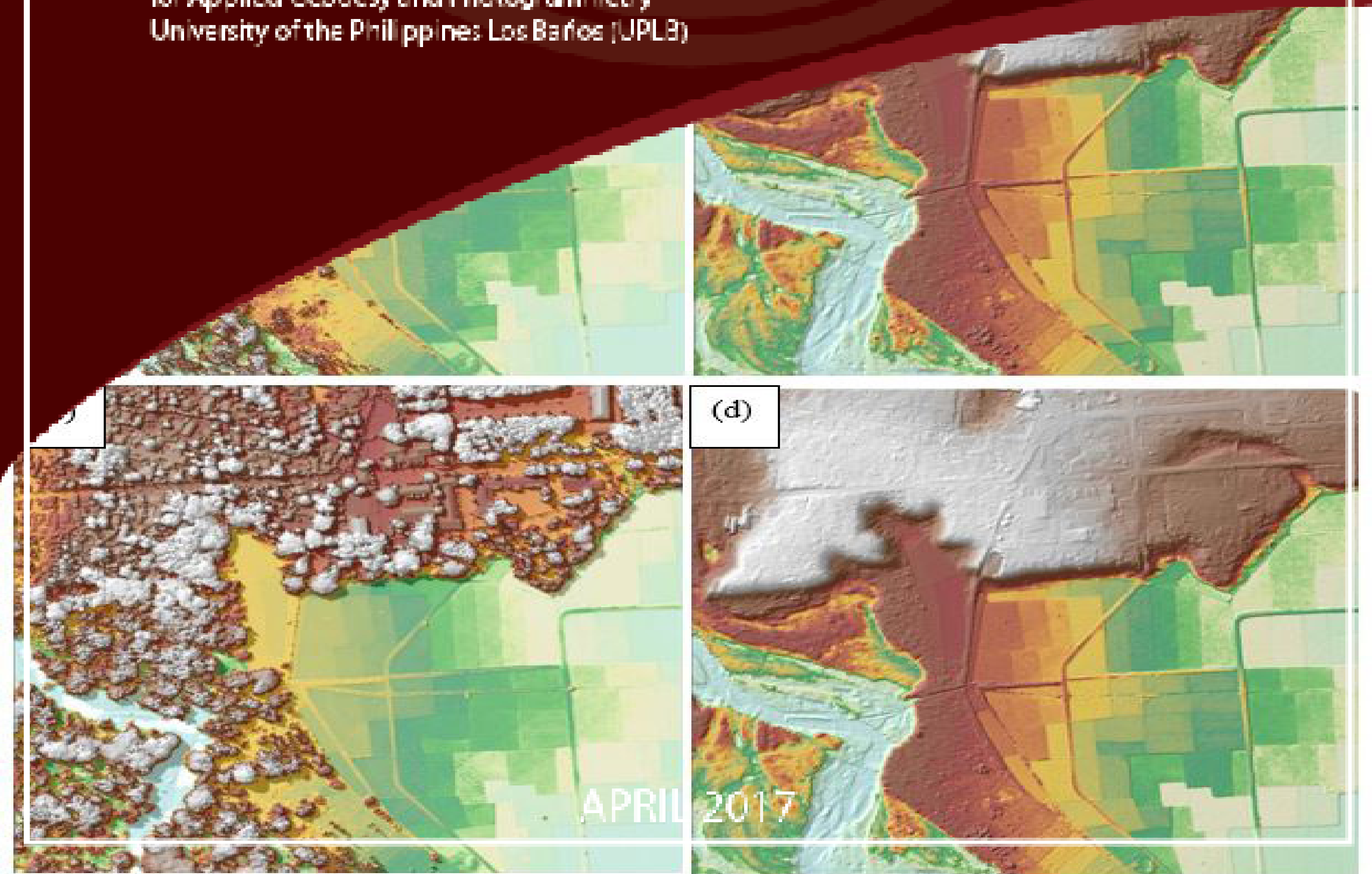
HAZARD MAPPING OF THE PHILIPPINES USING LIDAR (PHIL-LIDAR I)

LiDAR Surveys and Flood Mapping of Malatgao River

University of the Philippines Training Center for Applied Geodesy and Photogrammetry
University of the Philippines Los Baños (UPLB)



APRIL 2017

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LIDAR SURVEYS AND FLOOD MAPPING OF MALATGAO River

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

Chapter 1: OVERVIEW OF MALATGAO RIVER

Enrico C. Paringit, Dr. Eng, Edwin R. Abucay, Cristino L. Tiburan, Jr

1.1 Background of the Phil-LIDAR 1 Program

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

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

The implementing partner university for the Phil-LiDAR 1 Program is the University of the Philippines Los Banos (UPLB). UPLB 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 45 river basins in the MIMAROPA Region. The university is located at Los Banos, Laguna.

1.2 Overview of the Malatgao River Basin

Climate Type I and III prevails in MIMAROPA and Laguna based on the Modified Corona Classification of climate. Type I has two pronounced seasons, dry from November to April, and wet the rest of the year with a maximum rain period from June to September. On the other hand, Type III has no very pronounced maximum rain period and with short dry season lasting only from one to three months, during the period from December to February or from March to May.

Malatgao River Basin is a 214,840 ha watershed located in Palawan. It covers the barangays of Bagong Sikat, Dumagueña, Elvita, Estrella Village, Malatgao, Narra, Sandoval, Taritien and Tinagong Dagat in Narra municipality; Apo-aporawan, Culandanum and Jose Rizal in Aborlan; and, Berong and Panitian in Quezon. The river basin generally characterized by >50% slope. Four soil types can be found within the basin area including Brooke's clay, Babuyan silty clay loam, and Brooke's clay loam. Other areas are still unclassified (rough mountain land) and Hydrosol. Mossy forest can still be found in the area along with the closed canopy (mature trees covering >50%, arable land (crops mainly cereals and sugar), cultivated area mixed with brushland/grassland, cropland mixed with coconut plantation and coconut plantations.

Malatgao River passes through Bagong Sikat, Dumagueña, Elvita, Estrella Village, Malatgao, Narra, Sandoval, Taritien and Tinagong Dagat in Narra municipality; Apo-aporawan, Culandanum and Jose Rizal in Aborlan; and, Berong and Panitian in Quezon. Based on the 2010 NSO Census of Population and Housing, among the barangays in Narra municipality, Brgy. Narra is the most populated; Jose Rizal in Aborlan; and Panitian in Quezon.

Based on the studies conducted by the Mines and Geosciences Bureau, the barangays of Malatgao, Tinagong Dagat and Sandoval have high flooding risk while others have not been affected by flooding. The field surveys conducted by the PHIL-LiDAR 1 validation team found that three notable weather disturbance caused flooding in 2009 (Ondoy), 2013 (Yolanda), and 2016 (Lawin). Heavy rainfall in November 2016 also caused flooding in Malatgao. In terms of landslide susceptibility, only Narra, Elvita, Taritien, Estrella Village and Dumagueña are under a range of low to high risk, other barangays belong under low risk only.

CHAPTER 2: LIDAR DATA ACQUISITION OF THE MALATGAO 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 Malatgao floodplain in Palawan. These missions were planned for 19 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 and Table 2. Figure 1 shows the flight plan for Malatgao floodplain.

Table 1. Flight planning parameters for Pegasus LiDAR System

Block Name	Flying Height (AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK 42A	1000	30	50	100	30	130	5

Table 2. Flight planning parameters for Gemini LiDAR System

Block Name	Flying Height (AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK 42H	1100/1000/ 850	30	26/30/40	100/125	50	130	5
BLK 42I	850	30	50	125	40	130	5
BLK 42J	1000	30	26	100	50	130	5
BLK 42K	1000	30	26	100	50	130	5

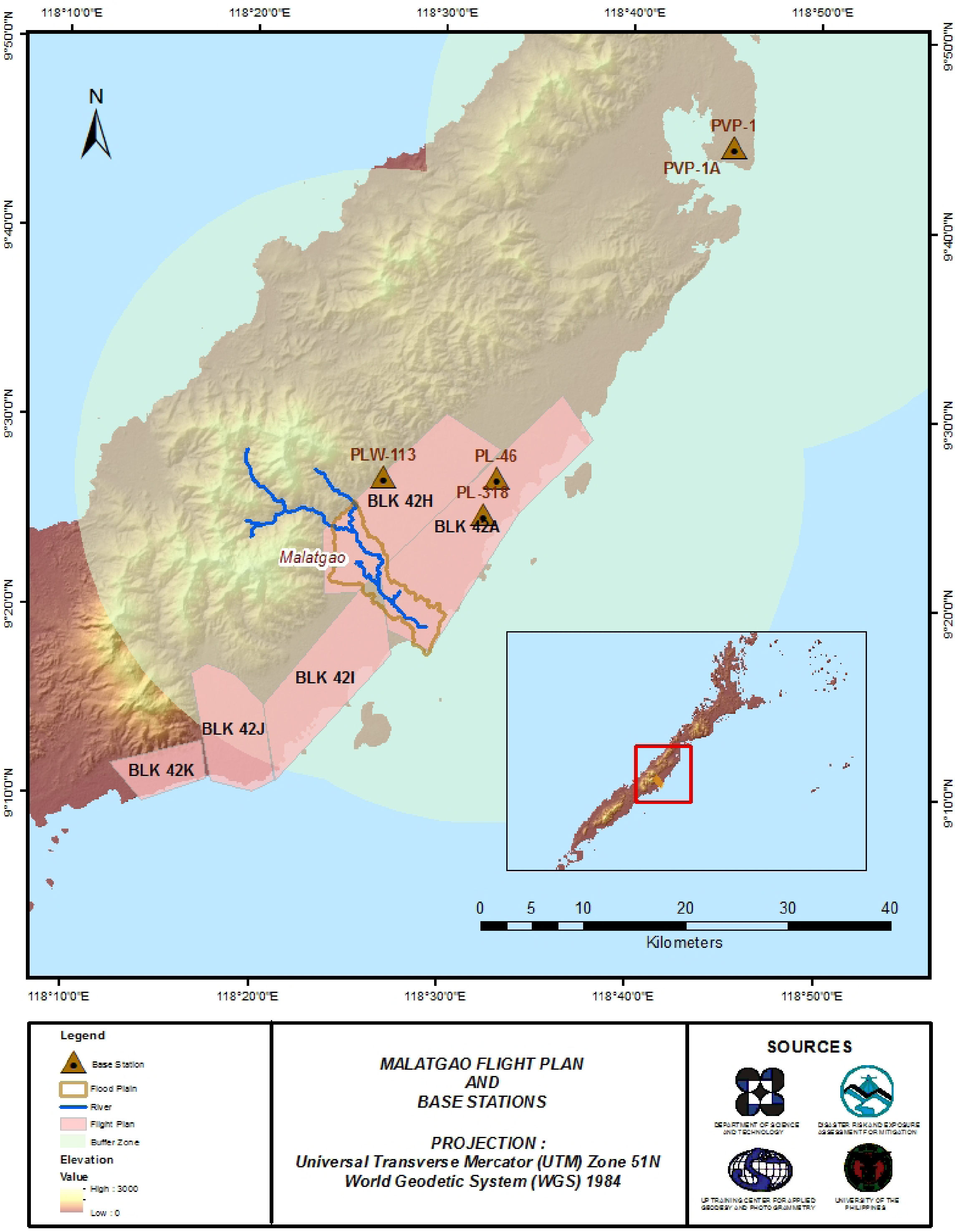

Figure 1. Flight plan and base stations used for Malatgao Floodplain.

2.2 Ground Base Station

The project team was able to recover one (1) NAMRIA control station: PLW-113, which is of second (2nd) order accuracy. Two (2) NAMRIA bench marks were recovered: PL-46 and PL-318. These benchmarks were used as vertical reference points and were also established as ground control points. The team also established two (2) reference points: PVP-1 and PVP-1A. The certification for the NAMRIA reference points and benchmarks are found in Annex 2 while the baseline processing reports for the established reference points are found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey (June 18; November 26-December 1, 2015). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 852 and SPS 882. Flight plans and location of base stations used during the aerial LiDAR acquisition in Malatgao Floodplain are shown in Figure 2.

Figure 2 to Figure 4 shows the recovered NAMRIA reference points within the area, in addition, Table 3 to Table 7 show the details about the following NAMRIA control stations and established points, Table 8 shows the list of all ground control points occupied during the acquisition together with the dates they are utilized during the survey.

Figure 2. GPS set-up over PL-318 as recovered inside Aborlan Municipal Hall, Aborlan Palawan (a) and NAMRIA vertical control point PL-318 (b) as recovered by the field team

Table 3. Details of the recovered NAMRIA vertical control point PL-318 with processed coordinates used as base station for the LiDAR acquisition

Station Name	PL-318	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1:50000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	9°24’58.86852” North 118°32’06.39402” East 16.365 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	9°24’54.50099” North 118°32’11.74904” East 66.814 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	9340.850 m 1043950.552 m

Figure 3.GPS set-up over PVP-1 located on the ground beside Puerto Princesa Airport Fire Station (a) and reference point PVP-1 (b) as recovered by the field team

Table 4. Details of the recovered horizontal control point PVP-1 used as base station for the LiDAR acquisition

Station Name	PVP-1	
Order of Accuracy	1st	
Relative Error (horizontal positioning)	1:100000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	9°44'31.66247" North 118°45'13.60677" East 17.172 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	9°44'27.23233" North 118°45'18.93228" East 61.835 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	33860.371 m 1079760.689 m

Table 5. Details of the recovered NAMRIA horizontal control point PLW-113 used as base station for the LiDAR acquisition

Station Name	PLW-113	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1:50000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	9°26'55.17200" North 118°26'46.88314" East 95.70958 m
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	494109.133 m 1044755.711 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	9°26'50.78858" North 118°26'52.23545" East 145.86900 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 92)	Easting Northing	658792.04 m 1044718.65 m

Table 6. Details of the recovered NAMRIA vertical control point PL-46 used as base station for the LiDAR acquisition

Station Name	PL-46	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1:50000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	9°26'56.28696" North 118°32'48.62908" East 15.833 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	9°26'51.91226" North 118°32'53.98117" East 66.241 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	10678.747 m 1047550.297 m

Table 7. Details of the established horizontal control point PVP-1A used as base station for the LiDAR acquisition

Station Name	PVP-1A	
Order of Accuracy	1st	
Relative Error (horizontal positioning)	1:100,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	9°44'32.50133" North 118°45'13.64985" East 17.110 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	9°44'28.07113" North 118°45'18.97534" East 67.394 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	33862.011 m 1079786.501 m

Table 8. Ground control points used during LiDAR data acquisition

Date Surveyed	Flight Number	Mission Name	Ground Control Points
June 18, 2015	3065P	1BLKAc169A	PL-46 and PLW-113
November 26, 2015	3537G	2BLK42HJ330A	PL-318
November 27, 2015	3541G	2BLK42I331A	PVP1 and PVP-1A
November 30, 2015	3553G	2BLK42HJ334A	PL-318
December 1, 2015	3557G	2BLK45HSL335A	PL-318

2.3 Flight Missions

Five (5) missions were conducted to complete the LiDAR data acquisition in Malatgao Floodplain, for a total of seventeen hours and forty two minutes (17+42) of flying time for RP-C9022. All missions were acquired using the Pegasus and Gemini LiDAR System. Table 9 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 10 presents the actual parameters used during the LiDAR data acquisition.

Table 9. Flight missions for LiDAR data acquisition in Malatgao 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
June 18, 2015	3065P	171.28	204.16	25.07	179.09	524	3	12
November 26, 2015	3537G	198.52	81.61	11.61	70	0	3	30
November 27, 2015	3541G	100.22	155.08	9.68	145.4	0	3	50
November 30, 2015	3553G	130.23	107.70	20.18	87.52	0	3	29
December 1, 2015	3557G	162.13	130.79	8.49	122.3	0	3	41
TOTAL		762.38	679.34	75.03	604.31	524	17	42

Table 10. Actual parameters used during LiDAR data acquisition

Flight Number	Flying Height (AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
3065P	1000	30	50	100	50	130	5
3537G	1100, 1000, 850	30	26, 30, 40	100, 125	50	130	5
3541G	850	30	50	125	40	130	5
3553G	1000	30	26	100	50	130	5
3557G	1200, 1000, 850	30	26, 40	100, 125	50	130	5

2.4. Survey Coverage

Malatgao Floodplain is located in the province of Palawan with majority of the floodplains situated within the municipalities of Aborlan and Narra. The municipalities of Narra and Aborlan were mostly covered by the survey. The list of municipalities and cities surveyed with at least one (1) km2 coverage, is shown in Table 11. The actual coverage of the LiDAR acquisition for Malatgao Floodplain is presented in Figure 4.

Table 11. List of municipalities and cities surveyed during Malatgao Floodplain LiDAR survey

Province	Municipality/City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed =(Total Area covered/ Area of Municipality)*100
Palawan	Aborlan	645.11	212.44	33%
	Narra	831.19	277.30	33%
	Quezon	917.97	35.53	4%
	Sofronio Espanola	477.50	15.29	3%
Total		2871.77	540.56	18.82%

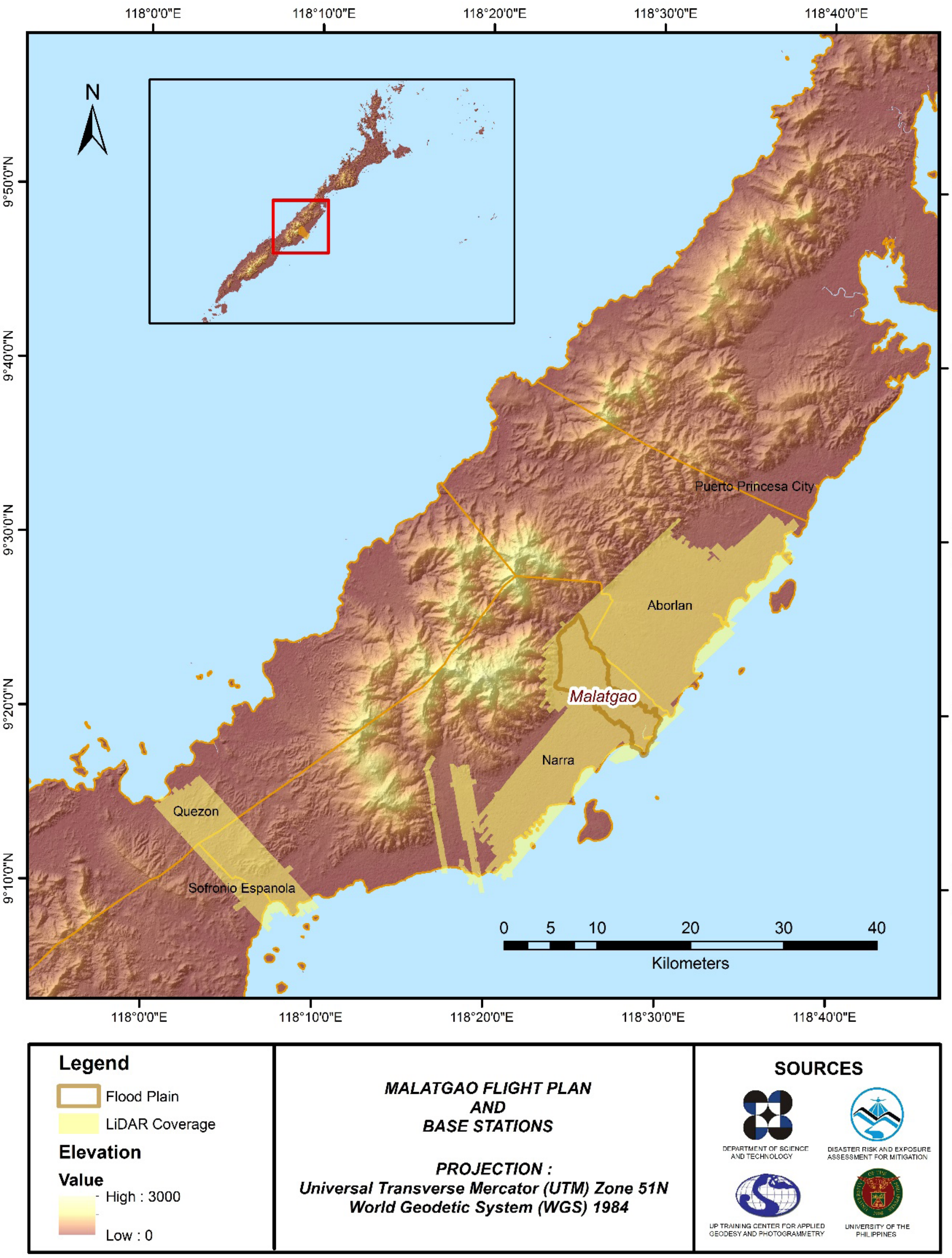

Figure 4. Actual LiDAR survey coverage for Malatgao Floodplain

CHAPTER 3: DATA PROCESSING FOR THE TUMAGA FLOODPLAIN

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

3.1 Overview of the LiDAR Data Pre-Processing

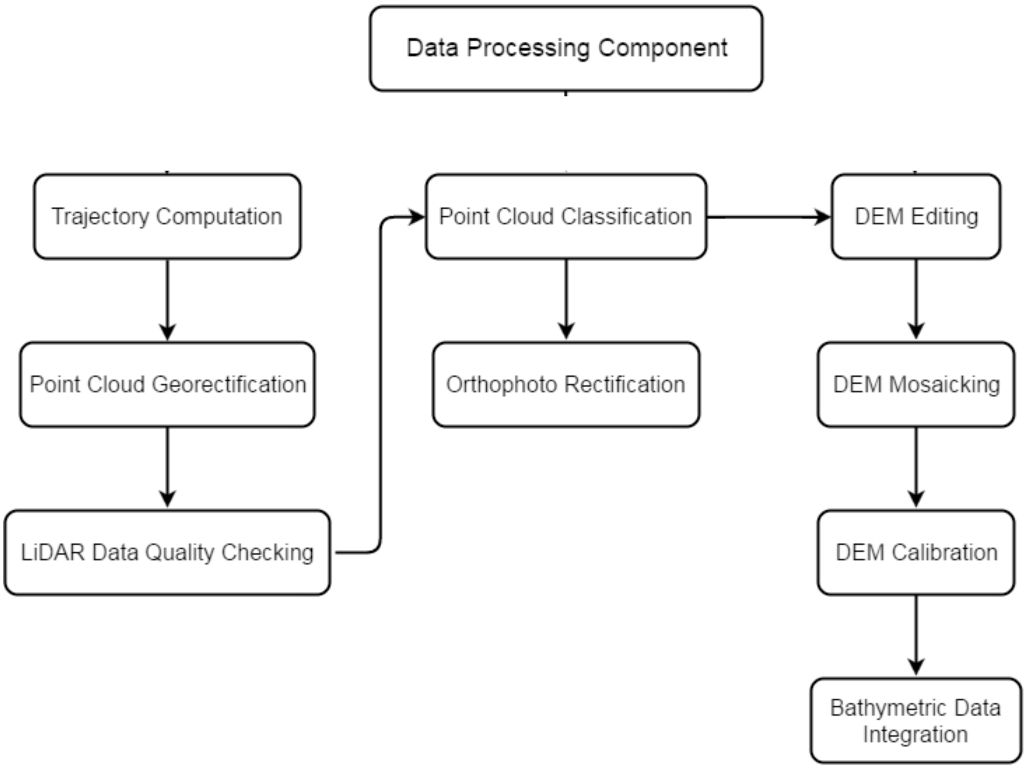

Figure 5. Schematic Diagram for Data Pre-Processing Component

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.

The processes are summarized in the flowchart shown in Figure 5.

3.2. Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR Missions for Malatgao Floodplain can be found in Annex 5. Missions flown during the first survey conducted on June 2015 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Gemini System while missions acquired during the surveys on November and December 2015 were flown using the Pegasus System over Narra, Palawan. The Data Acquisition Component (DAC) transferred a total of 80.3 gigabytes of Range data, 0.798 gigabytes of POS data, 22.35 megabytes of GPS base station data, and 37.7 gigabytes of raw image data to the data server on July 9, 2015 for the first survey and December 8, 2015 for the second and third survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Malatgao was fully transferred on December 8, 2015, as indicated on the Data Transfer Sheets for Malatgao Floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metric parameters of the computed trajectory for flight 3541G, one of the Malatgao flights, which is the North, East, and Down position RMSE values are shown in Figure 6. 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 November 27, 2015 00:00AM. The y-axis is the RMSE value for that particular position.

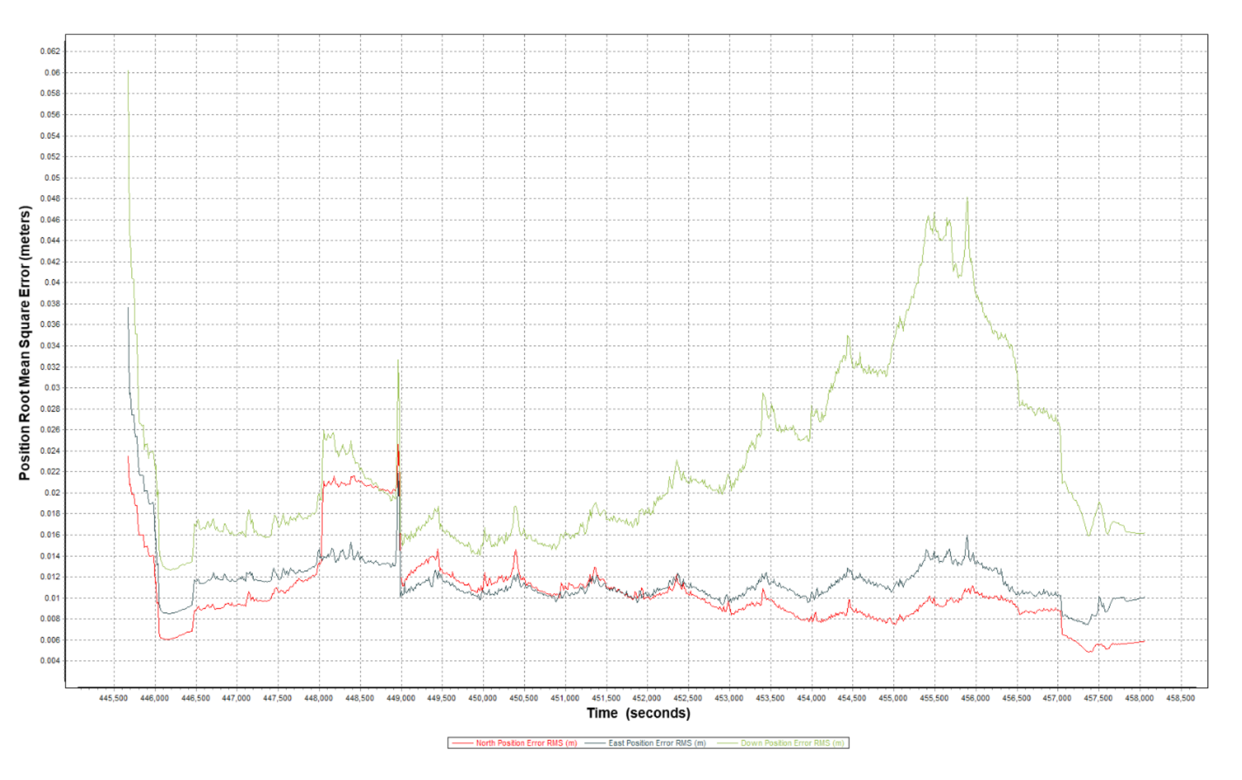

Figure 6. Smoothed Performance Metric Parameters of Malatgao Flight 3541G

The time of flight was from 44500 seconds to 458500 seconds, which corresponds to morning of November 27, 2015. 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 6 shows that the North position RMSE peaks at 2.47 cm, the East position RMSE peaks at 2.20 cm, and the Down position RMSE peaks at 3.27 cm, which are within the prescribed accuracies described in the methodology.

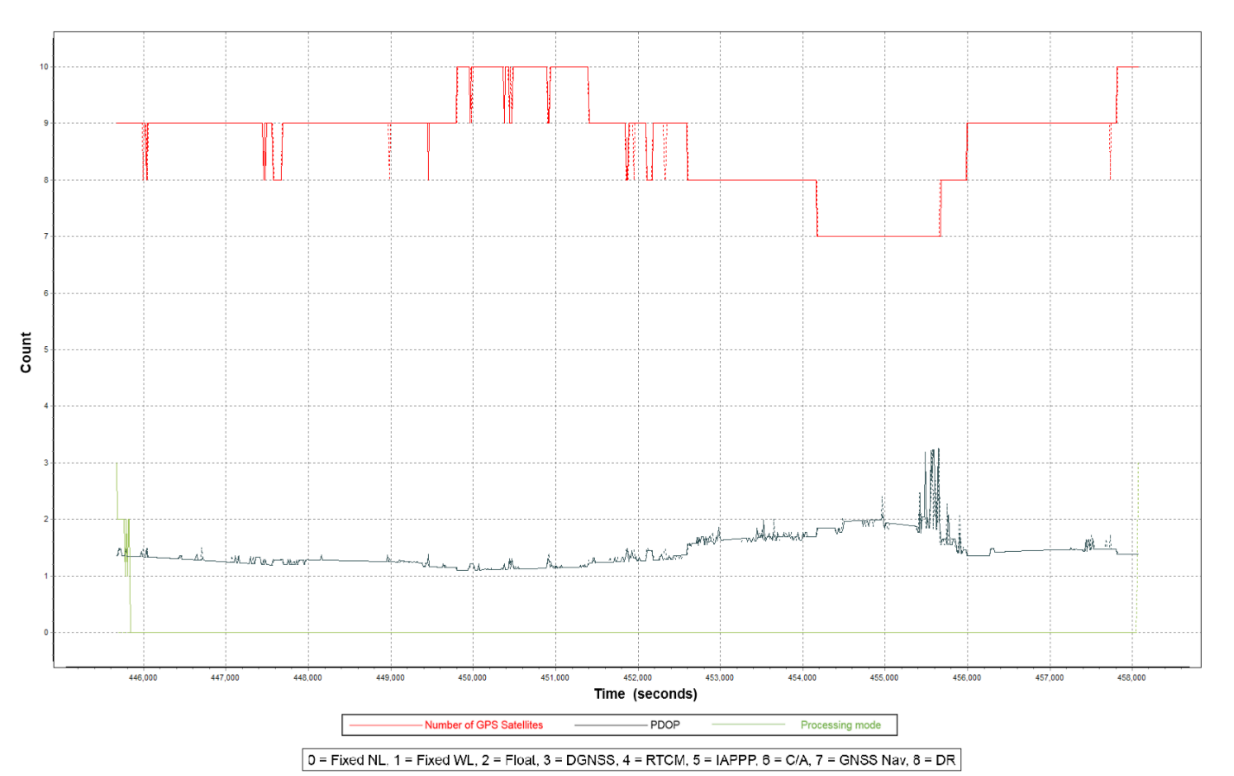

Figure 7. Solution Status Parameters of Malatgao Flight 3541G

The Solution Status parameters of flight 3541G, one of the Malatgao flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 7. The graphs indicate that the number of satellites during the acquisition did not go down to 7. Majority of the time, the number of satellites tracked was between 7 and 10. The PDOP value also did not go above the value of 4, which indicates optimal GPS geometry. The processing mode stayed at the value of 0 for majority of the survey. 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 Malatgao flights is shown in Figure 8.

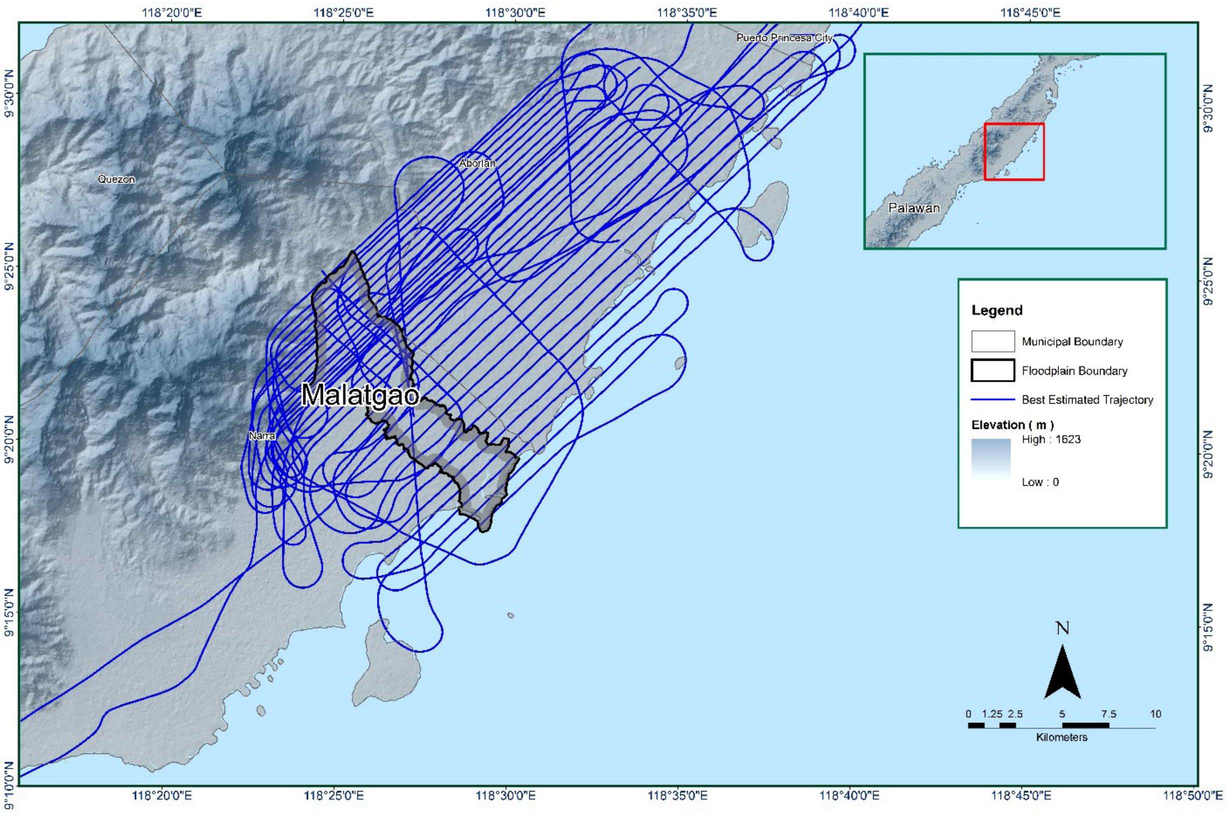

Figure 8. Best Estimated Trajectory for Malatgao Floodplain

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 43 flight lines, 30 flight lines containing one channel, since the Gemini system contains one channel only, while 13 flight lines contain two channel using the Pegasus system. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Malatgao Floodplain are given in Table 12.

Table 12. Self-Calibration Results values for Malatgao flights.

Parameter		Computed Value
Boresight Correction stdev	(<0.001degrees)	0.000305
IMU Attitude Correction Roll and Pitch Corrections stdev	(<0.001degrees)	0.000550
GPS Position Z-correction stdev	(<0.01meters)	0.0070

The optimum accuracy is obtained for all Malatgao flights based on the computed standard deviations of the corrections of the orientation parameters. Standard deviation values for individual blocks are available in the Annex 11. Mission Summary Reports.

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Malatgao Floodplain is shown in Figure 9. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

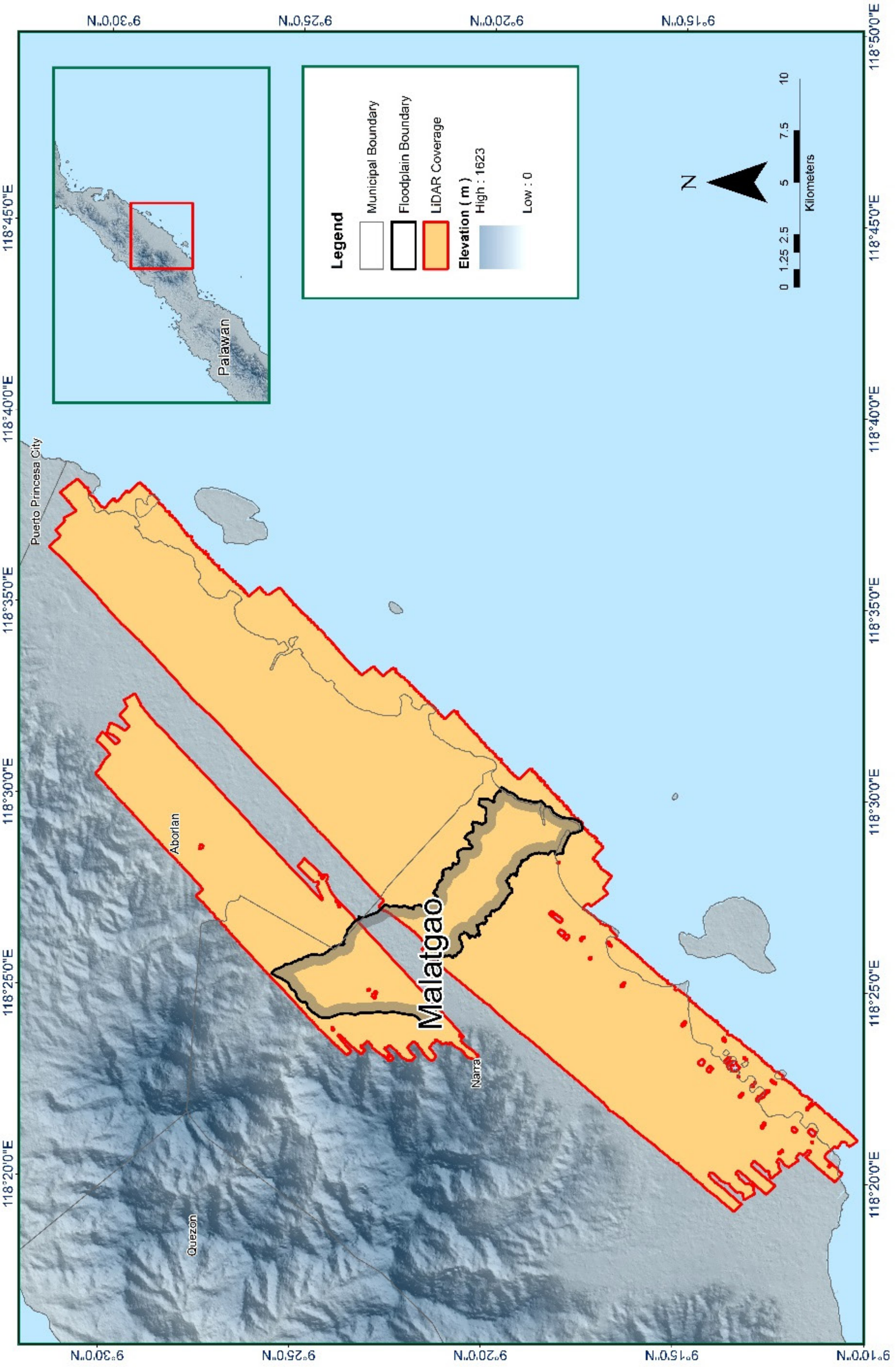

Figure 9. Boundary of the processed LiDAR data over Malatgao Floodplain

The total area covered by the Malatgao missions is 417.73 km2 that is comprised of four (4) flight acquisitions grouped and merged into three (3) blocks as shown in Table 13.

