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

LiDAR Surveys and Flood Mapping of Liangan River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
Mindanao State University-Iligan Institute of Technology

APRIL 2017

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

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

E.C. Paringit and A.E. Milano (eds.) (2017), LiDAR Surveys and Flood Mapping of Liangan River, Quezon City: University of the Philippines Training Center for Applied Geodesy and Photogrammetry-145pp

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National Library of the Philippines
ISBN: 978-621-430-078-5

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LIST OF ACRONYMS AND ABBREVIATIONS

AAC	Asian Aerospace Corporation
Ab	abutment
ALTM	Airborne LiDAR Terrain Mapper
ARG	automatic rain gauge
ATQ	Antique
AWLS	Automated Water Level Sensor
BA	Bridge Approach
BM	benchmark
CAD	Computer-Aided Design
CN	Curve Number
CSRS	Chief Science Research Specialist
DAC	Data Acquisition Component
DEM	Digital Elevation Model
DENR	Department of Environment and Natural Resources
DOST	Department of Science and Technology
DPPC	Data Pre-Processing Component
DREAM	Disaster Risk and Exposure Assessment for Mitigation [Program]
DRRM	Disaster Risk Reduction and Management
DSM	Digital Surface Model
DTM	Digital Terrain Model
DVBC	Data Validation and Bathymetry Component
FMC	Flood Modeling Component
FOV	Field of View
GiA	Grants-in-Aid
GCP	Ground Control Point
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center - River Analysis System
HC	High Chord
IDW	Inverse Distance Weighted [interpolation method]
IMU	Inertial Measurement Unit
kts	knots
LAS	LiDAR Data Exchange File format
LC	Low Chord
LGU	local government unit
LiDAR	Light Detection and Ranging
LMS	LiDAR Mapping Suite
m AGL	meters Above Ground Level
MMS	Mobile Mapping Suite
MSL	mean sea level
MSU-IIT	Mindanao State University - Iligan Institute of Technology
NSTC	Northern Subtropical Convergence
PAF	Philippine Air Force
PAGASA	Philippine Atmospheric Geophysical and Astronomical Services Administration
PDOP	Positional Dilution of Precision
PPK	Post-Processed Kinematic [technique]
PRF	Pulse Repetition Frequency
PTM	Philippine Transverse Mercator
QC	Quality Check
QT	Quick Terrain [Modeler]
RA	Research Associate
RIDF	Rainfall-Intensity-Duration-Frequency
RMSE	Root Mean Square Error
SAR	Synthetic Aperture Radar
SCS	Soil Conservation Service
SRTM	Shuttle Radar Topography Mission
SRS	Science Research Specialist
SSG	Special Service Group
TBC	Thermal Barrier Coatings
UP-TCAGP	University of the Philippines – Training Center for Applied Geodesy and Photogrammetry
UTM	Universal Transverse Mercator
WGS	World Geodetic System

CHAPTER 1: OVERVIEW OF THE PROGRAM AND LIANGAN RIVER

Enrico C. Paringit, Dr. Eng., Prof. Alan E. Milano, and Engr. Elizabeth Albiento

1.1 Background of the Phil-LiDAR 1 Program

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

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

The implementing partner university for the Phil-LiDAR 1 Program is the Mindanao State University - Iligan Institute of Technology (MSU-IIT). MSU-IIT 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 16 river basins in the Northern Mindanao Region. The university is located in Iligan City in the province of Lanao del Norte.

1.2 Overview of the Liangan River Basin

Liangan River is the stream that traverses the Liangan River basin. It is where Pangayawan waterfalls can be found flowing in the Municipality of Bacolod. The river basin is located in the Province of Lanao del Norte, Northern Mindanao (ph.geoview.info). The floodplain of Liangan River basin is shared by two municipalities. These municipalities include Bacolod and Maigo, Lanao del Norte. The land features of Bacolod and Maigo evenly rolls up to the Municipality of Munai. The Liangan River is where the Pangayawan waterfall is located with its three (3) tributary falls (bacolodldn.gov.ph). The flood plain barangays of Liangan River basin include Liangan West, Camp1 and Mahayahay of Maigo, Lanao del Norte, Liangan East, Alegria, Babalaya, Esperanza and Mati of Bacolod, Lanao del Norte.

Liangan river basin has an estimated area of 225.311 square kilometres and had a delineated floodplain area of 12.65 square kilometres. There were a 2,781 building features extracted within the floodplain area. According to the National Disaster Risk Reduction and Management Council (NDRRMC) on their NDRRC update on the effects of Typhoon “Pablo” (Bopha) last Decemeber 8, 2012 that there were 1,910 and 179 affected families in the municipalities of Bacolod and Maigo, Lanao del Norte respectively. This is equivalent to 9,500 persons from Bacolod and 895 persons from Maigo.

When a low pressure area hit the island of Mindanao in the eve of January 13, 2014, the municipality of Bacolod and other neighboring municipalities experienced heavy and continuous rainfall. Pre-emptive evacuation was undertaken in the flood prone barangays which were Brgy. Rupagan, Brgy. Minaulon and Brgy. Liangan East. Flood markers were constantly monitored and when an alert level was reached in the flood marker, a joint operation of the members of the MDRRMC, Bacolod Emergency Rescue Team, BFP, PNP and the 32IB Bravo Company was conducted.

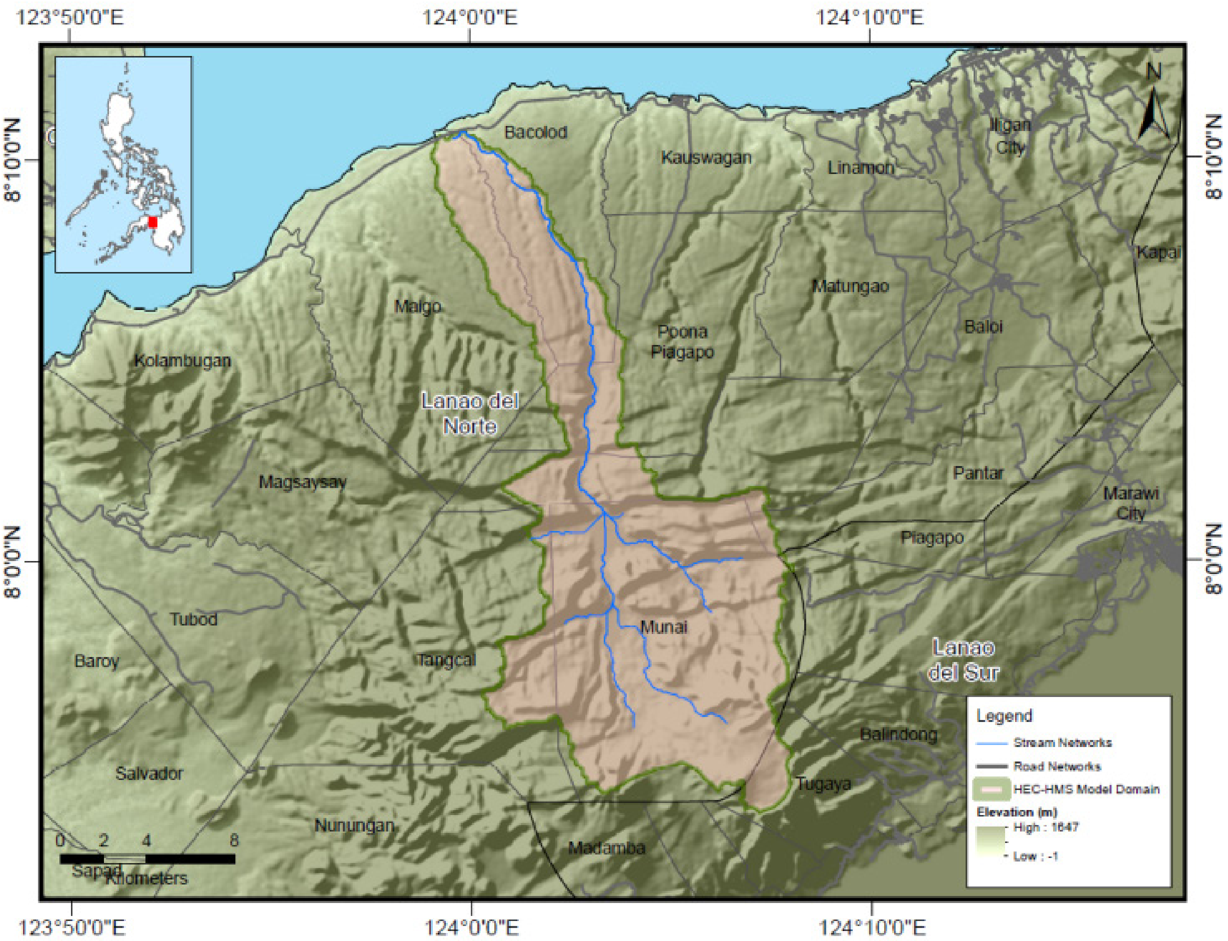

Figure 1. Map of the Liangan River Basin (in brown)

The event was then followed by tropical depression Agaton on January 20, 2014. Continuous monitoring was advised and suspension of classes in accordance to EO 66 was declared by the Local Chief Executive as the chairman of the MDRRMC. Joint monitoring effort was conducted by the MDRRMC with its own Bacolod Emergency Rescue Team and the PDRRMC. There were a total of 223 affected families or 819 persons during these events. These weather disturbances had brought also damages to houses and infrastructure with a total of Php 545,000 and Php 22,000,000 respectively.

CHAPTER 2: LIDAR DATA ACQUISITION OF THE LIANGAN FLOODPLAIN

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

2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Liangan Floodplain in Northern Mindanao. The missions were planned for 16 lines that run for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameters for the LiDAR system is found in Table 1. Figure 2 shows the flight plans for Liangan Floodplain.

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

Block Name	Flying Height (m AGL)	Overlap (%)	Field of view (ø)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK71A	1000	25	50	200	30	130	5
BLK71B	1000	25	50	200	30	130	5
BLK71C	1000	25	50	200	30	130	5
BLK71E	1000	25	50	200	30	130	5
BLK71F	1000	25	50	200	30	130	5
BLK71G	1000	25	50	200	30	130	5

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

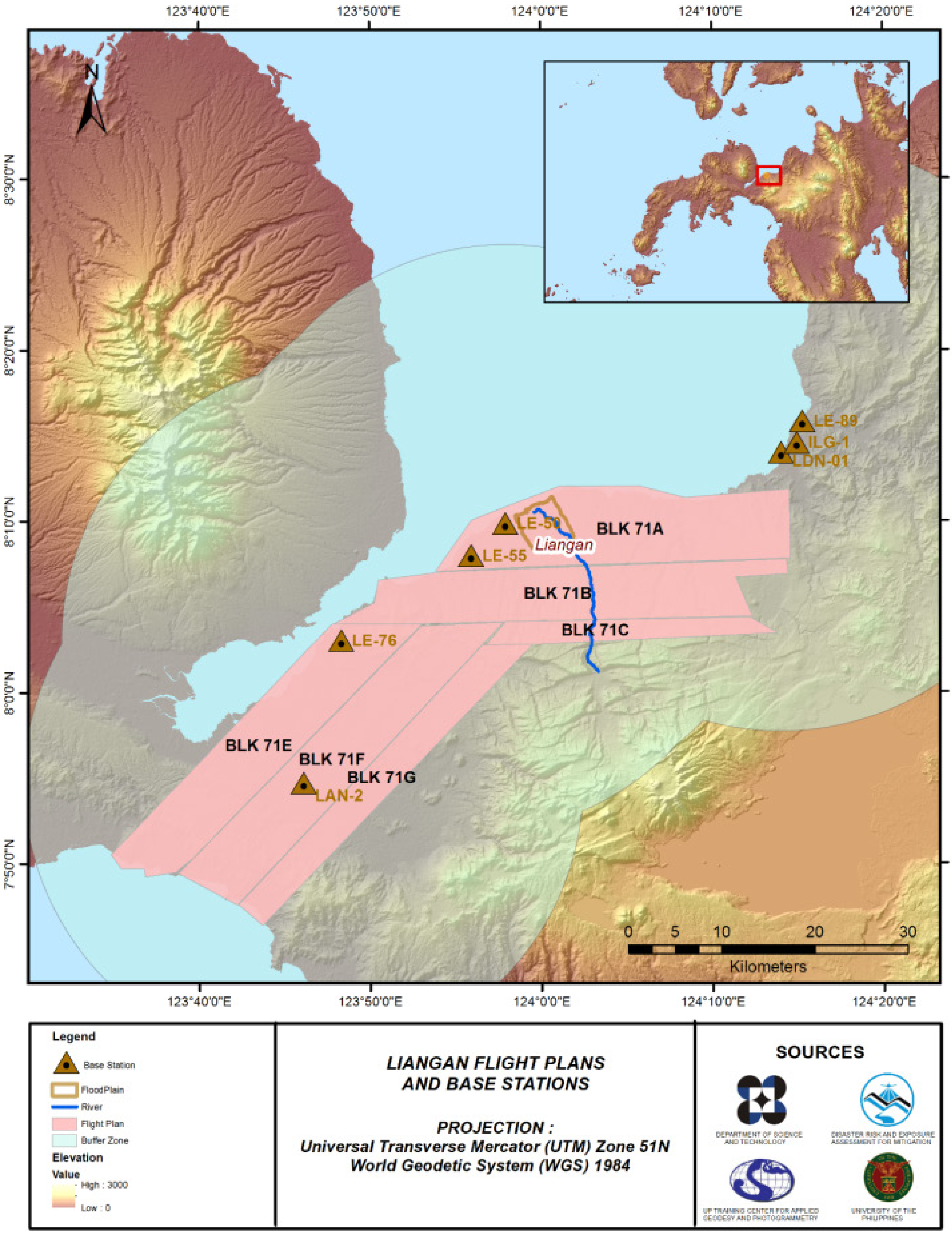
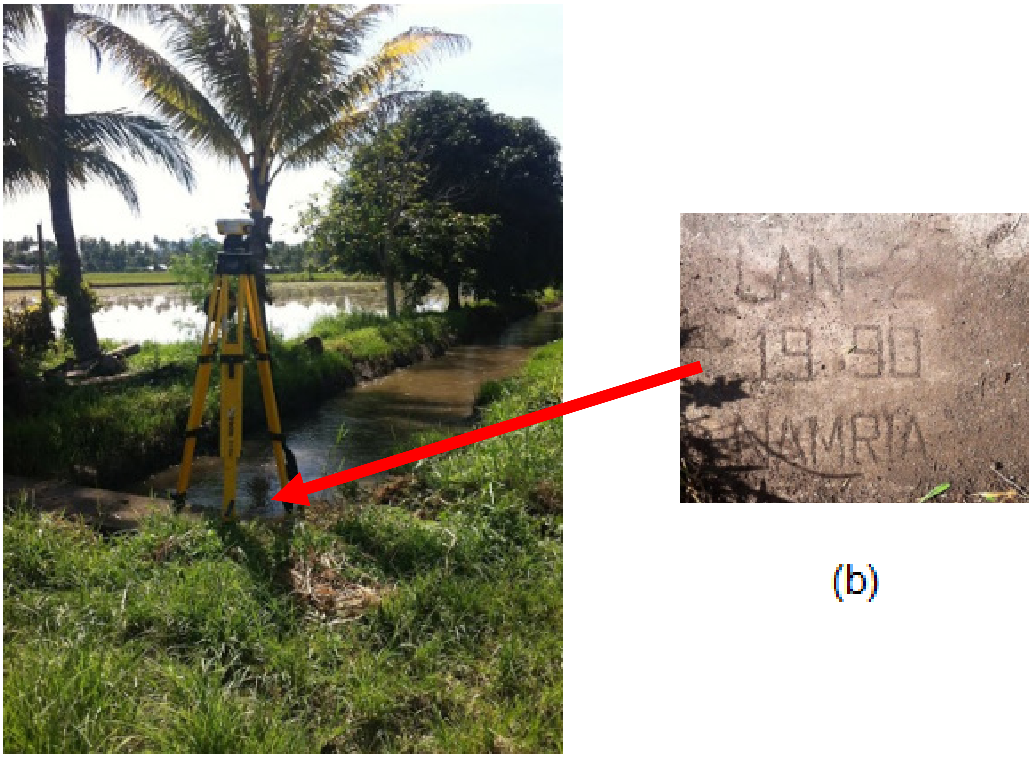


Figure 2. Flight Plan and base stations used for the Liangan Floodplain survey.

2.2 Ground Base Stations

The project team was able to recover two (2) NAMRIA horizontal ground control points: LAN-2 which is of first (1st) order accuracy and LDN-01, which is of (3rd) order accuracy. Four (4) NAMRIA benchmarks were recovered: LE-50, LE-55, LE-89, which are of first order accuracy, and LE-76 which is of second order accuracy. These benchmarks were used as vertical reference points and were also established as ground control points. The team also established reference point ILG-1. The certifications for the NAMRIA reference points and benchmarks are found in Annex 2, while the processing reports for the NAMRIA reference points, benchmarks, and established points are found in Annex 3. These were used as base stations during the flight operation for the entire duration of the survey (May 31 – July 9, 2014). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 882 and SPS 852. Flight plans and location of base stations used during the aerial LiDAR acquisition in Liangan floodplain are shown in Figure 2. The list of team members are found in Annex 4.

Figure 3 to Figure 9 show the recovered NAMRIA reference points within the area. In addition, Table 2 to Table 8 show the details about the NAMRIA control point and the established control point while Table 9 shows the list of all ground control points occupied during the acquisition together with the corresponding dates of utilization.



(a) (b)

Figure 3. GPS set-up over LAN-2 at Brgy. Pinoyak, Lala Lanao del Norte (a) and NAMRIA reference point LAN-2 (b) as recovered by the field team.

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

Station Name	**LAN-2**	
Order of Accuracy	**1st**	
Relative Error (Horizontal positioning)	**1:100,000**	
Geographic Coordinates, Philippine Reference 0f 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7° 54' 46.07859" North 123° 46' 0.85333" East 17.35400 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	364,025.74 meters 875,110.149 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	7° 54' 42.56546" North 123° 46' 6.31720" East 83.92120 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	584,533.45 meters 874,680.35 meters

(a) (b)

Figure 4. GPS set-up over LDN-01 at at the rooftop of Iligan City Philippine Port Authority Administration building, inside the Iligan City Pier compound, Iligan City (a) and NAMRIA reference point LDN-01 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point LDN-01 used as base station for the LiDAR Acquisition

Station Name	**LDN-01**	
Order of Accuracy	**3rd**	
Relative Error (Horizontal positioning)	**1:20,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	8° 14’ 1.44528” North 124° 13’ 56.94179” East 11.87000 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	415,436.191 meters 910,480.055 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	8° 13’ 57.88944” North 124° 14’ 2.37264” East 78.9500 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	635,751.93 meters 910,289.41 meters

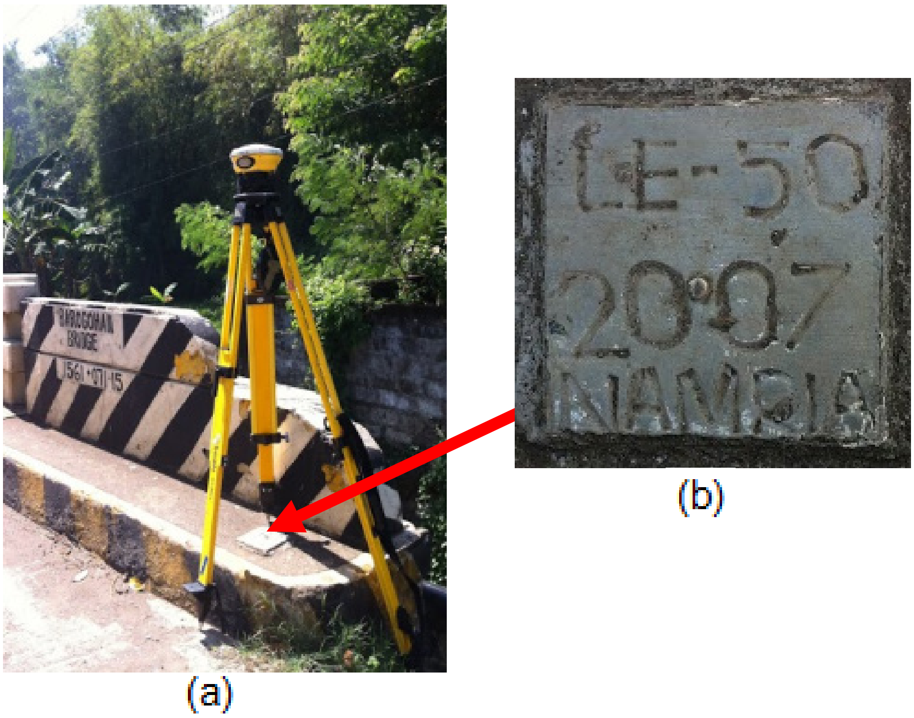


Figure 5. GPS set-up over LE-50 at Barogohan Bridge and at the NE of the Covenant Baptist Church, Maigo, Lanao del Norte (a) and NAMRIA reference point LE-50 (b) as recovered by the field team.

Table 4. Details of the recovered NAMRIA vertical control point LE-50 used as base station for the LiDAR Acquisition with established coordinates.

Station Name	LE-50	
Order of Accuracy	**1st**	
Relative Error (horizontal positioning)	**1:100,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	8° 09' 54.972" North North 123° 57' 50.357" East 6.91 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	8° 09' 51.11024" North 123° 57' 55.36634" East 73.452 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	606,345.902 meters 902,577.426 meters

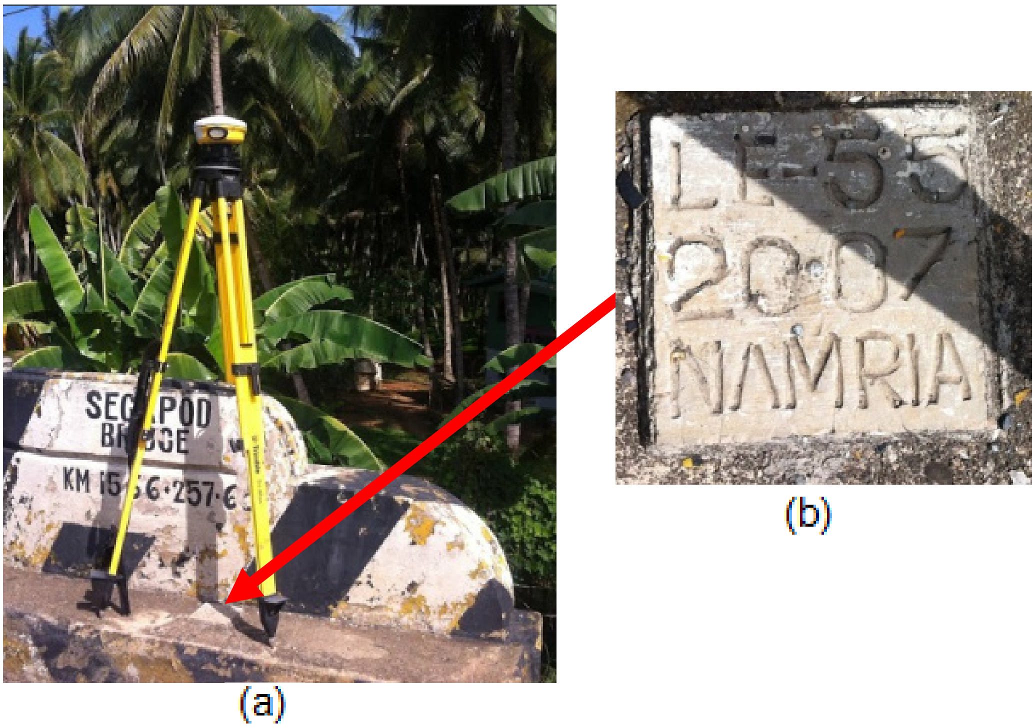
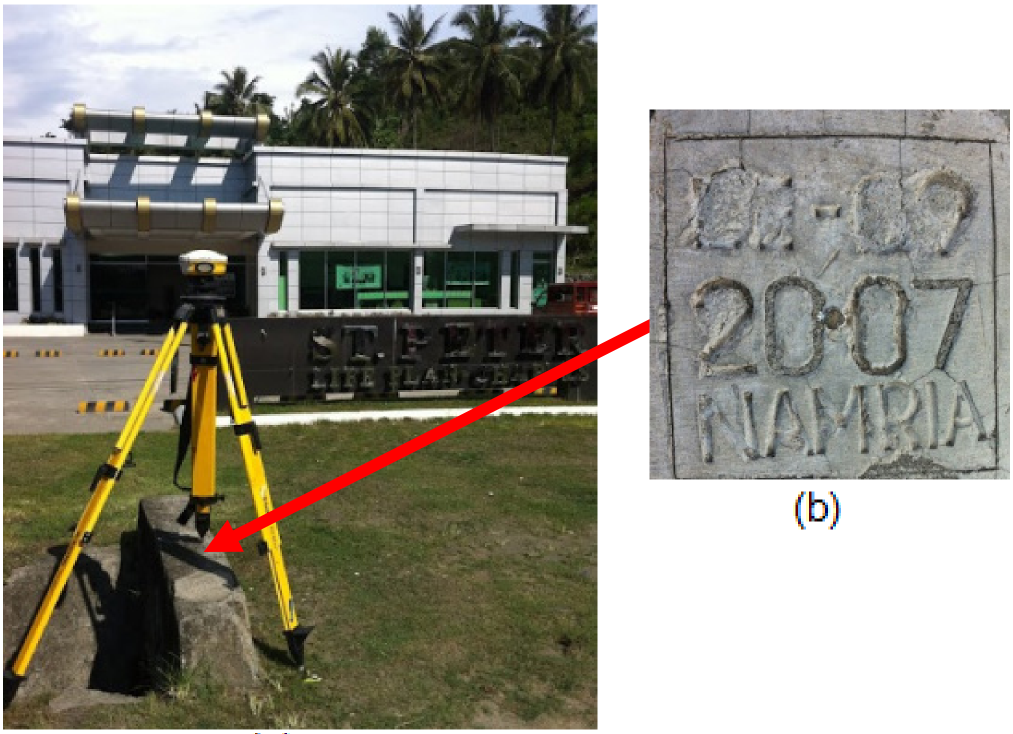


Figure 6. GPS set-up over LE-55 at Segapod Bridge, Brgy. Segapod, Maigo, Lanao del Norte (a) and NAMRIA reference point LE-55 (b) as recovered by the field team.

Table 5. Details of the recovered NAMRIA vertical control point LE-50 used as base station for the LiDAR Acquisition with established coordinates.

Station Name	LE-55	
Order of Accuracy	1st	
Relative Error (horizontal positioning)	1:100,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	8° 08' 3.015" North 123° 55' 49.058" East 8.48 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	8° 07' 59.16191" North 123° 55' 54.06681" East 75.001 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	602,641.751 meters 899,130.439 meters



(b)

(a)

Figure 7. GPS set-up over LE-89 in front of St. Peter Life Plan Chapel of Iligan City, Lanao del Norte (a) and NAMRIA reference point LE-55 (b) as recovered by the field team.

Table 6. Details of the recovered NAMRIA vertical control point LE-89 used as base station for the LiDAR Acquisition with established coordinates.

Station Name	LE-89	
Order of Accuracy	**3rd**	
Relative Error (horizontal positioning)	**1:20,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	8° 15’ 51.715” North 124° 15’ 12.365” East 6.39 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	8° 15’ 47.82322” North 124° 15’ 17.37373” East 73.451 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	638,201.305 meters 913,622.047 meters

(a)

(b)

Figure 8. GPS set-up over LE-76 at Bulod Bridge footwalk of Brgy. Bulod, Tubud, Lanao del Norte (a) and NAMRIA reference point LE-76 (b) as recovered by the field team.

Table 7. Details of the recovered NAMRIA vertical control point LE-89 used as base station for the LiDAR Acquisition with established coordinates.

Station Name	**LE-76**	
Order of Accuracy	**1st**	
Relative Error (horizontal positioning)	**1:100,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	8° 03’ 05.36825” North 123° 48’ 12.37307”East 9.355 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	8° 03’ 01.82183” North 123° 48’ 17.82405” East 75.717 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	588,530.790 meters 890,021.013 meters

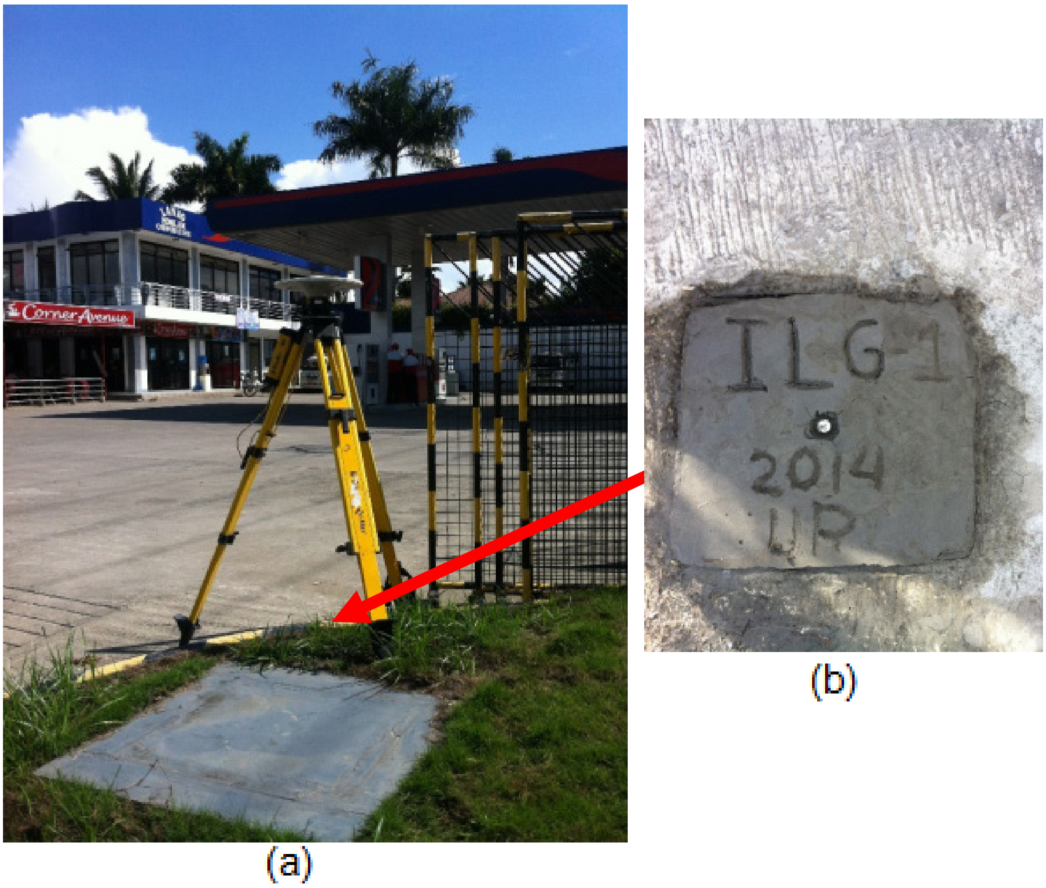


Figure 9. GPS set-up over ILG-1 at Iligan City (a) and reference point ILG-1 (b) as established by the field team.

Table 8. Details of the established reference point ILG-1 used as base station for the LiDAR Acquisition.

Station Name	ILG-1	
Order of Accuracy	3rd	
Relative Error (horizontal positioning)	1:20,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	8°14’35.60437” North 124°14’52.86635” East 6.546 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Easting Northing Ellipsoidal Height	8°14’32.04743” North 124°14’58.29621” East 73.645 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Latitude Longitude	637,459.968 meters 911,343.882 meters

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

Date Surveyed	Flight Number	Mission Name	Ground Control Points
May 31, 2014	1533P	1BLK71A151A	ILG-1, LE-89
June 2, 2014	1541P	1BLK71B153A	ILG-1, LE-89
June 27, 2014	1643P	1BLK67ABS178B	LDN-01, LE-89
June 28, 2014	1645P	1BLK71C179A	LE-50, LE-55
July 8, 2014	1685P	1BLK71S189A	LE-50, LAN-2
July 8, 2014	1687P	1BLK71S189B	LE-50, LAN-2
July 9, 2014	1689P	1BLK71S190A	LE-50, LE-76

2.3 Flight Missions

Seven (7) missions were conducted to complete the LiDAR Data Acquisition in Liangan Floodplain, for a total of twenty-six hours and seventeen minutes (26+17) of flying time for RP-C9022. All missions were acquired using the Pegasus LiDAR system. Table 10 shows the total area of actual coverage and the corresponding flying hours per mission, while 11 presents the actual parameters used during the LiDAR data acquisition.

Table 10. Flight missions for the LiDAR data acquisition of the Liangan Floodplain.

Date Surveyed	Flight Number	Flight Plan Area (km2)	Surveyed Area (km2)	Area Surveyed within the Floodplain (km2)	Area Surveyed Outside the Floodplain (km2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
May 31, 2014	1533P	265.97	176.59	21.34	155.24	609	4	47
June 2, 2014	1541P	503.06	270.90	1.40	269.50	275	4	47
June 27, 2014	1643P	265.97	37.02	0.00	37.02	787	1	59
June 28, 2014	1645P	566.66	200.60	0.38	200.23	741	4	11
July 8, 2014	1685P	258.45	158.49	0.00	158.49	569	4	5
July 8, 2014	1687P	329.56	57.29	2.97	54.32	NA	2	11
July 9, 2014	1689P	1197.60	240.77	0.00	240.77	NA	4	17
TOTAL	**3387.27**	**1141.65**	**26.09**	**1115.56**	**2981**	**26**	**17**	

Table 11. Actual parameters used during the LiDAR data acquisition of the Liangan Floodplain.

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (khz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
1533P	800	25	50	200	30	110-130	5
1541P	800	25	50	200	30	110-130	5
1643P	800	25	50	200	30	110-130	5
1645P	800	25	50	200	30	110-130	5
1685P	800	25	50	200	30	110-130	5
1687P	800	25	50	200	30	110-130	5
1689P	800	25	50	200	30	110-130	5

2.4 Survey Coverage

Liangan floodplain is located in the province of Lanao del Norte covering parts of Bacolod and Maigo. The list of municipalities/cities surveyed in these provinces during the LiDAR acquisition is shown in Table 12. In Figure 10, the actual coverage of the LiDAR acquisition for Liangan floodplain is shown.

Table 12. List of municipalities and cities surveyed during the Liangan Floodplain LiDAR survey.

Province	Municipality/ City	Area of Municipality/ City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Lanao del Norte	Kauswagan	45.08	45.07	100%
	Linamon	22.21	22.20	100%
	Matungao	52.50	52.46	100%
	Bacolod	62.26	62.10	100%
	Maigo	126.36	119.42	95%
	Poona Piagapo	88.11	82.58	94%
	Kolambugan	70.70	65.14	92%
	Baloi	65.18	52.68	81%
	Lala	125.18	62.94	50%
	Baroy	62.08	21.68	35%
	Pantao Ragat	71.36	23.57	33%
	Magsaysay	83.06	23.75	29%
	Tubod	121.95	30.83	25%
	Pantar	50.19	7.30	15%
	Tagoloan	25.06	2.87	11%
	Sultan Naga Dimaporo	143.65	13.60	9%
	Iligan City	650.87	43.08	7%
	Tangcal	118.94	0.14	0%
Lanao del Sur	Kapatagan	184.76	77.45	42%
Misamis Oriental	Laguindingan	37.87	0.00	0%
Zamboanga del Sur	Tukuran	119.01	35.59	30%
	Aurora	162.22	43.79	27%
	Labangan	176.44	0.51	0%
TOTAL		**2665.04**	**888.75**	**33.35%**

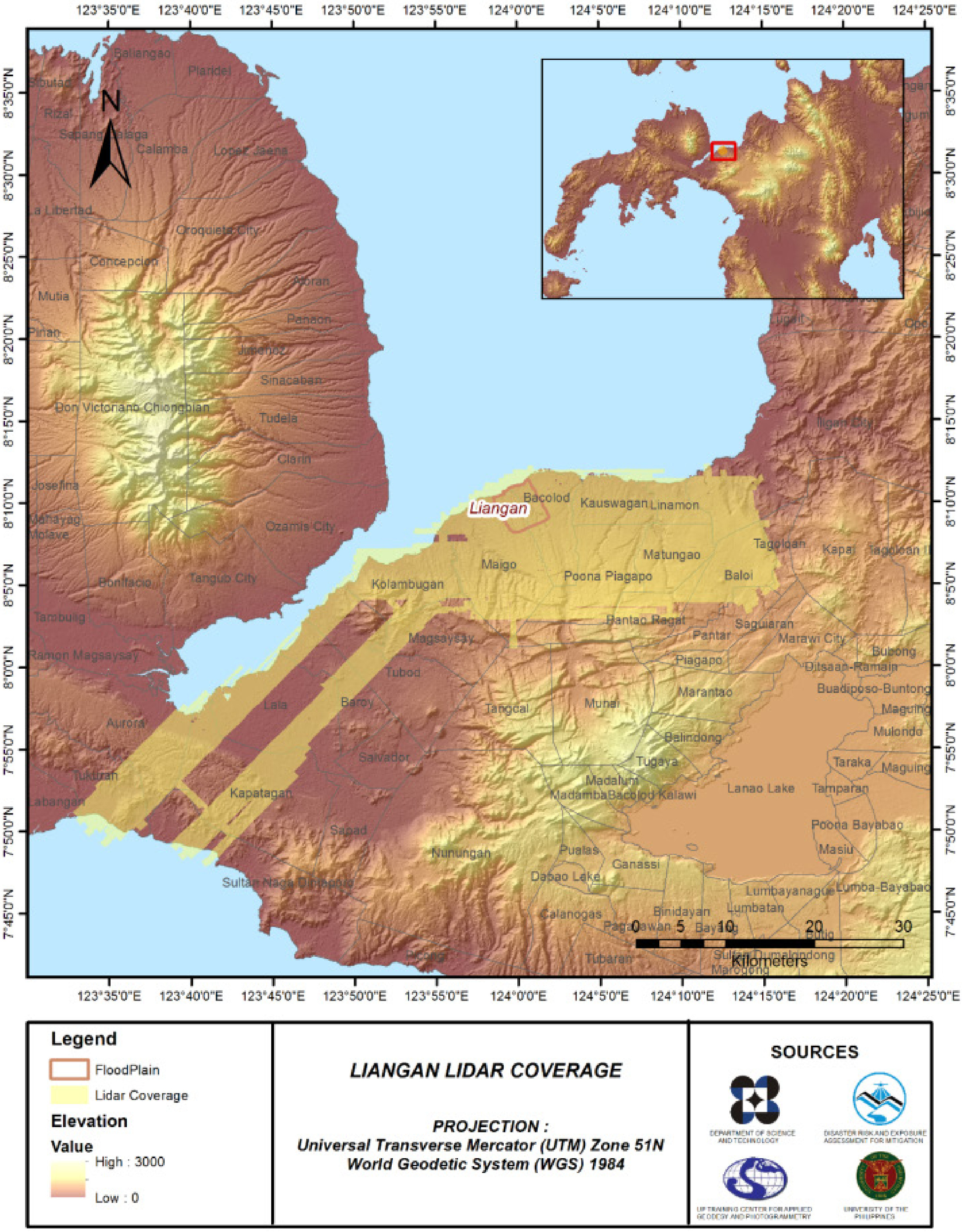


Figure 10. Actual LiDAR data acquisition for Liangan Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE LIANGAN FLOODPLAIN

Engr. Ma. Rosario Concepcion O. Ang, Engr. John Louie D. Fabila, Engr. Sarah Jane D. Samalburo, Engr. Joida F. Prieto, Engr. Harmond F. Santos, Ma. Ailyn L. Olanda, Engr. Chelou P. Prado, Engr. James Kevin M. Dimaculangan, Engr. Jommer M. Medina, and John Arnold C. Jaramilla

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 11.

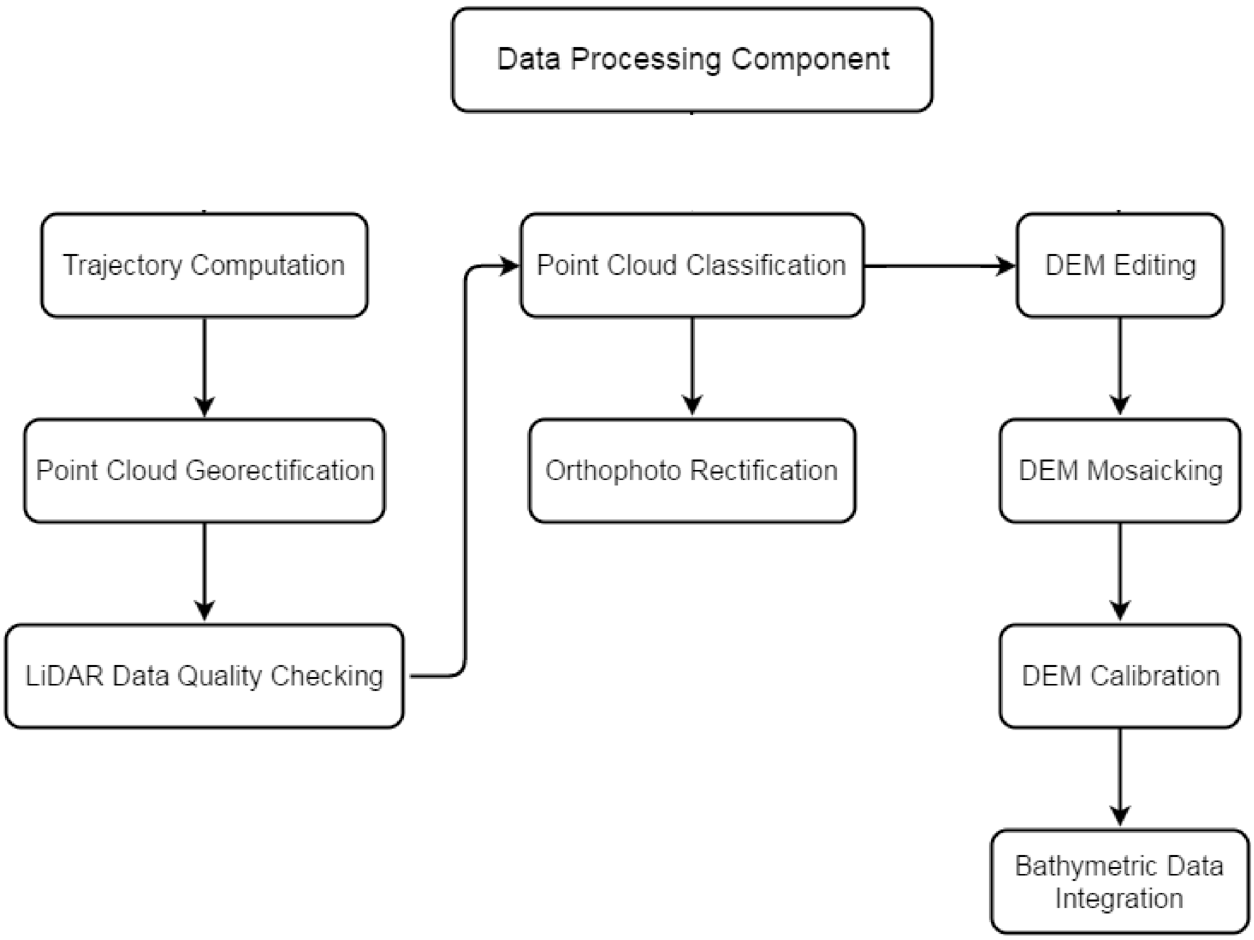


Figure 11. Schematic diagram for Data Pre-Processing Component.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Liangan floodplain can be found in Annex 5. Data Transfer Sheets. Missions flown during all the three surveys conducted on April 2013, May 2014 and June 2014 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus system over Bacolod and Maigo, Lanao del Norte.

The Data Acquisition Component (DAC) transferred a total of 537.56 Gigabytes of Range data, 5.1 Gigabytes of POS data, 183.25 Megabytes of GPS base station data, and 653.56 Gigabytes of raw image data to the data server on April 28, 2013 for the first survey, June 8, 2014 for the second survey and June 28, 2014 for the third survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Liangan was fully transferred on August 1, 2014, as indicated on the Data Transfer Sheets for Liangan floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metric parameters of the computed trajectory for flight 1533P, one of the Liangan flights, which is the North, East, and Down position RMSE values are shown in Figure 12. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on May 31, 2014 00:00 AM. The y-axis is the RMSE value for that particular position.

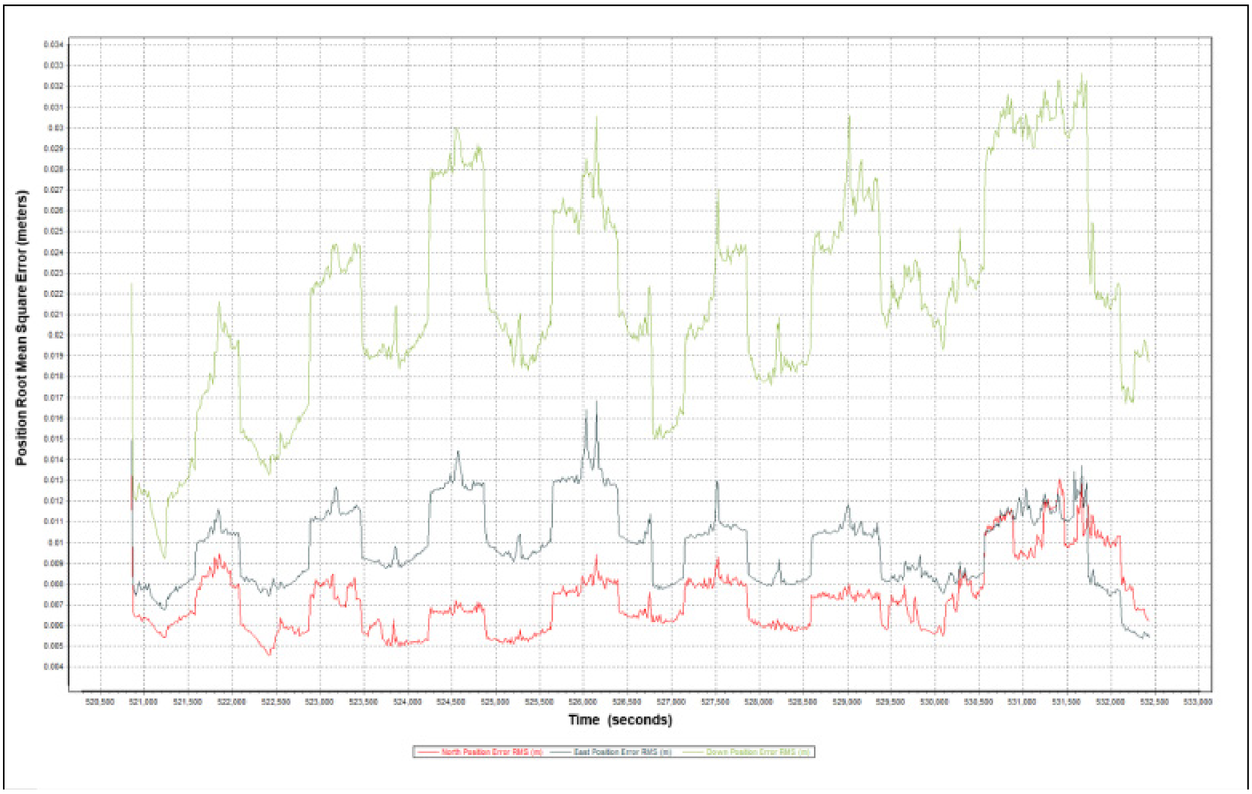


Figure 12. Smoothed Performance Metric Parameters of Liangan Flight 1533P

The time of flight was from 520500 seconds to 532500 seconds, which corresponds to afternoon of May 31, 2014. 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 12 shows that the North position RMSE peaks at 2.40 centimeters, the East position RMSE peaks at 2.80 centimeters, and the Down position RMSE peaks at 4.60 centimeters, which are within the prescribed accuracies described in the methodology.

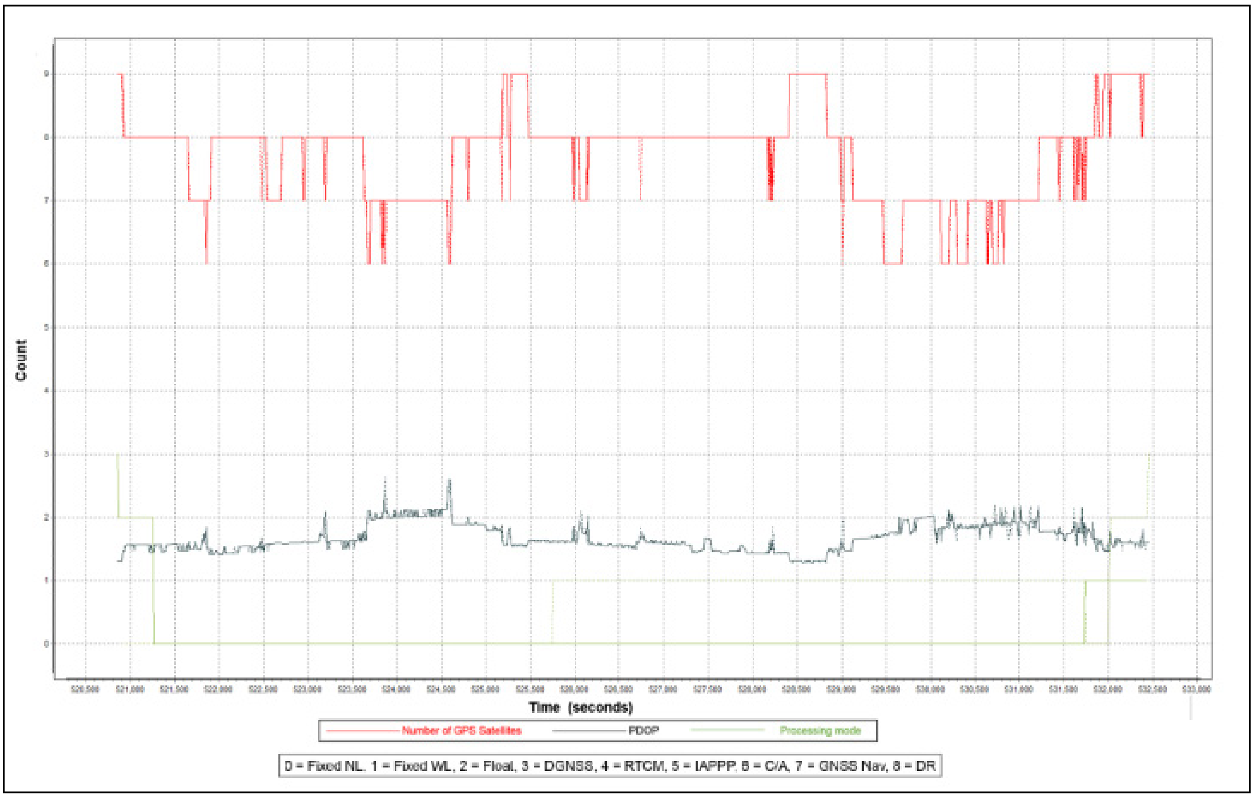


Figure 13. Solution Status Parameters of Liangan Flight 1533P

The Solution Status parameters of flight 1533P, one of the Liangan flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 13. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Majority of the time, the number of satellites tracked was between 6 and 9. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode stayed at the value of 0 for majority of the survey with some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Liangan flights is shown in Figure 14.

