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

LiDAR Surveys and Flood Mapping of Langogan River

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

April 2017

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

This research project is supported by the Department of Science and Technology (DOST)

E.C. Paringit, E.R. Abucay, (Eds.), (2017), LiDAR Surveys and Flood Mapping of Langogan River, in Enrico C. Paringit, (Ed.), Flood Hazard Mapping of the Philippines using LIDAR, Quezon City: University of the Philippines Training Center for Applied Geodesy and Photogrammetry – 108pp.

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National Library of the Philippines
ISBN: 987-621-430-143-0

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LIST OF ACRONYMS AND ABBREVIATIONS

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

CHAPTER 1: OVERVIEW OF THE PROGRAM AND LANGOGAN RIVER

Dr. Edwin Abucay and Enrico C. Paringit, Dr. Eng., 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 in 2014 entitled “Nationwide Hazard Mapping using LiDAR” 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 Tago River Basin

Langogan River Basin is located in Brgy. Langogan, Puerto Princesa City in the Province of Palawan. The DENR-RCBO identified it to be one of the 421 river basins in the Philippines having a drainage area of 203 sq. kms. and an estimated 325 million cubic meter annual run-off. It covers the barangays of Binduyan, Langogan, Marufinas, New Panggangan in Puerto Princesa City; Jolo, Magara, Tinitian in Roxas; and Caruray in San Vicente. In terms of geologic characteristics, Basement Complex (Pre-Jurassic) and Recent dominates the basin area. The river basin is generally characterized by undulating to very steep slopes and elevation more than 300 meters above mean sea level. The soil in the area is still unclassified (rough mountain land). Large area of the basin is dominated by open forest (broadleaved). Other dominat land cover types include other wooded land (shrubs) and closed forest (broadleaved).

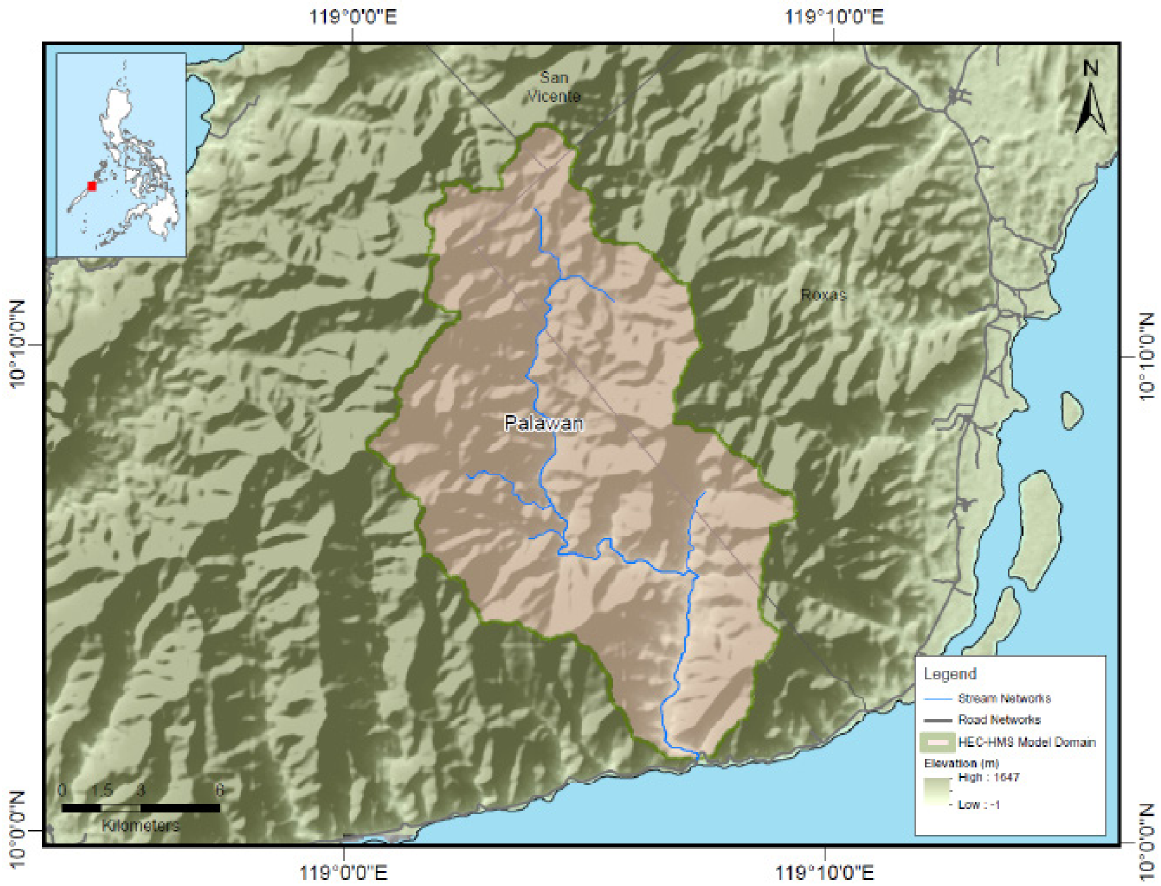

Figure 1. Map of Langogan River Basin (in brown).

Langogan River is the main tributary of Langogan River Basin. It has an approximate length of 13.22 km and drains towards Honda-- Bay. River cruise via a pumpboat via Langogan River is among the featured travel itineraries in the city which is a community based tourism project aims to support the locals. There is a total of 1,950 persons residing within the immediate vicinity of the river according the survey conducted by NSO in 2010. The most recent flooding event was brought by Typhoon Ruby on December 2014.The most intensive flooding happened during the flash floods that occurred near the riverside on November 02 – 03, 2013 when Typhoon Haiyan hit most of Palawan with intermittent rainfall. Langogan river passes through Langogan in Puerto Princesas City and Magara in Roxas. Based on the 2010 NSO Census of Population and Housing, Langogan is the most populated barangay in the area.

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 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.

Based on the studies conducted by the Mines and Geosciences Bureau, no barangay susceptible to flooding. However, all barangays have low to high susceptibilities to landslides. The field surveys conducted by the PHIL-LiDAR 1 validation team showed only three notable weather disturbances that caused flooding in 1994 (Norming), 2005 (Lando) and 2013 (Yolanda).

CHAPTER 2: LIDAR DATA ACQUISITION OF THE LANGOGAN FLOODPLAIN

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

2.1 Flight Plans

To initiate the LiDAR acquisition survey of the Langogan floodplain, the Data Acquisition Component (DAC) created flight plans within the delineated priority area for Langogan Floodplain in Palawan. These flight missions were planned for 18 lines and ran for at most four and a half hours (4.5) including take-off, landing and turning time using one sensor – the Gemini (see Annex 1 for sensor specifications). The flight planning parameters for the LiDAR system are outlined in Table 1. Figure 2, on the other hand, shows the flight plan for Langogan floodplain survey.
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Table 1. Flight planning parameters for Aquarius LiDAR System

Block Name	Flying Height (m AGL)	Overlap (%)	Max Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK 42eD	1000	30	40	100	50	130	5

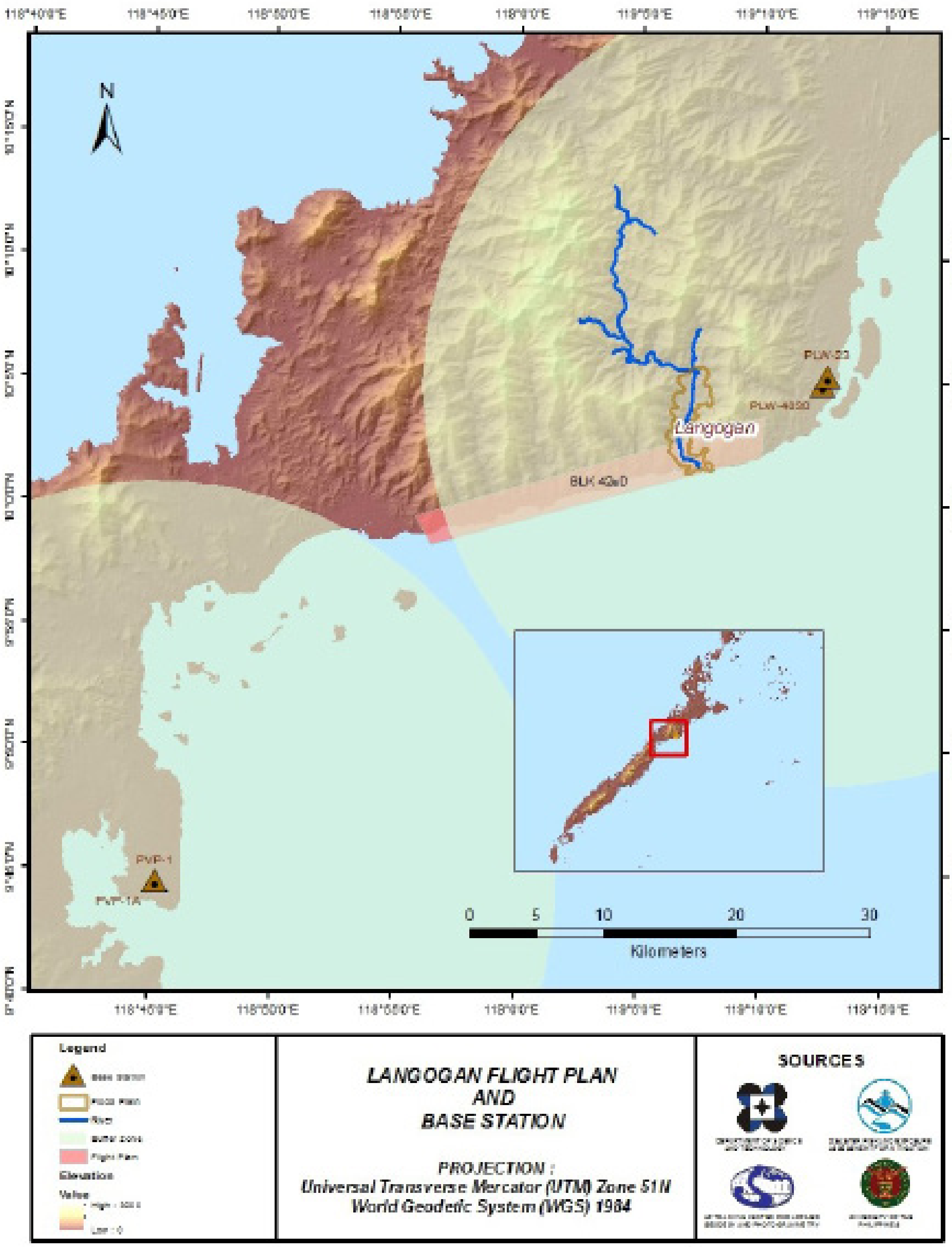


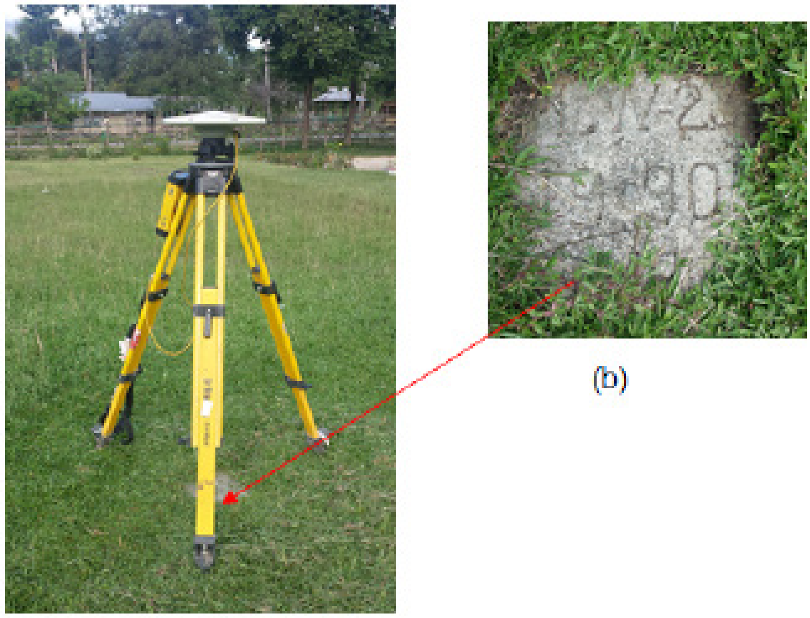
Figure 2. Flight plans and base stations used for Langogan floodplain using the Gemini sensor

2.2 Ground Base Station

The project team was able to recover one (1) NAMRIA ground control point, PLW-23 which is of first (1st) order accuracy. The project team also re-established ground control point PLW-4030 which is of fourth (4th) order accuracy; and established two (2) ground control 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 control points are found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey on November 16, 2015. Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 852 and TRIMBLE SPS 882. Flight plans and location of base stations used during the aerial LiDAR acquisition in Langogan floodplain are shown in Figure 2.

The succeeding sections depict the sets of reference points, control stations and established points, and the ground control points for the entire Langogan Floodplain LiDAR Survey. Figure 3 to Figure 5 show the recovered NAMRIA reference points within the area of the floodplain, while Table 2 to Table 5 show the details about the following NAMRIA control stations and established points. Table 6, on the other hand, shows the list of all ground control points occupied during the acquisition together with the corresponding dates of utilization.

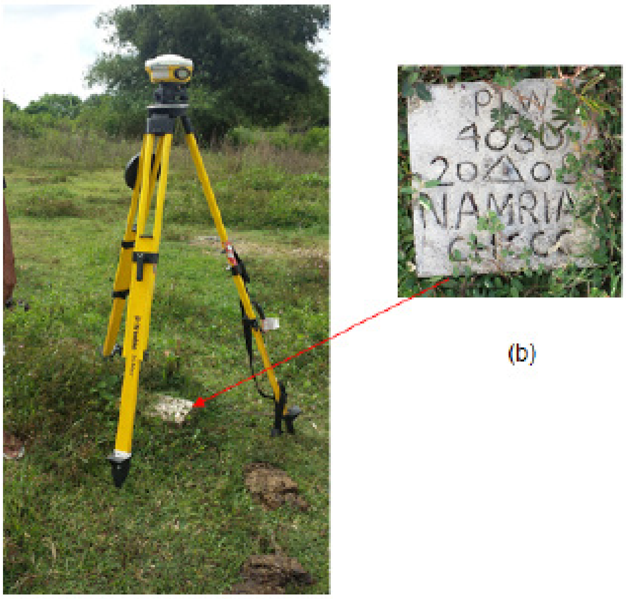


(a) (b)

Figure 3. GPS set-up over PLW-23 (a) as recovered at Jolo Elementary School, Puerto Princesa City; and NAMRIA reference point PLW-23 (b) as recovered by the field team.

Table 2. Details of the recovered NAMRIA horizontal control point PLW-23 used as base station for the LiDAR Acquisition.

Station Name	PLW-23	
Order of Accuracy	1st	
Relative Error (horizontal positioning)	1 in 100,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	10°5’19.52517” North 119°12’33.72062” East 10.427 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	577752.254 meters 1115630.596 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	10° 5’15.04804” North 119° 12’ 39.01413” East 61.07260 meters
Grid Coordinates, Universal Transverse Mercator Zone 50 North (UTM 50N PRS 92)	Easting Northing	742130.31 meters 1115973.89 meters



(b)

(a)

Figure 4. GPS set-up over PLW-4030 (a) as recovered on the ground beside Jolo Bridge Roxas, Palawan;and NAMRIA reference point PLW-4030 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point PLW-4030 used as base station for the LiDAR Acquisition.

Station Name	PLW-4030	
Order of Accuracy	1st	
Relative Error (horizontal positioning)	1:100,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	10°04’56.95146” North 119°12’22.75168” East 11.183 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	10°04’52.47562” North 119°12’28.04576” East 61.835 meters
Grid Coordinates, Universal Transverse Mercator Zone 50 North (UTM 50N PRS 92)	Easting Northing	741960.17 meters 1115211.366 meters

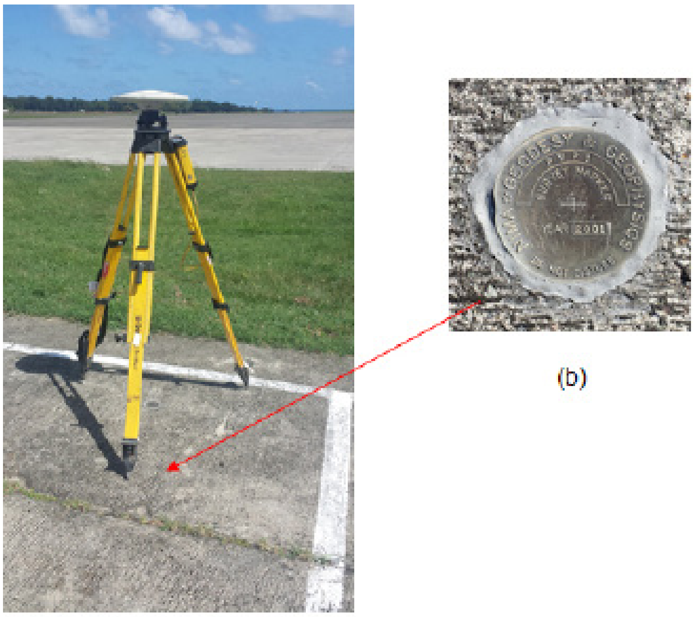


Figure 5. GPS set-up over PVP-1 (a) as recovered on the ground beside Puerto Princesa Airport Fire Station; and reference point PVP-1 (b) as recovered by the field team.

Table 4. Details of the reprocessed NAMRIA 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)	1:100,000	
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 meters
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 meters
Grid Coordinates, Universal Transverse Mercator Zone 50 North (UTM 50N WGS84)	Easting Northing	692547.525 meters 692547.525 meters

Table 5. Details of the recovered NAMRIA 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 meters
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 meters
Grid Coordinates, Universal Transverse Mercator Zone 50 North (UTM 50N WGS84)	Easting Northing	692548.704 meters 1077290.373 meters

Table 6. Ground control points used during the LiDAR data acquisition.

Date Surveyed	Flight Number	Mission Name	Ground Control Points
November 16, 2015	3497G	2BLK42DISL320A	PLW-23, PLW-4030, PVP-1, PVP-1A

2.3 Flight Missions

A total of one (1) mission was conducted to complete the LiDAR Data Acquisition in Langogan Floodplain, for a total of three hours and forty-five minutes (3+45) of flying time for RP-C9022 (See Annex 6). All missions were acquired using the Gemini LiDAR system. As shown below, the total area of actual coverage per mission and the corresponding flying hours are depicted in Table 7, while the actual parameters used during the LiDAR data acquisition are presented in Table 8.

Table 7. Flight missions for LiDAR data acquisition in Langogan floodplain.

Date Surveyed	Flight Number	Flight Plan Area (km^2)	Surveyed Area (km^2)	Area Surveyed within the Floodplain (km^2)	Area Surveyed Outside the Floodplain (km^2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
16-Nov-15	3497G	68.90	97.19	4.51	92.68	NA	3	45
TOTAL		68.90	97.19	4.51	92.68	NA	3	45

Table 8. Actual parameters used during LiDAR data acquisition

Flight Number	Flying Height (AGL) (m)	Overlap (%)	Field of View	PRF (kHz)	Scan Frequency (Hz)	Average Speed (Kts)	Average Turn Time (Minutes)	Flying Hours
3497G	600, 1100	30	40, 24	100	50	130	5	45

2.4 Survey Coverage

This certain LiDAR acquisition survey covered the Langogan floodplain (See Annex 7). It is situated within the province of Palawan with majority of the floodplain situated within the municipality of Puerto Princesa City. Puerto Princesa City is also mostly covered by the survey. The list of municipalities and cities surveyed with at least one (1) square kilometer coverage, is shown in Table 9. Figure 6, on the other hand, shows the actual coverage of the LiDAR acquisition for the Langogan floodplain.

Table 9. List of municipalities and cities surveyed during Langogan floodplain LiDAR survey.

Province	Municipality/City	Area of Municipality/City	Surveyed Area (km^2)	Percentage of Area Surveyed
Lanao del Norte	Puerto Princesa City	2186.36	63.64	3%
TOTAL		2186.36	63.64	3%

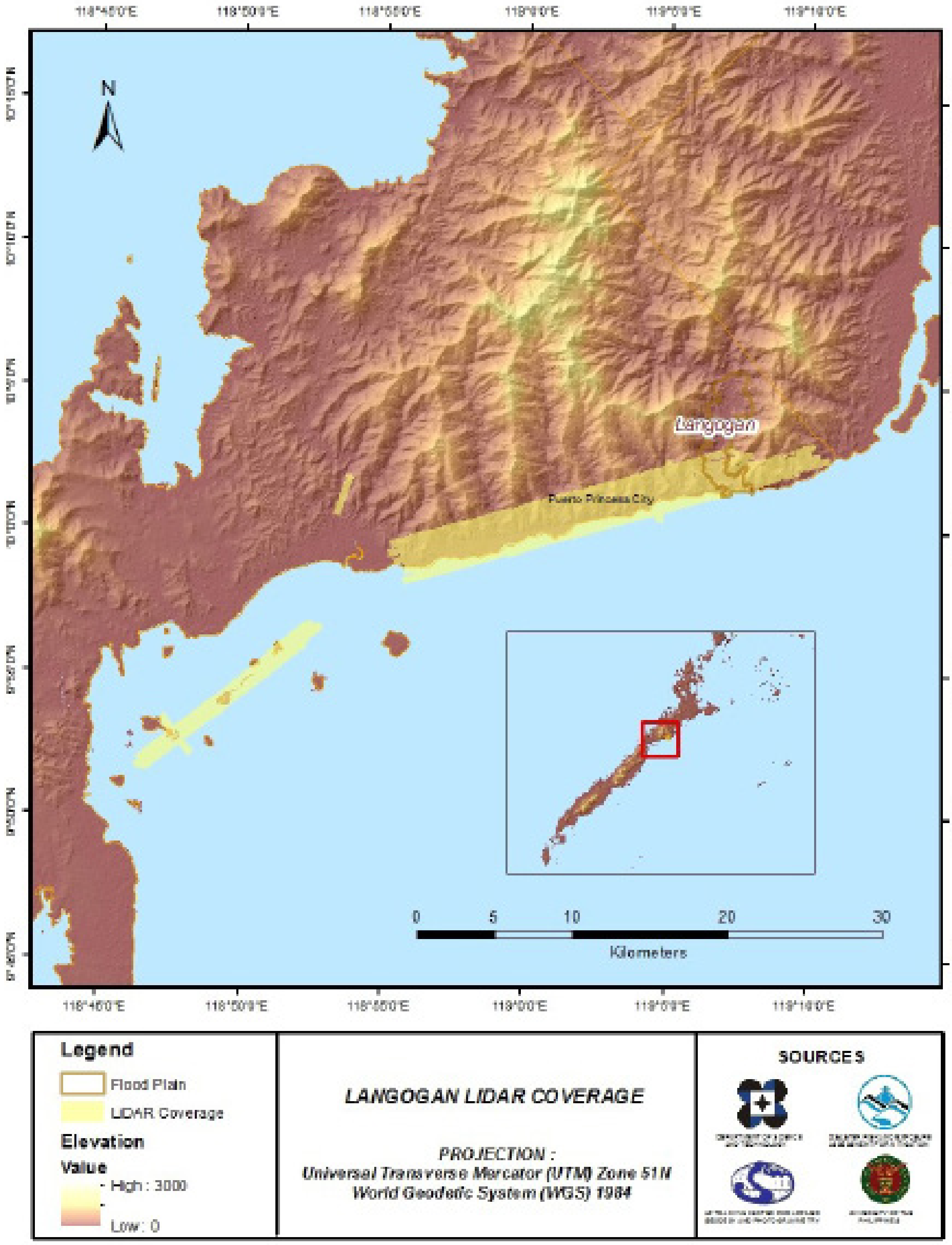


Figure 6. Actual LiDAR survey coverage for Langogan floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE LANGOGAN FLOODPLAIN

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

3.1 Overview of the LiDAR Data Pre-Processing

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

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

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

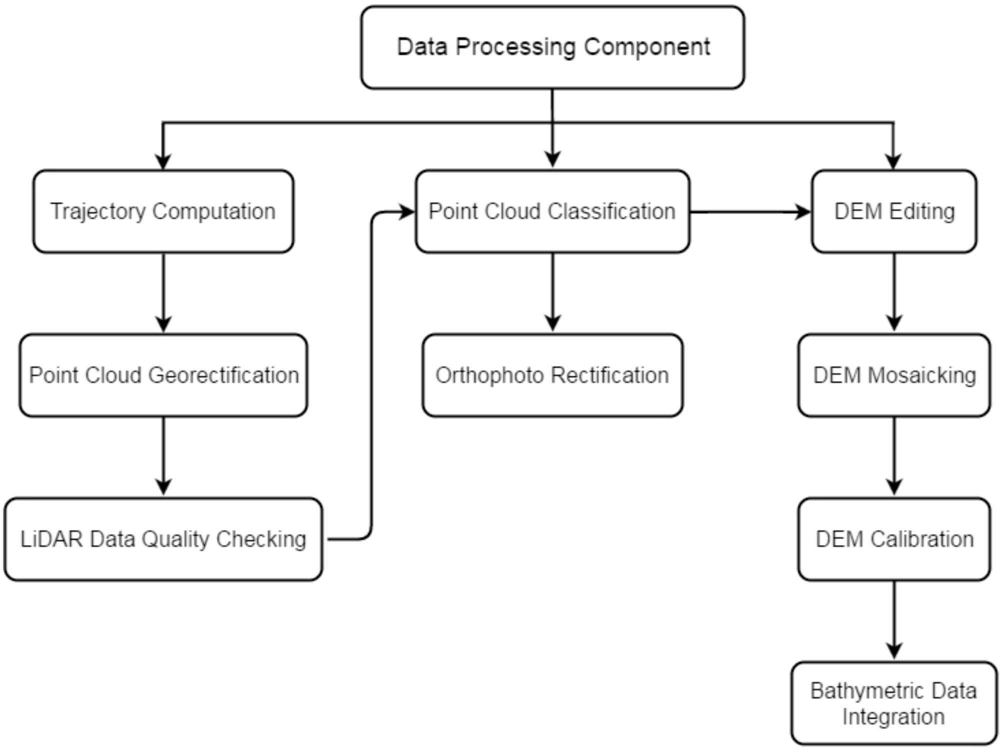

Figure 7. Schematic diagram for the data pre-processing.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Langogan floodplain can be found in Annex 5. Missions flown during the first survey conducted on November 2015 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Gemini system over Puerto Prinsesa City, Palawan.

The Data Acquisition Component (DAC) transferred a total of 17.40 Gigabytes of Range data, 220 Megabytes of POS data, and 7.61 Megabytes of GPS base station data to the data server on December 8, 2015. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Langogan was fully transferred on December 8, 2015, as indicated on the Data Transfer Sheets for Langogan floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metric parameters of the computed trajectory for flight 3497G, one of the Langogan flights, which is the North, East, and Down position RMSE values are shown in Figure 8. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on November 16, 2015 00:00AM. The y-axis is the RMSE value for that particular position.

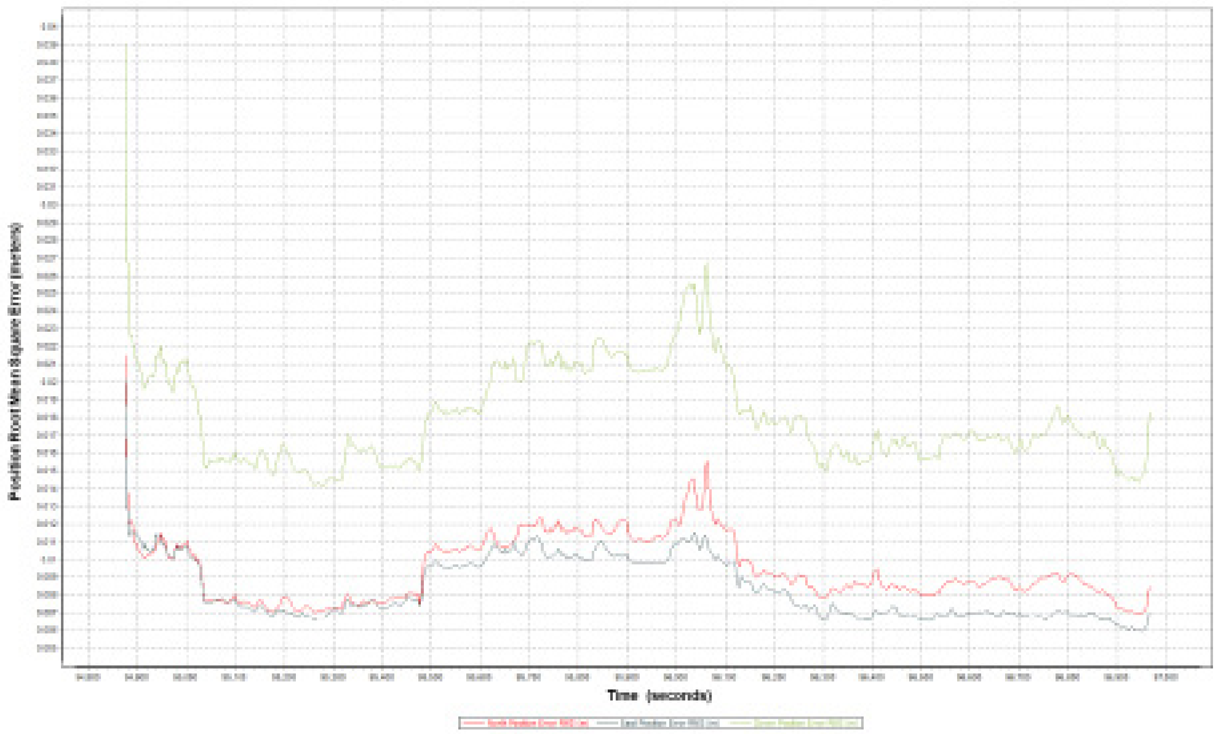

Figure 8. Smoothed Performance Metric Parameters of a Langogan Flight 3497G

The time of flight was from 94800 seconds to 97000 seconds, which corresponds to afternoon of November 16, 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 1.56 centimeters, the East position RMSE peaks at 1. 13 centimeters, and the Down position RMSE peaks at 2.69 centimeters, which are within the prescribed accuracies described in the methodology.

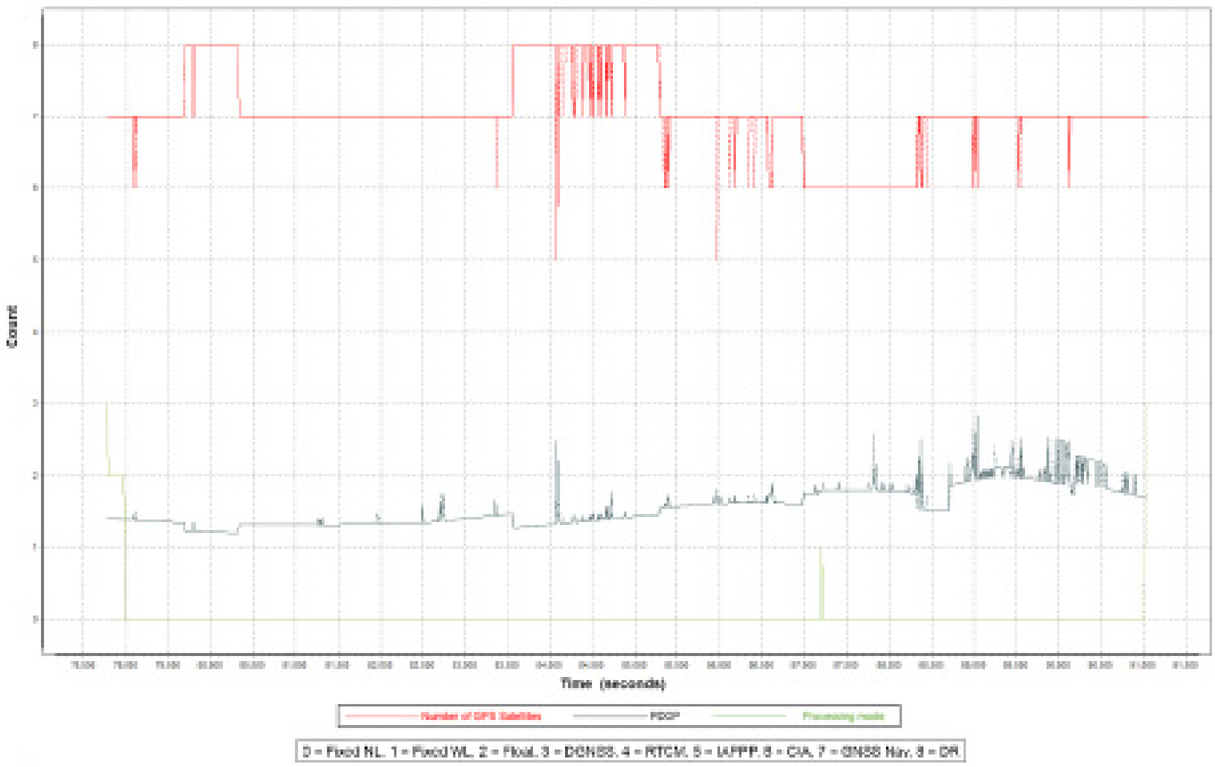

Figure 9. Solution Status Parameters of Langogan Flight 3497G.

