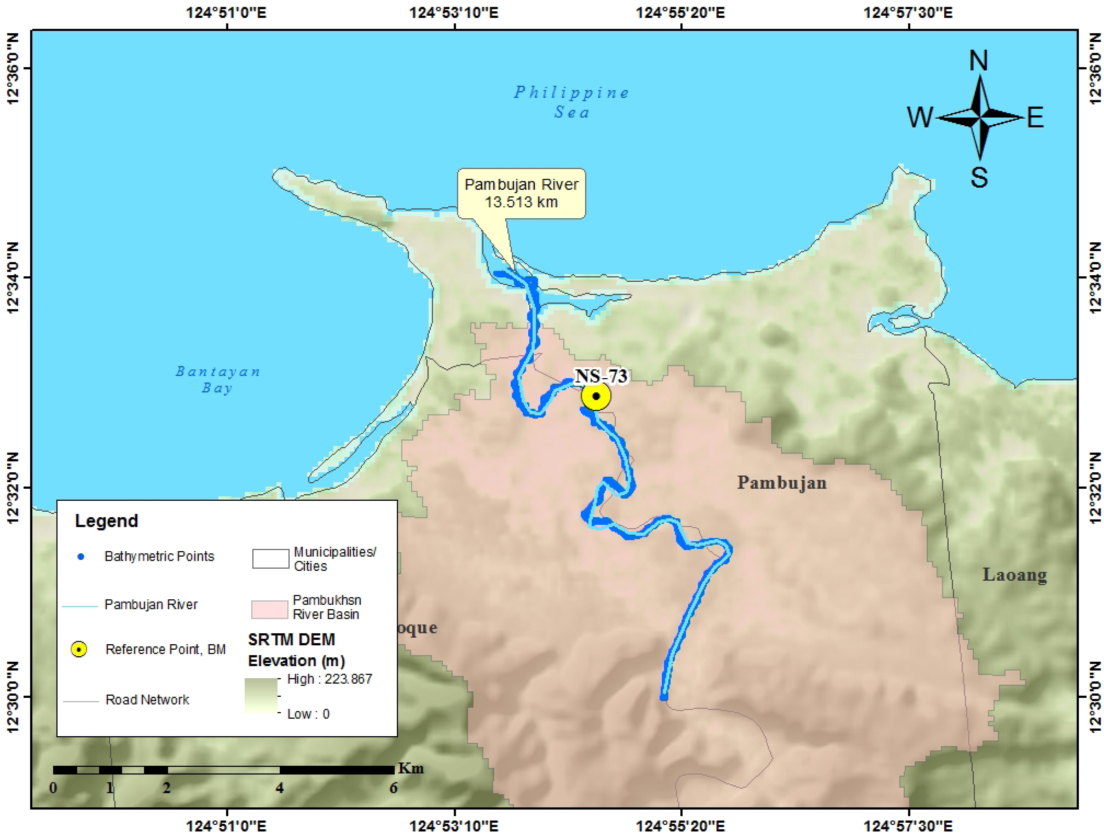

Figure 45.The extent of the Pambujan River Bathymetry Survey.

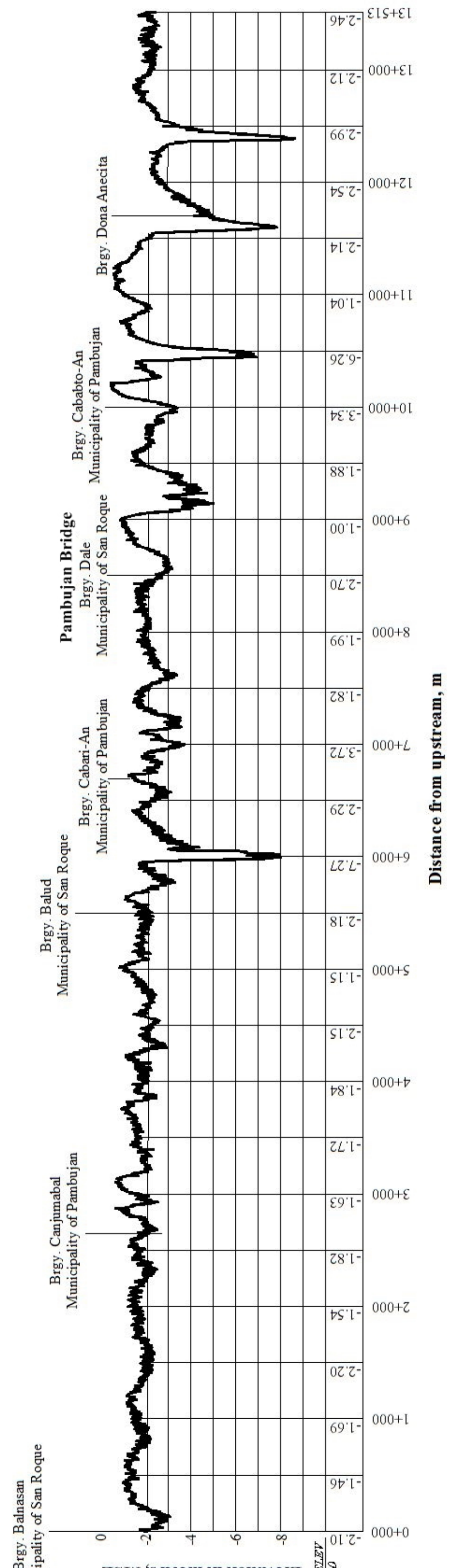

Figure 46.The Pambujan Riverbed Profile.

CHAPTER 5: FLOOD MODELING AND MAPPING

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

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).

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

All components and data, such as rainfall, water level, and flow in a certain period of time, which may affect the hydrologic cycle of the Pambukhan River Basin were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from an automatic rain gauge (ARG) temporarily installed by the Visayas State University Phil-Lidar 1 Flood Modeling Component (FMC).The location of the Pambukhan ARG is illustrated in Figure 47.

Total rain from Pambukhan rain gauge is 74.8 mm. It peaked to 6.2 mm on 20 January 2017, 20:30. The lag time between the peak rainfall and discharge is 29 hours.

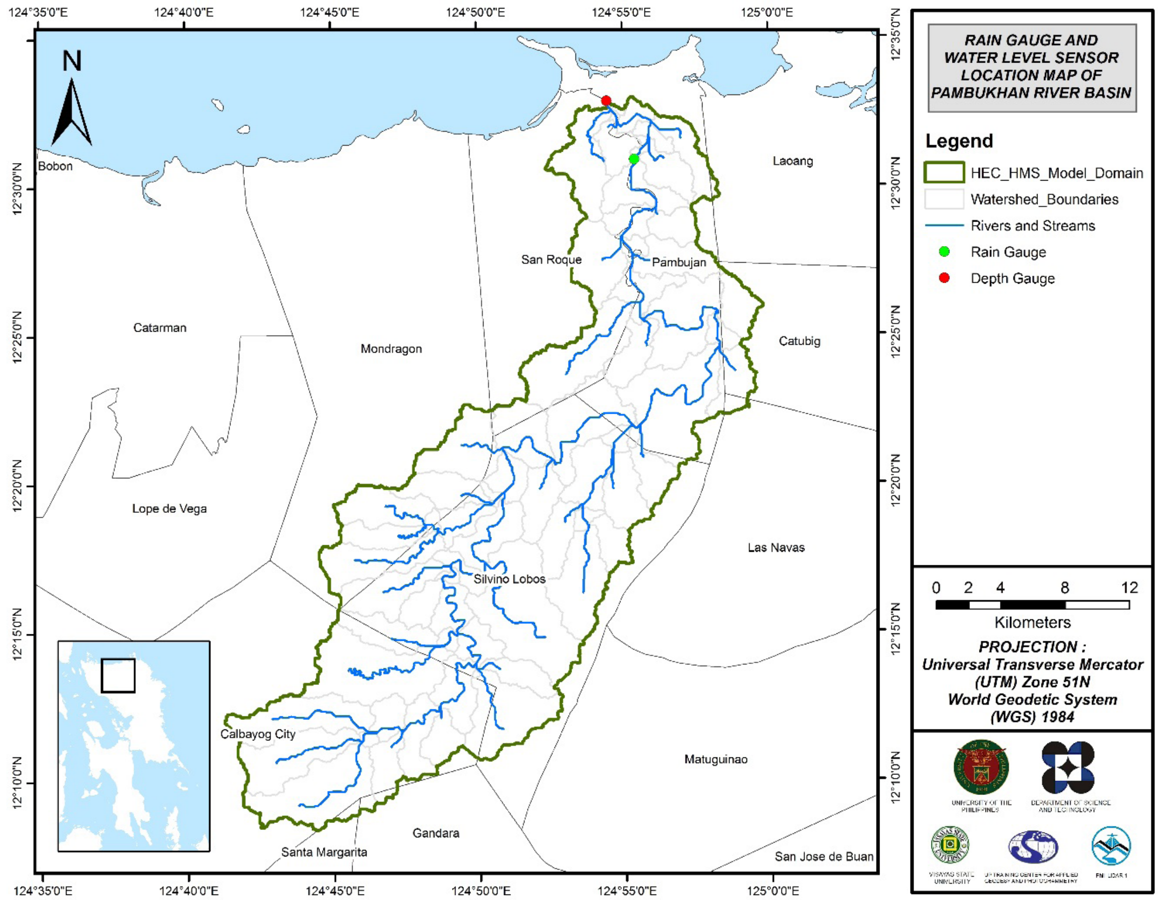

Figure 47. Location Map of the Pambukhan HEC-HMS model used for calibration.

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Pambukhan Bridge, Brgy. Dale, San Roque, Northern Samar (12.547844° N, 124.907402° E)to establish the relationship between the observed water levels from the Las Navas Bridge Automated Water Level Sensor (AWLS) HOBO Depth Gauge and the combined discharge from baseflow and bankfull

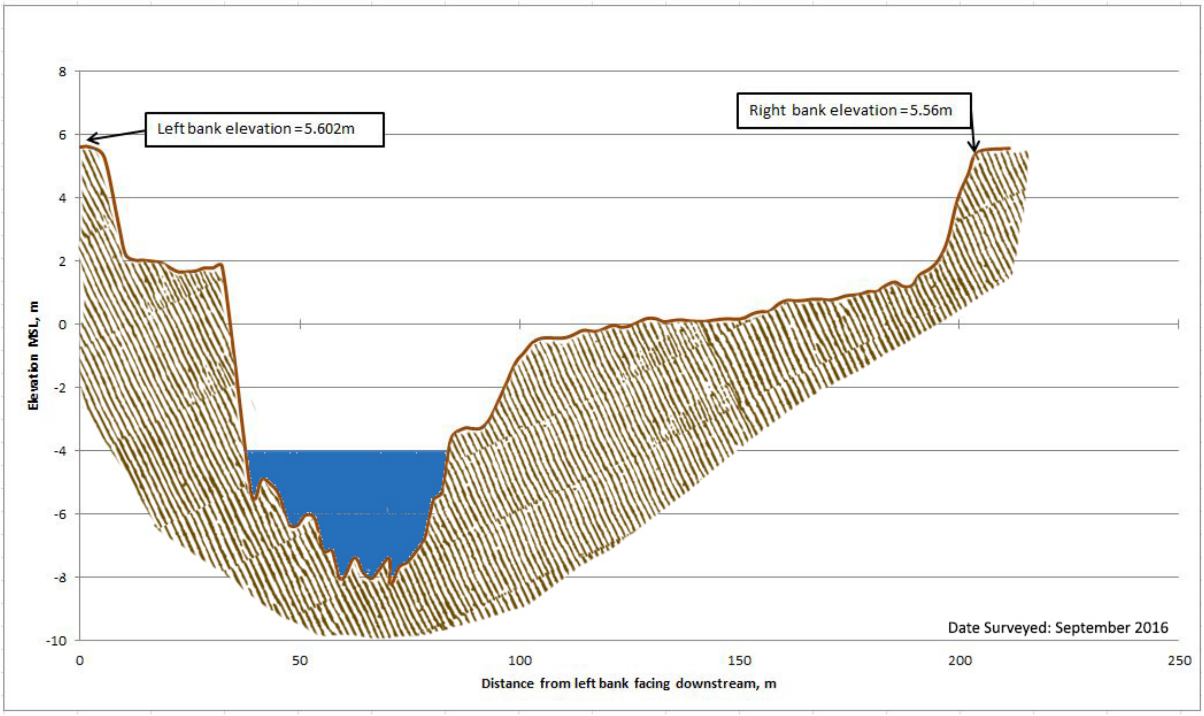

Figure 48.Cross-Section Plot of Pambukhan Bridge.

For Pambukhan Bridge, the rating curve is expressed as $Q = 43.187e^{0.2768h}$as shown in Figure 49.

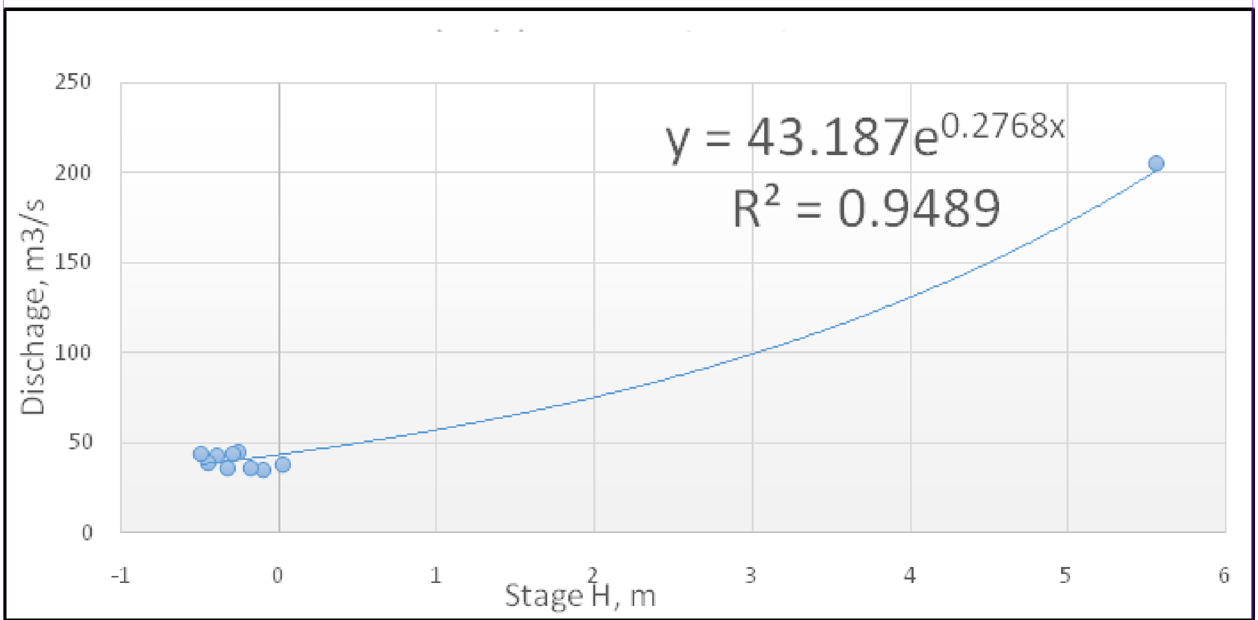

Figure 49.The rating curve at PambukhanBridge.

This rating curve equation was used to compute the river outflow at Pambukhan Bridge for the calibration of the HEC-HMS model shown in Figure 50. Total rain from Pambukhan rain gauge is 74.8 mm. It peaked to 6.2 mm on 20 January 2017, 20:30. The lag time between the peak rainfall and discharge is 29 hours.

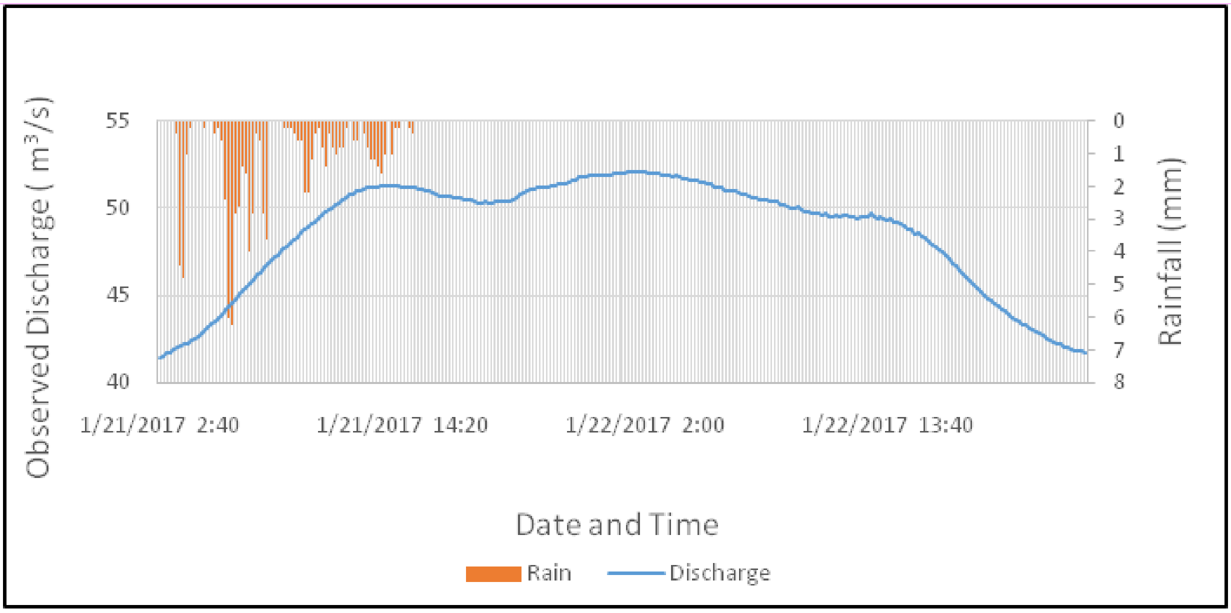

Figure 50.Rainfall and outflow data at Pambukhan Bridge, which was used for modeling.

5.2 RIDF Station

PAGASA computed the Rainfall Intensity Duration Frequency (RIDF) values for the Catarman Rain Gauge (Table 30). 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 51). This station was selected based on its proximity to the Pambukhan watershed. The extreme values for this watershed were computed based on a 36-year record.

Table 30. RIDF values for the Pambukhan River Basin based on average RIDF data of Catarman 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	22.5	34.2	42.4	57.5	80.9	96.4	125.2	156.6	180
5	29.9	45.4	56.2	77	110.3	135.9	183.5	229.5	255.4
10	34.7	52.8	65.4	90	129.7	162	222.1	277.8	305.4
15	37.5	57	70.5	97.3	140.7	176.7	243.9	305.1	333.6
20	39.4	60	74.2	102.4	148.4	187.1	259.1	324.1	353.3
25	40.9	62.2	76.9	106.3	154.3	195	270.9	338.8	368.5
50	45.5	69.2	85.5	118.4	172.6	219.5	307.1	384.1	415.3
100	50	76.1	94	130.5	190.7	243.8	343	429	461.8

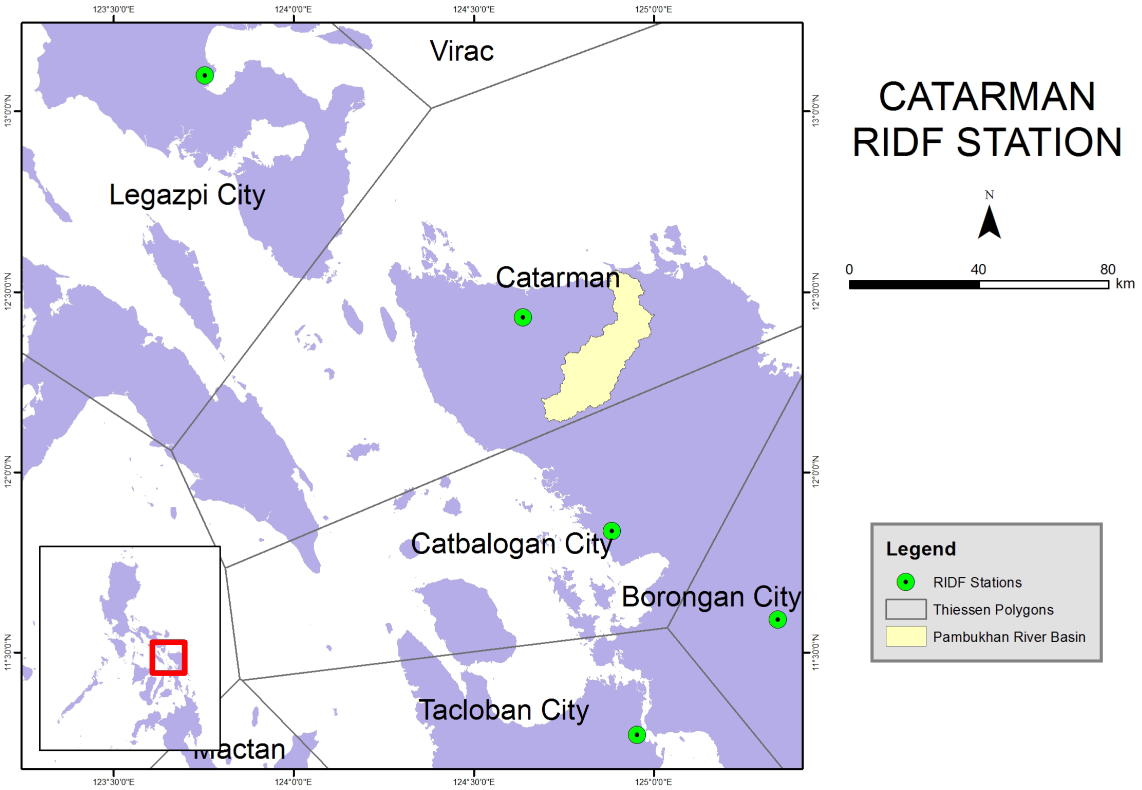

Figure 51. The location of the Catarman RIDF station relative to the Pambukhan River Basin.

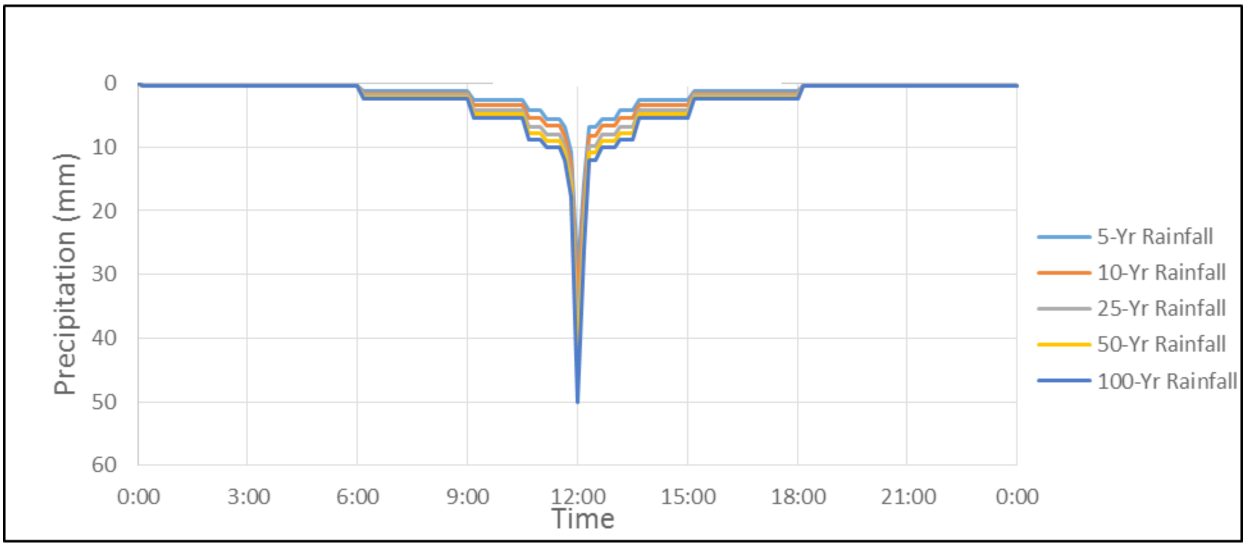

Figure 52. Synthetic storm generated for a 24-hr period rainfall for various return periods.

5.3 HMS Model

The soil shapefile was taken on 2004 from the Bureau of Soils; this is under the Department of Environment and Natural Resources Management. The land cover shape file is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Pambukhan River Basin are shown in Figure 53 and Figure 54,respectively.

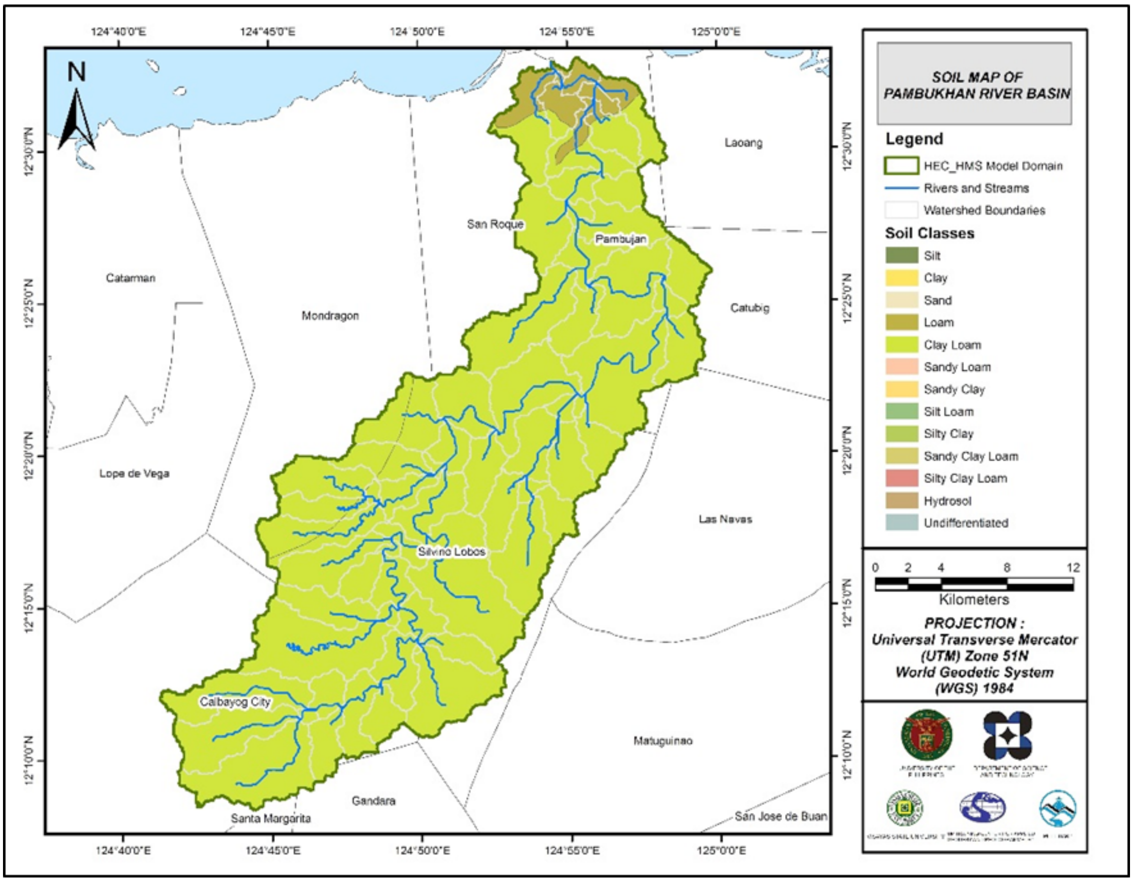

Figure 53. Soil Map of Pambukhan River Basin.

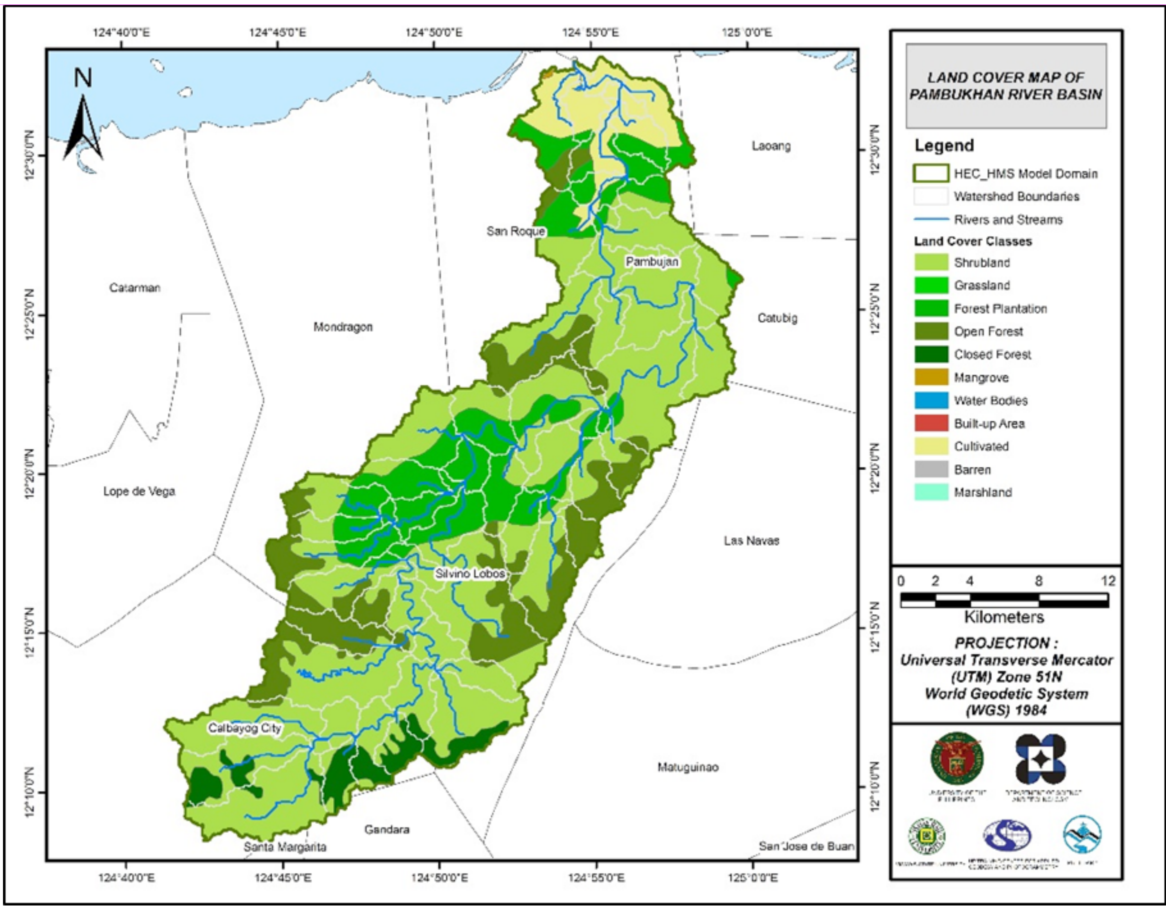

Figure 54. Land Cover Map of Pambukhan River Basin.

For Pambukhan, two soil classes were identified. These are loam, and clay loam. Moreover, six land cover types were identified. These are shrubland, grassland, forest plantation, open forest, closed forest, and cultivated.

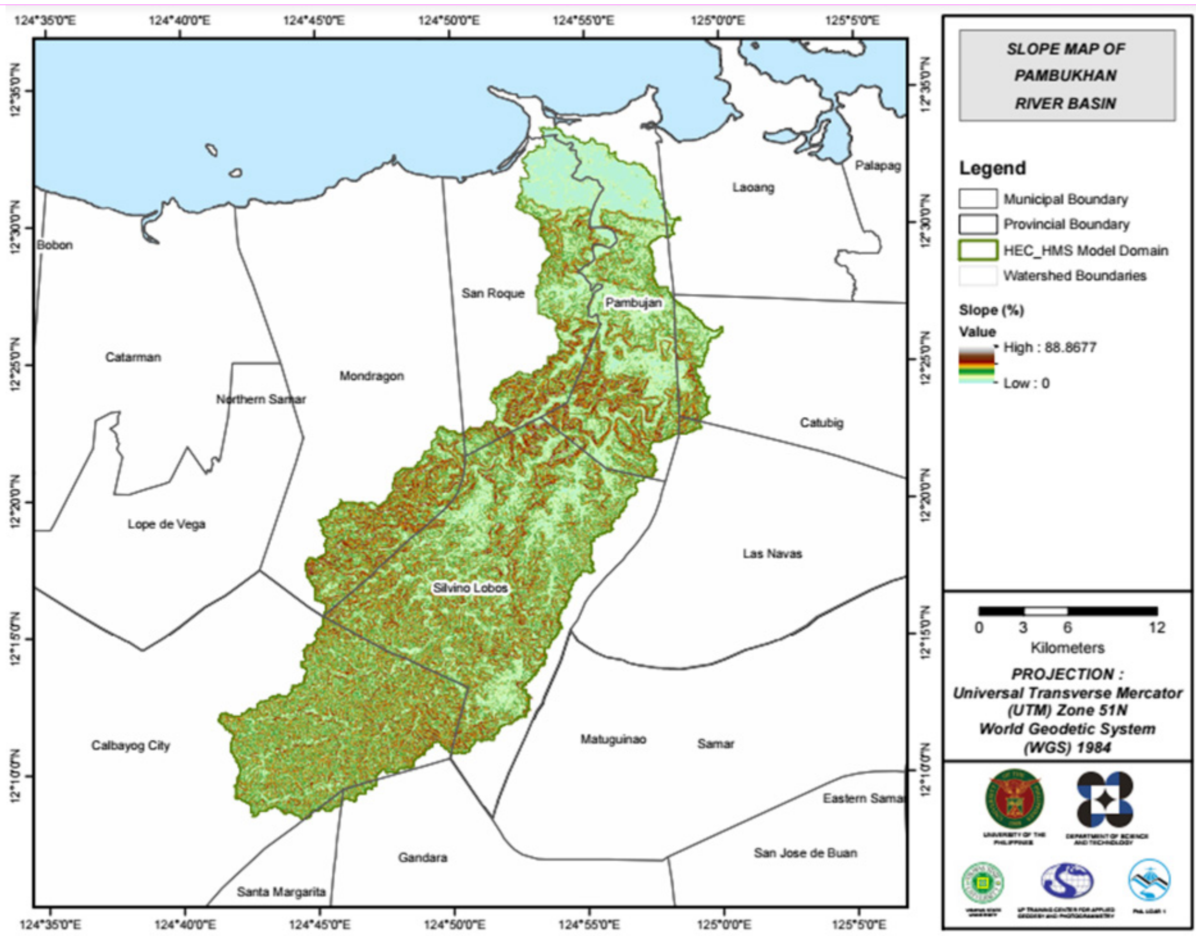

Figure 55. Slope Map of the Pambukhan River Basin.

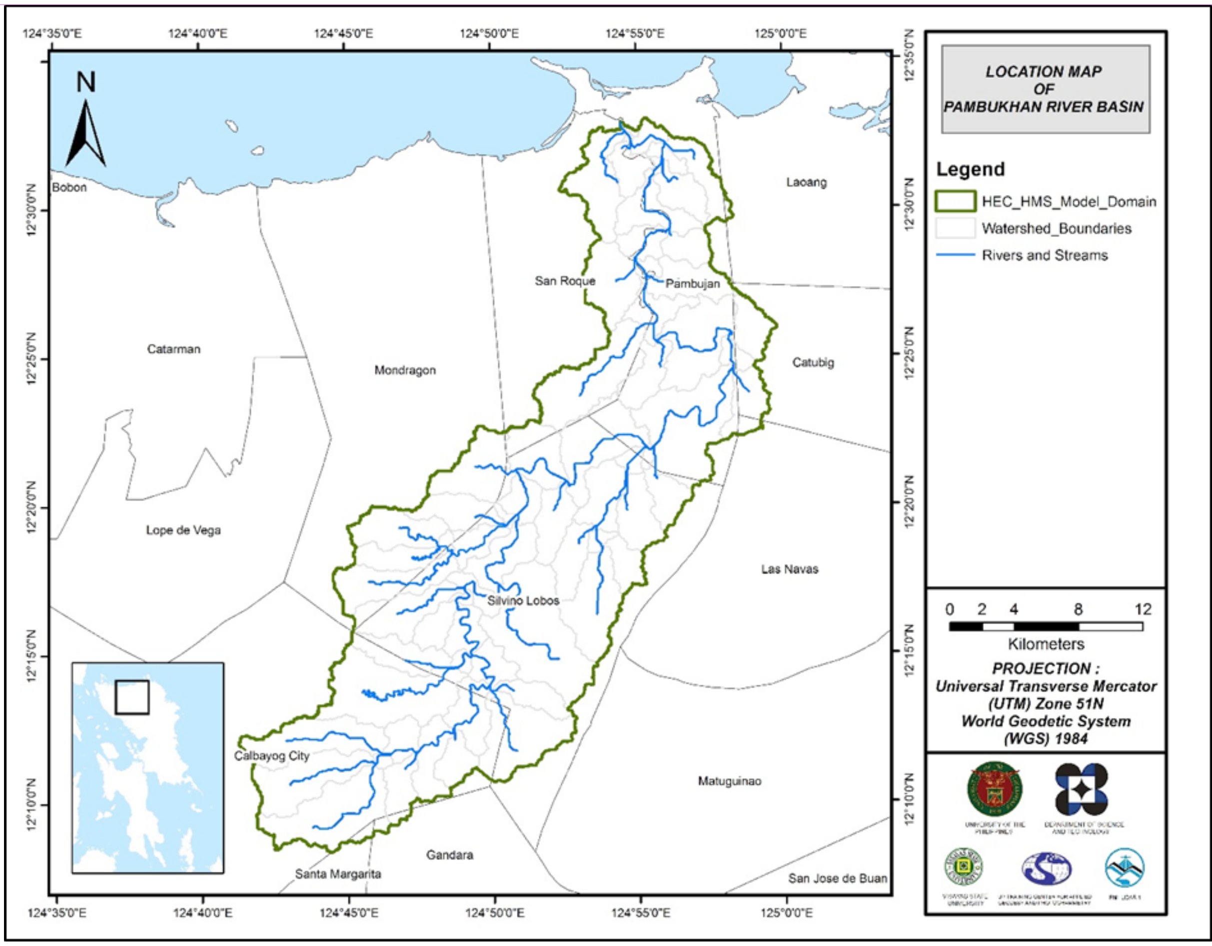

Figure 56. Stream Delineation Map of Pambukhan River Basin

Using the SAR-based DEM, the Pambukhan basin was delineated and further subdivided into subbasins. The model consists of 67 subbasins, 33 reaches, and 33 junctions as shown inFigure 57. The main outlet is at Pambukhan Bridge.

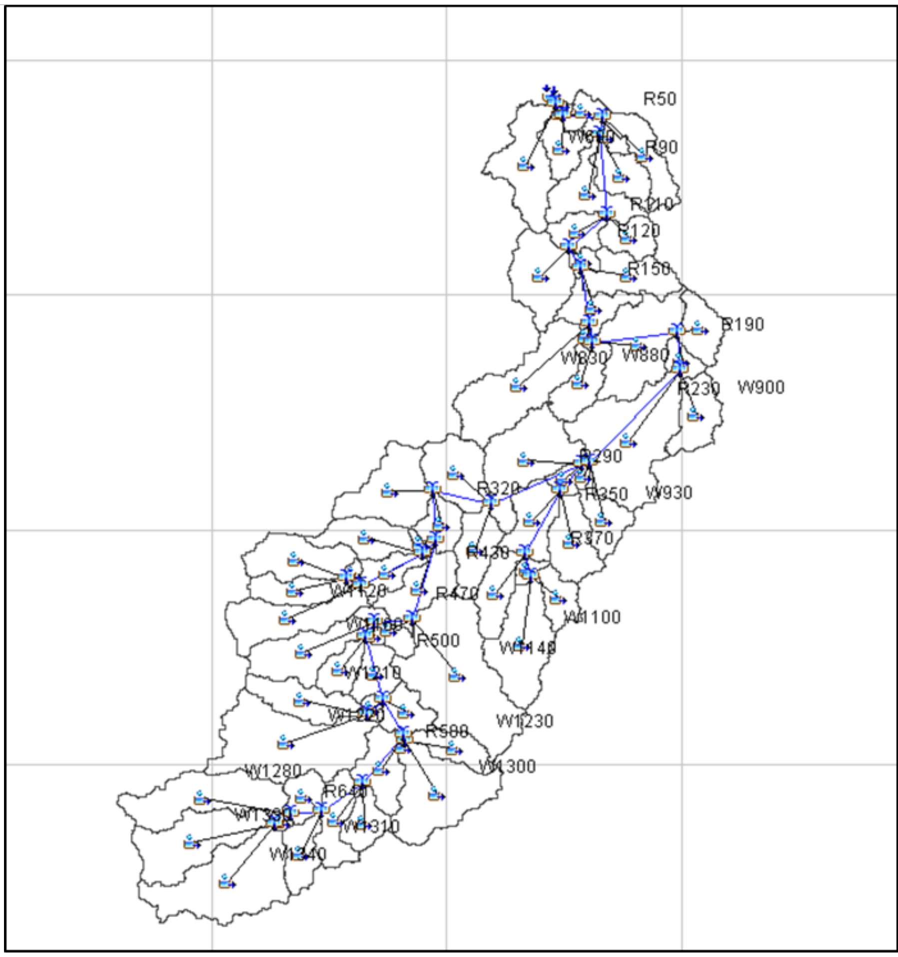

Figure 57.Pambukhan river basin model generated in HEC-HMS.

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 58).

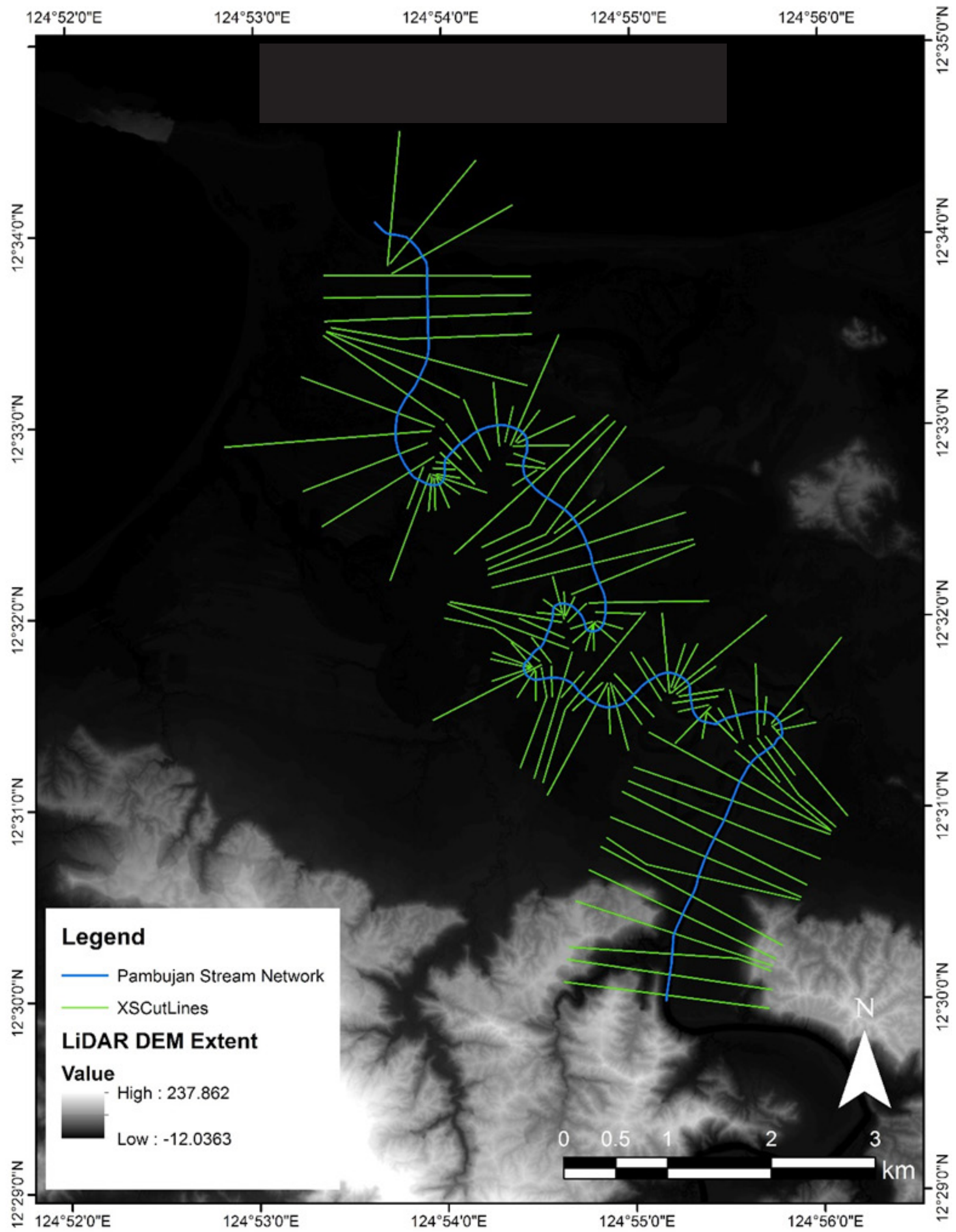

Figure 58.River cross-section of the Pambukhan River through the ArcMap HEC GeoRas tool.