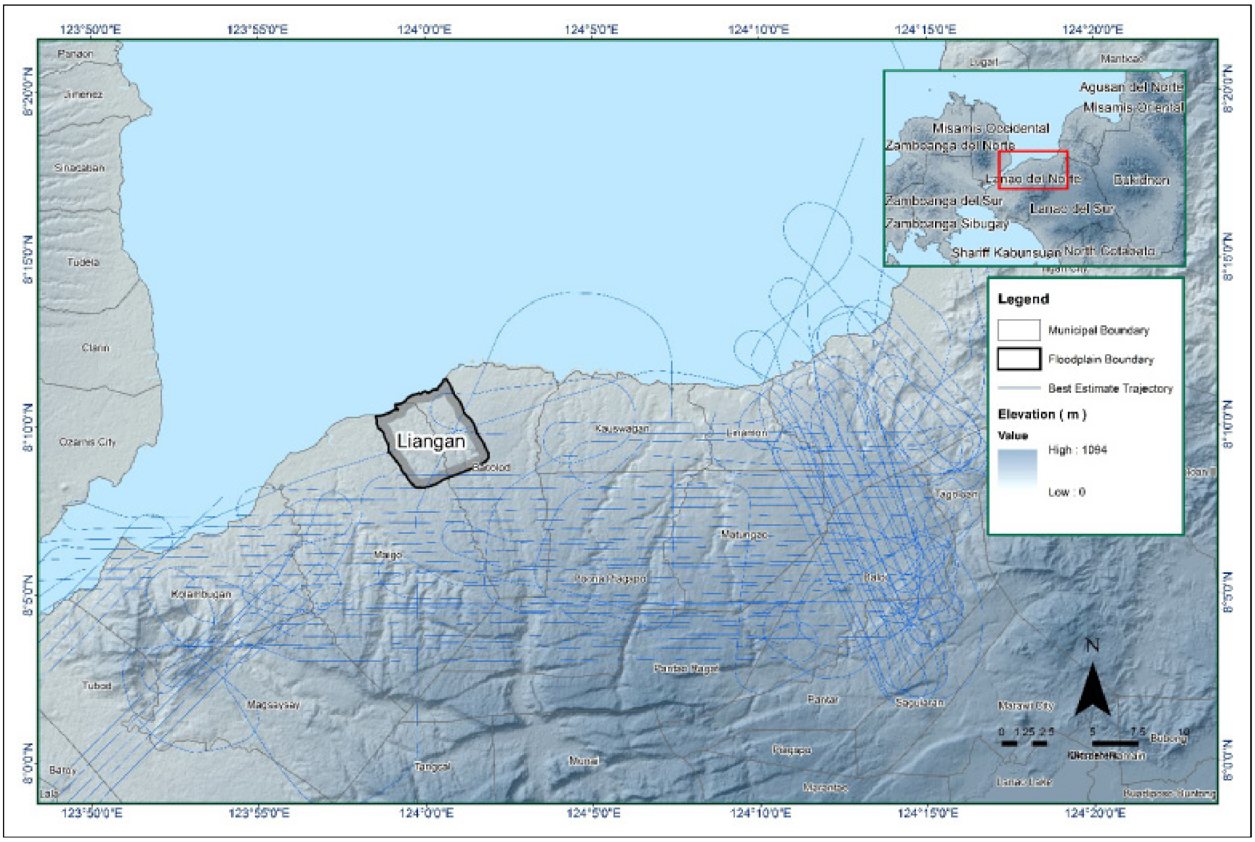


Figure 14. Best Estimated Trajectory of the LiDAR missions conducted over the Liangan Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 210 flight lines, with each flight line containing two channel, since the Pegasus system contains two channels. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Liangan floodplain are given in Table 11.

Table 11. Self-calibration Results values for Liangan flights.

Parameter	Acceptable Value	Computed Value
Boresight Correction (stdev)	<0.001degrees	0.000257
IMU Attitude Correction Roll and Pitch Correction (stdev)	<0.001degrees	0.001011
GPS Position Z-correction (stdev)	<0.01meters	0.0091

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

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Liangan Floodplain is shown in Figure 15. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

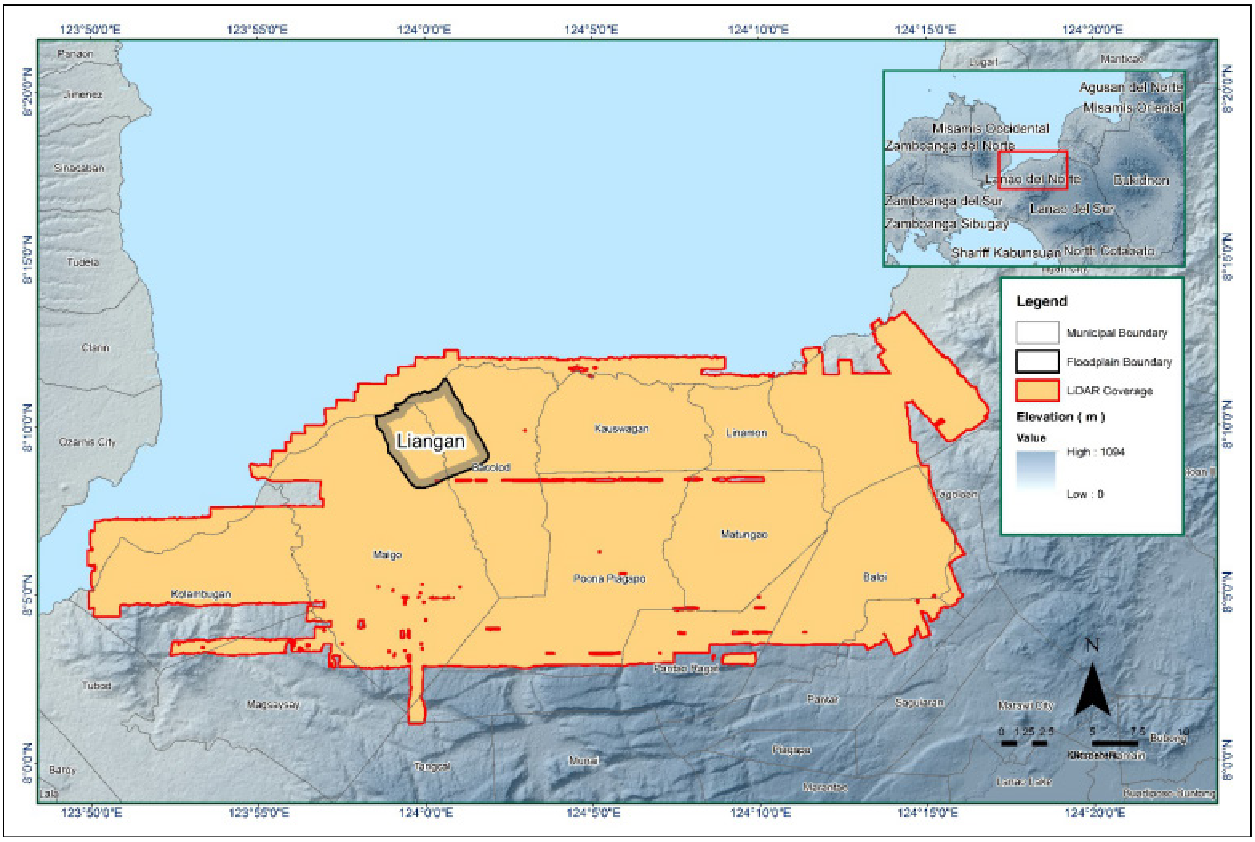


Figure 15. Boundary of the processed LiDAR data over Liangan Floodplain

The total area covered by the Liangan missions is 637.50 sq.km that is comprised of seven (7) flight acquisitions grouped and merged into three (3) blocks as shown in Table 12.

Table 12. List of LiDAR blocks for Liangan Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
NorthernMindanao_Blk71ABC	1533P	591.39
	1541P	
	1643P	
	1645P	
	1685P	
	1689P	
NorthernMindanao_Blk71ABC_additional	1687P	18.15
NorthernMindanao_Blk71B_supplement	1541P	27.96
TOTAL		**637.50 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 16. Since the Pegasus system employs two channels, we would expect an average value of 2 (blue) for areas where there is limited overlap, and a value of 3 (yellow) or more (red) for areas with three or more overlapping flight lines.

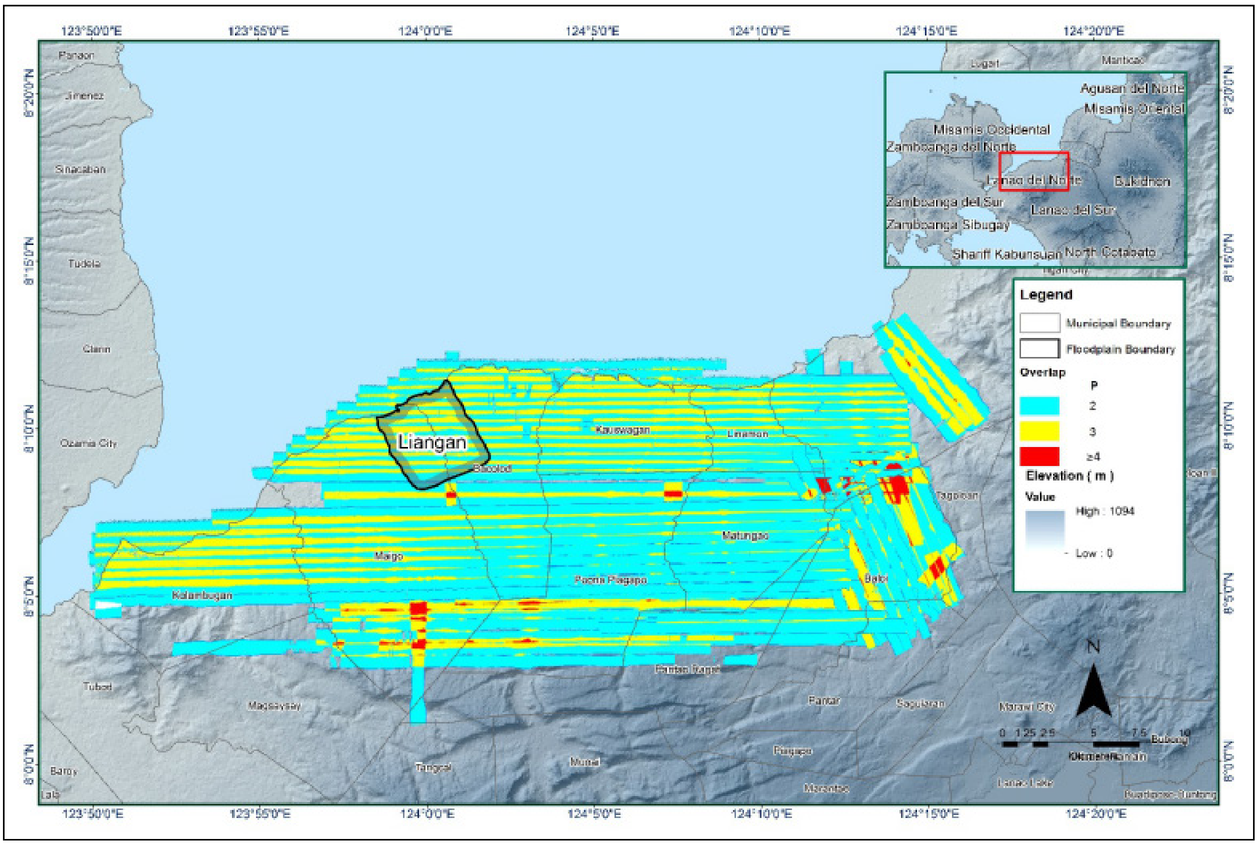


Figure 16. Image of data overlap for Liangan Floodplain.

The overlap statistics per block for the Liangan floodplain can be found in Annex 8. Mission Summary Reports. It should be noted that one pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 30.74% and 50.18% respectively, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 17. It was determined that all LiDAR data for Liangan floodplain satisfy the point density requirement, and the average density for the entire survey area is 4.12 points per square meter.

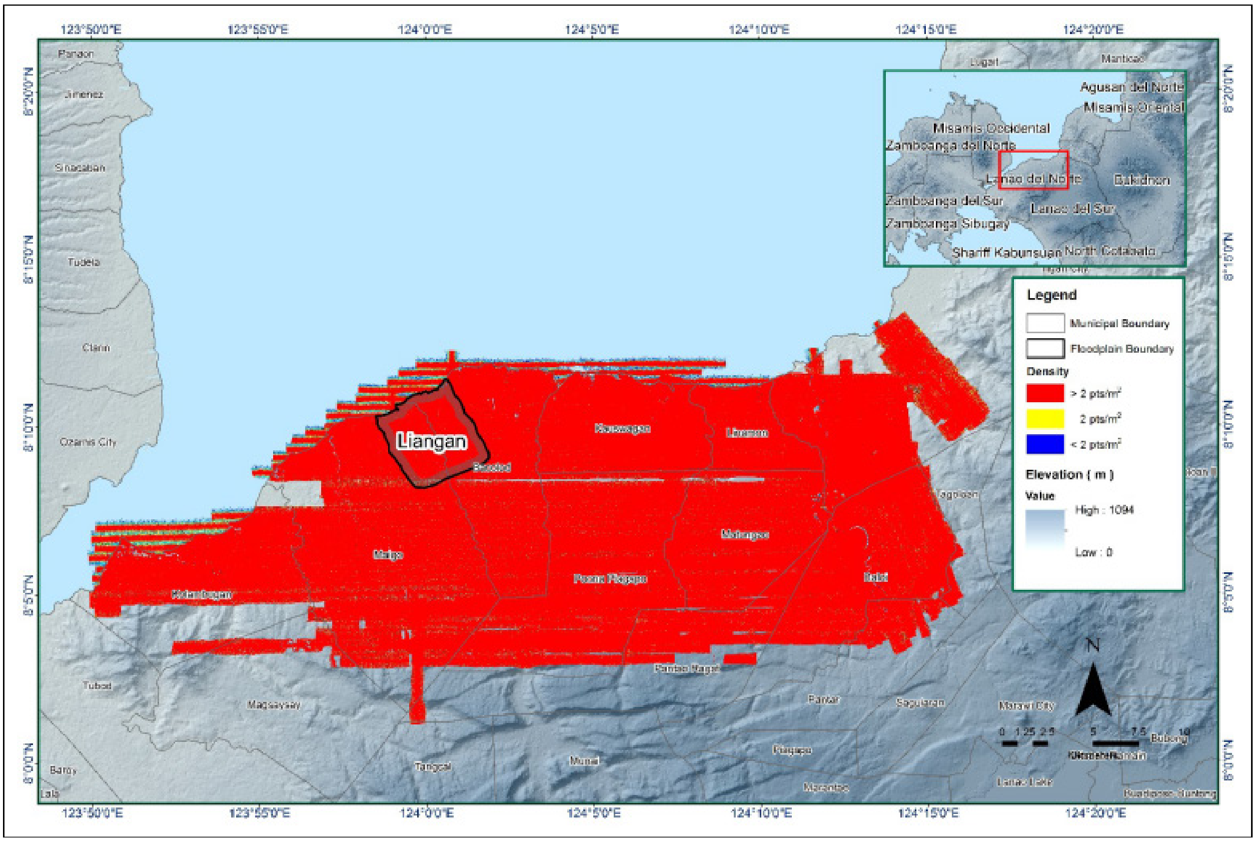


Figure 17. Pulse density map of merged LiDAR data for Liangan Floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 18. 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.

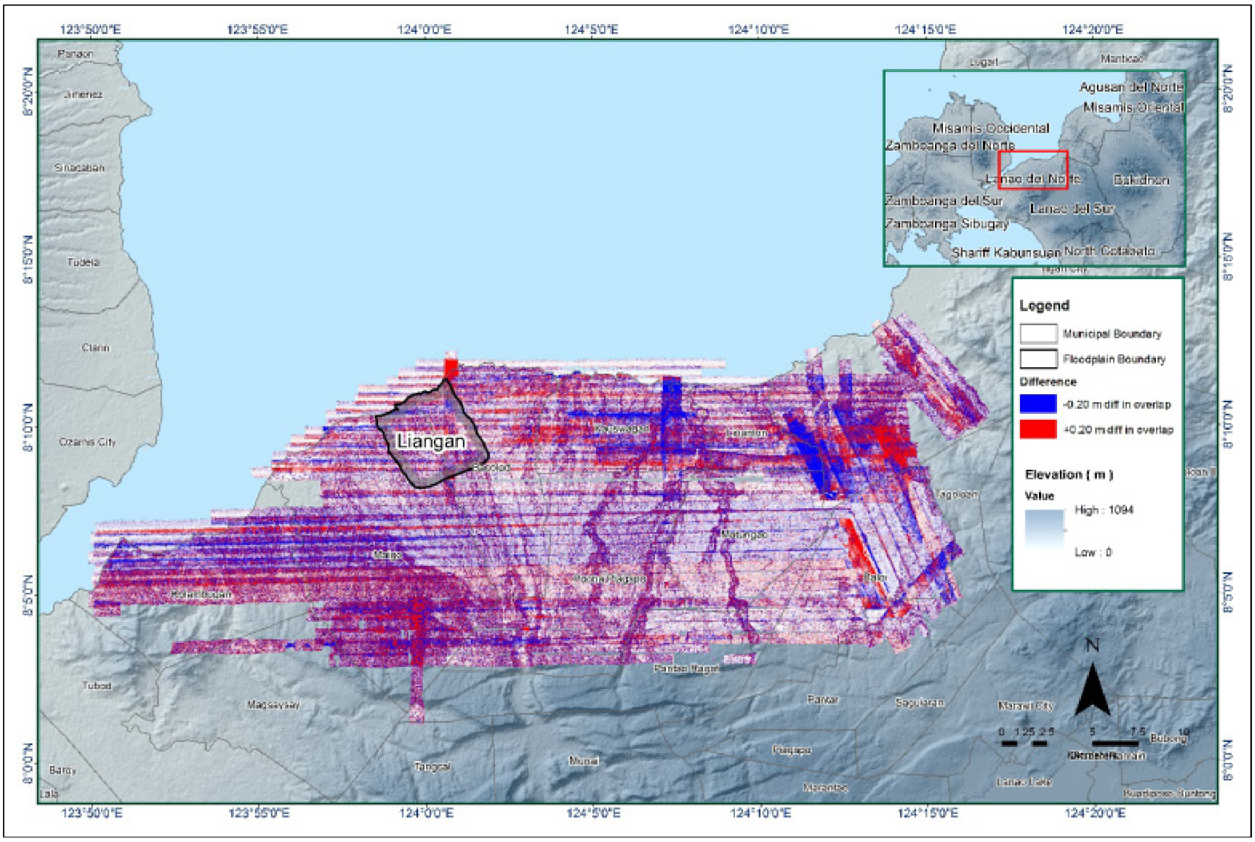


Figure 18. Elevation Difference Map between flight lines for Liangan Floodplain Survey.

A screen capture of the processed LAS data from a Liangan flight 1533P loaded in QT Modeler is shown in Figure 19. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed yellow line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

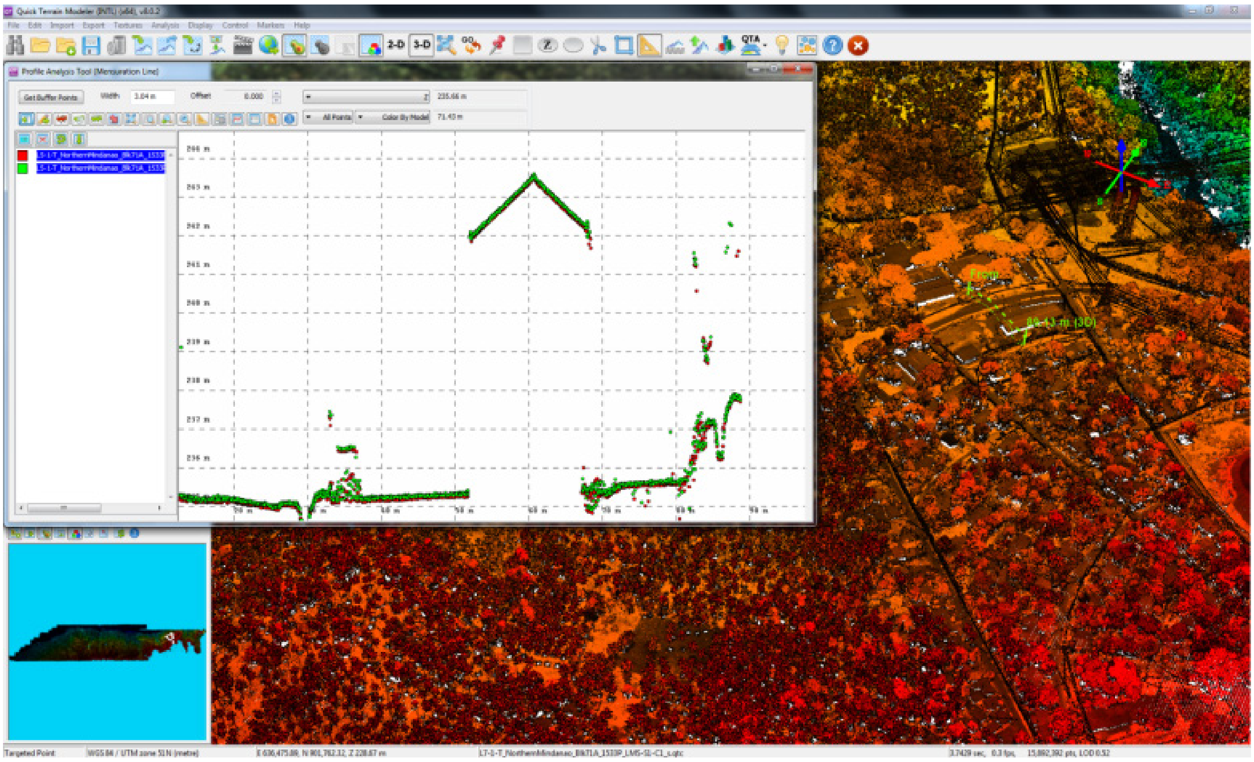


Figure 19. Quality checking for Liangan flight 1533P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 13. Silaga classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	971,394,571
Low Vegetation	1,183,110,947
Medium Vegetation	1,755,029,232
High Vegetation	1,519,151,675
Building	46,382,771

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Liangan floodplain is shown in Figure 20. A total of 1,421 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 13. The point cloud has a maximum and minimum height of 951.89 meters and 65.97 meters respectively.

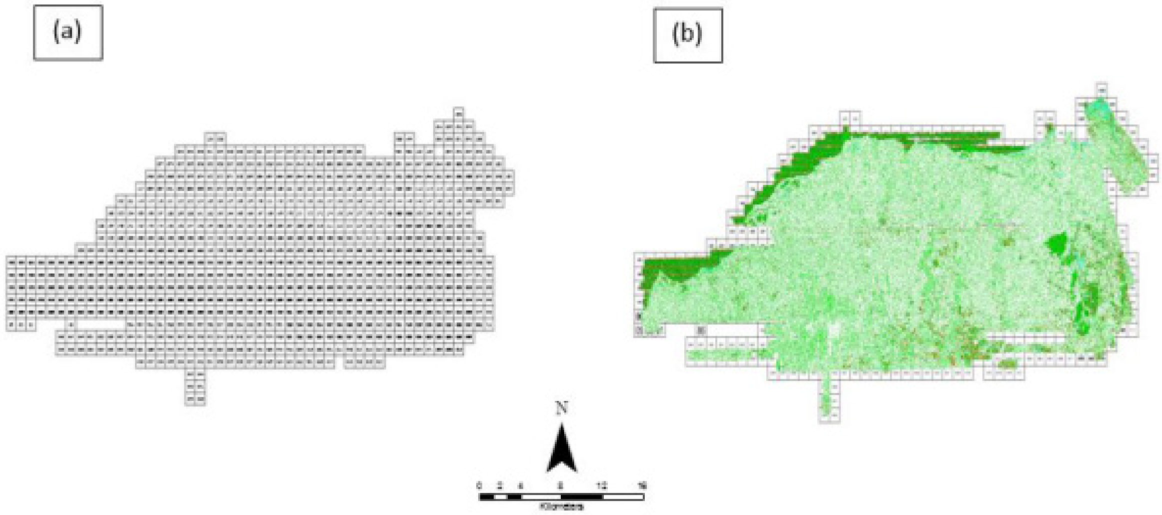


Figure 20. Tiles for Liangan Floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 21. The ground points are in orange, the vegetation is in different shades of green, and the buildings are in cyan. It can be seen that residential structures adjacent or even below canopy are classified correctly, due to the density of the LiDAR data.

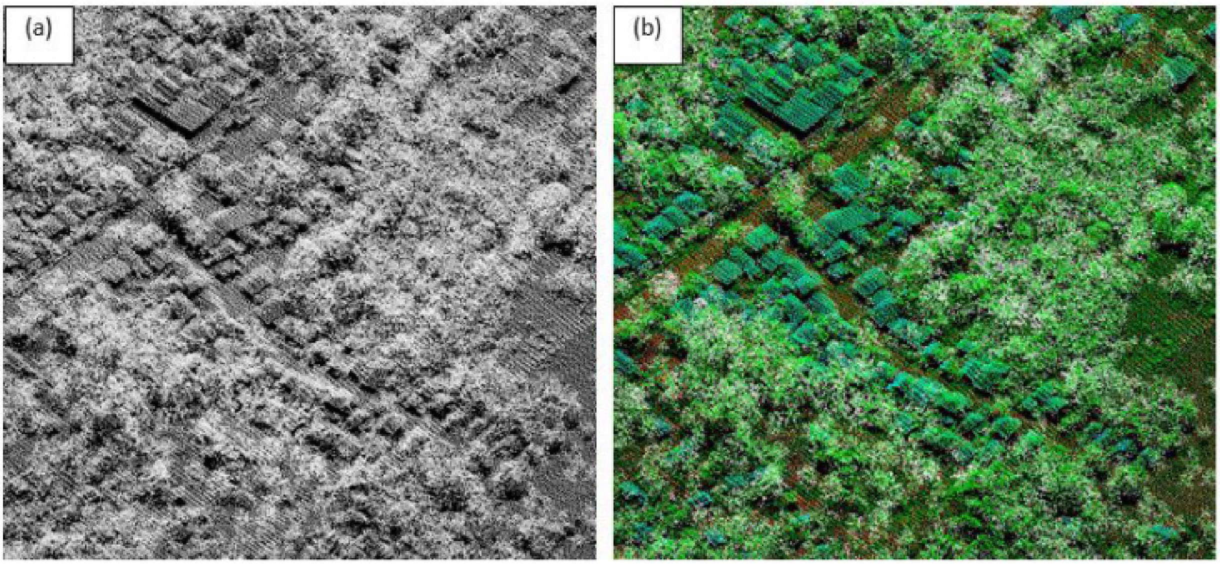


Figure 21. Point cloud before (a) and after (b) classification

The production of last return (V_ASCII) and the secondary (T_ ASCII) DTM, first (S_ ASCII) and last (D_ ASCII) return DSM of the area in top view display are shown in Figure 22. It shows that DTMs are the representation of the bare earth while on the DSMs, all features are present such as buildings and vegetation.

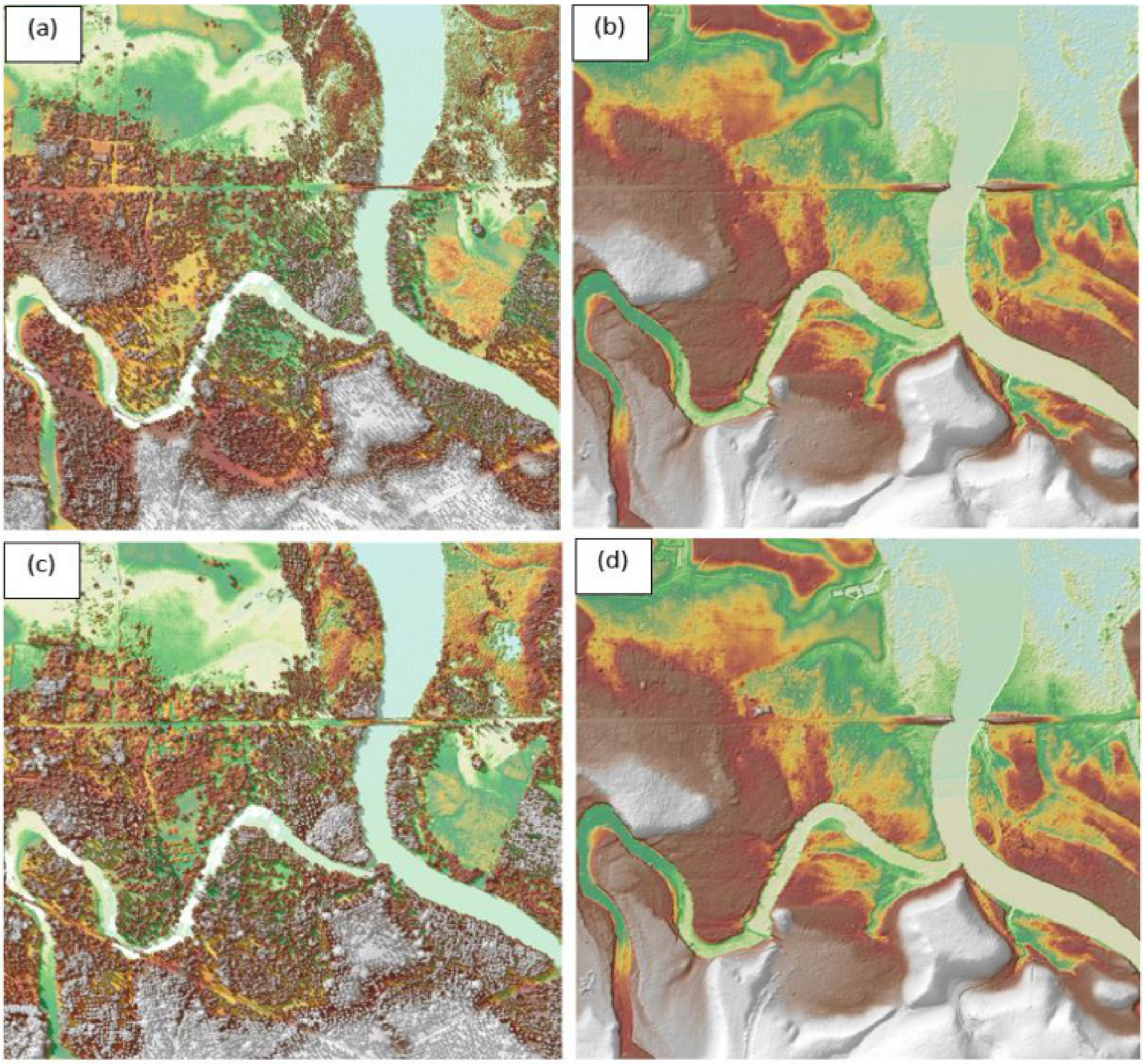


Figure 22. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Liangan Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 514 1km by 1km tiles area covered by Liangan floodplain is shown in Figure 23. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Liangan floodplain has a total of 325.04 sq.km orthophotogaph coverage comprised of 2,154 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 24.

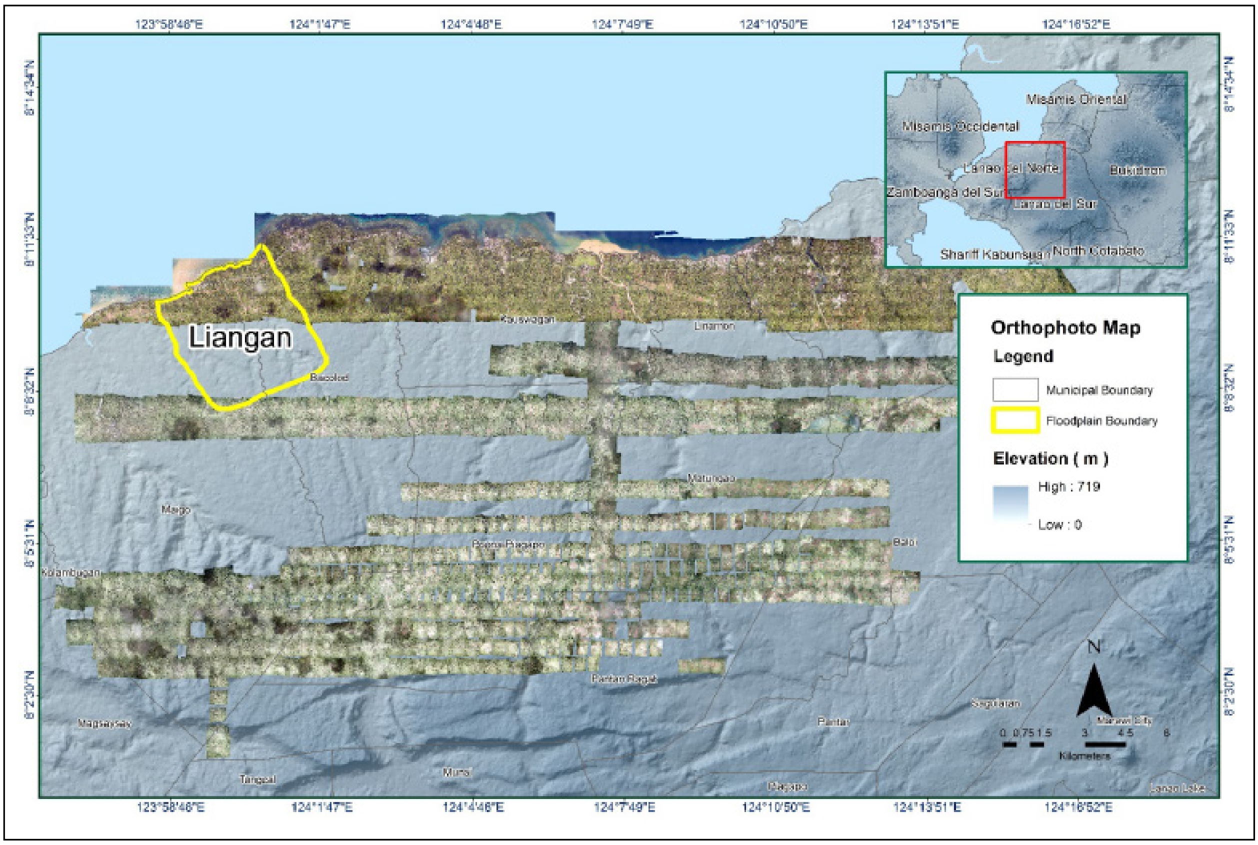


Figure 23. Liangan Floodplain with the available orthophotographs.

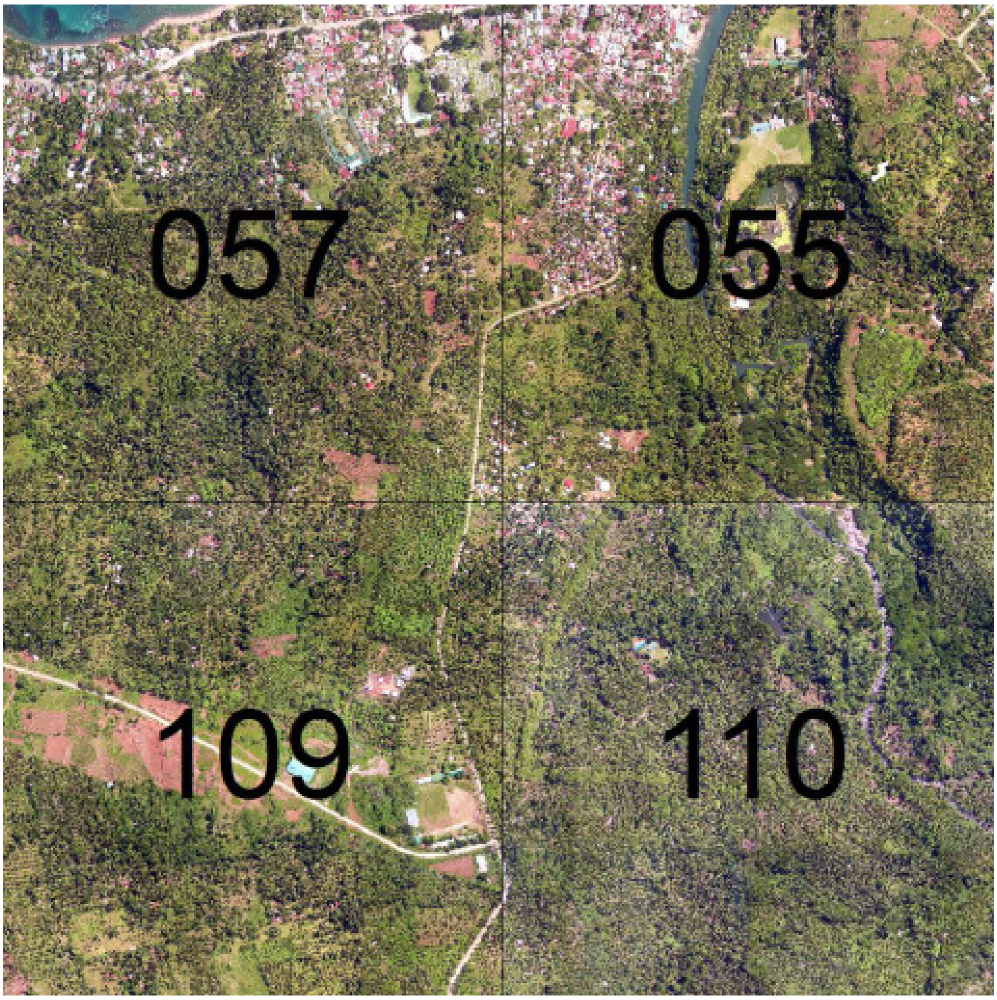


Figure 24. Sample orthophotograph tiles for Liangan Floodplain.

3.8 DEM Editing and Hydro-Correction

Three (3) mission blocks were processed for Liangan flood plain. These blocks are composed of NorthernMindanao blocks with a total area of 637.50 square kilometers. Table 14 shows the name and corresponding area of each block in square kilometers.

Table 14. LiDAR blocks with its corresponding areas.

LiDAR Blocks	Area (sq.km)
NorthernMindanao_Blk71ABC	591.39
NorthernMindanao_Blk71B_supplement	27.96
NorthernMindanao_Blk71ABC_additional	18.15
TOTAL	**637.50 sq. km**

Portions of DTM before and after manual editing are shown in Figure 25. The bridge (Figure 25) is considered to be an impedance to the flow of water along the river and has to be removed (Figure 25b) in order to hydrologically correct the river. The river embankment (Figure 25c) has been misclassified and removed during classification process and has to be retrieved to complete the surface (Figure 25d) to allow the correct flow of water.

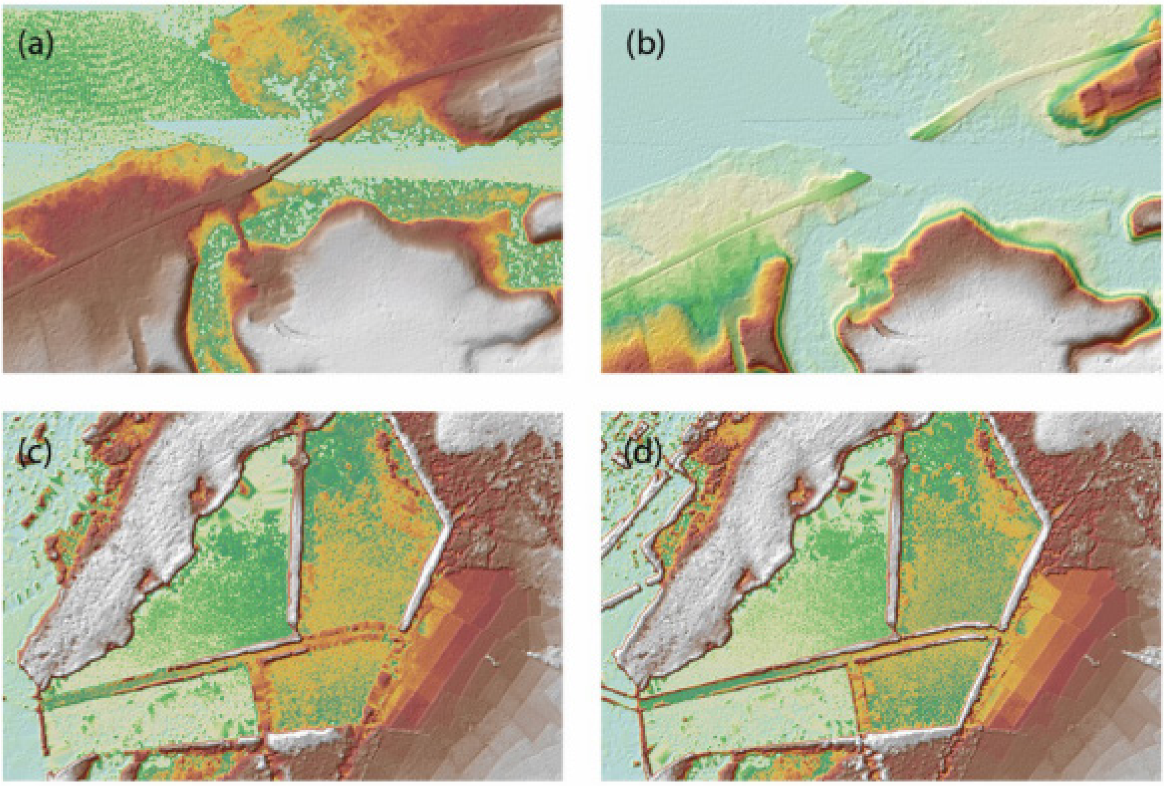


Figure 25. Portions in the DTM of Liangan Floodplain – a bridge before (a) and after (b) manual editing; a paddy field before (c) and after (d) data retrieval.

3.9 Mosaicking of Blocks

NorthernMindanao_Blk71ABC was used as the reference block at the start of mosaicking because it has the largest area among the four missions. The shift values applied to each LiDAR block during mosaicking is shown in Table 15.

Mosaicked LiDAR DTM for Liangan floodplain is shown in Figure 26. It can be seen that the entire Liangan floodplain is 99.70% covered by LiDAR data.

Table 15. Shift values of each LiDAR block of Liangan Floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
NorthernMindanao_Blk71ABC	0.00	0.00	0.00000
NorthernMindanao_Blk71B_supplement	0.00	0.00	0.00000
NorthernMindanao_Blk71ABC_additional	-3.25	10.70	-10.44

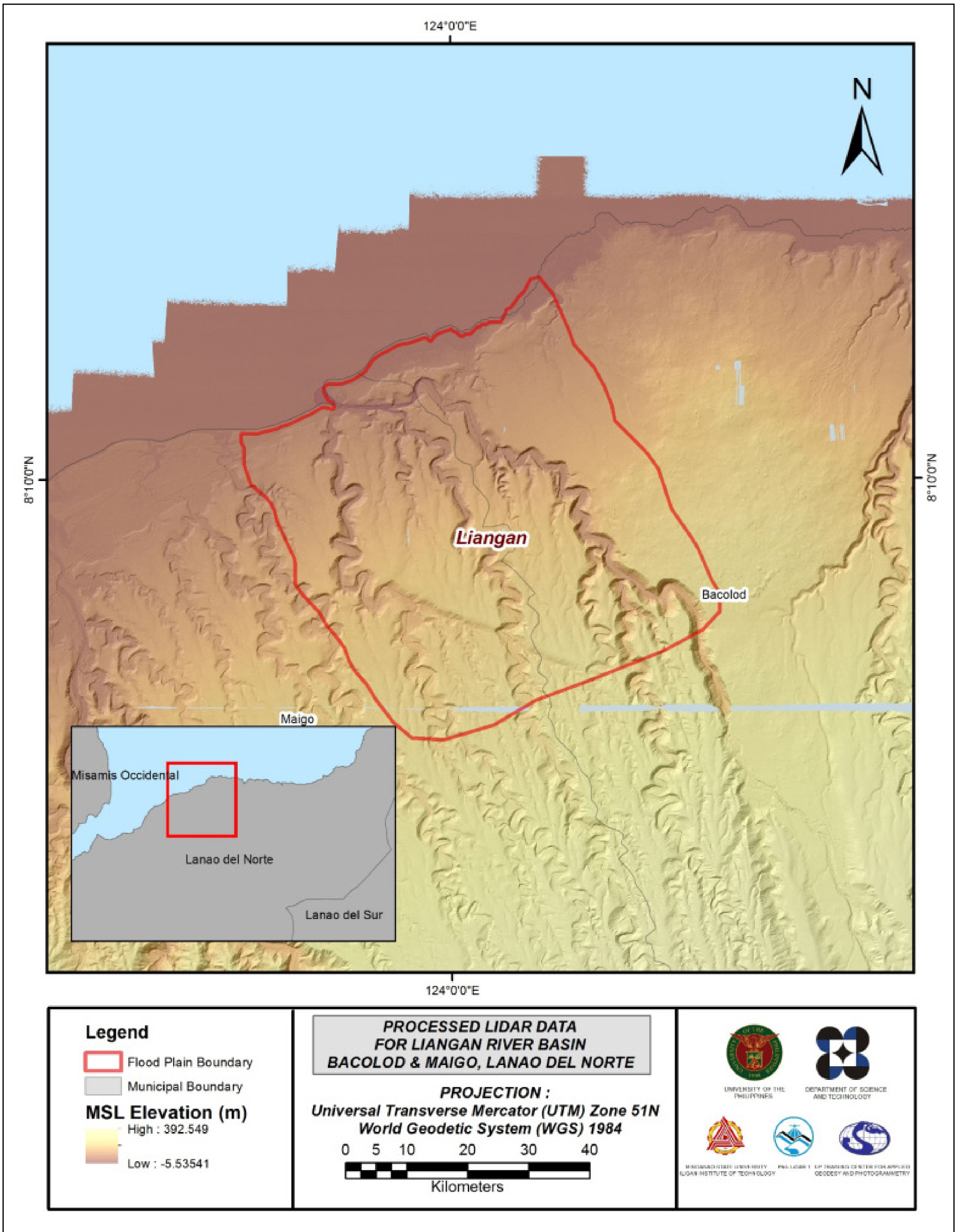


Figure 26 . Map of Processed LiDAR Data for Liangan Floodplain.

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 Liangan to collect points with which the LiDAR dataset is validated is shown in Figure 27. A total of 1573 survey points were used for calibration and validation of Liangan LiDAR data. Random selection of 80% of the survey points, resulting to 1258 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 28. 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 2.19 meters with a standard deviation of 0.07 meters. Calibration of Liangan LiDAR data was done by adding the height difference value, 2.19 meters, to Liangan mosaicked LiDAR data. Table 16 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

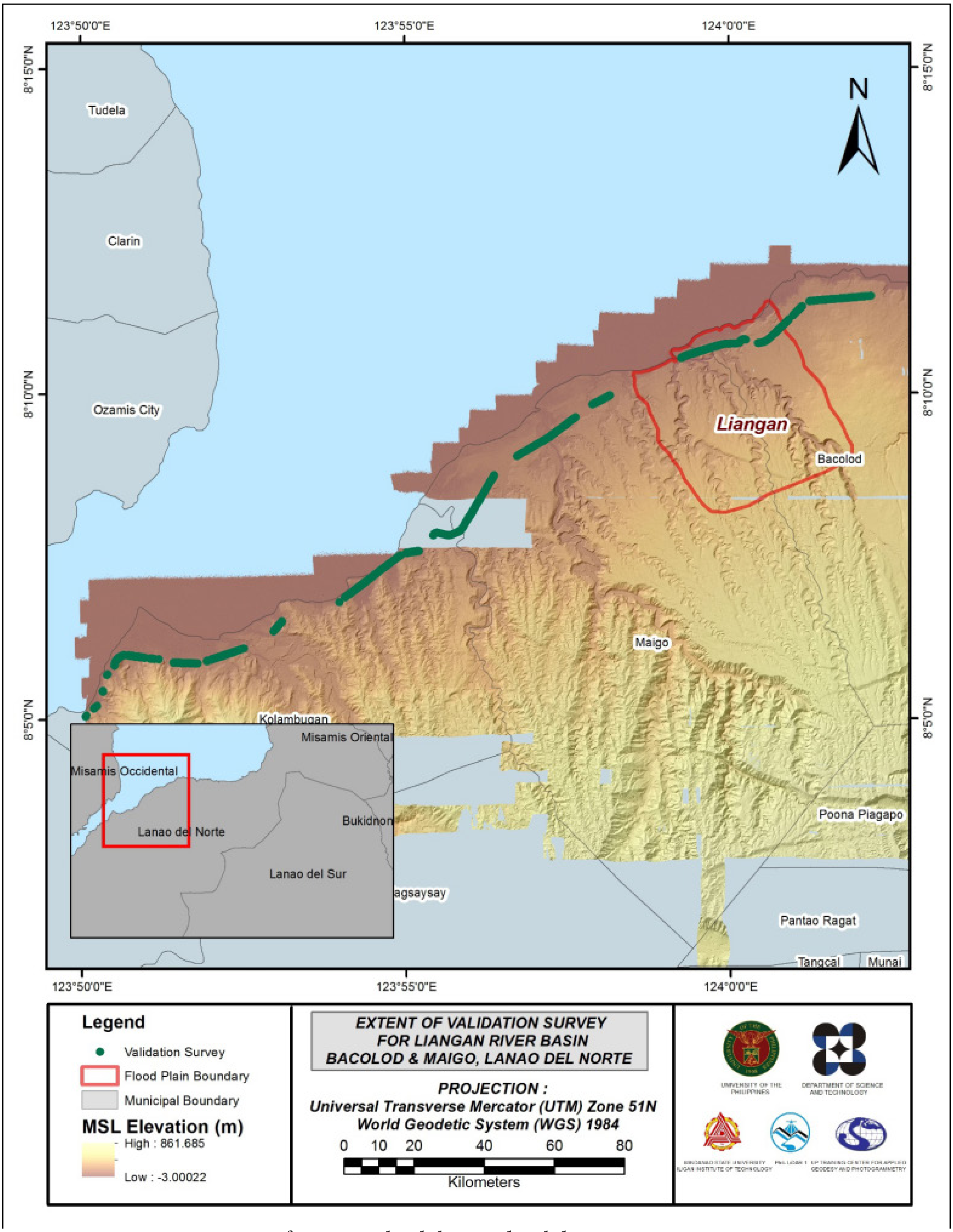


Figure 27. Map of Liangan Floodplain with validation survey points in green.

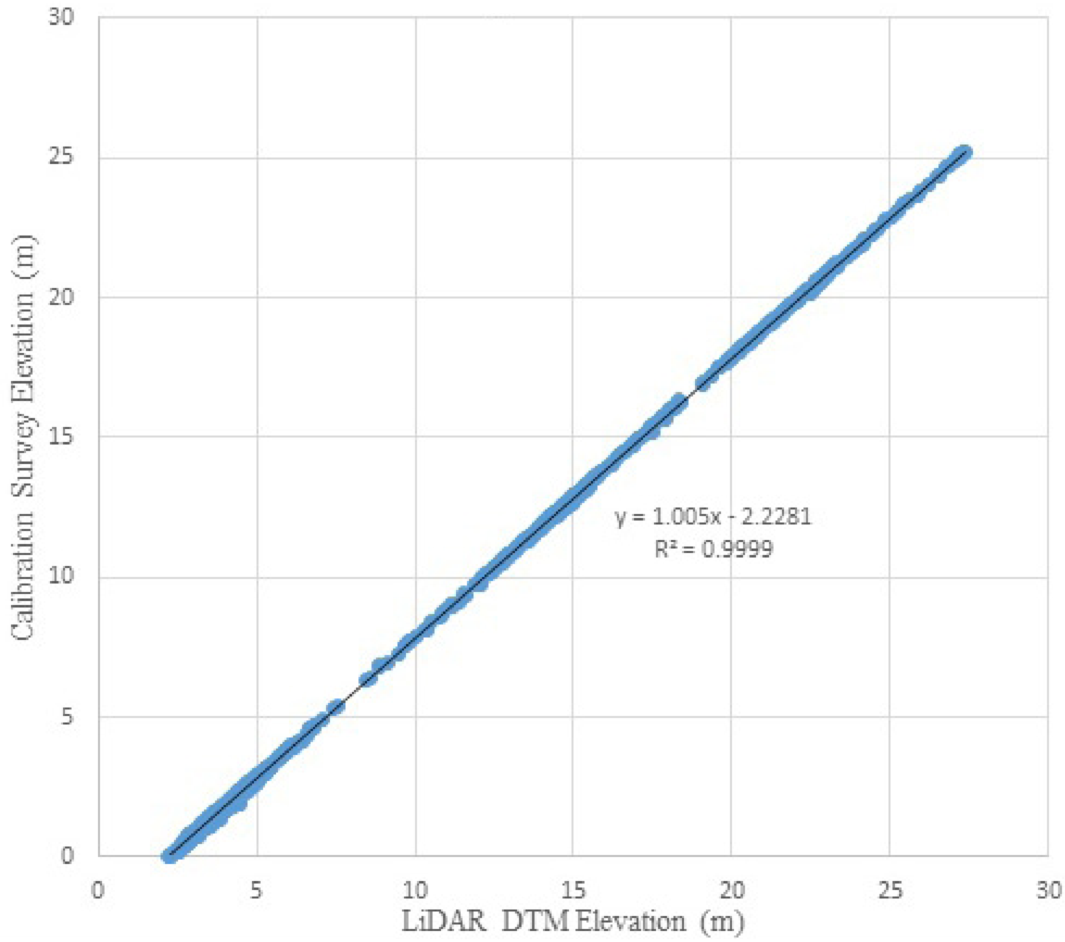


Figure 28. Correlation plot between calibration survey points and LiDAR data.