The Solution Status parameters of flight 3497G, one of the Langogan flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 9. The graphs indicate that the number of satellites during the acquisition did not go down to 5. Majority of the time, the number of satellites tracked was between 5 and 6. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode stayed at the value of 0 for majority of the survey with some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Langogan flights is shown in Figure 10.

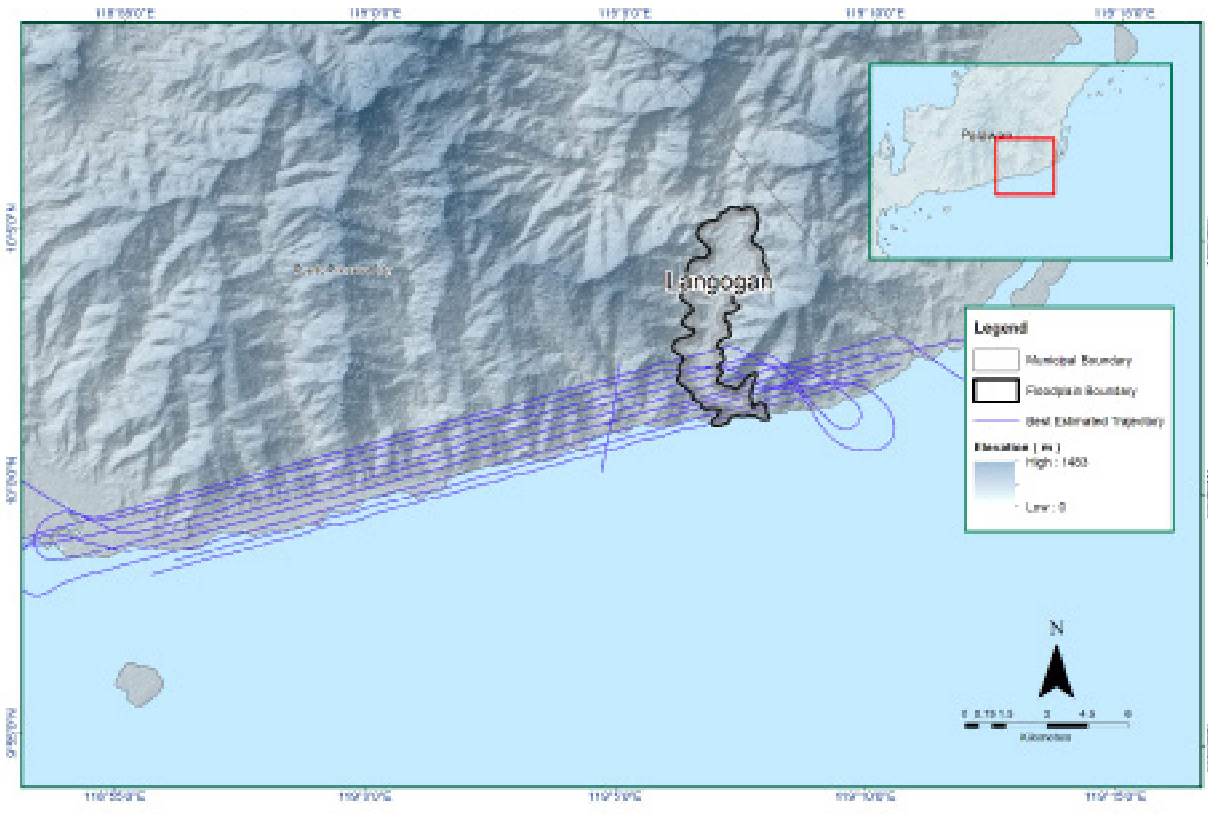

Figure 10. Best Estimated Trajectory of the LiDAR missions conducted over the Langogan Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS contains 48 flight lines, with each flight line containing one channel, since the Gemini system contain one channel only. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over the Langogan floodplain are given in Table 10.

Table 10. Self-calibration results values for Tago flights

Parameter	Acceptable Value	Computed Value
Boresight Correction stdev	(<0.001degrees)	0.000199
IMU Attitude Correction Roll and Pitch Corrections stdev	(<0.001degrees)	0.000854
GPS Position Z-correction stdev	(<0.01meters)	0.0029

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

3.5 LiDAR Data Quality Checking

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

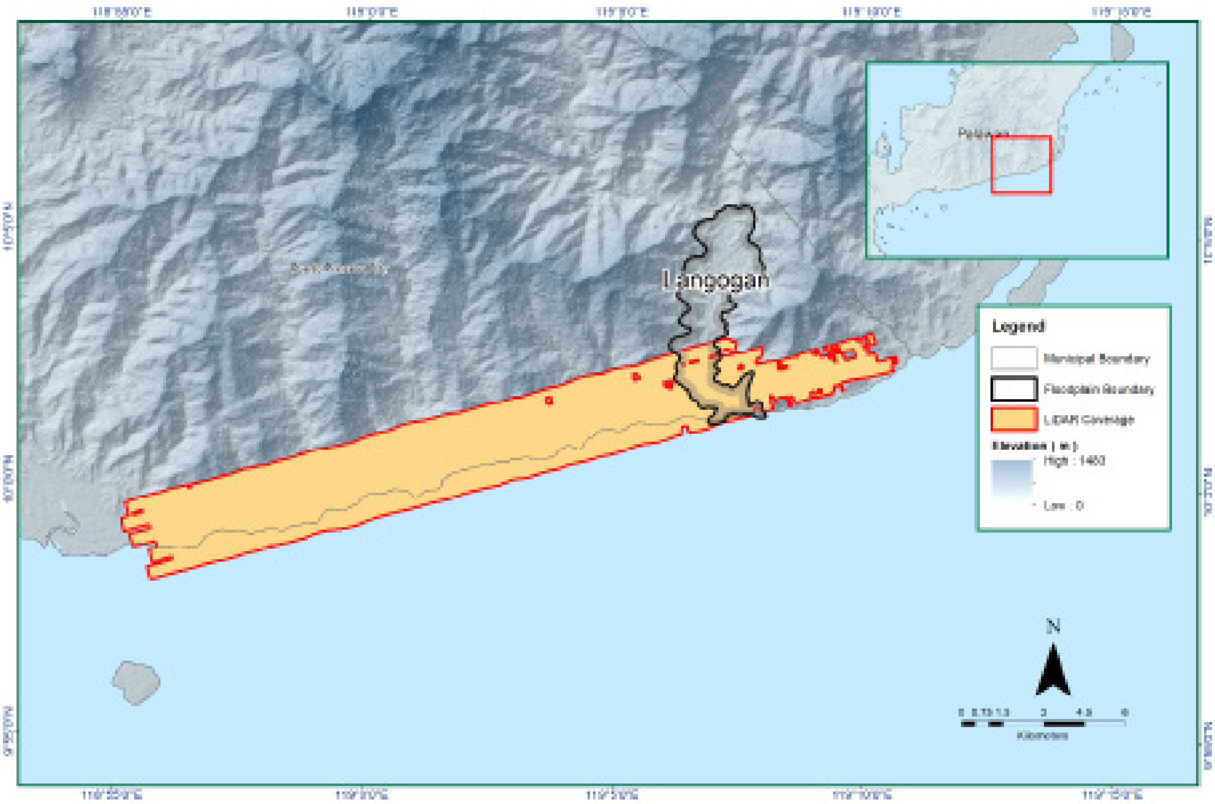

Figure 11. Boundaries of the processed LiDAR data over the Langogan Floodplain.

The total area covered by the Langogan mission is 74.20 sq.km that is comprised of one (1) flight acquisition grouped and merged into one (1) block as shown in Table 11.

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

LiDAR Blocks	Flight Numbers	Area (sq.km)
Palawan_reflights_Blk42eD	3497G	74.20
	TOTAL	**74.20 sq.km**

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 12. Since the Gemini system employs one channel, we would expect an average value of 1 (blue) for areas where there is limited overlap, and a value of 2 (yellow) or more (red) for areas with three or more overlapping flight lines.

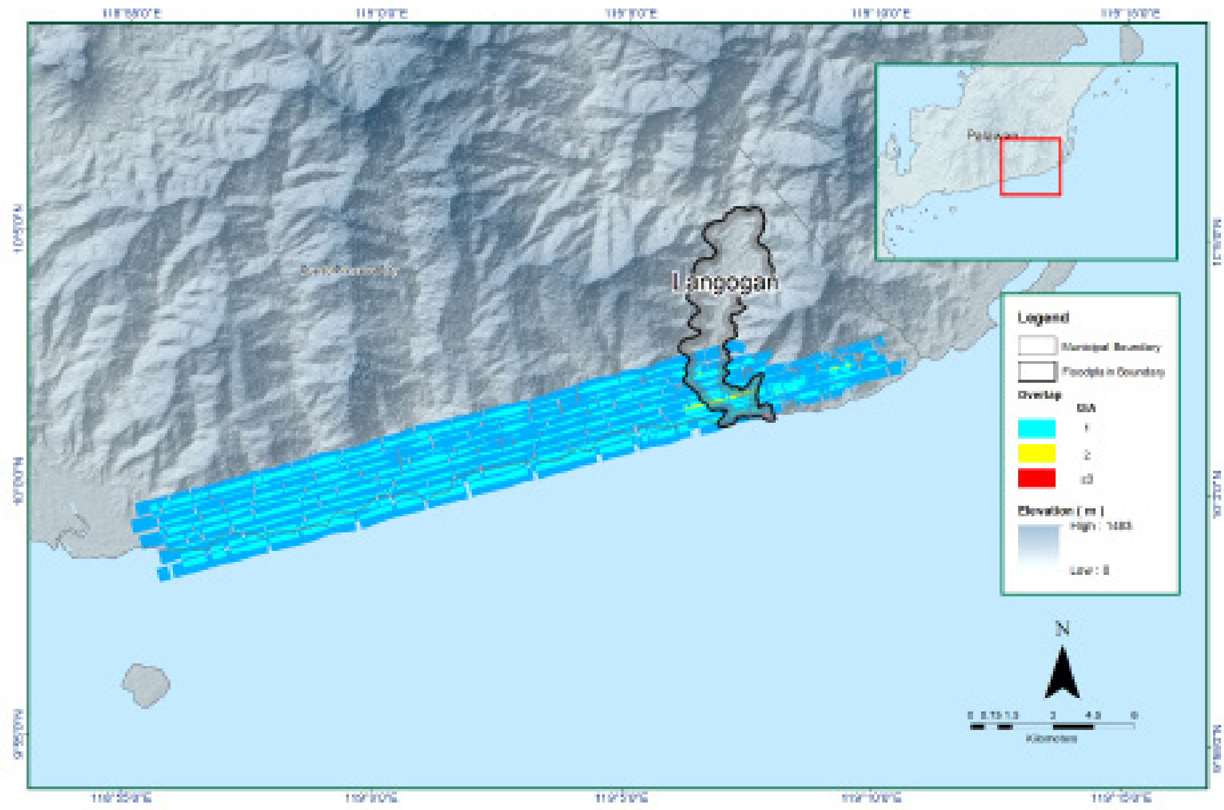

Figure 12. Image of data overlap for Langogan floodplain.

The overlap statistics per block for the Langogan floodplain can be found in the Mission Summary Reports (Annex 8). One pixel corresponds to 25.0 square meters on the ground. For this area, the percent overlap is 32.14%, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the two (2) points per square meter criterion is shown in Figure 13. It was determined that all LiDAR data for the Langogan floodplain satisfy the point density requirement, and the average density for the entire survey area is 6.35 points per square meter.

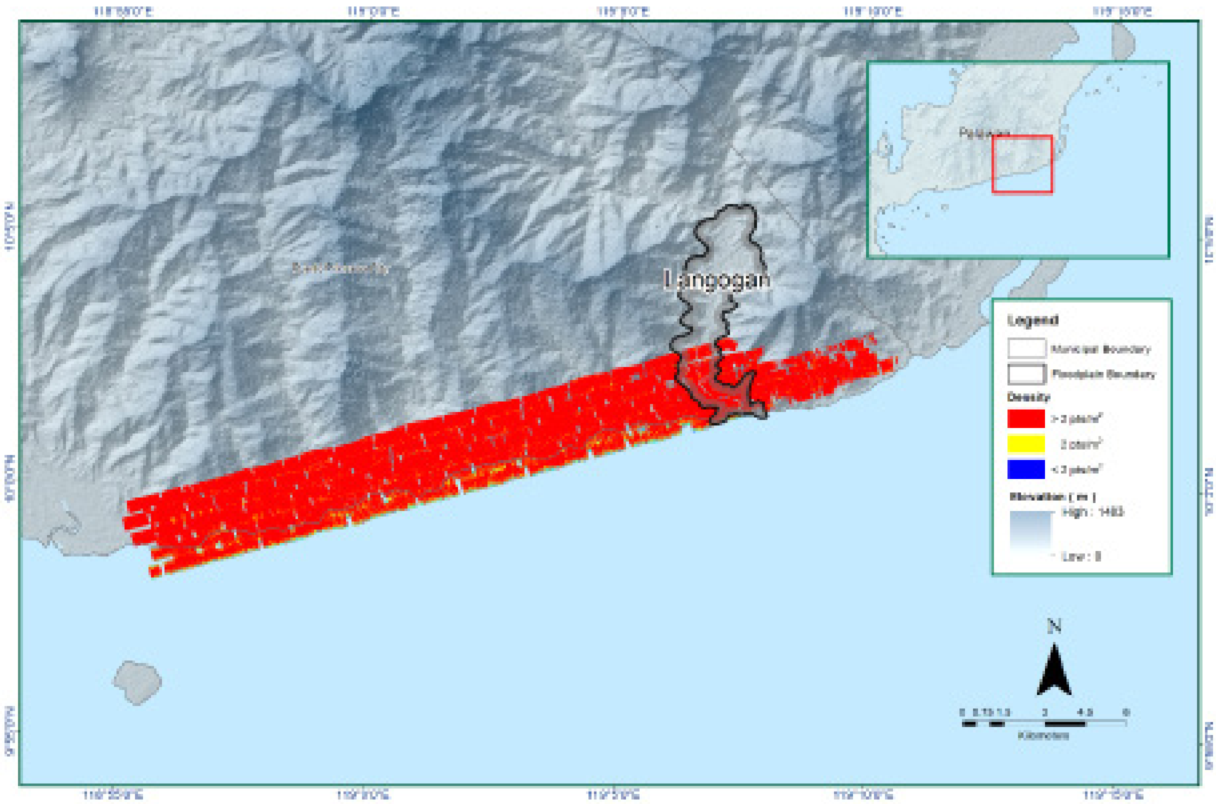

Figure 13. Pulse density map of the merged LiDAR data for Langogan floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 14. The default color range is from blue to red, where bright blue areas correspond to portions where elevations of a previous flight line, identified by its acquisition time, are higher by more than 0.20m relative to elevations of its adjacent flight line. Bright red areas indicate portions where elevations of a previous flight line are lower by more than 0.20m relative to elevations of its adjacent flight line. Areas with bright red or bright blue need to be investigated further using Quick Terrain Modeler software.

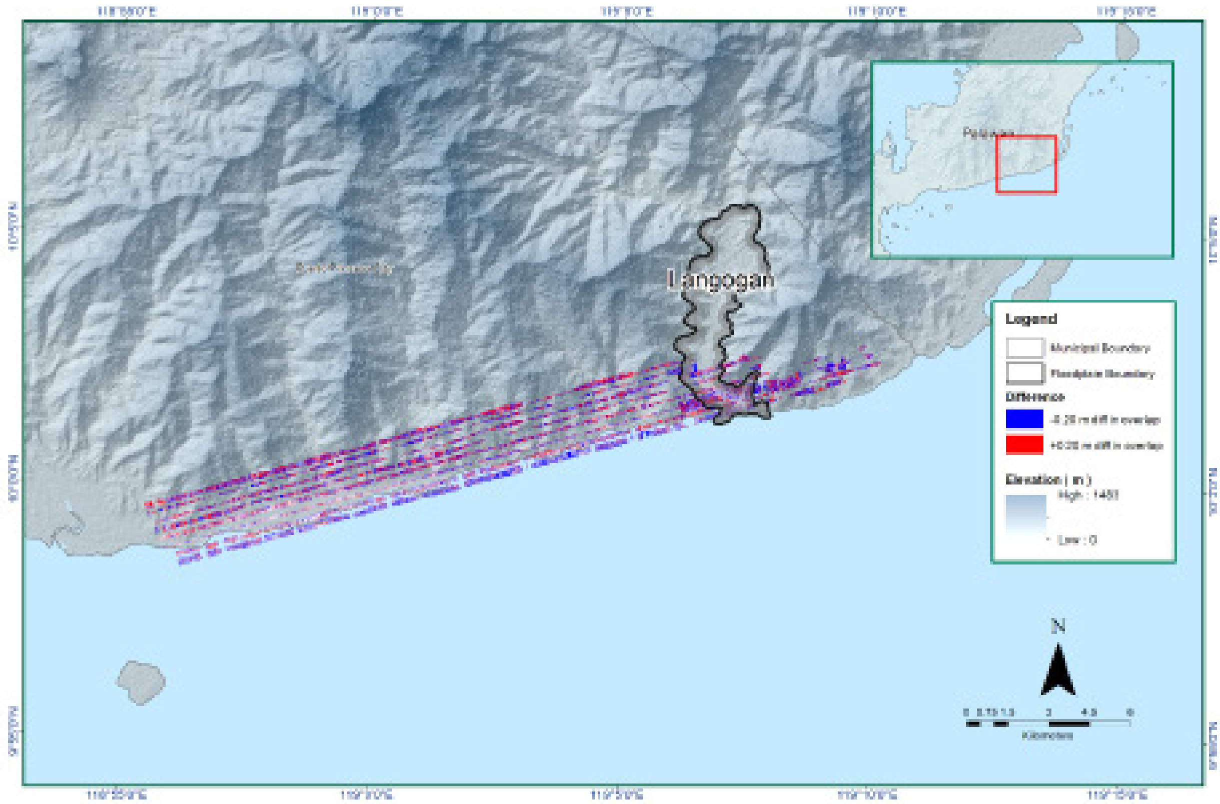

Figure 14. Elevation difference Map between flight lines for the Langogan Floodplain Survey

A screen capture of the processed LAS data from a Langogan flight 3497G loaded in QT Modeler is shown in Figure 15. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed red line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

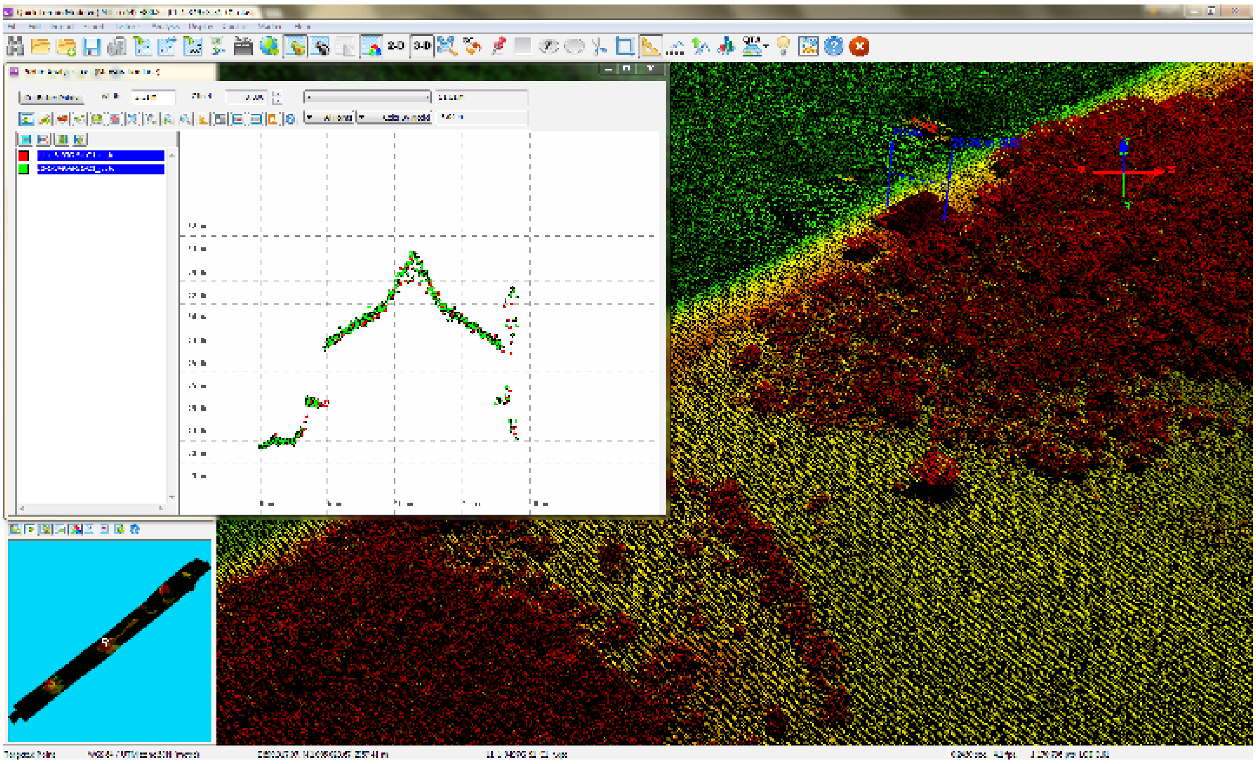

Figure 15. Quality checking for aLangogan flight 3497G using the Profile Tool of QT Modeler

3.6 LiDAR Point Cloud Classification and Rasterization

Table 12. Langogan classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	30,227,181
Low Vegetation	16,386,156
Medium Vegetation	76,491,030
High Vegetation	265,788,221
Building	5,414,882

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Langogan floodplain is shown in Figure 16. A total of 117 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 12. The point cloud has a maximum and minimum height of 655.63 meters and 51.32 meters, respectively.

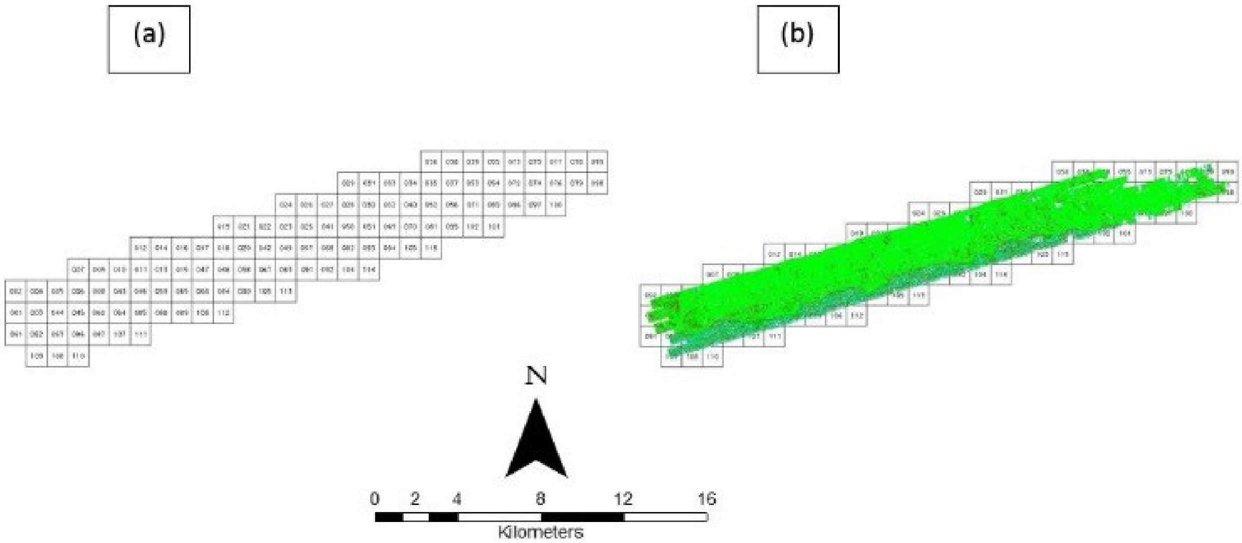

Figure 16. Tiles for Langogan floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 17. The ground points are in orange, while the vegetation is in different shades of green, and the buildings are in cyan. It can be seen that residential structures adjacent or even below the canopy are classified correctly, due to the density of the LiDAR data.

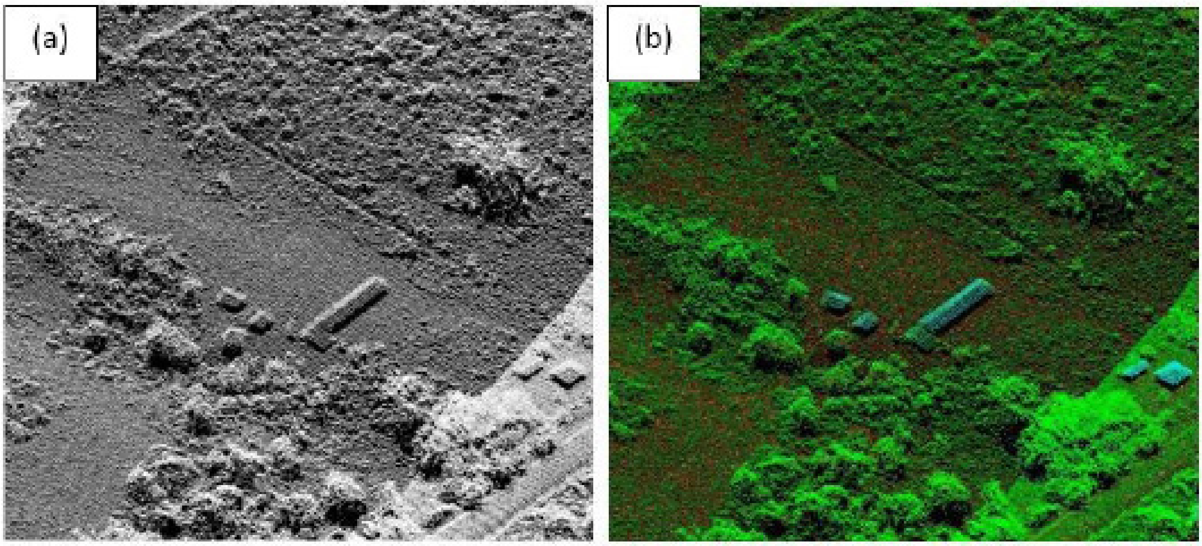

Figure 17. Point cloud before (a) and after (b) classification.

The production of the 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 show in Figure 18. It shows that DTMs are the representation of the bare earth, while on the DSMs, all features are present, such as buildings and vegetation.

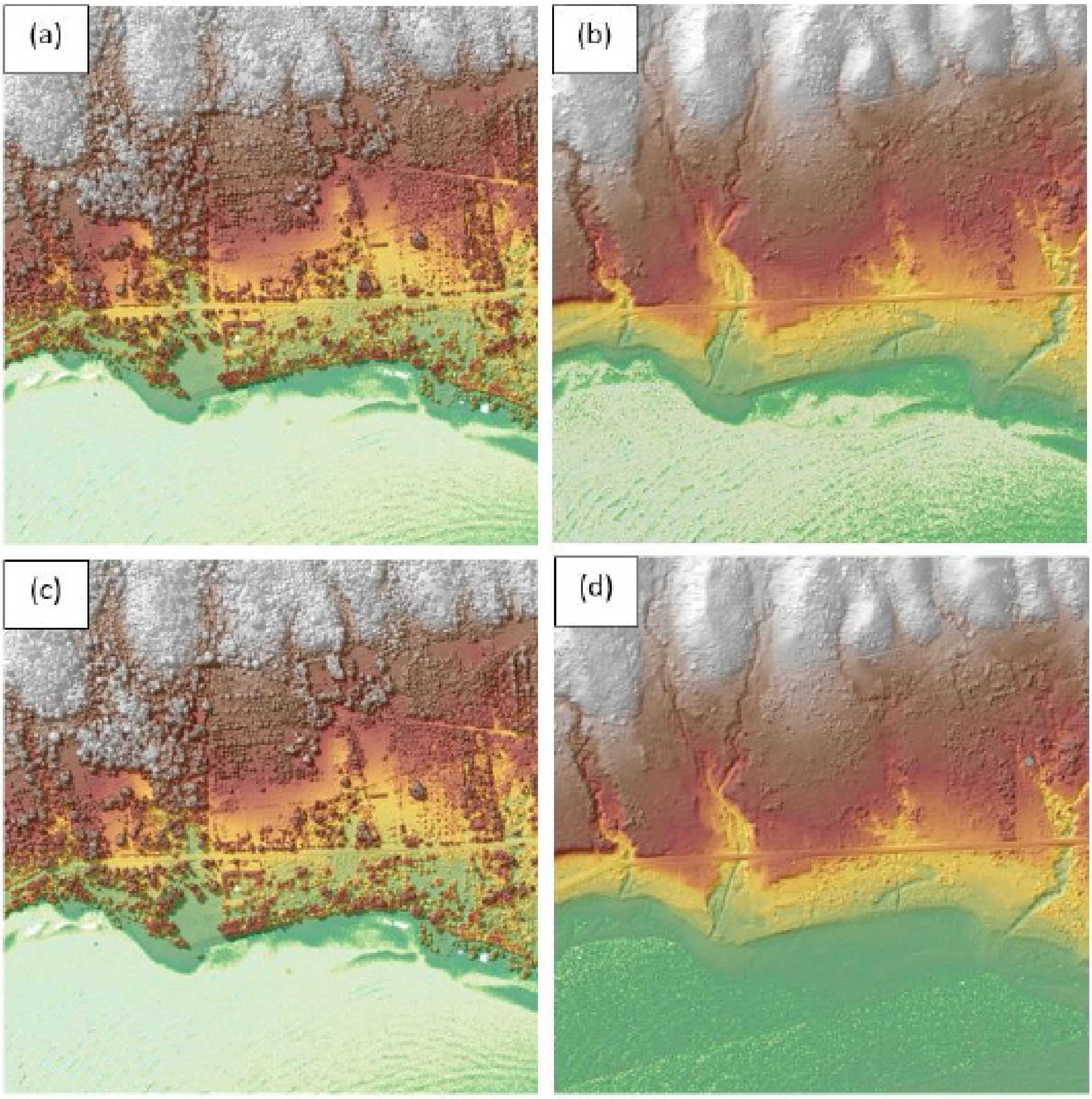

Figure 18. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Langogan floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

There are no available orthophotographs for the Langogan floodplain.

3.8 DEM Editing and Hydro-Correction

One (1) mission block was processed for Langogan flood plain. The block is composed of Palawan_Reflight block with a total area of 74.20 square kilometers. Table 13 shows the name and corresponding area of each block in square kilometers.

Table 13. LiDAR blocks with the corresponding area

LiDAR Blocks	Area (sq.km)
Palawan_Reflight_Blk42eD	74.20
TOTAL	**74.20 sq.km**

Figure 19 shows portions of a DTM before and after manual editing. As evident in the figure, a portion of a waterway (Figure 19a) has obstructed the flow of water along the river. To correct the river hydrologically, it was removed through manual editing (Figure 19b). The data gap (Figure 19c) has been filled to complete the surface (Figure 19d) to allow the correct flow of water.

