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

LiDAR Surveys and Flood Mapping of Iwahig River

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

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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
BSWM	Bureau of Soil and Water Management
CAD	Computer-Aided Design
CN	Curve Number
CSRS	Chief Science Research Specialist
DA	Department of Agriculture
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
RBCO	River Basin Control Office
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 Baños
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 IWAHIG RIVER

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1.1 Background of the Phil-LiDAR 1 Program

The University of the Philippines Training Center for Applied Geodesy and Photogrammetry (UP-TCAGP) launched a research program entitled "Nationwide Hazard Mapping using LiDAR" or Phil-LiDAR 1, 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 implementing partner university for the Phil-LiDAR 1 Program is the University of the Philippines Los Baños (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 Southern Luzon region. The university is located in Los Baños in the province of Laguna.

1.2 Overview of the Iwahig River Basin

The Iwahig River Basin is a 10,131-ha watershed covering two (2) municipalities in Palawan; namely, the municipalities of Narra and Quezon. It covers barangay Aramaywan, Bato-bato, Calategas, and Tacras in Narra; Isugod, Maasin, Tabon, and Calatagbak in Quezon. The DENR River Basin Control Office (RBCO) states that the Iwahig River Basin has a drainage are of 127 km² and an estimated 203 cubic meter (MCM) annual run-off (RBCO, 2015).

As to its topography, the river basin area is predominantly from Upper Miocene-Pliocene (Sedimentary & Rocks), Undifferentiated (Igneous Rocks) and Cretaceous-Paleogene. Majority of the area in the river basin has gently sloping to moderately steep slopes and elevation range of 10-150 meters above sea level (masl). Sibul clay is the dominant soil type in the area. However large area in basin are still unclassified (rough mountainous land). Other wooded land (shrubs) and closed forest (broadleaved) occupies large area in the basin. Other land cover types include open forest (broadleaved), other land (cultivated perennial).

The Iwahig River Basin's main stem, Iwahig River, is part of the forty-five (45) river systems under the PHIL-LIDAR 1 Program partner HEI, University of the Philippines Los Baños. The Iwahig river passes through Isugod, Maasin, and Calatagbak in Quezon; and Aramayawan and Tacras in Narra. According to the 2015 national census of PSA, a total of 1,980 persons are residing in Brgy. Maasin in the Municipality of Quezon, which is within the immediate vicinity of the river.

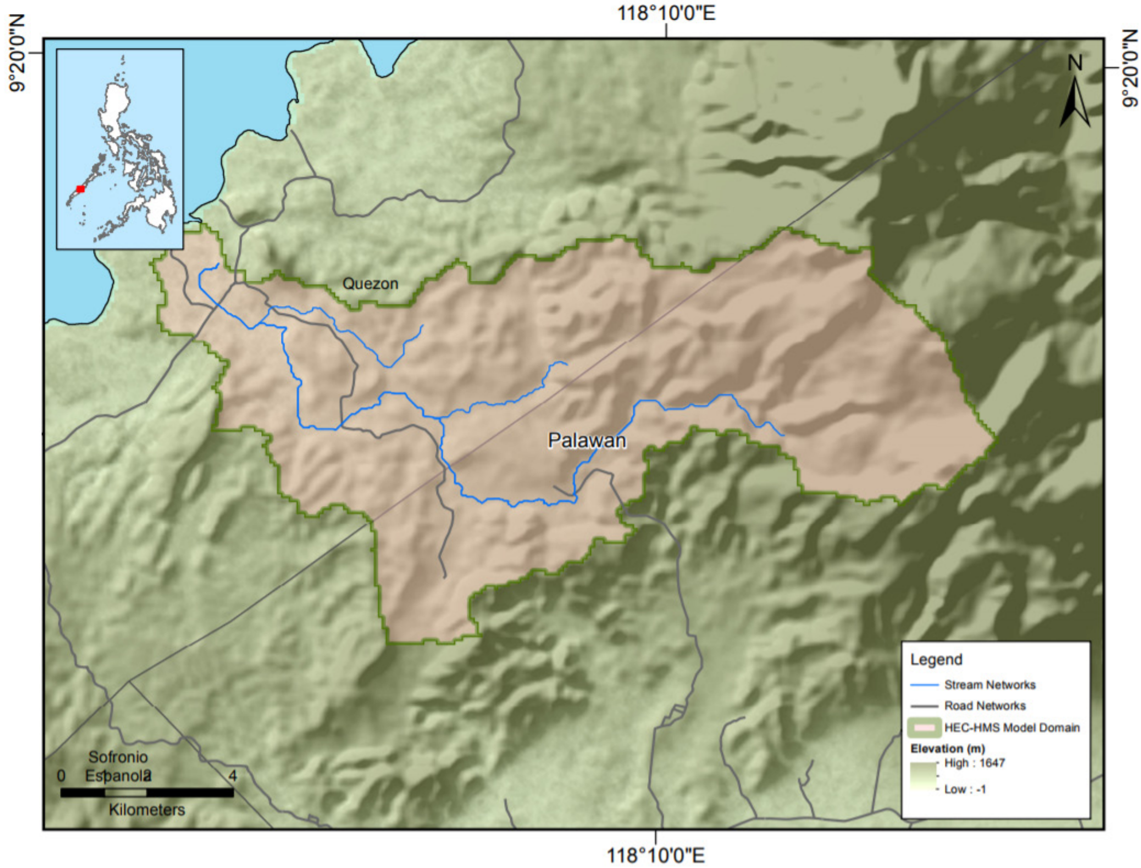

Figure 1. Map of Iwahig River Basin (in brown)

There are two (2) types of climate prevailing in the Iwahig River Basin: Climate Type I and III prevails in MIMAROPA and Laguna based on the Modified Corona Classification of climate. Type I has two pronounced seasons, dry from November to April, and wet the rest of the year with 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. Due to its tropical environment, the economy of the province of Palawan largely rests on agriculture particularly fishing, tourism, trade, commerce, and mineral extraction (Palawan Knowledge Platform for Biodiversity and Sustainable Development, 2007).

The study conducted by the Mines and Geosciences Bureau showed that portions of barangay Isugod near the river has moderate to high flood susceptibility. The field surveys conducted by the PHIL-LiDAR 1 validation team showed that there was no flooding event in the area attributed to weather disturbance. However, a heavy rainfall event in November 2013 caused flooding affecting barangay Maasin. On November 17, 2016, the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) issued a flood advisory for Iwahig River and its tributaries due to the moderate to heavy rains brought by the presence of a trough of low pressure area affecting Southern Luzon, Visayas and Mindanao as per NDRRMC report (National Disaster Risk Reduction and Management Council, 2016). In terms of landslides, barangay Calatagbak, Isugod, Aramaywan, Tacras, and Calategas has moderate susceptibilities to landslide.

CHAPTER 2: LIDAR DATA ACQUISITION OF THE IWAHIG FLOODPLAIN

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

2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Iwahig floodplain in Palawan. These missions were planned for 10 lines and ran for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameters for the LiDAR system are found in Table 1 and Table 2. Figure 2 shows the flight plan for Iwahig floodplain.

Table 1. Flight planning parameters for Pegasus LiDAR system.

Block Name	Flying Height (m AGL)	Overlap (%)	Field of view (ø)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK42I	800	30	50	200	30	130	5
BLK42J	800	30	50	200	30	130	5
BLK42K	800	30	50	200	30	130	5

Table 2. Flight planning parameters for Gemini LiDAR system

Block Name	Flying Height (m AGL)	Overlap (%)	Field of view (ø)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK42H	800	30	50	125	50	130	5
BLK42L	800	30	50	125	50	130	5

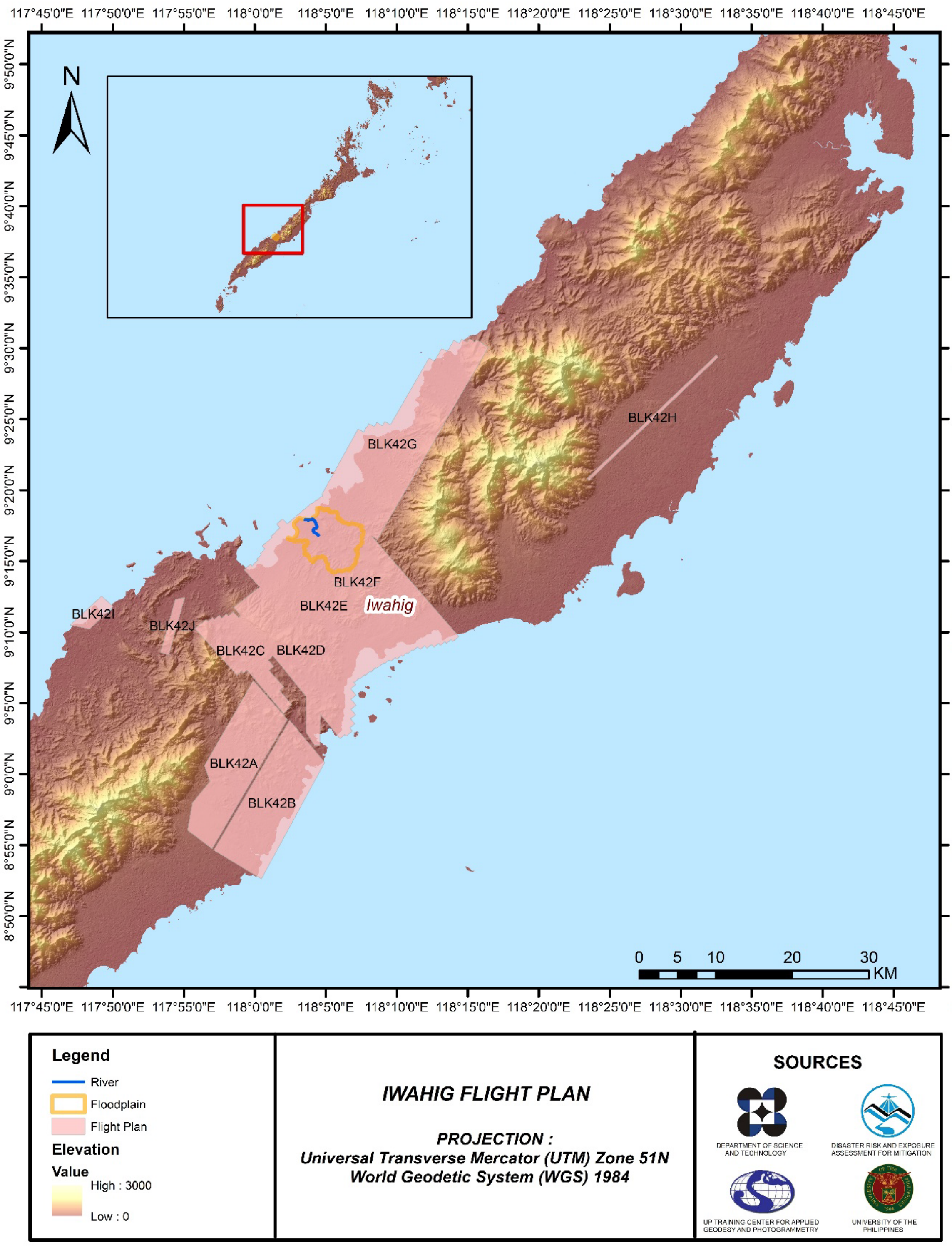


Figure 2. Flight plans used for Iwahig Floodplain

2.2 Ground Base Station

The project team was able to recover two (2) NAMRIA ground control points (GCPs): PLW-137 and PLW-71, which are of second (2nd) order accuracy, and one (1) NAMRIA benchmark, PL-318. The project team also established four (4) GCPs PLW-3043, PLW-383, QZT-1, and QZT-2. The certifications for the NAMRIA GCPs and benchmark are found in Annex 2, while the baseline processing reports for the established GCPs are found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey (June 11, 2015, July 13-15, 2015, and Dec 1, 2015). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 882 and SPS 852. Flight plans and location of base stations used during the aerial LiDAR acquisition in Iwahig floodplain are shown in Figure 3. The list of team members are shown in Annex 4.

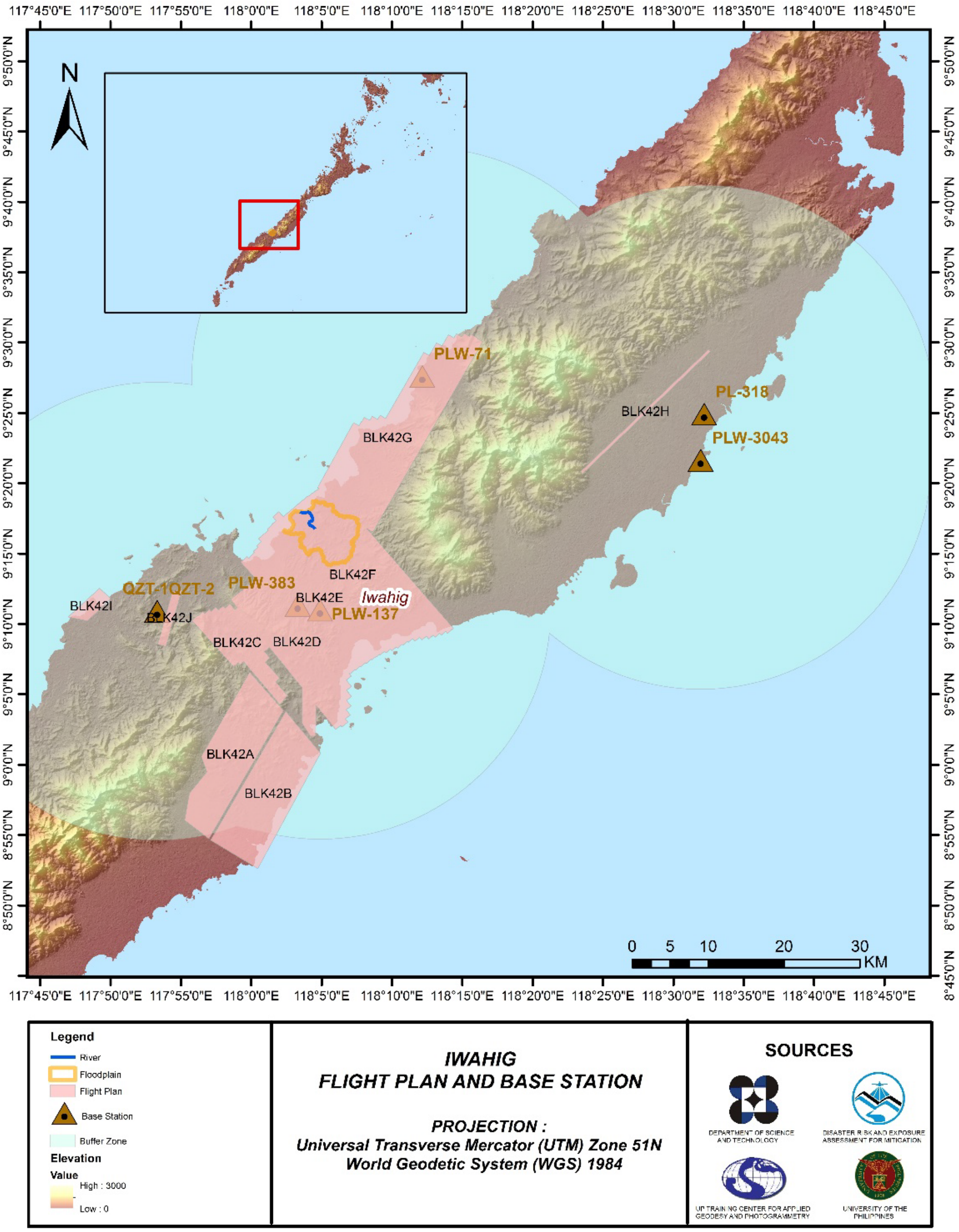


Figure 3. Flight plans and base stations for Iwahig floodplain.

Figure 4 to Figure 8 show the recovered NAMRIA reference points within the area. In addition, Table 3 to Table 9 show the details about the NAMRIA control stations and established points. Table 10 shows the list of all ground control points occupied during the acquisition together with the corresponding dates of utilization.

(a) (b)

Figure 4. GPS set-up over PLW-137 at the ridge near kilometer post 133 at Brgy. Ipilan, Municipality of Narra along Narra-Aboabo (Sofronio Espanola) – Quezon highway (a) and NAMRIA reference point PLW-137 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point PLW-137 used as base station for the LiDAR Acquisition.

Station Name	**PLW-137**	
Order of Accuracy	**2nd**	
Relative Error (Horizontal positioning)	**1 in 50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	9° 11’ 2.95364” North 118° 4’ 48.04729” East 35.83359 meters
Grid Coordinates, Philippine Transverse Mercator Zone 1A (PTM Zone 1 PRS 92)	Easting Northing	453844.056 meters 1,015,530.347 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	9° 11’ 58.60442” North 118° 4’ 53.42391” East 85.64700 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	618,656.03 meters 1,015,326.41 meters

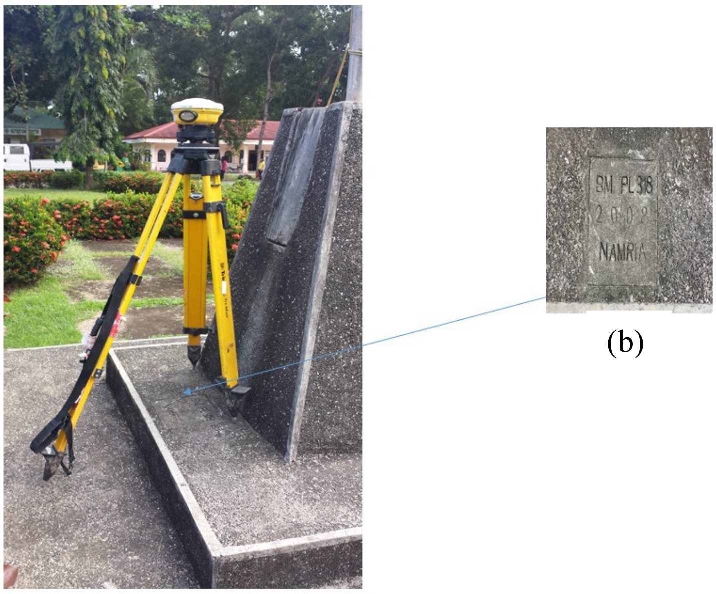
(a)

(b)

Figure 5. GPS set-up over PLW-71 (PAL-14) in Sitio Badlesan, Brgy. Berong in the municipality of Quezon (a) and NAMRIA reference point PLW-71 (PAL-14) (b) as recovered by the field team.

Table 4. Details of the recovered NAMRIA horizontal control point PLW-71 (PAL-14) used as base station for the LiDAR Acquisition.

Station Name	PLW-71 (PAL-14)	
Order of Accuracy	2nd	
Relative Error (Horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	9° 27’ 39.91263” North 118° 12’ 4.53547” East 3.87100 meters
Grid Coordinates, Philippine Transverse Mercator Zone 1A (PTM Zone 1 PRS 92)	Easting Northing	467,194.901 meters 1,046,143.749 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	9° 27’ 35.50449” North 118° 12’ 9.88716” East 53.39400 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	631,874.59 meters 1,045,990.79 meters



(b)

(a)

Figure 6. GPS set-up over PL-318 on the flagpole in front of Aborlan Municipal Hall, Palawan (a) and NAMRIA reference point PL-318 (b) as recovered by the field team.

Table 5. Details of the recovered NAMRIA vertical control point PL-318 used as base station for the LiDAR Acquisition with re-processed coordinates.

Station Name	PLW-318	
Order of Accuracy	2nd	
Relative Error (Horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	9° 24’ 58.83705” North 118° 32’ 6.27533” East 17.702 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	9° 24’ 54.46952” North 118° 32’ 11.63035” East 68.152 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	509337.208 meters 1043949.629 meters

Figure 7. GPS set-up over QZT-1 in Purok Bagong Sikat in Sitio Bugon, Barangay Malatgao, Municipality of Quezon along Quezon-Punta Baja (Rizal) highway.

Table 6. Details of the established NAMRIA horizontal control point QZT-1 used as base station for the LiDAR Acquisition with re-processed coordinates.

Station Name	QZT-1	
Order of Accuracy	2nd	
Relative Error (Horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	9° 10’ 58.89071” North 117° 53’ 13.01663” East 9.338 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	9° 10’ 54.52473” North 117° 53’ 18.39361” East 58.674 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	597443.464 meters 1015143.507 meters

Figure 8. GPS set-up over QZT-2 in front of the purok waiting shed, Purok Bagong Sikat in Sitio Bugon, Barangay Malatgao, Municipality of Quezon along Quezon-Punta Baja (Rizal) highway.

Table 7. Details of the established NAMRIA horizontal control point QZT-2 used as base station for the LiDAR Acquisition with re-processed coordinates.

Station Name	QZT-2	
Order of Accuracy	2nd	
Relative Error (Horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	9° 10’ 57.93286” North 117° 53’ 13.25970” East 6.864 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	9° 10’ 53.56696” North 117° 53’ 18.63670” East 56.200 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	597450.957 meters 1015114.108 meters

Table 8. Details of the recovered NAMRIA vertical control point PL-383 used as base station for the LiDAR Acquisition with re-processed coordinates.

Station Name	PL-383	
Order of Accuracy	2nd	
Relative Error (Horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	9° 11’ 23.95008” North 118° 3’ 12.74333’ East 75.579 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	9° 11’ 19.59710” North 118° 3’ 18.11940” East 123.314 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	615745.311 meters 1015962.645 meters

Table 9. Details of the established NAMRIA horizontal control point PLW-3043 used as base station for the LiDAR Acquisition with re-processed coordinates.

Station Name	PLW-3043	
Order of Accuracy	2nd	
Relative Error (Horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	9° 21’’ 42.33800” North 118° 31’ 50.87908” East 8.199 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	9° 21’ 37.98382” North 118° 31’ 56.23900” East 58.756 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	597450.957 meters 1015114.108 meters

Table 10. Ground control points used during LiDAR data acquisiton

Date Surveyed	Flight Number	Mission Name	Ground Control Points
June 11, 2015	3037P	1BLK42I162A	PLW-71
June 11, 2015	3039P	1BLK42J162B	PLW-383, PLW-137
July 13, 2015	3167P	1BLK42KLM194B	PLW-137, QZT-1, QZT-2
July 15, 2015	3173P	1BLK42KS196A	PLW-383, PLW-137
December 1, 2015	3557G	2BLK45HSL335A	PL-318, PLW-3043

2.3 Flight Missions

Five (5) missions were conducted to complete LiDAR data acquisition in Iwahig floodplain, for a total of fourteen hours and twenty one minutes (14+21) of flying time for RP-C9022 and RP-C9322. All missions were acquired using the Pegasus and Gemini LiDAR systems. Table 11 shows the total area of actual coverage and the corresponding flying hours per mission while Table 12 presents the actual parameters used during the LiDAR data acquisition.

Table 11. Flight Missions for LiDAR Data Acquisition in Iwahig 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
June 11, 2015	3037P	518.92	286.80	3.20	283.61	709	3	58
June 11, 2015	3039P	518.92	198.77	46.00	152.76	386	3	6
July 13, 2015	3167P	375.18	79.40	-	79.40	103	2	18
July 15, 2015	3173P	14.57	31.55	10.19	21.36	NA	1	18
December 1, 2015	3557G	495.80	129.98	0.76	129.22	NA	3	41
TOTAL		1923.39	726.5	60.15	666.35	1098	14	21

Table 12. Actual Parameters used during LiDAR Data Acquisiton

Flight Number	Flying Height (m AGL)	Overlap (%)	Field of View (θ)	PRF (Hz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Times (Minutes)
3037P	1500	30	40	200	36	130	5
3039P	1500	30	40	200	36	130	5
3167P	1100	30	50	200	15	130	5
3173P	1000	30	50	200	10	130	5
3557G	850	30	40	125	50	130	5

2.4 Survey Coverage

Iwahig Floodplain is located on the province of Palawan. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 13. The actual coverage of the LiDAR acquisition for Daraga floodplain is presented in Figure 9.

Table 13. List of municipalities and cities surveyed during Iwahig floodplain survey.

Province	Municipality/ City	Area of Municipality/City (km^2)	Total Area Surveyed (km^2)	Percentage of Area Surveyed
Palawan	Quezon	917.97	299.89	33%
	Aborlan	645.11	141.75	22%
	Narra	831.19	147.86	18%
	Sofronio Espanola	477.50	18.77	4%

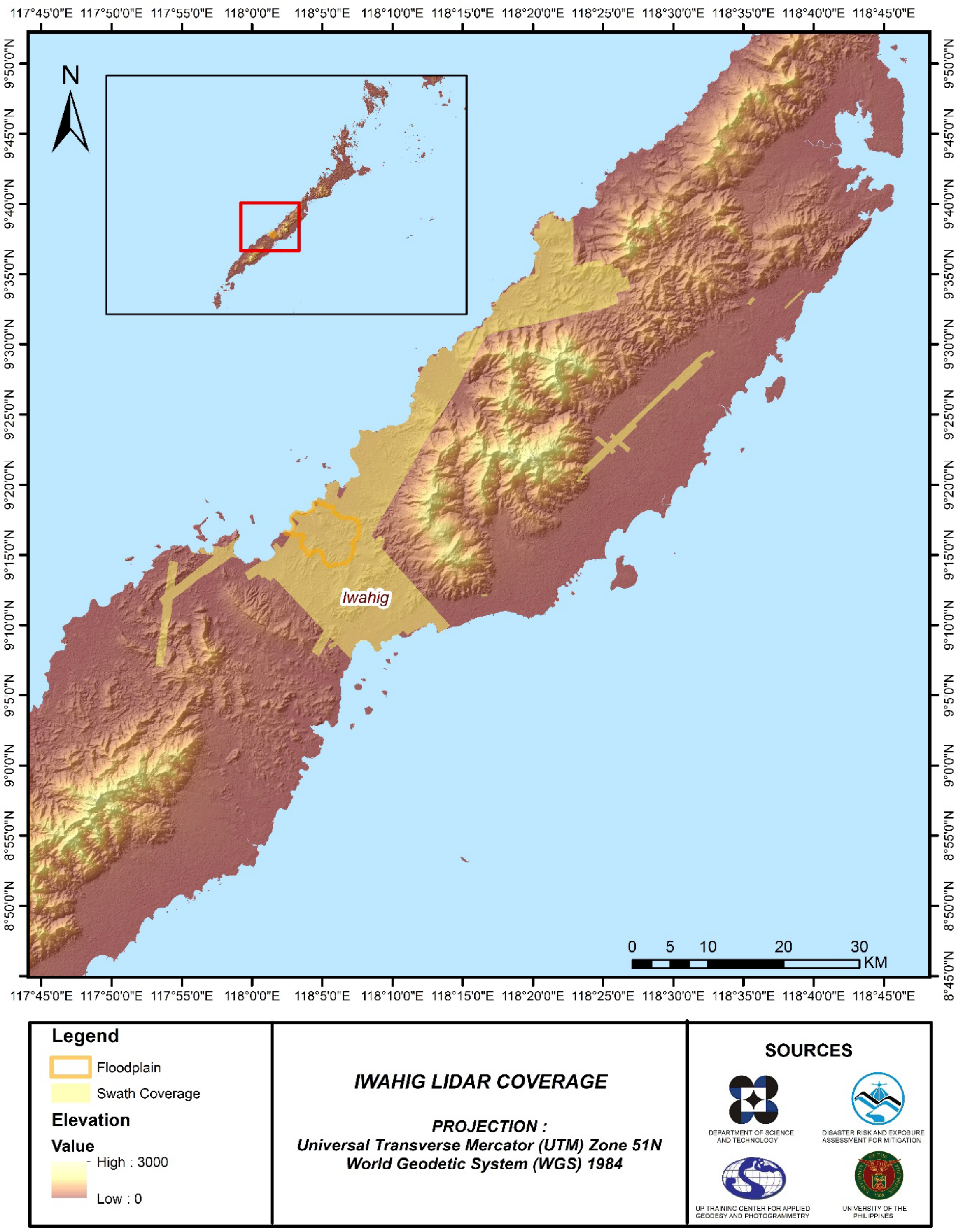


Figure 9. Actual LiDAR survey coverage for Iwahig Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE IWAHIG 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).

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 10.

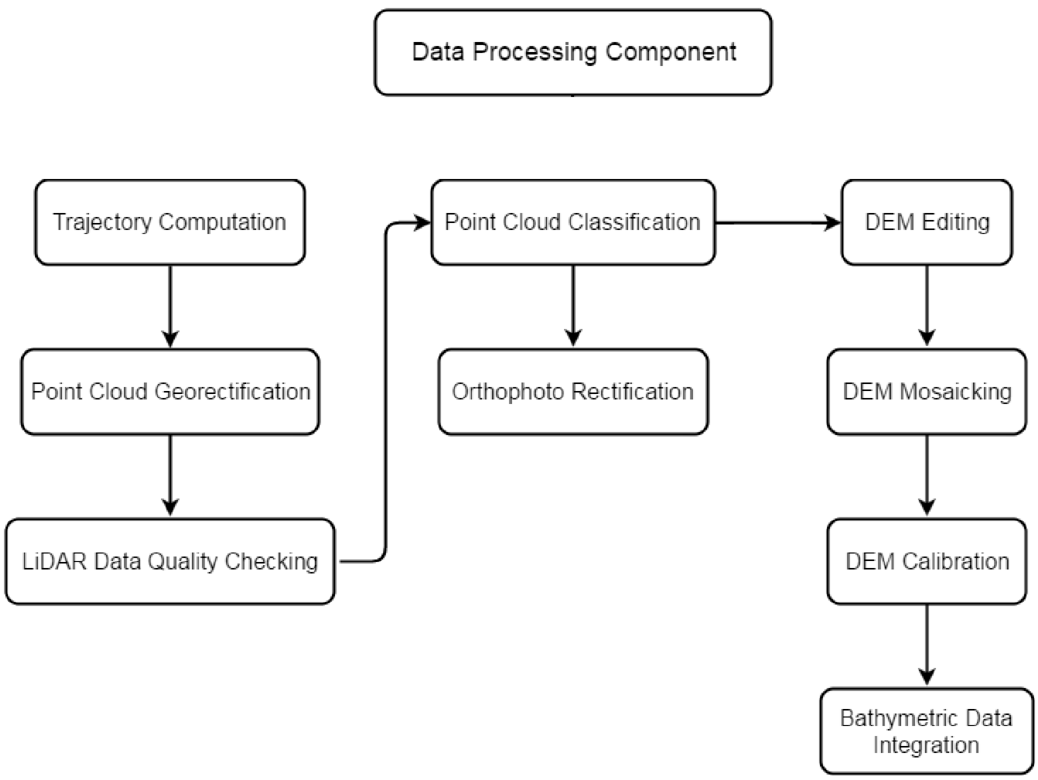

Figure 10. Schematic Diagram for Data Pre-Processing Component

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Sumagui floodplain can be found in Annex 5. Missions flown during the first survey conducted on February 2014 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Aquarius system while missions acquired during the second survey on October 2015 were flown using the Gemini system over Bansud, Oriental Mindoro.

The Data Acquisition Component (DAC) transferred a total of 126.91 Gigabytes of Range data, 2.34 Gigabytes of POS data, 127.79 Megabytes of GPS base station data, and 522.1 Gigabytes of raw image data to the data server on June 4, 2014 for the first survey and February 6, 2016 for the second survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Sumagui was fully transferred on November 11, 2015, as indicated on the Data Transfer Sheets for Sumagui floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 3039P, one of the Iwahig flights, which is the North, East, and Down position RMSE values are shown in Figure 11. 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 June 11, 2015 00:00AM. The y-axis is the RMSE value for that particular position.

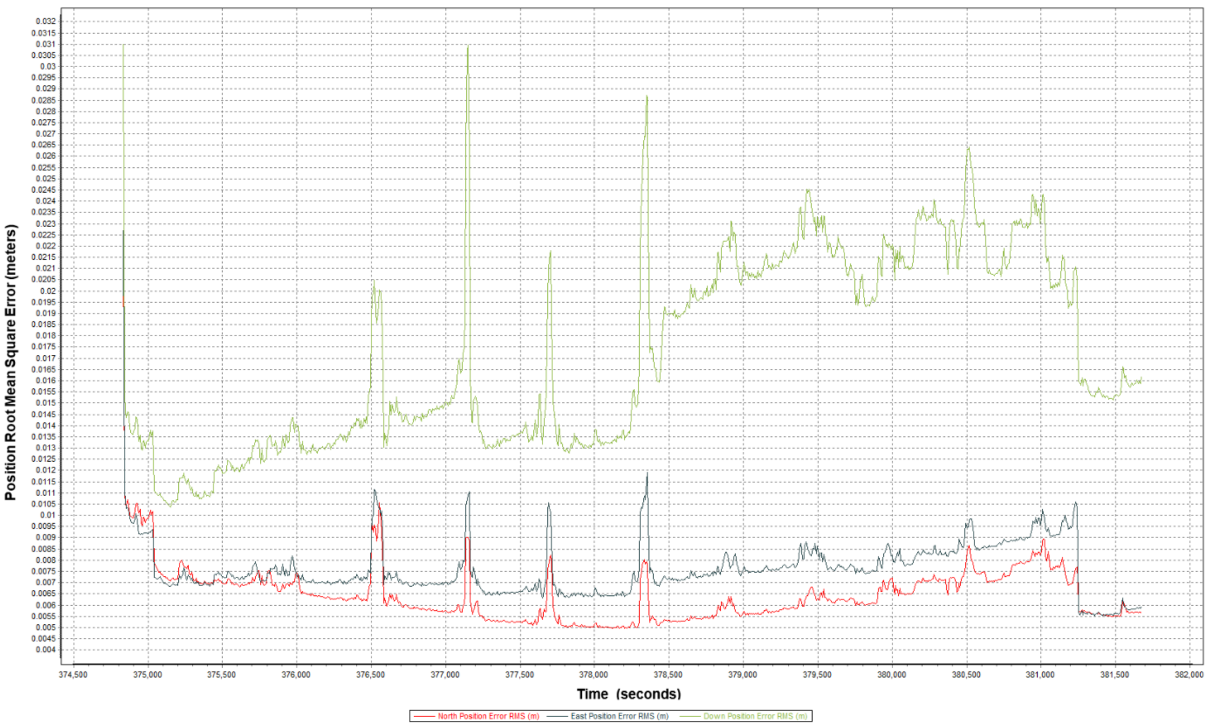

Figure 11. Smoothed Performance Metrics of Iwahig Flight 1098A.

The time of flight was from 374800 seconds to 381700 seconds, which corresponds to afternoon of June 11, 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 11 shows that the North position RMSE peaks at 1.06 centimeters, the East position RMSE peaks at 2.30 centimeters, and the Down position RMSE peaks at 3.10 centimeters, which are within the prescribed accuracies described in the methodology.