Table 13. List of LiDAR blocks for Malatgao Floodplain

LiDAR Blocks	Flight Numbers	Area (km^2)
Palawan_Blk42Ac	3065P	202.59
Palawan_Reflight_Blk42eH	3553G	89.57
	3557G	
Palawan_Reflight_Blk42eI	3541G	125.57
	TOTAL	**417.73 km^2**

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 10. Since the Gemini System employs one channel and two channels for the Pegasus System, we would expect an average value of 1 (blue) for areas where there is limited overlap, and a value of 2 (yellow) or more (red) for areas with three or more overlapping flight lines.

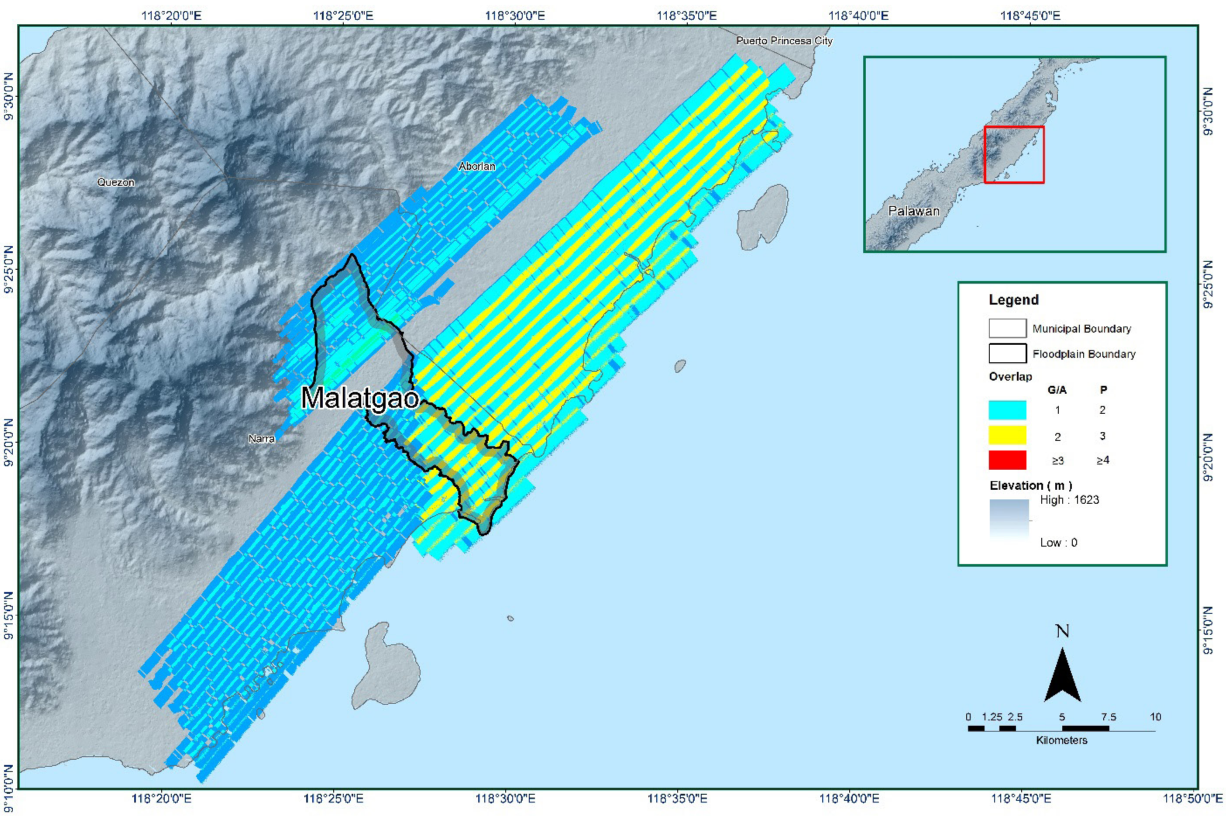

Figure 10. Image of data overlap for Malatgao Floodplain

The overlap statistics per block for the Malatgao Floodplain can be found in Annex 11. One pixel corresponds to 25.0 m2 on the ground. For this area, the minimum and maximum percent overlaps are 26.816% and 39.13% respectively, which passed the 25% requirement.

The 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 11. It was determined that all LiDAR data for Malatgao Floodplain satisfy the point density requirement, and the average density for the entire survey area is 4.11 points per m^2.

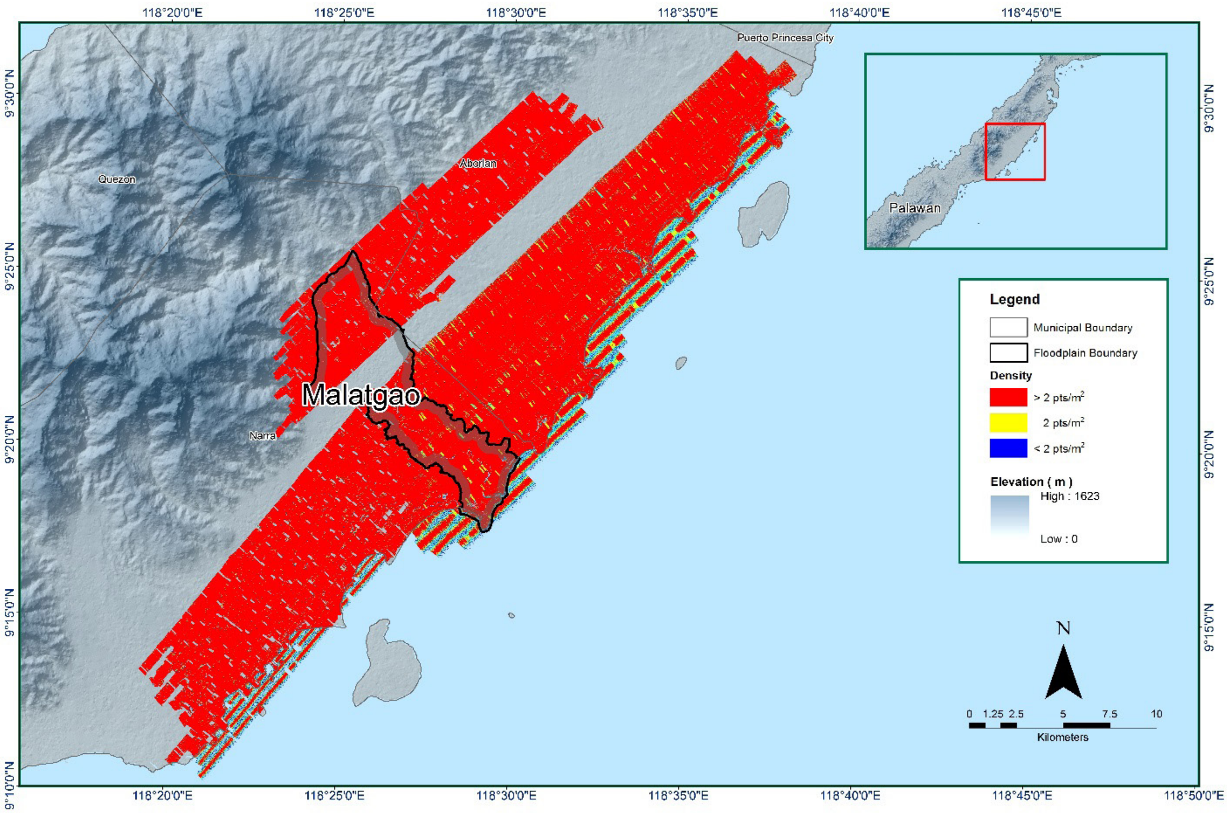

Figure 11. Density map of merged LiDAR data for Malatgao Floodplain

The elevation difference between overlaps of adjacent flight lines is shown in Figure 12. 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 0.20 m 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 0.20 m 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.

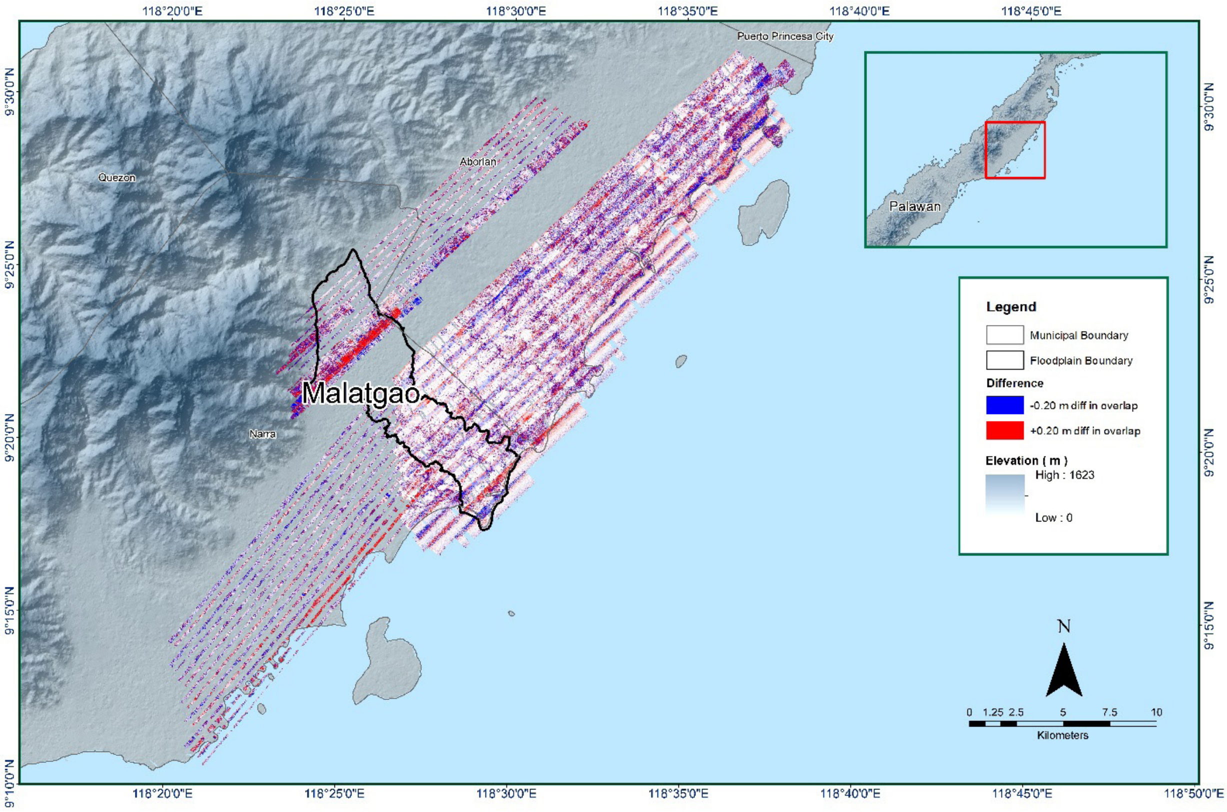

Figure 12. Elevation difference map between flight lines for Malatgao Floodplain

A screen capture of the processed LAS data from Malatgao Flight 3541G loaded in QT Modeler is shown in Figure 13. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed red line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20 cm mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

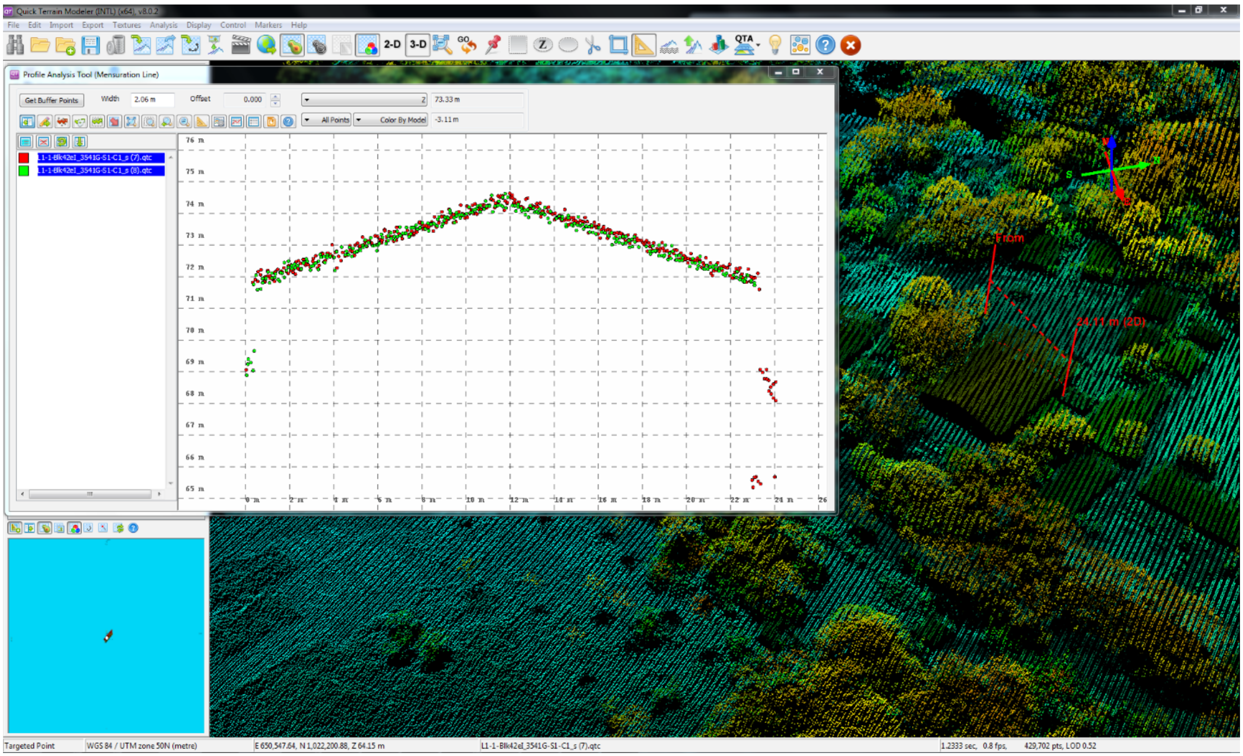

Figure 13. Quality checking for Malatgao Flight 3541G using the Profile Tool of QT Modeler

3.6 LiDAR Point Cloud Classification and Rasterization

Table 14. Malatgao classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	241,211,903
Low Vegetation	173,662,143
Medium Vegetation	160,403,456
High Vegetation	358,710,743
Building	6,348,454

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Malatgao Floodplain is shown in Figure 14. A total of 167 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 14. The point cloud has a maximum and minimum height of 125.92 m and 52.42 m respectively.

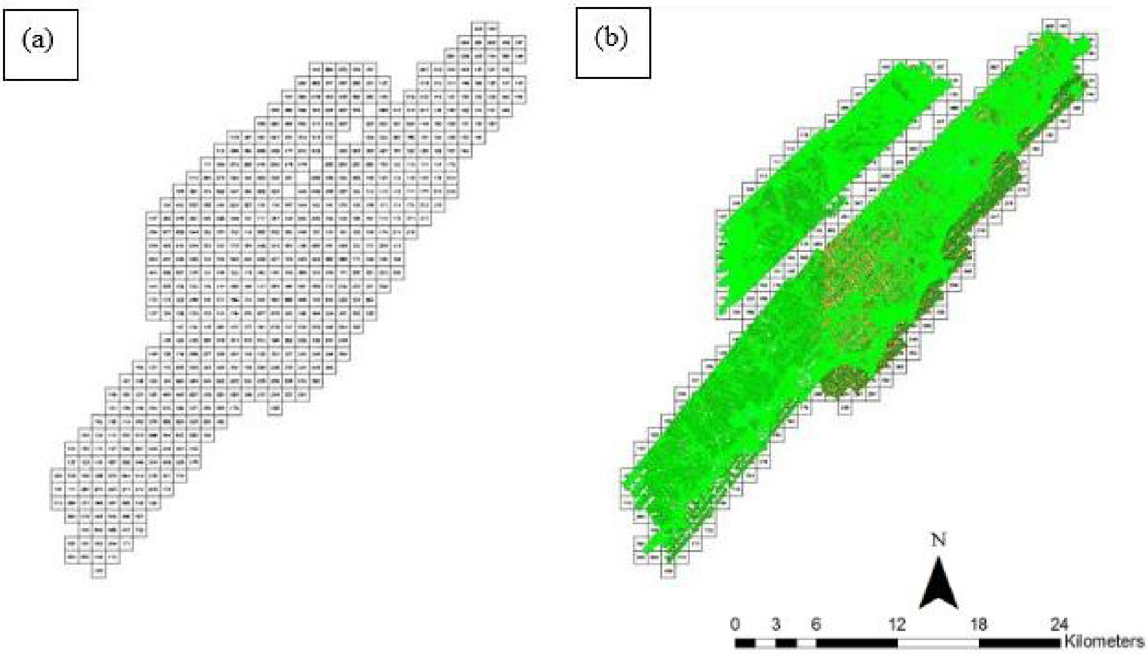

Figure 14. Tiles for Malatgao Floodplain (a) and classification results (b) in TerraScan

An isometric view of an area before and after running the classification routines is shown in Figure 15. 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.

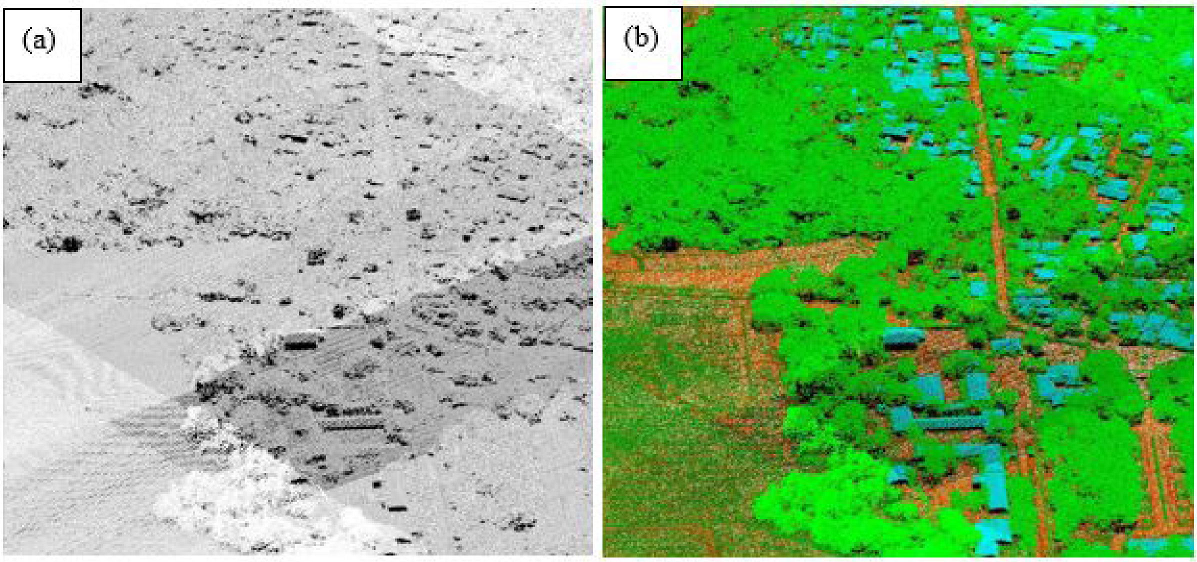

Figure 15. Point cloud before (a) and after (b) classification

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

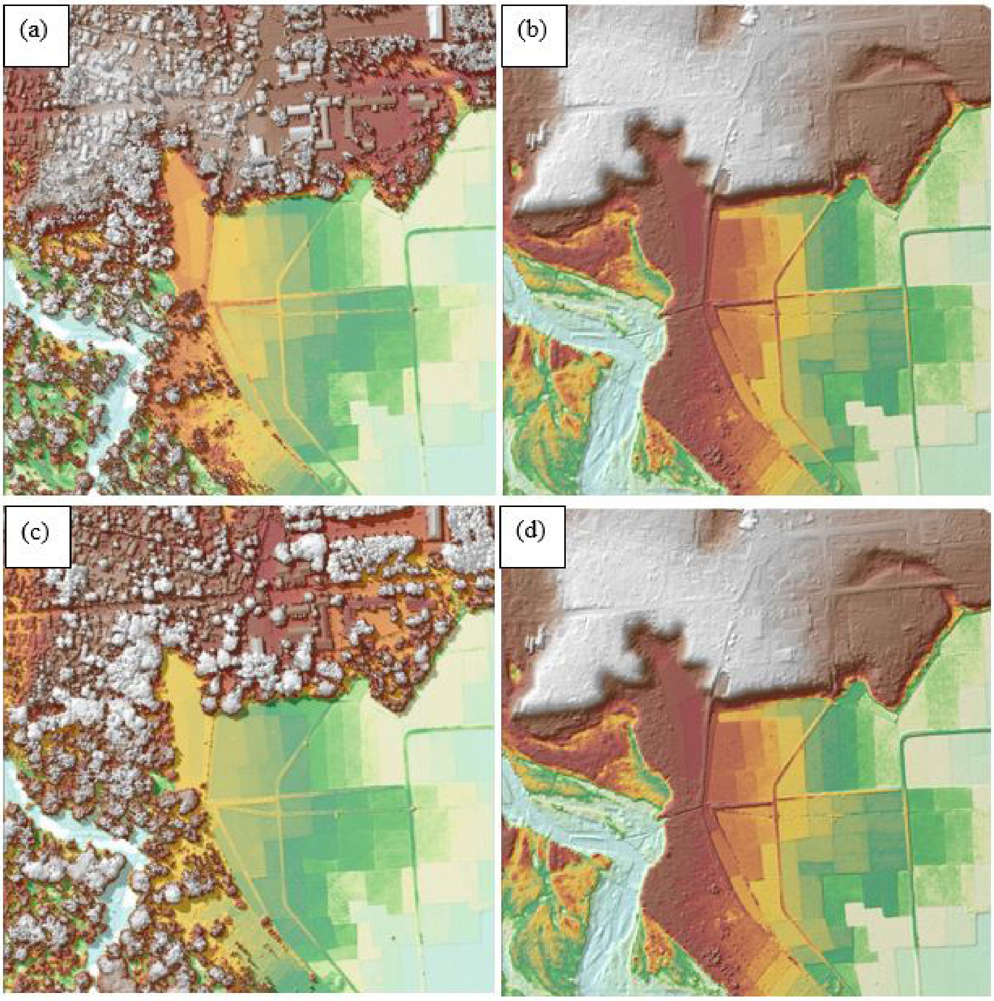

Figure 16. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Malatgao Floodplain

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 264 1km by 1km tiles area covered by Malatgao Floodplain is shown in Figure 17. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Malatgao Floodplain has a total of 201.542 km2 orthophotogaph coverage comprised of 524 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 18.

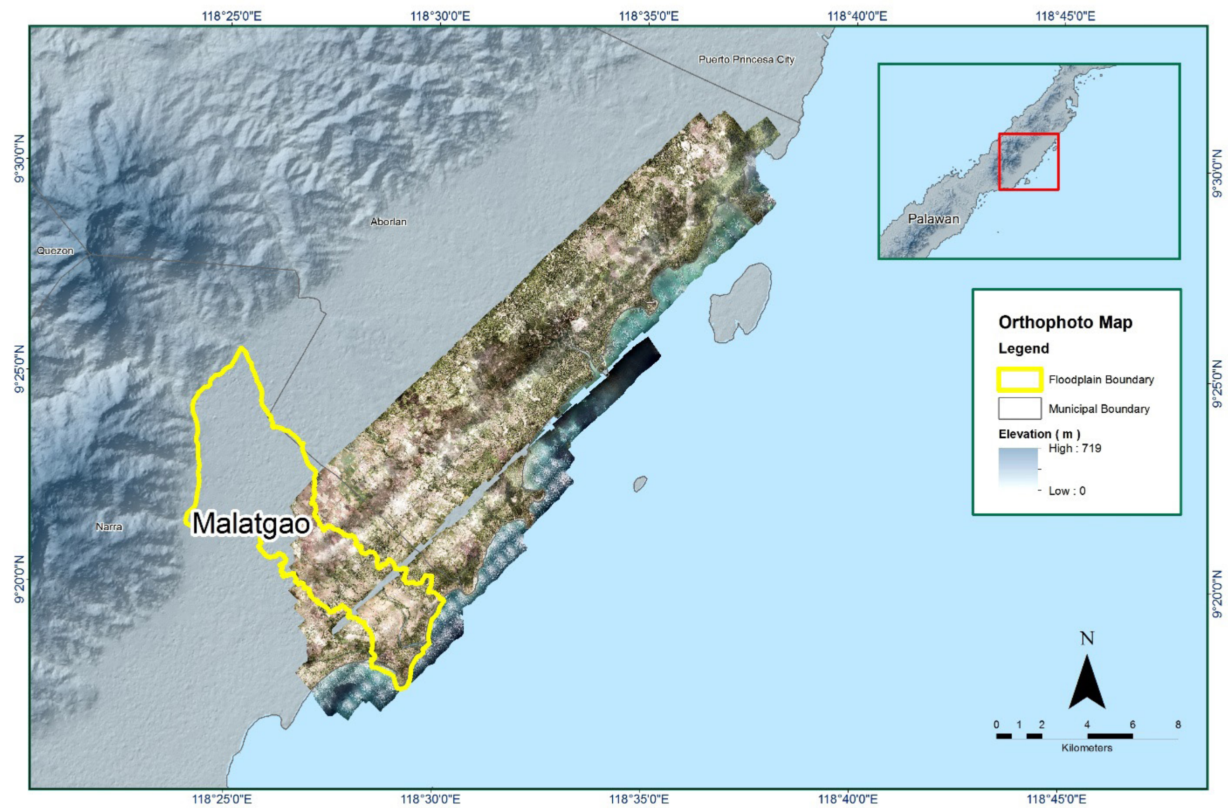

Figure 17. Malatgao Floodplain with available orthophotographs

Figure 18. Sample orthophotograph tiles for Malatgao Floodplain

3.8 DEM Editing and Hydro-Correction

Three (3) mission blocks were processed for Malatgao Floodplain. These blocks are composed of Palawan and Palawan_Reflights blocks with a total area of 417.73 km2. Table 15 shows the name and corresponding area of each block in km^2.

Table 15. LiDAR blocks with its corresponding area

LiDAR Blocks	Area (km2)
Palawan_Blk42Ac	202.59
Palawan_Reflight_Blk42eH	89.57
Palawan_Reflight_Blk42eI	125.57
TOTAL	**417.73 sq.km**

Portions of DTM before and after manual editing are shown in Figure 19. The terrain (Figure 19a) was deformed and the feature has to be retrieved (Figure 19b) from the t-ascii in order to correct the surface. The bridge (Figure 19c) is also considered to be impedance to the flow of water along the river and has to be removed (Figure 19d) in order to hydrologically correct the river.

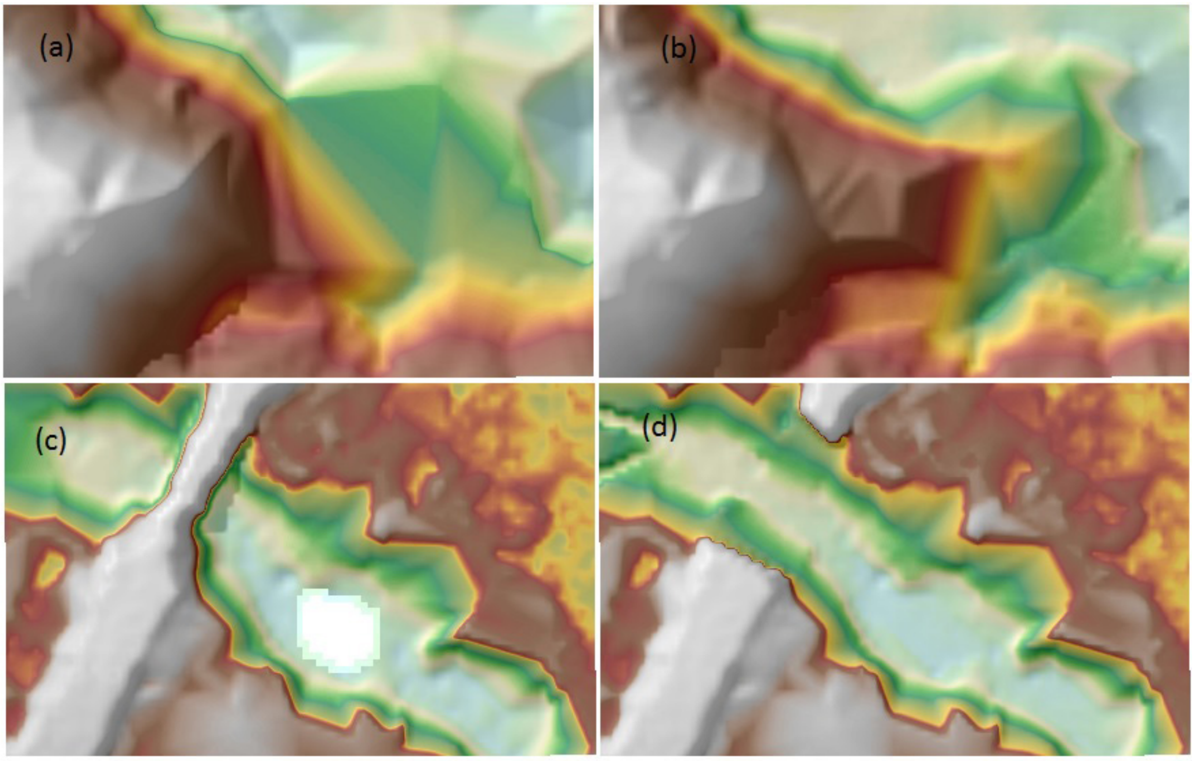

Figure 19. Portions in the DTM of Malatgao Floodplain –a flattened surface before (a) and after (b) object retrieval; and a bridge before (c) and after (d) manual editing

3.9 Mosaicking of Blocks

Palawan Block 42Aa was used as the reference block at the start of mosaicking because it was the first block mosaicked to the larger DTM of West Coast Palawan. Upon inspection of the blocks mosaicked for the Malatgao Floodplain, it was concluded that only the elevation of Palawan_Reflight_Blk42eH needed adjustment before merging the blocks.

Mosaicked LiDAR DTM for Malatgao Floodplain is shown in Figure 20. The entire Malatgao Floodplain is 86.14% covered by LiDAR data while portions with no LiDAR data were patched with the available IFSAR data.

Table 16. Shift Values of each LiDAR Block of Malatgao Floodplain

Mission Blocks	Shift Values (meters)		
	x	y	z
Palawan_Blk42Ac	0.00	0.00	0.00
Palawan_Reflight_Blk42eH	0.00	0.00	-1.59
Palawan_Reflight_Blk42eI	0.00	0.00	0.05

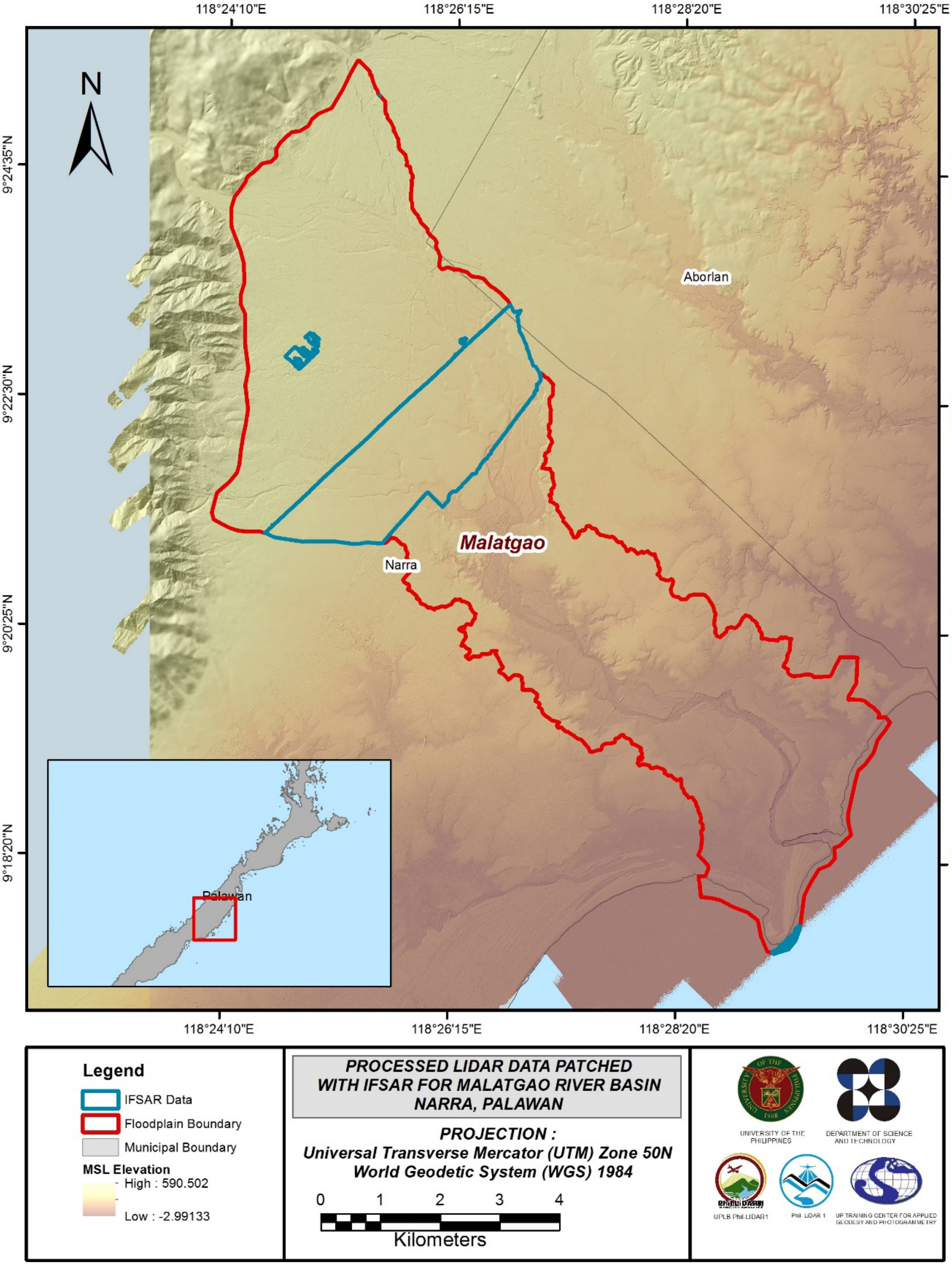

Figure 20. Map of Processed LiDAR Data for Malatgao FloodPlain

3.10 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Palawan to collect points with which the LiDAR dataset is validated is shown in Figure 21. A total of 2,816 survey points were used for calibration and validation of Malatgao LiDAR data. Random selection of 80% of the survey points, resulting to 2,253 points, were used for calibration.

A good correlation between the uncalibrated mosaicked LiDAR elevation values and ground survey elevation values is shown in Figure 22. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration points is 9.63 m with a standard deviation of 0.20 m. Calibration of Malatgao LiDAR data was done by adding the height difference value, 9.63 m, to Malatgao mosaicked LiDAR data. Table 7 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

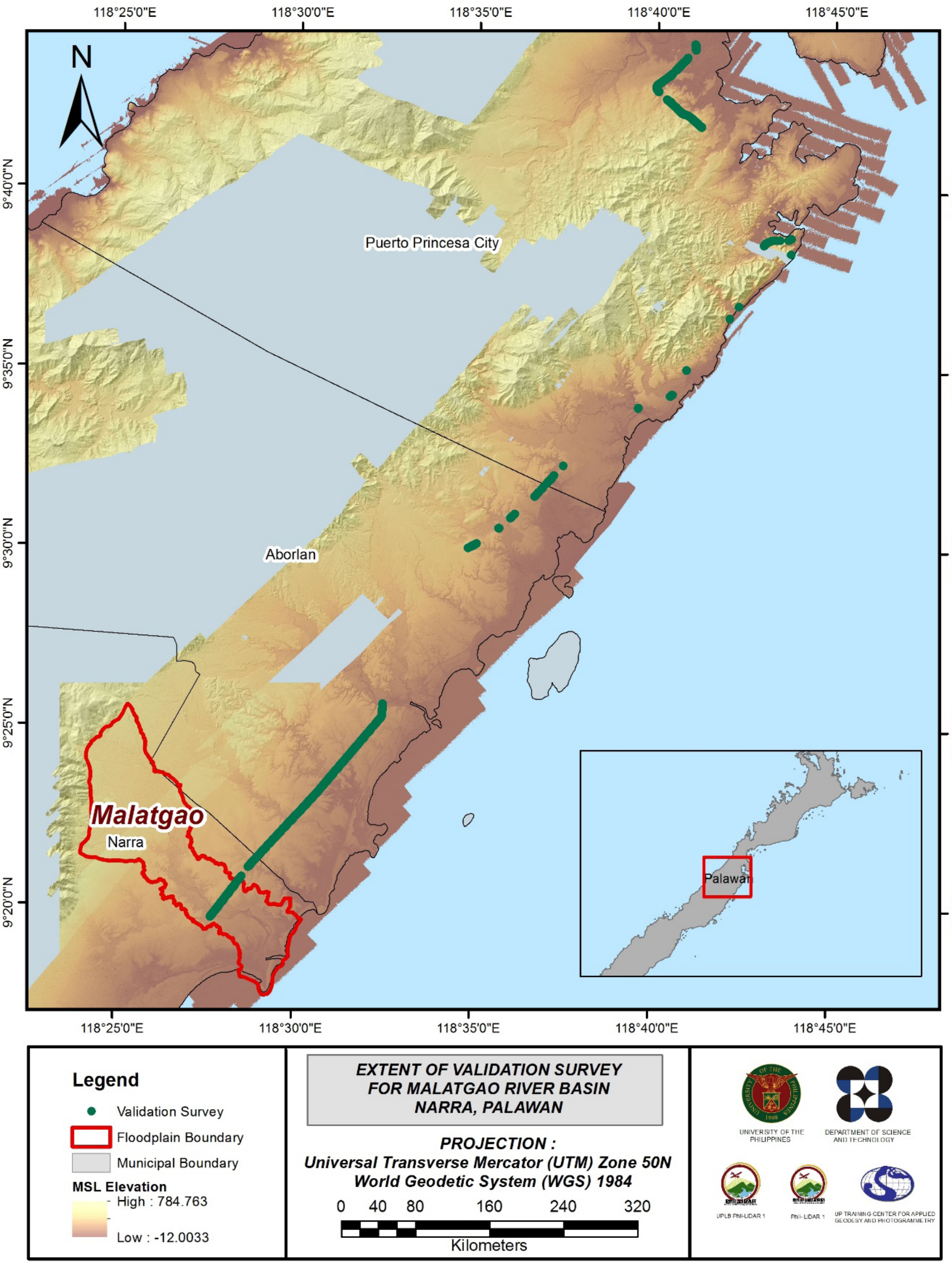

Figure 21. Map of Malatgao FloodPlain with validation survey points in green

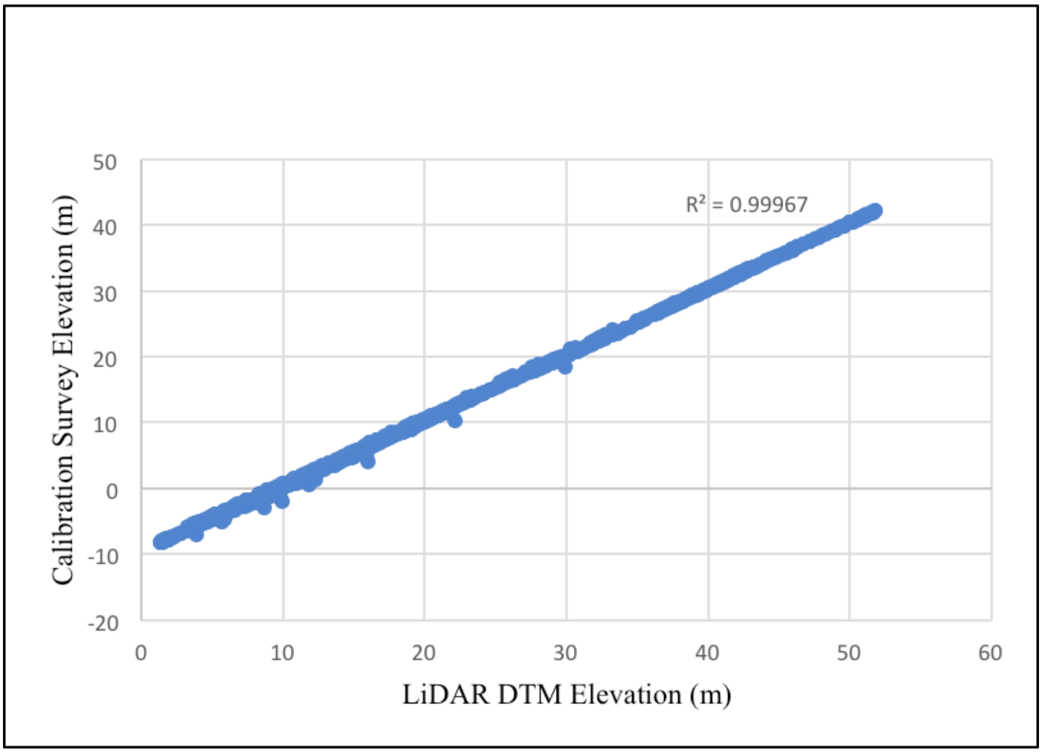

Figure 22. Correlation plot between calibration survey points and LiDAR data

Table 17. Calibration Statistical Measures

Calibration Statistical Measures	Value (meters)
Height Difference	9.63
Standard Deviation	0.20
Average	9.62
Minimum	9.23
Maximum	10.02

A total of 528 survey points lie within Malatgao Floodplain and were used for the validation of the calibrated Malatgao DTM. A good correlation between the calibrated mosaicked LiDAR elevation values and the ground survey elevation, which reflects the quality of the LiDAR DTM is shown in Figure 23. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.20 m with a standard deviation of 0.20 m, as shown in Table 18.