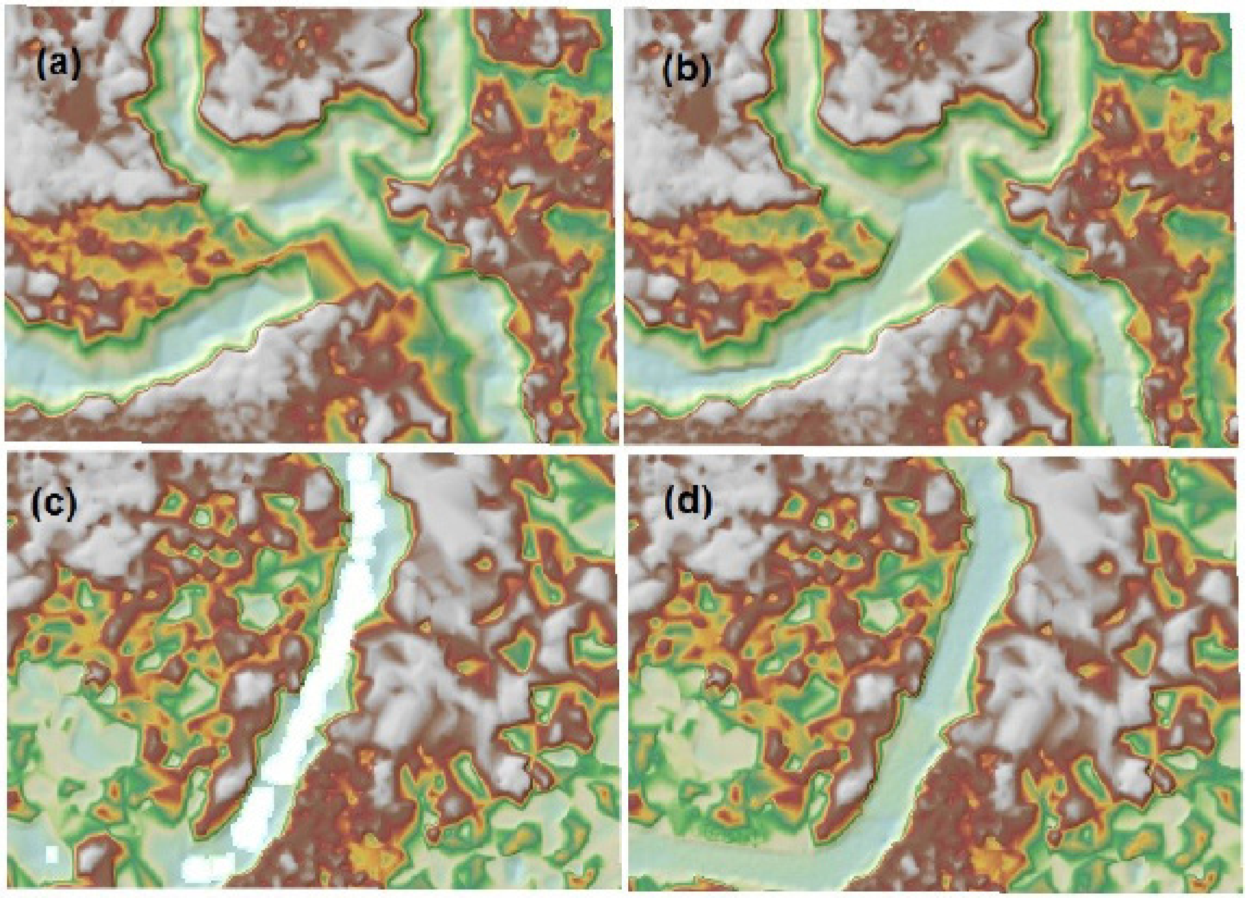

Figure 19. Portions in the DTM of the Langogan Floodplain – a portion of a waterway before (a) and after (b) manual editing; and a data gap before (c) and after (d) filling.

3.9 Mosaicking of Blocks

Palawan_Blk42Aa 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 Langogan floodplain, it was concluded that Palawan_Reflight_Blk42eD has horizontal and vertical shifting that needed adjustment before merging the DTM. Table 14 shows the shift values applied to each LiDAR block during mosaicking.

.

Mosaicked LiDAR DTM for Langogan floodplain is shown in Figure 20. It can be seen that the entire Langogan floodplain is 30.64% covered by LiDAR data while portions with no LiDAR data were patched with the available IFSAR data.

Table 14. Shift values of each LiDAR Block of Tago Floodplain

Mission Blocks	Shift Values (meters)		
	x	y	z
Palawan_Reflight_Blk42eD	0.54	0.75	0.45

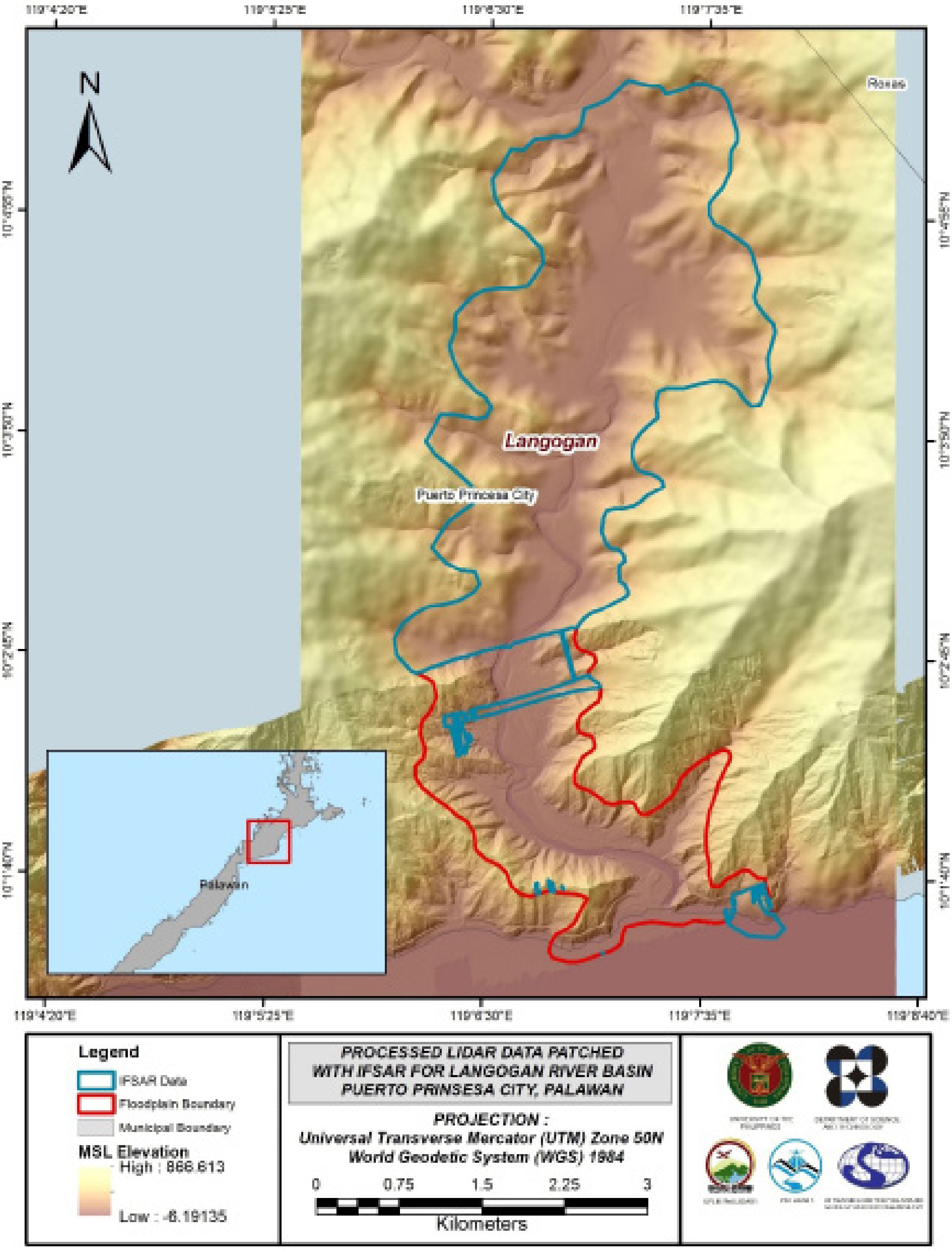

Figure 20. Map of processed LiDAR data for the Langogan Floodplain.

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 Langogan to collect points with which the LiDAR dataset is validated is shown in Figure 21, with the validation survey points highlighted in green. A total of 2,188 survey points were used for calibration and validation of Langogan LiDAR data. Random selection of 80% of the survey points, resulting to 1,696 points, was used for calibration.

A good correlation between the uncalibrated Langogan LiDAR DTM 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 11.26 meters with a standard deviation of 0.20 meters. Calibration of Langogan LiDAR data was done by adding the height difference value, 11.26 meters, to Langogan mosaicked LiDAR data. Table 15 shows the statistical values of the compared elevation values between Langogan LiDAR data and calibration data.

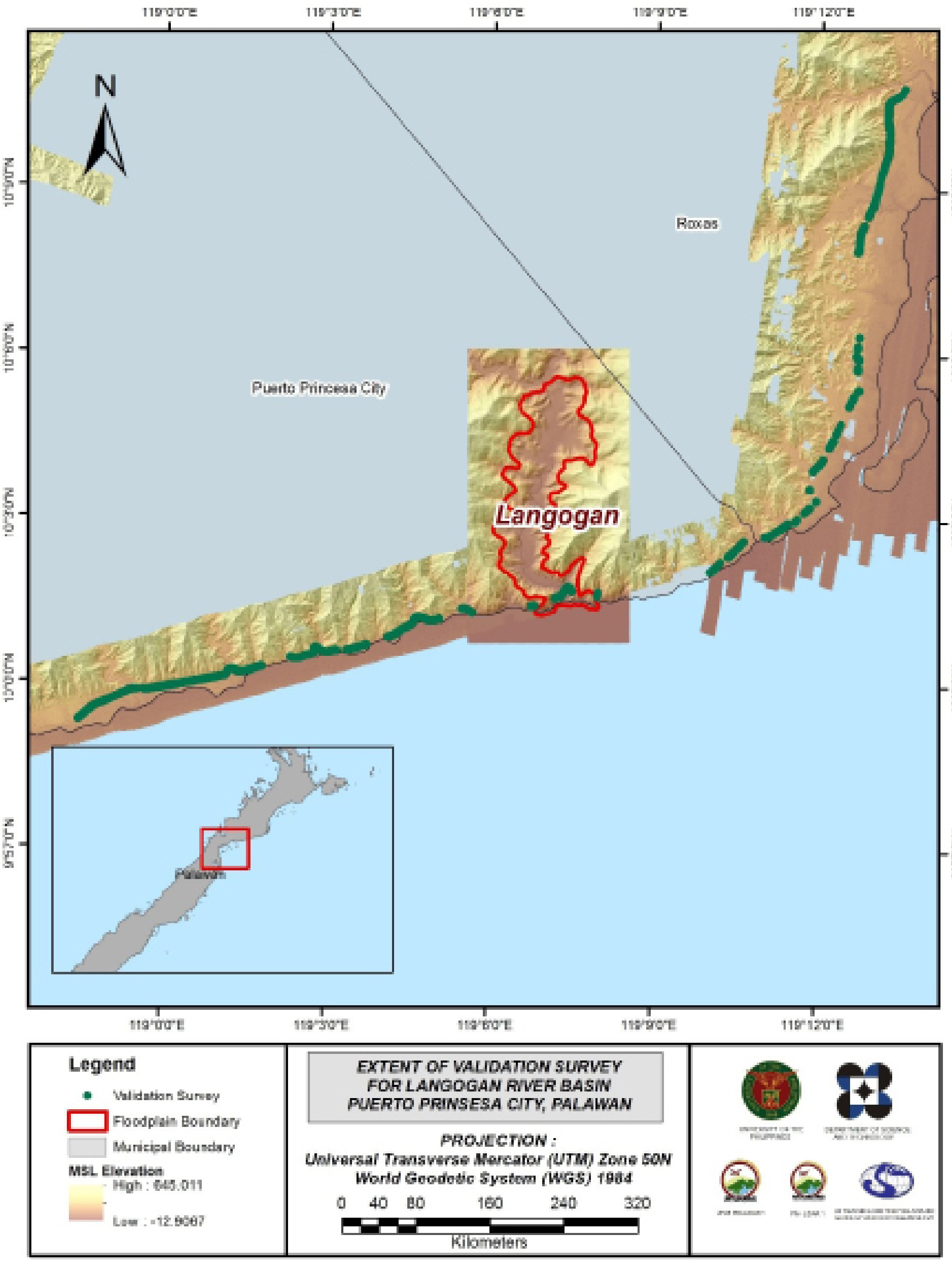

Figure 21. Map of Langogan Floodplain with validation survey points in green.

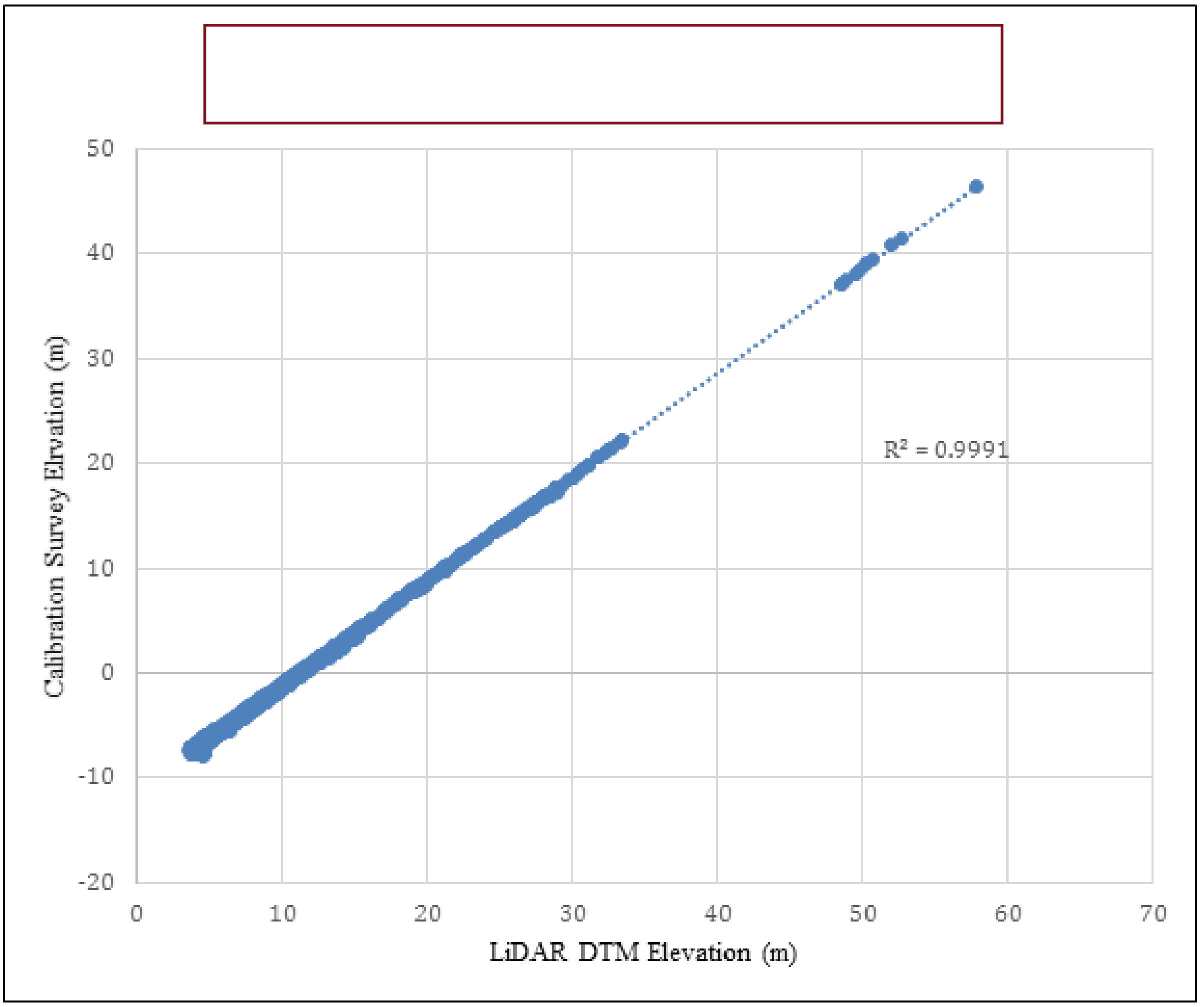

Figure 22. Correlation plot between calibration survey points and LiDAR data.

Table 15. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	11.26
Standard Deviation	0.20
Average	11.26
Minimum	10.86
Maximum	11.65

A total of 492 points were used for the validation of calibrated Langogan 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 0.19 meters with a standard deviation of 0.19 meters, as shown in Table 16.

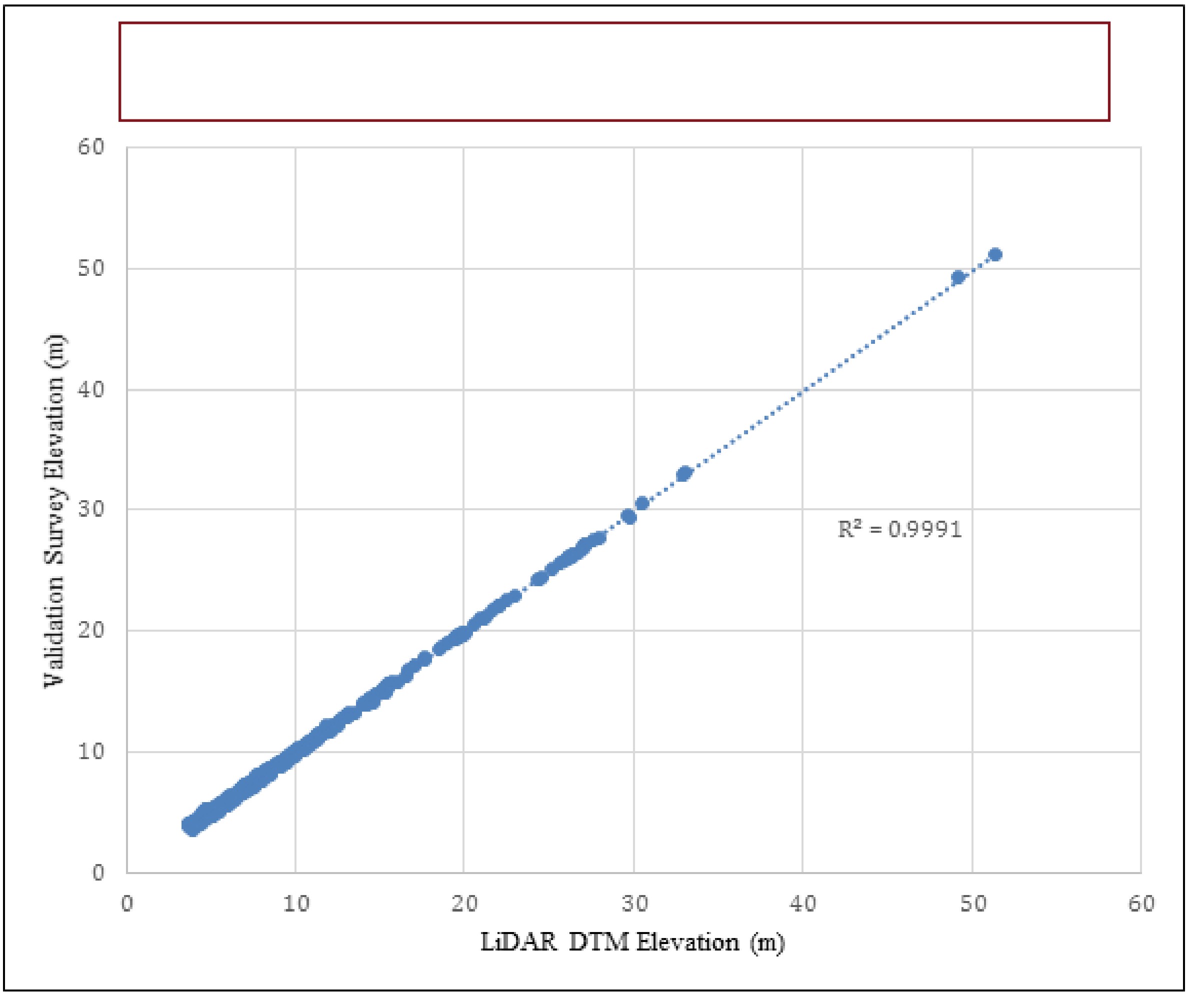

Figure 23. Correlation plot between the validation survey points and the LiDAR data.

Table 16. Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.19
Standard Deviation	0.19
Average	-0.006
Minimum	-0.39
Maximum	0.38

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, only centerline was available for Langogan with a total of 10,152 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 0.44 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Langogan integrated with the processed LiDAR DEM is shown in Figure 24.

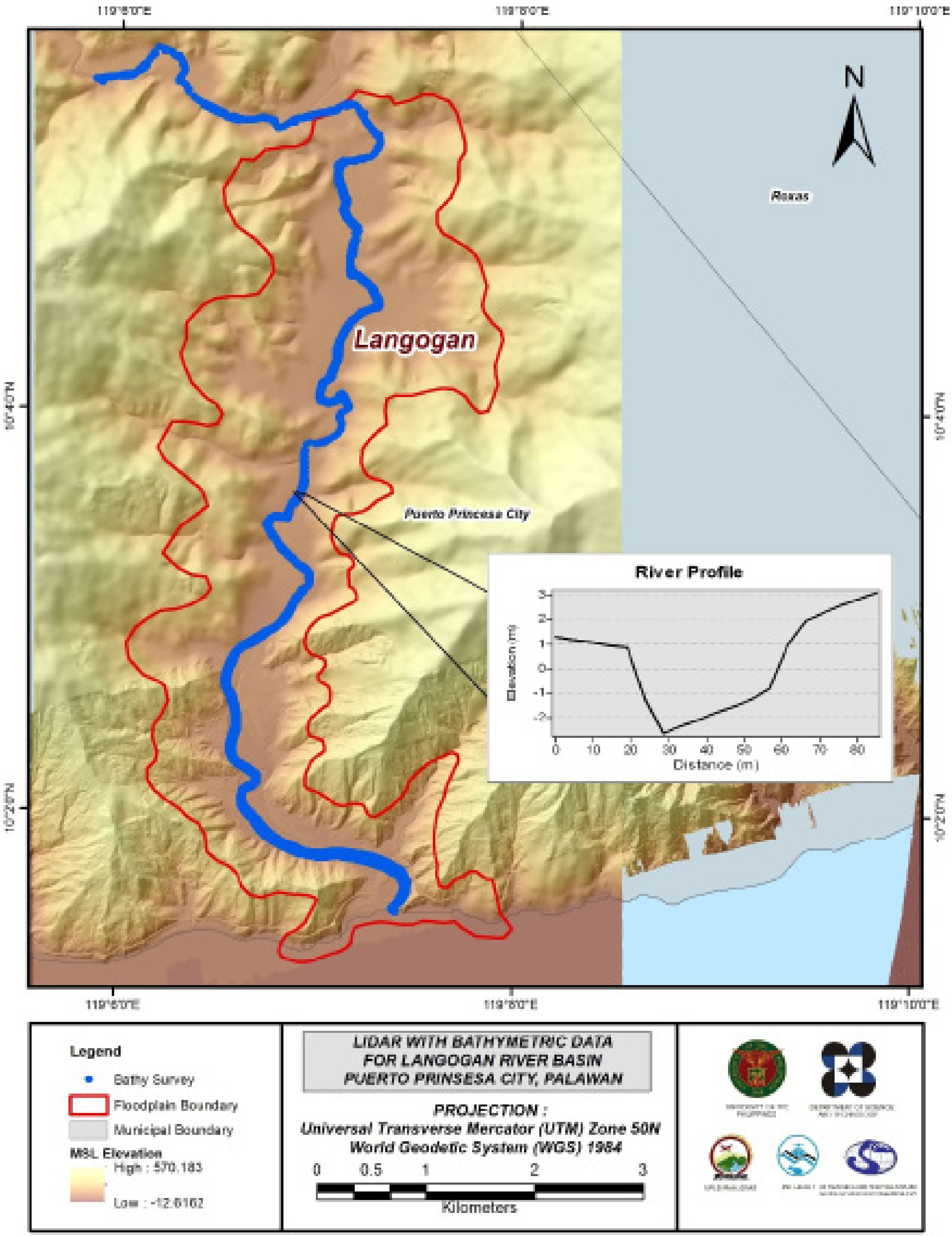

Figure 24. Map of Langogan floodplain with bathymetric survey points in blue.

3.12 Feature Extraction

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

3.12.1 Quality Checking (QC) of Digitized Features' Boundary

Langogan floodplain, including its 200 m buffer, has a total area of 776.76 sq km. For this area, a total of 24.0 sq km, corresponding to a total of 5,893 building features, are considered for QC. Figure 25 shows the QC blocks for Langogan floodplain.

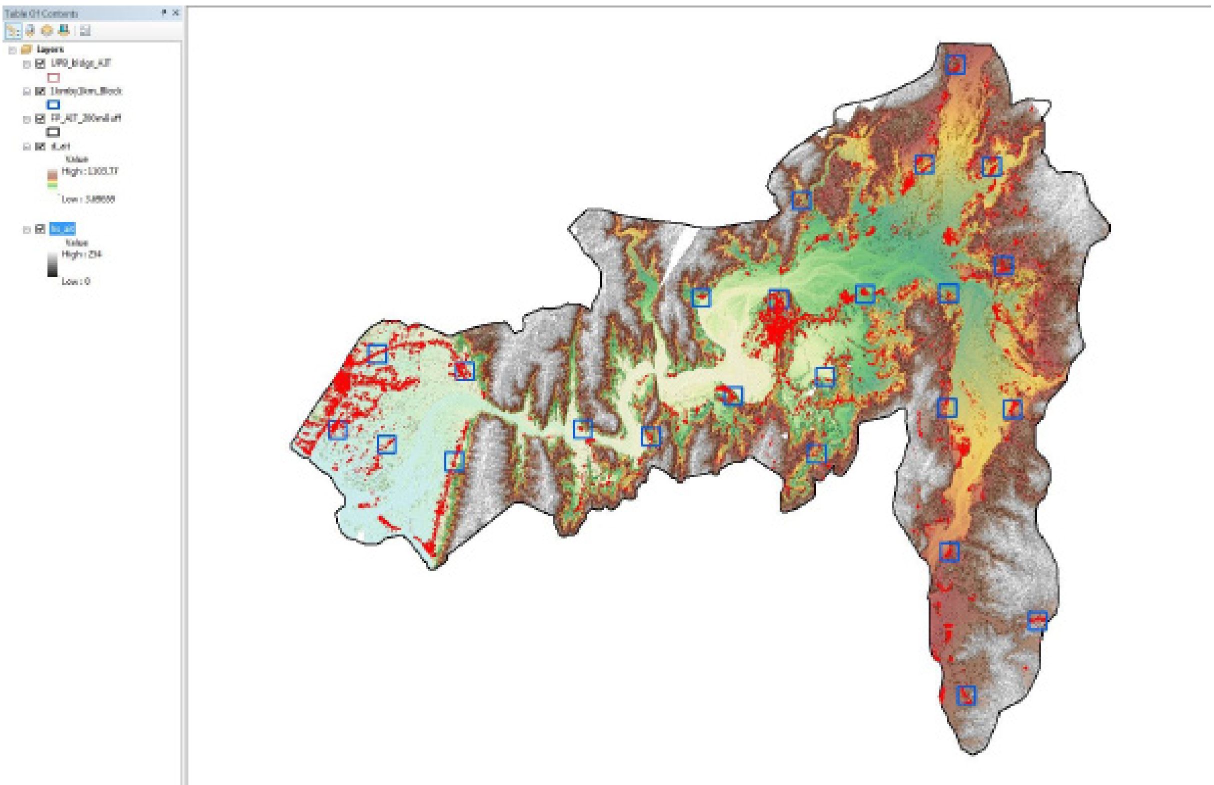

Figure 25. Blocks (in blue) of Langogan building features that was subjected to QC

Quality checking of Langogan building features resulted in the ratings shown in Table 17.

Table 17. Details of the quality checking ratings for the building features extracted for the Langogan River Basin.

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Langogan	99.44	99.98	97.30	PASSED

3.12.2 Height Extraction

Height extraction was done for 51,234 building features in Langogan floodplain. Of these building features, 843 were filtered out after height extraction, resulting to 50,391 buildings with height attributes. The lowest building height is at 2.00 meters, while the highest building is at 14.87 meters.

3.12.3 Feature Attribution

Data collected from various sources which includes OpenStreetMap and Google Maps/Earth were used in the attribution of building features. Areas where there is no available data were subjected for field attribution using ESRI's Collector App. The app can be accessed offline and data collected can be synced to ArcGIS Online when WiFi or mobile data is available.

Table 18 summarizes the number of building features per type. On the other hand, Table 19 shows the total length of each road type, while Table 20 shows the number of water features extracted per type.

Table 18. Building features extracted for Langogan Floodplain.

Facility Type	No. of Features
Residential	49,140
School	749
Market	37
Agricultural/Agro-Industrial Facilities	4
Medical Institutions	38
Barangay Hall	6
Military Institution	0
Sports Center/Gymnasium/Covered Court	11
Telecommunication Facilities	2
Transport Terminal	16
Warehouse	3
Power Plant/Substation	0
NGO/CSO Offices	1
Police Station	3
Water Supply/Sewerage	0
Religious Institutions	56
Bank	10
Factory	32
Gas Station	23
Fire Station	2
Other Government Offices	51
Other Commercial Establishments	207
Total	**50,391**

Table 19. Total length of extracted roads for Langogan Floodplain.

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/ Municipal Road	Provincial Road	National Road	Others	
Langogan	382.5	225.68	12.17	100.03	0.00	**720.38**

Table 20. Number of extracted water bodies for Langogan Floodplain

Floodplain	Water Body Type					Total
	Rivers/ Streams	Lakes/ Ponds	Sea	Dam	Fish Pen	
Langogan	147	164	0	0	0	**311**

A total of 25 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 completed Digital Surface Model (DSM) of the Langogan floodplain overlaid with its ground features.

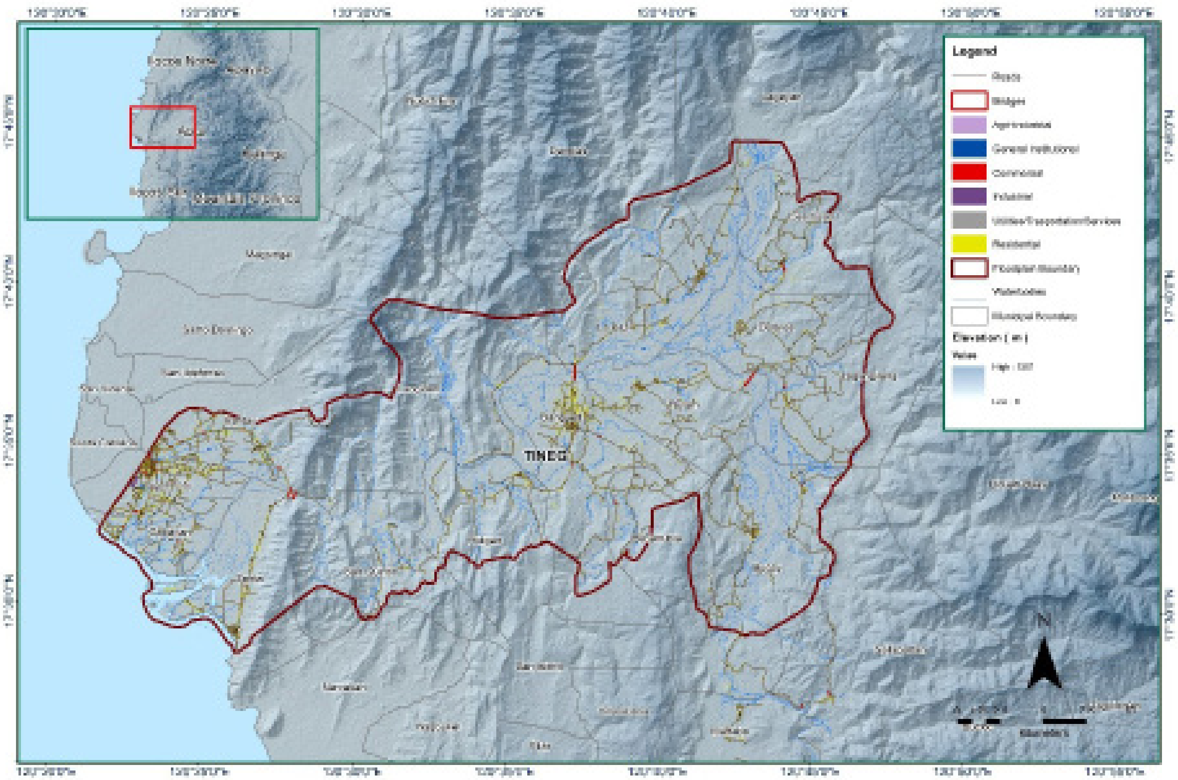

Figure 26. Extracted features of the Langogan Floodplain.

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

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For. Dona Rina Patricia C. Tajora, Elaine Bennet Salvador, For. Rodel C. Alberto

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

4.1 Summary of Activities

The Data Validation and Bathymetry Component (DVBC) with its partner HEI, the University of the Philippines Los Baños, conducted a field survey in Langogan River on November 3 to 15, 2015. Generally, the scope of work was comprised of (i) initial reconnaissance; (ii) control point survey for the establishment of a control point; (iii) the cross section survey and bridge as-built survey, and water level marking in the Mean Sea Level (MSL) of the Langogan Bridge in Brgy. Langogan, Puerto Prinsesa City; (iv) validation points acquisition covering the Langogan River Basin area; and (v) bathymetric survey of Langogan River. Figure 27 illustrates the extent of the entire survey in Langogan River.