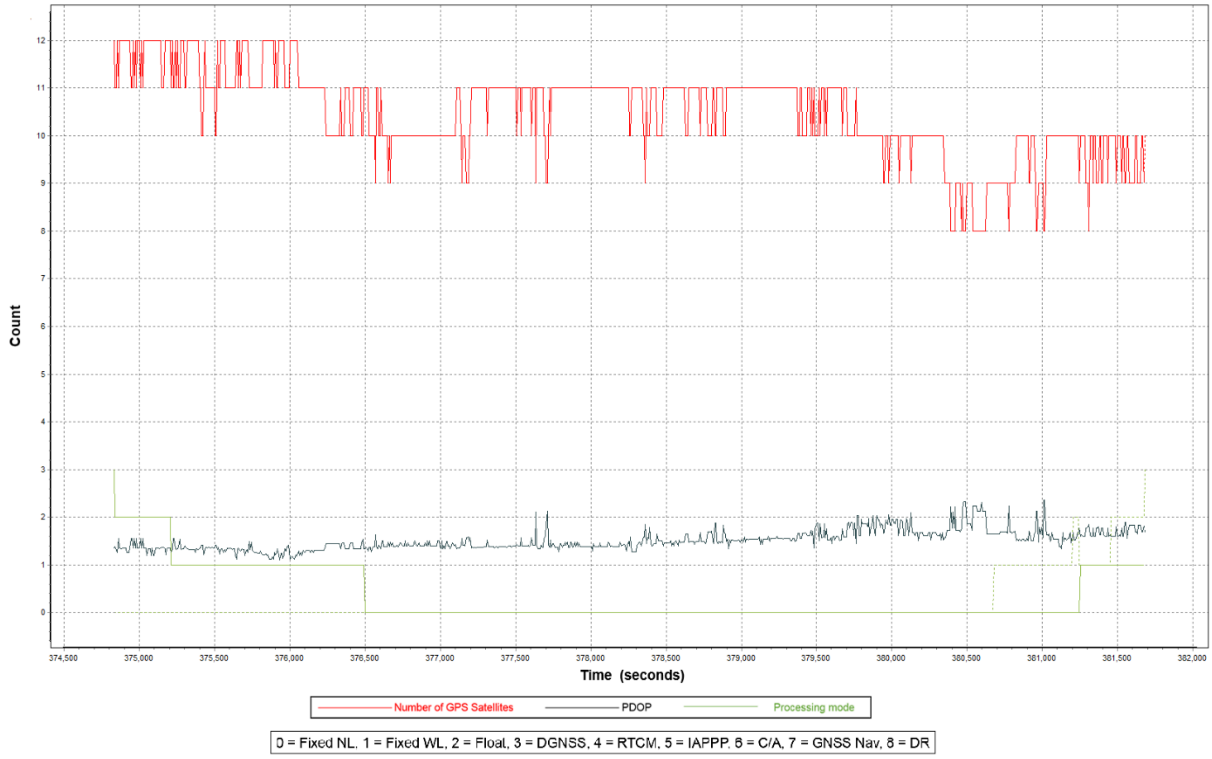

Figure 12. Solution Status Parameters of Iwahig Flight 3039P.

The Solution Status parameters of flight 3039P, one of the Iwahig flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 12. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Majority of the time, the number of satellites tracked was between 6 and 12. 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 Iwahig flights is shown in Figure 13.

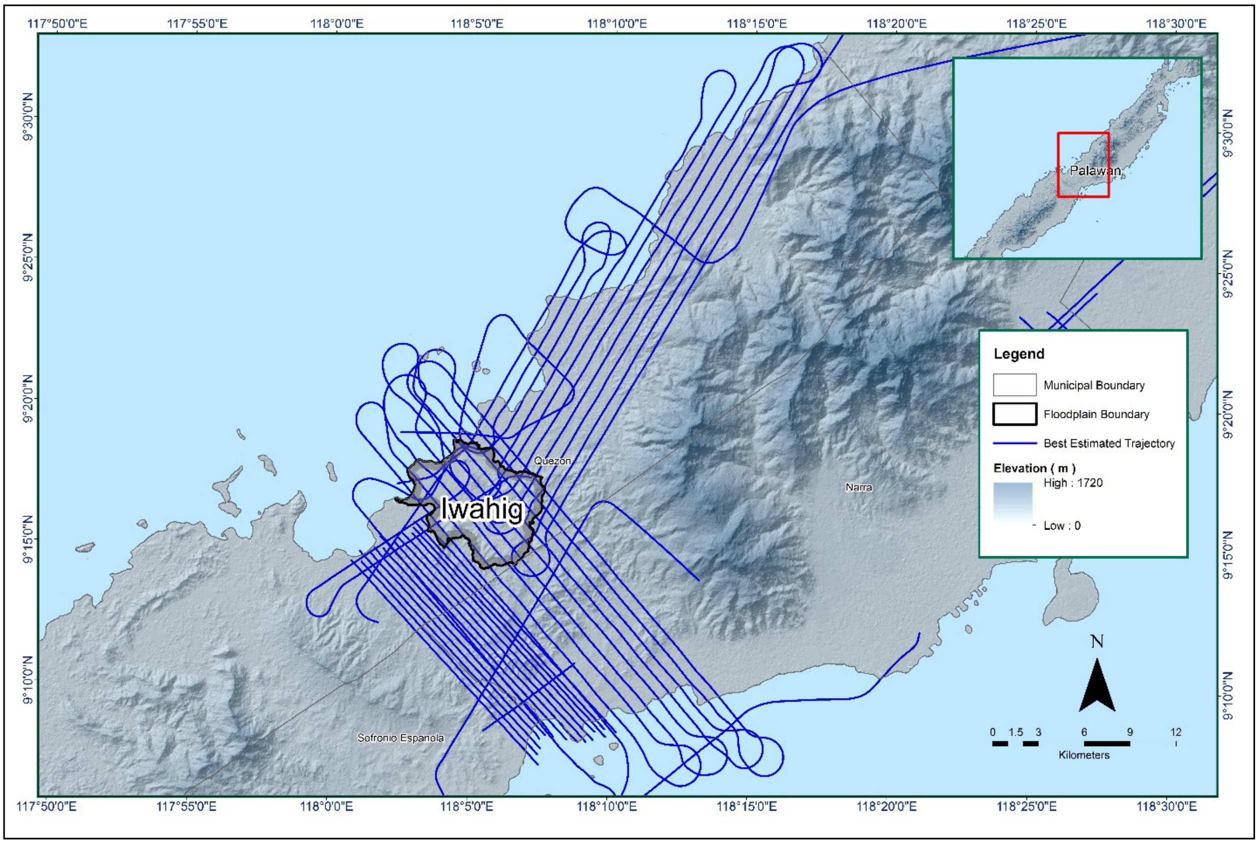

Figure 13. Best Estimated Trajectory for Iwahig Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 38 flight lines, with some flight lines containing one channel, since the Gemini system contain one channel only and two channels for the Pegasus sytem. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Iwahig floodplain are given in Table 14.

Table 14. Self-Calibration Results values for Iwahig flights.

Parameter	Value
Boresight Correction stdev (<0.001degrees)	0.000133
IMU Attitude Correction Roll and Pitch Corrections stdev (<0.001degrees)	0.000101
GPS Position Z-correction stdev (<0.01meters)	0.0011

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

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Iwahig Floodplain is shown in Figure 14. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

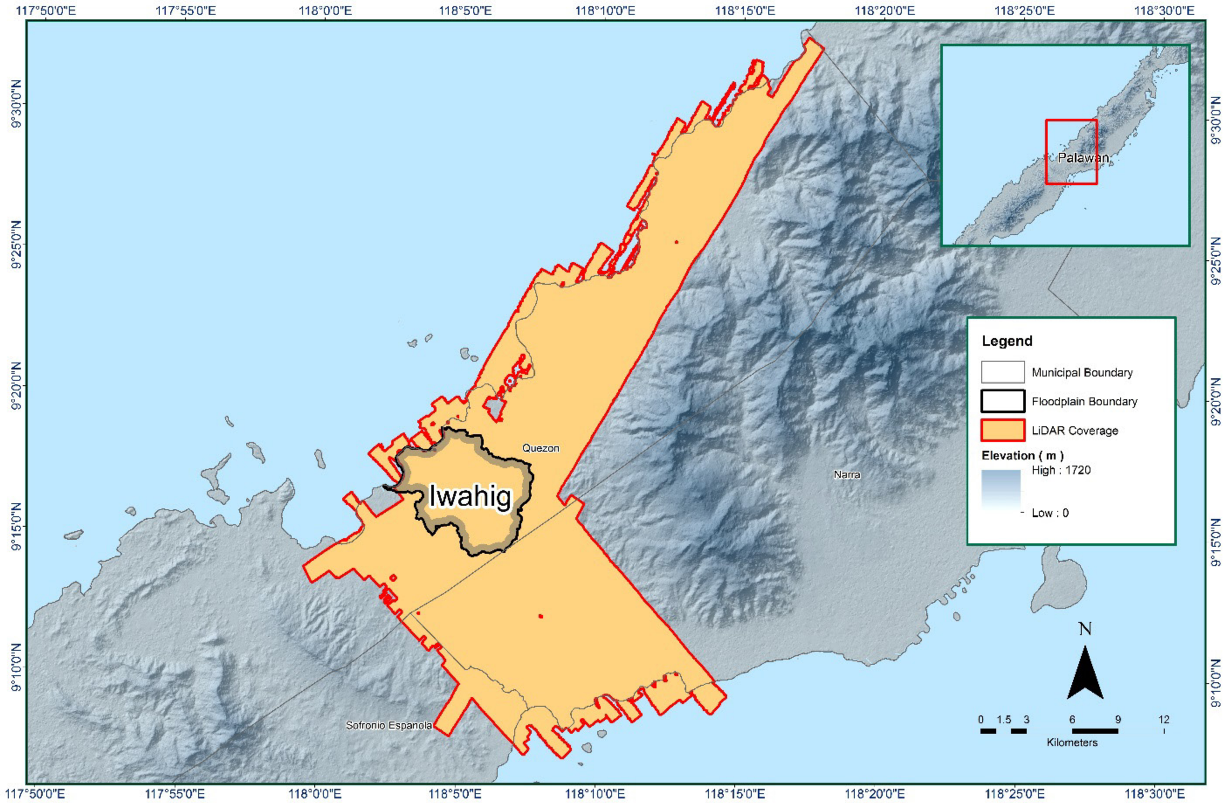

Figure 14. Boundary of the processed LiDAR data over Iwahig Floodplain

The total area covered by the Iwahig missions is 535.03 sq.km that is comprised of five (5) flight acquisitions grouped and merged into three (3) blocks as shown in Table 15.

Table 15. List of LiDAR blocks for Iwahig floodplain

LiDAR Blocks	Flight Numbers	Area (sq. km)
Palawan_Blk42J	3037P	153.94
Palawan_Blk42J_supplement	3167P	39.81
Palawan_Blk42K	3039P	217.85
Palawan_Blk42K_supplement	3173P	22.65
Palawan_reflights_Blk42KS	3557G	100.78
TOTAL		**535.03 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 15. 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. While for the Pegasus system which employs two channels, we would expect an average value of 2 (blue) for areas where there is limited overlap and a value of 3 (yellow) or more (red) for areas with three or more overlapping flight lines.

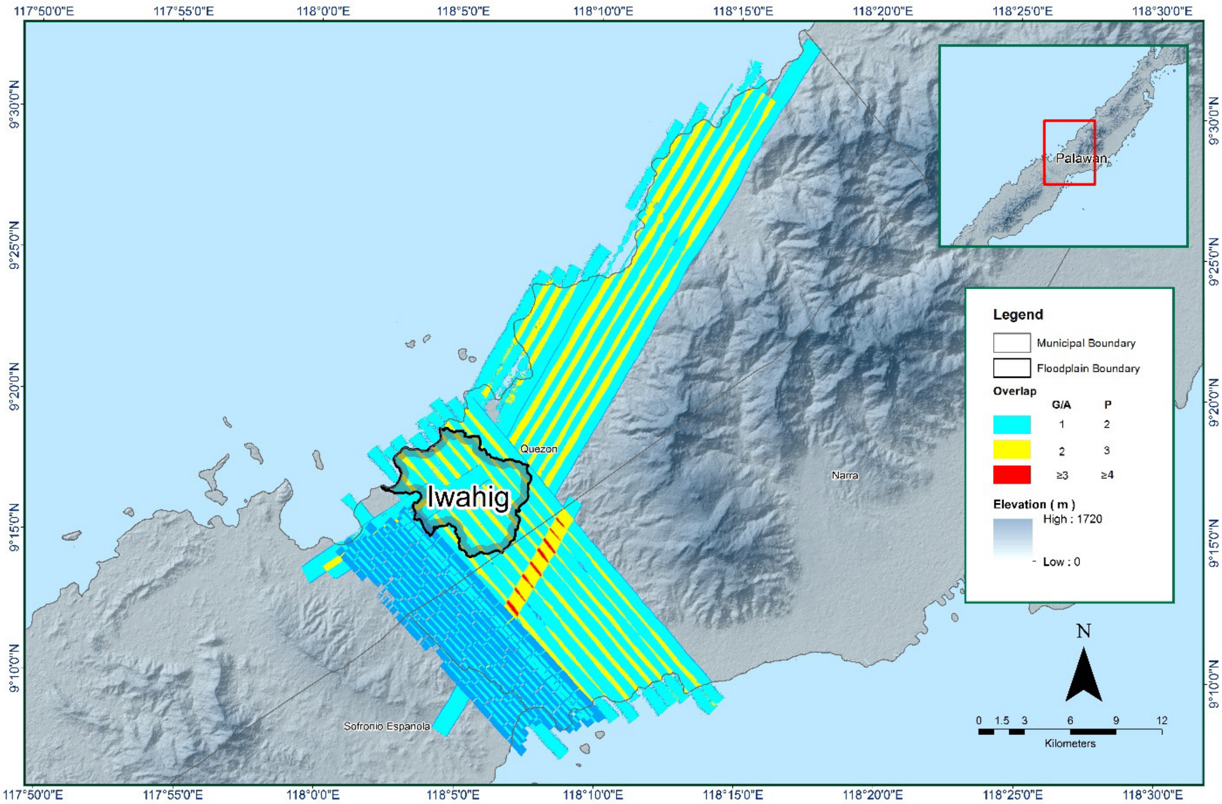

Figure 15. Image of data overlap for Iwahig Floodplain.

The overlap statistics per block for the Iwahig floodplain can be found in Annex 8. One pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 34.23% and 47.72% respectively, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 16. It was determined that all LiDAR data for Iwahig floodplain satisfy the point density requirement, and the average density for the entire survey area is 2.801 points per square meter.

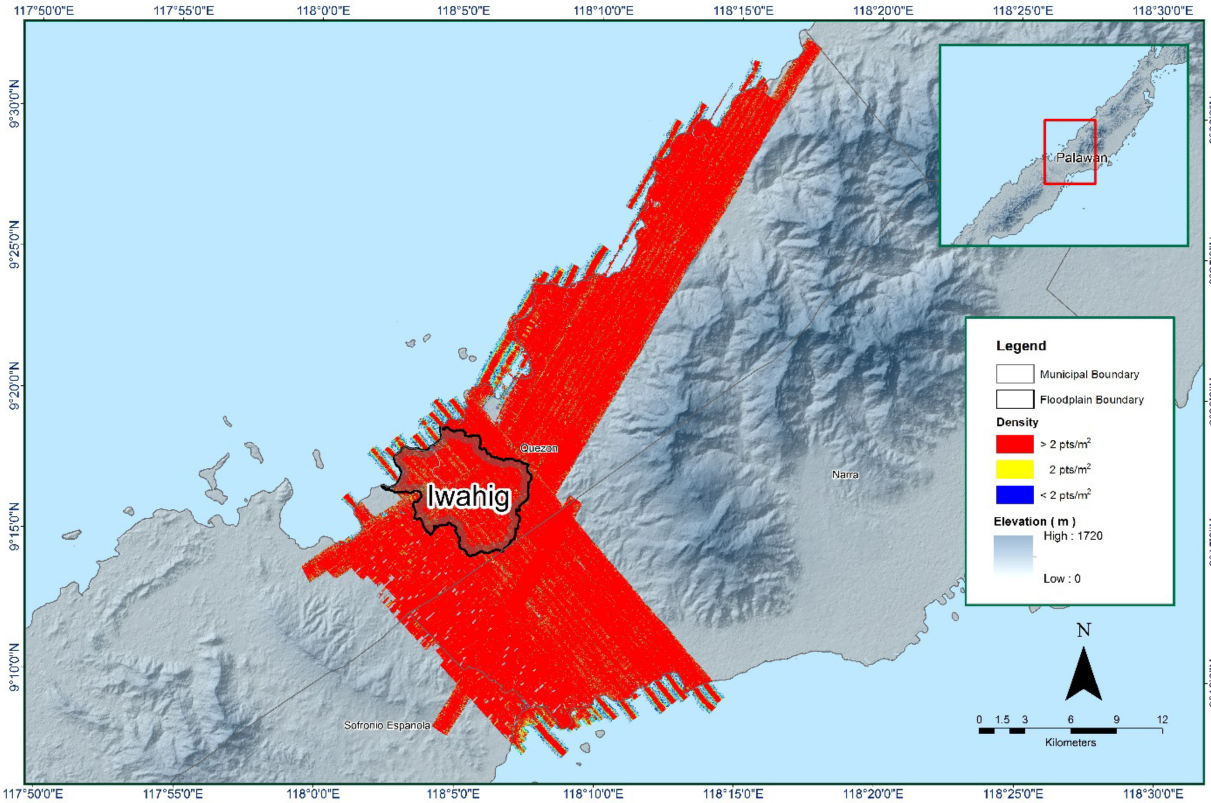

Figure 16. Pulse density map of merged LiDAR data for Iwahig Floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 17. 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.

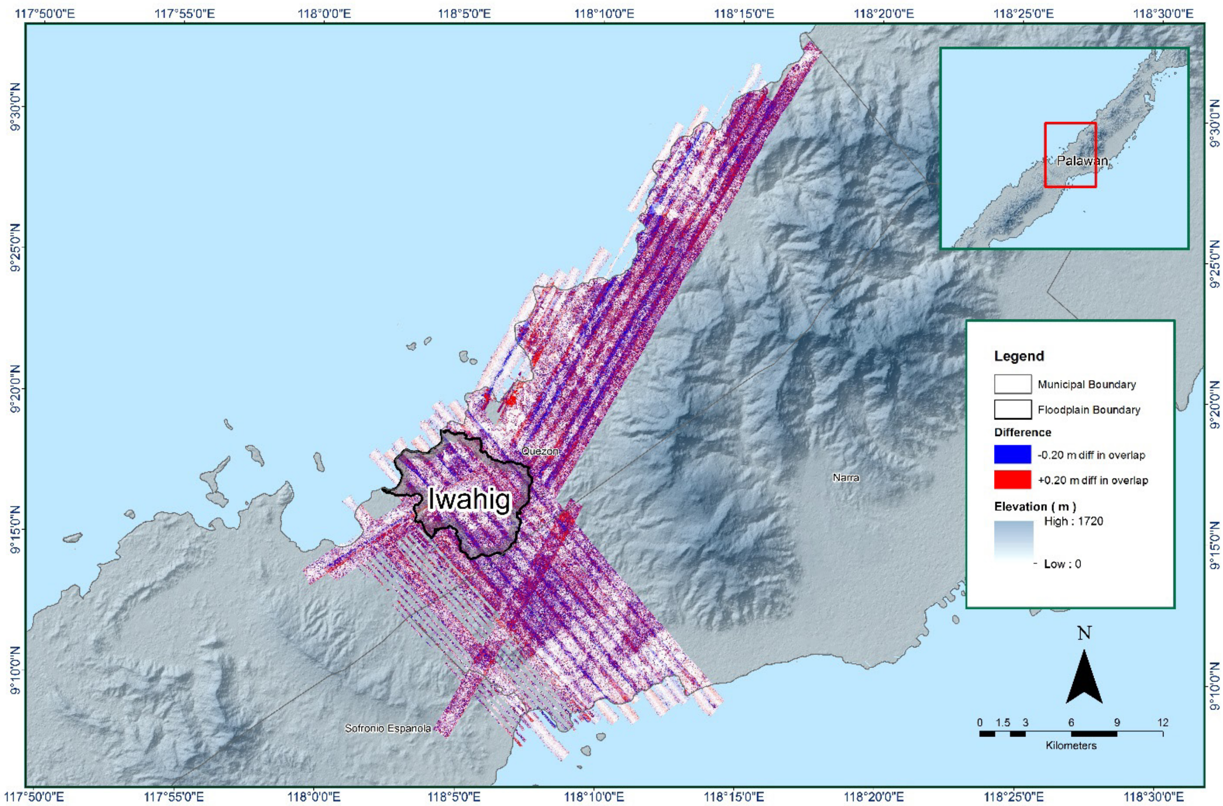

Figure 17. Elevation difference map between flight lines for Iwahig Floodplain.

A screen capture of the processed LAS data from an Iwahig flight 3039P loaded in QT Modeler is shown in Figure 18. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed red line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the researcher was satisfied with the quality of the LiDAR data. No reprocessing was done for this LiDAR dataset.

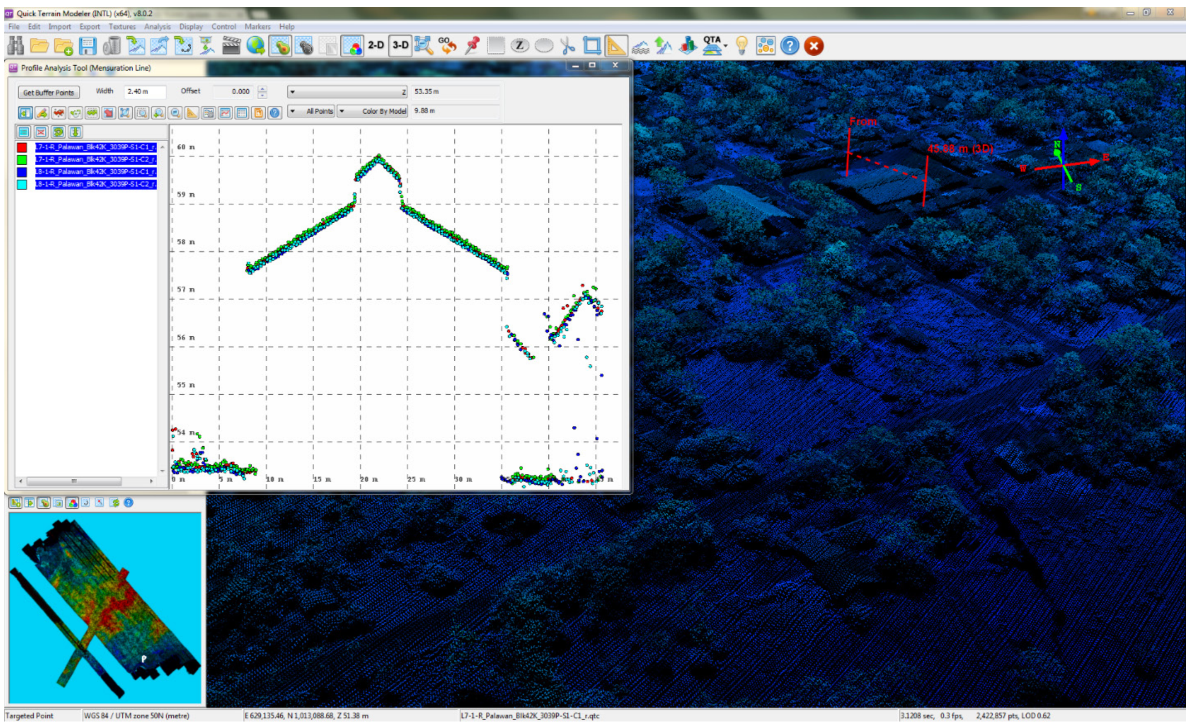

Figure 18. Quality checking for Iwahig flight 3039P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 16. Iwahig classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	331,189, 817
Low Vegetation	210,436,108
Medium Vegetation	547,030,883
High Vegetation	1,317,020,625
Building	17,555,986

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Iwahig floodplain is shown in Figure 19. A total of 796 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 16. The point cloud has a maximum and minimum height of 592.12 meters and 42.20 meters respectively.

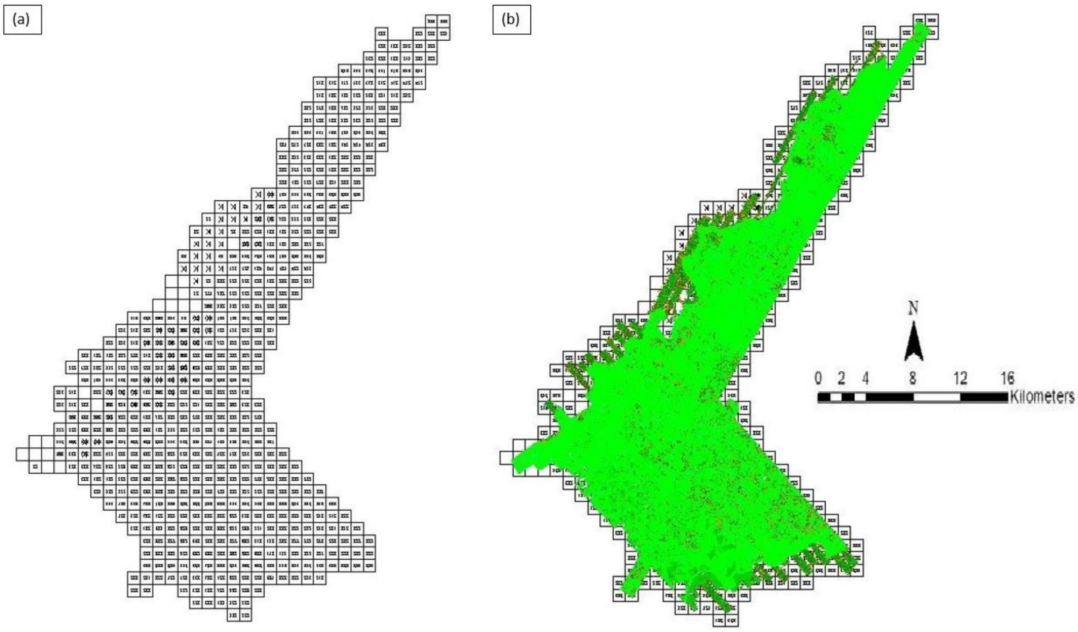

Figure 19. Tiles for Iwahig Floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 20. The ground points are in orange, the vegetation is in different shades of green, and the buildings are in cyan. It can be seen that residential structures adjacent or even below canopy are classified correctly, due to the density of the LiDAR data.

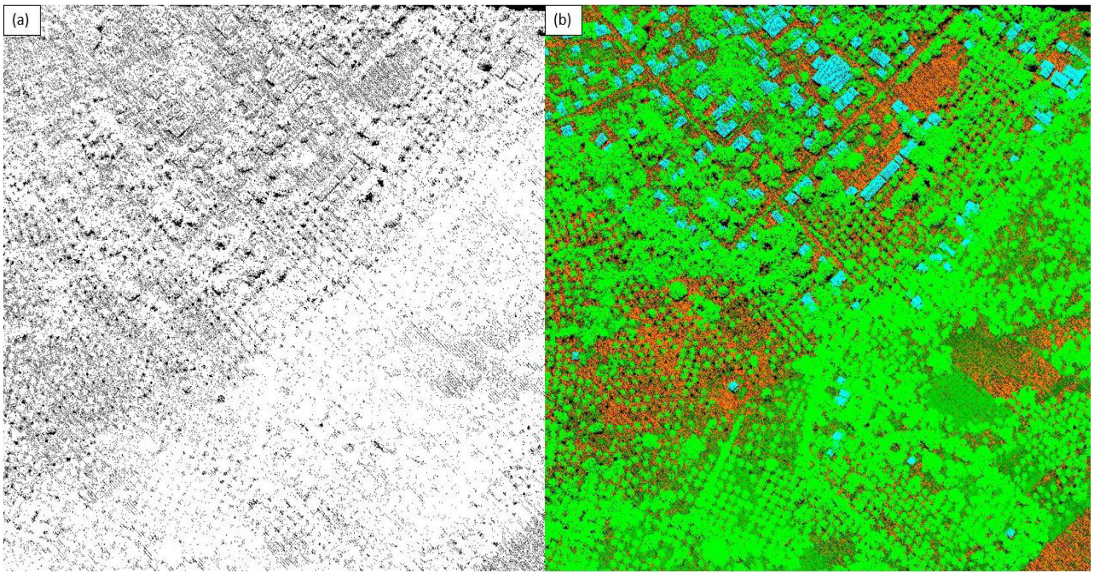

Figure 20. Point cloud before (a) and after (b) classification.

The production of last return (V_ASCII) and the secondary (T_ ASCII) DTM, first (S_ ASCII) and last (D_ ASCII) return DSM of the area in top view display are shown in Figure 21. It shows that DTMs are the representation of the bare earth while on the DSMs, all features are present such as buildings and vegetation.

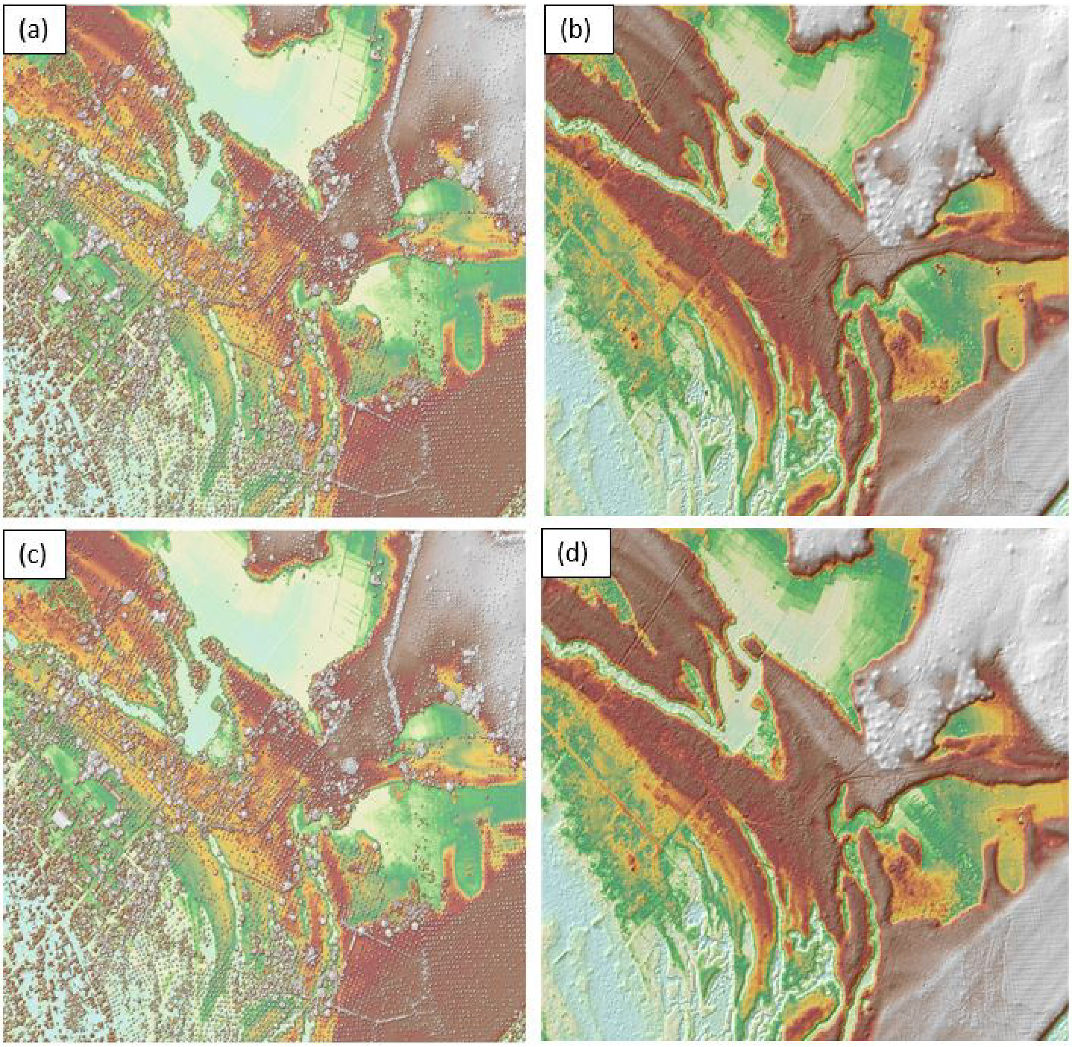

Figure 21. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Iwahig Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 475 1km by 1km tiles area covered by Iwahig floodplain is shown in Figure 22. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Iwahig floodplain has a total of 347.49 sq.km orthophotogaph coverage comprised of 694 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 23.

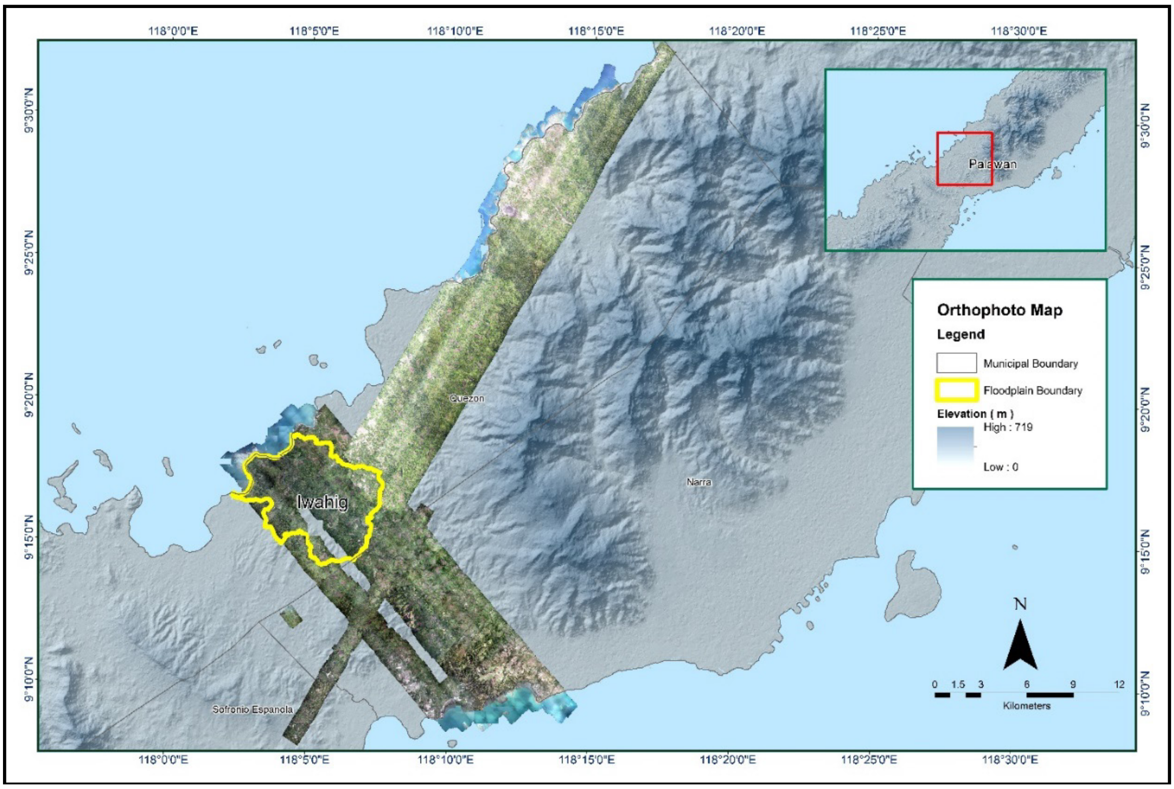

Figure 22. Iwahig Floodplain with available orthophotographs.