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

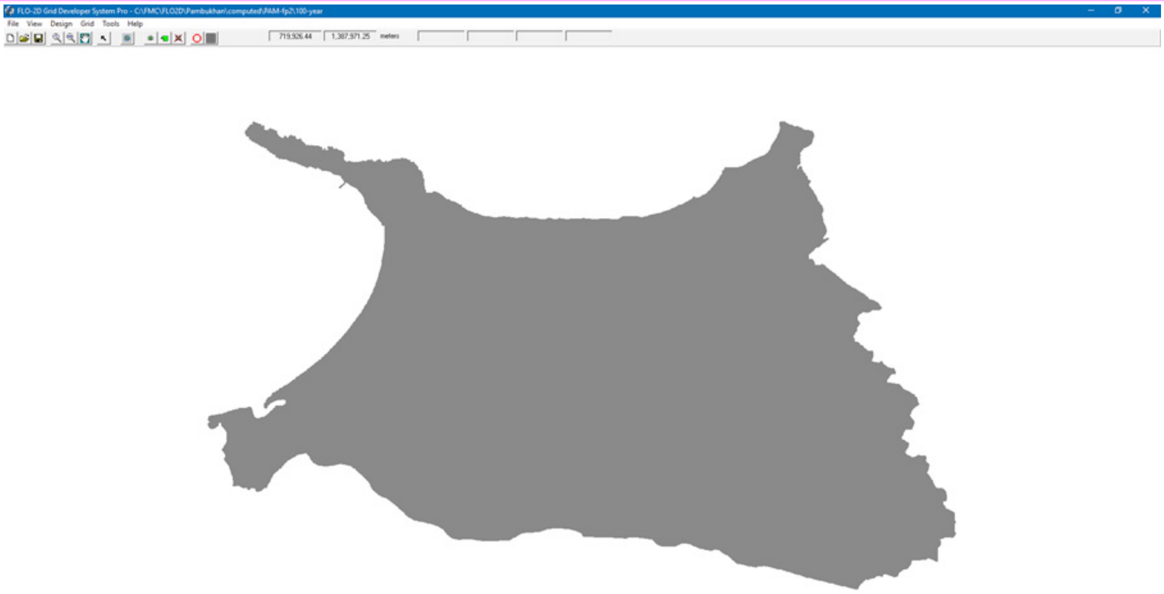

Figure 59. A screenshot of the river sub-catchment with the computational area to be modeled in FLO-2D Grid Developer System Pro (FLO-2D GDS Pro).

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 127.14526 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 m^2/s.The generated hazard maps for Pambukhanare in Figure 64, 66, and 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 79 788 672.00 m^2. The generated flood depth maps for Pambukhan are in Figure 65, 67, and 69.

There is a total of 145 490 468.92m^3 of water entering the model. Of this amount, 39 705 134.63 m^3 is due to rainfall while 105 785 334.29 m^3 is inflow from other areas outside the model. 15 269 651.00 m^3 of this water is lost to infiltration and interception, while 104 352 156.49 m^3 is stored by the flood plain. The rest, amounting up to 25 868 485.10 m^3, is outflow.

5.6 Results of HMS Calibration

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

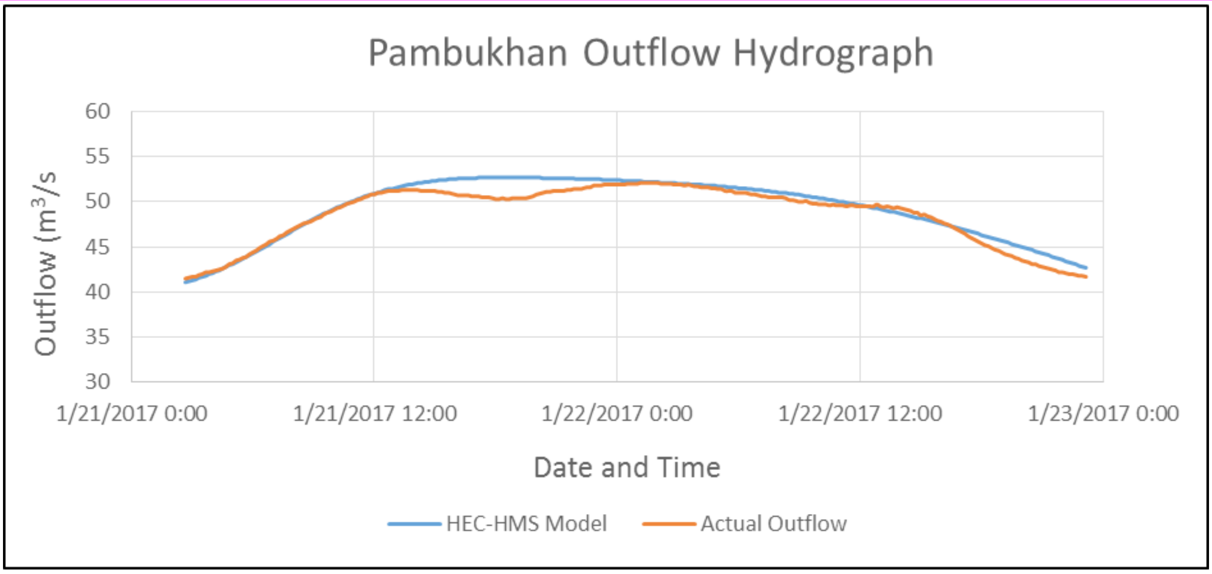

Figure 60. Outflow Hydrograph of Pambukhan produced by the HEC-HMS model compared with observed outflow.

Table 31shows the adjusted ranges of values of the parameters used in calibrating the model.

Table 31.Range of calibrated values for the Pambukhan River Basin.

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	14 - 30
			Curve Number	60 - 99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	2 - 31
			Storage Coefficient (hr)	3 - 51
	Baseflow	Recession	Recession Constant	0.1
			Ratio to Peak	0.1
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.04

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 14mm to 30mm means that there is an 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 60 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).

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 2 hours to 51 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant of 0.1 indicates that the basin is likely to quickly go back to its original discharge and instead, will be higher. Ratio to peak of 0.1 indicates a steeper receding limb of the outflow hydrograph.

Manning's roughness coefficient of 0.04 corresponds to the common roughness of Pambukhan watershed, which is determined to be cultivated with mature field crops (Brunner, 2010).

Table 32. Summary of the Efficiency Test of the Pambukhan HMS Model

Accuracy measure	Value
RMSE	0.9
r^2	0.95
NSE	0.91
PBIAS	-1.21
RSR	0.30

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It computed as 0.9 (m3/s).

The Pearson correlation coefficient (r^2) 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 0.95.

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 0.91.

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 -1.21.

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 0.30.

5.7 Calculated Outflow hydrographys and Discharge Values for different Rainfall Return Periods

5.7.1 Hydrograph using the Rainfall Runoff Model

The summary graph (Figure 61) shows the Pambukhan outflow using the CatarmanRainfall 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 increasing outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

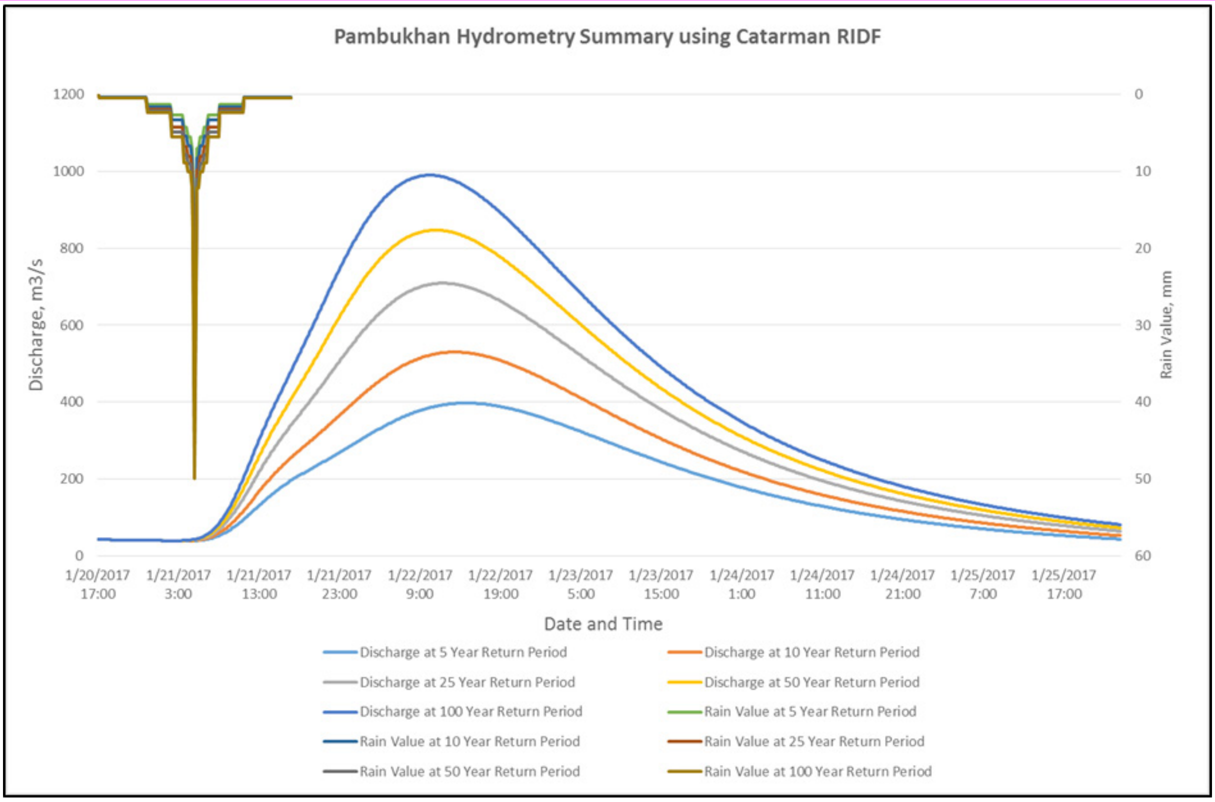

Figure 61. The Outflow hydrograph at the PambukhanStation, generated using the Tacloban RIDF simulated in HEC-HMS.

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of the Pambukhandischarge using the Catarman Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 33.

Table 33. The peak values of the Pambukhan HEC-HMS Model outflow using the Tacloban RIDF.

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m^3/s)	Time to Peak
5-Year	255.4	29.9	314.8	21 hours, 40 minutes
10-Year	305.4	34.7	433	21 hours, 40 minutes
25-Year	368.5	40.9	609.8	21 hours, 40 minutes
50-Year	415.3	45.5	750.7	21 hours, 40 minutes
100-Year	461.8	50	899.8	21 hours, 40 minutes

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

The river discharge values for the river entering the floodplain is shown in Figure 62 and the peak value is summarized in Table 34.

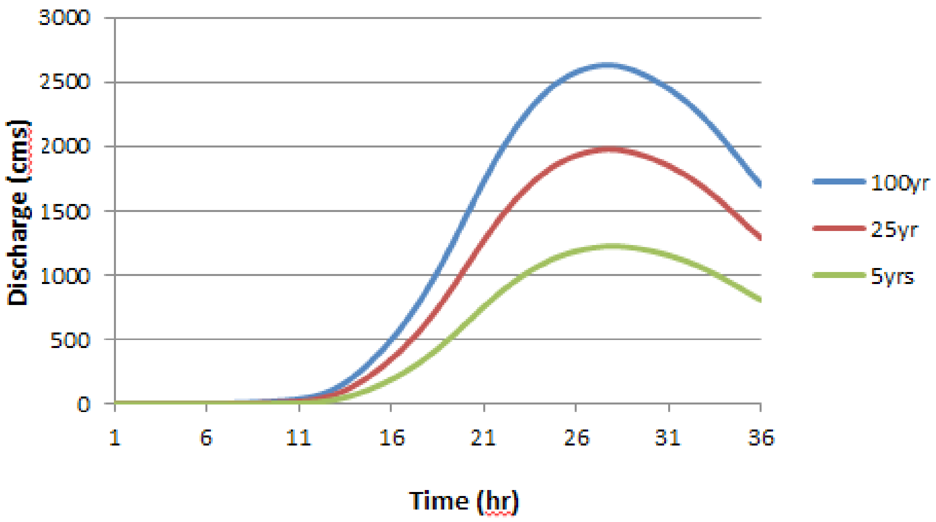

Figure 62.Pambukhanriver generated discharge using 5-, 25-, and 100-year rainfall intensity-duration-frequency (RIDF) in HEC-HMS.

Table 34.Summary of Pambukhan river discharge generated in HEC-HMS.

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	2631.2	27 hours, 50 minutes
25-Year	1978.0	27 hours, 50 minutes
5-Year	1224.6	27 hours, 50 minutes

The comparison of the discharge results using Dr. Horritt's recommended hydrological method against the bankful and specific discharge estimates is shown in Table 35.

Table 35. Validation of river discharge estimates.

Discharge Point	$Q_{MED(SCS)}$, cms	$Q_{BANKFUL}$, cms	$Q_{MED(SPEC)}$, cms	VALIDATION	
				Bankful Discharge	Specific Discharge
Pambukhan	1077.648	4073.131	637.117	Fail	Fail

The result from the HEC-HMS river discharge estimates wasnot able to satisfy the conditions for validation using the bankful and specific discharge methods. It will need further recalculation. The passing values are based on theory but are supported using other discharge computation methods. 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 Pambukhan River using the calibrated HMS base flow.

Figure 63. Sample output map of the Pambukhan 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 Pambukhan floodplain. The floodplain, with an area of 114.86 sq. km., covers three municipalites namely Laoang, Pambujan, and San Roque. Table 36 shows the percentage of area affected by flooding per municipality.

Table 36. Municipalities affected in Pambukhan floodplain.

Municipality	Total Area	Area Flooded	% Flooded
Laoang	207.6	9.72	5%
Pambujan	150.63	61.71	41%
San Roques	166.51	41.61	25%

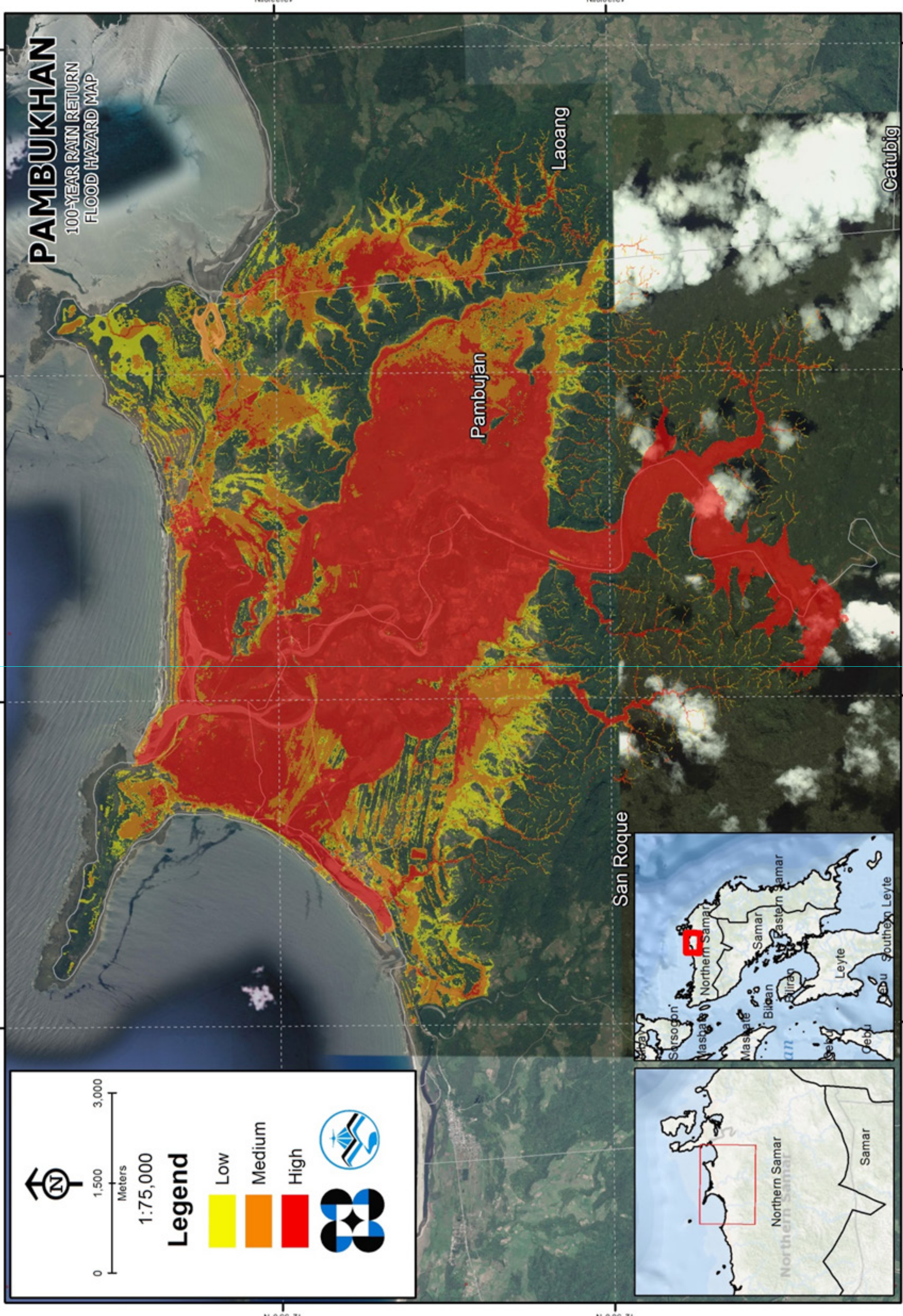

Figure 64.A 100-year Flood Hazard Map for Pambukhan Floodplain overlaid on Google Earth imagery.

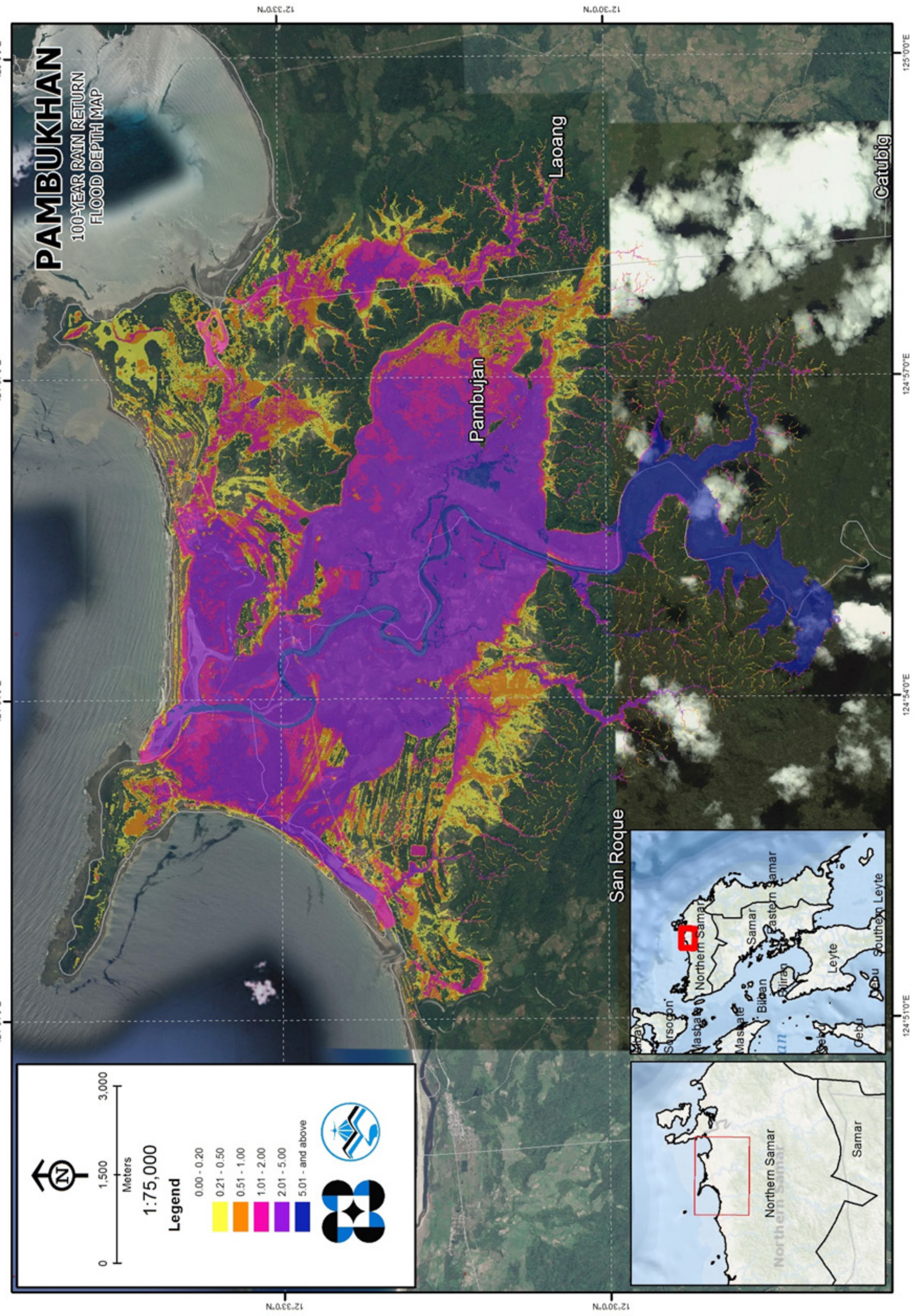

Figure 65. A 100-year Flow Depth Map for Pambukhan Floodplain overlaid on Google Earth imagery.

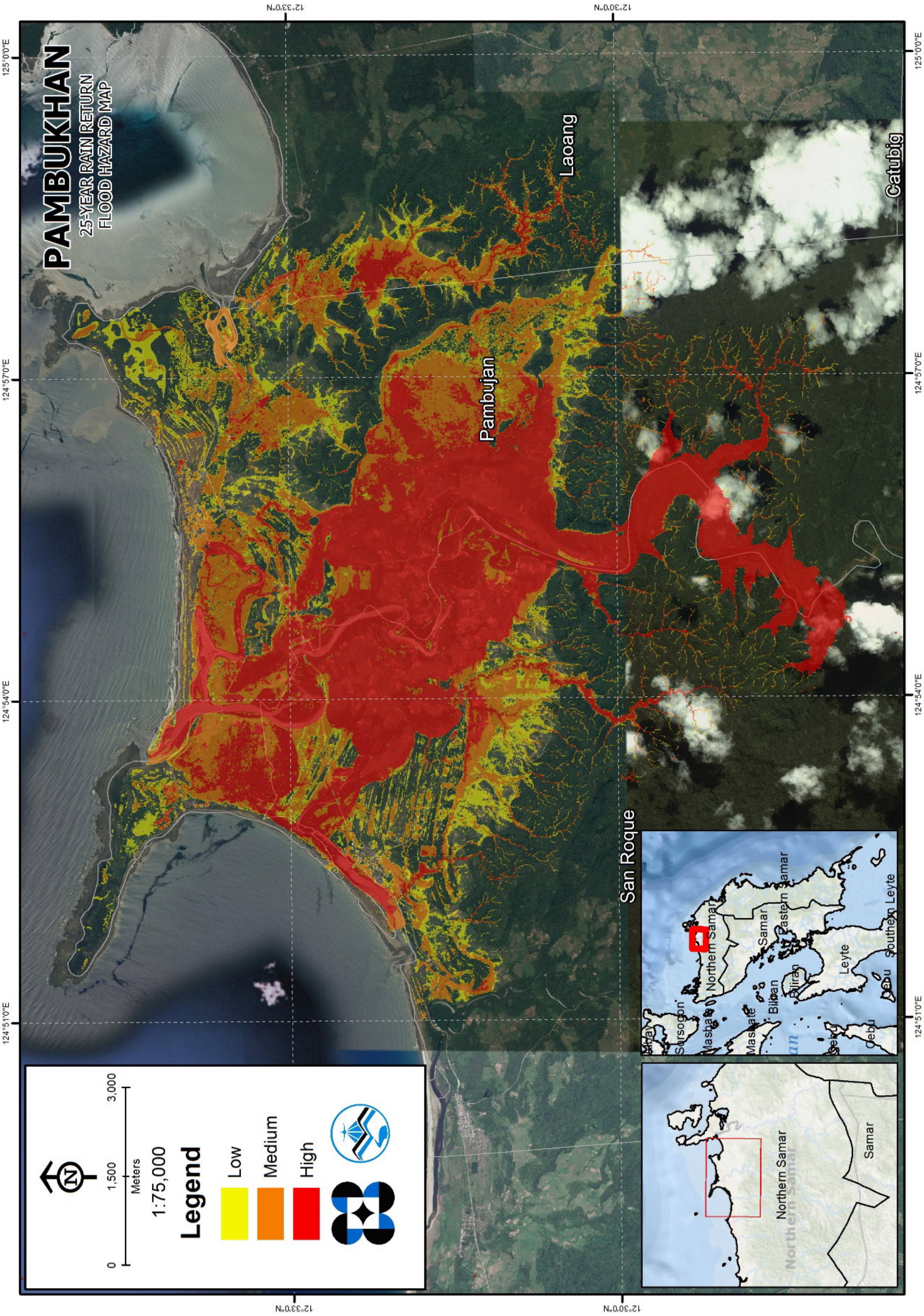

Figure 66. A 25-year Flood Hazard Map for Pambukhan Floodplain overlaid on Google Earth imagery.

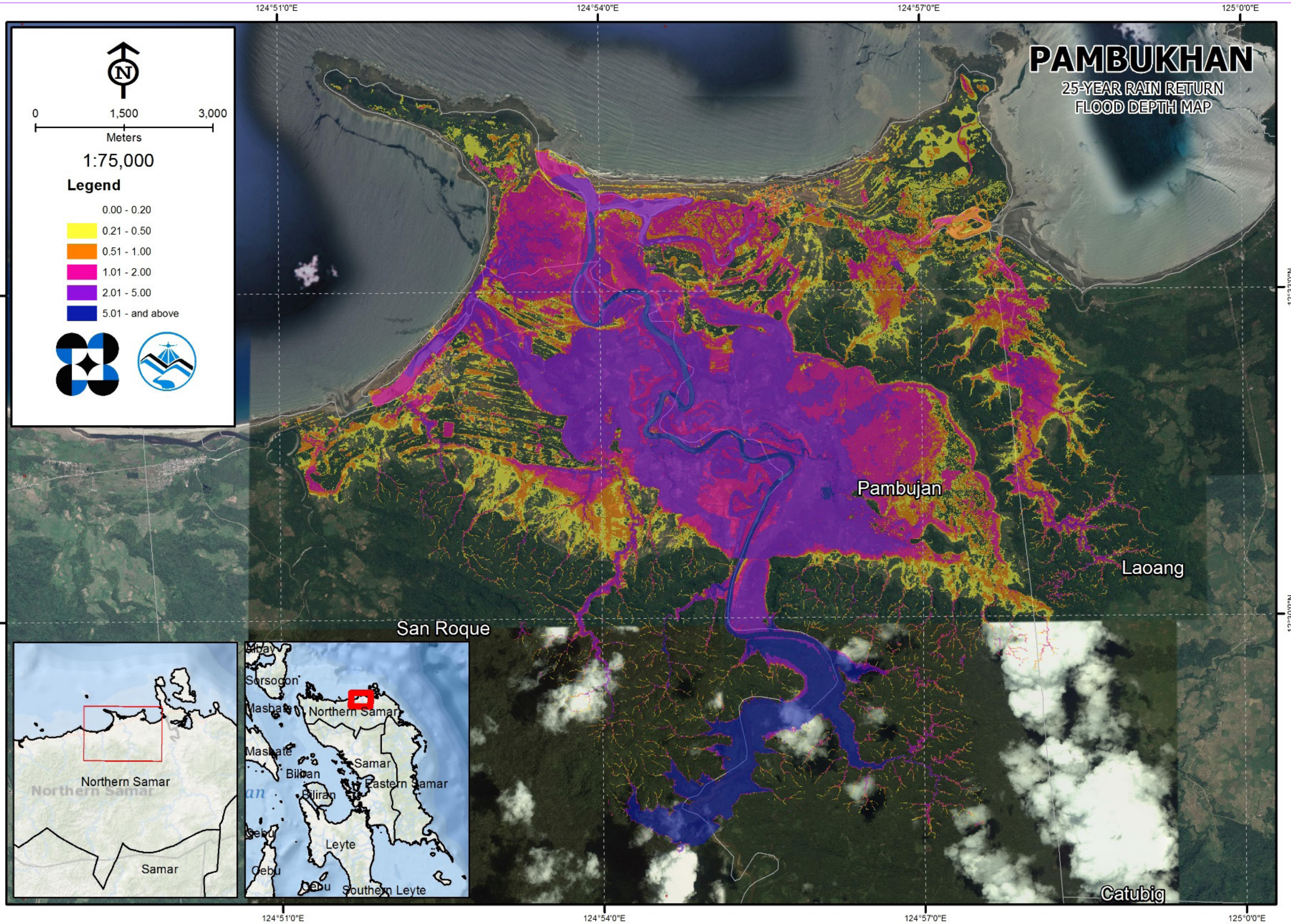

Figure 67.A 25-year Flow Depth Map for Pambukhan Floodplain overlaid on Google Earth imagery.

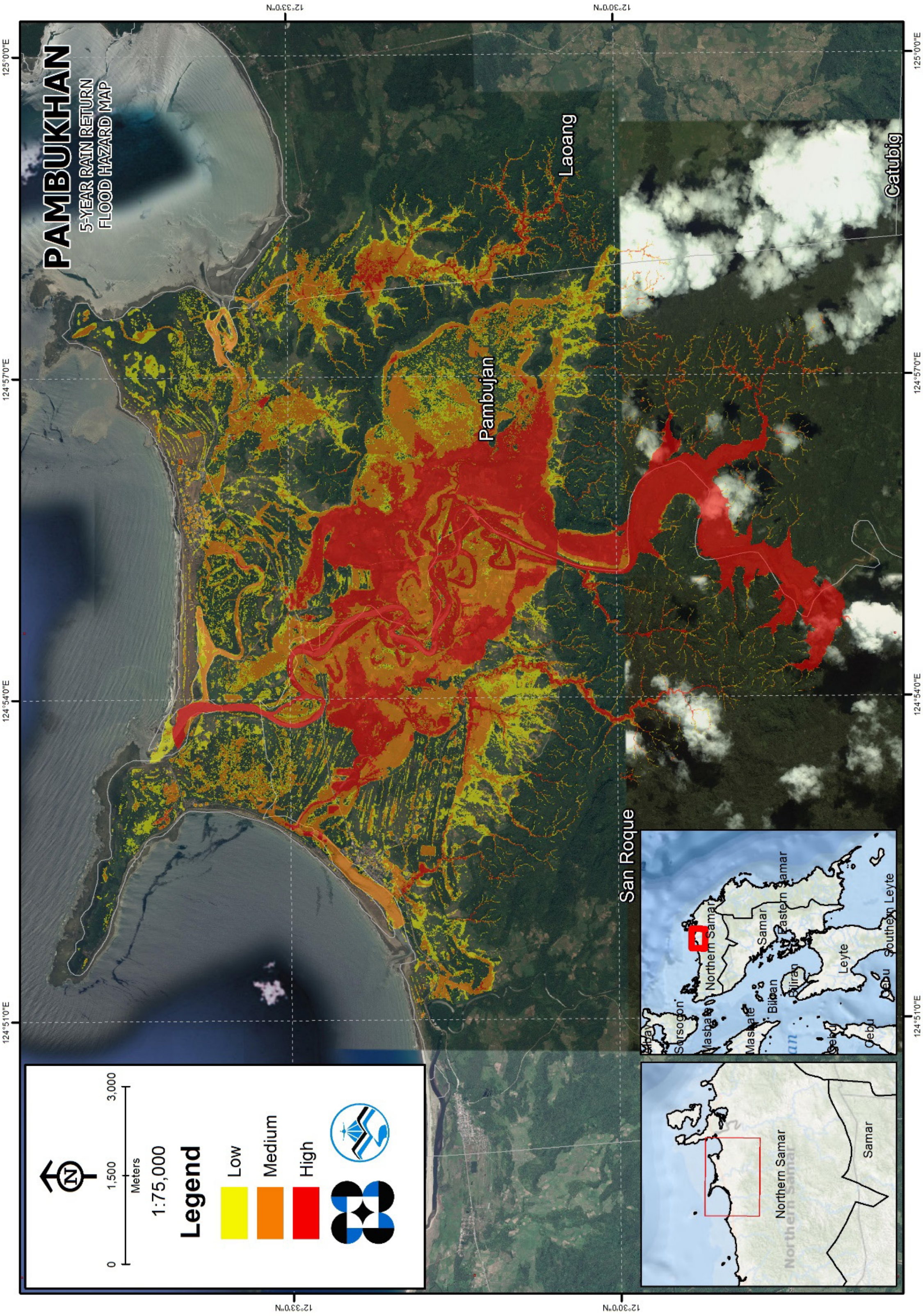

Figure 68. A 5-year Flood Hazard Map for Pambukhan Floodplain overlaid on Google Earth imagery.

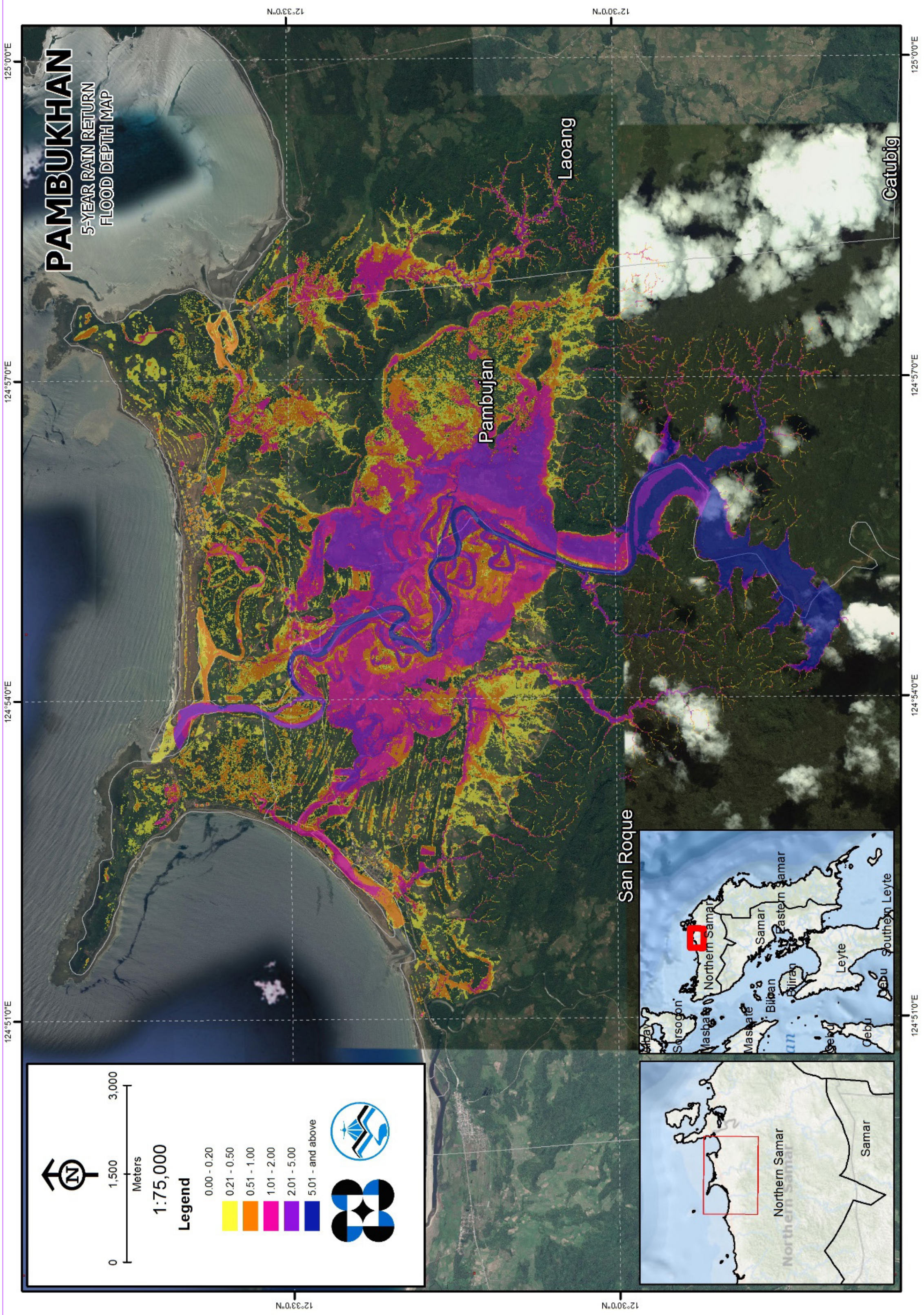

Figure 69. A 5-year Flood Depth Map for Pambukhan Floodplain overlaid on Google Earth imagery.

5.10 Inventory of Areas Exposed to Flooding of Affected Areas

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

For the 5-year return period, 3.18% of the municipality of San Julian with an area of 207.60 sq. km. will experience flood levels of less 0.20 meters. 0.51% of the area will experience flood levels of 0.21 to 0.50 meters while 0.49%, 0.44%, 0.07%, and 0.00009% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively.Listed in Table 37 are the affected areas in Laoang in square kilometers by flood depth per barangay. Annex 12 and Annex 13 show the educational and health institutions exposed to flooding.

Table 37. Affected Areas in Laoang, Northern Samarduring 5-Year Rainfall Return Period.

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Laoang (in sq. km.)					
	Burabud	Cabago-An	Cangcahipos	Catigbian	Palmera	Yabyaban
0.03-0.20	0.88	1.94	0.88	0.09	0.77	2.04
0.21-0.50	0.25	0.47	0.044	0.0036	0.071	0.21
0.51-1.00	0.26	0.41	0.036	0.0025	0.055	0.25
1.01-2.00	0.21	0.44	0.026	0.00073	0.033	0.2
2.01-5.00	0.0012	0.046	0.0062	0	0.0045	0.078
> 5.00	0	0	0	0	0	0.0002

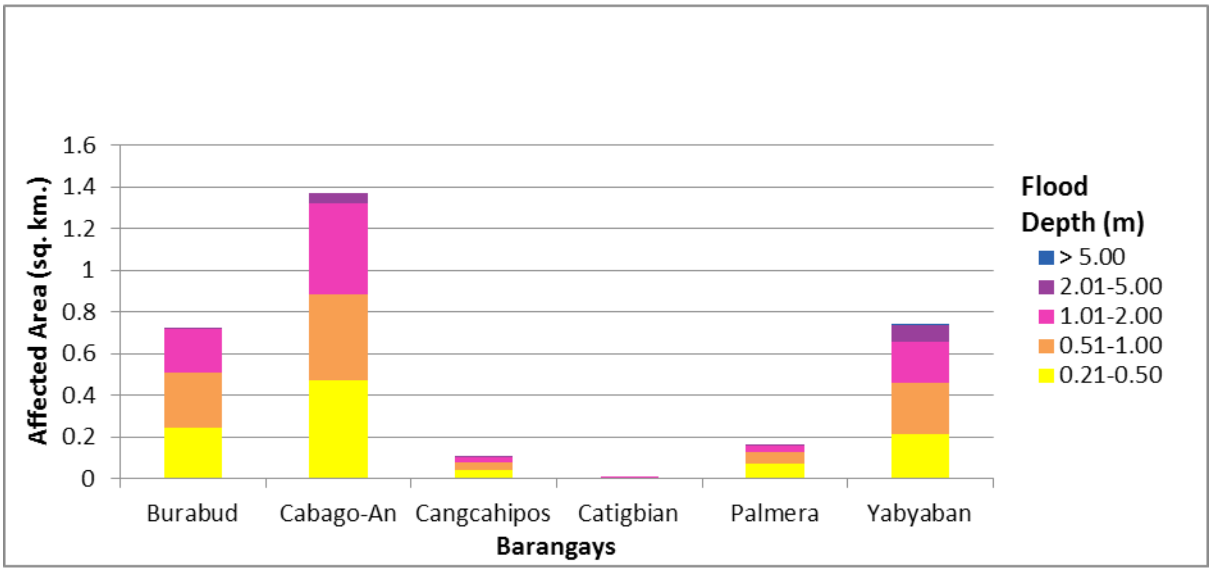

Figure 70. Affected Areas in Laoang, Northern Samarduring 5-Year Rainfall Return Period.

For the municipality of Pambukhan, with an area of 150.63 sq. km., 23.51% will experience flood levels of less 0.20 meters. 4.98% of the area will experience flood levels of 0.21 to 0.50 meters while 3.76%, 2.88%, 2.44%, and 1.30% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively.Listed in Table 38 and Table 39 are the affected areas in Pambukhanin square kilometers by flood depth per barangay.

Table 38.Affected Areas in Pambukhan, Northern Samarduring 5-Year Rainfall Return Period.

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Pambukhan (in sq. km.)								
	Cababto-An	Camparanga	Canjumadal	Doña Anecita	Geparayan	Ginulgan	Inanahawan	Manahao	Paninirongan
0.03-0.20	5.83	3.99	1.71	1.36	6.04	3.46	0.0052	4.15	2.64
0.21-0.50	1.62	1.32	0.31	0.58	0.22	0.11	0	1.29	0.35
0.51-1.00	1.24	0.92	0.52	0.35	0.21	0.07	0	0.99	0.13
1.01-2.00	0.95	0.3	1.33	0.037	0.31	0.071	0	0.51	0.12
2.01-5.00	0.85	0.001	2.2	0.012	0.39	0.079	0	0.015	0.0017
> 5.00	0.049	0	0.17	0.0035	1.08	0.66	0	0	0

Table 39.Affected Areas in Pambukhan, Northern Samarduring 5-Year Rainfall Return Period.

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Pambukhan (in sq. km.)								
	Poblacion District 1	Poblacion District 2	Poblacion District 3	Poblacion District 4	Poblacion District 5	Poblacion District 6	Poblacion District 7	Poblacion District 8	San Ramon
0.03-0.20	0.21	0.045	0.11	0.83	0.55	0.39	0.74	0.44	2.92
0.21-0.50	0.088	0.002	0.023	0.22	0.12	0.1	0.22	0.064	0.86
0.51-1.00	0.055	0.0013	0.024	0.15	0.027	0.019	0.019	0.039	0.91
1.01-2.00	0.014	0.0006	0.0008	0.014	0.018	0.0063	0.0014	0.0002	0.64
2.01-5.00	0	0	0	0	0	0	0	0	0.12
> 5.00	0	0	0	0	0	0	0	0	0

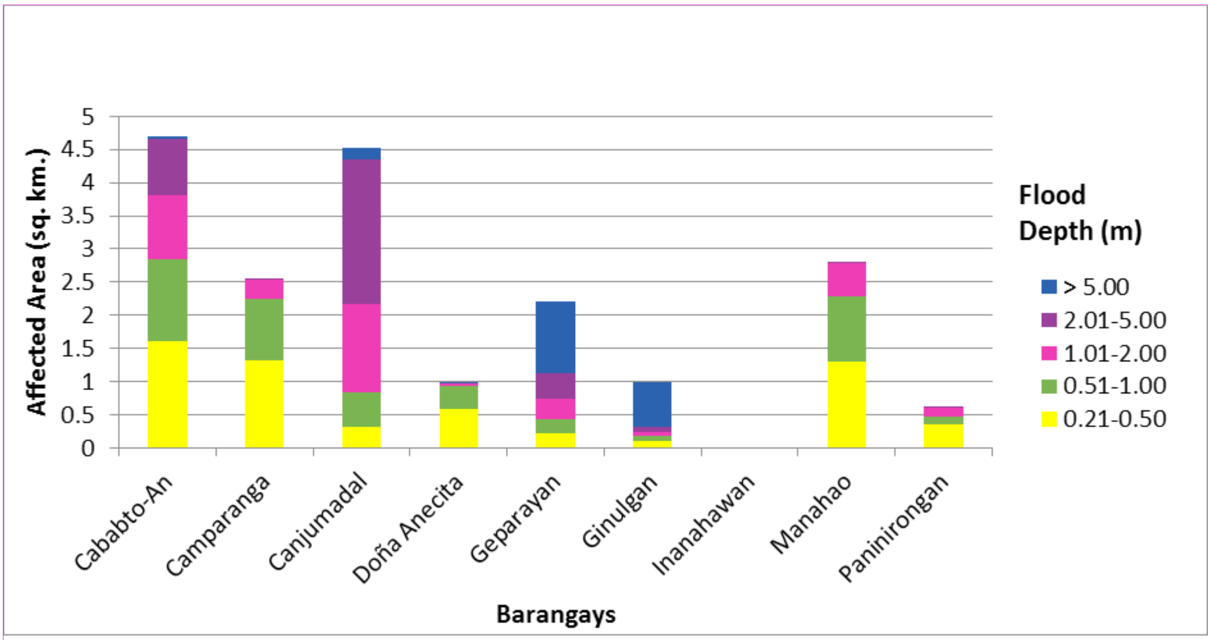

Figure 71. Affected Areas in Pambukhan, Northern Samar during 5-Year Rainfall Return Period.

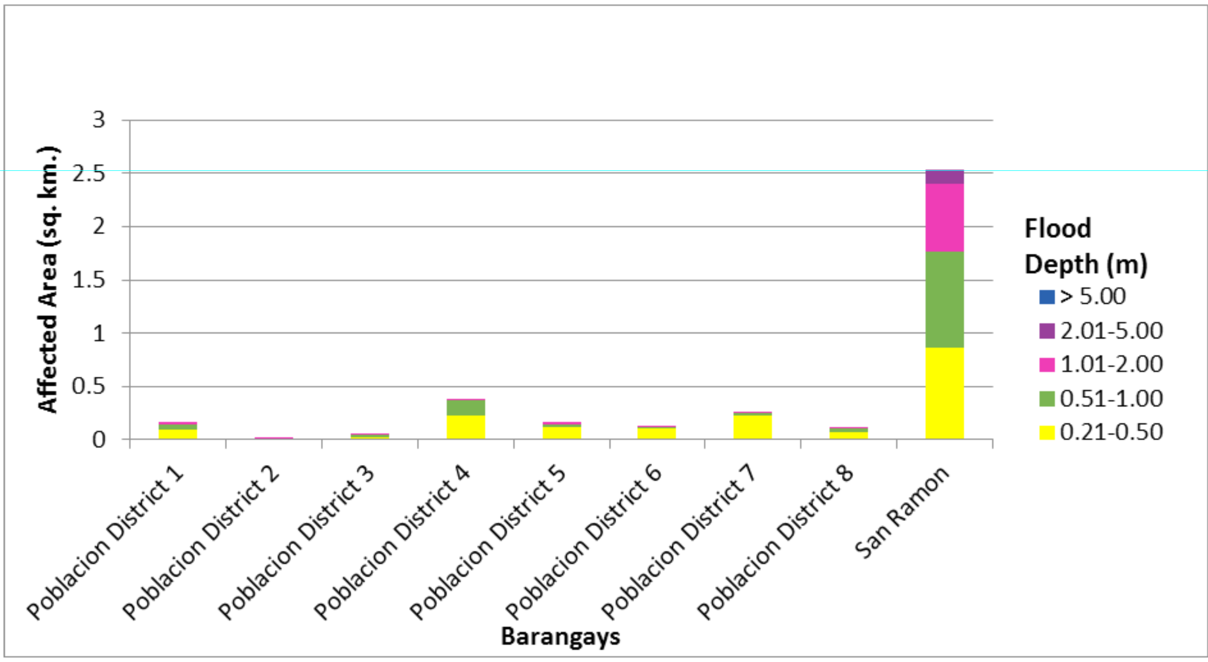

Figure 72. Affected Areas in Pambukhan, Northern Samar during 5-Year Rainfall Return Period.