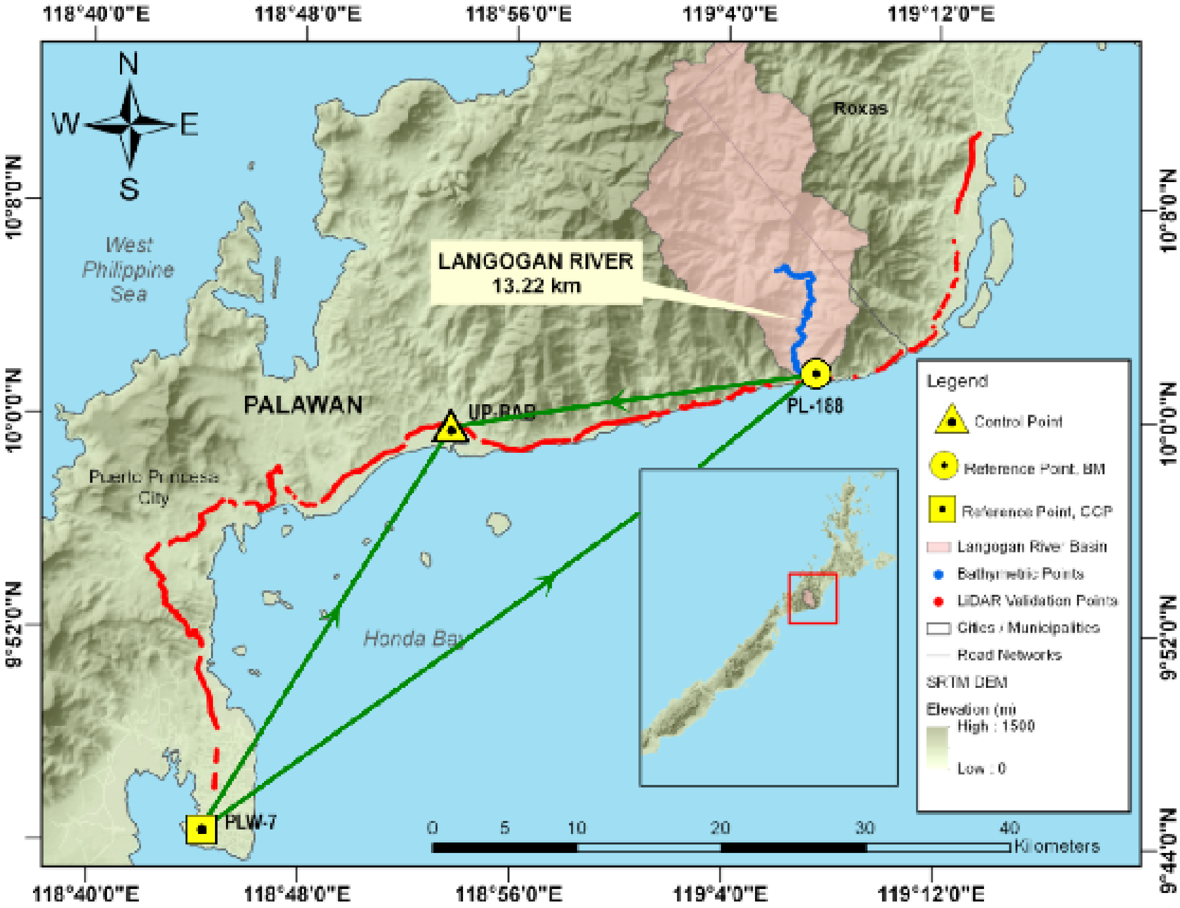


Figure 27. Langogan River Survey Extent

4.2 Control Survey

The GNSS network utilized for the Langogan River Basin is composed of a single loop established on November 06, 2015, which occupied the following reference points: PLW-7, a first order GCP in Brgy. Maningning, Puerto Prinsesa City; and PL-188, a first order benchmark in Brgy. Langogan, Puerto Prinsesa City, Palawan.

A control point was also established along approach of bridge namely UP-BAB, located at Babuyan Bridge, in Brgy. Maoyon, Puerto Prinsesa, Palawan.

Table 21 depicts the summary of reference and control points utilized, with their corresponding locations, while Figure 28 shows the GNSS network established in the Langogan River Survey.

Table 21. List of reference and control points used during the survey in Langogan River (Source: NAMRIA, UP-TCAGP).

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (m)	Elevation in MSL (m)	Date Established
PLW-7	1st order GCP	9°44'25.33347"	118°44'25.60607"	85.742	-	1990
PL-188	1st order BM	-	-	57.865	6.467	2008
UP-BAB	UP Established	-	-	-	-	11-6-2015

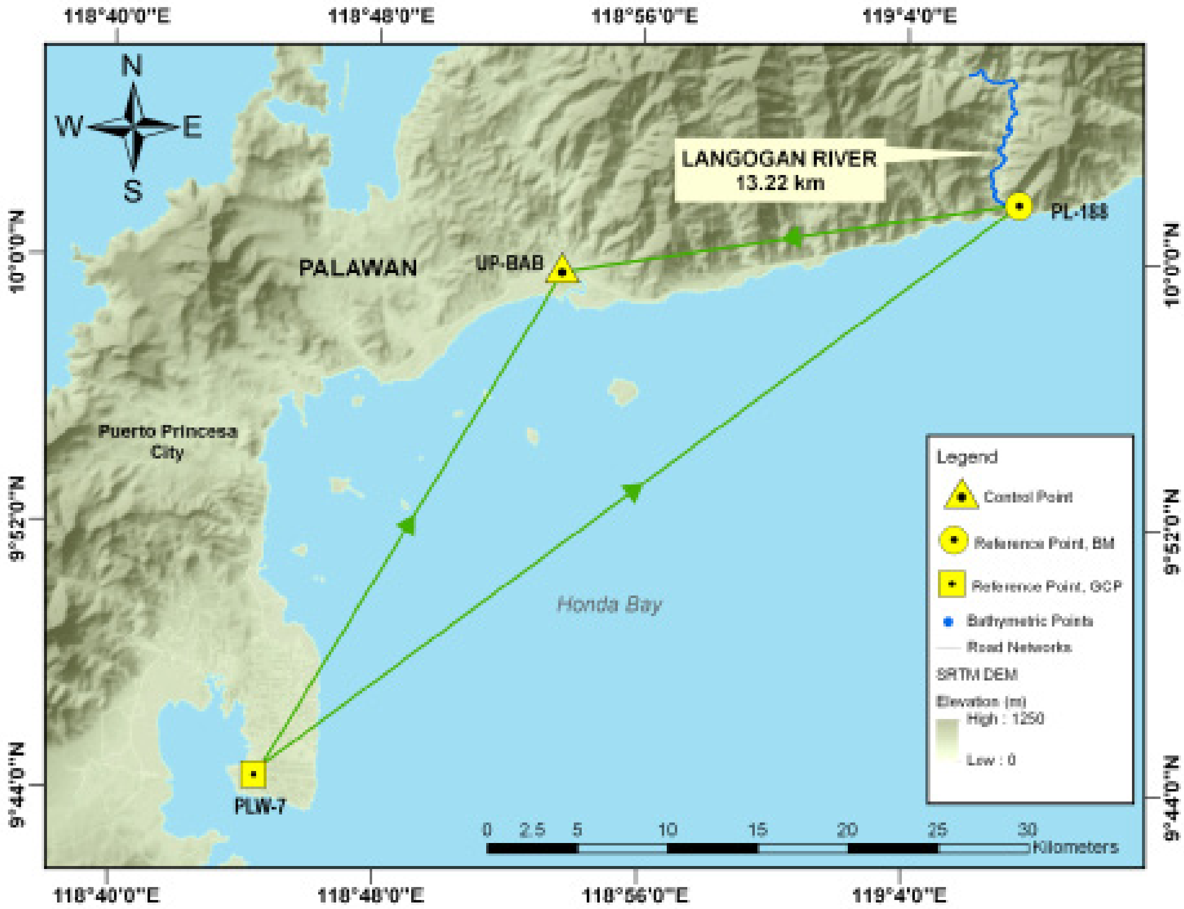


Figure 28. The GNSS Network established in the Langogan River Survey.

Figure 29 to Figure 31 depict the setup of the GNSS on recovered reference points and established control points in the Langogan River.

Figure 29. GNSS receiver set up, Trimble® SPS SPS 852, at PLW-7 at an old water tank inside the Water District compound, Brgy. Maningning, Puerto Prinsesa, Palawan.

Figure 30. GNSS receiver set up, Trimble® SPS SPS 882, at PL-188 located in Langogan Bridge, Brgy. Langogan, Puerto Prinsesa, Palawan.

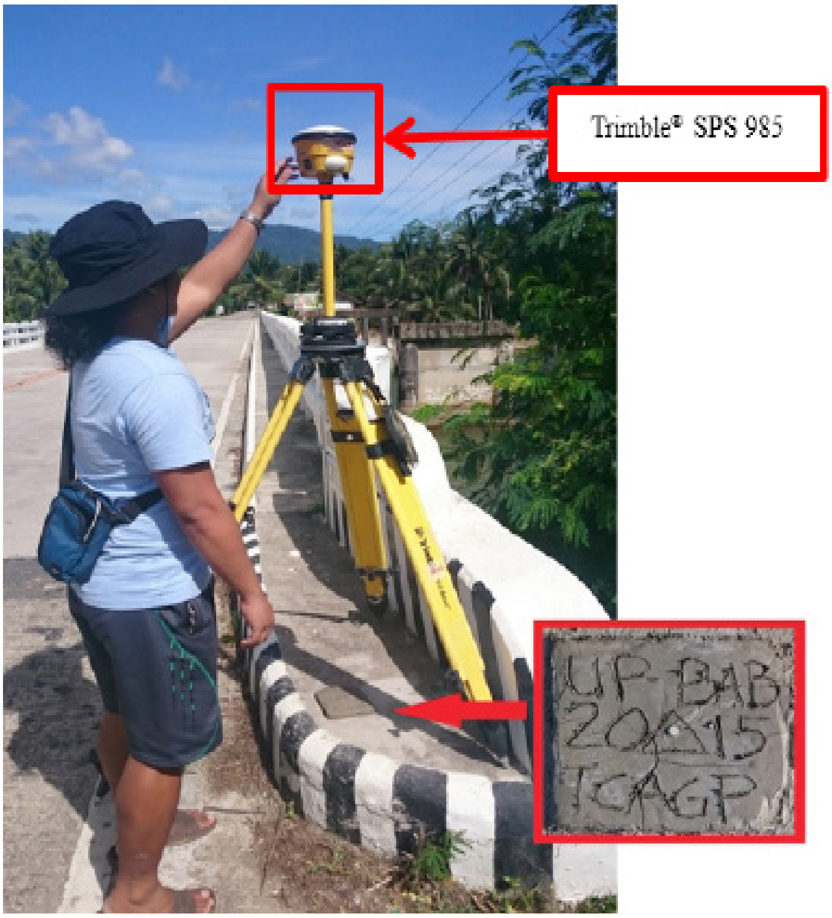


Figure 31. GNSS receiver set up, Trimble® SPS SPS 852, at UP-BAB in Babuyan Bridge, Brgy.Maoyon, Puerto Prinsesa, Palawan.

4.3 Baseline Processing

The GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/- 20 cm and +/- 10 cm requirement respectively. In cases where one or more baselines did not meet all of these criteria, masking was performed. Masking is the removal or covering of portions of the baseline data using the same processing software. The data is then repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, a resurvey is initiated. Table 22 presents the baseline processing results of control points in the Langogan River Basin, as generated by the TBC software.

Table 22. The Baseline processing report for the Langogan River GNSS static observation survey

Observation	Date of Observation	Solution Type	H. Prec. (m)	V. Prec (m)	Geodetic Az.	Ellipsoid Dist. (m)	ΔHeight (Meter)
PL188 --- UPBAB (B3)	Nov 6, 2015	Fixed	0.003	0.020	261°37'42"	25533.659	-0.319
PLW7 --- UPBAB (B2)	Nov 6, 2015	Fixed	0.003	0.016	30°40'20"	32806.731	-28.137
PLW7 --- PL188 (B1)	Nov 6, 2015	Fixed	0.005	0.016	52°43'22"	52773.818	-27.907

4.4 Network Adjustment

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

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

Where:

x_e is the Easting Error,
y_e is the Northing Error, and
z_e is the Elevation Error

For complete details, see the Network Adjustment Report shown in Table 23 to Table 26

The three (3) control points, PLW-7, PL-188 and UP-BAB were occupied and observed simultaneously to form GNSS LOOP. Coordinates of PLW-7 and elevation value of PL-188 were held fixed during the processing of the control points as presented in Table 23. Through these reference points, the coordinates and elevation of the unknown control points will be computed

Table 23. Constraints applied to the adjustment of the control points.

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
PL188	Grid				Fixed
PLW7	Global	Fixed	Fixed		
Fixed = 0.000001(Meter)					

Likewise, the list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 24. The fixed control point PL-188 and PLW-7, has no values for standard elevation and coordinates error, respectively.

Table 24. Adjusted grid coordinates for the control points used in the Langogan River flood plain survey

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
PL188	74882.798	0.010	1111141.324	0.008	6.467	?	e
PLW7	32397.249	?	1079651.883	?	35.303	0.055	LL
UPBAB	49529.234	0.009	1107714.961	0.007	6.924	0.062	

The results of the computation for accuracy are as follows:

a. PLW-7
Horizontal accuracy = Fixed
Vertical accuracy = 5.5 cm < 10 cm

b. PL-188
Horizontal accuracy = $\sqrt{((1.0)^2 + (0.8)^2}$
= $\sqrt{(1.0 + 0.64)}$
= 1.28 cm < 20 cm
Vertical accuracy = Fixed

c. UP-BAB
Horizontal accuracy = $\sqrt{((0.9)^2 + (0.7)^2}$
= $\sqrt{(0.81 + 0.49)}$
= 1.14 cm < 20 cm
Vertical accuracy = 6.2 cm < 10 cm

Following the given formula, the horizontal and vertical accuracy result of the three (3) occupied control points are within the required precision.

Table 25. Adjusted geodetic coordinates for control points used in the Langogan River Flood Plain validation.

Point ID	Latitude	**Longitude**	**Ellipsoid Height (Meter)**	**Height Error (Meter)**	**Constraint**
PL188	N10°01'44.89328	E119°07'24.55714"	57.865	?	e
PLW7	N9°44'25.33347"	E118°44'25.60607"	85.742	0.055	LL
UPBAB	N9°59'43.61069"	E118°53'35.10634"	57.580	0.062	

Table 26. The reference and control points utilized in the Langogan River Static Survey, with their corresponding locations (Source: NAMRIA, UP-TCAGP)

Point ID	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
PLW-7	1st Order GCP	9°44'25.33347"	118°44'25.60607"	85.742	1079652	32397.25	35.303
PL-188	1st Order BM	10°01'44.89328"	119°07'24.55714"	57.865	1111141	74882.8	6.467
UP-BAB	UP Established	9°59'43.61069"	118°53'35.10634"	57.58	1107715	49529.23	6.924

4.5 Cross-section and Bridge-as-built survey and Water Level Marking

The bridge cross-section and as-built survey were conducted at the upstream side of Langogan Bridge in Brgy. Langogan, Puerto Prinsesa City on November 7, 2015 using GNSS receiver Trimble® SPS 882 in PPK survey technique (Figure 32).

Figure 32. Cross–Section Survey on Langogan River.

The length of the cross-sectional line surveyed at Langogan Bridge is about one hundred forty-nine (149) meters with one hundred thirty-seven (137) cross-sectional points using the control point PL-188 as the GNSS base station. The location map, cross-section diagram, and the accomplished bridge data form are shown in Figure 33 to Figure 35, respectively.

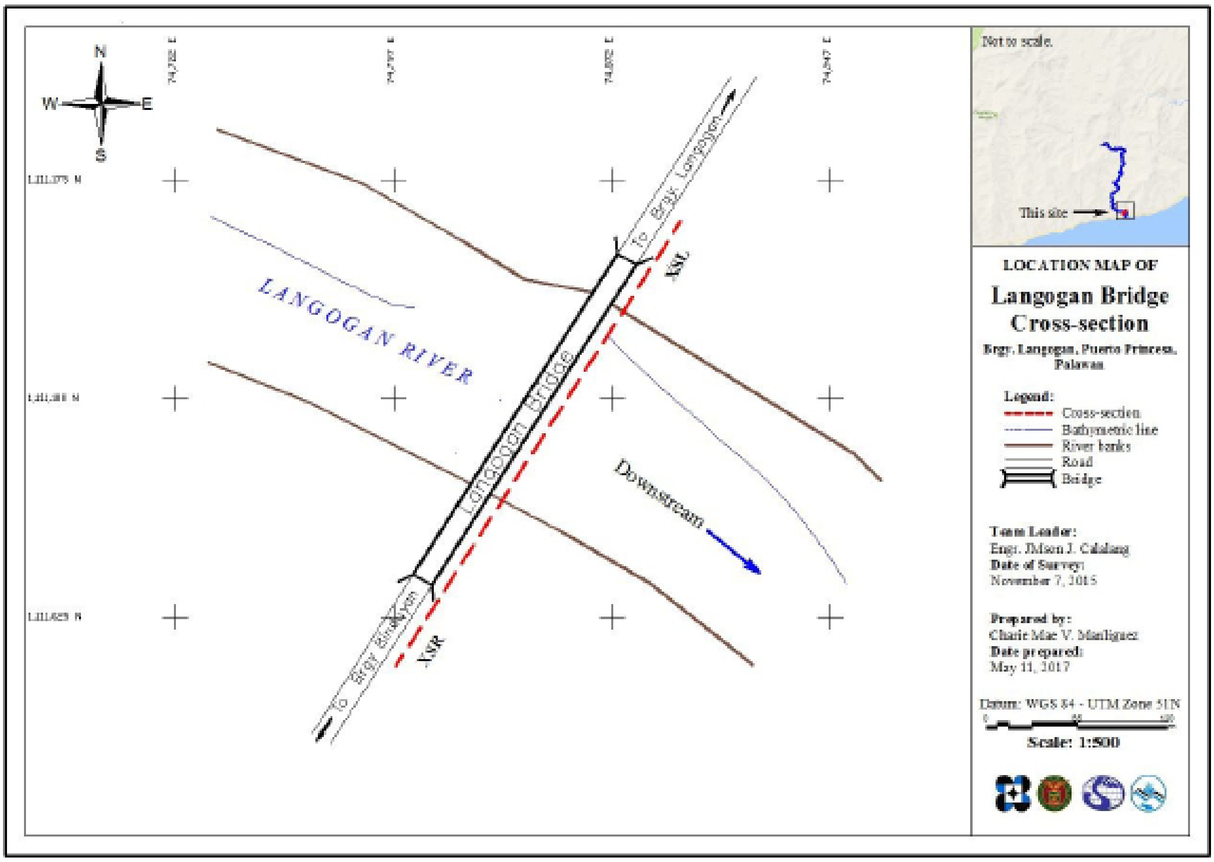


Figure 33. Location map of the Langogan Bridge Cross Section.

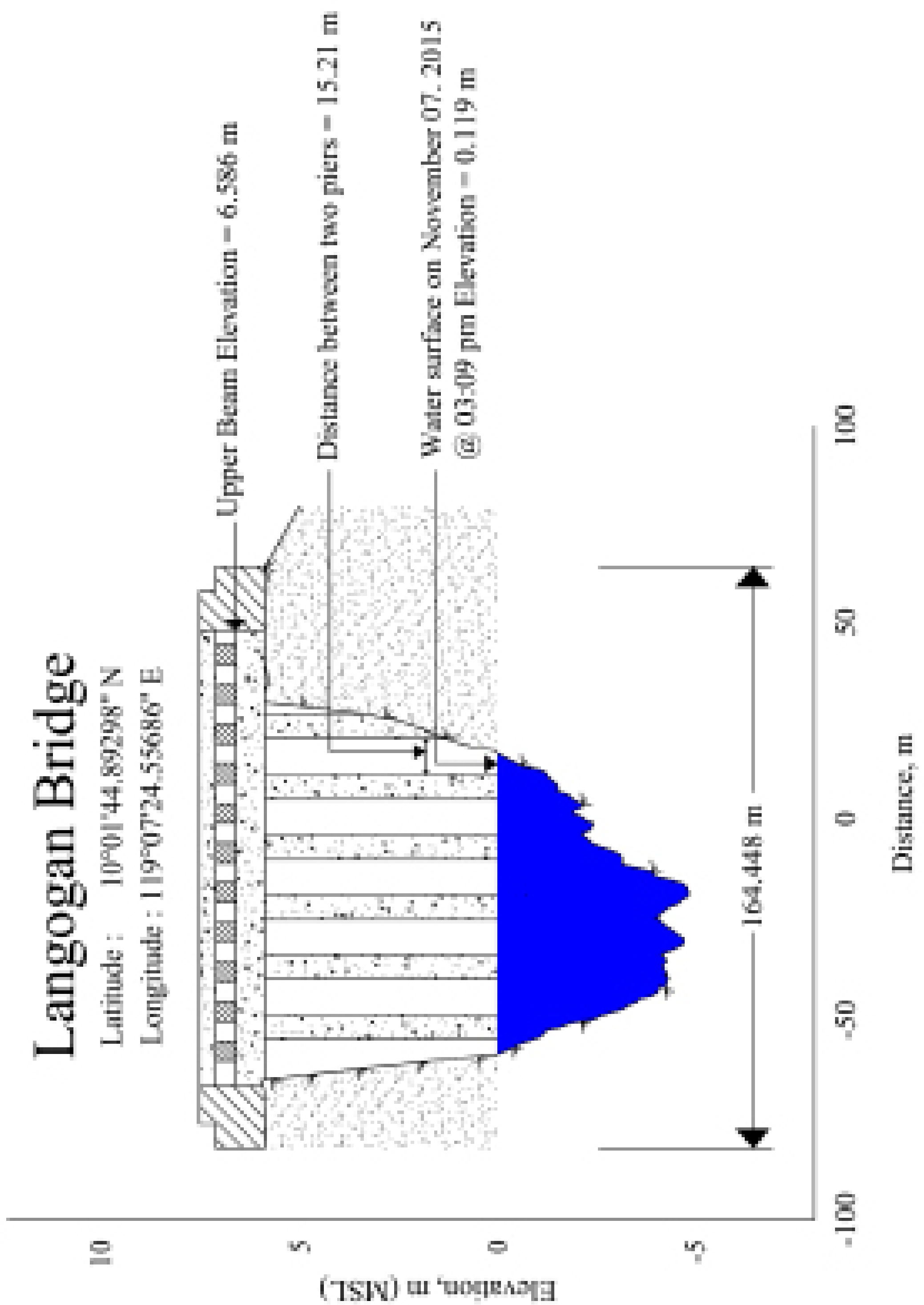


Figure 34. The Langogan Bridge cross-section survey drawn to scale.

Bridge Data Form

Bridge Name: Langogan Bridge **Date:** November 07, 2015

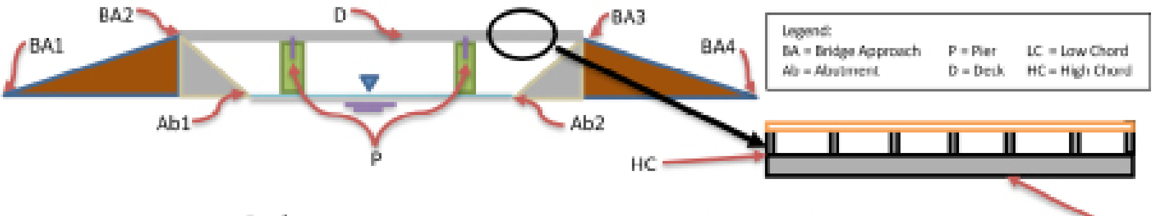
River Name: Langogan River **Time:** 02:49 pm

Location (Brgy, City, Region): Brgy. Langogan,Puerto Prinsesa City, Palawan

Survey Team: Team JM

Flow condition: low (normal) high **Weather Condition:** (fair) rainy

Latitude:10d01'44.89298" N **Longitude:** 119d07'24.55686" E



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

Elevation 6.586 meters **Width:** 7.30 meters **Span** (BA3-BA2): 130.669

	Station	High Chord Elevation	Low Chord Elevation
1	Pier 1	6.452	4.952
2	Pier 2	6.591	5.091
3	Pier 3	6.558	5.058

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

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	0	6.586	BA3	137.138	6.034
BA2	30.703	6.469	BA4	164.448	5.492

Abutment: Is the abutment sloping? Yes (No) If yes, fill in the following information:

	Station (Distance from BA1)	Elevation
Ab1	28.0	6.047
Ab2	128.426	1.016

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

Shape: Rectangular Columns **Number of Piers:** 6 **Height of column footing:** 5.1

	Station (Distance from BA1)	Elevation	Pier Width
Pier 1	45.893	6.452	1.2
Pier 2	60.878	6.550	1.2
Pier 3	76.093	6.591	1.2
Pier 4	91.296	6.586	1.2
Pier 5	106.586	6.558	1.2
Pier 6	121.930	6.451	1.2

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

Figure 35. The Langogan Bridge as-built survey data.

The water surface elevation of Langogan River was determined using Trimble® SPS 882 in PPK mode survey on November 07, 2015 at 03:09 P.M. This was translated into marking on the bridge's pier using the same technique as shown in Figure 36. It now serves as the reference for flow data gathering and depth gauge deployment of the University of the Philippines Los Baños (UPLB), the partner HEI responsible for the monitoring of Langogan River.

Figure 36. Water level markings on Langogan Bridge.

The length of the cross-sectional line surveyed at Langogan Bridge is about one hundred forty-nine (149) meters with one hundred thirty-seven (137) cross-sectional points using the control point PL-188 as the GNSS base station. The location map, cross-section diagram, and the accomplished bridge data form are shown in Figure 33 to Figure 35, respectively.

4.6 Validation Points Acquisition Survey

The validation points acquisition survey was conducted on November 06, 09, 10, and 12, 2015 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 37. It was secured with ropes tied to ensure that it was horizontally and vertically balanced. The antenna height was 2.10 m and measured from the ground up to the bottom of notch of the GNSS Rover receiver.

Figure 37. GNSS Receiver Trimble® SPS 882 installed on a vehicle for Ground Validation Survey.

The survey traversed the concrete roads of Puerto Princesa City starting from Brgy. Langogan and travelling down to Brgy. Caramay in the Municipality of Roxas. The survey gathered a total 8,513 points using control points PL-188 as the GNSS base station on November 6 and 9, 2015, UP-BAB on November 10, 2015 and PLW-7 on November 12, 2015 for the entire extent of validation points acquisition survey as illustrated in the map in Figure 38.

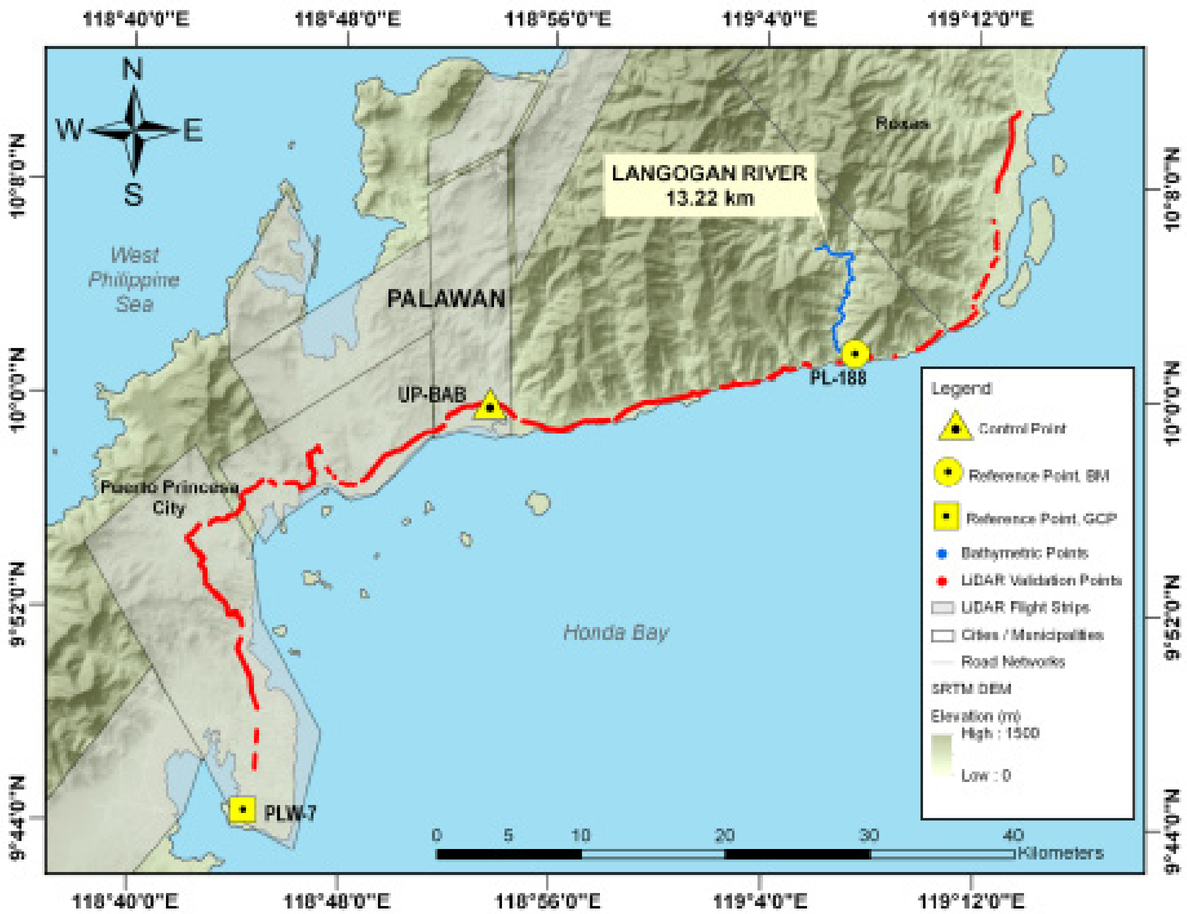


Figure 38. The extent of the LiDAR ground validation survey (in red) for Langogan River Basin

4.7 Bathymetric Survey

A bathymetric survey was performed on November 13, 2015 using a boat with an installed Ohmex™ single beam echo sounder and a mounted Trimble® SPS 882 GNSS receiver implementing PPK survey technique, as illustrated in Figure 39. The survey started in the middle portion of the river in Brgy. Langogan, Puerto Princesa City with coordinates 10°03’37.08265” 119°06’56.40443”, and ended at the mouth of the river I the same barangay with coordinates 10°01’32.20117” 119°07’25.34792”. The control points UP_BAT-1 and UP_BAT-2 were used as GNSS base stations all throughout the entire survey.

Figure 39. Set up of the bathymetric survey at Langogan River.

A manual bathymetric survey was conducted on November 9 and 11, 2015 Trimble® SPS 882 in GNSS PPK survey technique as shown in Figure 40. The survey began at the upstream portion of the river in Brgy. Langogan, Puerto Princesa City with coordinates 10°05'38.34011" 119°05'52.51475", traversed the river by foot and ended at the starting point of bathmetric survey using a boat.