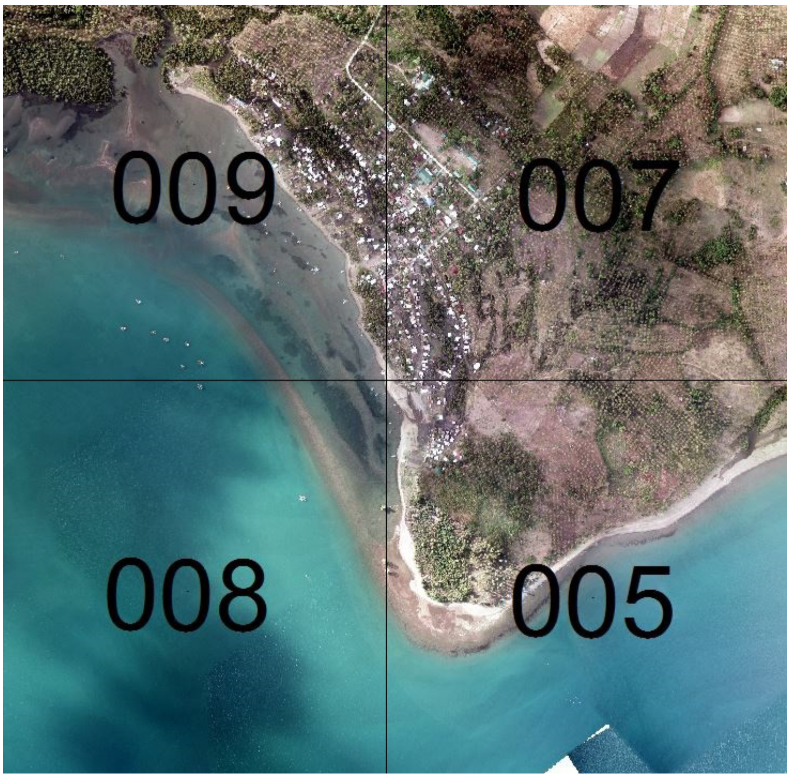

Figure 23. Sample orthophotograph tiles for Iwahig Floodplain.

3.8 DEM Editing and Hydro-Correction

Three (3) mission blocks were processed for Iwahig flood plain. These blocks are composed of Palawan and Palawan_reflights blocks with a total area of 535.03 square kilometers. Table 17 shows the name and corresponding area of each block in square kilometers.

Table 17. LiDAR blocks with its corresponding area.

LiDAR Blocks	Area (sq.km)
Palawan_Blk42J	153.94
Palawan_Blk42J_supplement	39.81
Palawan_Blk42K	217.85
Palawan_Blk42K_supplement	22.65
Palawan_reflights_Blk42KS	100.78
TOTAL	**535.03 sq.km**

Portions of DTM before and after manual editing are shown in Figure 24. The land bridge in Figure 24a would be an impedance to the flow of water along the river and was removed in order to hydrologically correct the river, as done in Figure 24b. Another portion of the DTM presented in Figure 24c shows the part of the river which needed to be filled in order to allow the correct flow of water which resulted to the output in Figure 24d.

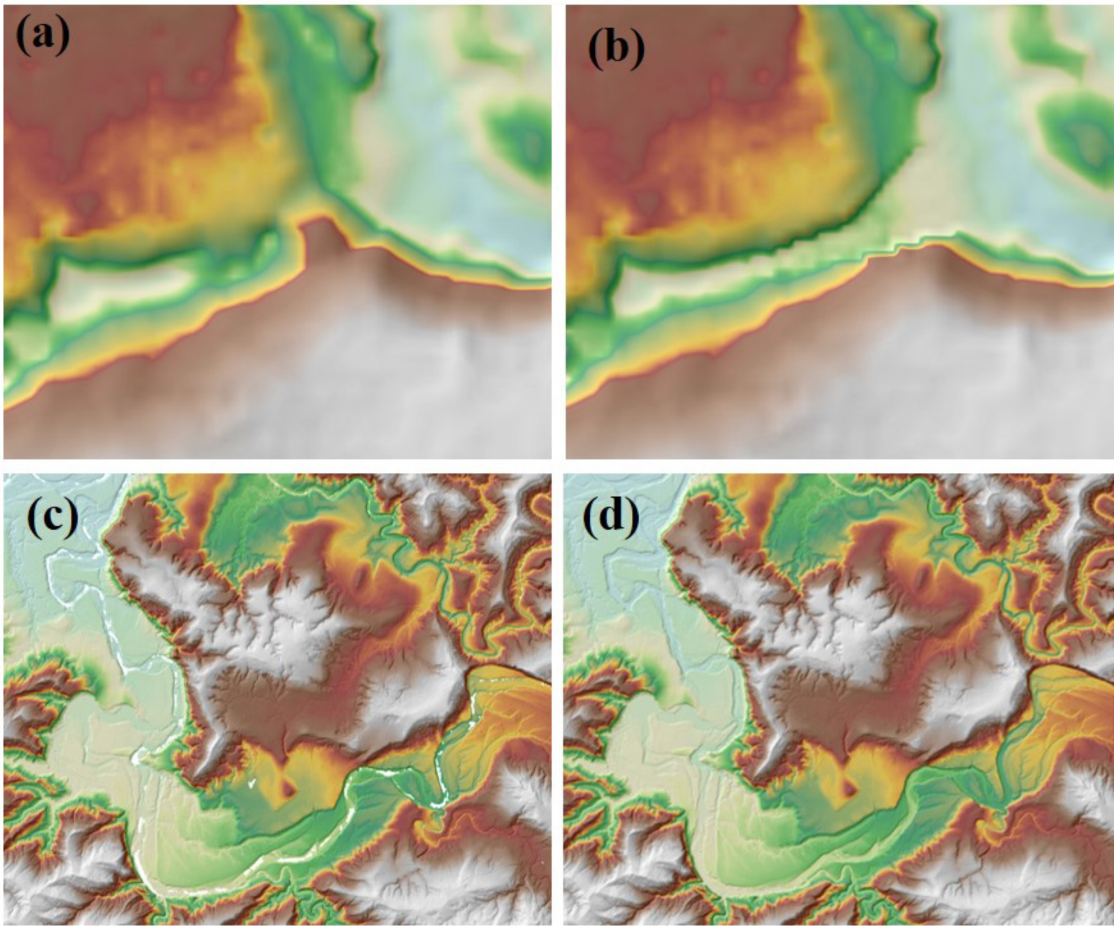

Figure 24. Portions in the DTM of Iwahig Floodplain – a land bridge before (a) and after (b) interpolation process and part of the river with data gap before (c) and after (d) filling data gap

3.9 Mosaicking of Blocks

Palawan Block 42J 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. This was followed by PWN42 J supplement, PWN42 K, PWN42K supplement and PWNr42Ks, respectively. Given that Palawan block 42J was mosaicked to the other blocks of West Coast Palawan, the block was also inspected for elevation shifts that it might need. Table 18 shows the area of each LiDAR block and the shift values applied during mosaicking.

Mosaicked LiDAR DTM for Iwahig floodplain is shown in Figure 25. It can be seen that the entire Iwahig floodplain is 100% covered by LiDAR data.

Table 18. Shift Values of each LiDAR Block of Iwahig Floodplain.

Mission Blocks	Shift Values		
	x	y	z
Palawan_Blk42J	0.00	0.00	-0.99
Palawan_Blk42J_supplement	0.00	0.00	7.52
Palawan_Blk42K	0.00	0.00	7.34
Palawan_Blk42K_supplement	0.00	0.00	7.36
Palawan_reflights_Blk42KS	0.00	0.00	-3.28

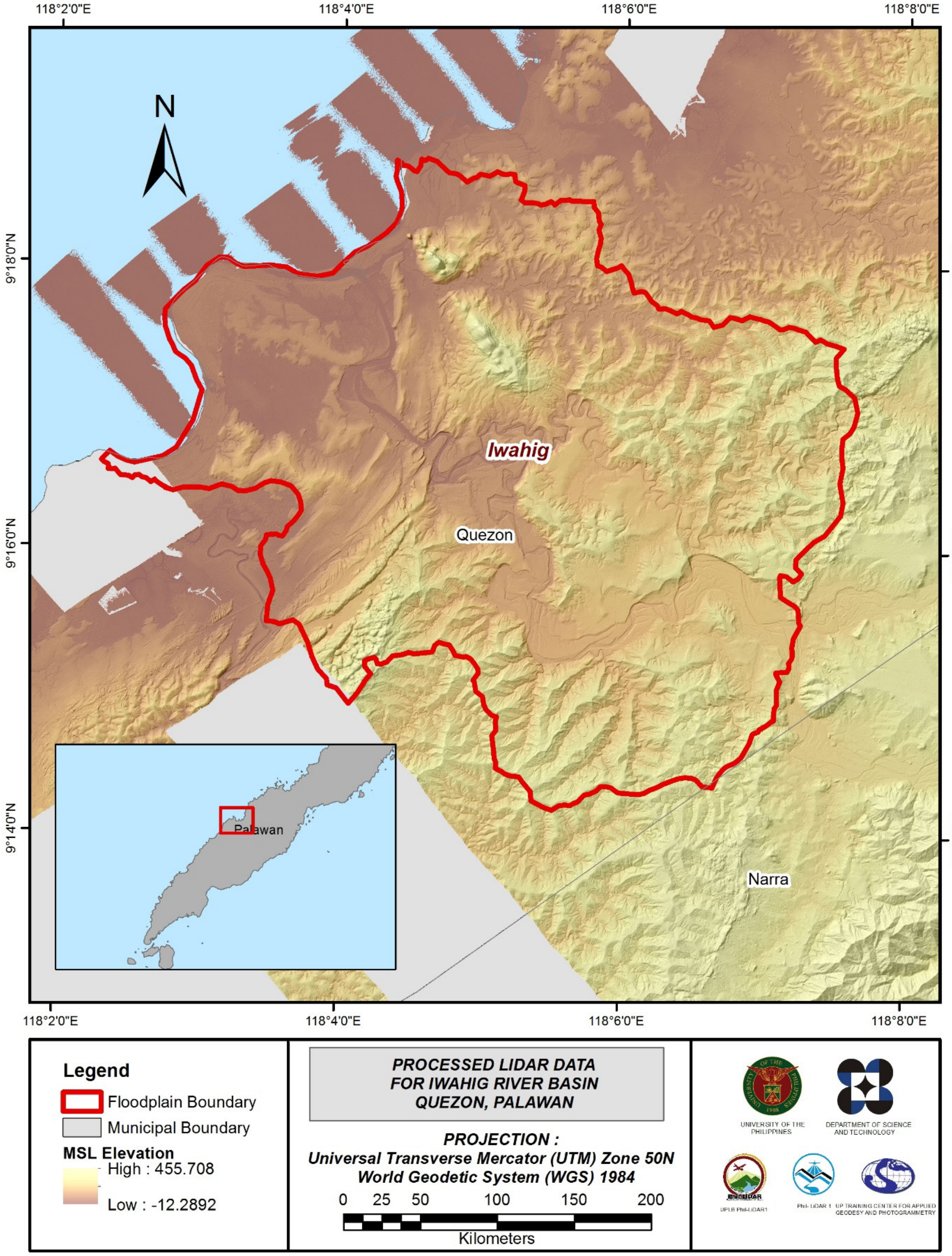

Figure 25. Map of Processed LiDAR Data for Iwahig Floodplain.

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 Iwahig to collect points with which the LiDAR dataset is validated is shown in Figure 26. A total of 54274 survey points were used for calibration and validation of Iwahig LiDAR data. Random selection of 80% of the survey points, resulting to 43,419 points, were used for calibration.

A good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values is shown in Figure 27. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration elevation values is 10.82 meters with a standard deviation of 0.20 meters. Calibration of Iwahig LiDAR data was done by adding the height difference value, 10.82 meters, to Iwahig mosaicked LiDAR data. Table 19 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

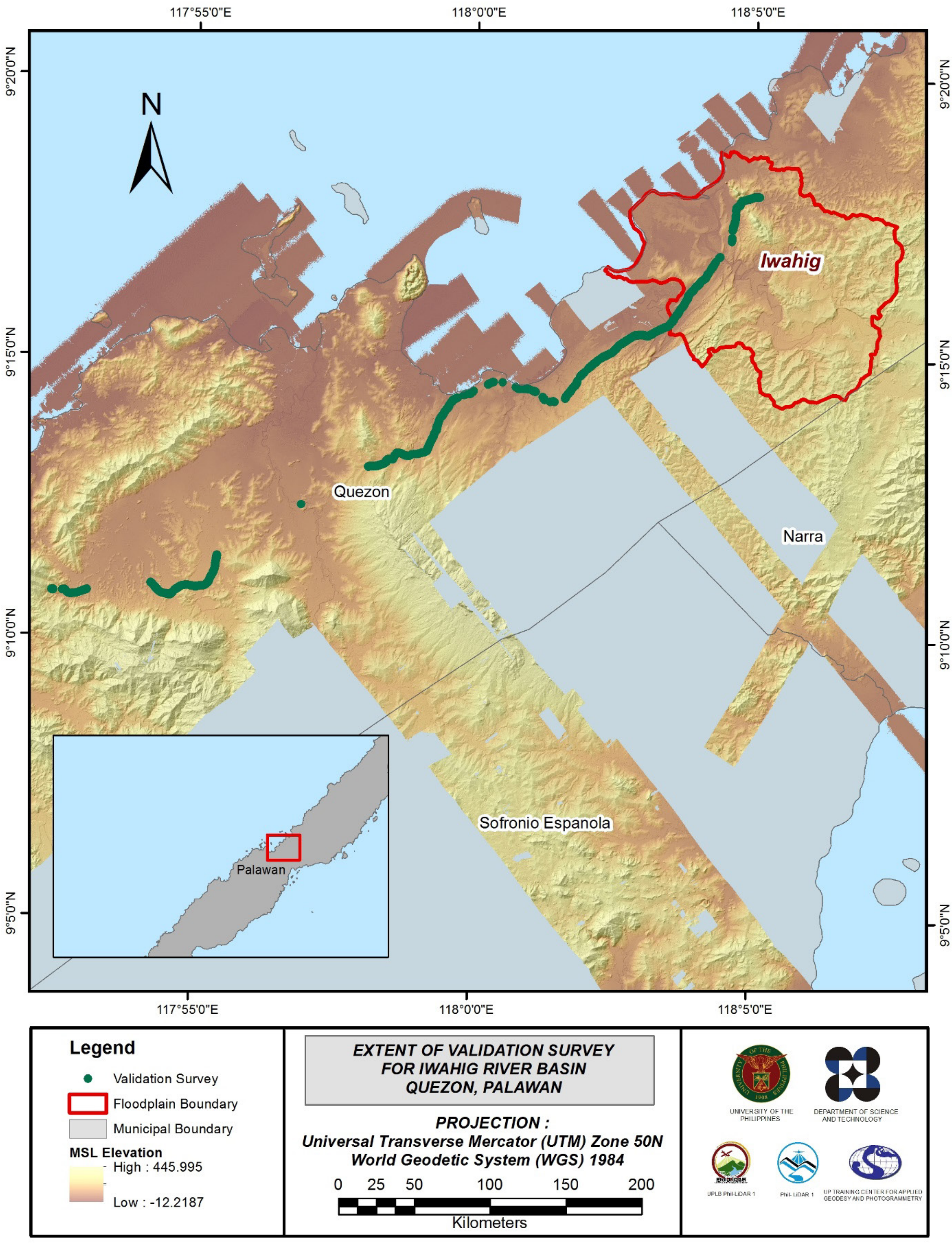

Figure 26. Map of Iwahig Floodplain with validation survey points in green.

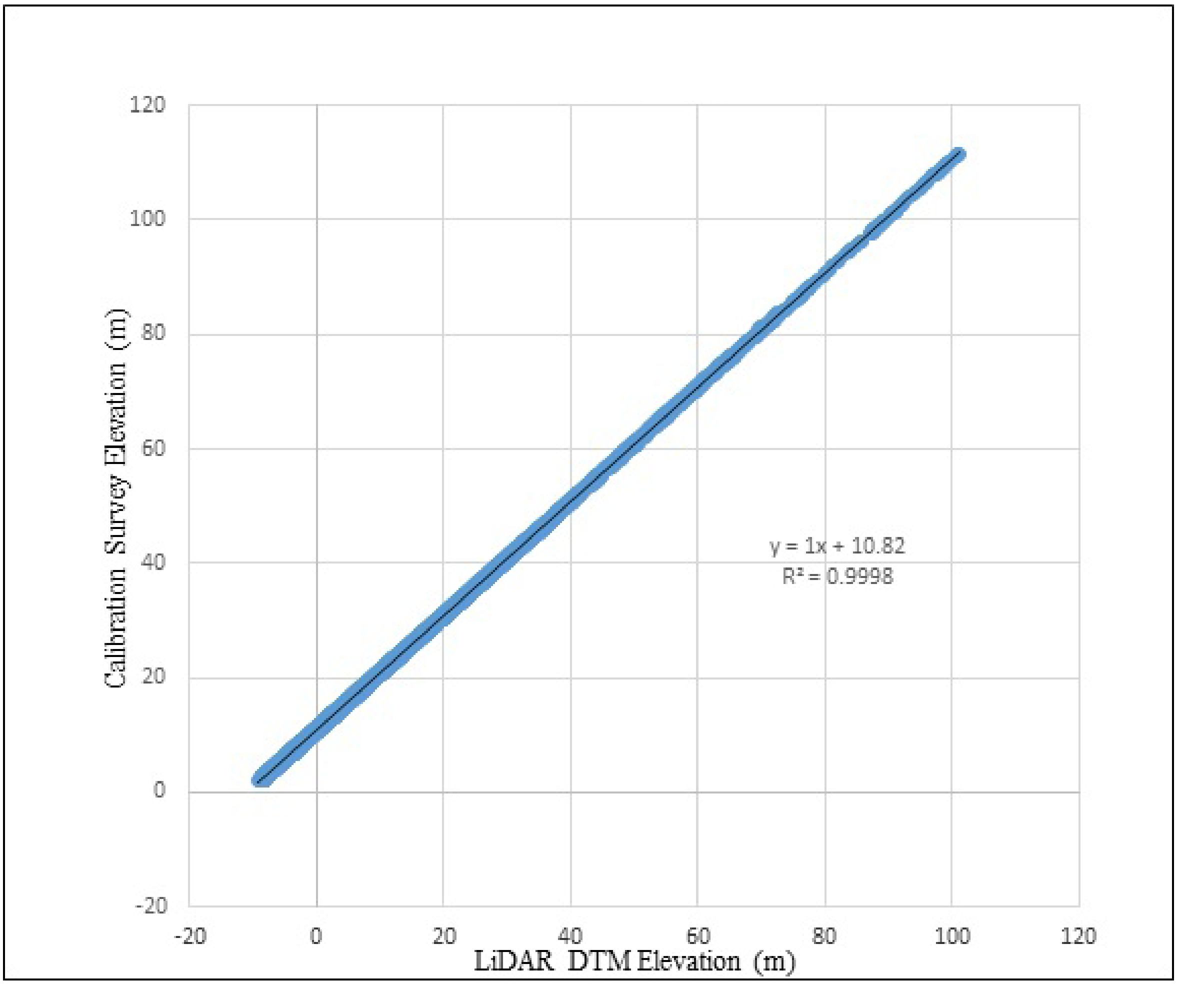

Figure 27. Correlation plot between calibration survey points and LiDAR data

Table 19. Calibration Statistical Measures

Calibration Statistical Measures	Value (meters)
Height Difference	10.82
Standard Deviation	0.20
Average	10.82
Minimum	10.36
Maximum	11.27

The remaining 20% of the total survey points were intersected to the flood plain, resulting to 114 points. These were used for the validation of calibrated Iwahig 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 28. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.20 meters with a standard deviation of 0.19 meters, as shown in Table 20.

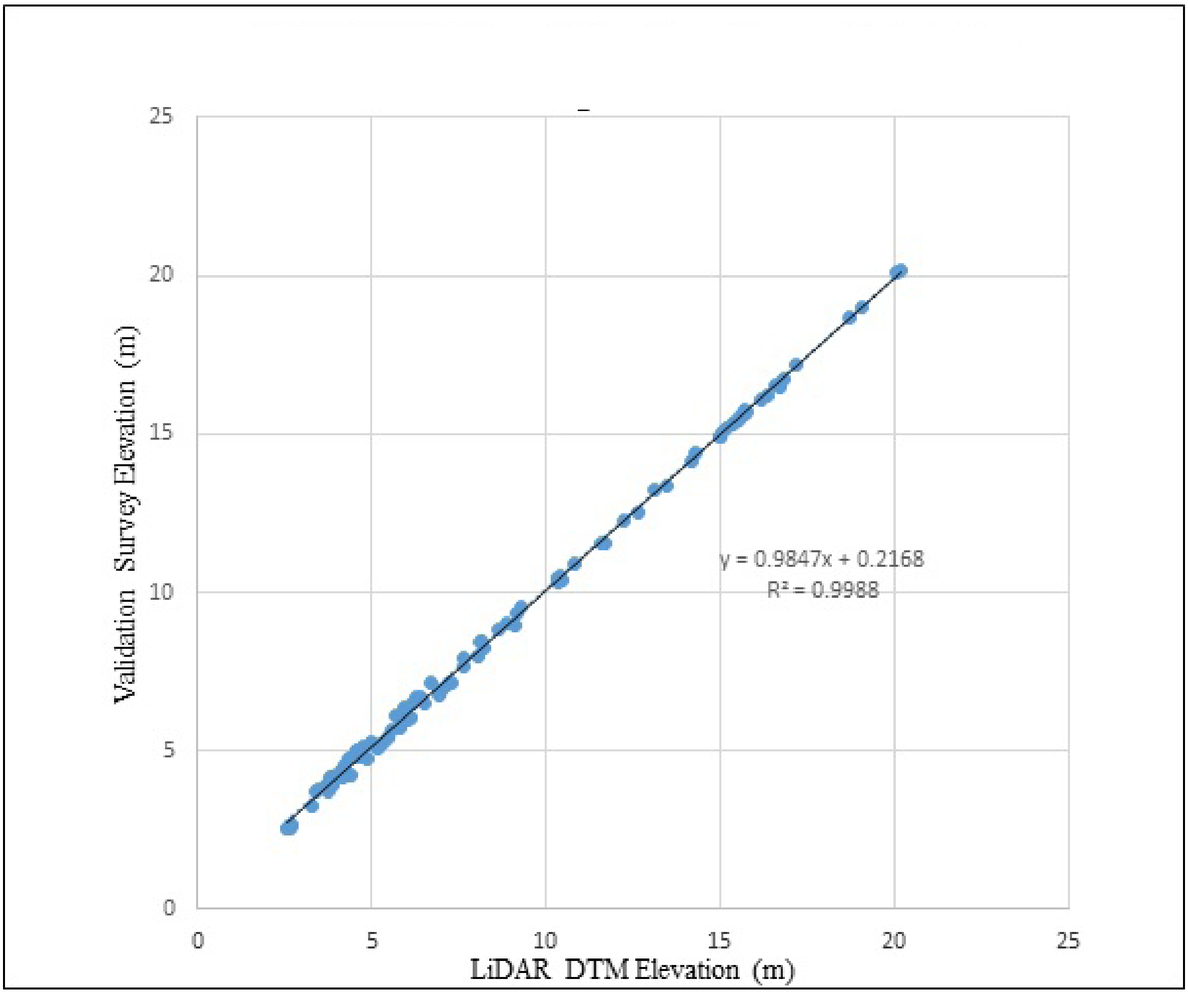

Figure 28. Correlation plot between validation survey points and LiDAR data.

Table 20. Validation Statistical Measures.

Validation Statistical Measures	Value (meters)
RMSE	0.20
Standard Deviation	0.19
Average	0.09
Minimum	-0.21
Maximum	0.48

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and zigzag data were available for Iwahig with 1,437 bathymetric 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 0.25 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Iwahig integrated with the processed LiDAR DEM is shown in Figure 29.

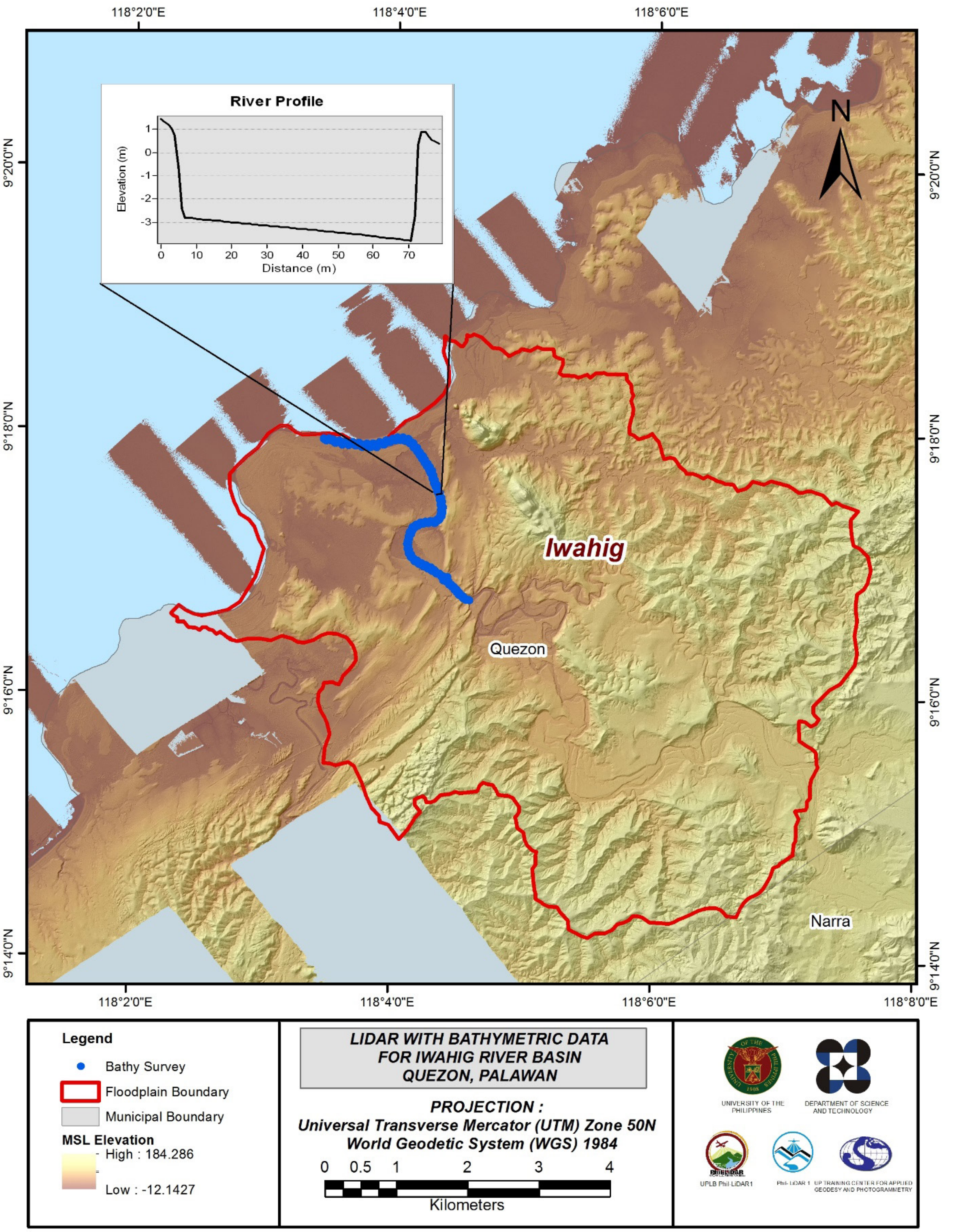

Figure 29. Map of Iwahig Floodplain with bathymetric survey points shown in blue.

CHAPTER 4: LIDAR VALIDATION SURVEY AND MEASUREMENTS OF IWAHIG RIVER BASIN

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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).

4.1 Summary of Activities

AB Surveying and Development (ABSD) conducted a field survey in Iwahig River on November 29, December 7, and December 12, 2015 with the following scope: reconnaissance; control survey; and cross-section and as-built survey at Iwahig Bridge in Brgy. Maasin, Municipality of Quezon, Palawan. Random checking points for the contractor's cross-section and bathymetry data were gathered by DVBC on August 16-28, 2016 using an Ohmex™ Single Beam Echo Sounder and Trimble® SPS 882 GNSS PPK survey technique. In addition to this, validation points acquisition survey was conducted covering the Iwahig River Basin area. The entire survey extent is illustrated in Figure 30.

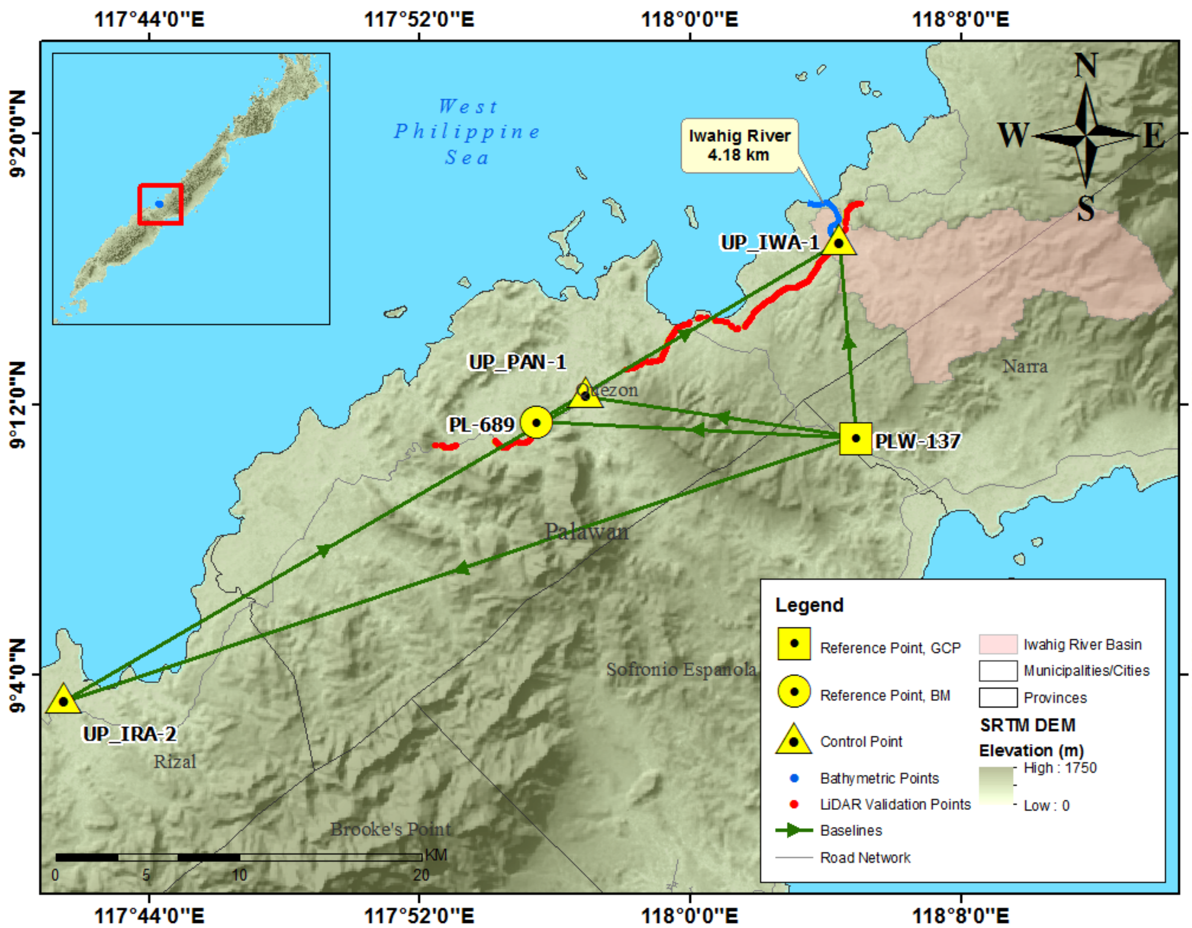


Figure 30. Iwahig River Survey Extent

4.2 Control Survey

The GNSS network used for Iwahig River is composed of two (2) loops established on August 17, 2016 occupying the following reference points: PL-689, a first-order BM, in Brgy. Sowangan, Quezon, Palawan; and PLW-137 a second-order GCP, in Brgy. Ipilan, Narra, Palawan.

Three (3) control points established in the area by ABSD were also occupied: UP_IWA-1 at the approach of Iwahig Bridge in Brgy. Maasin, Quezon, Province of Palawan, UP_PAN-1 at the approach of Panitian Bridge in Brgy. Malatgao, Quezon, Palawan, and UP_IRA-2 located on the side of Iraan Bridge in Brgy. Iraan, Rizal, Palawan.

The summary of reference and control points and its location is summarized in Table 21 while GNSS network established is illustrated in Figure 31.

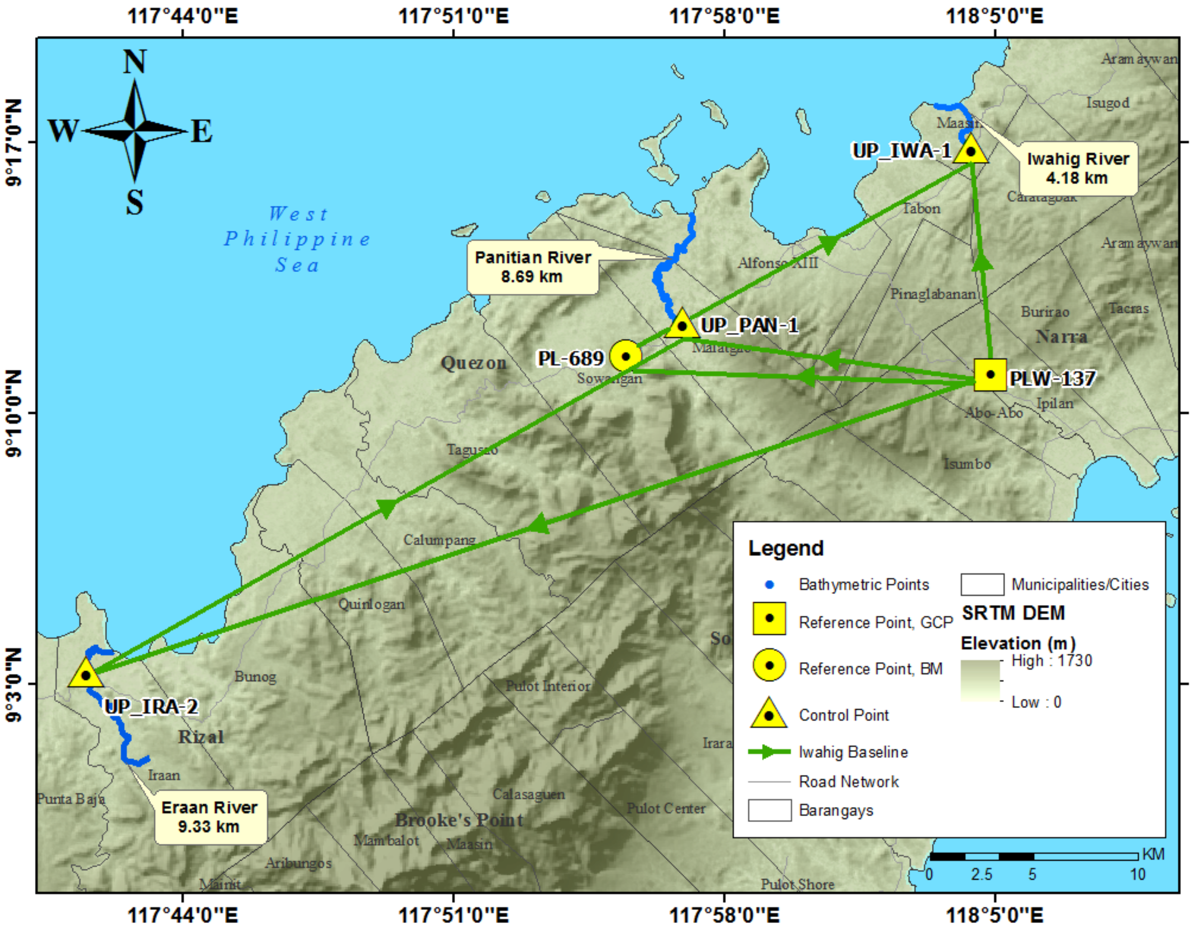


Figure 31. GNSS Network covering Iwahig River

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

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (m)	MSL Elevation (m)	Date established
PL-689	1st order, BM	9° 11' 28.58925"N	117° 55' 26.91800"E	63.739	21.206	2012
PLW-137	2nd order, GCP	9° 10' 58.60442"N	118° 4' 53.42391"E	85.647	42.162	2007
UP_IWA-1	Established	9° 16' 52.29568"N	118° 4' 23.41753"E	48.751	5.820	12-12-15
UP_PAN-1	Established	9° 12' 21.10428"N	117° 56' 55.87963"E	52.045	9.455	12-12-15
UP_IRA-2	Established	9° 3' 19.98819"N	117° 41' 29.97870"E	48.192	6.420	12-04-15

The GNSS set-ups on recovered reference points and established control points in Iwahig River are shown from Figure 32 to Figure 36.