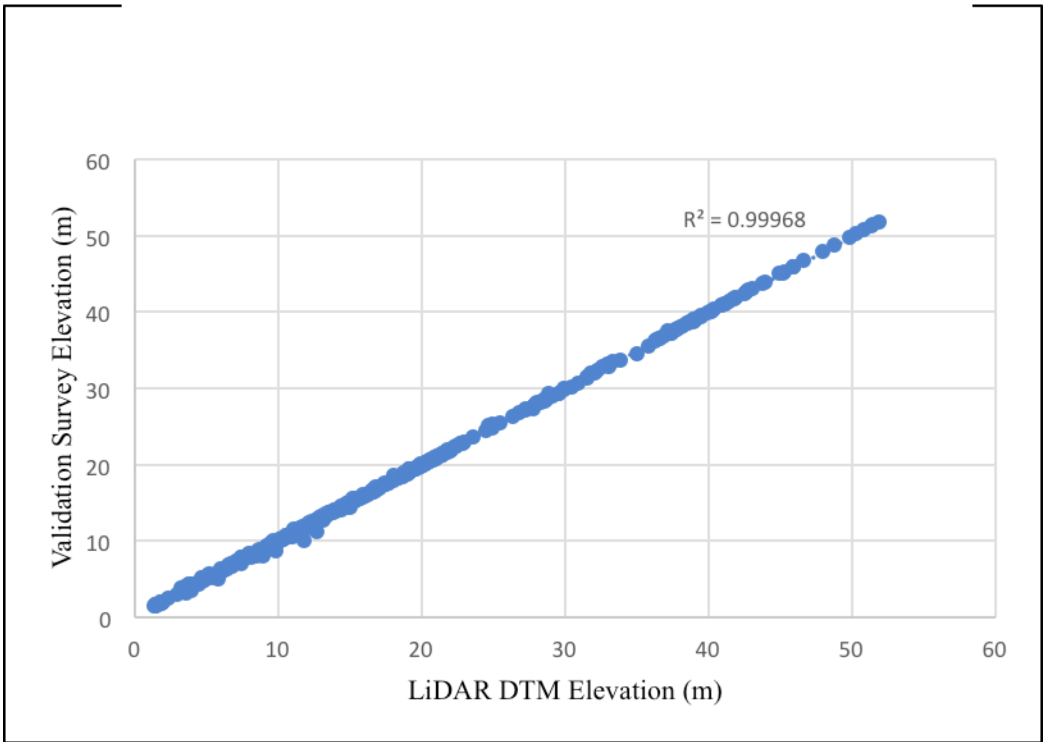

Figure 23. Correlation plot between validation survey points and LiDAR data

Table 18. Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.20
Standard Deviation	0.20
Average	0.003
Minimum	-0.39
Maximum	0.39

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, zigzag and centerline were available for Malatgao with a total of 4,969 survey points. The resulting raster surface produced was done by Kernel Interpolation with Barrier method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.47 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Malatgao integrated with the processed LiDAR DEM is shown in Figure 24.

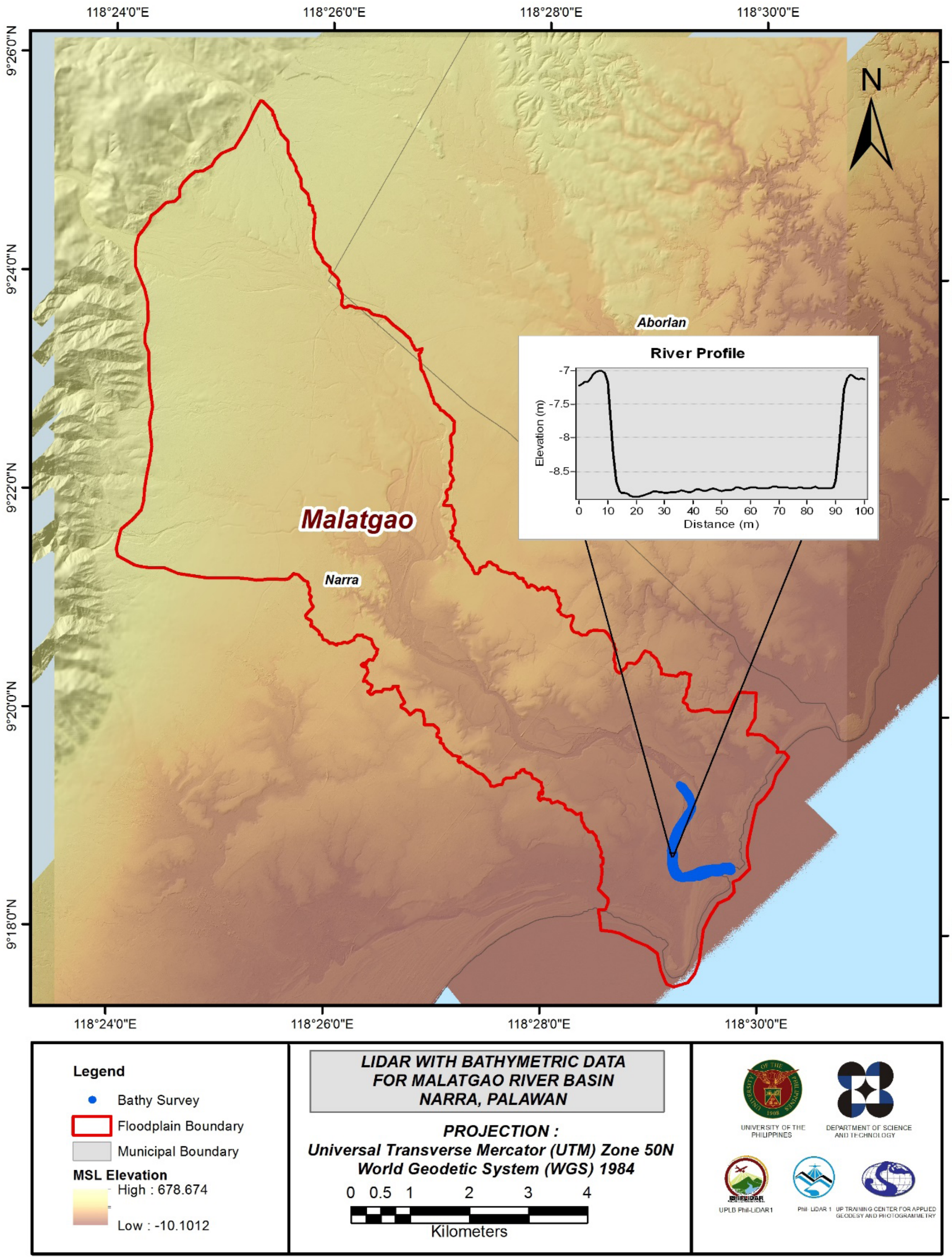

Figure 24. Map of Malatgao FloodPlain with bathymetric survey points shown in blue

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

Malatgao Floodplain, including its 200 m buffer, has a total area of 208.01 km2. For this area, a total of 6.0 km2, corresponding to a total of 1031 building features, are considered for QC. Figure 25 shows the QC blocks for Malatgao Floodplain.

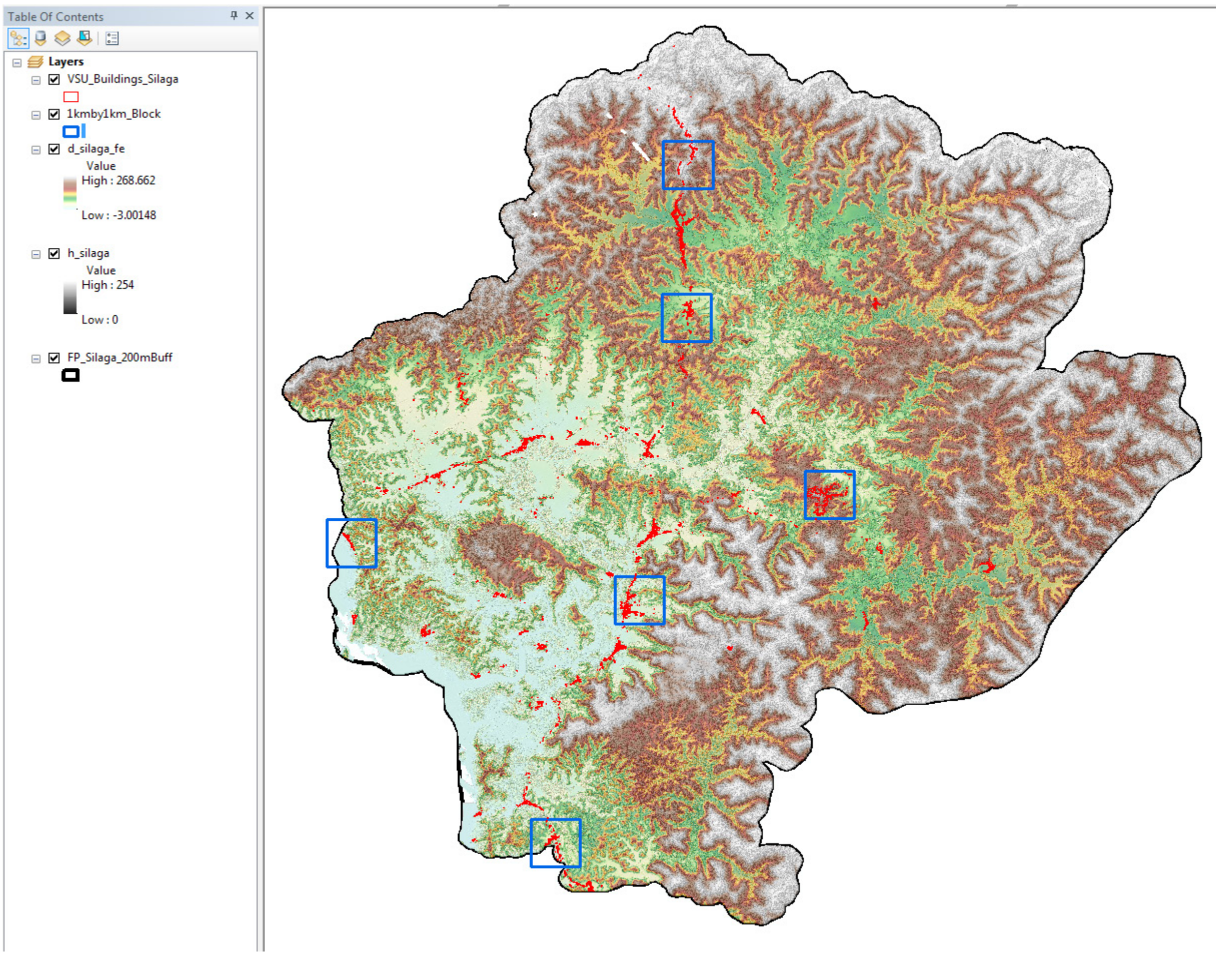

Figure 25. QC blocks for Malatgao building features

Quality checking of Malatgao building features resulted in the ratings shown in Table 19.

Table 19. Quality Checking Ratings for Malatgao Building Features

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Malatgao	89.53	99.92	86.89	PASSED

3.12.2 Height Extraction

Height extraction was done for 5,690 building features in Malatgao Floodplain. Of these building features, none was filtered out after height extraction, resulting to 5,690 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 8.74 m.

3.12.3 Feature Attribution

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

Table 20 summarizes the number of building features per type. On the other hand, Table 21 shows the total length of each road type, while Table 12 shows the number of water features extracted per type.

Table 20. Building Features Extracted for Malatgao Floodplain

Facility Type	No. of Features
Residential	5,486
School	83
Market	1
Agricultural/Agro-Industrial Facilities	16
Medical Institutions	2
Barangay Hall	9
Military Institution	14
Sports Center/Gymnasium/Covered Court	10
Telecommunication Facilities	1
Transport Terminal	0
Warehouse	4
Power Plant/Substation	3
NGO/CSO Offices	0
Police Station	0
Water Supply/Sewerage	0
Religious Institutions	18
Bank	0
Factory	0
Gas Station	1
Fire Station	0
Other Government Offices	21
Other Commercial Establishments	21
Total	**5,690**

Table 21 Total Length of Extracted Roads for Malatgao Floodplain

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Malatgao	22.95	13.63	0.00	19.77	0.00	56.35

Table 22. Number of Extracted Water Bodies for Malatgao Floodplain

Floodplain	Road Network Length (km)					Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Malatgao	157	49	0	0	0	206

A total of 44 bridges and culverts over small channels that are part of the river network were also extracted for the floodplain.

3.12.4 Final Quality Checking of Extracted Features

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

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

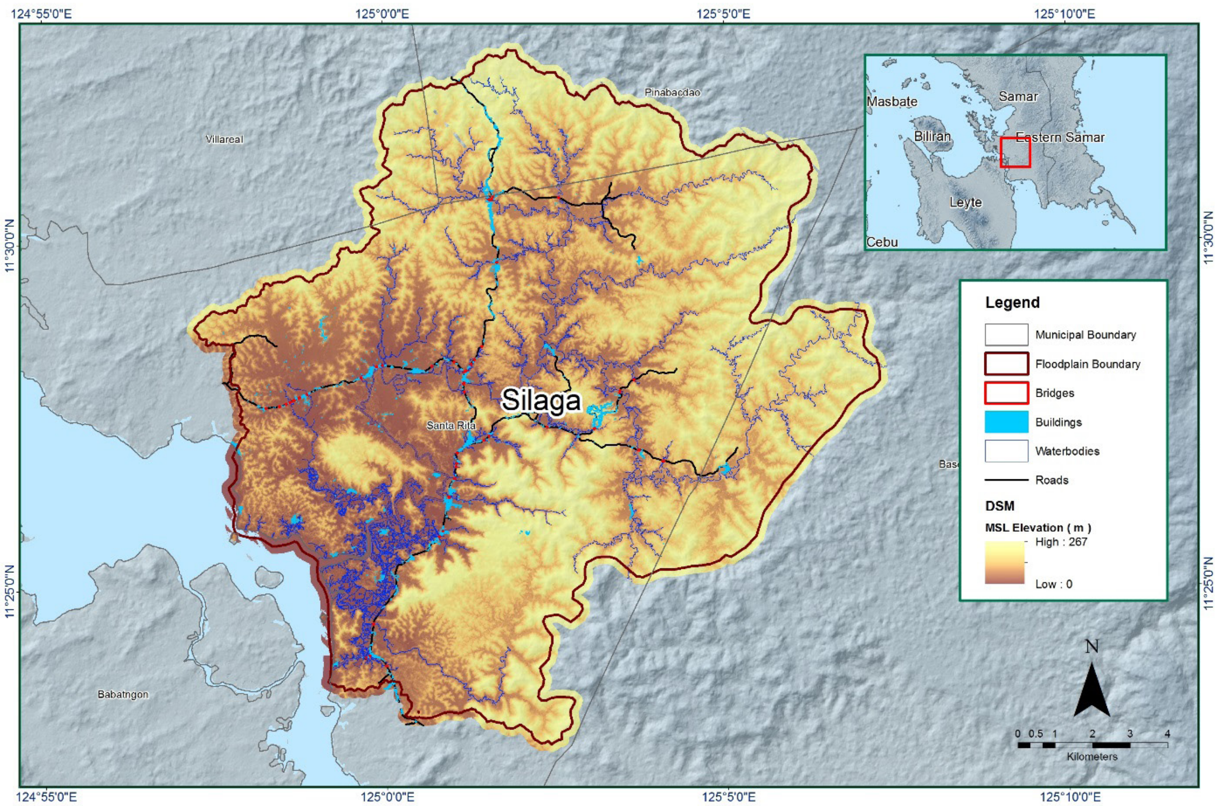

Figure 26. Extracted features for Malatgao Floodplain

CHAPTER 4: SURVEY AND MEASUREMENTS IN THE MALATGAO RIVER BASIN SURVEY

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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 Basin OverviewSummary of Activities

The Malatgao River Basin covers three (3) municipalities in Palawan; namely, the municipalities of Narra, Aborlan, and Quezon. The DENR River Basin Control Office (RBCO) states that the Malasgao River Basin has a drainage are of 226 km² and an estimated 362 cubic meter (MCM) annual run-off (RBCO, 2015).

Its main stem, Malatgao River, is part of the forty-five (45) river systems under the PHIL-LIDAR 1 Program partner HEI, University of the Philippines Los Baños. According to the 2015 national census of PSA, a total of 11,865 persons are residing within the immediate vicinity of the river which is distributed among Barangay Malatgao, Tinagong Dagat, Sandoval, Bagong Sikat, Estrella Village, and Dumagueña in the Municipality of Narra, Palawan. The economy of the province of Palawan is primarily agriculture-based; particularly fishing, tourism, trade, commerce, and mineral extraction (Palawan Knowledge Platform for Biodiversity and Sustainable Development, 2007). Due to the Southwest Monsoon enhanced by a Low Pressure Area, flooding incidents occurred in Barangay Elvita, Malinao, Princess Urduja, Bagong Sikat, and Aramaywan in Narra on August 22, 2016. In Brgy. Bagong Sikat, ten (10) families or fifty (50) persons were evacuated to Sikat Evacuation Center as per NDRRMC report (National Disaster Risk Reduction and Management Council, 2016).

In line with this, AB Surveying and Development (ABSD) conducted a field survey in Malatgao River on November 27-28, 2015 and Dec. 6, 7, 8, 9 and 29, 2015, January 2-5, 2016 and February 6, 2016 with the following scope: reconnaissance; control survey; and cross-section and as-built survey at Malatgao Bridge in Brgy. Tinagong Dagat, Municipality of Narra, Palawan. Random checking points for the contractor's cross-section and bathymetry data were gathered by DVBC on August 16-28, 2016 using an Ohmex™ Single Beam Echo Sounder and Trimble® SPS 882 GNSS PPK survey technique. In addition to this, validation points acquisition survey was conducted covering the Malasgao River Basin area. The entire survey extent is illustrated in Figure 27.

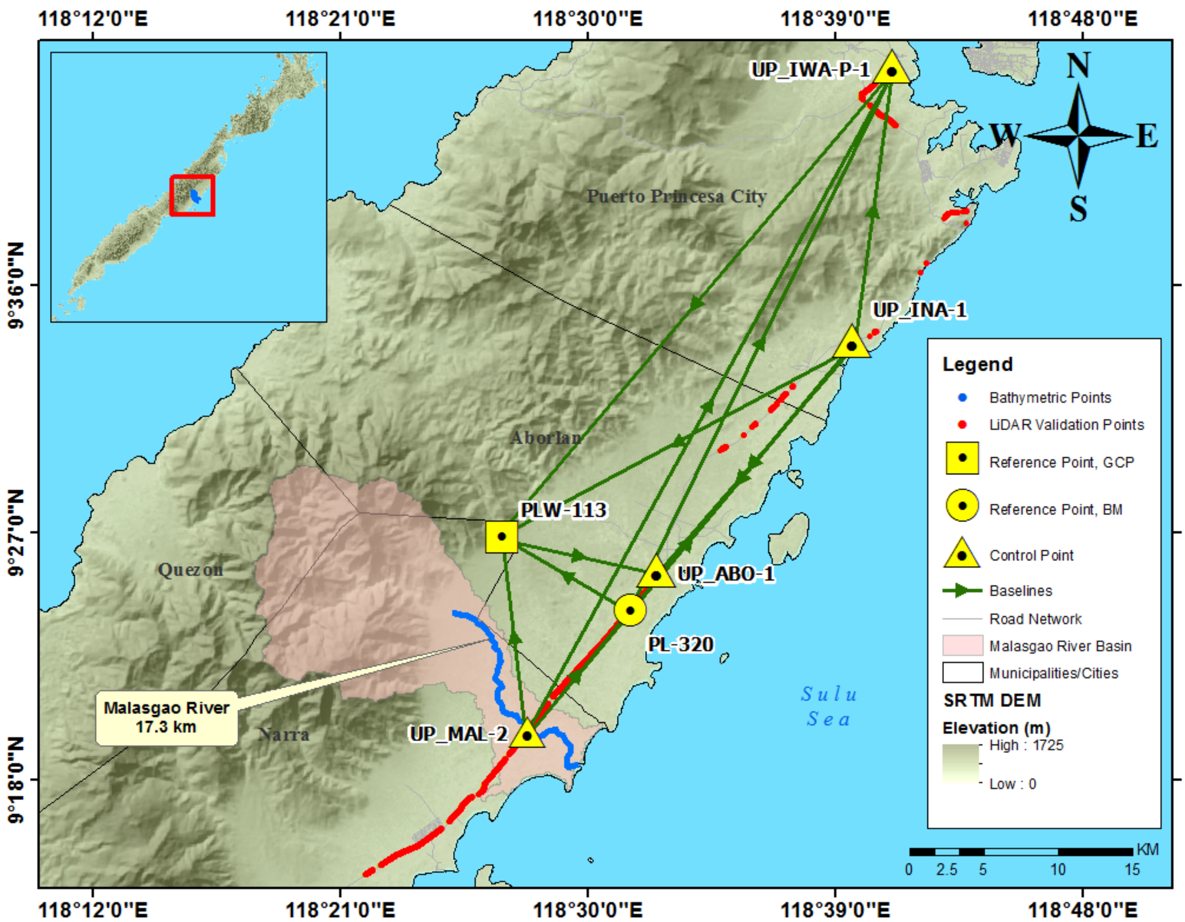

Figure 27. Malatgao River Survey Extent

4.2 Control Survey

The GNSS network used for Malatgao River is composed of nine (9) loops established on August 25, 2016, occupying the following reference points: PL-320, a first-order BM, in Brgy. Ramon Magsaysay, Aborlan, Palawan and PLW-113 a second-order GCP, in Brgy. Dumagueña, Narra, Palawan.

Four (4) control points established in the area by ABSD were also occupied: UP_MAL-2 at the approach of Malatgao Bridge in Brgy. Tinagong Dagat, Narra, Province of Palawan, UP_IWA-P-1 at the approach of Iwahig Penal Bridge in Brgy. Iwahig, Puerto Princesa City, Palawan, UP_ABO-1 located beside the approach of Aborlan Bridge in Brgy. Gogognan, Aborlan, Palawan, and UP_INA-1 located beside the approach of Inagauan Bridge in Brgy. Inagauan Sub-Colony, Puerto Princesa City, Palawan.

The summary of reference and control points and its location is summarized in Table 23, while GNSS network established is illustrated in Figure 28.

Table 23 List of reference and control points used during the survey in Malatgao River (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS UTM Zone 50N)				
		Latitude	Longitude	Ellipsoidal Height (m)	MSL Elevation (m)	Date Established
PL-320	1st order, BM	9° 24' 10.67926" N	118° 31' 31.30061"E	58.025	7.089	2008
PLW-113	2nd order, GCP	9° 26' 50.78624" N	118° 26' 52.23491"E	144.388	93.784	2007
UP_ MAL-2	Established	9° 19' 47.08536"N	118° 27' 48.23703"E	67.449	16.469	11-27-15
UP_ IWA-P-1	Established	9° 43' 58.38961"N	118° 41' 03.58218"E	55.529	5.044	11-25-15
UP_ABO-1	Established	9° 25' 39.66712"N	118° 32' 29.34660"E	59.322	8.415	11-26-15
UP_INA-1	Established	9° 33' 58.62160"N	118° 39' 34.84567"E	56.382	5.672	11-27-15

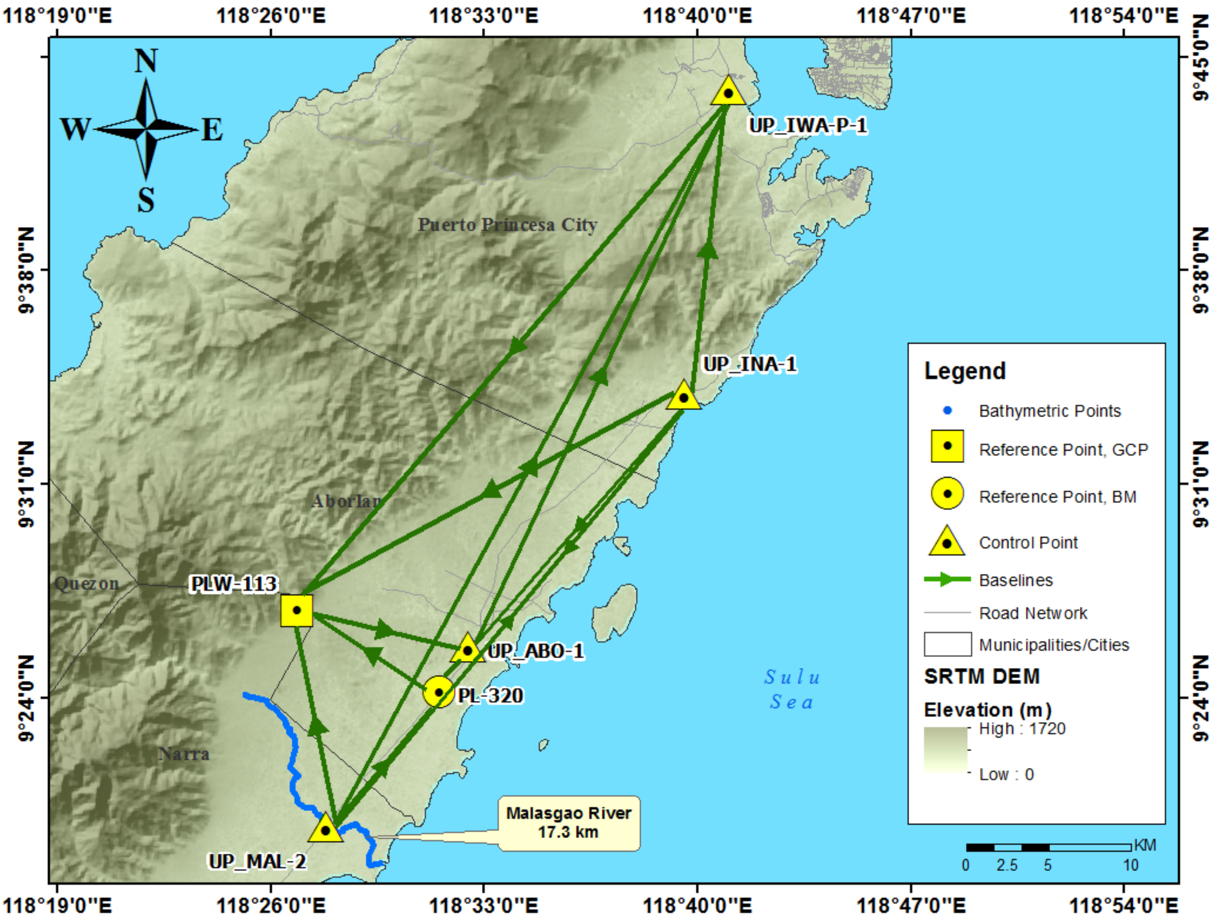

Figure 28. Malatgao River Basin Control Survey Extent

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

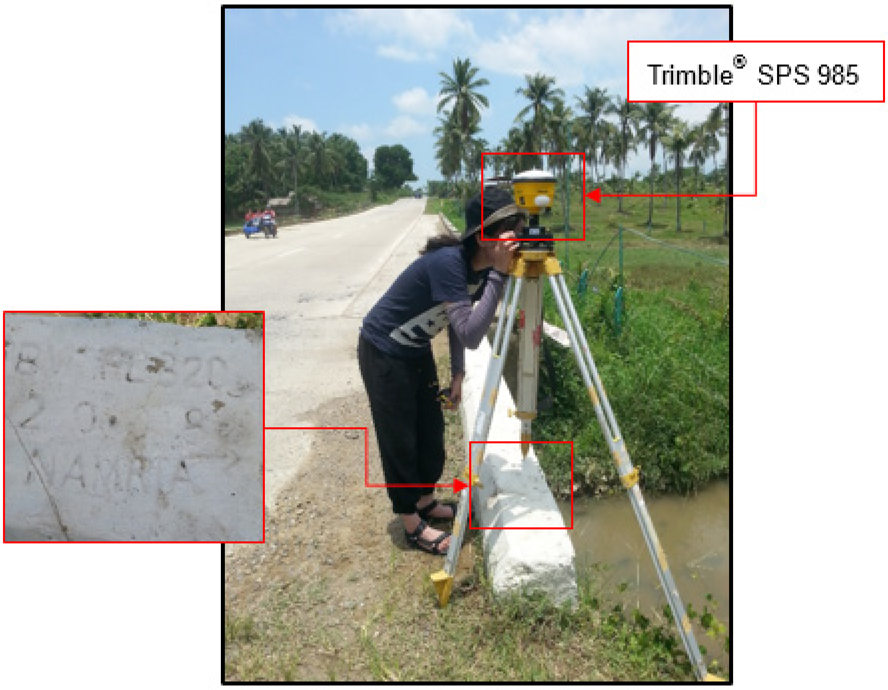

Figure 29. GNSS receiver set up, Trimble® SPS 985, at PL-320, located on top of a culvert headwall along the National Road in Brgy. Ramon Magsaysay, Aborlan, Province of Palawan

Figure 30. GNSS base set up, Trimble® SPS 852, at PLW-113, located southwest of Aborlan Water System in Brgy. Dumagueña, Narra, Province of Palawan

Figure 31. GNSS receiver set up, Trimble® SPS 882, at UP_MAL-2, located at the approach of Malatgao Bridge in Brgy. Tinagong Dagat, Narra, Province of Palawan

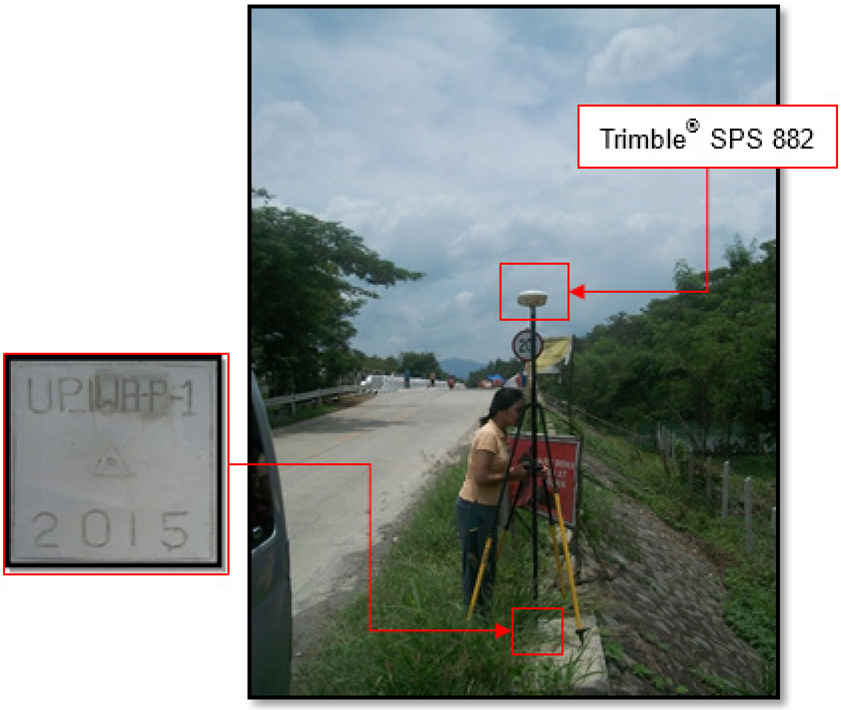

Figure 32. GNSS receiver set up, Trimble® SPS 982, at UP_IWA-P-1, located at the approach of Iwahig Penal Bridge in Brgy. Iwahig, Puerto Princesa City, Palawan

Figure 33. GNSS receiver set-up, Trimble® SPS 852, at UP_ABO-1, an established control point, beside the approach of Aborlan Bridge in Brgy. Gogognan, Aborlan, Palawan

Figure 34. GNSS receiver set up, Trimble® SPS 882, at UP_INA-1, located beside the approach of Inagauan Bridge in Brgy. Inagauan Sub-Colony, Puerto Princesa City, Palawan

4.3 Baseline Processing

GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/- 20 cm and +/- 10 cm requirement, respectively. In case where one or more baselines did not meet all of these criteria, masking is performed. Masking is done by removing/masking portions of these baseline data using the same processing software. It is repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, resurvey is initiated. Baseline processing result of control points in Malatgao River Basin is summarized in Table 24 generated by TBC software.

Table 24. Baseline Processing Report for Malatgao River Static Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
PLW-113 --- UP_ABO-1	8-25-2016	Fixed	0.009	0.023	101°59'15"	10513.593	-85.092
UP_IWA-P-1 --- PLW-113	8-25-2016	Fixed	0.004	0.024	219°26'55"	40874.066	88.833
PL-320 --- PLW-113	8-25-2016	Fixed	0.018	0.029	300°01'31"	9832.467	86.391
PL-320 --- UP_IWA-P-1	8-25-2016	Fixed	0.004	0.018	205°34'21"	40449.118	2.530
UP_MAL-2 --- PL-320	8-25-2016	Fixed	0.010	0.021	220°02'59"	10578.751	9.435
UP_INA-1 --- UP_ABO-1	8-25-2016	Fixed	0.008	0.025	220°15'41"	20085.570	2.974
UP_INA-1 --- PLW-113	8-25-2016	Fixed	0.005	0.025	240°32'45"	26716.978	88.012
UP_INA-1 --- PL-320	8-25-2016	Fixed	0.010	0.019	219°14'35"	23320.185	1.618
UP_INA-1 --- UP_IWA-P-1	8-25-2016	Fixed	0.005	0.019	188°21'15"	18624.653	0.847
UP_MAL-2 --- UP_INA-1	8-25-2016	Fixed	0.005	0.014	39°28'10"	33898.188	-11.058
UP_MAL-2 --- UP_IWA-P-1	8-25-2016	Fixed	0.024	0.024	208°33'52"	50759.890	11.894
UP_MAL-2 --- PLW-113	8-25-2016	Fixed	0.005	0.021	352°31'24"	13129.154	76.935

As shown Table 24 a total of twelve (12) baselines were processed with coordinate and elevation values of UP_IWA-P-1 and the coordinate values of PLW-113 held fixed. All of them passed the required accuracy.

4.4. Network Adjustment

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

Where:

is the Easting Error,
is the Northing Error, and
is the Elevation Error

for each control point. See the Network Adjustment Report shown from Table 25 to 27 for the complete details. Refer to Anne 10 for the computation for the accuracy of ABSD.
The six (6) control points, PLW-113, PL-320, UP-MAL-2, UP-IWA-P-1, UP_ABO-1, and UP_INA-1 were occupied and observed simultaneously to form a GNSS loop. The coordinates and elevation of UP_IWA-P-1 and the coordinates of PLW-113 were held fixed during the processing of the control points as presented in Table 25. Through these reference points, the coordinates and elevations of the unknown control points will be computed.

Table 25. Control Point Constraints

Point ID	**Type**	**East σ (Meter**	**North σ (Meter)**	**Height σ (Meter)**	**Elevation σ (Meter)**
PLW-113	Global	Fixed	Fixed		
UP_IWA-P-1	Grid				Fixed
UP_IWA-P-1	Global	Fixed	Fixed		
Fixed = 0.000001(m)					

Table 26. Adjusted Grid Coordinated

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Cons traint
PL-320	667487.736	0.013	1039767.829	0.008	7.089	0.049	
PLW-113	658953.945	?	1044650.284	?	93.784	0.054	LL
UP_ABO-1	669246.540	0.018	1042509.427	0.016	8.415	0.080	
UP_INA-1	682153.657	0.009	1057898.445	0.007	5.672	0.047	
UP_IWA-P-1	684768.852	?	1076338.886	?	5.044	?	LLe
UP_MAL-2	660716.408	0.012	1031641.078	0.009	16.469	0.047	

With the mentioned equation,   for horizontal and   for the vertical; the computation for the accuracy are as follows:

a. PL-320
Horizontal accuracy = $\sqrt{((1.3)^2 + (0.8)^2}$
= $\sqrt{(1.69 + 0.64)}$
= 2.33 < 20 cm
Vertical accuracy = 4.9 < 10 cm

b. PLW-113
Horizontal accuracy = Fixed
Vertical accuracy = Fixed

c. UP_ABO-1
Horizontal accuracy = $\sqrt{((1.8)^2 + (1.6)^2}$
= $\sqrt{(3.24 + 2.56)}$
= 5.8 < 20 cm
Vertical accuracy = 8.0 < 10 cm

d. UP_INA-1
Horizontal accuracy = $\sqrt{((0.9)^2 + (0.7)^2}$
= $\sqrt{(0.81 + 0.49)}$
= 1.30 < 20 cm
Vertical accuracy = 4.7 < 10 cm

e. UP_IWA-P-1
Horizontal accuracy = Fixed
Vertical accuracy = Fixed

f. UP_MAL-2
Horizontal accuracy = $\sqrt{((1.2)^2 + (0.9)^2}$
= $\sqrt{(1.44 + 0.81)}$
= 2.25 < 20 cm
Vertical accuracy = 4.7 < 10 cm

Following the given formula, the horizontal and vertical accuracy result of the four (4) occupied control points are within the required precision.