Table 16. Calibration Statistical Measures

Calibration Statistical Measures	Value (meters)
Height Difference	2.19
Standard Deviation	0.07
Average	2.19
Minimum	2.04
Maximum	2.53

The remaining 20% of the total survey points, resulting to 315 points, were used for the validation of calibrated Liangan 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 29. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.08 meters with a standard deviation of 0.08 meters, as shown in Table 17.

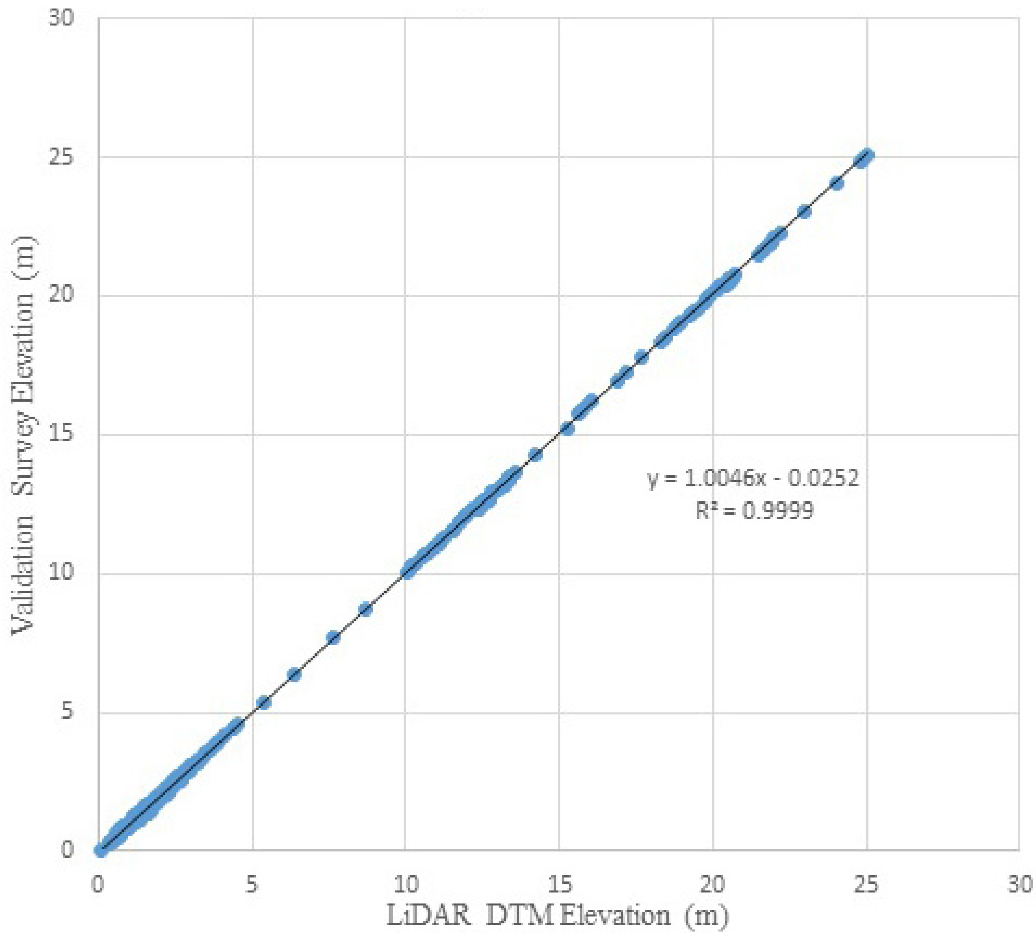


Figure 29. Correlation plot between validation survey points and LiDAR data.

Table 17. Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.08
Standard Deviation	0.08
Average	0.00
Minimum	-0.15
Maximum	0.27

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, only centerline data was available for Liangan with 467 bathymetric survey points. The resulting raster surface produced was done by Inverse Distance Weighted (IDW) interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.02 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Liangan integrated with the processed LiDAR DEM is shown in Figure 30.

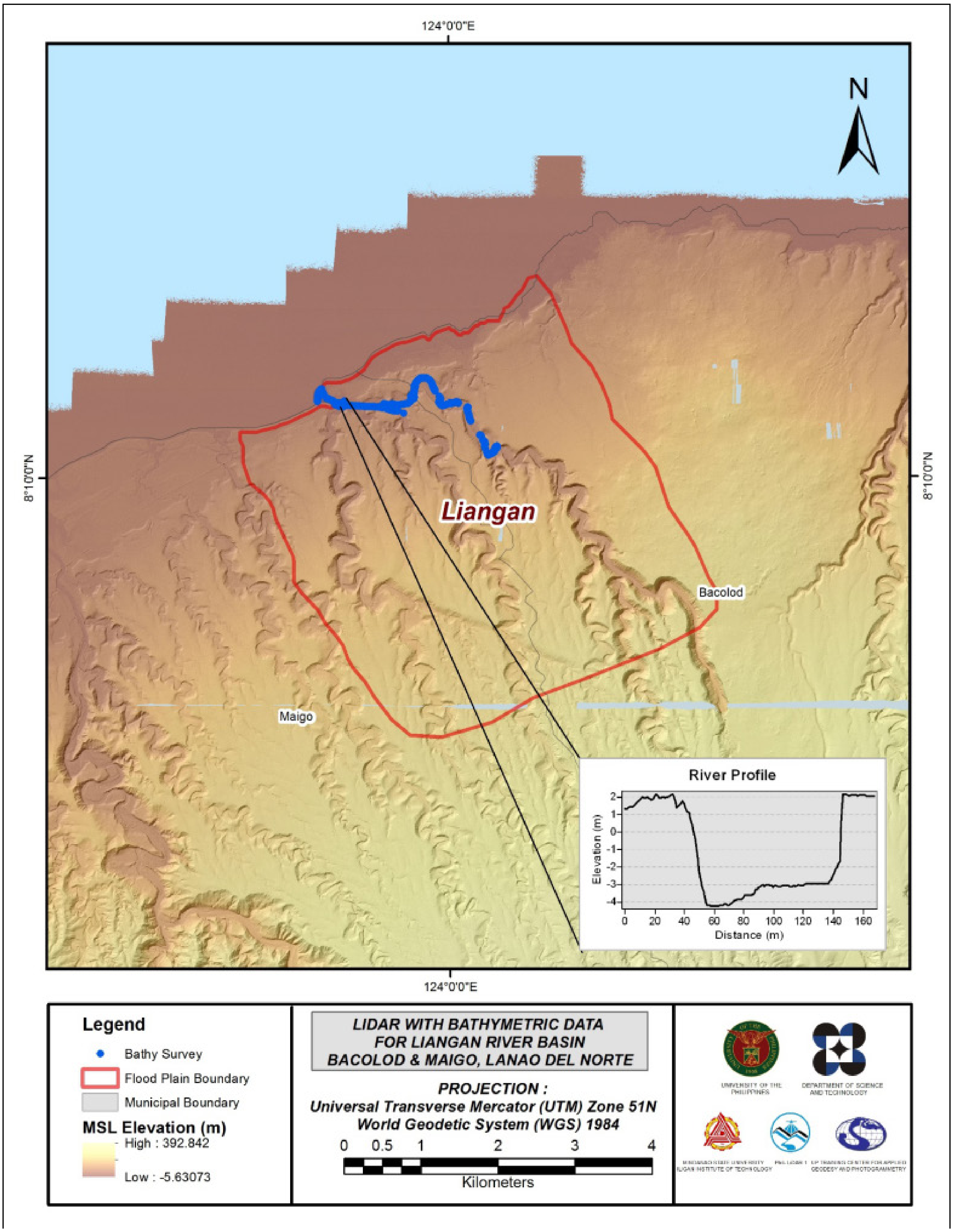


Figure 30. Map of Liangan Floodplain with bathymetric survey points shown in blue.

3.12 Feature Extraction

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

3.12.1 Quality Checking of Digitized Features' Boundary

Liangan floodplain, including its 200 m buffer, has a total area of 25.79 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 574 building features, are considered for QC. Figure 31 shows the QC blocks for Liangan floodplain.

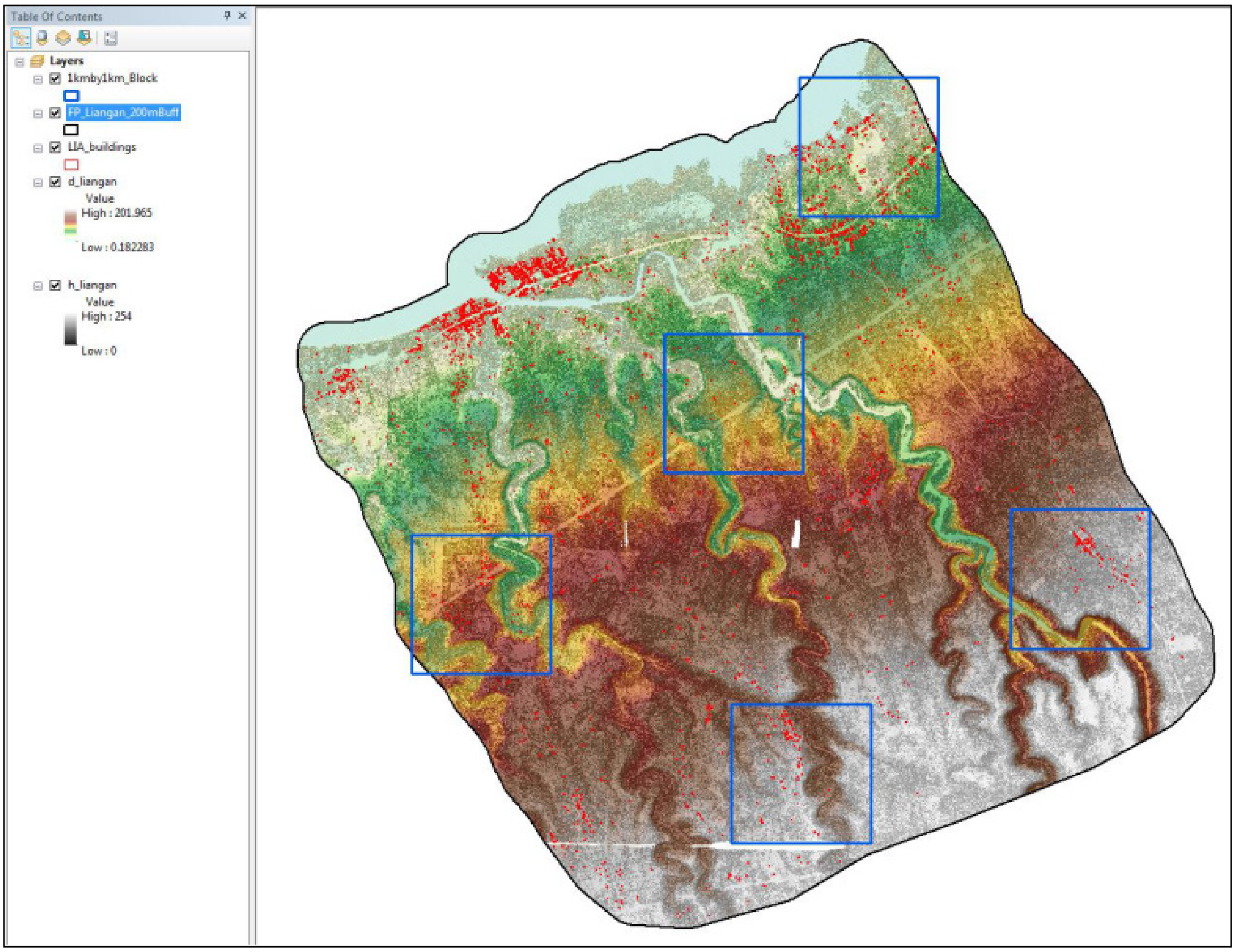


Figure 31. Blocks (in blue) of Liangan building features that were subjected to QC

Quality checking of Liangan building features resulted in the ratings shown in Table 18.

Table 18. Quality Checking Ratings for Liangan Building Features

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Liangan	99.37	99.79	98.78	PASSED

3.12.2 Height Extraction

Height extraction was done for 2,843 building features in Liangan floodplain. Of these building features, 62 were filtered out after height extraction, resulting to 2,781 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 7.67 m.

3.12.3 Feature Attribution

Liangan floodplain is shared by two (2) municipalities namely municipality of Bacolod, and municipality of Maigo. The building attribution on the municipalities of Bacolod and Maigo was done with the Barangay Registry Information System (BRIS) approach. In BRIS approach, trainings, assistance and a database system were delivered to barangays and municipalities for them to conduct the building attribution. The attribution of road, bridge and water body features was done using NAMRIA maps, municipal records, and participatory mapping of municipals.

Table 19 summarizes the number of building features per type. On the other hand, Table 20 shows the total length of each road type, while Table 21 shows the number of water features extracted per type.

Table 19. Building features extracted for Liangan Floodplain.

Facility Type	No. of Features
Residential	2,596
School	57
Market	18
Agricultural/Agro-Industrial Facilities	50
Medical Institutions	4
Barangay Hall	6
Military Institution	0
Sports Center/Gymnasium/Covered Court	3
Telecommunication Facilities	2
Transport Terminal	0
Warehouse	2
Power Plant/Substation	0
NGO/CSO Offices	1
Police Station	0
Water Supply/Sewerage	2
Religious Institutions	29
Bank	0
Factory	0
Gas Station	0
Fire Station	0
Other Government Offices	4
Other Commercial Establishments	7
Total	**2,781**

Table 20. Total length of extracted roads for Liangan Floodplain.

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Liangan	30.43	0.00	0.00	5.16	0.00	35.59

Table 21. Number of extracted water bodies for Liangan Floodplain.

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

A total of 5 bridges and culverts over small channels that are part of the river network were also extracted for the floodplain.

3.12.4 Final Quality Checking of Extracted Features

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

Figure 32 shows the Digital Surface Model (DSM) of Liangan floodplain overlaid with its ground features.

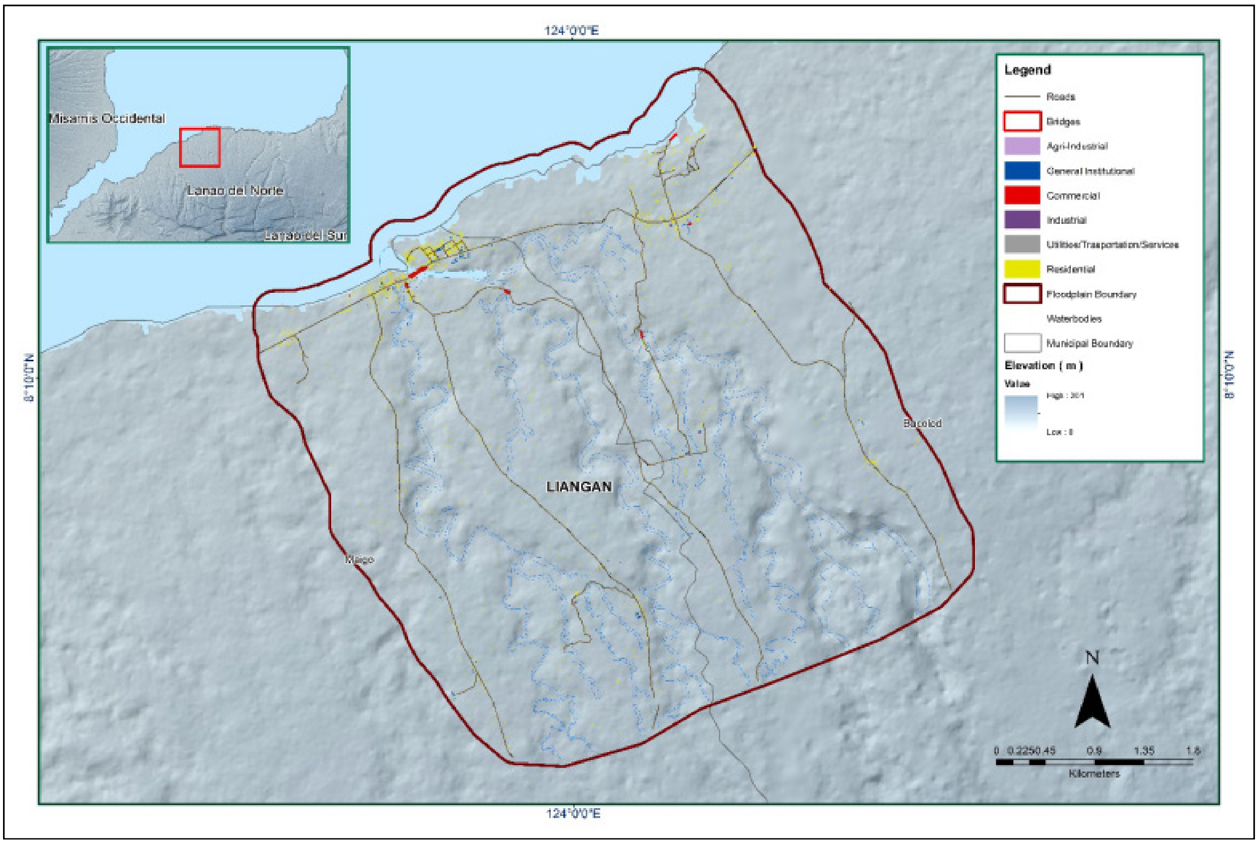


Figure 32. Extracted features of the Liangan Floodplain.

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

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

4.1. Summary of Activities

The Data Validation and Bathymetry Component (DVBC) conducted a field survey in Liangan River on October 15 to 26, 2014 with the following scope of work: reconnaissance; control survey for the establishment of a control point in Lanao del Norte; cross-section survey; ground validation data acquisition survey of about 25 km; and bathymetric survey from Brgy. Esperanza down to the mouth of the river in Brgy. Liangan West, then draining to Panguil Bay with an estimated length of 3.7 km. A Hi-Target™ Single Beam Echo Sounder and a dual frequency GPS receiver were used and GNSS PPK survey technique was utilized for this survey.

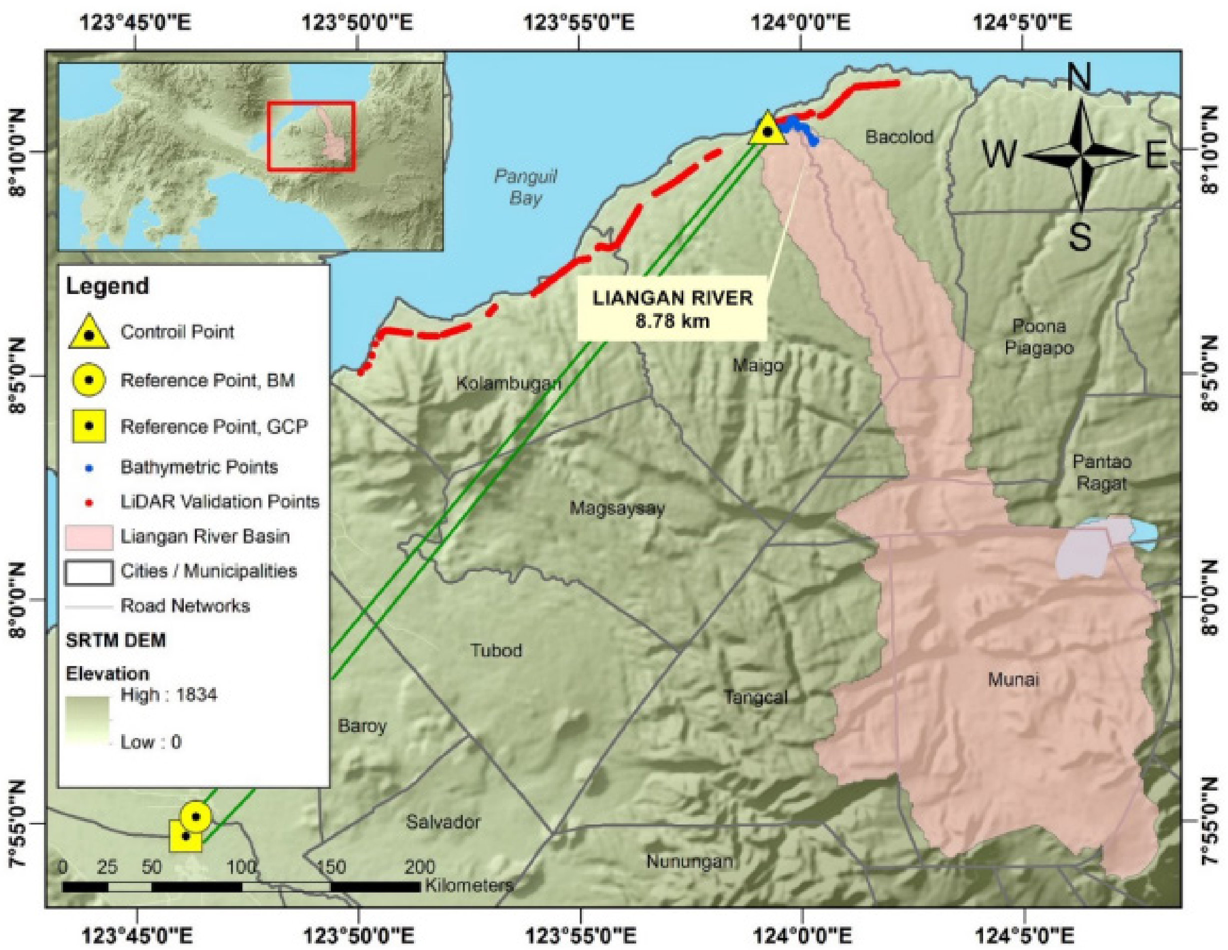

Figure 33. Extent of the bathymetric survey (in blue line) in Liangan River and the LiDAR data validation survey (in red).

4.2 Control Survey

The GNSS network used for Maranding River Basin is composed of a single loop established on October 25, 2014 occupying the following reference points; LAN-2, a first order GCP, in Brgy. Maranding, Municipality of Kapatagan; and LE-92, a first order BM, in Brgy. Maranding, Municipality of Lala, all in Lanao Del Norte.

A control point was established along the approach of Liangan Bridge namely UP-L, located in Brgy. Liangan West, Municipality of Maigo, Lanao Del Norte.

The summary of reference and control points and its location is summarized in Table 22 while the GNSS network established is illustrated in Figure 34.

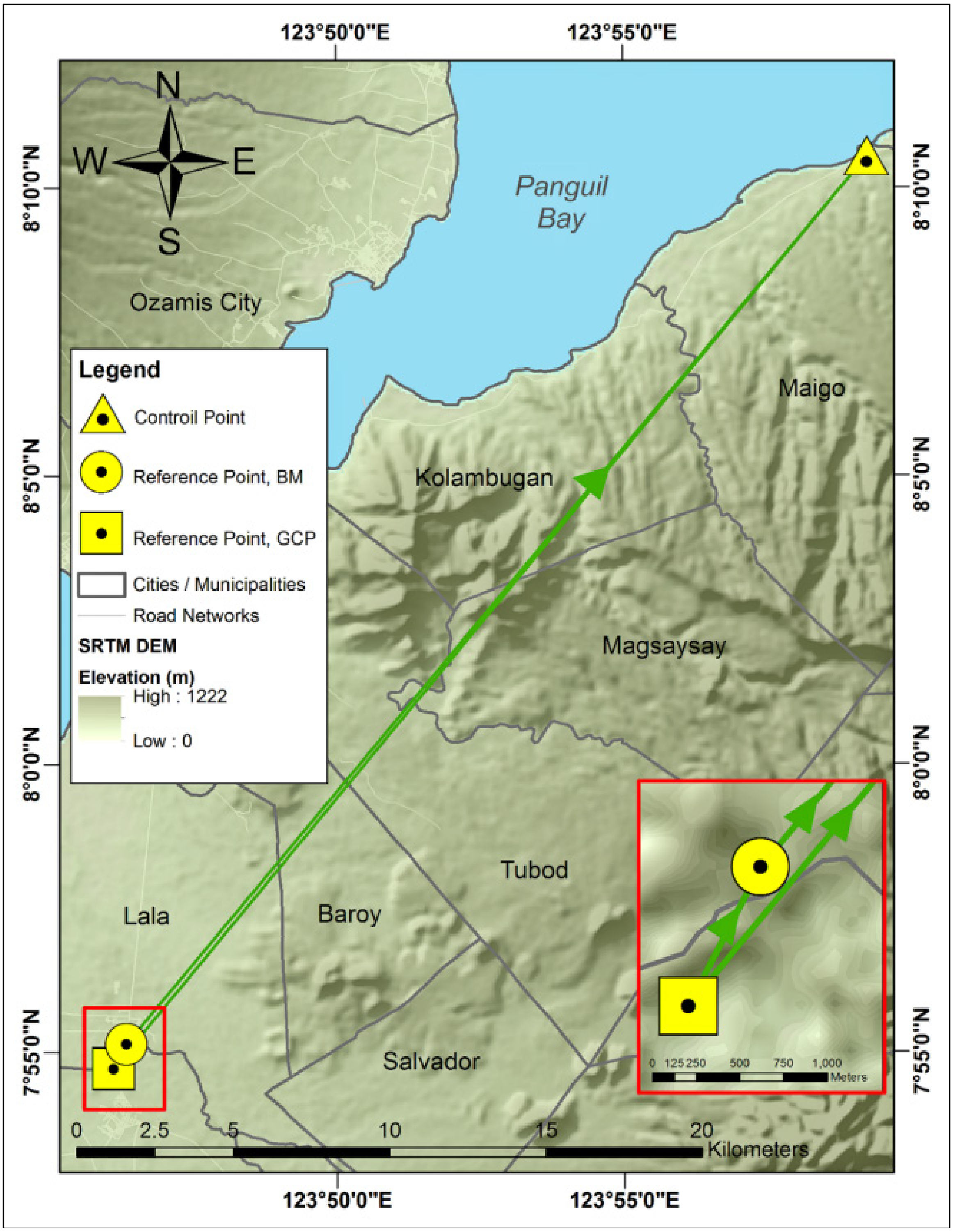

Figure 34. The GNSS Network established in the Liangan River Survey.

Table 22. References used and control points established in the Liangan River Survey (Source: NAMRIA, UP-TCAGP).

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (Meter)	Elevation in MSL (Meter)	Date Established
SME-18	2nd Order GCP	11°21'43.08127"	125°36'37.41862"	78.217	17.66	Sep 12, 2014
SE-85	1st Order BM	11°24'45.65441"	125°32'20.98934"	67.52	6.31	Sep 12, 2014
SME-12	Used as Marker	11°07'19.15395"	125°21'29.28283"	67.212	2.721	Sep 13, 2014
SMR-3322	Used as Marker	11°17'40.55190"	125°07'10.82309"	70.666	6.636	Sep 17, 016
SE-49	Used as Marker	11°12'34.48802"	125°31'52.42238"	66.981	3.779	Sep 13, 2014
SM-33S	Used as Marker	11°07'33.79721"	125°12'32.14831"	68.705	3.951	Sep 17, 2014
UP-CNG	UP Established	11°35'44.92939"	125°26'23.62776"	67.094	6.035	Sep 12, 2014
UP-SLG	UP Established	11°27'57.66166"	125°01'08.84182"	73.078	9.958	Sep 19, 2014

The GNSS set up in UP-L and control points in Lanao del Norte are shown in Figure 35 to Figure 37.

Figure 35. GNSS base set up, Trimble® SPS 852, at LAN-2, situated on top of a concrete irrigation canal gate in Brgy. Pinoyak, Municipality of Lala, Lanao Del Norte

Figure 36. GNSS base set up, Trimble® SPS 852, at LE-92, located at the approach of Maranding Bridge, in Brgy. Maranding, Municipality of Lala, Lanao Del Norte

Figure 37. GNSS receiver setup, Trimble® SPS 882, at UP-L, located at the approach of Liangan Bridge, in Brgy. Esperanza, Municipality of Bacolod, Lanao Del Norte

4.3 Baseline Processing

GNSS baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/-20cm and +/-10cm requirement, respectively. In cases where one or more baselines did not meet all of these criteria, masking is performed. Masking is done by removing/masking portions of these baseline data using the same processing software. It is repeatedly processed until all baseline requirement are met. If the reiteration yields out of the required accuracy, resurvey is initiated. Static survey was conducted on October 25, 2014 and the Baseline processing result of control points in Liangan River Basin is summarized in Table 23 generated TBC software.

Table 23. Baseline processing report for the Liangan River GNSS static observation survey.

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
LE-92 --- LAN-2	10-25-2014	Fixed	0.001	0.002	207°34'21"	897.957	-4.965
LE-92 --- UP-L	10-25-2014	Fixed	0.005	0.014	39°53'57"	37006.02	-16.030
LAN-2 --- UP-L	10-25-2014	Fixed	0.005	0.015	39°36'31"	37883.78	-11.063

As shown in Table 23, a total of three (3) baselines were processed with reference point LAN-2 held fixed for coordinate values; and LE 92 fixed for 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:

$20cm$ and $ze < 10\ cm$

where:

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

The three (3) control points, LAN-2, LE-92, and UP-L were occupied and observed simultaneously to form a GNSS loop. Coordinates of LAN-2 and elevation values of LE-92 were held fixed during the processing of the control points as presented in Table 24. Through these reference points, the coordinates and elevation of the unknown control points were occupied.

Table 24. Constraints applied to the adjustment of the control points.

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
LAN-2	Local	Fixed	Fixed		
LE-92	Grid				Fixed
Fixed = 0.000001 (Meter)					

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 25. The fixed control points LAN-2 and LE-02 have no standard errors for coordinate values; and LE-92 for elevation values.

Table 25. Adjusted grid coordinates for the control points used in the Liangan River Floodplain survey.

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
LAN-2	584699.973	?	874628.035	?	13.471	0.009	LL
LE-92	585114.005	0.005	875424.530	0.003	18.440	?	e
UP-L	608790.643	0.012	903851.418	0.009	2.042	0.048	

The network is fixed at reference point LAN-2 with known coordinates and LE-92 with known elevation. With the mentioned equation, $\sqrt{((xe)^2 + (ye)^2)} < 20cm$ for horizontal and $ze < 10\ c$ for the vertical, the computation for the horizontal and vertical accuracy are as follows:

a. LAN-2

horizontal accuracy	=	Fixed
vertical accuracy	=	0.90 cm < 10 cm

b. LE-92

horizontal accuracy	=	$\sqrt{((0.50)^2 + (0.30)^2}$
	=	$\sqrt{(0.25 + 0.09)}$
	=	0.5 cm < 20 cm
vertical accuracy	=	Fixed

c. UP-L

horizontal accuracy	=	$\sqrt{((1.20)^2 + (0.90)^2}$
	=	$\sqrt{(1.44 + 0.81)}$
	=	1.5 cm < 20 cm
vertical accuracy	=	4.80 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 26. Adjusted geodetic coordinates for control points used in the Liangan River Floodplain validation.

Point ID	Latitude	Longitude	Ellipsoid	Height	Constraint
LAN-2	N7°54'42.56546"	E123°46'06.31720"	82.151	0.009	LL
LE-92	N7°55'08.47531"	E123°46'19.88700"	87.116	?	e
UP-L	N8°10'32.39730"	E123°59'15.35400"	71.088	0.048	

The corresponding geodetic coordinates of LE-92 and UP-L are within the required accuracy as shown in Table 26. Based on the result of the computation, the accuracy condition is satisfied; hence, the required accuracy for the program was met.

The summary of reference and control points is indicated in Table 27.

Table 27. The reference and control points utilized in the Liangan River Static Survey, with their corresponding locations (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
LAN-2	1st order, GCP	7°54'42.56546"	123°46'06.31720"	82.151	874628.035	584699.973	13.471
LE-92	1st order, BM	7°55'08.47531"	123°46'19.88700"	87.116	875424.53	585114.005	18.44
UP-L	UP Established	8°10'32.39730"	123°59'15.35400"	71.088	903851.418	608790.643	2.042

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

Cross-section and as-built survey were conducted on October 16, 2014 at the upstream part of a hanging bridge in Brgy. Esperanza, Bacolod, Lanao del Norte. A survey grade GNSS receiver Trimble® SPS 882 in PPK technique was utilized for this survey as shown in Figure 38. Babalaya Hanging Bridge was chosen to be cross-sectioned because there were no concrete bridges found in the Liangan River upstream and this is where the partner HEI, MSU-IIT conduct their flow measurement.

Figure 38. Cross-section survey using Trimble® SPS 882 under a hanging bridge in Brgy. Esperanza, Bacolod, Lanao del Norte

The cross-sectional line of Liangan river is about 84 m with thirty-four (34) cross-sectional points gathered using LE-92 as the GNSS base station. The location map and cross-section diagram are shown in Figure 39 and Figure 40.

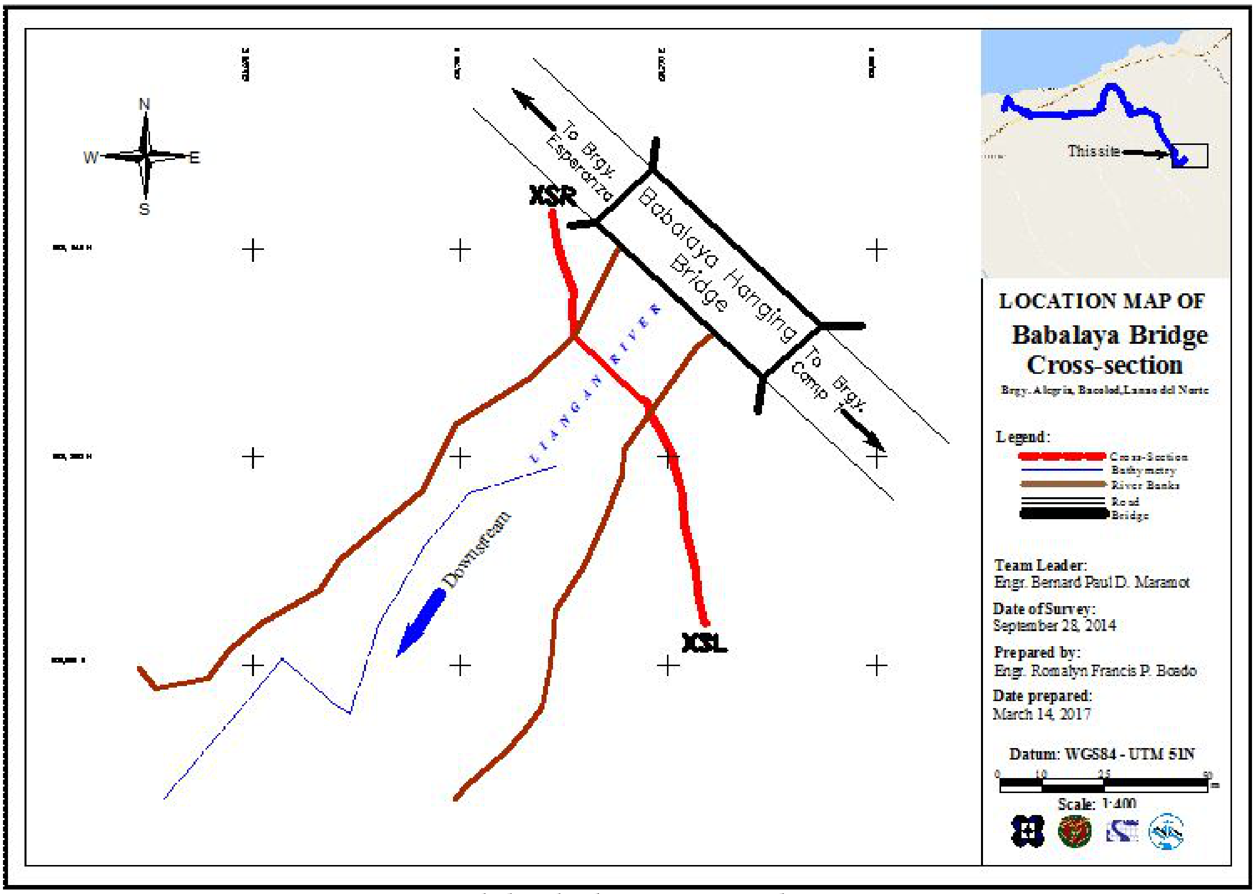

Figure 39. Babalaya bridge corss-section location map

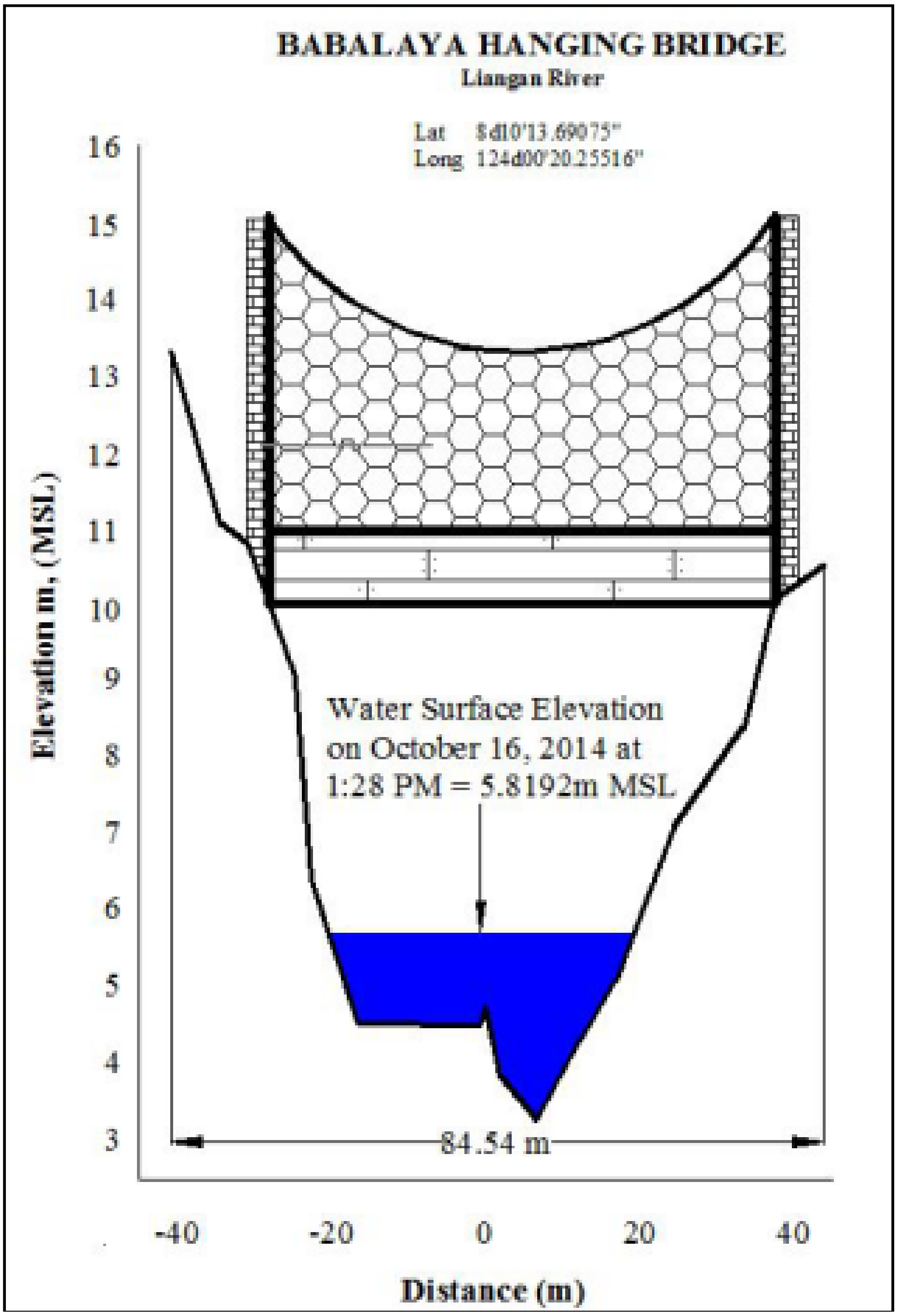

Figure 40. Cross-section diagram of Babalaya Hanging Bridge

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on October 18, 2014 using a survey grade dual frequency GNSS Rover Trimble® SPS 882 receiver mounted on a pole, attached in front of a vehicle as shown in Figure 41. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The antenna height was 2.347 m measured from the ground up to the bottom of the notch of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with LE-92 occupied as the GNSS base station in the conduct of the survey.

Figure 41. Ground Validation Set-up, Trimble® SPS 882 Rover, for Liangan River Basin

The survey started from Brgy. Binuni, Municipality of Bacolod and traversed major roads going to Brgy. Manga in Kolambugan covering four (4) barangays in Bacolod, fourteen (14) in Municipality of Kolambugan, and five (5) barangays in Municipality of Maigo; and ended in Brgy. Manga, Kolambugan. The survey gathered a total of 1,896 ground validation points with an approximate length of 25 km as illustrated in Figure 42.

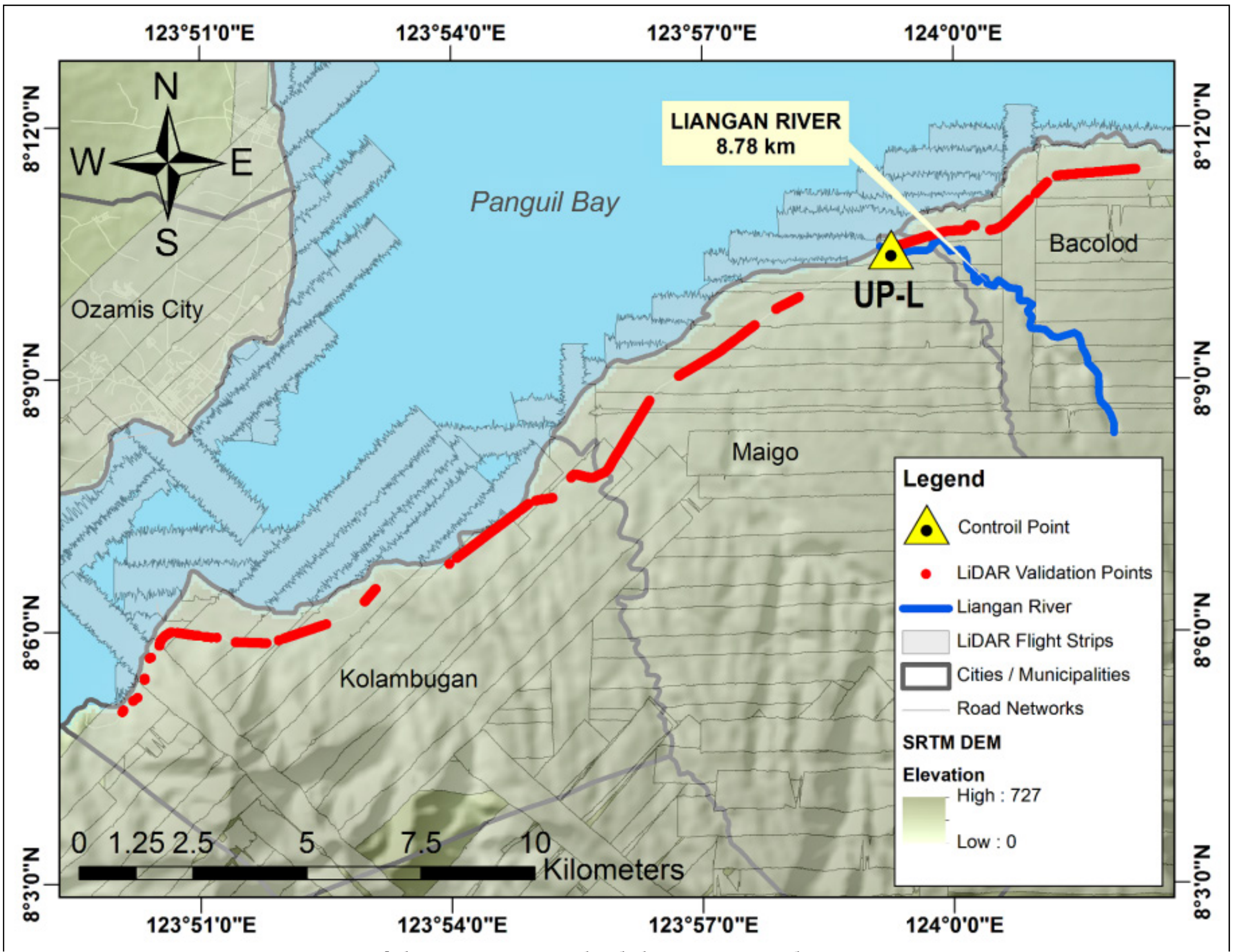

Figure 42. Extent of the LiDAR ground validation survey along Liangan River Basin

4.7 River Bathymetric Survey

Bathymetric survey was executed on December 18, 2014 using Trimble® SPS 882 in GNSS PPK survey technique and a Hi-Target™ Single Beam Echo Sounder mounted on a pole attached to a boat as shown in Figure 43. The survey started from Brgy. Alegria, Mun. of Bacolod with coordinates from the upstream part of the river in Brgy. Alegria, Municipality of Bacolod with coordinates 8°10'29.72262" 124°00'07.74227" and ended at the mouth of the river in Brgy. Liangan West, Mun. of Maigo with coordinates 8°10'32.30943" 123°59'03.88597".

Figure 43. Bathymetric survey using Hi-Target™ Single Beam Echo Sounder and mounted Trimble® SPS 882

Manual bathymetric survey on the other hand was executed on December 16 and 17, 2014 using Trimble® SPS 882 in GNSS PPK survey technique as shown in Figure 44. The survey started from the upstream part of the river in Brgy. Alegria, Municipality of Bacolod with coordinates 8°10'12.29611" 124°00'20.24262", walked down the river by foot and ended at the starting point of bathymetric survey using boat.

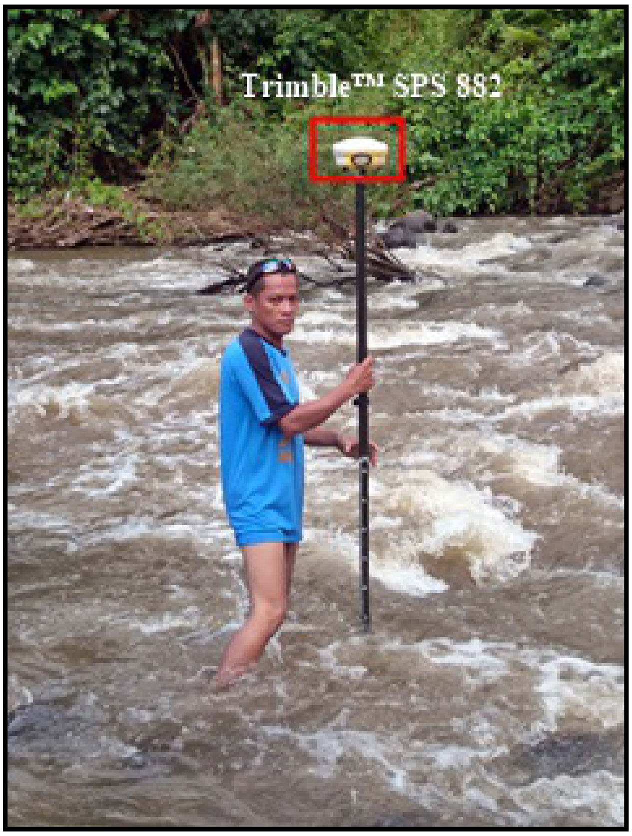

Figure 44. Actual execution of manual bathymetric survey along Liangan River

The bathymetric survey covered approximately 3.72 km of Liangan River with a total of 466 points acquired from Brgy. Esperanza to Brgy. Liangan West as shown in Figure 45. A CAD drawing was also produced to illustrate the Liangan riverbed profile, shown in Figure 46. There is an abrupt change in elevation between the upstream in Brgy. Esperanza to its downstream in Brgy. Liangan West which is the mouth of the river. The lowest part of the river was observed to be between Brgy. Alegria and Liangan West having an elevation of 6.30 m below Mean Sea Level (MSL). Towards the mouth of the river, the elevation is quite uniform ranging from -2 and -2.96 m (MSL).

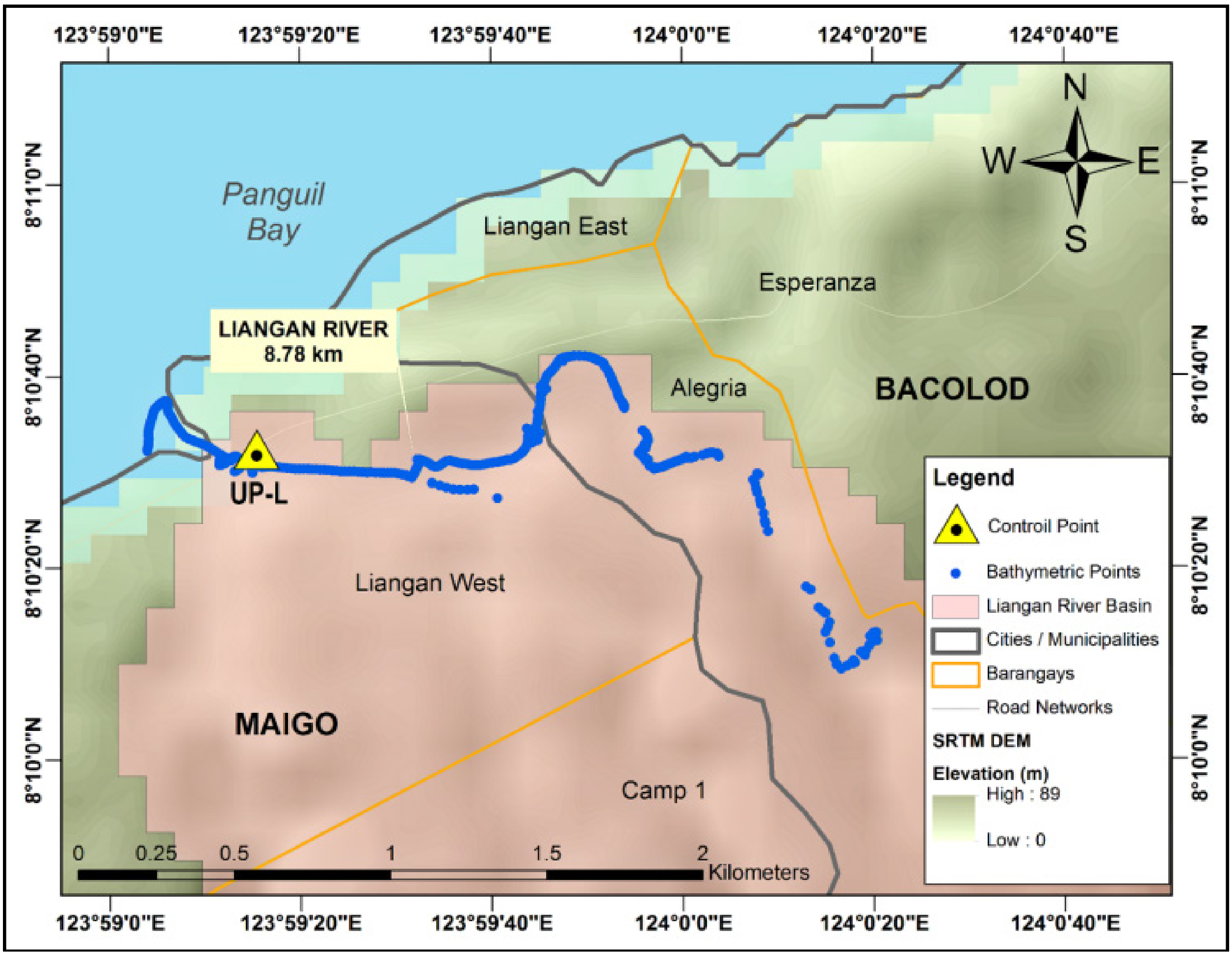

Figure 45. Extent of the Liangan River Bathymetry Survey

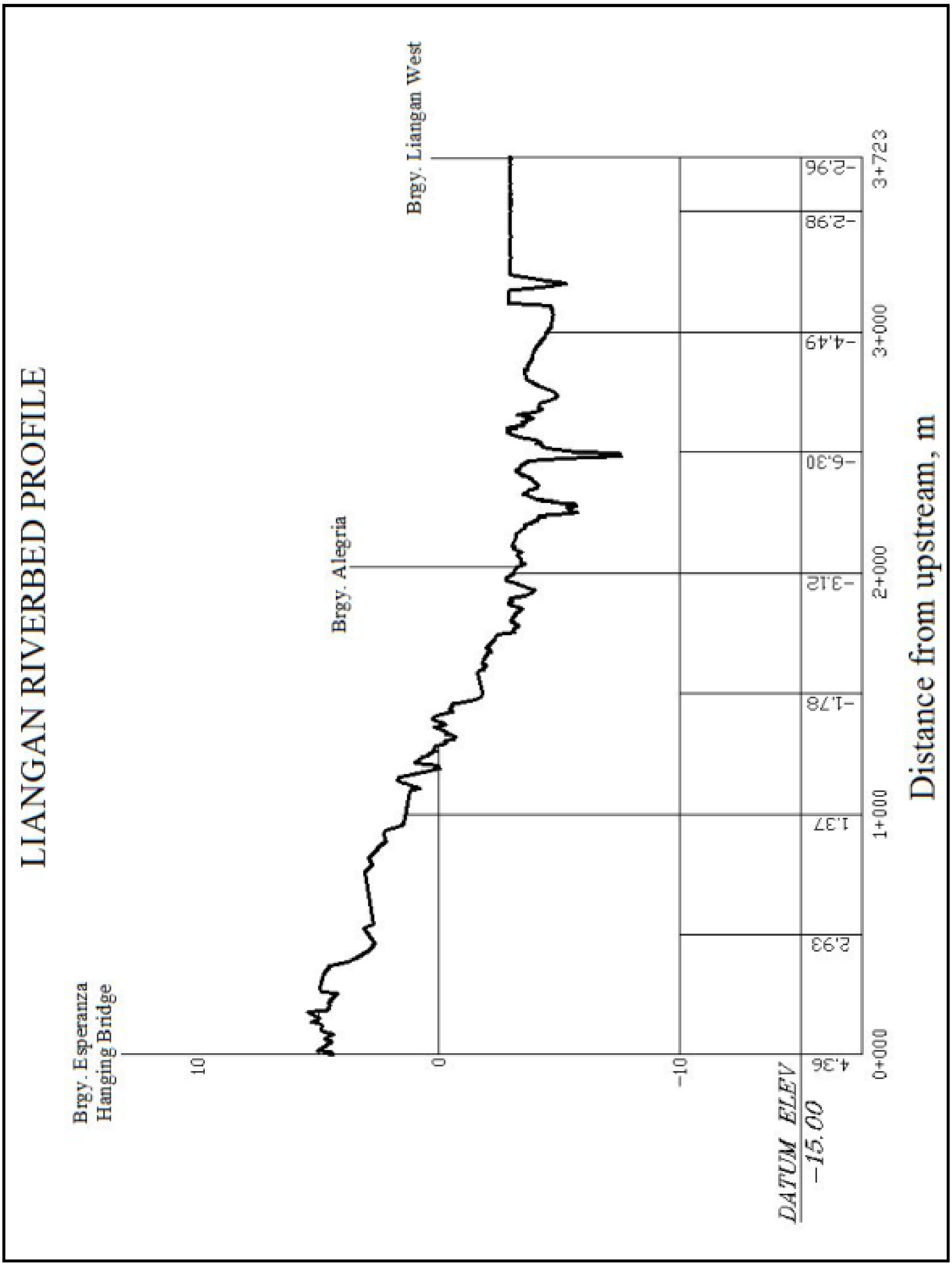

Figure 46. Liangan riverbed profile.