For the municipality of San Roque, with an area of 166.51 sq. km., 14.11% will experience flood levels of less 0.20 meters. 2.37% of the area will experience flood levels of 0.21 to 0.50 meters while 2.24%, 3.24%, 1.83%, and 1.22% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 40 and Table 41 are the affected areas in square kilometers by flood depth per barangay.

Table 40.Affected Areas in San Roque, Northern Samarduring 5-Year Rainfall Return Period.

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in San Roque (in sq. km.)							
	Balnasan	Balud	Bantayan	Coroconog	Dale	Lao-Angan	Lawaan	Malobago
0.03-0.20	1.73	0.36	0.013	6.78	1.39	1.28	5.93	1.23
0.21-0.50	0.25	0.19	0.0066	1.27	0.49	0.27	0.18	0.07
0.51-1.00	0.71	0.62	0.0083	0.74	0.51	0.24	0.13	0.038
1.01-2.00	1.32	1.09	0.0038	0.58	1.3	0.045	0.15	0.028
2.01-5.00	0.77	0.46	0	0.23	0.64	0.001	0.68	0.0065
> 5.00	0.29	0.15	0	0.0008	0.1	0	1.49	0

Table 41.Affected Areas in San Roque, Northern Samarduring 5-Year Rainfall Return Period.

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in San Roque (in sq. km.)					
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
0.03-0.20	1.41	1.51	0.5	0.34	0.42	0.62
0.21-0.50	0.45	0.22	0.16	0.084	0.09	0.21
0.51-1.00	0.27	0.093	0.16	0.028	0.085	0.097
1.01-2.00	0.46	0.06	0.24	0.0017	0.024	0.074
2.01-5.00	0.14	0.02	0.074	0	0	0.022
> 5.00	0	0	0	0	0	0

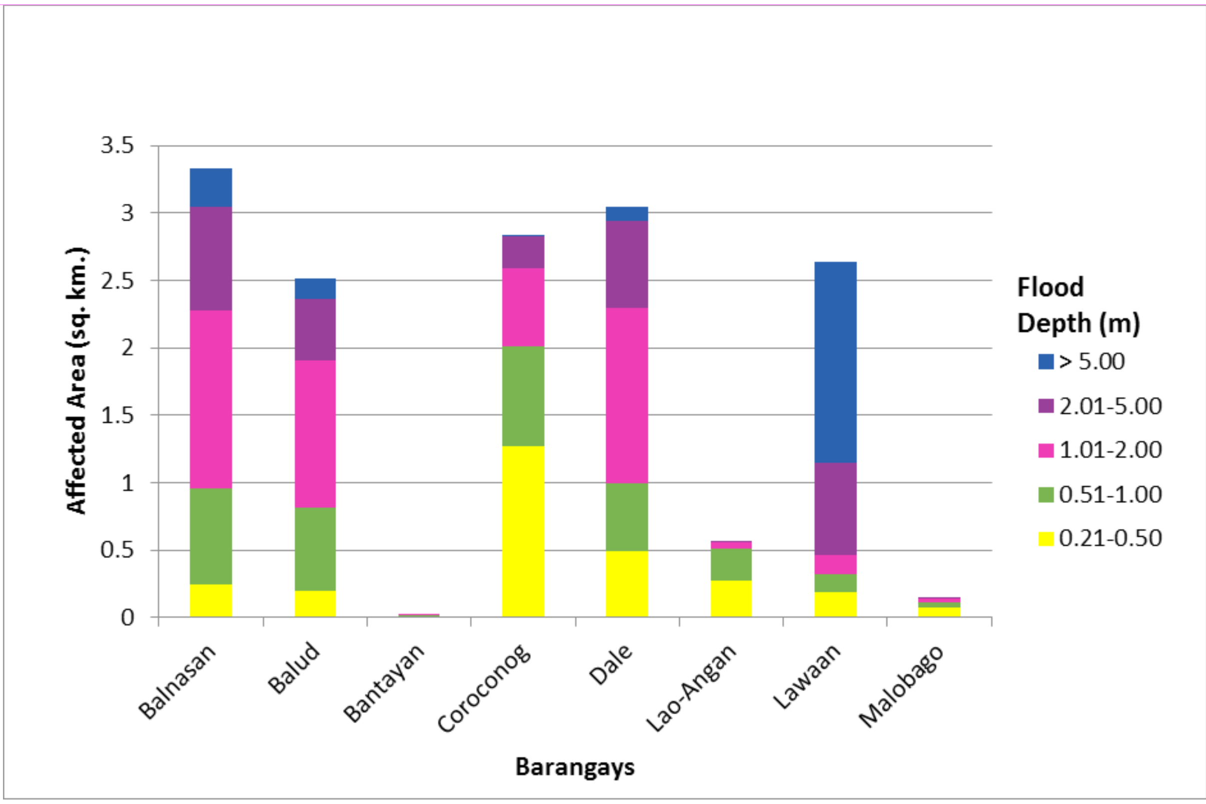

Figure 73. Affected Areas in San Roque, Northernduring 5-Year Rainfall Return Period.

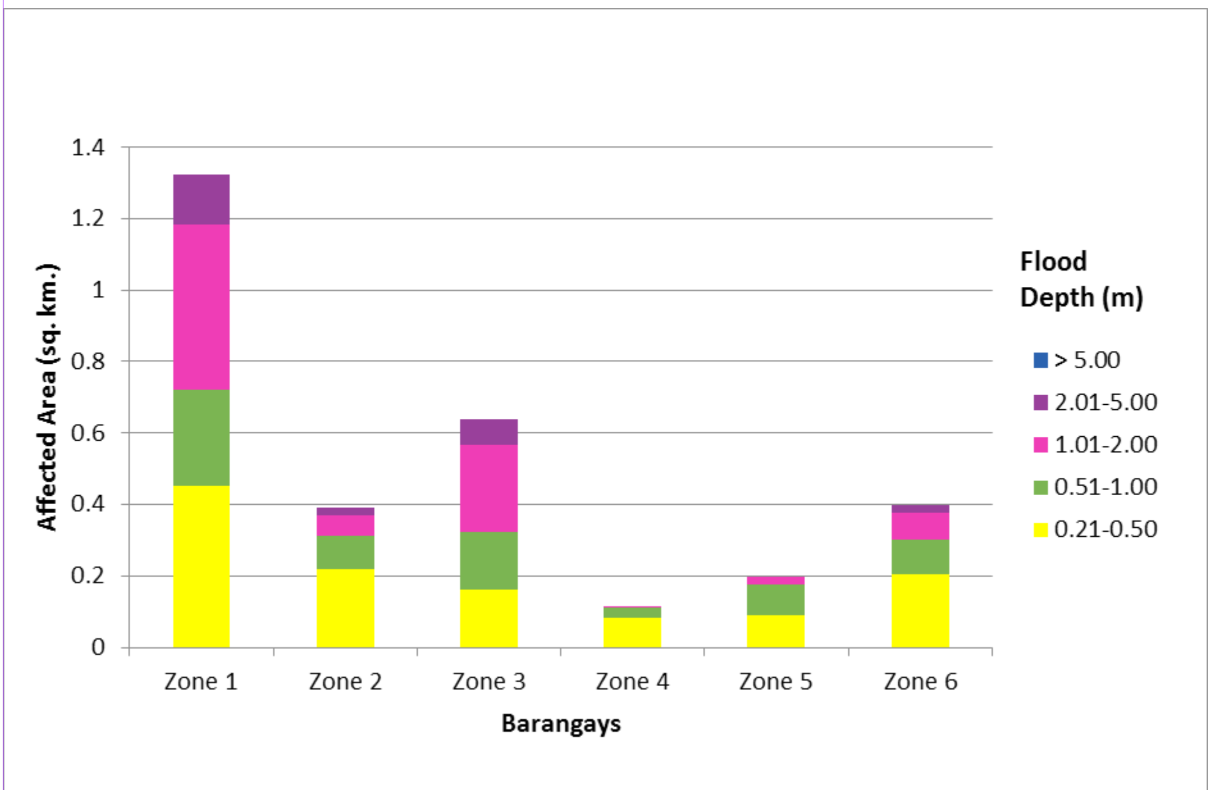

Figure 74. Affected Areas in San Roque, Northernduring 5-Year Rainfall Return Period.

For the 25-year return period, 2.86% of the municipality of Laoang with an area of 207.60 sq. km. will experience flood levels of less than 0.20 meters. 0.50% of the area will experience flood levels of 0.21 to 0.50 meters while 0.52%, 0.64%, 0.16%, and 0.0006% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 42 are the affected areas in San Julian in square kilometers by flood depth per barangay.

Table 42.Affected Areas in Laoang, Northern Samar during 25-Year Rainfall Return Period.

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Laoang (in sq. km.)					
	Burabud	Cabago-An	Cangcahipos	Catigbian	Palmera	Yabyaban
0.03-0.20	0.66	1.67	0.87	0.09	0.75	1.91
0.21-0.50	0.3	0.43	0.046	0.0037	0.072	0.19
0.51-1.00	0.27	0.44	0.04	0.0027	0.067	0.27
1.01-2.00	0.37	0.6	0.031	0.00083	0.04	0.29
2.01-5.00	0.0089	0.17	0.0092	0	0.0099	0.12
> 5.00	0	0	0	0	0	0.0014

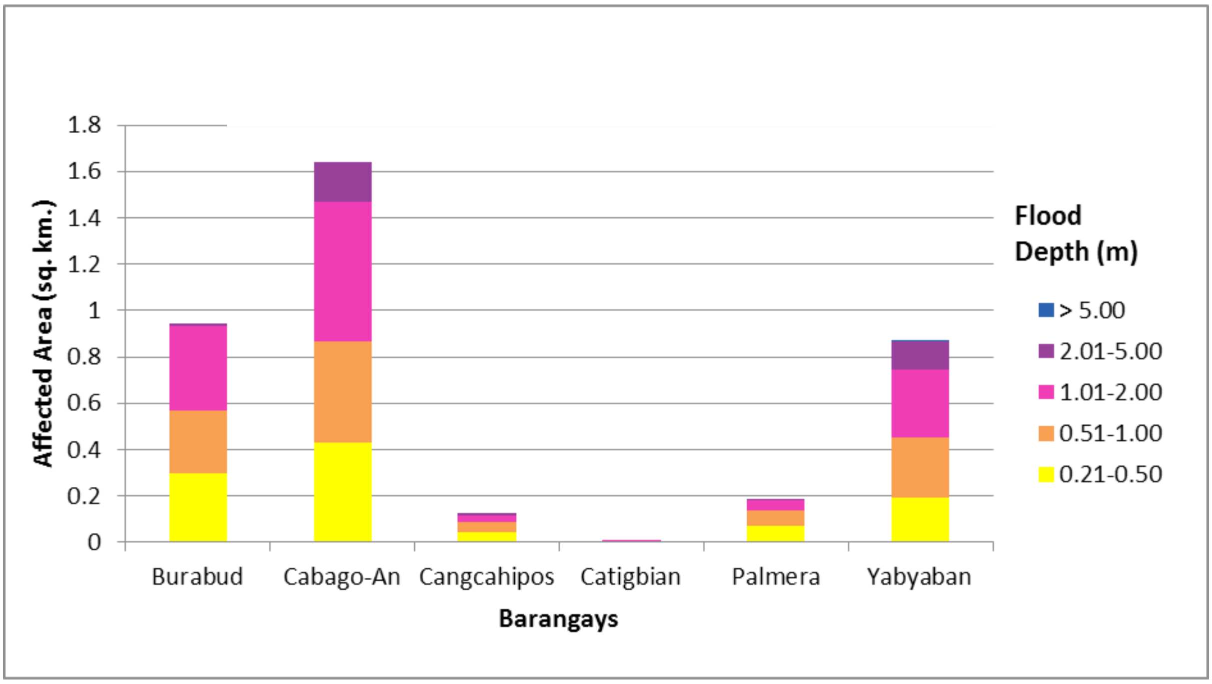

Figure 75. Affected Areas in Laoang, Northern Samarduring 25-Year Rainfall Return Period.

For the municipality of Pambukhan, with an area of 150.63 sq. km., 18.68% will experience flood levels of less 0.20 meters. 4.02% of the area will experience flood levels of 0.21 to 0.50 meters while 3.83%, 6.04%, 4.74%, and 1.53% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 43 and Table 44 are the affected areas in Pambukhan in square kilometers by flood depth per barangay.

Table 43.Affected Areas in Pambukhan, Northern Samarduring 25-Year Rainfall Return Period.

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Pambukhan (in sq. km.)								
	Cababto-An	Camparanga	Canjumadal	Doña Anecita	Geparayan	Ginulgan	Inanahawan	Manahao	Paninirongan
0.03-0.20	3.2	3.29	1.51	0.19	5.9	3.38	0.0052	3.23	2.29
0.21-0.50	1.05	1.39	0.17	0.077	0.23	0.12	0	1.2	0.45
0.51-1.00	1.45	1.23	0.2	0.18	0.2	0.078	0	1.32	0.18
1.01-2.00	2.62	0.61	0.91	1.47	0.23	0.081	0	1.07	0.2
2.01-5.00	2.11	0.019	3.2	0.43	0.44	0.069	0	0.13	0.12
> 5.00	0.1	0	0.23	0.011	1.25	0.71	0	0	0

Table 44.Affected Areas in Pambukhan, Northern Samarduring 25-Year Rainfall Return Period.

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Pambukhan (in sq. km.)								
	Poblacion District 1	Poblacion District 2	Poblacion District 3	Poblacion District 4	Poblacion District 5	Poblacion District 6	Poblacion District 7	Poblacion District 8	San Ramon
0.03-0.20	0.11	0.043	0.099	0.7	0.5	0.35	0.58	0.4	2.35
0.21-0.50	0.039	0.0027	0.026	0.26	0.15	0.13	0.35	0.09	0.34
0.51-1.00	0.097	0.0016	0.032	0.19	0.04	0.032	0.051	0.037	0.45
1.01-2.00	0.11	0.0007	0.0042	0.054	0.028	0.0085	0.0016	0.014	1.69
2.01-5.00	0.0048	0	0	0	0.0024	0	0	0	0.62
> 5.00	0	0	0	0	0	0	0	0	0

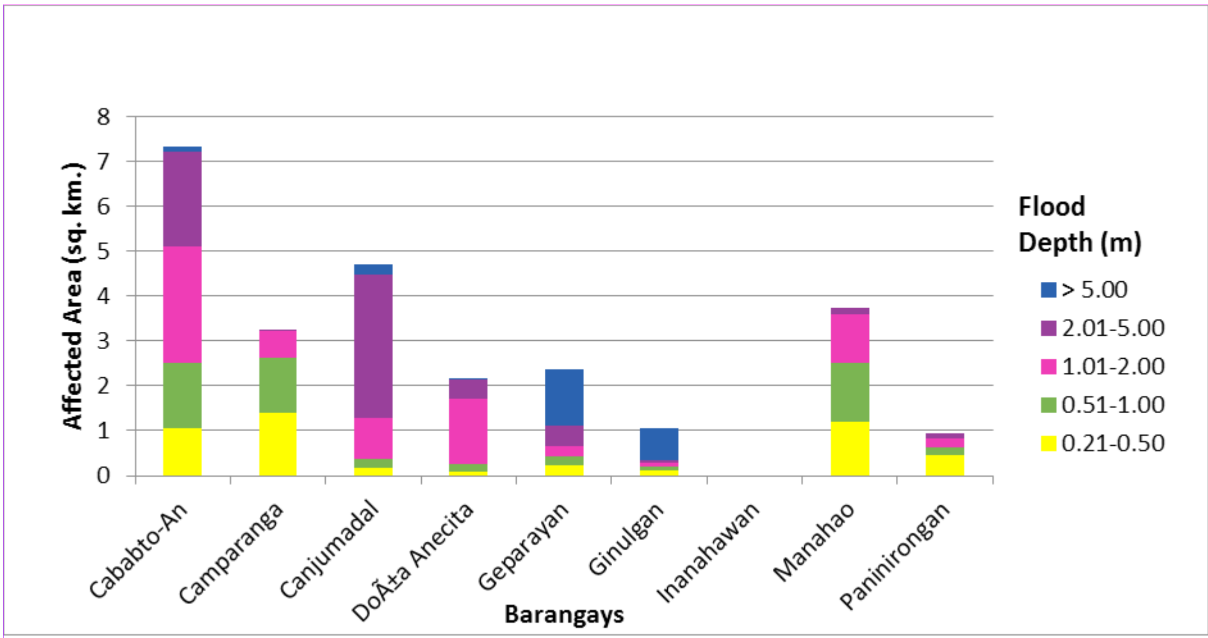

Figure 76. Affected Areas in Pambukhan, Northern Samarduring 25-Year Rainfall Return Period.

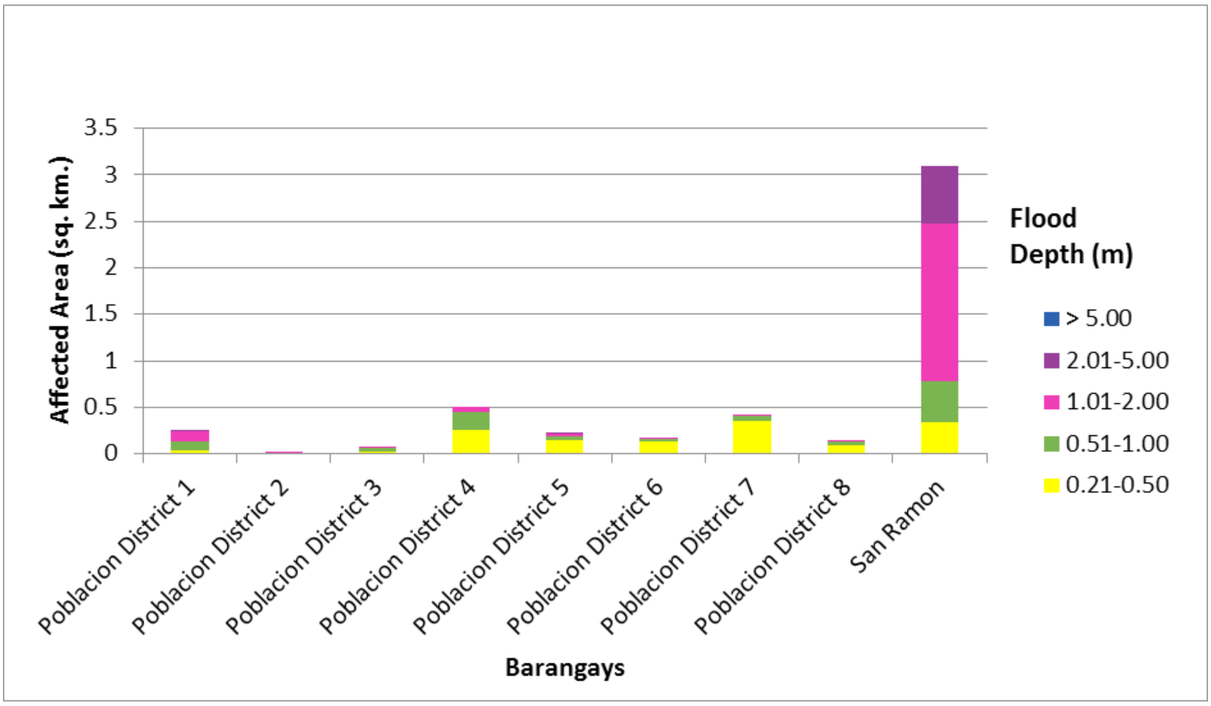

Figure 77. Affected Areas in Pambukhan, Northern Samarduring 25-Year Rainfall Return Period.

For the municipality of San Roque, with an area of 166.51 sq. km., 12.12% will experience flood levels of less 0.20 meters. 2.21% of the area will experience flood levels of 0.21 to 0.50 meters while 1.82%, 2.43%, 4.80%, and 1.62% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 45 and Table 46 are the affected areas in square kilometres by flood depth per barangay.

Table 45.Affected Areas in San Roque, Northern Samarduring 25-Year Rainfall Return Period.

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in San Roque (in sq. km.)							
	Balnasan	Balud	Bantayan	Coroconog	Dale	Lao-Angan	Lawaan	Malobago
0.03-0.20	1.55	0.19	0.0049	6.27	0.24	1.14	5.72	1.19
0.21-0.50	0.16	0.1	0.0099	1.17	0.29	0.3	0.19	0.097
0.51-1.00	0.12	0.15	0.0085	0.98	0.47	0.27	0.13	0.041
1.01-2.00	0.95	0.52	0.0085	0.69	0.97	0.11	0.13	0.035
2.01-5.00	1.95	1.75	0.0001	0.49	2.26	0.0025	0.38	0.011
> 5.00	0.33	0.17	0	0.0023	0.2	0	2	0

Table 46.Affected Areas in San Roque, Northern Samarduring 25-Year Rainfall Return Period.

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in San Roque (in sq. km.)					
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
0.03-0.20	1.15	1.41	0.22	0.27	0.34	0.47
0.21-0.50	0.52	0.25	0.12	0.1	0.1	0.24
0.51-1.00	0.25	0.13	0.15	0.058	0.11	0.16
1.01-2.00	0.13	0.082	0.23	0.018	0.064	0.1
2.01-5.00	0.67	0.028	0.41	0.0037	0.00016	0.035
> 5.00	0	0	0	0	0	0

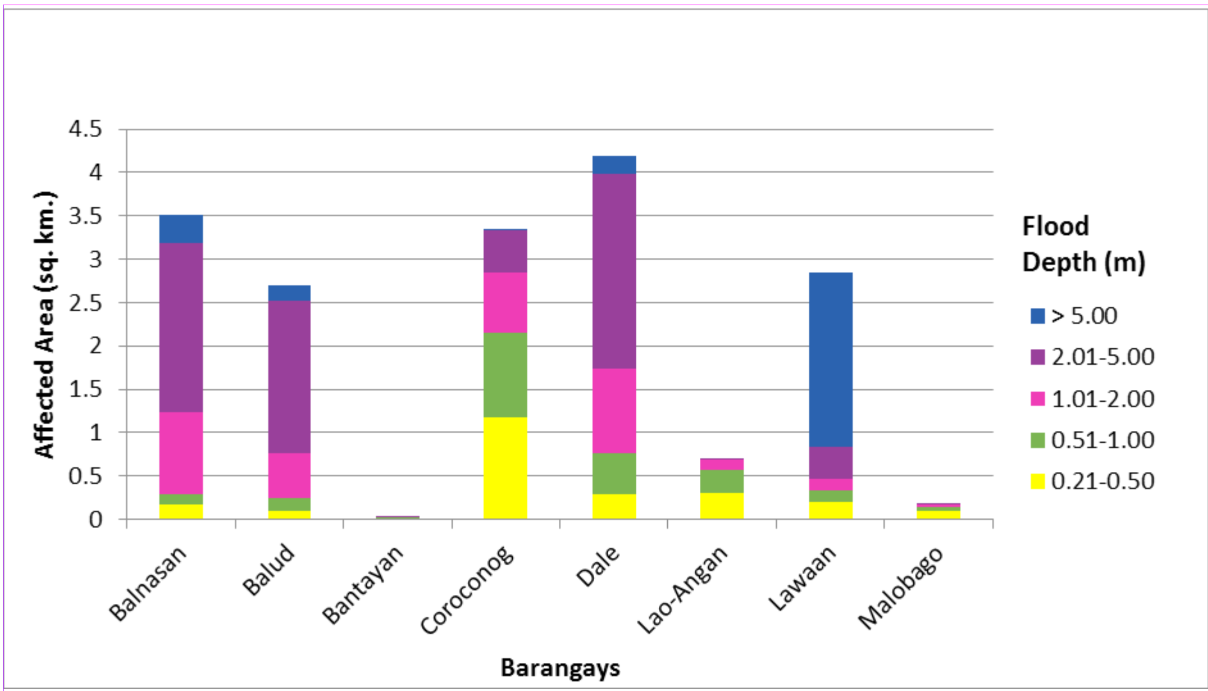

Figure 78. Affected Areas in San Roque, Northern Samar during 25-Year Rainfall Return Period.

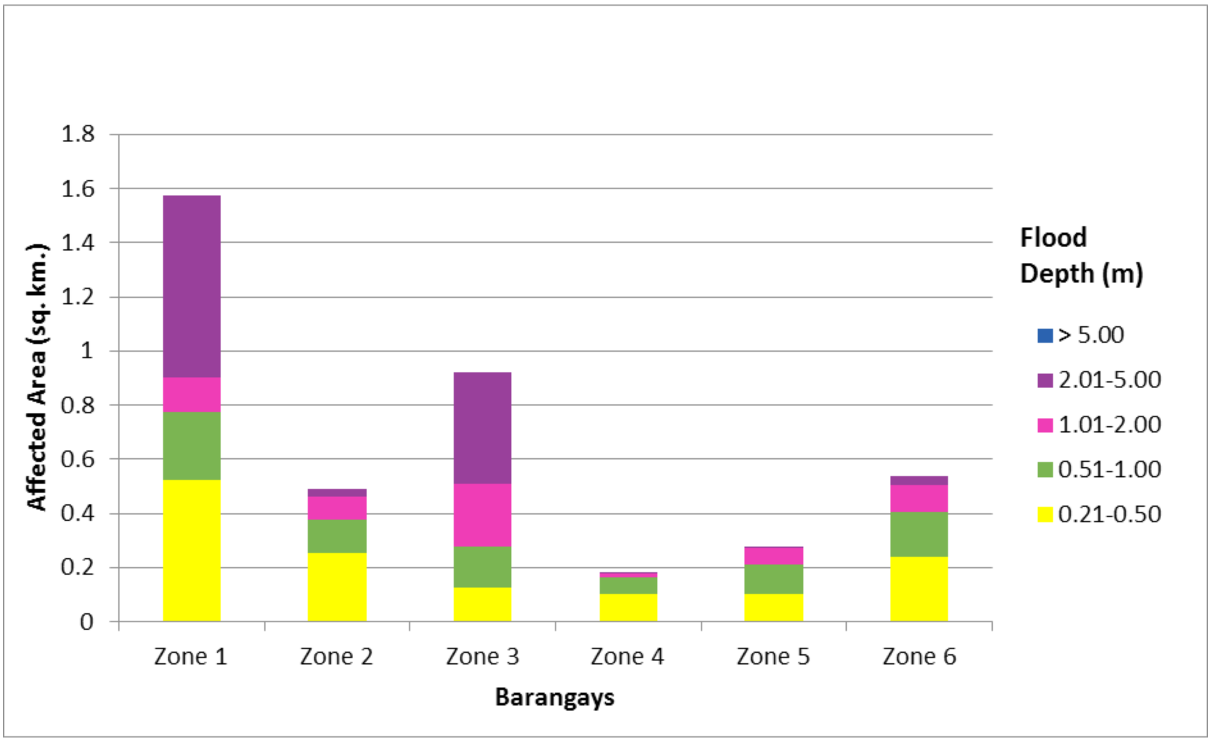

Figure 79. Affected Areas in San Roque, Northern Samar during 25-Year Rainfall Return Period.

For the 100-year return period, 2.69% of the municipality of Laoang with an area of 207.60 sq. km. will experience flood levels of less than 0.20 meters. 0.48% of the area will experience flood levels of 0.21 to 0.50 meters while 0.54%, 0.70%, 0.27%, and 0.0018% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively.Listed in Table 47 are the affected areas in Laoang square kilometers by flood depth per barangay.

Table 47. Affected Areas in Laoang, Northern Samarduring 100-Year Rainfall Return Period.

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Laoang (in sq. km.)					
	Burabud	Cabago-An	Cangcahipos	Catigbian	Palmera	Yabyaban
0.03-0.20	0.53	1.55	0.86	0.089	0.73	1.83
0.21-0.50	0.31	0.39	0.052	0.0048	0.068	0.18
0.51-1.00	0.3	0.43	0.042	0.0026	0.073	0.26
1.01-2.00	0.42	0.6	0.035	0.0011	0.047	0.35
2.01-5.00	0.04	0.34	0.012	0	0.015	0.16
> 5.00	0	0.00016	0	0	0	0.0036

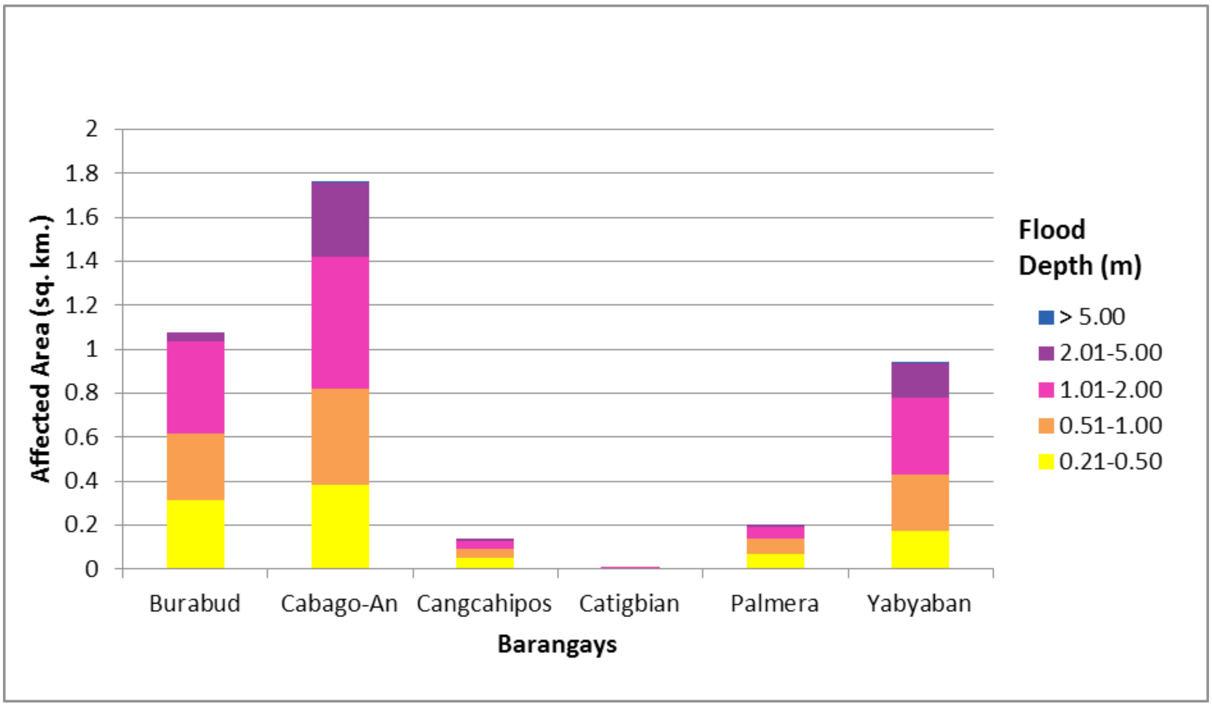

Figure 80. Affected Areas in Laoang, Northern Samarduring 100-Year Rainfall Return Period.

For the municipality of Pambukhan, with an area of 150.63 sq. km., 16.69% will experience flood levels of less 0.20 meters. 3.63% of the area will experience flood levels of 0.21 to 0.50 meters while 3.45%, 5.17%, 8.11%, and 1.79% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 48 and Table 49 are the affected areas in Pambukhan in square kilometers by flood depth per barangay.

Table 48.Affected Areas in Pambukhan, Northern Samar during 100-Year Rainfall Return Period.

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Pambukhan (in sq. km.)								
	Cababto-An	Camparanga	Canjumadal	Doña Anecita	Geparayan	Ginulgan	Inanahawan	Manahao	Paninirongan
0.03-0.20	2.41	2.84	1.42	0.12	5.8	3.33	0.0052	2.83	1.94
0.21-0.50	0.88	1.4	0.14	0.054	0.23	0.12	0	0.89	0.42
0.51-1.00	0.9	1.36	0.12	0.092	0.21	0.084	0	1.23	0.42
1.01-2.00	1.92	0.9	0.43	0.72	0.23	0.084	0	1.51	0.27
2.01-5.00	4.32	0.041	3.6	1.35	0.45	0.076	0	0.5	0.19
> 5.00	0.12	0	0.49	0.012	1.33	0.74	0	0.00014	0

Table 49.Affected Areas in Pambukhan, Northern Samar during 100-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Pambukhan (in sq. km.)								
	Poblacion District 1	Poblacion District 2	Poblacion District 3	Poblacion District 4	Poblacion District 5	Poblacion District 6	Poblacion District 7	Poblacion District 8	San Ramon
0.03-0.20	0.029	0.038	0.053	0.51	0.46	0.32	0.5	0.38	2.16
0.21-0.50	0.017	0.0054	0.012	0.23	0.17	0.14	0.4	0.1	0.26
0.51-1.00	0.023	0.0026	0.02	0.2	0.05	0.047	0.087	0.04	0.32
1.01-2.00	0.12	0.0026	0.057	0.24	0.032	0.0096	0.0017	0.02	1.25
2.01-5.00	0.18	0.0002	0.018	0.024	0.0042	0	0	0	1.46
> 5.00	0	0	0	0	0	0	0	0	0.0018

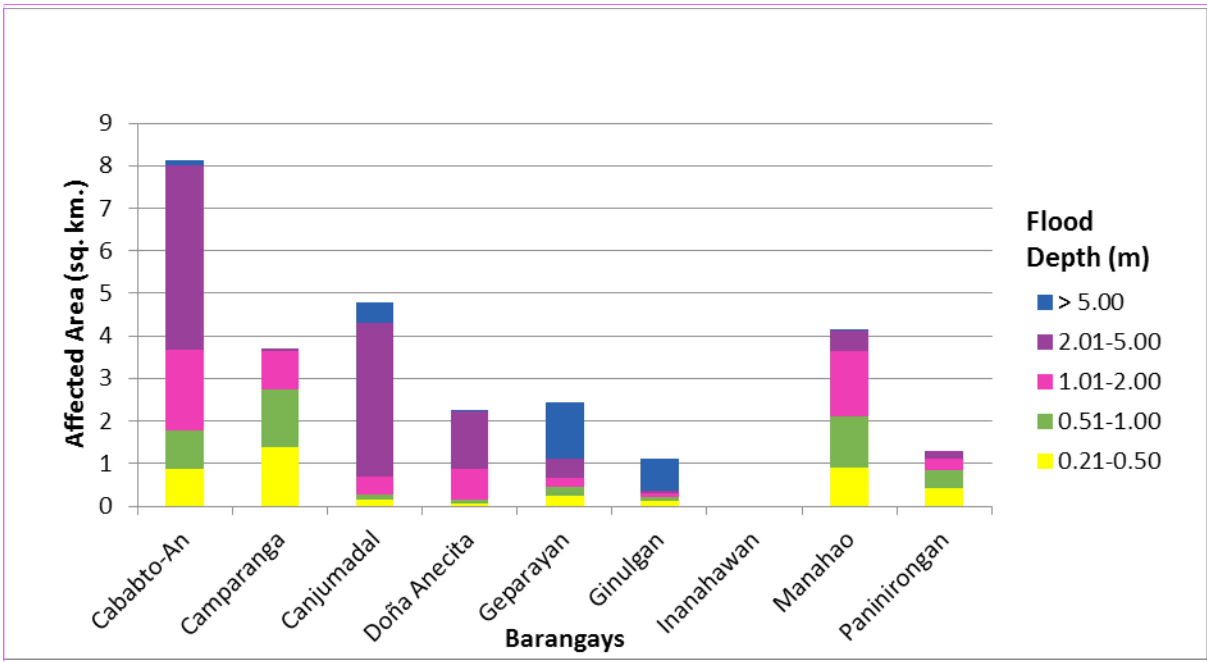

Figure 81. Affected Areas in Pambukhan, Northern Samar during 100-Year Rainfall Return Period.

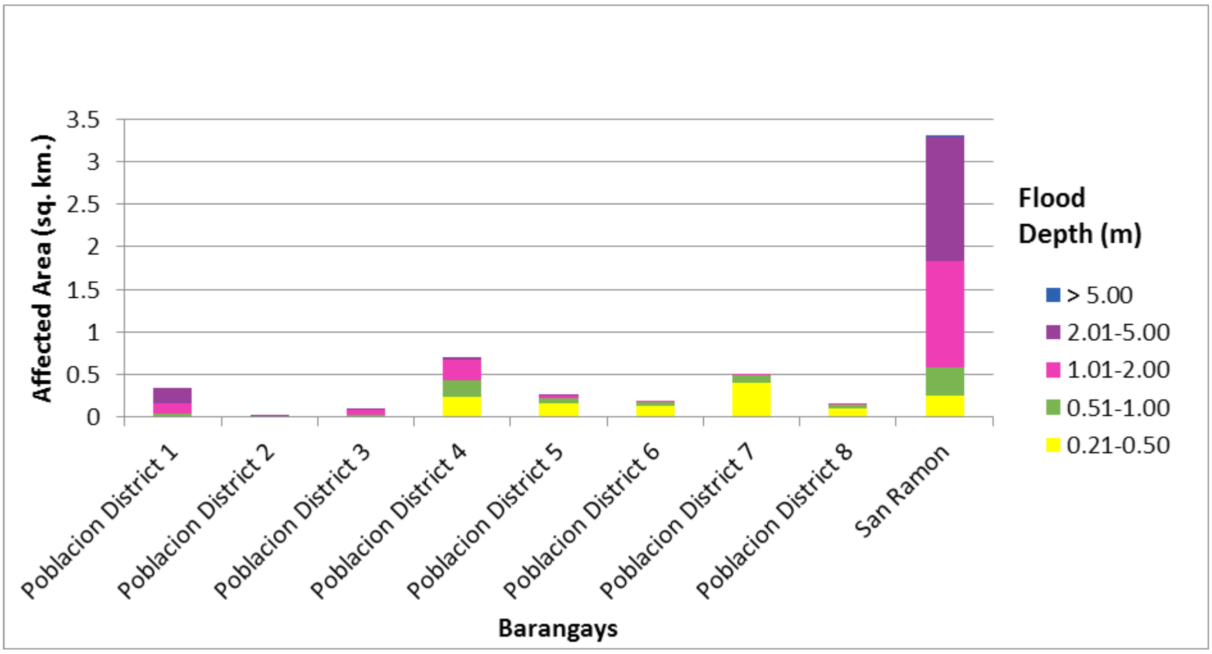

Figure 82. Affected Areas in Pambukhan, Northern Samar during 100-Year Rainfall Return Period.

For the municipality of San Roque with an area of 166.51 sq. km., 11.24% will experience flood levels of less 0.20 meters. 2.016% of the area will experience flood levels of 0.21 to 0.50 meters while 1.73%, 6.03%, and 1.86% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, and more than 2 meters, respectively. Listed in Table 50 and Table 51 are the affected areas in square kilometres by flood depth per barangay.

Table 50.Affected Areas in San Roque, Northern Samar during 100-Year Rainfall Return Period.

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in San Roque (in sq. km.)							
	Balnasan	Balud	Bantayan	Coroconog	Dale	Lao-Angan	Lawaan	Malobago
0.03-0.20	1.45	0.087	0.0021	6	0.046	1.06	5.59	1.16
0.21-0.50	0.15	0.082	0.0085	1.11	0.072	0.31	0.2	0.11
0.51-1.00	0.093	0.15	0.0099	1.11	0.26	0.29	0.13	0.047
1.01-2.00	0.23	0.23	0.011	0.78	0.85	0.17	0.14	0.038
2.01-5.00	2.69	2.14	0.00014	0.61	2.95	0.0064	0.29	0.015
> 5.00	0.44	0.19	0	0.0083	0.25	0	2.21	0

Table 51.Affected Areas in San Roque, Northern Samar during 100-Year Rainfall Return Period.

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in San Roque (in sq. km.)					
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
0.03-0.20	0.96	1.35	0.1	0.22	0.3	0.39
0.21-0.50	0.56	0.27	0.1	0.11	0.1	0.24
0.51-1.00	0.33	0.16	0.16	0.079	0.12	0.21
1.01-2.00	0.15	0.093	0.24	0.028	0.092	0.13
2.01-5.00	0.72	0.035	0.53	0.007	0.0024	0.044
> 5.00	0.0025	0.0001	0	0	0	0

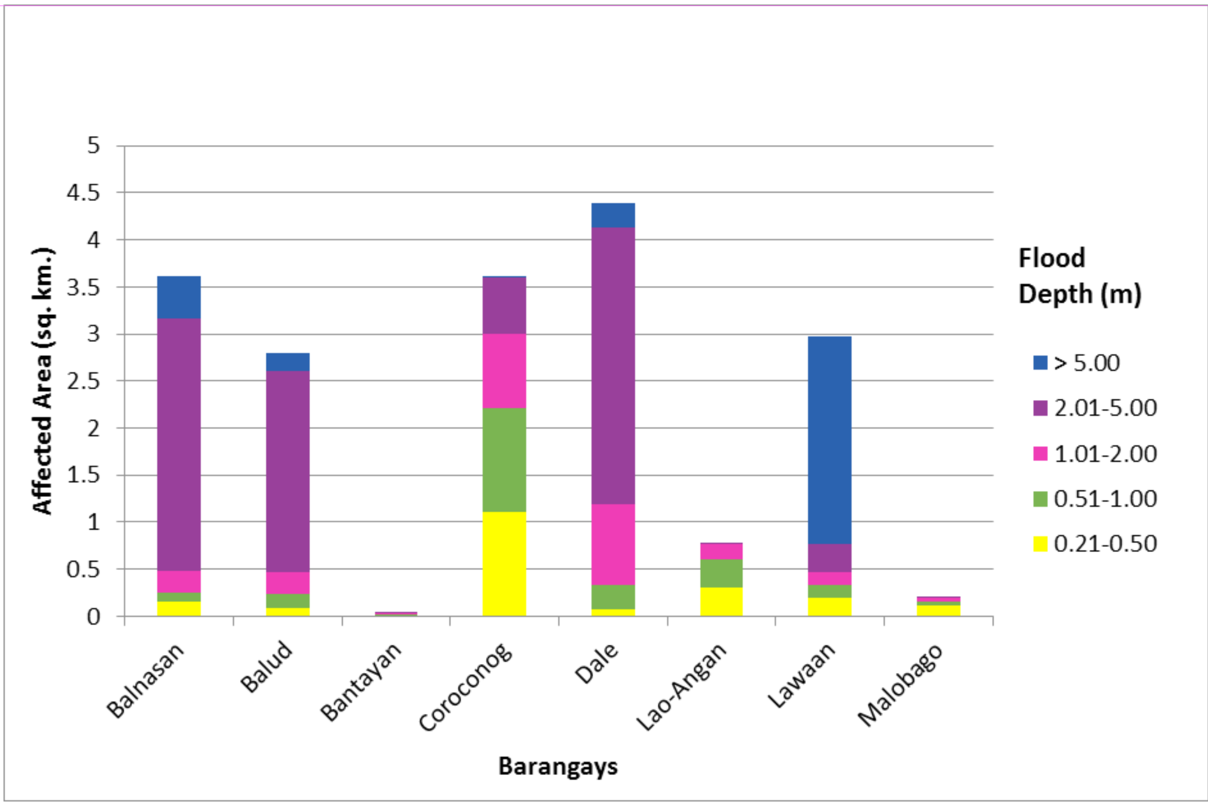

Figure 83. Affected Areas in San Roque, Northern Samar during 100-Year Rainfall Return Period.

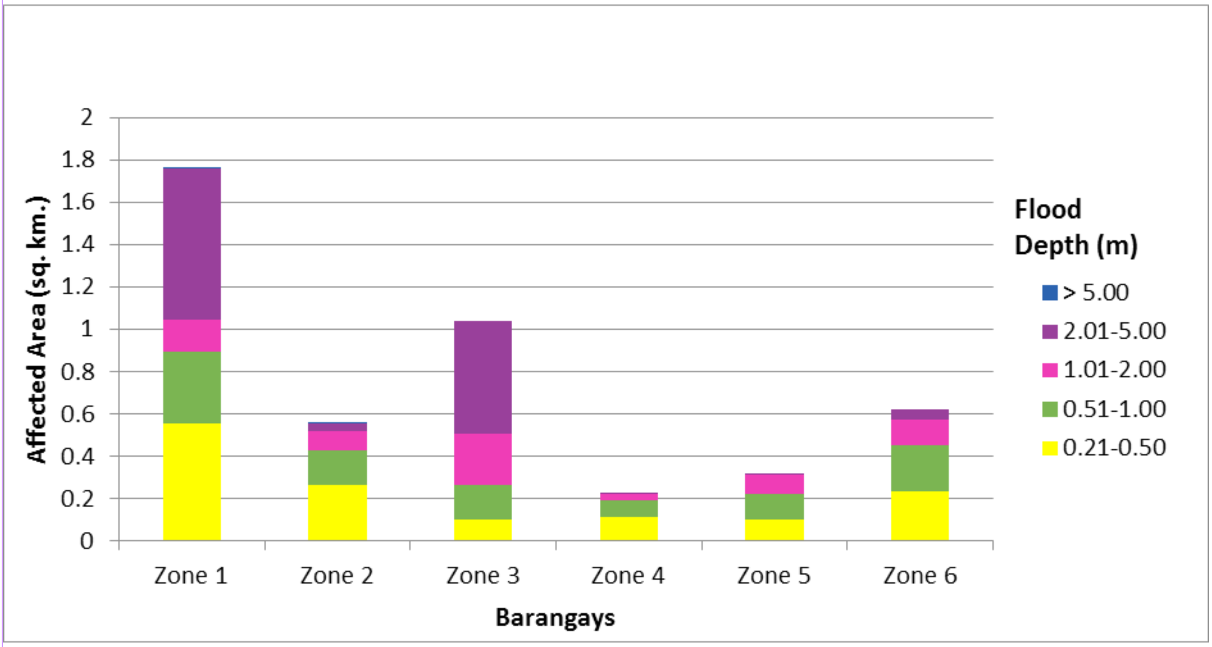

Figure 84. Affected Areas in San Roque, Northern Samar during 100-Year Rainfall Return Period

Among the barangays in the municipality of Laoang, Cabago-an is projected to have the highest percentage of area that will experience flood levels at 1.59%. Meanwhile, Yabyaban posted the second highest percentage of area that may be affected by flood depths at 1.33%.