Figure 32. GNSS receiver set up, Trimble® SPS 882, at PL-689, located at the approach of Malatgao Bridge in Brgy. Sowangan, Quezon, Province of Palawan

Figure 33. GNSS base set up, Trimble® SPS 852, at PLW-137, located at the top of a ridge along the National Highway in Brgy. Ipilan, Narra, Province of Palawan

Figure 35. GNSS receiver set up, Trimble® SPS 985, at UP_PAN-1, located on the approach of Panitian Bridge in Brgy. Malatgao, Quezon, Province of Palawan

Figure 36. GNSS receiver set up, Trimble® SPS 985, at UP_IRA-2, located on the side of Iraan Bridge in Brgy. Iraan, Rizal, Province of Palawan

4.3 Baseline Processing

GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/- 20 cm and +/- 10 cm requirement, respectively. In case where one or more baselines did not meet all of these criteria, masking is performed. Masking is done by removing/masking portions of these baseline data using the same processing software. It is repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, resurvey is initiated. Baseline processing result of control points in Iwahig River Basin is summarized in Table 22 generated by TBC software.

Table 22. Baseline Processing Report for Iwahig River Static Survey
(Source: NAMRIA, UP-TCAGP)

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	Height (m)
PLW-137 --- UP_IRA-2	8-17-2016	Fixed	0.005	0.019	251°49'48"	45109.494	-37.444
UP_PAN-1 --- UP_IRA-2	8-17-2016	Fixed	0.021	0.026	239°33'45"	32796.203	-3.860
UP_PAN-1 --- PLW- 137	8-17-2016	Fixed	0.010	0.016	279°52'26"	14796.881	-33.609
PLW-137 --- PL-689	8-17-2016	Fixed	0.007	0.025	273°03'42"	17318.825	-21.920
UP_IWA-1 --- PL- 689	8-17-2016	Fixed	0.010	0.023	238°44'29"	19159.366	14.998
PLW-137 --- UP_IWA-1	8-17-2016	Fixed	0.007	0.023	355°10'58"	10904.997	-36.888

As shown Table 22 a total of six (6) baselines were processed with coordinate and ellipsoidal height values of PLW-137 held fixed. All of them passed the required accuracy.

4.4 Network Adjustment

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

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

Where:

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

for each control point. See the Network Adjustment Report shown in Table 23 to Table 25 for complete details.

The five (5) control points, PLW-137, PL-689, UP-IWA-1, UP_PAN-1, and UP-IRA-2 were occupied and observed simultaneously to form a GNSS loop. The coordinates and ellipsoidal height of PLW-137 were held fixed during the processing of the control points as presented in Table 23. Through this reference point, the coordinates and ellipsoidal height of the unknown control points will be computed.

Table 23. Control Point Constraints

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
PLW-137	Global	Fixed	Fixed	Fixed	
Fixed = 0.000001(Meter)					

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 24.

Table 24. Adjusted Grid Coordinates

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
PL-689	601526.626	0.011	1016129.888	0.008	15.037	0.045	
PLW-137	618819.123	?	1015257.220	?	35.993	?	LLh
UP_IRA-2	576013.324	0.009	1001066.106	0.005	0.251	0.035	
UP_IWA-1	617870.638	0.011	1026118.407	0.008	-0.349	0.042	
UP_PAN-1	604237.406	0.017	1017749.961	0.005	3.286	0.032	

With the mentioned equation $\sqrt{((x_e)^2 + (y_e)^2)} < 20cm$ for horizontal and $|z_e < 10\ cm$ for the vertical; the computation for the accuracy for:

a.PL-689

horizontal accuracy	=	√((1.1)² + (0.8)²
	=	√ (1.21 + 0.64)
	=	1.85 < 20 cm
vertical accuracy	=	4.5 < 10 cm

b.PLW-137

horizontal accuracy	=	Fixed
vertical accuracy	=	Fixed

c.UP_IRA-2

horizontal accuracy	=	√((0.9)² + (0.5)²
	=	√ (0.81 + 0.25)
	=	1.05 < 20 cm
vertical accuracy	=	3.5 < 10 cm

d.UP_IWA-1

horizontal accuracy	=	√((1.1)² + (0.8)²
	=	√ (1.21 + 0.64)
	=	1.85 < 20 cm
vertical accuracy	=	4.2 < 10 cm

e.UP_PAN-1

horizontal accuracy	=	√((1.7)² + (0.5)²
	=	√ (2.89 + 0.25)
	=	3.14 < 20 cm
vertical accuracy	=	3.2 < 10 cm

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

Table 25. Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
PL-689	N9°11'28.58925"	E117°55'26.91800"	63.739	0.045	
PLW-137	N9°10'58.60442"	E118°04'53.42391"	85.647	?	LLh
UP_IRA-2	N9°03'19.98819"	E117°41'29.97870"	48.192	0.035	
UP_IWA-1	N9°16'52.29568"	E118°04'23.41753"	48.751	0.042	
UP_PAN-1	N9°12'21.10428"	E117°56'55.87963"	52.045	0.032	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 25. Based on the result of the computation, the equation is satisfied; hence, the required accuracy for the program was met.

The summary of reference control points used is indicated in Table 26.

Table 26. Reference and control points and its location (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)					
		Latitude	Longitude	Ellipsoidal Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
PL-689	1st order, BM	9°11'28.58925"N	117°55'26.91800"E	63.739	1016130.888	601526.626	21.206
PLW-137	2nd order, GCP	9°10'58.60442"N	118°04'53.42391"E	85.647	1015257.220	618819.123	42.162
UP_ IWA-1	Established	9°16'52.29568"N	118°04'23.41753"E	48.751	1026118.407	617870.638	5.820
UP_ PAN-1	Established	9°12'21.10428"N	117°56'55.87963"E	52.045	1017749.961	604237.406	9.455
UP_IRA-2	Established	9°03'19.98819"N	117°41'29.97870"E	48.192	1001066.106	576013.324	6.420

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

Cross-section and as-built surveys were conducted on November 29, 2015 at the upstream side of Iwahig Bridge in Brgy. Maasin, Municipality of Quezon as shown in Figure 37. A total station was utilized for this survey as shown in Figure 38.

Figure 37. Iwahig Bridge facing upstream

Figure 38. As-built survey of Iwahig Bridge

The cross-sectional line of Iwahig Bridge is about 153 m with fifty seven (57) cross-sectional points using the control points UP_IWA-1 and UP_IWA-2 as the GNSS base stations. The location map, cross-section diagram, and bridge data form are shown in Figure 39, Figure 40 and Figure 41, respectively.

No bridge cross-section or bridge points checking data were gathered for Iwahig Bridge because Iwahig Bridge was under construction during the time of quality checking.

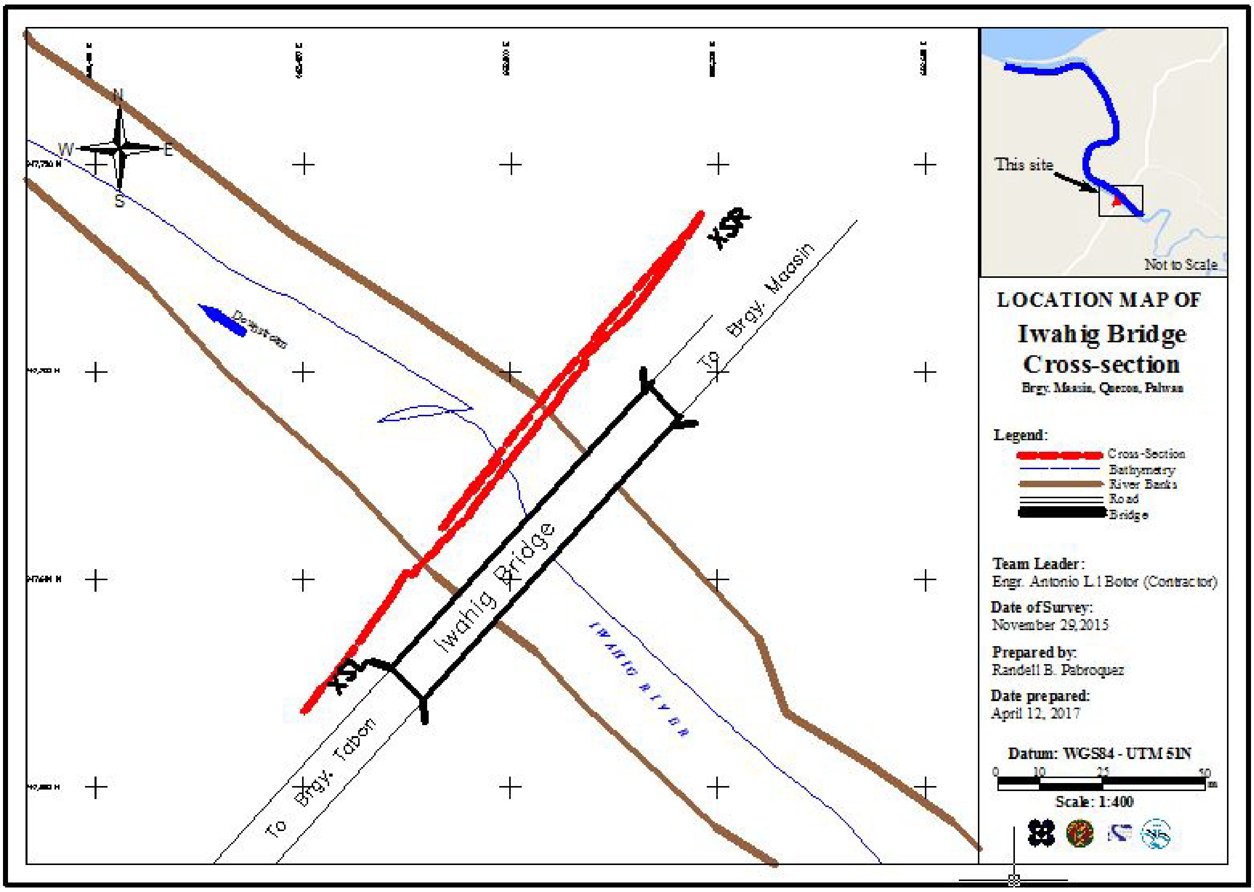


Figure 39. Location Map of Iwahig Bridge River Cross-Section survey

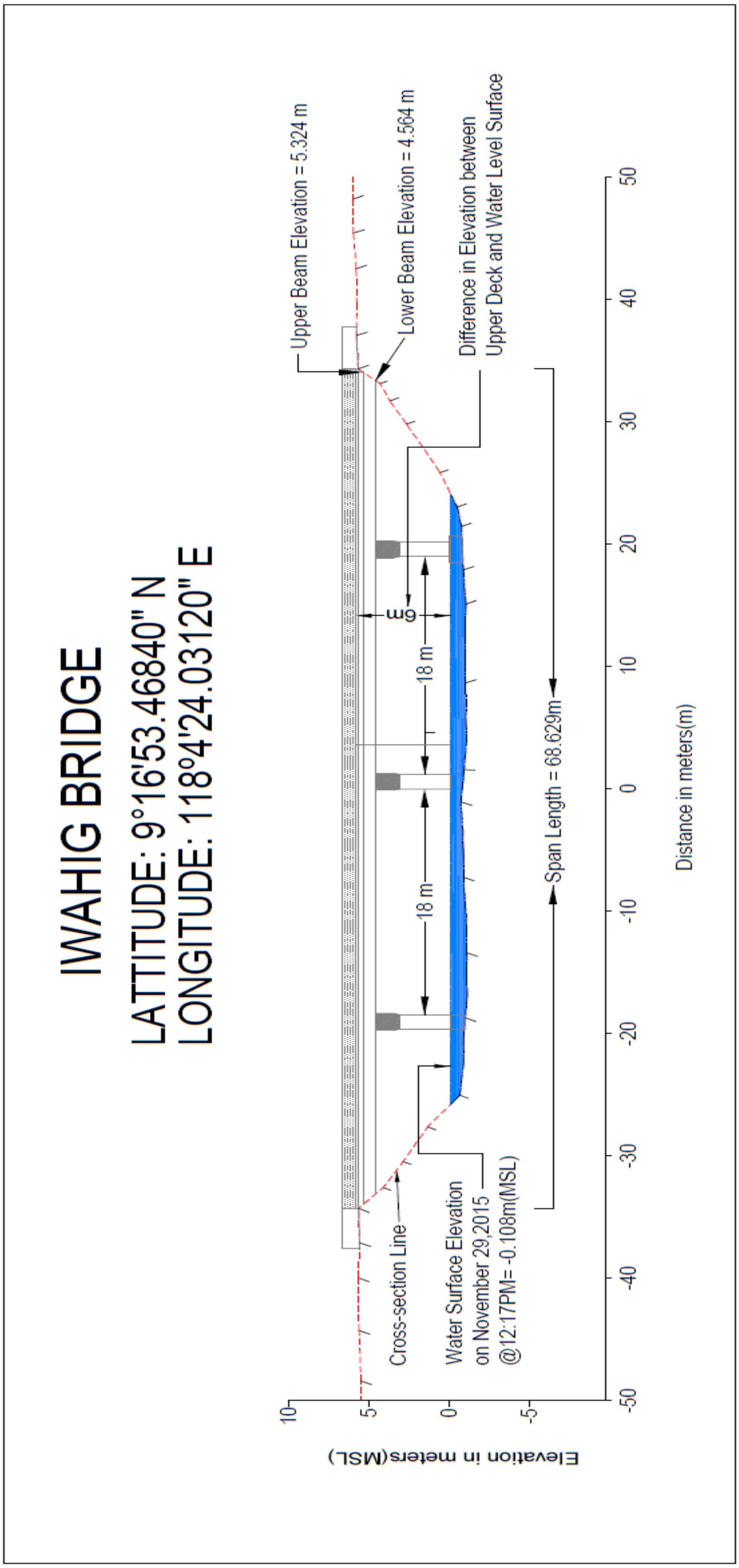


Figure 40. Iwahig Bridge cross-section diagram

Bridge Data Form

Bridge Name: IWAHIG BRIDGE

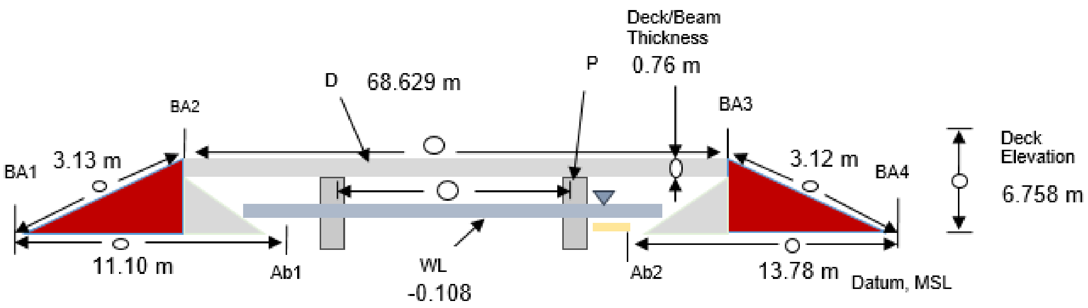
River Name: IWAHIG RIVER
Location (Brgy, City, Region): Brgy. Maasin, Quezon, Palawan

Survey Team: William Mamaril, Leonilo Alpas
Date and Time: November 29, 2015; 12:17 P.M.

Flow Condition: low ✔normal high

Weather Condition: ✔fair rainy

Cross-sectional View (not to scale)



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

Line Segment	Measurement (m)	Remarks
1. BA1-BA2	3.13 m	
2. BA2-BA3	68.629 m	
3. BA3-BA4	3.12 m	
4. BA1-Ab1	11.10 m	
5. Ab2-BA4	13.78 m	
6. Deck/beam thickness	0.76 m	
7. Deck elevation	6.758 m	

Note: Observer should be facing downstream

Figure 41. Bridge as-built form of Iwahig Bridge

Water surface elevation of Iwahig River was determined by a Horizon® Total Station on November 29, 2015 at 12:17 PM at Iwahig Bridge area with a value of -0.108 m in MSL as shown in Figure 40. This was translated into marking on the bridge's pier as shown in Figure 42. The marking will serve as reference for flow data gathering and depth gauge deployment of the partner HEI responsible for Iwahig River, the University of the Philippines Los Baños.

Figure 42. Water-level markings on Iwahig Bridge

4.6. Validation Points Acquisition Survey

Validation points acquisition survey was conducted by DVBC from August 16-28, 2016 using a survey grade GNSS Rover receiver, Trimble® SPS 985, mounted on a range pole which was attached on the side of the vehicle as shown in Figure 43. It was secured with cable ties and ropes to ensure that it was horizontally and vertically balanced. The antenna height was 2.560 m and measured from the ground up to the bottom of the quick release of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with UP_PAN-1 occupied as the GNSS base station in the conduct of the survey.

Figure 43. Validation points acquisition survey set-up for Iwahig River

The survey started from Brgy. Maasin, Municipality of Quezon, Palawan going south west along national high way covering six (6) barangays in the Municipality of Quezon, and ended in Brgy. Tagusao, Municipality of Quezon, Palawan. The survey gathered a total of 2,690 points with approximate length of 29.98 km using UP_PAN-1 as GNSS base station for the entire extent of validation points acquisition survey as illustrated in the map in Figure 44.

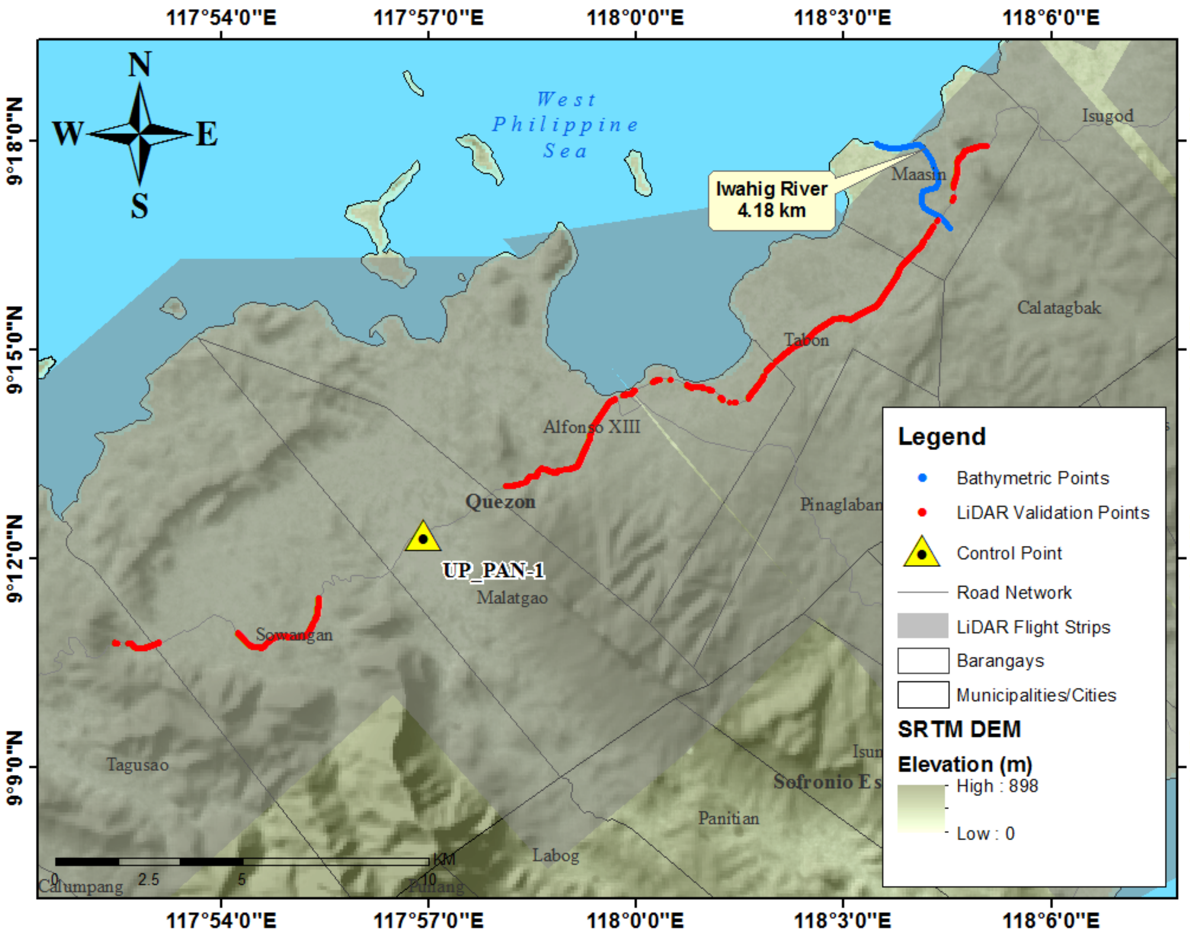


Figure 44. Validation point acquisition survey of Iwahig River Basin area

4.7 Bathymetric Survey

Bathymetric survey was executed on December 7, 2015 using an echo sounder as illustrated in Figure 45. The survey started in Brgy. Maasin, Municipality of Quezon, Palawan with coordinates 9°16’43.38753”N, 118°04’35.55273”E and ended at the mouth of the river in Brgy. Maasin, Municipality of Quezon as well, with coordinates 9°17’56.46024”N, 118°03’27.80874”E. The control point UP_IWA-2 was used as GNSS base station all throughout the entire survey.

Gathering of random points for the checking of ABSD’s bathymetric data was performed by DVBC on August 18, 2016 using an Ohmex™ Single Beam Echo Sounder and Trimble® SPS 882 GNSS PPK survey technique, see Figure 46. The bathymetric survey of Iwahig river is illustrated in Figure 47. A map showing the DVBC bathymetric checking points is shown in Figure 48.

Linear square correlation (R2) and RMSE analysis were performed on the two (2) datasets. The linear square coefficient range is determined to ensure that the submitted data of the contractor is within the accuracy standard of the project which is ±20 cm and ±10 cm for horizontal and vertical, respectively. The R2 value must be within 0.85 to 1. An R2 approaching 1 signifies a strong correlation between the vertical (elevation values) of the two datasets. A computed R2 value of 0.997 was obtained by comparing the data of the contractor and DVBC; signifying a strong correlation between the two (2) datasets.

In addition to the Linear Square correlation, Root Mean Square (RMSE) analysis is also performed in order to assess the difference in elevation between the DVBC checking points and the contractor's. The RMSE value should only have a maximum radial distance of 5 m and the difference in elevation within the radius of 5 meters should not be beyond 0.50 m. For the bathymetric data, a computed value of 0.648 was acquired. The computed R2 and RMSE values are within the accuracy requirement of the program.

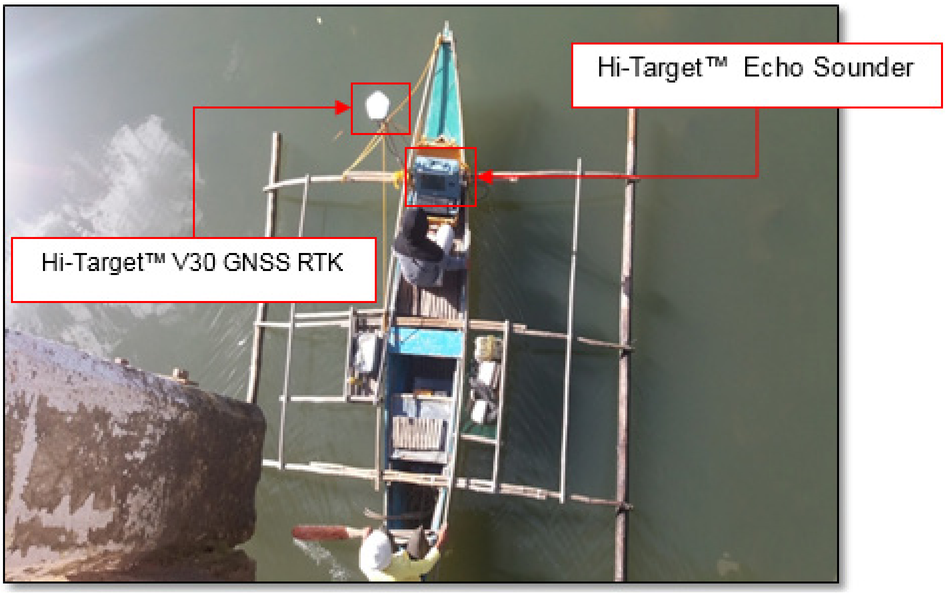


Figure 45. Bathymetric survey of ABSD at Iwahig River using Hi-Target™ Echo Sounder (upstream)

Figure 46. Gathering of random bathymetric points along Iwahig River

The bathymetric survey for Iwahig River gathered a total of 3,657 points covering 4.18 km of the river traversing Brgy. Maasin in the Municipality of Quezon (Figure 47).

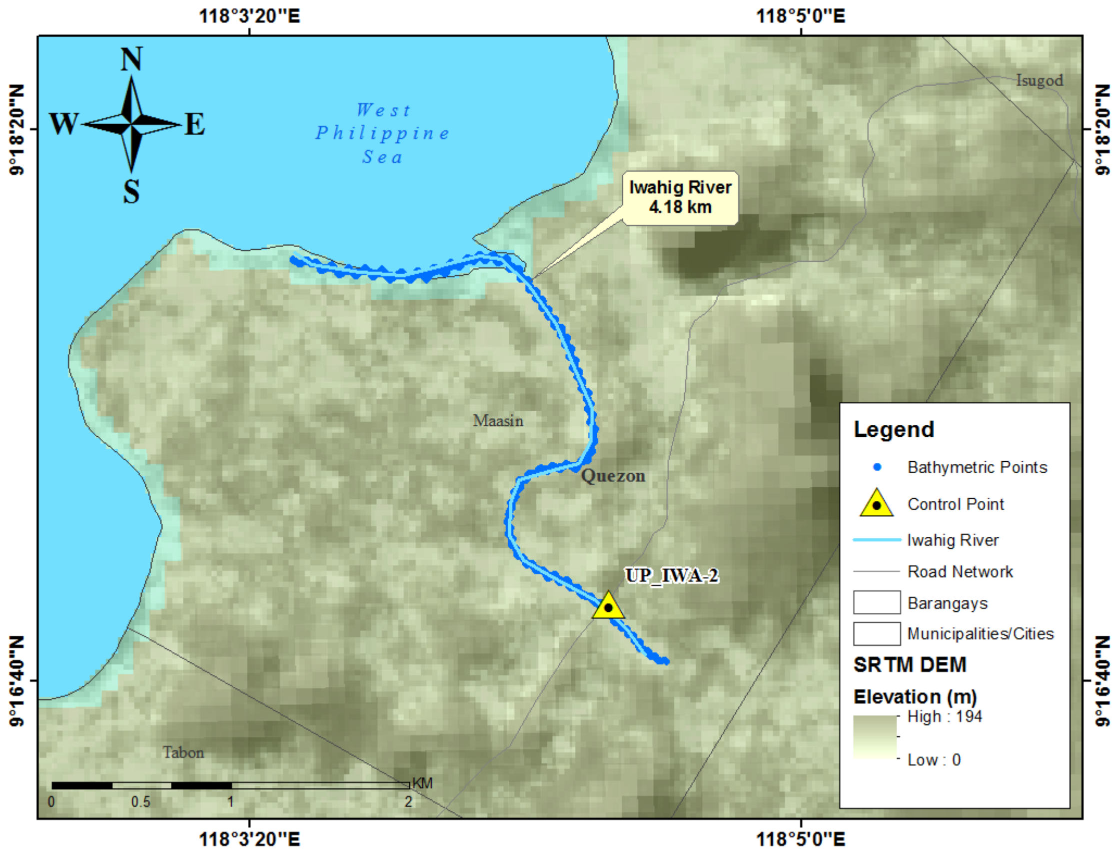


Figure 47. Bathymetric survey of Iwahig River

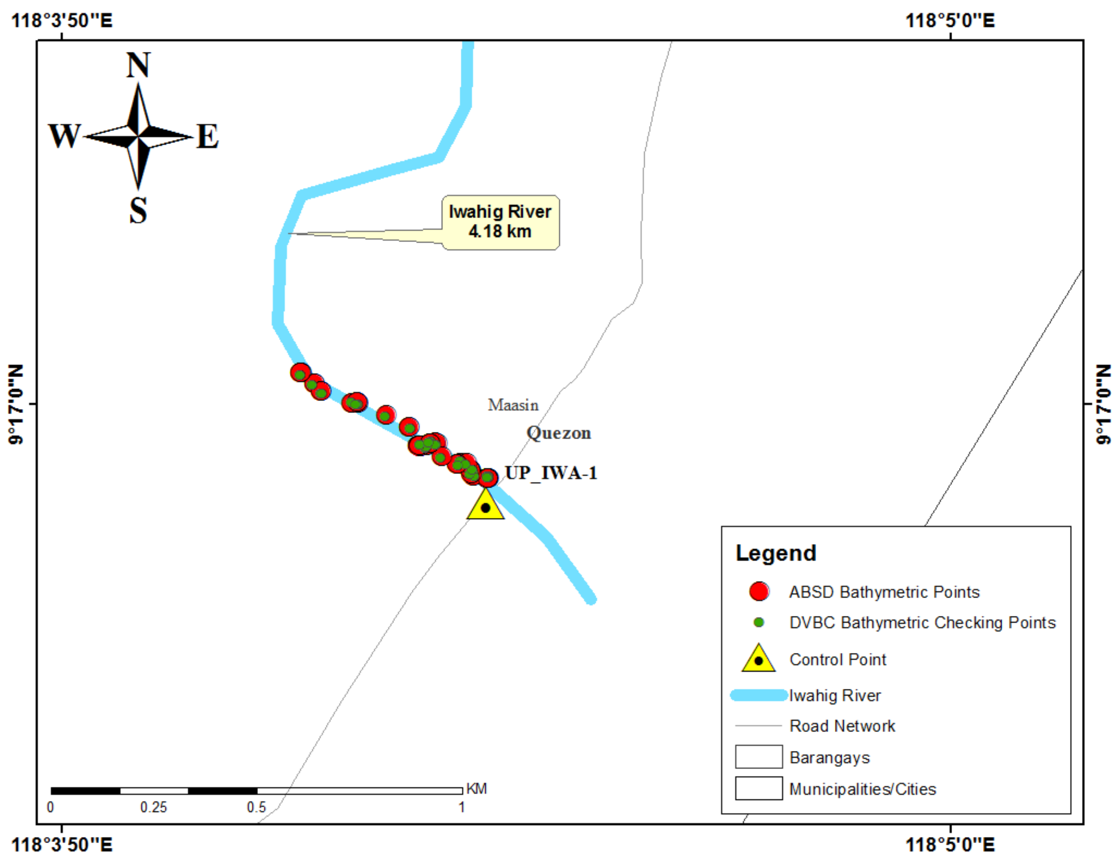


Figure 48. Quality checking points gathered along Iwahig River by DVBC

A CAD drawing was also produced to illustrate the riverbed profile of Iwahig River. As shown in Figure 49, the highest and lowest elevation has a 5-m difference. The highest elevation observed was -1.134 m below MSL while the lowest was -6.694 m below MSL located in Brgy. Maasin, Municipality of Quezon.

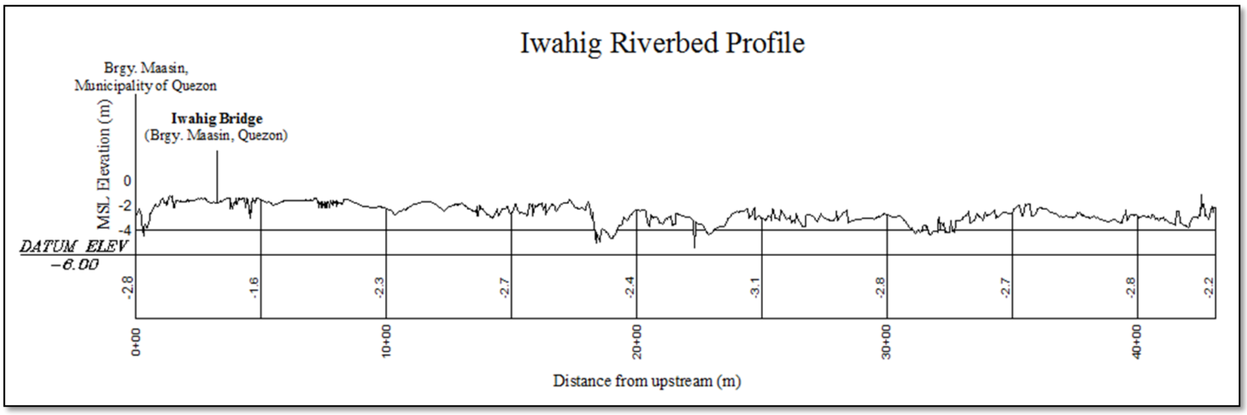


Figure 49. Iwahig Riverbed Profile

CHAPTER 5: FLOOD MODELING AND MAPPING

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

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).

5.1 Data Used for Hydrologic Modeling

No gathered rainfall data for Iwahig river basin. The HMS model is not calibrated. The values generated HMS model are by default.

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Puerto Princesa Rain Gauge. The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the values in such a way a certain peak value will be attained at a certain time. This station chosen based on its proximity to the Iwahig watershed. The extreme values for this watershed were computed based on a 58-year record, with the computed extreme values shown in Table 27.