CHAPTER 5: FLOOD MODELING AND MAPPING

Alfredo Mahar Francisco A. Lagmay, Christopher Noel L. Uichanco, Sylvia Sueno, Marc Moises, Hale Ines, Miguel del Rosario, Kenneth Punay, and Neil R. Tingin

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

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

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

5.1.2 Precipitation

Precipitation data was taken from the Portable Automatic Rain Gauge (ARG) installed upstream by the Data Validation Component (DVC) of MSU-IIT. The ARG was specifically installed in the municipality of Salvador with coordinates 8°9’33.61”N Latitude and 124°1’29.72”E Longitude. The location of the rain gauge is shown in Figure 47 below.

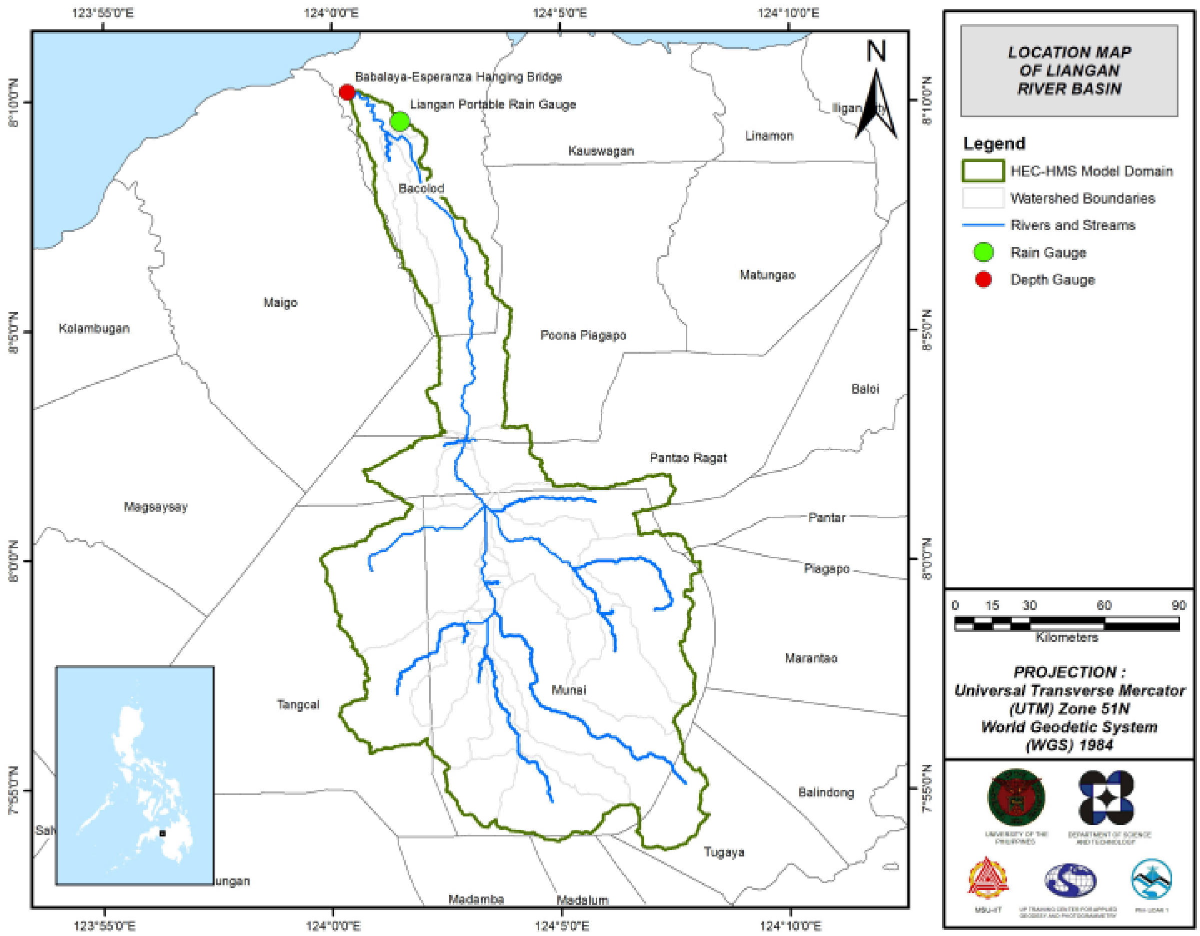

Figure 47. Location map of the Liangan HEC-HMS model used for calibration.

5.1.3 Rating Curves and River Outflow

HQ curve analysis is important in determining the equation to be used in establishing Q values with R-Squared values closer to 1. A trendline is more accurate if the R-Squared value is closer or at 1.

Figure 48 shows the highest R-Squared value of 0.945 compared to the graphs using the original Q. In this case, Q boxed values with Q at bank-full were plotted versus the stage.

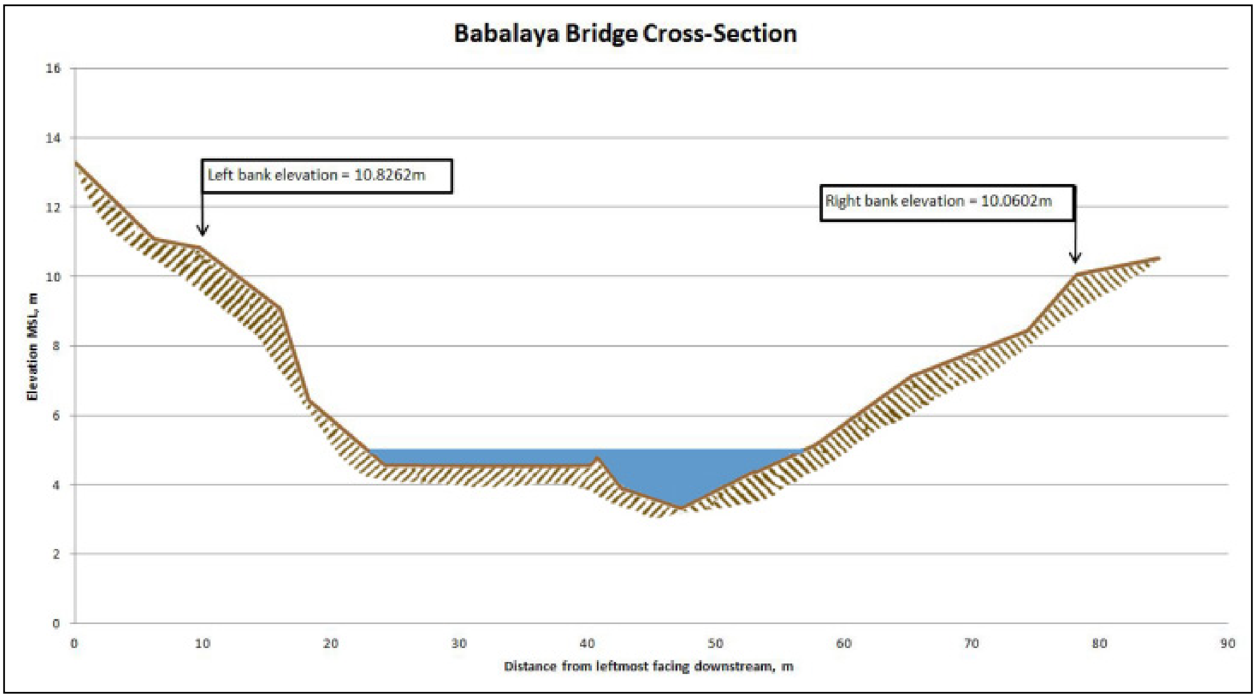

Figure 48. Cross-section plot of Babalaya-Ezperanza Bridge

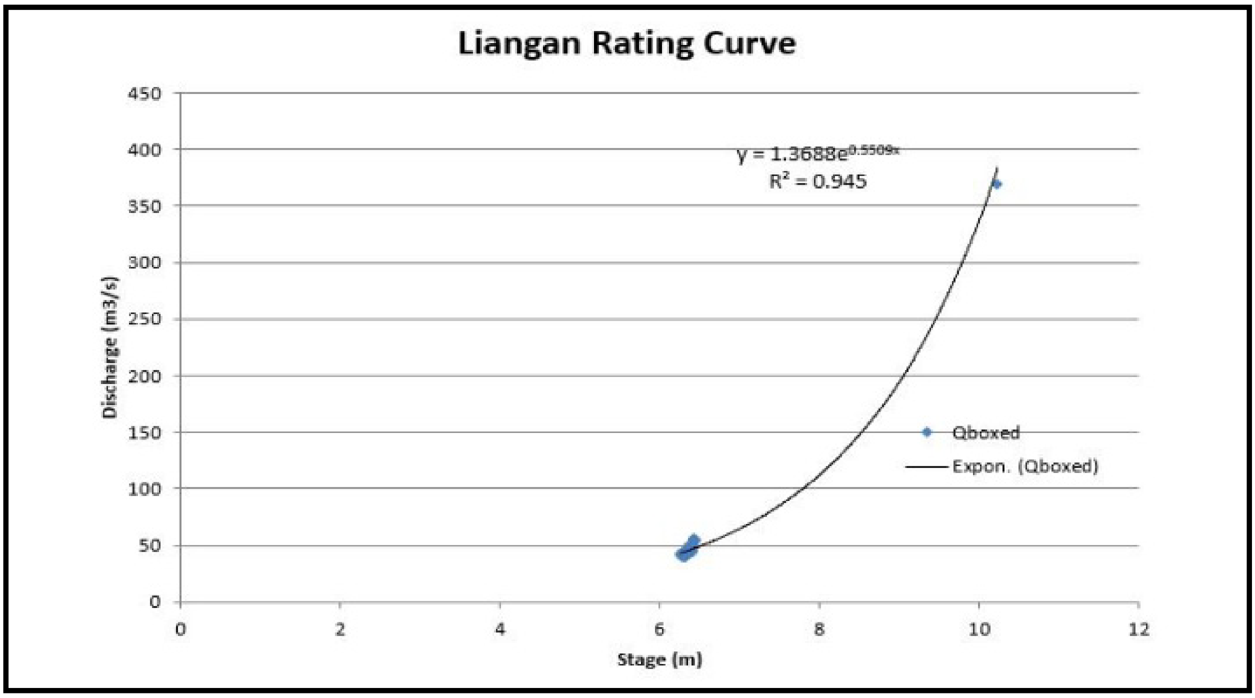

Figure 49. Rating Curve at Babalaya-Ezperanza Bridge

This rating curve equation was used to compute the river outflow at Babalaya-Ezperanza Bridge for the calibration of the HEC-HMS model shown in Figure 50. Total rainfall taken from the ARG at Mati for this event was 62.6 mm. It peaked to 5.6 mm on 21 June 2016 16:00. Peak discharge is 66.9 cms at 21:10, June 21, 2016. The lag time between the peak rainfall and discharge is 6 hours and 20 minutes.

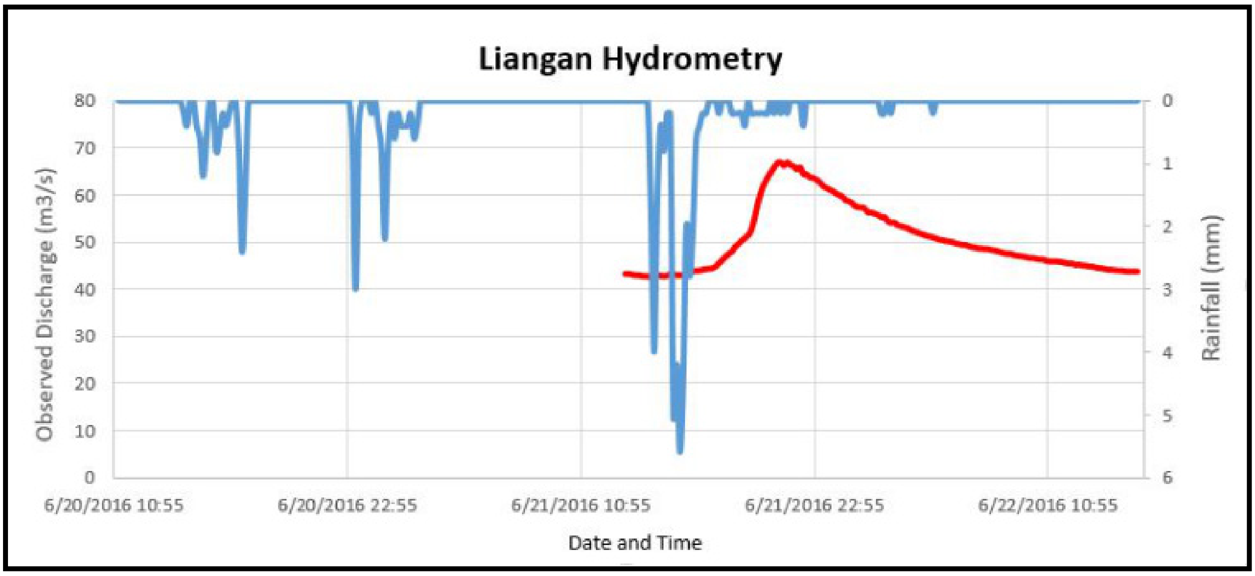

Figure 50. Rainfall and outflow data of the Liangan River Basin used for modeling.

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Cagayan de Oro Rain Gauge. The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the value in such a way certain peak value will be attained at a certain time. This station chosen based on its proximity to the Liangan watershed. The extreme values for this watershed were computed based on a 54-year record.

Table 28. RIDF values for Cagayan de Oro Rain Gauge computed by PAGASA

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	**10 mins**	**20 mins**	**30 mins**	**1 hr**	**2 hrs**	**3 hrs**	**6 hrs**	**12 hrs**	**24 hrs**
2	18.6	29.5	37	48.3	62.3	69.4	81.6	91.8	100.1
5	24.5	38.4	48.2	63.7	84.3	92.6	109.9	128.1	141.7
10	28.4	44.3	55.6	73.9	98.8	107.9	128.7	152.1	169.2
15	30.6	47.7	59.8	79.6	107.1	116.6	139.3	165.6	184.7
20	32.2	50	62.8	83.7	112.8	122.7	146.7	175.1	195.6
25	33.3	51.8	65	86.8	117.3	127.4	152.4	182.4	204
50	37	57.3	72	96.3	130.9	141.8	170	204.9	229.8
100	40.6	62.8	78.9	105.8	144.5	156.1	187.4	227.3	255.5

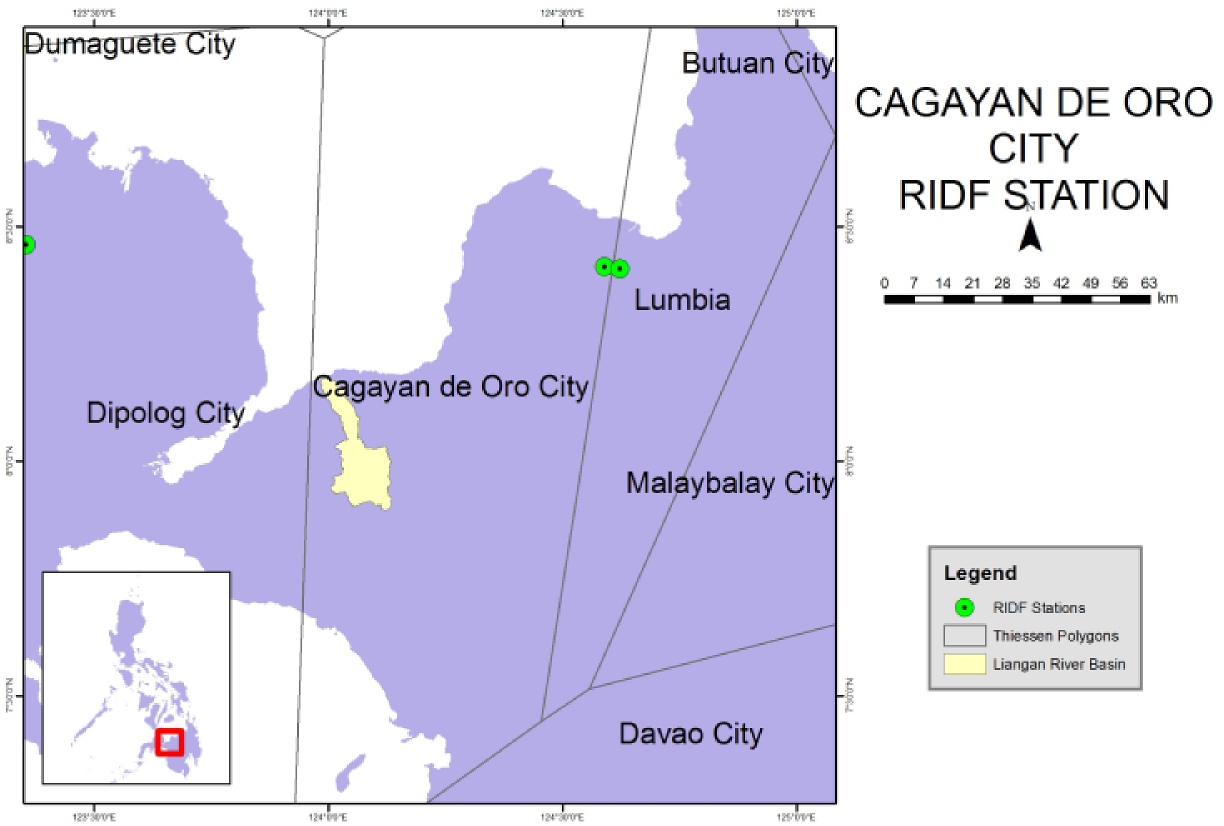

Figure 51. Location of Cagayan de Oro RIDF station relative to Liangan River Basin

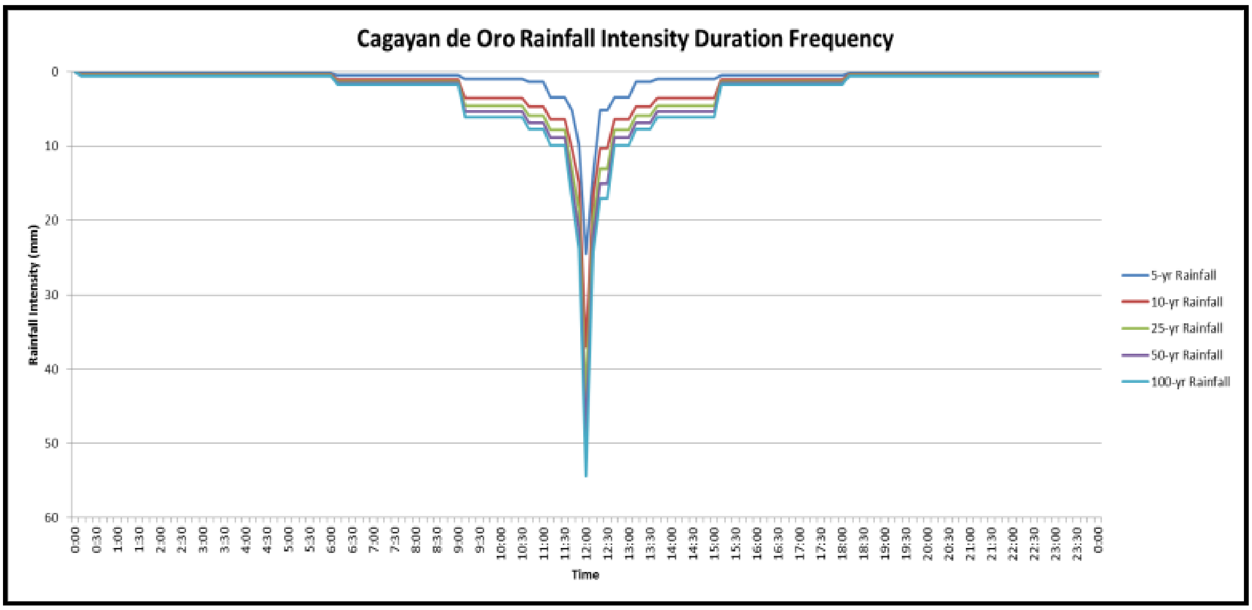

Figure 52. Synthetic storm generated for a 24-hour period rainfall for various return periods

5.3 HMS Model

The soil texture dataset was generated before 2004 from the Bureau of Soils and Water Management (BSWM); this is under the Department of Agriculture. The soil texture map (Figure 53) of the Liangan River basin was used as one of the factors for the estimation of the CN parameter.

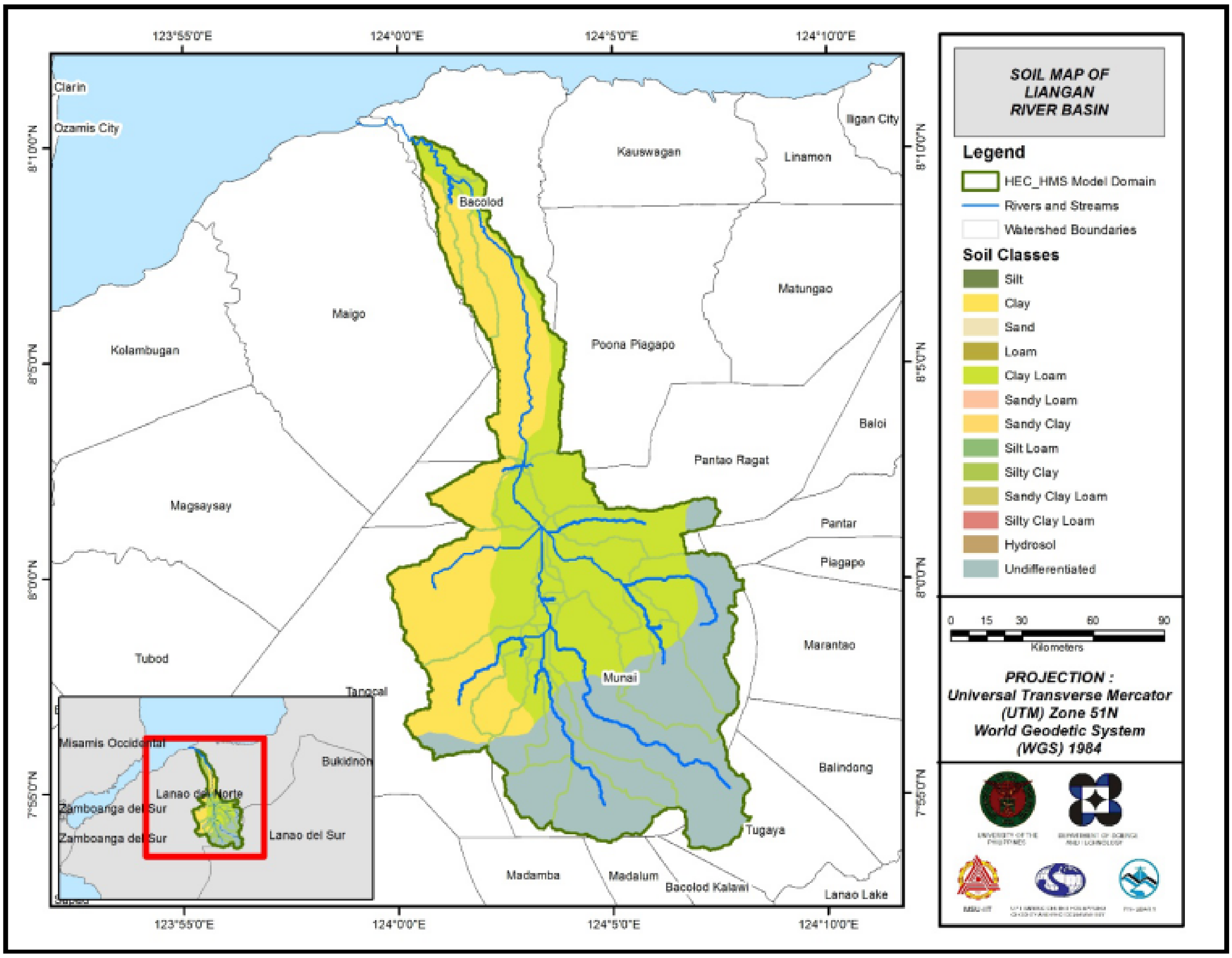

Figure 53. Soil Map of Liangan River Basin

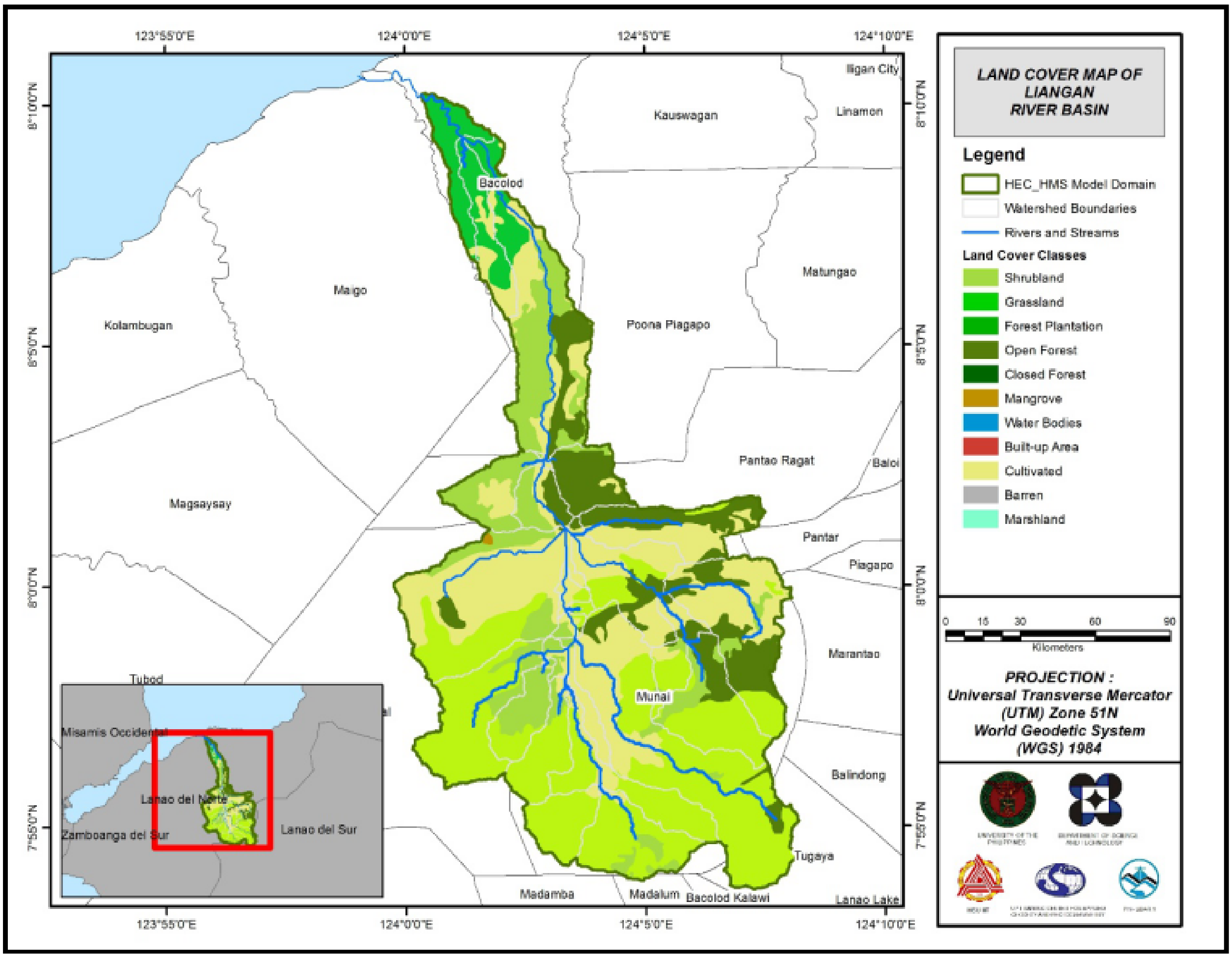

Figure 54. Land Cover Map of Liangan River Basin

For Liangan, the soil classes identified were clay, clay loam, and undifferentiated. The land cover types identified were shrubland, grassland, forest plantation, open forest, closed forest, and cultivated.

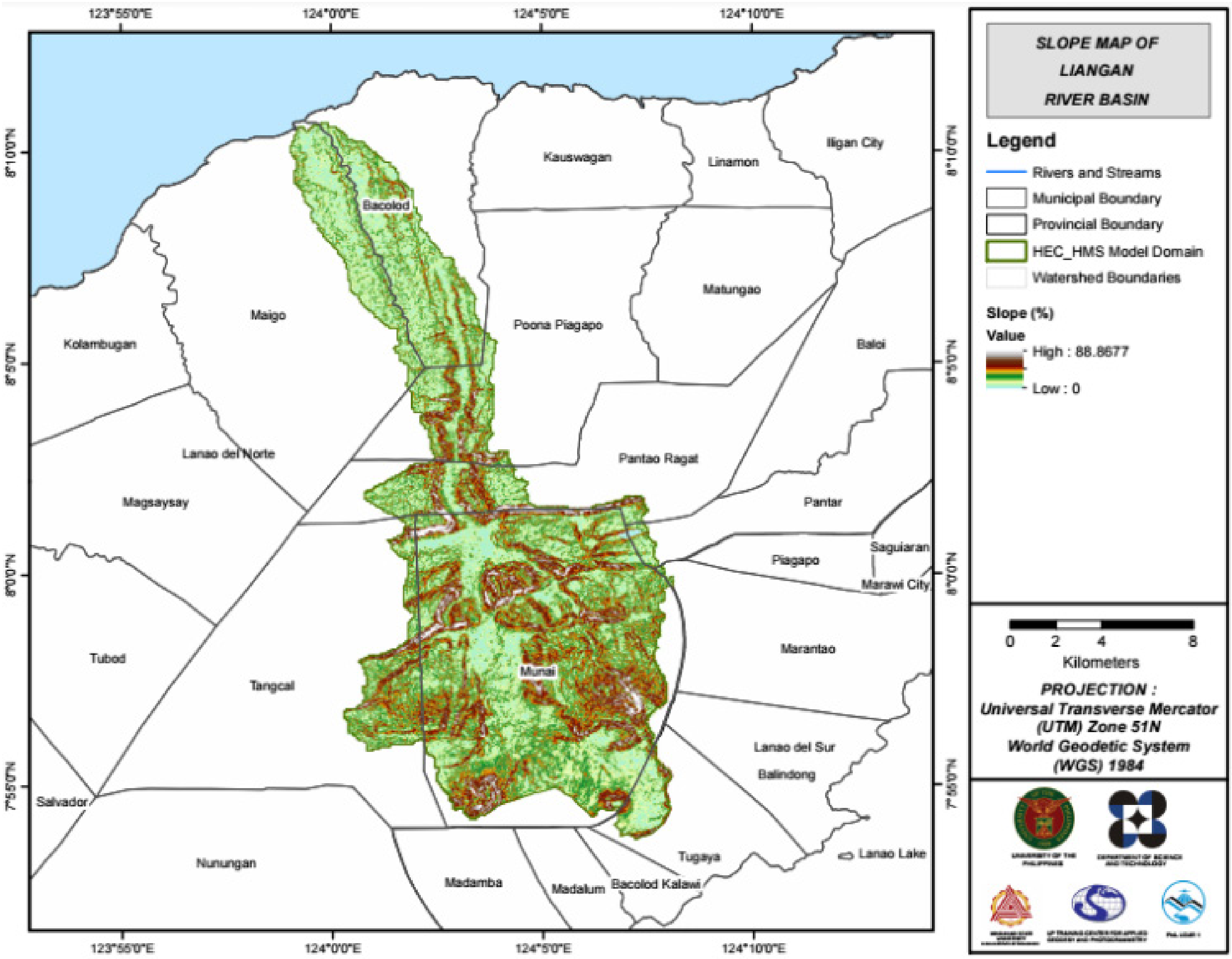

Figure 55. Slope Map of Liangan River Basin

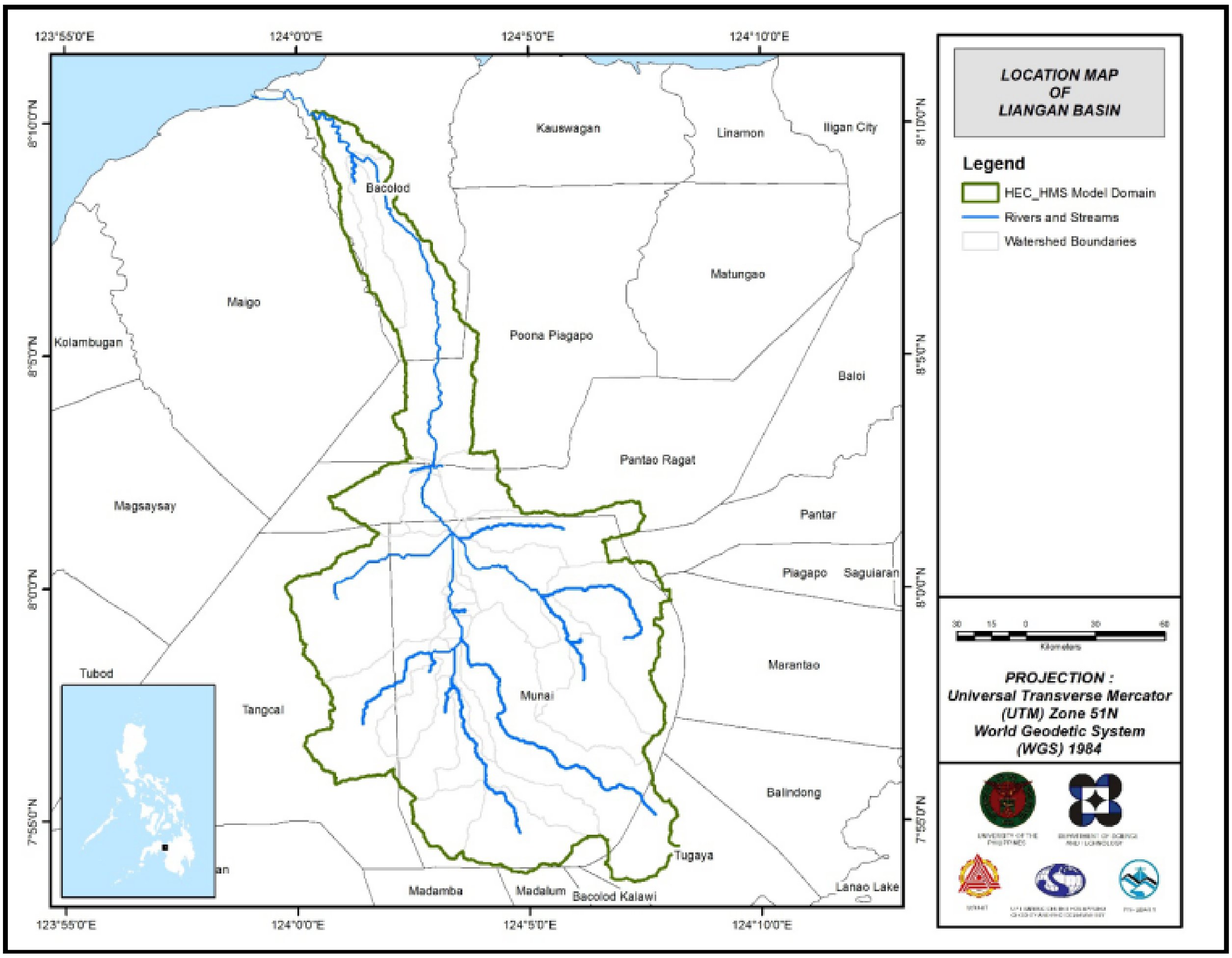

Figure 56. Stream Delineation Map of Liangan River Basin

Using the SAR-based DEM, the Liangan basin was delineated and further subdivided into subbasins. The model consists of 30 sub basins, 15 reaches, and 15 junctions. The main outlet is Lia_Point. This basin model is illustrated in Figure 56. Finally, it was calibrated using hydrological data derived from the depth gauge and flow meter deployed at Liangan Bridge.

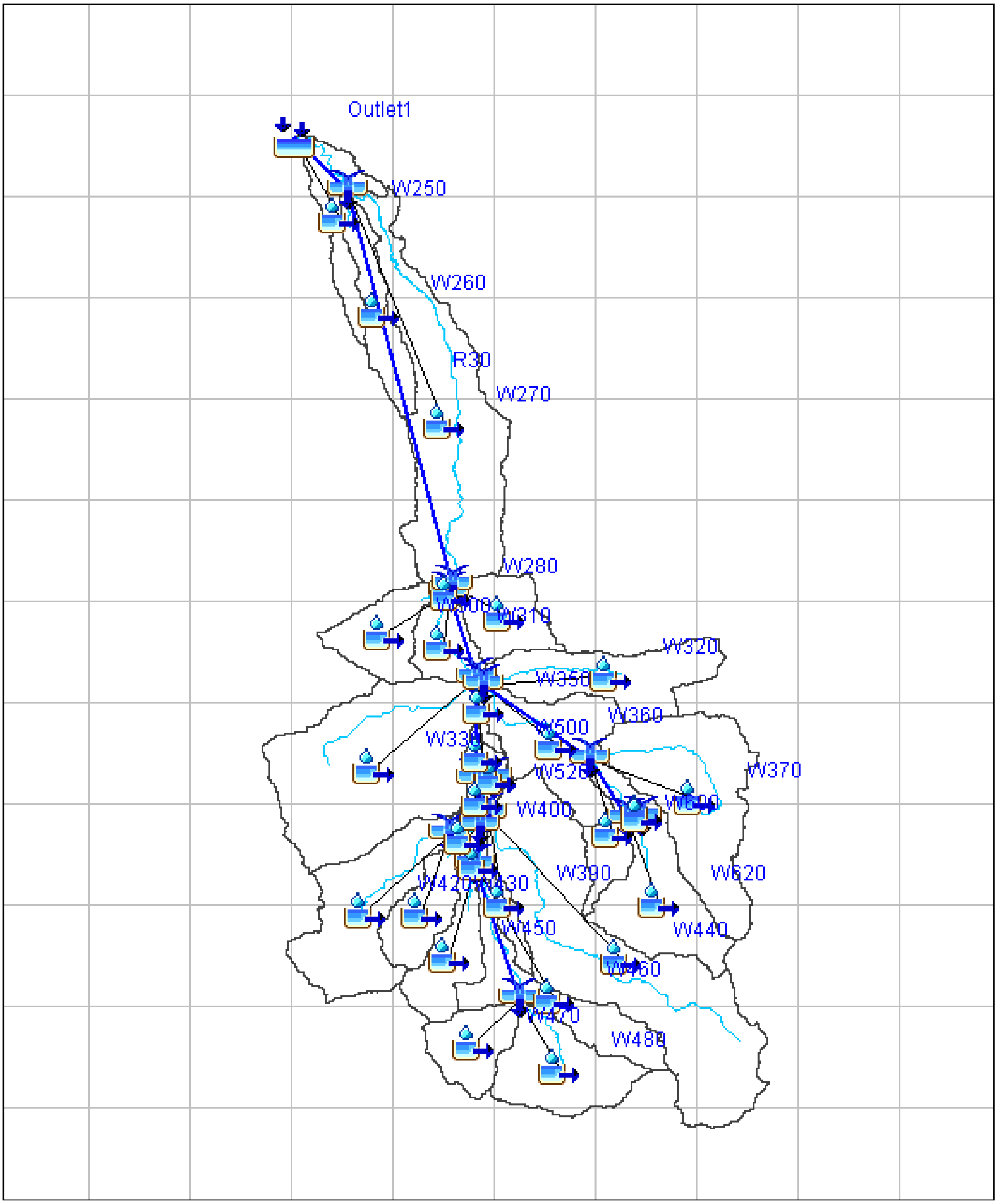

Figure 57. The Liangan Hydrologic Model generated in HEC-GeoHMS

5.4 Cross-section Data

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

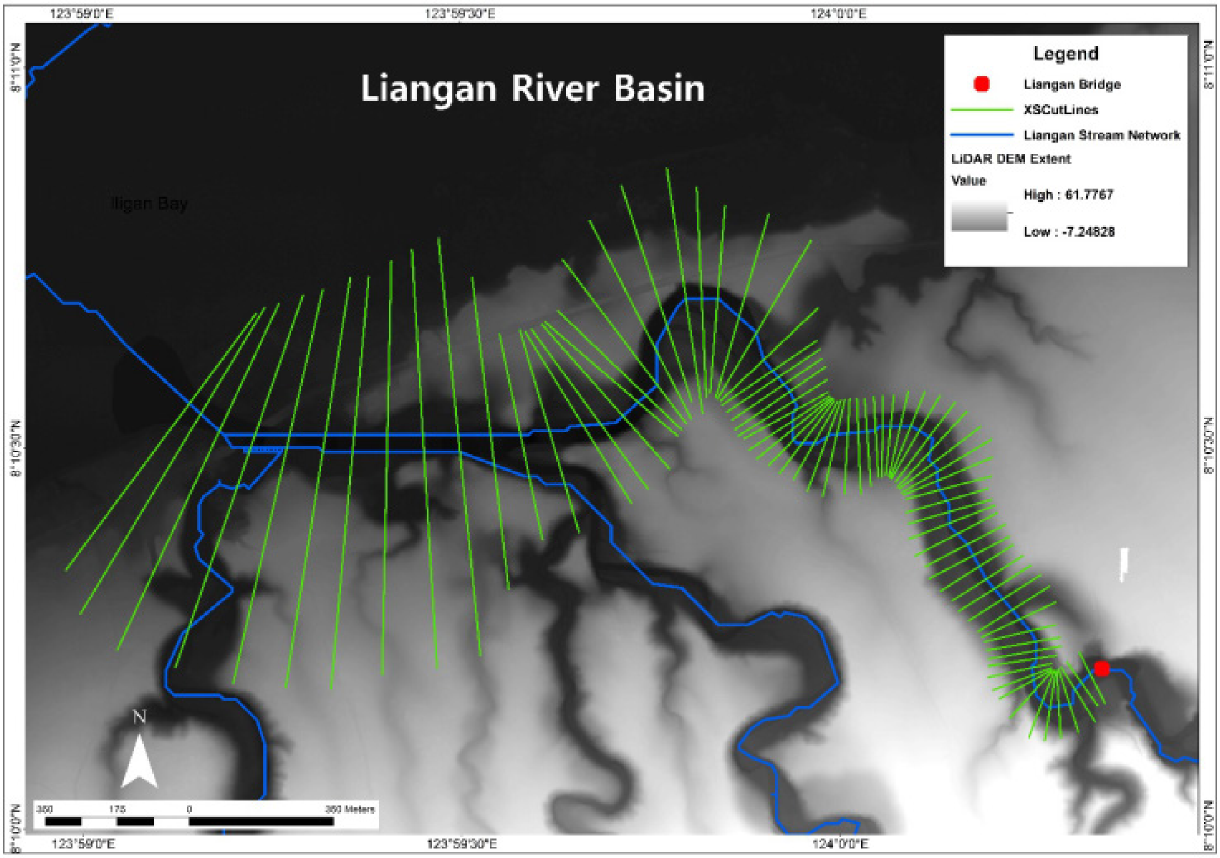

Figure 58. River cross-section of Liangan River generated through Arcmap HEC GeoRAS tool

5.5 Flo 2D Model

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

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

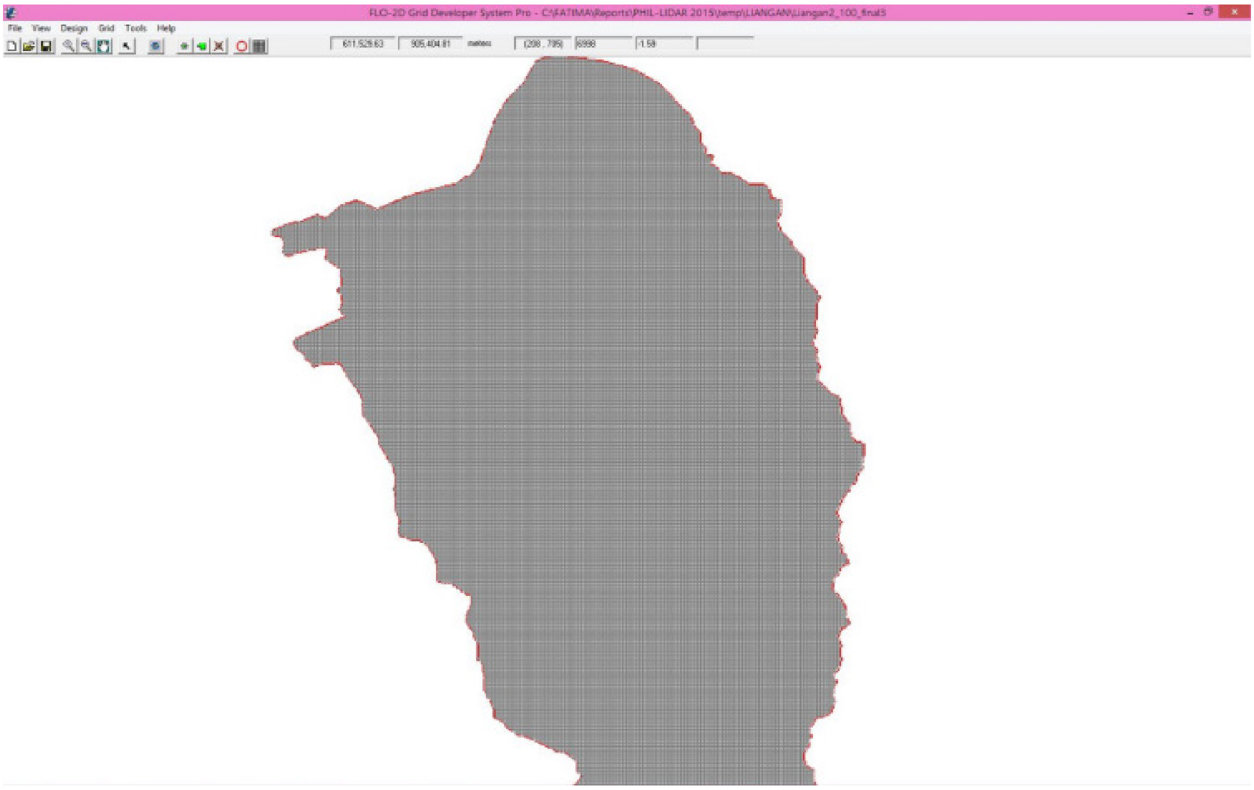

Figure 59. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 22.73016 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m2/s. The generated hazard maps for Liangan are in Figures 63, 65, and 67.

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 21148900.00 m2. The generated flood depth maps for Liangan are in Figures 64, 66, and 68.

There is a total of 82386741.24 m3 of water entering the model. Of this amount, 10149608.38 m3 is due to rainfall while 72237132.86 m3 is inflow from other areas outside the model. 1793094.88 m3 of this water is lost to infiltration and interception, while 974120.34 m3 is stored by the floodplain. The rest, amounting up to 79619530.89 m3, is outflow.

5.6 Results of HMS Calibration

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

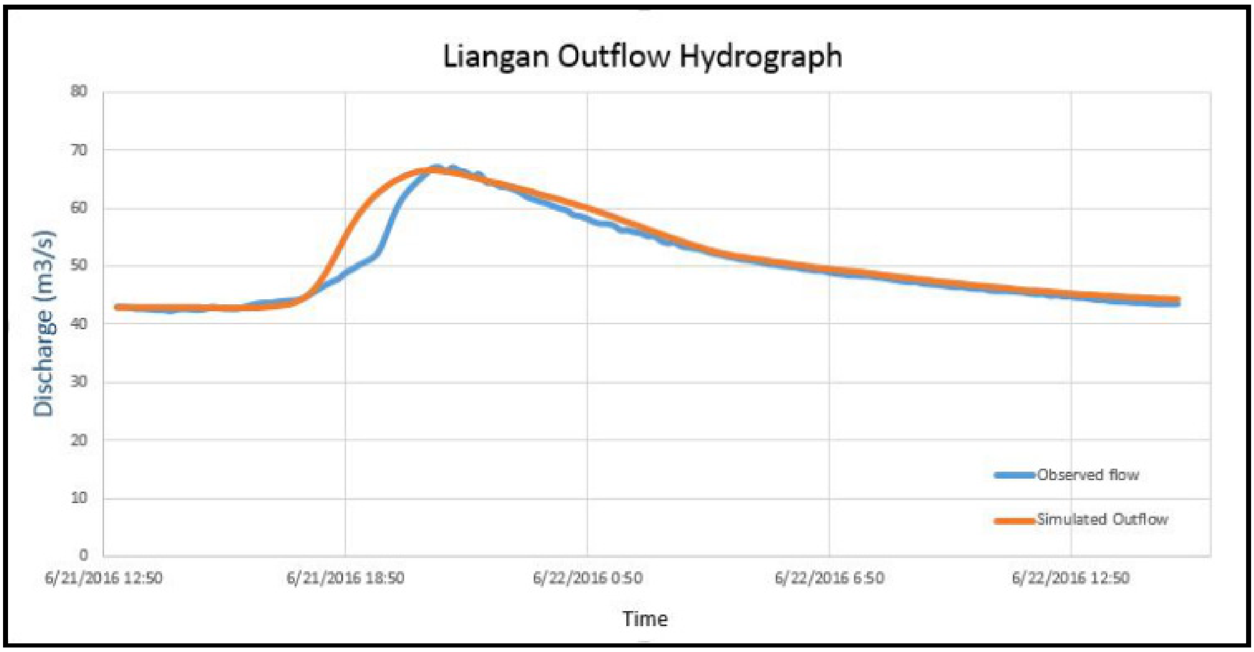

Figure 60. Outflow Hydrograph of Liangan Bridge generated in HEC-HMS model compared with observed outflow

Enumerated in Table 29 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 29. Range of calibrated values for Liangan

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	9 - 61
			Curve Number	55 - 89
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.1 – 7.5
			Storage Coefficient (hr)	0.07 - 9
	Baseflow	Recession	Recession Constant	0.95
			Ratio to Peak	0.435
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.045

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 9mm to 61mm means that there is a minimal to average amount of infiltration or rainfall interception by vegetation per subbasin.