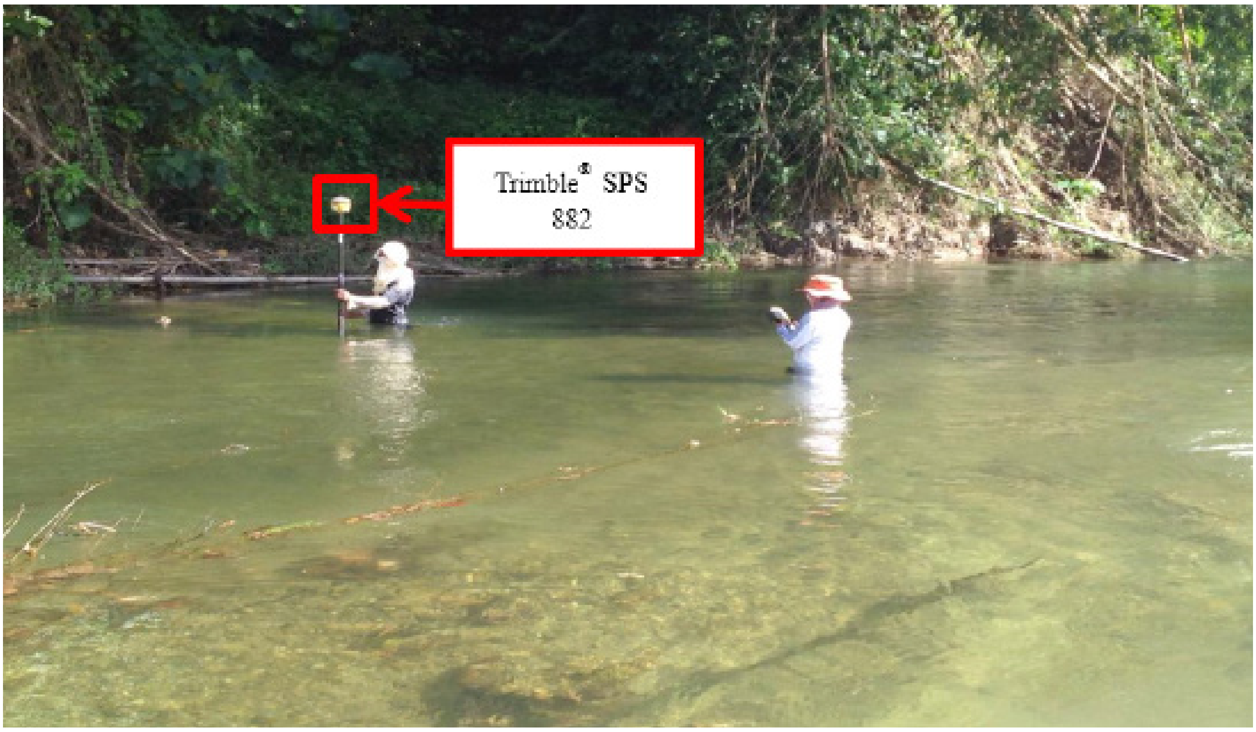


Figure 40. Setup of manual bathymetry survey for Langogan River using a Trimble® SPS 882.

Overall, the bathymetric survey for Langogan River gathered a total of 10,148 points covering an approximate distance of 13.22 kilometers acquired using the control point PL-188 as the GNSS base station. The entire traverse covered for the bathymetry survey is shown in the map in Figure 41. To further illustrate this, a CAD drawing of the riverbed profile of the Langogan River was produced. As seen in Figure 42, the highest and lowest elevation has 26-m difference. The highest elevation observed was 19.526 m in MSL located at the upstream part of the river, while the lowest elevation observed was -7.416 m in MSL located at the mouth of the river.

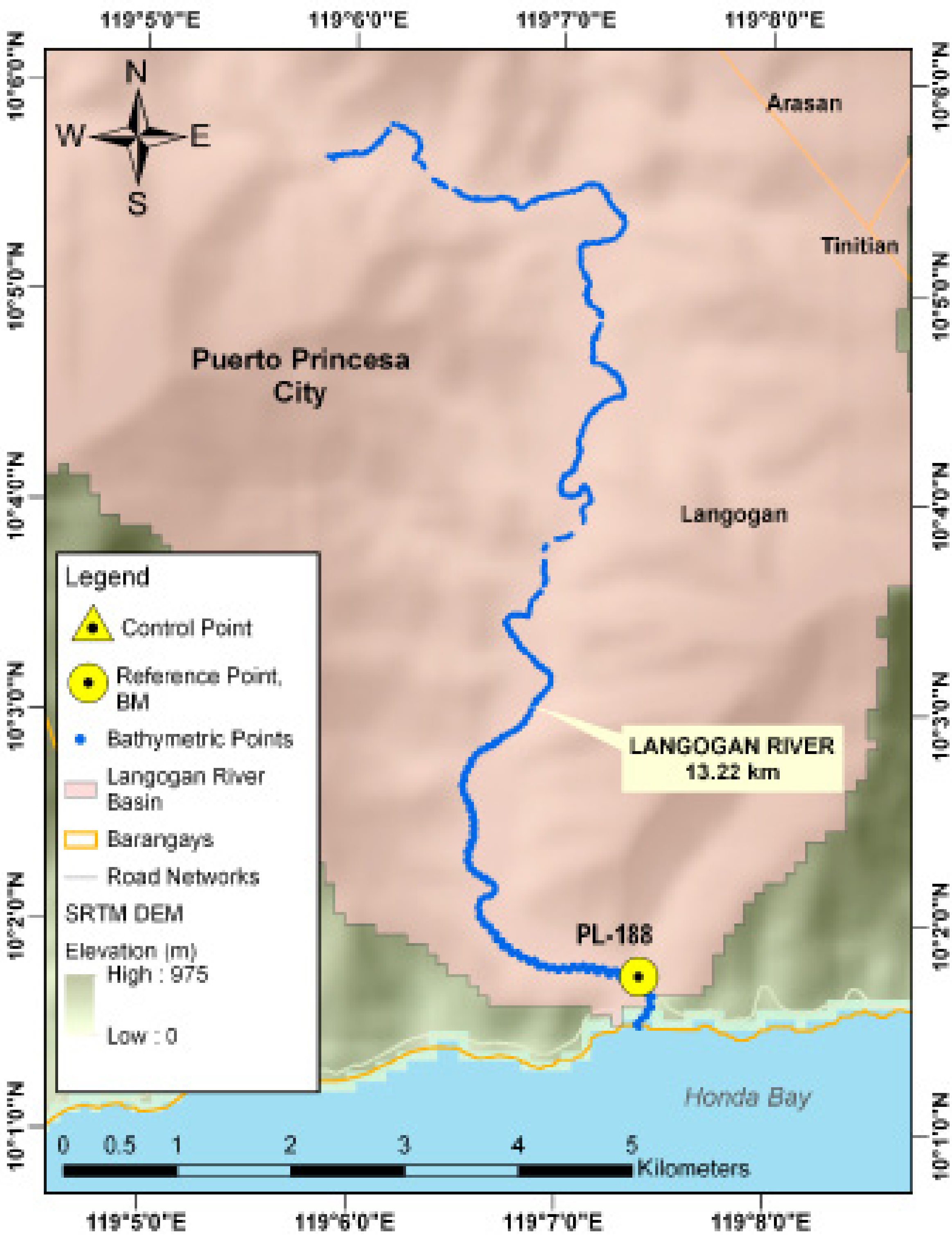


Figure 41. The extent of the Langogan River Bathymetry Survey.

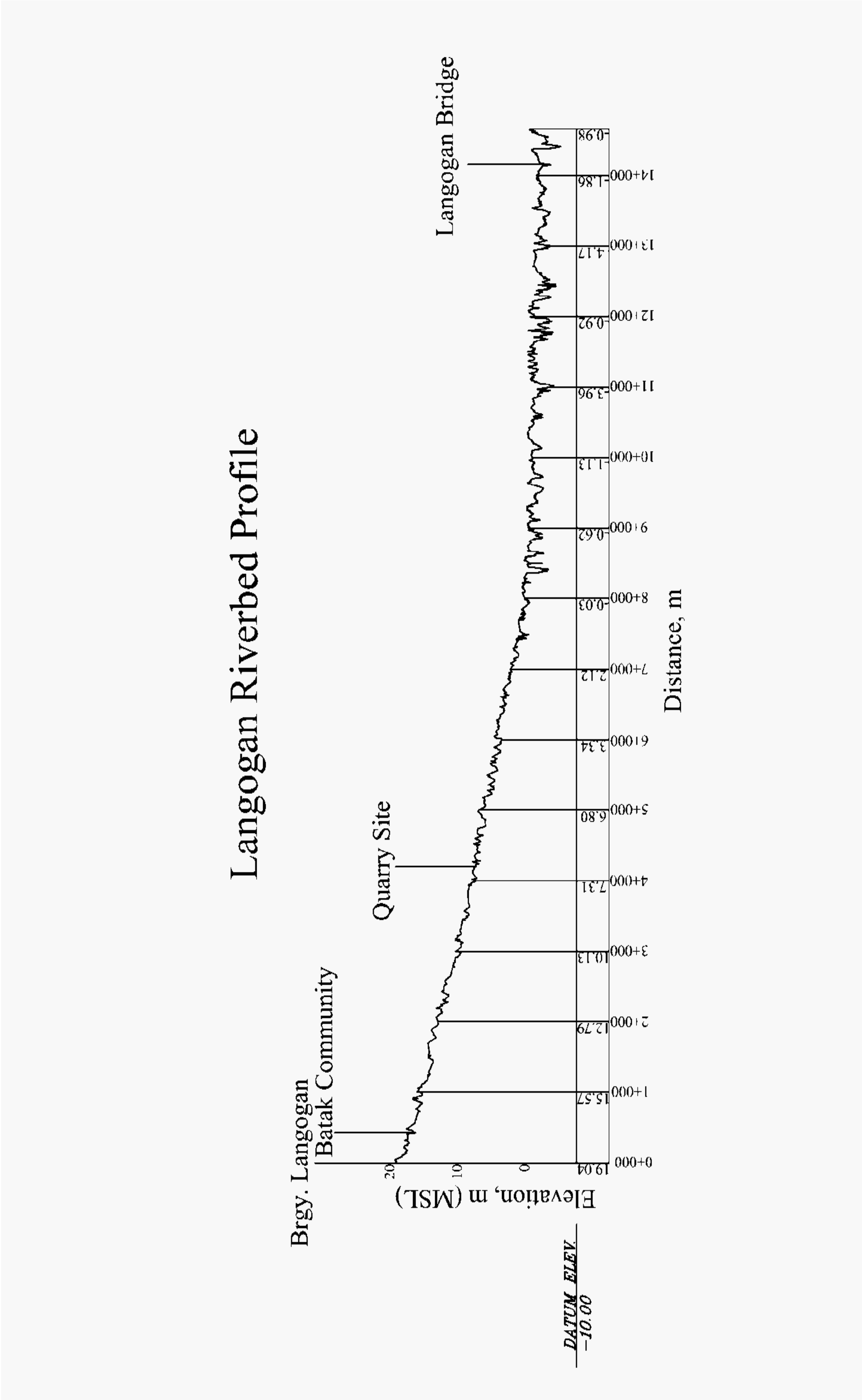


Figure 42. The Langogan Riverbed Profile.

CHAPTER 5: FLOOD MODELING AND MAPPING

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

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

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

5.1.2 Precipitation

There is no gathered rainfall data for Langogan River Basin. The HMS model is not calibrated. The values generated HMS model is set to default.

5.2 RIDF Station

PAGASA computed the Rainfall Intensity Duration Frequency (RIDF) values for the Puerto Princesa Rain Gauge (Table 27). The RIDF rainfall amount for 24 hours was converted into a synthetic storm by interpolating and re-arranging the values in such a way that certain peak values will be attained at a certain time (Figure 43). This station was selected based on its proximity to the Langogan watershed. The extreme values for this watershed were computed based on a 58-year record.

Table 27. RIDF values for the Puerto Princesa Rain Gauge, as computed by PAGASA

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

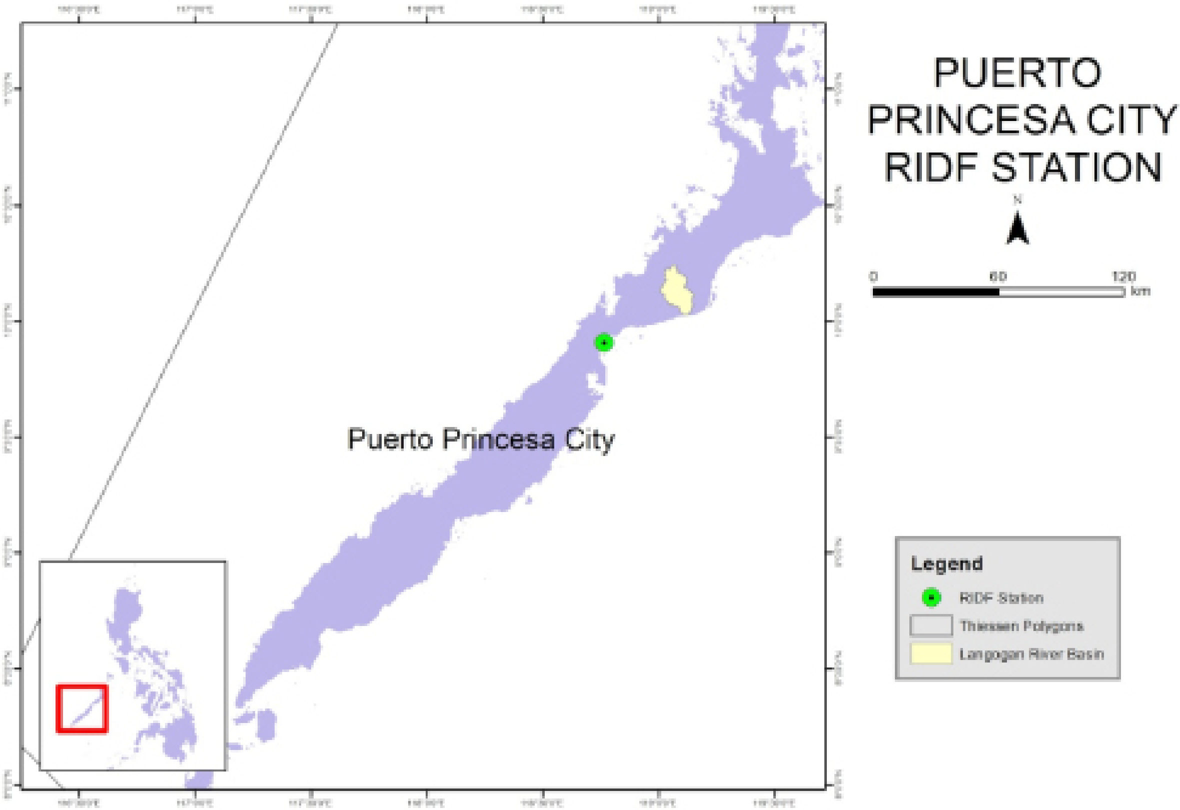

Figure 43. Location of Puerto Princesa RIDF Station relative to Langogan River Basin.

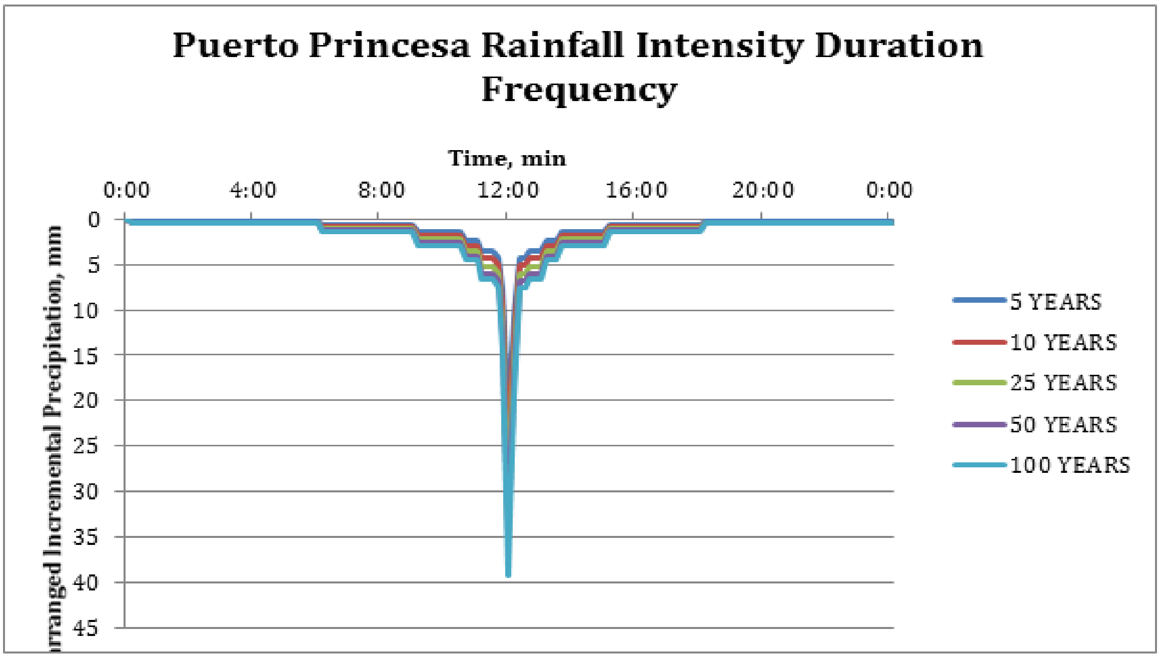

Figure 44. Synthetic storm generated for a 24-hr period rainfall for various return periods.

5.3 HMS Model

The soil dataset was generated before 2004 from the Bureau of Soils under the Department of Environment and Natural Resources Management. The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Langogan River Basin are shown in Figure 45 and Figure 46, respectively.

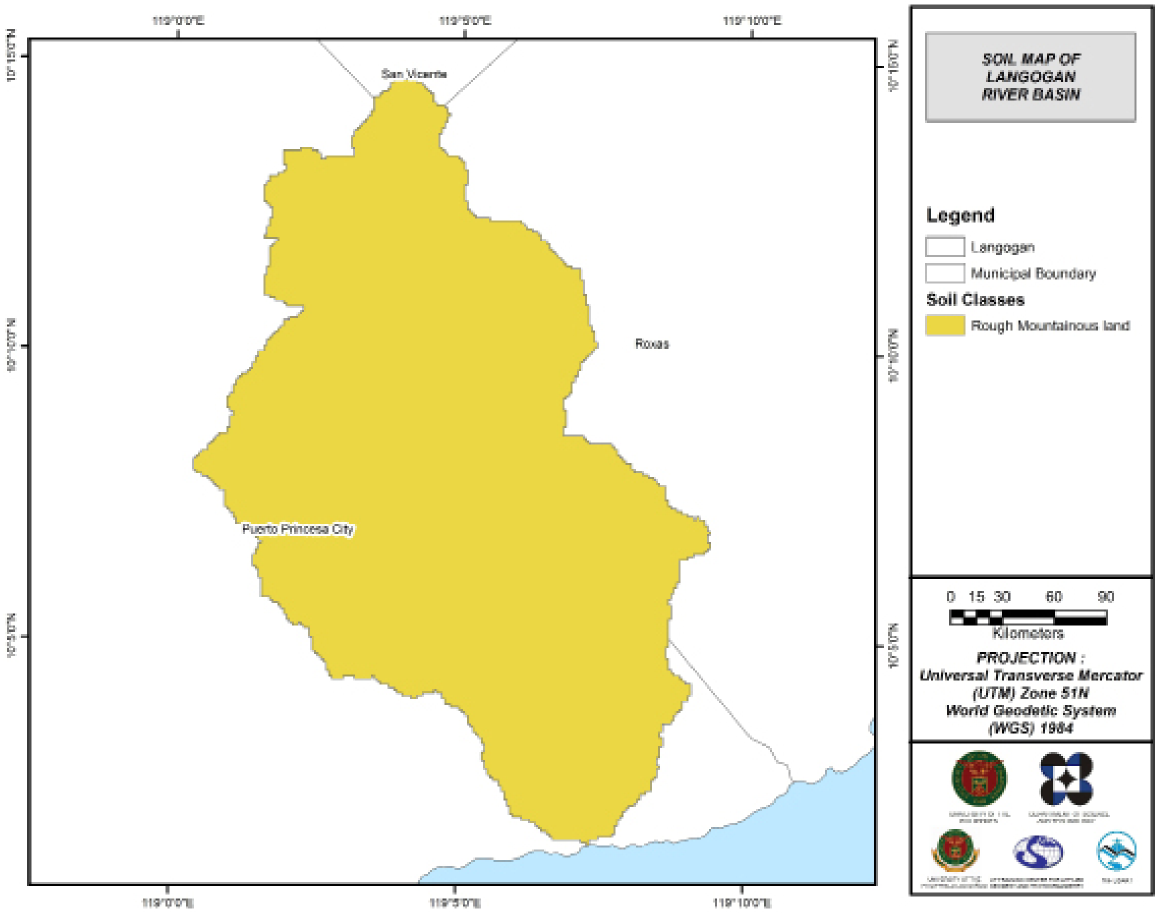

Figure 45. Soil Map of Langogan River Basin.

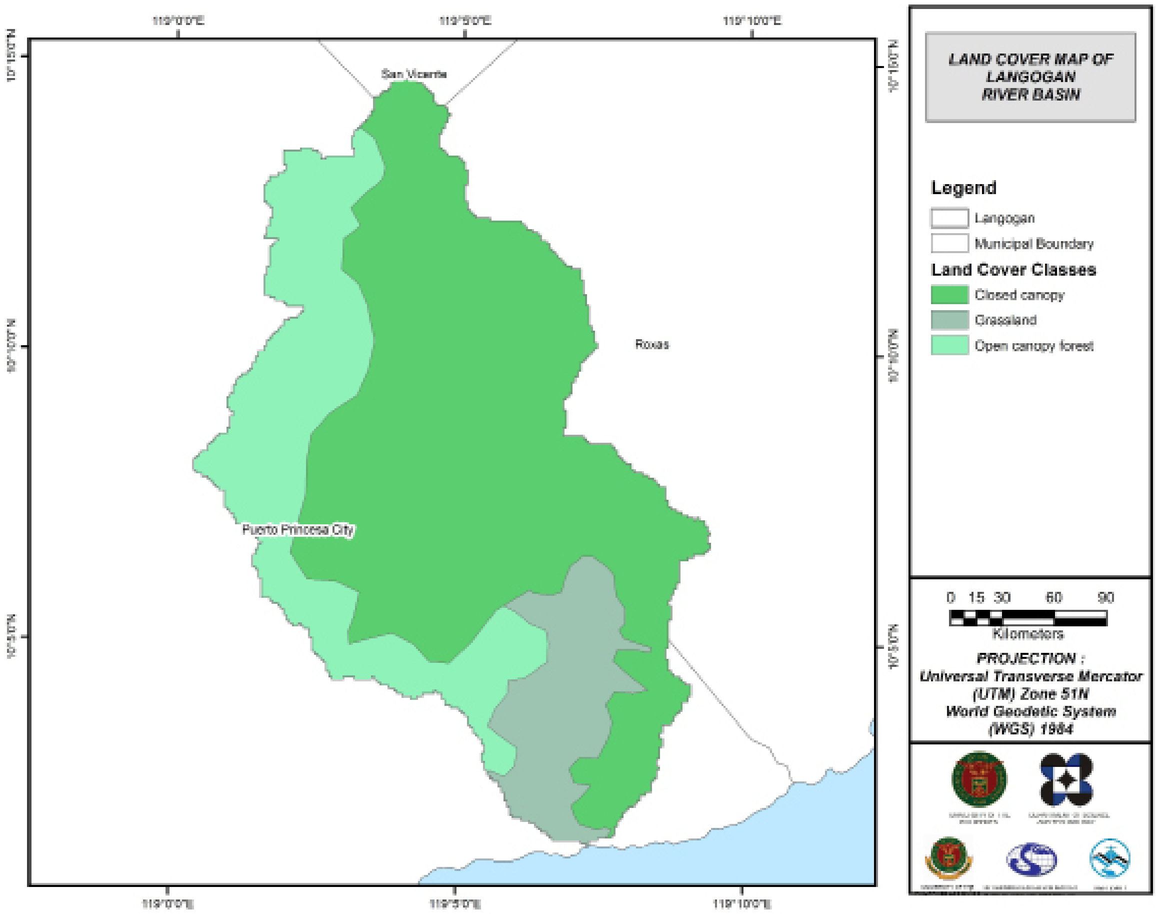

Figure 46. Land Cover Map of Langogan River Basin.

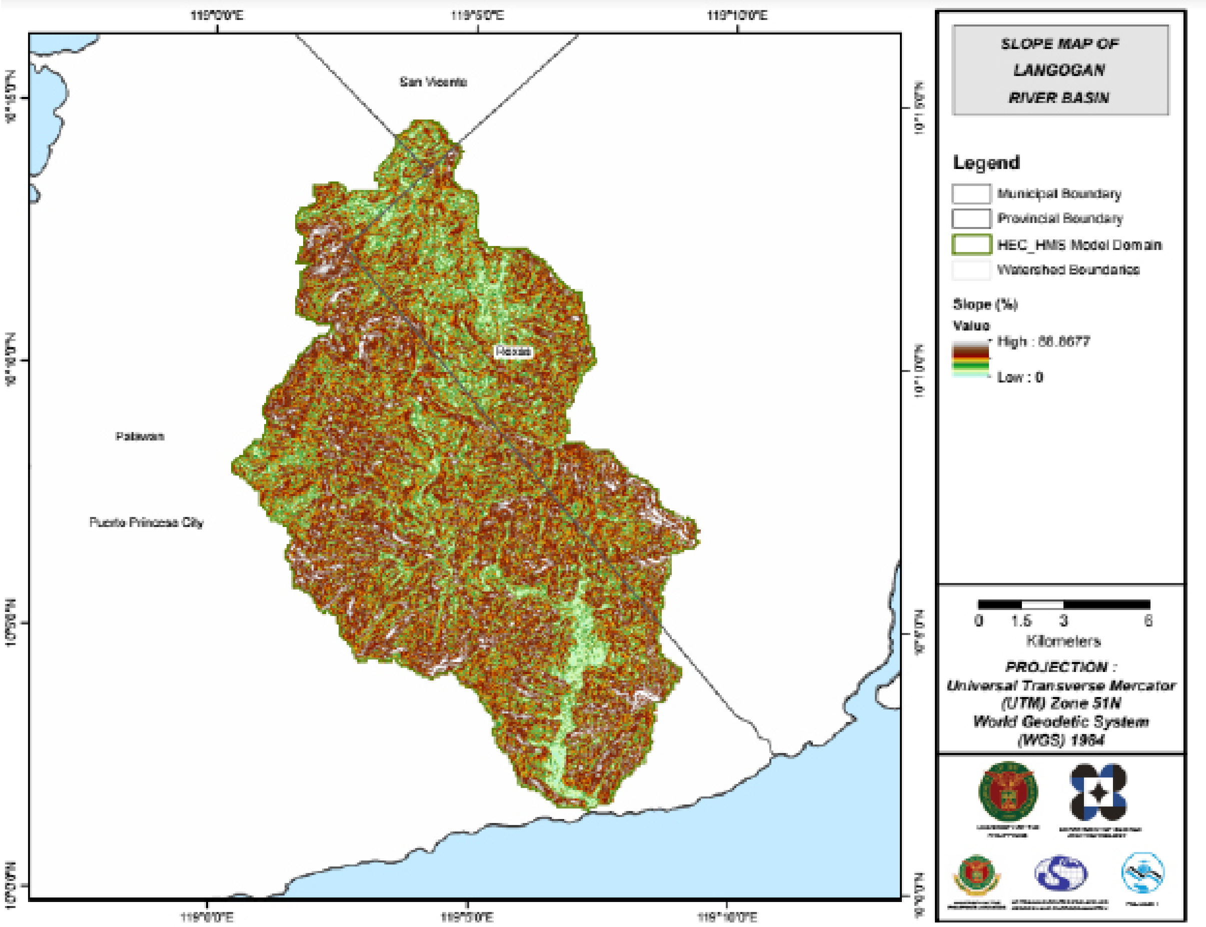

Figure 47. Slope Map of the Langogan River Basin.

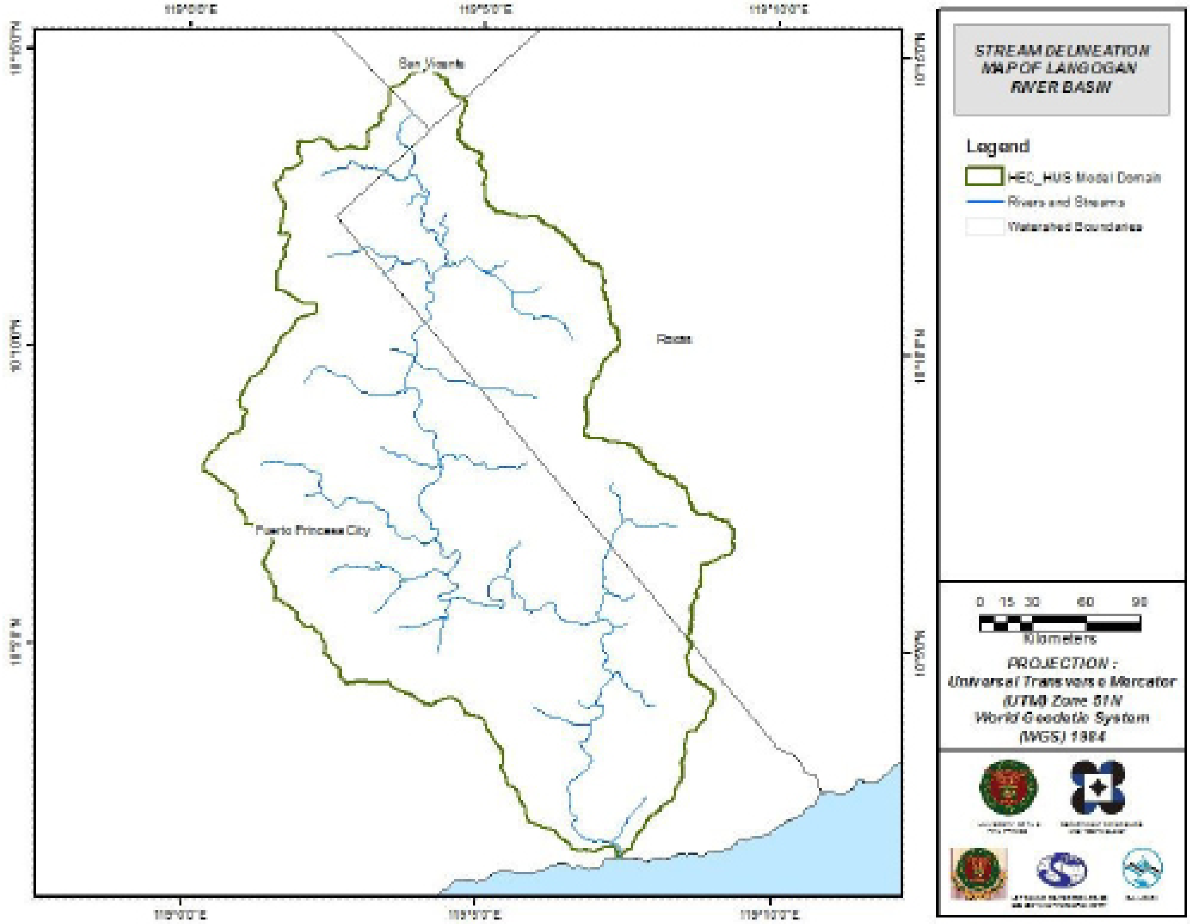

Figure 48. Stream Delineation Map of Langogan River Basin.

Using the SAR-based DEM, the Langogan basin was delineated and further subdivided into subbasins. The model consists of 64 sub basins, 31 reaches, and 30 junctions as shown in Figure 49 (See Annex 10). The main outlet is labelled as Langogan_outlet.

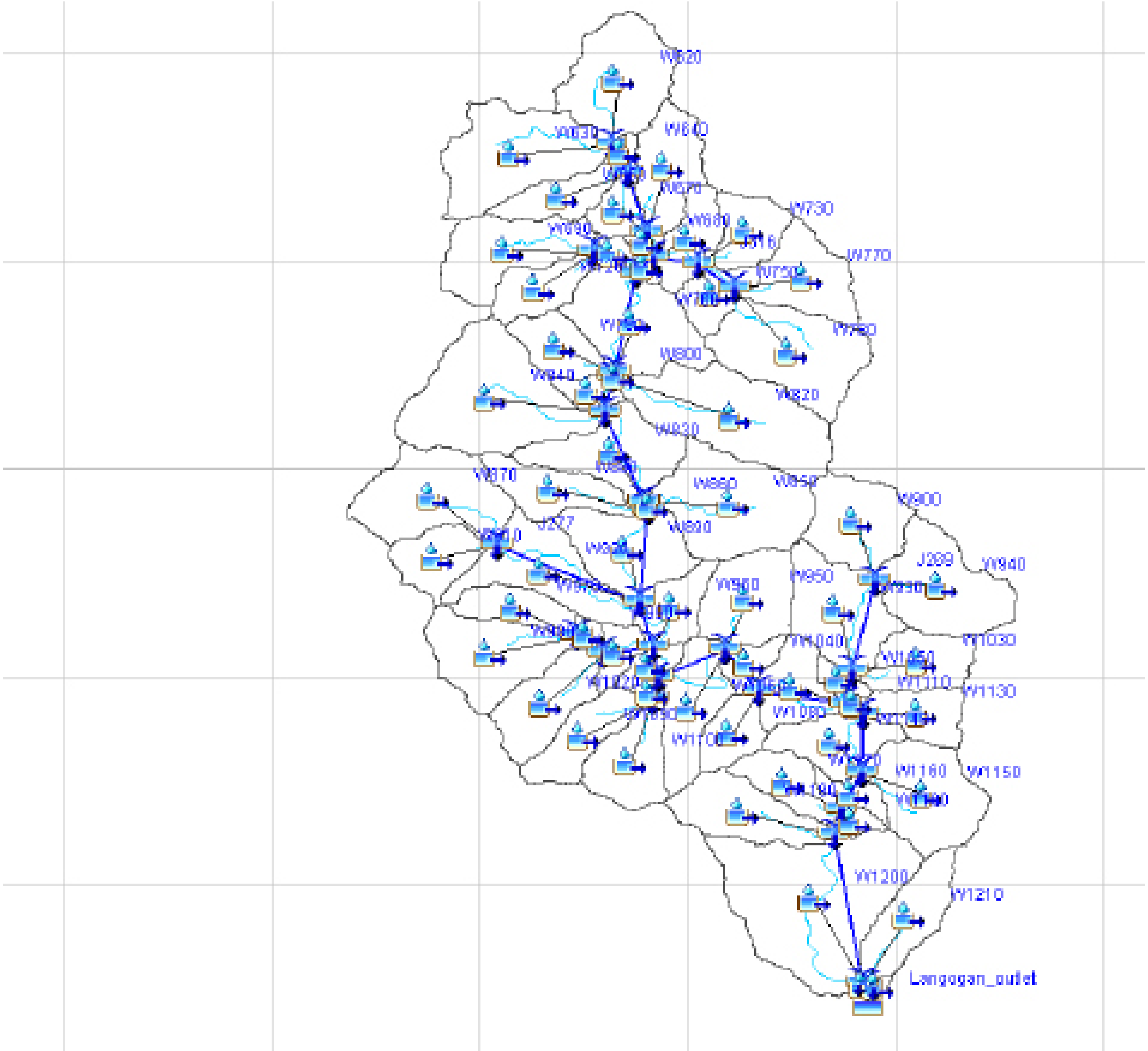

Figure 49. Langogan river basin model generated in HEC-HMS.