Table 27. RIDF values for Puerto Prinsesa Rain Gauge computed by PAGASA

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	10 min	20 min	30 min	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

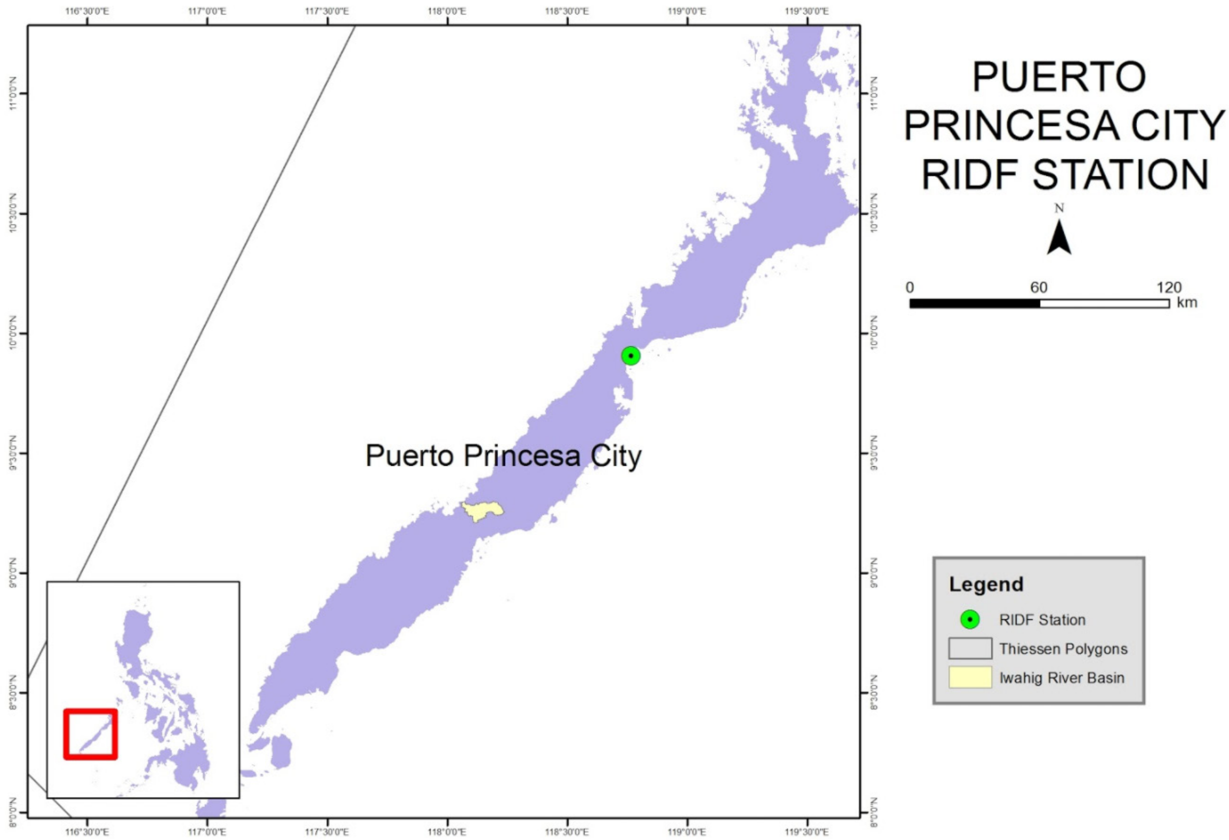


Figure 50.Location of Puerto Prinsesa RIDF relative to Iwahig River Basin

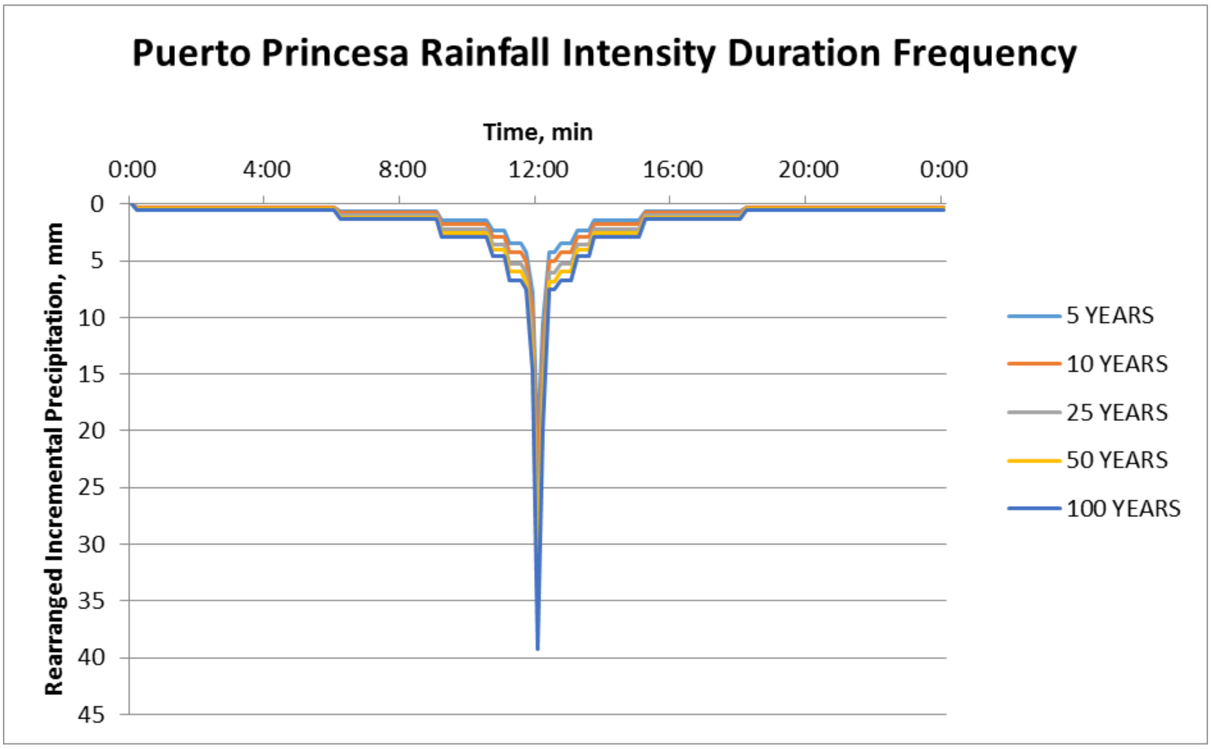


Figure 51. Synthetic storm generated for a 24-hr period rainfall for various return periods.

5.3 HMS Model

The soil dataset was generated before 2004 by the Bureau of Soils and Water Management under the Department of Agriculture (DA-BSWM). The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Iwahig River Basin are shown in Figure 52 and Figure 53, respectively.

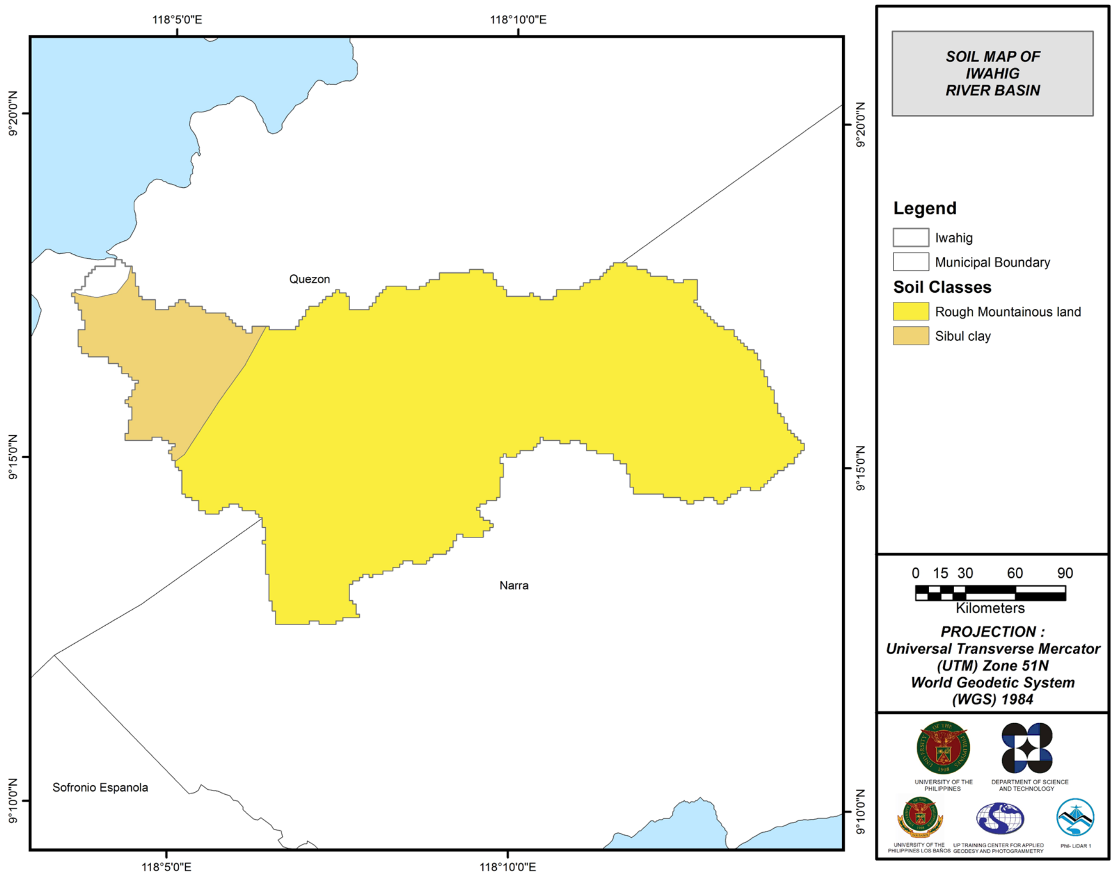


Figure 52. Soil map of Iwahig River Basin used for the estimation of the CN parameter. (Source: DA)

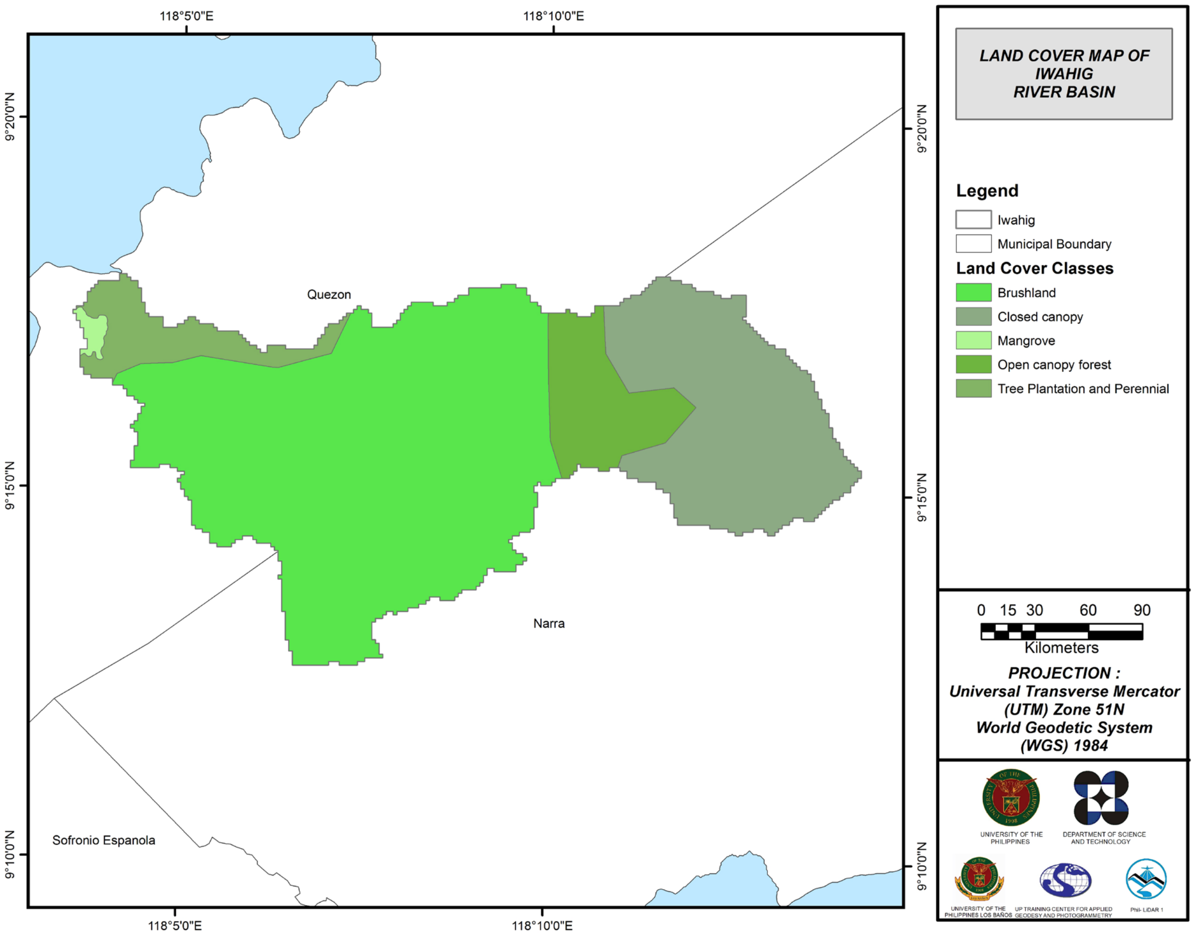


Figure 53. Land cover map of Ibod River Basin used for the estimation of the CN and watershed lag parameters of the rainfall-runoff model. (Source: NAMRIA)

For Iwahig river basin, the two (2) soil classes identified were rough mountainous land and Sibul clay. The five (5) land cover types identified were largely brushland, followed by closed canopy, mangrove, open canopy forest, and tree plantation and perennial land cover.

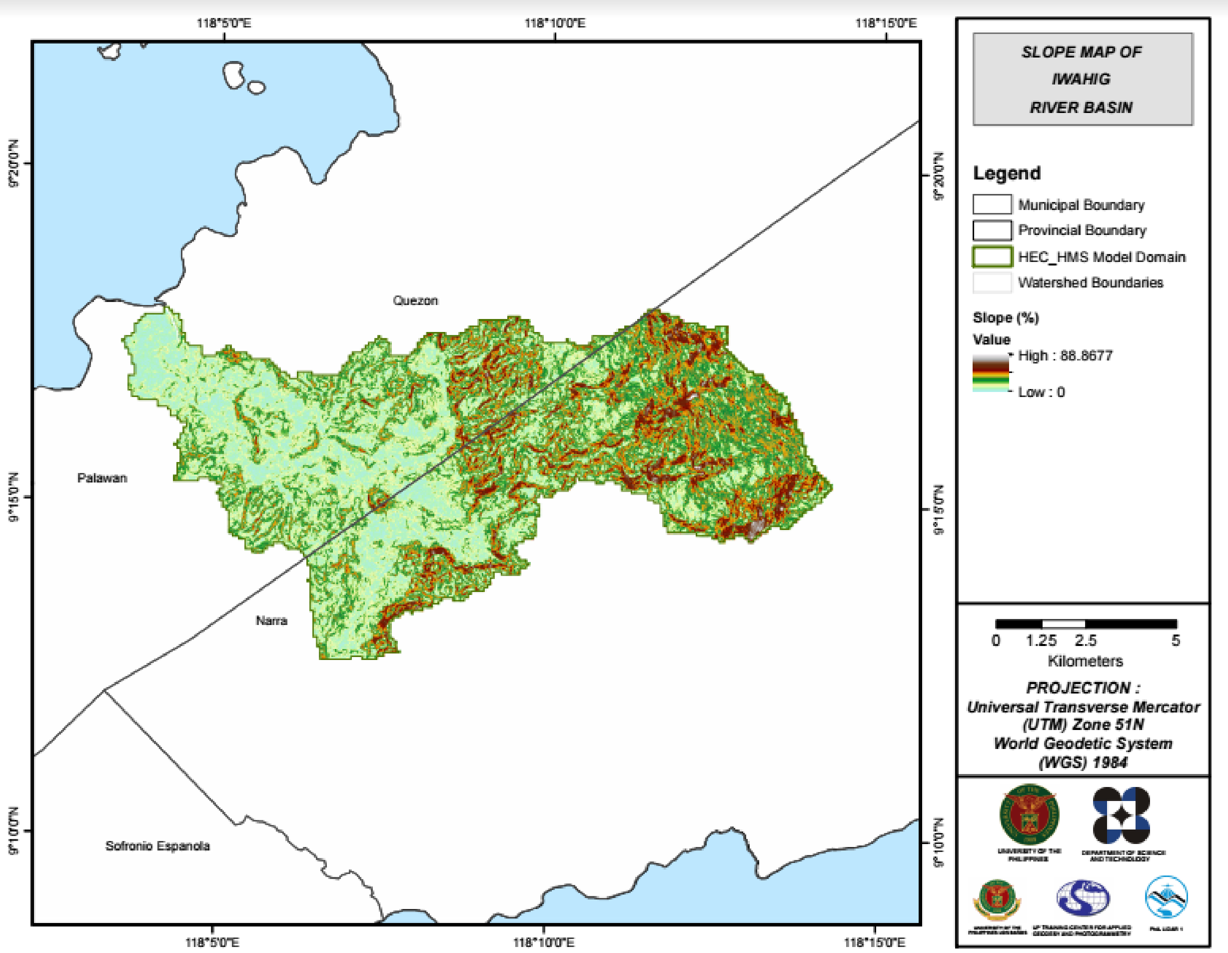


Figure 54. Slope map of Iwahig River Basin

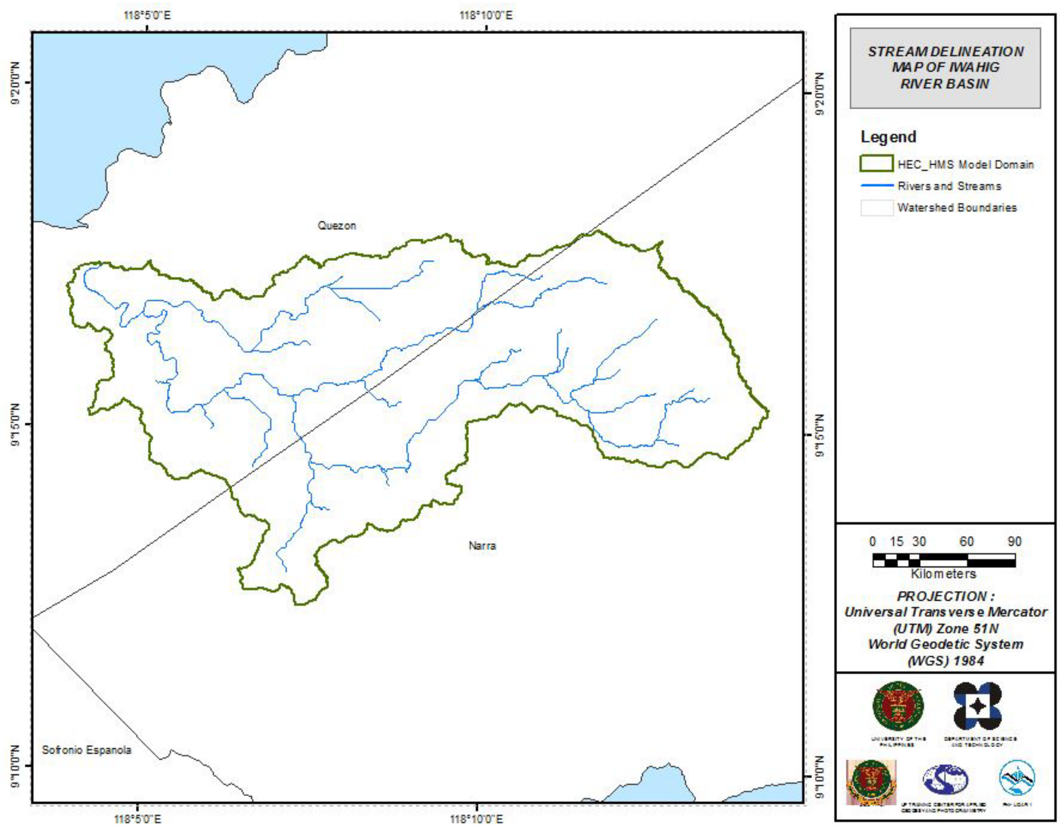


Figure 55. Stream delineation map of Iwahig River Basin

Using SAR-based DEM, the Iwahig basin was delineated and further subdivided into subbasins. The model consists of 52 sub basins, 25 reaches, and 22 junctions. The main outlet is labelled as Iwahig_Outlet. This basin model is illustrated in Figure 56. The basins were identified based on soil and land cover characteristics of the area.

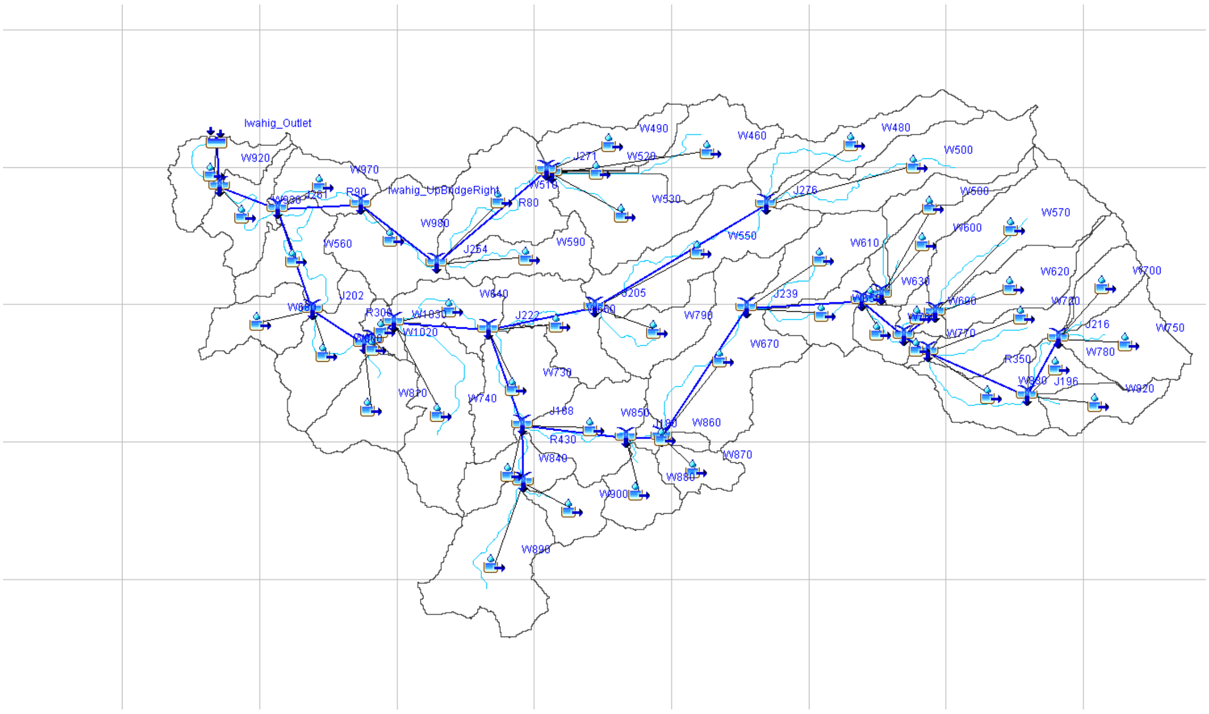


Figure 56. HEC-HMS generated Iwahig River Basin Model.

5.4 Cross-section Data

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

(This image is not available for this floodplain.)

Figure 57. River cross-section of Iwahig River generated through Arcmap HEC GeoRAS tool

5.5 Flo 2D Model

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

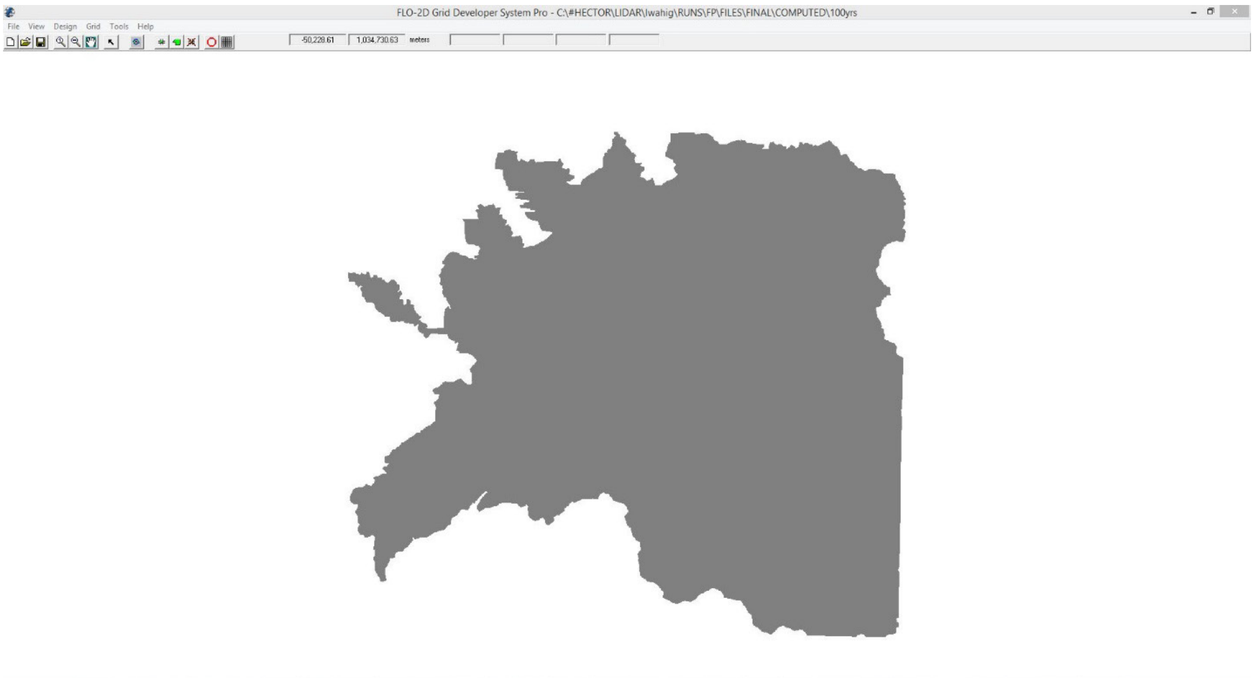


Figure 58. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 70.52734 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m2/s.

The creation of a flood hazard map from the model also automatically creates a flow depth map depicting the maximum amount of inundation for every grid element. The legend used by default in Flo-2D Mapper is not a good representation of the range of flood inundation values, so a different legend is used for the layout. In this particular model, the inundated parts cover a maximum land area of 72 635 040.00 m2.
There is a total of 50 265 454.59 m3 of water entering the model. Of this amount, 21 454 125.32 m3 is due to rainfall while 28 811 329.27 m3 is inflow from other areas outside the model. 7 288 264.50 m3 of this water is lost to infiltration and interception, while 9 233 428.77 m3 is stored by the flood plain. The rest, amounting up to 33 743 805.20 m3, is outflow.

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

The river discharge values for the nine rivers entering the floodplain are shown in Figure 59 to Figure 62 and the peak values are summarized in Table 28 to Table 31.

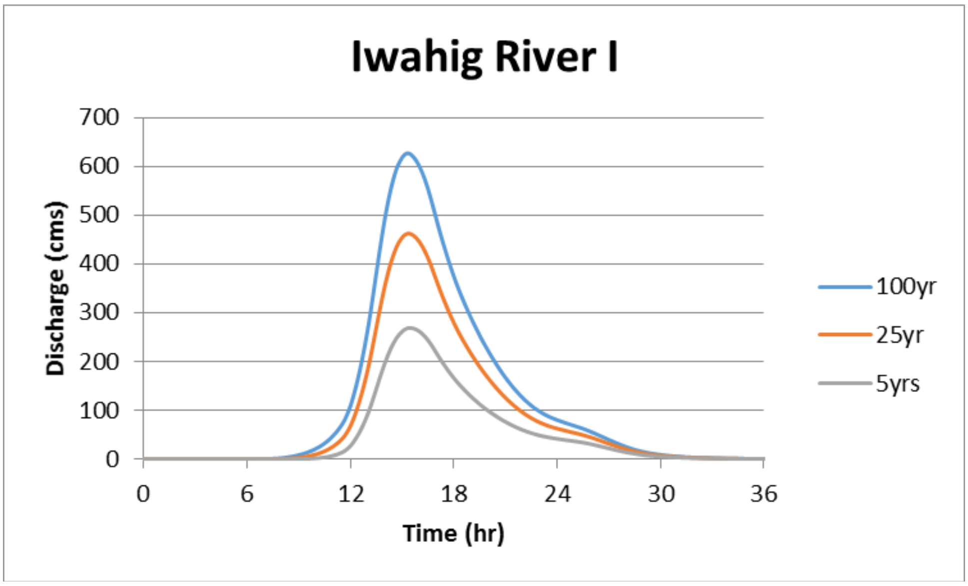


Figure 59. Iwahig river (1) generated discharge using interpolated 5-, 25-, and 100-year rainfall intensity-duration-frequency (RIDF) in HEC-HMS

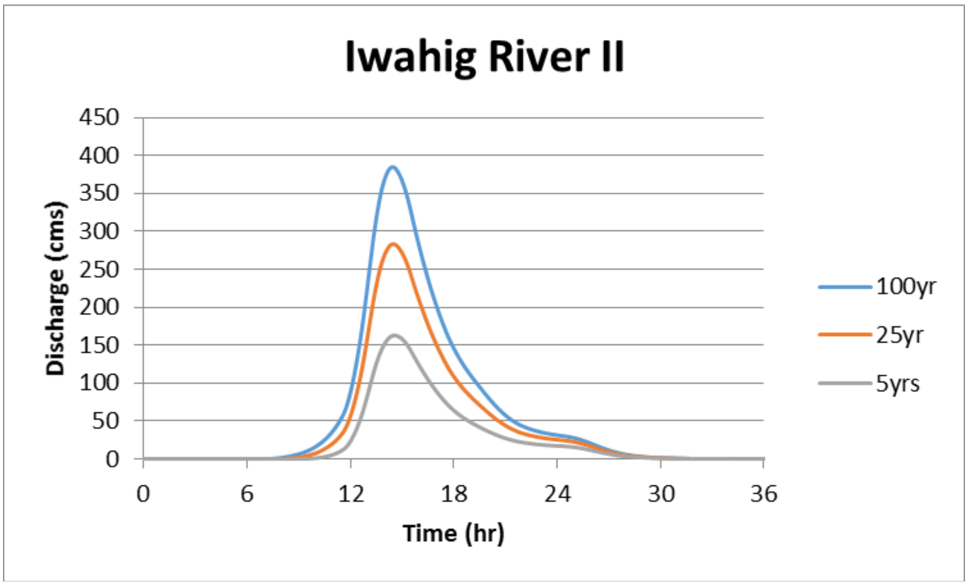


Figure 60. Iwahig river (2) generated discharge using interpolated 5-, 25-, and 100-year rainfall intensity-duration-frequency (RIDF) in HEC-HMS

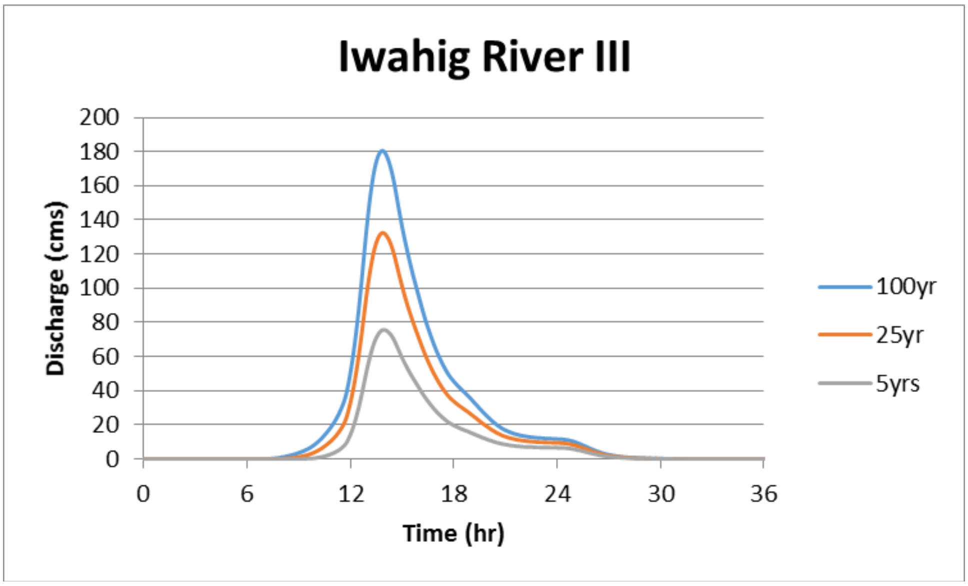


Figure 61. Iwahig river (3) generated discharge using interpolated 5-, 25-, and 100-year rainfall intensity-duration-frequency (RIDF) in HEC-HMS

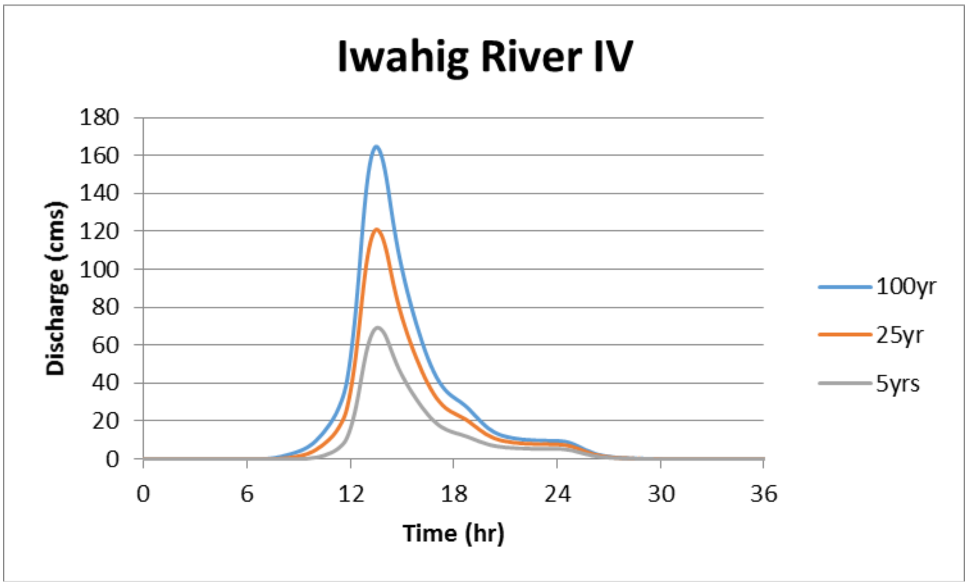


Figure 62. Iwahig river (4) generated discharge using interpolated 5-, 25-, and 100-year rainfall intensity-duration-frequency (RIDF) in HEC-HMS

Table 28. Summary of Iwahig river (1) discharge generated in HEC-HMS

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	626.7	15hrs, 20minutes
25-Year	462.2	15hrs, 20minutes
5-Year	268.7	15hrs, 30minutes

Table 29. Summary of Iwahig river (2) discharge generated in HEC-HMS

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	384.6	14hrs, 30minutes
25-Year	283.2	14hrs, 30minutes
5-Year	162.9	14hrs, 30minutes

Table 30. Summary of Iwahig river (3) discharge generated in HEC-HMS

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	180.6	13hrs, 50minutes
25-Year	132.4	13hrs, 50minutes
5-Year	75.6	14hrs

Table 31. Summary of Iwahig river (4) discharge generated in HEC-HMS

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	164.7	13hrs, 30minutes
25-Year	121	13hrs, 30minutes
5-Year	69.1	13hrs, 40minutes

Table 32. Validation of river discharge estimates

Discharge Point	$Q_{MED(SCS)}$, cms	$Q_{BANKFUL}$, cms	$Q_{MED(SPEC)}$, cms	VALIDATION	
				Bankful Discharge	Specific Discharge
Iwahig (1)	1418.296	78.173	1220.150	FAIL	PASS
Iwahig (2)	1785.696	1389.550	1409.025	PASS	PASS
Iwahig (3)	192.632	132.820	247.134	PASS	PASS
Iwahig (4)	443.520	443.482	544.574	PASS	PASS

All three values from the HEC-HMS river discharge estimates were able to satisfy the conditions for validation using the specific discharge method. The calculated values are based on theory but are supported using other discharge computation methods so they were good to use for flood modeling. However, these values will need further investigation for the purpose of validation. It is therefore recommended to obtain actual values of the river discharges for higher-accuracy modeling.

5.6 HEC-HMC Model Values (Uncalibrated)

Enumerated in Table 33 are the range of values of the parameters in the model.

Table 33. Range of calibrated values for Iwahig River Basin

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	2 - 14
			Curve Number	48 - 86
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.3 - 5
			Storage Coefficient (hr)	0.6 - 8

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 2 to 14mm 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 48 to 86 for curve number is slightly lower than the advisable range 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 0.3 hours to 8 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

5.7 River Analysis Model Simulation

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

Figure 63. Sample output of Iwahig RAS Model

5.8 Flood Hazard and Flow Depth Map

The resulting hazard and flow depth maps for 5-, 25-, and 100-year rain return scenarios of the Iwahig floodplain are shown in Figure 60 to Figure 65. The floodplain, with an area of 69.62 sq. km., covers two municipalities namely Narra and Quezon. Table 29 shows the percentage of area affected by flooding per municipality.