Table 27. Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
PL-320	UP_MAL-2	E118°31'31.30061"	58.025	0.049	
PLW-113	UP_MAL-2	E118°26'52.23491"	144.388	0.054	LL
UP_ABO-1	UP_MAL-2	E118°32'29.34660"	59.322	0.080	
UP_INA-1	UP_MAL-2	E118°39'34.84567"	56.382	0.047	
UP_IWA-P-1	UP_MAL-2	E118°41'03.58218"	55.529	?	LLe
UP_MAL-2	UP_MAL-2	E118°27'48.23731"	67.449	0.047	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 27. Based on the result of the computation, the equation is satisfied; hence, the required accuracy for the program was met.

The summary of reference control points used is indicated in Table 28.

Table 28. Reference and control points used and its location (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Ellipsoidal Height (m)	Easting (m)	MSL Elevation (m)
PL-320	1st order, BM	9° 24' 10.67926" N	118° 31' 31.30061"E	58.025	1039767.829	667487.736	7.089
PLW-113	2nd order, GCP	9° 26' 50.78624" N	118° 26' 52.23491"E	144.388	1044650.284	658953.945	93.784
UP_ MAL-2	Established	9° 19' 47.08536"N	118° 27' 48.23703"E	67.449	1031641.078	660716.408	16.469
UP_ IWA-P-1	Established	9° 43' 58.38961"N	118° 41' 03.58218"E	55.529	1076338.886	684768.852	5.044
UP_ ABO-1	Established	9° 25' 39.66712"N	118° 32' 29.34660"E	59.322	1042509.427	669246.54	8.415
UP_INA-1	Established	9° 33' 58.62160"N	118° 39' 34.84567"E	56.382	1057898.445	682153.657	5.672

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

Cross-section and as-built surveys were conducted on November 28, 2015 at the upstream side of Malatgao Bridge in Brgy. Tinagong Dagat, Municipality of Narra as shown in Figure 35. A total station was utilized for this survey as shown in Figure 36.

Figure 35. Malatgao Bridge facing upstream

Figure 36. As-built survey of Malatgao Bridge

The cross-sectional line of Malatgao Bridge is about 284 m with fifty-seven (57) cross-sectional points using the control points UP_MAL-1 and UP_MAL-2 as the GNSS base stations. The cross-section diagram, location map, and the bridge data form are shown in Figure 37 to 39.

Gathering of random points for the checking of ABSD's bridge cross-section and bridge points data was performed by DVBC on August 24, 2016 using a survey grade GNSS Rover receiver attached to a 2-m pole.

Linear square correlation (R2) and RMSE analysis were performed on the two (2) datasets. The linear square coefficient range is determined to ensure that the submitted data of the contractor is within the accuracy standard of the project which is ±20 cm and ±10 cm for horizontal and vertical, respectively. The R2 value must be within 0.85 to 1. An R2 approaching 1 signifies a strong correlation between the vertical (elevation values) of the two datasets. A computed R2 value of 0.991 was obtained by comparing the data of the contractor and DVBC; signifying a strong correlation between the two (2) datasets.

In addition to the Linear Square correlation, Root Mean Square (RMSE) analysis is also performed in order to assess the difference in elevation between the DVBC checking points and the contractor's. The RMSE value should only have a maximum radial distance of 5 m and the difference in elevation within the radius of 5 meters should not be beyond 0.50 m. For the bridge cross-section data, a computed value of 0.157 was acquired. The computed R2 and RMSE values are within the accuracy requirement of the program.

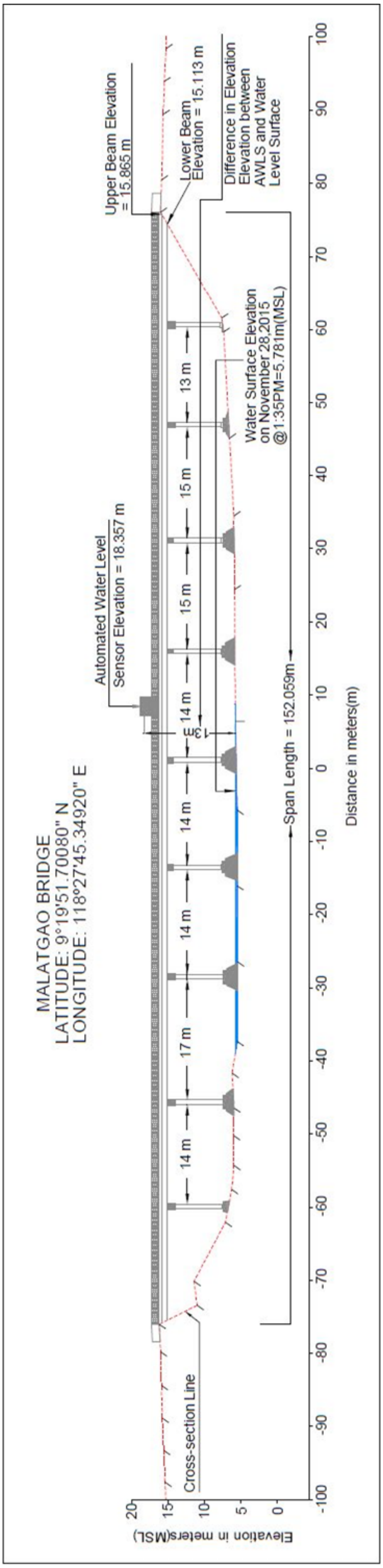

Figure 37. Malatgao Bridge Cross-section Diagram

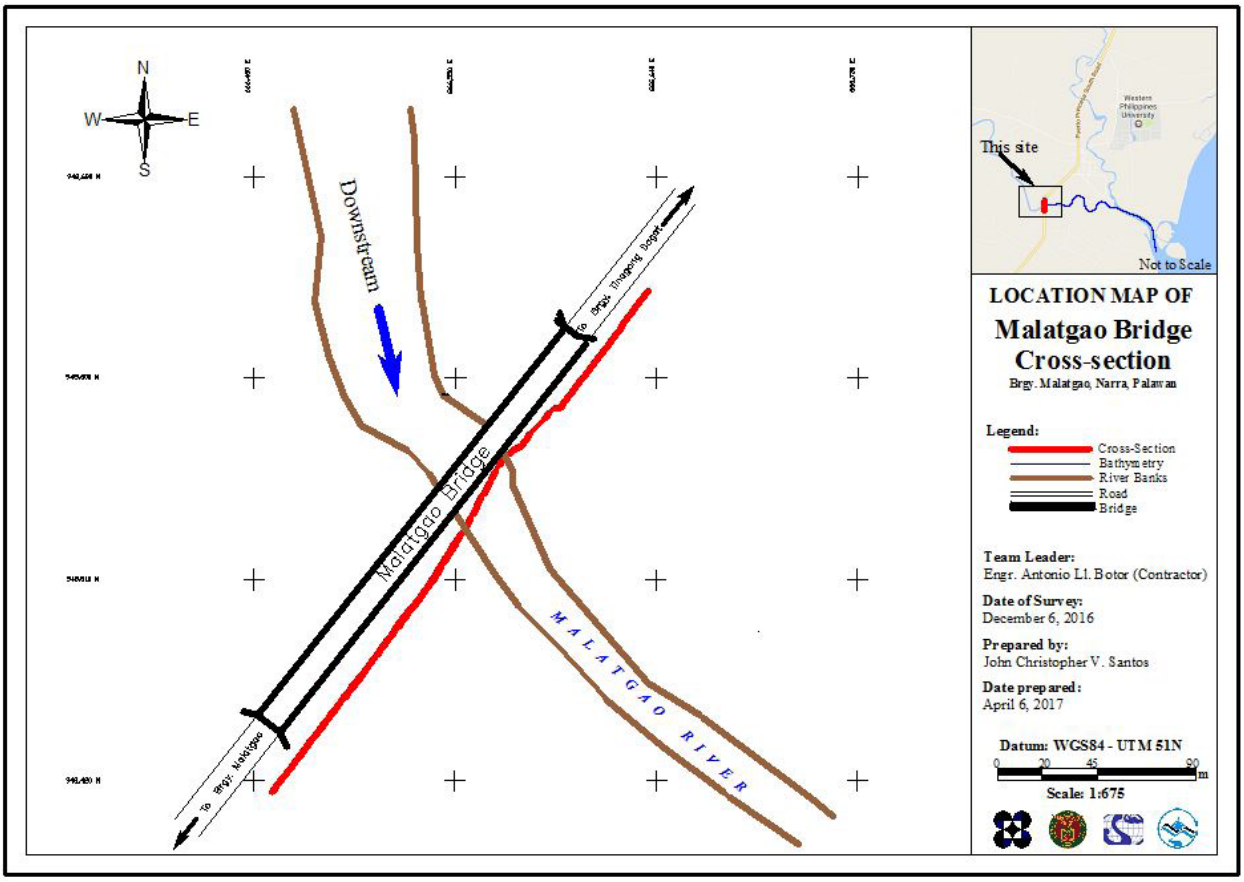

Figure 38. Malatgao Bridge Location Map

Bridge Data Form

Bridge Name: MALATGAO BRIDGE

River Name: MALASGAO RIVER

Location (Brgy, City, Region): Brgy. Tinagong Dagat, Narra, Province of Palawan

Survey Team: Nilo Alpas, Bernard Burcia

Date and Time: November 28, 2015, 1:35 pm

Flow Condition: low ✔ normal high

✔

Legend:
BA = Bridge Approach
P = Pier
Ab = Abutment
D = Deck
WL = Water Level/Surface
MSL = Mean Sea Level
◯ = Measurement Value

Line Segment	Measurement (m)	Remarks
1. BA1-BA2	2.66 m	
2. BA2-BA3	152.059 m	
3. BA3-BA4	2.55 m	
4. BA1-Ab1	14.29 m	
5. Ab2-BA4	14.29 m	
6. Deck/beam thickness	1.23 m	
7. Deck elevation	16.28 m	

Note: Observer should be facing downstream

Figure 39. Malatgao Bridge Data Sheet

Water surface elevation of Malatgao River was determined by a Horizon® Total Station on November 28, 2015 at 1:35 PM at Malatgao Bridge area with a value of 5.781 m in MSL as shown in Figure 37. This was translated into marking on the bridge's pier as shown in Figure 40. The marking will serve as reference for flow data gathering and depth gauge deployment of the partner HEI responsible for Malatgao River, the University of the Philippines Los Baños.

Figure 40. Water-level markings on Malatgao Bridge

4.6. Validation Points Acquisition Survey

Validation points acquisition survey was conducted by DVBC from August 16-28, 2016 using a survey grade GNSS Rover receiver, Trimble® SPS 985, mounted on a range pole, which was attached on the side of the vehicle as shown in Figure 41. It was secured with cable ties and ropes to ensure that it was horizontally and vertically balanced. The antenna height was 2.590 m and measured from the ground up to the bottom of the quick release of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with UP_MAL-2 occupied as the GNSS base station in the conduct of the survey.

Figure 41. Validation points acquisition survey set-up for Malatgao River

The survey started from Brgy. Gogognan, Municipality of Aborlan, Palawan going south west along the national high way, covering four (4) barangays in the Municipality of Aborlan and five (5) barangays in the Municipality of Narra and ended in Brgy. Malinao, Municipality of Narra, Palawan. The survey gathered a total of 4,004 points with approximate length of 28.61 km using UP_MAL-2 as GNSS base station for the entire extent of validation points acquisition survey as illustrated in the map in Figure 42.

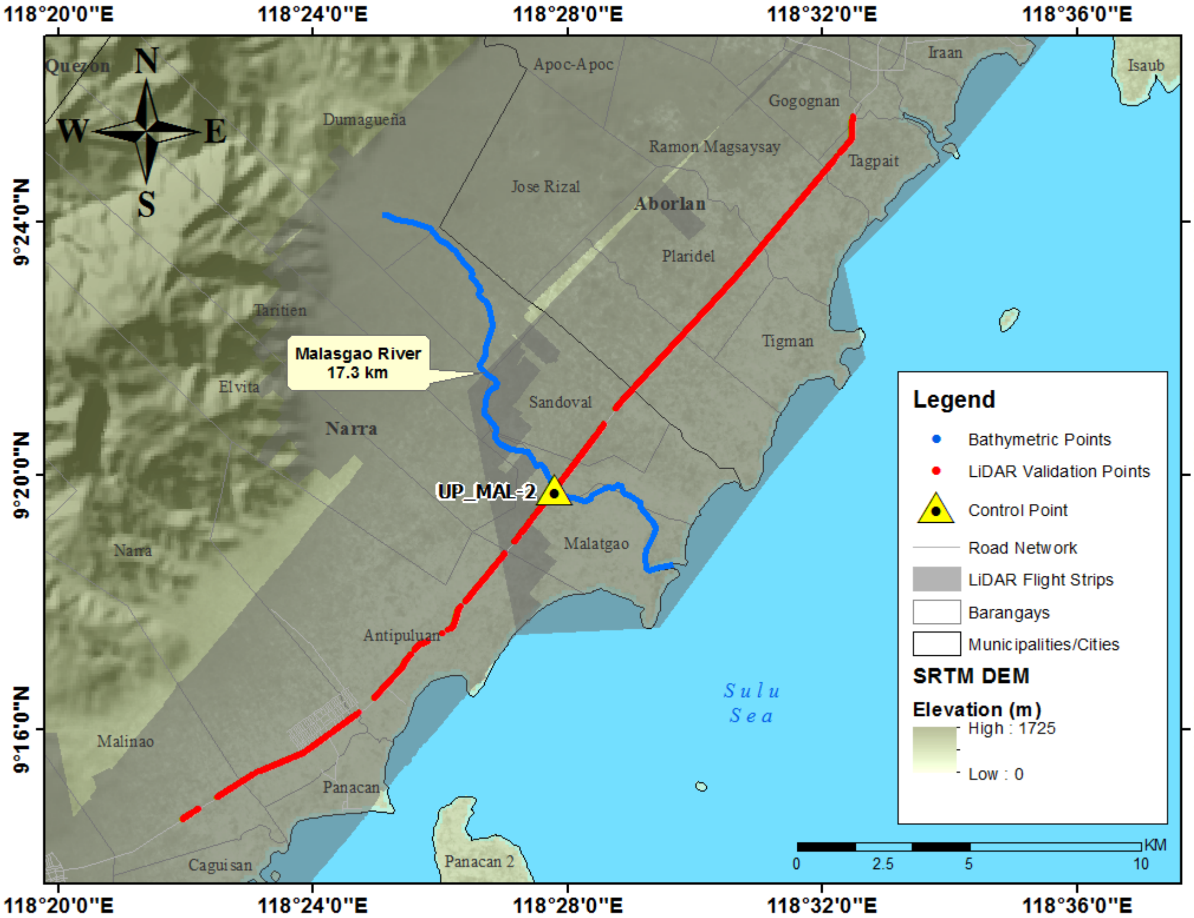

Figure 42. Validation points acquisition covering the Malatgao River Basin Area

4.7. Bathymetric Survey

Bathymetric survey was executed on December 6 and 29, 2015 and from January 2 to 5, 2016 using a single-beam echo sounder as illustrated in Figure 43. The survey started in Brgy. Dumagueña, Municipality of Narra, Palawan with coordinates 9° 24' 7.40861"N, 118° 25' 3.30177"E and ended at the mouth of the river in Brgy. Malatgao, Municipality of Narra, with coordinates 9° 18' 34.39833"N, 118° 29' 45.50748"E. The control point UP_MAL-0, UP_MAL-1, and UP_MAL-2 were used as GNSS base stations all throughout the entire survey.

Gathering of random points for the checking of ABSD's bathymetric data was performed by DVBC on August 26, 2016, using a survey grade GNSS Rover receiver attached to a 2-m pole, see Figure 44. A map showing the DVBC bathymetric checking points is shown in Figure 46.

Linear square correlation (R2) and RMSE analysis were also performed on the two (2) datasets and a computed R2 value of 0.995 is within the required range for R2, which is 0.85 to 1. Additionally, an RMSE value of 0.214 was obtained. Both the computed R2 and RMSE values are within the accuracy required by the program.

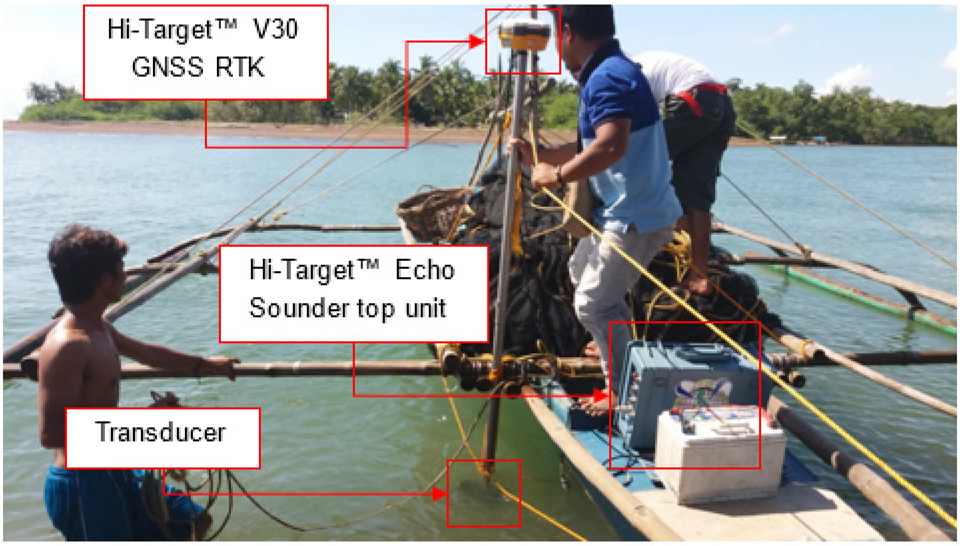

Figure 43. Bathymetric survey of ABSD at Malasgao River using Hi-Target™ Echo Sounder (downstream)

Figure 44. Gathering of random bathymetric points along Malatgao River

The bathymetric survey for Malatgao River gathered a total of 8,612 points covering 17.3 km of the river traversing barangays Dumagueña, Bagong Sikat, Sandoval, Estrella Village, Tinagong Dagat, and Malatgao in the Municipality of Narra. A CAD drawing was also produced to illustrate the riverbed profile of Malasgao River. As shown in Figure 47, the highest and lowest elevation has a 61-m difference. The highest elevation observed was 61.077 m above MSL located in Brgy. Dumagueña, Municipality of Narra while the lowest was -0.122 m below MSL located in Brgy. Malatgao, Municipality of Narra.

Figure 45. Bathymetric survey of Malatgao River

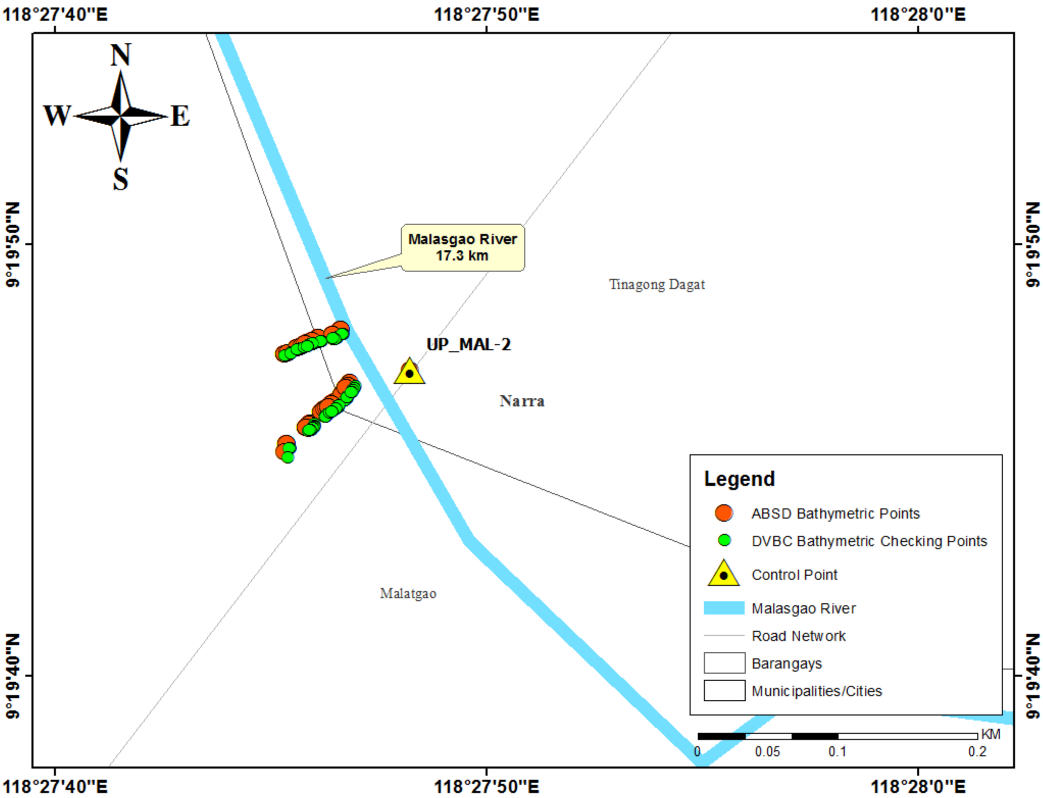

Figure 46. Quality checking points gathered along Malatgao River by DVBC

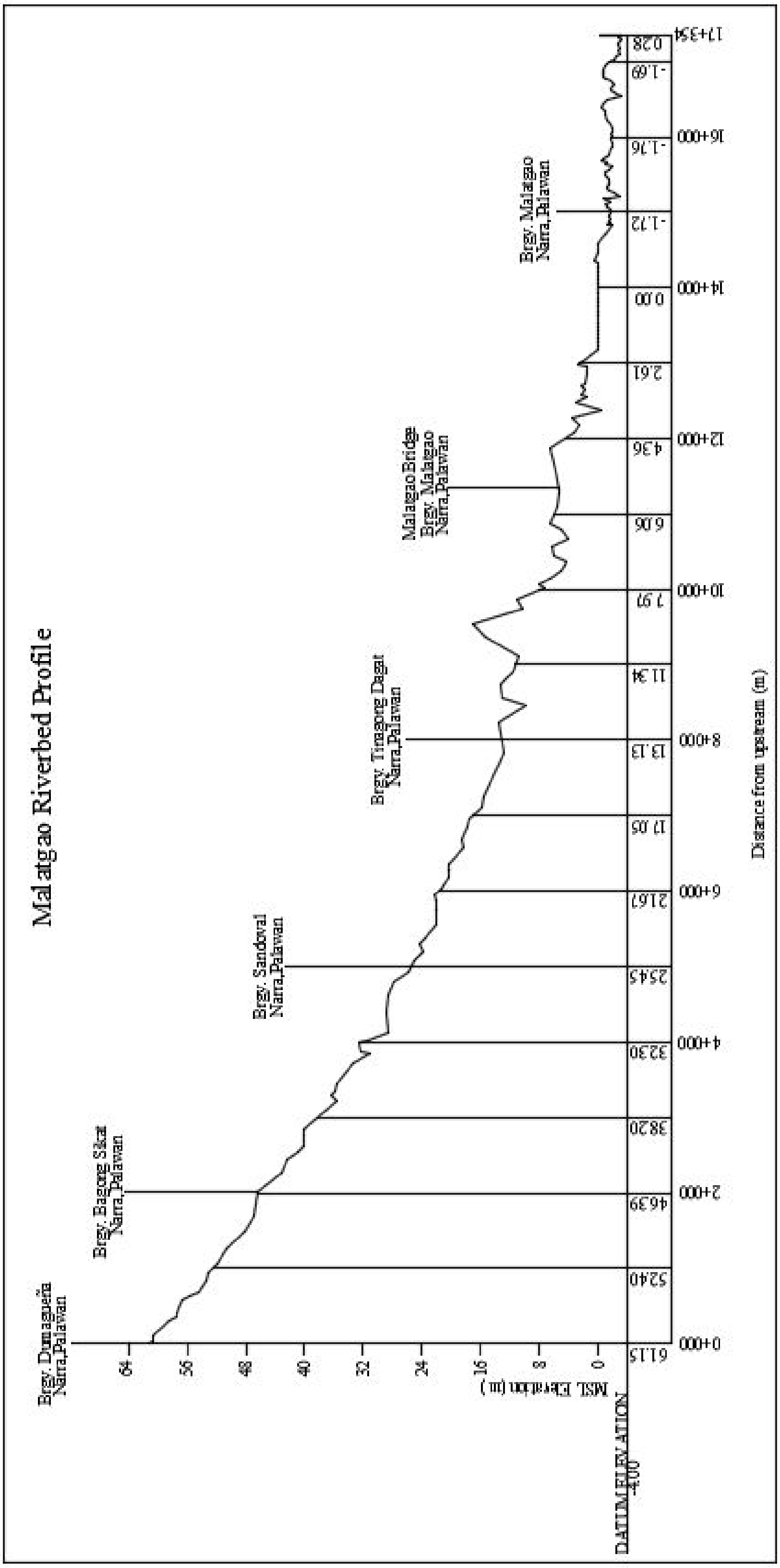

Figure 47. Malatgao Riverbed Profile

CHAPTER 5: FLOOD MODELING AND MAPPING

Dr. Alfredo Mahar Lagmay, Christopher Uichanco, Sylvia Sueno, Marc Moises, Hale Ines, Miguel del Rosario, Kenneth Punay, Neil Tingin, Khristoffer Quinton, John Alvin B. Reyes, Alfi Lorenz B. Cura, Angelica T. Magpantay, Maria Michaela A. Gonzales Paulo Joshua U. Quilao, Jayson L. Arizapa, Kevin M. Manalo

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

Components and data that affect the hydrologic cycle of the river basin was monitored, collected, and analyzed. These include the rainfall, water level, and flow in a certain period of time.

5.1.2. Precipitation

Precipitation data was taken from two portable rain gauges installed near the Malatgao River Basin, namely Aborlan (9.428366˚ N, 118.540607˚ E) and Batang-batang (9.227298° N, 118.321165° E) River Basins. The location of the rain gauge is seen in Figure 48.

The total precipitations for each rain gauge are as follows: 115.60 mm for Aborlan RG and 43.18 mm for Batang-batang RG. The peak rainfall for each rain gauge are as follows: 13.20 mm on January 11, 2017 at 8:30 am for Aborlan RG and 11.94 mm on January 11, 2017 at 3: 15 am.

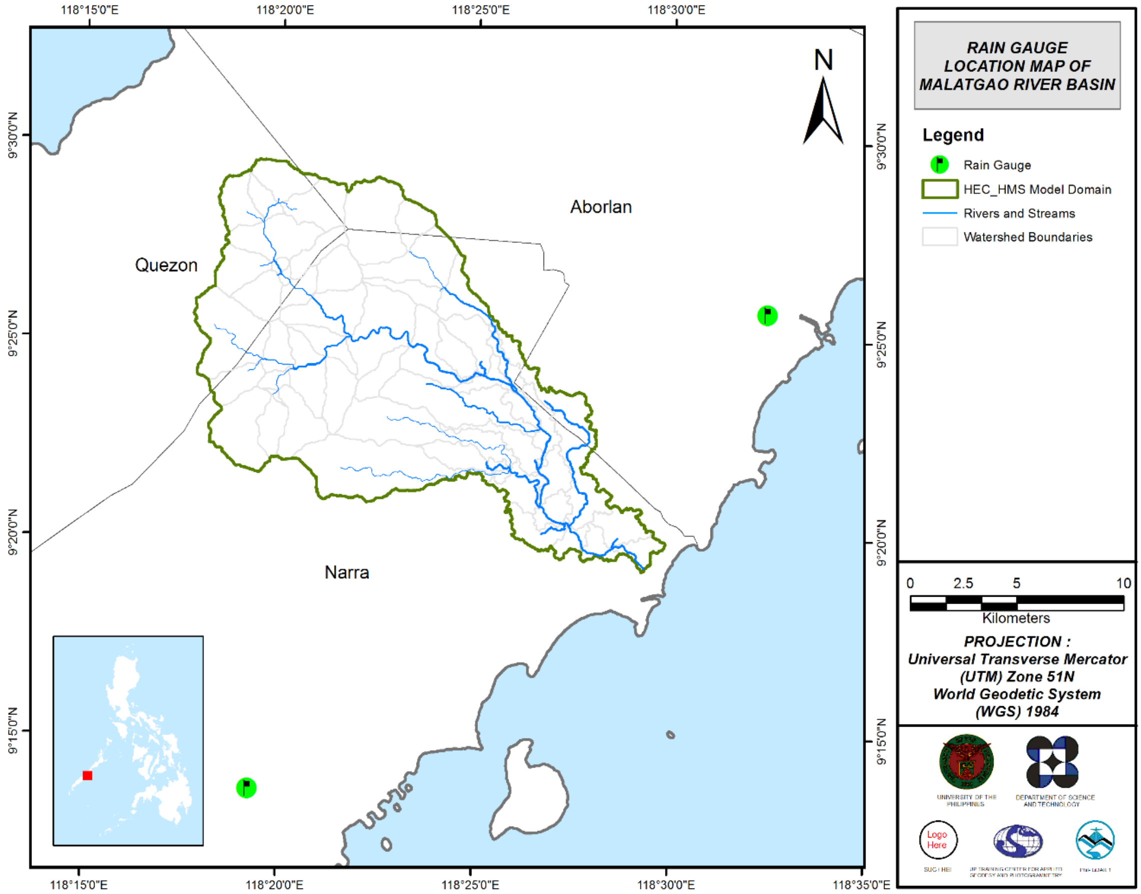

Figure 48. The location map of Malatgao HEC-HMS model used for calibration

5.1.3. Rating Curves and River Outflow

A rating curve was developed at Malatgao Bridge, Narra, Palawan (9.329308° N, 118.463135° E). It gives the relationship between the observed water levels from the Malatgao Bridge and outflow of the watershed at this location using Bankfull Method in Manning's Equation.

For Malatgao Bridge, the rating curve is expressed as Q = 13.806x -79.728 as shown in Figure 49.

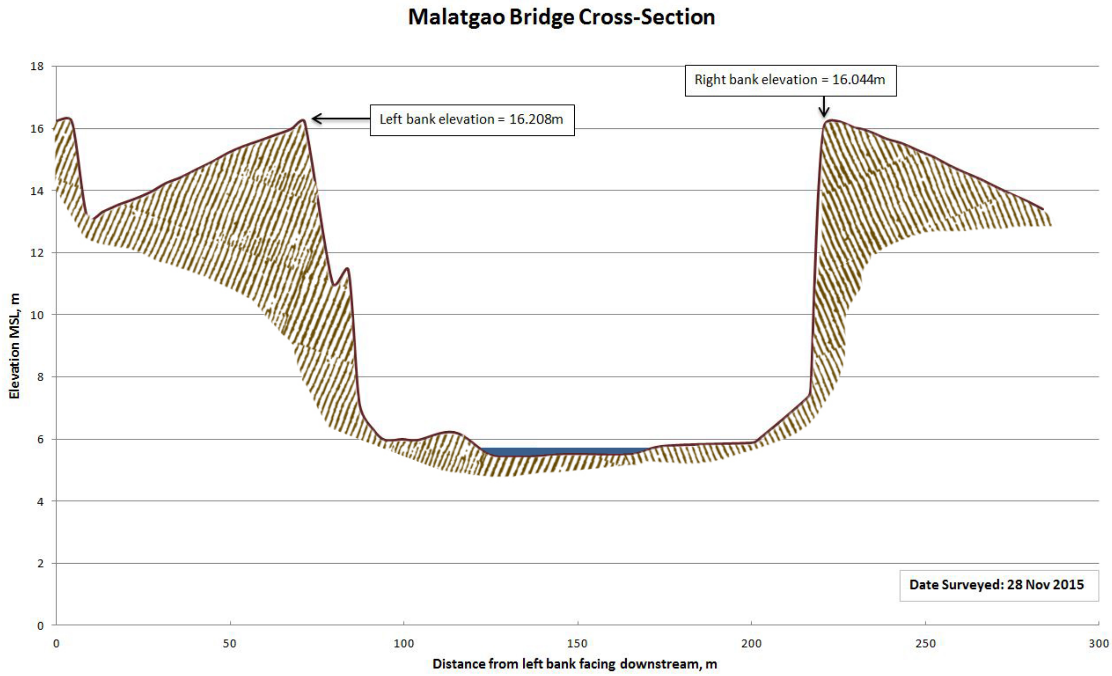

Figure 49. Cross section plot of Malatgao Bridge

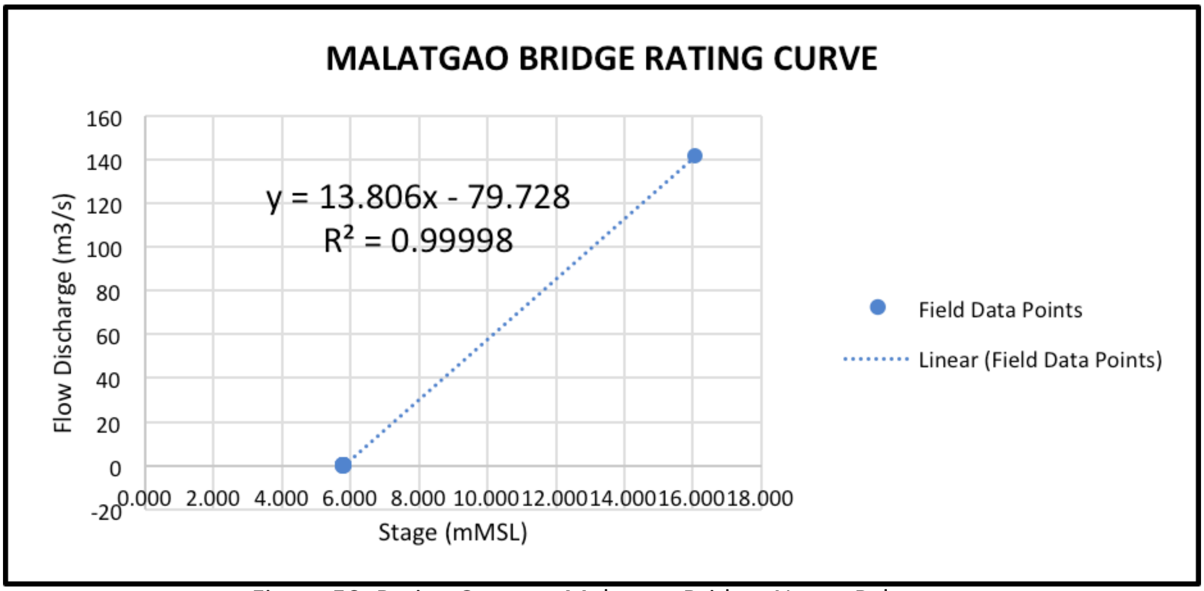

Figure 50. Rating Curve at Malatgao Bridge, Narra, Palawan

For the calibration of the HEC-HMS model, shown in Figure 51, actual flow discharge during a rainfall event was collected in the Malatgao bridge. Peak discharge is 21.80 cu.m/s on January 11, 2017 at 10:35 am.

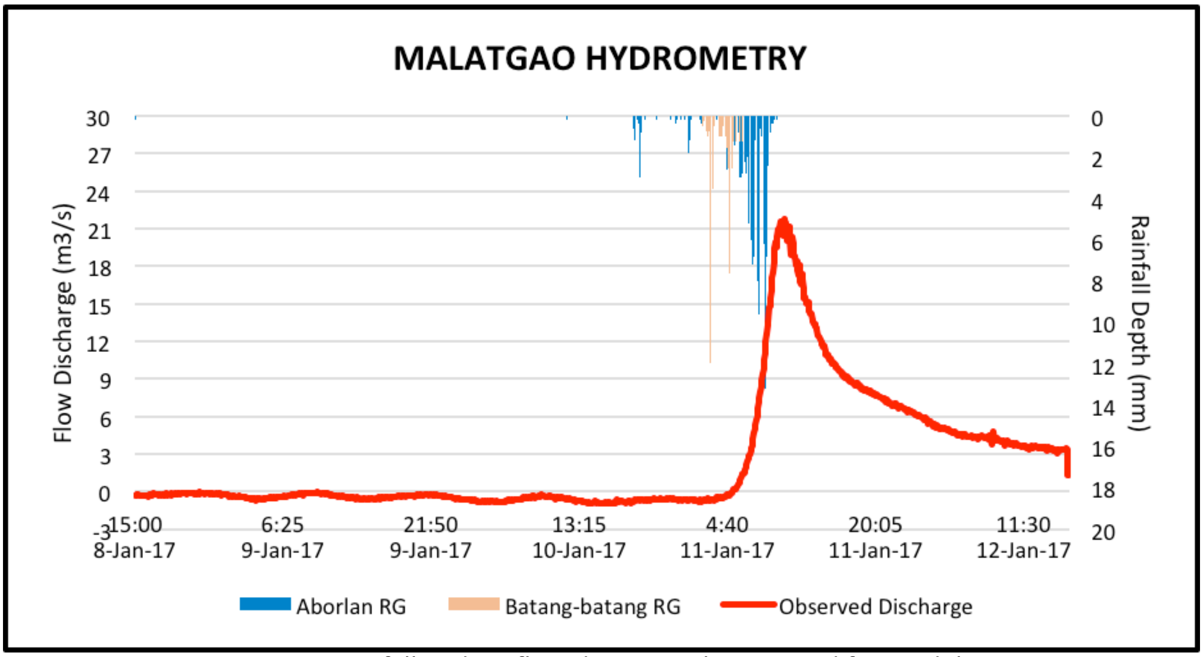

Figure 51. Rainfall and outflow data at Malatgao used for modeling

5.2. RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Puerto Princesa Rain Gauge. The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the values in such a way a certain peak value will be attained at a certain time. This station chosen based on its proximity to the Malatgao watershed. The extreme values for this watershed were computed based on a 58-year record.