Among the barangays in the municipality of Pambukhan, Cababto-An is projected to have the highest percentage of area that will experience flood levels at 5.07%. Meanwhile, Geparayan posted the second highest percentage of area that may be affected by flood depths at 3.98%.

Among the barangays in the municipality of San Roque, Coroconog is projected to have the highest percentage of area that will experience flood levels at 4.63%. Meanwhile, Lawaan posted the second highest percentage of area that may be affected by flood depths at 4.12%.

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

Table 52. Area 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	13.18	11.03	10.10
Medium	18.78	18.52	16.10
High	17.45	31.15	39.32

Of the 45 identified Education Institutions in Pambukhan Flood plain, 4 schools were assessed to be exposed to the Low level flooding during a 5 year scenario while 6 were assessed to be exposed to Medium and 8 to High level flooding in the same scenario. In the 25 year scenario, 10 schools were assessed to be exposed to the Low level flooding while 6 schools were assessed to be exposed to Medium and 11 to High level flooding. For the 100 year scenario, 8 schools were assessed for Low level flooding and 11 schools for Medium level flooding. In the same scenario, 15 schools were assessed to be exposed to High level flooding

Of the 12 identified Medical Institutions in Pambukhan Flood plain, 1 was assessed to be exposed to the Low level flooding during a 5 year scenario while 2 were assessed to be exposed to Medium and 3 to High level flooding in the same scenario. In the 25 year scenario, 2 were assessed to be exposed to the Low level flooding while 3 were assessed to be exposed to Medium level flooding. For the 100 year scenario, 5 schools were assessed for Low level flooding and 1 for Medium level flooding.

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 gather secondary data regarding flood occurrence in the area within the major river system in the Philippines.

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

The validation personnel will then go to the specified points identified in a river basin and will gather 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.

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 85 and Figure 86.

The flood validation consists of 232 points randomly selected all over the Pambukhan flood plain. The points were grouped depending on the RIDF return period of the event. Comparing it with the flood depth of the nearest storm event, the map has an RMSE value of 0.50m for the 5-year, and 0.64m for the 100-year return period. Table 53 shows a contingeny matrix of the comparison. The validation points are found in Annex 11.

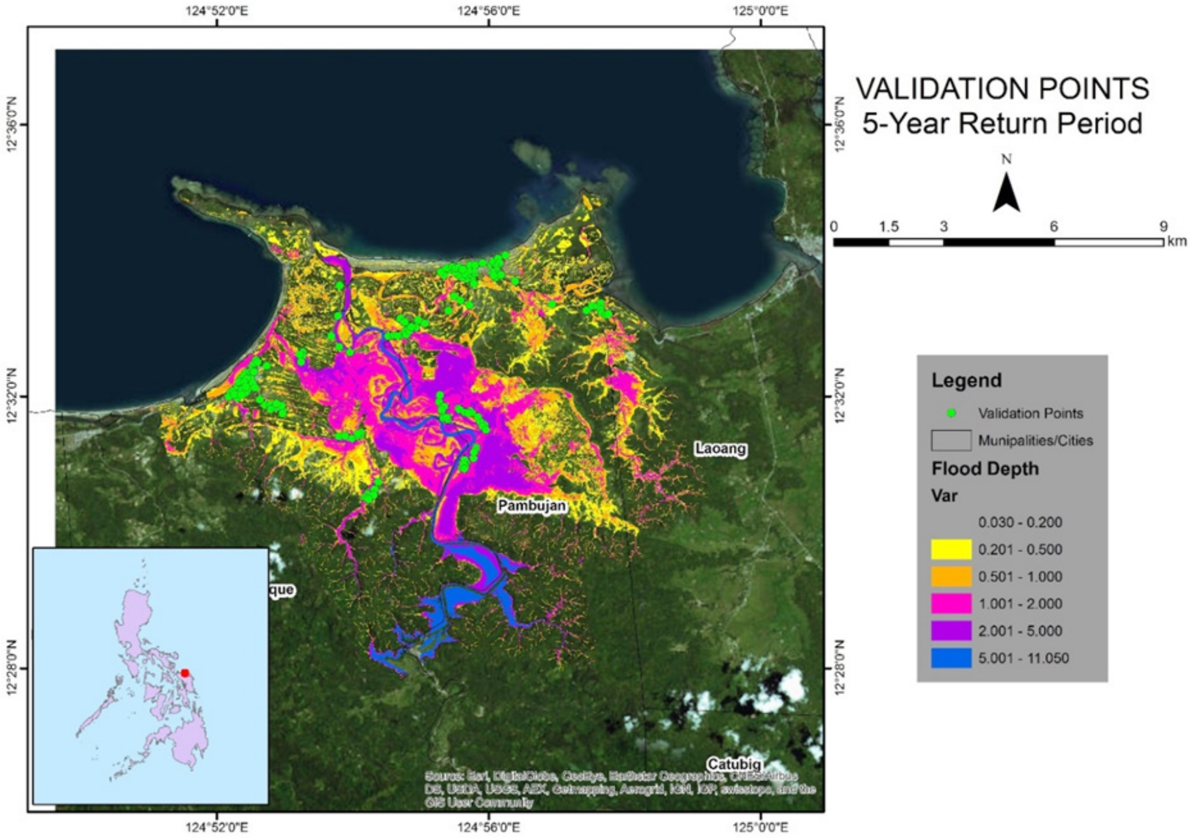

Figure 85. Validation Points for a 5-year Flood Depth Map of the Pambukhan Floodplain.

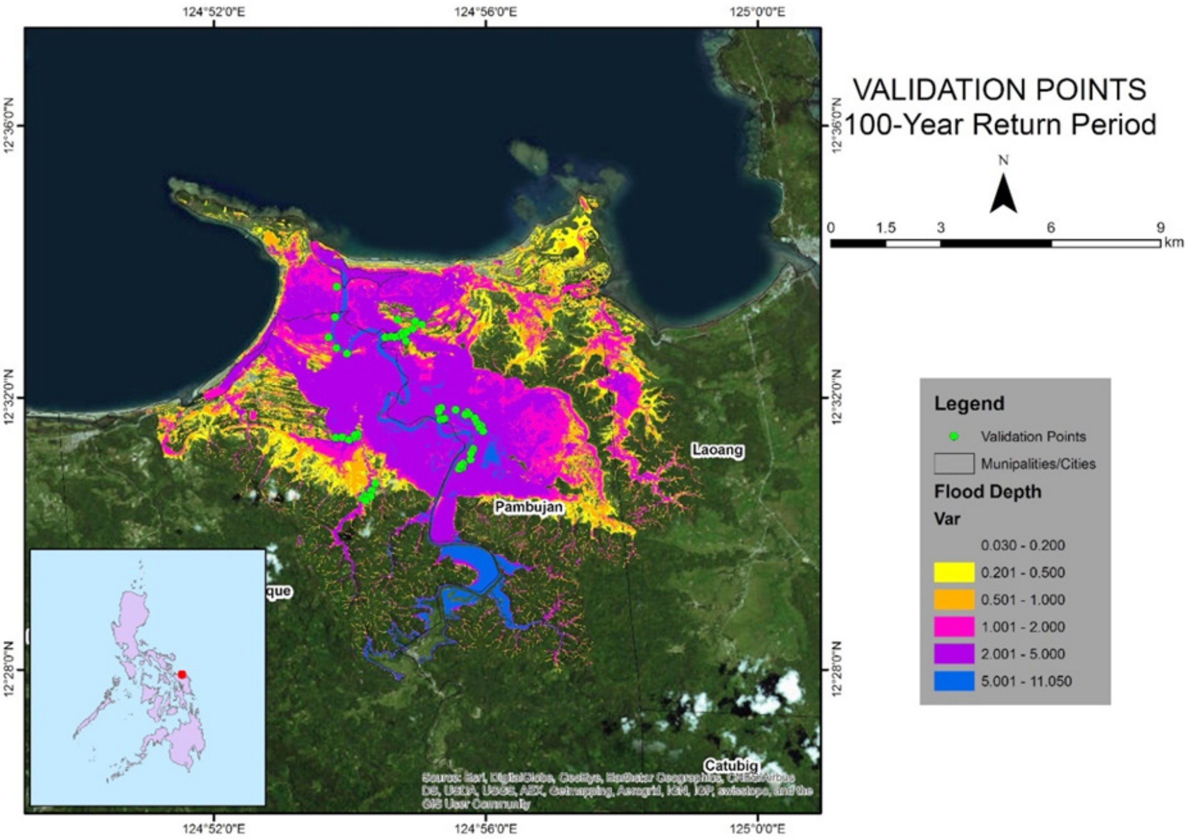

Figure 86. Validation points for 100-year Flood Depth Map of Pambukhan Floodplain

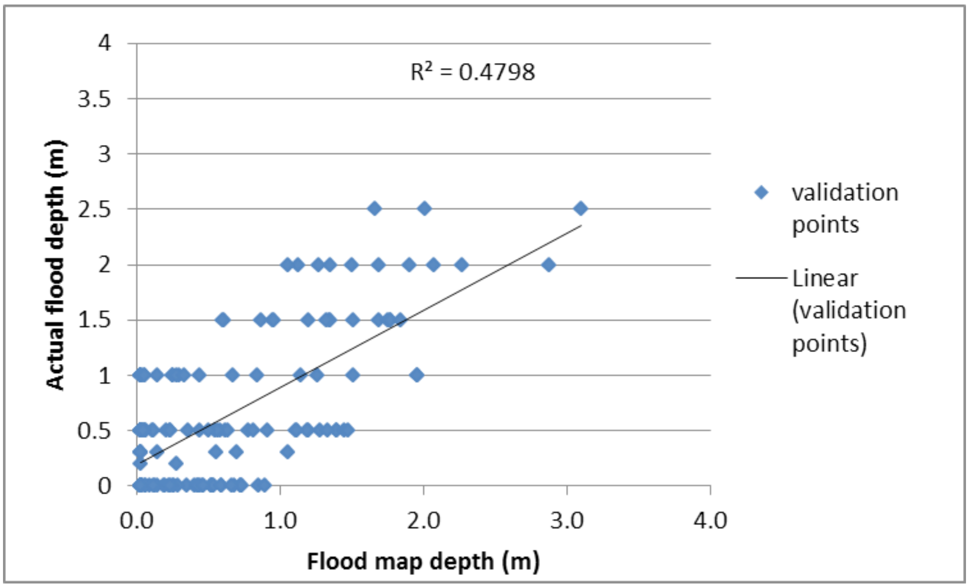

Figure 87. Flood map depth vs actual flood depth for 5-year return period

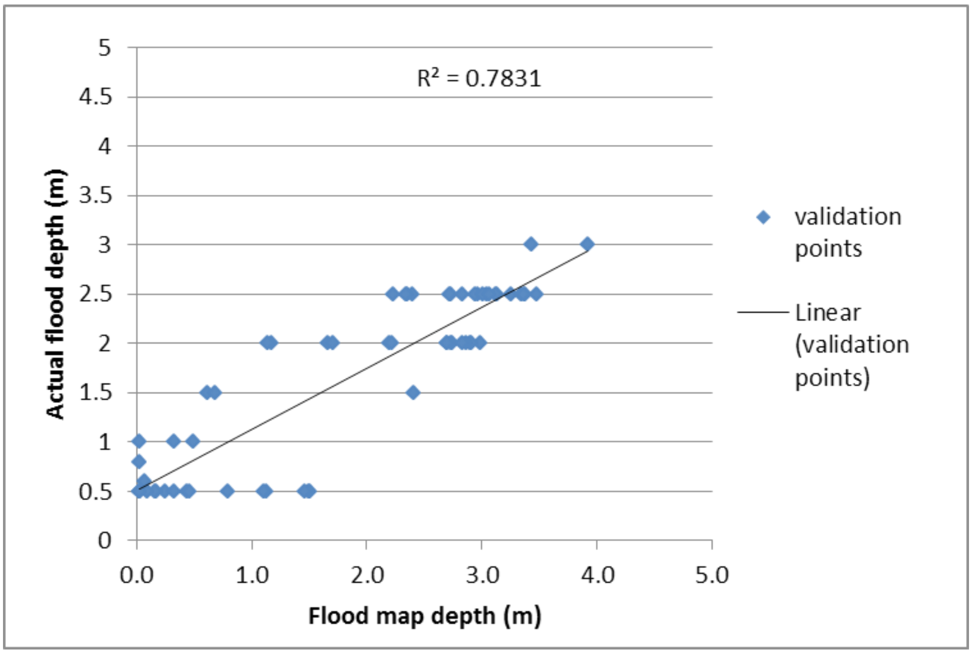

Figure 88. Flood map depth vs actual flood depth for 100-year return period

Table 53. Actual Flood Depth versus Simulated Flood Depth at different levels in the Pambukhan River Basin.

PAMBUKHAN BASIN		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	
Actual Flood Depth (m)	0-0.20	41	13	14	0	0	0	68
	0.21-0.50	31	10	11	16	0	0	68
	0.51-1.00	14	8	2	5	0	0	29
	1.01-2.00	0	0	7	21	15	0	43
	2.01-5.00	0	0	0	1	23	0	24
	> 5.00	0	0	0	0	0	0	0
	Total	86	31	34	43	38	0	232

On the whole, the overall accuracy generated by the flood model is estimated at 41.81%, with 97 points correctly matching the actual flood depths. In addition, there were 91 points estimated one level above and below the correct flood depths while there were 44 points estimated two levels above and below the correct flood. A total of 74 points were overestimated while a total of 61 points were underestimated in the modelled flood depths of Pambukhan. Table 54 depicts the summary of the Accuracy Assessment in the Pambukhan River Basin Flood Depth Map.

Table 54.Summary of the Accuracy Assessment in the Pambukhan River Basin Survey.

	No. of Points	%
Correct	97	41.81
Overestimated	74	31.90
Underestimated	61	26.29
Total	232	100

REFERENCES

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

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

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

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

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

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

ANNEXES

Annex 1. Technical Specifications of the LIDAR Sensors used in the Pambukhan Floodplain Survey

1. AQUARIUS SENSOR

Figure A-1.1. Aquarius Sensor

Table A-1.1. Parameters and Specifications of Aquarius Sensor

Parameter	Specification
Operational altitude	300-600 m AGL
Laser pulse repetition rate	33, 50. 70 kHz
Scan rate	0-70 Hz
Scan half-angle	0 to ± 25 ˚
Laser footprint on water surface	30-60 cm
Depth range	0 to > 10 m (for k < 0.1/m)
Topographic mode	
Operational altitude	300-2500
Range Capture	Up to 4 range measurements, including 1st, 2nd, 3rd, and last returns
Intensity capture	12-bit dynamic measurement range
Position and orientation system	POS AVTM 510 (OEM) includes embedded 72-channel GNSS receiver (GPS and GLONASS)
Data Storage	Ruggedized removable SSD hard disk (SATA III)
Power	28 V, 900 W, 35 A
Image capture	5 MP interline camera (standard); 60 MP full frame (optional)
Full waveform capture	12-bit Optech IWD-2 Intelligent Waveform Digitizer (optional)
Dimensions and weight	Sensor:250 x 430 x 320 mm; 30 kg; Control rack: 591 x 485 x 578 mm; 53 kg
Operating temperature	0-35˚C

Relative humidity	0-95% no-condensing

2. GEMINI SENSOR

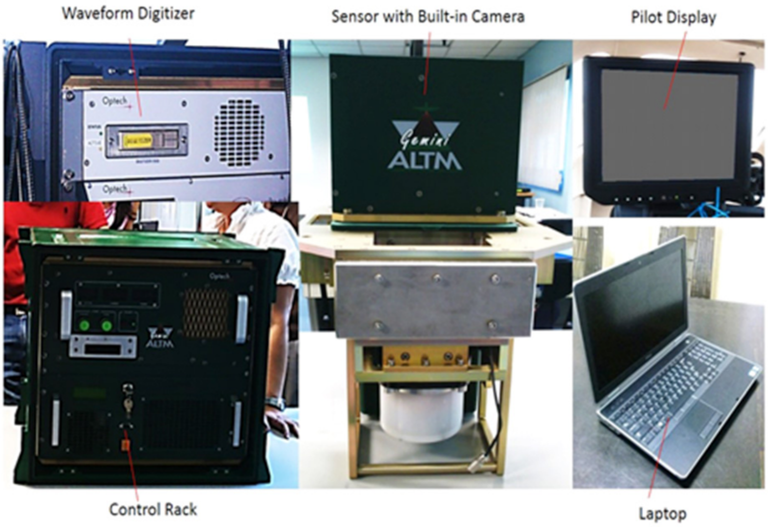

Figure A-1.2. Gemini Sensor

Table A-1.2. Parameters and Specifications of Gemini Sensor

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

Annex 2. NAMRIA Certificate of Reference Points Used in the LiDAR Survey

1. SMN-16

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

July 03, 2015

CERTIFICATION

To whom it may concern:

This is to certify that according to the records on file in this office, the requested survey information is as follows -

Province: **NORTHERN SAMAR**
Station Name: **SMN-16**
Order: **2nd**

Island: **VISAYAS**
Municipality: **MONDRAGON**
Barangay: **BAGASBAS**
MSL Elevation:

PRS92 Coordinates

Latitude: **12° 31' 32.33268"**	Longitude: **124° 48' 56.69485"**	Ellipsoidal Hgt: **5.45500 m.**

WGS84 Coordinates

Latitude: **12° 31' 27.72792"**	Longitude: **124° 49' 1.74020"**	Ellipsoidal Hgt: **63.99100 m.**

PTM / PRS92 Coordinates

Northing: **1385085.603 m.**	Easting: **479974.965 m.**	Zone: **5**

UTM / PRS92 Coordinates

Northing: **1,385,272.01**	Easting: **697,302.11**	Zone: **51**

Location Description

SMN-1

Station Mark SMN-16 is located in Brgy. Bagasbas, Municipality of Mondragon, Province of Northern Samar, Island of Samar. to located the station, from Mondragon Town Proper, travel in North direction for about 10 km going to Brgy. Bagasbas. the station was established 30 m North from Bagasbas Elem. School, was about 1 m East of the Basketball court and 4 m west of the chapel.

Mark is the head of a 4" copper nail flushed in a 30X30 cm. cement block embedded in the ground protruding about 20 cm., with inscriptions "SMN-16; 2007; NAMRIA."

Requesting Party: **UP-DREAM**
Purpose: **Reference**
OR Number: **8084005 I**
T.N.: **2015-1258**

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

6

9 9 0 7 0 3 2 0 1 5 1 6 2 6 3 8

CIP/4701/12/09/814

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. SMN-16

2. SMN-22

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

September 04, 2015

CERTIFICATION

To whom it may concern:

This is to certify that according to the records on file in this office, the requested survey information is as follows -

	Province: **NORTHERN SAMAR**	
	Station Name: **SMN-22**	
	Order: **2nd**	
Island: **VISAYAS**	Barangay: **SIMORA**	
Municipality: **LAOANG**	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **12° 28' 27.20633"**	Longitude: **125° 1' 25.36067"**	Ellipsoidal Hgt: **-1.70407 m.**
	WGS84 Coordinates	
Latitude: **12° 28' 22.63174"**	Longitude: **125° 1' 30.40861"**	Ellipsoidal Hgt: **57.47400 m.**
	PTM / PRS92 Coordinates	
Northing: **1379390.508 m.**	Easting: **502577.525 m.**	Zone: **5**
	UTM / PRS92 Coordinates	
Northing: **1,379,746.87**	Easting: **719,951.32**	Zone: **51**

Location Description

SMN-22
From Laoang town proper, travel about 15 km. north going to Brgy. Simora. The monument is located inside the Elementary School, 5 m. east from the School's Entrance gate, 5 m. east from the school path way, 10 m. north from the school classroom, and 25 m. north from the chapel, where the station is located. Mark is the head of a 4" copper nail flushed in a 30X30 cm. cement block embedded in the ground protruding about 20 cm., with inscriptions "SMN-22; 2007; NAMRIA."

Requesting Party: **Christopher Cruz**
Purpose: **Reference**
OR Number: **8087193 I**
T.N.: **2015-2547**

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

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

CIP/4701/12/09/814

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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

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Figure A-2.2. SMN-22

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

1. CMN-01

Table A-3.1.CMN-01

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
CMN-01 --- SMN-19 (B1)	SMN-19	CMN-01	Fixed	0.004	0.018	261°10'06"	19716.093	7.117
CMN-01 --- SMN-19 (B2)	SMN-19	CMN-01	Fixed	0.004	0.016	261°10'06"	19716.092	7.056

Acceptance Summary

Processed	Passed	Flag		Fail	
2	2	0		0	

Vector Components (Mark to Mark)

From:	SMN-19				
Grid		Local		Global	
Easting	697302.106 m	Latitude	N12°31'32.33268"	Latitude	N12°31'27.72792"
Northing	1385272.014 m	Longitude	E124°48'56.69484"	Longitude	E124°49'01.74020"
Elevation	8.997 m	Height	5.456 m	Height	63.991 m

Standard Errors

Vector errors:					
σ ΔEasting	0.002 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.005 m
σ ΔNorthing	0.002 m	σ Ellipsoid Dist.	0.002 m	σ ΔY	0.007 m
σ ΔElevation	0.009 m	σ ΔHeight	0.009 m	σ ΔZ	0.003 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000248767		
Y	-0.0000327811	0.0000524301	
Z	-0.0000118537	0.0000172626	0.0000085902

2. CMN-03

Table A-3.2.CMN-03

Vector Components (Mark to Mark)

From:	SMN-22				
Grid		Local		Global	
Easting	719951.311 m	Latitude	N12°28'27.20631"	Latitude	N12°28'22.63174"
Northing	1379746.868 m	Longitude	E125°01'25.36070"	Longitude	E125°01'30.40861"
Elevation	2.366 m	Height	-1.704 m	Height	57.474 m

To:	CMN-03				
Grid		Local		Global	
Easting	718234.013 m	Latitude	N12°29'56.60839"	Latitude	N12°29'52.02635"
Northing	1382481.531 m	Longitude	E125°00'29.19031"	Longitude	E125°00'34.23621"
Elevation	4.145 m	Height	-0.122 m	Height	58.953 m

Vector					
ΔEasting	-1717.298 m	NS Fwd Azimuth	328°18'36"	ΔX	1729.089 m
ΔNorthing	2734.663 m	Ellipsoid Dist.	3228.537 m	ΔY	488.102 m
ΔElevation	1.779 m	ΔHeight	1.582 m	ΔZ	2682.431 m

Standard Errors

Vector errors:					
σ ΔEasting	0.001 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.004 m
σ ΔNorthing	0.001 m	σ Ellipsoid Dist.	0.001 m	σ ΔY	0.005 m
σ ΔElevation	0.006 m	σ ΔHeight	0.006 m	σ ΔZ	0.002 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000131932		
Y	-0.0000175996	0.0000266165	
Z	-0.0000049526	0.0000073425	0.0000030832

3. NS-61

Table A-3.3.NS-61

Vector Components (Mark to Mark)

From:	SMN-16				
Grid		Local		Global	
Easting	697302.106 m	Latitude	N12°31'32.33268"	Latitude	N12°31'27.72792"
Northing	1385272.014 m	Longitude	E124°48'56.69484"	Longitude	E124°49'01.74020"
Elevation	8.997 m	Height	5.456 m	Height	63.991 m

To:	NS-61				
Grid		Local		Global	
Easting	696390.555 m	Latitude	N12°31'17.86801"	Latitude	N12°31'13.26354"
Northing	1384821.249 m	Longitude	E124°48'26.40323"	Longitude	E124°48'31.44902"
Elevation	8.653 m	Height	5.208 m	Height	63.733 m

Vector					
ΔEasting	-911.551 m	NS Fwd Azimuth	244°04'53"	ΔX	695.978 m
ΔNorthing	-450.765 m	Ellipsoid Dist.	1016.833 m	ΔY	601.027 m
ΔElevation	-0.345 m	ΔHeight	-0.248 m	ΔZ	-433.971 m

Standard Errors

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

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000012353		
Y	-0.0000007094	0.0000013533	
Z	-0.0000003640	0.0000003117	0.0000005407

4. NS-81

Table A-3.4.NS-81

Vector Components (Mark to Mark)

From:	SMN-22				
Grid		Local		Global	
Easting	719951.311 m	Latitude	N12°28'27.20631"	Latitude	N12°28'22.63174"
Northing	1379746.868 m	Longitude	E125°01'25.36070"	Longitude	E125°01'30.40861"
Elevation	2.366 m	Height	-1.704 m	Height	57.474 m

Standard Errors

Vector errors:					
σ ΔEasting	0.002 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.004 m
σ ΔNorthing	0.001 m	σ Ellipsoid Dist.	0.001 m	σ ΔY	0.005 m
σ ΔElevation	0.007 m	σ ΔHeight	0.007 m	σ ΔZ	0.002 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000158482		
Y	-0.0000178008	0.0000299576	
Z	-0.0000062225	0.0000079062	0.0000036553

Annex 4. The LiDAR Survey Team Composition

Data Acquisition Component Sub-Team	Designation	Name	Agency/ Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	ENGR. LOUIE P. BALICANTA	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUNA	UP TCAGP
		LOVELYN ASUNCION	UP TCAGP
FIELD TEAM			
LiDAR Operation	Senior Science Research Specialist (SSRS)	PAULINE JOANNE ARCEO	UP-TCAGP
		AUBREY MATIRA PAGADOR	UP-TCAGP
	Research Associate (RA)	JONALYN GONZALES	UP-TCAGP
		MA. VERLINA E. TONGA	
		MILLIE SHANE REYES	
		MARY CATHERINE ELIZABETH BALIGUAS	
Ground Survey, Data Download and Transfer	RA	JONATHAN ALMALVEZ	UP-TCAGP
		REGINA FELISMINO	

LiDAR Operation	Airborne Security	SSG. RANDY SISON JR.	PHILIPPINE AIR FORCE (PAF)
		SSG. RAYMUND DOMINE	
	Pilot	CAPT. RANDY LAGCO	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. CESAR ALFONSO III	AAC
		CAPT. NEIL ACHILLES AGAWIN	AAC
		CAPT. FERDINAND DE OCAMPO	AAC

Table A-4.1. The LiDAR Survey Team Composition

Annex 5. Data Transfer Sheet for Pambukhan Floodplain

DATA TRANSFER SHEET
CATARMAN 5/5/2016

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS	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	
April 8,2016	3913G	2BLK33LK099A	GEMINI	NA	186	392	163	NA	NA	14.1	NA	184	1KB	1KB	8/9	NA	Z:\DAC\RAW DATA
April 9,2016	8426AC	3BLK33BC100A	AQUARIUS/CASI	NA	370	827	261	68.6	61.2	15.1	272	195	1KB	1KB	7	NA	Z:\DAC\RAW DATA
April 9,2016	8427AC	3BLK33CS100B	AQUARIUS/CASI	NA	NA	209	103	16.8	61.2	4.13	69.2	195	1KB	1KB	7	NA	Z:\DAC\RAW DATA
April 9,2016	3917G	2BLK33EG100A	GEMINI	NA	241	1.54	255	NA	NA	22.4	NA	195	1KB	2KB	13/8/9	NA	Z:\DAC\RAW DATA
April 10,2016	8428AC	3BLK33CSH101A	GEMINI	NA	197	530	255	34.5	106	8.9	143	123	1KB	1KB	46	NA	Z:\DAC\RAW DATA

Received from

Name R. PUNTO
Position RA
Signature

Received by

Name AC Bongat
Position SSRS
Signature 5/11/16

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

DATA TRANSFER SHEET
Catarman 9/16/15

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
23-Aug	8180AC	3BLK33R235A	aquarius	na	254	519	212	70.2	2.17/26.9	10.6	64.9	9.87	1KB	1KB	3	8	Z:\DAC\RAW DATA
24-Aug	8182AC	3BLK33R236A	aquarius	na	207	451	213	na	na	9.06	104	12.5	1KB	1KB	5	207	Z:\DAC\RAW DATA
24-Aug	8183AC	3BLK33STV236B	aquarius	na	334	305	152	37.2/14	39.2/11	5.81	35.1	12.5	1KB	1KB	5	na	Z:\DAC\RAW DATA
25-Aug	8184AC	3BLK33PS2237A	aquarius	na	62	173	109	14.7	47.7/31.1	2.97	12.6	9.59	1KB	1KB	4	11	Z:\DAC\RAW DATA
25-Aug	8185AC	3BUNDLEADJUSTMENT237B	aquarius	na	40	108	74.1	11.5	109/87.3	2.04	11	9.59	1KB	1KB	4	7	Z:\DAC\RAW DATA
26-Aug	8186AC	3BLK33SPST238A	aquarius	na	222	555	250	64.5	219	6.73	12.8	9.12	1KB	1KB	12	29	Z:\DAC\RAW DATA
27-Aug	8188AC	3BLK33S239A	aquarius	na	86	200	115	22.2	88.6	3.93	19.8	3.23	1KB	1KB	4	107	Z:\DAC\RAW DATA
28-Aug	8190AC	3BLK33CD240A	aquarius	na	273	460	222	59.9	na	8.77	25.3	7	1KB	1KB	6/5	14	Z:\DAC\RAW DATA

Received from

Name C. Joaquin
Position RA
Signature [signature]

Received by

Name JOIDA F. PRIETO
Position SSRS
Signature [signature] 09/16/15

Figure A-5.2. Transfer Sheet for Pambukhan Floodplain – B

DATA TRANSFER SHEET
catarman 9/8/2015

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	
1-Aug	8137	CASILCTF213A	aquarius	na	63	159	73.2	13.7	80.9	3.13	na	1.79	1KB	1KB	5	NA	Z:\DAC\RAW DATA
4-Aug	8142	AQUALCTF216A	aquarius	na	36	140	101	na	na	2.2	8.44	21.4	1KB	1KB	3/4	NA	Z:\DAC\RAW DATA
10-Aug	8154	3BLK331NO222A	aquarius	na	235	505	185	na	na	9.78	68	27.1	1KB	1KB	11/14	NA	Z:\DAC\RAW DATA
11-Aug	8156	3BLK331LNS223A	aquarius	na	271	1.02	217	na	na	11.4	77.4	32.8	1KB	2KB	11	22	Z:\DAC\RAW DATA
11-Aug	8157	3BLK331NS223B	aquarius	na	205	1.01	169	na	na	14	26.3	34.9	1KB	1KB	6	NA	Z:\DAC\RAW DATA
12-Aug	8158	3BLK331P224A	aquarius	na	299	635	217	na	na	12.4	51.6	49.3	1KB	1KB	16	42	Z:\DAC\RAW DATA
12-Aug	8159	3BLK331NSPS224B	aquarius	na	135	943	77.3	na	na	6.12	37.4	49.3	1KB	1KB	16	NA	Z:\DAC\RAW DATA
13-Aug	8160	3BLK331PQRS225A	aquarius	na	122	284	149	na	na	5.68	30.4	12.6	1KB	1KB	15	122	Z:\DAC\RAW DATA

Received from

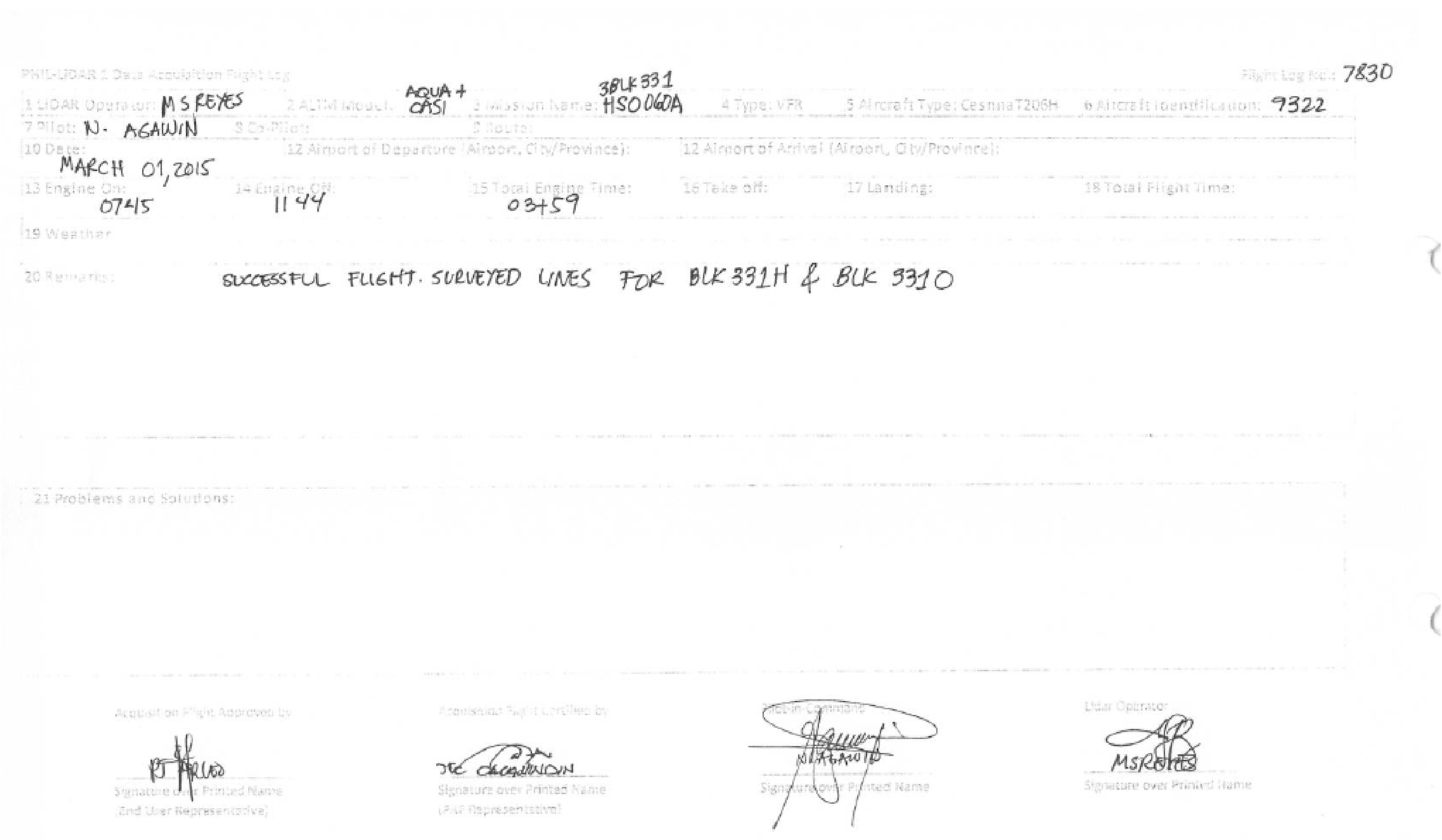
Name O. SORQUIN
Position RA
Signature

Received by

Name JOIDA F. PRIETO
Position SSRS 9/8/15
Signature

Figure A-5.3. Transfer Sheet for Pambukhan Floodplain – C

Annex 6. Flight logs for the flight missions


PHIL-LIDAR 1 Data Acquisition Flight Log — Flight Log No.: 7830

1 LiDAR Operator: M S REYES | 2 ALTM Model: AQUA + CASI | 3 Mission Name: 3BLK331 HSO060A | 4 Type: VFR | 5 Aircraft Type: CesnnaT206H | 6 Aircraft Identification: 9322

7 Pilot: N. AGAWIN | 8 Co-Pilot: | 9 Route:

10 Date: MARCH 01, 2015 | 12 Airport of Departure (Airport, City/Province): | 12 Airport of Arrival (Airport, City/Province):

13 Engine On: 0745 | 14 Engine Off: 1144 | 15 Total Engine Time: 03+59 | 16 Take off: | 17 Landing: | 18 Total Flight Time:

19 Weather

20 Remarks: SUCCESSFUL FLIGHT. SURVEYED LINES FOR BLK 331H & BLK 331O

21 Problems and Solutions:

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

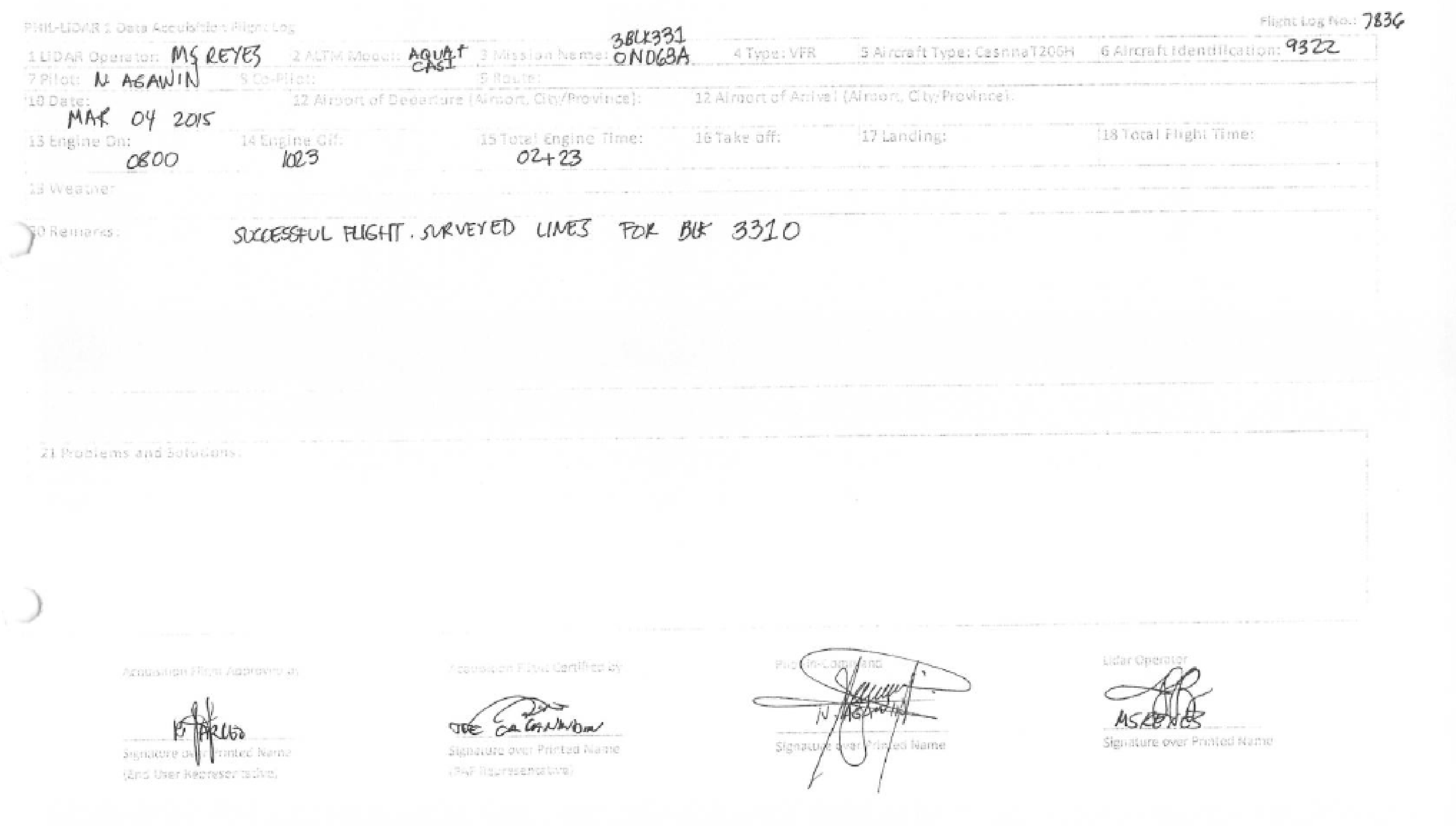
Acquisition Flight Certified by: Signature over Printed Name (PAF Representative)

Pilot-in-Command: N. AGAWIN — Signature over Printed Name

Lidar Operator: MS REYES — Signature over Printed Name

Figure A-6.1. Flight Log for 7830AC Mission

2. Flight Log for 7836AC Mission


PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 7836

1 LIDAR Operator: MS REYES | 2 ALTM Model: AQUA+ CASI | 3 Mission Name: 3BLK331 OND68A | 4 Type: VFR | 5 Aircraft Type: CesnnaT206H | 6 Aircraft Identification: 9322

7 Pilot: N AGAWIN | 8 Co-Pilot: | 9 Route:

10 Date: MAR 04 2015 | 12 Airport of Departure (Airport, City/Province): | 12 Airport of Arrival (Airport, City/Province):

13 Engine On: 0800 | 14 Engine Off: 1023 | 15 Total Engine Time: 02+23 | 16 Take off: | 17 Landing: | 18 Total Flight Time:

19 Weather

20 Remarks: SUCCESSFUL FLIGHT. SURVEYED LINES FOR BLK 3310

21 Problems and Solutions:

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

Acquisition Flight Certified by: JOE CA GANADON Signature over Printed Name (PAF Representative)

Pilot-in-Command: N AGAWIN Signature over Printed Name

Lidar Operator: MS REYES Signature over Printed Name

Figure A-6.2. Flight Log for 7836AC Mission

3. Flight Log for 8154AC Mission

DREAM Program's Data Acquisition Flight Log

Flight Log No.: 8154

1 LiDAR Operator: MS Reyes	2 ALTM Model: AQUA+CASI	3 Mission Name: 3BLK331L222A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9322
7 Pilot: CC Alfonso III	8 Co-Pilot: R LAGCO	9 Route: Cat - Cat			
10 Date: 10 AUG 2015	12 Airport of Departure (Airport, City/Province): CATARMAN		12 Airport of Arrival (Airport, City/Province): Catarman		
13 Engine On: 0616H	14 Engine Off: 0935 H	15 Total Engine Time: 3+23	16 Take off: 621	17 Landing: 934	18 Total Flight Time: 3+13
19 Weather					

20 Flight Classification

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

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

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

21 Remarks

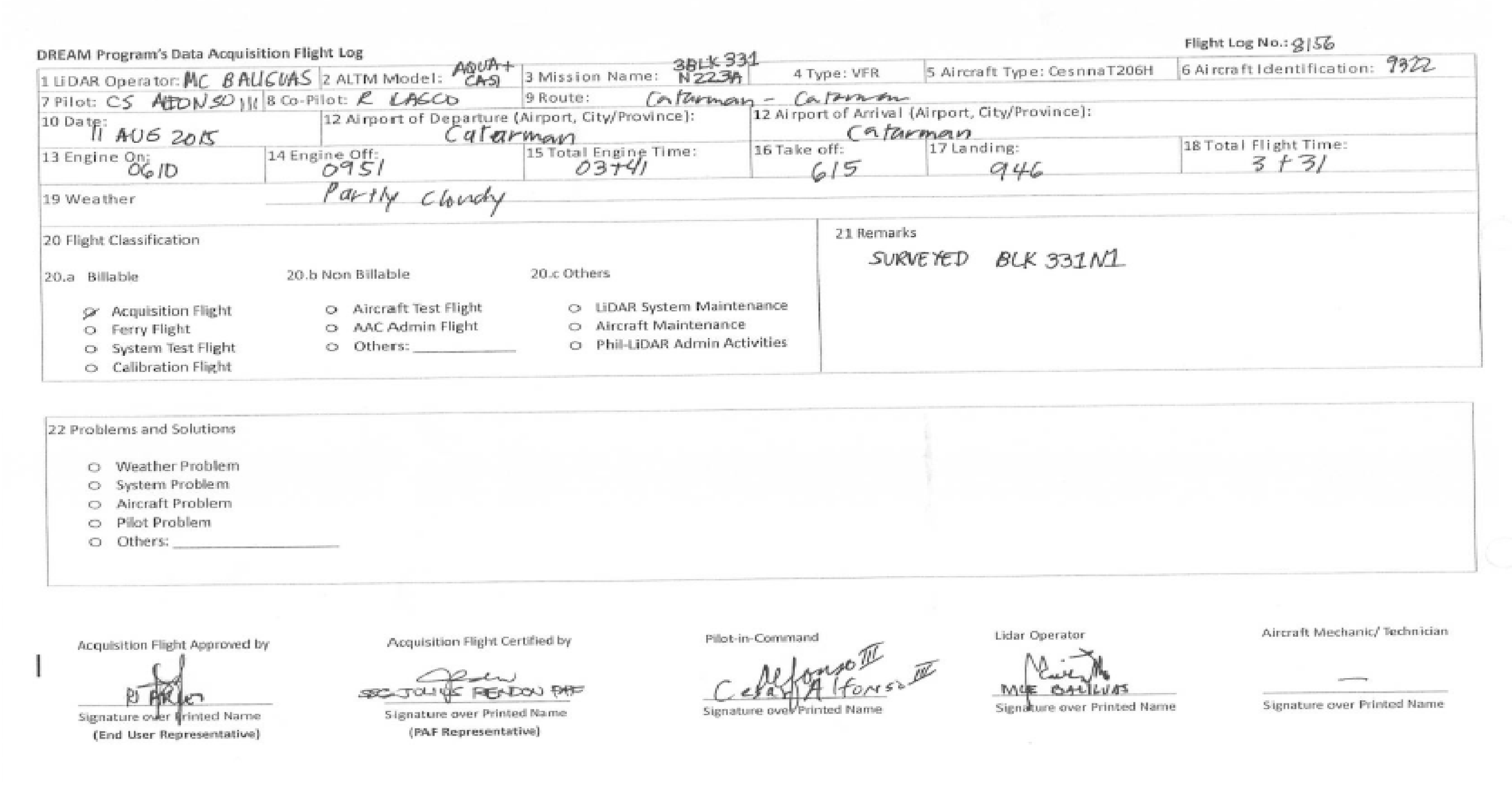
Surveyed Blk 331 N & O

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator	Aircraft Mechanic/ Technician
[illegible]	SSC JULIUS RENDON PAF	Cesar Alfonso III	MS 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 8154AC Mission