5.4 Cross-section Data

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

5.5 Flo 2D Model

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

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

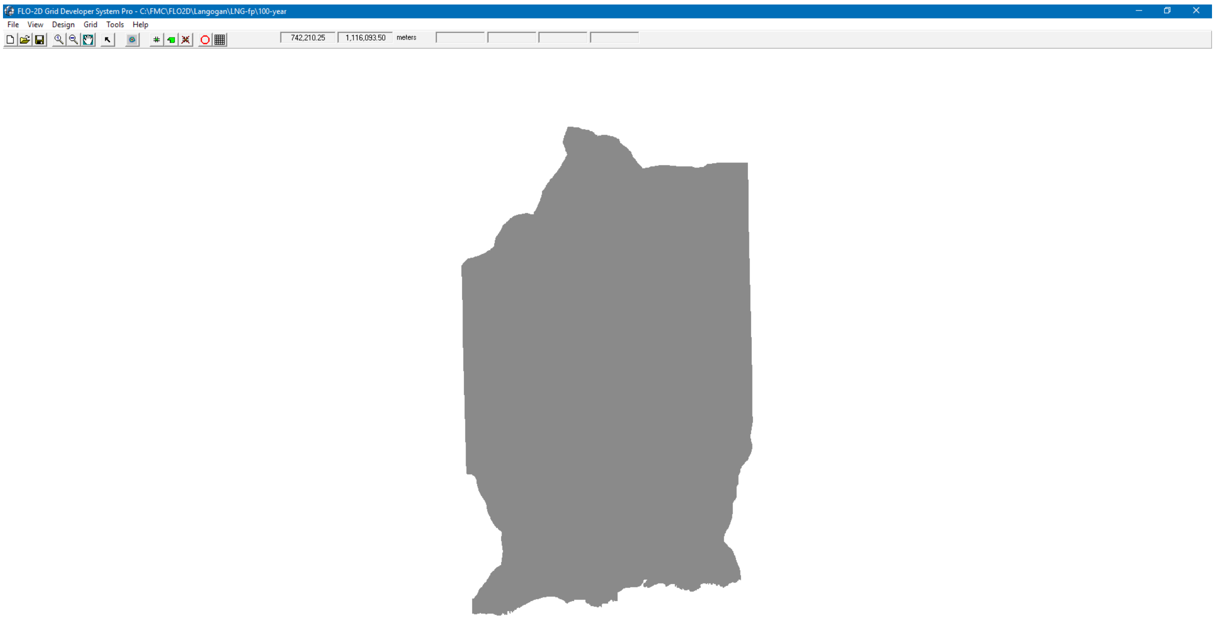

Figure 50. A screenshot of the river sub-catchment with the computational area to be modeled in FLO-2D Grid Developer System Pro (FLO-2D GDS Pro).

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 26.90186 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m2/s. The generated hazard maps for Langogan are in Figure 52, 54, and 56.

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 38 861 300.00 m2.

There is a total of 46 483 702.26 m3 of water entering the model. Of this amount, 12 978 057.80 m3 is due to rainfall while 33 505 644.46 m3 is inflow from other areas outside the model. 4 000 850.75m3 of this water is lost to infiltration and interception, while 21 193 462.30 m3 is stored by the flood plain. The rest, amounting up to 21 289 386.30 m3, is outflow. The generated flood depth maps for Langogan are in Figure 53, 55, and 57.

5.6 HEC-HMS Model Values (Uncalibrated)

Table 28 shows the range of values of the parameters in the model.

Table 28. Range of values for the Langogan River Basin.

Hydrologic Element	Calculation Type	Method	Parameter	Range of Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	8 - 10
			Curve Number	55 - 60
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.2 - 3
			Storage Coefficient (hr)	0.4 - 5

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 8 to 10mm means that there is minimal 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 55 to 60 for curve number is lower than the advisable for Philippine watersheds depending on the soil and land cover of the area (M. Horritt, personal communication, 2012).

Time of concentration and storage coefficient are the travel time and index of temporary storage of runoff in a watershed. The range of calibrated values from 0.2 hours to 5 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.

5.7 River Analysis (RAS) Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. For this publication, only a sample output map river was to be shown. Figure 51 shows a generated sample map of the Langogan River using the calibrated HMS base flow.

Figure 51. Sample output map of the Langogan RAS Model.

5.8 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. Figure 52 to Figure 57 show the 5-, 25-, and 100-year rain return scenarios of the Langogan floodplain. The floodplain, with an area of 38.69 sq. km., covers Puerto Princesa City. Table 29 shows the percentage of area affected by flooding per municipality

Table 29. Municipality affected in Langogan floodplain.

Province	Municipality	Total Area	Area Flooded	% Flooded
Palawan	Puerto Princesa	2186.36	38.42	1.76%

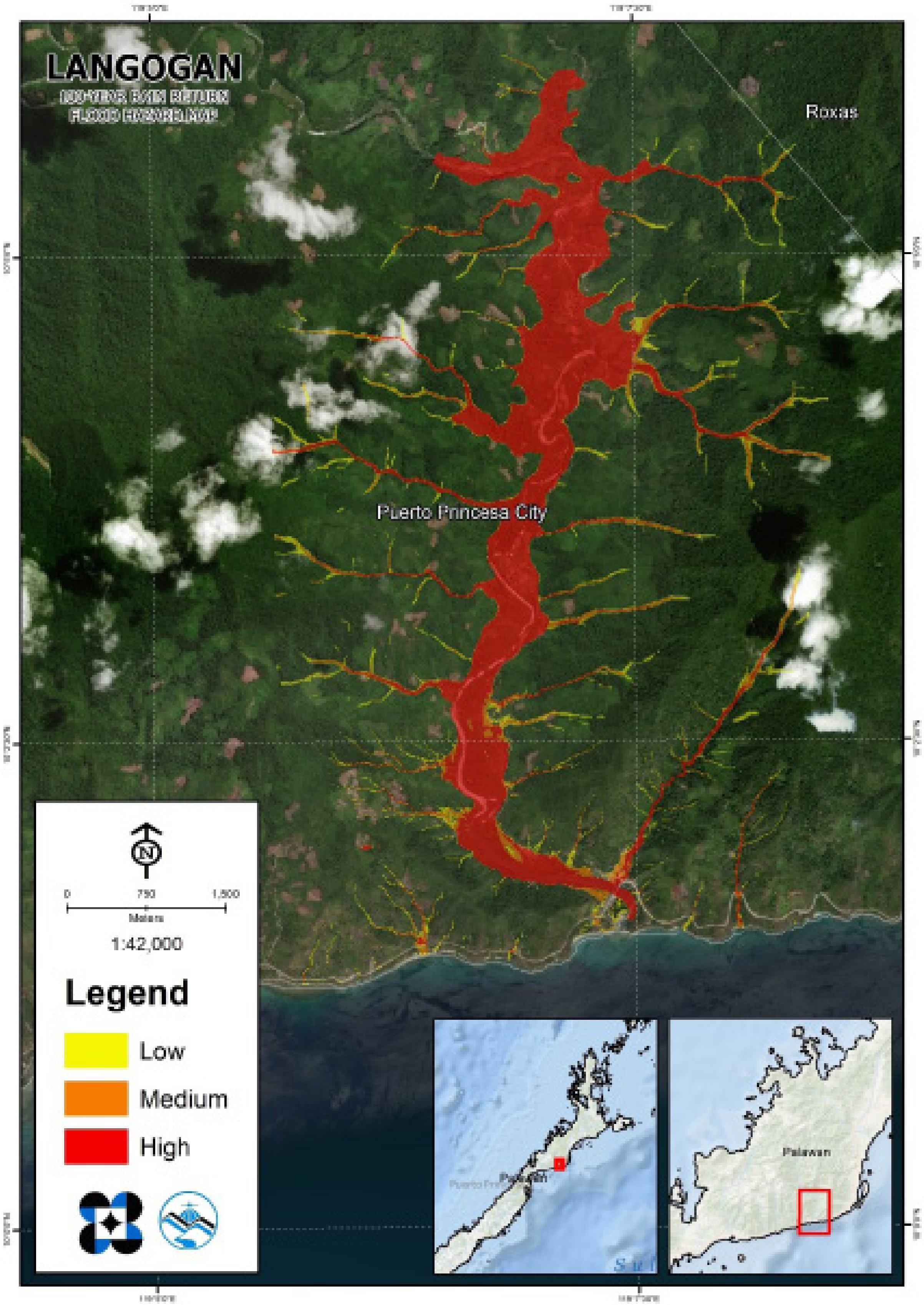

Figure 52. A 100-year Flood Hazard Map for Langogan Floodplain overlaid on Google Earth imagery.

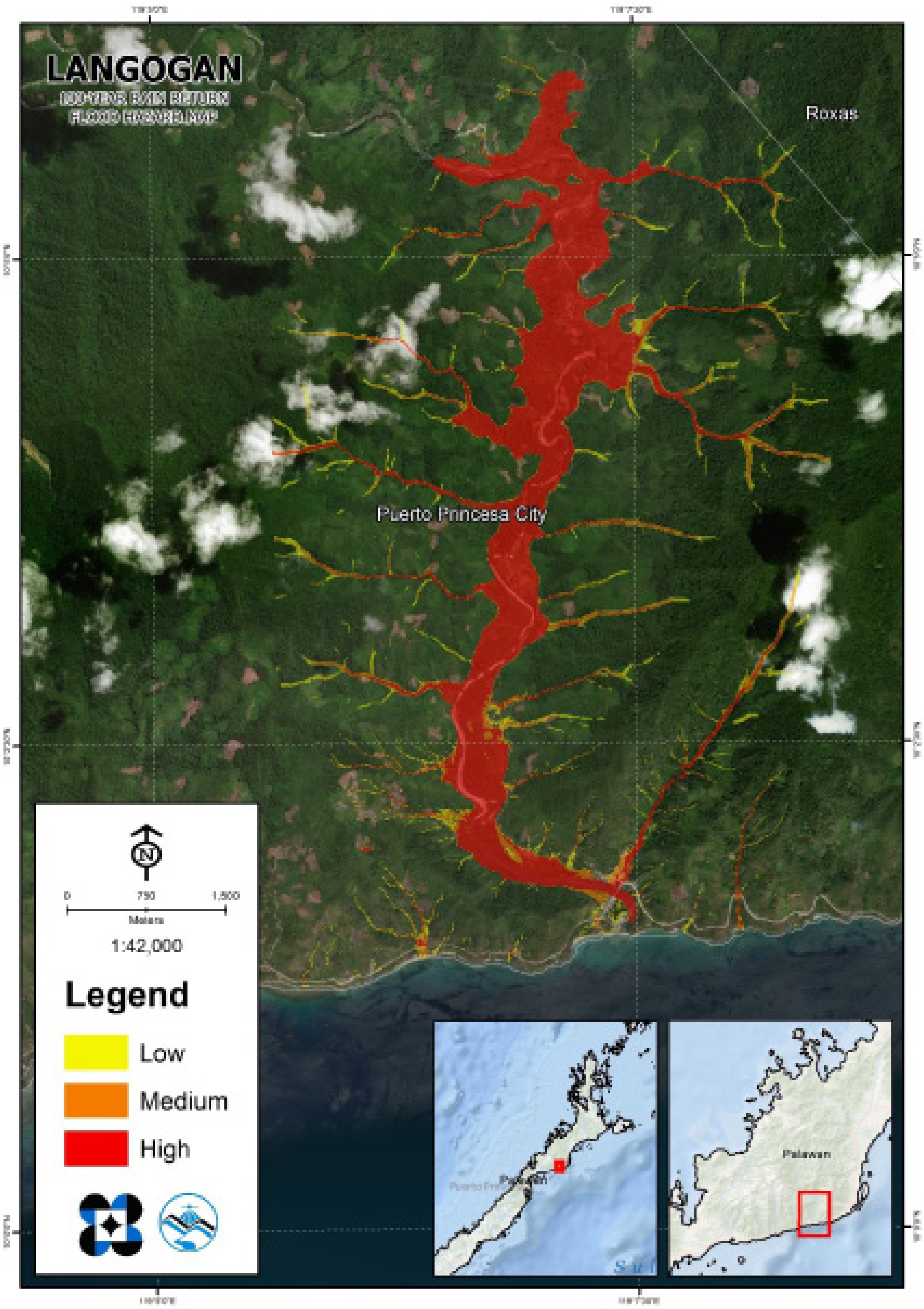

Figure 53. A 100-year Flow Depth Map for Langogan Floodplain overlaid on Google Earth imagery.

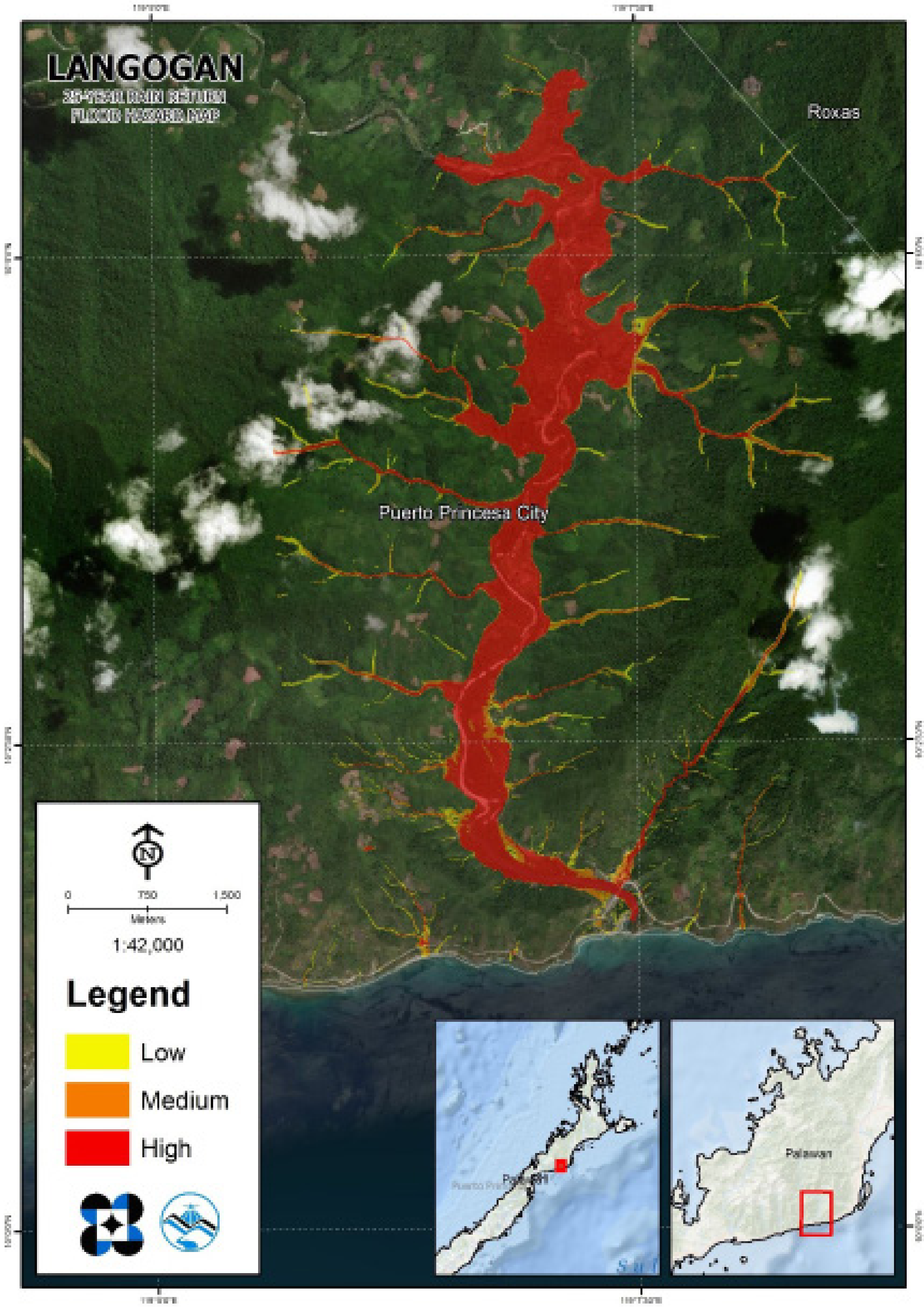

Figure 54. A 25-year Flood Hazard Map for Langogan Floodplain overlaid on Google Earth imagery.

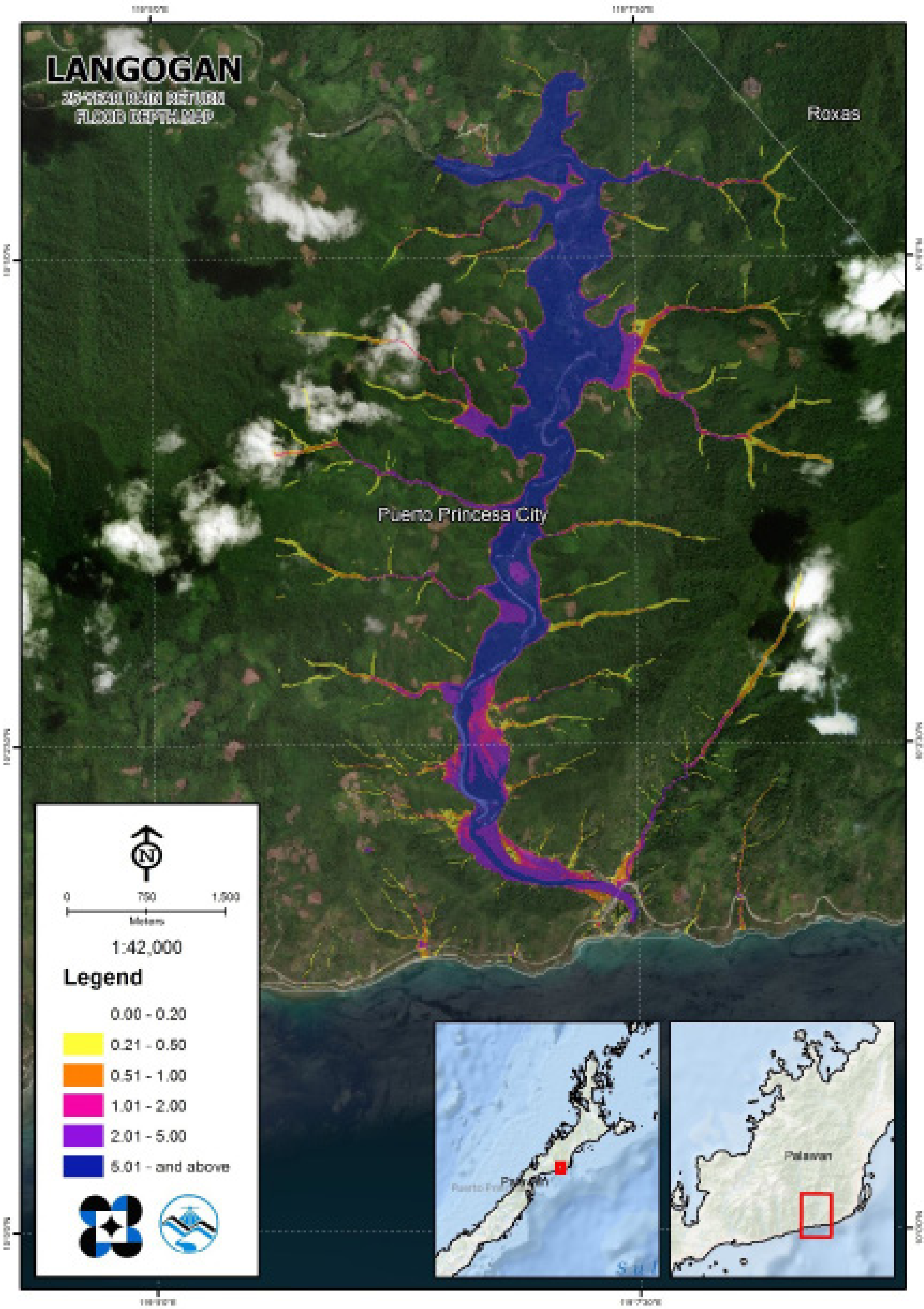

Figure 55. A 25-year Flow Depth Map for Langogan Floodplain overlaid on Google Earth imagery.

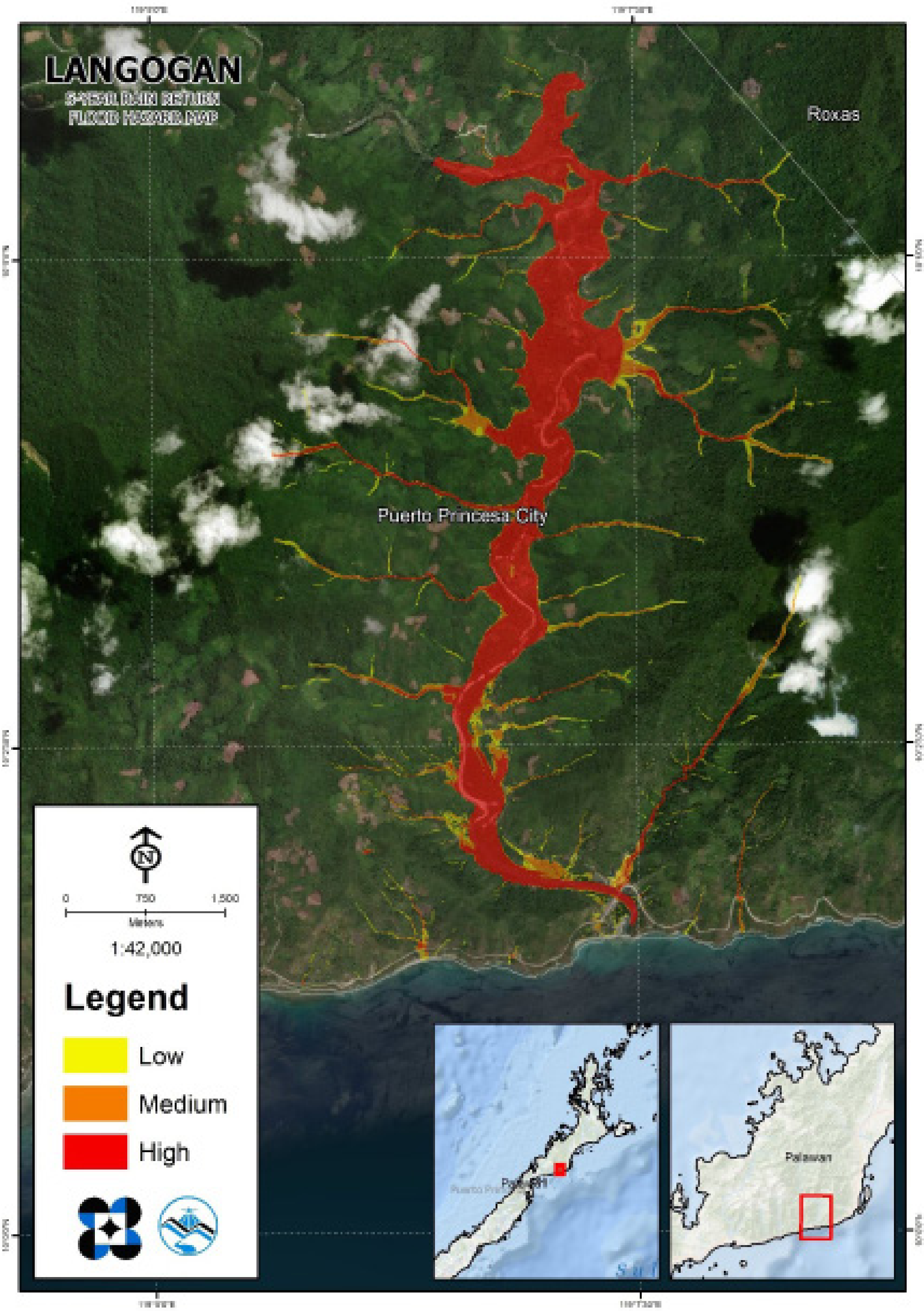

Figure 56. A 5-year Flood Hazard Map for Langogan Floodplain overlaid on Google Earth imagery.

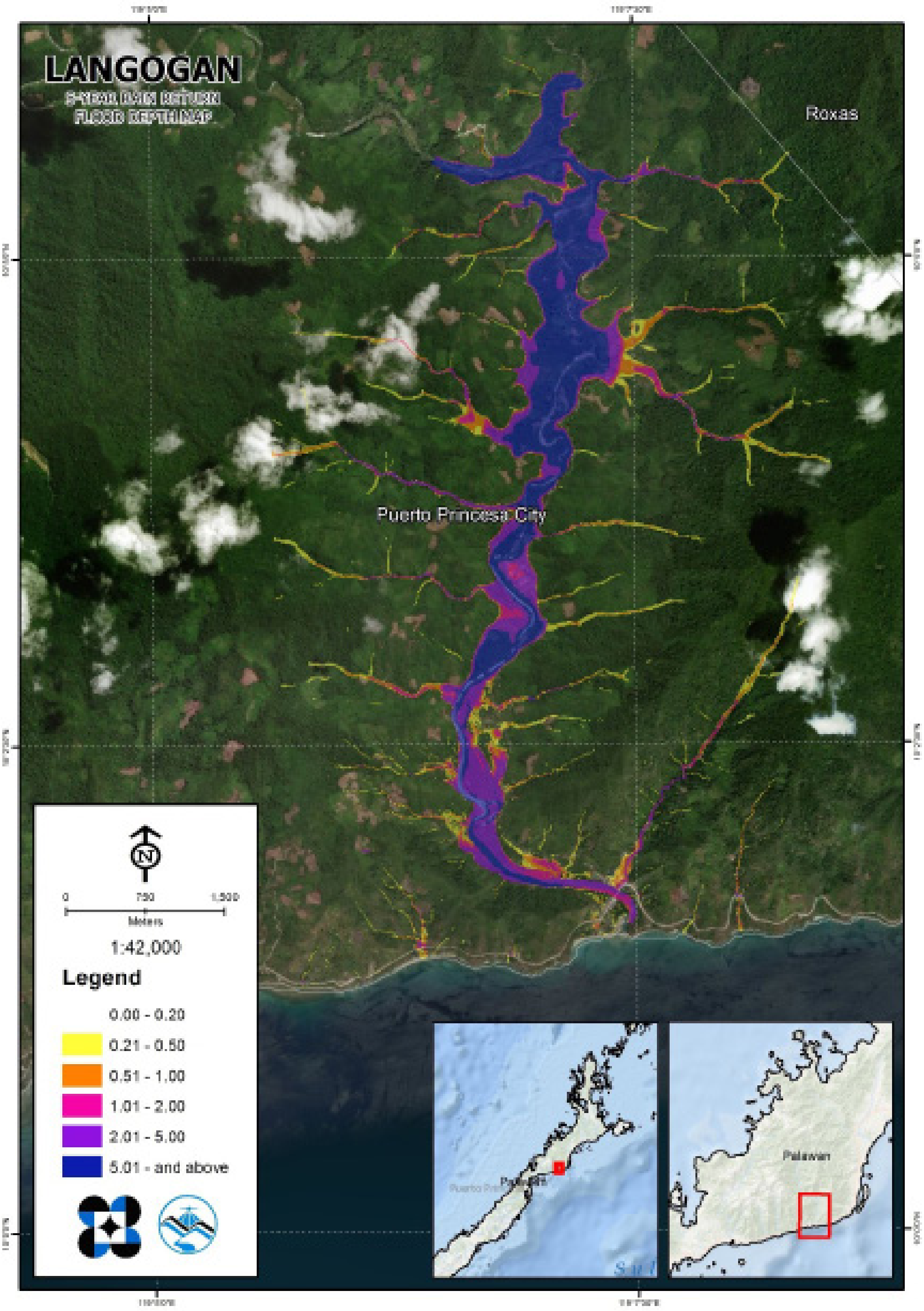

Figure 57. A 5-year Flood Depth Map for Langogan Floodplain overlaid on Google Earth imagery.

5.9 Inventory of Areas Exposed to Flooding

Listed below are the affected barangays in the Langogan River Basin, grouped accordingly by municipality. For the said basin, one (1) municipality consisting of one (1) barangay is expected to experience flooding when subjected to a 5-year rainfall return period.

For the 5-year return period, 1.51% of the municipality of Puerto Princesa City with an area of 2186.36 sq. km. will experience flood levels of less than 0.20 meters. 0.04% of the area will experience flood levels of 0.21 to 0.50 meters while 0.02%, 0.02%, 0.05%, and 0.10% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Table 30 depicts the areas affected in Puerto Prinsesa City in square kilometers by flood depth per barangay. Annex 12 and Annex 13 show the educational and health institutions exposed to flooding, respectively.

Table 30. Affected areas in Puerto Prinsesa City, Palawan during a 5-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Area of affected barangays in Puerto Prinsesa City (in sq. km.)
	Langogan
0.03-0.20	3.53
0.21-0.50	1.42
0.51-1.00	2.16
1.01-2.00	1.72
2.01-5.00	1.1
> 5.00	0.067

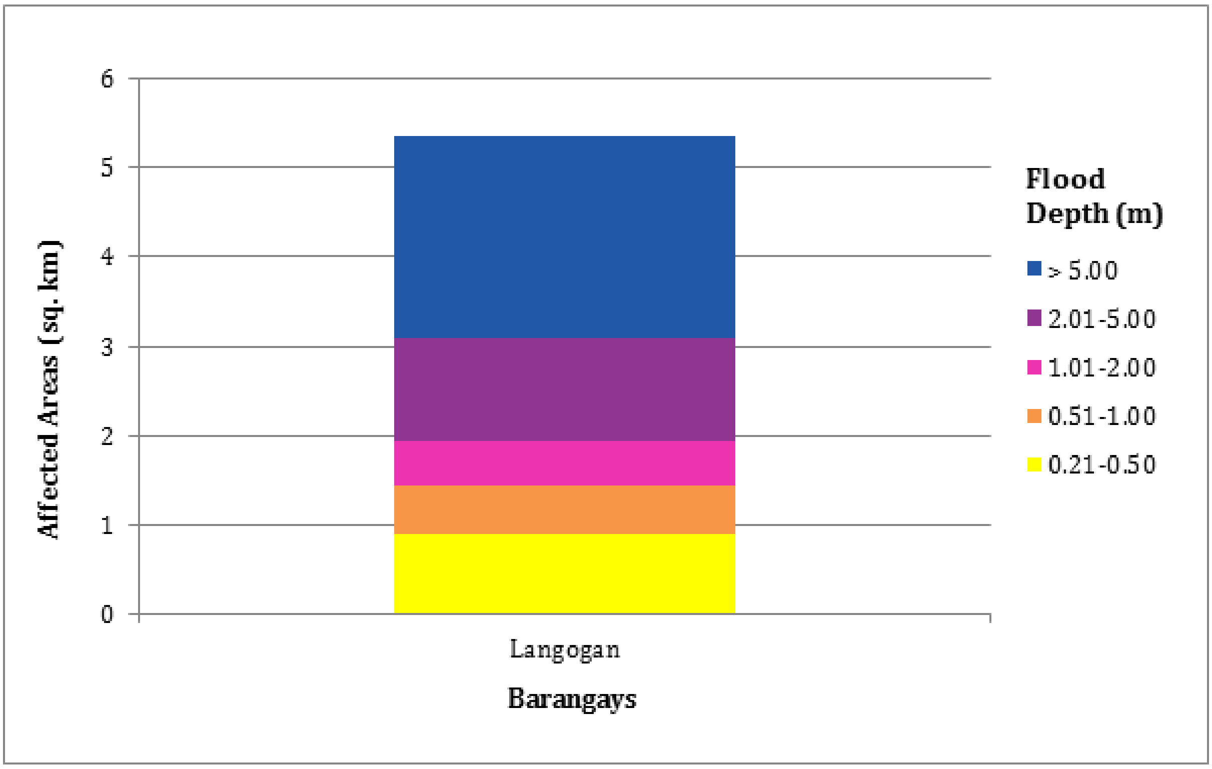

Figure 58. Affected areas in Puerto Prinsesa City, Palawan during a 5-Year Rainfall Return Period.