Table 29. RIDF values for Puerto Princesa 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	14.8	22	27.3	36.2	49.8	58.8	75.1	88	104.1
5	21.3	31.9	39.7	52.3	73	86.9	112.8	135.4	156.4
10	25.6	38.5	48	63	88.4	105.5	137.8	166.8	191.1
15	28.1	42.2	52.6	69	97	116	151.9	184.5	210.6
20	29.8	44.7	55.9	73.3	103.1	123.4	161.7	196.8	224.3
25	31.1	46.7	58.4	76.5	107.8	129.1	169.3	206.4	234.9
50	35.2	52.9	66.1	86.5	122.2	146.5	192.7	235.8	267.3
100	39.2	59	73.7	96.4	136.5	163.8	216	265	299.6

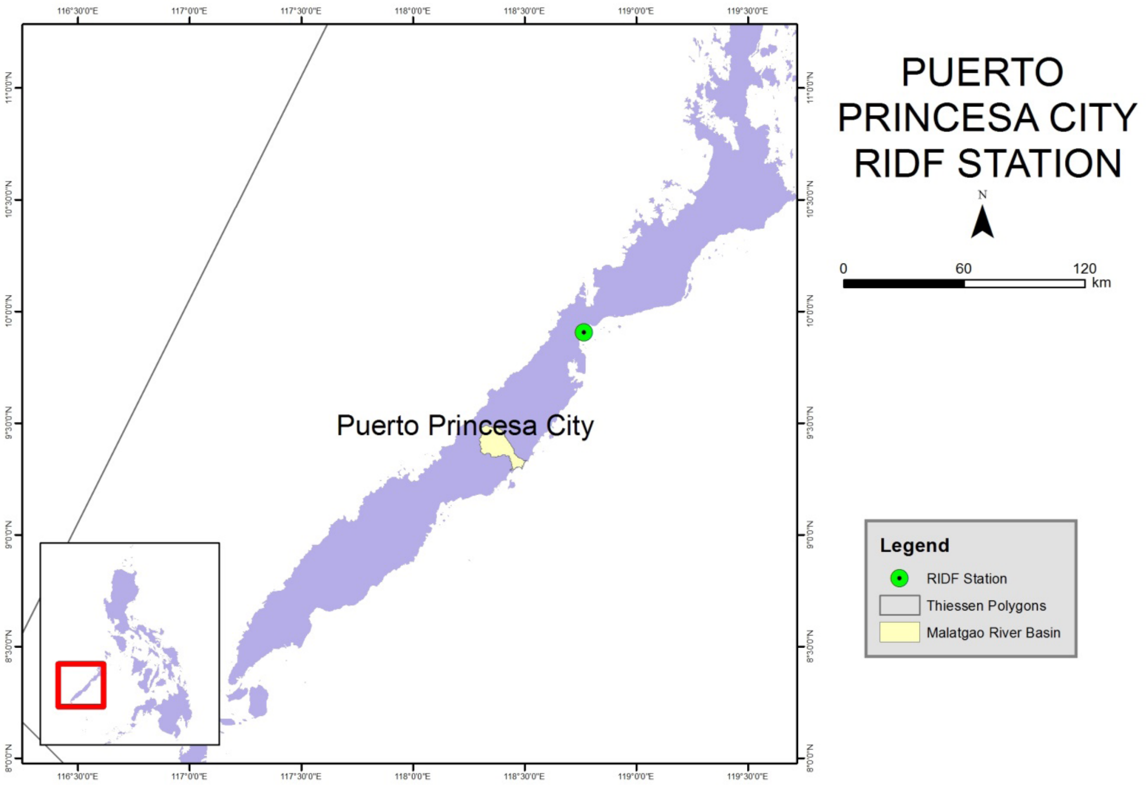

Figure 52. Location of Puerto Princesa RIDF relative to Malatgao River Basin

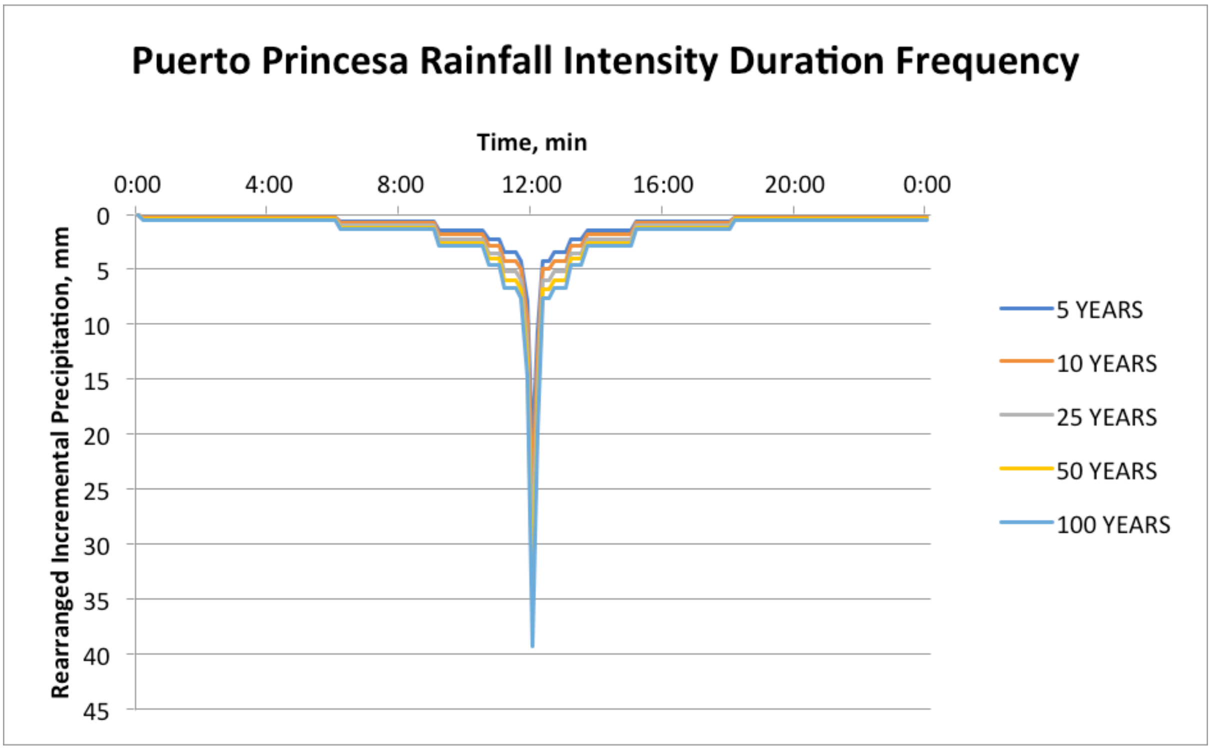

Figure 53. Synthetic Storm Generated for a 24-hr Period Rainfall for various Return Periods

5.3. HMS Model

The soil shape file was taken on 2004 from the Bureau of Soils; this is under the Department of Agriculture. The land cover shape file is from the National Mapping and Resource information Authority (NAMRIA).

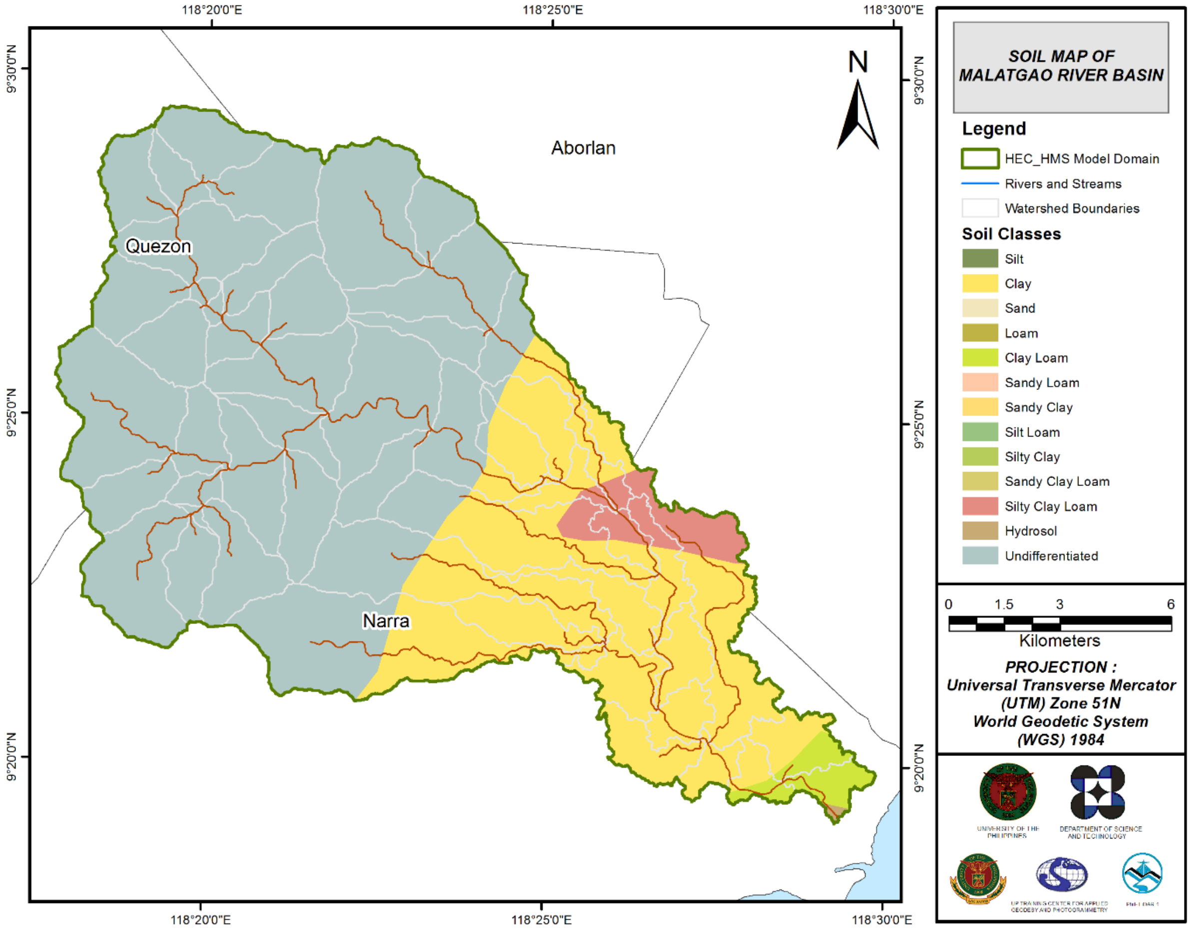

Figure 54. The soil map of the Malatgao River Basin used for the estimation of the CN parameter. (Source of data: Digital soil map of the Philippines published by the Bureau of Soil and Water Management – Department of Agriculture)

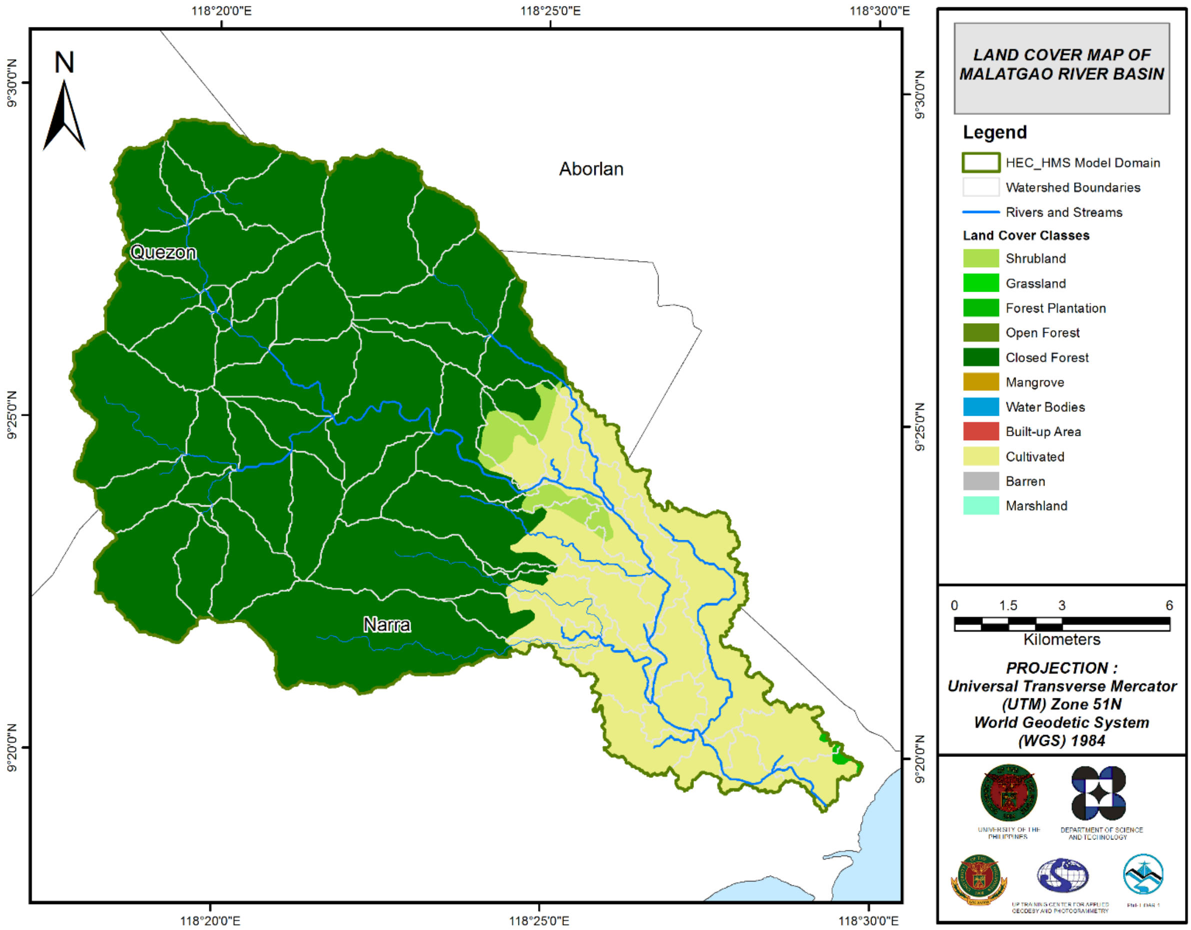

Figure 55. The land cover map of the Malatgao River Basin used for the estimation of the CN and watershed lag parameters of the rainfall-runoff model. (Source of data: Digital soil map of the Philippines published by the Bureau of Soil and Water Management – Department of Agriculture)

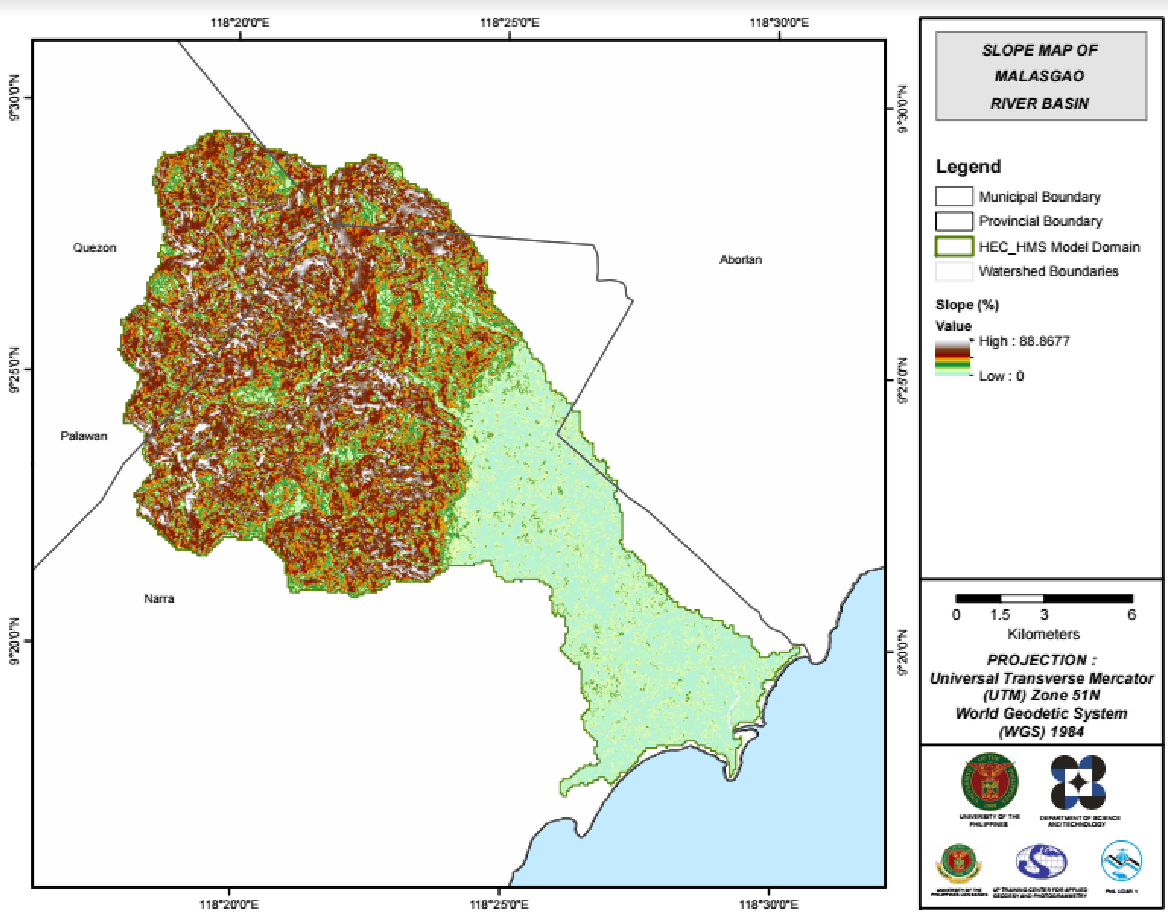

Figure 56. Slope Map of the Malatgao River Basin

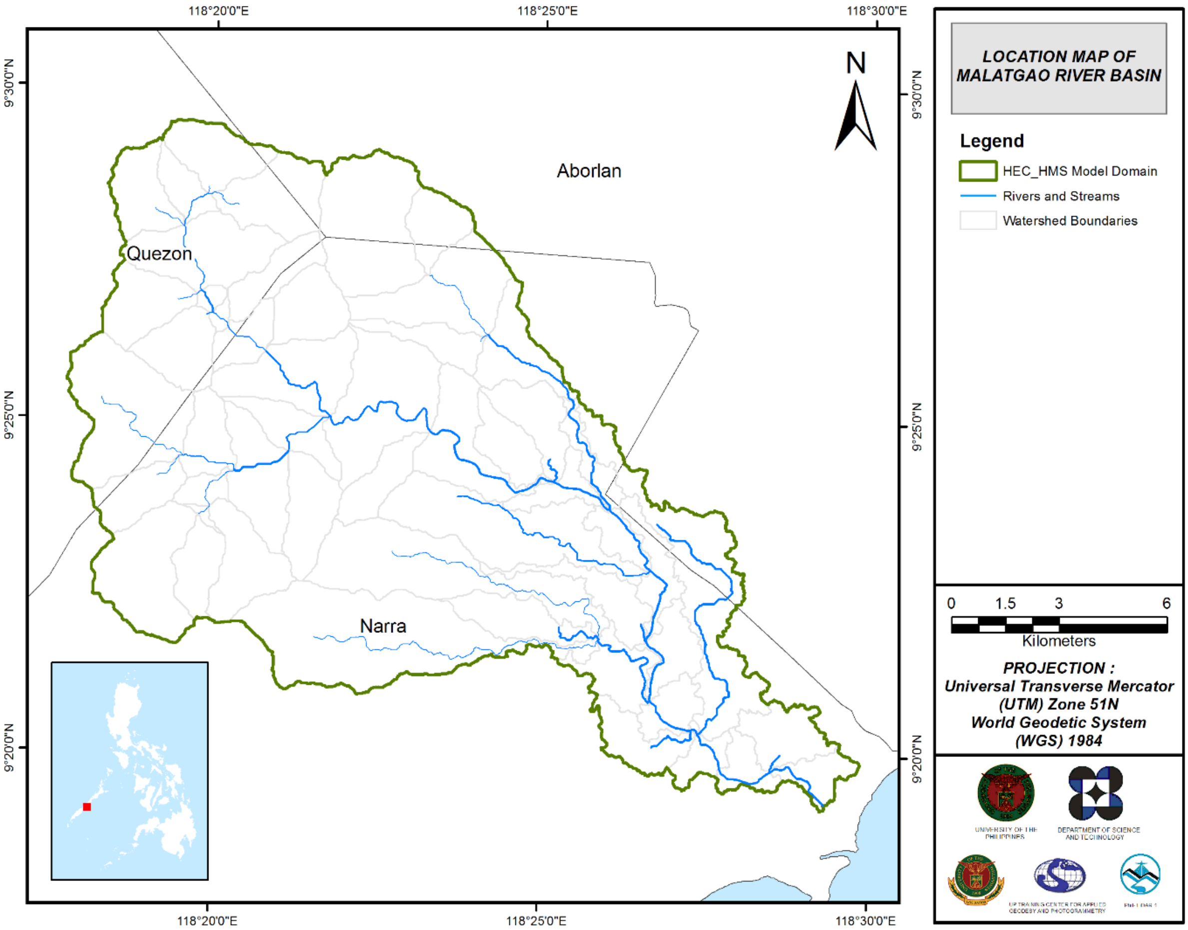

Figure 57. Stream Delineation Map of the Malatgao River Basin

Using SAR-based DEM, the Malatgao River Basin was delineated and further subdivided into sub basins. The model consists of 56 sub basins, 29 reaches, and 29 junctions. The main outlet is at Malatgao Bridge.

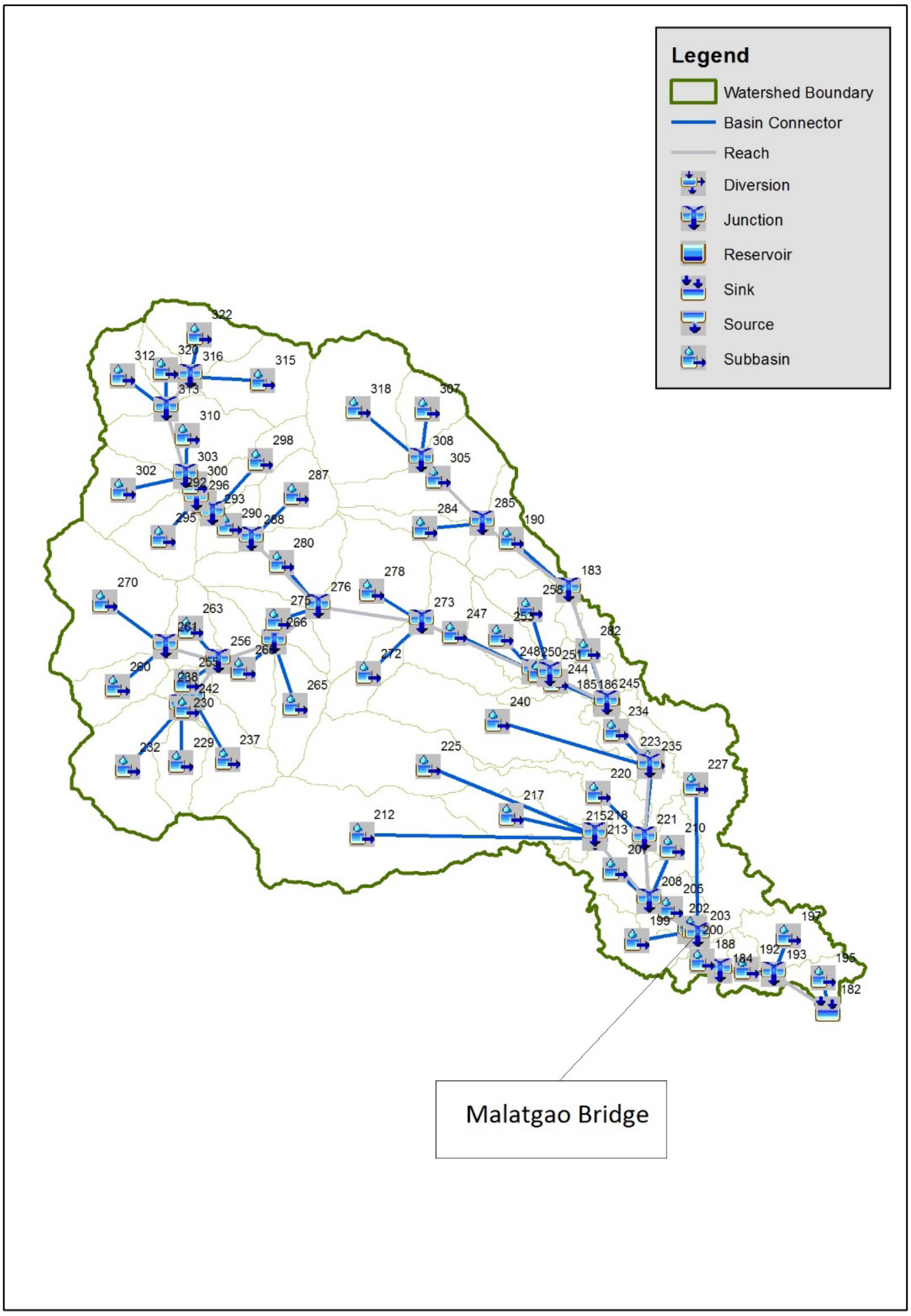

Figure 58. The Malatgao River Basin Model generated using HEC-HMS

5.4. Cross-section Data

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

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 x 10 m in size. Each element is assigned a unique grid element number which serves as its identifier, then attributed with the parameters required for modeling, 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 northwest of the model to the southeast, following the main channel. As such, boundary elements in those particular regions of the model are assigned as inflow and outflow elements respectively.

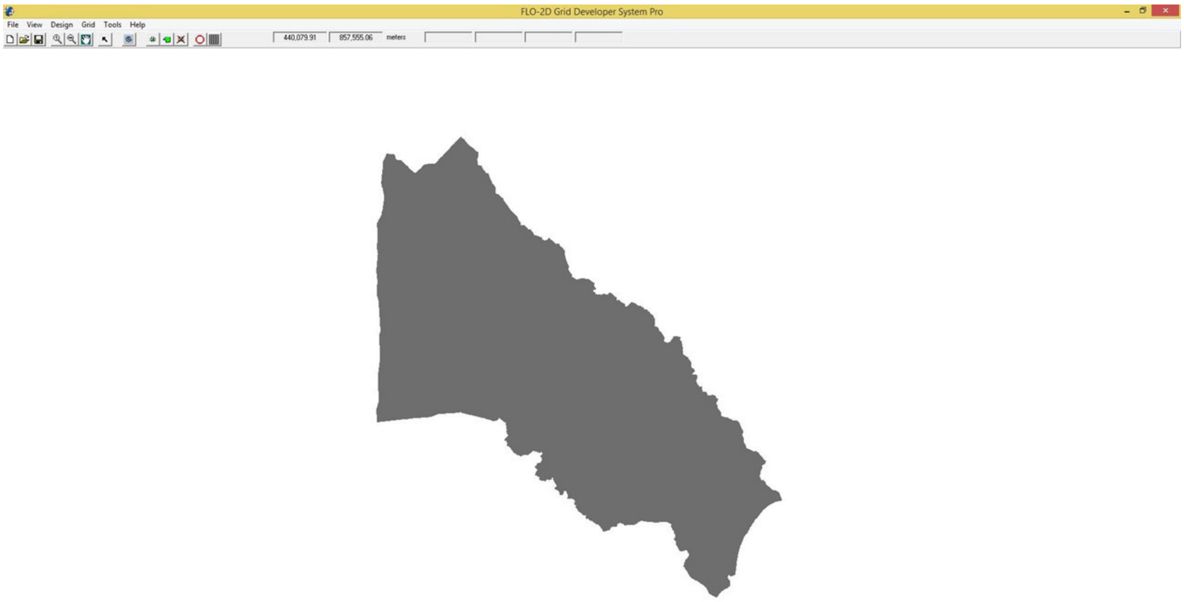

Figure 59. Screenshot of sub catchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 64.43530 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 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 84,573,888.00 m2.

There is a total of 56,123,382.83 m3 of water entering the model. Of this amount, 24,755,034.83 m3 is due to rainfall while 31368348.00 m3 is inflow from other areas outside the model. 9,811,887.00 m3 of this water is lost to infiltration and interception, while 10,153,466.55 m3 is stored by the floodplain. The rest, amounting up to 36,158,044.53 m3, is outflow.

5.6. Results of HMS Calibration

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

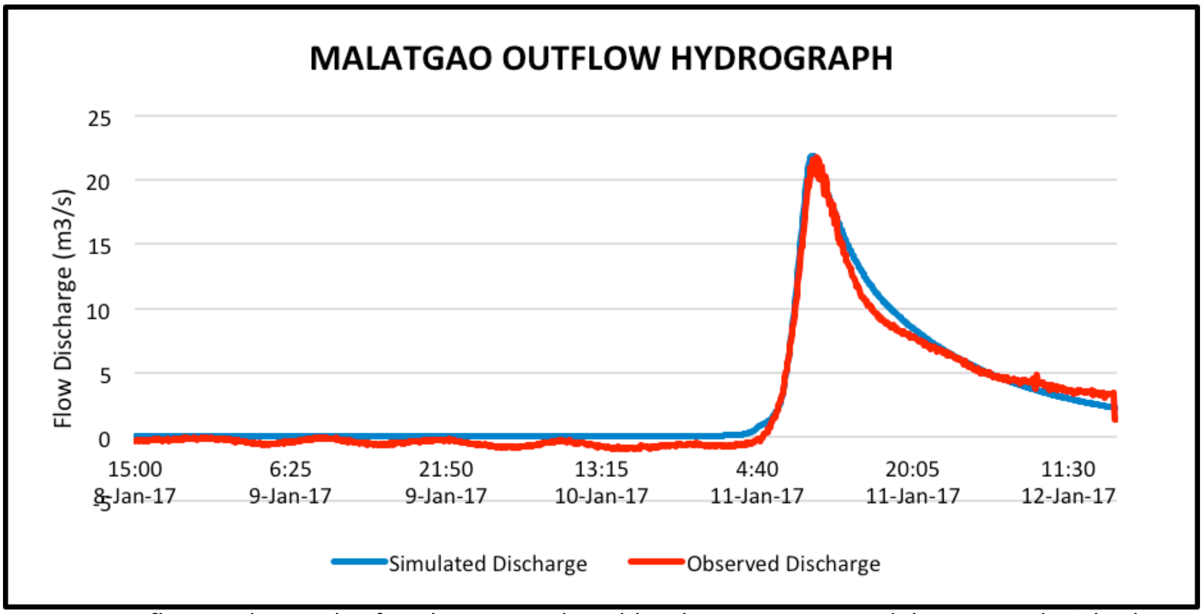

Figure 60. Outflow Hydrograph of Malatgao produced by the HEC-HMS model compared with observed outflow

Enumerated in Table 30 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 30. Range of Calibrated Values for Malatgao

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve Number	Initial Abstraction (mm)	1 - 29
			Curve Number	35 - 89
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.07 - 3
			Storage Coefficient (hr)	0.2 - 29
	Baseflow	Recession	Recession Constant	0.02 - 1
			Ratio to Peak	0.06 – 0.5
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.003 – 0.04

Initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as initial abstraction decreases. The range of values from 1 to 29 mm means that there is minimal to average amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 35 to 89 for curve number means that there is a diverse characteristic for this watershed depending on its sub basin.

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 29 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 base flow recedes between storm events and ratio to peak is the ratio of the base flow discharge to the peak discharge. Same as the curve number, the characteristics of this watershed differ per reach.

Manning's roughness coefficient of 0.003 to 0.04 also indicates different characteristics of the river reaches.

Table 31. Summary of the Efficiency Test of Malatgao HMS Model

Root Mean Square Error (RMSE)	0.699
Pearson Correlation Coefficient (r2)	0.994
Nash-Sutcliffe (E)	0.979
Percent Bias (PBIAS)	-17.809
Observation Standard Deviation Ratio (RSR)	0.144

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 0.699.

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 0.994.
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 0.979.

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 -17.809.

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 0.144.

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

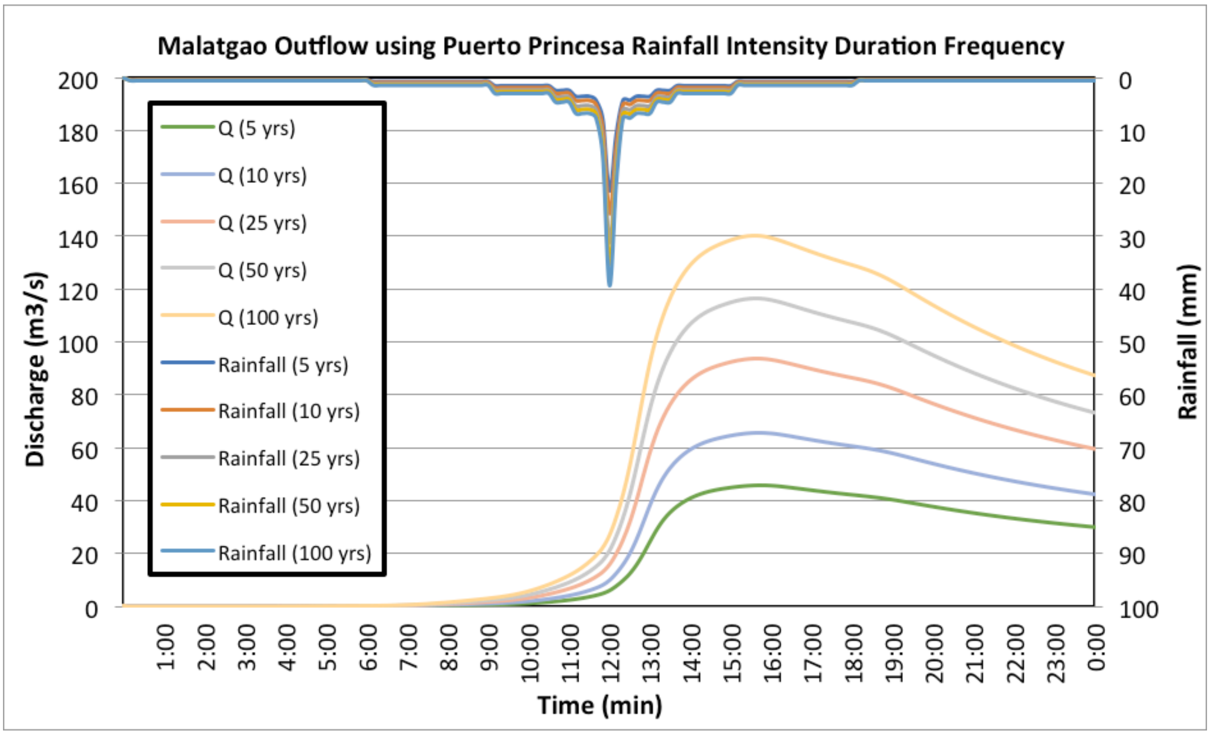

Figure 61. Outflow hydrograph at Malatgao Station generated using Puerto Princesa RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow, time to peak and lag time of the Malatgao discharge using the Puerto Princesa Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 32.

Table 32. Peak values of the Malatgao HECHMS Model Outflow using the Puerto Princesa RIDF

RIDF Period	Total Precipitation (mm)	Peak Rainfall (mm)	Peak Outflow (m3/s)	Time to Peak
5-year RIDF	156.40	21.30	45.711	3 hours 40 minutes
10-year RIDF	191.10	25.60	65.588	3 hours 40 minutes
25-year RIDF	234.90	31.10	93.752	3 hours 40 minutes
50-year RIDF	267.30	35.20	116.561	3 hours 40 minutes
100-year RIDF	299.60	39.20	140.203	3 hours 40 minutes

5.8. River Analysis Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website.

5.9. Flood Hazard and Flow Depth Map

The resulting hazard and flow depth maps for 5-, 25-, and 100-year rain return scenarios of the Malatgao Floodplain are shown in Figure 62 to 67. The floodplain with an area of 208.46 km2, covers two municipalities namely Aborlan, and Narra. Table 33 shows the percentage of area affected by flooding per municipality.