4. Flight Log for 8156AC Mission



DREAM Program's Data Acquisition Flight Log

Flight Log No.: 8156

1 LiDAR Operator: MC BALICUAS	2 ALTM Model: AQUA+ CAS)	3 Mission Name: 3BLK331 N223A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9322
7 Pilot: CS ALFONSO III	8 Co-Pilot: R LASCO	9 Route: Catarman - Catarman			
10 Date: 11 AUG 2015	12 Airport of Departure (Airport, City/Province): Catarman		12 Airport of Arrival (Airport, City/Province): Catarman		
13 Engine On: 0610	14 Engine Off: 0951	15 Total Engine Time: 03+41	16 Take off: 615	17 Landing: 946	18 Total Flight Time: 3+31
19 Weather	Partly Cloudy				

20 Flight Classification

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

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

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

21 Remarks

SURVEYED BLK 331N1

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

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

Acquisition Flight Certified by: SSG JOLLIE RENDON PAF — Signature over Printed Name (PAF Representative)

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

Lidar Operator: MCE BALICUAS — Signature over Printed Name

Aircraft Mechanic/ Technician: — Signature over Printed Name

Figure A-6.4. Flight Log for 8156AC Mission

5. Flight Log for 8157AC Mission

DREAM Program's Data Acquisition Flight Log

Flight Log No.: 8157

1 LiDAR Operator: MSREYES	2 ALTM Model: AQUA+ CASI	3 Mission Name: 3BLK331 N223B	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9322
7 Pilot: CS ALFONSO III	8 Co-Pilot: R LASCO	9 Route: Catarman - Catarman			
10 Date: 11 AUG 2015	12 Airport of Departure (Airport, City/Province): CATARMAN		12 Airport of Arrival (Airport, City/Province): Catarman		
13 Engine On: 1034	14 Engine Off: 1321	15 Total Engine Time: 02+47	16 Take off: 1039	17 Landing: 1316	18 Total Flight Time: 2+37
19 Weather: Partly Cloudy					

20 Flight Classification

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

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

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

21 Remarks

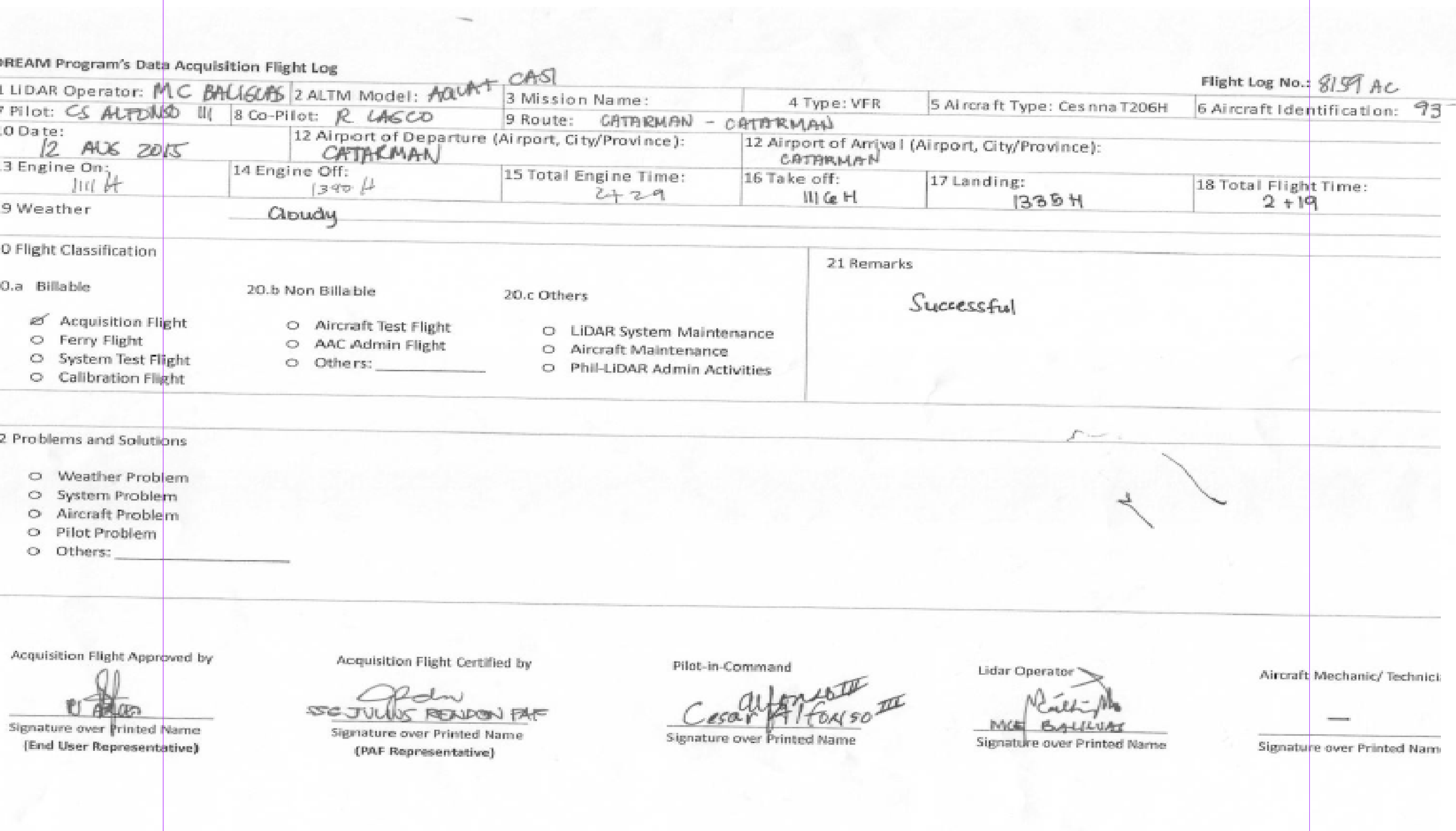
SURVEYED BLK331N2

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator	Aircraft Mechanic/ Technician
[signature]	SGT JULIUS RENDON PAF	Cesar Alfonso III	MS 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-6.5. Flight Log for 8157AC Mission

6. Flight Log for 8159AC Mission



DREAM Program's Data Acquisition Flight Log

Flight Log No.: 8159 AC

1 LiDAR Operator: MC BALIGUAS	2 ALTM Model: AQUA	3 Mission Name: CASI	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 93
7 Pilot: CS ALFONSO III	8 Co-Pilot: R LAGCO	9 Route: CATARMAN - CATARMAN			
10 Date: 12 AUG 2015	12 Airport of Departure (Airport, City/Province): CATARMAN		12 Airport of Arrival (Airport, City/Province): CATARMAN		
13 Engine On: 1111 H	14 Engine Off: 1340 H	15 Total Engine Time: 2+29	16 Take off: 1116 H	17 Landing: 1335 H	18 Total Flight Time: 2+19
19 Weather: Cloudy					

20 Flight Classification

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

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

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

21 Remarks

Successful

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

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

Acquisition Flight Certified by: SSG JULIUS RENDON PAF — Signature over Printed Name (PAF Representative)

Pilot-in-Command: Cesar Alfonso III — Signature over Printed Name

Lidar Operator: MCE BALIGUAS — Signature over Printed Name

Aircraft Mechanic/ Technician: Signature over Printed Name

Figure A-6.6. Flight Log for 8159AC Mission

7. Flight Log for 8431AC Mission

Data Acquisition Flight Log

Flight Log No.: 8431

1 LiDAR Operator: MCE BALIGUAS	2 ALTM Model: AQUARIUS + CASI	3 Mission Name: 3BLK33D102A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP 9322
7 Pilot: R. Lagco	8 Co-Pilot: J. Jeciel	9 Route: Catarman - Catarman			
10 Date: April 11, 2016	12 Airport of Departure (Airport, City/Province): Catarman		12 Airport of Arrival (Airport, City/Province): Catarman		
13 Engine On: 0715 H	14 Engine Off: 1126 H	15 Total Engine Time: 4 + 11	16 Take off: 0720 H	17 Landing: 1120 H	18 Total Flight Time: 4 + 00
19 Weather: Partly Cloudy					

20 Flight Classification

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

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

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

21 Remarks

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator	Aircraft Mechanic/ Technician
A. BALADAN	TS SANDY V UY	RANDY G. LAGCO	MCE BALIGUAS	—
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

Figure A-6.7. Flight Log for 8431AC Mission

Annex 7. Flight status reports

Catarman Mission

March 1 to 9, 2015, August 10 to12, 2015 and April 9 to 11, 2016

Table A-7.1. Flight Status Report

FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
3917G	BLK33E, G	3BLK49CD028A	A PAGADOR	09 APR 2016	Completed BLk33E and BLK33G
7830AC	BLK 331H & O	3BLK331HSO060A	MS REYES	01-Mar-15	Surveyed 7 lines for Blk331H and 11 lines for Blk331O.
7836AC	BLK 331O	3BLK331ON063A	MS REYES	04-Mar-15	Surveyed 7 lines for Blk 331O.
7846AC	BLK 331L	3BLK331L068A	PJ ARCEO	09-Mar-15	Surveyed 17 lines for Blk 331L.
8154AC	BLK331 N &O	3BLK331NO222A	MS REYES	10-Aug-15	SURVEYED 13 LINES FOR BLK N AND O
8156AC	BLK331 L & N	3BLK331LNS223A	MC BALIGUAS	11-Aug-15	SURVEYED 17 LINES FOR Blk331N & L
8157AC	BLK331N2	3BLK331NS223B	MS REYES	11-Aug-15	SURVEYED 13 LINES FOR Blk331N
8159AC	BLK331N & P	3BLK331NSPS224B	MC BALIGUAS	12-Aug-15	SURVEYED 8 LINES FOR Blk331N & P
8431AC	BLK33D	3BLK33D102A	MCE BALIGUAS	11-Apr-16	Completed BLK33D; No CASI DATA; No DIGITIZER

SWATH PER FLIGHT MISSION

Flight No. :	3917G
Area:	BLK33E, G
Total Area:	119.023 km2
Mission Name:	2BLK33EG100A
Altitude:	850m then 750m
SCF:	40 Hz
Lidar FOV:	25deg

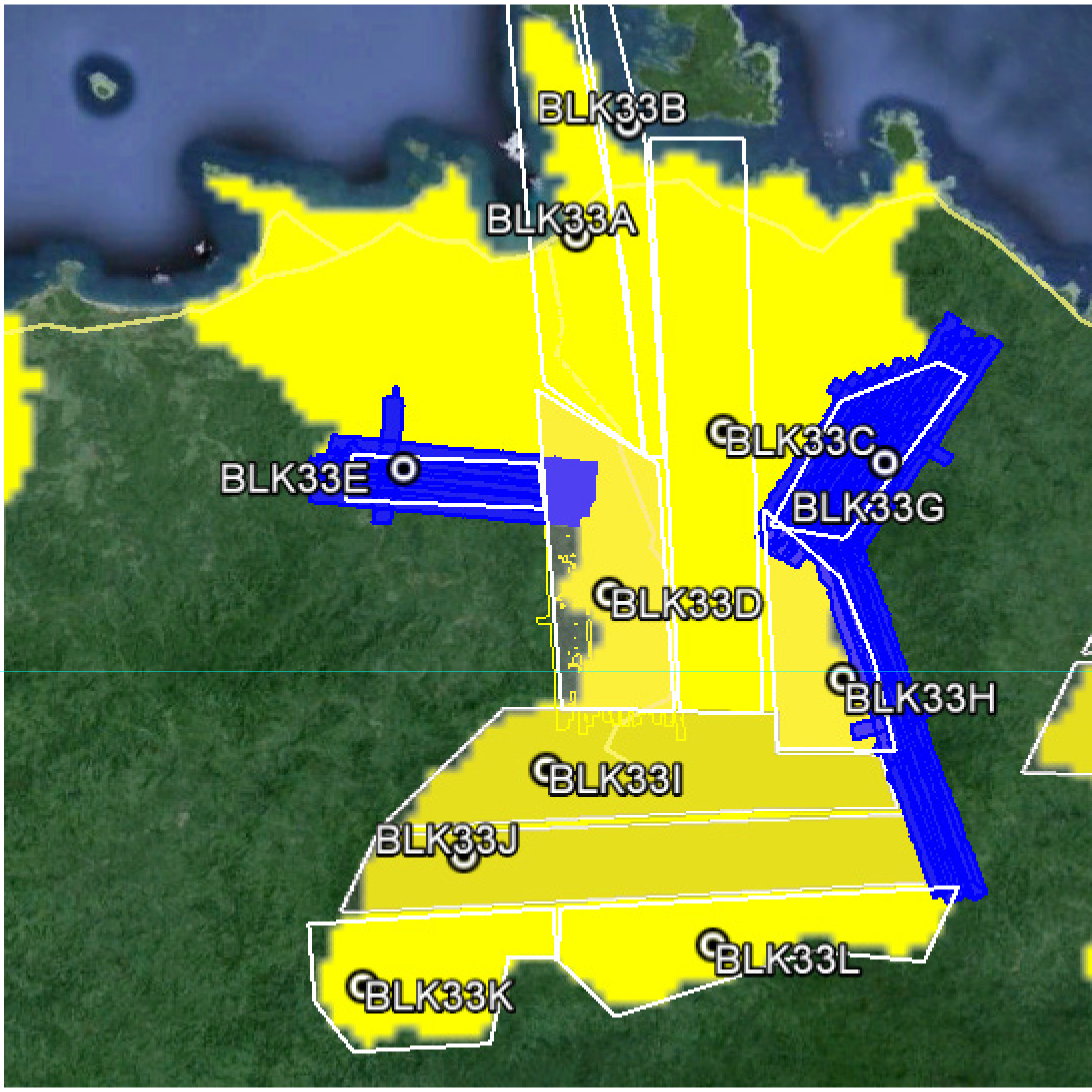
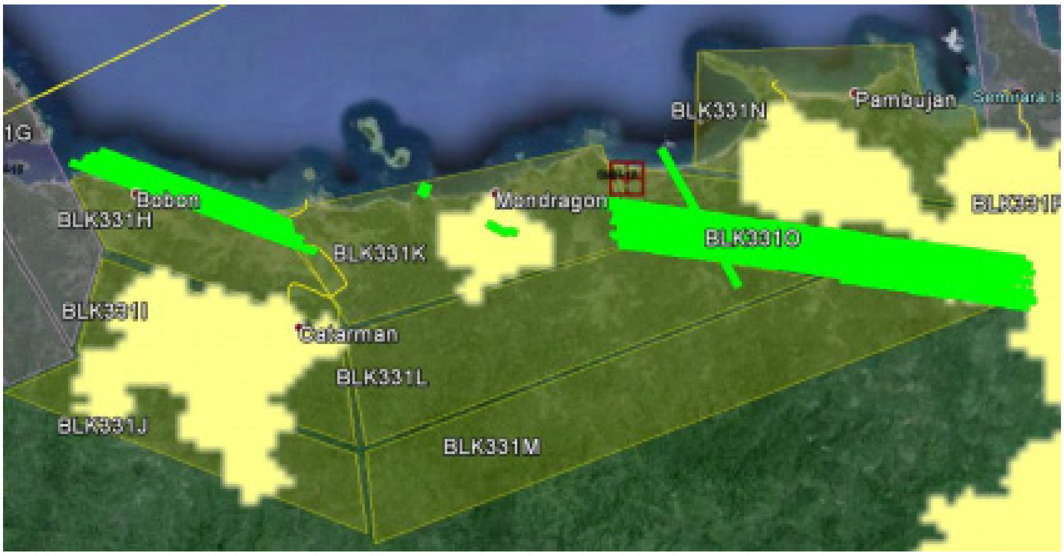


Figure A-7.1. Swath for Flight No. 3917G

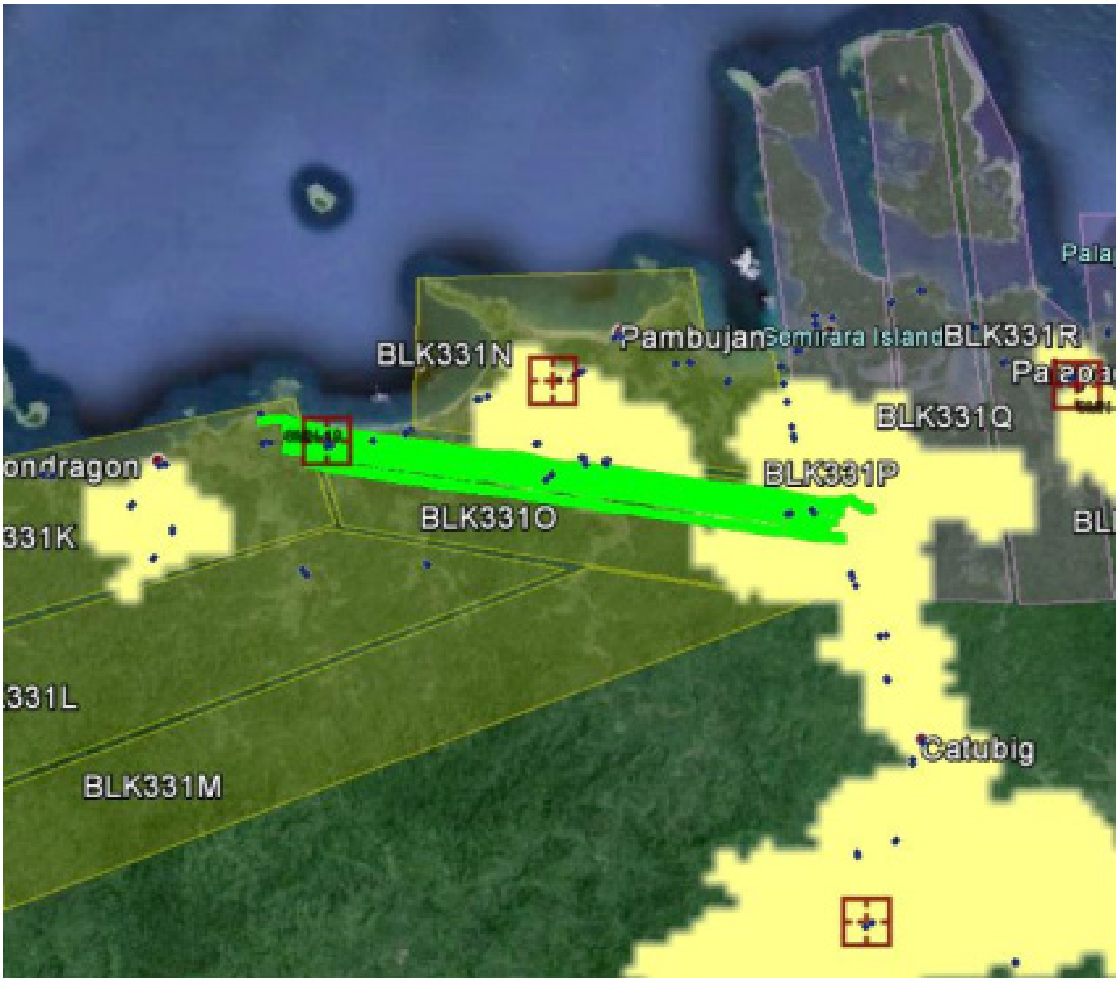
Flight No. : 7830AC



LINE#	ALT	PRF	FREQ	ANGLE	MP	DIV	RC	MPM	HDG	Plan File
46	673	50	50.00	18.00	OFF	NAR	ON	OFF	98.00	BLK331HON_MAR01.pln
46	684	50	50.00	18.00	OFF	NAR	ON	OFF	98.00	BLK331HON_MAR01.pln
45	672	50	50.00	18.00	OFF	NAR	ON	OFF	278.00	BLK331HON_MAR01.pln
44	669	50	50.00	18.00	OFF	NAR	ON	OFF	98.00	BLK331HON_MAR01.pln
47	673	50	50.00	18.00	OFF	NAR	ON	OFF	278.00	BLK331HON_MAR01.pln
43	675	50	50.00	18.00	OFF	NAR	ON	OFF	278.00	BLK331HON_MAR01.pln
44	669	50	50.00	18.00	OFF	NAR	ON	OFF	98.00	BLK331HON_MAR01.pln
42	669	50	50.00	18.00	OFF	NAR	ON	OFF	98.00	BLK331HON_MAR01.pln
41	672	50	50.00	18.00	OFF	NAR	ON	OFF	278.00	BLK331HON_MAR01.pln
40	669	50	50.00	18.00	OFF	NAR	ON	OFF	98.00	BLK331HON_MAR01.pln
39	671	50	50.00	18.00	OFF	NAR	ON	OFF	278.00	BLK331HON_MAR01.pln
38	670	50	50.00	18.00	OFF	NAR	ON	OFF	98.00	BLK331HON_MAR01.pln
37	672	50	50.00	18.00	OFF	NAR	ON	OFF	278.00	BLK331HON_MAR01.pln
37	671	50	50.00	18.00	OFF	NAR	ON	OFF	278.00	BLK331HON_MAR01.pln
21	673	50	50.00	18.00	OFF	NAR	ON	OFF	290.00	BLK331HON_MAR01.pln
22	672	50	50.00	18.00	OFF	NAR	ON	OFF	110.00	BLK331HON_MAR01.pln
23	673	50	50.00	18.00	OFF	NAR	ON	OFF	290.00	BLK331HON_MAR01.pln
24	670	50	50.00	18.00	OFF	NAR	ON	OFF	110.00	BLK331HON_MAR01.pln
25	673	50	50.00	18.00	OFF	NAR	ON	OFF	290.00	BLK331HON_MAR01.pln
26	662	50	50.00	18.00	OFF	NAR	ON	OFF	110.00	BLK331HON_MAR01.pln
27	662	50	50.00	18.00	OFF	NAR	ON	OFF	290.00	BLK331HON_MAR01.pln

Figure A-7.2. Swath for Flight No. 7830AC

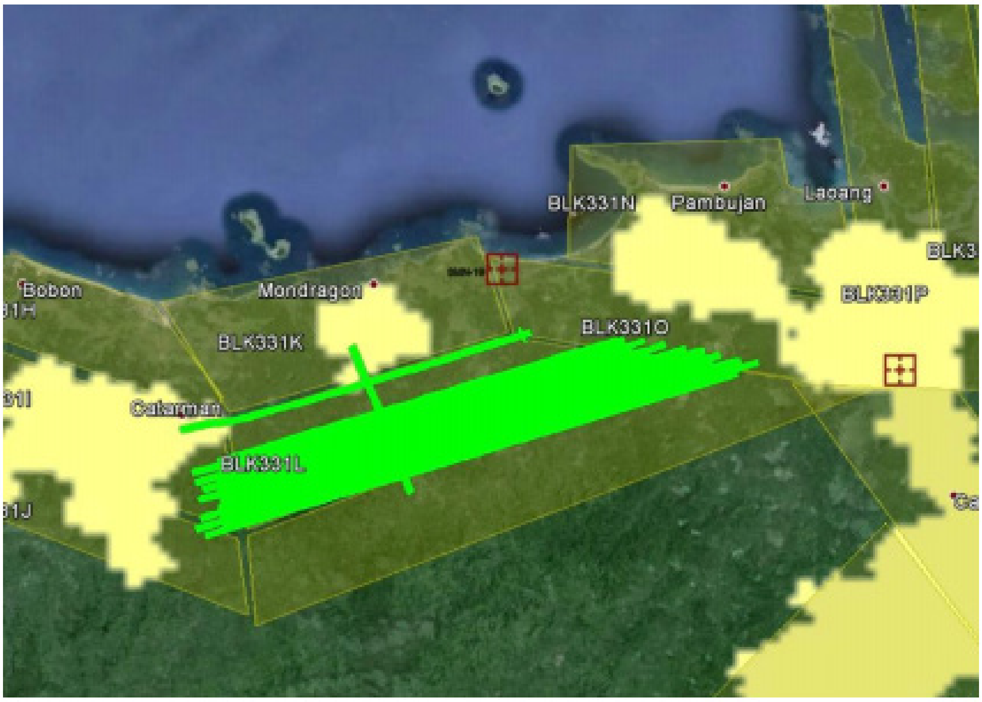
Flight No. : 7836AC



LINE#	ALT	PRF	FREQ	ANGLE	MP	DIV	RC	MPM	HDG	Plan File
9	670	50	50.00	18.00	OFF	NAR	ON	OFF	98.00	BLK331NO MAR 04.pln
8	565	50	50.00	18.00	OFF	NAR	ON	OFF	278.00	BLK331NO MAR 04.pln
7	564	50	50.00	18.00	OFF	NAR	ON	OFF	98.00	BLK331NO MAR 04.pln
6	570	50	50.00	18.00	OFF	NAR	ON	OFF	278.00	BLK331NO MAR 04.pln
5	566	50	50.00	18.00	OFF	NAR	ON	OFF	98.00	BLK331NO MAR 04.pln
4	567	50	50.00	18.00	OFF	NAR	ON	OFF	278.00	BLK331NO MAR 04.pln
3	565	50	50.00	18.00	OFF	NAR	ON	OFF	98.00	BLK331NO MAR 04.pln

Figure A-7.3. Swath for Flight No. 7836AC

Flight No. : 7846AC



LINE#	ALT	PRF	FREQ	ANGLE	MP	DIV	RC	MPM	HDG	Plan File
1	695	50	50.00	18.00	OFF	NAR	ON	OFF	73.00	BLK331L.pln
1	680	50	50.00	18.00	OFF	NAR	ON	OFF	73.00	BLK331L.pln
23	671	50	50.00	18.00	OFF	NAR	ON	OFF	73.00	BLK331L.pln
22	677	50	50.00	18.00	OFF	NAR	ON	OFF	253.00	BLK331L.pln
21	671	50	50.00	18.00	OFF	NAR	ON	OFF	73.00	BLK331L.pln
20	679	50	50.00	18.00	OFF	NAR	ON	OFF	253.00	BLK331L.pln
19	665	50	50.00	18.00	OFF	NAR	ON	OFF	73.00	BLK331L.pln
18	677	50	50.00	18.00	OFF	NAR	ON	OFF	253.00	BLK331L.pln
17	672	50	50.00	18.00	OFF	NAR	ON	OFF	253.00	BLK331L.pln
16	672	50	50.00	18.00	OFF	NAR	ON	OFF	253.00	BLK331L.pln
15	667	50	50.00	18.00	OFF	NAR	ON	OFF	73.00	BLK331L.pln
14	678	50	50.00	18.00	OFF	NAR	ON	OFF	253.00	BLK331L.pln
13	672	50	50.00	18.00	OFF	NAR	ON	OFF	253.00	BLK331L.pln
12	696	50	50.00	18.00	OFF	NAR	ON	OFF	73.00	BLK331L.pln
11	674	50	50.00	18.00	OFF	NAR	ON	OFF	73.00	BLK331L.pln
10	686	50	50.00	18.00	OFF	NAR	ON	OFF	253.00	BLK331L.pln
9	670	50	50.00	18.00	OFF	NAR	ON	OFF	73.00	BLK331L.pln
8	679	50	50.00	18.00	OFF	NAR	ON	OFF	253.00	BLK331L.pln

Figure A-7.4. Swath for Flight No. 7846AC

Flight No. :	8154AC
Area:	BLK N & O
Total Area:	22.194 km^2
Mission Name:	3BLK331NO222A
Altitude:	500 m
SCF:	45 Hz
Lidar FOV:	20deg

Figure A-7.5. Swath for Flight No. 8154AC

Flight No. :	8156AC
Area:	BLK L & N
Total Area:	81.745 km^2
Mission Name:	3BLK331LNS223A
Altitude:	500 m
SCF:	45 Hz
Lidar FOV:	20deg

Figure A-7.6. Swath for Flight No. 8156AC

Flight No. :	8157AC
Area:	BLK 331N
Total Area:	63.5 km^2
Mission Name:	3BLK331NS223B
Altitude:	500 m
SCF:	45 Hz
Lidar FOV:	20deg3.25

Figure A-7.7. Swath for Flight No. 8157AC

Flight No. :	8159AC
Area:	BLK N & P
Total Area:	33.81 km^2
Mission Name:	3BLK331NSPS224B
Altitude:	500 m
SCF:	45 Hz
Lidar FOV:	20deg

Figure A-7.8. Swath for Flight No. 8159AC

Flight No. : 8159AC
Area: BLK N & P
Total Area: 33.81 km^2

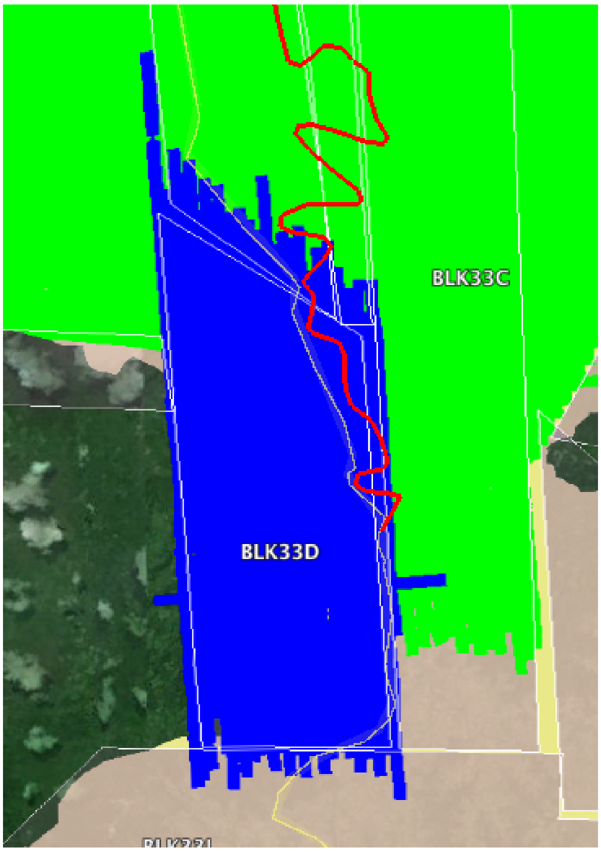


Figure A-7.9. Swath for Flight No. 8159AC

Annex 8. Mission Summary Reports

Flight Area	**Catarman**
Mission Name	**Blk331N**
Inclusive Flights	8157AC,8156AC
Range data size	25.4 GB
Base data size	67.7 MB
POS	386 MB
Image	NA
Transfer date	September 8, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.1653
RMSE for East Position (<4.0 cm)	1.2712
RMSE for Down Position (<8.0 cm)	3.085
Boresight correction stdev (<0.001deg)	0.001879
IMU attitude correction stdev (<0.001deg)	0.003677
GPS position stdev (<0.01m)	0.0030
Minimum % overlap (>25)	35.78%
Ave point cloud density per sq.m. (>2.0)	2.20
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	150
Maximum Height	164.21
Minimum Height	58.70
Classification (# of points)	
Ground	36,546,278
Low vegetation	39,124,561
Medium vegetation	75,292,893
High vegetation	20,120,535
Building	907,283
Orthophoto	None
Processed by	Engr. Regis Guhiting, Engr. Melanie Hingpit, Engr. Ma. AilynOlanda

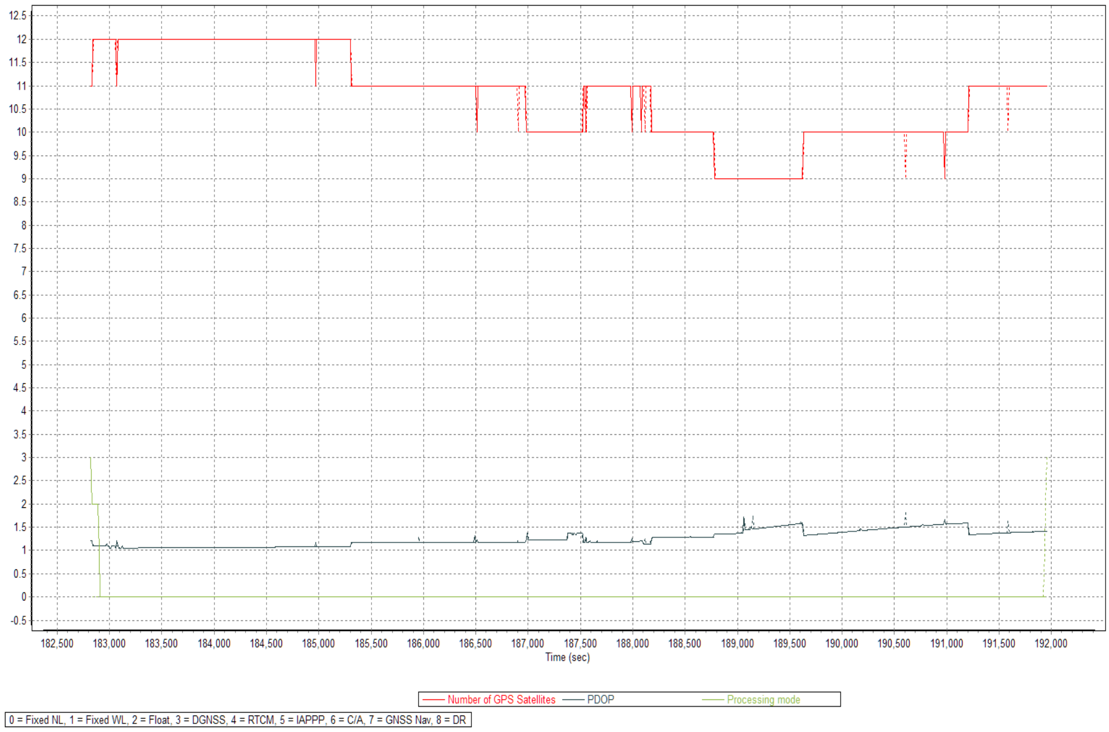


Figure 1.1.1. Solution Status

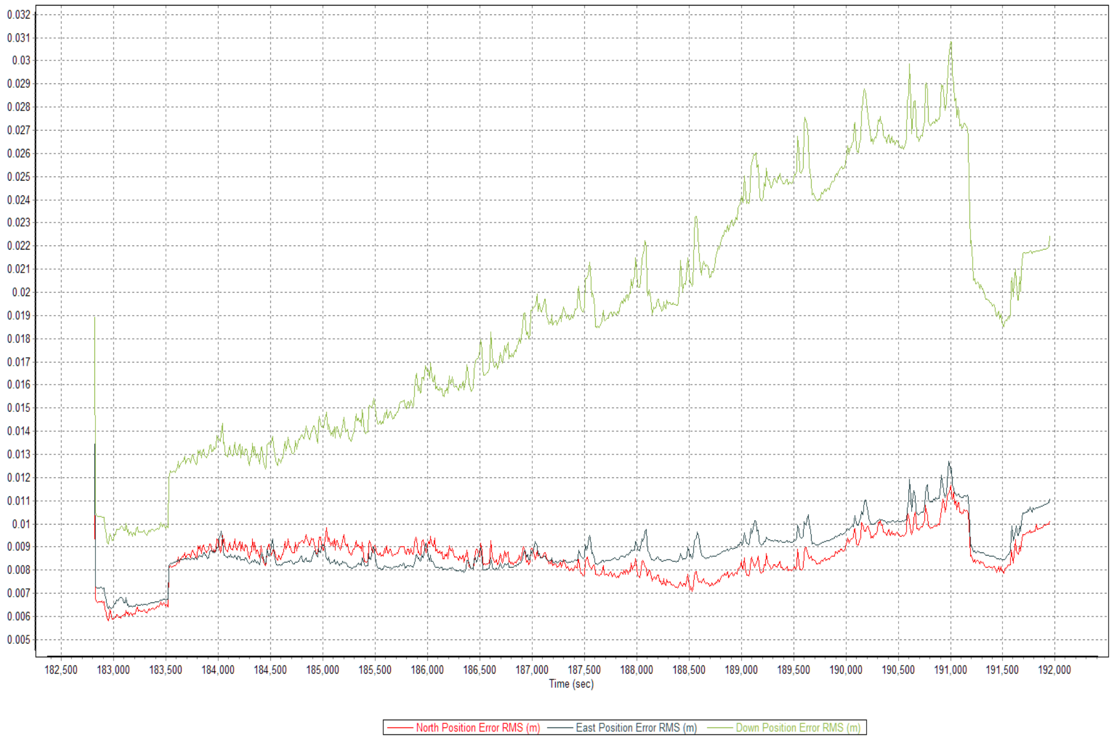


Figure 1.1.2. Smoothed Performance Metric Parameters

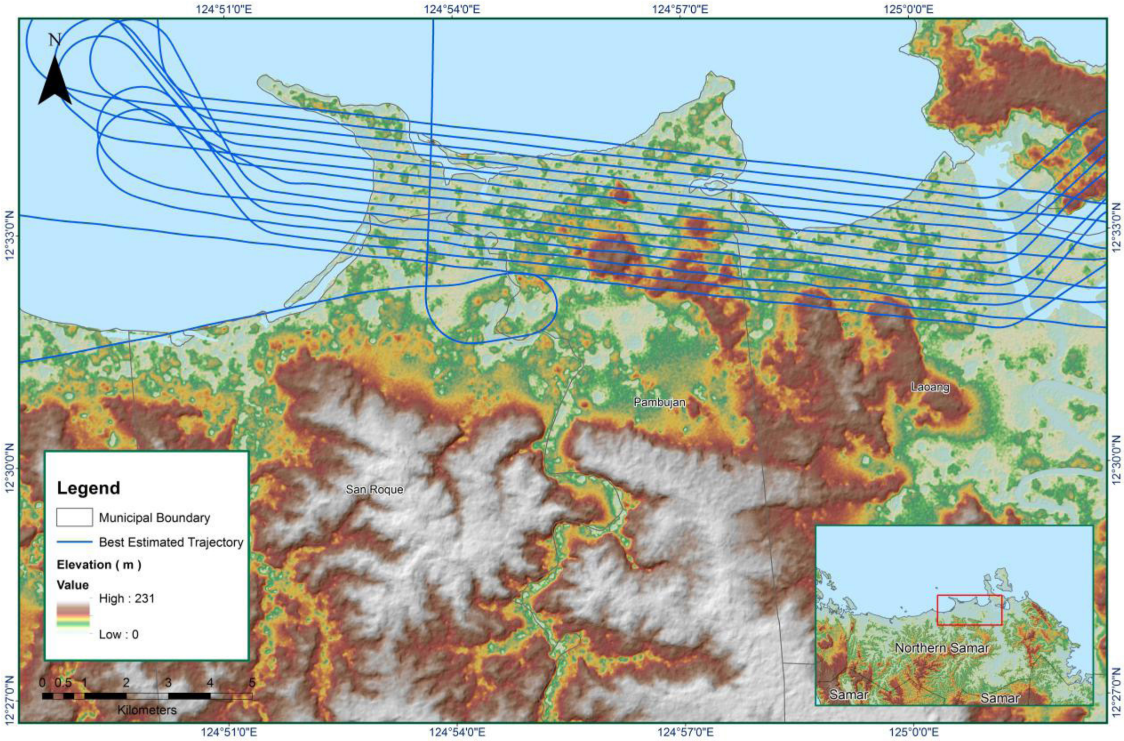


Figure 1.1.3. Best Estimated Trajectory

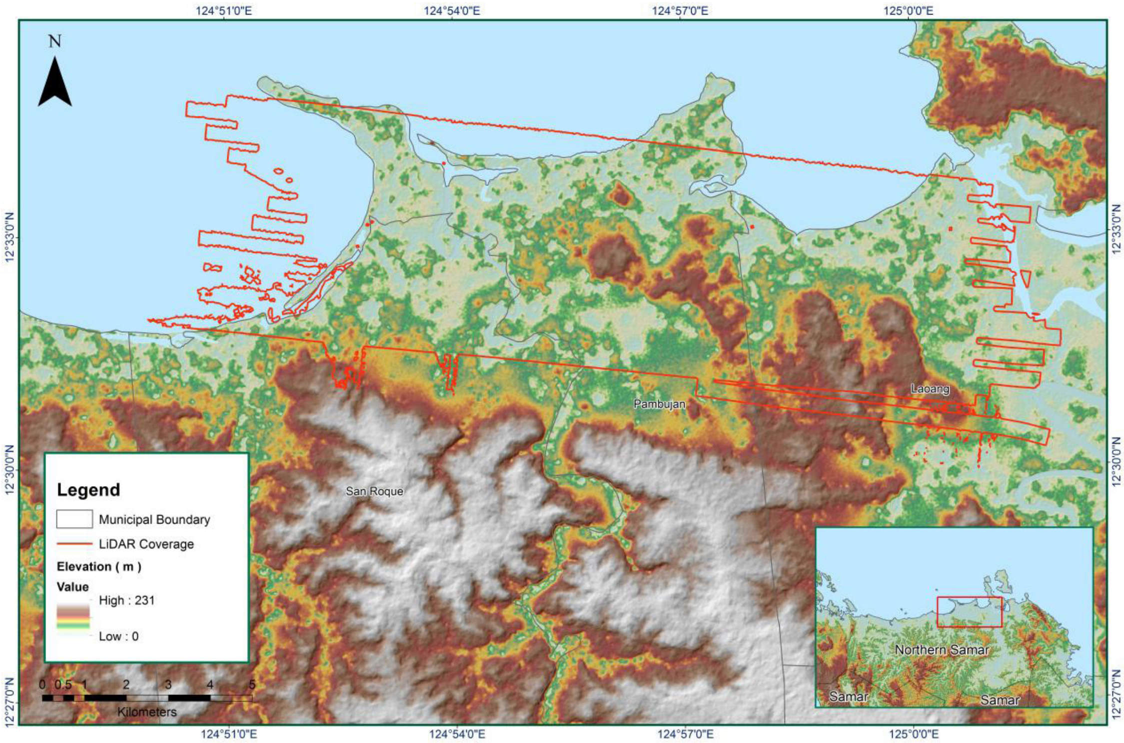


Figure 1.1.4. Coverage of LiDAR data

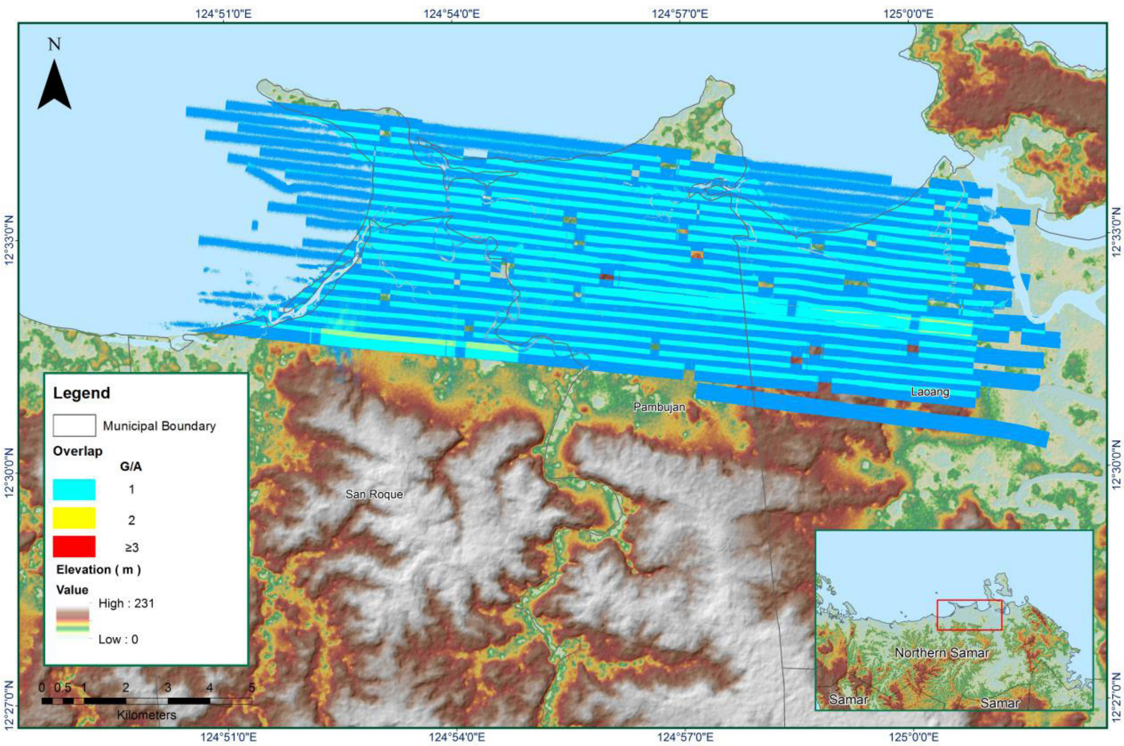


Figure 1.1.5. Image of data overlap

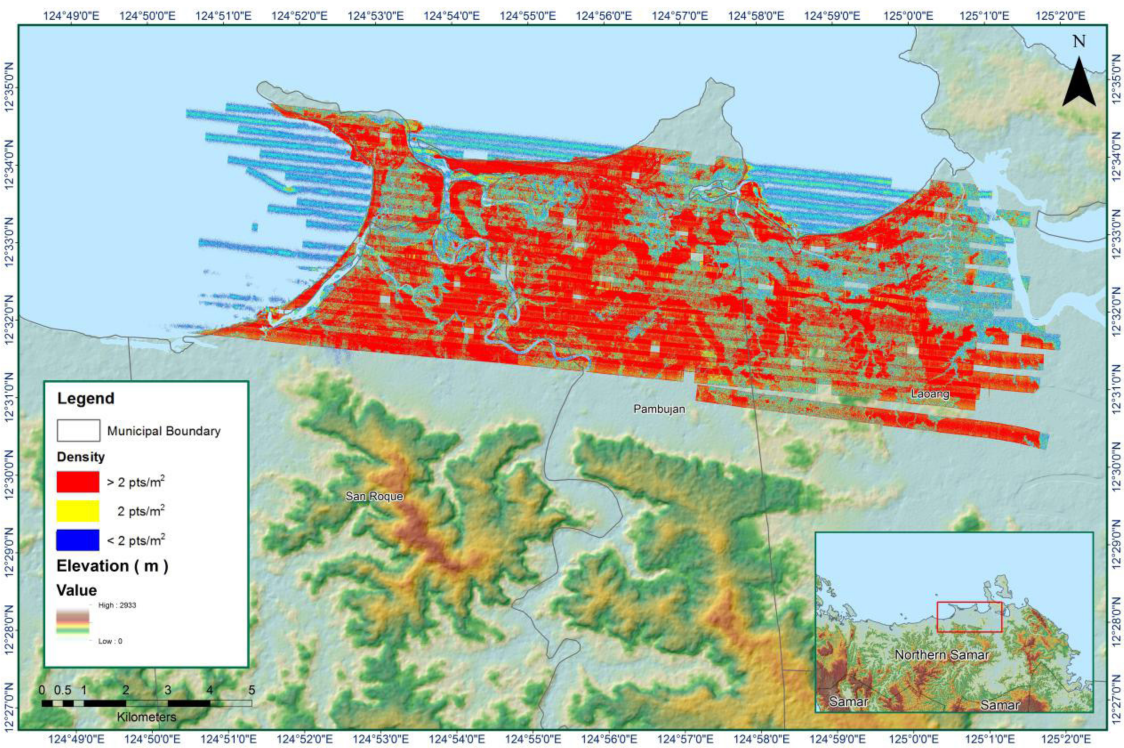


Figure 1.1.6. Density Map of merged LiDAR data

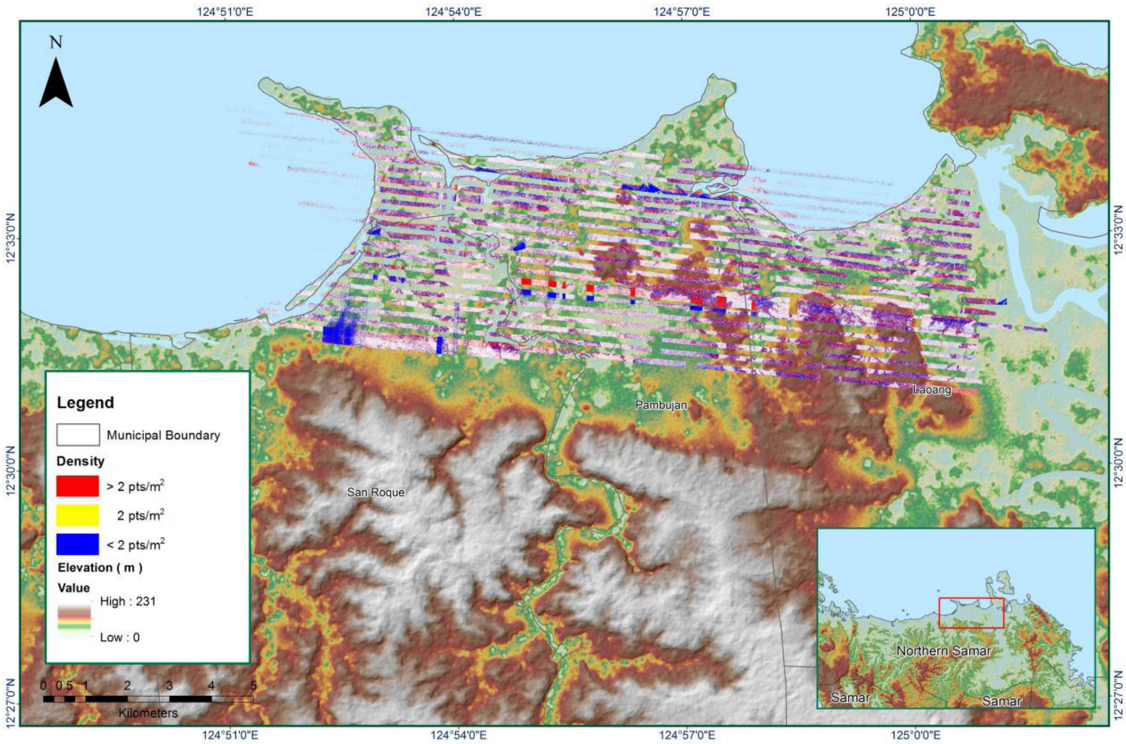


Figure 1.1.7. Elevation Difference Between flight lines

Flight Area	Catarman
Mission Name	**Blk331O**
Inclusive Flights	7830AC, 7836AC
Range data size	16.92 GB
POS	348 MB
Image	na
Transfer date	July 3, 2015
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)	1.36
RMSE for Down Position (<8.0 cm)	3.2
Boresight correction stdev (<0.001deg)	0.000468
IMU attitude correction stdev (<0.001deg)	0.001769
GPS position stdev (<0.01m)	0.0036
Minimum % overlap (>25)	38.89
Ave point cloud density per sq.m. (>2.0)	2.89
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	146
Maximum Height	318.23 m
Minimum Height	55.58 m
Classification (# of points)	
Ground	97,621,027
Low vegetation	44,030,503
Medium vegetation	38,753,556
High vegetation	33,405,153
Building	2,661
Orthophoto	No
Processed by	Engr. Irish Cortez, Engr. Mark Joshua Salvacion, Engr.Krisha Marie Bautista