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 55 to 89 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 0.07 to 9 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 0.95 indicates that the basin is unlikely to quickly go back to its original discharge and instead, will be higher. Ratio to peak of 0.435 indicates a steeper receding limb of the outflow hydrograph.

Manning's roughness coefficient of 0.045 corresponds to the common roughness Liangan watershed, which is determined to be cultivated with mature field crops (Brunner, 2010).

Table 30. Efficiency Test of the Liangan HMS Model

Accuracy measure	Value
RMSE	2.16
r2	0.94
NSE	0.91
PBIAS	-1.82
RSR	0.3

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 2.16 (m3/s).

The Pearson correlation coefficient (r2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.94.

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 -1.82.

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 0.3.

5.7 Calculated outflow hydrographs and discharge values for different rainfall return periods

5.7.1 Hydrograph using the Rainfall Runoff Model

The summary graph (Figure 61) shows the Liangan outflow using the Cagayan de Oro Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAG-ASA) data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

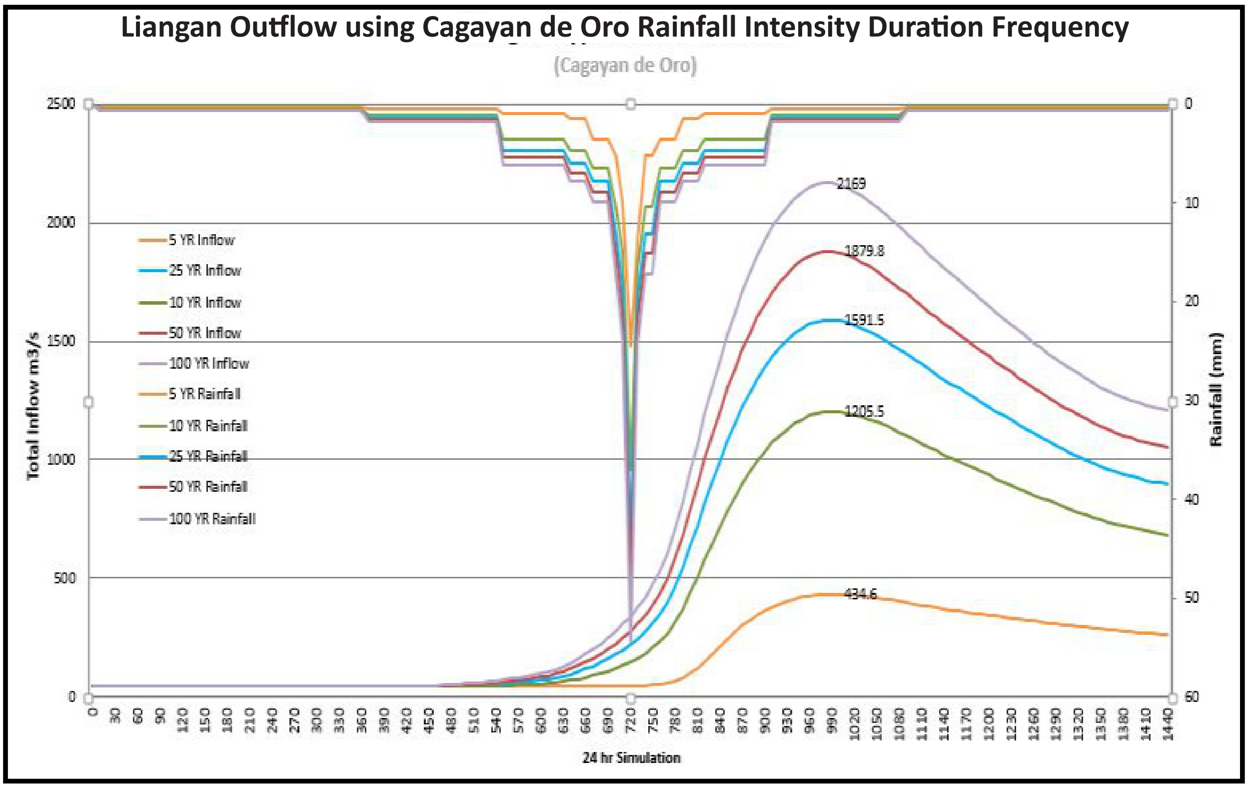

Figure 61. Outflow hydrograph at Liangan Station generated using Cagayan de Oro RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of the Liangan discharge using the Cagayan de Oro Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 31.

Table 31. Peak values of the Liangan HECHMS Model outflow using Cagayan de Oro RIDF

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	141.7	24.5	434.6	16 hours, 30 minutes
10-Year	300.7	37	1205.5	16 hours, 30 minutes
25-Year	373.6	44	1591.5	16 hours, 30 minutes
50-Year	427.6	49.2	1879.8	16 hours, 20 minutes
100-Year	481.2	54.4	2169	16 hours, 20 minutes

5.8 River Analysis (RAS) Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. The sample generated map of Liangan River using the calibrated HMS base flow is shown in Figure 62.

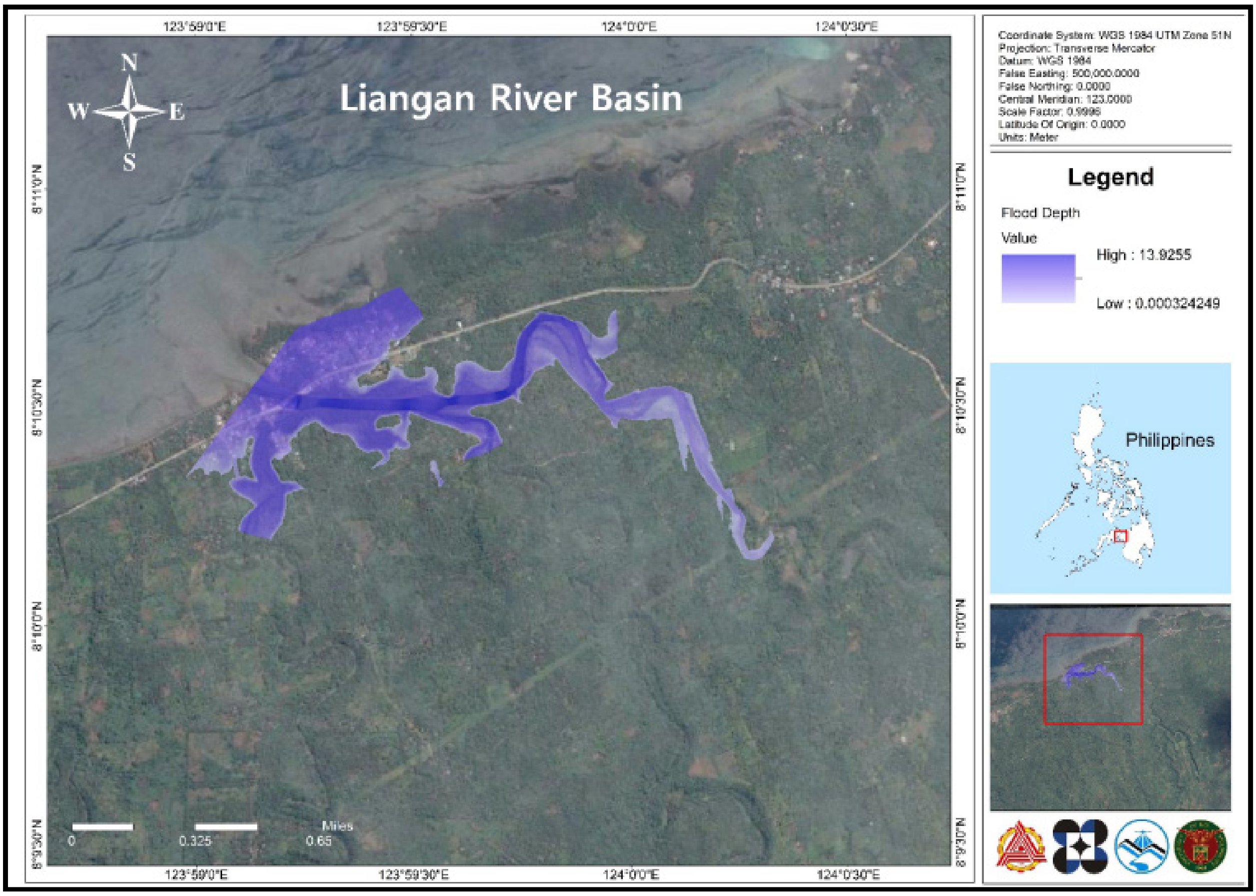

Figure 62. Sample output of Liangan RAS Model

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. Figure 63 to Figure 68 shows the 5-, 25-, and 100-year rain return scenarios of the Liangan floodplain. The floodplain, with an area of 44.65 sq. km., covers two municipalities namely Bacolod and Maigo. Table 34 shows the percentage of area affected by flooding per municipality.

Table 32. Municipalities affected in Liangan Floodplain

Municipality	Total Area	Area Flooded	% Flooded
Bacolod	62.2594	21.69	35%
Maigo	126.356	22.96	18%

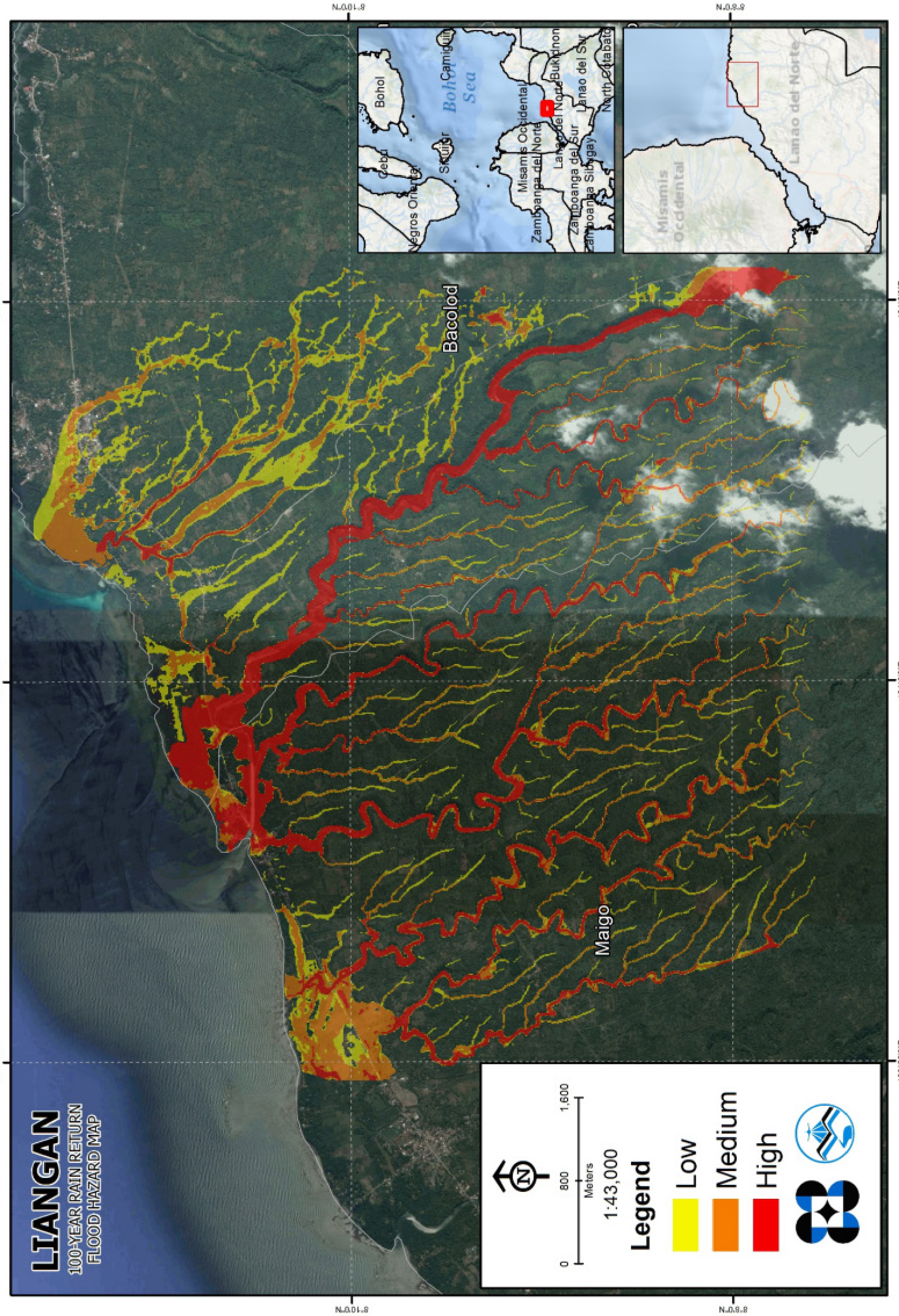

Figure 63. A 100-year flood hazard map for the Liangan Floodplain

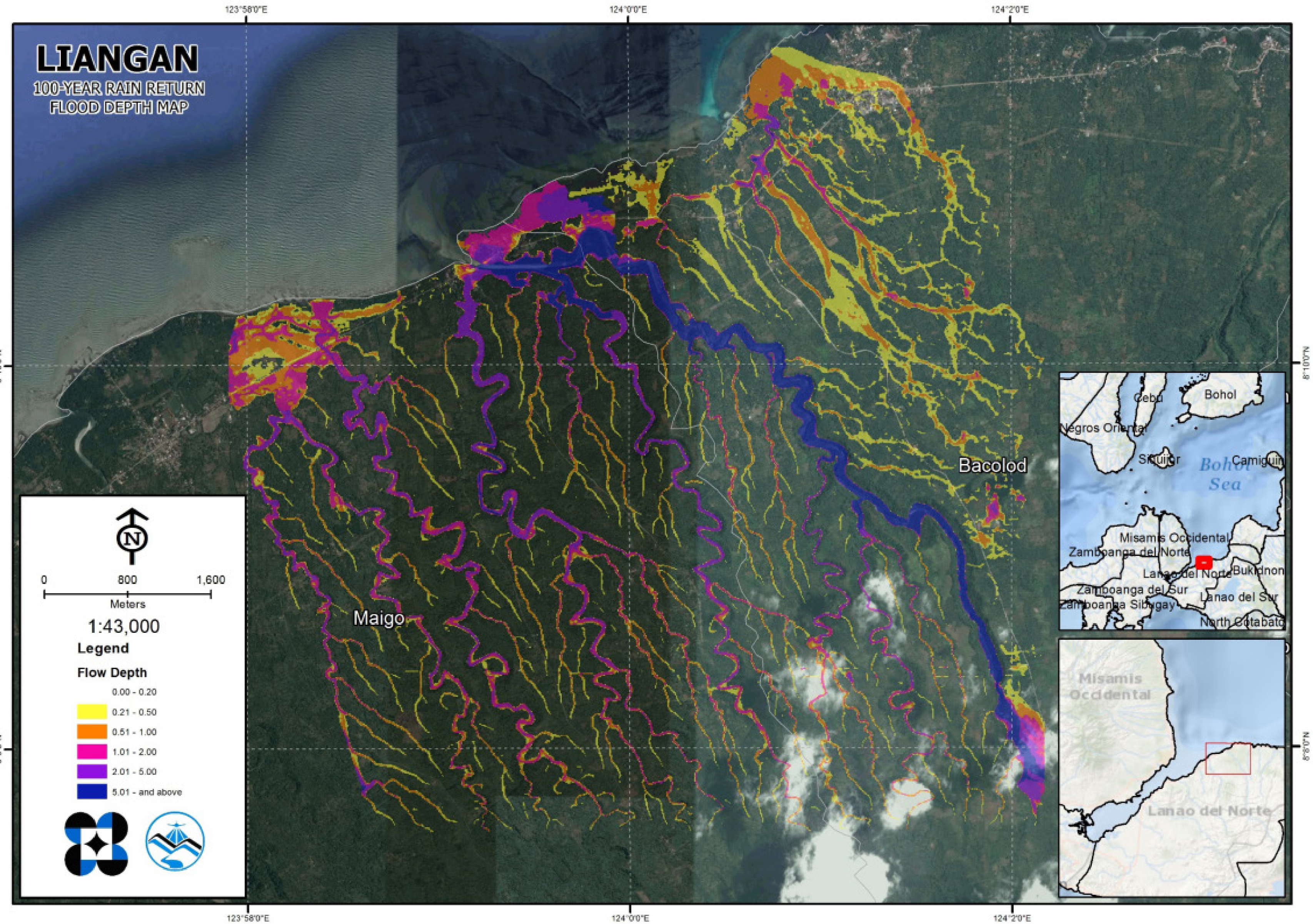

Figure 64. A 100-year Flow Depth Map for the Liangan Floodplain

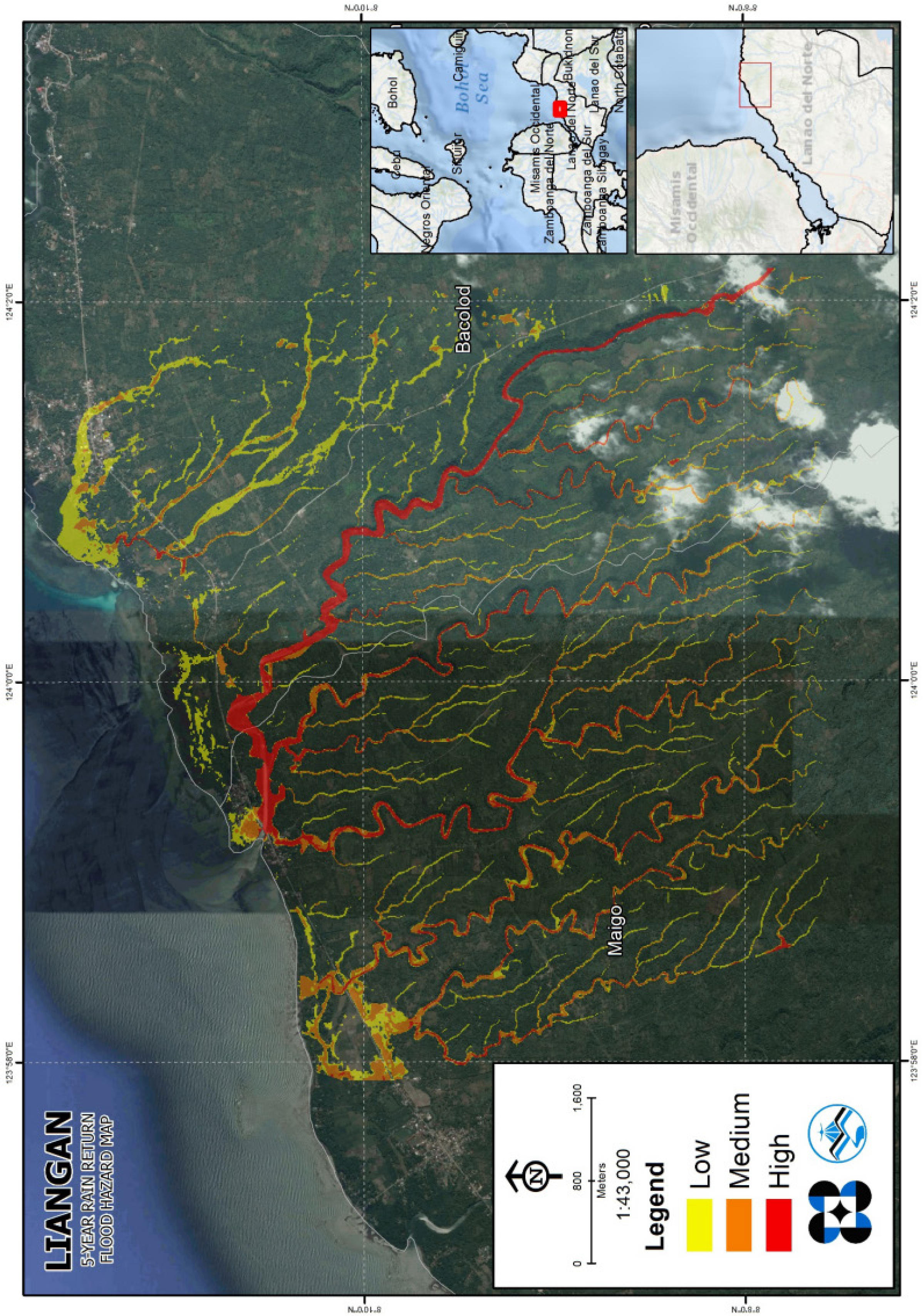

Figure 65. A 25-year Flood Hazard Map for Liangan Floodplain

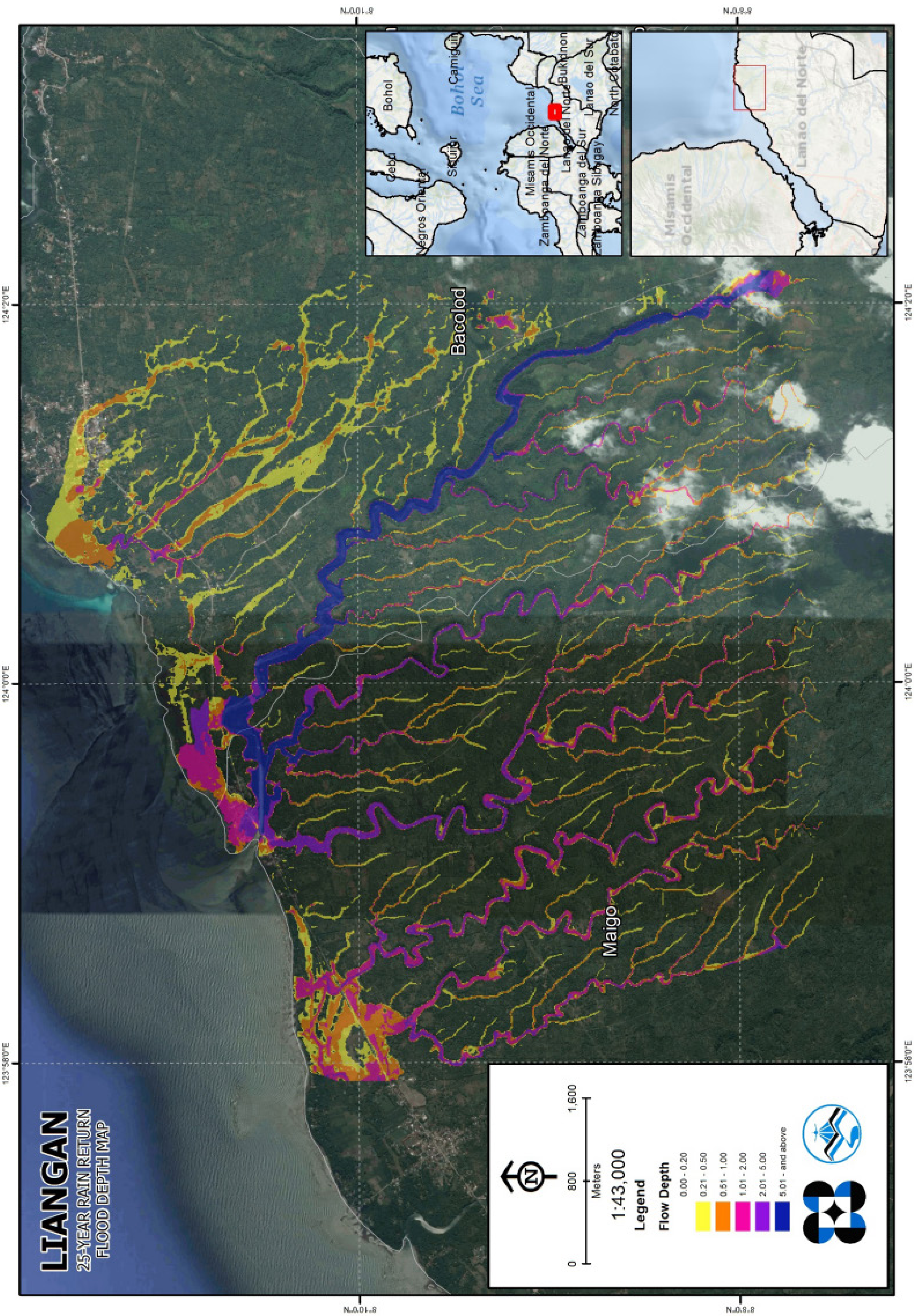

Figure 66. A 25-year Flow Depth Map for Liangan Floodplain

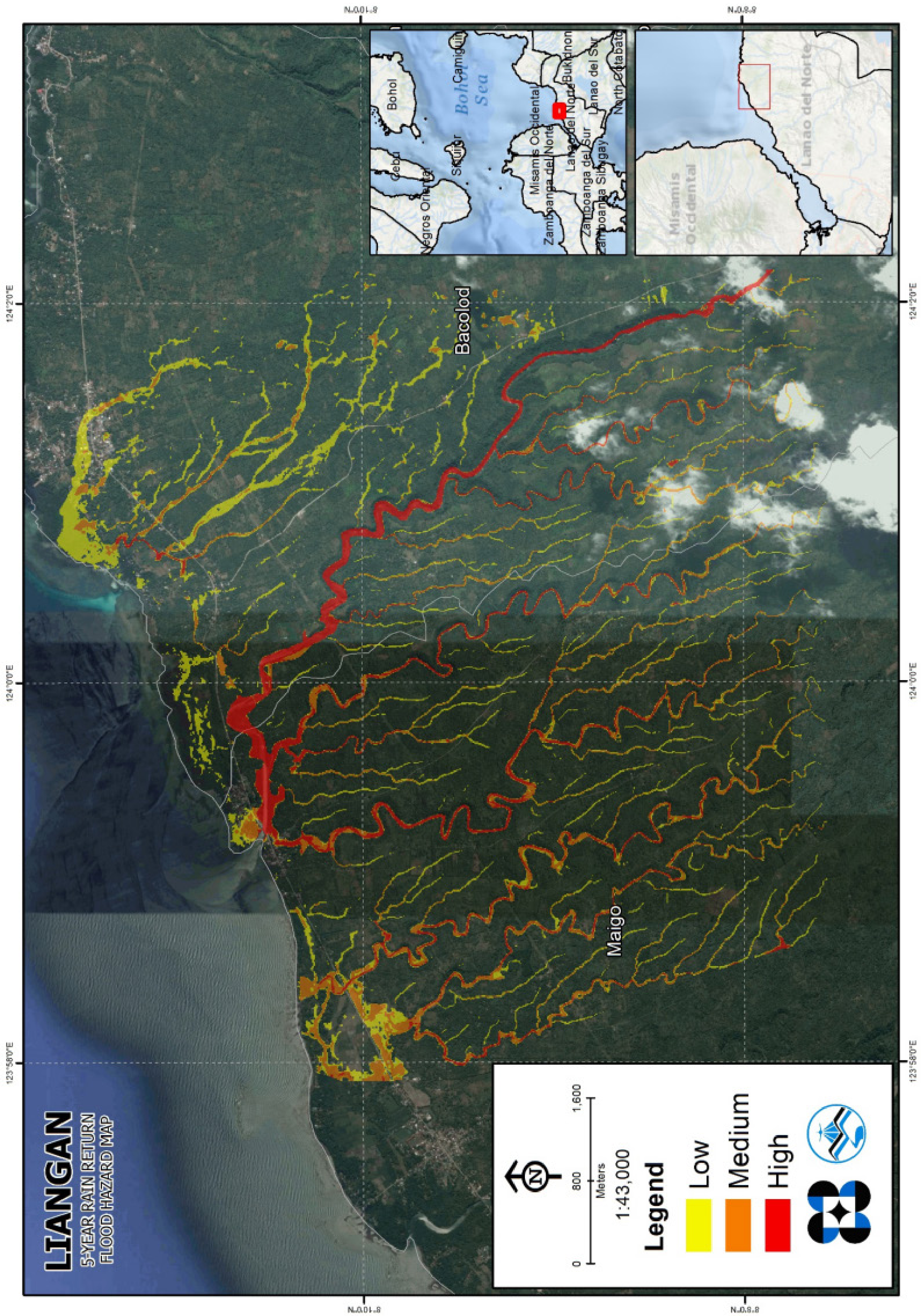

Figure 67. A 5-year Flood Hazard Map for Liangan Floodplain

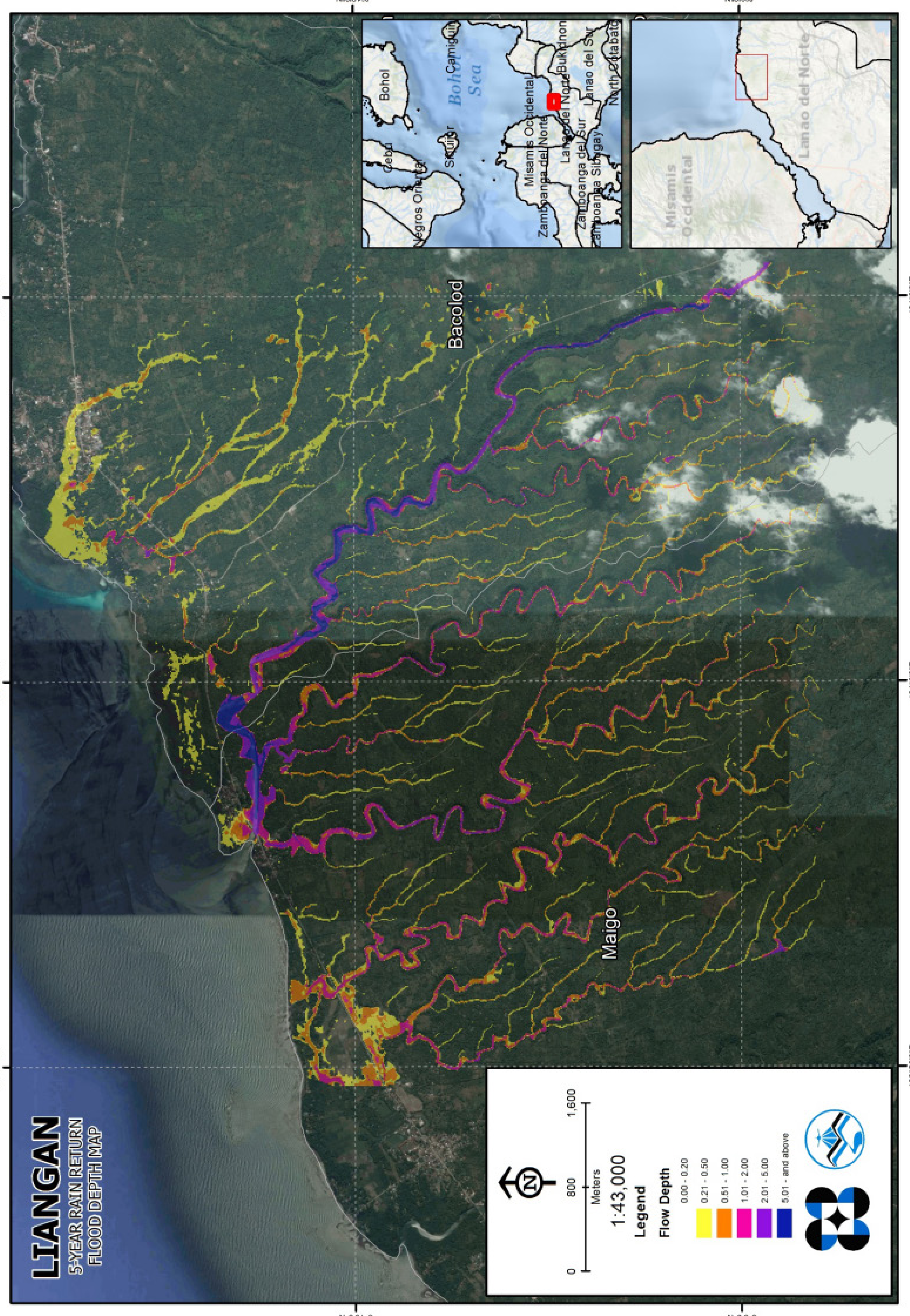

Figure 68. A 5-year Flow depth map for Liangan Floodplain.

5.10 Inventory of Areas Exposed to Flooding

Affected barangays in Liangan river basin, grouped by municipality, are listed below. For the said basin, two municipalities consisting of 17 barangays are expected to experience flooding when subjected to 5-, 25-, and 100-yr rainfall return period.

For the 5-year return period, 30.56% of the municipality of Bacolod with an area of 62.26 sq. km. will experience flood levels of less 0.20 meters. 2.45% of the area will experience flood levels of 0.21 to 0.50 meters while 0.71%, 0.34%, 0.47%, and 0.31% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 33 are the affected areas in square kilometres by flood depth per barangay.

Table 33. Affected areas in Bacolod, Lanao del Norte during a 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Bacolod (in sq. km.)								
	Alegria	Babalaya	Babalaya Townsite	Esper-anza	Kahayag	Liangan East	Mati	Pagaya-wan	Poblacion Bacolod
0.03-0.20	1.72	3.16	2.93	3.68	1.86	0.2	2.94	1.77	0.76
0.21-0.50	0.082	0.16	0.11	0.56	0.081	0.034	0.26	0.1	0.13
0.51-1.00	0.051	0.1	0.066	0.11	0.039	0.0001	0.026	0.025	0.02
1.01-2.00	0.054	0.051	0.05	0.037	0.016	0	0.0003	0.0043	0
2.01-5.00	0.14	0.05	0.068	0.0065	0.026	0	0	0.0015	0
> 5.00	0.14	0.014	0.029	0.0015	0.0047	0	0	0	0

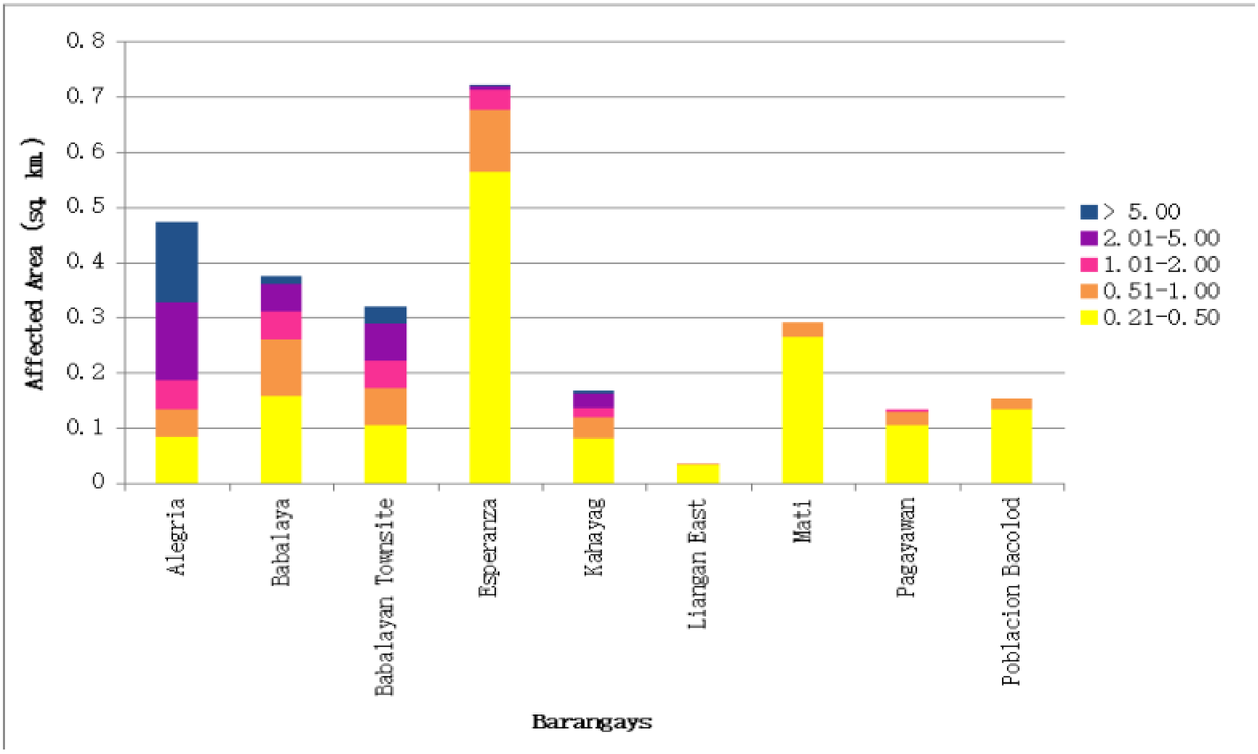

Figure 69. Affected Areas in Bacolod, Lanao del Norte during 5-Year Rainfall Return Period

For the municipality of Maigo, with an area of 126.36 sq. km., 15.88% will experience flood levels of less 0.20 meters. 0.87% of the area will experience flood levels of 0.21 to 0.50 meters while 0.74%, 0.48%, 0.15%, and 0.04% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 34 are the affected areas in square kilometres by flood depth per barangay.

Table 34. Affected Areas in Maigo, Lanao del Norte during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Maigo (in sq. km.)							
	Camp 1	Claro M. Recto	Inoma	Liangan West	Mahayahay	Mentring	Poblacion	Santa Cruz
0.03-0.20	3.3	1.6	0.62	2.72	6.07	1.21	0.27	4.28
0.21-0.50	0.12	0.22	0.022	0.15	0.28	0.058	0.014	0.24
0.51-1.00	0.081	0.27	0.0078	0.11	0.21	0.039	0.015	0.2
1.01-2.00	0.092	0.13	0.0028	0.14	0.1	0.0054	0.017	0.13
2.01-5.00	0.04	0.0041	0	0.13	0.0065	0	0.0028	0.0093
> 5.00	0	0	0	0.055	0	0	0	0.0001

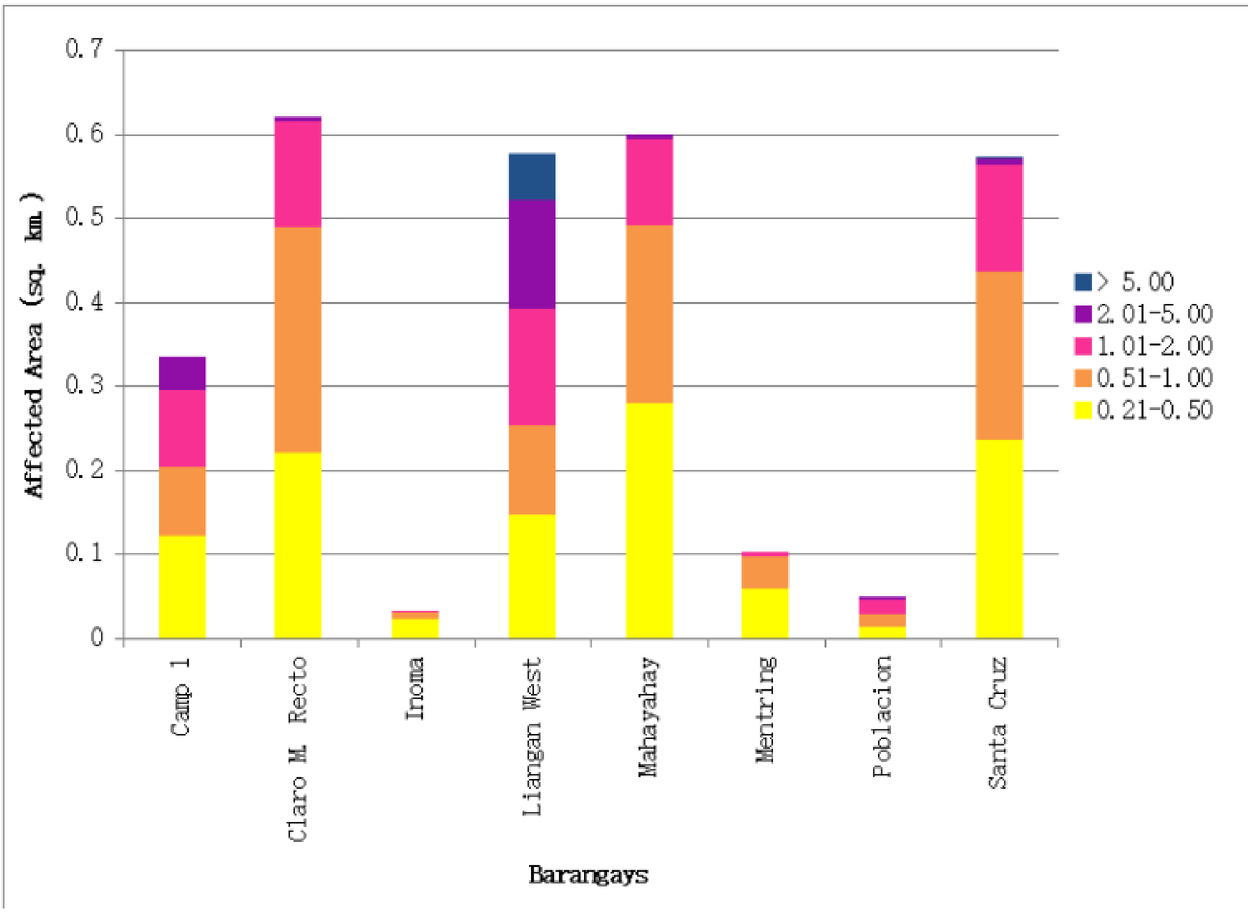

Figure 70. Affected Areas in Maigo, Lanao del Norte during 5-Year Rainfall Return Period

For the 25-Year return period, 27.51% of the municipality of Bacolod with an area of 62.26 sq. km. will experience flood levels of less 0.20 meters. 3.34% of the area will experience flood levels of 0.21 to 0.50 meters while 1.54%, 0.75%, 0.50%, 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 35 are the affected areas in square kilometres by flood depth per barangay.

Table 35. Affected Areas in Bacolod, Lanao del Norte during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Bacolod (in sq. km.)								
	Alegria	Babalaya	Babalaya Townsite	Esper-anza	Kahayag	Liangan East	Mati	Pagaya-wan	Poblacion Bacolod
0.03-0.20	1.42	3.02	2.73	3.21	1.71	0.098	2.64	1.64	0.66
0.21-0.50	0.085	0.16	0.13	0.71	0.092	0.033	0.49	0.19	0.18
0.51-1.00	0.089	0.14	0.079	0.37	0.07	0.014	0.093	0.044	0.061
1.01-2.00	0.098	0.075	0.062	0.081	0.044	0.082	0.0049	0.019	0.0002
2.01-5.00	0.11	0.05	0.051	0.026	0.054	0.011	0	0.0033	0
> 5.00	0.4	0.097	0.2	0.0045	0.059	0	0	0.0046	0

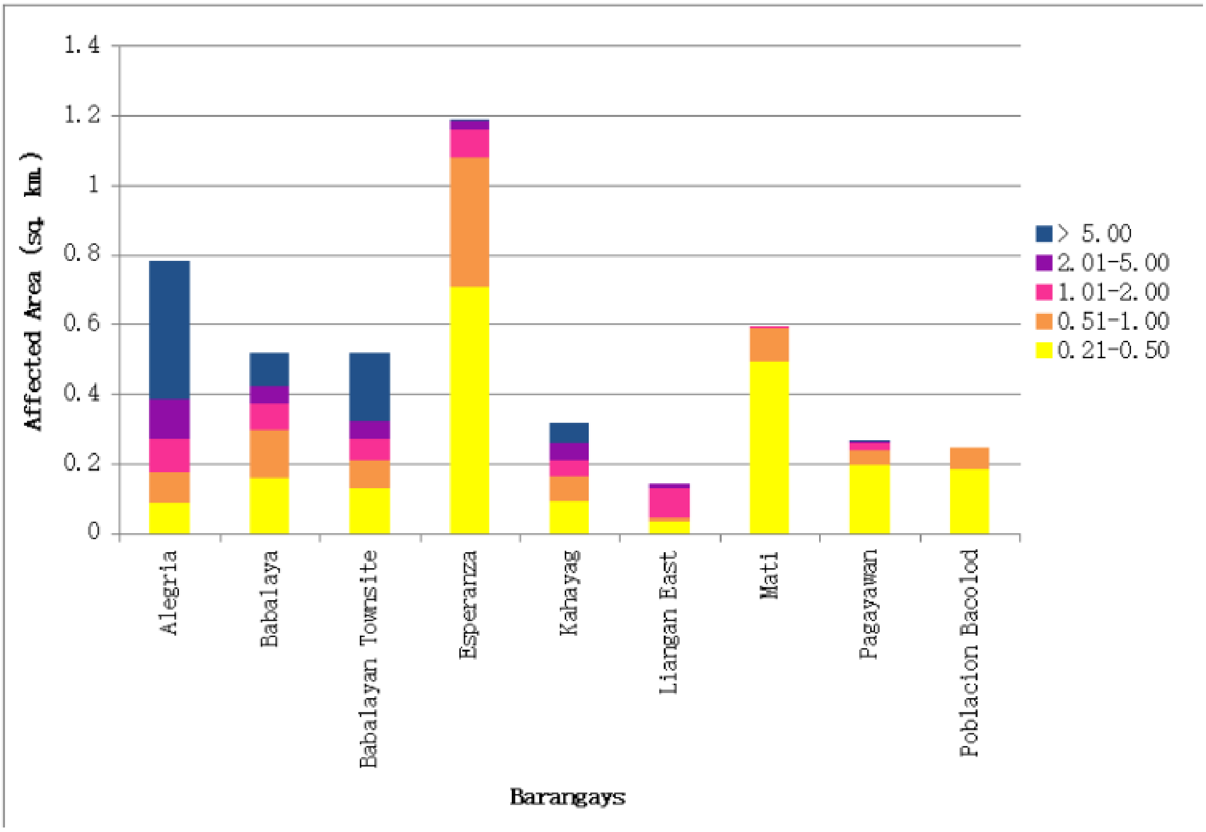

Figure 71. Affected Areas in Bacolod, Lanao del Norte during 25-Year Rainfall Return Period

For the municipality of Maigo, with an area of 126.36 sq. km., 14.86% will experience flood levels of less 0.20 meters. 0.89% of the area will experience flood levels of 0.21 to 0.50 meters while 0.87%, 0.85%, 0.54%, and 0.16% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 36 are the affected areas in square kilometres by flood depth per barangay.

Table 36. Affected Areas in Maigo, Lanao del Norte during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Maigo (in sq. km.)							
	Camp 1	Claro M. Recto	Inoma	Liangan West	Mahayahay	Mentring	Poblacion	Santa Cruz
0.03-0.20	3.18	1.24	0.6	2.47	5.82	1.17	0.24	4.07
0.21-0.50	0.14	0.21	0.027	0.15	0.3	0.064	0.017	0.23
0.51-1.00	0.085	0.36	0.013	0.1	0.25	0.053	0.014	0.22
1.01-2.00	0.079	0.32	0.0071	0.15	0.22	0.031	0.024	0.25
2.01-5.00	0.16	0.082	0.0006	0.24	0.09	0.001	0.021	0.087
> 5.00	0.004	0	0	0.19	0	0	0	0.0009

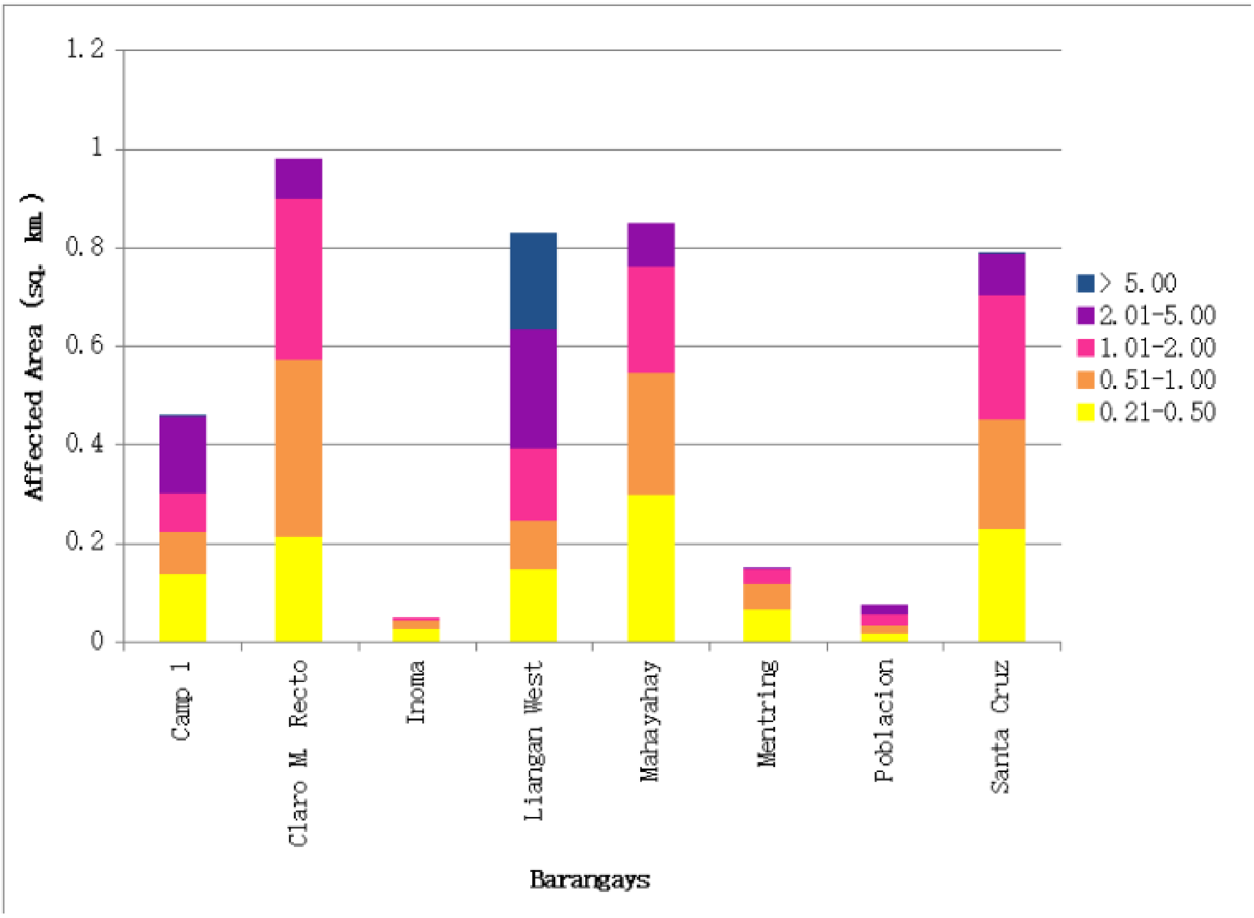

Figure 72. Affected Areas in Maigo, Lanao del Norte during 25-Year Rainfall Return Period

For the 100-year return period, 26.28% of the municipality of Bacolod with an area of 62.26 sq. km. 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 1.83%, 0.90%, 0.71%, and 1.49% 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 square kilometres by flood depth per barangay.