Table 33. Municipalities affected in Malatgao Floodplain

Municipality	Total Area	Area Flooded	% Flooded
Aborlan	645.11	64.76	10.04
Narra	831.19	143.37	17.25

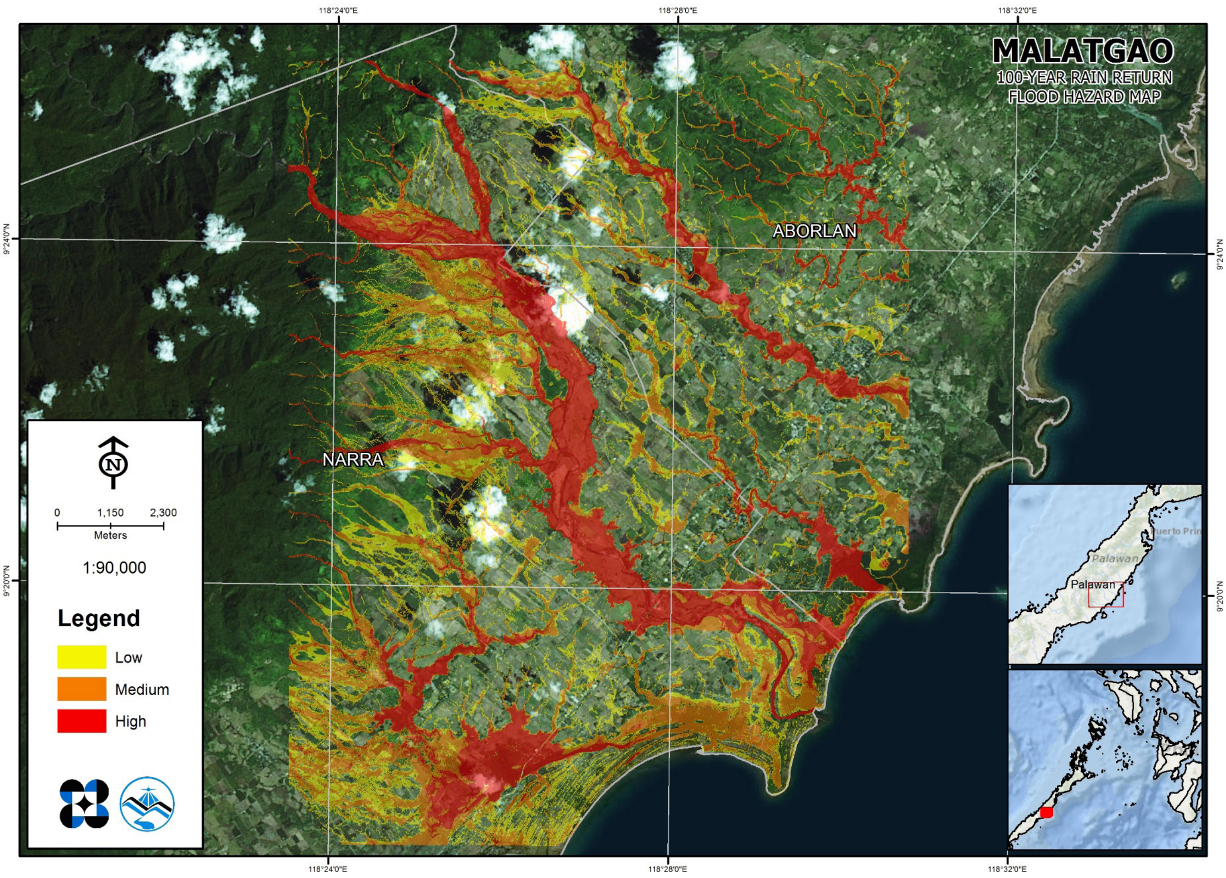

Figure 62. A 100-year Flood Hazard Map for Malatgao Floodplain

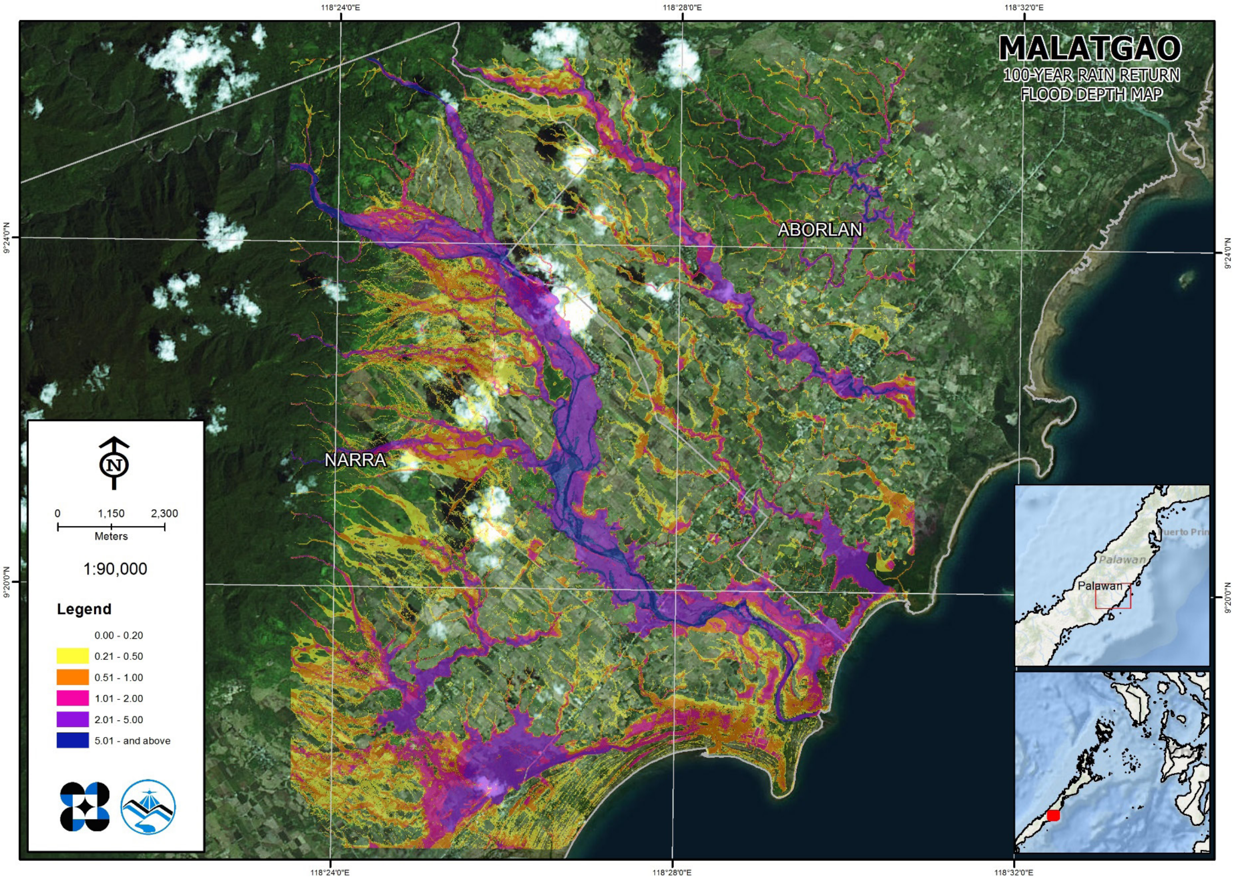

Figure 63. A 100-year Flood Depth Map for Malatgao Floodplain

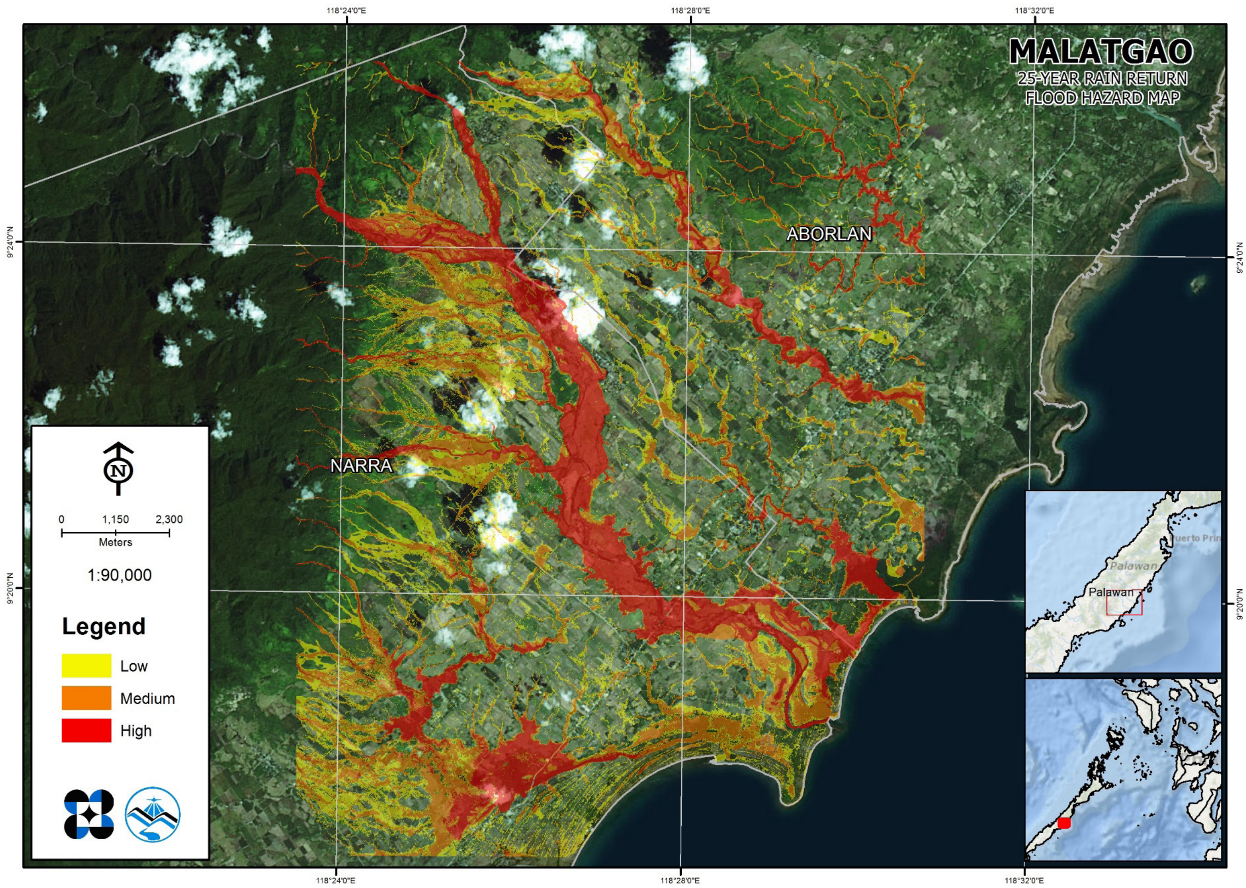

Figure 64. A 25-year Flood Hazard Map for Malatgao Floodplain

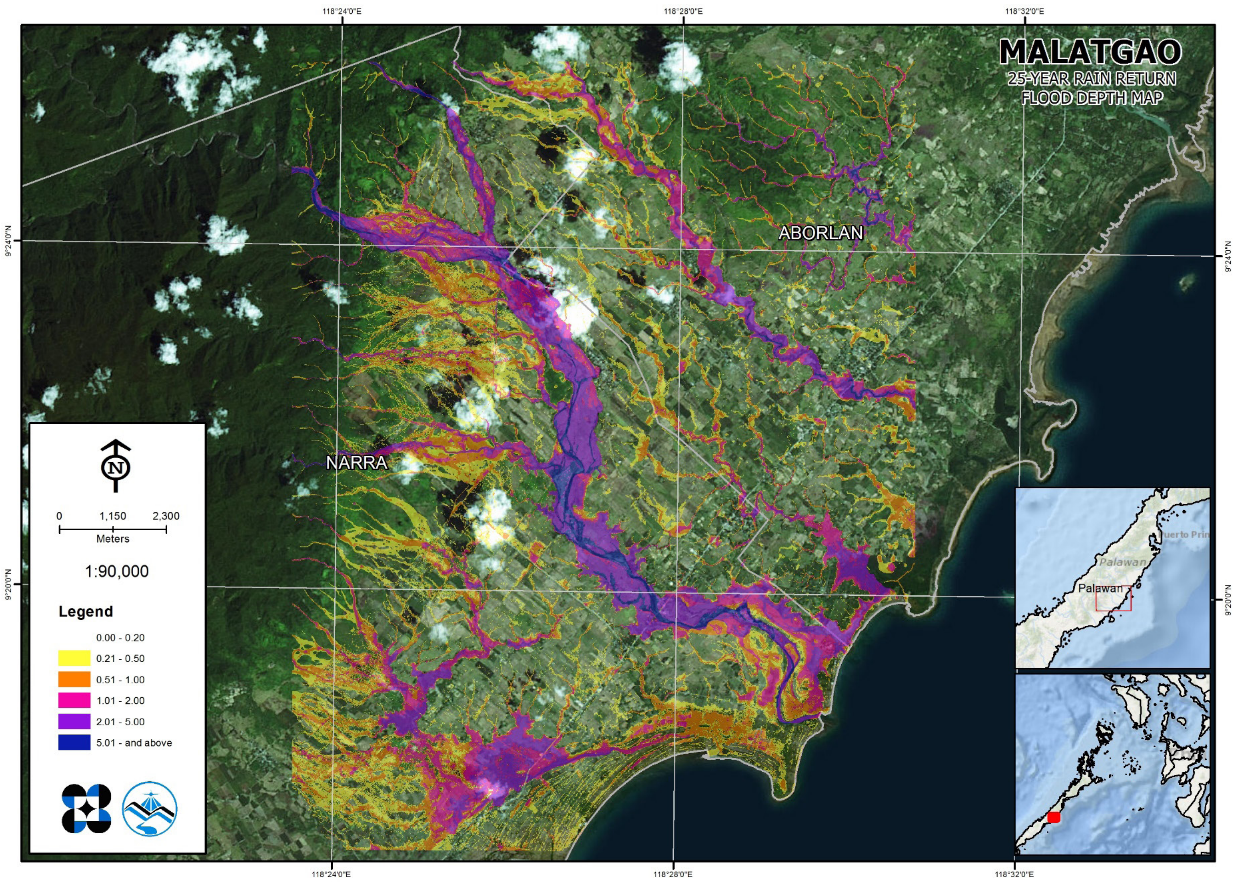

Figure 65. A 25-year Flood Depth Map for Malatgao Floodplain

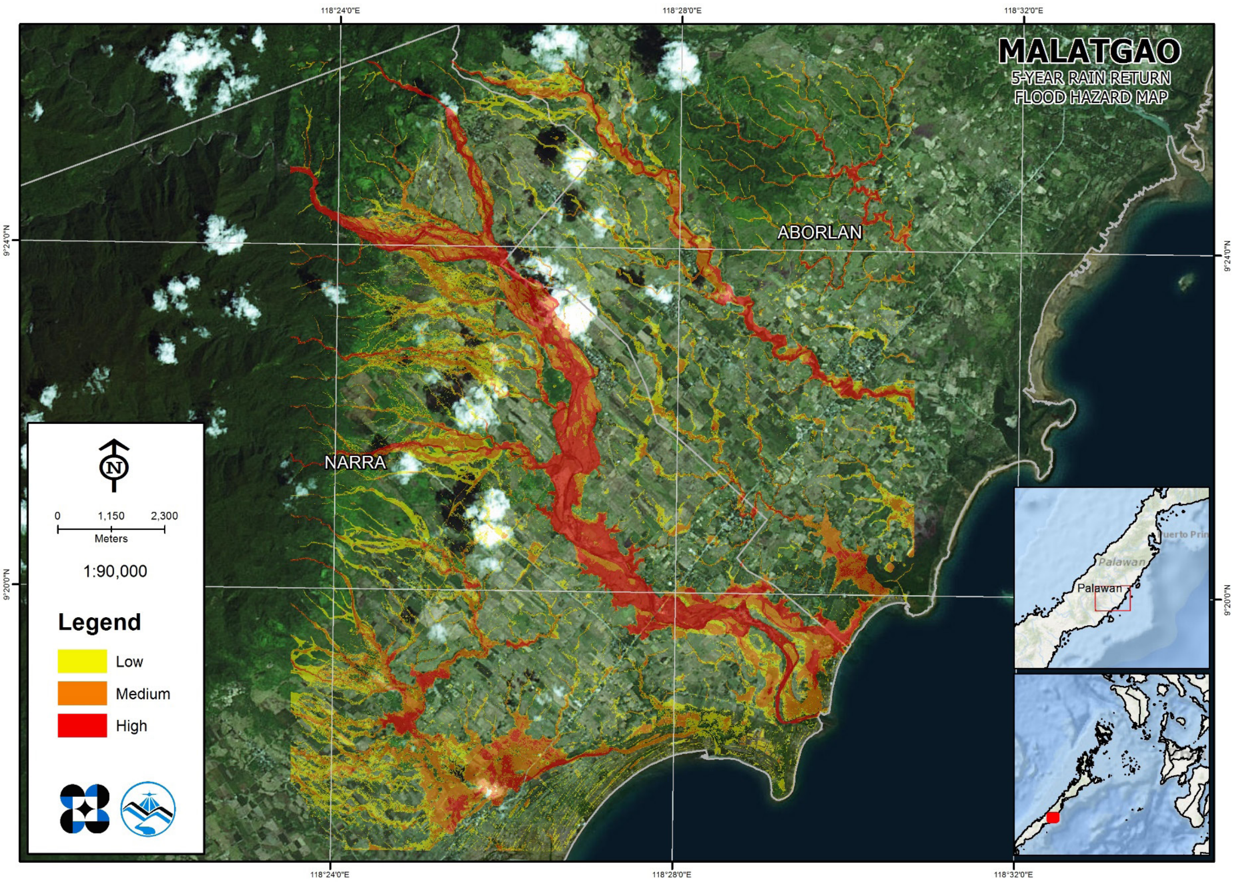

Figure 66. A 5-year Flood Hazard Map for Malatgao Floodplain

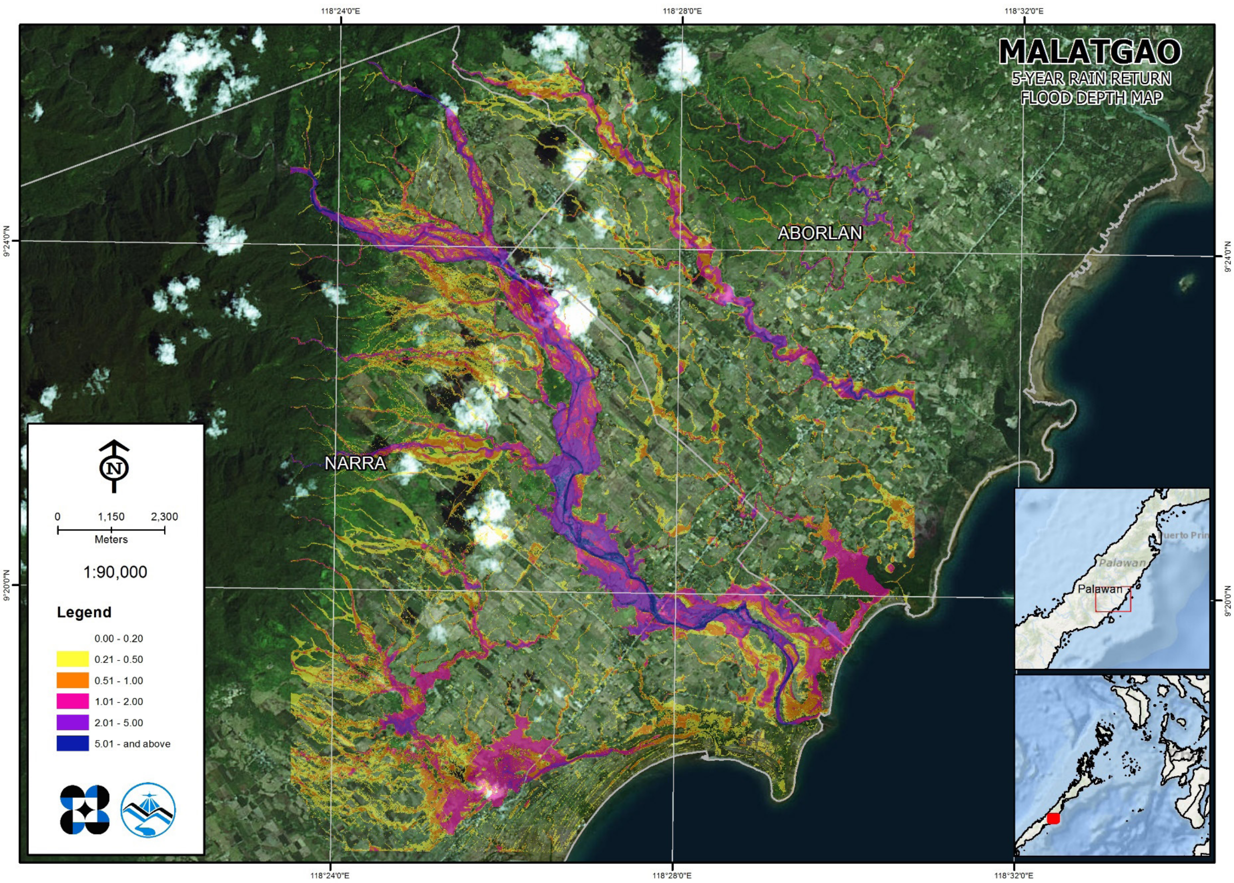

Figure 67. A 5-year Flood Depth Map for Malatgao Floodplain

5.10. Inventory of Areas Exposed to Flooding

Affected barangays in Malatgao River Basin, grouped by municipality, are listed below. For the said basin, two municipalities consisting of 18 barangays are expected to experience flooding when subjected to a 5-yr rainfall return period.

For the 5-year return period, 8.36% of the municipality of Aborlan with an area of 645.11 km2 will experience flood levels of less 0.20 m. 0.69% of the area will experience flood levels of 0.21 to 0.50 m while 0.47%, 0.36%, 0.15%, and 0.01% of the area will experience flood depths of 0.51 to 1 m, 1.01 to 2 m, 2.01 to 5 m and more than 5 m, respectively. Listed in Table 34 are the affected areas in km2 by flood depth per barangay.

Table 34. Affected Areas in Aborlan, Palawan during a 5-Year Rainfall Return Period

MALATGAO BASIN		Affected Barangays in Aborlan							
		Apo-Aporawan	Apoc-Apoc	Gogognan	Jose Rizal	Magbabadil	Plaridel	Ramon Magsaysay	Tigman
Affected Area (km2)	0.03-0.20	13.94	0.98	0.029	16.94	0.029	12.56	8.81	0.64
	0.21-0.50	1.35	0.025	0.00037	1.61	0.004	0.9	0.44	0.16
	0.51-1.00	0.82	0.02	0.0005	1.14	0.0024	0.64	0.33	0.059
	1.01-2.00	0.5	0.015	0	0.71	0	0.76	0.28	0.029
	2.01-5.00	0.06	0.00079	0	0.1	0	0.57	0.25	0.016
	> 5.00	0.0041	0	0	0.0001	0	0.045	0.024	0

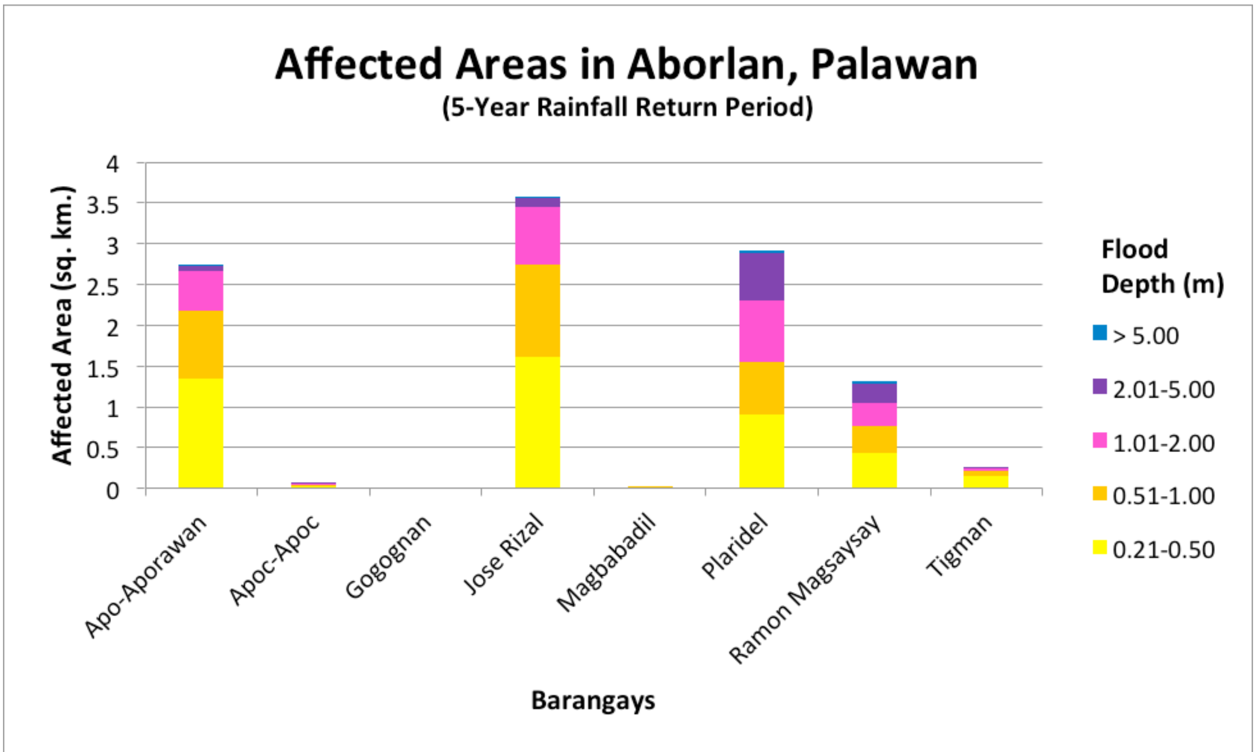

Figure 68. Affected Areas in Aborlan, Palawan during a 5-Year Rainfall Return Period

For the municipality of Narra, with an area of 831.19 km2, 11.78% will experience flood levels of less 0.20 m. 2.002% of the area will experience flood levels of 0.21 to 0.50 m while 1.30%, 1.30%, 0.75%, and 0.13% of the area will experience flood depths of 0.51 to 1 m, 1.01 to 2 m, 2.01 to 5 m, and more than 5 m, respectively.

Table 35. Affected Areas in Narra, Palawan during a 5-Year Rainfall Return Period

MALATGAO BASIN		Affected Barangays in Narra									
		Antipuluan	Bagong Sikat	Dumagueña	Elvita	Estrella Village	Malatgao	Narra	Sandoval	Taritien	Tinagong Dagat
ffected Area (km2)	0.03-0.20	15.39	4.15	18.06	11.59	9.95	8.68	0.042	11.1	15.42	3.52
	0.21-0.50	4.85	1.06	2.09	1.36	1.67	2.15	0.0012	1.03	2.06	0.37
	0.51-1.00	3.17	0.96	1.45	0.6	0.94	1.43	0.00012	0.65	0.98	0.59
	1.01-2.00	2.92	1.57	1.52	0.5	0.53	1.1	0	0.46	0.42	1.8
	2.01-5.00	0.3	1.16	1.01	0.049	0.73	1.25	0	0.71	0.2	0.86
	> 5.00	0	0.071	0.088	0.01	0.2	0.5	0	0.095	0.015	0.11

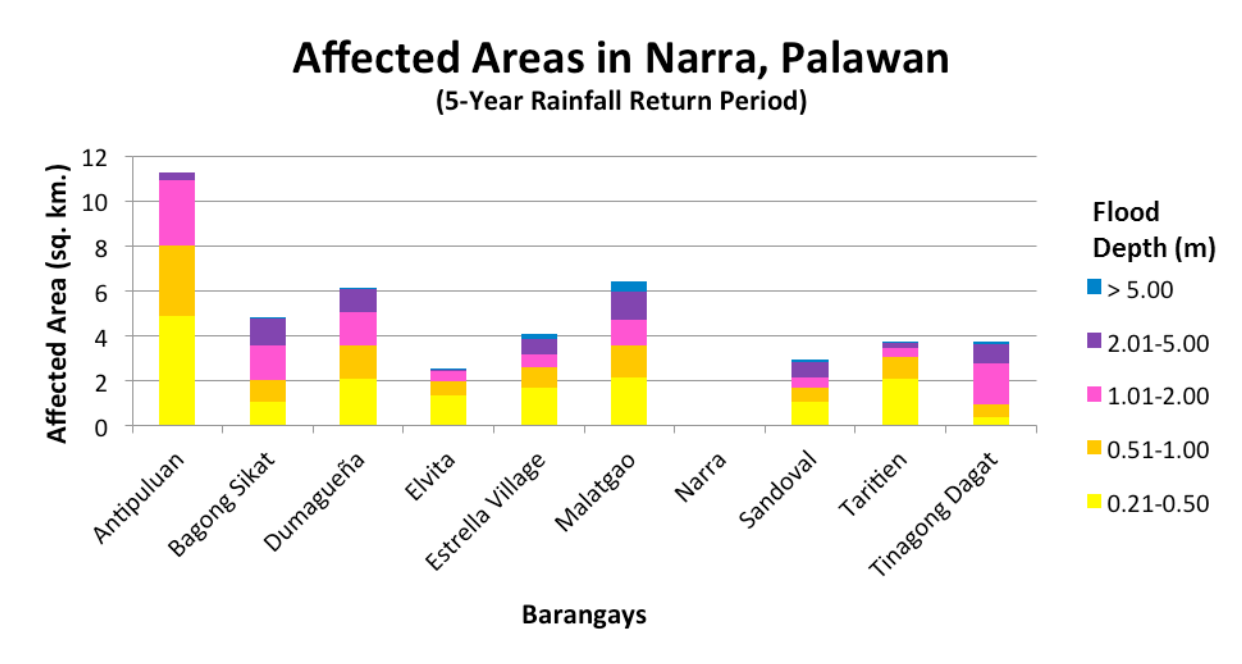

Figure 69. Affected Areas in Narra, Palawan during a 5-Year Rainfall Return Period

For the 25-year return period, 7.92% of the municipality of Aborlan with an area of 645.11 km2 will experience flood levels of less 0.20 m. 0.77% of the area will experience flood levels of 0.21 to 0.50 m while 0.53%, 0.46%, 0.33%, and 0.03% of the area will experience flood depths of 0.51 to 1 m, 1.01 to 2 m, 2.01 to 5 m and more than 5 m, respectively. Listed in Table 36 are the affected areas in km2 by flood depth per barangay.

Table 36. Affected Areas in Aborlan, Palawan during a 25-Year Rainfall Return Period

MALATGAO BASIN		Affected Barangays in Aborlan							
		Apo-Aporawan	Apoc-Apoc	Gogognan	Jose Rizal	Magbabadil	Plaridel	Ramon Magsaysay	Tigman
Affected Area (km2)	0.03-0.20	13.18	0.96	0.028	16.04	0.028	11.83	8.47	0.56
	0.21-0.50	1.51	0.029	0.00026	1.85	0.0033	0.99	0.47	0.13
	0.51-1.00	1.09	0.02	0.00042	1.16	0.0036	0.64	0.36	0.14
	1.01-2.00	0.57	0.021	0.00022	1.18	0.00018	0.79	0.36	0.043
	2.01-5.00	0.33	0.0031	0	0.27	0	1.12	0.4	0.021
	> 5.00	0.012	0	0	0.0003	0	0.11	0.067	0

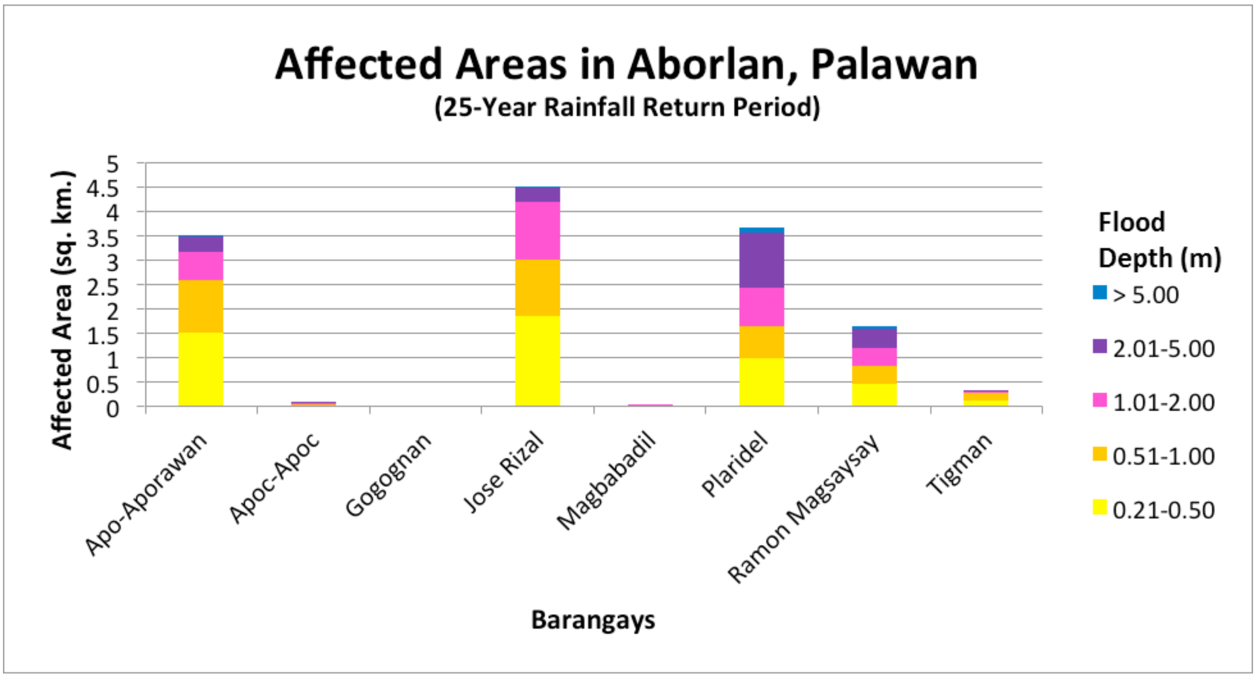

Figure 70. Affected Areas in Aborlan, Palawan during a 25-Year Rainfall Return Period

For the municipality of Narra, with an area of 831.19 km2, 10.48% will experience flood levels of less 0.20 m. 2.26% of the area will experience flood levels of 0.21 to 0.50 m while 1.58%, 1.33%, 1.39%, and 0.23% of the area will experience flood depths of 0.51 to 1 m, 1.01 to 2 m, 2.01 to 5 m, and more than 5 m, respectively.

Table 37. Affected Areas in Narra, Palawan during a 25-Year Rainfall Return Period

MALATGAO BASIN		Affected Barangays in Narra									
		Antipuluan	Bagong Sikat	Dumagueña	Elvita	Estrella Village	Malatgao	Narra	Sandoval	Taritien	Tinagong Dagat
ffected Area (km2)	0.03-0.20	12.32	3.29	16.99	10.77	8.96	7.23	0.041	10.22	14.11	3.17
	0.21-0.50	5.4	1.26	2.2	1.7	1.96	2.12	0.0015	1.24	2.56	0.32
	0.51-1.00	3.71	0.93	1.51	0.74	1.3	2.3	0.00067	0.83	1.41	0.39
	1.01-2.00	3.2	1.19	1.71	0.58	0.67	1.15	0	0.6	0.66	1.29
	2.01-5.00	1.99	2.07	1.62	0.29	0.74	1.62	0	0.94	0.33	1.95
	> 5.00	0	0.23	0.19	0.015	0.4	0.69	0	0.22	0.026	0.14

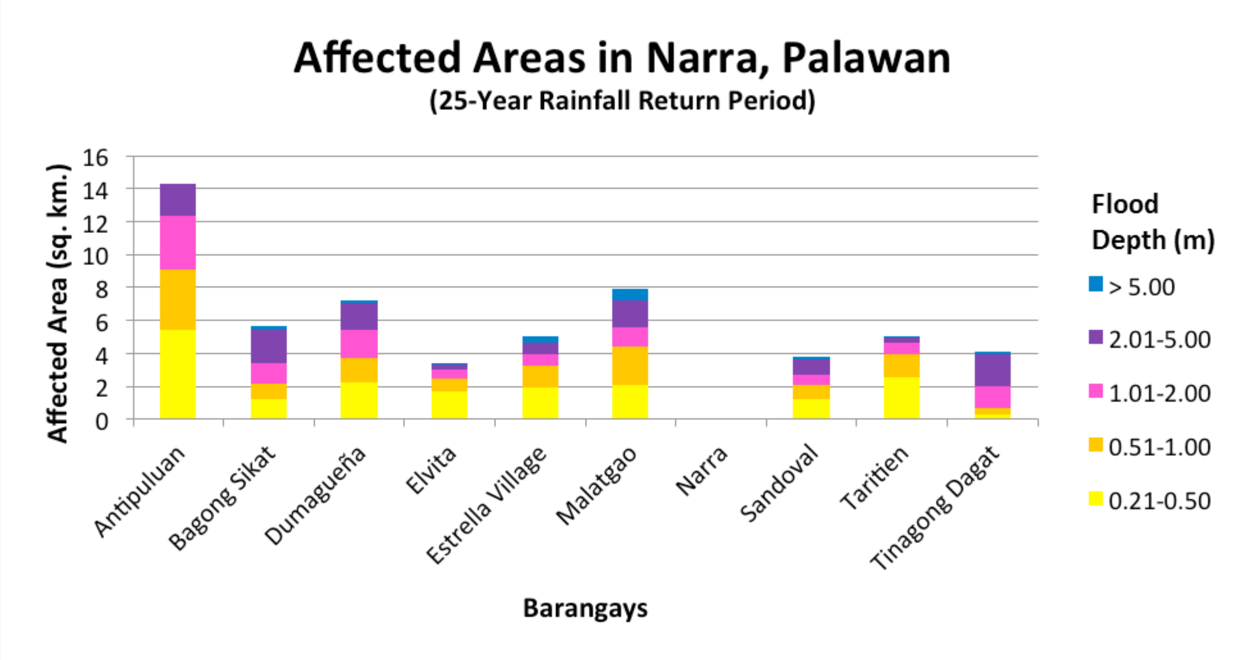

Figure 71. Affected Areas in Narra, Palawan during a 25-Year Rainfall Return Period

For the 100-year return period, 7.62% of the municipality of Aborlan with an area of 645.11 km2 will experience flood levels of less 0.20 m. 0.86% of the area will experience flood levels of 0.21 to 0.50 m while 0.56%, 0.47%, 0.48%, and 0.05% of the area will experience flood depths of 0.51 to 1 m, 1.01 to 2 m, 2.01 to 5 m and more than 5 m, respectively. Listed in Table 38 are the affected areas in km2 by flood depth per barangay.

Table 38. Affected Areas in Aborlan, Palawan during a 100-Year Rainfall Return Period

MALATGAO BASIN		Affected Barangays in Aborlan							
		Apo-Aporawan	Apoc-Apoc	Gogognan	Jose Rizal	Magbabadil	Plaridel	Ramon Magsaysay	Tigman
Affected Area (km2)	0.03-0.20	12.64	0.95	0.028	15.39	0.027	11.36	8.24	0.52
	0.21-0.50	1.65	0.031	0.00037	2.1	0.003	1.13	0.52	0.13
	0.51-1.00	1.25	0.02	0.00047	1.2	0.0041	0.65	0.37	0.13
	1.01-2.00	0.53	0.024	0.00026	1.3	0.0005	0.73	0.38	0.087
	2.01-5.00	0.6	0.0063	0	0.52	0	1.43	0.49	0.026
	> 5.00	0.022	0	0	0.0015	0	0.18	0.11	0.0003

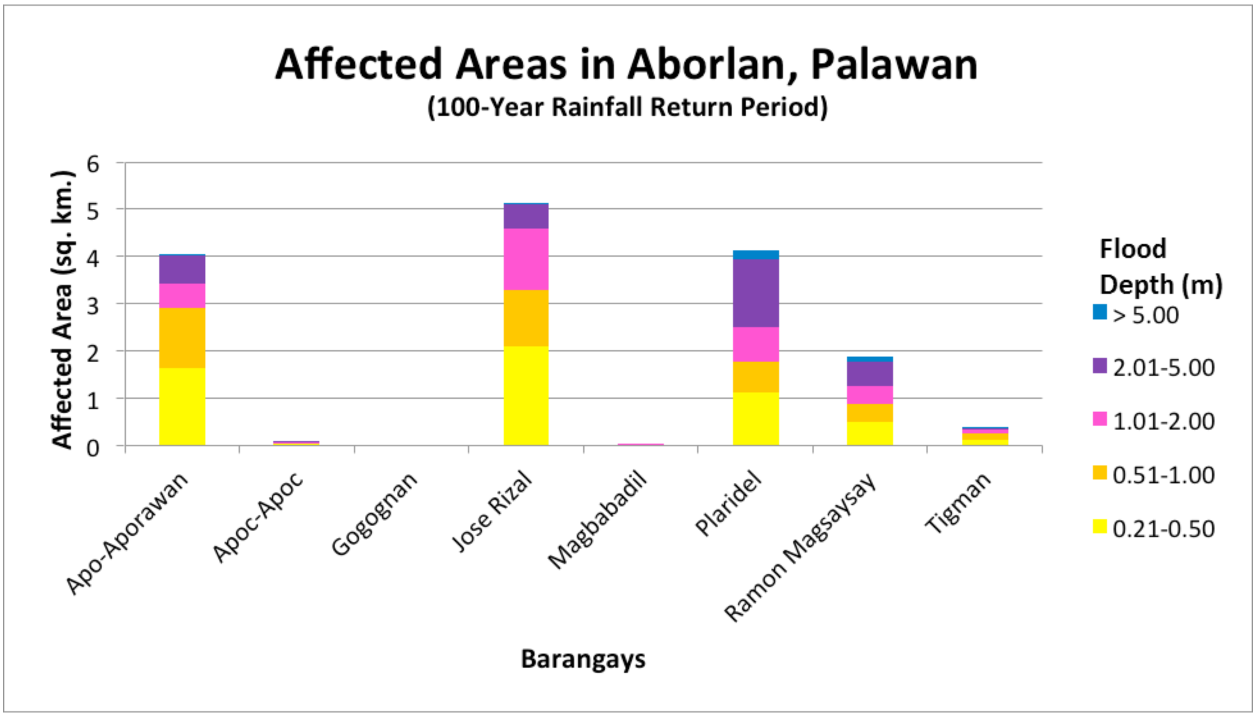

Figure 72. Affected Areas in Aborlan, Palawan during a 100-Year Rainfall Return Period

For the municipality of Narra, with an area of 831.19 km2, 9.70% will experience flood levels of less 0.20 m. 2.41% of the area will experience flood levels of 0.21 to 0.50 m while 1.80%, 1.40%, 1.69%, and 0.27% of the area will experience flood depths of 0.51 to 1 m, 1.01 to 2 m, 2.01 to 5 m, and more than 5 m, respectively.