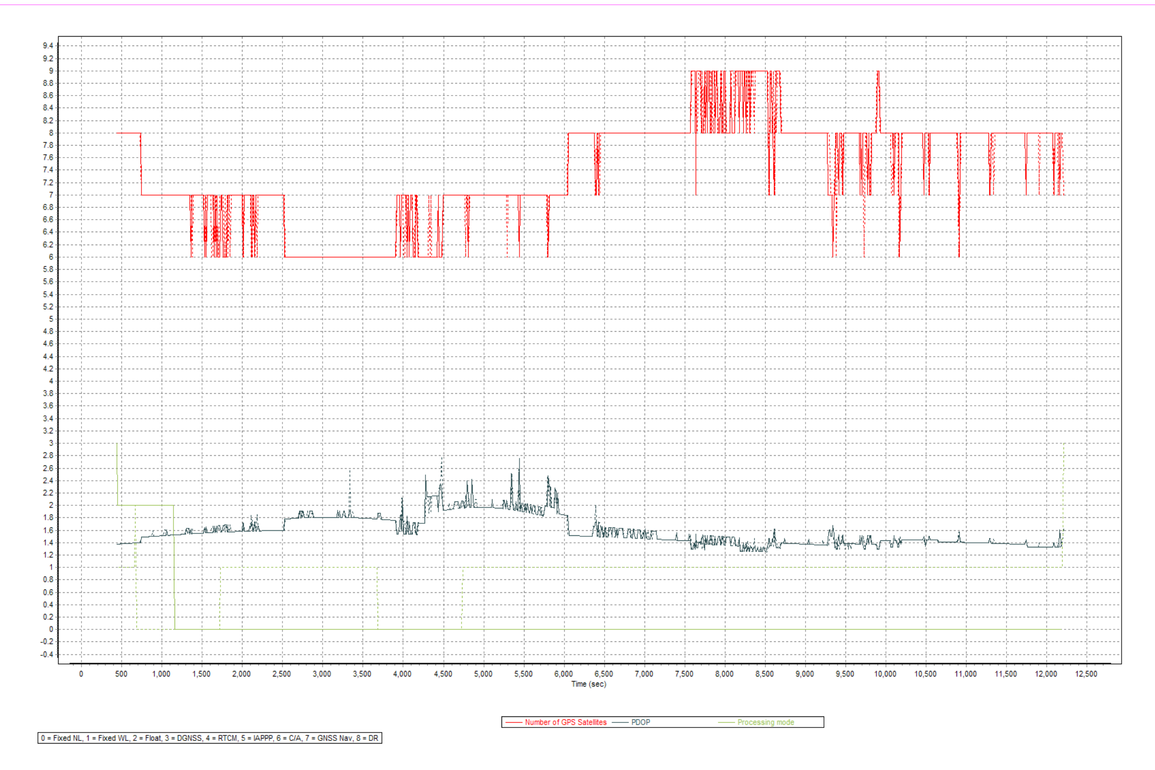


Figure 1.2.1 Solution Status

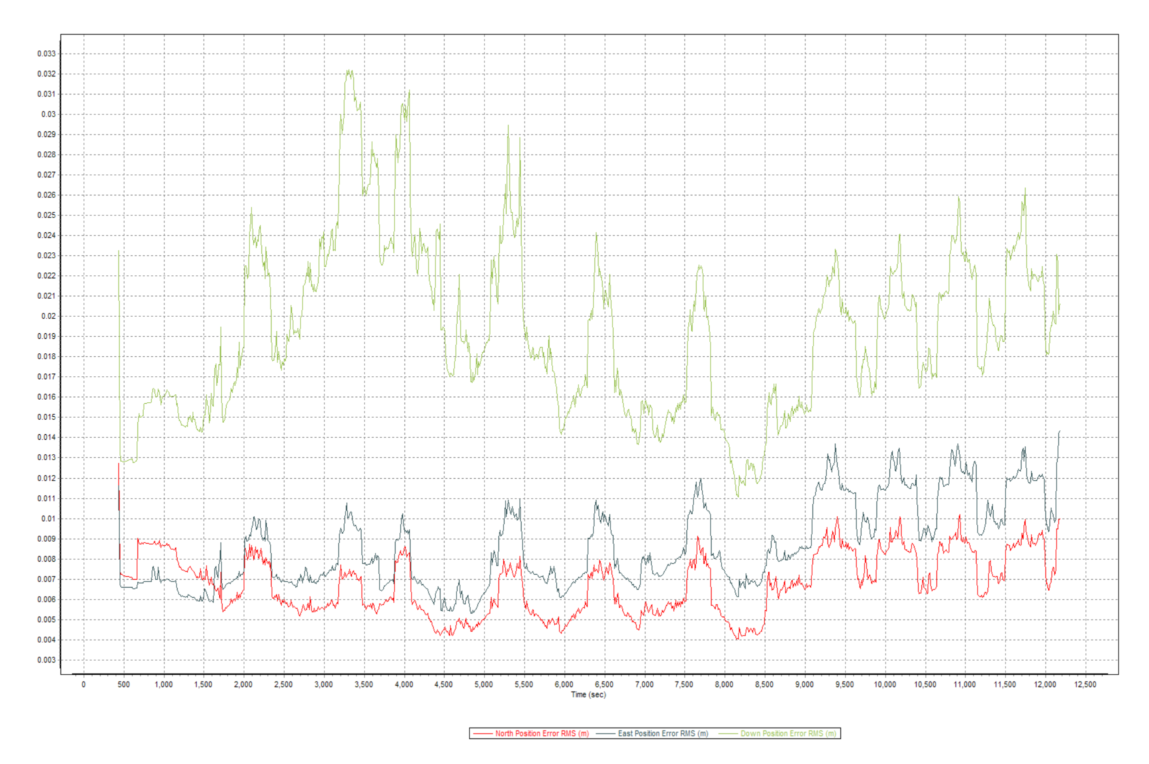


Figure 1.2.2 Smoothed Performance Metric Parameters

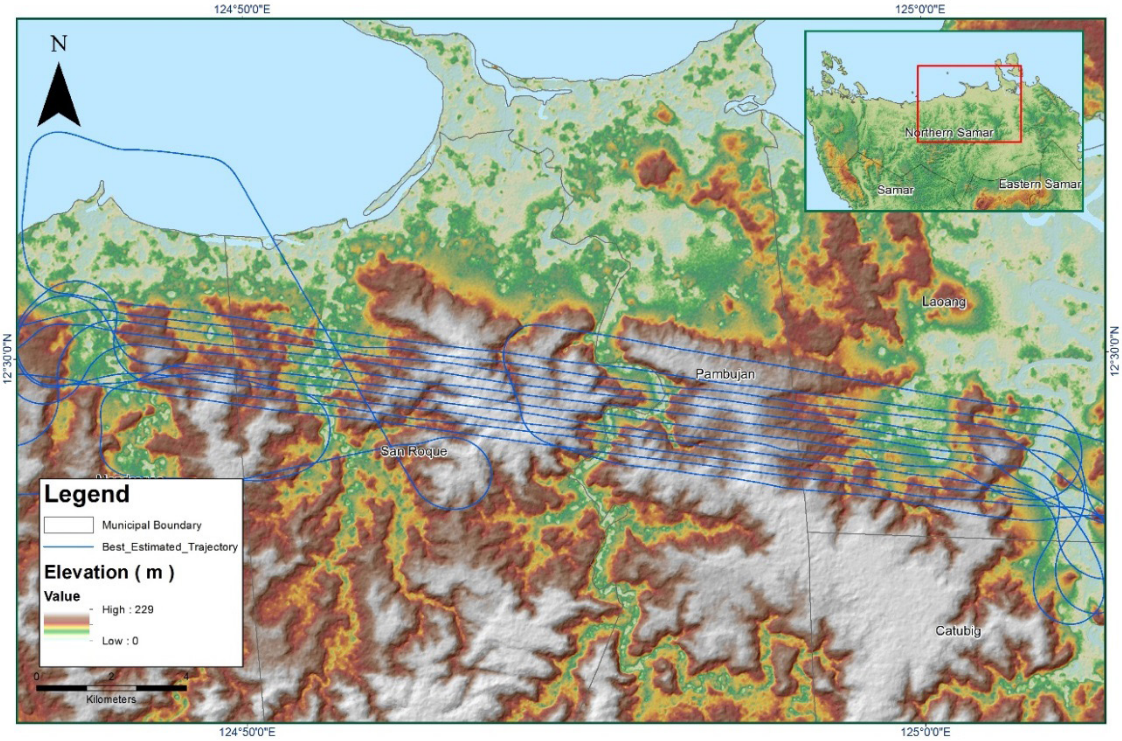


Figure 1.2.3 Best Estimated Trajectory

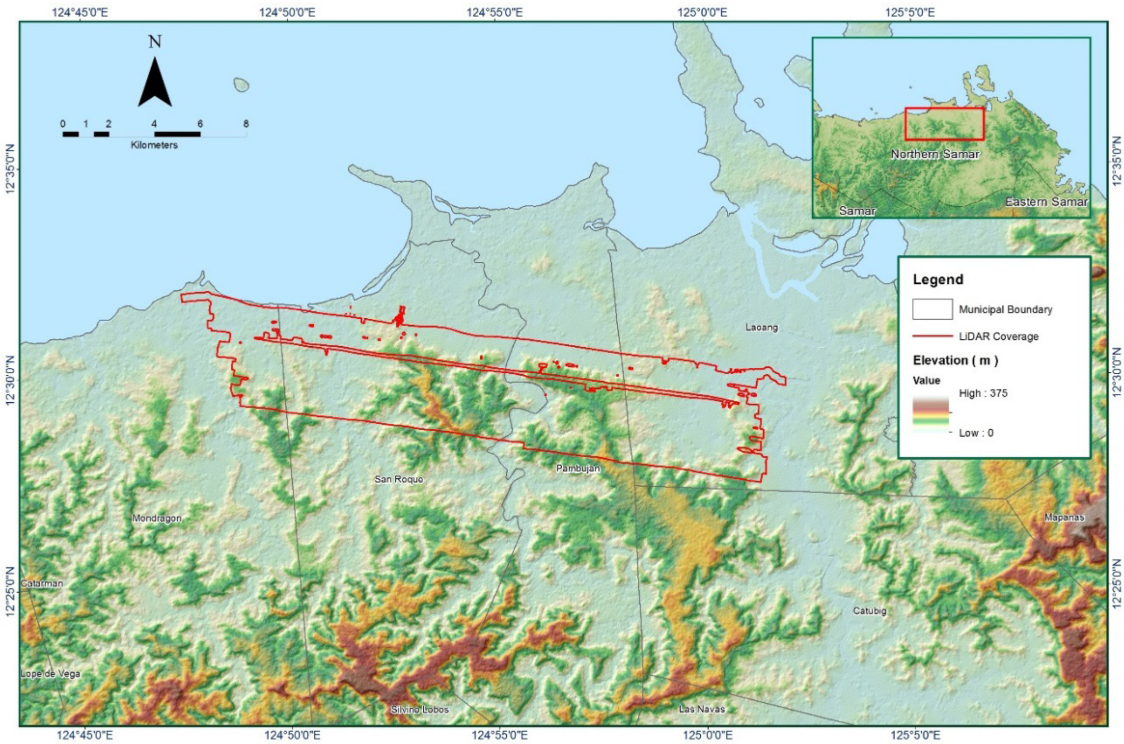


Figure 1.2.4 Coverage of LiDAR data

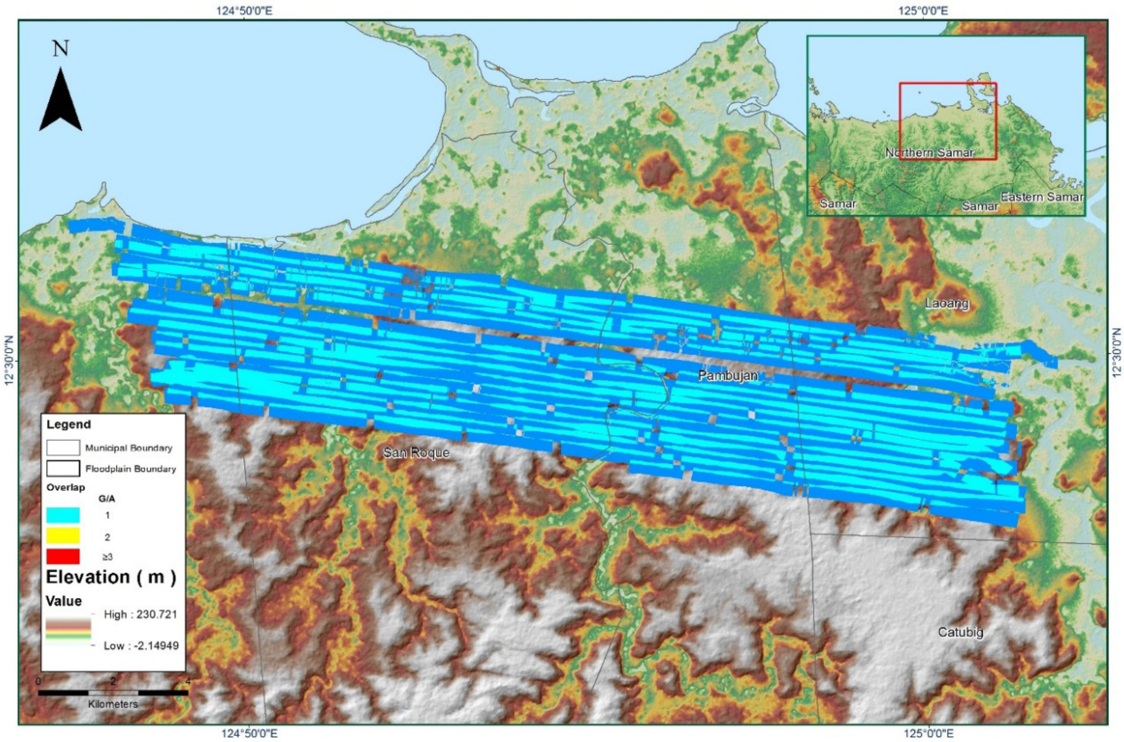


Figure 1.2.5 Image of data overlap

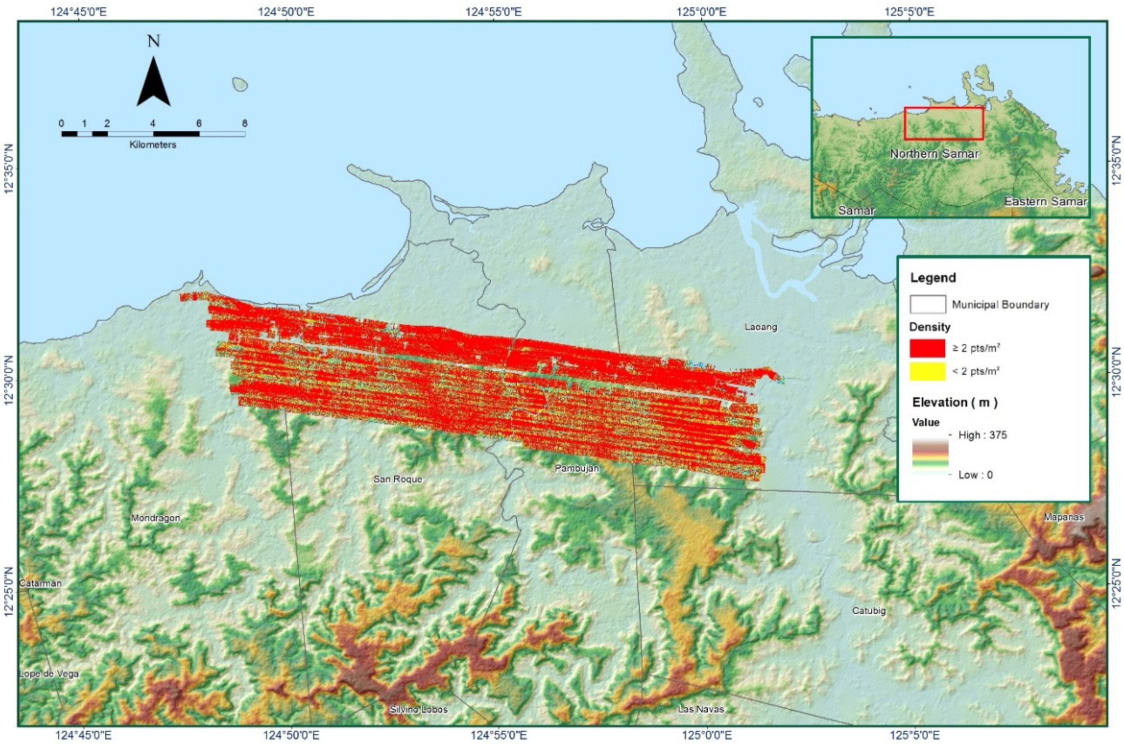


Figure 1.2.6 Density map of merged LiDAR data

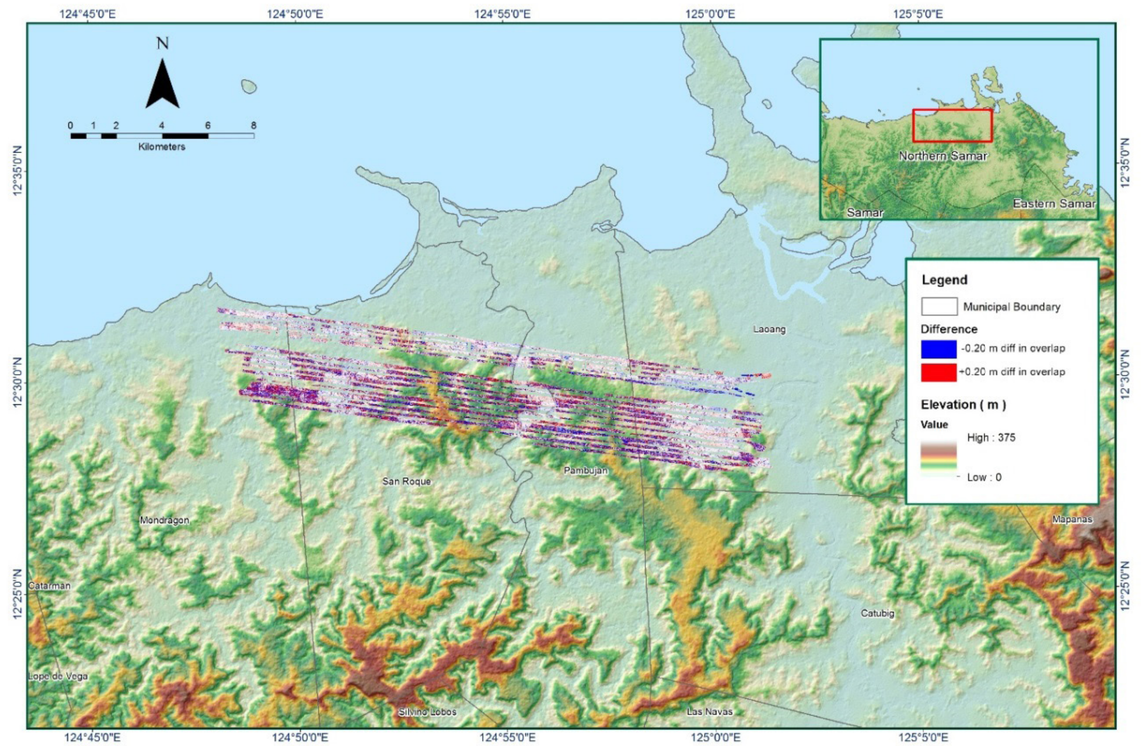


Figure 1.2.7 *Elevation difference between flight lines*

Flight Area	Catarman
Mission Name	**Blk331O_supplement**
Inclusive Flights	8154AC
Range data size	9.78 GB
Base data size	27.1 MB
POS	185 MB
Image	N/A
Transfer date	September 8, 2015
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)	0.9612
RMSE for East Position (<4.0 cm)	1.4965
RMSE for Down Position (<8.0 cm)	3.5715
Boresight correction stdev (<0.001deg)	0.000683
IMU attitude correction stdev (<0.001deg)	0.002528
GPS position stdev (<0.01m)	0.0034
Minimum % overlap (>25)	37.42%
Ave point cloud density per sq.m. (>2.0)	2.64
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	93
Maximum Height	253.49
Minimum Height	52.21
Classification (# of points)	
Ground	51,112,338
Low vegetation	29,763,575
Medium vegetation	29,143,624
High vegetation	5,682,557
Building	-
Orthophoto	None
Processed by	Engr. Irish Cortez, Engr. Mark Joshua Salvacion, Kathryn Claudine Zarate

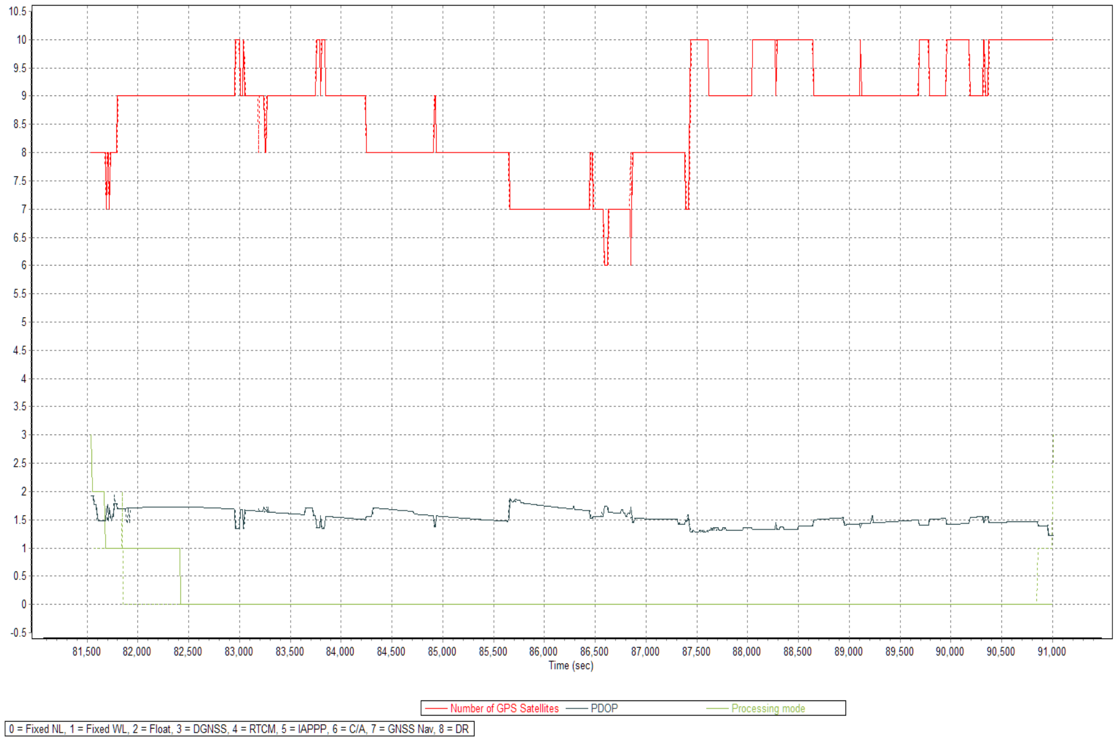


Figure 1.3.1. Solution Status

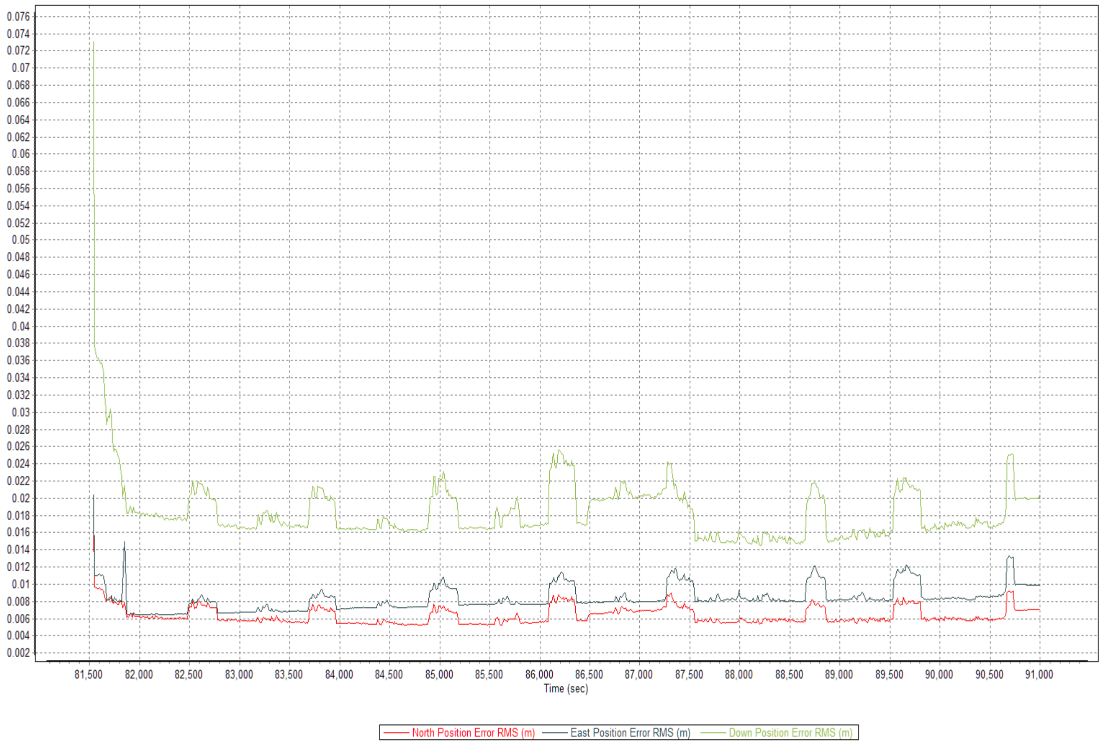


Figure 1.3.2. Smoothed Performance Metric Parameters

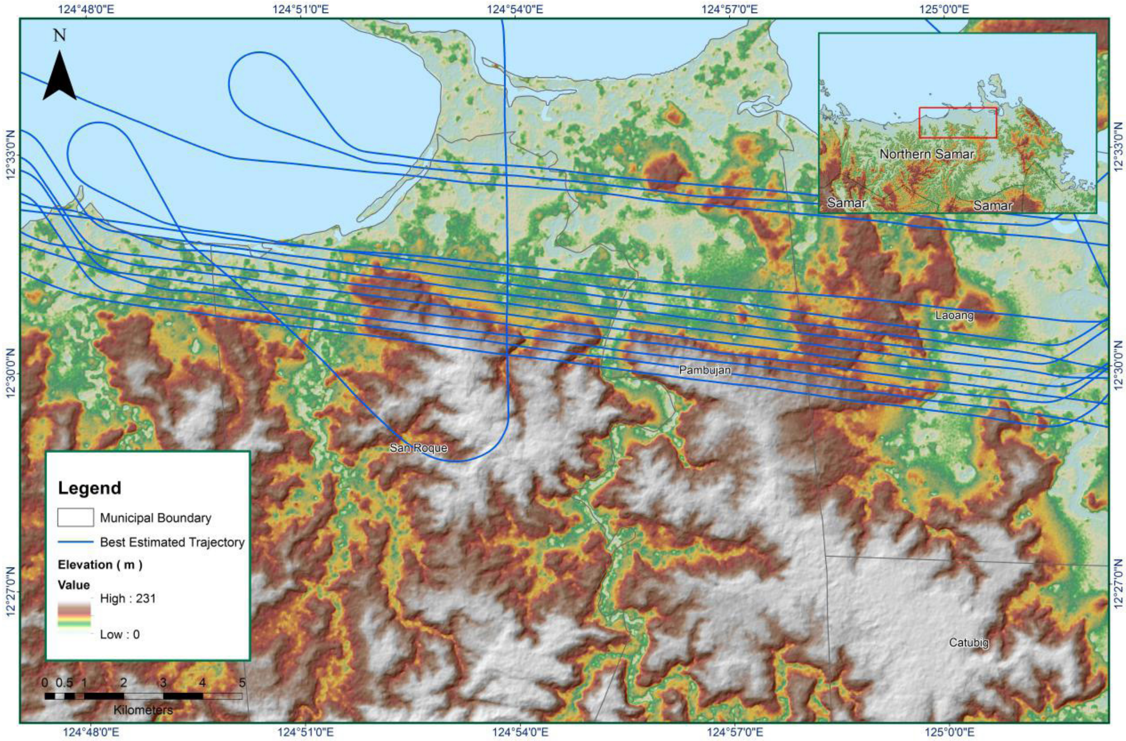


Figure 1.3.3. Best Estimated Trajectory

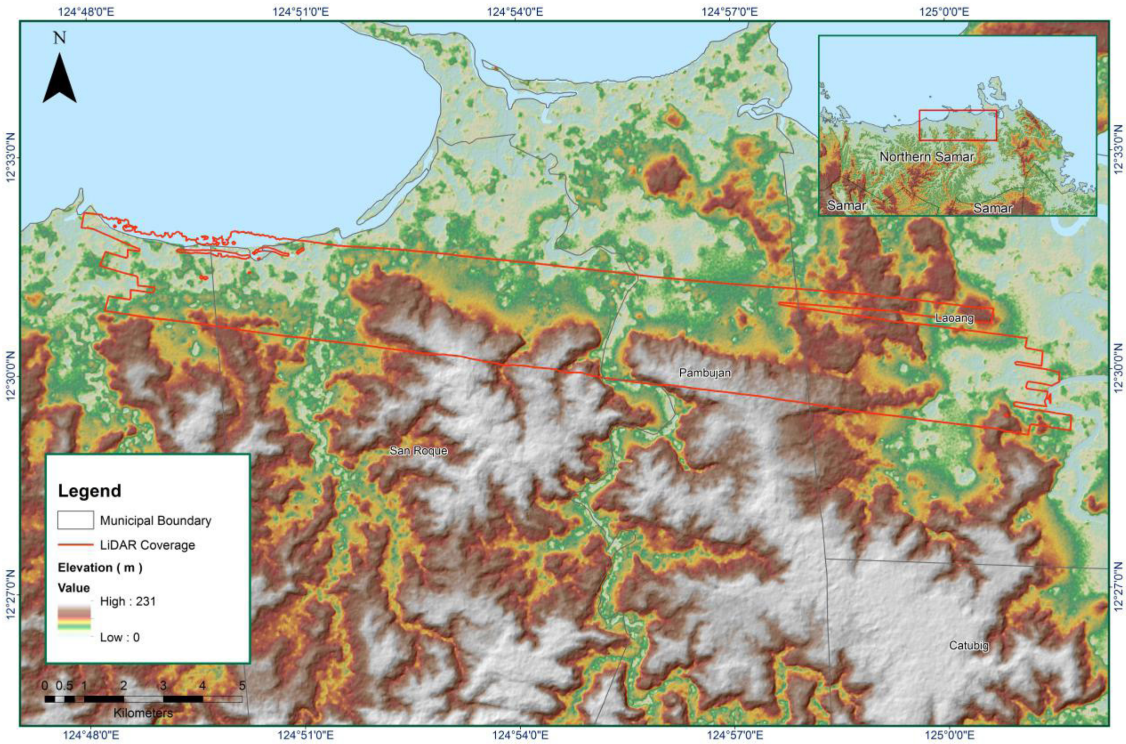


Figure 1.3.4. Coverage of LiDAR data

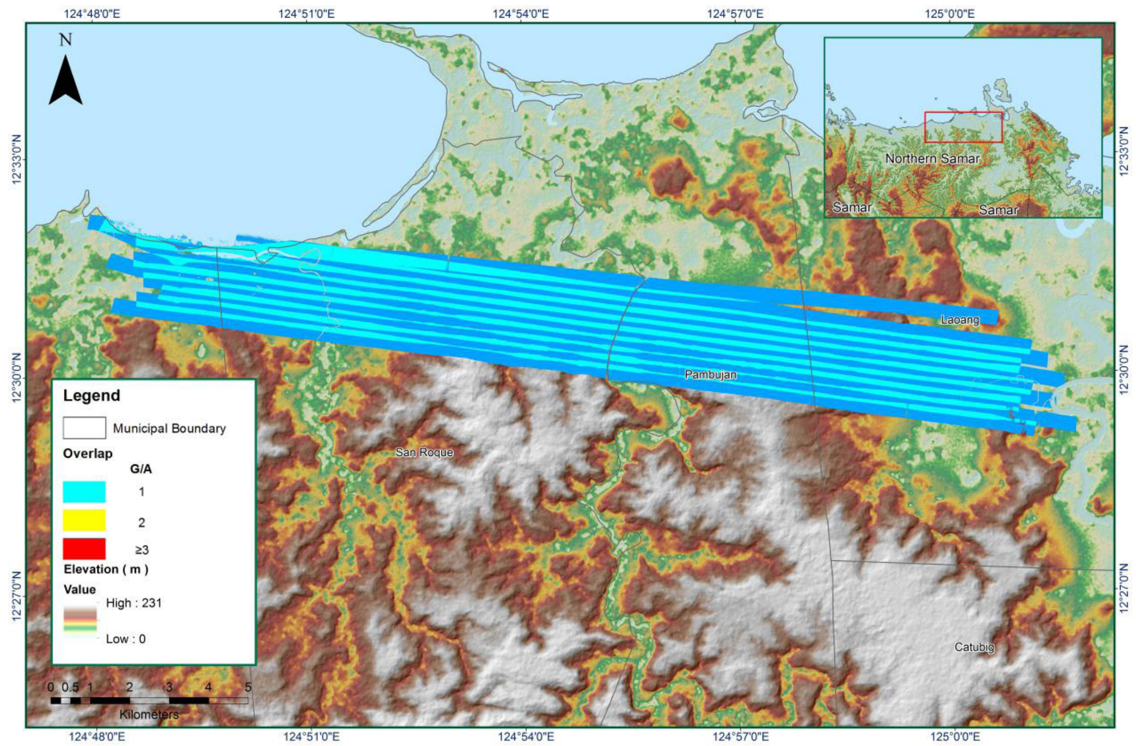


Figure 1.3.5. Image of data overlap

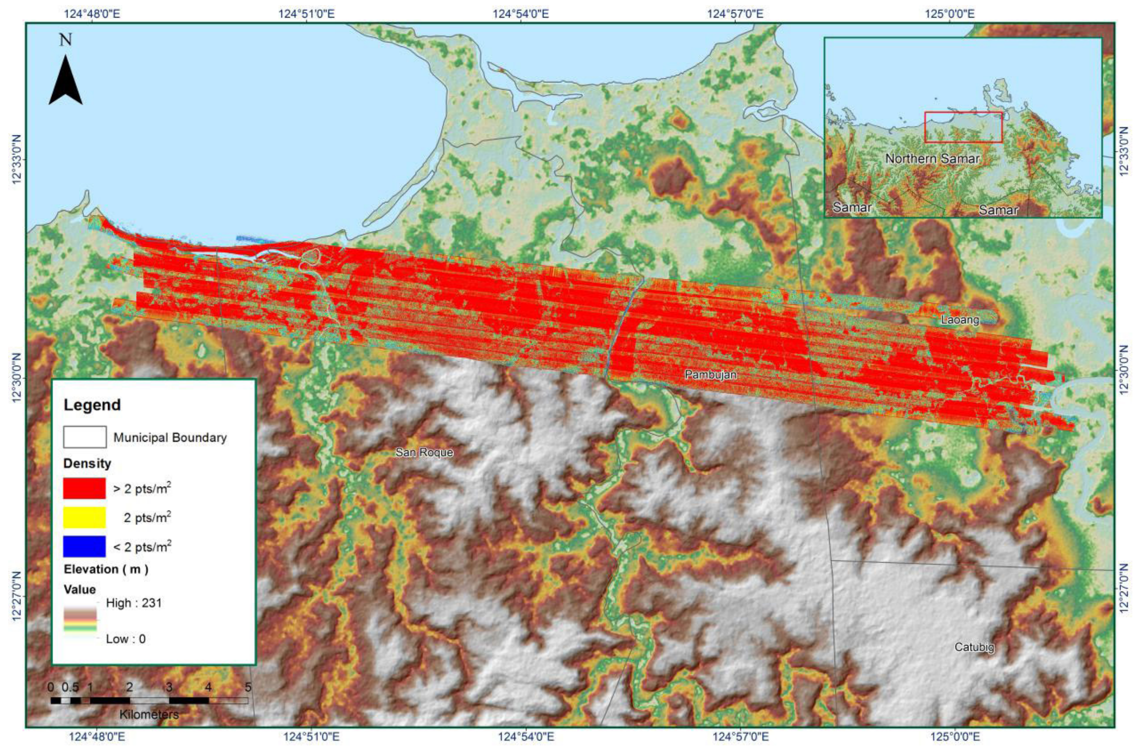


Figure 1.3.6. Density Map of merged LiDAR data

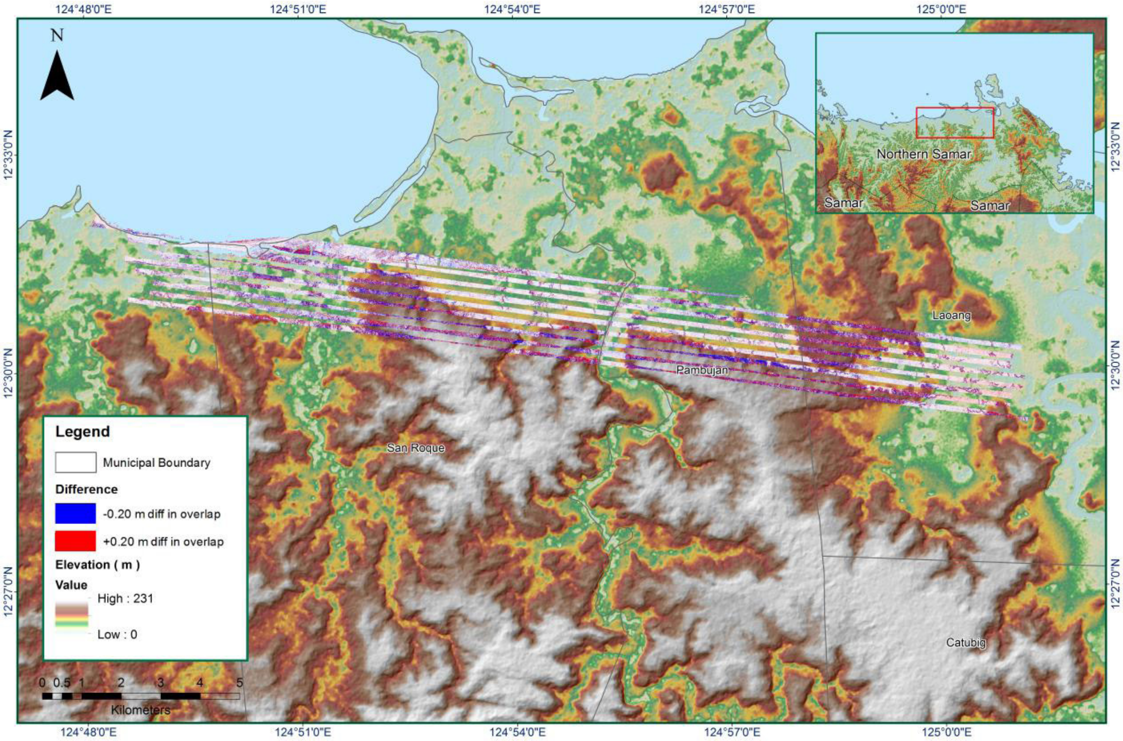


Figure 1.3.7. Elevation Difference Between flight lines

Flight Area	Catarman

Mission Name	**Blk331L**
Inclusive Flights	7846AC
Range data size	14.9 GB
POS	225 MB
Image	na
Transfer date	July 3, 2015
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)	1.04
RMSE for East Position (<4.0 cm)	1.0
RMSE for Down Position (<8.0 cm)	3.0
Boresight correction stdev (<0.001deg)	0.000404
IMU attitude correction stdev (<0.001deg)	0.001306
GPS position stdev (<0.01m)	0.0031
Minimum % overlap (>25)	40.05
Ave point cloud density per sq.m. (>2.0)	2.95
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	206
Maximum Height	531.87 m
Minimum Height	41.99 m
Classification (# of points)	
Ground	68,426,849
Low vegetation	24,906,844
Medium vegetation	66,893,807
High vegetation	201,192,687
Building	1,902,909
Orthophoto	No
Processed by	Engr. Irish Cortez, Engr. Melanie Hingpit, Engr. Melissa Fernandez