For the 25-year return period, 1.47% of the municipality of Puerto Princesa City with an area of 2186.36 sq. km. will experience flood levels of less than 0.20 meters. 0.04% of the area will experience flood levels of 0.21 to 0.50 meters while 0.02%, 0.02%, 0.05%, and 0.14% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Table 31 depicts the areas affected in Puerto Prinsesa City in square kilometers by flood depth per barangay

Table 31. Affected areas in Puerto Prinsesa City, Palawan during a 25-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Area of affected barangays in Puerto Prinsesa City (in sq. km.)
	Langogan
0.03-0.20	3.53
0.21-0.50	1.42
0.51-1.00	2.16
1.01-2.00	1.72
2.01-5.00	1.1
> 5.00	0.067

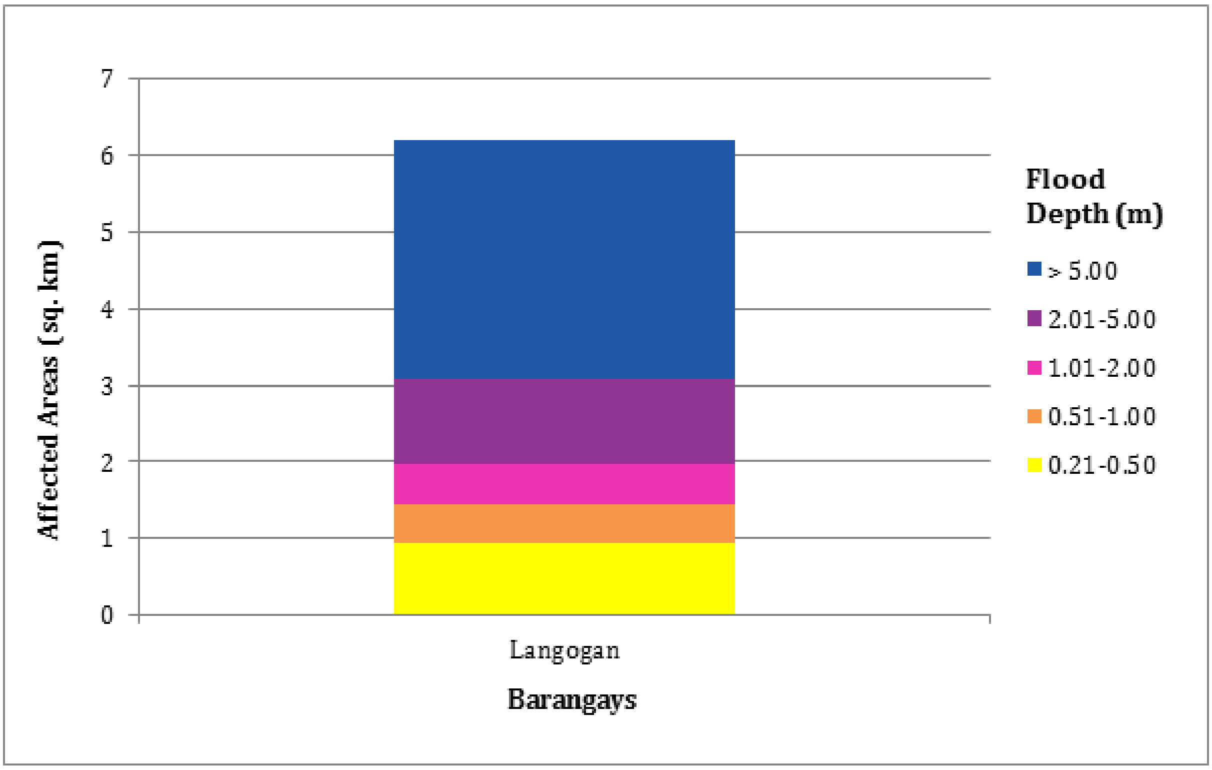

Figure 59. Affected areas in Puerto Prinsesa City, Palawan during a 25-Year Rainfall Return Period.

For the 100-year return period, 1.46% of the municipality of Puerto Princesa City with an area of 2186.36 sq. km. will experience flood levels of less than 0.20 meters. 0.05% of the area will experience flood levels of 0.21 to 0.50 meters while 0.02%, 0.02%, 0.05%, and 0.15% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Table 32 depicts the areas affected in Puerto Prinsesa City in square kilometers by flood depth per barangay.

Table 31. Affected areas in Puerto Prinsesa City, Palawan during a 25-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Area of affected barangays in Puerto Prinsesa City (in sq. km.)
	Langogan
0.03-0.20	3.53
0.21-0.50	1.42
0.51-1.00	2.16
1.01-2.00	1.72
2.01-5.00	1.1
> 5.00	0.067

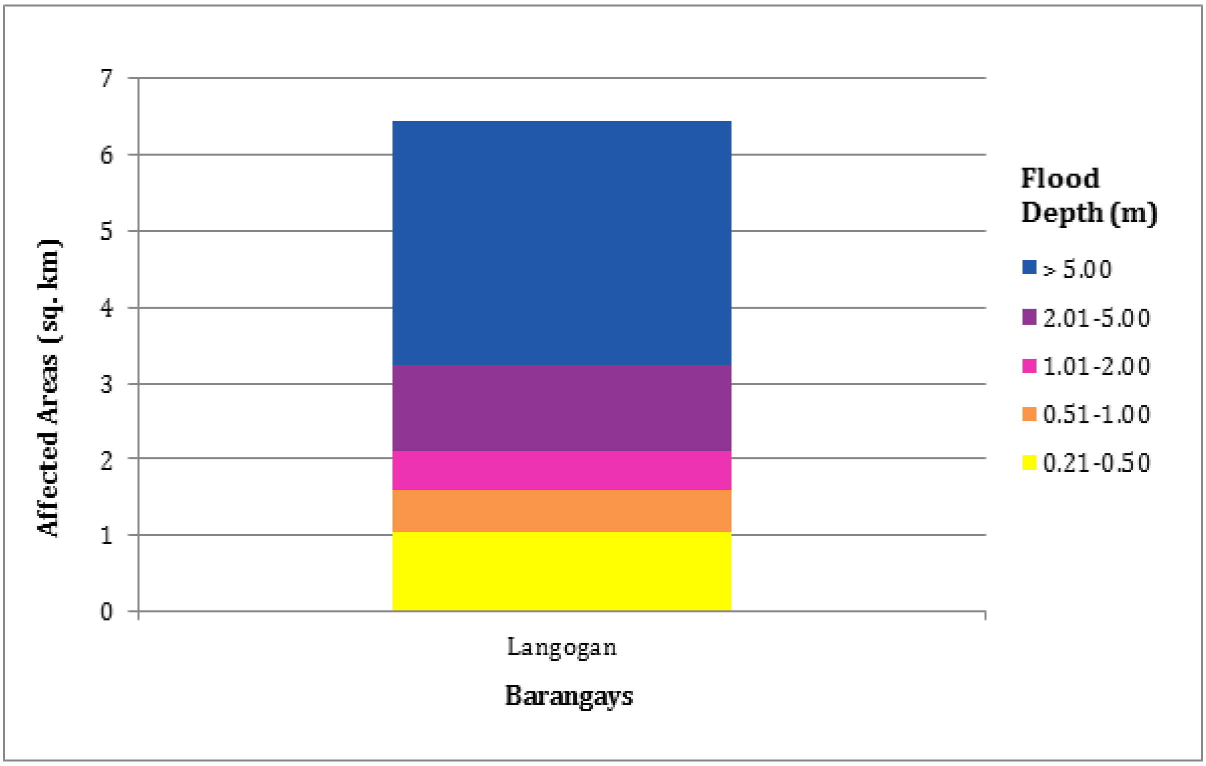

Figure 60. Affected areas in Puerto Prinsesa City, Palawan during a 100-Year Rainfall Return Period.

Brgy. Langogan is the only barangay affected in the municipality of Puerto Princesa City in Palawan. The barangay is projected to experience flood in 1.76% of the municipality.

5.10 Flood Validation

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

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

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

The actual data from the field were compared to the simulated data to assess the accuracy of the Flood Depth Maps produced and to improve on the results of the flood map. The points in the flood map versus its corresponding validation depths are shown in Figure 62.

The flood validation consists of 20 points randomly selected all over the Langogan flood plain (Figure 61). Comparing it with the flood depth map of the nearest storm event, the map has an RMSE value of 5.657m. Table 33 shows a contingency matrix of the comparison. The validation points are found in Annex 11.

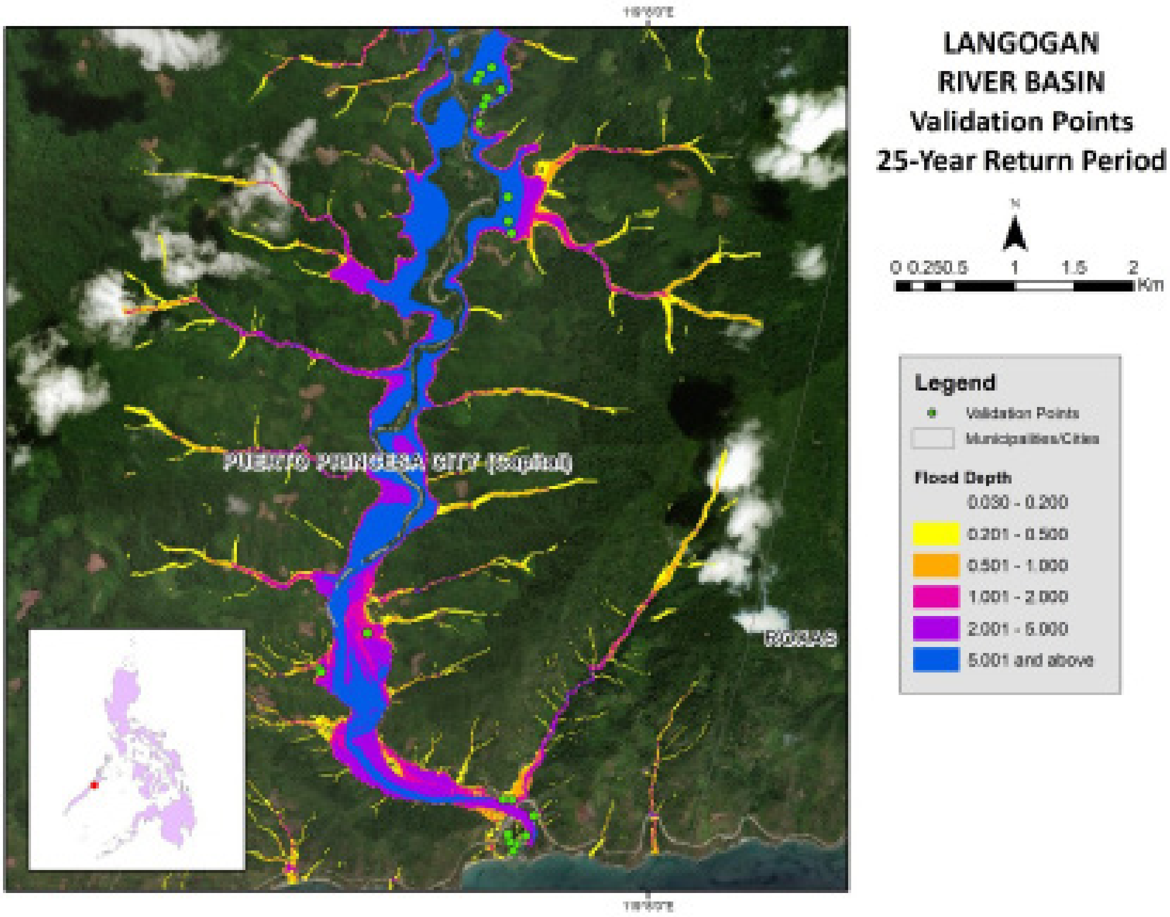

Figure 61. Validation Points for a 25-year Flood Depth Map of the Langogan Floodplain.

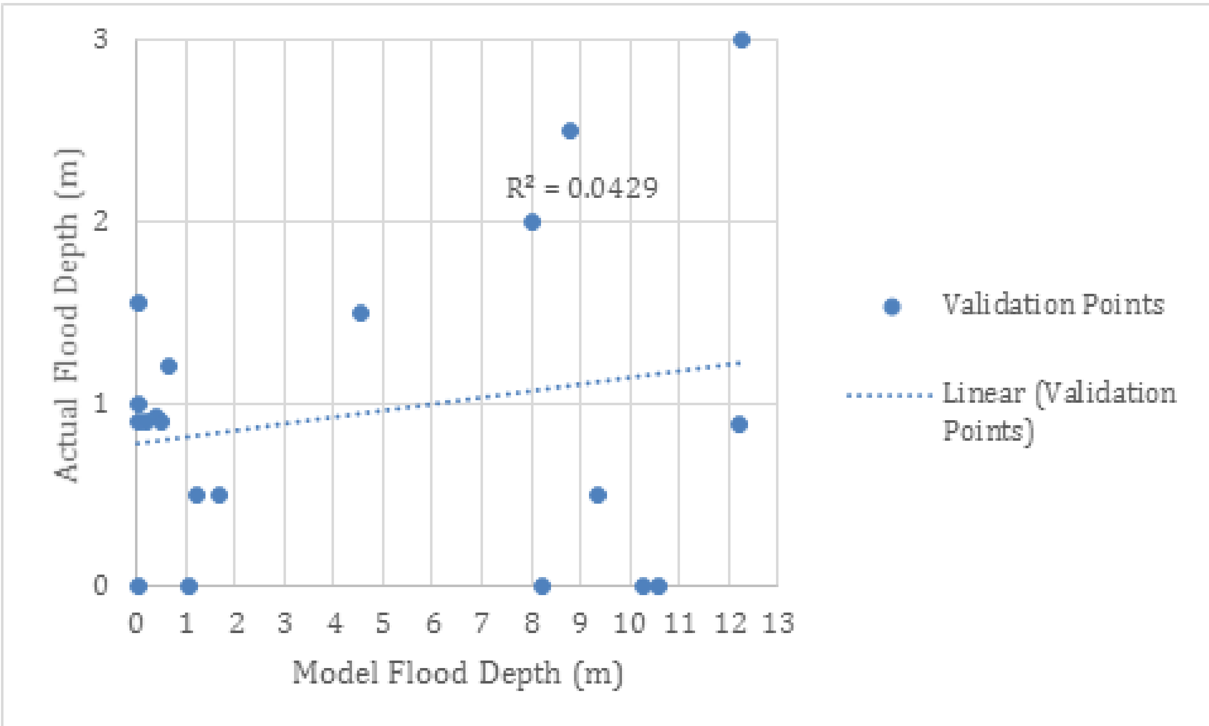

Figure 62. Flood depth map vs actual flood depth.

Table 33. Actual Flood Depth versus Simulated Flood Depth at different levels in the Langogan River Basin.

LANGOGAN 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	1	0	0	1	0	3	5
	0.21-0.50	0	0	0	2	0	1	3
	0.51-1.00	3	2	0	0	0	1	6
	1.01-2.00	1	0	1	0	1	1	4
	2.01-5.00	0	0	0	0	0	2	2
	> 5.00	0	0	0	0	0	0	0
	Total	5	2	1	3	1	8	20

On the whole, the overall accuracy generated by the flood model is estimated at 5.00% with 1 points correctly matching the actual flood depths. In addition, there were 4 points estimated one level above and below the correct flood depths while there were 6 points and 7 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 7 points were underestimated in the modelled flood depths of Langogan.

Table 34 depicts the summary of the Accuracy Assessment in the Langogan River Basin Flood Depth Map.

Table 34. Summary of the Accuracy Assessment in the Langogan River Basin Survey.

	No. of Points	%
Correct	160	**26.40**
Overestimated	46	**7.59**
Underestimated	400	**66.01**
Total	606	**100.00**

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ANNEXES

Annex 1. Technical Specifications of the LiDAR Sensors used in the Langogan Floodplain Survey

1. GEMINI SENSOR

Figure A-1.1 Gemini Sensor

Table A-1.1 Parameters and Specifications of Gemini Sensor

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

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

1. PLW-23

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: PLW-23	
	Order: 1st	
Island: LUZON	Barangay: JOLO	
Municipality: PUERTO PRINCESA CITY (CAPITAL)	MSL Elevation:	
	PRS92 Coordinates	
Latitude: 10° 5' 19.52517"	Longitude: 119° 12' 33.72062"	Ellipsoidal Hgt: 10.42790 m.
	WGS84 Coordinates	
Latitude: 10° 5' 15.04664"	Longitude: 119° 12' 39.01413"	Ellipsoidal Hgt: 61.07260 m.
	PTM / PRS92 Coordinates	
Northing: 1115630.596 m.	Easting: 577752.254 m.	Zone: 1A
	UTM / PRS92 Coordinates	
Northing: 1,115,973.09	Easting: 742,130.31	Zone: 50

Location Description

PLW-23
From the municipality of Roxas, on the intersection at Andres Soriano Memorial Elementary School, travel southwest along the provincial highway for 39.3 kilometers or 1 hour and 25 minutes drive to Jolo elementary School. The station is located inside the compound of Jolo elementary school. It is Northwest 10.00 meters of the school building. Station mark is a cross cut on top of a 0.15 m x 0.012 m in diameter brass rod centered in a 0.30 m x 0.30 m x 1.0 m concrete block, flush with the ground surface and inscribed with station name. Sub-surface mark is a bottle set on concrete block; 68 cm. below station. Reference mark nos. 1,2,3 and 4 are cross cut on top of 0.15 m x 0.01 m in diameter brass rod in a 0.30 m x 0.30 m x 1 meter concrete block, flush with the ground surface, and inscribed with the reference mark numbers and with arrows pointing to the station.

Requesting Party: UP DREAM
Purpose: Reference
OR Number: 8088735 I
T.N.: 2015-3960

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

NAMRIA OFFICES:
Main: Lawton Avenue, Fort Bonifacio, 1634 Taguig City, Philippines Tel. No.: (632) 810-4831 to 41
Branch: 421 Barraca St. San Nicolas, 1010 Manila, Philippines, Tel. No. (632) 241-3494 to 98
www.namria.gov.ph

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.1. PLW-23

2. PLW-7 (reference for PVP-1)

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:	**1,077,285.52**	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

NAMRIA OFFICES:
Main : Lawton Avenue, Fort Bonifacio, 1634 Taguig City, Philippines Tel. No.: (632) 810-4831 to 41
Branch : 421 Barraca St. San Nicolas, 1010 Manila, Philippines, Tel. No. (632) 241-3494 to 98
www.namria.gov.ph

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.2. PLW-7

ANNEX 3. Baseline Processing Reports of Reference Points Used in the LiDAR Survey

1. PLW-4030

Table A-3.1. PLW-4030

PLW-23 - PLW-4030 (11:45:04 AM-3:31:34 PM) (S1)

Baseline observation:	PLW-23 --- PLW-4030 (B1)
Processed:	12/16/2015 2:07:32 PM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.001 m
Vertical precision:	0.002 m
RMS:	0.000 m
Maximum PDOP:	2.098
Ephemeris used:	Broadcast
Antenna model:	NGS Absolute
Processing start time:	11/20/2015 11:45:29 AM (Local: UTC+8hr)
Processing stop time:	11/20/2015 3:31:34 PM (Local: UTC+8hr)
Processing duration:	03:46:05
Processing interval:	5 seconds

Vector Components (Mark to Mark)

From:	PLW-23				
Grid		**Local**		**Global**	
Easting	84385.284 m	**Latitude**	N10°06'19.52518"	**Latitude**	N10°06'15.04804"
Northing	1117566.788 m	**Longitude**	E119°12'33.72062"	**Longitude**	E119°12'39.01413"
Elevation	9.470 m	**Height**	10.427 m	**Height**	61.073 m

To:	PLW-4030				
Grid		**Local**		**Global**	
Easting	84042.682 m	**Latitude**	N10°04'58.95146"	**Latitude**	N10°04'52.47562"
Northing	1116875.986 m	**Longitude**	E119°12'22.75168"	**Longitude**	E119°12'28.04576"
Elevation	10.228 m	**Height**	11.183 m	**Height**	61.835 m

Vector					
ΔEasting	-342.602 m	**NS Fwd Azimuth**	206°42'51"	**ΔX**	231.889 m
ΔNorthing	-690.802 m	**Ellipsoid Dist.**	769.753 m	**ΔY**	269.625 m
ΔElevation	0.758 m	**ΔHeight**	0.756 m	**ΔZ**	-682.686 m

Standard Errors

Vector errors:					
σ ΔEasting	0.000 m	**σ NS fwd Azimuth**	0°00'00"	**σ ΔX**	0.001 m
σ ΔNorthing	0.000 m	**σ Ellipsoid Dist.**	0.000 m	**σ ΔY**	0.001 m
σ ΔElevation	0.001 m	**σ ΔHeight**	0.001 m	**σ ΔZ**	0.000 m

2

2. PVP-1

Table A-3.2. 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°44'25.60807"
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	-1410.861 m
ΔNorthing	37.929 m	Ellipsoid Dist.	1628.402 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

Aposteriori Covariance Matrix ($Meter^2$)

	X	Y	Z
X	0.0000028744		
Y	-0.0000040460	0.0000083673	
Z	-0.0000002132	0.0000005346	0.0000010341

2

2. PVP-1

Table A-3.2. PVP-1

Vector Components (Mark to Mark)

From:	PVP1				
Grid		Local		Global	
Easting	33860.371 m	Latitude	N8°44'31.66247"	Latitude	N8°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	0.877 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

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000000874		
Y	-0.0000000471	0.0000002060	
Z	-0.0000000153	0.0000000347	0.0000000448

2

ANNEX 4. The LiDAR Survey Team Composition

Table A-4.1. The LiDAR Survey Team Composition

Data Acquisition Component Sub-Team	Designation	Name	Agency/ Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	ENGR. CZAR JAKIRI SARMIENTO	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	ENGR. LOVELYN ASUNCION	UP-TCAGP
		LOVELY GRACIA ACUNA	UP-TCAGP
FIELD TEAM			
LiDAR Operation	Senior Science Research Specialist (SSRS)	GEROME HIPOLITO	UP-TCAGP
Ground Survey, Data Download and Transfer	Research Associate (RA)	MARY CATHERINE BALIGUAS	UP-TCAGP
		IRO NIEL ROXAS	
		JONATHAN ALMALVEZ	
LiDAR Operation	Airborne Security	SSG. PRADYUMNA DAS RAMIREZ	PHILIPPINE AIR FORCE (PAF)
		AT2C JUNMAR PARANGUE	
	Pilot	CAPT. MARK TANGONAN	ASIAN AEROSPACE CORPORATION (AAC)
	Pilot	CAPT. ALBERT PAUL LIM	
	Pilot	CAPT. RANDY LAGCO	

ANNEX 5. Data Transfer Sheet for Langogan Floodplain

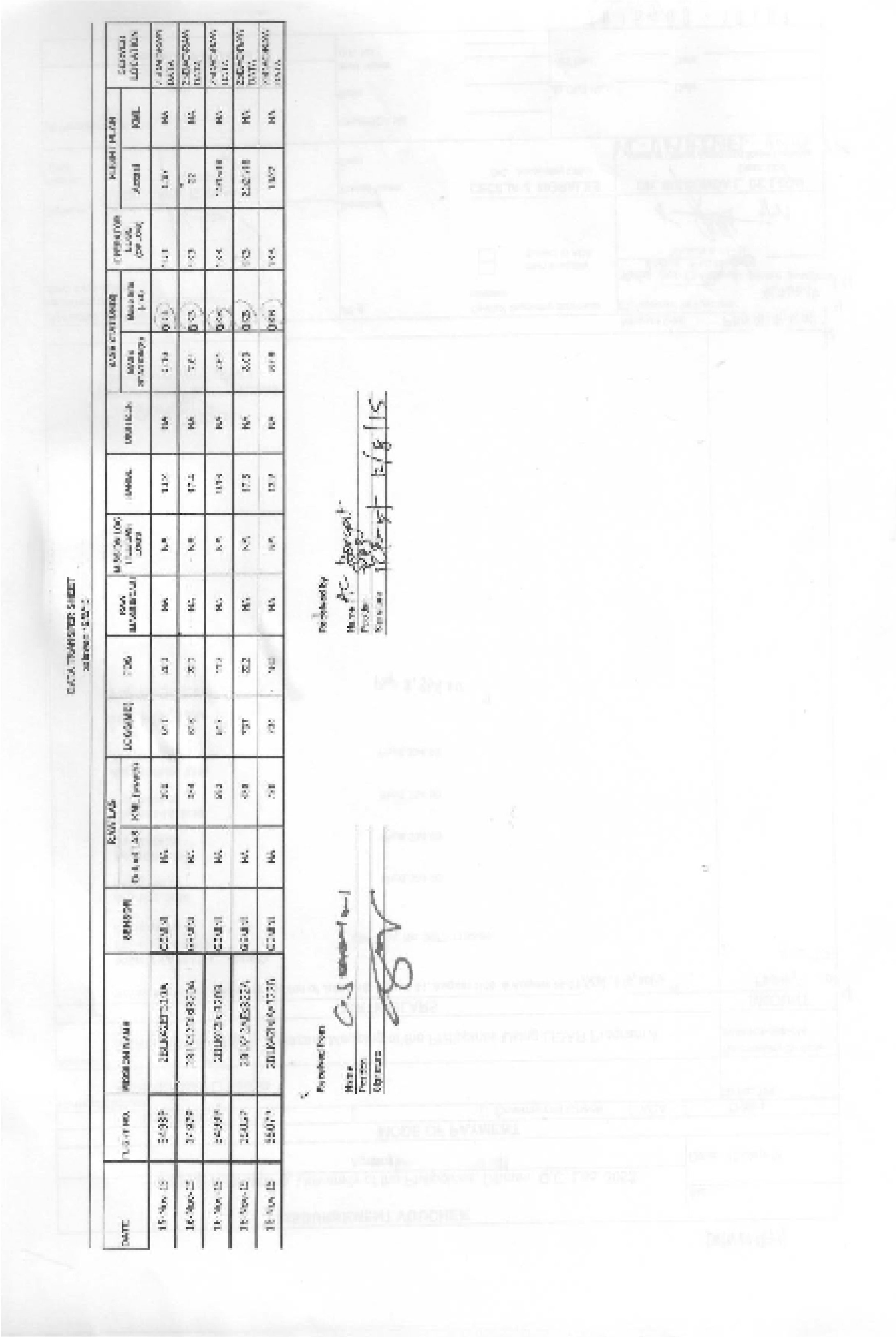

Figure A-5.1. Transfer Sheet for Langogan Floodplain - A

Annex 6. Flight Logs for the Flight Missions

1. Flight Log for 3497G

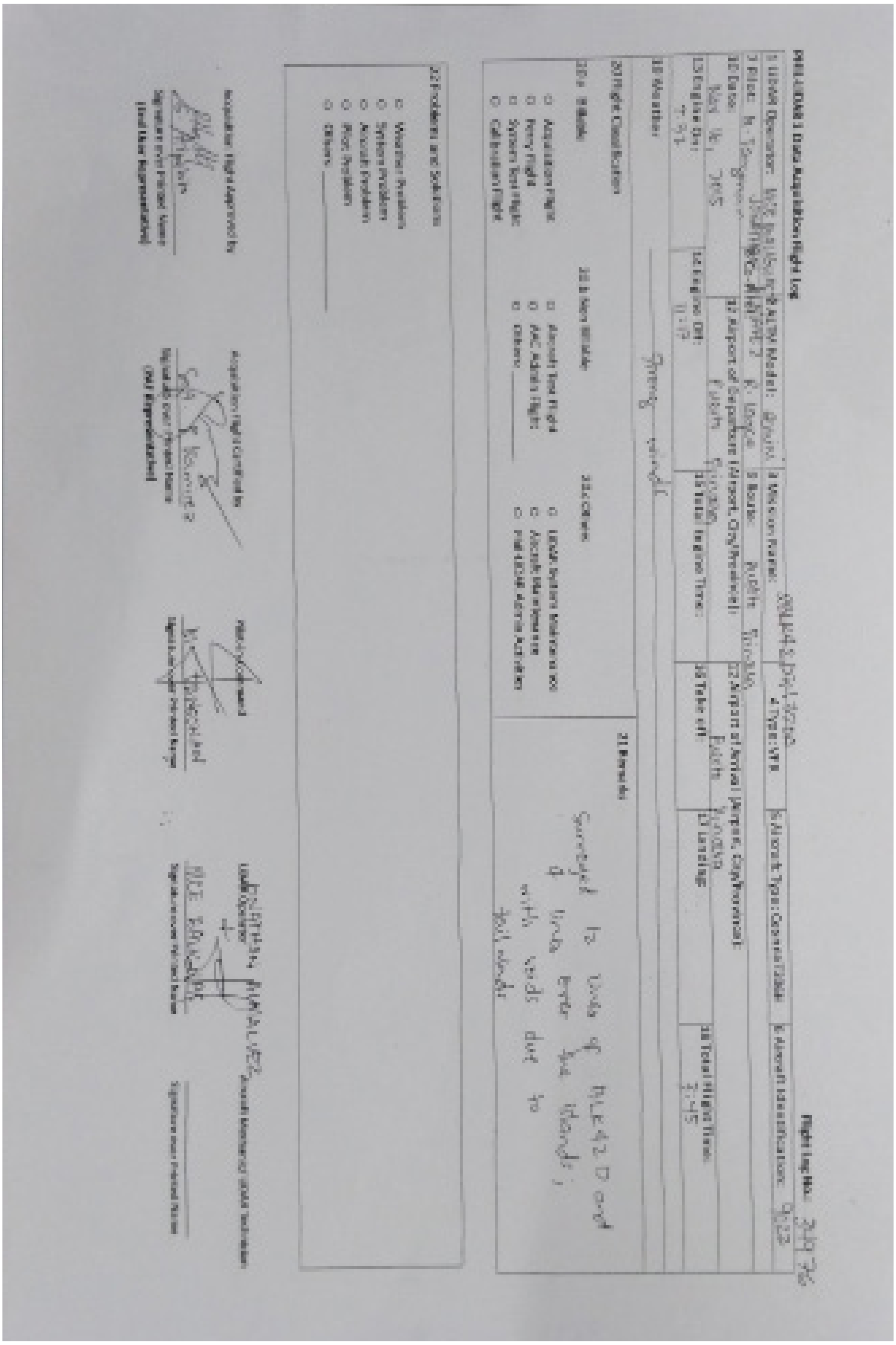

Figure A-6.1. Flight Log for Mission 3497G

ANNEX 7. Flight Status Report

LANGOGAN FLOODPLAIN
November 16, 2015

FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
3497G	BLK42 eD,islands	2BLK42Disl320A	MCE Baliguas and JM Almalvez	16-Nov-2015	Voids near mountain of 42eD; moved to islands

SWATH PER FLIGHT MISSION

Flight No. :	3497G
Area:	BLK42 eD, islands
Mission name:	2BLK42DisI320A
Parameters:	Scan Frequency: 50 Hz
	Scan Angle: 40 degrees PRF: 100