Table 34. Municipalities affected in Iwahig Floodplain

Municipality	Total Area	Area Flooded	% Flooded
Narra	831.19	4.14	0.5
Quezon	917.97	65.37	7.12

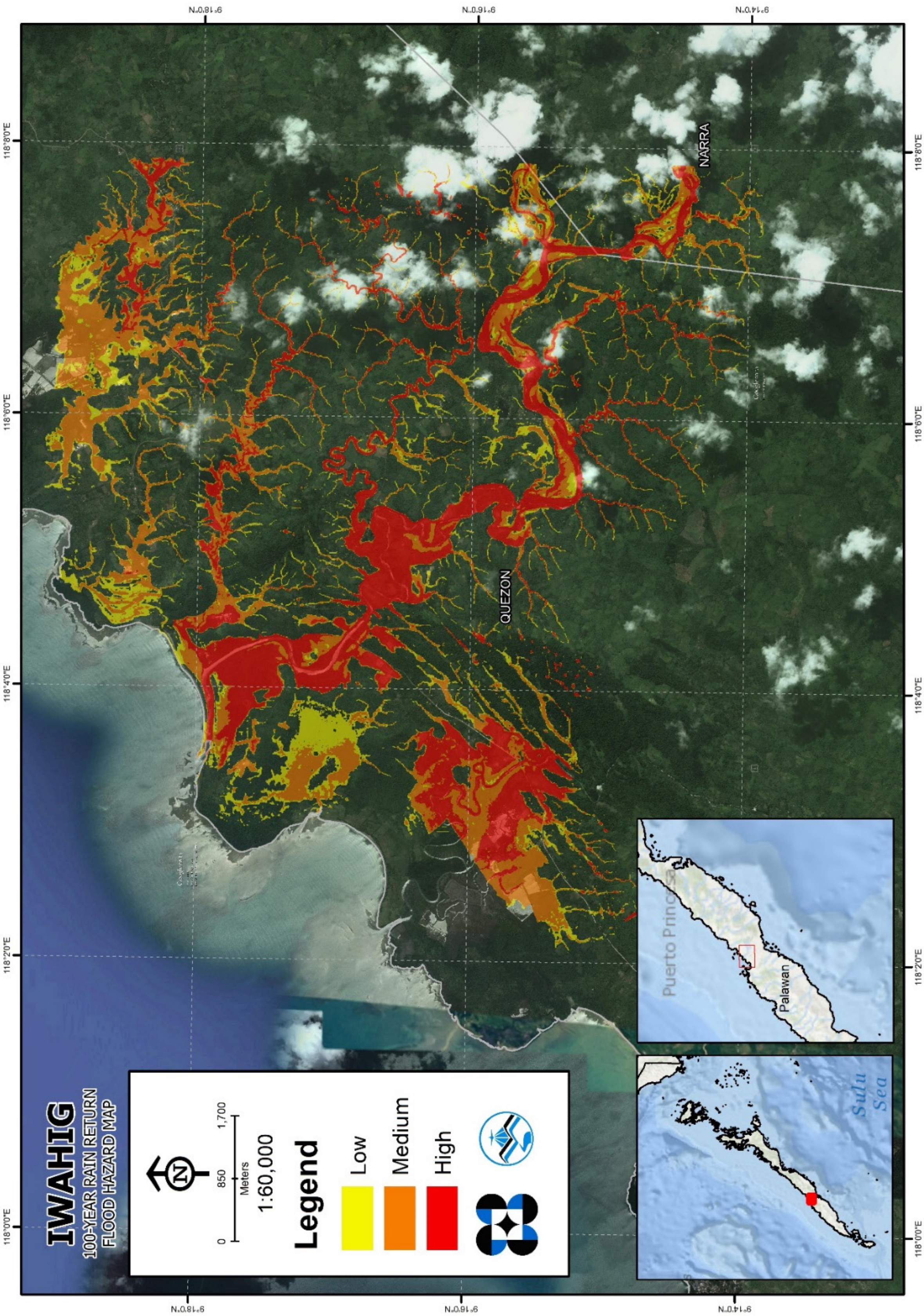


Figure 64. 100-year Flood Hazard Map for Iwahig Floodplain overlaid on Google Earth imagery

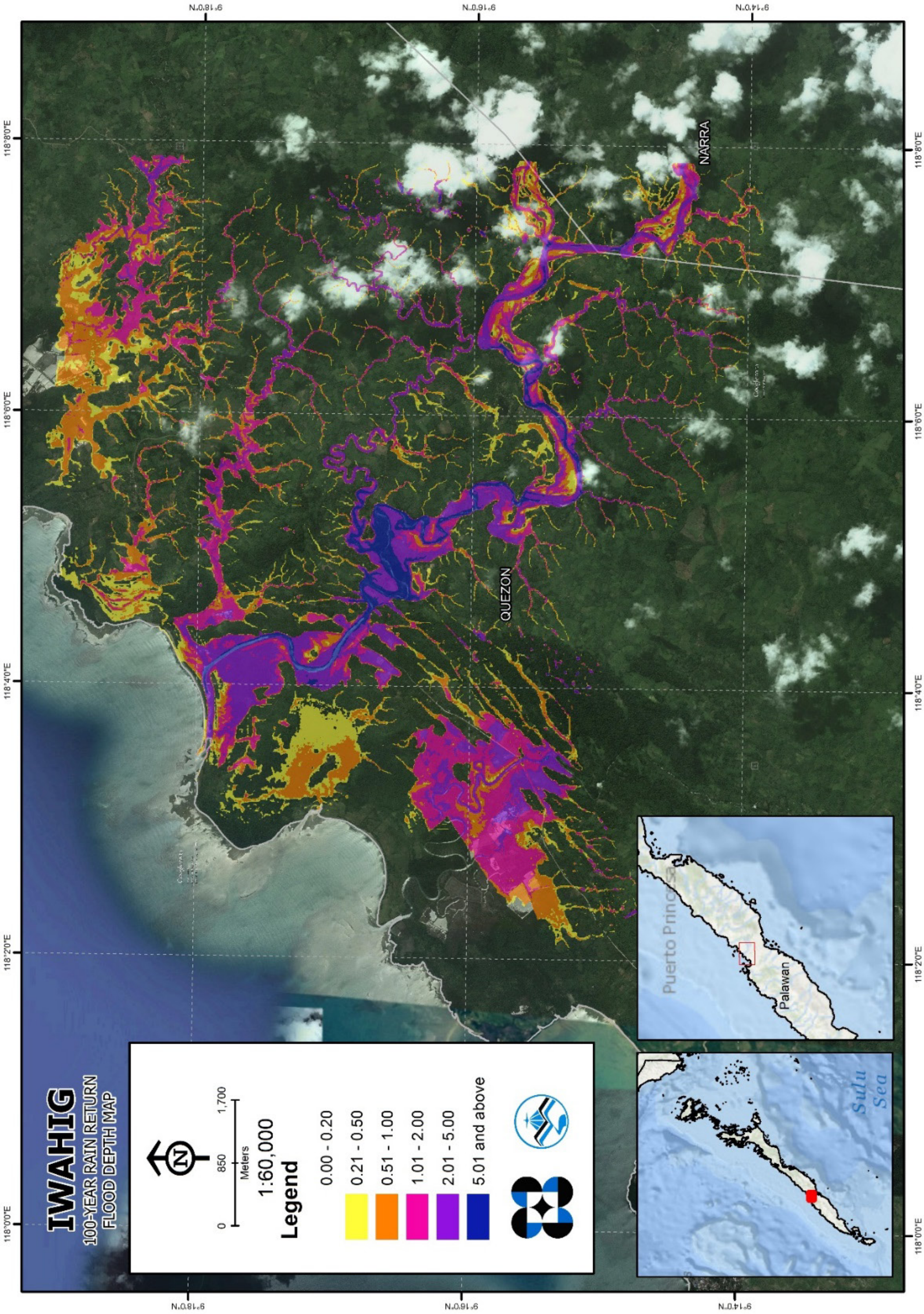


Figure 65. 100-year Flow Depth Map for Iwahig Floodplain overlaid on Google Earth imagery

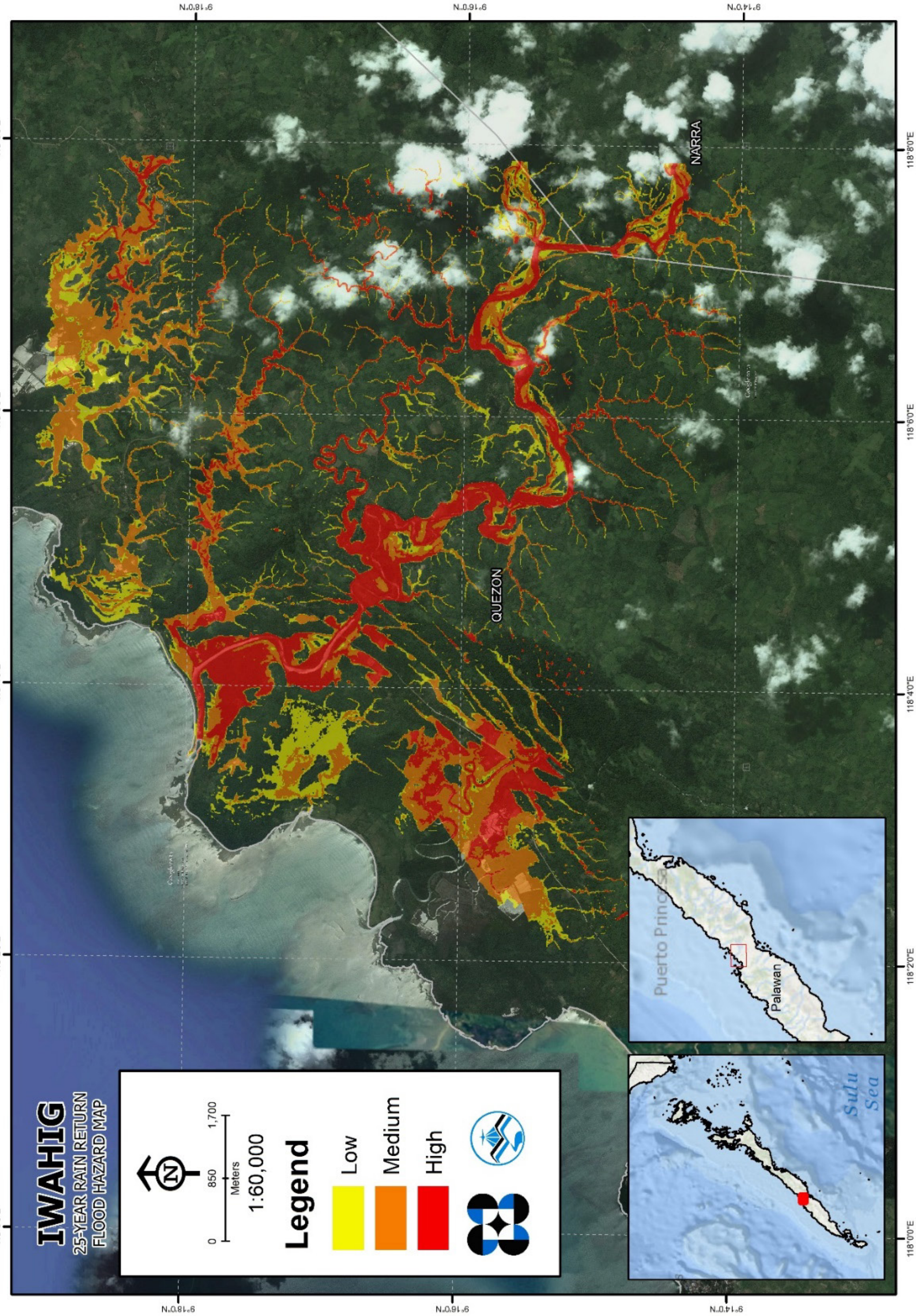


Figure 66. 25-year Flood Hazard Map for Iwahig Floodplain overlaid on Google Earth imagery

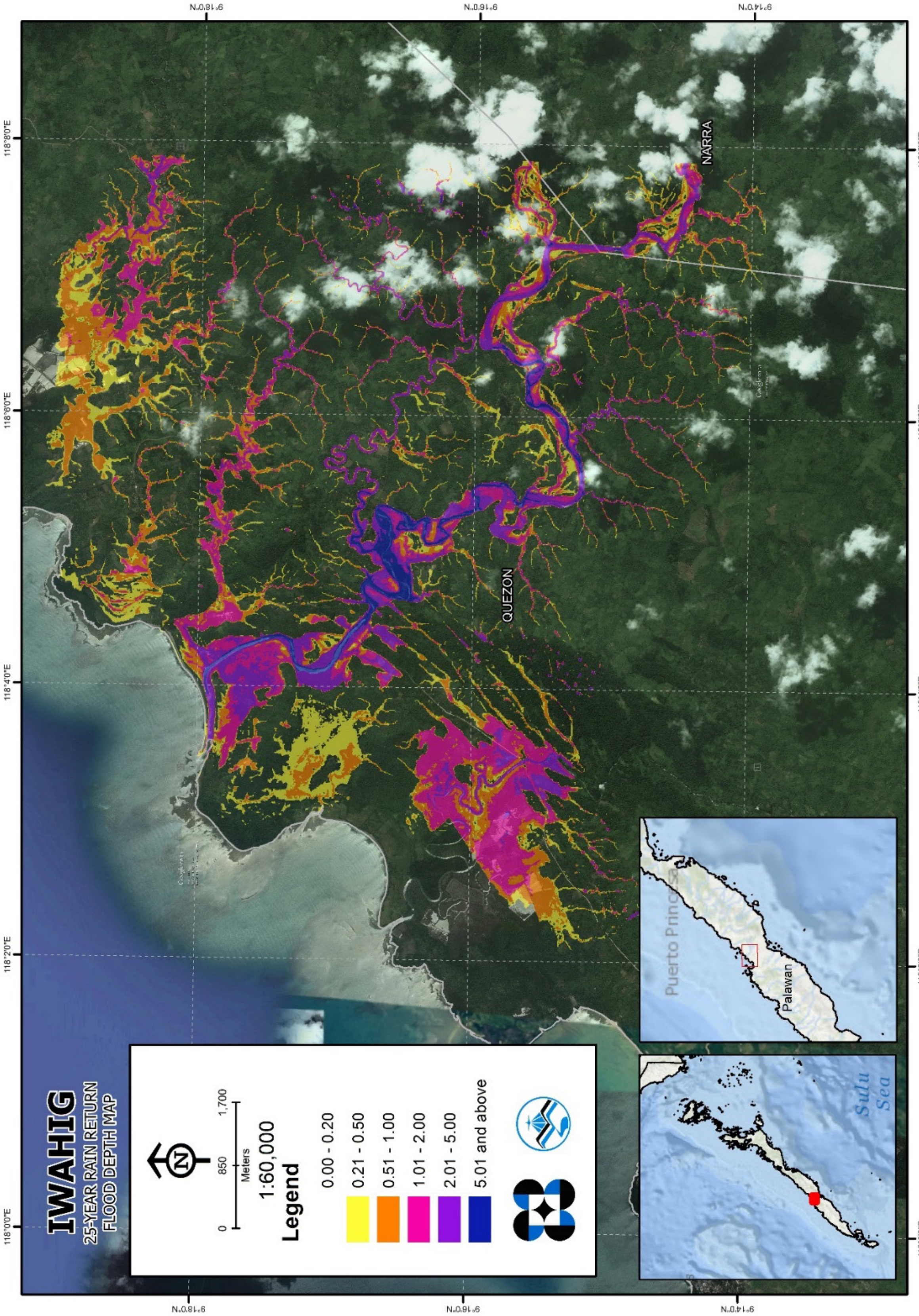


Figure 67. 25-year Flow Depth Map for Iwahig Floodplain overlaid on Google Earth imagery

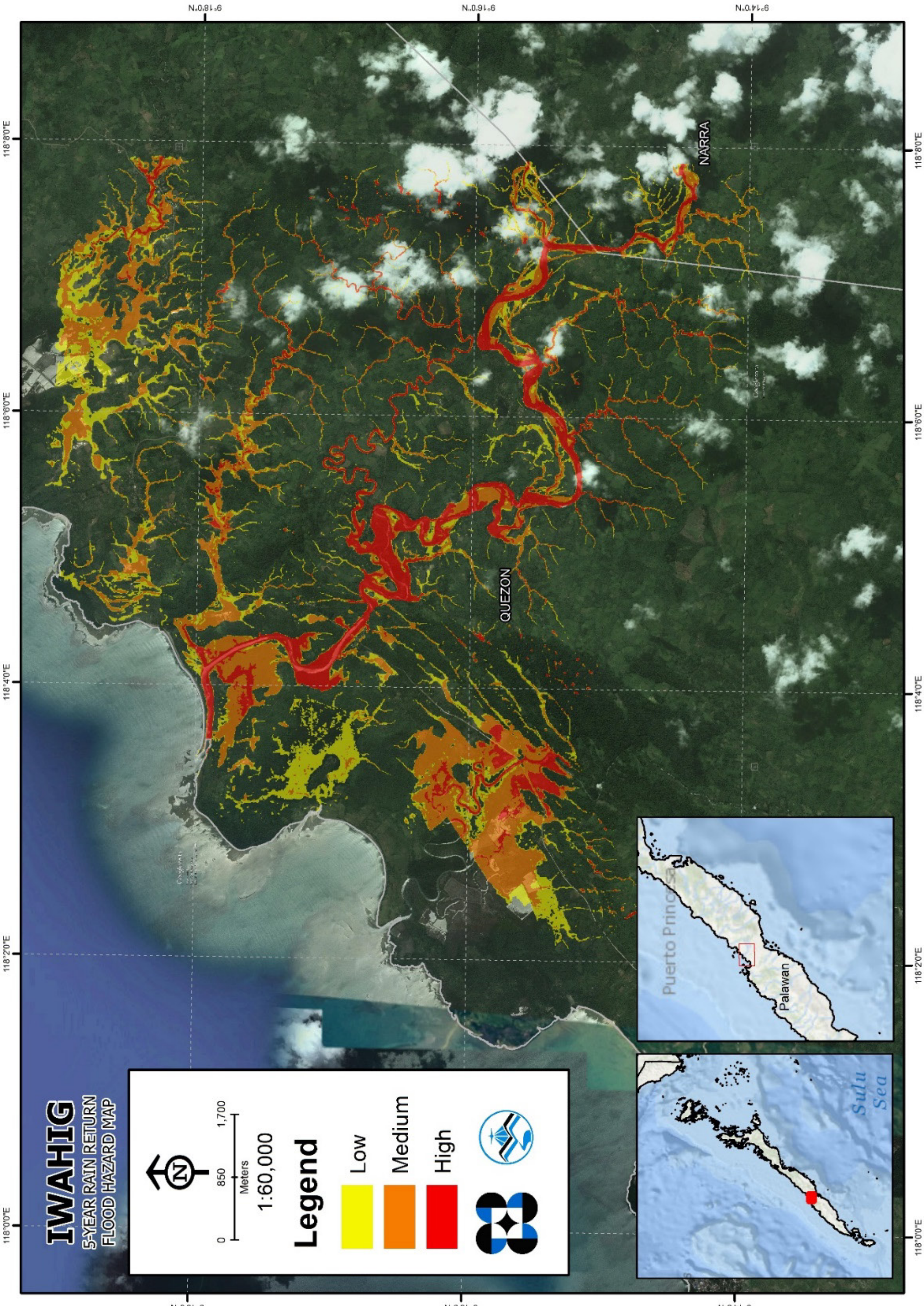


Figure 68. 5-year Flood Hazard Map for Iwahig Floodplain overlaid on Google Earth imagery

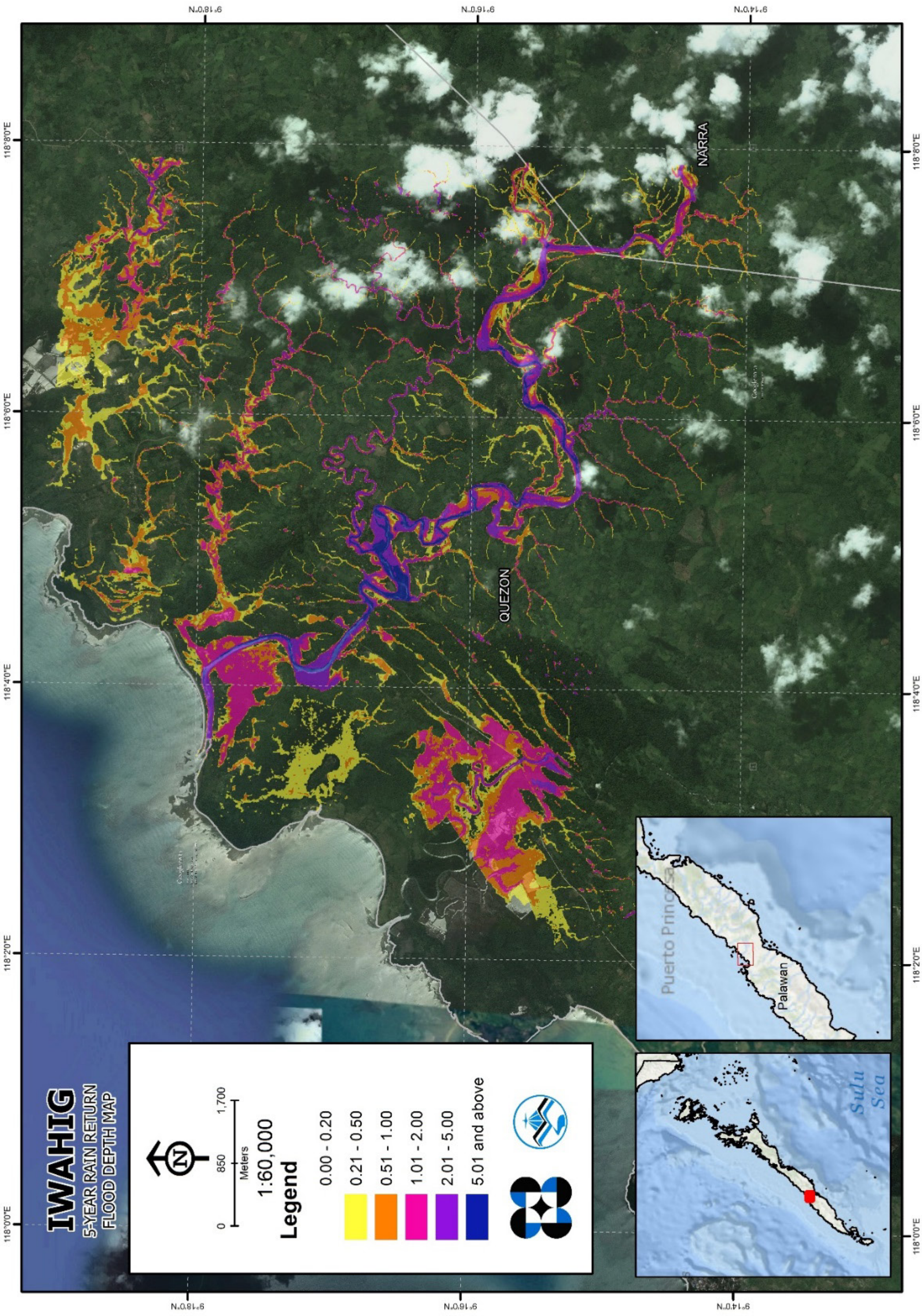


Figure 69. 5-year Flood Depth Map for Iwahig Floodplain overlaid on Google Earth imagery

5.9 Inventory of Areas Exposed to Flooding

Listed below are the barangays affected by the Iwahig River Basin, grouped accordingly by municipality. For the said basin, two (2) municipalities consisting of 6 barangays are expected to experience flooding when subjected to a 5-year rainfall return period.

For the 5-year return period, 0.4% of the municipality of Narra with an area of 831.19 sq. km. will experience flood levels of less 0.20 meters, while 0.03% of the area will experience flood levels of 0.21 to 0.50 meters; 0.03%, 0.03%, 0.02%, and 0.0001% 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 and Figure 66 depict the areas affected in Narra in square kilometers by flood depth per barangay.

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

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Bansud	
	Burirao	Tacras
0.03-0.20	0.41	2.9
0.21-0.50	0.014	0.23
0.51-1.00	0.01	0.21
1.01-2.00	0.0067	0.22
2.01-5.00	0.0033	0.15
> 5.00	0	0.0009

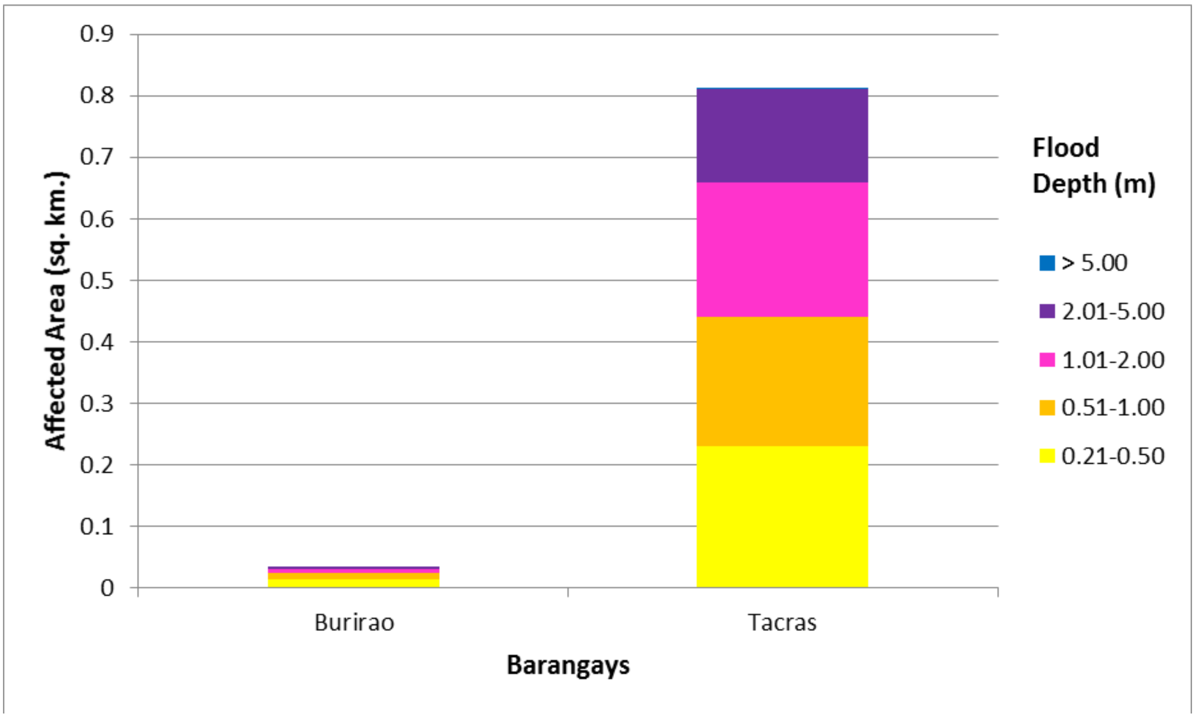


Figure 70. Affected areas in Narra, Palawan during a 5-Year Rainfall Return Period

For the municipality of Quezon, with an area of 917.97 sq. km., 5.16% will experience flood levels of less 0.20 meters. 0.45% of the area will experience flood levels of 0.21 to 0.50 meters while 0.44%, 0.58%, 0.39%, and 0.09% 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 and Figure 67 depict the affected areas in square kilometers by flood depth per barangay.

Table 36. Affected Areas in Bongabong, Oriental Mindoro during 5-Year Rainfall Return Period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Bongabong			
	Calatagbak	Isugod	Maasin	Tabon
0.03-0.20	23.74	8.66	10	4.98
0.21-0.50	1.2	0.96	1.49	0.49
0.51-1.00	1.21	1.34	0.94	0.57
1.01-2.00	1.36	1.22	1.16	1.6
2.01-5.00	1.46	0.11	0.84	1.2
> 5.00	0.53	0.026	0.26	0.0011

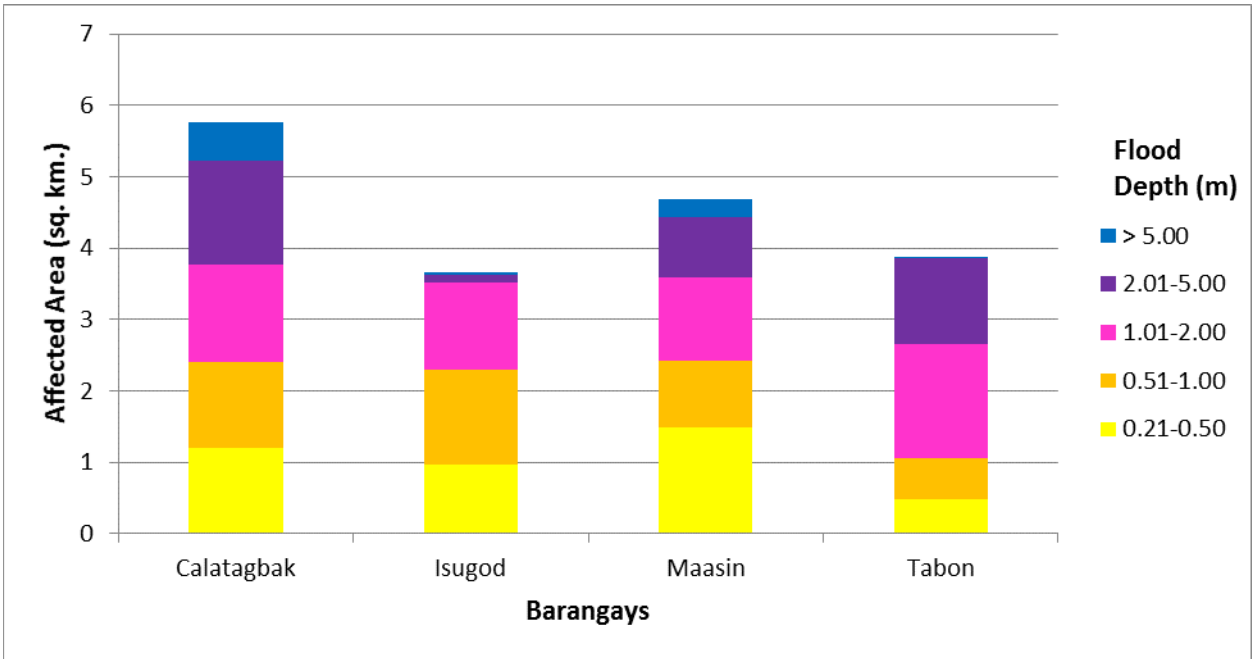


Figure 71. Affected areas in Quezon, Palawan during a 5-Year Rainfall Return Period.

For the 25-year return period, 0.38% of the municipality of Narra with an area of 831.19 sq. km. will experience flood levels of less 0.20 meters, while 0.03% of the area will experience flood levels of 0.21 to 0.50 meters; 0.03%, 0.03%, 0.03%, and 0.0008% 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 and Figure 68 depict the areas affected in Narra in square kilometers by flood depth per barangay.

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

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Bansud	
	Burirao	Tacras
0.03-0.20	0.41	2.76
0.21-0.50	0.015	0.21
0.51-1.00	0.011	0.23
1.01-2.00	0.0081	0.26
2.01-5.00	0.004	0.24
> 5.00	0	0.007

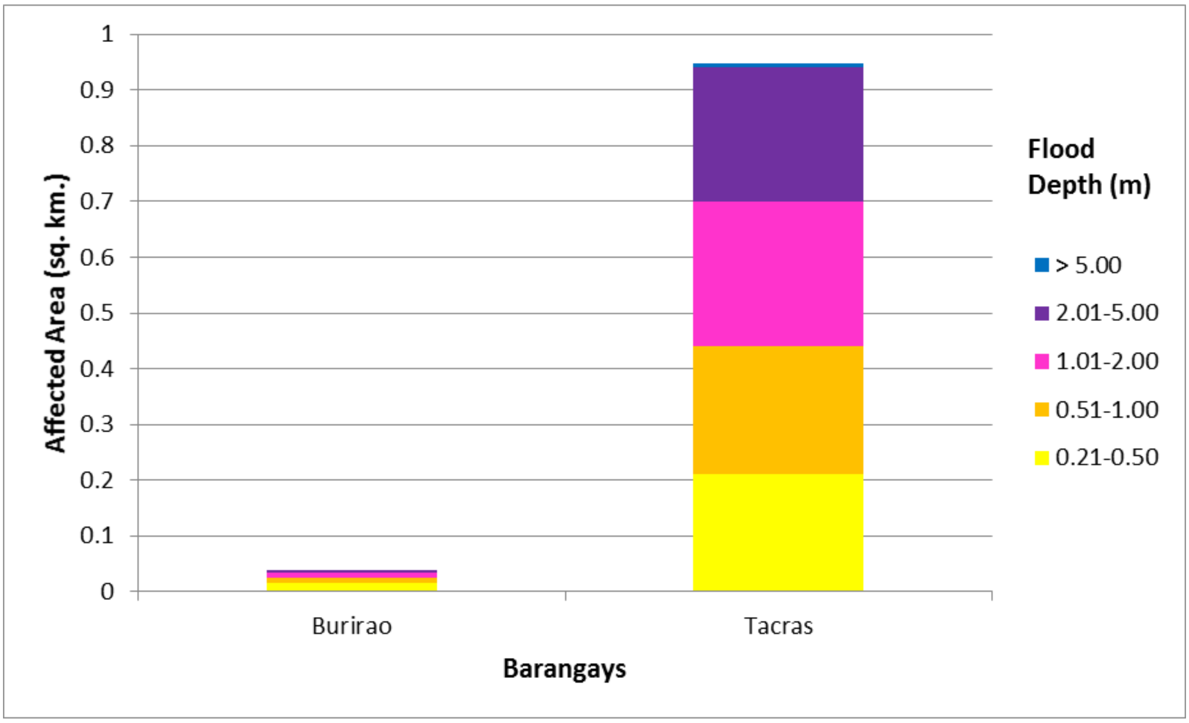


Figure 72. Affected areas in Narra, Palawan during a 25-Year Rainfall Return Period.

For the municipality of Quezon, with an area of 917.97 sq. km., 4.77% will experience flood levels of less 0.20 meters. 0.4% of the area will experience flood levels of 0.21 to 0.50 meters while 0.42%, 0.57%, 0.81%, 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 33 and Figure 69 depict the affected areas in square kilometers by flood depth per barangay.