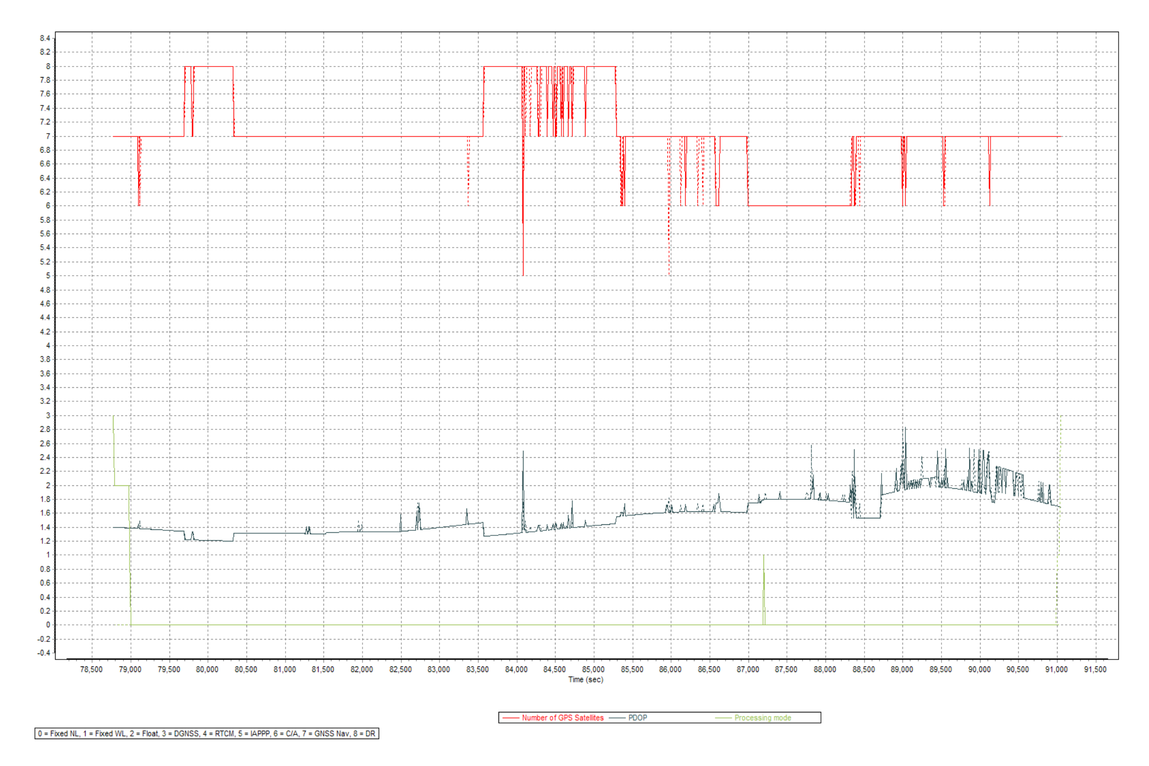


Figure 1.4.1 Solution Status

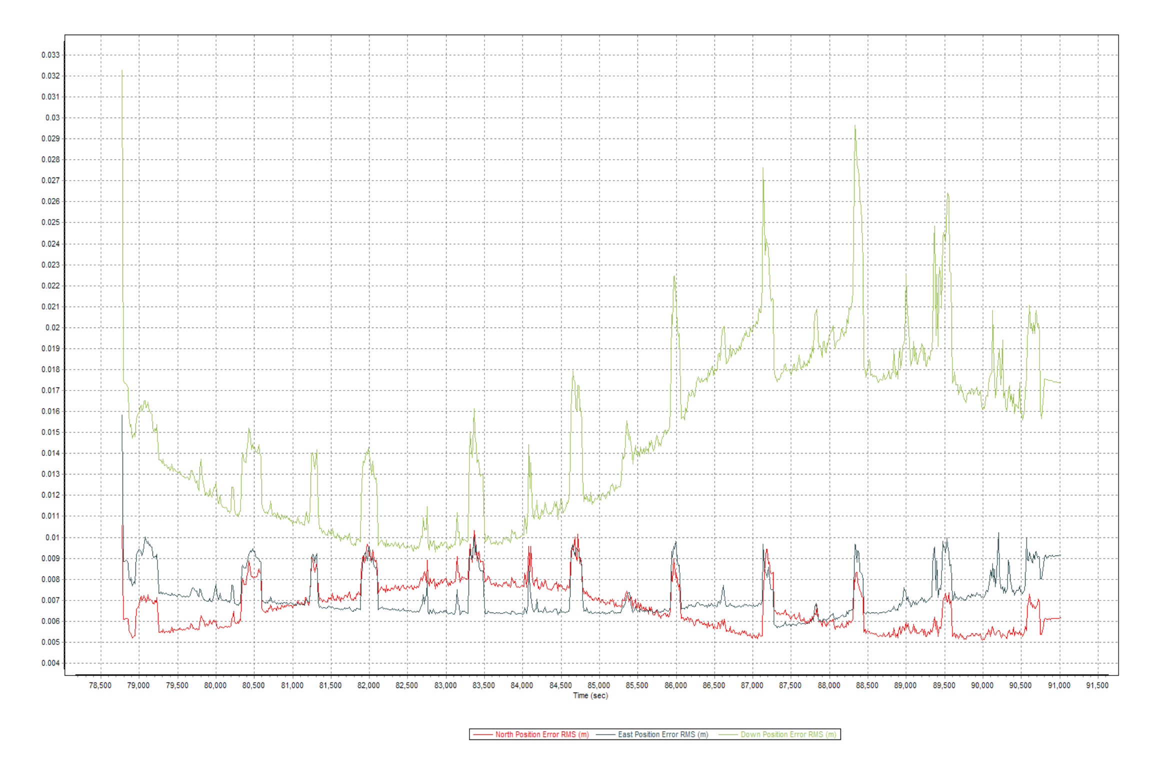


Figure 1.4.2 Smoothed Performance Metric Parameters

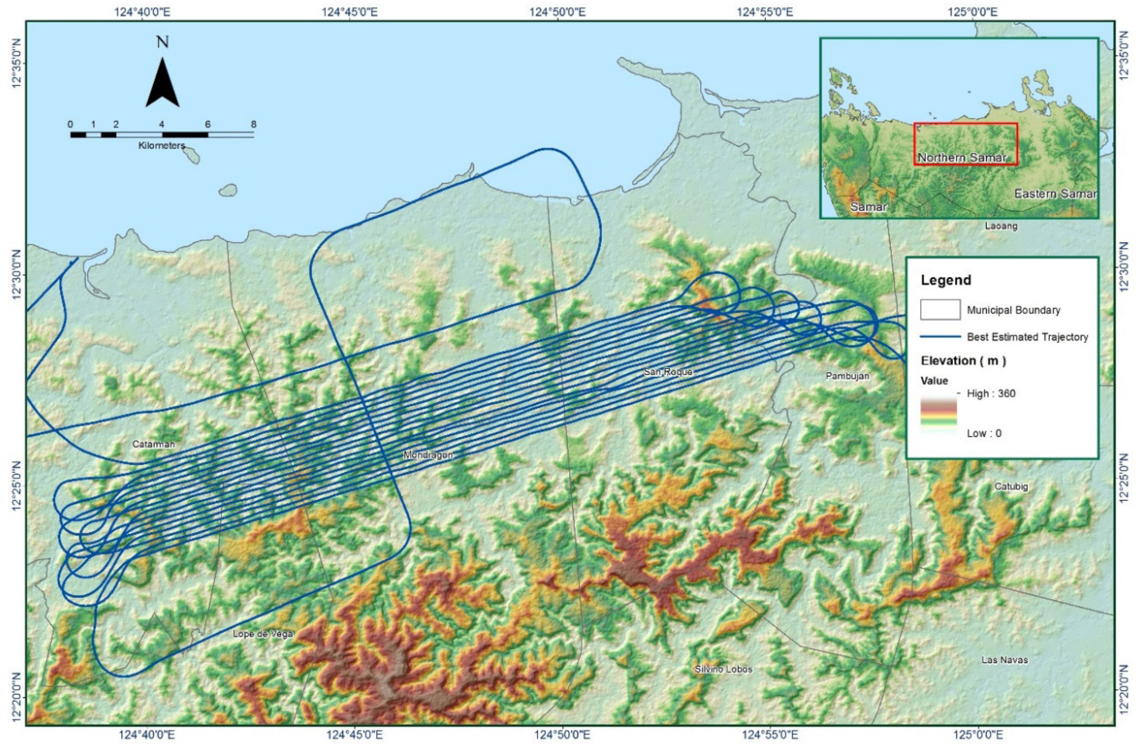


Figure 1.4.3 Best Estimated Trajectory

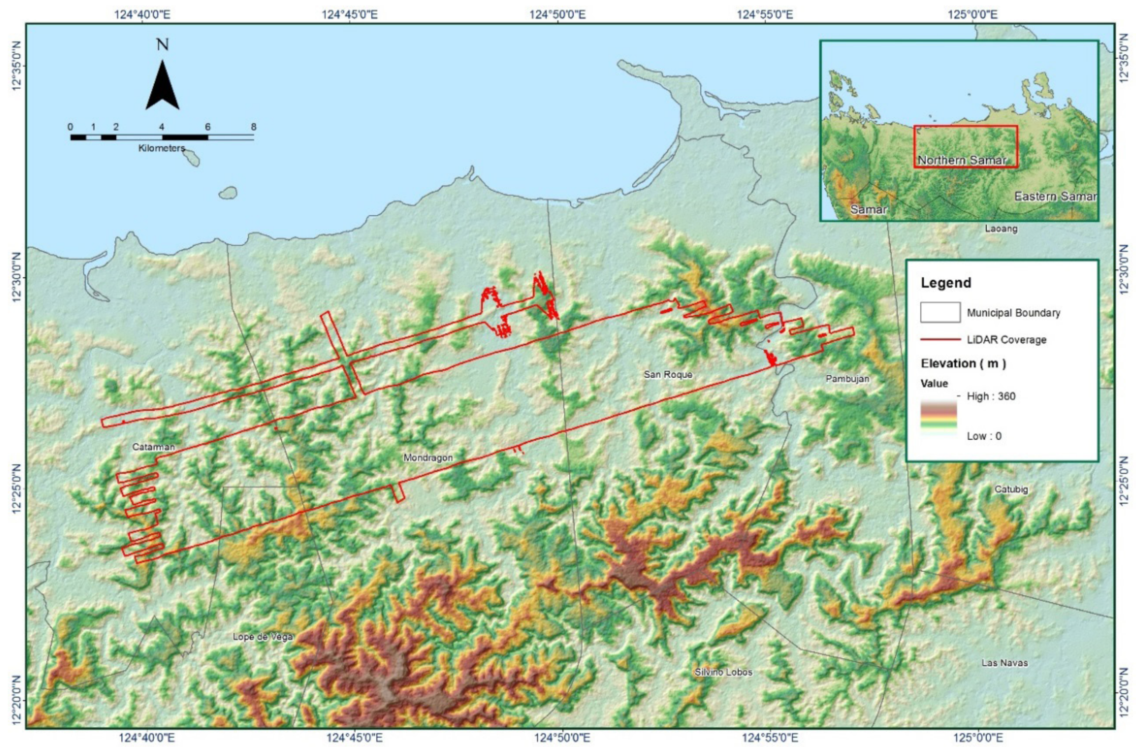


Figure 1.4.4 Coverage of LiDAR data

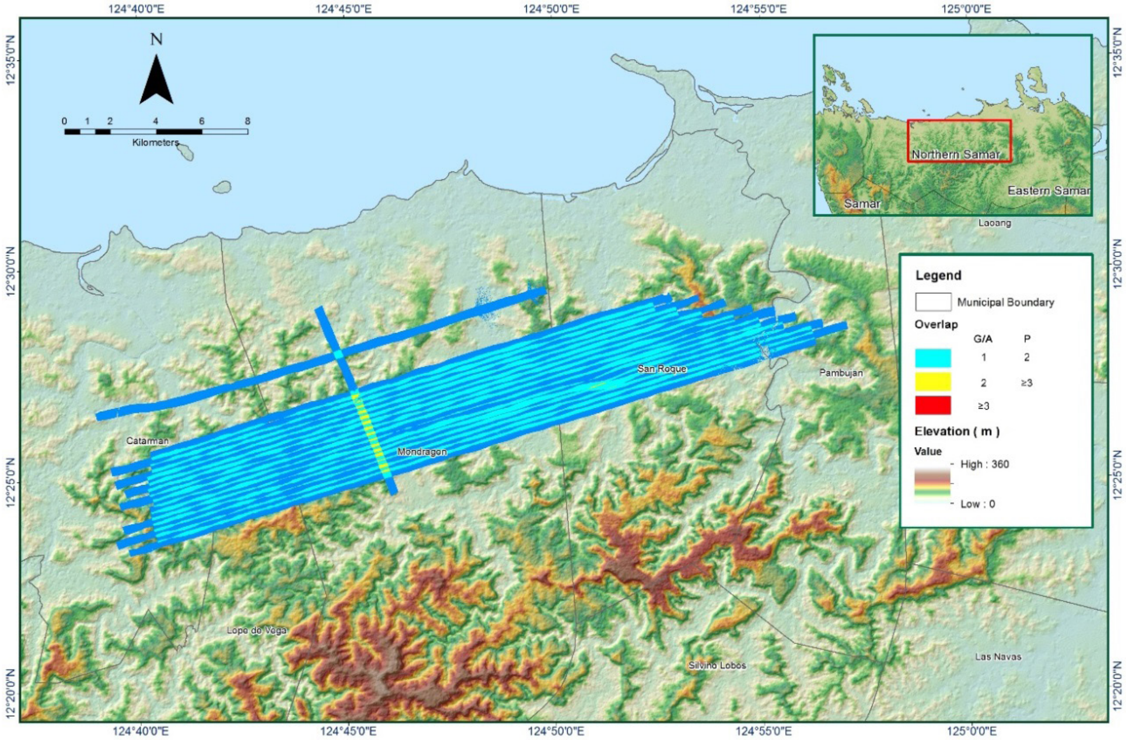


Figure 1.4.5 Image of data overlap

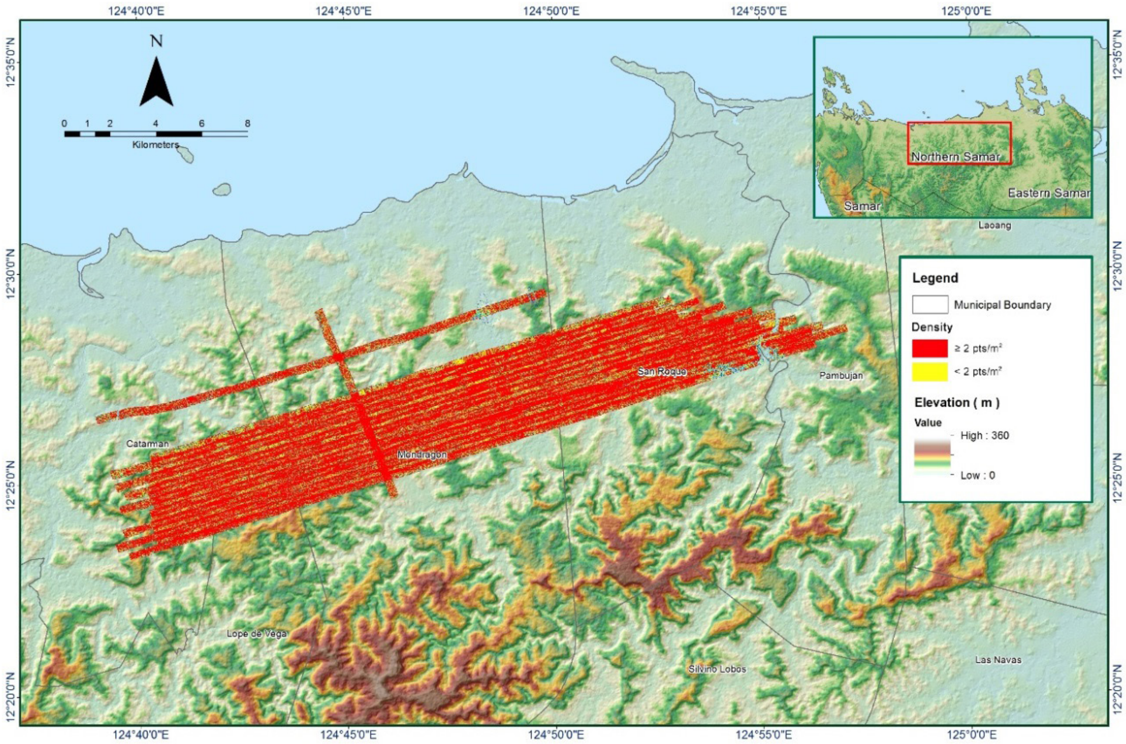


Figure 1.4.6 Density map of merged LiDAR data

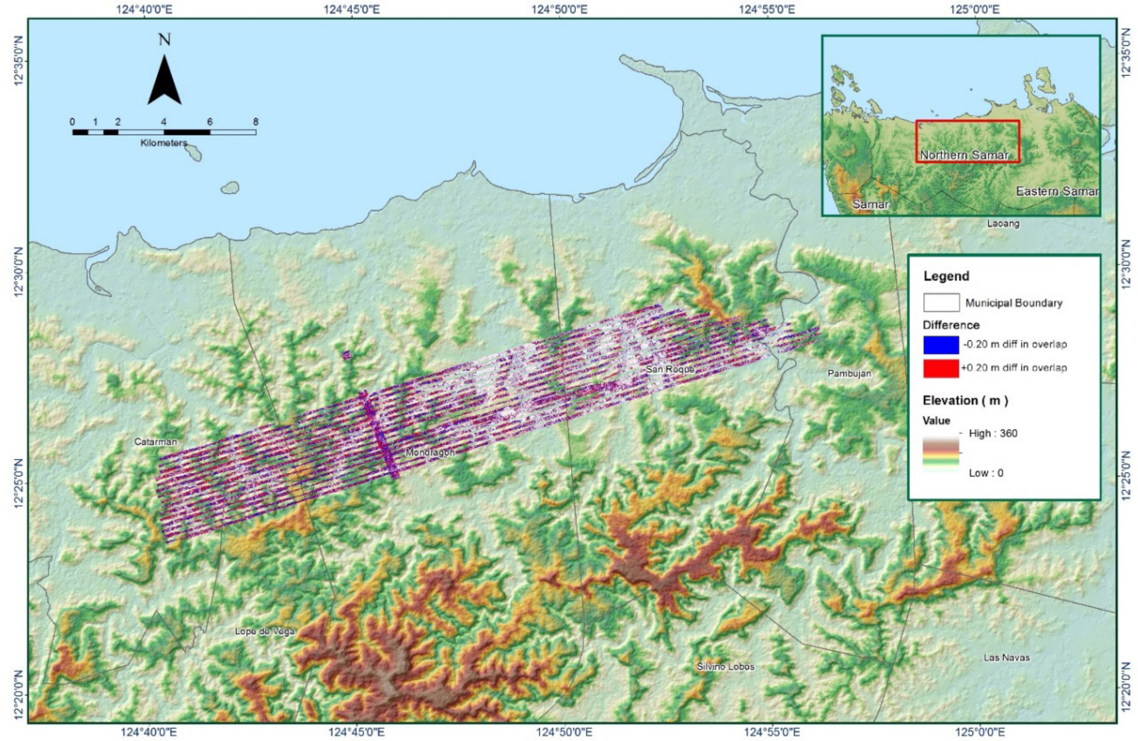


Figure 1.4.7 *Elevation difference between flight lines*

Flight Area	CatarmanReflights
Mission Name	**Blk 331O**
Inclusive Flights	3917G
Range data size	22.4 GB
POS data size	255 MB
Base data size	195 MB
Image	NA
Transfer date	May 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)	1.215
RMSE for East Position (<4.0 cm)	1.810
RMSE for Down Position (<8.0 cm)	3.612
Boresight correction stdev (<0.001deg)	0.000824
IMU attitude correction stdev (<0.001deg)	0.002066
GPS position stdev (<0.01m)	0.0129
Minimum % overlap (>25)	24.93%
Ave point cloud density per sq.m. (>2.0)	4.41
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	57
Maximum Height	282.75 m
Minimum Height	54.24 m
Classification (# of points)	
Ground	9,468,129
Low vegetation	4,080,365
Medium vegetation	53,608,692
High vegetation	68,936,471
Building	1,105
Orthophoto	No
Processed by	Engr. Kenneth Solidum, Aljon Rei Araneta, JovyNarisma

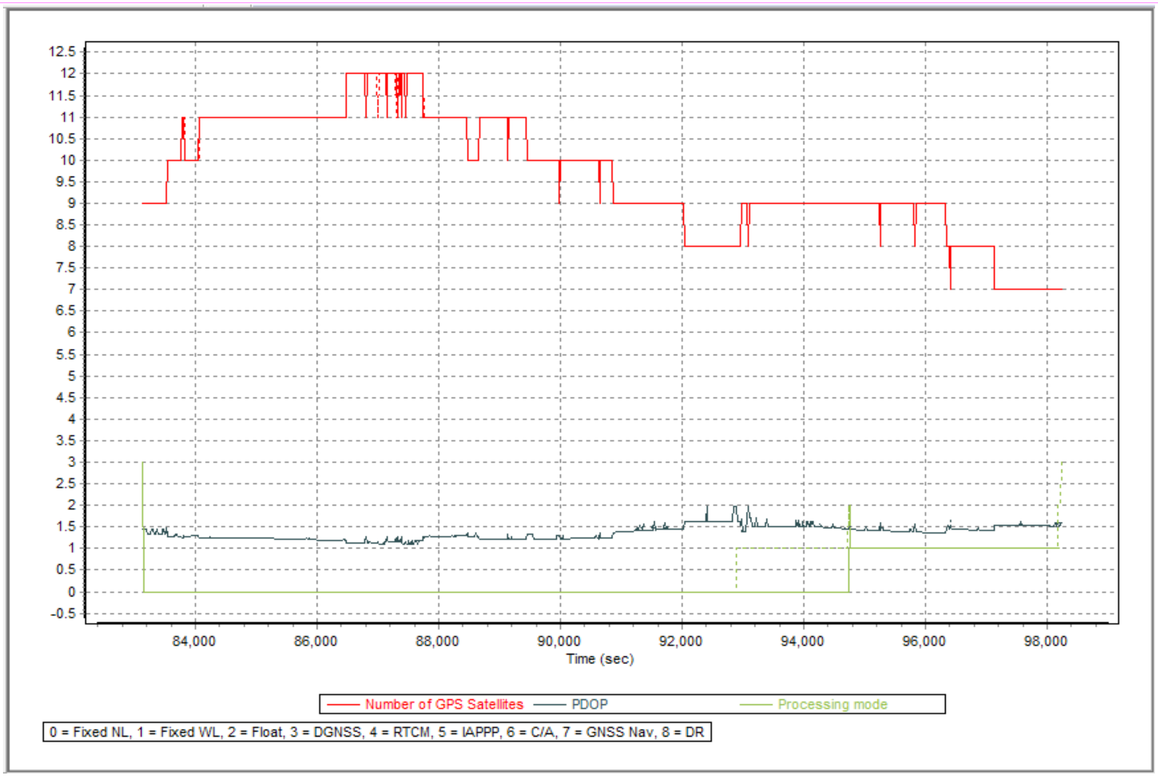


Figure 1.5.1. Solution Status

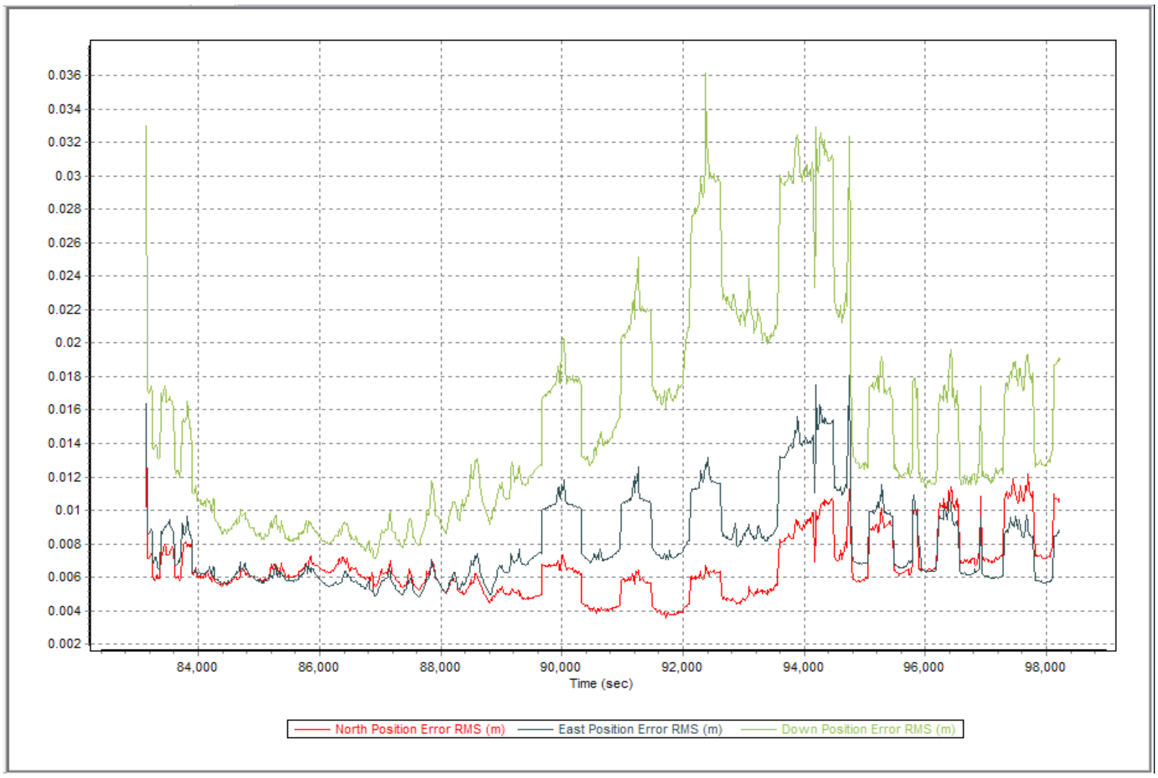


Figure 1.5.2. Smoothed Performance Metric Parameters

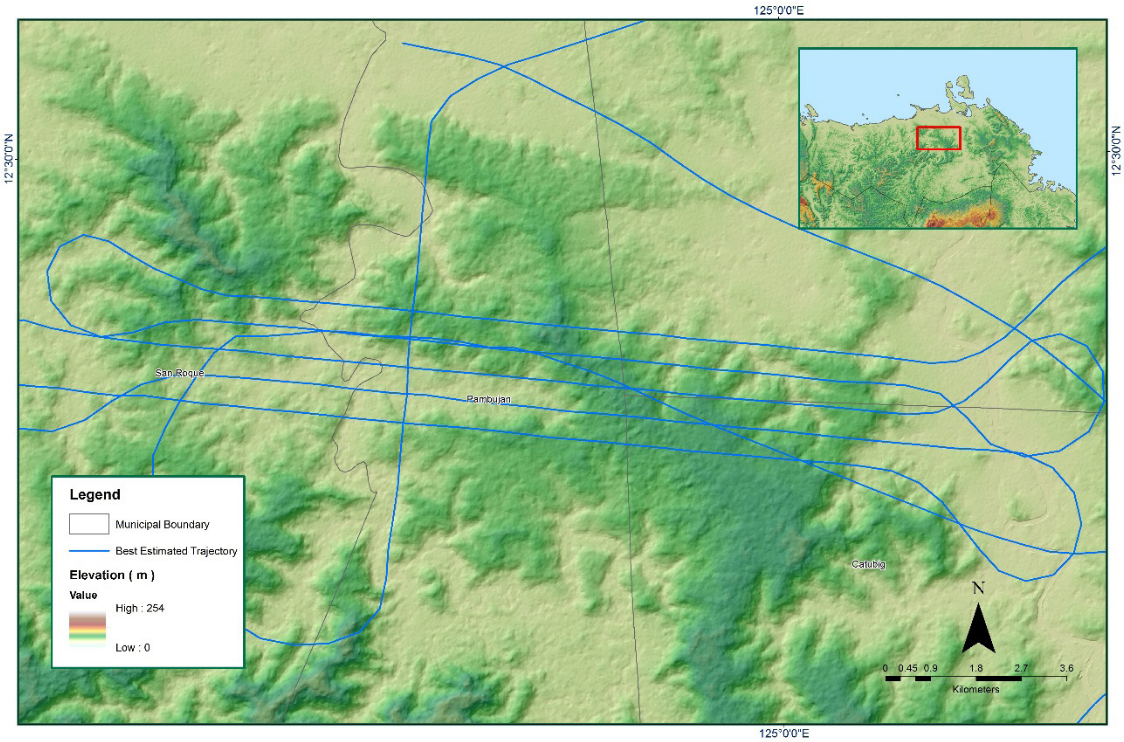


Figure 1.5.3. Best Estimated Trajectory

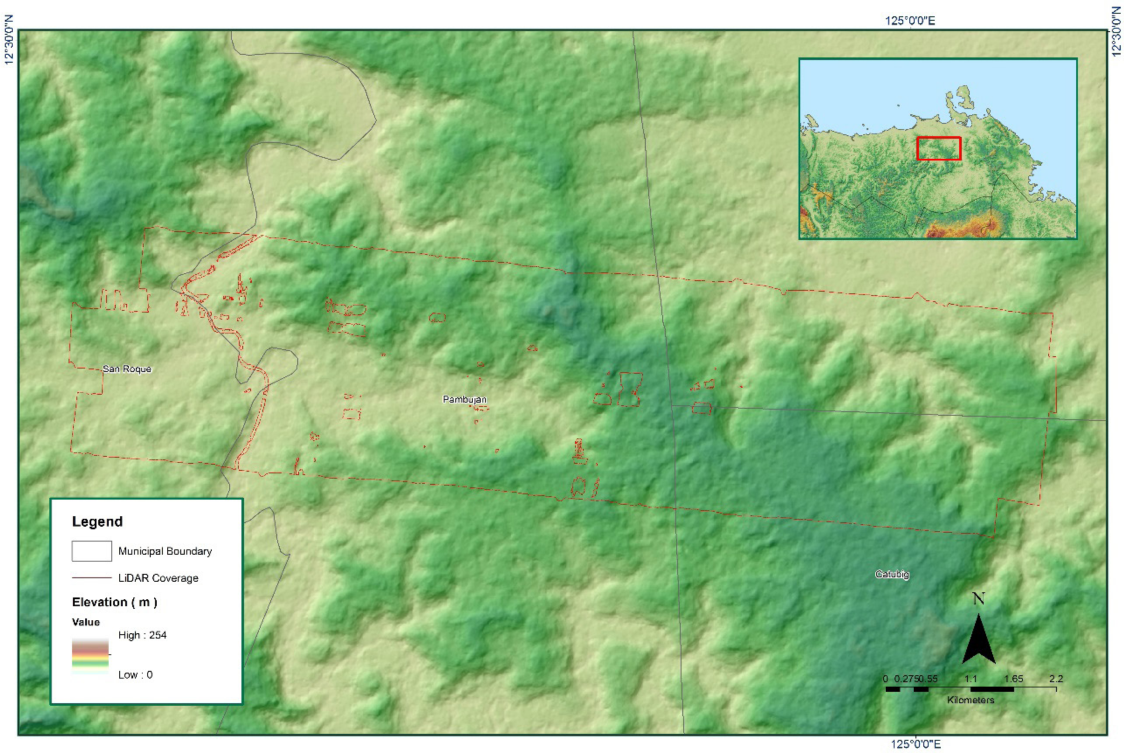


Figure 1.5.4. Coverage of LiDAR Data

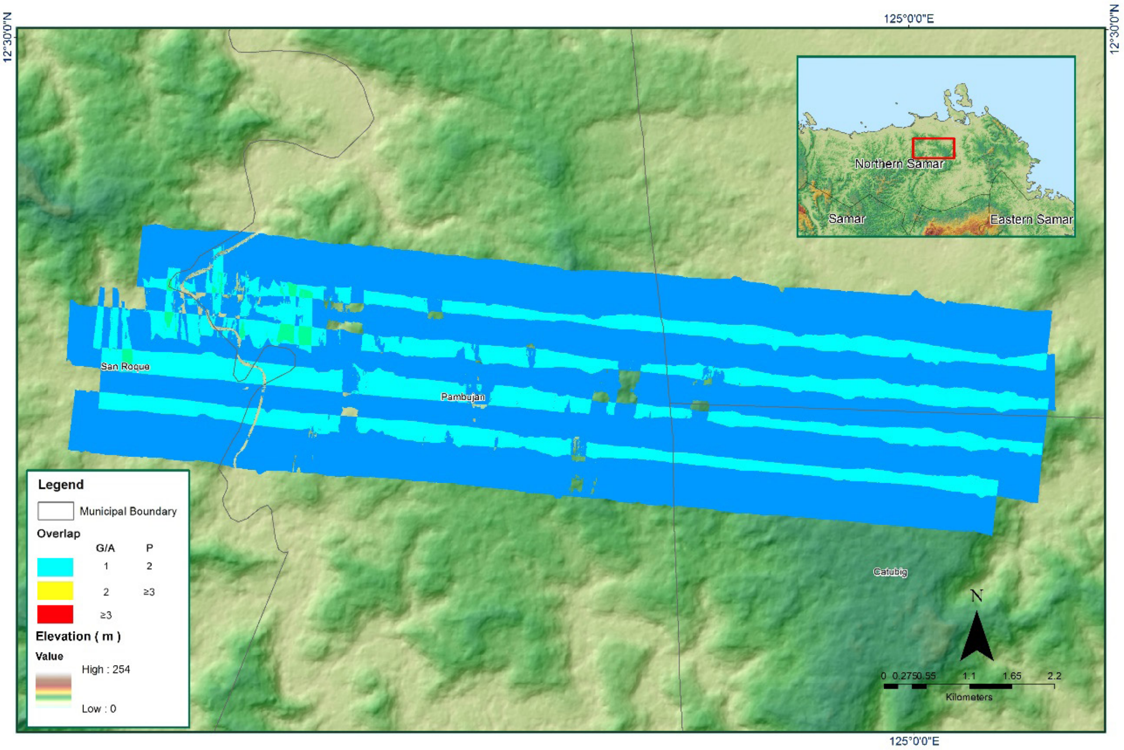


Figure 1.5.5. Image of data overlap

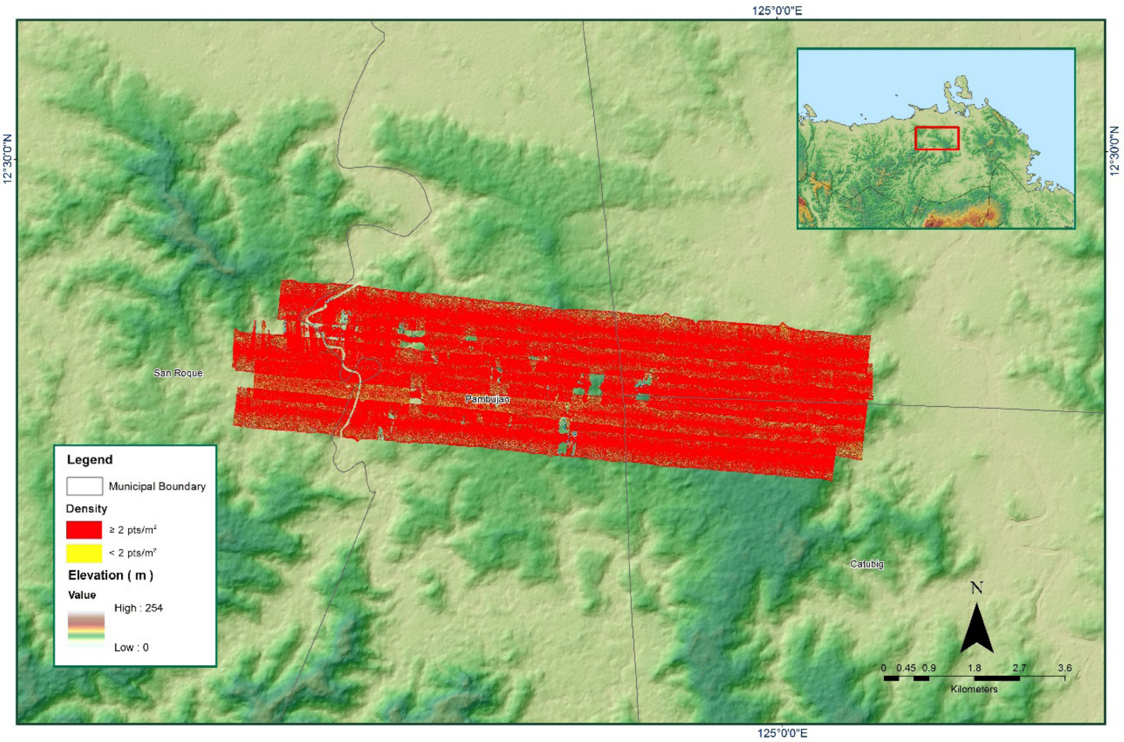


Figure 1.5.6. Density map of merged LiDAR data

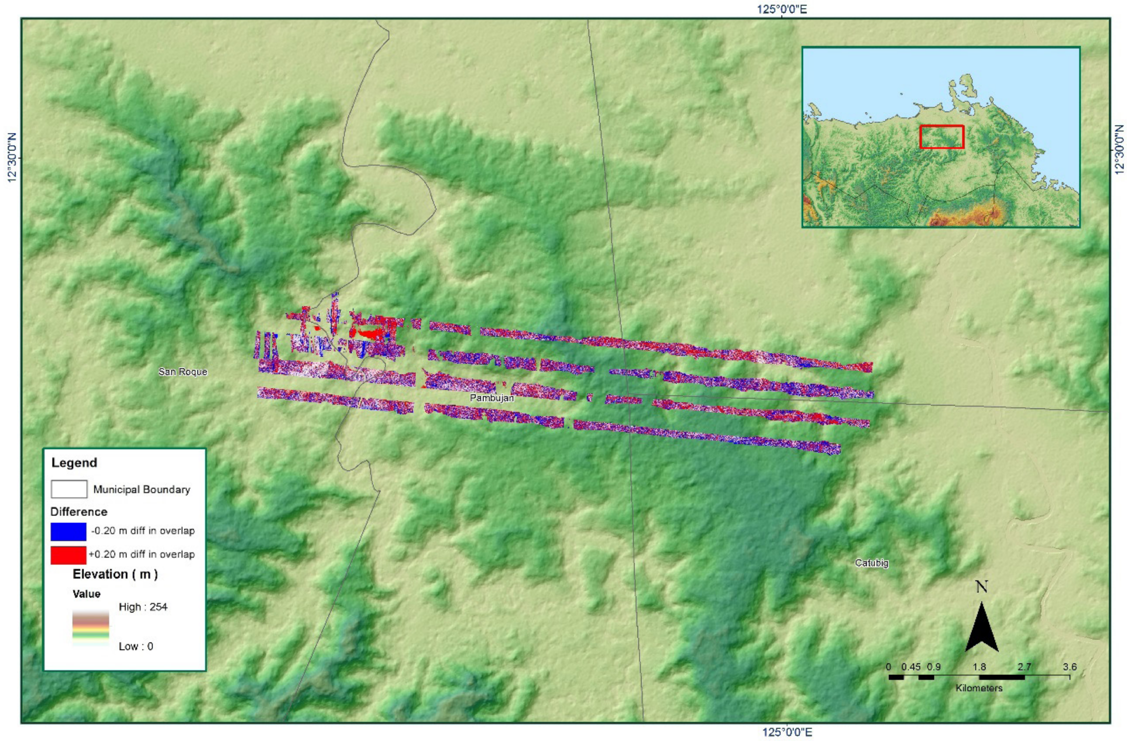


Figure 1.5.7. Elevation difference between flight lines

Flight Area	CatarmanReflights
Mission Name	**Blk 33P**
Inclusive Flights	8431AC
Range data size	12.5 GB
POS data size	237 MB
Base data size	118 MB
Image	NA
Transfer date	August 4, 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)	1.215
RMSE for East Position (<4.0 cm)	1.810
RMSE for Down Position (<8.0 cm)	3.612
Boresight correction stdev (<0.001deg)	0.000386
IMU attitude correction stdev (<0.001deg)	0.002274
GPS position stdev (<0.01m)	0.00072
Minimum % overlap (>25)	39.46%
Ave point cloud density per sq.m. (>2.0)	4.25
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	124
Maximum Height	359.03 m
Minimum Height	36.5 m
Classification (# of points)	
Ground	55,230,816
Low vegetation	53,022,783
Medium vegetation	86,171,794
High vegetation	134,845,707
Building	2,941,531
Orthophoto	No
Processed by	Engr. Kenneth Solidum, Engr. Merven Matthew Natino, Engr. Elainne Lopez