Table 37. Affected Areas in Bacolod, Lanao del Norte during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Bacolod (in sq. km.)								
	Alegria	Babalaya	Babalaya Townsite	Esper-anza	Kahayag	Liangan East	Mati	Pagaya-wan	Poblacion Bacolod
0.03-0.20	1.35	2.96	2.64	3.03	1.59	0.093	2.51	1.57	0.62
0.21-0.50	0.079	0.17	0.16	0.71	0.085	0.038	0.57	0.24	0.2
0.51-1.00	0.069	0.14	0.085	0.48	0.089	0	0.13	0.058	0.08
1.01-2.00	0.11	0.089	0.063	0.14	0.074	0.056	0.0097	0.022	0.0027
2.01-5.00	0.13	0.062	0.062	0.039	0.099	0.044	0	0.006	0
> 5.00	0.46	0.12	0.25	0.0065	0.088	0.0061	0	0.0059	0

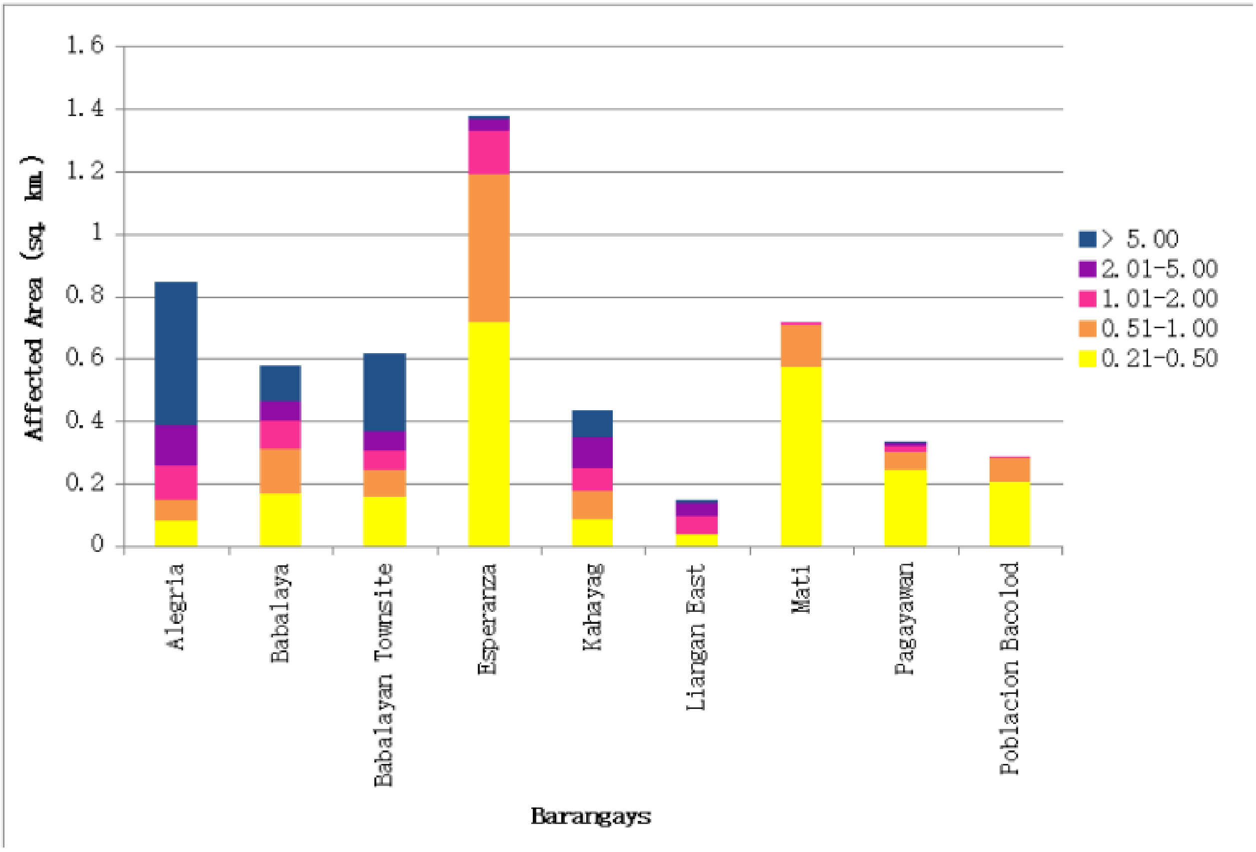

Figure 73. Affected Areas in Bacolod, Lanao del Norte during 100-Year Rainfall Return Period

For the municipality of Maigo, with an area of 126.36 sq. km., 14.56% will experience flood levels of less 0.20 meters. 0.89% of the area will experience flood levels of 0.21 to 0.50 meters while 0.89%, 0.92%, 0.71%, and 0.19% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 38 are the affected areas in square kilometres by flood depth per barangay.

Table 38. Affected Areas in Maigo, Lanao del Norte during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Maigo (in sq. km.)							
	Camp 1	Claro M. Recto	Inoma	Liangan West	Mahayahay	Mentring	Poblacion	Santa Cruz
0.03-0.20	3.13	1.15	0.6	2.41	5.73	1.15	0.23	4
0.21-0.50	0.14	0.2	0.026	0.15	0.31	0.065	0.019	0.22
0.51-1.00	0.093	0.36	0.016	0.12	0.25	0.055	0.015	0.22
1.01-2.00	0.068	0.37	0.0077	0.15	0.25	0.042	0.023	0.26
2.01-5.00	0.18	0.15	0.0014	0.26	0.13	0.002	0.03	0.15
> 5.00	0.023	0	0	0.22	0.000003	0	0	0.0014

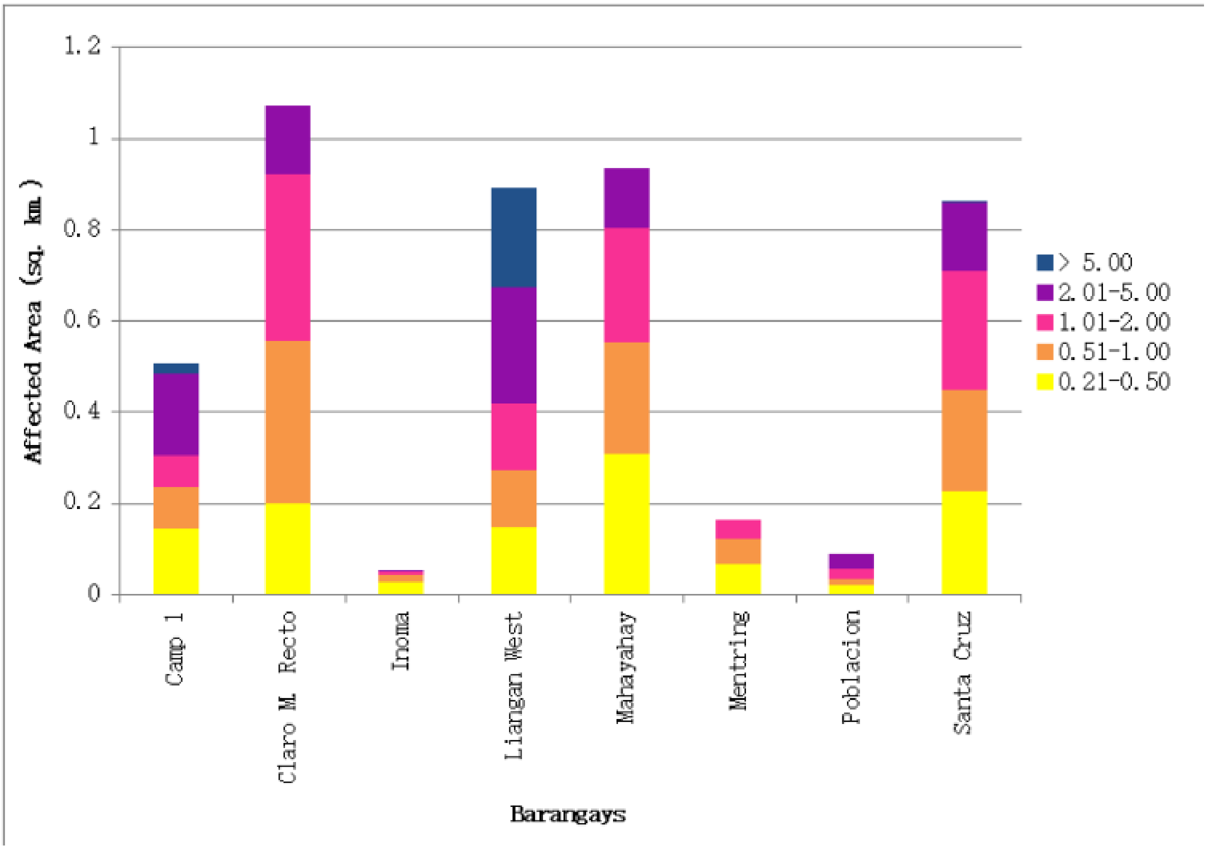

Figure 74. Affected Areas in Maigo, Lanao del Norte during 100-Year Rainfall Return Period

Among the barangays in the municipality of Bacolod, Esperanza is projected to have the highest percentage of area that will experience flood levels at 7.07%. Meanwhile, Babalaya posted the second highest percentage of area that may be affected by flood depths at 5.68%.

Among the barangays in the municipality of Maigo, Mahayahay is projected to have the highest percentage of area that will experience flood levels at 5.28%. Meanwhile, Santa Cruz posted the second highest percentage of area that may be affected by flood depths at 3.84%.

Moreover, the generated flood hazard maps for the Liangan 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 39. Areas covered by each warning level with respect to the rainfall scenarios

Warning Level	Area Covered in sq. km.		
	5 year	25 year	100 year
Low	2.61	3.22	3.41
Medium	1.74	2.90	3.14
High	1.36	2.81	3.53
TOTAL	**5.71**	**8.93**	**10.08**

Of the 21 identified Education Institutions in Liangan Flood plain, none was assessed to be exposed to any level of flooding during a 5 year scenario. In the 25 and 100 year scenario, only Esperanza Elementary School was assessed to be exposed to the Low level flooding. See Annex 12 for a detailed enumeration of schools inside Liangan floodplain.

Of the 3 identified Medical Institutions in Liangan Flood plain, none was assessed to be exposed to any level of flooding during a 5, 25, and 100 year scenario. See Annex 13 for a detailed enumeration of medical insitutions inside Liangan floodplain.

5.11 Flood Validation

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

From the Flood Depth Maps produced by Phil-LiDAR 1 Program, multiple points representing the different flood depths for different scenarios are identified for validation.

The validation personnel went to the specified points identified in a river basin and gathered data regarding the actual flood level in each location. Data gathering was done through a local DRRM office to obtain maps or situation reports about the past flooding events or through interview of some residents with knowledge of or have had experienced flooding in a particular area. The flood validation data were obtained on March 2016.

After which, the actual data from the field will be compared to the simulated data to assess the accuracy of the Flood Depth Maps produced and to improve on what is needed. The points in the flood map versus its corresponding validation depths are shown in Figure 77.

The flood validation consists of 156 points randomly selected all over the Liangan floodplain. It has an RMSE value of 0.58.

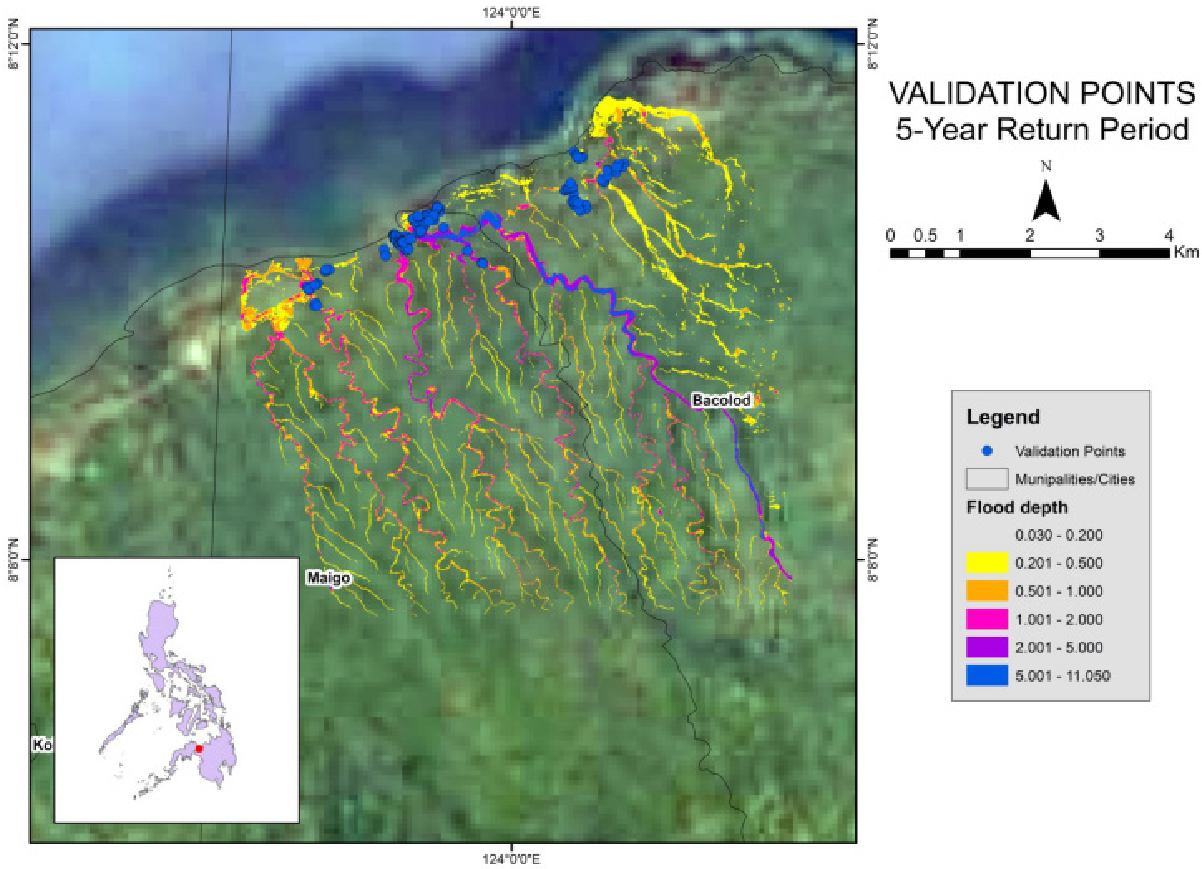

Figure 75. Validation points for a 5-year Flood Depth Map of the Liangan Floodplain.

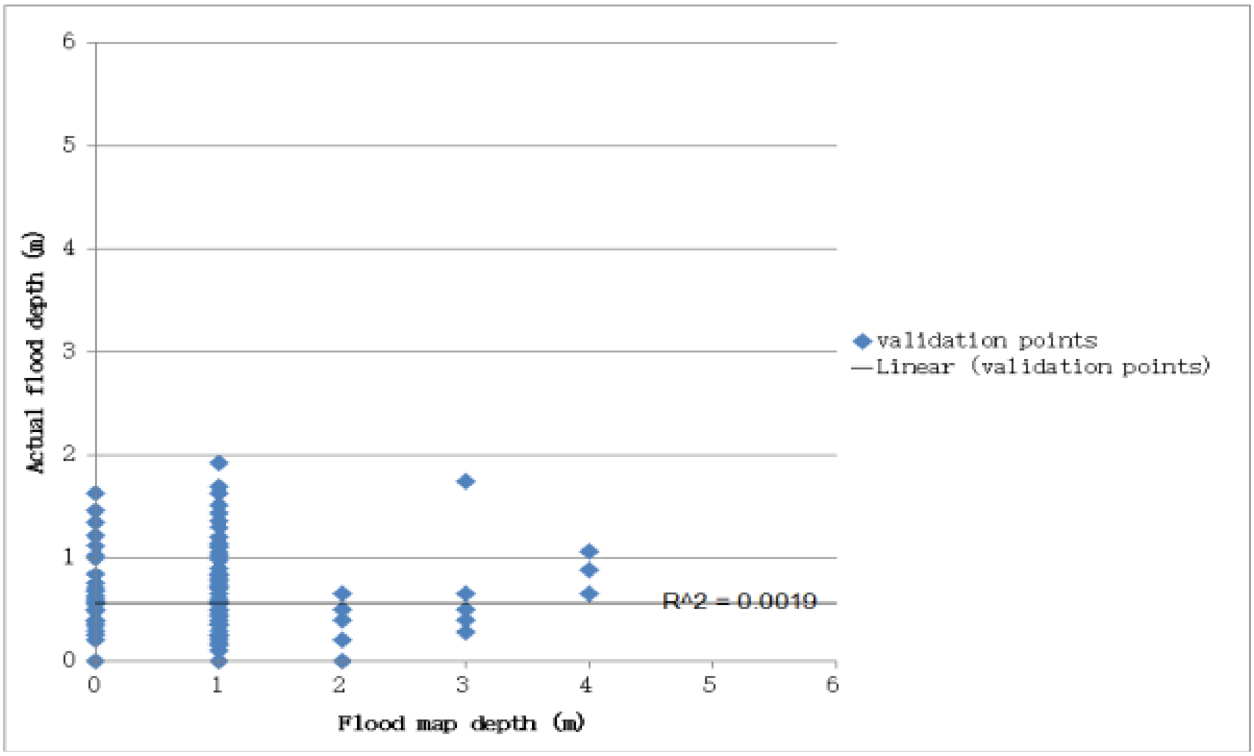

Figure 76. Flood map depth vs. actual flood depth

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

Actual Flood Depth (m)	Modeled Flood Depth (m)						
	0-0.20	0.21-0.50	0.51-1.00	1.01-2.00	2.01-5.00	> 5.00	Total
0-0.20	54	6	0	0	0	0	60
0.21-0.50	59	17	10	0	0	0	86
0.51-1.00	32	8	7	5	2	0	54
1.01-2.00	19	4	5	10	2	0	40
2.01-5.00	0	1	0	1	0	0	2
> 5.00	0	0	0	0	0	0	0
Total	164	36	22	16	4	0	242

On the whole, the overall accuracy generated by the flood model is estimated at 31.06%, with 73 points correctly matching the actual flood depths. In addition, there were 68 points estimated one level above and below the correct flood depths, while there were 46 points and 42 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 25 points were overestimated, while a total of 137 points were underestimated in the modeled flood depths of Liangan River Basin. Table 54 depicts the summary of the Accuracy Assessment in the Liangan River Basin Flood Depth Map.

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

	No. of Points	%
Correct	88	36.36
Overestimated	25	10.33
Underestimated	129	53.31
Total	242	100

REFERENCES

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Sarmiento C.J.S., Paringit E.C., et al. 2014. DREAM Data Aquisition 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 Pegasus Sensor used in the Liangan Floodplain Survey

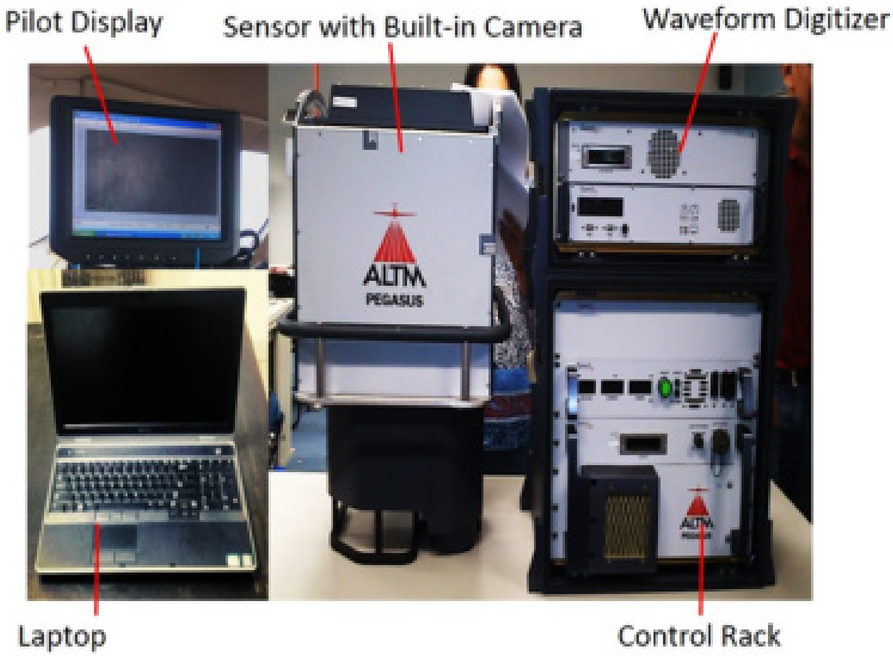

Figure A-1.1. Pegasus Sensor

Table A-1.1. Parameters and Specification of Pegasus Sensor

Parameter	Specification
Operational envelope (1,2,3,4)	150-5000 m AGL, nominal
Laser wavelength	1064 nm
Horizontal accuracy (2)	1/5,500 x altitude, 1σ
Elevation accuracy (2)	< 5-20 cm, 1σ
Effective laser repetition rate	Programmable, 100-500 kHz
Position and orientation system	POS AV ™AP50 (OEM)
Scan width (FOV)	Programmable, 0-75 ˚
Scan frequency (5)	Programmable, 0-140 Hz (effective)
Sensor scan product	800 maximum
Beam divergence	0.25 mrad (1/e)
Roll compensation	Programmable, ±37˚ (FOV dependent)
Vertical target separation distance	<0.7 m
Range capture	Up to 4 range measurements, including 1st, 2nd, 3rd, and last returns
Intensity capture	Up to 4 intensity returns for each pulse, including last (12 bit)
Image capture	5 MP interline camera (standard); 60 MP full frame (optional)
Full waveform capture	12-bit Optech IWD-2 Intelligent Waveform Digitizer
Data storage	Removable solid state disk SSD (SATA II)
Power requirements	28 V, 800 W, 30 A
Dimensions and weight	Sensor: 630 x 540 x 450 mm; 65 kg;
	Control rack: 650 x 590 x 490 mm; 46 kg
Operating Temperature	-10°C to +35°C
Relative humidity	0-95% non-condensing

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

1. LAN-2

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

June 24, 2014

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: **LANAO DEL NORTE**
Station Name: **LAN-2**
Order: **1st**

Island: **MINDANAO**		Barangay: **PINOYAK**
Municipality: **LALA**		
	PRS92 Coordinates	
Latitude: **7° 54' 46.07859"**	Longitude: **123° 46' 0.85333"**	Ellipsoidal Hgt: **17.35400 m.**
	WGS84 Coordinates	
Latitude: **7° 54' 42.56546"**	Longitude: **123° 46' 6.31720"**	Ellipsoidal Hgt: **83.92120 m.**
	PTM Coordinates	
Northing: **875110.149 m.**	Easting: **364025.74 m.**	Zone: **5**
	UTM Coordinates	
Northing: **874,680.35**	Easting: **584,533.45**	Zone: **51**

Location Description

LAN-2
From Iligan City, travel southwest along the National highway for 74.5 kilometers to the municipality of Lala. Travel farther along the national highway for 1.4 kilometers up to Maranding junction. Thence from the junction travel southeast along the national highway for another 1.3 kilometers to a dirt road going to Pinoyak barangay proper. Turn right on the dirt road and national highway intersection and continue travelling westward for 400 meters up to the irrigation canal. Station is located on top of the concrete irrigation canal water gate. Station mark is 0.15 m x 0.01 m in diameter brass rod, with cross cut on top, set in a drill hole on top of the concrete irrigation canal water gate; centered in cement patty and inscribed on top with the station name. All reference marks are 0.15 m x 0.01 m in diameter brass rod, with cross cut on top, set in drill holes on top of the concrete irrigation canal water gate; centered in cement patty and inscribed with the reference mark numbers and arrow pointing to the station.

Requesting Party:	**Engr. Cruz**
Pupose:	**Reference**
OR Number:	**8796376 A**
T.N.:	**2014-1441**

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

9906242014111658

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

Figure A-2.1. LAN-2

2. LDN-01

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

April 18, 2013

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: **LANAO DEL NORTE**	
	Station Name: **LDN-01**	
Island: **MINDANAO**	Order: **3rd**	Barangay: **POBLACION**
Municipality: **ILIGAN CITY**		
	PRS92 Coordinates	
Latitude: **8° 14' 1.44528"**	Longitude: **124° 13' 56.94179"**	Ellipsoidal Hgt: **11.87000 m.**
	WGS84 Coordinates	
Latitude: **8° 13' 57.88944"**	Longitude: **124° 14' 2.37264"**	Ellipsoidal Hgt: **78.95000 m.**
	PTM Coordinates	
Northing: **910480.055 m.**	Easting: **415436.191 m.**	Zone: **5**
	UTM Coordinates	
Northing: **910,289.41**	Easting: **635,751.93**	Zone: **51**

Location Description

LDN-01
From Iligan City, travel northeast going to Iligan City Pier for about 15 minutes drive. The station is located at the roof top of Iligan City PPA Administration building, inside the Iligan City Pier compound. Mark is a 30x30 cm cement putty monument, on top of PPA Administration building, with 4-inches on the center of the cement putty monument inscribed with station name LDN-01 2007 NCIP.

Requesting Party: **UP DREAM/ Melchor Nery**
Pupose: **Reference**
OR Number: **3943540 B**
T.N.: **2013-0307**

RUEL DM. BELEN, MNSA
Director, Mapping and Geodesy Department

9904182013101154

CERTIFICATION INTERNATIONAL ISO 9001:2008
CIP/4701/12/09/814

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Figure A-2.2. LDN-01

3. LE-50

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

June 24, 2014

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: **LANAO DEL NORTE** Station Name: **LE-50**	
Island: **Mindanao**	Municipality: **MAIGO**	Barangay: **CLARO M. RECTO**
Elevation: **5.3895 m.**	Order: **1st Order**	Datum: **Mean Sea Level**

Location Description

BM LE-50 is in the Province of Lanao Del Norte, Town of Maigo, Brgy. C.M. Recto, along the Butuan - Zamboanga National Road, and about 50 meters North East of the Covenant Baptist Church. The station is located at the South West end of the Barogohan Bridge footwalk and about 70 meters South West of KM post 1561.

A brass rod is set on a drilled hole and cemented flushed on top of a 15cm x 15cm cement putty with inscription "LE-50, 2007, NAMRIA".

Requesting Party: **Engr. Cruz**
Pupose: **Reference**
OR Number: **8796376 A**
T.N.: **2014-1440**

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

9906242014111639

CERTIFICATION INTERNATIONAL ISO 9001:2008 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-2.3. LE-50

4. LE-55

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

July 25, 2014

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: **LANAO DEL NORTE**
Station Name: **LE-55**

Island: **Mindanao**	Municipality: **MAIGO**	Barangay: **SEGAPOD**
Elevation: **6.7618 m.**	Order: **1st Order**	Datum: **Mean Sea Level**

Location Description

BM LE-55 is in the Province of Lanao Del Norte, Town of Maigo, Brgy. Sogapod, along the Butuan-Zamboanga National Road. The station is located at the south east end of the Segapod Bridge Footwalk, and about 275 north west of KM Post 1565.

A brass rod is set on a drilled hole and cemented flushed on top of a 15 cm x 15 cm cement putty with inscription "LE-55, 2007, NAMRIA".

Requesting Party: **UP-TCAGP / Engr. Christopher Cruz**
Pupose: **Reference**
OR Number: **8799582 A**
T.N.: **2014-1722**

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

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

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-2.4. LE-55

5. LE-89

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

July 25, 2014

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: **LANAO DEL NORTE** Station Name: **LE-89**	
Island: **Mindanao**	Municipality: **LALA**	Barangay:
Elevation: **10.8140 m.**	Order: **1st Order**	Datum: **Mean Sea Level**

Location Description

BM LE-89
Is in the Province of Lanao del Norte, Municipality of Lala, Brgy. Panguil, along the Iligan - Zamboanga National Road. The station is located on top of a riprap, about 6 meters North West of KM post 1600 and about 8 meters West of centerline of the highway.

A brass rod is set on a drilled hole and cemented flushed on top of a 15cm x 15cm cement putty with inscription "LE-89, 2007 NAMRIA".

Requesting Party: **UP-TCAGP / Engr. Christopher Cruz**
Pupose: **Reference**
OR Number: **8799582 A**
T.N.: **2014-1724**

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

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

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-2.5. LE-89

6. LE-76

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

July 25, 2014

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: **LANAO DEL NORTE**
Station Name: **LE-89**

Island: **Mindanao**	Municipality: **LALA**	Barangay:
Elevation: **10.8140 m.**	Order: **1st Order**	Datum: **Mean Sea Level**

Location Description

BM LE-89
Is in the Province of Lanao del Norte, Municipality of Lala, Brgy. Panguil, along the Iligan - Zamboanga National Road. The station is located on top of a riprap, about 6 meters North West of KM post 1600 and about 8 meters West of centerline of the highway.

A brass rod is set on a drilled hole and cemented flushed on top of a 15cm x 15cm cement putty with inscription "LE-89, 2007 NAMRIA".

Requesting Party:	**UP-TCAGP / Engr. Christopher Cruz**
Pupose:	**Reference**
OR Number:	**8799582 A**
T.N.:	**2014-1724**

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

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

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-2.6. LE-76

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

1. LE-50

Figure A-3.1. LE-50

LE50 - LAN2 (10:05:34 AM-2:59:59 PM) (S1)

Baseline observation:	LE50 --- LAN2 (B1)
Processed:	7/27/2014 10:28:26 PM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.012 m
Vertical precision:	0.024 m
RMS:	0.005 m
Maximum PDOP:	3.688
Ephemeris used:	Broadcast
Antenna model:	NGS Absolute
Processing start time:	6/20/2014 10:05:34 AM (Local: UTC+8hr)
Processing stop time:	6/20/2014 2:59:59 PM (Local: UTC+8hr)
Processing duration:	04:54:25
Processing interval:	5 seconds

Vector Components (Mark to Mark)

From:	LAN2				
Grid		Local		Global	
Easting	584699.973 m	Latitude	N7°54'42.56546"	Latitude	N7°54'42.56546"
Northing	874628.035 m	Longitude	E123°46'06.31720"	Longitude	E123°46'06.31720"
Elevation	15.242 m	Height	83.921 m	Height	83.921 m

To:	LE50				
Grid		Local		Global	
Easting	606345.902 m	Latitude	N8°09'51.11024"	Latitude	N8°09'51.11024"
Northing	902577.426 m	Longitude	E123°57'55.36634"	Longitude	E123°57'55.36634"
Elevation	4.394 m	Height	73.452 m	Height	73.452 m

Vector					
ΔEasting	21645.929 m	NS Fwd Azimuth	37°51'51"	ΔX	-15847.070 m
ΔNorthing	27949.392 m	Ellipsoid Dist.	35361.439 m	ΔY	-15348.392 m
ΔElevation	-10.847 m	ΔHeight	-10.469 m	ΔZ	27636.144 m

2

2. LE-55

Figure A-3.2. LE-55

LE50 B - LE55 (9:12:04 AM-1:23:24 PM) (S1)

Baseline observation:	LE50 B --- LE55 (B1)
Processed:	7/27/2014 10:49:08 PM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.007 m
Vertical precision:	0.022 m
RMS:	0.003 m
Maximum PDOP:	3.817
Ephemeris used:	Broadcast
Antenna model:	NGS Absolute
Processing start time:	6/28/2014 9:12:24 AM (Local: UTC+8hr)
Processing stop time:	6/28/2014 1:23:24 PM (Local: UTC+8hr)
Processing duration:	04:11:00
Processing interval:	5 seconds

Vector Components (Mark to Mark)

From:	LE50 B				
Grid		Local		Global	
Easting	606345.902 m	Latitude	N8°09'51.11024"	Latitude	N8°09'51.11024"
Northing	902577.426 m	Longitude	E123°57'55.36634"	Longitude	E123°57'55.36634"
Elevation	4.394 m	Height	73.452 m	Height	73.452 m

To:	LE55				
Grid		Local		Global	
Easting	602641.751 m	Latitude	N8°07'59.16191"	Latitude	N8°07'59.16191"
Northing	899130.439 m	Longitude	E123°55'54.06681"	Longitude	E123°55'54.06681"
Elevation	5.896 m	Height	75.001 m	Height	75.001 m

Vector					
ΔEasting	-3704.151 m	NS Fwd Azimuth	227°11'47"	ΔX	2807.203 m
ΔNorthing	-3446.987 m	Ellipsoid Dist.	5061.227 m	ΔY	2479.320 m
ΔElevation	1.502 m	ΔHeight	1.549 m	ΔZ	-3404.292 m

2

3. LE-89

Figure A-3.3. LE-89

LDN01 - LE89 PM (1:59:14 PM-4:08:49 PM) (S1)

Baseline observation:	LDN01 --- LE89 PM (B1)
Processed:	7/27/2014 10:37:49 PM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.003 m
Vertical precision:	0.015 m
RMS:	0.002 m
Maximum PDOP:	1.981
Ephemeris used:	Broadcast
Antenna model:	NGS Absolute
Processing start time:	6/27/2014 1:59:14 PM (Local: UTC+8hr)
Processing stop time:	6/27/2014 4:08:49 PM (Local: UTC+8hr)
Processing duration:	02:09:35
Processing interval:	5 seconds

Vector Components (Mark to Mark)

From:	LDN01				
Grid		Local		Global	
Easting	635916.865 m	Latitude	N8°13'57.88944"	Latitude	N8°13'57.88944"
Northing	910238.155 m	Longitude	E124°14'02.37264"	Longitude	E124°14'02.37264"
Elevation	9.384 m	Height	78.950 m	Height	78.950 m

To:	LE89 PM				
Grid		Local		Global	
Easting	638201.305 m	Latitude	N8°15'47.82322"	Latitude	N8°15'47.82322"
Northing	913622.047 m	Longitude	E124°15'17.37373"	Longitude	E124°15'17.37373"
Elevation	3.968 m	Height	73.451 m	Height	73.451 m

Vector					
ΔEasting	2284.440 m	NS Fwd Azimuth	34°12'00"	ΔX	-1621.760 m
ΔNorthing	3383.892 m	Ellipsoid Dist.	4083.501 m	ΔY	-1696.687 m
ΔElevation	-5.416 m	ΔHeight	-5.499 m	ΔZ	3341.640 m

2

4. LE-76

Figure A-3.4. LE-76

Vector Components (Mark to Mark)

From:	LE-50				
Grid		Local		Global	
Easting	606180.417 m	Latitude	N8°09'54.67217"	Latitude	N8°09'51.11024"
Northing	902629.434 m	Longitude	E123°57'49.92699"	Longitude	E123°57'55.36634"
Elevation	4.394 m	Height	6.900 m	Height	73.452 m

To:	LE-76				
Grid		Local		Global	
Easting	588530.790 m	Latitude	N8°03'05.36825"	Latitude	N8°03'01.82183"
Northing	890021.013 m	Longitude	E123°48'12.37307"	Longitude	E123°48'17.82405"
Elevation	7.017 m	Height	9.335 m	Height	75.717 m

Vector					
ΔEasting	-17649.627 m	NS Fwd Azimuth	234°35'42"	ΔX	13688.663 m
ΔNorthing	-12608.421 m	Ellipsoid Dist.	21696.715 m	ΔY	11332.042 m
ΔElevation	2.623 m	ΔHeight	2.435 m	ΔZ	-12447.993 m

Standard Errors

Vector errors:					
σ ΔEasting	0.021 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.024 m
σ ΔNorthing	0.006 m	σ Ellipsoid Dist.	0.015 m	σ ΔY	0.034 m
σ ΔElevation	0.036 m	σ ΔHeight	0.036 m	σ ΔZ	0.009 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0005606089		
Y	-0.0003223999	0.0011623638	
Z	-0.0000556148	0.0002703935	0.0000791896

2

4. ILG-1

Figure A-3.4. ILG-1

LE-89 - ILG-1 (7:50:33 AM-1:43:04 PM) (S2)	
Baseline observation:	LE-89 --- ILG-1 (B2)
Processed:	07/02/2017 1:00:55 PM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.003 m
Vertical precision:	0.010 m
RMS:	0.002 m
Maximum PDOP:	2.216
Ephemeris used:	Broadcast
Antenna model:	NGS Absolute
Processing start time:	02/06/2014 7:50:39 AM (Local: UTC+8hr)
Processing stop time:	02/06/2014 1:43:04 PM (Local: UTC+8hr)
Processing duration:	05:52:25
Processing interval:	5 seconds

Vector Components (Mark to Mark)

From:	LE-89				
Grid		Local		Global	
Easting	638036.487 m	Latitude	N8°15'51.38523"	Latitude	N8°15'47.82322"
Northing	913673.269 m	Longitude	E124°15'11.94582"	Longitude	E124°15'17.37373"
Elevation	3.968 m	Height	6.381 m	Height	73.451 m

To:	ILG-1				
Grid		Local		Global	
Easting	637459.968 m	Latitude	N8°14'35.60437"	Latitude	N8°14'32.04743"
Northing	911343.882 m	Longitude	E124°14'52.86635"	Longitude	E124°14'58.29621"
Elevation	4.039 m	Height	6.546 m	Height	73.645 m

Vector					
ΔEasting	-576.519 m	NS Fwd Azimuth	194°04'52"	ΔX	294.412 m
ΔNorthing	-2329.387 m	Ellipsoid Dist.	2400.067 m	ΔY	604.978 m
ΔElevation	0.071 m	ΔHeight	0.165 m	ΔZ	-2303.832 m

Annex 4. The LIDAR Survey Team Composition

Table A-4.1. The LiDAR Survey Team Composition

Data Acquisition Component Sub-Team	Designation	Name	Agency/ Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, DR.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader - I	ENGR. CZAR JAKIRI SARMIENTO	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUÑA	UP-TCAGP
		LOVELYN ASUNCION	

FIELD TEAM

LiDAR Operation, Ground Survey, Data Download and Transfer	Senior Science Research Specialist (SSRS)	JASMINE ALVIAR	UP-TCAGP
	Research Associate (RA)	ENGR. IRO NIEL ROXAS	UP-TCAGP
	RA	GRACE SINADJAN	UP-TCAGP
	RA	LANCE CINCO	UP-TCAGP
	RA	JONATHAN ALMALVEZ	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. LEE JAY PUNZALAN	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. CESAR ALFONSO II	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. RANDY LAGCO	AAC

Annex 5. Data Transfer Sheet for Liangan Floodplain

DATA TRANSFER SHEET
06/20/2014(Northern Mindanao)

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	
29-May-14	1525P	1RXB149A	PEGASUS	1.6	457	9.27	265	na	na	26.5	NA	9.83	1KB	1KB	40	NA	Z:\Airborne_Raw\1525P
31-May-14	1533P	1BLK67151A	PEGASUS	3.32	270	14.4	224	43.2	428	33.3	NA	8.87	1KB	1KB	47/38	NA	Z:\Airborne_Raw\1533P
2-Jun-14	1541P	1BLK71B153A	PEGASUS	4	242	0	285	19.7	139	39	674MB	12.6	1KB	1KB	47/45/40/34	NA	Z:\Airborne_Raw\1541P
3-Jun-14	1545P	1BLK71C154A	PEGASUS	4.13	2259	13	253	69.7	533	40.1	272MB	9.95	1KB	1KB	141	NA	Z:\Airborne_Raw\1545P
4-Jun-14	1549P	1BLK71D155A	PEGASUS	3.48	150	14.3	264	NA	NA	34.6	NA	11.2	1KB	1KB	54/50/45	NA	Z:\Airborne_Raw\1549P
7-Jun-14	1561P	1RXE158A	PEGASUS	NA	44	NA	187	NA	NA	22	NA	8.1	1KB	1KB	71	NA	Z:\Airborne_Raw\1561P
8-Jun-14	1565P	1BLK71B159A	PEGASUS	NA	16	5.35	168	22.1	183	13.3	NA	7.75	1KB	1KB	36	NA	Z:\Airborne_Raw\1565P

Received from
Name C. JOAQUIN
Position RA
Signature

Received by
Name JOIDA F. PRIETO
Position SSRS
Signature
6/23/2014

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

DATA TRANSFER SHEET
07/28/2014(Northern Mindanao - ready)

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	
6/8/2014	1565P	1BLK71B159A	Pegasus	NA	16	6.93	168	NA	NA	13.3	NA	7.75	1KB	1KB	36	NA	Z:\Airborne_Raw
6/9/2014	1569P	1BLKRXE160A	Pegasus	4.16	832	16.5	290	8.86	62	38.5	NA	10	1KB	1KB	85	NA	Z:\Airborne_Raw
6/16/2014	1597P	1BLKRXE167A	Pegasus	2.18	332	10.5	237	NA	NA	21.3	NA	7.52	1KB	1KB	68	NA	Z:\Airborne_Raw
6/19/2014	1609P	1RXS170A	Pegasus	2.16	526	11.2	259	45.3	309	22.1	NA	7.07	1KB	1KB	77/76	NA	Z:\Airborne_Raw
6/20/2014	1613P	1BLK71G171A	Pegasus	3.44	177	13.7	258	67.3	437	33.2	NA	5.92	1KB	1KB	46	NA	Z:\Airborne_Raw
6/23/2014	1625P	1BLK67BC174A	Pegasus	3.09	1112	11.7	212	60.3	415	29.4	86.6	4.97	1KB	1KB	52/56	NA	Z:\Airborne_Raw
6/24/2014	1629P	1BLKRXES175A	Pegasus	2.79	370	10.7	187	36.3	288	26.1	NA	4.45	1KB	1KB	73	NA	Z:\Airborne_Raw
6/27/2014	1641P	1BLK68A178A	Pegasus	2.94	1995	12.6	268	57.4	398	28.9	57.2	7.7	1KB	1KB	65/65/60/58	NA	Z:\Airborne_Raw
6/27/2014	1643P	1BLK67ABS178B	Pegasus	532	95	4.33	119	NA	NA	5.65	NA	7.7	1KB	1KB	48	NA	Z:\Airborne_Raw
6/28/2014	1645P	1BLK71C179A	Pegasus	2.84	NA	11.4	242	51.8	375	27.4	NA	6.25	1KB	1KB	59/68	NA	Z:\Airborne_Raw

Received from
Name TIN ANDAYA
Position RA
Signature

Received by
Name JOIDA PRIETO
Position
Signature 7/28/14

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

DATA TRANSFER SHEET
08/05/2014(Northern Mindanao - ready)

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	SHP	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	
7/3/2014	1665P	1BLK71ES184A	Pegasus	606	93	4.69	94.5	169	NA	NA	6.77	NA	6.94	1KB	1KB	35	NA	Z:\Airborne_Raw
7/5/2014	1673P	1BLK71ES186A	Pegasus	1.05	379	7.58	335	190	22.4	167	12.5	27.8	5.09	1KB	1KB	92/84	NA	Z:\Airborne_Raw
7/6/2014	1677P	1BLK71S187A	Pegasus	696	68	5.33	188	141	11.2	86	7.79	NA	4.94	1KB	1KB	130	NA	Z:\Airborne_Raw
7/8/2014	1685P	1BLK71S189A	Pegasus	2.31	515	11	578	242	37	288	22.4	47.4	4.39	1KB	1KB	184	NA	Z:\Airborne_Raw
7/8/2014	1687P	1BLK71S189B	Pegasus	749	79	4.81	176	136	NA	NA	7.47	NA	4.39	1KB	1KB	NA	NA	Z:\Airborne_Raw
7/9/2014	1689P	1BLK71S190A	Pegasus	2.56	156	12.6	740	257	NA	NA	27.1	NA	3.68	1KB	1KB	196/207	NA	Z:\Airborne_Raw
7/10/2014	1693P	1RXES191A	Pegasus	1.78	551	8.11	448	175	NA	NA	16.9	NA	4.08	1KB	1KB	53	NA	Z:\Airborne_Raw

Received from

Name TIN ANDAYA
Position ILA
Signature

Received by

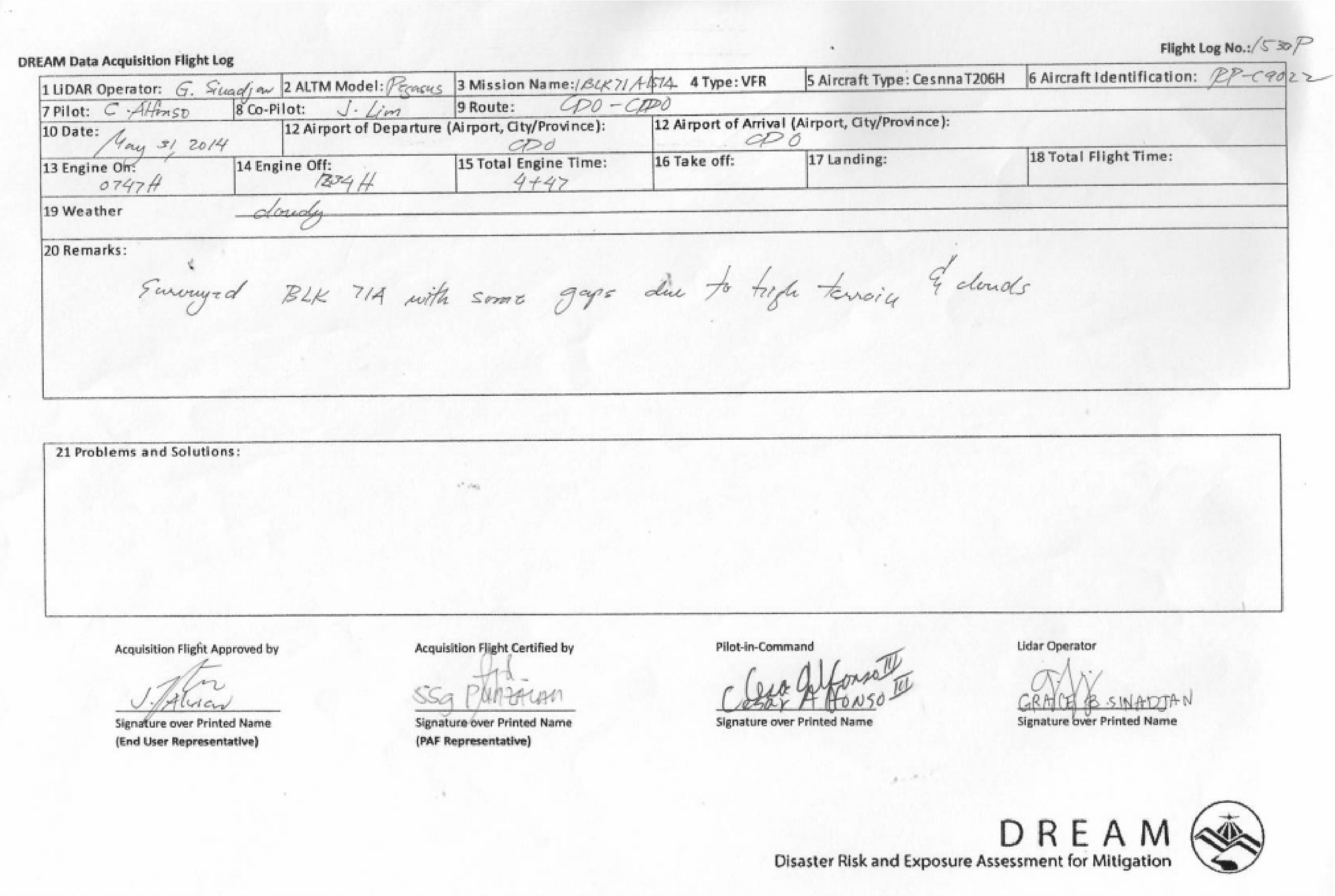
Name JOIDA F. PRIETO
Position SSRS
Signature

8/6/14

Figure A-5.3. Transfer Sheet for Liangan Floodplain - C

Annex 6. Flight Logs for the Flight Missions

1. Flight Log for Mission 1533P


DREAM Data Acquisition Flight Log

Flight Log No.: 1530P

1 LiDAR Operator: G. Sinadjan	2 ALTM Model: Pegasus	3 Mission Name: 1BLK71A151A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso	8 Co-Pilot: J. Lim	9 Route: CDO - CDO			
10 Date: May 31, 2014	12 Airport of Departure (Airport, City/Province): CDO		12 Airport of Arrival (Airport, City/Province): CDO		
13 Engine On: 0747H	14 Engine Off: 1234H	15 Total Engine Time: 4+47	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: cloudy					

20 Remarks:

Surveyed BLK 71A with some gaps due to high terrain & clouds

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
J. Alviar	SSg Punzalan	Cesar Alfonso III	Grace B. Sinadjan
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

DREAM
Disaster Risk and Exposure Assessment for Mitigation

Figure A-6.1. Flight Log for Mission 1533P

2. Flight Log for 1541P Mission

Flight Log No.: 1541P

DREAM Data Acquisition Flight Log

1 LiDAR Operator: G. Sinadjan	2 ALTM Model: Pegasus	3 Mission Name: 1BLK 71B534	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso	8 Co-Pilot: J. Lim	9 Route: CPO - CPO			
10 Date: June 7, 2014		12 Airport of Departure (Airport, City/Province): CPO	12 Airport of Arrival (Airport, City/Province): CPO		
13 Engine On: 0937H	14 Engine Off: 1424H	15 Total Engine Time: 4+47	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: cloudy					

20 Remarks:

Mission successful; some gaps due to high terrain; lowered altitude

21 Problems and Solutions:

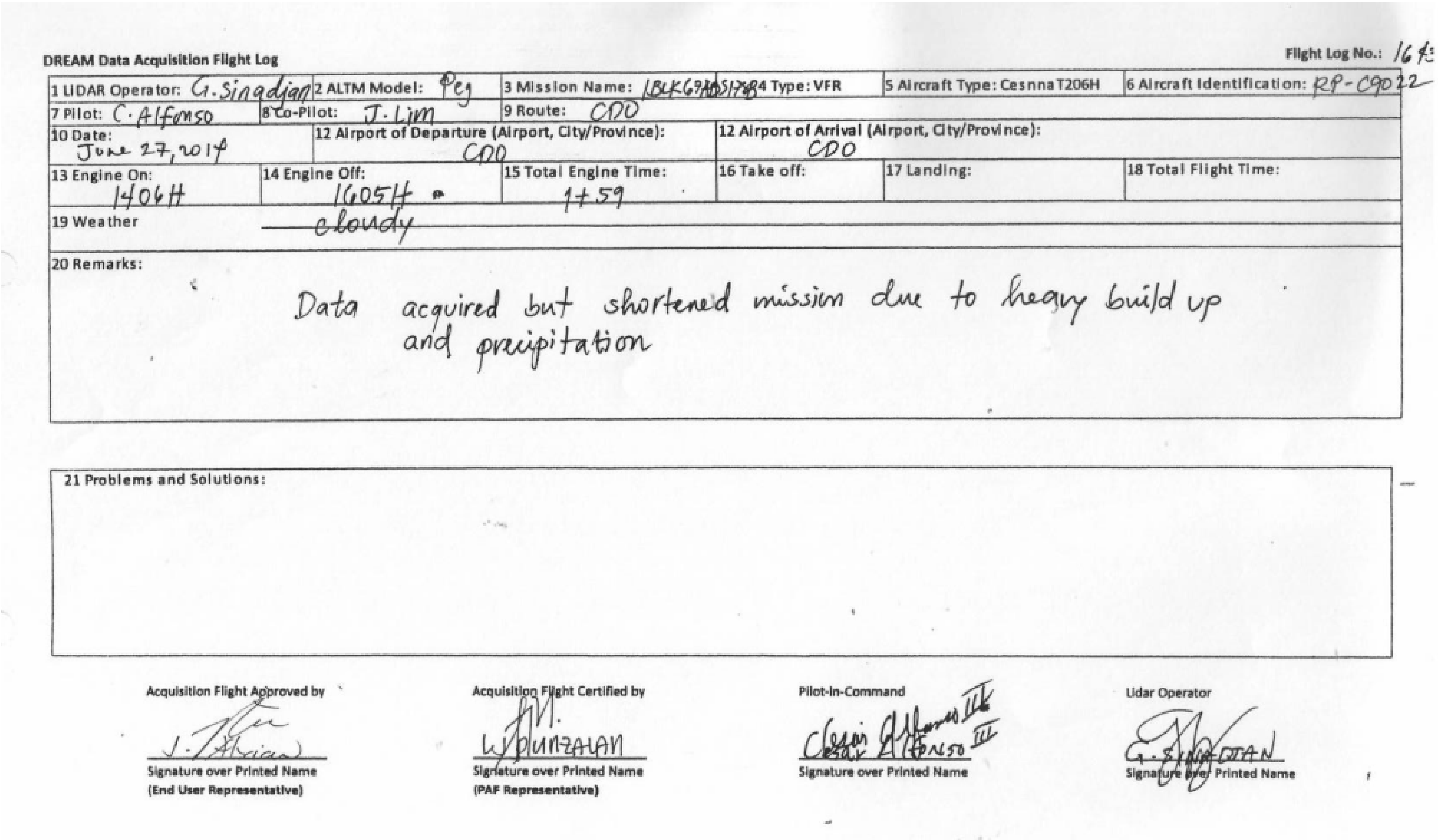
Camera assertion failed — restarted

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
V. Alviar	SSg Pumbalan	Cesar Alfonso III	Grace B. Sinadjan
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

DREAM
Disaster Risk and Exposure Assessment for Mitigation

Figure A-6.2. Flight Log for Mission 1541P

3. Flight Log for 1543P Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 1643

1 LIDAR Operator: G. Sinadjan	2 ALTM Model: Peg	3 Mission Name: 1BLK67ADS178A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso	8 Co-Pilot: J. Lim	9 Route: CDO			
10 Date: June 27, 2014	12 Airport of Departure (Airport, City/Province): CDO		12 Airport of Arrival (Airport, City/Province): CDO		
13 Engine On: 1406H	14 Engine Off: 1605H	15 Total Engine Time: 1+59	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: cloudy					

20 Remarks:

Data acquired but shortened mission due to heavy build up and precipitation

21 Problems and Solutions:

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

Acquisition Flight Certified by: W. Punzalan — Signature over Printed Name (PAF Representative)

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

Lidar Operator: G. Sinadjan — Signature over Printed Name

Figure A-6.3. Flight Log for Mission 1543P

4. Flight Log for 1545P Mission

DREAM Data Acquisition Flight Log

Flight Log No.: 164?