Table 38. Affected areas in Quezon, Palawan during a 25-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Bongabong			
	Calatagbak	Isugod	Maasin	Tabon
0.03-0.20	22.79	8.07	8.41	4.55
0.21-0.50	1.05	0.8	1.49	0.33
0.51-1.00	1.06	1.06	1.49	0.29
1.01-2.00	1.58	1.71	1.28	0.7
2.01-5.00	2.12	0.66	1.68	2.95
> 5.00	0.9	0.04	0.35	0.0052

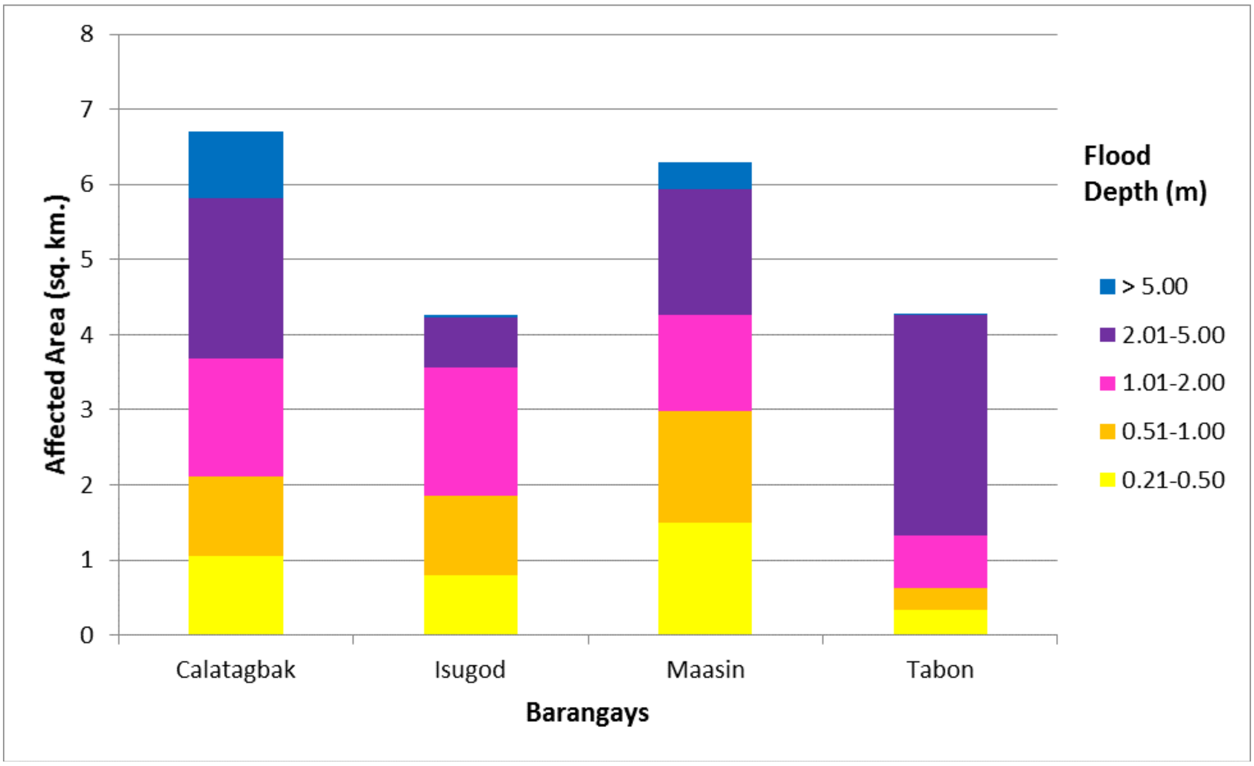


Figure 73. Affected areas in Quezon, Palawan during a 25-Year Rainfall Return Period.

For the 100-year return period, 0.37% of the municipality of Narra with an area of 831.19 sq. km. will experience flood levels of less 0.20 meters, while 0.02% of the area will experience flood levels of 0.21 to 0.50 meters; 0.03%, 0.03%, 0.04%, and 0.002% 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 34 and Figure 70 depict the areas affected in Narra in square kilometers by flood depth per barangay.

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

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Bansud	
	Burirao	Tacras
0.03-0.20	0.41	2.69
0.21-0.50	0.015	0.19
0.51-1.00	0.012	0.21
1.01-2.00	0.0089	0.27
2.01-5.00	0.0046	0.32
> 5.00	0	0.019

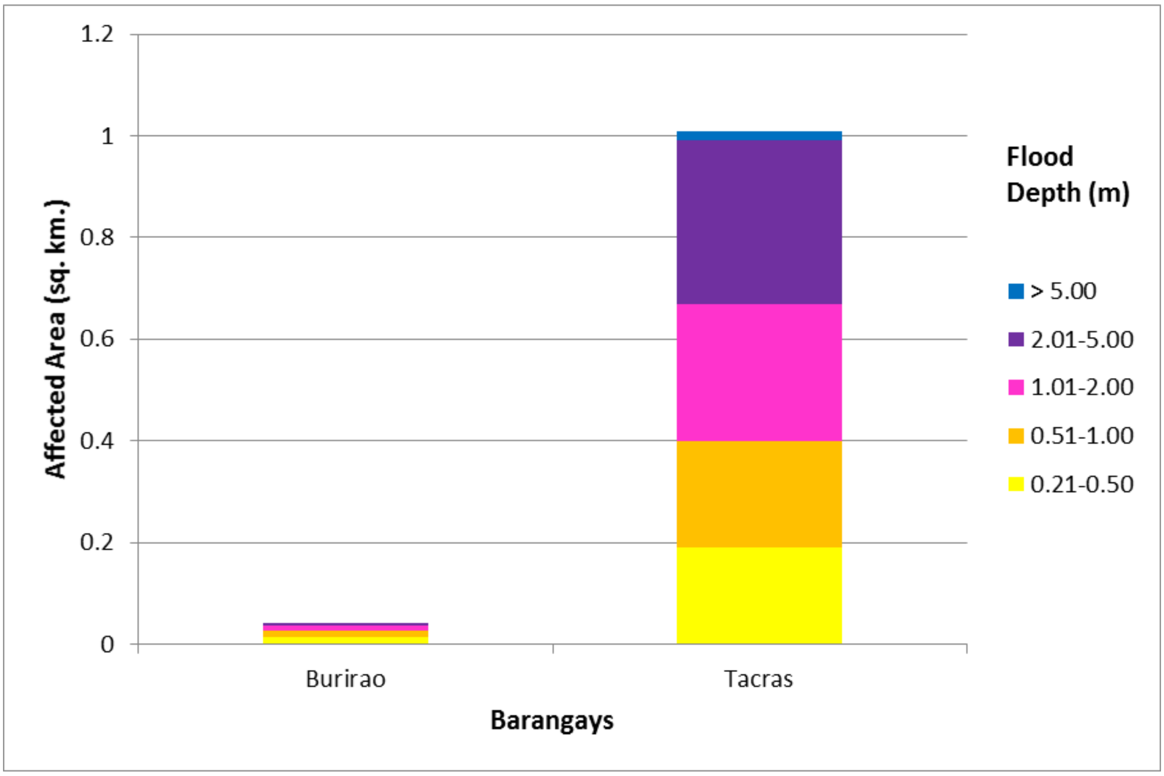


Figure 74. Affected areas in Narra, Palawan during a 100-Year Rainfall Return Period.

For the municipality of Quezon, with an area of 917.97 sq. km., 4.56% will experience flood levels of less 0.20 meters. 0.28% of the area will experience flood levels of 0.21 to 0.50 meters while 0.37%, 0.63%, 1.04%, and 0.23% 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 35 and Figure 71 depict the affected areas in square kilometers by flood depth per barangay.

Table 40. Affected areas in Quezon, Palawan during a 100-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Bongabong			
	Calatagbak	Isugod	Maasin	Tabon
0.03-0.20	22.26	7.76	7.56	4.29
0.21-0.50	1.07	0.66	0.56	0.29
0.51-1.00	0.97	0.98	1.18	0.3
1.01-2.00	1.51	1.45	2.54	0.32
2.01-5.00	2.43	1.43	2.35	3.31
> 5.00	1.27	0.05	0.5	0.32

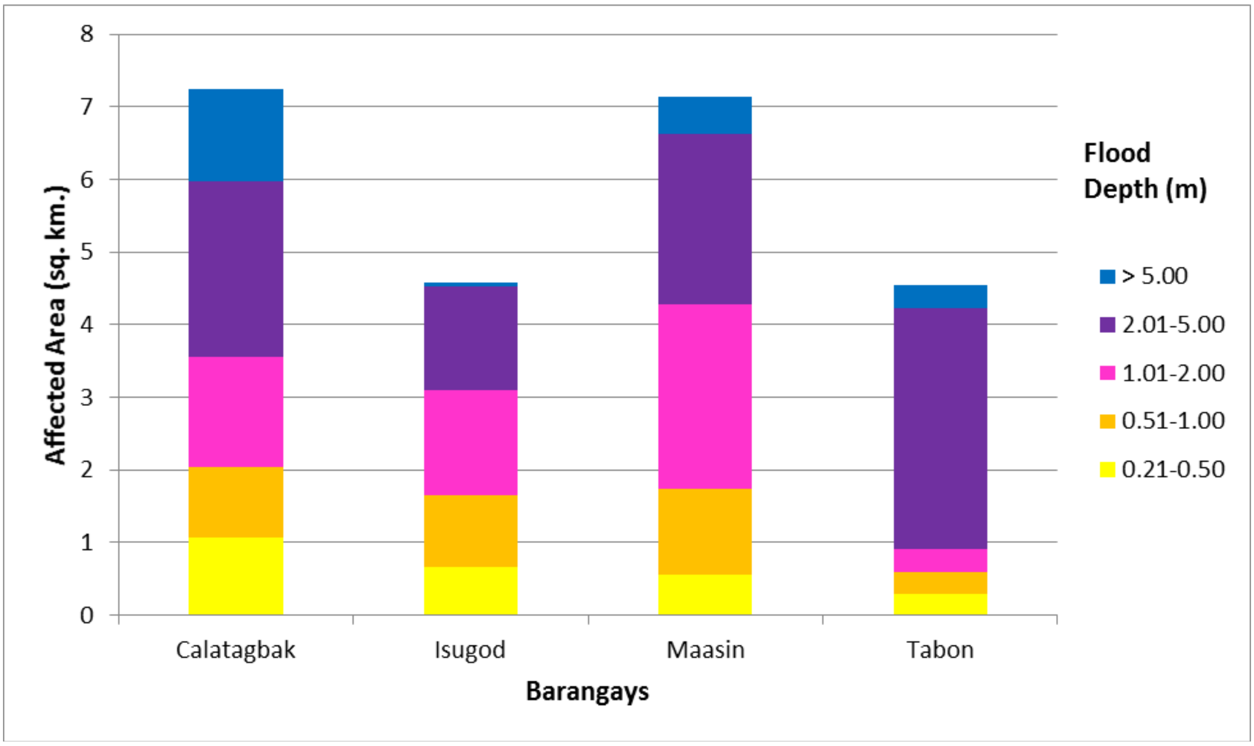


Figure 75. Affected areas in Quezon, Palawan during a 100-Year Rainfall Return Period.

Among the barangays in the municipality of Narra, Tacras is projected to have the highest percentage of area that will experience flood levels of at 0.45%. On the other hand, Burirao posted the percentage of area that may be affected by flood depths of at 0.05%.

Among the barangays in the municipality of Quezon, Calatagbak is projected to have the highest percentage of area that will experience flood levels of at 3.21%. On the other hand, Maasin posted the percentage of area that may be affected by flood depths of at 1.6%.

5.10 Flood Validation

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

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

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

After which, the actual data from the field was compared to the simulated data to assess the accuracy of the Flood Depth Maps produced and to improve on what is needed. The points in the flood map versus its corresponding validation depths are shown in Figure 73.

The flood validation consists of 129 points randomly selected all over the Iwahig Quezon flood plain. Comparing it with the flood depth map of the nearest storm event, the map has an RMSE value of 0.93m. Table 36 shows a contingency matrix of the comparison.

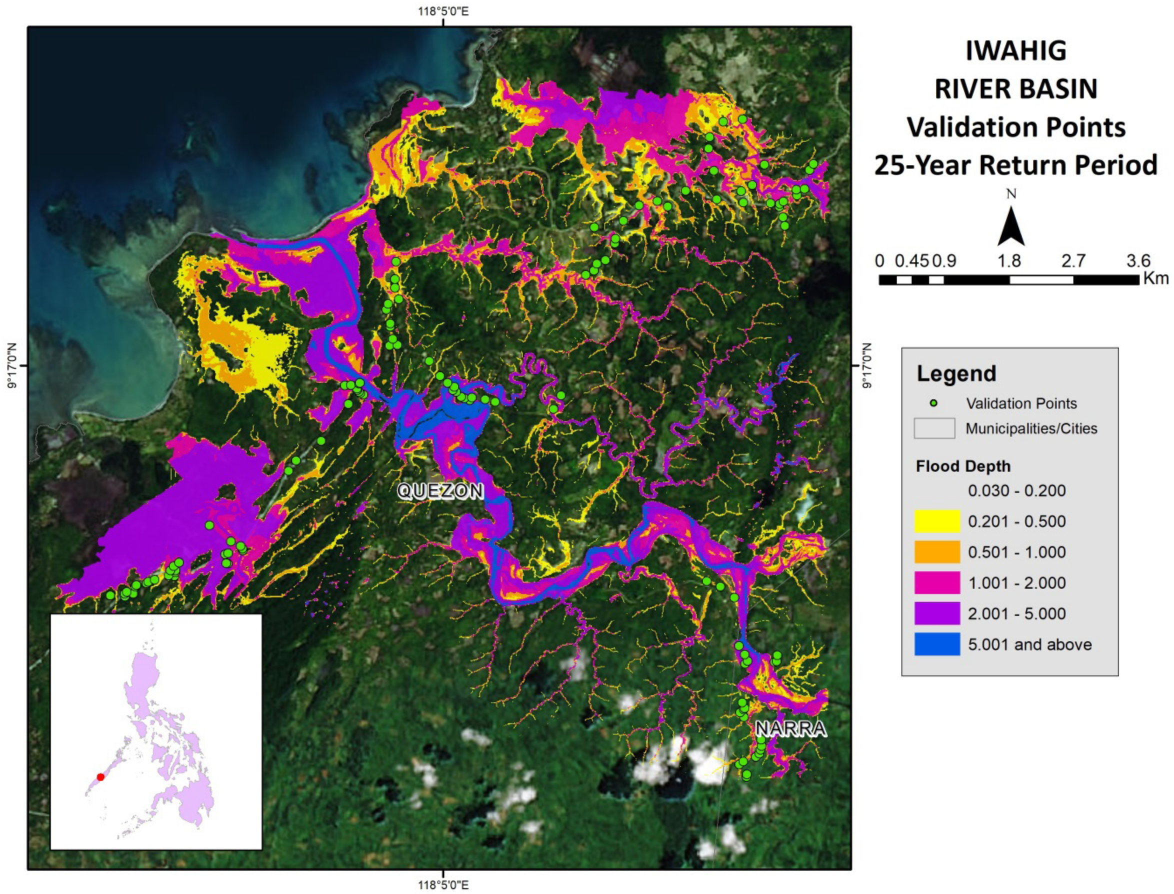


Figure 76. Validation points for 25-year Flood Depth Map of Iwahig Floodplain

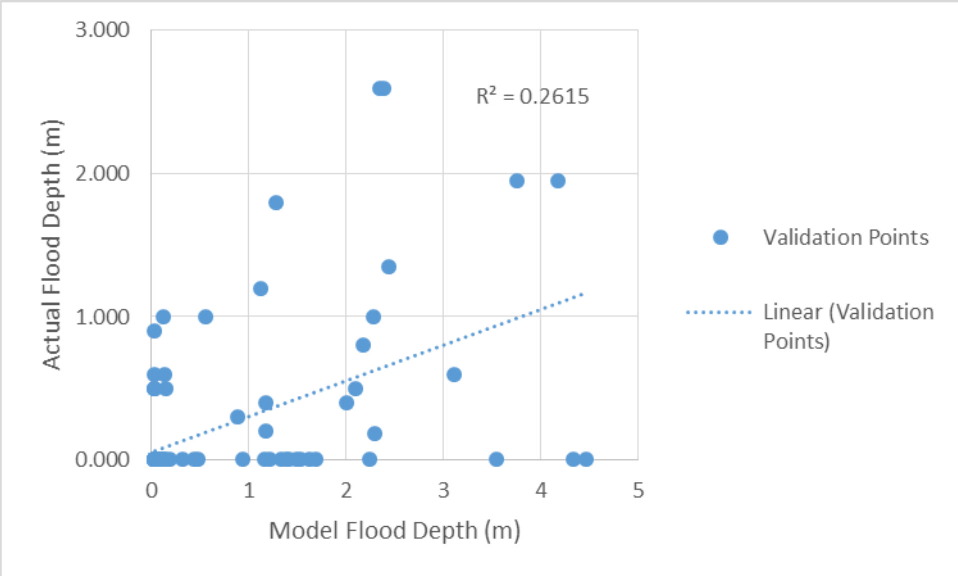


Figure 77. Flood map depth vs. actual flood depth

Table 41. Actual flood vs simulated flood depth at different levels in the Iwahig River Basin.

Actual Flood Depth (m)	Modeled Flood Depth (m)						
	0-0.20	0.21-0.50	0.51-1.00	1.01-2.00	2.01-5.00	>5.00	Total
0-0.20	87	3	1	10	5	0	106
0.21-0.50	4	0	1	1	2	0	8
0.51-1.00	4	0	1	0	3	0	8
1.01-2.00	0	0	0	2	3	0	5
2.01-5.00	0	0	0	0	2	0	2
>5.00	0	0	0	0	0	0	0
Total	95	3	3	13	15	0	129

The overall accuracy generated by the flood model is estimated at 71.32% with 92 points correctly matching the actual flood depths. In addition, there were 11 points estimated one level above and below the correct flood depths while there were 9 points and 17 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 8 points were underestimated in the modelled flood depths of Iwahig. Table 37 depicts the summary of the Accuracy Assessment in the Iwahig River Basin Survey.

Table 42. Summary of the Accuracy Assessment in the Iwahig River Basin Survey

	No. of Points	%
Correct	92	**71.32**
Overestimated	29	**22.48**
Underestimated	8	**6.20**
Total	129	**100.00**

REFERENCES

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

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

Brunner, G. H. 2010a. HEC-RAS River Analysis System Hydraulic Reference Manual. Davis, CA: U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center.

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

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

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

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

ANNEXES

Annex 1. Optech Technical Specification of the Pegasus and Gemini Sensors

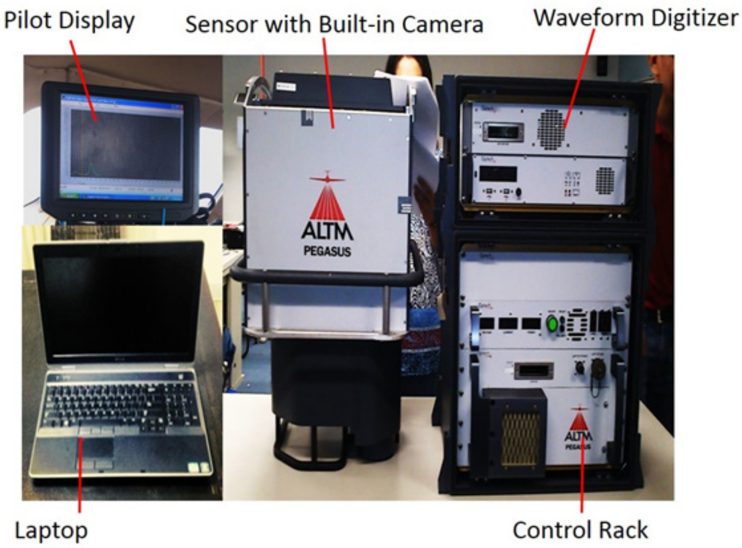


Figure A-1.1 Pegasus Sensor

Table A-1.1 Parameters and Specifications of the Pegasus Sensor

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

Dimensions and weight	Sensor: 630 x 540 x 450 mm; 65 kg;
	Control rack: 650 x 590 x 490 mm; 46 kg
Operating Temperature	-10°C to +35°C
Relative humidity	0-95% non-condensing

Figure A-1.2 Gemini Sensor

Table A-1.2 Parameters and Specifications of the 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 Certificates of Reference Points Used

1. PL-318

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

December 02, 2015

CERTIFICATION

To whom it may concern:

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

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

Location Description

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

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

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

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

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. PL-318

2. PLW-317

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

June 23, 2015

CERTIFICATION

To whom it may concern:

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

	Province: **PALAWAN**	
	Station Name: **PLW-137**	
	Order: **2nd**	
Island: **LUZON**	Barangay: **IPILAN**	
Municipality: **PUERTO PRINCESA CITY (CAPITAL)**	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **9° 11' 2.95364"**	Longitude: **118° 4' 48.04729"**	Ellipsoidal Hgt: **35.83359 m.**
	WGS84 Coordinates	
Latitude: **9° 10' 58.60442"**	Longitude: **118° 4' 53.42391"**	Ellipsoidal Hgt: **85.64700 m.**
	PTM / PRS92 Coordinates	
Northing: **1015530.347 m.**	Easting: **453844.056 m.**	Zone: **1A**
	UTM / PRS92 Coordinates	
Northing: **1,015,326.41**	Easting: **618,656.03**	Zone: **50**

Location Description

PLW-137
From Narra poblacion, travel SW towards Brgy. Abo-Abo for 36 kms. Upon reaching the junction turn NW and travel for 4 kms. until reaching Brgy. Ipil. Station is located at the top of the ridge along the highway approximately 170 m SE of KM 133. Mark is the head of 4" copper nail flushed in a cement putty 30cm x 30cm x 120cm embedded 1 m on the ground with inscriptions "PLW-137 2007 NAMRIA."

Requesting Party: **UP-DREAM**
Purpose: **Reference**
OR Number: **8083538 I**
T.N.: **2015-1341**

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

9906232015114515

Figure A-2.2. PLW-317

3. PLW-71

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

June 23, 2015

CERTIFICATION

To whom it may concern:

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

	Province: **PALAWAN**	
	Station Name: **PLW-71 (PAL-14)**	
	Order: **2nd**	
Island: **LUZON**	Barangay: **BERONG, SO. BADLESAN**	
Municipality: **PUERTO PRINCESA CITY (CAPITAL)**	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **9° 27' 39.91263"**	Longitude: **118° 12' 4.53547"**	Ellipsoidal Hgt: **3.87100 m.**
	WGS84 Coordinates	
Latitude: **9° 27' 35.50449"**	Longitude: **118° 12' 9.88716"**	Ellipsoidal Hgt: **53.39400 m.**
	PTM / PRS92 Coordinates	
Northing: **1046143.749 m.**	Easting: **467194.901 m.**	Zone: **1A**
	UTM / PRS92 Coordinates	
Northing: **1,045,990.79**	Easting: **631,874.59**	Zone: **50**

Location Description

PLW-71 (PAL-14)
From Puerto Princesa City travel south bound by a shuttle van going to the municipality of Quezon for almost 3 to 4 hours. The station is located near the house of Ex Brgy. Capt. Victorino Danglong in sitio Badlesan at the back of the house of Mr. Tranquilino (June) Talo Jr. Mark is a 4" copper nail centered on top of a 30 x 30 x 100 cm concrete monument, 80 cm embedded on the ground and 20 cm protruding on the ground with inscription PAL-14 2005 NCIP.

Requesting Party: **UP-DREAM**
Purpose: **Reference**
OR Number: **8083538 I**
T.N.: **2015-1343**

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

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

Figure A-2.3. PLW-71

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

1. PLW-3043

Baseline Processing Report

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
PLW-3043 --- PL-318 (B2)	PLW-3043	PL-318	Fixed	0.035	0.030	4°26'57"	6054.978	9.503
PPPC --- PL-318 (B4)	PPPC	PL-318	Fixed	0.005	0.015	209°28'59"	45447.618	-2.322
PPPC --- PL-318 (B6)	PPPC	PL-318	Fixed	0.004	0.015	209°28'59"	45447.613	-2.290

Acceptance Summary

Processed	Passed	Flag	Fail
3	3	0	0

Vector Components (Mark to Mark)

From:	PLW-3043				
Grid		Local		Global	
Easting	8789.146 m	Latitude	N9°21'42.33800"	Latitude	N9°21'37.98382"
Northing	1037903.794 m	Longitude	E118°31'50.87908"	Longitude	E118°31'56.23900"
Elevation	7.628 m	Height	8.199 m	Height	58.756 m

To:	PL-318				
Grid		Local		Global	
Easting	9337.208 m	Latitude	N9°24'58.83705"	Latitude	N9°24'54.46952"
Northing	1043949.629 m	Longitude	E118°32'06.27533"	Longitude	E118°32'11.63035"
Elevation	17.219 m	Height	17.702 m	Height	68.152 m

Vector					
ΔEasting	548.062 m	NS Fwd Azimuth	4°26'57"	ΔX	53.384 m
ΔNorthing	6045.835 m	Ellipsoid Dist.	6054.978 m	ΔY	-1081.262 m
ΔElevation	9.591 m	ΔHeight	9.503 m	ΔZ	5957.428 m

Standard Errors

Vector errors:					
σ ΔEasting	0.014 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.016 m
σ ΔNorthing	0.007 m	σ Ellipsoid Dist.	0.006 m	σ ΔY	0.013 m
σ ΔElevation	0.015 m	σ ΔHeight	0.015 m	σ ΔZ	0.007 m

Figure A-3.1. Baseline Processing Report - A

2. PLW-383

Baseline Processing Report

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
PLW-137 — PL-383 (B1)	PLW-137	PL-383	Fixed	0.003	0.017	282°30'09"	2980.122	39.745

Acceptance Summary

Processed	Passed	Flag	Fail
1	1	0	0

Vector Components (Mark to Mark)

From:	PLW-137				
Grid		Local		Global	
Easting	618656.024 m	Latitude	N9°11'02.95363"	Latitude	N9°10'58.60442"
Northing	1015326.411 m	Longitude	E118°04'48.04733"	Longitude	E118°04'53.42391"
Elevation	35.993 m	Height	35.834 m	Height	85.647 m

To:	PL-383				
Grid		Local		Global	
Easting	615745.311 m	Latitude	N9°11'23.95008"	Latitude	N9°11'19.59710"
Northing	1015962.645 m	Longitude	E118°03'12.74333"	Longitude	E118°03'18.11940"
Elevation	75.817 m	Height	75.579 m	Height	125.314 m

Vector					
ΔEasting	-2910.713 m	NS Fwd Azimuth	282°30'09"	ΔX	2597.342 m
ΔNorthing	636.234 m	Ellipsoid Dist.	2980.122 m	ΔY	1312.697 m
ΔElevation	39.824 m	ΔHeight	39.745 m	ΔZ	643.029 m

Standard Errors

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

Figure A-3.2. Baseline Processing Report - B

3. QZT-1

Baseline Processing Report

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
plw 137 --- qzt 1 (B1)	plw 137	qzt 1	Fixed	0.005	0.011	269°40'42"	21218.741	-26.495
plw 137 --- qzt 2 (B2)	plw 137	qzt 2	Fixed	0.018	0.037	269°35'56"	21211.522	-28.970

Acceptance Summary

Processed	Passed	Flag	Fail
2	2	0	0

Vector Components (Mark to Mark)

From:	plw 137				
Grid		Local		Global	
Easting	618656.024 m	Latitude	N9°11'02.95363"	Latitude	N9°10'58.60442"
Northing	1015326.411 m	Longitude	E118°04'48.04733"	Longitude	E118°04'53.42391"
Elevation	35.993 m	Height	35.834 m	Height	85.647 m

To:	qzt 1				
Grid		Local		Global	
Easting	597443.484 m	Latitude	N9°10'58.89071"	Latitude	N9°10'54.52473"
Northing	1015143.507 m	Longitude	E117°53'13.01663"	Longitude	E117°53'18.39361"
Elevation	10.136 m	Height	9.338 m	Height	58.674 m

Vector					
ΔEasting	-21212.540 m	NS Fwd Azimuth	269°40'42"	ΔX	18740.467 m
ΔNorthing	-182.904 m	Ellipsoid Dist.	21218.741 m	ΔY	9950.677 m
ΔElevation	-25.857 m	ΔHeight	-26.495 m	ΔZ	-128.040 m

Figure A-3.3. Baseline Processing Report – C

4. QZT-2

Baseline Processing Report

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
plw 137 --- qzt 1 (B1)	plw 137	qzt 1	Fixed	0.005	0.011	269°40'42"	21218.741	-26.495
plw 137 --- qzt 2 (B2)	plw 137	qzt 2	Fixed	0.018	0.037	269°35'56"	21211.522	-28.970

Acceptance Summary

Processed	Passed	Flag	Fail
2	2	0	0

Vector Components (Mark to Mark)

From:	plw 137				
Grid		Local		Global	
Easting	618656.024 m	Latitude	N9°11'02.95363"	Latitude	N9°10'58.60442"
Northing	1015326.411 m	Longitude	E118°04'48.04733"	Longitude	E118°04'53.42391"
Elevation	35.993 m	Height	35.834 m	Height	85.647 m

To:	qzt 2				
Grid		Local		Global	
Easting	597450.975 m	Latitude	N9°10'57.93286"	Latitude	N9°10'53.56696"
Northing	1015114.108 m	Longitude	E117°53'13.25970"	Longitude	E117°53'18.63670"
Elevation	7.660 m	Height	6.864 m	Height	56.200 m

Vector					
ΔEasting	-21205.049 m	NS Fwd Azimuth	269°35'56"	ΔX	18732.854 m
ΔNorthing	-212.303 m	Ellipsoid Dist.	21211.522 m	ΔY	9949.197 m
ΔElevation	-28.333 m	ΔHeight	-28.970 m	ΔZ	-157.483 m

Standard Errors

Vector errors:					
σ ΔEasting	0.007 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.011 m
σ ΔNorthing	0.003 m	σ Ellipsoid Dist.	0.007 m	σ ΔY	0.016 m
σ ΔElevation	0.019 m	σ ΔHeight	0.019 m	σ ΔZ	0.005 m

Figure A-3.4. Baseline Processing Report – D

5. PL-318

Baseline Processing Report

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
PLW-3043 --- PL-318 (B2)	PLW-3043	PL-318	Fixed	0.035	0.030	4°26'57"	6054.978	9.503
PPPC --- PL-318 (B4)	PPPC	PL-318	Fixed	0.005	0.015	209°28'59"	45447.618	-2.322
PPPC --- PL-318 (B6)	PPPC	PL-318	Fixed	0.004	0.015	209°28'59"	45447.613	-2.290

Acceptance Summary

Processed	Passed	Flag	Fail
3	3	0	0

Vector Components (Mark to Mark)

From:	PLW-3043				
Grid		Local		Global	
Easting	8789.146 m	Latitude	N9°21'42.33800"	Latitude	N9°21'37.98382"
Northing	1037903.794 m	Longitude	E118°31'50.87908"	Longitude	E118°31'56.23900"
Elevation	7.628 m	Height	8.199 m	Height	58.756 m

To:	PL-318				
Grid		Local		Global	
Easting	9337.208 m	Latitude	N9°24'58.83705"	Latitude	N9°24'54.46952"
Northing	1043949.629 m	Longitude	E118°32'06.27533"	Longitude	E118°32'11.63035"
Elevation	17.219 m	Height	17.702 m	Height	68.152 m

Vector					
ΔEasting	548.062 m	NS Fwd Azimuth	4°26'57"	ΔX	53.384 m
ΔNorthing	6045.835 m	Ellipsoid Dist.	6054.978 m	ΔY	-1081.262 m
ΔElevation	9.591 m	ΔHeight	9.503 m	ΔZ	5957.428 m

Standard Errors

Vector errors:					
σ ΔEasting	0.014 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.016 m
σ ΔNorthing	0.007 m	σ Ellipsoid Dist.	0.006 m	σ ΔY	0.013 m
σ ΔElevation	0.015 m	σ ΔHeight	0.015 m	σ ΔZ	0.007 m

Figure A-3.5. Baseline Processing Report – E

Annex 4. The LiDAR Survey Team Composition

Table A-4.1 LiDAR Survey Team Composition

<table>
<tr><th>Date Acquisition Component Sub-team</th><th>Designation</th><th>Name</th><th>Agency/Affiliation</th></tr>
<tr><td>PHIL-LiDAR 1</td><td>Program Leader</td><td>ENRICO C. PARINGIT, D.ENG</td><td>UP-TCAGP</td></tr>
<tr><td rowspan="2">Data Acquisition Component Leader</td><td rowspan="2">Data Component Project Leader –I</td><td>ENGR. CZAR JAKIRI S. SARMIENTO</td><td rowspan="2">UP-TCAGP</td></tr>
<tr><td>ENGR. LOUIE P. BALICANTA</td></tr>
<tr><td rowspan="3">Survey Supervisor</td><td>Chief Science Research Specialist (CSRS)</td><td>ENGR. CHRISTOPHER CRUZ</td><td>UP-TCAGP</td></tr>
<tr><td rowspan="2">Supervising Science Research Specialist (Supervising SRS)</td><td>LOVELY GRACIA ACUNA</td><td>UP-TCAGP</td></tr>
<tr><td>ENGR. LOVELYN ASUNCION</td><td>UP-TCAGP</td></tr>
<tr><td colspan="4">FIELD TEAM</td></tr>
<tr><td rowspan="6">LiDAR Operation</td><td rowspan="2">Senior Science Research Specialist (SSRS)</td><td>JASMINE ALVIAR</td><td rowspan="2">UP-TCAGP</td></tr>
<tr><td>ENGR GEROME HIPOLITO</td></tr>
<tr><td rowspan="4">Research Associate (RA)</td><td>GRACE SINADJAN</td><td rowspan="4">UP-TCAGP</td></tr>
<tr><td>ENGR. LARAH PARAGAS</td></tr>
<tr><td>ENGR. IRO NIEL ROXAS</td></tr>
<tr><td>MA. CATHERINE BALIGUAS</td></tr>
<tr><td rowspan="2">Ground Survey, Data download and transfer</td><td rowspan="2">RA</td><td>JERIEL PAUL ALAMBAN</td><td rowspan="2">UP-TCAGP</td></tr>
<tr><td>JONATHAN ALMALVEZ</td></tr>
<tr><td rowspan="6">LiDAR Operation</td><td rowspan="2">Airborne Security</td><td>SSG. LEEJAY PUNZALAN</td><td rowspan="2">PHILIPPINE AIR FORCE (PAF)</td></tr>
<tr><td>JUMAR PARANGUE</td></tr>
<tr><td rowspan="4">Pilot</td><td>CAPT. MARK LAWRENCE TANGONAN</td><td rowspan="4">ASIAN AEROSPACE CORPORATION (AAC)</td></tr>
<tr><td>CAPT. JUSTINE JOYA</td></tr>
<tr><td>CAPT. ALBERT LIM</td></tr>
<tr><td>CAPT. RANDY LAGCO</td></tr>
</table>

Annex 5. Data Transfer Sheet for Daguitan-Marabong Floodplain

DATA TRANSFER SHEET
PALAWAN 12/17/15

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
20-Nov-15	3565	2BLK42PQR337A	GEMINI	NA	92	535	202	na	na	25.4	na	6.96	1KB	1KB	22/24/22/48/51	NA	Z:\DAC\RAW DATA
21-Nov-15	3571	2BLK42Tv338A	GEMINI	NA	171	370	160	na	na	14.6	na	640	1KB	1KB	22/24/22/48/51	NA	Z:\DAC\RAW DATA
26-Nov-15	3573	2BLK42Ov339A	GEMINI	NA	484	1	227	na	na	19.7	na	12.1	1KB	1KB	24/22/48/53/51/30	NA	Z:\DAC\RAW DATA
27-Nov-15	3575	2BLK42OQ339B	GEMINI	NA	734	530	218	na	na	22.3	na	12.1	1KB	1KB	24/22/30/53/50/48/51	NA	Z:\DAC\RAW DATA
28-Nov-15	3581	2BLK42NPQ341A	GEMINI	NA	872	484	232	na	na	21.2	na	8.55	1KB	NA	24/22/21/27/30/53/50/48/51	NA	Z:\DAC\RAW DATA
30-Nov-15	3585	2BLK42Nv342A	GEMINI	NA	1080	558	234	na	na	23	na	5.29	1KB	1KB	24/22/21/28/27/30/53/50/48/51	NA	Z:\DAC\RAW DATA
30-Nov-15	3593	2BLK42TwEwF344A	GEMINI	NA	1343	523	227	na	na	20.9	na	11.4	1KB	1KB	53/50/48/17	NA	Z:\DAC\RAW DATA
1-Dec-15	3595	2BLK42US344B	GEMINI	NA	253	387	156	na	na	17.4	na	11.4	1KB	1KB	17/16	NA	Z:\DAC\RAW DATA

Received from

Name C. Joaquin
Position
Signature

Received by

Name AC Bongat
Position SSRS
Signature 1/5/2016

Figure A-5.1. Data Transfer Sheet for Iwahig Floodplain - A

DATA TRANSFER SHEET
8/3/2015(palawan)