Table 39. Affected Areas in Narra, Palawan during a 100-Year Rainfall Return Period

MALATGAO BASIN		Affected Barangays in Narra									
		Antipuluan	Bagong Sikat	Dumagueña	Elvita	Estrella Village	Malatgao	Narra	Sandoval	Taritien	Tinagong Dagat
ffected Area (km2)	0.03-0.20	10.08	2.8	16.34	10.21	8.32	6.65	0.04	9.77	13.31	3.09
	0.21-0.50	5.61	1.33	2.36	1.94	2.16	2.12	0.002	1.36	2.81	0.35
	0.51-1.00	4.47	1.05	1.53	0.87	1.47	2.55	0.001	0.91	1.71	0.4
	1.01-2.00	3.27	0.95	1.78	0.57	0.8	1.49	0	0.75	0.84	1.2
	2.01-5.00	3.2	2.49	1.94	0.5	0.76	1.65	0	0.98	0.4	2.08
	> 5.00	0.0032	0.34	0.27	0.018	0.52	0.66	0	0.27	0.035	0.13

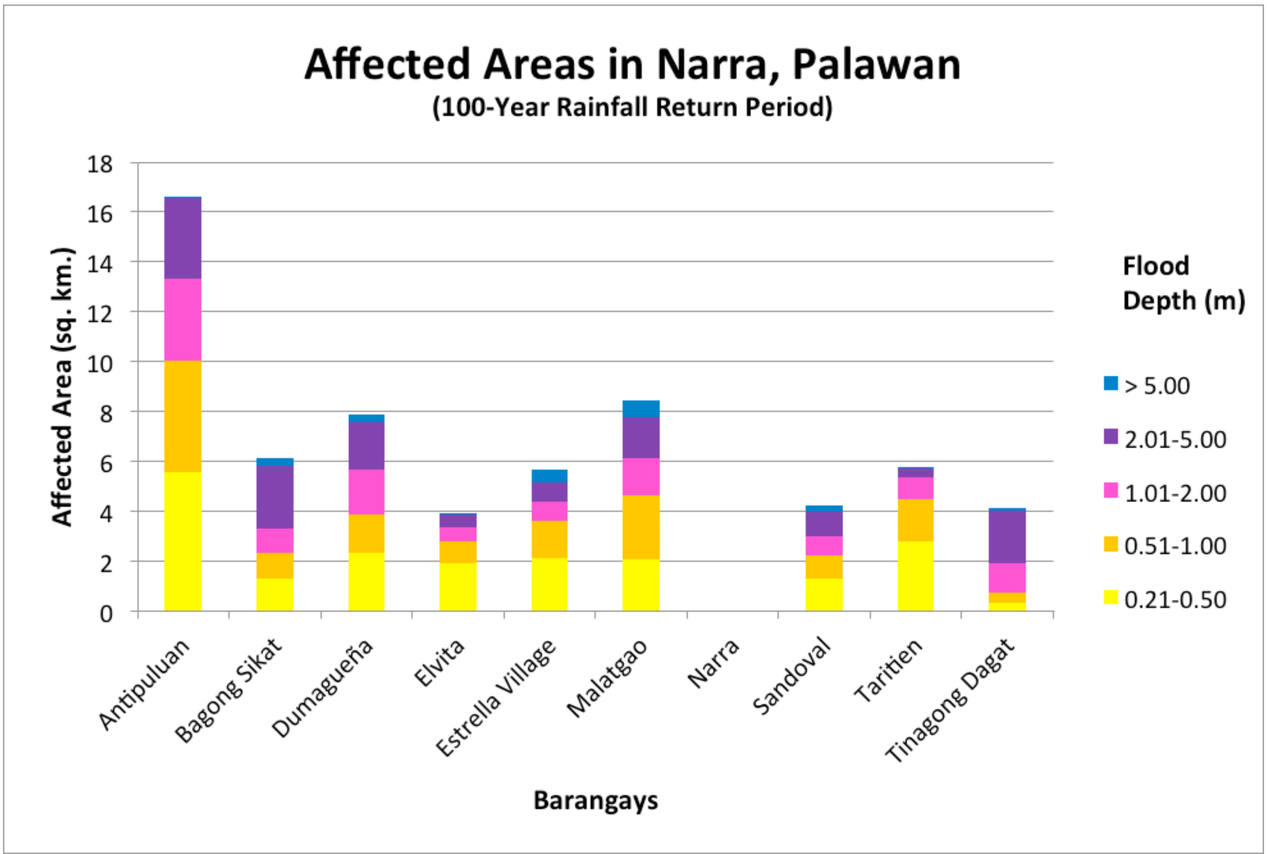

Figure 73. Affected Areas in Narra, Palawan during a 100-Year Rainfall Return Period

Among the barangays in the municipality of Aborlan, Jose Rizal is projected to have the highest percentage of area that will experience flood levels at 3.18%. Meanwhile, Apo-Aporawan posted the second highest percentage of area that may be affected by flood depths at 2.59%.

Among the barangays in the municipality of Narra, Antipuluan is projected to have the highest percentage of area that will experience flood levels at 3.20%. Meanwhile, Dumagueña posted the second highest percentage of area that may be affected by flood depths at 2.91%.

5.11. Flood Validation

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

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

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

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 74.

The flood validation consists of 81 points randomly selected all over the Malatgao Floodplain. Comparing it with the flood depth map of the nearest storm event, the map has an RMSE value of 1.202m. Table 40 shows a contingency matrix of the comparison.

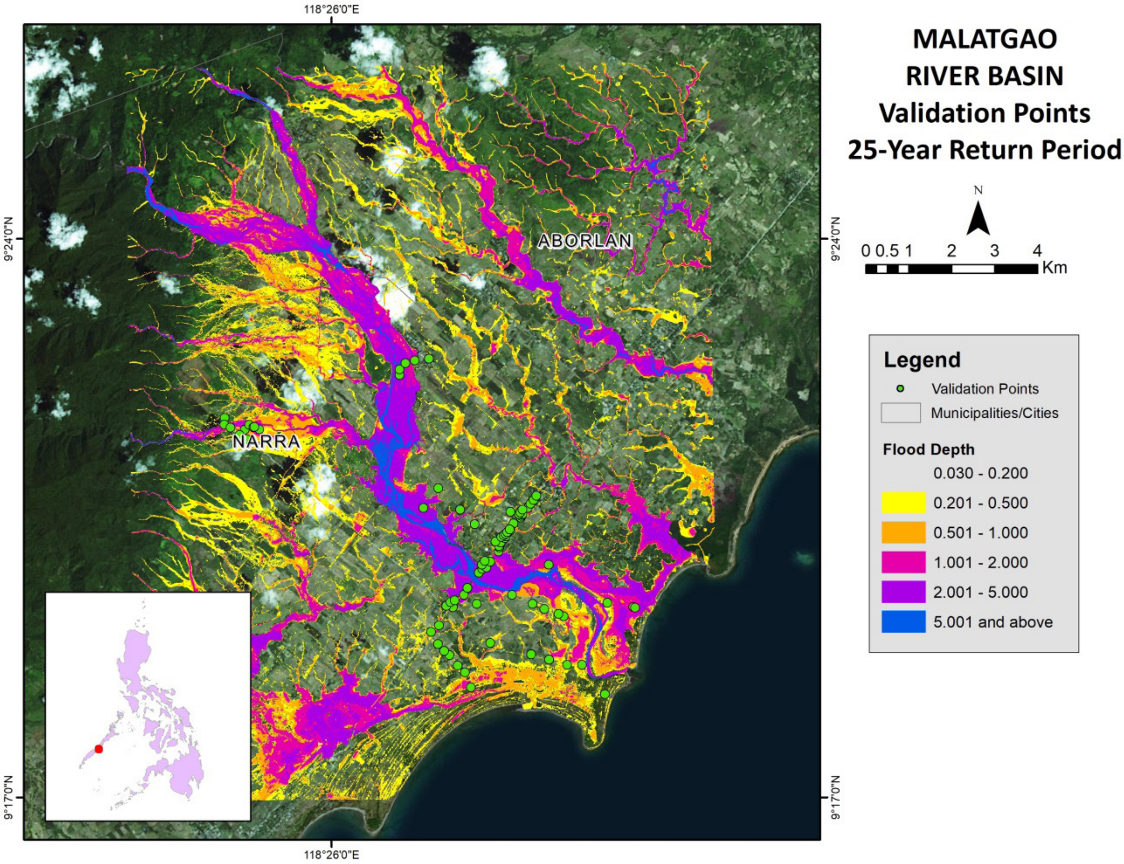

Figure 74. Validation points for a 25-year Flood Depth Map of Malatgao Floodplain

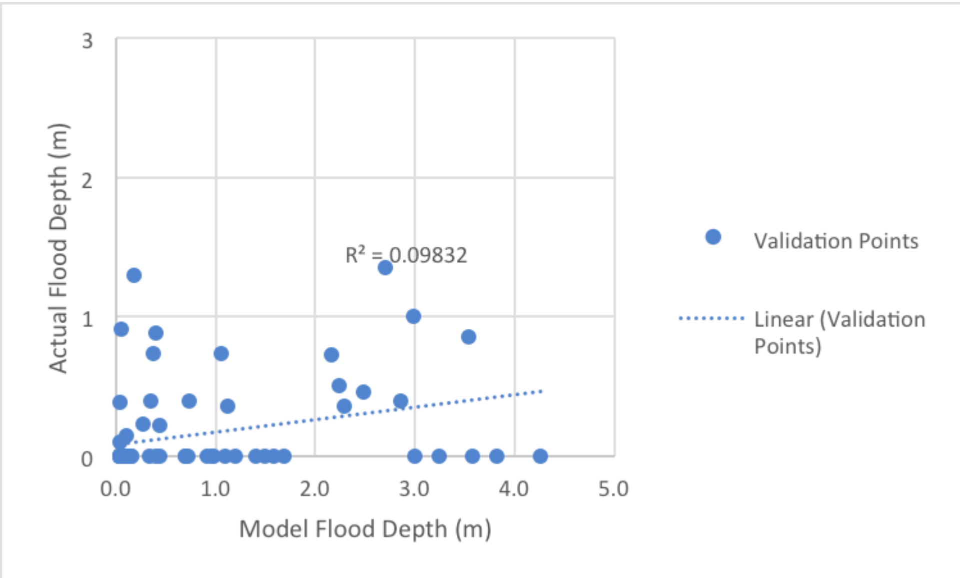

Figure 75. Flood Map Depth vs Actual Flood Depth

Table 40. Actual Flood Depth vs Simulated Flood Depth at different levels in the Malatgao River Basin

MALATGAO BASIN		**Modeled Flood Depth (m)**						
		0-0.20	**0.21-0.50**	**0.51-1.00**	**1.01-2.00**	**2.01-5.00**	**> 5.00**	**Total**
Actual Flood Depth (m)	0-0.20	42	3	6	6	5	0	62
	0.21-0.50	1	3	1	1	3	0	9
	0.51-1.00	1	2	0	1	4	0	8
	1.01-2.00	1	0	0	0	1	0	2
	2.01-5.00	0	0	0	0	0	0	0
	> 5.00	0	0	0	0	0	0	0
	Total	**45**	8	7	8	13	0	81

The overall accuracy generated by the flood model is estimated at 55.56% with 45 points correctly matching the actual flood depths. In addition, there were 7 points estimated one level above and below the correct flood depths while there were 12 points and 15 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 4 points were overestimated while a total of 5 points were underestimated in the modeled flood depths of Malatgao. Table 41 depicts the summary of the Accuracy Assessment in the Malatgao River Basin Survey.

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

	No. of Points	%
Correct	45	55.56
Overestimated	31	38.27
Underestimated	5	6.17
Total	81	100.00

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ANNEXES

ANNEX 1. TECHNICAL SPECIFICATIONS OF THE LIDAR SENSORS USED IN THE MATLAGAO FLOODPLAIN SURVEY

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

1 Target reflectivity ≥20%

2 Dependent on selected operational parameters using nominal FOV of up to 40° in standard atmospheric conditions with 24-km visibility

3 Angle of incidence ≤20°

4 Target size ≥ laser footprint5 Dependent on system configuration

GEMINI SENSOR

Parameter	Specification
Operational envelope (1,2,3,4)	150-4000 m AGL, nominal
Laser wavelength	1064 nm
Horizontal accuracy (2)	1/5,500 x altitude, (m AGL)
Elevation accuracy (2)	<5-35 cm, 1 σ
Effective laser repetition rate	Programmable, 33-167 kHz
Position and orientation system	POS AV™ AP50 (OEM); 220-channel dual frequency GPS/GNSS/Galileo/L-Band receiver
Scan width (WOV)	Programmable, 0-50˚
Scan frequency (5)	Programmable, 0-70 Hz (effective)
Sensor scan product	1000 maximum
Beam divergence	Dual divergence: 0.25 mrad (1/e) and 0.8 mrad (1/e), nominal
Roll compensation	Programmable, ±5˚ (FOV dependent)
Range capture	Up to 4 range measurements, including 1st, 2nd, 3rd, and last returns
Intensity capture	Up to 4 intensity returns for each pulse, including last (12 bit)
Video Camera	Internal video camera (NTSC or PAL)
Image capture	Compatible with full Optech camera line (optional)
Full waveform capture	12-bit Optech IWD-2 Intelligent Waveform Digitizer (optional)
Data storage	Removable solid state disk SSD (SATA II)
Power requirements	28 V; 900 W;35 A(peak)

Dimensions and weight	Sensor: 260 mm (w) x 190 mm (l) x 570 mm (h); 23 kg Control rack: 650 mm (w) x 590 mm (l) x 530 mm (h); 53 kg
Operating temperature	-10˚C to +35˚C (with insulating jacket)
Relative humidity	0-95% no-condensing

ANNEX 2. NAMRIA CERTIFICATION OF REFERENCE POINTS USED IN THE LIDAR SURVEY

1. PL-46

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

June 23, 2015

CERTIFICATION

To whom it may concern:

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

	Province: **PALAWAN** Station Name: **PL-46 (PLW)**	
Island: **PALAWAN**	Municipality: **ABORLAN**	Barangay: **IRAAN**
Elevation: **13.5877 +/- 0.03 m.**	Order: **1st Order**	Datum: **Mean Sea Level**
Latitude:	Longitude:	

Location Description

PL-46

From Puerto Princesa travel south along the National Highway towards Aborland located at Iraan Bridge before km 66. Mark is the head of a 4" copper nail, drilled hole and set flushed on a cement putty with inscription "PL-46 20008 NAMRIA". The station is located in Brgy. Poblacion along the Aborlan.

Requesting Party: **UP-DREAM**
Purpose: **Reference**
OR Number: **8083538 I**
T.N.: **2015-1342**

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

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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

CIP/4701/12/09/814

2. PL-318

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

December 02, 2015

CERTIFICATION

To whom it may concern:

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

	Province: **PALAWAN** Station Name: **PL-318**	
Island: **Luzon**	Municipality: **ABORLAN**	Barangay: **RAMON**
Elevation: **12.6796 +/- 0.03 m.**	Order: **1st Order**	Datum: **Mean Sea Level**
Latitude:	Longitude:	

Location Description

Station Mark: Mark is the head of a four (4) inch copper nail, set in a drilled and flushed with a cement putty with the inscription of BM PL 318, 2008, NAMRIA. The station is located in Brgy. Magsaysay, Aborlan.

Access: From Puerto Princesa travel south along the National Road towards Aborlan. Station is located on the Flagpole pedestal in front of Aborlan Municipal Hall, about 80 meters from the center of the highway.

Requesting Party: **UP DREAM**
Purpose: **Reference**
OR Number: **8088735 I**
T.N.: **2015-3962**

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

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CERTIFICATION INTERNATIONAL ISO 9001:2008 ACCREDITED NSA-001 CIP/4701/12/09/814

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3. PLW-113

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

June 23, 2015

CERTIFICATION

To whom it may concern:

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

	Province: **PALAWAN**	
	Station Name: **PLW-113**	
	Order: **2nd**	
Island: **LUZON**	Barangay: **CABIGAAN**	
Municipality: **PUERTO PRINCESA CITY (CAPITAL)**	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **9° 26' 55.17200"**	Longitude: **118° 26' 46.88314"**	Ellipsoidal Hgt: **95.70958 m.**
	WGS84 Coordinates	
Latitude: **9° 26' 50.78858"**	Longitude: **118° 26' 52.23545"**	Ellipsoidal Hgt: **145.86900 m.**
	PTM / PRS92 Coordinates	
Northing: **1044755.711 m.**	Easting: **494109.133 m.**	Zone: **1A**
	UTM / PRS92 Coordinates	
Northing: **1,044,718.65**	Easting: **658,792.04**	Zone: **50**

Location Description

PLW-113
From Poblacion Aborlan approximately 500 m. turn W at the junction going to Brgy. Cabigaan. Travel approximately 14 kms. up to Aborlan Water System. Station is located outside, SE of Aborlan Water System. Mark is the head of a 4 in. copper nail flushed in a cement putty 30cm x 30cm x 120cm embedded 1m on the ground with inscriptions "PLW-113 2007 NAMRIA."

Requesting Party: **UP-DREAM**
Purpose: **Reference**
OR Number: **8083538 I**
T.N.: **2015-1339**

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

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

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ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

4. PLW-7

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

November 05, 2015

CERTIFICATION

To whom it may concern:

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

	Province: **PALAWAN**	
	Station Name: **PLW-7**	
	Order: **1st**	
Island: **Luzon**	Barangay: **MANINGNING (POB.)**	
Municipality: **PUERTO PRINCESA CITY (CAPITAL)**	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **9° 44' 29.76476"**	Longitude: **118° 44' 20.28049"**	Ellipsoidal Hgt: **36.86700 m.**
	WGS84 Coordinates	
Latitude: **9° 44' 25.33347"**	Longitude: **118° 44' 25.60607"**	Ellipsoidal Hgt: **87.11600 m.**
	PTM / PRS92 Coordinates	
Northing: **1077161.858 m.**	Easting: **526219.677 m.**	Zone: **1A**
	UTM / PRS92 Coordinates	
Northing: **1,077,265.52**	Easting: **690,761.68**	Zone: **50**

Location Description

PLW-7
From the City Hall building of Puerto Princesa, travel east along Rizal Avenue for 400 meter up to the Puerto Princesa Water District Compound. The station is located on top of the concrete Water tank of Puerto Princesa; located inside the Water District Compound. Station mark is a cross cut top of 0.15 m x 0.01 m. in diameter brass rod set in a drill hole centered on a cement putty on top center of a 17.93 meters high water tank.

Requesting Party: **Louie P. Balicanta**
Purpose: **Reference**
OR Number: **8088551 I**
T.N.: **2015-3638**

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

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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

ANNEX 3. BASELINE PROCESSING REPORTS OF CONTROL POINTS USED IN THE LIDAR SURVEY

1. PL-46

Vector Components (Mark to Mark)

From:	PLW 113				
Grid		Local		Global	
Easting	-385.117 m	Latitude	N9°26'55.17199"	Latitude	N9°26'50.78858"
Northing	1047659.012 m	Longitude	E118°26'46.88318"	Longitude	E118°26'52.23545"
Elevation	95.265 m	Height	95.710 m	Height	145.869 m

To:	PL 46				
Grid		Local		Global	
Easting	10678.747 m	Latitude	N9°26'56.28696"	Latitude	N9°26'51.91226"
Northing	1047550.297 m	Longitude	E118°32'48.62908"	Longitude	E118°32'53.98117"
Elevation	15.378 m	Height	15.833 m	Height	66.241 m

Vector					
ΔEasting	11063.863 m	NS Fwd Azimuth	89°48'50"	ΔX	-9658.079 m
ΔNorthing	-108.715 m	Ellipsoid Dist.	11035.352 m	ΔY	-5339.316 m
ΔElevation	-79.887 m	ΔHeight	-79.877 m	ΔZ	20.985 m

Standard Errors

Vector errors:					
σ ΔEasting	0.006 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.009 m
σ ΔNorthing	0.003 m	σ Ellipsoid Dist.	0.006 m	σ ΔY	0.012 m
σ ΔElevation	0.014 m	σ ΔHeight	0.014 m	σ ΔZ	0.003 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000858869		
Y	-0.0000752793	0.0001329191	
Z	0.0000004586	0.0000135321	0.0000100914

2

2. PL-318

Vector Components (Mark to Mark)

From:	PPPC				
Grid		Local		Global	
Easting	32253.940 m	Latitude	N9°46'26.84462"	Latitude	N9°46'22.40515"
Northing	1083327.994 m	Longitude	E118°44'19.55192"	Longitude	E118°44'24.87462"
Elevation	18.430 m	Height	18.687 m	Height	68.864 m

To:	PL-318				
Grid		Local		Global	
Easting	9340.850 m	Latitude	N9°24'58.86852"	Latitude	N9°24'54.50099"
Northing	1043950.552 m	Longitude	E118°32'06.39402"	Longitude	E118°32'11.74904"
Elevation	15.881 m	Height	16.365 m	Height	66.814 m

Vector					
ΔEasting	-22913.090 m	NS Fwd Azimuth	209°28'59"	ΔX	16460.213 m
ΔNorthing	-39377.442 m	Ellipsoid Dist.	45447.618 m	ΔY	16500.552 m
ΔElevation	-2.549 m	ΔHeight	-2.322 m	ΔZ	-39016.373 m

Standard Errors

Vector errors:					
σ ΔEasting	0.002 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.004 m
σ ΔNorthing	0.001 m	σ Ellipsoid Dist.	0.002 m	σ ΔY	0.007 m
σ ΔElevation	0.008 m	σ ΔHeight	0.008 m	σ ΔZ	0.002 m

3. PVP-1

Vector Components (Mark to Mark)

From:	PLW-7				
Grid		Local		Global	
Easting	32230.670 m	Latitude	N9°44'29.76476"	Latitude	N9°44'25.33347"
Northing	1079722.760 m	Longitude	E118°44'20.28049"	Longitude	E118°44'25.60607"
Elevation	36.677 m	Height	36.867 m	Height	87.116 m

To:	PVP1				
Grid		Local		Global	
Easting	33860.371 m	Latitude	N9°44'31.66247"	Latitude	N9°44'27.23233"
Northing	1079760.689 m	Longitude	E118°45'13.60677"	Longitude	E118°45'18.93228"
Elevation	17.009 m	Height	17.172 m	Height	67.457 m

Vector					
ΔEasting	1629.701 m	NS Fwd Azimuth	87°56'40"	ΔX	-1410.961 m
ΔNorthing	37.929 m	Ellipsoid Dist.	1626.402 m	ΔY	-807.369 m
ΔElevation	-19.668 m	ΔHeight	-19.695 m	ΔZ	54.174 m

Standard Errors

Vector errors:					
σ ΔEasting	0.001 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.002 m
σ ΔNorthing	0.001 m	σ Ellipsoid Dist.	0.001 m	σ ΔY	0.003 m
σ ΔElevation	0.003 m	σ ΔHeight	0.003 m	σ ΔZ	0.001 m

4. PVP-1A

Vector Components (Mark to Mark)

From:	PVP1				
Grid		Local		Global	
Easting	33860.371 m	Latitude	N9°44'31.66247"	Latitude	N9°44'27.23233"
Northing	1079760.689 m	Longitude	E118°45'13.60677"	Longitude	E118°45'18.93228"
Elevation	17.009 m	Height	17.172 m	Height	67.457 m

To:	PVP1A				
Grid		Local		Global	
Easting	33862.011 m	Latitude	N9°44'32.50133"	Latitude	N9°44'28.07113"
Northing	1079786.501 m	Longitude	E118°45'13.64985"	Longitude	E118°45'18.97534"
Elevation	16.947 m	Height	17.110 m	Height	67.394 m

Vector					
ΔEasting	1.640 m	NS Fwd Azimuth	2°54'59"	ΔX	0.977 m
ΔNorthing	25.812 m	Ellipsoid Dist.	25.805 m	ΔY	-4.508 m
ΔElevation	-0.063 m	ΔHeight	-0.062 m	ΔZ	25.389 m

Standard Errors

Vector errors:					
σ ΔEasting	0.000 m	σ NS fwd Azimuth	0°00'02"	σ ΔX	0.000 m
σ ΔNorthing	0.000 m	σ Ellipsoid Dist.	0.000 m	σ ΔY	0.000 m
σ ΔElevation	0.000 m	σ ΔHeight	0.000 m	σ ΔZ	0.000 m

ANNEX 4. THE LIDAR SURVEY TEAM COMPOSITION

Data Acquisition Component Sub -Team	Designation	Name	Agency / Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	ENGR. CZAR JAKIRI SARMIENTO	UP-TCAGP
		ENGR. LOUIE P. BALICANTA	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUNA	UP-TCAGP
		ENGR. LOVELYN ASUNCION	UP-TCAGP
FIELD TEAM			
LiDAR Operation	Senior Science Research Specialist (SSRS)	JASMINE ALVIAR	UP-TCAGP
		ENGR GEROME HIPOLITO	UP-TCAGP
	Research Associate (RA)	GRACE SINADJAN	UP-TCAGP
	RA	LARAH KRISELLE PARAGAS	UP-TCAGP
	RA	MARY CATHERINE ELIZABETH BALIGUAS	UP-TCAGP
	RA	JONATHAN ALMALVEZ	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	KENNETH QUISADO	UP-TCAGP
	RA	IRO ROXAS	UP-TCAGP

LiDAR Operation	Airborne Security	SSG. OLIVER SACLOT	PHILIPPINE AIR FORCE (PAF)
	Airborne Security	SSG. PRADYUMNA DAS RAMIREZ	PHILIPPINE AIR FORCE (PAF)
	Airborne Security	TSG. JUMAR PARANGUE	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. MARK LAWRENCE TANGONAN	ASIAN AERO-SPACE CORPO-RATION (AAC)
	Pilot	CAPT. NEIL ACHILLES AGAW-IN	AAC
	Pilot	CAPT. RANDY LAGCO	AAC
	Pilot	CAPT. ALBERT LIM	AAC

ANNEX 5. DATA TRANSFER SHEET FOR MALATGAO FLOODPLAIN FLIGHTS

DATA TRANSFER SHEET
7/9/2015(Palawan)

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	
18-Jun	3065P	1BLK42Ac169A	pegasus	1.09	na	7.83	187	37.7	266	20.6	60.1	3.9	1kb	na	96/15	na	Z:\DAC\RAW DATA
28-Jun	3105P	1BLK42QR179A	pegasus	1.45	na	9.25	213	36.9	40	29.4	59.3	9.17	1KB	na	108	na	Z:\DAC\RAW DATA
29-Jun	3109P	1BLK42QR180A	pegasus	988	na	6	147	na	na	18.3	16.3	6.79	1KB	na	108/117	6	Z:\DAC\RAW DATA

Received from

Name
Position
Signature

Received by

Name
Position
Signature

DATA TRANSFER SHEET
PALAWAN 12/08/15

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
20-Nov-15	3513G	2BLK42isIAs324A	GEMINI	NA	176/846	991	180	1.81/13.3	10/74/33	8.14	NA	3.97	1KB	1KB	21/22/16/16/22	NA	Z:\DAC\RAW DATA
21-Nov-15	3517G	2BLK42B325A	GEMINI	NA	32	410	65	4.34	34	2.53	NA	4.14	1KB	1KB	21/22/18/16/19	NA	Z:\DAC\RAW DATA
26-Nov-15	3537G	2BLK42HJ330A	GEMINI	NA	18/218	709	199	NA	NA	11.9	NA	8.03	1KB	1KB	13/13/15/13	NA	Z:\DAC\RAW DATA
27-Nov-15	3541G	2BLK42I331A	GEMINI	NA	265	619	229	NA	NA	24.7	NA	5.79	1KB	1KB	13/13	NA	Z:\DAC\RAW DATA
28-Nov-15	3545G	2BLK42B40A332A	GEMINI	NA	760	667	228	NA	NA	15.8	NA	10.1	1KB	NA	22/21/22/16/16/22	NA	Z:\DAC\RAW DATA
30-Nov-15	3553G	2BLK42HJ334A	GEMINI	NA	202	389	187	NA	NA	16	NA	8.36	1KB	1KB	13/13/13/15	NA	Z:\DAC\RAW DATA
30-Nov-15	3555G	2BLK42JK334B	GEMINI	NA	76	495	238	NA	NA	19.1	NA	8.36	1KB	1KB	13/15	NA	Z:\DAC\RAW DATA
1-Dec-15	3557G	2BLK42HsL335A	GEMINI	NA	226	447	195	NA	NA	19	NA	4.3	1KB	1KB	22/24/22	NA	Z:\DAC\RAW DATA
3-Dec-15	3565G	2BLK42PQR337A	GEMINI	NA	NA	535	202	NA	NA	25.4	NA	6.96	1KB	1KB	22/24/22/48/51	NA	Z:\DAC\RAW DATA

Received from

Name
Position
Signature

Received by

Name
Position
Signature

ANNEX 6. FLIGHT LOGS FOR THE FLIGHT MISSIONS

1. Flight Log for 3065P Mission

PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 3065P

1 LiDAR Operator: C Sinadjan	2 ALTM Model: PEG	3 Mission Name: 1BLK42AC169A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9022
7 Pilot: M Tangonan	8 Co-Pilot: J Joya	9 Route:			
10 Date: 6-18-15	12 Airport of Departure (Airport, City/Province): RPVP		12 Airport of Arrival (Airport, City/Province): RPVP		
13 Engine On: 9:01	14 Engine Off: 12:13	15 Total Engine Time: 3+12	16 Take off: 9:06	17 Landing: 12:08	18 Total Flight Time: 3+02
19 Weather: partly cloudy					

20 Flight Classification

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

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

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

21 Remarks

Completed lines in BLK 42AC

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

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

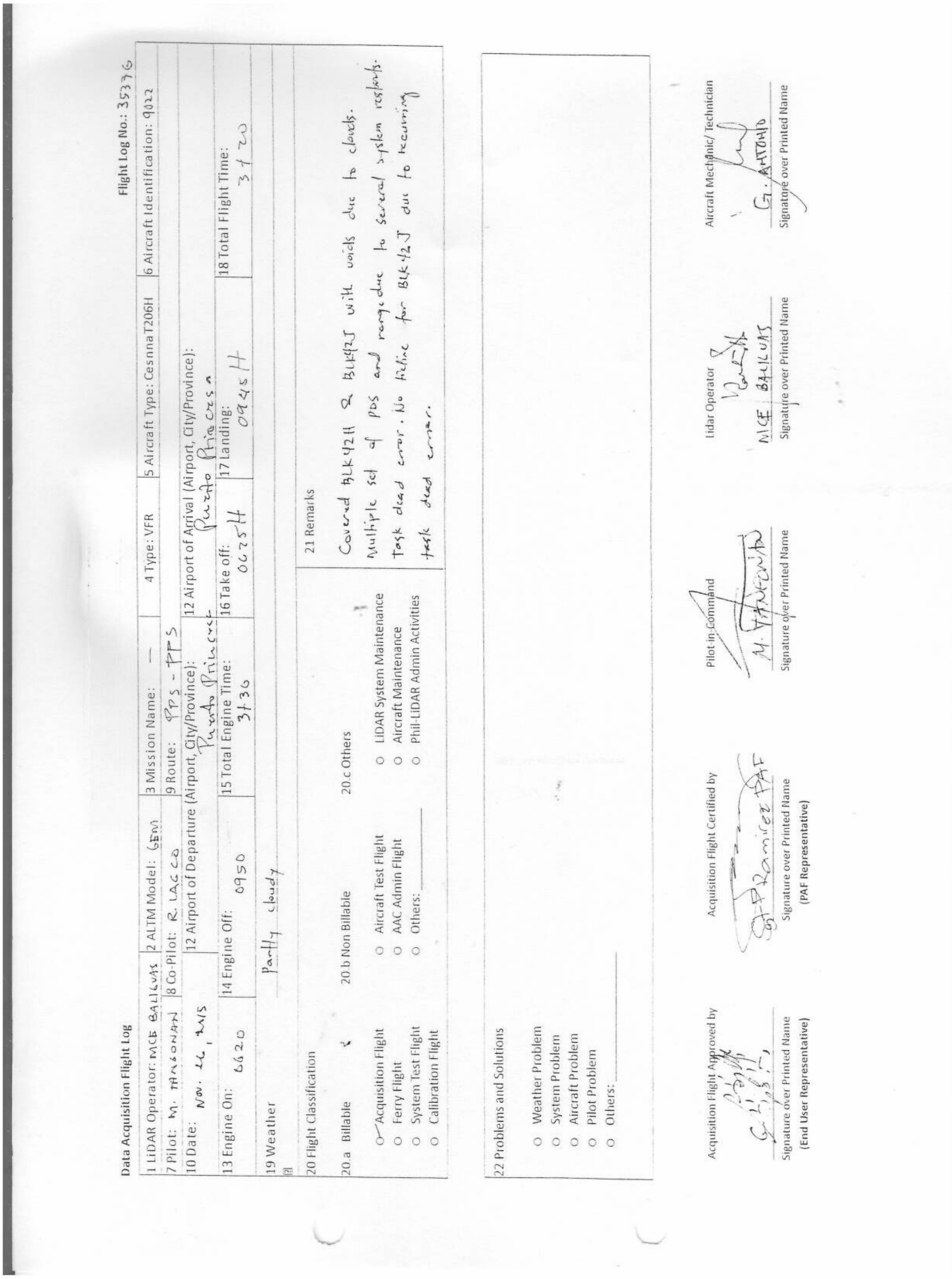
Acquisition Flight Certified by: SSC [signature] Signature over Printed Name (PAF Representative)

Pilot-in-Command: M.C. Tangonan [signature] Signature over Printed Name

LiDAR Operator: Grace Sinadjan [signature] Signature over Printed Name

Aircraft Mechanic/ LiDAR Technician: N/A Signature over Printed Name

2. Flight Log for 3537G Mission



Data Acquisition Flight Log

Flight Log No.: 3537G

1 LiDAR Operator: MCE BALICUAS	2 ALTM Model: GEM	3 Mission Name: —	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9022
7 Pilot: M. TANGONAN	8 Co-Pilot: R. LAGCO	9 Route: PPS - PPS			
10 Date: Nov. 26, 2015	12 Airport of Departure (Airport, City/Province): Puerto Princesa		12 Airport of Arrival (Airport, City/Province): Puerto Princesa		
13 Engine On: 0620	14 Engine Off: 0950	15 Total Engine Time: 3+30	16 Take off: 0625H	17 Landing: 0945H	18 Total Flight Time: 3+20
19 Weather: Partly cloudy					

20 Flight Classification

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

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

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

21 Remarks

Covered BLK42H & BLK42J with voids due to clouds. Multiple set of PDS and range due to several system restarts. Task dead error. No tieline for BLK42J due to recurring task dead error.

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

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

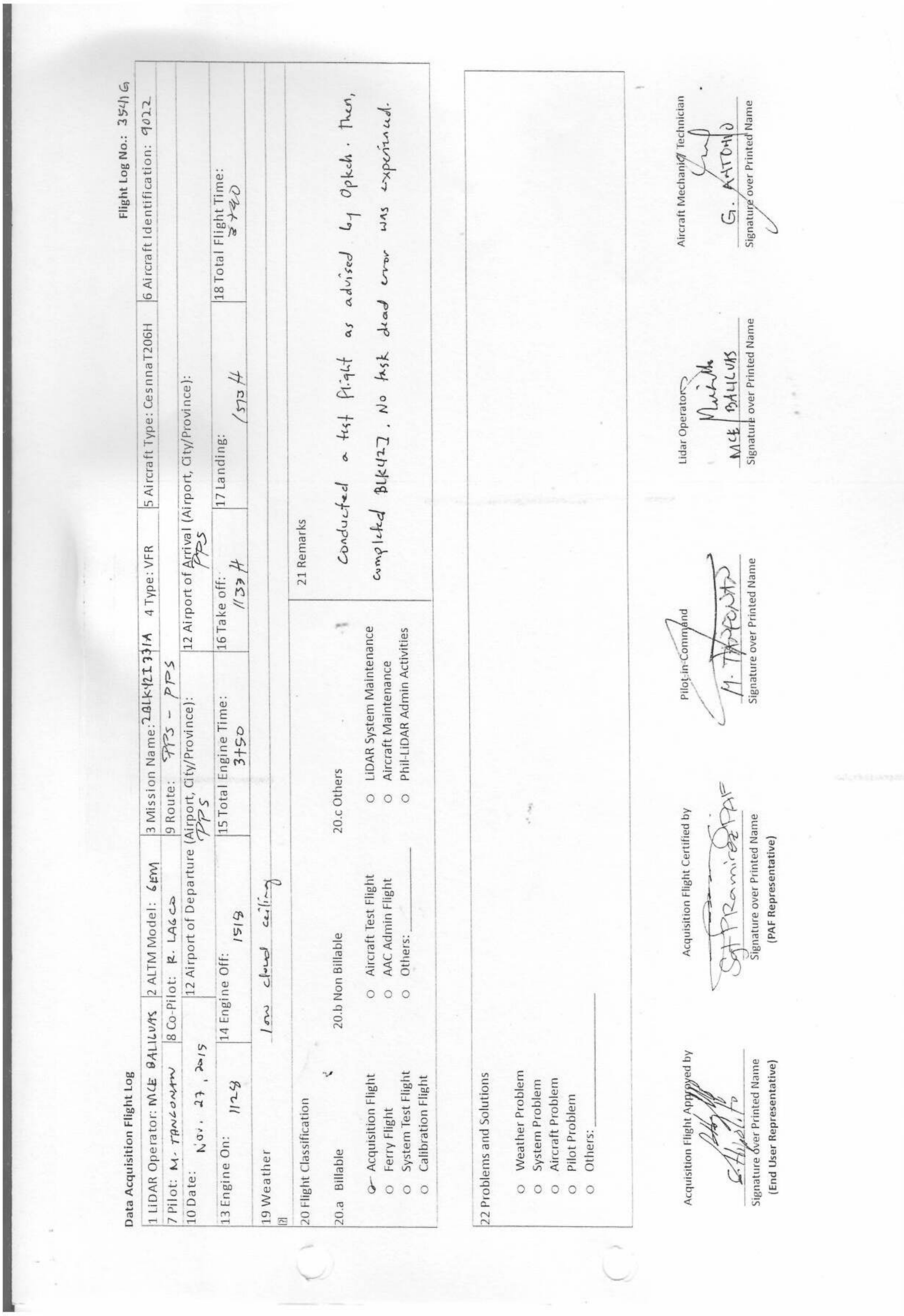
Acquisition Flight Certified by: SSgt P Ramirez PAF — Signature over Printed Name (PAF Representative)

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

Lidar Operator: MCE BALICUAS — Signature over Printed Name

Aircraft Mechanic/ Technician: G. ANTONIO — Signature over Printed Name

3. Flight Log for 3541G Mission



Data Acquisition Flight Log

Flight Log No.: 3541G

1 LiDAR Operator: MCE BALICUAS	2 ALTM Model: GEM	3 Mission Name: 2BLK42I331A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9022
7 Pilot: M. TANGONAN	8 Co-Pilot: R. LAGCO	9 Route: PPS - PPS			
10 Date: Nov. 27, 2015	12 Airport of Departure (Airport, City/Province): PPS		12 Airport of Arrival (Airport, City/Province): PPS		
13 Engine On: 1128	14 Engine Off: 1518	15 Total Engine Time: 3+50	16 Take off: 1133H	17 Landing: 1513H	18 Total Flight Time: 3+40
19 Weather: low cloud ceiling					

20 Flight Classification

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

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

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

21 Remarks

Conducted a test flight as advised by Opkch. Then, completed BLK42I. No task dead error was experienced.