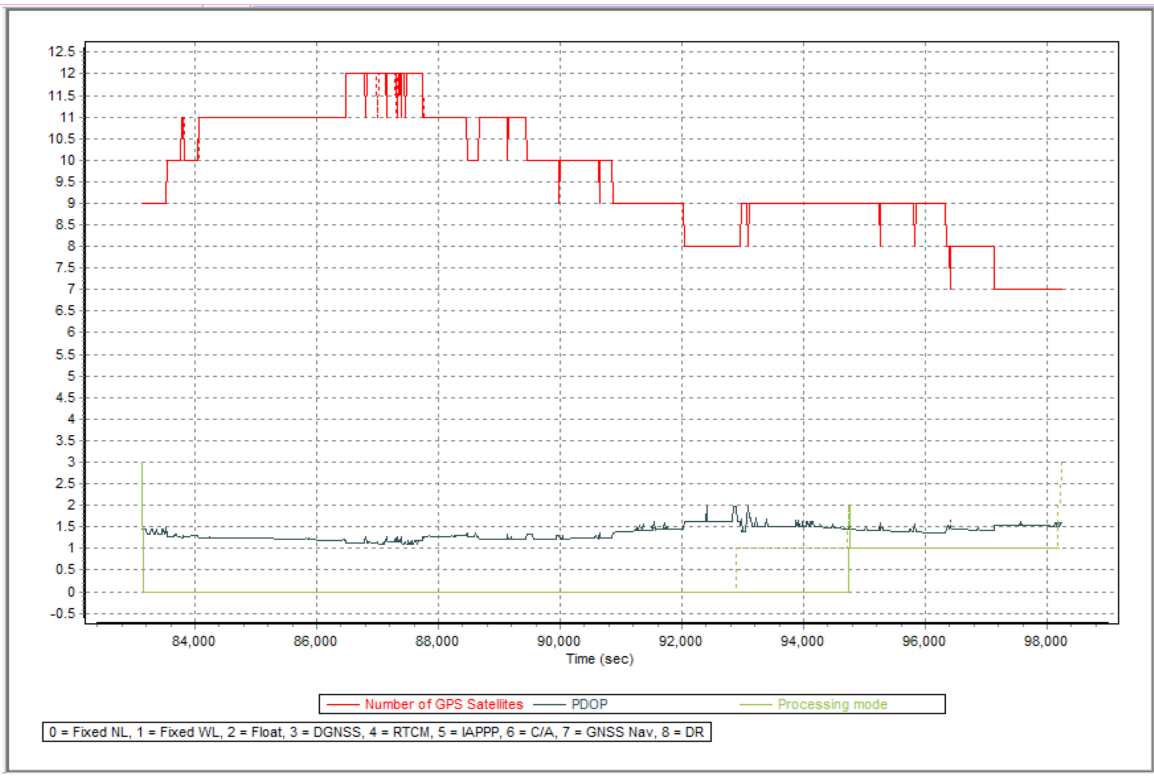


Figure 1.6.1. Solution Status

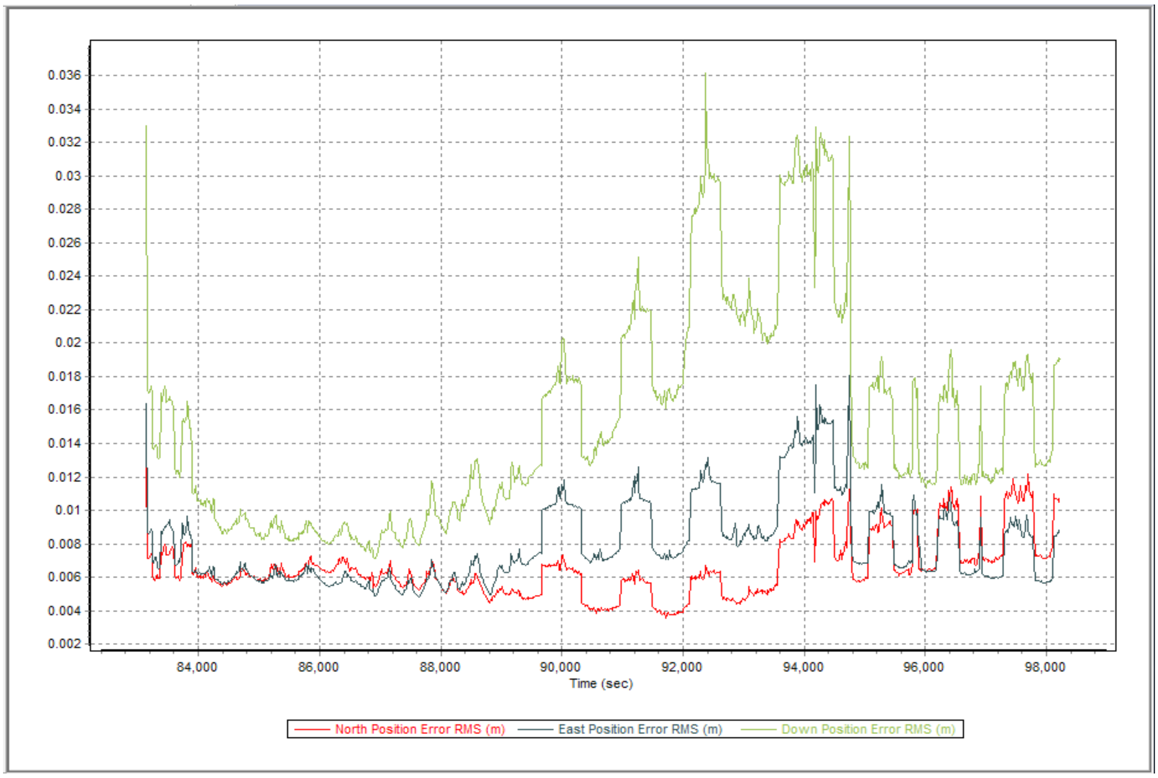


Figure 1.6.2. Smoothed Performance Metric Parameters

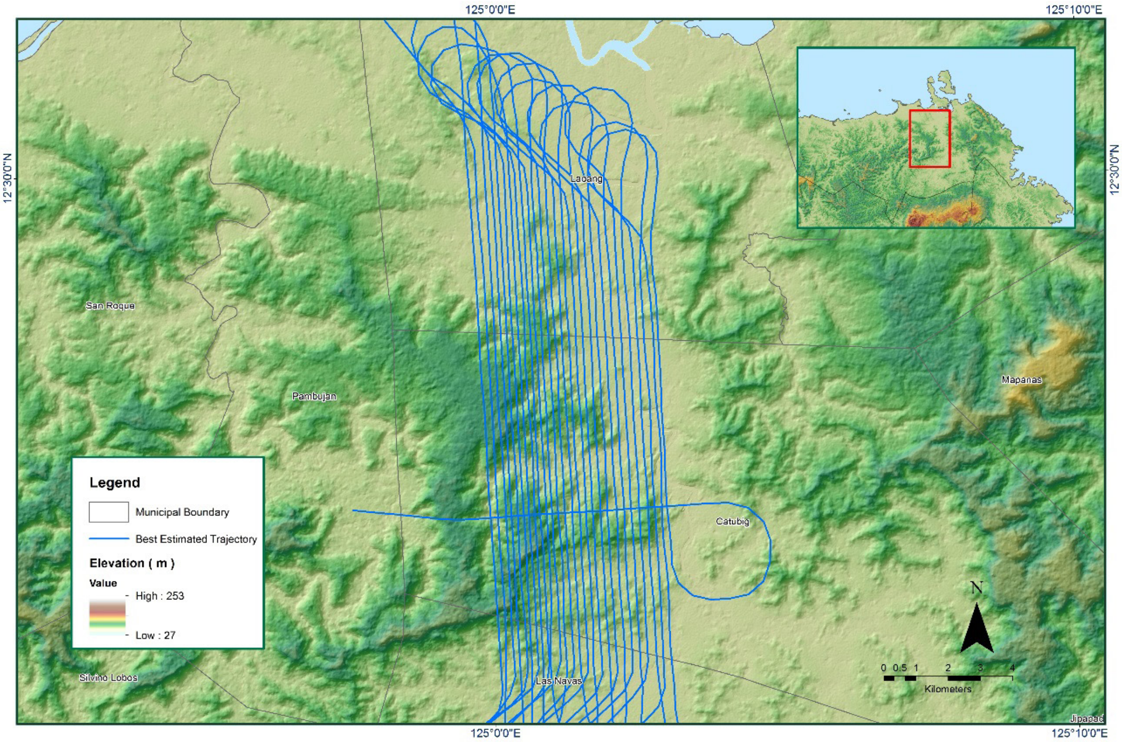


Figure 1.6.3. Best Estimated Trajectory

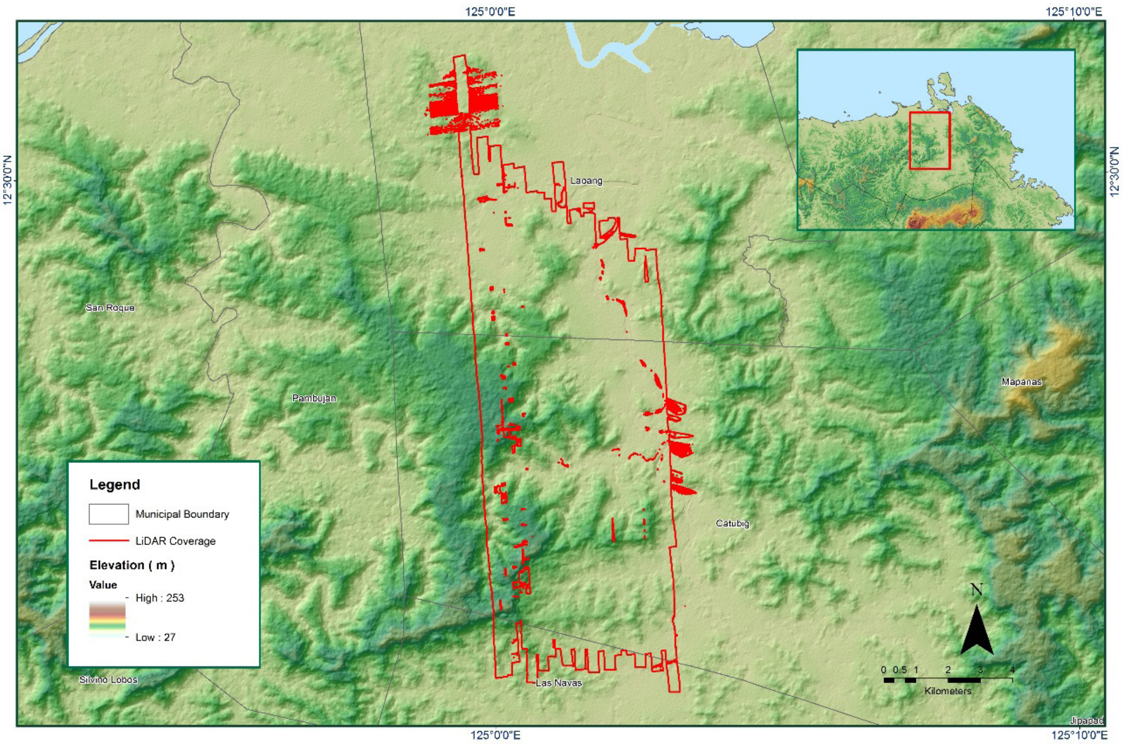


Figure 1.6.4. Coverage of LiDAR Data

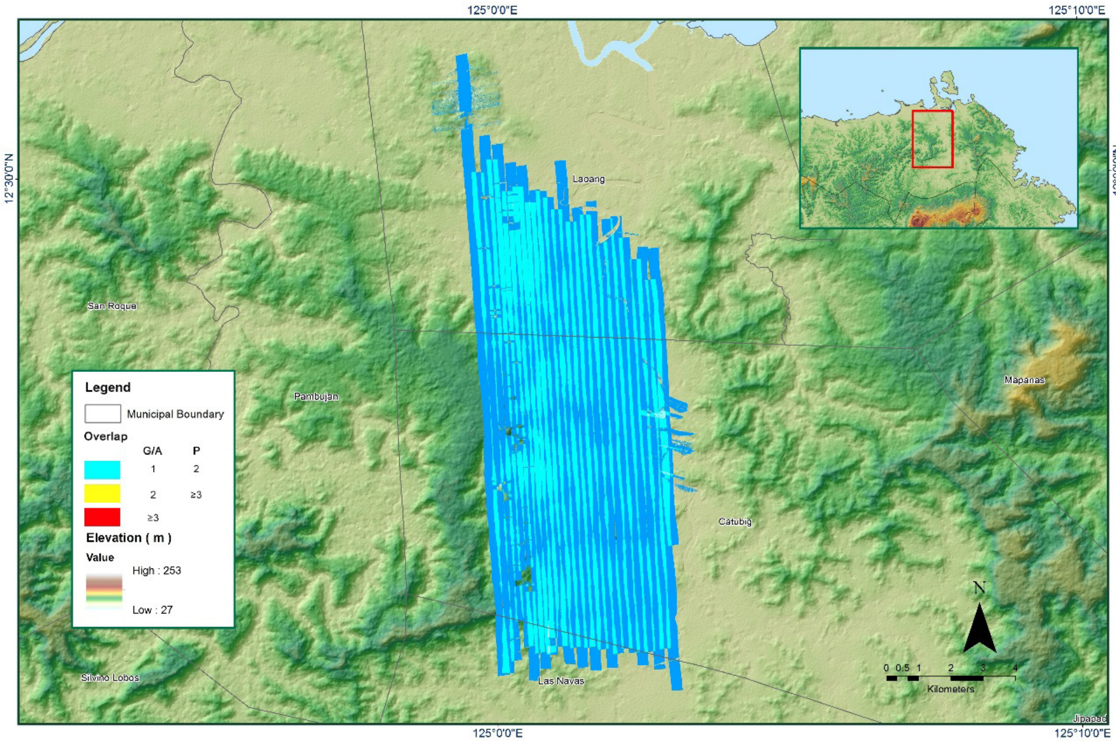


Figure 1.6.5. Image of data overlap

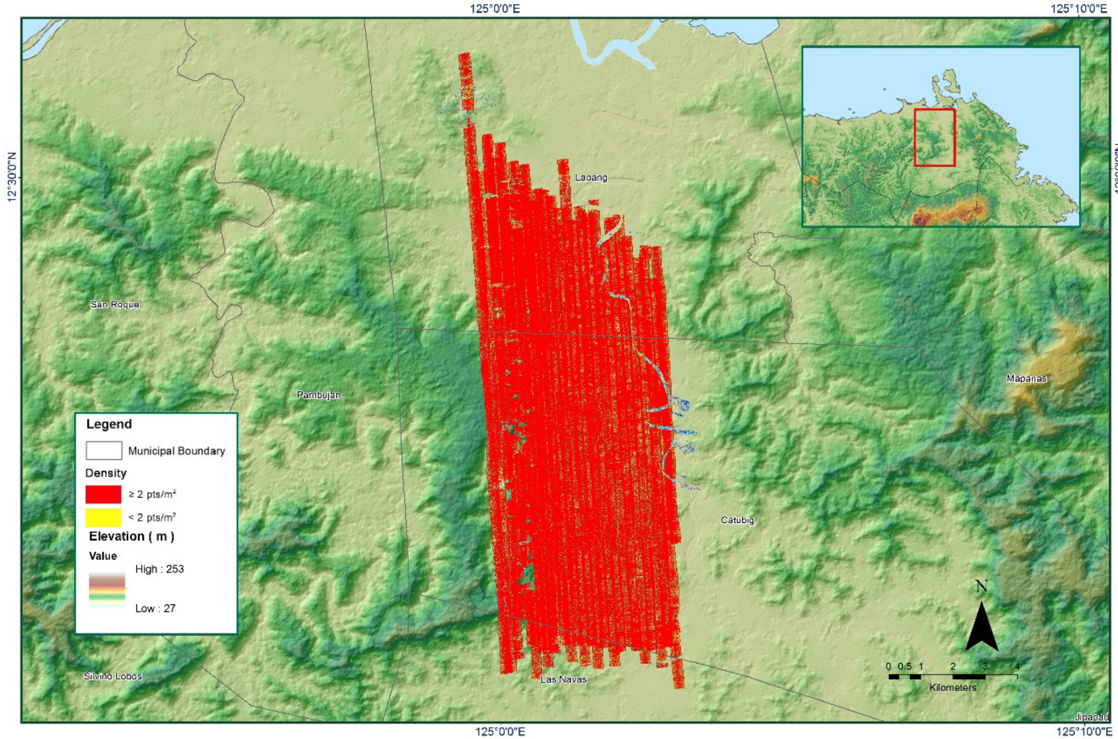


Figure 1.6.6. Density map of merged LiDAR data

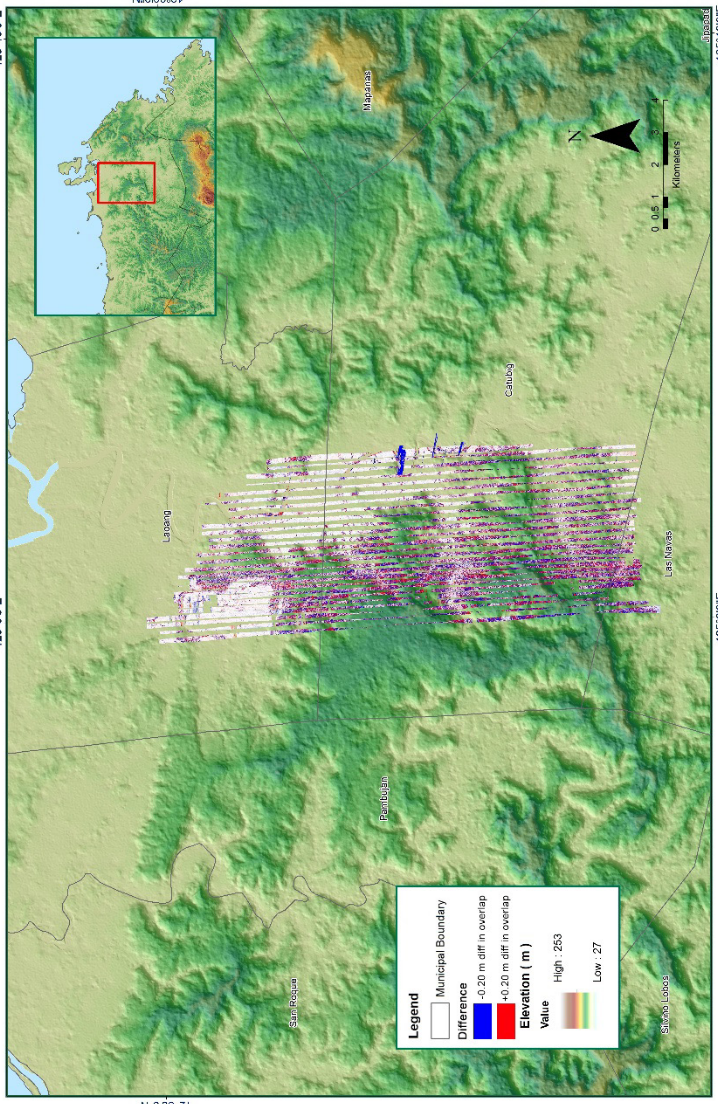


Figure 1.6.7. Elevation difference between flight lines

Annex 9. Pambukhan Model Basin Parameters

Table A-9.1.Pambukhan Model Basin Parameters

Subbasin	SCS Curve Number			Clark Unit Hydropgraph		Recession Baseflow				
	Initial Abstraction	Curve Number	Impervious	Time of Concentration	Storage Coefficient	Initial Type	Initial Discharge (m3/s)	Recession Constant	Threshold Type	Ratio to Peak
W1000	27.324	60	0	10.43	17.021	Discharge	0.66428	0.1	Ratio to Peak	0.1
W1010	16.648	60	0	2.4488	3.9964	Discharge	0.0672239	0.1	Ratio to Peak	0.1
W1020	18.333	60	0	18.957	30.937	Discharge	0.70623	0.1	Ratio to Peak	0.1
W1030	21.135425	60	0	8.2883	13.526	Discharge	0.62969	0.1	Ratio to Peak	0.1
W1040	16.648	60	0	5.733	9.3563	Discharge	0.37883	0.1	Ratio to Peak	0.1
W1050	22.428	60	0	7.7452	12.64	Discharge	0.53263	0.1	Ratio to Peak	0.1
W1060	18.286	60	0	3.6374	5.9362	Discharge	0.11703	0.1	Ratio to Peak	0.1
W1070	23.593	60	0	8.8653	14.468	Discharge	0.8001	0.1	Ratio to Peak	0.1
W1080	16.648	60	0	2.2915	3.7398	Discharge	0.0749727	0.1	Ratio to Peak	0.1
W1090	23.073	60	0	7.0363	11.483	Discharge	0.3721	0.1	Ratio to Peak	0.1
W1100	26.145	60	0	11.595	18.924	Discharge	1.151	0.1	Ratio to Peak	0.1
W1110	22.388	60	0	8.3543	13.634	Discharge	0.48557	0.1	Ratio to Peak	0.1
W1120	21.53	60	0	13.235	21.6	Discharge	0.97416	0.1	Ratio to Peak	0.1
W1130	25.169	60	0	8.5234	13.91	Discharge	0.26688	0.1	Ratio to Peak	0.1
W1140	26.946	60	0	20.387	33.272	Discharge	2.3667	0.1	Ratio to Peak	0.1
W1150	28.394	60	0	3.8485	6.2808	Discharge	0.065547	0.1	Ratio to Peak	0.1

SCS Curve Number			Clark Unit Hydropgraph		Recession			Subbasin	
Initial Abstraction	Curve Number	Impervious	Time of Concentration	Storage Coefficient	Initial Type	Initial Discharge (m3/s)	Reces Const		
25.332	60	0	11.438	18.666	Discharge	0.88241	0.1	W800	Ratio to P
24.438	60	0	6.8861	11.238	Discharge	0.35605	0.1	W810	Ratio to P
28.958	60	0	12.784	20.863	Discharge	0.4134	0.1	W820	Ratio to P
25.0860157	60	0	3.7604	6.1369	Discharge	0.0990087	0.1	W830	Ratio to P
29.973	60	0	10.3390251	16.873	Discharge	0.39921	0.1	W840	Ratio to P
21.851	60	0	9.1106	14.868	Discharge	0.66954	0.1	W850	Ratio to P
26.902	60	0	25.293	41.279	Discharge	1.9302	0.1	W860	Ratio to P
29.13	60	0	8.1842	13.357	Discharge	0.43389	0.1	W870	Ratio to P
29.406	60	0	11.846	19.332	Discharge	0.62659	0.1	W880	Ratio to P
30.062	60	0	1.8157	2.9633	Discharge	0.014219	0.1	W890	Ratio to P
27.794	60	0	11.505427	18.777	Discharge	0.5853	0.1	W900	Ratio to P
27.505	60	0	5.8768	9.591	Discharge	0.39671	0.1	W910	Ratio to P
29.272	60	0	17.561	28.659	Discharge	1.232	0.1	W920	Ratio to P
30.062	60	0	4.6401	7.5726	Discharge	0.33657	0.1	W930	Ratio to P
29.021	60	0	11.871	19.374	Discharge	1.3483	0.1	W940	Ratio to P
26.508	60	0	9.0259	14.73	Discharge	0.45981	0.1	W950	Ratio to P
30.062	60	0	2.8663	4.6778	Discharge	0.0624935	0.1	W960	Ratio to P
28.3179827	60	0	15.327	25.014	Discharge	1.2075	0.1	W970	Ratio to P
29.596	60	0	19.496	31.817	Discharge	1.6972	0.1	W980	Ratio to P
20.649	60	0	5.2714	8.603	Discharge	0.0318407	0.1	W990	Ratio to P
18.27	60	0	11.792	19.244	Discharge	1.0253	0.1		Ratio to P
17.736	60	0	4.2484	6.9333	Discharge	0.0239801	0.1		Ratio to P
22.341	60	0	10.062	16.422	Discharge	0.20823	0.1		Ratio to P
22.468	60	0	8.7998	14.361	Discharge	0.16404	0.1		Ratio to P
19.256	75	0	7.1299	11.636	Discharge	0.39339	0.1		Ratio to P
15.872	70	0	14.4894804	23.647	Discharge	0.57085	0.1		Ratio to P
18.897	68	0	12.12	19.78	Discharge	0.72523	0.1		Ratio to P
13.758	70	0	10.4	16.973	Discharge	0.50724	0.1		Ratio to P
14.171	65	0	6.0509	9.875	Discharge	0.36386	0.1		Ratio to P
20.435	65	0	4.8649	7.9395	Discharge	0.37793	0.1		Ratio to P
21.128	60	0	7.3427	11.983	Discharge	0.92861	0.1		Ratio to P

	SCS Curve Number				Clark Unit Hydropgraph		Recession Baseflow			
	Initial Ab-straction		Curve Number	Impervious	Time of Concen-tration	Storage Coef-ficient	Initial Type	Initial Discharge (m3/s)	Recession Constant	Threshold T
Peak	15.75	0.1	60	0	4.1683	6.8027	Discharge	0.12569	0.1	Ratio to Pe
Peak	20.678	0.1	60	0	10.313	16.831099	Discharge	0.44812	0.1	Ratio to Pe
Peak	29.66	0.1	60	0	10.6851473	17.4381604	Discharge	0.68369	0.1	Ratio to Pe
Peak	26.912	0.1	99	0	14.536	23.723	Discharge	1.5183	0.1	Ratio to Pe
Peak	30.062	0.1	60	0	2.1357	3.4855	Discharge	0.0545072	0.1	Ratio to Pe
Peak	30.062	0.1	60	0	4.6879	7.6506	Discharge	0.20496	0.1	Ratio to Pe
Peak	29.248883	0.1	60	0	6.179	10.084	Discharge	0.47961	0.1	Ratio to Pe
Peak	30.062	0.1	60	0	17.1490334	27.9872225	Discharge	1.3173	0.1	Ratio to Pe
Peak	26.868	0.1	60	0	8.2173	13.411	Discharge	0.54518	0.1	Ratio to Pe
Peak	28.518	0.1	60	0	31.3921048	51.232	Discharge	1.9518	0.1	Ratio to Pe
Peak	30.062	0.1	60	0	9.3103	15.194	Discharge	0.58587	0.1	Ratio to Pe
Peak	25.13	0.1	60	0	13.913	22.705	Discharge	1.309	0.1	Ratio to Pe
Peak	18.846	0.1	99	0	2.2059	3.6001	Discharge	0.0626193	0.1	Ratio to Pe
Peak	24.154	0.1	91	0	9.8011	15.995	Discharge	0.4618332	0.1	Ratio to Pe
Peak	23.971	0.1	90	0	4.5487	7.4236	Discharge	0.14937	0.1	Ratio to Pe
Peak	22.93	0.1	60	0	9.3746	15.299	Discharge	0.81252	0.1	Ratio to Pe
Peak	27.514	0.1	60	0	9.1827	14.986	Discharge	1.0328	0.1	Ratio to Pe
Peak	16.648	0.1	90	0	5.3139	8.6723	Discharge	0.38016	0.1	Ratio to Pe
Peak	24.805	0.1	60	0	10.691	17.447	Discharge	0.65766	0.1	Ratio to Pe
Peak	18.845	0.1	60	0	7.8601	12.828	Discharge	0.59514	0.1	Ratio to Pe
Peak		0.1								
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Annex 10. Pambukhan Model Reach Parameters

Table A-10.1.Pambukhan Model Reach Parameters

Reach	Time Step Method	Length	Slope	Manning's n	Shape	Width	Side Slope
R10	Automatic Fixed Interval	672.7	0.000120265	0.04	Trapezoid	135.75	45
R110	Automatic Fixed Interval	3297.2	0.0013487	0.04	Trapezoid	58.47	45
R120	Automatic Fixed Interval	1405.1	0.000120265	0.04	Trapezoid	53.25	45
R150	Automatic Fixed Interval	3534.6	1.20E-04	0.04	Trapezoid	43.46	45
R170	Automatic Fixed Interval	1059.7	0.0026553	0.04	Trapezoid	33.23	45
R180	Automatic Fixed Interval	7316.7	0.0010557	0.04	Trapezoid	32.69	45
R190	Automatic Fixed Interval	2391	0.000402019	0.04	Trapezoid	29.52	45
R20	Automatic Fixed Interval	807.4	0.000412847	0.04	Trapezoid	105.11	45
R230	Automatic Fixed Interval	11304	0.000120265	0.04	Trapezoid	34.23	45
R240	Automatic Fixed Interval	554.97	0.000120265	0.04	Trapezoid	29.59	45
R250	Automatic Fixed Interval	2110.5	0.0052752	0.04	Trapezoid	7.63	45
R280	Automatic Fixed Interval	4737.7	0.0015578	0.04	Trapezoid	37.81	45
R290	Automatic Fixed Interval	8069	0.0011249	0.04	Trapezoid	9.63	45
R30	Automatic Fixed Interval	2968.5	0.0019794	0.04	Trapezoid	87.62	45
R320	Automatic Fixed Interval	3275	0.000120265	0.04	Trapezoid	41.66	45
R340	Automatic Fixed Interval	1047.5	0.0011167	0.04	Trapezoid	10.57	45
R350	Automatic Fixed Interval	4430	0.000878815	0.04	Trapezoid	3.65	45
R370	Automatic Fixed Interval	1451.5	0.0035384	0.04	Trapezoid	4.74	45
R400	Automatic Fixed Interval	1306.7	0.0051525	0.04	Trapezoid	8.89	45
R410	Automatic Fixed Interval	4813.6	0.000975967	0.04	Trapezoid	7.48	45
R430	Automatic Fixed Interval	6597.7	0.000985171	0.04	Trapezoid	25.63	45
R450	Automatic Fixed Interval	1691	0.0019518	0.04	Trapezoid	11.98	45
R470	Automatic Fixed Interval	4041.1	1.20E-04	0.04	Trapezoid	19.23	45

Reach	Time Step Method	Length	Slope	Manning's n	Shape	Width	Side Slope
R50	Automatic Fixed Interval	1042.8	0.0020454	0.04	Trapezoid	75.17	45
R500	Automatic Fixed Interval	6213.9	0.0013775	0.04	Trapezoid	12.53	45
R520	Automatic Fixed Interval	1800.7	0.000120265	0.04	Trapezoid	7.28	45
R540	Automatic Fixed Interval	3810.6	0.000190957	0.04	Trapezoid	10.26	45
R550	Automatic Fixed Interval	398.99	0.000120265	0.04	Trapezoid	6.42	45
R580	Automatic Fixed Interval	6013.7	0.0021544	0.04	Trapezoid	8.6	45
R610	Automatic Fixed Interval	3696.5	0.000120265	0.04	Trapezoid	8.85	45
R630	Automatic Fixed Interval	1929.5	0.000120265	0.04	Trapezoid	10.57	45
R640	Automatic Fixed Interval	1359.4	0.0111148	0.04	Trapezoid	9.54	45
R90	Automatic Fixed Interval	6081.1	1.20E-04	0.04	Trapezoid	60.08	45

Annex 11. Pambukhan Field Validation Points

Table A-11.1.PambukhanField Validation Points

GPS No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Latitude	Longitude					
1013	12.55428725	124.9235612	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1022	12.55682428	124.9264449	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1032	12.55786054	124.9248359	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1062	12.56219834	124.9293368	0.52	0	-0.52	Nona/ December 13-14, 2015	5 Year
1072	12.56213481	124.9278753	0.26	0	-0.26	Nona/ December 13-14, 2015	5 Year
1082	12.56249229	124.9270283	0.59	0	-0.59	Nona/ December 13-14, 2015	5 Year
1092	12.56302882	124.9280129	0.19	0	-0.19	Nona/ December 13-14, 2015	5 Year
1103	12.56338497	124.9288402	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1113	12.56347138	124.9299349	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1122	12.56408812	124.9296608	0.09	0	-0.09	Nona/ December 13-14, 2015	5 Year
1132	12.56417018	124.928976	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1142	12.56396667	124.9282026	0.41	0	-0.41	Nona/ December 13-14, 2015	5 Year
1152	12.56338698	124.9273784	0.53	0	-0.53	Nona/ December 13-14, 2015	5 Year
1162	12.56306427	124.9258726	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1172	12.56370407	124.9251945	0.15	0	-0.15	Nona/ December 13-14, 2015	5 Year
1192	12.56428535	124.92363	0.06	0	-0.06	Nona/ December 13-14, 2015	5 Year

GPS No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Latitude	Longitude					
1202	12.5630004	124.922431	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1213	12.56385595	124.9216466	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1222	12.5647658	124.9231267	0.13	0	-0.13	Nona/ December 13-14, 2015	5 Year
1232	12.56514257	124.9245224	0.52	0	-0.52	Nona/ December 13-14, 2015	5 Year
1242	12.56476278	124.9252672	0.46	0	-0.46	Nona/ December 13-14, 2015	5 Year
1252	12.56499295	124.9260394	0.73	0	-0.73	Nona/ December 13-14, 2015	5 Year
1262	12.56450714	124.9269645	0.53	0	-0.53	Nona/ December 13-14, 2015	5 Year
1282	12.56549	124.9288169	0.35	0	-0.35	Nona/ December 13-14, 2015	5 Year
1292	12.5654558	124.9299639	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1302	12.5659966	124.9319058	0.44	0	-0.44	Nona/ December 13-14, 2015	5 Year
1313	12.56544029	124.9340122	0.29	0	-0.29	Nona/ December 13-14, 2015	5 Year
1322	12.56631939	124.9345441	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1332	12.56714257	124.9356666	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1352	12.56793919	124.937518	0.20	0	-0.20	Nona/ December 13-14, 2015	5 Year
1362	12.56602753	124.9360903	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1372	12.56494375	124.9352227	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1382	12.56435995	124.935196	0.54	0	-0.54	Nona/ December 13-14, 2015	5 Year

GPS No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Latitude	Longitude					
1392	12.56386936	124.9345389	0.23	0	-0.23	Nona/ December 13-14, 2015	5 Year
1402	12.56337935	124.9342805	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1413	12.56243907	124.9349964	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1422	12.56309034	124.936368	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1432	12.56150583	124.9398958	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1442	12.55592432	124.9488839	0.73	0	-0.73	Nona/ December 13-14, 2015	5 Year
1452	12.55440233	124.9573099	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1462	12.55548418	124.958717	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1472	12.55536164	124.9600885	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1482	12.5561917	124.9608206	0.42	0	-0.42	Nona/ December 13-14, 2015	5 Year
1492	12.55530071	124.9609049	0.07	0	-0.07	Nona/ December 13-14, 2015	5 Year
1502	12.55449923	124.960846	0.43	0	-0.43	Nona/ December 13-14, 2015	5 Year
1512	12.54417549	124.8878009	0.04	0.5	0.46	Nona/ December 13-14, 2015	5 Year
1522	12.55382549	124.9611881	0.68	0	-0.68	Nona/ December 13-14, 2015	5 Year
1532	12.5533696	124.9621099	0.59	0	-0.59	Nona/ December 13-14, 2015	5 Year
1542	12.55350807	124.9627105	0.47	0	-0.47	Nona/ December 13-14, 2015	5 Year
1612	12.54268016	124.8874876	1.40	0.5	-0.90	Nona/ December 13-14, 2015	5 Year

GPS No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Latitude	Longitude					
1622	12.53433991	124.8701123	0.44	1	0.56	Nona/ December 13-14, 2015	5 Year
1632	12.53465365	124.8707501	0.11	0.5	0.39	Nona/ December 13-14, 2015	5 Year
1652	12.53581672	124.8717809	0.30	1	0.70	Nona/ December 13-14, 2015	5 Year
1662	12.53651242	124.8724025	0.15	1	0.85	Nona/ December 13-14, 2015	5 Year
1672	12.53771187	124.8726445	0.06	1	0.94	Nona/ December 13-14, 2015	5 Year
1682	12.53909756	124.8737933	0.25	1	0.75	Nona/ December 13-14, 2015	5 Year
1692	12.53839265	124.874746	0.03	0.5	0.47	Nona/ December 13-14, 2015	5 Year
1702	12.53763333	124.8750055	0.03	0.5	0.47	Nona/ December 13-14, 2015	5 Year
1713	12.53637931	124.8747473	0.24	0.5	0.26	Nona/ December 13-14, 2015	5 Year
1722	12.53682439	124.8740933	0.03	0.5	0.47	Nona/ December 13-14, 2015	5 Year
1732	12.53493243	124.8741538	0.78	0.5	-0.28	Nona/ December 13-14, 2015	5 Year
1742	12.53488499	124.8729361	0.58	0.5	-0.08	Nona/ December 13-14, 2015	5 Year
1752	12.5328994	124.8715547	1.40	0.5	-0.90	Nona/ December 13-14, 2015	5 Year
1762	12.53410547	124.8736973	0.62	0.5	-0.12	Nona/ December 13-14, 2015	5 Year
1772	12.53573014	124.874832	0.64	0.5	-0.14	Nona/ December 13-14, 2015	5 Year
1782	12.54078962	124.8754424	0.03	1	0.97	Nona/ December 13-14, 2015	5 Year
1792	12.54145254	124.8758872	0.25	1	0.75	Nona/ December 13-14, 2015	5 Year

GPS No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Latitude	Longitude					
1802	12.54228705	124.8763167	0.03	1	0.97	Nona/ December 13-14, 2015	5 Year
1813	12.54168129	124.8767161	0.84	1	0.16	Nona/ December 13-14, 2015	5 Year
1822	12.54330913	124.8876914	0.21	0.5	0.29	Nona/ December 13-14, 2015	5 Year
1832	12.54177491	124.8873659	0.55	0.5	-0.05	Nona/ December 13-14, 2015	5 Year
1852	12.53110668	124.878593	0.85	0	-0.85	Nona/ December 13-14, 2015	5 Year
1862	12.53067132	124.8798795	0.90	0	-0.90	Nona/ December 13-14, 2015	5 Year
1872	12.53043135	124.8805699	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1882	12.53114322	124.8812675	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1892	12.53110643	124.8820036	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
1902	12.52988183	124.882828	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
2012	12.54356353	124.8870196	1.45	0.5	-0.95	Nona/ December 13-14, 2015	5 Year
2112	12.5407742	124.878913	0.67	1	0.33	Nona/ December 13-14, 2015	5 Year
2212	12.53928482	124.875804	0.03	1	0.97	Nona/ December 13-14, 2015	5 Year
2392	12.56090359	124.9297801	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
2412	12.53832743	124.8733368	0.03	1	0.97	Nona/ December 13-14, 2015	5 Year
2432	12.55564143	124.9286235	0.12	0	-0.12	Nona/ December 13-14, 2015	5 Year
2482	12.56294039	124.9346348	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year

GPS No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Latitude	Longitude					
254	12.53761338	124.874098	0.03	0.5	0.47	Nona/ December 13-14, 2015	5 Year
262	12.53689312	124.8721642	0.03	1	0.97	Nona/ December 13-14, 2015	5 Year
272	12.53673906	124.8733821	0.03	0.5	0.47	Nona/ December 13-14, 2015	5 Year
292	12.53322537	124.869588	0.28	1	0.72	Nona/ December 13-14, 2015	5 Year
302	12.53376215	124.870993	0.82	0.5	-0.32	Nona/ December 13-14, 2015	5 Year
313	12.53363768	124.8727017	0.57	0.5	-0.07	Nona/ December 13-14, 2015	5 Year
332	12.53565285	124.8738285	0.36	0.5	0.14	Nona/ December 13-14, 2015	5 Year
342	12.53650496	124.8754996	0.03	0.5	0.47	Nona/ December 13-14, 2015	5 Year
352	12.53544917	124.8760934	1.20	0.5	-0.70	Nona/ December 13-14, 2015	5 Year
382	12.53249254	124.8772728	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
392	12.53119284	124.8798487	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
402	12.53020881	124.8800662	0.74	0	-0.74	Nona/ December 13-14, 2015	5 Year
413	12.53053947	124.881021	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
422	12.5307388	124.8817446	0.25	0	-0.25	Nona/ December 13-14, 2015	5 Year
432	12.53102244	124.8825858	0.24	0	-0.24	Nona/ December 13-14, 2015	5 Year
442	12.53150021	124.8813495	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year
452	12.52909359	124.8827949	0.03	0	-0.03	Nona/ December 13-14, 2015	5 Year

GPS No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Latitude	Longitude					
1212	12.56046639	124.8967975	0.15	0.3	0.15	Nona/ December 13-14, 2015	5 Year
1312	12.5530826	124.8963952	0.03	0.3	0.27	Nona/ December 13-14, 2015	5 Year
1412	12.54548307	124.8967557	0.03	0.3	0.27	Nona/ December 13-14, 2015	5 Year
1962	12.52816823	124.9233157	0.56	0.3	-0.26	Nona/ December 13-14, 2015	5 Year
1972	12.5276188	124.9233145	2.07	2	-0.07	Nona/ December 13-14, 2015	5 Year
1982	12.52971134	124.9288949	1.69	1.5	-0.19	Nona/ December 13-14, 2015	5 Year
1992	12.52920046	124.9292624	1.77	1.5	-0.27	Nona/ December 13-14, 2015	5 Year
2002	12.52632287	124.93237	1.51	1.5	-0.01	Nona/ December 13-14, 2015	5 Year
2013	12.51704302	124.9270744	0.66	0	-0.66	Nona/ December 13-14, 2015	5 Year
2022	12.51711829	124.9278395	1.75	1.5	-0.25	Nona/ December 13-14, 2015	5 Year
2032	12.51619477	124.9276812	1.26	1	-0.26	Nona/ December 13-14, 2015	5 Year
2042	12.51607264	124.9271204	0.70	0.3	-0.40	Nona/ December 13-14, 2015	5 Year
2072	12.54813502	124.9091589	0.03	0.3	0.27	Nona/ December 13-14, 2015	5 Year
2092	12.54838907	124.9112927	1.15	1	-0.15	Nona/ December 13-14, 2015	5 Year
2102	12.54819671	124.9116202	0.61	1.5	0.89	Nona/ December 13-14, 2015	5 Year
2113	12.54930438	124.9128673	0.60	1.5	0.90	Nona/ December 13-14, 2015	5 Year
2132	12.54966714	124.913646	0.03	1	0.97	Nona/ December 13-14, 2015	5 Year

GPS No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Latitude	Longitude					
2142	12.55241758	124.9117425	0.03	1	0.97	Nona/ December 13-14, 2015	5 Year
2162	12.53196892	124.9211889	3.10	2.5	-0.60	Nona/ December 13-14, 2015	5 Year
2172	12.53057283	124.9219308	2.27	2	-0.27	Nona/ December 13-14, 2015	5 Year
2182	12.53083485	124.9224803	1.50	2	0.50	Nona/ December 13-14, 2015	5 Year
2192	12.52990228	124.9218329	1.69	2	0.31	Nona/ December 13-14, 2015	5 Year
2202	12.52820218	124.9221983	1.35	1.5	0.15	Nona/ December 13-14, 2015	5 Year
2213	12.53035616	124.9259524	1.77	1.5	-0.27	Nona/ December 13-14, 2015	5 Year
2222	12.53003597	124.9262961	0.95	1.5	0.55	Nona/ December 13-14, 2015	5 Year
2232	12.52937246	124.9275204	0.96	1.5	0.54	Nona/ December 13-14, 2015	5 Year
2242	12.52721647	124.9312155	0.87	1.5	0.63	Nona/ December 13-14, 2015	5 Year
2252	12.52595868	124.931894	1.20	1.5	0.30	Nona/ December 13-14, 2015	5 Year
2262	12.52072636	124.9303316	1.51	1	-0.51	Nona/ December 13-14, 2015	5 Year
2272	12.52017307	124.9300203	1.28	0.5	-0.78	Nona/ December 13-14, 2015	5 Year
2292	12.51811397	124.9296447	1.33	0.5	-0.83	Nona/ December 13-14, 2015	5 Year
2302	12.51741257	124.9273103	1.96	1	-0.96	Nona/ December 13-14, 2015	5 Year
2313	12.5158035	124.9268201	1.06	0.3	-0.76	Nona/ December 13-14, 2015	5 Year
2492	12.54408991	124.8993753	0.28	0.2	-0.08	Nona/ December 13-14, 2015	5 Year

GPS No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Latitude	Longitude					
2502	12.54808011	124.8947729	0.03	0.2	0.17	Nona/ December 13-14, 2015	5 Year
462	12.52348962	124.8966068	0.07	0.5	0.43	Nona/ December 13-14, 2015	5 Year
472	12.52360236	124.8981638	0.06	0.5	0.44	Nona/ December 13-14, 2015	5 Year
481	12.52298604	124.8998837	0.44	0.5	0.06	Nona/ December 13-14, 2015	5 Year
492	12.52362809	124.9012583	0.50	0.5	0.00	Nona/ December 13-14, 2015	5 Year
502	12.52380495	124.9019878	0.03	0.5	0.47	Nona/ December 13-14, 2015	5 Year
513	12.52443854	124.9019093	0.03	0.5	0.47	Nona/ December 13-14, 2015	5 Year
522	12.52419052	124.9012883	0.03	0.5	0.47	Nona/ December 13-14, 2015	5 Year
532	12.51229743	124.9062685	0.03	0.5	0.47	Nona/ December 13-14, 2015	5 Year
542	12.51060077	124.9053853	1.11	0.5	-0.61	Nona/ December 13-14, 2015	5 Year
552	12.50934918	124.903776	0.91	0.5	-0.41	Nona/ December 13-14, 2015	5 Year
562	12.50862264	124.9029572	0.24	0.5	0.26	Nona/ December 13-14, 2015	5 Year
572	12.50842256	124.9035014	0.12	0.5	0.38	Nona/ December 13-14, 2015	5 Year
582	12.509073	124.9043691	0.06	0.5	0.44	Nona/ December 13-14, 2015	5 Year
592	12.50907828	124.905157	0.03	0.5	0.47	Nona/ December 13-14, 2015	5 Year
602	12.50808259	124.9038709	0.03	0.5	0.47	Nona/ December 13-14, 2015	5 Year
672	12.54807123	124.9087735	0.03	0.3	0.27	Nona/ December 13-14, 2015	5 Year

GPS No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Latitude	Longitude					
692	12.54824641	124.910239	1.27	2	0.73	Nona/ December 13-14, 2015	5 Year
702	12.5481263	124.9110128	1.13	2	0.87	Nona/ December 13-14, 2015	5 Year
722	12.54849242	124.913155	0.03	1	0.97	Nona/ December 13-14, 2015	5 Year
732	12.54942575	124.9139919	2.01	2.5	0.49	Nona/ December 13-14, 2015	5 Year
752	12.55014927	124.9155633	1.66	2.5	0.84	Nona/ December 13-14, 2015	5 Year
762	12.55034004	124.9143908	0.03	0.5	0.47	Nona/ December 13-14, 2015	5 Year
772	12.55152382	124.9128368	0.33	1	0.67	Nona/ December 13-14, 2015	5 Year
782	12.55198105	124.916113	0.06	1	0.94	Nona/ December 13-14, 2015	5 Year
792	12.55122911	124.9177488	0.05	0.5	0.45	Nona/ December 13-14, 2015	5 Year
813	12.53365201	124.9214586	1.90	2	0.10	Nona/ December 13-14, 2015	5 Year
822	12.52837837	124.9222889	1.35	2	0.65	Nona/ December 13-14, 2015	5 Year
832	12.52793815	124.9222394	2.88	2	-0.88	Nona/ December 13-14, 2015	5 Year
842	12.5281057	124.9229883	1.06	2	0.94	Nona/ December 13-14, 2015	5 Year
852	12.52911472	124.928397	1.84	1.5	-0.34	Nona/ December 13-14, 2015	5 Year
862	12.52831408	124.9306989	1.34	1.5	0.16	Nona/ December 13-14, 2015	5 Year
872	12.52507556	124.9327112	1.32	1.5	0.18	Nona/ December 13-14, 2015	5 Year
882	12.51964971	124.9297522	1.19	0.5	-0.69	Nona/ December 13-14, 2015	5 Year

GPS No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Latitude	Longitude					
892	12.51776143	124.9273687	1.96	1	-0.96	Nona/ December 13-14, 2015	5 Year
902	12.51664546	124.9272267	1.12	0.5	-0.62	Nona/ December 13-14, 2015	5 Year
912	12.51552304	124.9273798	1.48	0.5	-0.98	Nona/ December 13-14, 2015	5 Year

Annex 12. Educational Institutions affected by flooding in Pambukhan Flood Plain

Table A-12.1.Educational Institutions in Laoang, Northern Samar affected by flooding in PambukhanFlood Plain

NORTHERN SAMAR				
LAOANG				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Camparanga Elementary School	Burabud			

Table A-12.2.Educational Institutions in Pambukhan, Northern Samar affected by flooding in PambukhanFlood Plain

NORTHERN SAMAR				
PAMBUKHAN				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Brgy. 1 Elementary School	Cababto-An			Medium
Cababto-an Elementary School	Cababto-An	Medium	High	High
San Roque-Pambukhan Vocational High School	Cababto-An	High	High	High
Cabari-an Elementary School	Cabari-An	High	High	High
Day Care Center	Cabari-An	Medium	High	High
Camparanga Elementary School	Camparanga			
Day Care Center	Camparanga			
Canjumadal Elementary School	Canjumadal	High	High	High
Day Care Center	Canjumadal	Medium	High	High
Doña Anecita Elementary School	Doña Anecita			
Day Care Center	Geparayan	High	High	High
Giparayan Elementary School	Geparayan	High	High	High
Pambukhan II Elementary School	Ginulgan	High	High	High
Zoilo T. Lobos National High School	Ginulgan	High	High	High
Day Care Center	Paninirongan			
Doña Anecita Elementary School	Paninirongan	Low	Low	Low
Lao-angan Elementary School	Paninirongan			Low
Paninirongan Elementary School	Paninirongan			
Brgy. 2 Day Care Center	Poblacion District 1		Low	High
Day Care Center	Poblacion District 1		Low	High
St. John the Baptist Day Care Center	Poblacion District 1			Medium
Day Care Center	Poblacion District 2	Medium	Medium	High
Brgy. 6, Day Care Center	Poblacion District 3			Low
Pambukhan Elementary School	Poblacion District 3			
Pambukhan National High School	Poblacion District 3		Low	Low
Pambukhan Elementary School	Poblacion District 4			
Pambukhan National High School	Poblacion District 4			
Brgy. 8, Day Care Center	Poblacion District 5	Low	Medium	Medium
Pambukhan National High School	Poblacion District 5	Medium	Medium	Medium

Table A-12.3.Educational Institutions in San Roque, Northern Samar affected by flooding in PambukhanFlood Plain