1 LiDAR Operator: I. Roxas	2 ALTM Model: Peg	3 Mission Name:	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso	8 Co-Pilot: J. Lim	9 Route: CDO			
10 Date: June 28, 2014	12 Airport of Departure (Airport, City/Province): CDO		12 Airport of Arrival (Airport, City/Province): CDO		
13 Engine On: 0920H	14 Engine Off: 1331H	15 Total Engine Time: 4+11	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: heavy buildup					

20 Remarks:

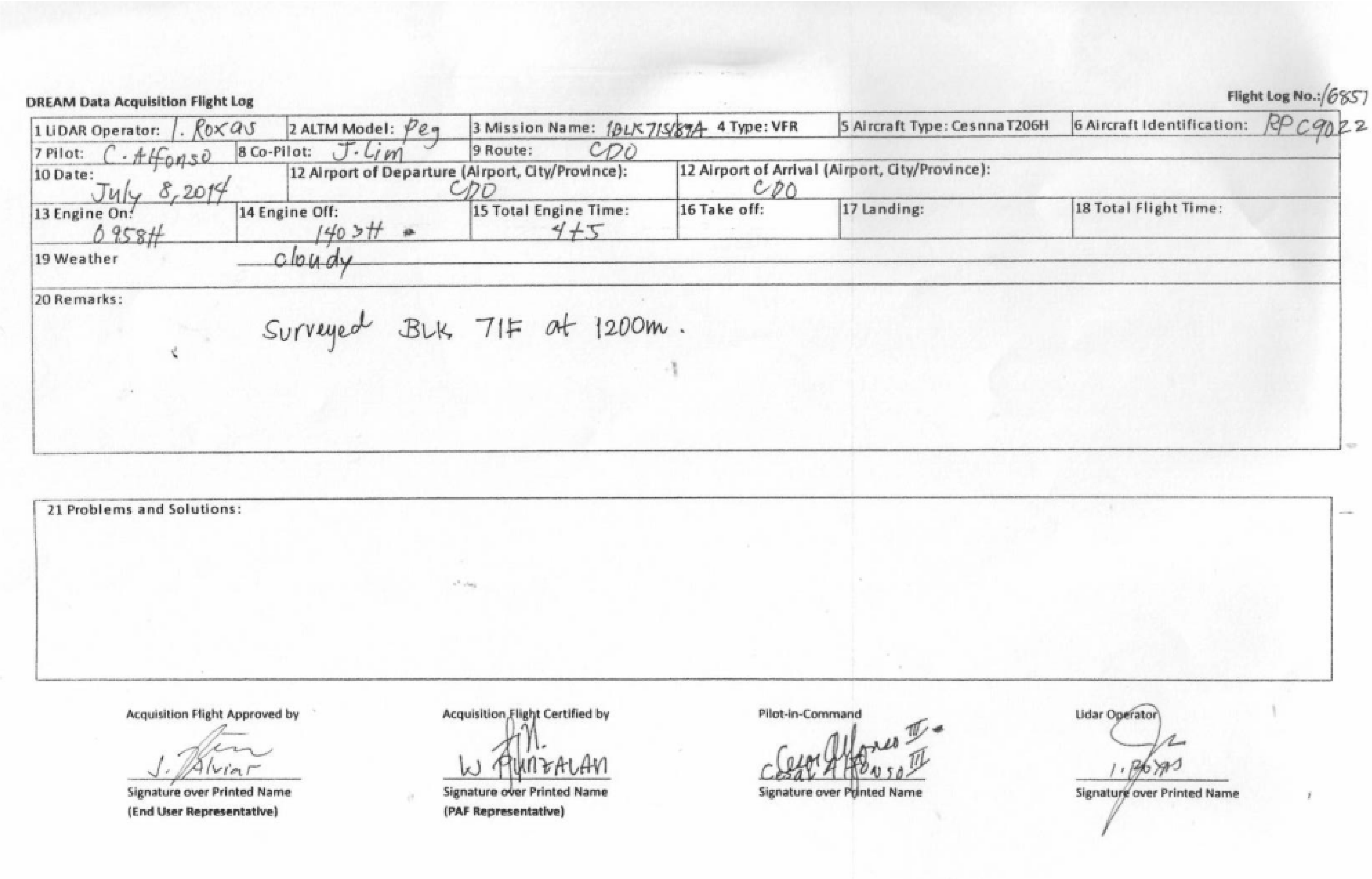
Data acquired in BLK 71C and covered gaps in BLK 71B, had to cut mission due to heavy build up and high terrain of remaining survey areas.

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
J. Alviar	W. Punzalan	Cesar Alfonso III	I. Roxas
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

Figure A-6.4. Flight Log for Mission 1545P

5. Flight Log for 1685P Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 16857

1 LiDAR Operator: I. Roxas	2 ALTM Model: Peg	3 Mission Name: 1BLK71S187A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RPC9022
7 Pilot: C. Alfonso	8 Co-Pilot: J. Lim	9 Route: CDO			
10 Date: July 8, 2014	12 Airport of Departure (Airport, City/Province): CDO		12 Airport of Arrival (Airport, City/Province): CDO		
13 Engine On: 0958H	14 Engine Off: 1403H	15 Total Engine Time: 4+5	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: cloudy					

20 Remarks:

Surveyed BLK 71F at 1200m.

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
J. Alviar	W. Punzalan	Cesar Alfonso III	I. Roxas
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

Figure A-6.5. Flight Log for Mission 1685P

6. Flight Log for 1687P Mission

Flight Log No.: 1687P

DREAM Data Acquisition Flight Log

1 LIDAR Operator: G. Sinadjan	2 ALTM Model: Peg	3 Mission Name: 1BLK71S189B	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso	8 Co-Pilot: J. Lim	9 Route: CDO			
10 Date: July 8, 2014	12 Airport of Departure (Airport, City/Province): CDO		12 Airport of Arrival (Airport, City/Province): CDO		
13 Engine On: 1454H	14 Engine Off: 1705H	15 Total Engine Time: 2+11	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather	very cloudy				

20 Remarks:

Filled gaps in BLK 71A and BLK71C

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
J. Alviar	LJ Punzalan	Cesar Alfonso III	Grace B. Sinadjan
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

DREAM
Disaster Risk and Exposure Assessment for Mitigation

Figure A-6.6. Flight Log for Mission 1687P

7. Flight Log for 1689P Mission

Flight Log No.: 1689P

DREAM Data Acquisition Flight Log

1 LiDAR Operator: I. Roxas	2 ALTM Model: Peg	3 Mission Name:	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso	8 Co-Pilot: J. Lim	9 Route: CDO			
10 Date: July 9, 2014	12 Airport of Departure (Airport, City/Province): CDO		12 Airport of Arrival (Airport, City/Province): CDO		
13 Engine On: 1135H	14 Engine Off: 1552H	15 Total Engine Time: 4+17	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: Cloudy					

20 Remarks:

Mission successful at 1200m flying height

21 Problems and Solutions:

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

Acquisition Flight Certified by: W. Punzalan — Signature over Printed Name (PAF Representative)

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

Lidar Operator: I. Roxas — Signature over Printed Name

DREAM
Disaster Risk and Exposure Assessment for Mitigation

Figure A-6.7. Flight Log for Mission 1689P

Annex 7. Flight Status Reports

Nprthern Mindanao
May 31 - July 9, 2014

Table A-7.1. Flight Status Report

FLIGHT NO.	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
1533P	BLK 71A	1BLK71A151A	G. Sinadjan	May 31	Surveyed BLK 71A with some gaps due to high terrain and clouds; 183.36 sq.km
1541P	BLK 71B	1BLK71B153A	G. Sinadjan	June 2	Surveyed BLK 71B with some gaps due to terrain; 290.78 sq.km.
1643P	BLK 71A	1BLK67ABS178B	G. Sinadjan	June 27	Data acquired but shortened mission due to heavy build up and precipitation; 67.506 sq.km (gap-filling)
1645P	BLK 71A, BLK 71B, BLK 71C	1BLK71C179A	I. Roxas	June 28	Data acquired in BLK 71C and covered gaps in BLK 71B, had to cut mission due to heavy build up and high terrain of remaining survey areas; 115.47 sq.km
1685P	BLK 71F	1BLK71S189A	I.Roxas	July 8	Surveyed BLK 71F at 1200m; 233.71 sq.km
1687P	BLK 71ACS	1BLK71S189B	G.Sinadjan	July 8	Filled in gaps in BLK 71A and BLK 71C; gap-filling
1689P	BLK 71E and BLK 71ABCs	1BLK71S190A	I.Roxas	July 9	Surveyed BLK 71E and the gaps in BLK 71ABC; 278.697 sq.km

LAS BOUNDARIES PER FLIGHT

Flight No. :	1533P		
Area:	BLK 71A		
Mission Name:	1BLK71A151A		
Parameters:	Altitude:	800m;	Scan Frequency: 30Hz;
	Scan Angle:	25deg;	Overlap: 25%

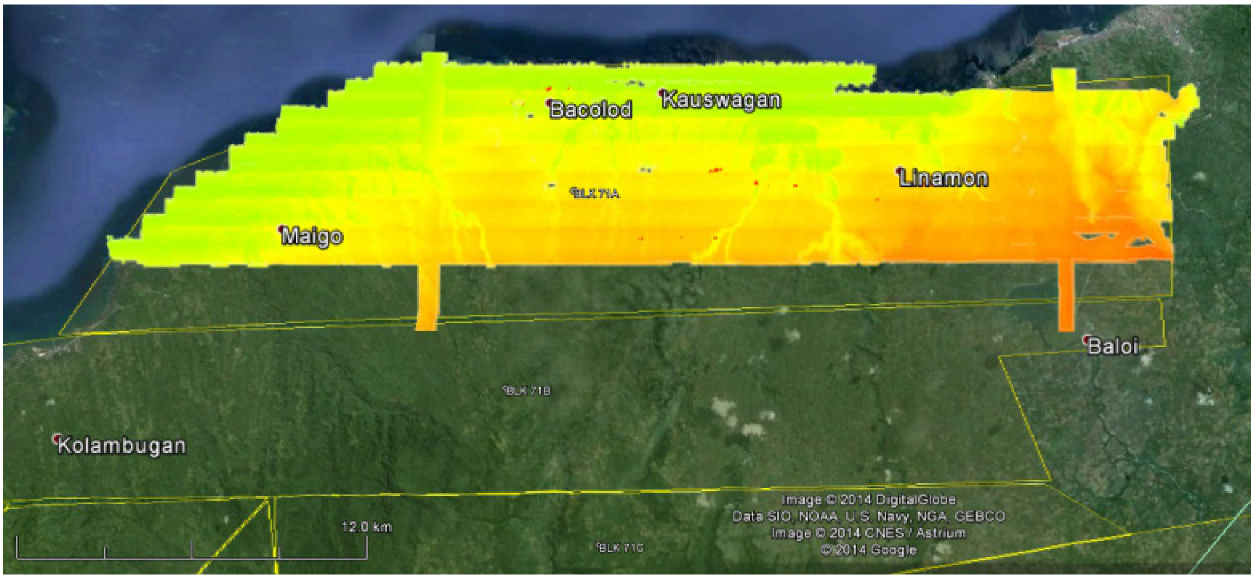


Figure A-7.1. Swath for Flight No. 1533P

Flight No. :	1541P		
Area:	BLK 71B		
Mission Name:	1BLK71B153A		
Parameters:	Altitude:	800m;	Scan Frequency: 30Hz;
	Scan Angle:	25deg;	Overlap: 25%

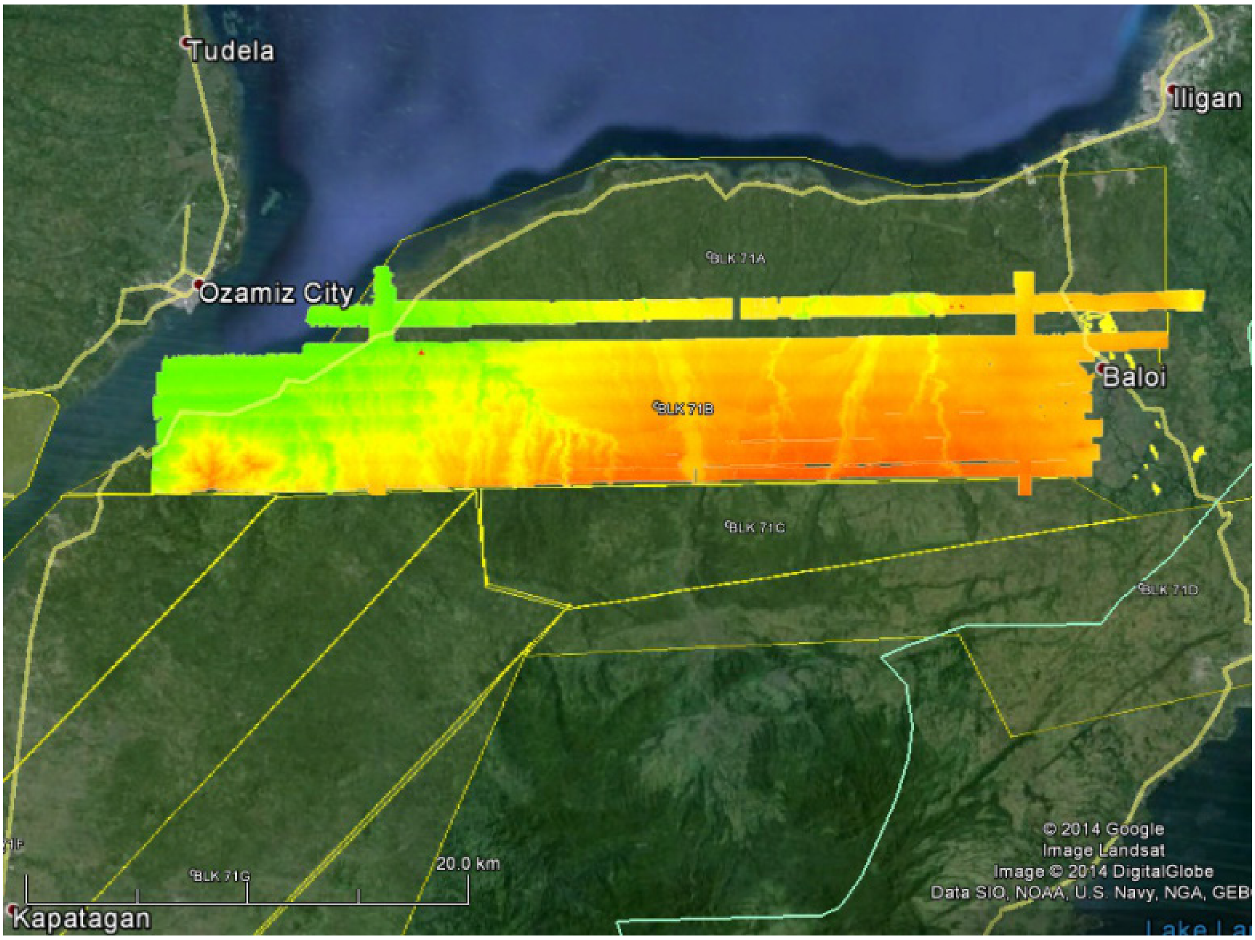


Figure A-7.2. Swath for Flight No. 1541P

Flight No. :	1643P		
Area:	BLK 71A		
Mission Name:	1BLK67ABS178B		
Parameters:	Altitude:	800m;	Scan Frequency: 30Hz;
	Scan Angle:	25deg;	Overlap: 25%

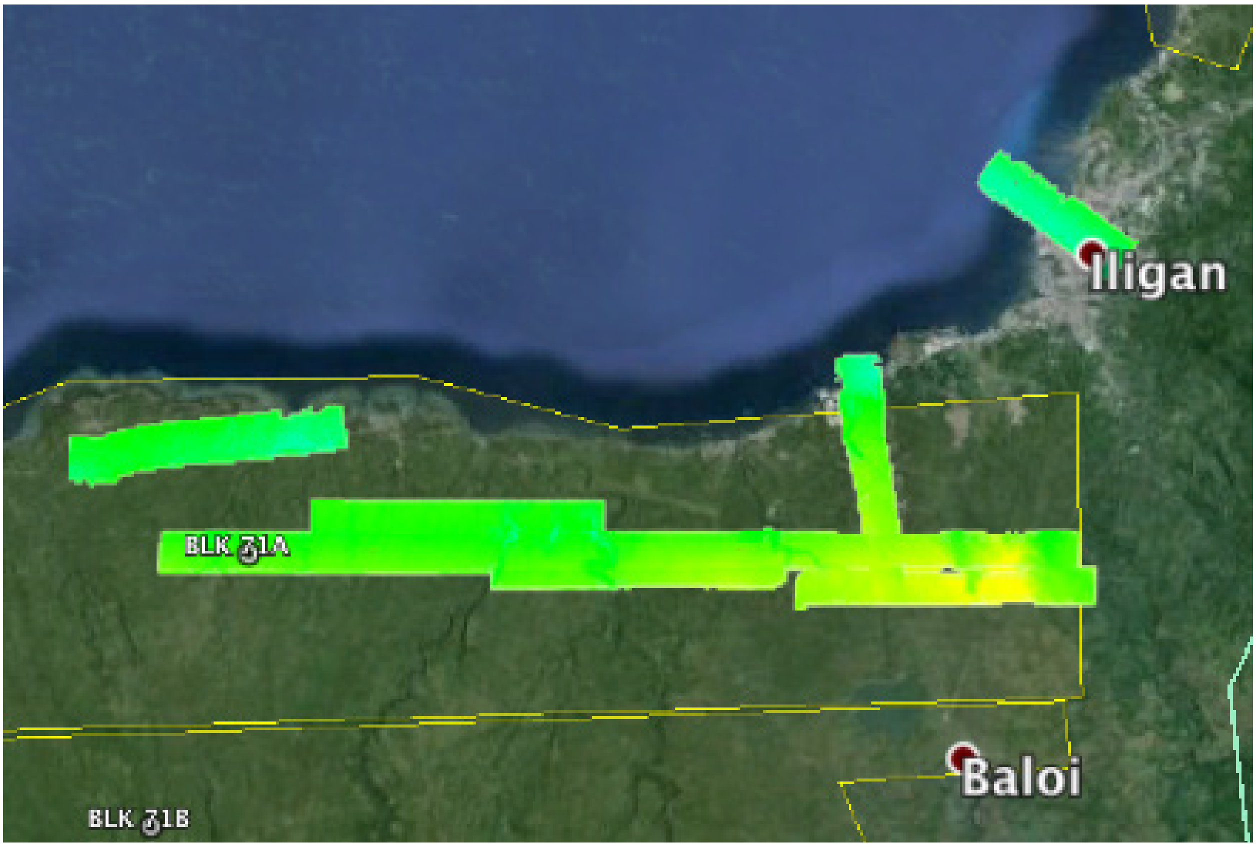


Figure A-7.3. Swath for Flight No. 1643P

Flight No. :	1645P		
Area:	BLK 71A, BLK 71B, BLK 71C		
Mission Name:	1BLK71C179A		
Parameters:	Altitude:	800m;	Scan Frequency: 30Hz;
	Scan Angle:	25deg;	Overlap: 25%

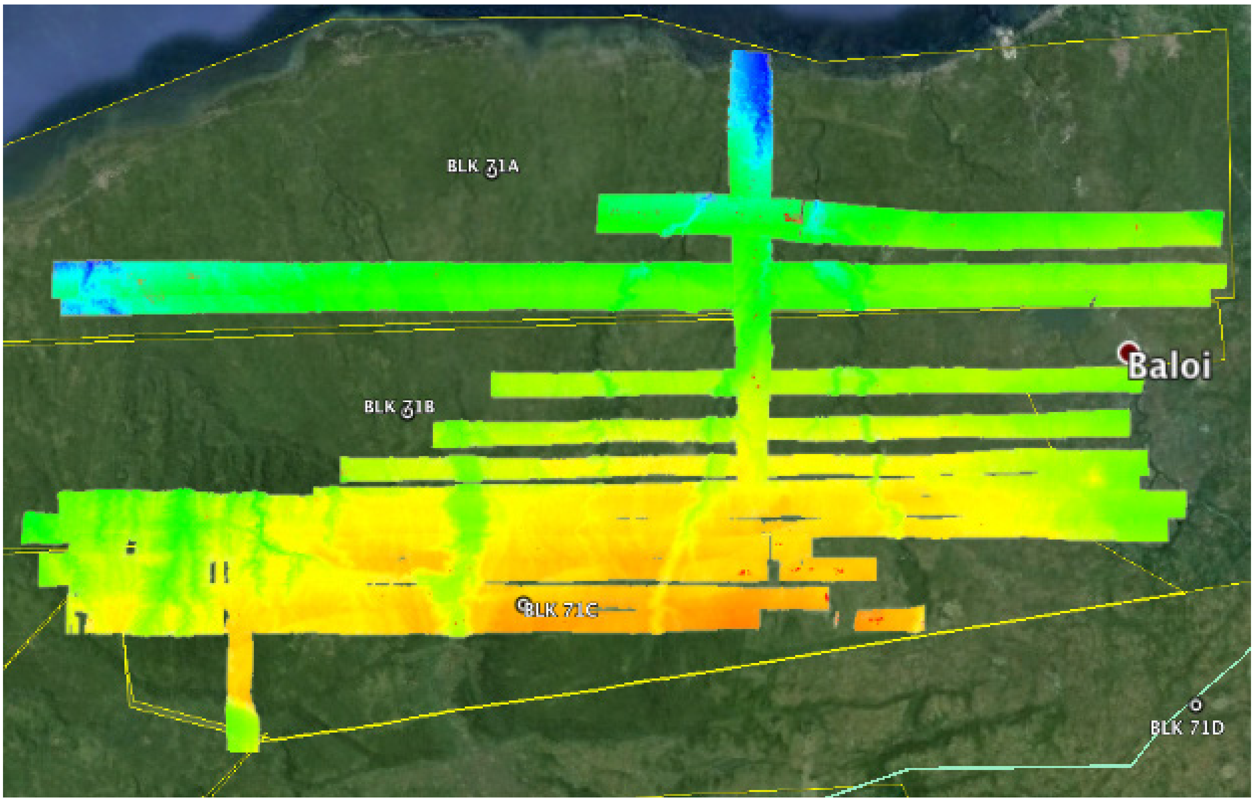


Figure A-7.4. Swath for Flight No. 1645P

Flight No. :	1685P			
Area:	BLK 71F			
Mission Name:	1BLK71S189A			
Parameters:	Altitude:	800m;	Scan Frequency: 30Hz;	
	Scan Angle:	25deg;	Overlap: 25%	

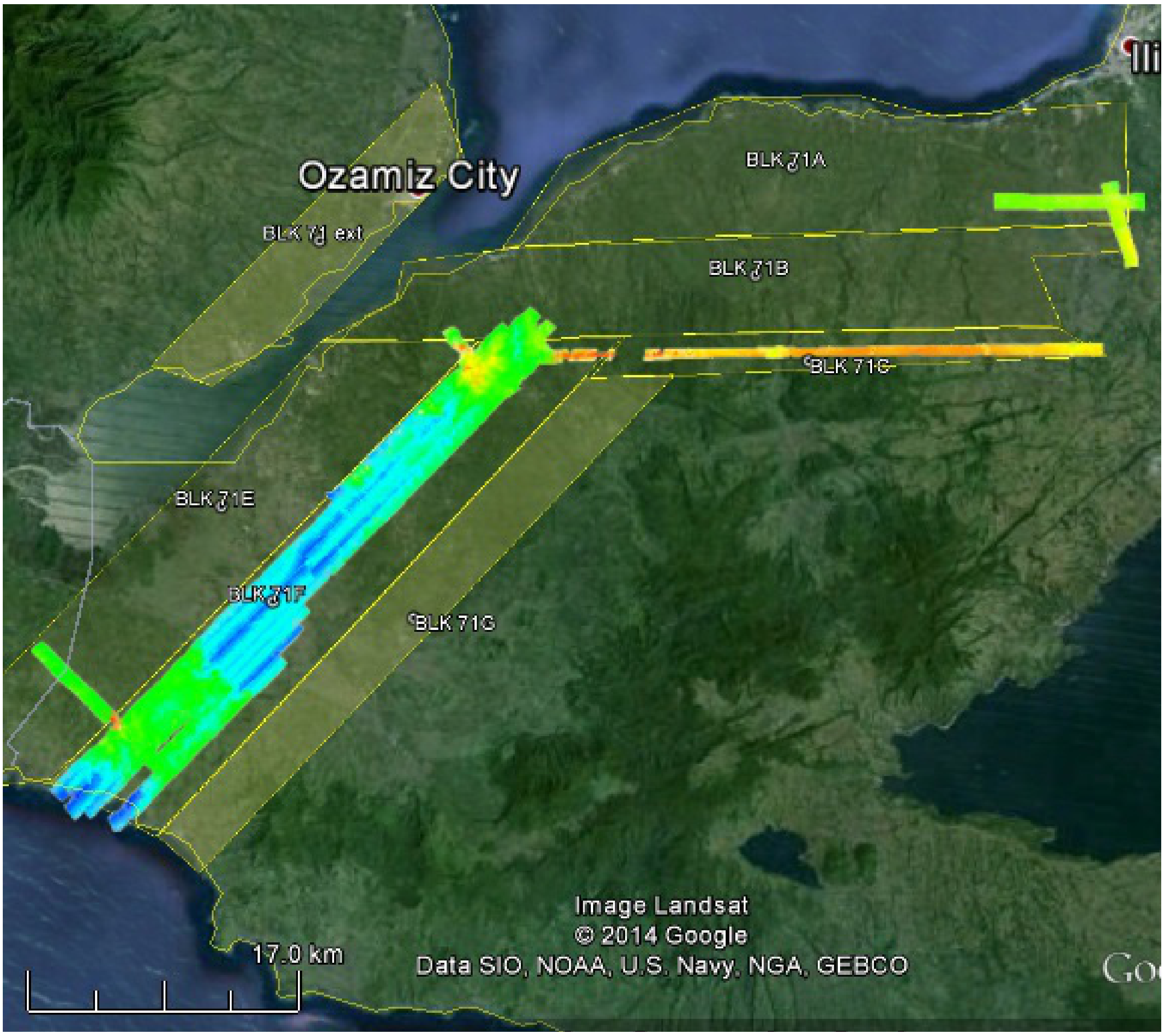


Figure A-7.5. Swath for Flight No. 1685P

Flight No. :	1687P		
Area:	BLK 71ACS		
Mission Name:	1BLK71S189B		
Parameters:	Altitude:	800m;	Scan Frequency: 30Hz;
	Scan Angle:	25deg; Overlap: 25%	

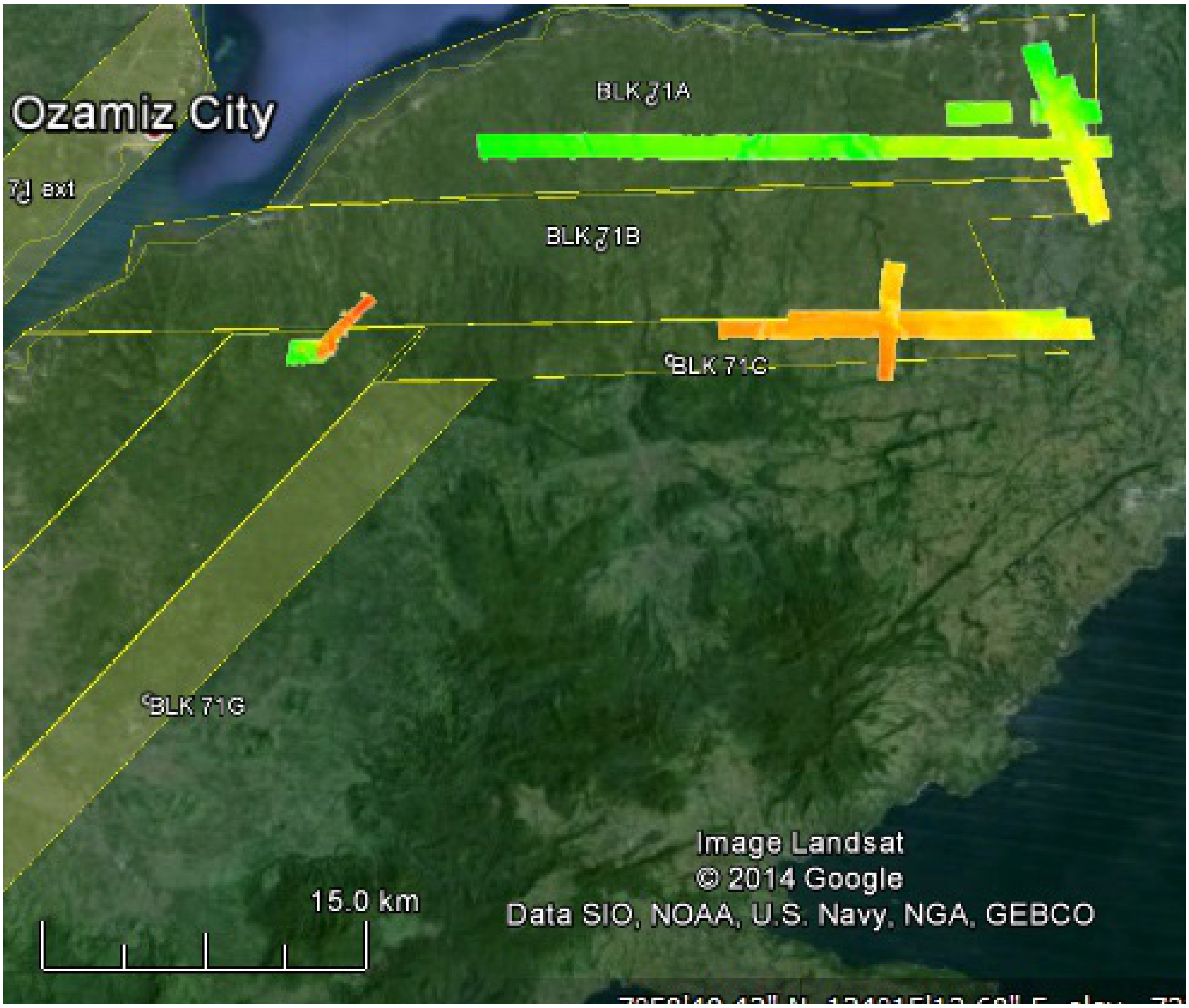


Figure A-7.6. Swath for Flight No. 1687P

Flight No. :	1689P		
Area:	BLK 71E and BLK 71ABCs		
Mission Name:	1BLK71S190A		
Parameters:	Altitude:	800m;	Scan Frequency: 30Hz;
	Scan Angle:	25deg; Overlap: 25%	

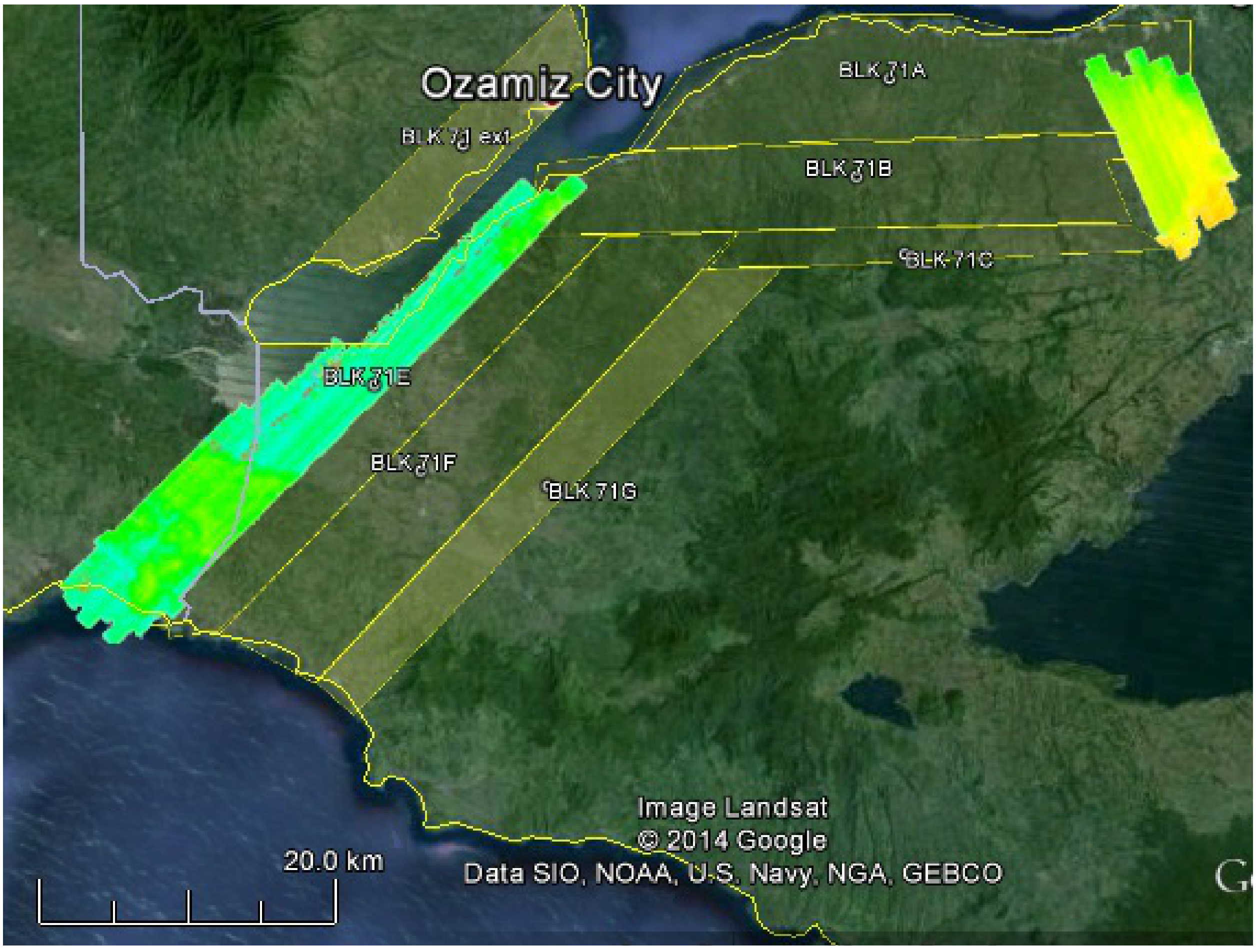


Figure A-7.7. Swath for Flight No. 1689P

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Blk71ABC

Flight Area	Northern Mindanao
Mission Name	Blk71ABC
Inclusive Flights	1533P, 1541P, 1643P, 1645P, 1685P, 1689P
Range data size	154.85 GB
POS	1369 MB
|Base data size	43.49 MB
Image	151.7 GB
Transfer date	August 01, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.2
RMSE for East Position (<4.0 cm)	1.4
RMSE for Down Position (<8.0 cm)	4.0
Boresight correction stdev (<0.001deg)	0.001254
IMU attitude correction stdev (<0.001deg)	0.001356
GPS position stdev (<0.01m)	0.0252
Minimum % overlap (>25)	50.18%
Ave point cloud density per sq.m. (>2.0)	4.23
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	711
Maximum Height	951.89 m
Minimum Height	65.97 m
Classification (# of points)	
Ground	448,326,038
Low vegetation	554,302,928
Medium vegetation	898,361,476
High vegetation	739,706,375
Building	21,364,020
Orthophoto	
Processed by	Engr. Carlyn Ann Ibañez, Engr. Kenneth Solidum, Engr. Melanie Hingpit, Engr. John Dill Macapagal