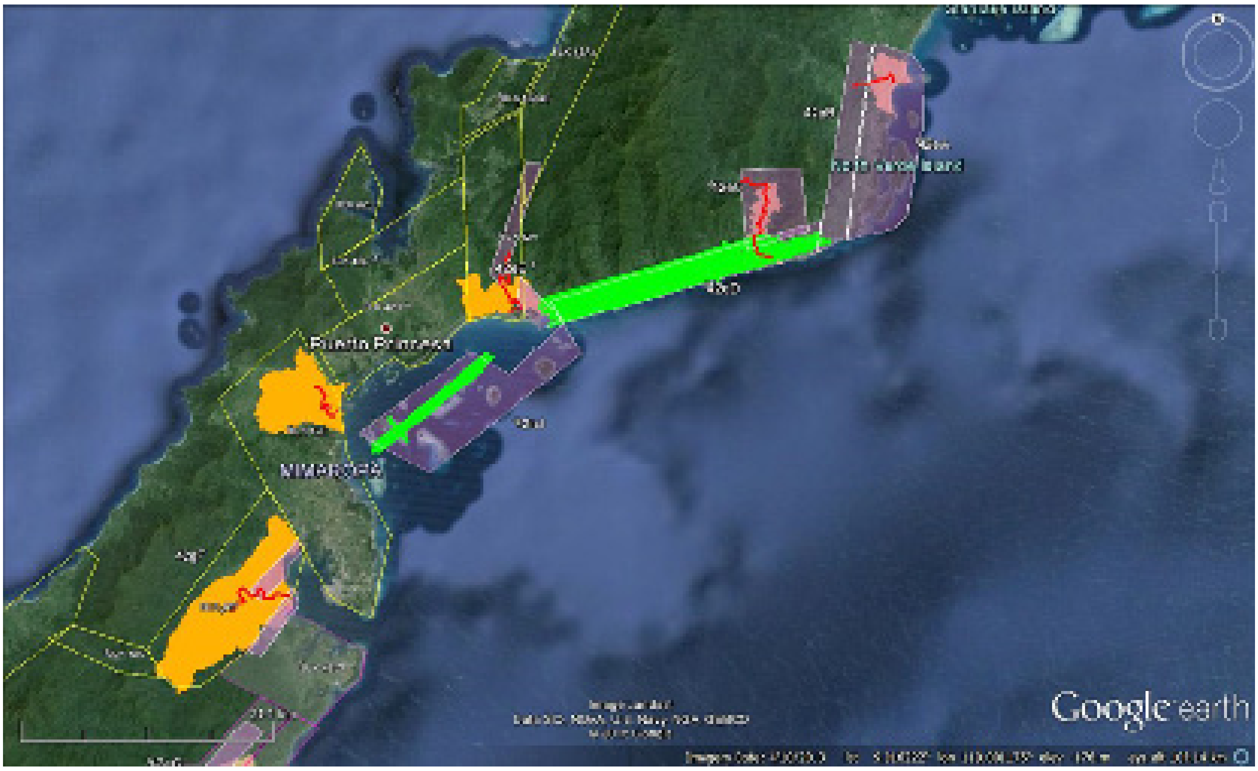

Figure A-7.1. Swath for Flight No. 3497G

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Blk42eD

Flight Area	Palawan Reflights
Mission Name	Blk42eD
Inclusive Flights	3493G
Range data size	13.2 GB
POS	208 MB
Image	NA
Transfer date	December 8, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.51
RMSE for East Position (<4.0 cm)	2.13
RMSE for Down Position (<8.0 cm)	3.58
Boresight correction stdev (<0.001deg)	0.020137
IMU attitude correction stdev (<0.001deg)	0.037835
GPS position stdev (<0.01m)	0.0029
Minimum % overlap (>25)	
Ave point cloud density per sq.m. (>2.0)	5.03
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	117
Maximum Height	655.63 m
Minimum Height	51.32 m
Classification (# of points)	
Ground	30,227,181
Low vegetation	16,386,156
Medium vegetation	76,491,030
High vegetation	265,788,221
Building	5,414,882
Orthophoto	No
Processed by	Engr. Regis Guhiting, Engr. Edgardo Gubatanga Jr., Marie Denise Bueno

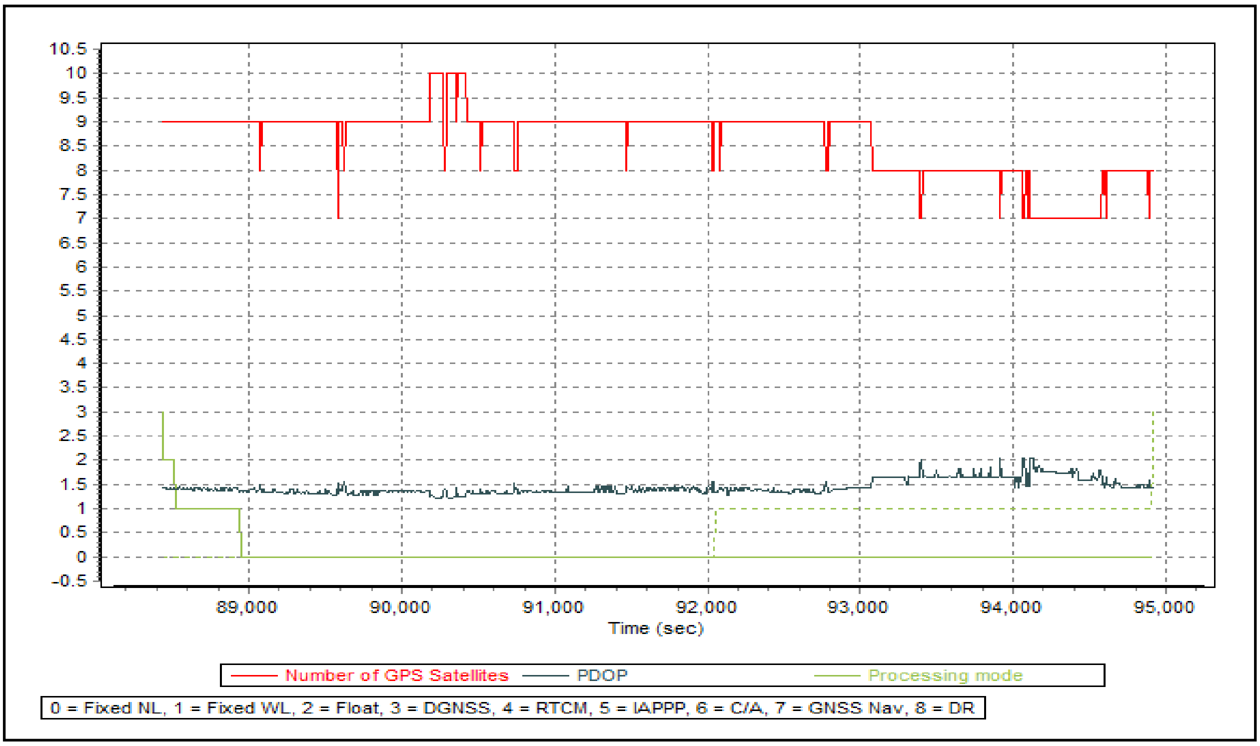

Figure A-8.1. Solution Status

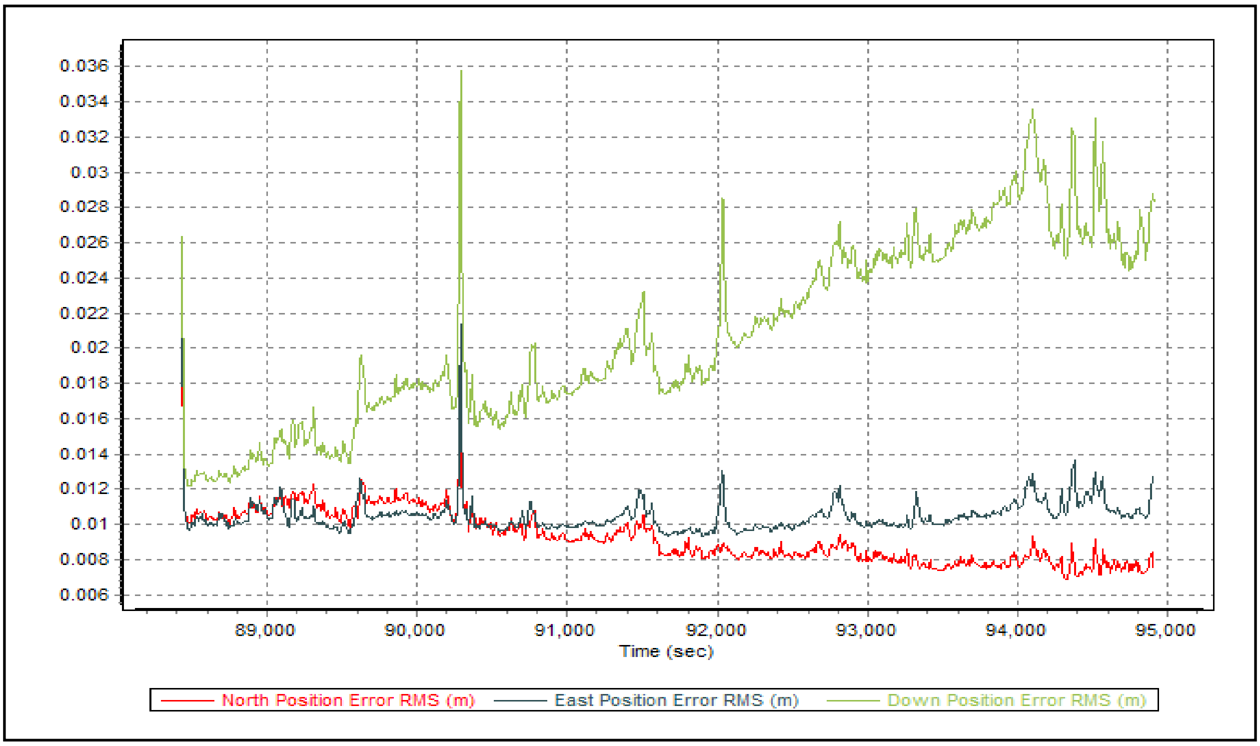

Figure A-8.2. Smoothed Performance Metrics Parameters

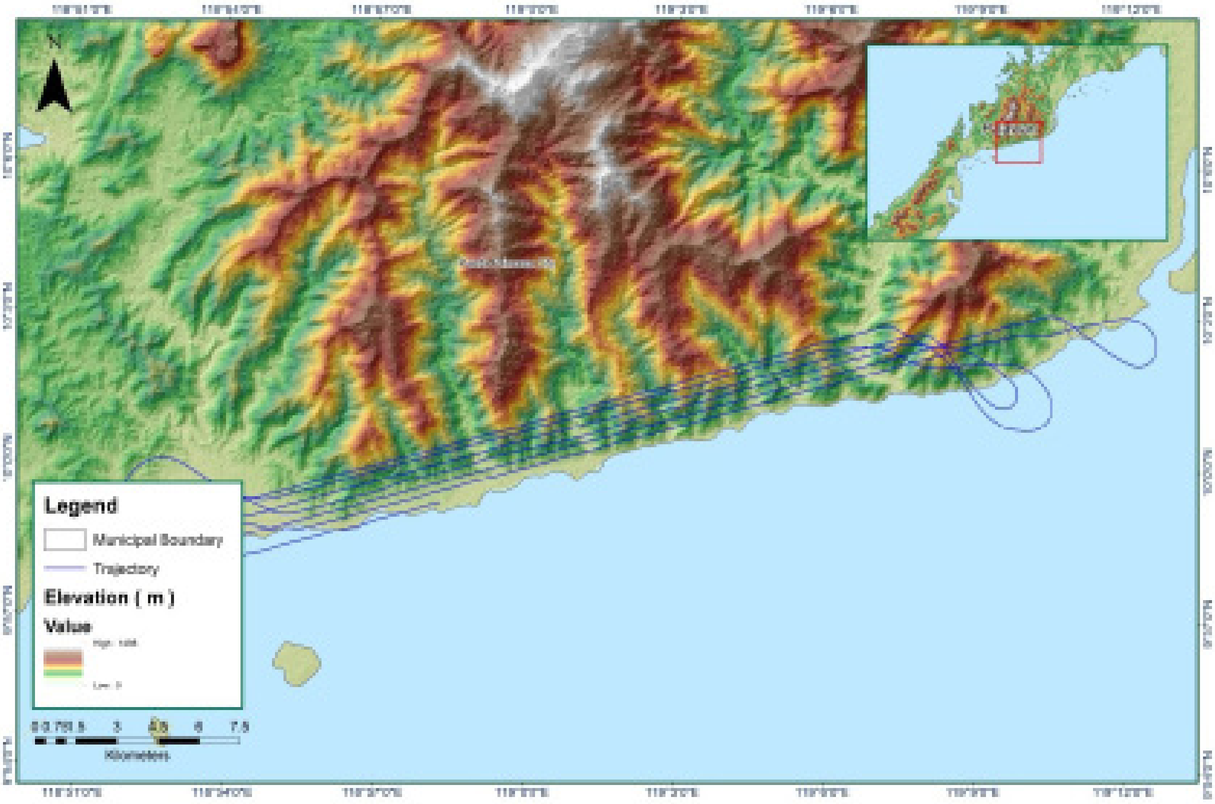

Figure A-8.3. Best Estimated Trajectory

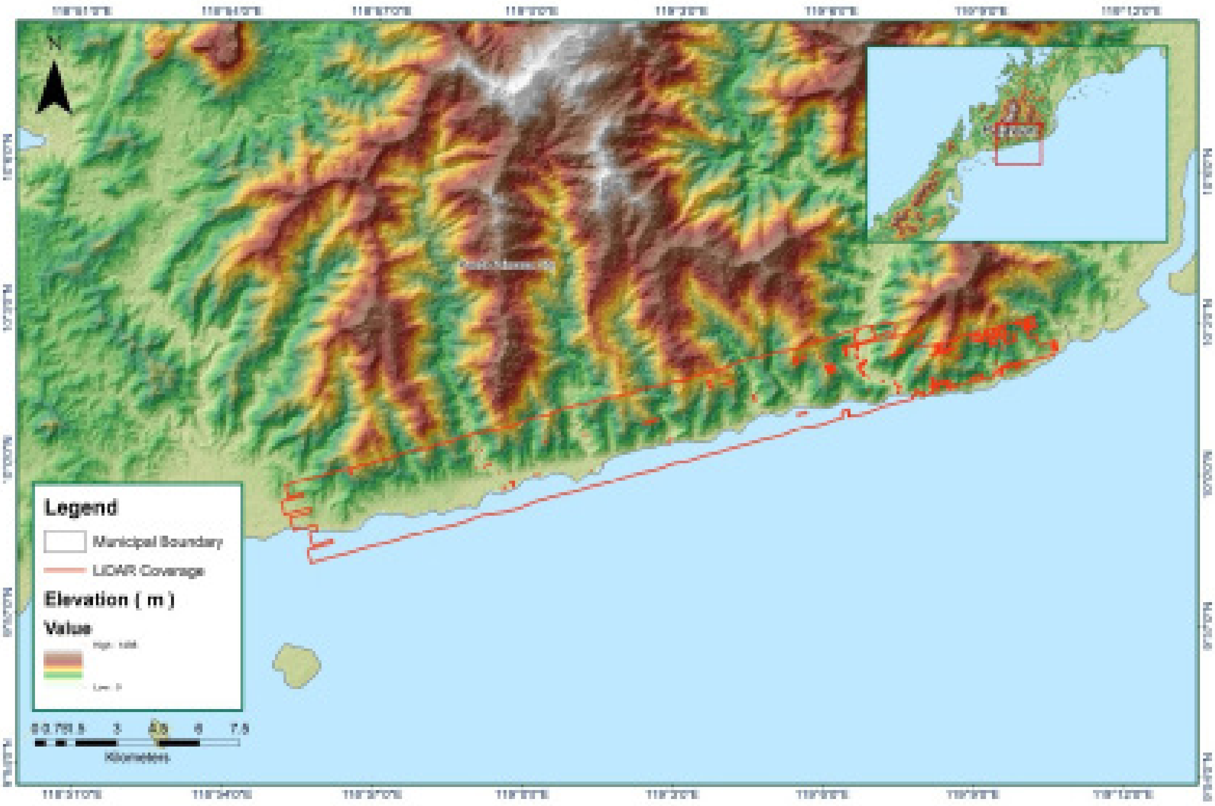

Figure A-8.4 Coverage of LiDAR data

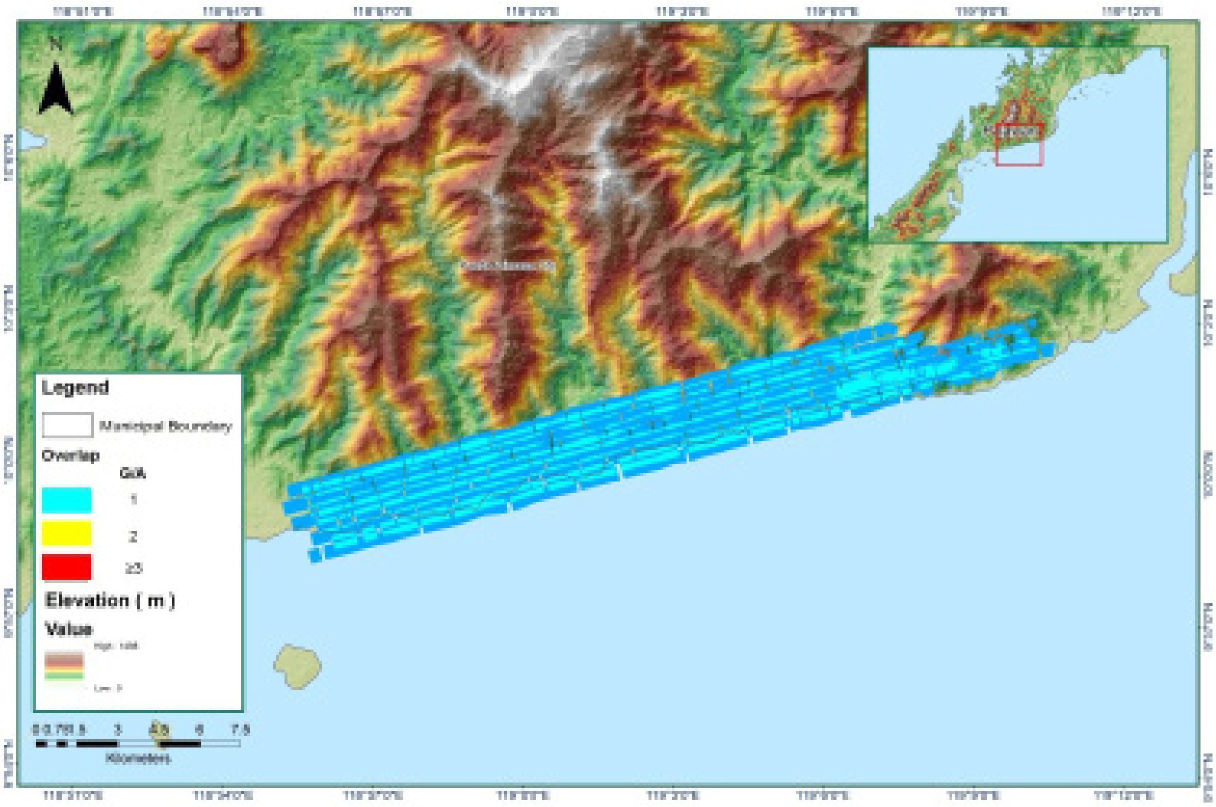

Figure A-8.5. Image of data overlap

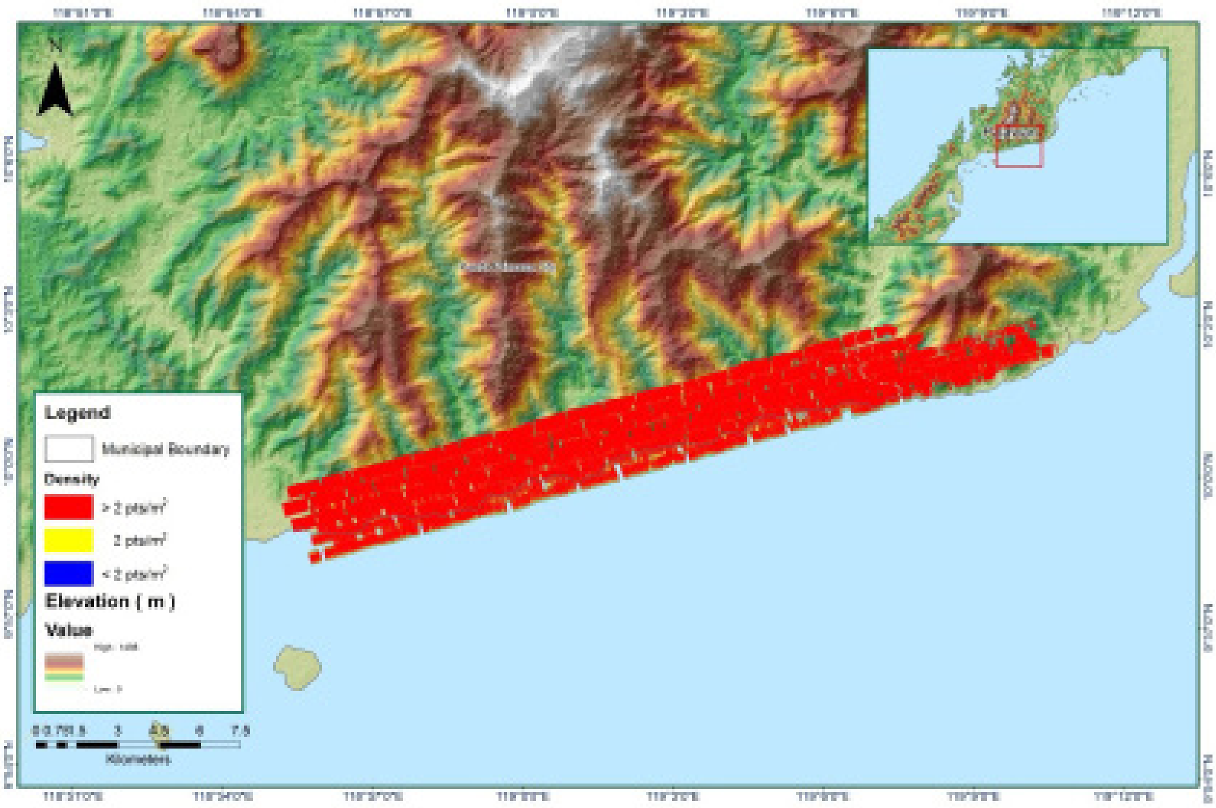

Figure A-8.6. Density map of merged LiDAR data

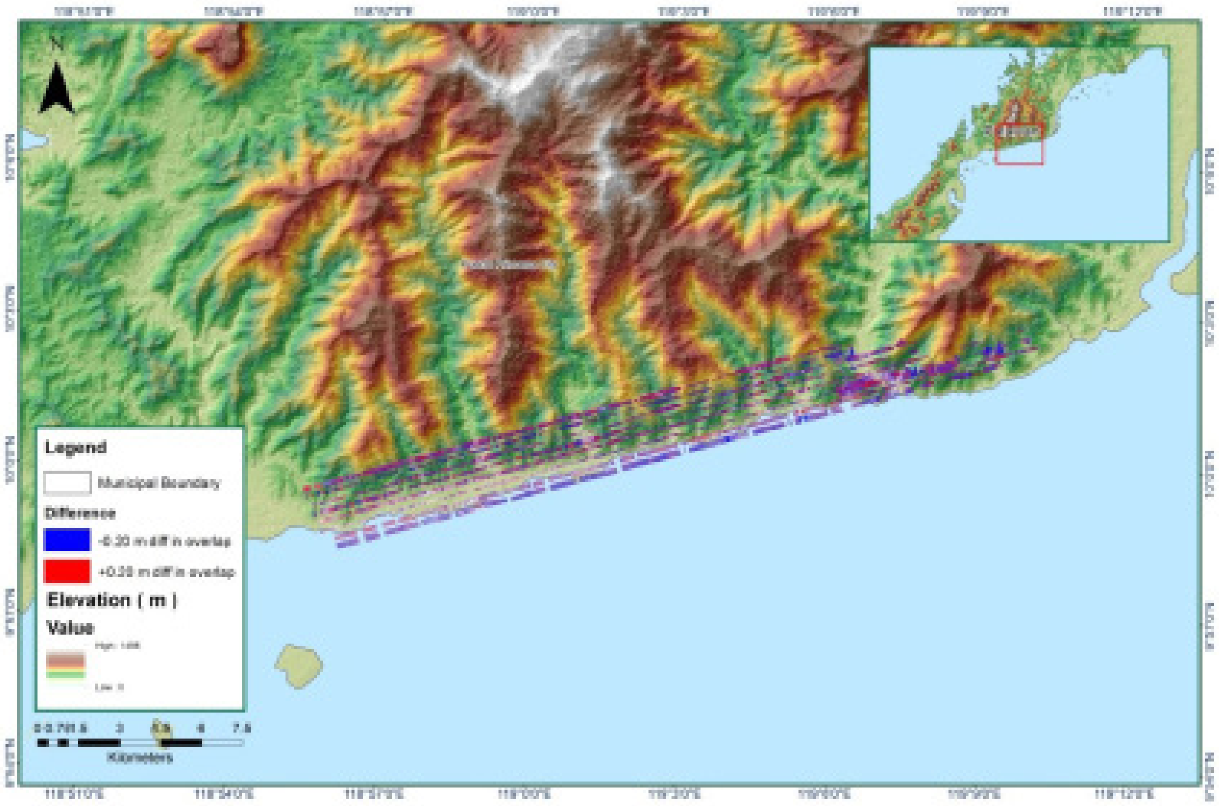

Figure A-8.7. Elevation difference between flight lines

Annex 9. Langogan Model Basin Parameters

Table A-9.1. Langogan Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform	
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)
W1000	10.35	55	0	1.0911	1.7807
W1010	10.35	55	0	1.2437	2.0298
W1020	8.9617	58.629	0	1.4215	2.3199
W1030	10.048	55.829	0	1.3419	2.19
W1040	10.35	55	0	1.1986	1.9561
W1050	9.7069	56.679	0	0.83347	1.3602
W1060	10.265	55.302	0	2.4432	3.9874
W1070	10.35	55	0	0.44825	0.73154
W1080	9.5394	57.106	0	0.91219	1.4887
W1090	9.58	57.002	0	1.5654	2.5547
W1100	8.9877	58.558	0	1.0586	1.7276
W1110	9.15	58	0	0.45279	0.73896
W1120	9.71	56.671	0	1.3317	2.1734
W1130	9.8683	56.274	0	1.1785	1.9233
W1140	8.9885	58.556	0	1.5503	2.5301
W1150	9.8813	56.241	0	1.4591	2.3812
W1160	9.1665	58.08	0	1.1312	1.8461
W1170	8.6978	59.352	0	1.2722	2.0762
W1180	9.15	58	0	0.72487	1.183
W1190	8.6814	59.397	0	1.489	2.43
W1200	9.1699	58.071	0	3.2348	5.2793
W1210	10.365	55.061	0	1.5935	2.6007
W1240	9.9171	56.152	0	0.51284	0.83695
W1250	9.883	56.237	0	0.21799	0.35575
W620	10.051	55.822	0	2.662	4.3443
W630	8.4785	59.966	0	2.0966	3.4216
W640	10.388	55.00781	0	0.87134	1.422
W650	9.1619	58.092	0	1.406	2.2945
W660	10.35	55	0	2.1211	3.4617
W670	10.35	55	0	1.5452	2.5218
W680	10.35	55	0	0.59927	0.97802
W690	8.7223	59.284	0	1.6	2.6113
W700	10.35	55	0	1.8809	3.0697
W710	10.35	55	0	0.98449	1.6067
W720	8.8002	59.069	0	1.0869	1.7737
W730	10.35	55	0	1.5422	2.5168
W740	10.35	55	0	0.61119	0.99746
W750	10.35	55	0	1.2353	2.0161
W760	10.231	55.385	0	2.535	4.1371
W770	10.35	55	0	1.5031	2.4531

Table A-9.1. Langogan Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform	
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)
W780	10.35	55	0	2.1967	3.585
W790	8.5515	59.76	0	0.98399	1.6059
W800	10.35	55	0	0.28692	0.46825
W810	9.4166	57.423	0	0.71197	1.1619
W820	10.35	55	0	2.6082	4.2565
W830	10.227	55.392	0	1.7957	2.9307
W840	8.5152	59.863	0	1.8846	3.0756
W850	10.35	55	0	1.9403	3.1666
W860	10.35	55	0	0.29528	0.4819
W870	8.4711	59.987	0	1.7375	2.8356
W880	9.9471	56.078	0	1.6686	2.7232
W890	10.35	55	0	1.9538	3.1886
W900	10.35	55	0	1.2434	2.0292
W910	8.4914	59.93	0	1.0947	1.7866
W920	9.9455	56.082	0	2.5039	4.0864
W930	10.288	55.246	0	1.651	2.6945
W940	10.35	55	0	1.3608	2.2209
W950	10.35	55	0	1.2652	2.0649
W960	10.35	55	0	1.2381	2.0206
W970	9.7173	56.653	0	1.3034	2.1272
W980	9.072	58.332	0	1.3803	2.2526
W990	10.35	55	0	0.62848	1.0257

Annex 10. Langogan Model Reach Parameters

Table A-10.1. Langogan Model Reach Parameters

Reach	Muskingum-Cunge Channel Routing			
	Length (m)	Slope (m/m)	Shape	Side Slope
R120	1531	0.06649	Trapezoid	1
R1260	130.71	0.008666	Trapezoid	1
R130	666.69	0.012733	Trapezoid	1
R140	1158.5	0.012733	Trapezoid	1
R180	3473.3	0.016118	Trapezoid	1
R190	128.28	0.016118	Trapezoid	1
R200	1128.1	0.024141	Trapezoid	1
R230	3194.6	0.033222	Trapezoid	1
R240	235.56	0.033222	Trapezoid	1
R30	1077.4	0.013907	Trapezoid	1
R310	3122.9	0.003189	Trapezoid	1
R320	5102.2	0.075263	Trapezoid	1
R350	2126.2	0.0259	Trapezoid	1
R370	915.69	0.075031	Trapezoid	1
R380	1470.5	0.05189	Trapezoid	1
R390	2775.2	0.018472	Trapezoid	1
R410	1754.4	0.003288	Trapezoid	1
R420	3501.1	0.005909	Trapezoid	1
R430	1886.5	0.004338	Trapezoid	1
R460	678.41	0.071096	Trapezoid	1
R470	962.55	0.011353	Trapezoid	1
R480	2768.4	0.00463	Trapezoid	1
R50	2084.1	0.028331	Trapezoid	1
R500	605.27	0.00463	Trapezoid	1
R530	1975.5	0.007164	Trapezoid	1
R540	1173.7	0.00161	Trapezoid	1
R570	1130.8	0.00161	Trapezoid	1
R590	5693.7	0.00128	Trapezoid	1
R610	486.13	0.005314	Trapezoid	1
R80	701.84	0.009274	Trapezoid	1
R90	1537.9	0.005255	Trapezoid	1

Annex 11. Langogan Field Validation Points

Table A-11.1. Langogan Field Validation Points

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event	Date	Rain Return /Scenario
	Latitude	Longitude						
1	10.04231	119.1121	1.04	0	-1.04			25-Year
2	10.03955	119.1085	1.7	0.5	-1.2	Norming		25-Year
3	10.03937	119.1086	1.24	0.5	-0.74	Lando	November 27	25-Year
4	10.07244	119.123	4.53	1.5	-3.03		1995	25-Year
5	10.07343	119.1227	8.01	2	-6.01		1995	25-Year
6	10.07522	119.1227	9.38	0.5	-8.88		1995	25-Year
7	10.08079	119.1206	0.03	0	-0.03			25-Year
8	10.08334	119.1222	12.29	3	-9.29		June 5	25-Year
9	10.08505	119.1215	8.24	0	-8.24	Yolanda		25-Year
10	10.0845	119.1206	10.27	0	-10.27			25-Year
11	10.08217	119.1209	8.78	2.5	-6.28		November 5	25-Year
12	10.08273	119.1211	12.2	0.89	-11.31		November 1998	25-Year
13	10.08403	119.1204	10.61	0	-10.61	Yolanda		25-Year
14	10.02698	119.1241	0.03	1	0.97	Yolanda		25-Year
15	10.02635	119.1233	0.4	0.93	0.53	Yolanda		25-Year
16	10.0258	119.1231	0.06	0.9	0.84	Yolanda		25-Year
17	10.02656	119.1228	0.17	0.9	0.73	Yolanda		25-Year
18	10.02708	119.1227	0.03	1.55	1.52	Yolanda		25-Year
19	10.02846	119.1247	0.1		-0.1	Yolanda		25-Year
20	10.02971	119.1223	0.5	0.9	0.4	Yolanda		25-Year
21	10.02968	119.123	0.63	1.2	0.57	Yolanda		25-Year

ANNEX 12. Educational Institutions affected by flooding Langogan Flood Plain

There are no educational institutions affected in this river basin

Annex 13. Medical Institutions affected by flooding in Langogan Flood Plain

There are no medical institutions affected in this river basin

Annex 13. Phil LiDAR 1 UPLB Team Composition

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