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

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

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

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

Lidar Operator: MCE BALICUAS — Signature over Printed Name

Aircraft Mechanic/ Technician: G. ANTONIO — Signature over Printed Name

4. Flight Log for 3553G Mission

Data Acquisition Flight Log

Flight Log No.: 3553

1 LiDAR Operator: J. Almalvez	2 ALTM Model: Gem	3 Mission Name: 2BLK42H1334A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9022
7 Pilot: A. Lim	8 Co-Pilot: P. Lagao	9 Route: PPS - PPS			
10 Date: Nov 30, 2015	12 Airport of Departure (Airport, City/Province): PPS		12 Airport of Arrival (Airport, City/Province): PPS		
13 Engine On: 0451H	14 Engine Off: 1020H	15 Total Engine Time: 5+29	16 Take off: 0456H	17 Landing: 1015H	18 Total Flight Time: 5+19
19 Weather: Cloudy					

20 Flight Classification

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

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

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

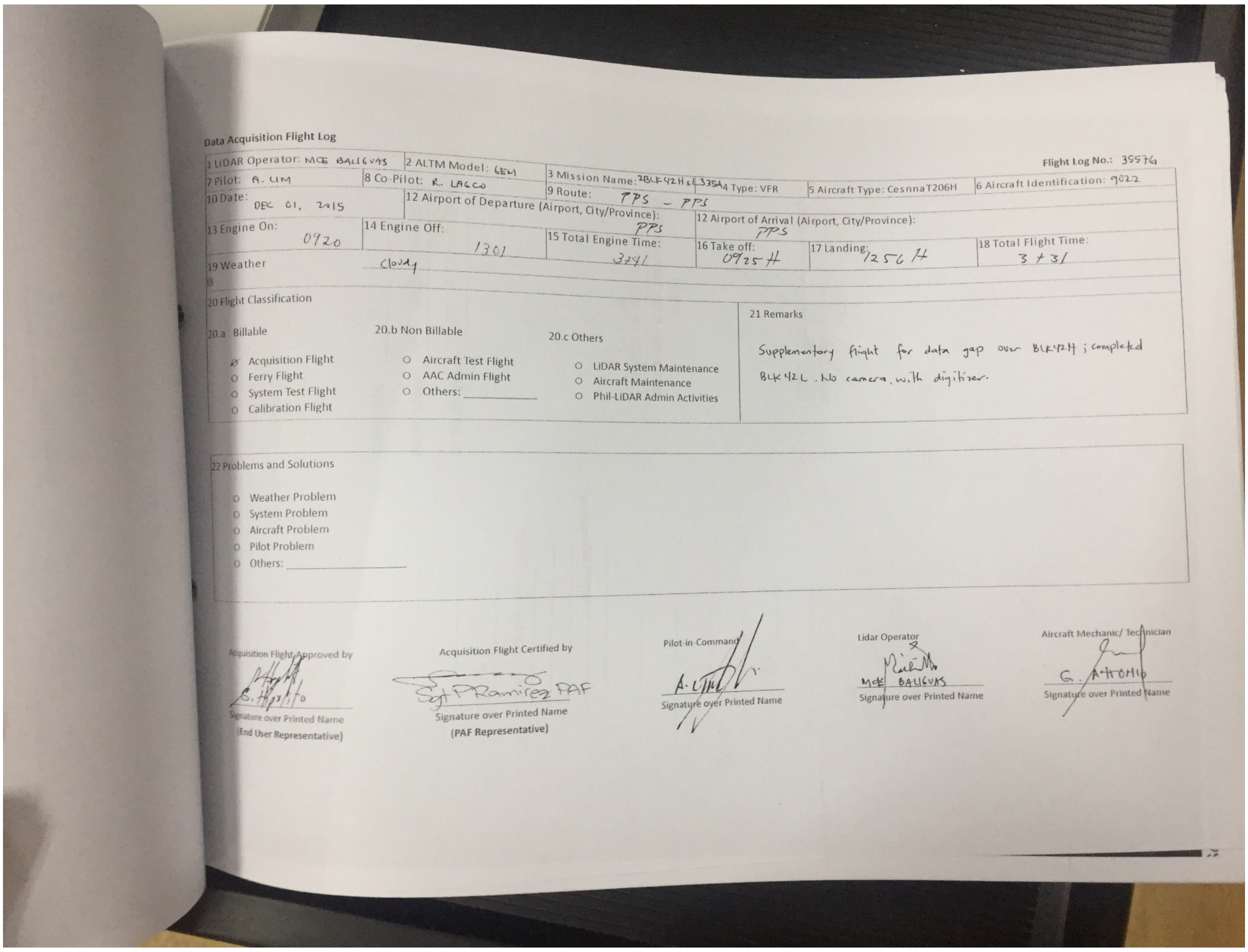
21 Remarks

Surveyed 4 lines of BLK42K & 8 lines of BLK42A & covered voids

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator	Aircraft Mechanic/ Technician
G. Higbi, Ph	Sgt P Ramirez PAF	A. Lim	J. Almalvez	N/A
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

5. Flight Log for 3557G Mission


Data Acquisition Flight Log

Flight Log No.: 3557G

1 LiDAR Operator: MCE BALIGUAS
2 ALTM Model: GEM
3 Mission Name: 2BLK42Hs L335A
4 Type: VFR
5 Aircraft Type: CesnnaT206H
6 Aircraft Identification: 9022
7 Pilot: A. LIM
8 Co-Pilot: R. LAGCO
9 Route: PPS - PPS
10 Date: DEC 01, 2015
12 Airport of Departure (Airport, City/Province): PPS
12 Airport of Arrival (Airport, City/Province): PPS
13 Engine On: 0920
14 Engine Off: 1301
15 Total Engine Time: 3+41
16 Take off: 0925 H
17 Landing: 1256 H
18 Total Flight Time: 3+31
19 Weather: Cloudy

20 Flight Classification

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

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

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

21 Remarks

Supplementary flight for data gap over BLK42H; completed BLK42L. No camera, with digitizer.

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

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

Acquisition Flight Certified by: Sgt P Ramirez PAF — Signature over Printed Name (PAF Representative)

Pilot-in-Command: A. LIM — Signature over Printed Name

Lidar Operator: MCE BALIGUAS — Signature over Printed Name

Aircraft Mechanic/ Technician: G. ANTONIO — Signature over Printed Name

ANNEX 7. FLIGHT STATUS REPORT

FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS

3065P	BLK 42Ac	1BLK42Ac169A	G. Sinadjan	June 18, 2015	Surveyed BLK 42Ac, east coast; precipitation in some parts of area
3537G	BLK 42H and BLK 42J	2BLK42HJ330A	MCE Baligu-as	November 26, 2015	Cloudy; Multiple POS and range data due to several system restarts by task dead problem; 2 lines in J, no tie line due to tdp, pls use 3553 & 3555's tie line then integrate
3541G	BLK 42 I	2BLK42I331A	MCE Baligu-as	November 27, 2015	Conducted test flight, no tdp experienced so proceed to acquisition; base is a bit far; 1 line in BLK42 H
3553G	BLK 42H	2BLK42HJ334A	JM Almalvez	November 30, 2015	Surveyed 4 lines of BLK42J and 8 lines of BLK42H and covered voids from previous flight.
3557	BLK42 eH, Ks	2BLK42HsL335A	MCE Baligu-as	Dece,mber 1, 2015	Supplementary flight for data gap over BLK42eH and completed BLK42Ks. No camera, with digitizer.

SWATH PER FLIGHT MISSION

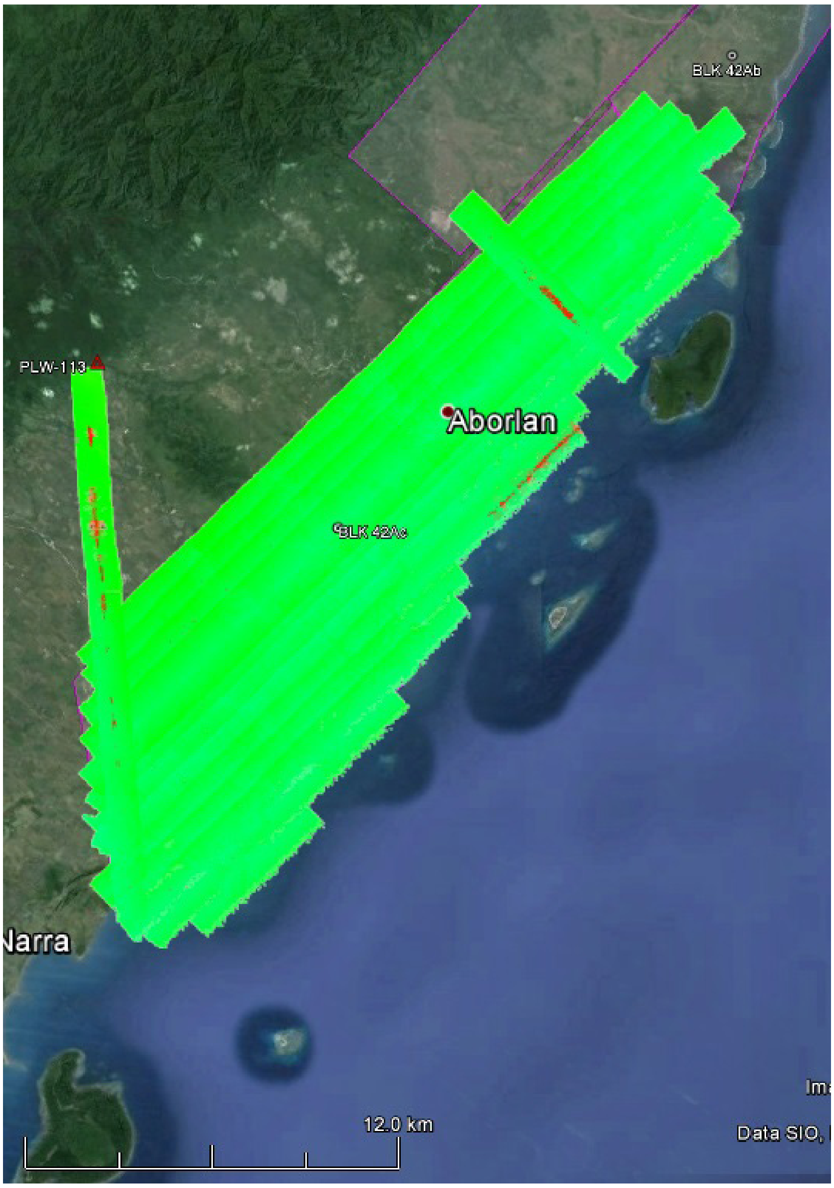
Flight No. : 3065P

Area: BLK 42Ac

Mission Name: 1BLK42Ac169A

Parameters:	Altitude: 1000	Scan Frequency: 30
	Scan Angle: 25	Overlap: 30

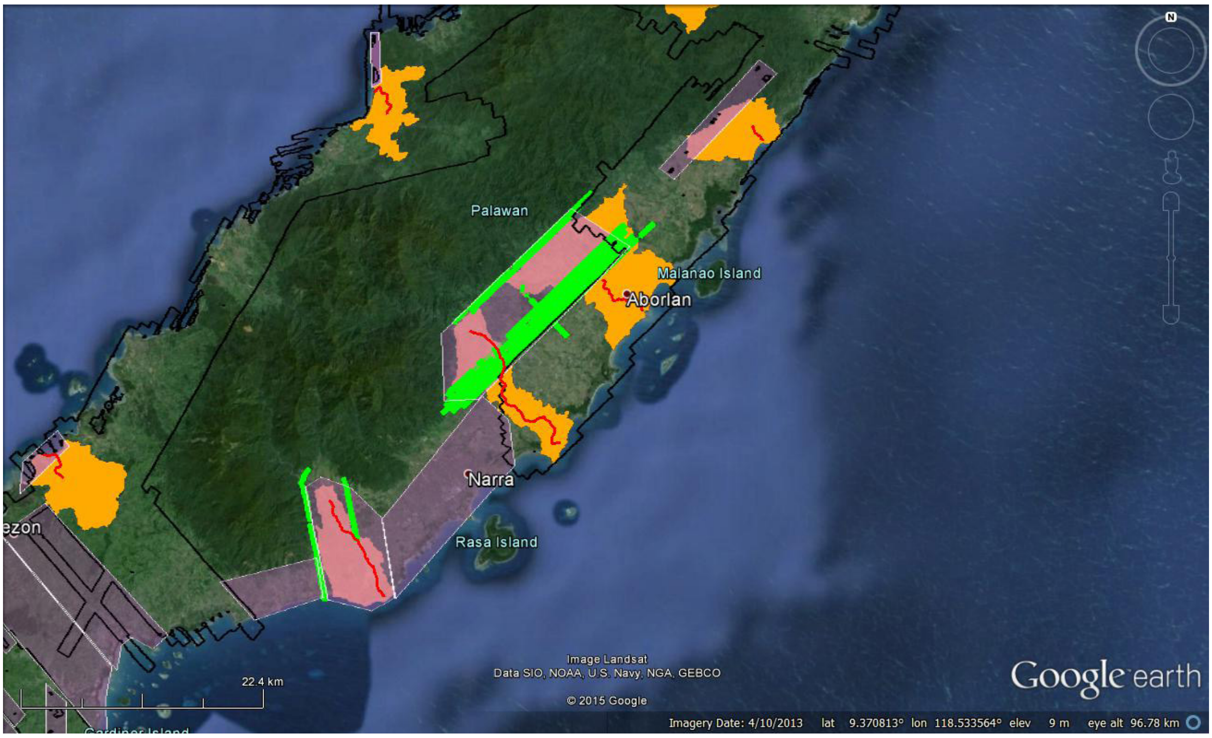
SWATH



Flight No. :	3537GP	
Area:	BLK 42H and J	
Mission Name:	2BLK42HJ330A	
Parameters:	Altitude: 1100/1000/850	Scan Frequency: 50

Scan Angle: 26/30/40 Overlap: 30

SWATH



Flight No. : 3541GP

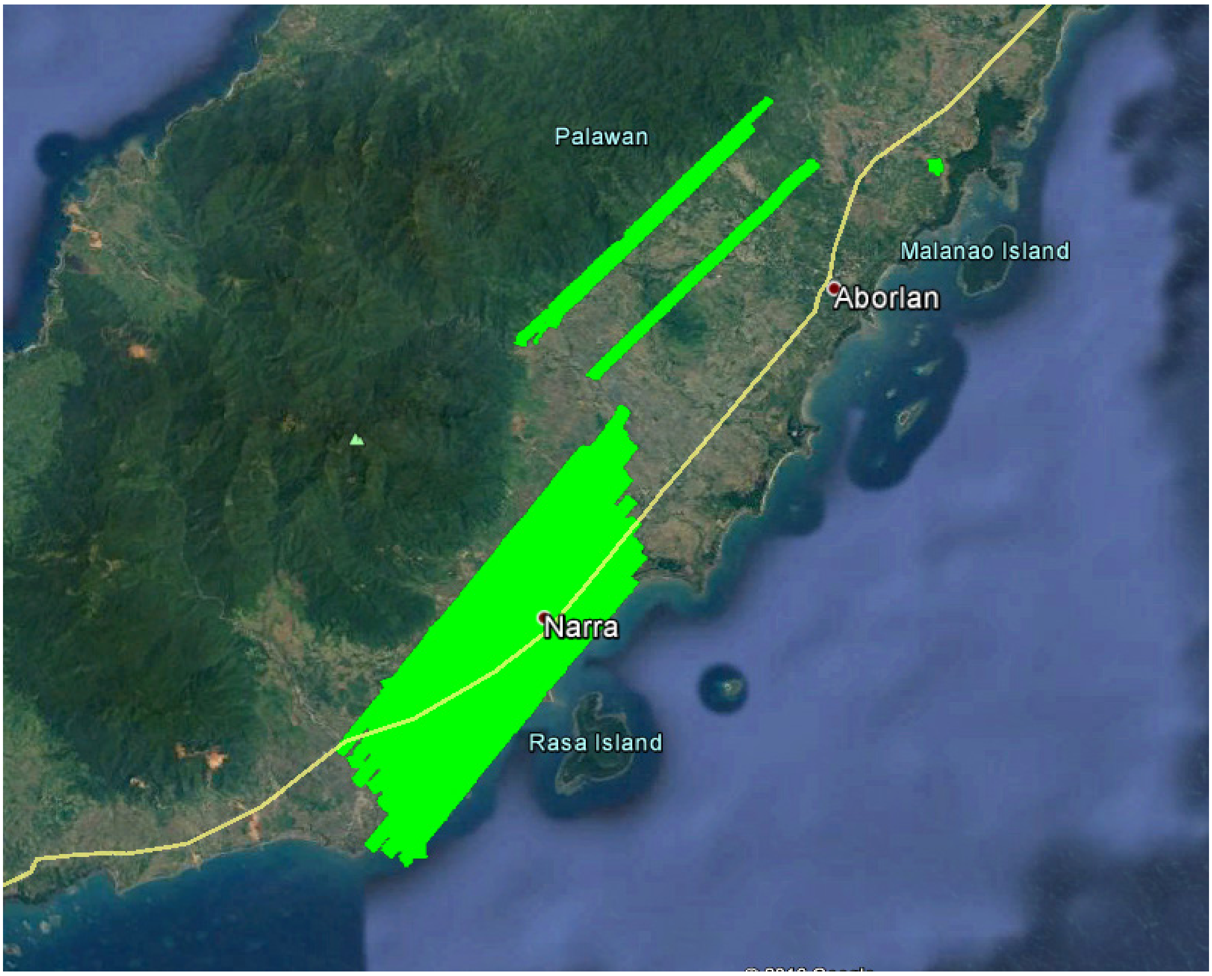
Area: BLK 42i

Mission Name: 2BLK42I331A

Parameters: Altitude: 850 Scan Frequency: 50

Scan Angle: 40 Overlap: 30

SWATH



Flight No. : 3553G

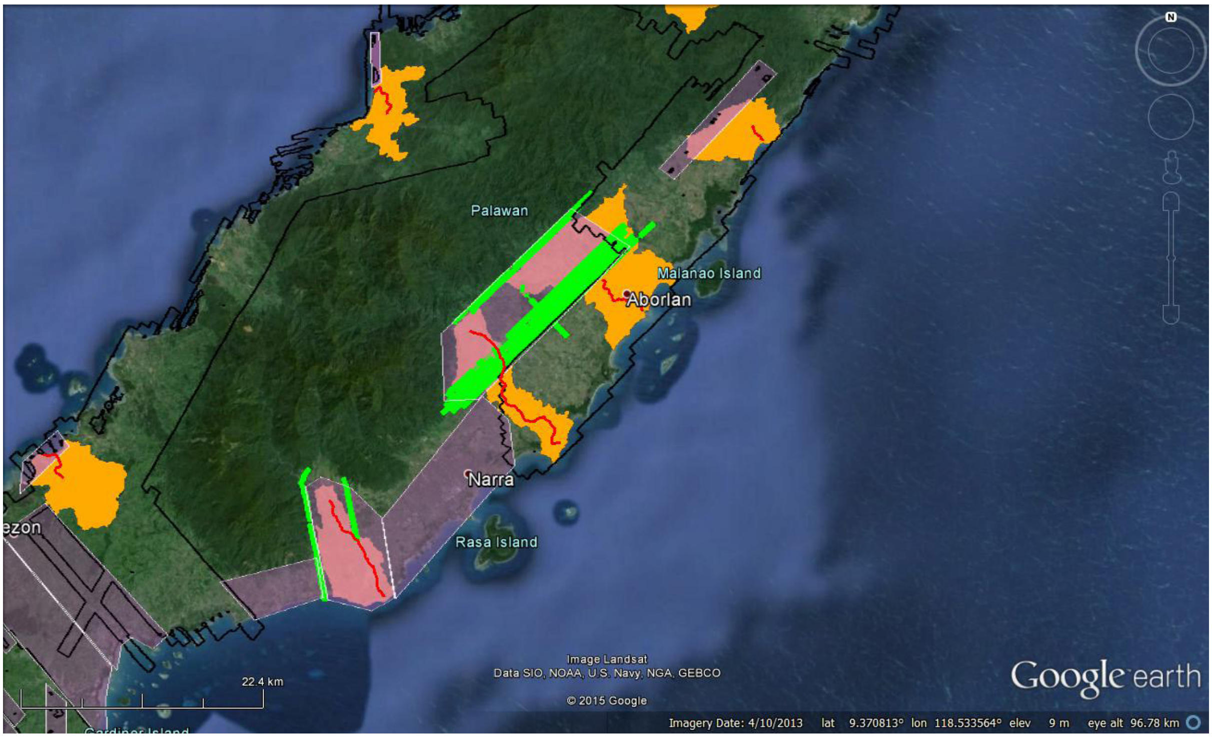
Area: BLK 42H and J

Mission Name: 2BLK42HJ334A

Parameters: Altitude: 1000 Scan Frequency: 50

Scan Angle: 26 Overlap: 30

SWATH



Flight No. : 3557G

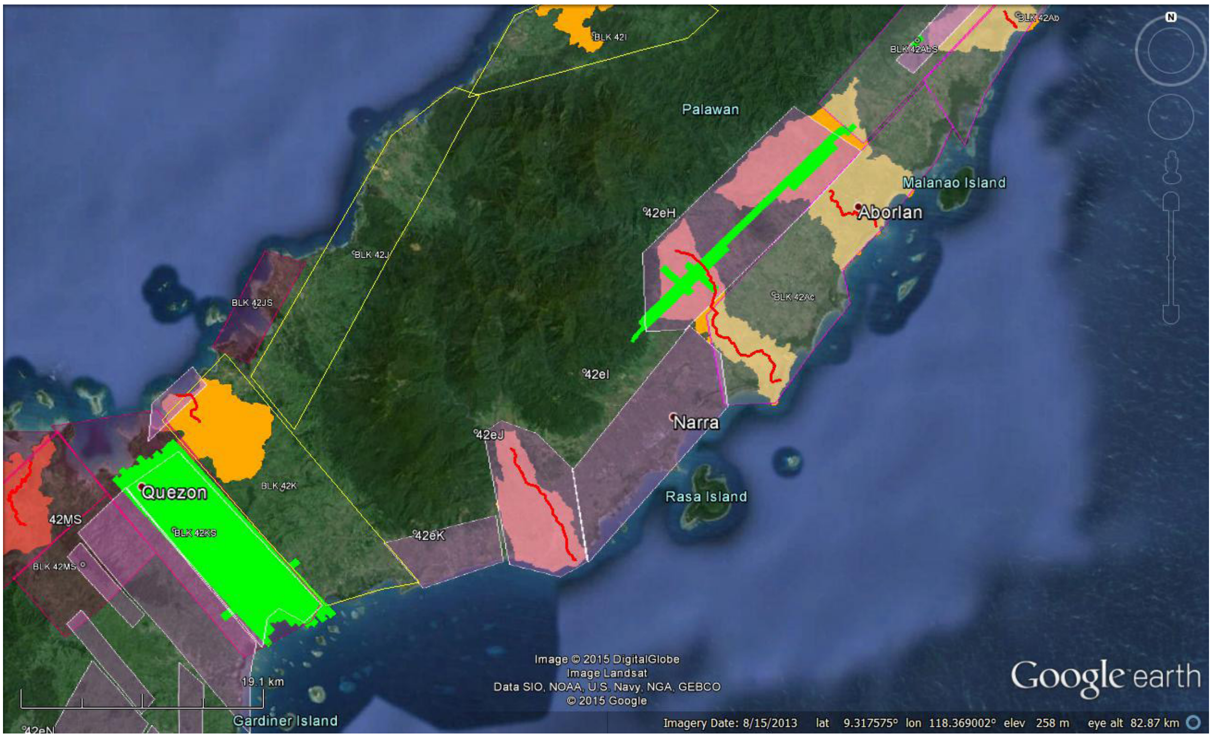
Area: BLK 42eH, Ks

Mission Name: 2BLK45HsL335A

Parameters: Altitude: 1000 Scan Frequency: 50

Scan Angle: 20 Overlap: 30

SWATH



ANNEX 8. MISSION SUMMARY REPORTS [MISSING]

ANNEX 9. MALATGAO MODEL BASIN PARAMETERS

Subbasin	SCS CURVE NUMBER LOSS			CLARK UNIT HYDROGRAPH TRANSFORM		RECESSION BASEFLOW		
	Initial Abstraction (MM)	Curve Number	Imperviousness (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Discharge (CU.M/S)	Recession Constant	Ratio to Peak
W1000	5.60536	49.401	0.0	1.299	6.917	0.0014421	0.0882133	0.43407
W1010	5.60472	50.398	0.0	0.1398	5.5715	.00096299	0.0585284	0.43407

W1020	3.75592	35.218	0.0	0.0752	1.3822	3.82986E-5	0.0585185	0.061965
W1030	2.51648	35.218	0.0	3.2431	6.3203	0.0013871	0.20048	0.43407
W1040	1.2695	88.893	0.0	2.2860	3.7308	0.0015018	1	0.5
W1050	1.4690	87.367	0.0	1.6971	2.7697	.000884814	1	0.5
W1080	1.2844	88.777	0.0	1.9132	3.1224	.000817919	1	0.5
W1090	5.9960	62.88704	0.0	1.9315	3.1522	0.0018518	1	0.5
W1130	1.24	89	0.0	2.3212	3.7882	.000806175	1	0.5
W1140	5.46424	51.611	0.0	1.6989	4.1021	.000691325	0.0878	0.29528
W1180	28.56	46.707	0.0	0.14518	8.642	.000767644	0.44882	0.44388
W1190	1.7218	85.509	0.0	0.10919	0.17820	2.55324E-6	1	0.5
W540	8.28	55	0.0	0.98488	1.6073	0.0017476	1	0.5
W550	8.28	55	0.0	1.0004	1.6326	.000836535	1	0.5
W560	8.28	55	0.0	1.9158	3.1266	0.0043848	1	0.5
W570	8.28	55	0.0	1.4220	2.3207	0.0022755	1	0.5
W580	8.28	55	0.0	1.2331	2.0125	0.0016314	1	0.5
W590	8.28	55	0.0	1.9158	3.1265	0.0028854	1	0.5
W600	8.28	55	0.0	0.88974	1.4521	0.0012496	1	0.5
W610	8.28	55	0.0	1.6162	2.6376	0.0031630	1	0.5
W620	8.28	55	0.0	1.2519	2.0431	0.0017835	1	0.5
W630	8.28	55	0.0	0.61841	1.0093	.000211733	1	0.5
W640	8.28	55	0.0	1.4132	2.3063	0.0012729	1	0.5
W650	8.28	55	0.0	1.0337	1.6870	0.0016751	1	0.5
W660	8.28	55	0.0	0.57817	0.94357	.000165729	1	0.5
W670	8.28	55	0.0	0.81932	1.3371	.000978402	1	0.5
W680	8.28	55	0.0	0.96753	1.5790	0.0016373	1	0.5
W690	8.28	55	0.0	1.5370	2.5083	0.0010710	1	0.5
W710	8.28	55	0.0	1.8211	2.9720	0.0027517	1	0.5
W720	8.28	55	0.0	2.2943	3.7443	0.0040202	1	0.5
W730	8.28	55	0.0	1.3240	2.1608	0.0013373	1	0.5
W740	8.28	55	0.0	1.4007	2.2860	0.0012247	1	0.5
W750	8.28	55	0.0	2.1730	3.5463	0.0045788	1	0.5
W760	8.28	55	0.0	1.2860	2.0988	0.0022287	1	0.5
W770	8.28	55	0.0	1.4203	2.3179	0.0017728	1	0.5
W780	8.28	55	0.0	1.0300	1.6810	0.0012231	1	0.5
W790	8.28	55	0.0	1.2166	1.9855	0.0014393	1	0.5
W800	2.9919	77.251	0.0	1.0490	1.7120	0.0015462	1	0.5
W810	8.28	55	0.0	0.81964	1.3377	.000507352	1	0.5
W820	3.4811	74.481	0.0	1.0581	1.7268	0.0012447	1	0.5
W830	1.24	89	0.0	0.46396	0.75719	3.78344E-5	1	0.5
W840	6.8210	59.832	0.0	2.9078142	4.7456	0.0025194	1	0.5
W850	1.7847	85.059	0.0	1.8207	2.9713	.000832032	1	0.5
W860	8.28	55	0.0	0.50595	0.82570	.000111229	1	0.5
W870	16.2096	37.072	0.0	0.66288	9.0195	0.0047179	0.0166469	0.4706
W880	8.28	55	0.0	1.3078	2.1344	0.0020681	1	0.5
W900	8.28	55	0.0	1.8452	3.0114	0.0033132	1	0.5
W910	8.28	55	0.0	1.1158	1.8211	0.0012406	1	0.5
W920	2.49216	43.097	0.0	2.094	29.245	0.0052702	0.27332	0.46119

W930	9.288	35.51	0.0	0.92469	11.309	0.0051230	0.12995	0.44485
W940	2.49232	35.342	0.0	0.63521	17.983	0.0011944	0.19065	0.45196
W950	4.33912	35.243	0.0	0.36359	11.048	0.0014053	0.20048	0.4447
W960	3.00328	46.786	0.0	1.4845	3.5075	0.0015701	0.0390222	0.20087
W970	3.62656	78.438	0.0	0.0737	2.082	2.69251E-6	0.13167	0.09108
W980	13.0672	41.118	0.0	1.0351	13.877	0.0073976	0.19254	0.45601
W990	5.71816	50.221	0.0	0.11728	17.069	0.0011974	0.12392	0.4706

ANNEX 10. MALATGAO MODEL REACH PARAMETERS

REACH	MUSKINGUM CUNGE CHANNEL ROUTING						
	Time Step Method	Length (M)	Slope(M/M)	Manning's n	Shape	Width (M)	Side Slope (xH:1V)
R110	Automatic Fixed Interval	638.41	0.0382323	0.04	Trapezoid	30	1
R1100	Automatic Fixed Interval	3297.2	0.0255215	0.04	Trapezoid	30	1
R1150	Automatic Fixed Interval	1298.1	0.0040677	0.00882	Trapezoid	30	1
R1200	Automatic Fixed Interval	42.426	.000230893	0.04	Trapezoid	30	1
R130	Automatic Fixed Interval	2752.2	0.0772164	0.04	Trapezoid	30	1
R150	Automatic Fixed Interval	1394.4	0.0386163	0.04	Trapezoid	30	1
R170	Automatic Fixed Interval	3262.6	0.0241845	0.04	Trapezoid	30	1
R180	Automatic Fixed Interval	4769.0	0.0197306	0.04	Trapezoid	30	1
R200	Automatic Fixed Interval	1907.5	0.0365448	0.04	Trapezoid	30	1
R220	Automatic Fixed Interval	1695.7	0.0556103	0.04	Trapezoid	30	1
R230	Automatic Fixed Interval	1766.1	0.0042699	0.04	Trapezoid	30	1
R260	Automatic Fixed Interval	486.27	0.0046510	0.04	Trapezoid	30	1
R290	Automatic Fixed Interval	4600.7	0.0117281	0.04	Trapezoid	30	1
R300	Automatic Fixed Interval	1586.1	0.11207	0.04	Trapezoid	30	1
R310	Automatic Fixed Interval	1895.8	0.0077227	0.04	Trapezoid	30	1
R320	Automatic Fixed Interval	3931.6	0.0141880	0.04	Trapezoid	30	1
R330	Automatic Fixed Interval	436.98	0.14089	0.04	Trapezoid	30	1
R360	Automatic Fixed Interval	2284.6	0.0071590	0.004	Trapezoid	30	1
R40	Automatic Fixed Interval	1266.4	0.0447551	0.04	Trapezoid	30	1
R410	Automatic Fixed Interval	124.85	0.0166430	0.0090625	Trapezoid	30	1
R430	Automatic Fixed Interval	2522.8	0.0040005	0.009	Trapezoid	30	1
R450	Automatic Fixed Interval	2200.7	0.0040481	0.008863	Trapezoid	30	1
R460	Automatic Fixed Interval	3546.1	0.0049122	0.0040043	Trapezoid	30	1
R470	Automatic Fixed Interval	1562.7	.000305443	0.0044189	Trapezoid	30	1
R480	Automatic Fixed Interval	311.42	0.0043068	0.0026133	Trapezoid	30	1
R520	Automatic Fixed Interval	1801.0	0.0040677	0.04	Trapezoid	30	1
R530	Automatic Fixed Interval	2231.3	0.0043068	0.04	Trapezoid	30	1
R70	Automatic Fixed Interval	2182.1	0.0472501	0.04	Trapezoid	30	1
R90	Automatic Fixed Interval	738.41	0.0268328	0.04	Trapezoid	30	1

ANNEX 11. MALATGAO FIELD VALIDATION POINTS

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event	Date	Rain Return/Scenario
	Latitude	Longitude						
1	9.358069	118.4157	0.15	0	-0.15			25-Year
2	9.360117	118.4152	0.69	0	-0.69			25-Year
3	9.361156	118.4161	1.05	0.74	-0.31	Yolanda	November 2013	25-Year
4	9.360639	118.417	0.73	0.4	-0.33	Ondoy	September 2009	25-Year
5	9.3602	118.4182	0.39	0	-0.39			25-Year
6	9.359043	118.4141	0.12	0	-0.12			25-Year
7	9.362554	118.411	0.05	0	-0.05			25-Year
8	9.361185	118.4109	2.29	0.36	-1.93	Yolanda	November 2013	25-Year
9	9.360539	118.4122	1.09	0	-1.09			25-Year
10	9.343924	118.4744	0.17	1.3	1.13		January 2010	25-Year
11	9.342509	118.473	0.03	0	-0.03			25-Year
12	9.340347	118.4632	0.03	0	-0.03			25-Year
13	9.34344	118.4602	0.03	0	-0.03			25-Year
14	9.347868	118.4556	0.03	0	-0.03			25-Year
15	9.343745	118.4525	2.98	1	-1.98		2010	25-Year
16	9.336843	118.4685	0.03	0	-0.03			25-Year
17	9.337771	118.4695	0.07	0	-0.07			25-Year
18	9.33875	118.4702	0.03	0	-0.03			25-Year
19	9.340483	118.4714	0.96	0	-0.96			25-Year
20	9.306278	118.4624	0.37	0.74	0.37	Rainfall	Nov. 2016	25-Year
21	9.309411	118.4612	0.35	0.4	0.05	Lawin	Oct. 2016	25-Year
22	9.310841	118.4597	0.1	0.15	0.05		2013	25-Year
23	9.31303	118.458	0.03	0	-0.03			25-Year
24	9.313913	118.4569	0.03	0	-0.03			25-Year
25	9.315318	118.4555	0.03	0	-0.03			25-Year
26	9.31789	118.4541	1.11	0.36	-0.75		Dec. 2014	25-Year
27	9.319286	118.4557	0.03	0	-0.03			25-Year
28	9.304843	118.4904	0.15	0	-0.15			25-Year
29	9.310989	118.4856	0.44	0.22	-0.22	Yolanda	Nov. 2013	25-Year
30	9.31104	118.4825	0.39	0.88	0.49		Nov. 2010	25-Year
31	9.312081	118.4788	0.05	0.91	0.86		Jan. 2013	25-Year
32	9.313166	118.475	0.04	0	-0.04			25-Year
33	9.31556	118.4665	0.03	0.39	0.36		2011	25-Year
34	9.321118	118.4818	0.91	0	-0.91			25-Year
35	9.321672	118.4807	0.72	0	-0.72			25-Year
36	9.322659	118.4777	0.03	0.1	0.07	Lawin	Oct. 2016	25-Year
37	9.323711	118.4753	0.26	0.23	-0.03	Yolanda	Nov. 2013	25-Year

38	9.325601	118.4711	0.69	0	-0.69			25-Year
39	9.32375	118.4637	0.03	0	-0.03			25-Year
40	9.323089	118.4963	1.4	0	-1.4			25-Year
41	9.322911	118.4967	1.58	0	-1.58			25-Year
42	9.323949	118.491	0.44	0	-0.44			25-Year
43	9.331886	118.4787	1.19	0	-1.19			25-Year
44	9.330282	118.4641	2.23	0.51	-1.72		42664	25-Year
45	9.33104	118.4648	2.16	0.73	-1.43		Jan. 2014	25-Year
46	9.331664	118.4653	2.85	0.4	-2.45		Oct. 2003	25-Year
47	9.371554	118.4475	2.7	1.35	-1.35	Lawin	Oct. 2016	25-Year
48	9.372669	118.4476	3.54	0.86	-2.68	Lawin	Oct. 2016	25-Year
49	9.373978	118.4488	2.48	0.46	-2.02	Lawin	Oct. 2016	25-Year
50	9.374589	118.4507	0.03	0	-0.03			25-Year
51	9.374925	118.4537	0.33	0	-0.33			25-Year
52	9.322992	118.4587	0.06	0	-0.06			25-Year
53	9.325589	118.461	4.26	0	-4.26			25-Year
54	9.327069	118.4617	3.57	0	-3.57			25-Year
55	9.331333	118.4657	3.82	0	-3.82			25-Year
56	9.332555	118.4665	1.68	0	-1.68			25-Year
57	9.334656	118.4682	1.49	0	-1.49			25-Year
58	9.335508	118.4683	0.03	0	-0.03			25-Year
59	9.33582	118.4683	0.03	0	-0.03			25-Year
60	9.336529	118.4687	0.03	0	-0.03			25-Year
61	9.337513	118.4695	0.03	0	-0.03			25-Year
62	9.339175	118.4708	0.03	0	-0.03			25-Year
63	9.341743	118.4728	0.03	0	-0.03			25-Year
64	9.34237	118.4732	0.03	0	-0.03			25-Year
65	9.344618	118.4749	0.03	0	-0.03			25-Year
66	9.345457	118.4755	0.07	0	-0.07			25-Year
67	9.346293	118.4761	0.06	0	-0.06			25-Year
68	9.32334	118.4573	0.09	0	-0.09			25-Year
69	9.324103	118.4581	0.03	0	-0.03			25-Year
70	9.324445	118.459	0.06	0	-0.06			25-Year
71	9.331924	118.4648	3.24	0	-3.24			25-Year
72	9.332712	118.4653	3	0	-3			25-Year
73	9.336749	118.4676	0.03	0	-0.03			25-Year
74	9.337669	118.4688	0.03	0	-0.03			25-Year
75	9.338316	118.4696	0.09	0	-0.09			25-Year
76	9.338743	118.47	0.03	0	-0.03			25-Year
77	9.339318	118.4705	0.07	0	-0.07			25-Year
78	9.342995	118.4707	0.08	0	-0.08			25-Year
79	9.342481	118.4725	0.03	0	-0.03			25-Year
80	9.342847	118.4728	0.14	0	-0.14			25-Year
81	9.343418	118.4732	0.97	0	-0.97			25-Year

ANNEX 12. EDUCATIONAL INSTITUTIONS AFFECTED BY FLOODING IN MAGATLAO FLOODPLAIN

There are no medical institutions affected in this river basin

ANNEX 13. MEDICAL INSTITUTIONS AFFECTED BY FLOODING IN MAGATLAO FLOODPLAIN

There are no medical institutions affected in this river basin

Annex 14. Phil-LiDAR 1 UPLB Team Composition

Project Leader
Asst. Prof. Edwin R. Abucay (CHE, UPLB)

Project Staffs/Study Leaders
Asst. Prof. Efraim D. Roxas (CHE, UPLB)
Asst. Prof. Joan Pauline P. Talubo (CHE, UPLB)
Ms. Sandra Samantela (CHE, UPLB)
Dr. Cristino L. Tiburan (CFNR, UPLB)
Engr. Ariel U. Glorioso (CEAT, UPLB)
Ms. Miyah D. Queliste (CAS, UPLB)
Mr. Dante Gideon K. Vergara (SESAM, UPLB)

Sr. Science Research Specialists
Gillian Katherine L. Inciong
For. John Alvin B. Reyes

Research Associates
Alfi Lorenz B. Cura
Angelica T. Magpantay
Gemmalyn E. Magnaye
Jayson L. Arizapa
Kevin M. Manalo
Leendel Jane D. Punzalan
Maria Michaela A. Gonzales
Paulo Joshua U. Quilao
Sarah Joy A. Acepcion
Ralphael P. Gonzales

Computer Programmers
Ivan Marc H. Escamos
Allen Roy C. Roberto

Information Systems Analyst
Jan Martin C. Magcale

Project Assistants
Daisili Ann V. Pelegrina
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