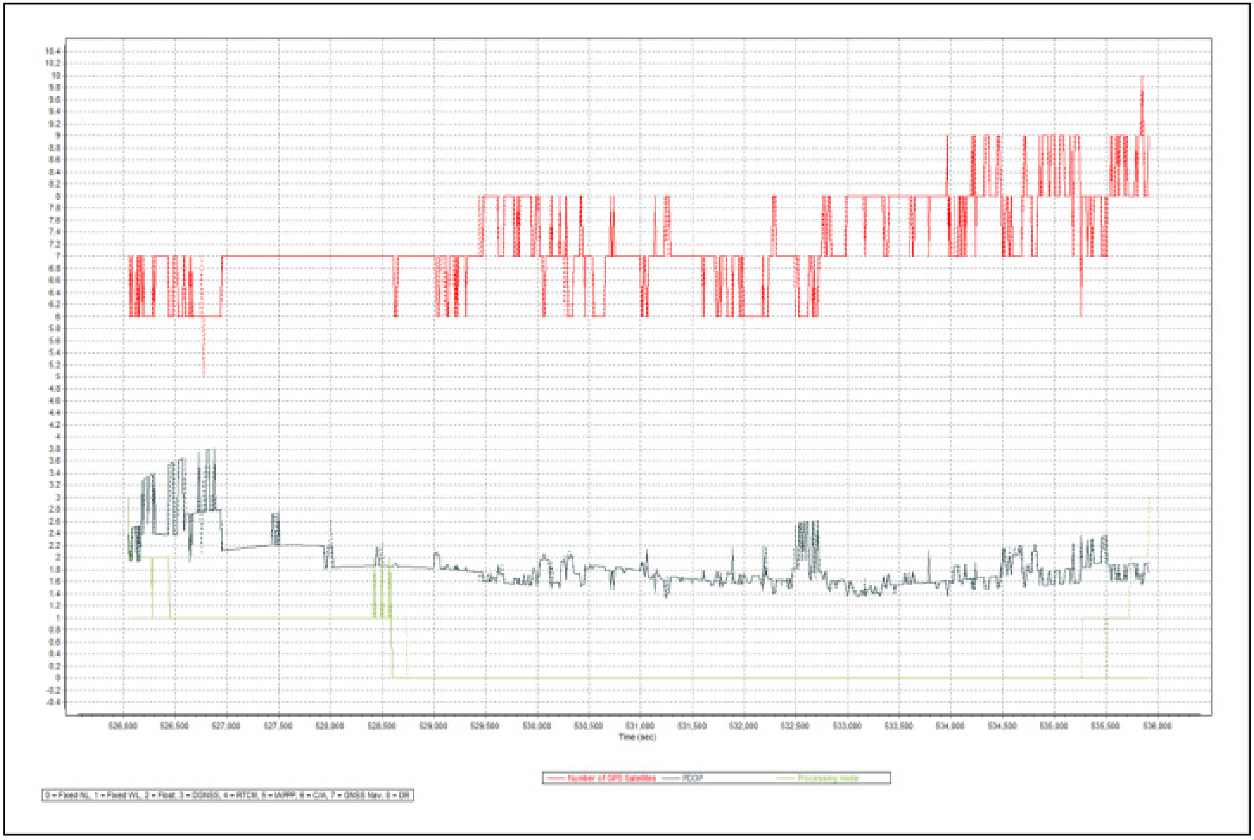


Figure A-8.1. Solution Status

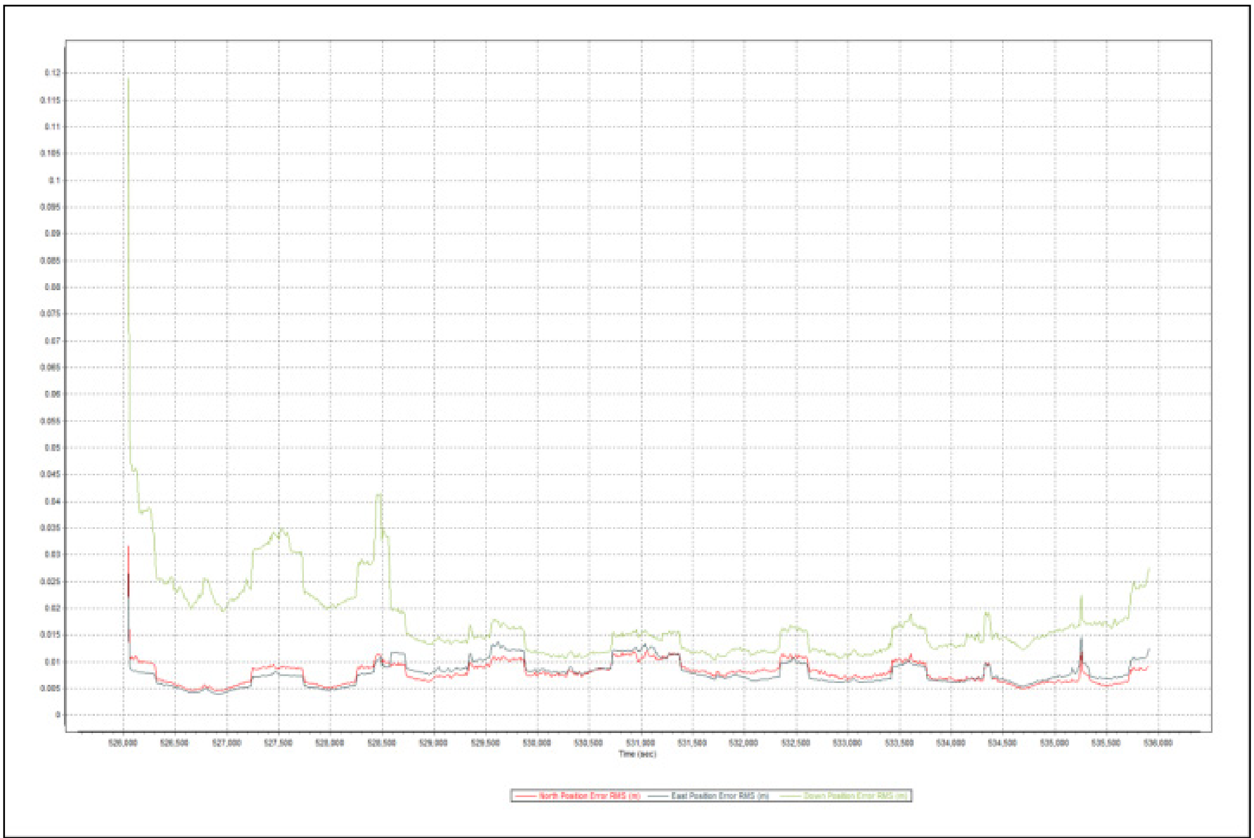


Figure A-8.2. Smoothed Performance Metrics Parameters

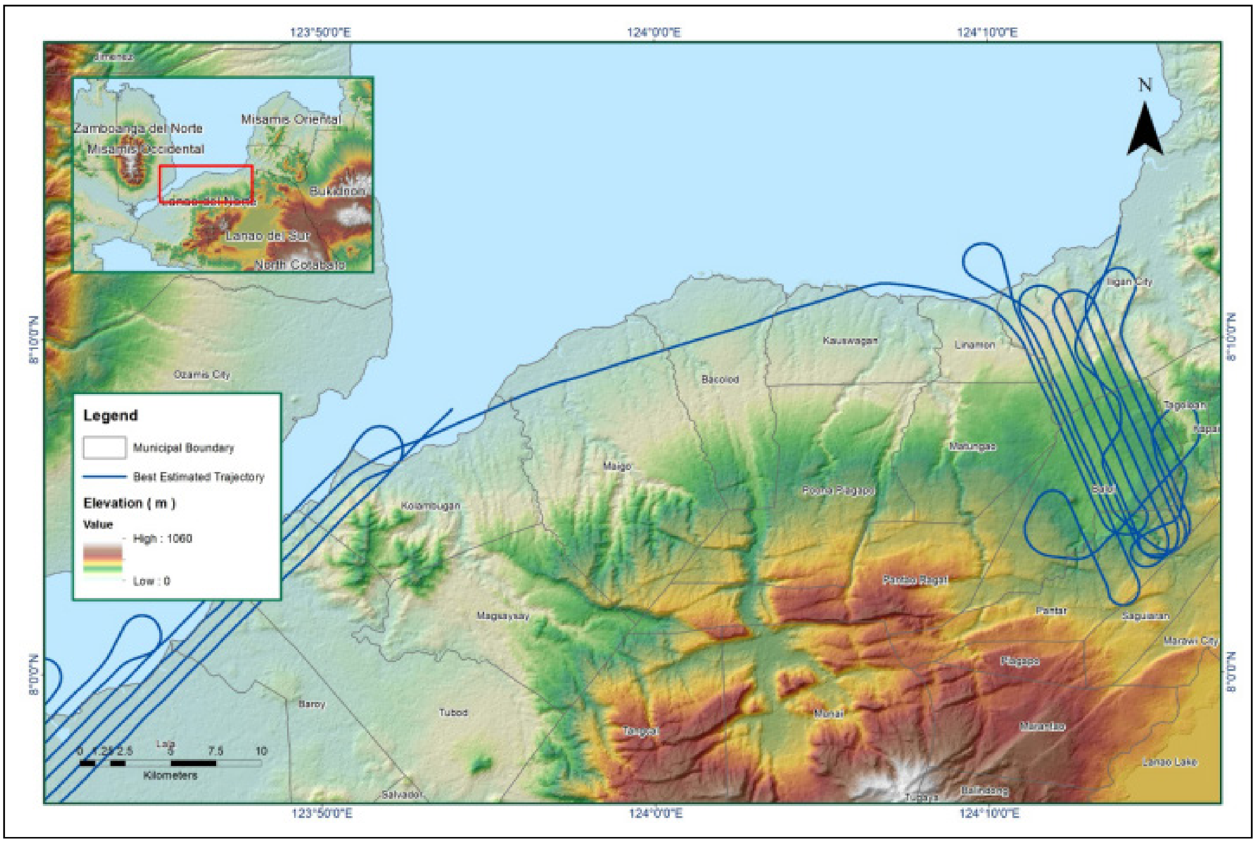


Figure A-8.3. Best Estimated Trajectory

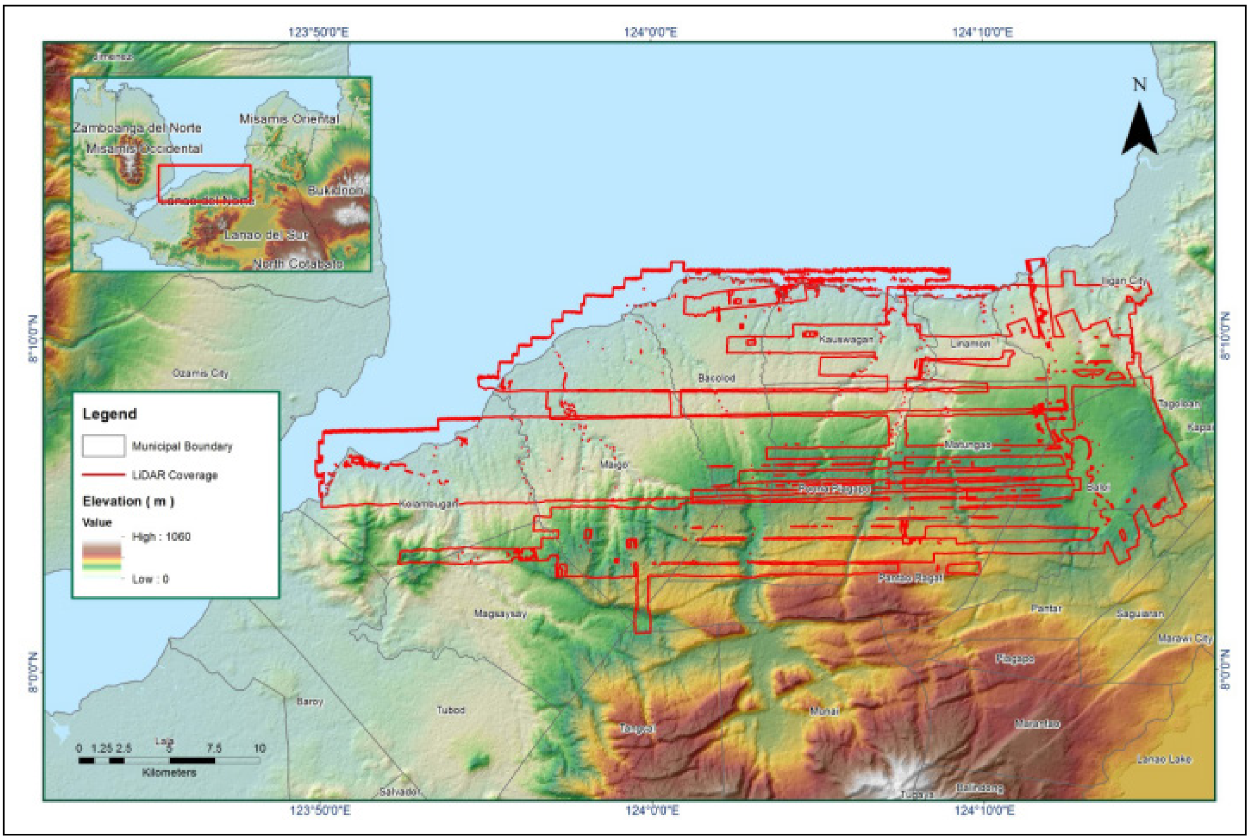


Figure A-8.4. Coverage of LiDAR data

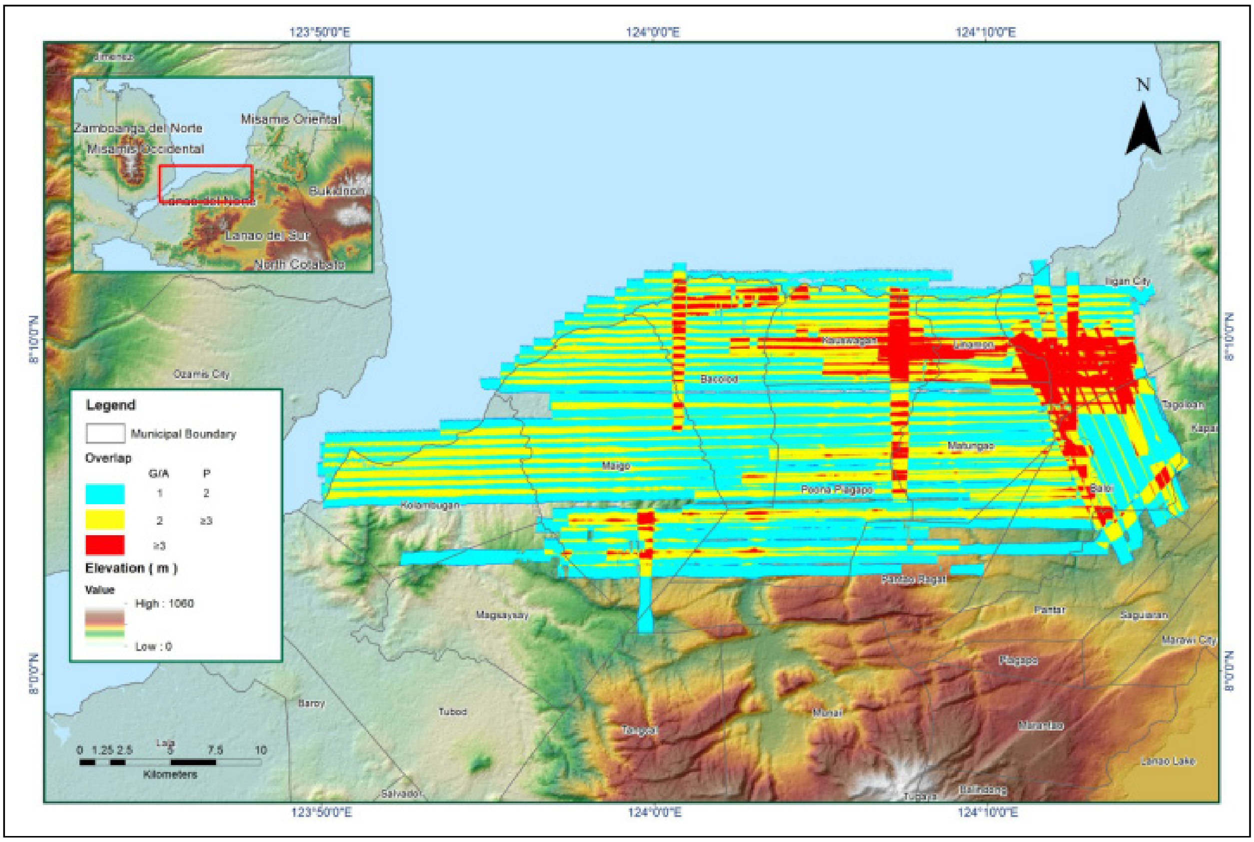


Figure A-8.5. Image of Data Overlap

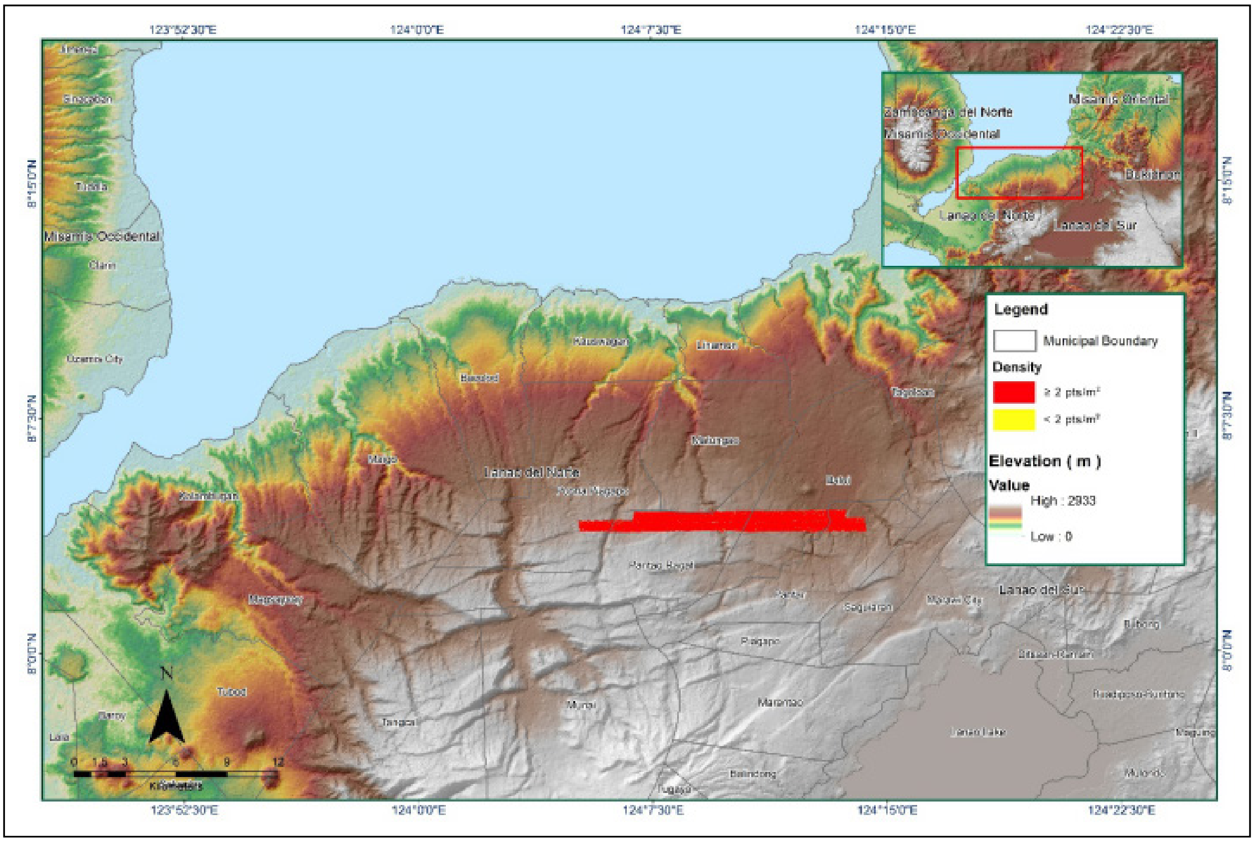


Figure A-8.6. Density map of merged LiDAR data

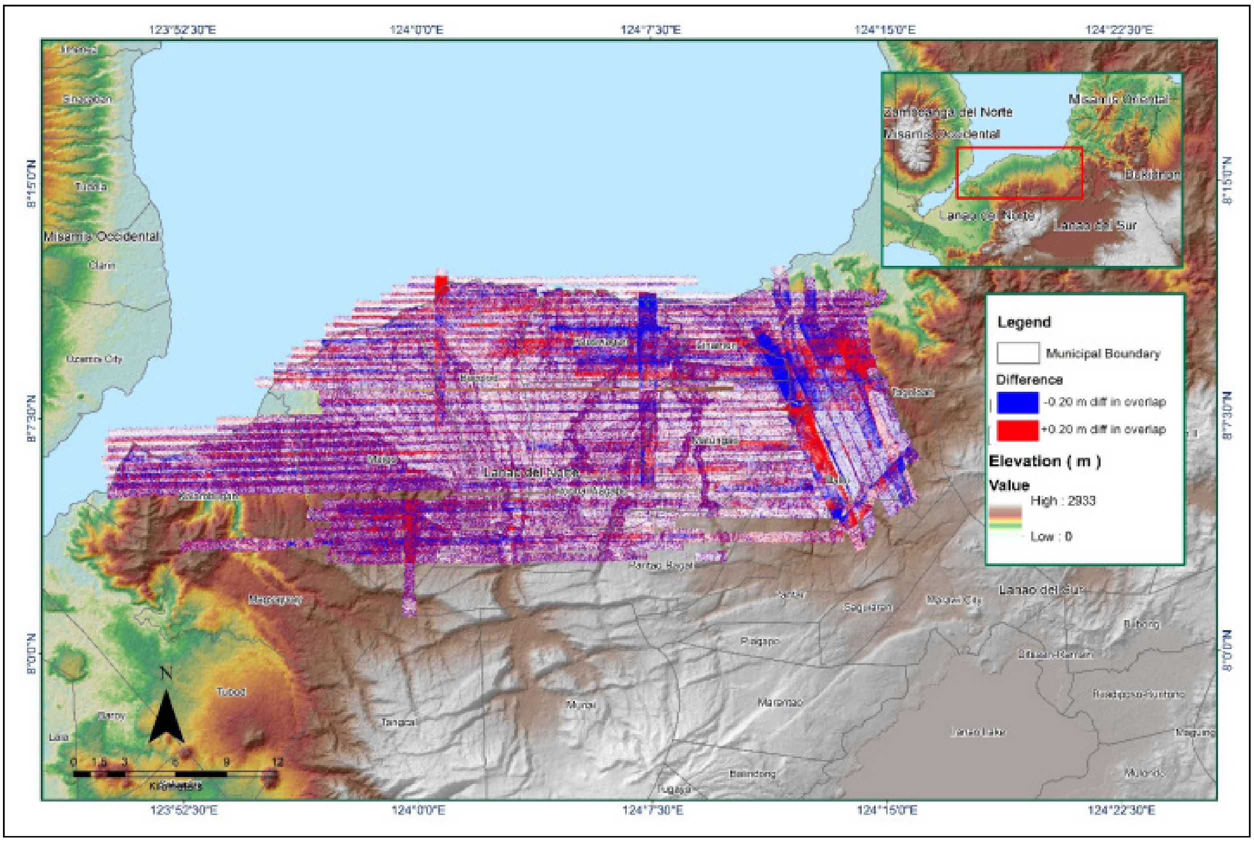


Figure A-8.7. Elevation difference between flight lines

Table A-8.2. Mission Summary Report for Mission Blk33G

Flight Area	Northern Mindanao
Mission Name	Blk71B_supplement
Inclusive Flights	1541P
Range data size	39 GB
POS	285 MB
Base data size	12.6 MB
Image	19.7 GB
Transfer date	June 23, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.3
RMSE for East Position (<4.0 cm)	1.5
RMSE for Down Position (<8.0 cm)	4.5
Boresight correction stdev (<0.001deg)	0.008634
IMU attitude correction stdev (<0.001deg)	0.016988
GPS position stdev (<0.01m)	0.0268
Minimum % overlap (>25)	30.74%
Ave point cloud density per sq.m. (>2.0)	4.17
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	82
Maximum Height	699.62
Minimum Height	69.85
Classification (# of points)	
Ground	21,553,715
Low vegetation	22,924,976
Medium vegetation	40,296,362
High vegetation	53,453,732
Building	526,883
Orthophoto	
Processed by	Victoria Rejuso, Engr. Mark Joshua Salvacion, Engr. Gladys Mae Apat

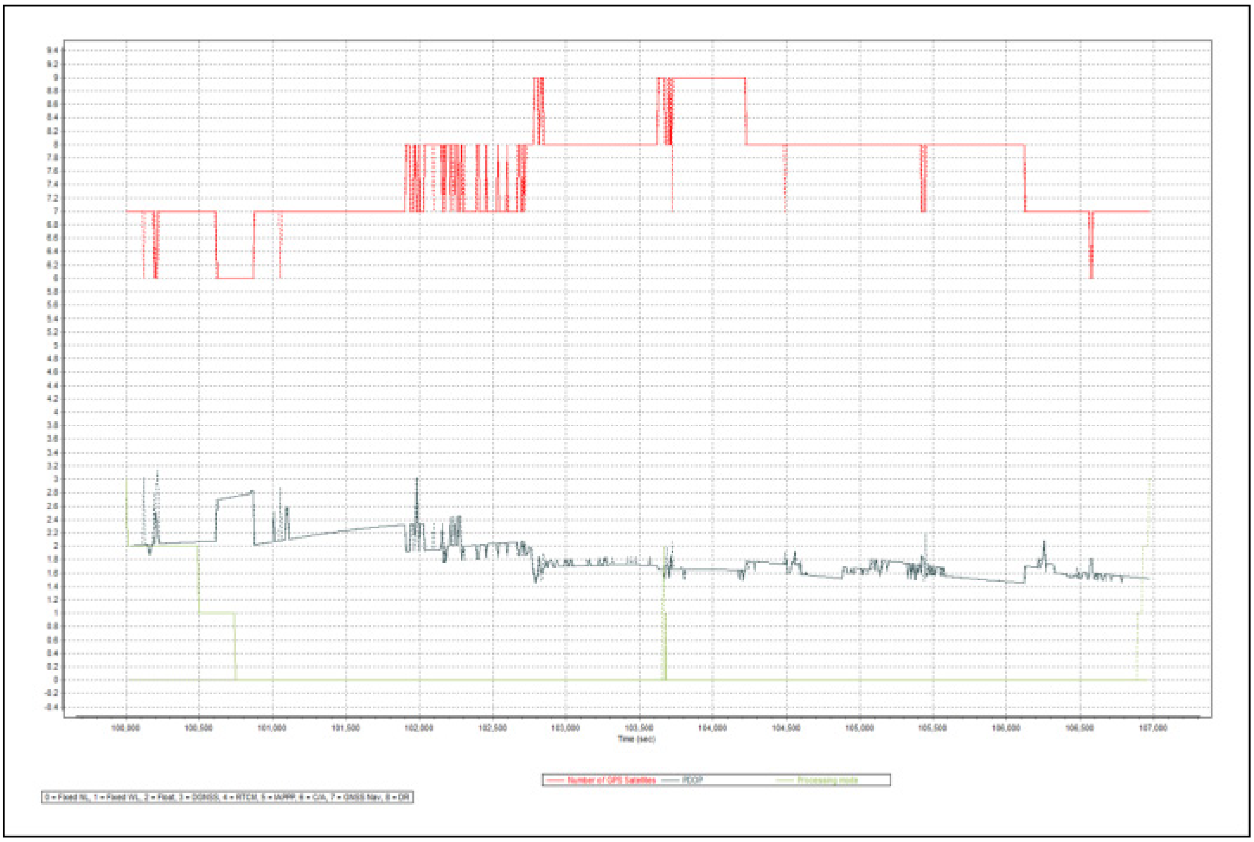


Figure A-8.8. Solution Status Parameters

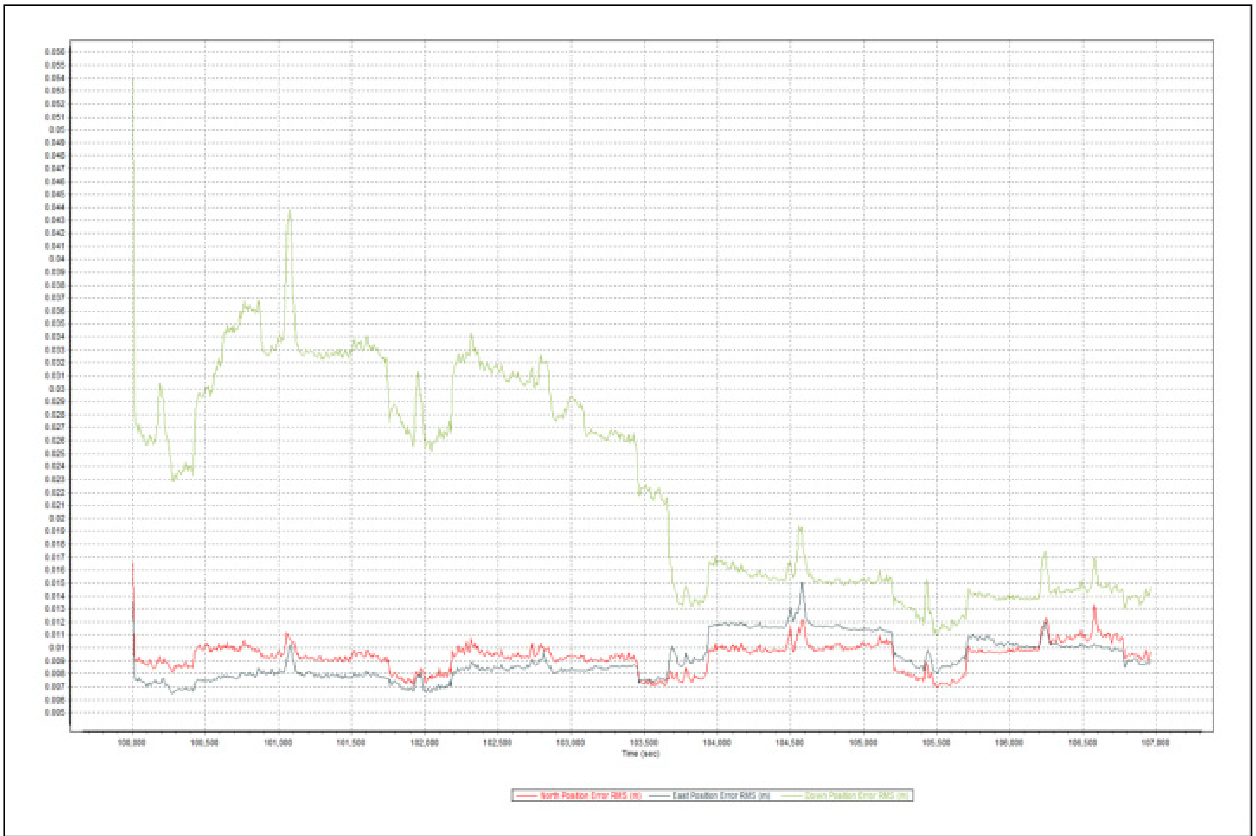


Figure A-8.9. Smoothed Performance Metrics Parameters

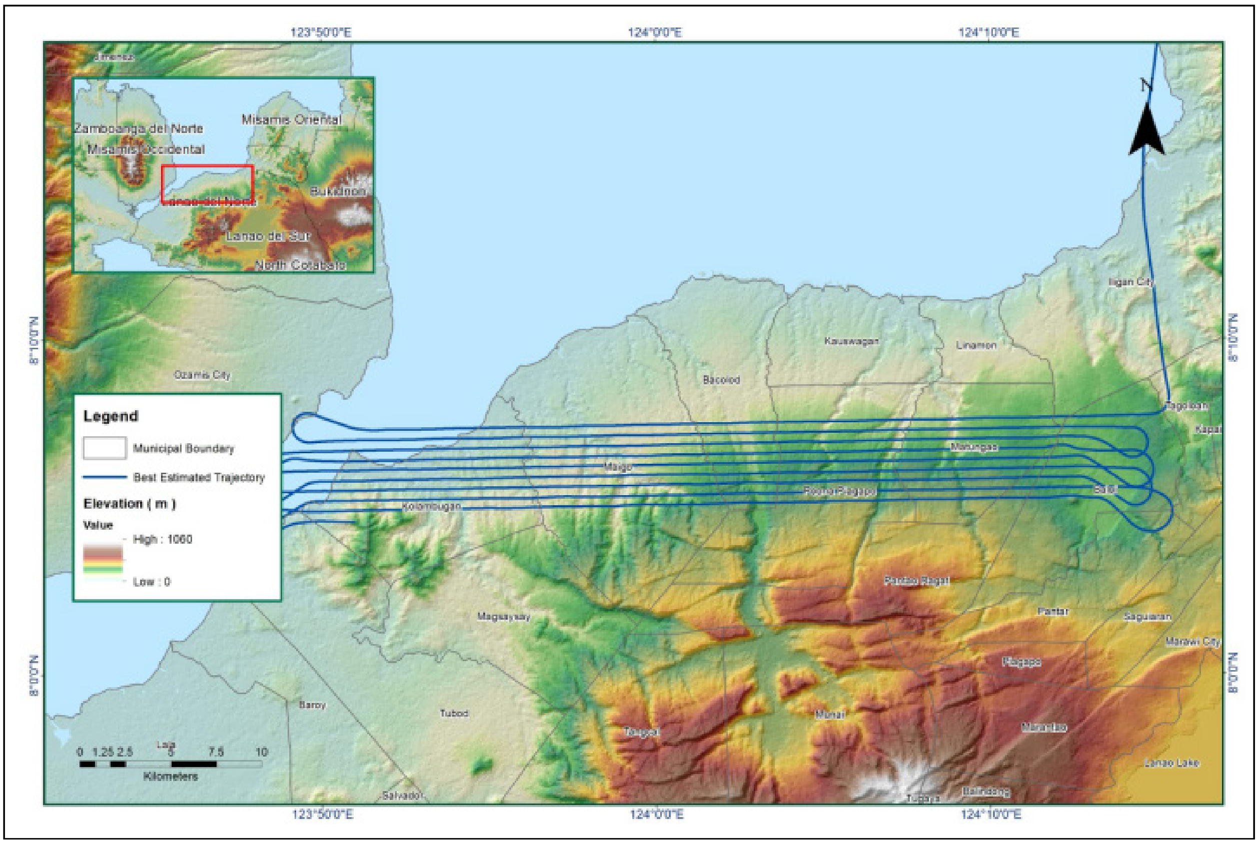


Figure A-8.10. Best Estimated Trajectory

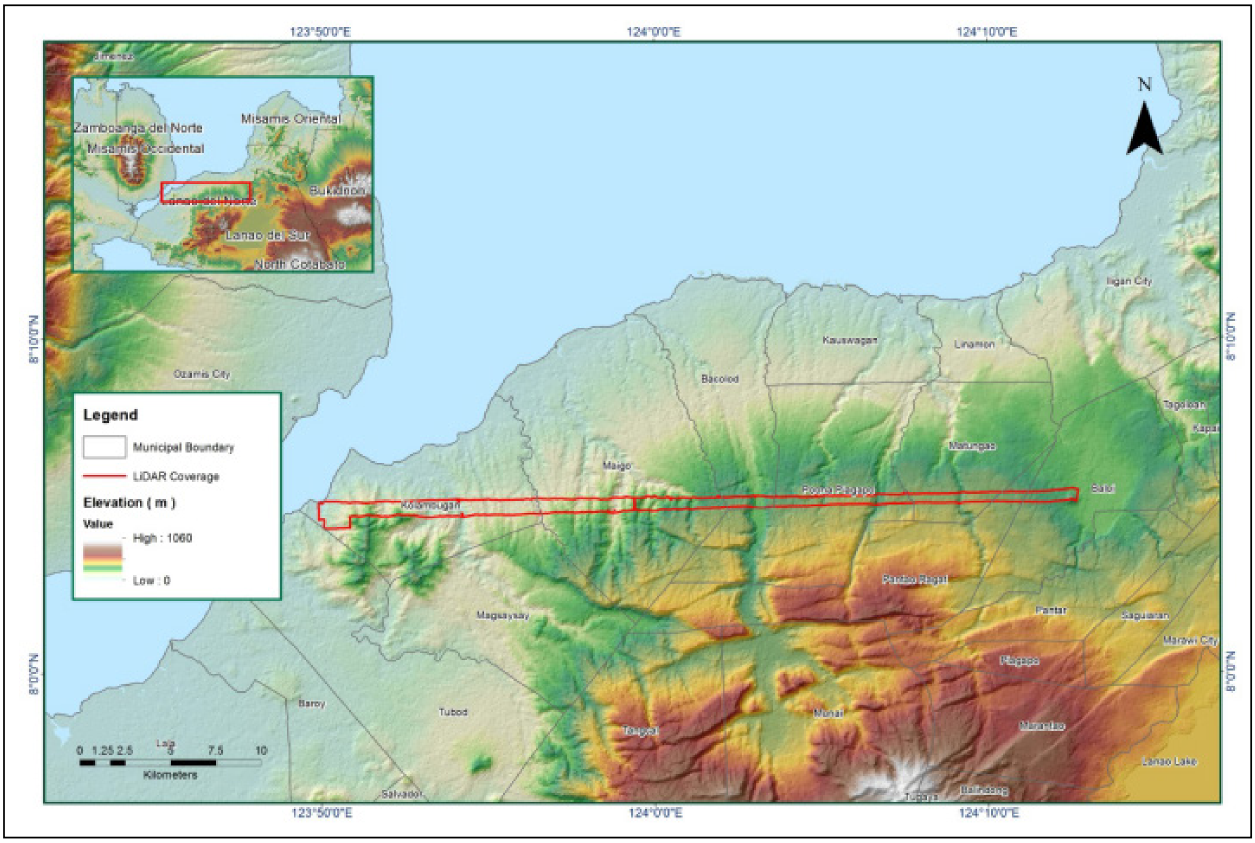


Figure A-8.11. Coverage of LiDAR data

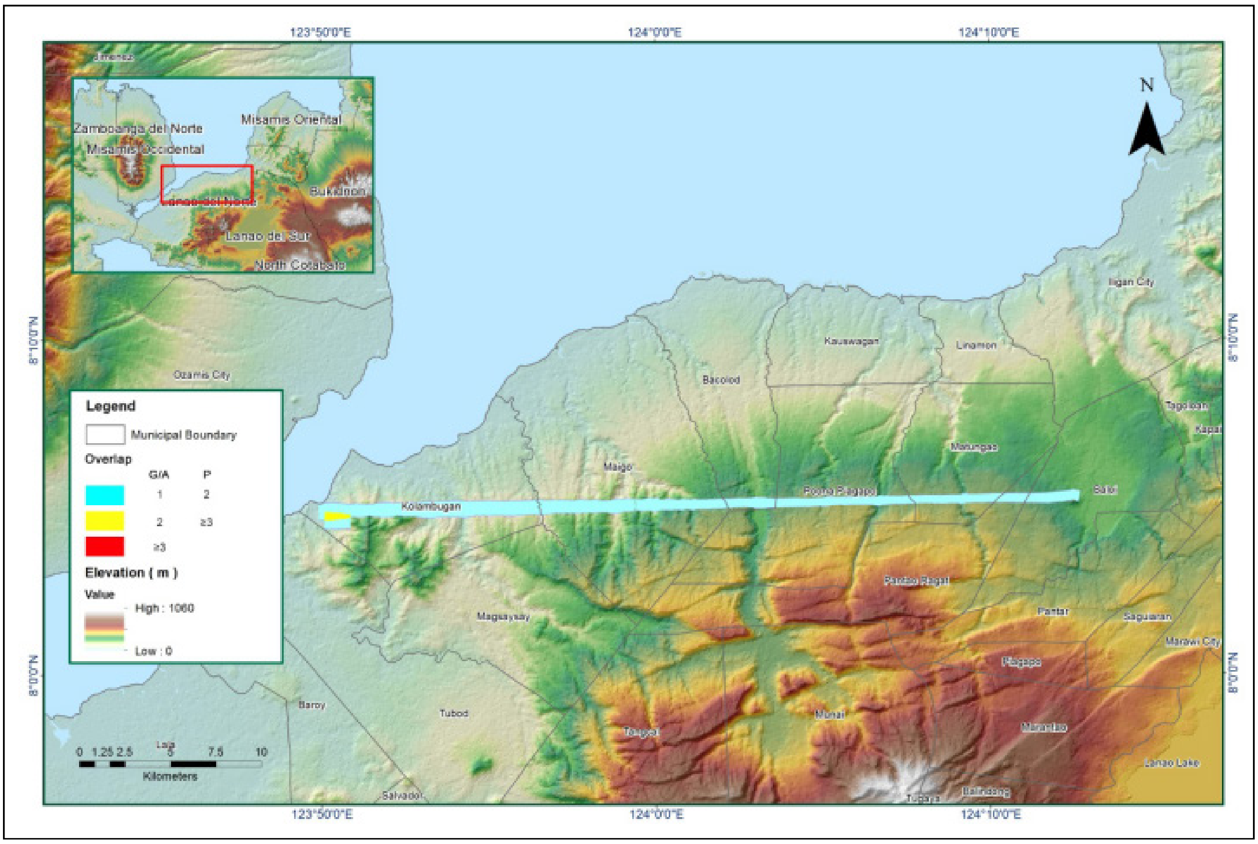


Figure A-8.12. Image of Data Overlap

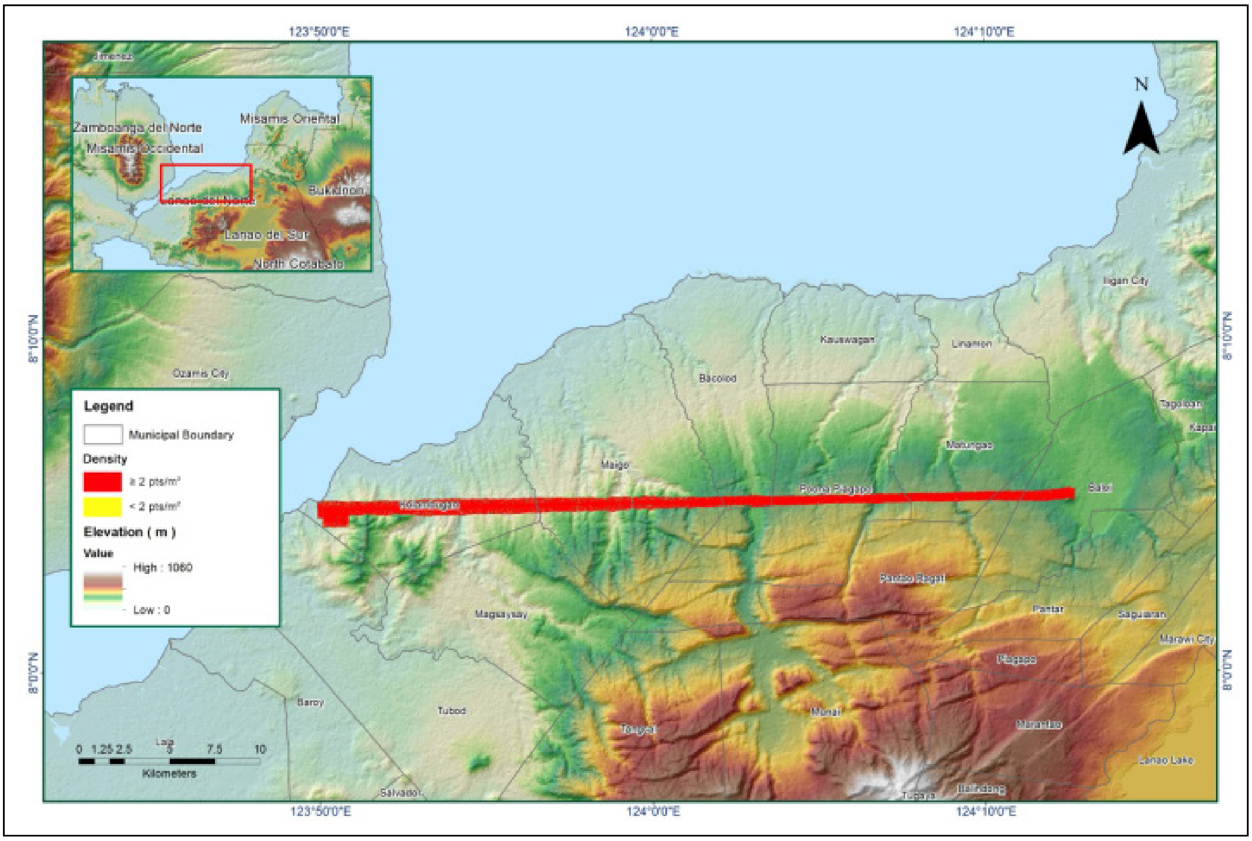


Figure A-8.13. Density map of merged LiDAR data

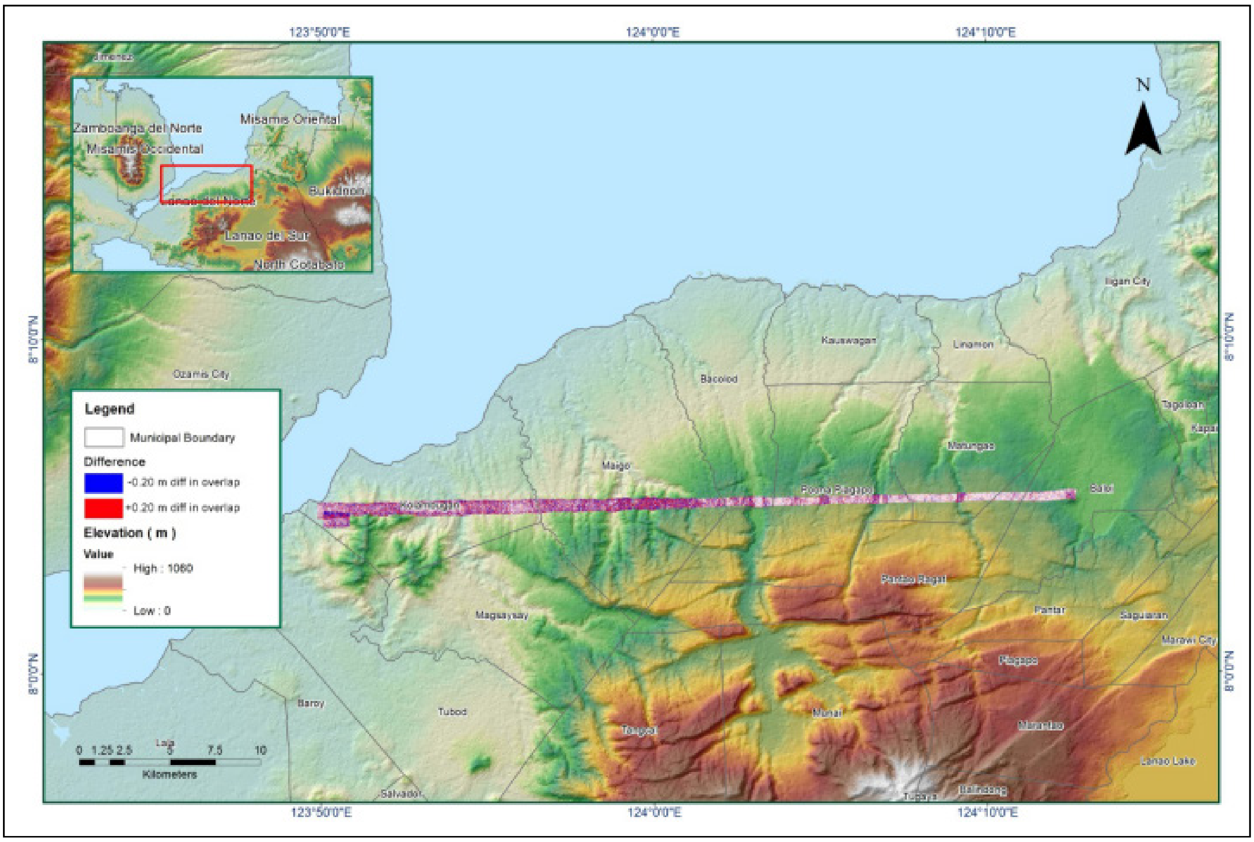


Figure A-8.14. Elevation difference between flight lines

Annex 9. Liangan Model Basin Parameters

Table A-9.1. Liangan Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
W250	14.979	83.101	0	4.98555	6.026911	Discharge	1.0453	0.95	Ratio to Peak	0.435
W260	12.668	85.326	0	4.75146	5.743978	Discharge	1.1499	0.95	Ratio to Peak	0.435
W270	18.904	79.577	0	5.731155	6.928356	Discharge	4.8185	0.95	Ratio to Peak	0.435
W280	13.352	84.655	0	0.349947	0.423046	Discharge	0.0326063	0.95	Ratio to Peak	0.435
W290	19.588	78.994	0	1.84356	2.228736	Discharge	1.1309	0.95	Ratio to Peak	0.435
W300	21.783	77.177	0	2.058885	2.488972	Discharge	1.1859	0.95	Ratio to Peak	0.435
W310	19.842	78.779	0	1.52415	1.842609	Discharge	0.79678	0.95	Ratio to Peak	0.435
W320	17.358	80.929	0	3.268215	3.950899	Discharge	2.0455	0.95	Ratio to Peak	0.435
W330	14.799	83.270	0	3.77136	4.559188	Discharge	5.0930	0.95	Ratio to Peak	0.435
W350	11.163	86.840	0	0.9438255	1.140983	Discharge	0.17907	0.95	Ratio to Peak	0.435
W360	13.673	84.344	0	2.815695	3.403818	Discharge	2.0256	0.95	Ratio to Peak	0.435
W370	28.688	71.970	0	3.844665	4.647724	Discharge	3.3933	0.95	Ratio to Peak	0.435
W390	16.99623	81.252	0	2.132865	2.578436	Discharge	0.41872	0.95	Ratio to Peak	0.435
W400	20.127	78.540	0	1.0148355	1.226827	Discharge	0.20656	0.95	Ratio to Peak	0.435
W410	9.1450	88.956	0	1.332342	1.610652	Discharge	0.0140158	0.95	Ratio to Peak	0.435
W420	26.822	73.307	0	3.808485	4.603974	Discharge	2.6017	0.95	Ratio to Peak	0.435
W430	25.051	74.622	0	1.92186	2.323342	Discharge	1.0336	0.95	Ratio to Peak	0.435
W440	38.192	65.855	0	7.495875	9.061683	Discharge	6.2762	0.95	Ratio to Peak	0.435
W450	38.292	65.796	0	2.92626	3.537598	Discharge	1.1777	0.95	Ratio to Peak	0.435
W460	48.880	60.111	0	4.53384	5.480893	Discharge	1.7307	0.95	Ratio to Peak	0.435
W470	58.227	55.851	0	2.908305	3.515826	Discharge	1.0635	0.95	Ratio to Peak	0.435
W480	60.965	54.715	0	4.287735	5.183412	Discharge	1.8571	0.95	Ratio to Peak	0.435
W500	11.699	86.294	0	1.304586	1.577099	Discharge	0.24057	0.95	Ratio to Peak	0.435

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
W520	17.118	81.143	0	0.708156	0.856087	Discharge	0.19217	0.95	Ratio to Peak	0.435
W540	20.133	78.535	0	0.496422	0.600125	Discharge	0.0905579	0.95	Ratio to Peak	0.435
W560	22.002	77	0	0.0553188	0.066874	Discharge	.000350396	0.95	Ratio to Peak	0.435
W600	23.823	75.562	0	2.196315	2.655037	Discharge	0.89816	0.95	Ratio to Peak	0.435
W620	55.251	57.140	0	3.262815	3.944393	Discharge	2.0892	0.95	Ratio to Peak	0.435
W640	19.581	79	0	0.2475225	0.299219	Discharge	0.0022776	0.95	Ratio to Peak	0.435
W660	19.581	79	0	0.0810603	0.097993	Discharge	.000525594	0.95	Ratio to Peak	0.435

Annex 10. Liangan Model Reach Parameters

Table A-10.1. Liangan Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R10	Automatic Fixed Interval	4142.3	0.0081751	0.045	Trapezoid	34.64	1
R100	Automatic Fixed Interval	4970.1	0.0152192	0.045	Trapezoid	12.768	1
R140	Automatic Fixed Interval	463.55	0.0240020	0.045	Trapezoid	7.346	1
R150	Automatic Fixed Interval	1085.0	0.0136445	0.045	Trapezoid	8.682	1
R170	Automatic Fixed Interval	1267.3	0.0118097	0.045	Trapezoid	4.686	1
R210	Automatic Fixed Interval	5068.3	0.0717450	0.045	Trapezoid	10.284	1
R30	Automatic Fixed Interval	16289	0.0262013	0.045	Trapezoid	18.448	1
R40	Automatic Fixed Interval	245.56	0.0180162	0.045	Trapezoid	18.858	1
R510	Automatic Fixed Interval	3393.3	0.0066003	0.045	Trapezoid	11.856	1
R530	Automatic Fixed Interval	1298.2	0.0132646	0.045	Trapezoid	11.934	1
R550	Automatic Fixed Interval	501.42	0.15377	0.045	Trapezoid	11	1
R610	Automatic Fixed Interval	2518.4	0.0380181	0.045	Trapezoid	7.492	1
R650	Automatic Fixed Interval	462.43	0.13945	0.045	Trapezoid	6.416	1
R70	Automatic Fixed Interval	3558.5	0.0164298	0.045	Trapezoid	26.946	1
R80	Automatic Fixed Interval	339.41	0.0392283	0.045	Trapezoid	11.87	1

Annex 11. Liangan Field Validation Points

Table A-11.1. Liangan Field Validation Points

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
1	8.008049	123.773	0.03	0.96	-0.59	2011	5-Year
2	8.007788	123.7717	0.03	0.4	-0.11	2011	5-Year
3	8.008853	123.7701	0.03	0.41	-0.15		5-Year
4	8.008981	123.7701	0.03	0.43	-0.27		5-Year
5	8.009294	123.77	0.03	0.41	-0.1	2009	5-Year
6	8.009422	123.7698	0.03	0.54	-0.22		5-Year
7	8.009585	123.7694	0.03	0.19	-1.45		5-Year
8	8.01069	123.7673	0.03	0.42	-0.23		5-Year
9	7.88947	123.7622	0.03	0.58	-0.21	Yolanda / November 2015	5-Year
10	7.88869	123.7743	0.03	0.16	0.06	2010	5-Year
11	7.876198	123.8141	0.03	1.3	0.13	2013	5-Year
12	7.984674	123.7959	0.03	1.8	-0.6		5-Year
13	7.926459	123.6908	0.03	1.1	0.06	Lando / August 2015	5-Year
14	7.923024	123.6876	0.03	1.55	0.06	Lando / August 2015	5-Year
15	7.92303	123.6874	0.03	0.6	0.09	Lando / August 2015	5-Year
16	7.922939	123.6873	0.03	0.6	0.21	Lando / August 2015	5-Year
17	8.011248	123.7678	0.03	0.53	0.06	2011	5-Year
18	7.898086	123.7715	0.03	0.38	0.47	Yolanda / November 2015	5-Year
19	8.008067	123.773	0.03	0.2	-0.17	2011	5-Year
20	7.916233	123.7867	0.07	0.72	0.03	2011	5-Year
21	7.875964	123.8142	0.03	1.3	0.08	Pablo / 2013	5-Year
22	8.009878	123.7687	0.03	0.27	0.07		5-Year
23	8.010399	123.7687	0.06	0.27	-0.07		5-Year
24	8.010392	123.7671	0.08	0.72	-0.09		5-Year
25	7.924133	123.6834	0.07	0.4	-0.11	Lando / August 2015	5-Year
26	8.007821	123.7713	0.03	0.67	0.24	2011	5-Year
27	7.924316	123.6835	0.1	0.7	0.31	Lando / August 2015	5-Year
28	7.924293	123.6836	0.1	0.89	1.21	Lando / August 2015	5-Year
29	7.89798	123.7715	0.09	0.4	0.32	Yolanda / November 2015	5-Year
30	7.890638	123.765	0.03	1.75	0.19	Yolanda / November 2015	5-Year
31	7.926212	123.6925	0.14	1	0.34	Lando / August 2015	5-Year
32	7.926383	123.6918	0.07	1.1	0.34	Lando / August 2015	5-Year
33	8.006125	123.7735	0.06	0.75	0.42	2011	5-Year
34	7.926292	123.6924	0.15	1.1	0.54	Lando / August 2015	5-Year
35	7.926154	123.6926	0.16	1.1	0.37	Lando / August 2015	5-Year
36	7.926376	123.692	0.11	1.1	-1.02	Lando / August 2015	5-Year
37	7.905192	123.7709	0.1	0.37	-0.47	Yolanda / November 2015	5-Year
38	7.92258	123.6873	0.14	0.34	-1.06	Lando / August 2015	5-Year
39	7.904212	123.7713	0.11	0.43	-0.67	Yolanda / November 2015	5-Year
40	7.895726	123.7691	0.14	0.2	-0.42	Yolanda / November 2015	5-Year
41	7.926413	123.6913	0.13	1.1	-0.7	Lando / August 2015	5-Year
42	8.007878	123.7735	0.04	0.12	-0.64	2012	5-Year

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
43	7.89553	123.7699	0.14	0.2	-0.64	Yolanda / November 2015	5-Year
44	7.926415	123.6915	0.14	1.1	-1.17	Lando / August 2015	5-Year
45	8.007918	123.771	0.14	0.67	-1.52		5-Year
46	8.007869	123.771	0.14	1.64	-0.44		5-Year
47	7.915393	123.702	0.23	0.56	0.4	August 2015	5-Year
48	8.009722	123.769	0.16	0.51	0.48		5-Year
49	8.011805	123.7631	0.24	0.69	0.1		5-Year
50	7.915007	123.7038	0.26	0.3	-0.95	August 2015	5-Year
51	7.901476	123.7689	0.15	0.072	-0.33	Yolanda / November 2015	5-Year
52	7.926416	123.6917	0.2	1.1	-0.42	Lando / August 2015	5-Year
53	7.899485	123.7736	0.03	0.15	-0.94		5-Year
54	7.926368	123.6922	0.21	1.1	-0.38	Lando / August 2015	5-Year
55	7.926336	123.6921	0.21	1.1	-0.86	Lando / August 2015	5-Year
56	7.92635	123.6922	0.21	1.1	-1.09	Lando / August 2015	5-Year
57	7.895501	123.7685	0.23	0.2	-1.11	Yolanda / November 2015	5-Year
58	8.011914	123.7631	0.26	0.69	-1		5-Year
59	7.882893	123.8087	0.09	1.08	-0.69	Pablo / 2013	5-Year
60	7.916952	123.707	0.21	0.54	-0.81	August 2015	5-Year
61	8.011774	123.7632	0.29	0.49	-0.81		5-Year
62	7.891492	123.7654	0.13	0.16	-0.2	2011	5-Year
63	7.901485	123.769	0.24	0.072	-0.12	Yolanda / November 2015	5-Year
64	8.011763	123.7639	0.33	0.62	-0.14		5-Year
65	8.011916	123.7631	0.35	0.62	-1.42	2011	5-Year
66	7.899302	123.7741	0.03	0.15	-0.13		5-Year
67	7.895651	123.7696	0.33	0.38	-0.04	Yolanda / November 2015	5-Year
68	7.90502	123.7712	0.32	0.43	-0.22	Yolanda / November 2015	5-Year
69	7.904041	123.7705	0.29	0.05	-0.12	Yolanda / November 2015	5-Year
70	7.923345	123.69	0.16	0.47	-0.25		5-Year
71	7.898449	123.7754	0.03	0.2	-1.42		5-Year
72	7.883112	123.8084	0.24	1.08	-0.52	Pablo / 2013	5-Year
73	7.923328	123.69	0.19	0.85	-0.46	Lando / August 2015	5-Year
74	8.013006	123.7629	0.43	0.49	-1.21		5-Year
75	7.898736	123.7756	0.06	0.38	0.21		5-Year
76	7.898853	123.7748	0.05	0.2	0.37		5-Year
77	7.89997	123.7738	0.28	0.28	-1.11		5-Year
78	8.007792	123.7711	0.44	0.67	0.09		5-Year
79	7.898566	123.7758	0.06	0.15	0.17		5-Year
80	7.883193	123.8085	0.32	1.08	-1.33	Pablo / 2013	5-Year
81	7.886652	123.8052	0.4	1.02	-0.4	Pablo / 2013	5-Year
82	7.905038	123.7713	0.47	0.43	-0.32	Yolanda / November 2015	5-Year
83	7.904985	123.7714	0.47	0.43	-0.42	Yolanda / November 2015	5-Year
84	7.921037	123.7767	0.03	0.1	-1.42		5-Year
85	7.883141	123.8078	0.41	1.08	0.1	Pablo / 2013	5-Year

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
86	7.898377	123.7751	0.11	0.2	-1.36	Yolanda / November 2015	5-Year
87	7.980171	123.7929	0.03	2	0.14		5-Year
88	7.909178	123.7714	0.55	0.7	0.14	Yolanda / November 2015	5-Year
89	7.898844	123.7745	0.23	0.15	-0.22		5-Year
90	7.921636	123.7772	0.03	0.4	0.15	Sendong / December 2011	5-Year
91	7.89852	123.7756	0.19	0.2	-0.71		5-Year
92	7.889216	123.7745	0.42	0.79	0.26	Yolanda / November 2015	5-Year
93	7.916166	123.7768	0.17	0.47	0.22	Yolanda / November 2015	5-Year
94	7.888988	123.7599	0.45	0.58	-0.42	Yolanda / November 2015	5-Year
95	7.888591	123.8047	0.03	0.3	-0.15	Pablo / 2013	5-Year
96	7.898437	123.7754	0.21	0.2	-0.4		5-Year
97	7.898557	123.7754	0.22	0.45	-0.24		5-Year
98	7.956313	123.7764	0.12	1.7	-0.01	Frank / 2013	5-Year
99	7.921291	123.7769	0.03	1.34	-0.32		5-Year
100	7.902654	123.7708	0.58	0.1	-0.12	Yolanda / November 2015	5-Year
101	7.898622	123.7749	0.28	0.2	0.03		5-Year
102	8.007904	123.7731	0.66	0.45	-0.38	2011	5-Year
103	7.918463	123.7864	0.03	0.7	0.4	Pablo / 2013	5-Year
104	7.909165	123.7718	0.65	0.42	0.83	Yolanda / November 2015	5-Year
105	7.909201	123.7717	0.66	0.57	-0.55	Yolanda / November 2015	5-Year
106	7.888854	123.7589	0.55	0.58	1.69		5-Year
107	7.920463	123.7754	0.11	0.8	0.02		5-Year
108	7.909238	123.7715	0.71	0.7	-0.88	Yolanda / November 2015	5-Year
109	8.008247	123.7705	0.79	0.76	-0.21		5-Year
110	7.920307	123.775	0.11	0.95	-0.86	2014	5-Year
111	7.909174	123.7717	0.73	0.7	0.06	Yolanda / November 2015	5-Year
112	7.888031	123.804	0.17	1.08	-0.59	Pablo / 2013	5-Year
113	7.888855	123.7591	0.6	0.58	0.04		5-Year
114	7.888916	123.759	0.6	0.58	-1.29		5-Year
115	8.008168	123.7706	0.8	0.82	-0.6		5-Year
116	8.00817	123.7706	0.8	0.79	-0.42		5-Year
117	7.890517	123.7758	0.6	0.35	-0.76	Yolanda / November 2015	5-Year
118	7.909224	123.7716	0.76	0.7	-0.27	Yolanda / November 2015	5-Year
119	7.909224	123.7716	0.76	0.7	0.6	Yolanda / November 2015	5-Year
120	7.923094	123.6898	0.61	1.17	0.22	Lando / August 2015	5-Year
121	7.888814	123.759	0.64	0.58	-0.51	Yolanda / November 2015	5-Year
122	7.888671	123.7589	0.64	0.58	-0.47		5-Year
123	7.916201	123.707	0.75	0.53	-0.47	August 2015	5-Year
124	7.923653	123.6899	0.63	1.3	-0.63	Lando / August 2015	5-Year
125	7.888833	123.7589	0.66	0.58	-0.17		5-Year
126	7.923515	123.69	0.64	2.2	-0.12	Lando / August 2015	5-Year
127	7.890977	123.7747	0.69	0.4	-0.27	Yolanda / November 2015	5-Year
128	7.888952	123.76	0.7	0.58	-0.28	Yolanda / November 2015	5-Year
129	7.888834	123.7591	0.73	0.58	-0.08		5-Year

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
130	7.888835	123.7591	0.73	0.58	-0.08		5-Year
131	7.875455	123.7777	0.62	0.72	0.02	Yolanda / November 2015	5-Year
132	7.890981	123.7652	0.76	0.4	-0.21		5-Year
133	7.979723	123.793	0.41	1.8	-0.56		5-Year
134	7.89759	123.7753	0.56	0.64	0.11	Yolanda / November 2015	5-Year
135	7.898055	123.7744	0.66	0.56	0.08	Yolanda / November 2015	5-Year
136	7.890399	123.7751	0.96	0.35	0.06	Yolanda / November 2015	5-Year
137	7.890429	123.7751	0.96	0.35	0.09	Yolanda / November 2015	5-Year
138	7.979925	123.7938	0.61	1.8	0.03		5-Year
139	7.979925	123.7938	0.61	1.8	-0.18		5-Year
140	7.889377	123.7626	1.08	0.5	-0.2	Yolanda / November 2015	5-Year
141	7.980021	123.7942	1.26	1.5	-0.7		5-Year
142	7.980021	123.7942	1.26	1.5	0.08		5-Year
143	7.920059	123.7752	1.25	0.5	0.08	Pablo / 2013	5-Year
144	7.917468	123.7863	1.11	1.2	0.1		5-Year
145	7.921269	123.777	1.4	1.4	-0.65	Sendong / December 2011	5-Year
146	7.917265	123.7858	1.33	1.5	-0.5	Frank / 2013	5-Year
147	7.92071	123.7789	1.19	0.8	-0.18	Pablo / 2013	5-Year
148	7.920598	123.7789	1.19	0.8	-0.41	Pablo / 2013	5-Year
149	7.921156	123.7769	1.6	1.5	0.03	Sendong / December 2011	5-Year
150	7.917364	123.7858	1.37	1.5	-0.54		5-Year
151	7.980167	123.7934	1.84	2	-0.19		5-Year
152	7.917112	123.7857	1.53	1.5	-0.35		5-Year
153	7.917249	123.7857	1.57	1.6	0.03		5-Year
154	7.917345	123.7857	1.65	1.7	0.03		5-Year
155	7.917361	123.7856	1.86	1.6	-0.32		5-Year
156	7.917309	123.7856	1.86	1.6	-0.7		5-Year

Annex 12. Educational Institutions affected by flooding in Liangan Floodplain

Table A-12.1. Educational Institutions in Bacolod, Lanao del Norte affected by flooding in Liangan Floodplain

LANAO DEL NORTE				
BACOLOD				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Babalaya Elementary School	Alegria			
Babalaya Elementary School	Babalaya			
Abandoned	Esperanza			
Daycare Center	Esperanza			
Esperanza Elementary School	Esperanza		Low	Low
Francisco Bornilla	Esperanza			
Felisa Elementary School	Mati			
Felisa Santos Elementary School	Mati			
Felisa Elementary School	Pagayawan			
Felisa Santos Elementary School	Pagayawan			

Table A-12.2. Educational Institutions in Maigo, Lanao del Norte affected by flooding in Liangan Floodplain

MAIGO				
Building Name	Barangay	Rainfall Scenario		
		Building Name	Barangay	Rainfall Scenario
		5-year	25-year	100-year
Day Care Center	Liangan West	Medium	High	High
Liangan East Elementary School	Liangan West			
Liangan National High School	Liangan West			
Liangan West, Elementary School	Liangan West			
School	Liangan West			
Alegria Elementary School	Mahayahay			
Australian Aid Care Center	Mahayahay			
New School Building	Mahayahay			
New School Building	Santa Cruz			
Old School Building	Santa Cruz			
Old School Building	Santa Cruz			

Annex 13. Health Institutions affected by flooding in Liangan Floodplain

Table A-13.1. Health Institutions in Bacolod, Lanao del Norte affected by flooding in Liangan Floodplain

LANAO DEL NORTE				
BACOLOD				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Medical Institution	Esperanza			

Table A-13.2. Health Institutions in Maigo, Lanao del Norte affected by flooding in Liangan Floodplain

LANAO DEL NORTE				
BACOLOD				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Botika ng Barangay	Mahayahay			
Health Center	Mahayahay			