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		L
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
14-Jun-15	3049P	1BLK42S165A	Pegasus	969	na	7	162	31	252	18.3	29.3	16.3	1KB	1KB	70/67	na	Z:\ DA
20-Jun-15	3073P	1BLK42S171A	Pegasus	361	na	3.65	107	12.3	88	7.1	NA	4.15	1KB	1KB	92	na	Z:\ DA
7-Jul	3141P	1BLK42QRT188A	Pegasus	1.84	na	11.6	258	2.11	15/20/9/1	35.5	108	8.43	1KB	1KB	95	na	Z:\ DA
8-Jul	3145P	1BLK42QRT189A	Pegasus	752	na	5.41	124	184	101	14.8	NA	11.9	1KB	1KB	176/95	na	Z:\ DA
11-Jul	3157P	1BLK42PO192A	Pegasus	2.29	na	13	279	35.2	369	43.3	113	20.6	1KB	1KB	206	na	Z:\ DA
11-Jul	3159P	1BLK42PO192B	Pegasus	1.11	na	8.95	199	55.5	1	21.6	25.9	20.6	1KB	1KB	NA	na	Z:\D DAT
12-Jul	3161P	1BLK42LM193A	Pegasus	1.51	427/407	9.62	214	41.7	359	28.8	67.6	4.29	1KB	1KB	215	na	Z:\D DAT
13-Jul	3165P	1BLK42LM194A	Pegasus	1.5	na	10.5	255	36.4	295	28.9	na	11.5	1KB	1KB	na	na	Z:\D DAT
13-Jul	3167P	1BLK42JS194B	Pegasus	329	na	3.65	106	4.93	2	7.36	11	11.5	1KB	1KB	106/123	NA	Z:\D DAT
15-Jul	3173P	1BLK42KS196A	Pegasus	160	96/28	2.73	63.2	na	na	3.33	7.6	1.19	1KB	1KB	11	NA	Z:\D DAT

Received from

Name c. [illegible]
Position RA
Signature

Received by

Name AC Bongat
Position SSRS
Signature 8/5/2015

Figure A-5.2. Data Transfer Sheet for Iwahig Floodplain - B

DATA TRANSFER SHEET
7/2/2015(palawan+catarman)

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
8-Jun-15	3025P	1BLK42GH159A	Pegasus	1.04	1395	7.48	187	33.9	246	15.1	NA	7.08	1KB	1KB	14/28	na	Z:\DAC\RAW DATA
8-Jun-15	3027P	1BLK42FS159B	Pegasus	652	175	5.26	133	18.8	146	13.5	30.2	5.15	1KB	1KB	24	na	Z:\DAC\RAW DATA
11-Jun	3037P	1BLK42U162A	Pegasus	1.63	na	13.1	217	45.3	359	31.8	21.7	1.05	1KB	1KB	37/71	na	Z:\DAC\RAW DATA
11-Jun	3039P	1BLK42J162B	Pegasus	966	na	7.85	167	20.4	140/57	17.5	47.5	3.9	1KB	1KB	37/62/65/71	na	Z:\DAC\RAW DATA
12-Jun	3041P	1BLK42B163A	Pegasus	563	na	5.68	122	17	129	11.5	na	8.33	1KB	1KB	30	na	Z:\DAC\RAW DATA
13-Jun	3045P	1BLK42BS164A	Pegasus	589	na	6.01	144	15.7	116	10.5	na	7.09	1KB	1KB	32	na	Z:\DAC\RAW DATA
13-Jun	3047P	1BLK42Aa164B	Pegasus	1.4	na	10.9	221	53.5	434	19.6	73	3.69	1KB	1KB	114	na	Z:\DAC\RAW DATA
17-Jun	3061P	1BLK42Ab168A	Pegasus	1.3	na	10.7	205	39.9	105/152/54	24.4	na	5.03	1KB	1KB	59/66/55	na	Z:\DAC\RAW DATA
21-Feb	7814AC	3BLK331I052A	Aquarius	NA	34	81.5	55.1	9.53	31.1/72.5	1.68	na	3.66	1KB	1KB	4	NA	Z:\DAC\RAW DATA

CATARMAN FLIGHT

Received from

Name C. JOAQUIN
Position RA
Signature

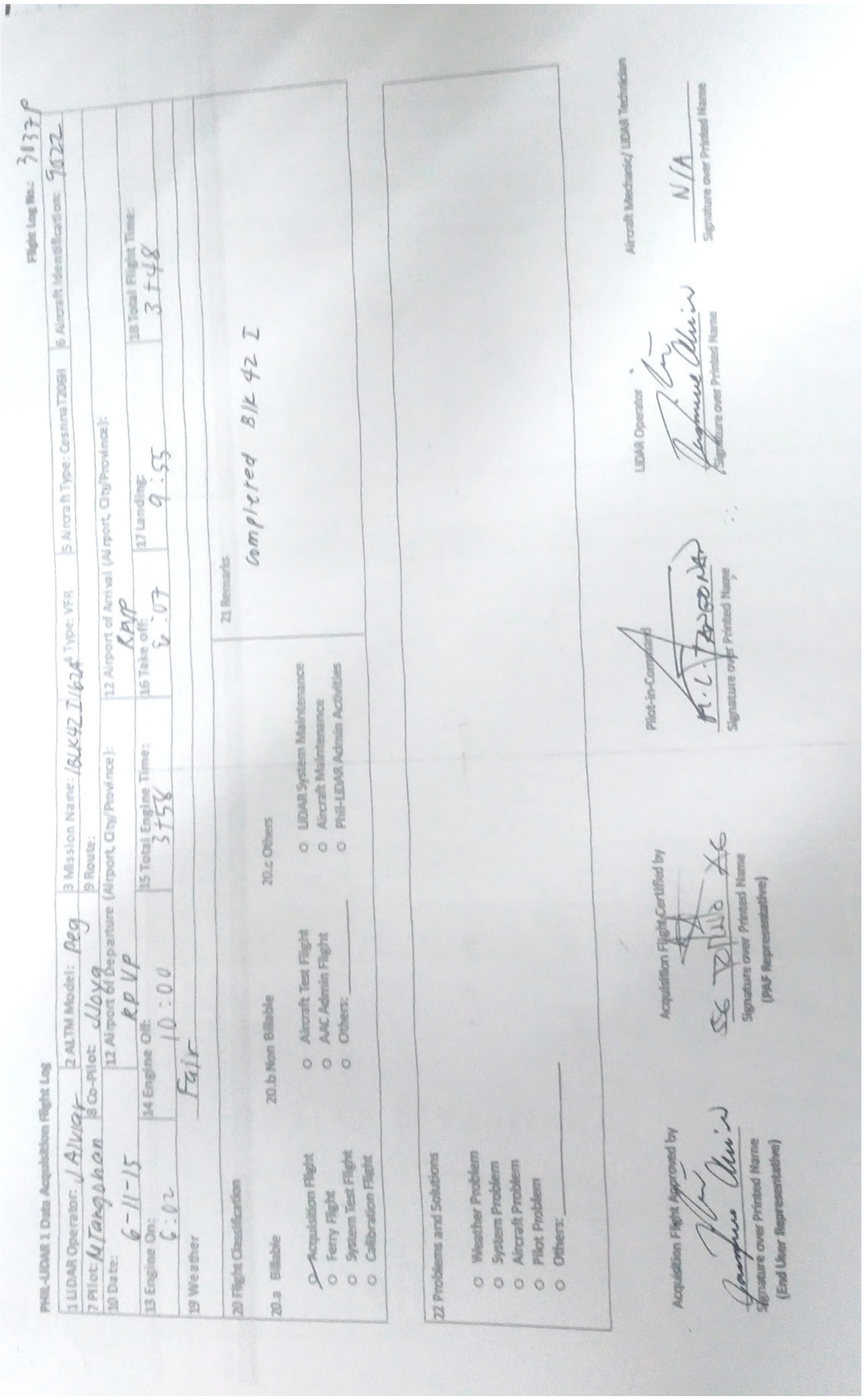
Received by

Name JOIDA PRIETO 7/13/15
Position SSRS
Signature

Figure A-5.3. Data Transfer Sheet for Iwahig Floodplain - C

Annex 6. Flight logs

1. Flight Log for 1BLK42IJ162A Mission



PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 3137P

1 LIDAR Operator: J Alviar	2 ALTM Model: Peg	3 Mission Name: 1BLK42I162A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9022
7 Pilot: M Tangonan	8 Co-Pilot: J Loyo	9 Route:			
10 Date: 6-11-15	12 Airport of Departure (Airport, City/Province): RPVP		12 Airport of Arrival (Airport, City/Province): RPVP		
13 Engine On: 6:02	14 Engine Off: 10:00	15 Total Engine Time: 3+58	16 Take off: 6:07	17 Landing: 9:55	18 Total Flight Time: 3+48
19 Weather	Fair				

20 Flight Classification

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

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

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

21 Remarks

Completed Blk 42 I

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

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

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

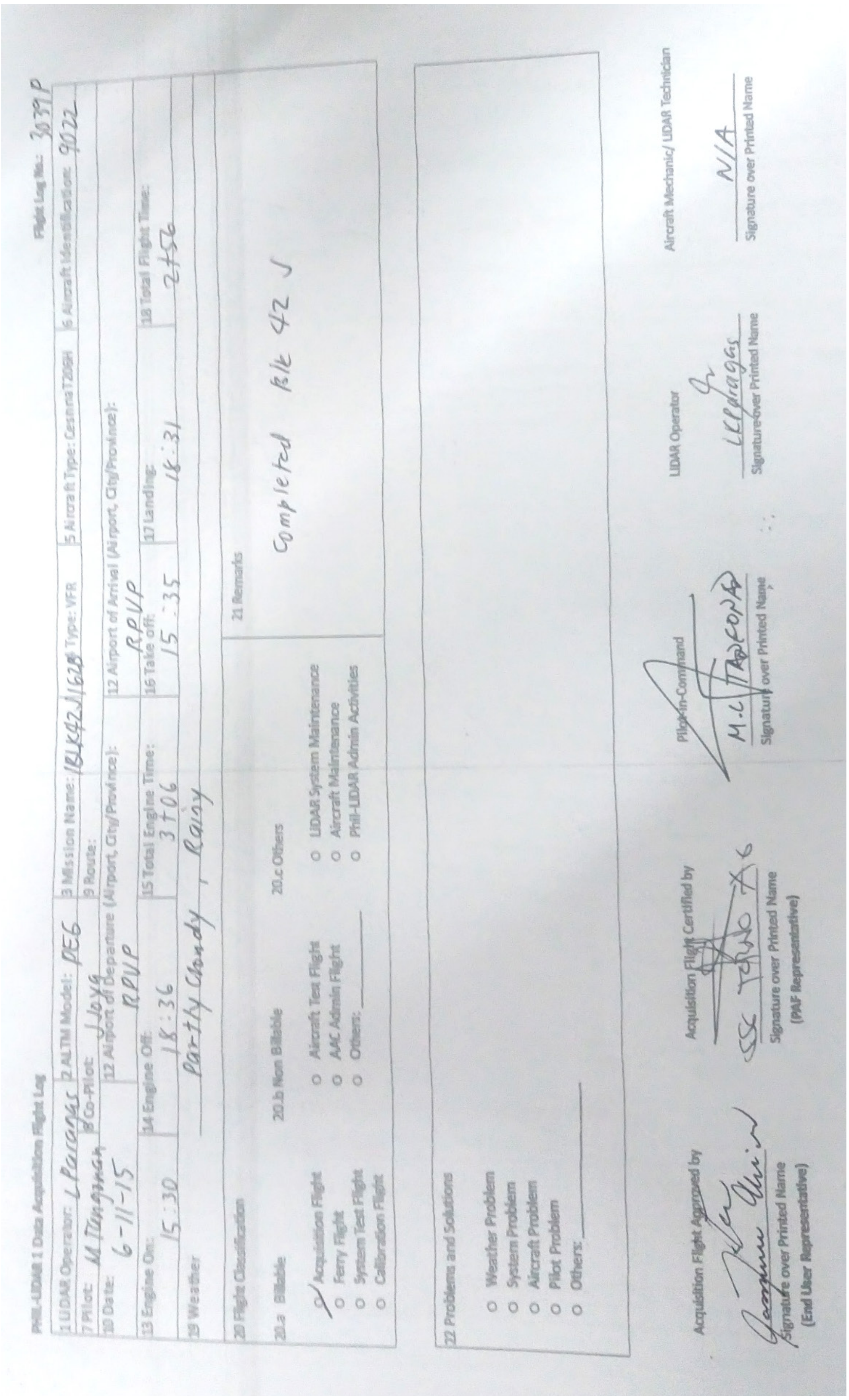
Pilot-in-Command: M. L. Tangonan, Signature over Printed Name

LIDAR Operator: Signature over Printed Name

Aircraft Mechanic/ LIDAR Technician: N/A, Signature over Printed Name

Figure A-6.1. Flight Log for 1BLK42IJ162A Mission

2. Flight Log for 1BLK42J162B Mission


PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 3039P

1 LIDAR Operator: L Paragas	2 ALTM Model: PEG	3 Mission Name: 1BLK42J162B	4 Type: VFR	5 Aircraft Type: Cessna T206H	6 Aircraft Identification: 9022
7 Pilot: M Tangonan	8 Co-Pilot: J Joyo	9 Route:			
10 Date: 6-11-15	12 Airport of Departure (Airport, City/Province): RPVP	12 Airport of Arrival (Airport, City/Province): RPVP			
13 Engine On: 15:30	14 Engine Off: 18:36	15 Total Engine Time: 3+06	16 Take off: 15:35	17 Landing: 18:31	18 Total Flight Time: 2+56
19 Weather: Partly Cloudy, Rainy					

20 Flight Classification

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

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

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

21 Remarks

Completed Blk 42 J

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

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

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

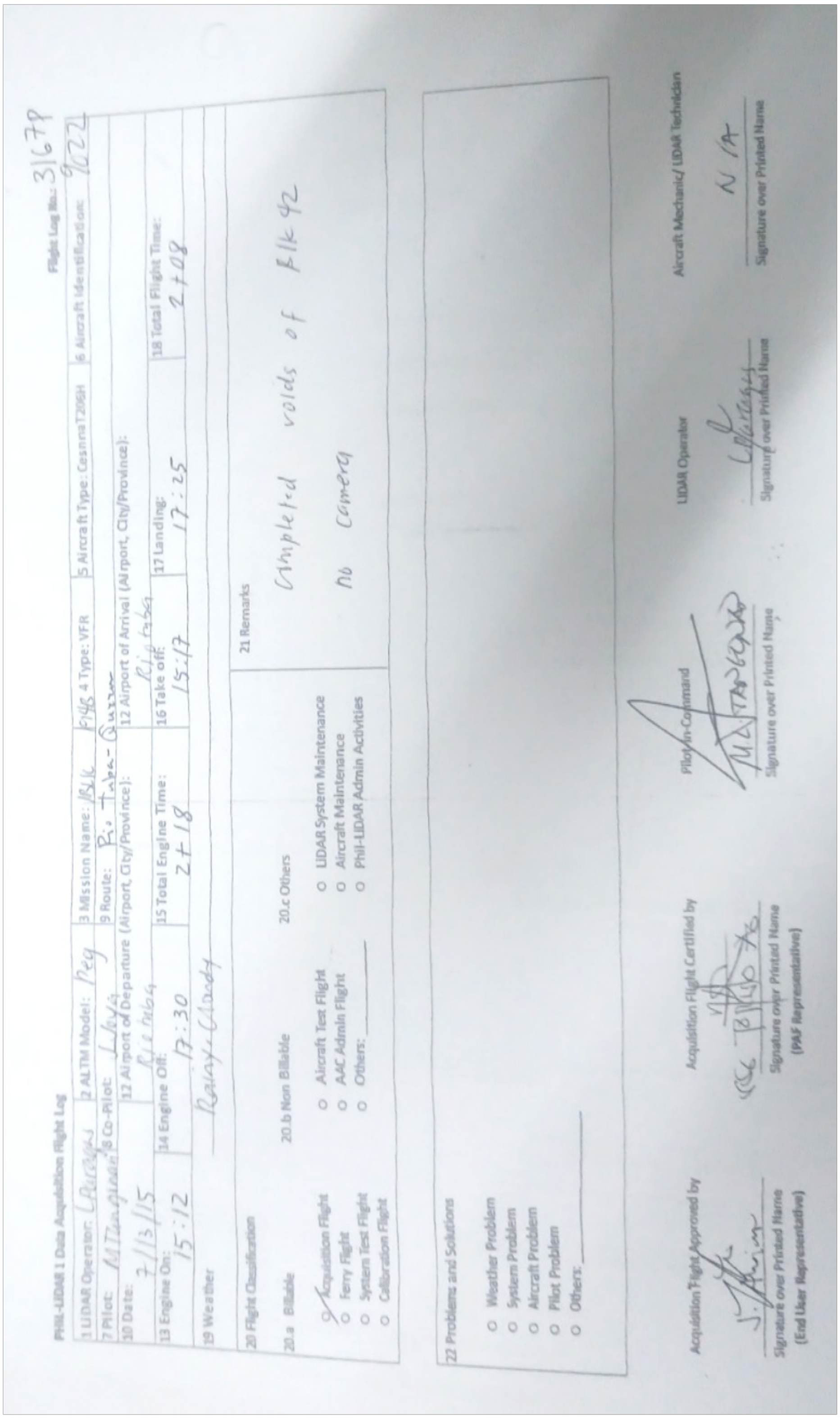
Pilot-in-Command: M.C Tadeona; Signature over Printed Name

LIDAR Operator: L K Paragas; Signature over Printed Name

Aircraft Mechanic/ LIDAR Technician: N/A; Signature over Printed Name

Figure A-6.2. Flight Log for 1BLK42J162B Mission

3. Flight Log for 1BLK42JS194B Mission



PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 31678

1 LiDAR Operator: LParagas	2 ALTM Model: Peg	3 Mission Name: 1BLK F194B	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9022
7 Pilot: MTangonan	8 Co-Pilot: LJoya	9 Route: Ri - Tuba - Quezon			
10 Date: 7/13/15	12 Airport of Departure (Airport, City/Province): Ri tuba		12 Airport of Arrival (Airport, City/Province): Ri tuba		
13 Engine On: 15:12	14 Engine Off: 17:30	15 Total Engine Time: 2+18	16 Take off: 15:17	17 Landing: 17:25	18 Total Flight Time: 2+08
19 Weather: Rainy, Cloudy					

20 Flight Classification

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

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

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

21 Remarks

Completed voids of Blk 42
no camera

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

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

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

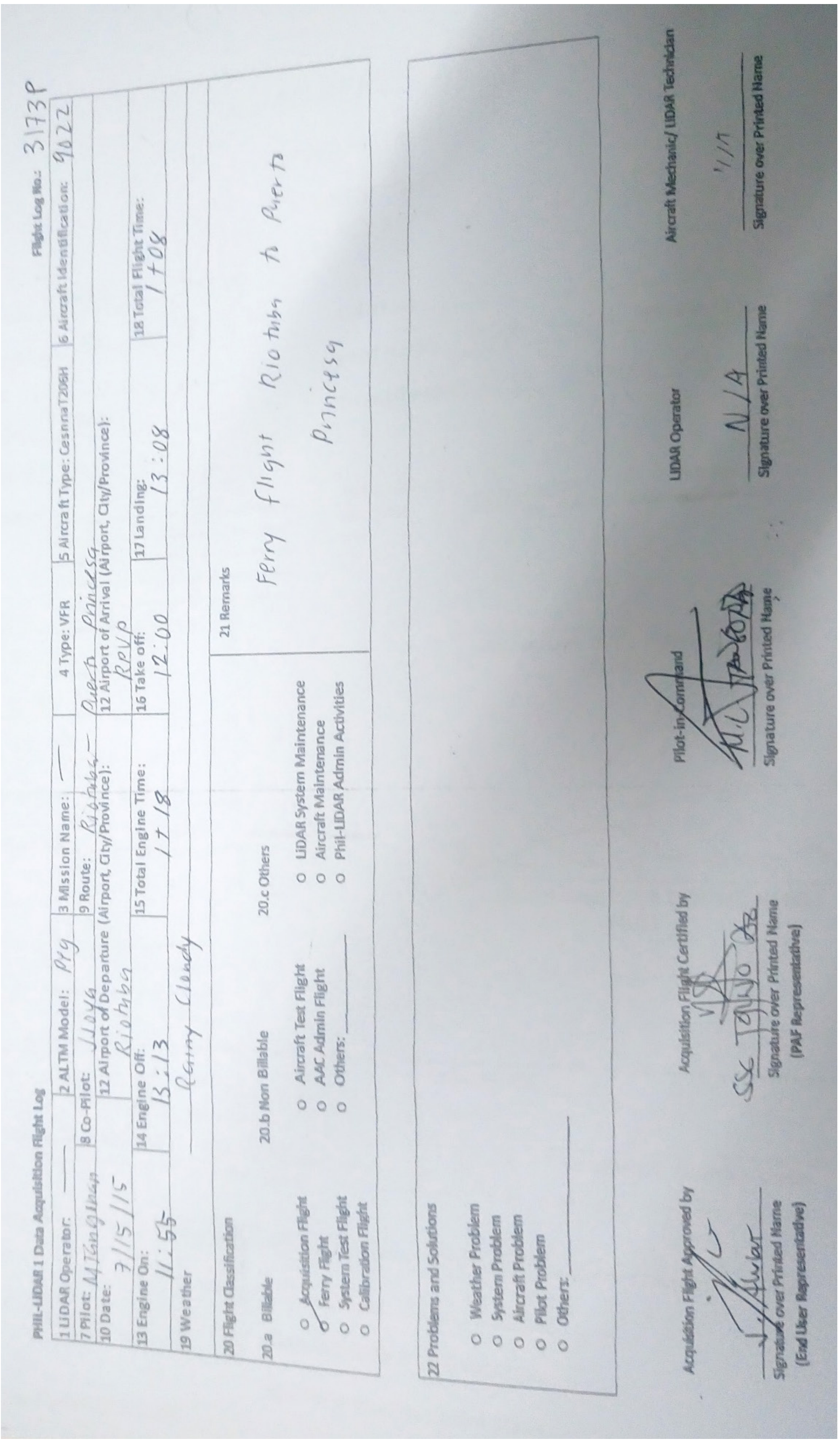
Pilot-in-Command — M.TANGONAN — Signature over Printed Name

LiDAR Operator — LParagas — Signature over Printed Name

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

Figure A-6.3. Flight Log for 1BLK42JS194B Mission

4. Flight Log for 1BLK42KS196A Mission



PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 3173P

1 LIDAR Operator: —	2 ALTM Model: Peg	3 Mission Name: —	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9022
7 Pilot: M. Tangonan	8 Co-Pilot: J. Loyola	9 Route: Riotuba – Puerto Princesa			
10 Date: 7/15/15	12 Airport of Departure (Airport, City/Province): Riotuba		12 Airport of Arrival (Airport, City/Province): RPVP		
13 Engine On: 11:55	14 Engine Off: 13:13	15 Total Engine Time: 1+18	16 Take off: 12:00	17 Landing: 13:08	18 Total Flight Time: 1+08
19 Weather: Rainy Cloudy					

20 Flight Classification

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

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

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

21 Remarks

Ferry flight Riotuba to Puerto Princesa

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

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

Acquisition Flight Certified by: SSC Tabujo Jr. — Signature over Printed Name (PAF Representative)

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

LIDAR Operator: N/A — Signature over Printed Name

Aircraft Mechanic/ LIDAR Technician: N/A — Signature over Printed Name

Figure A-6.4. Flight Log for 1BLK42KS196A Mission

Annex 7. Flight Status Report

FLIGHT STATUS REPORT
Palawan West Coast
June 11, 2015; July 13-15, 2015; and Dec 1, 2015

FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
3037P	BLK 42IJ	1BLK42IJ162A	J. Alviar	11-June-15	CHANGED PLAN ORIENTATION DUE TO TERRAIN AND CLOUD COVER
3039P	BLK 42J	1BLK42J162B	L. Paragas	11-June-15	SURVEYED BLK 42J, PRECIPITATION IN SOME PARTS OF SURVEY AREA
3167P	BLK 42JS	1BLK42JS194B	L. Paragas	13-July-15	SURVEYED REMAINING GAP IN BLK 42J
3173P	BLK 42KS	1BLK42KS196A	J. Alviar	15-July-15	SURVEYED GAP IN BLK 42K TO COVER WEST COASTAL ROAD
3557G	BLK42 H, L	2BLK42HsL335A	MCE Baliguas	01-Dec-15	Supplementary flight for data gap over BLK42H and completed BLK42L. No camera, with digitizer.

LAS/SWATH BOUNDARIES PER MISSION FLIGHT

Flight No. :	3037P		
Area:	BLK 42IJ		
Mission Name:	1BLK42IJ162A		
Parameters:	PRF 200	SF 30	FOV 50

LAS/SWATH

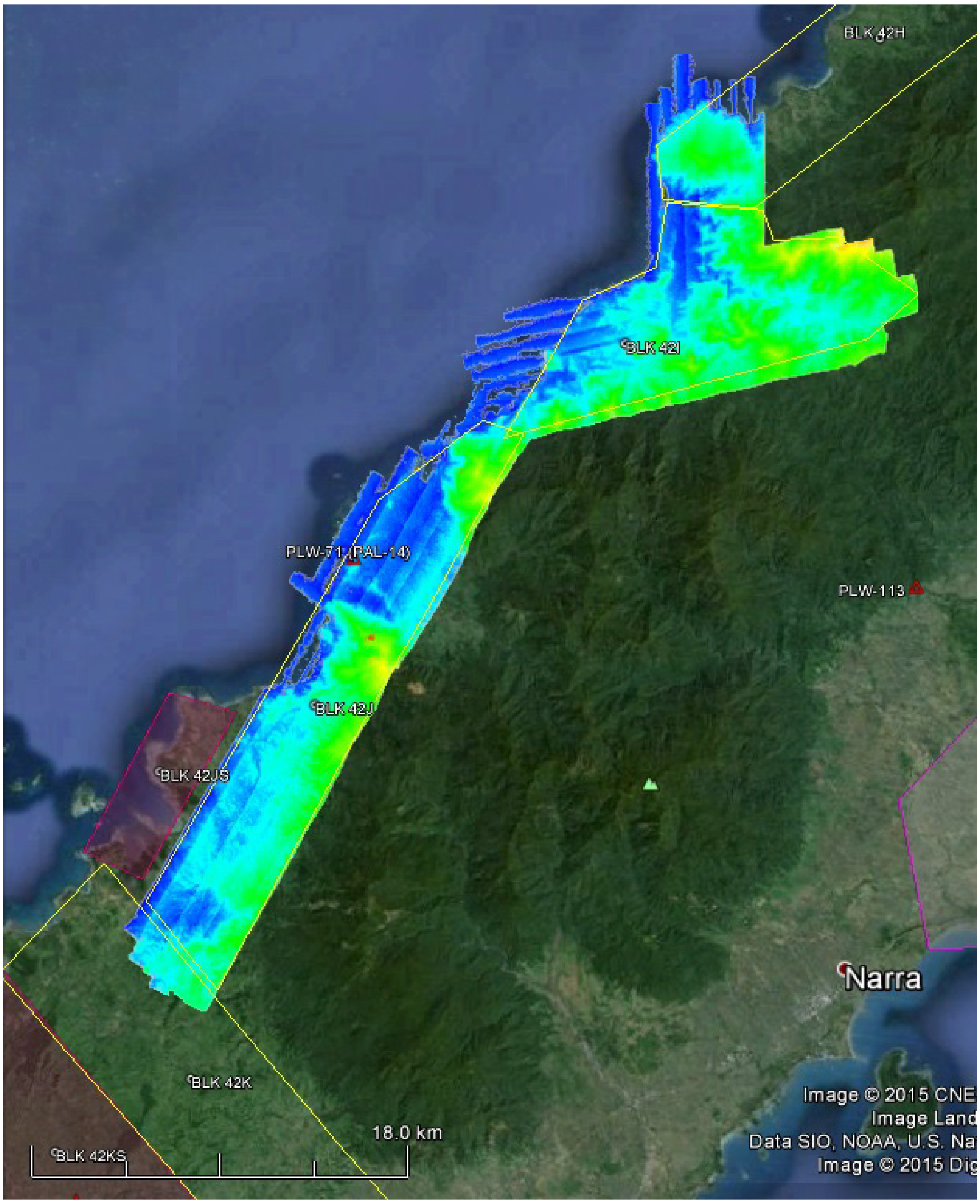


Figure A-7.1. Swath for Flight No. 3037P

Flight No. :	3039P		
Area:	BLK 42J		
Mission Name:	1BLK42J162B		
Parameters:	PRF 200	SF 30	FOV 50

LAS/SWATH

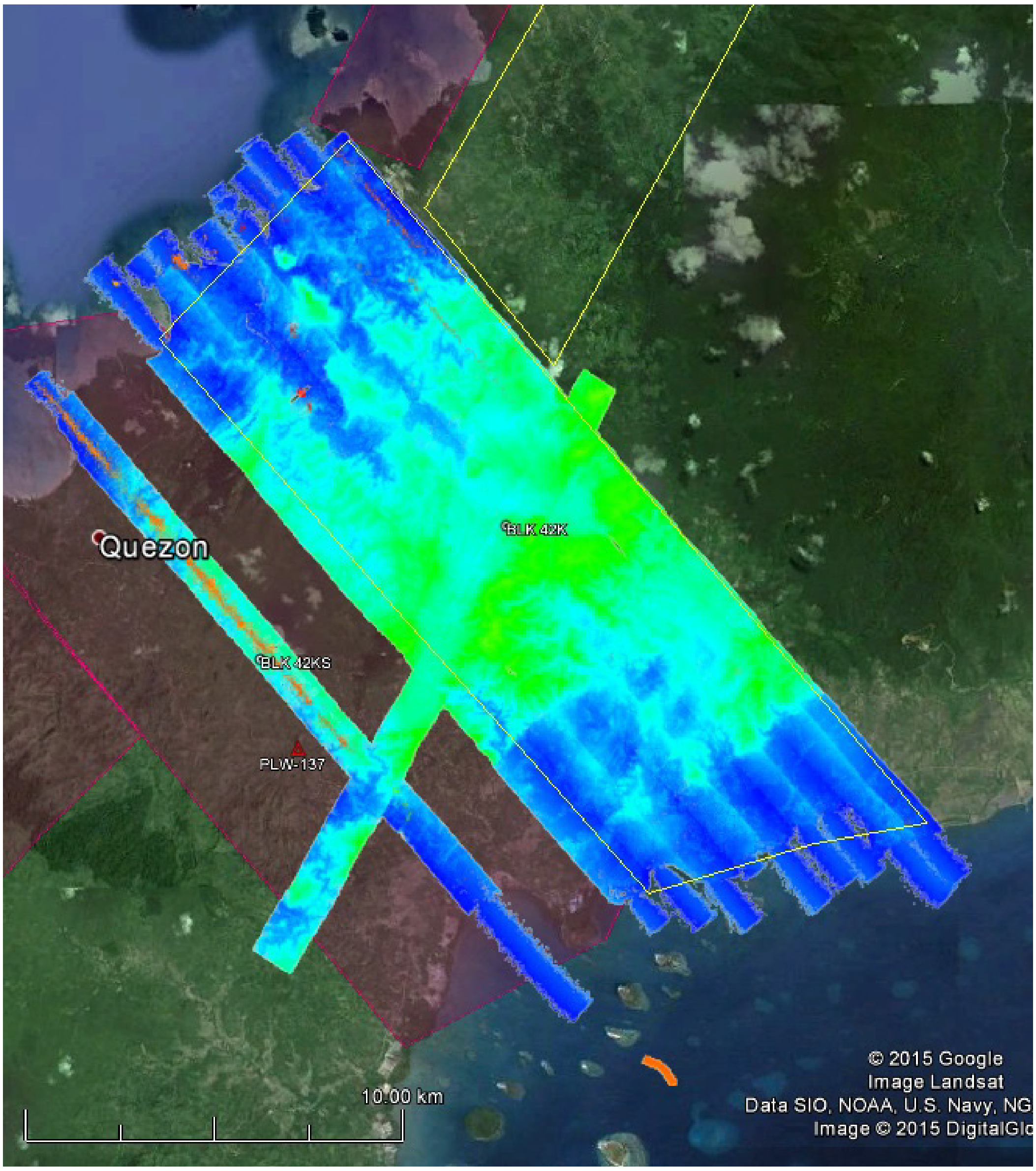


Figure A-7.2. Swath for Flight No. 3039P

Flight No. :	3167P		
Area:	BLK 42JS		
Mission Name:	1BLK42JS194B		
Parameters:	PRF 200	SF 30	FOV 50

LAS

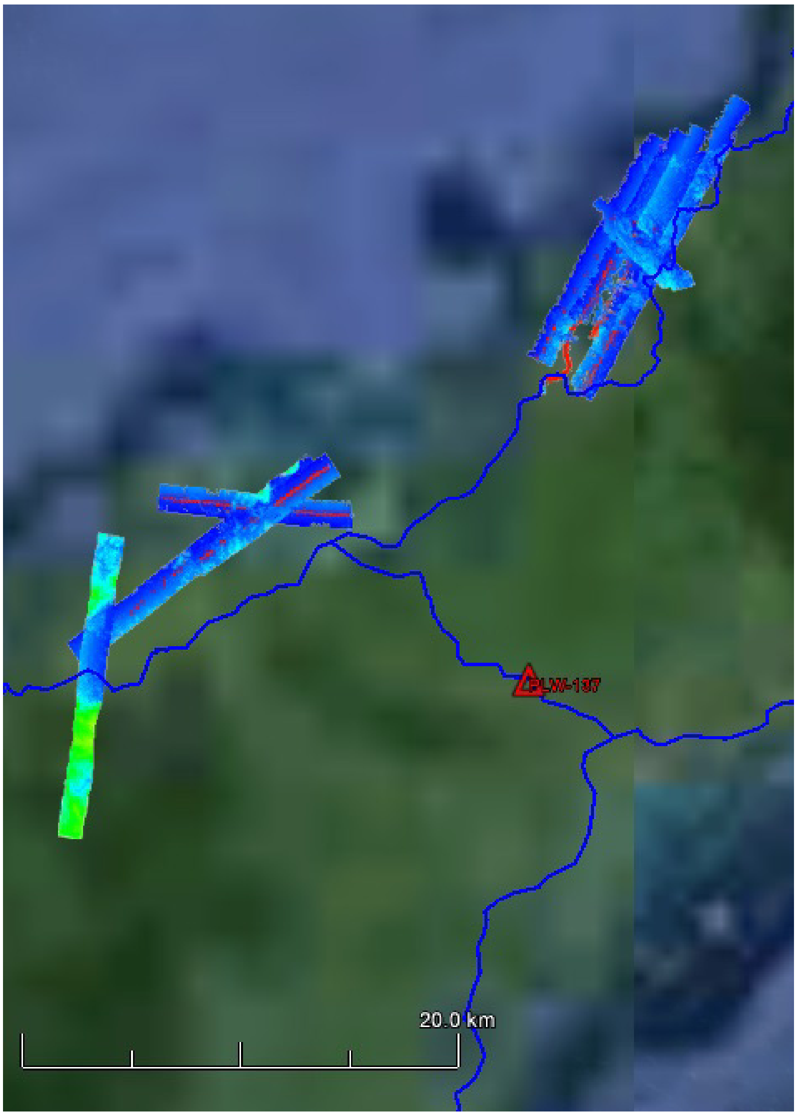


Figure A-7.4. Swath for Flight No. 3167P

Flight No. :	3173P		
Area:	BLK 42KS		
Mission Name:	1BLK42KS196A		
Parameters:	PRF 200	SF 30	FOV 50

LAS

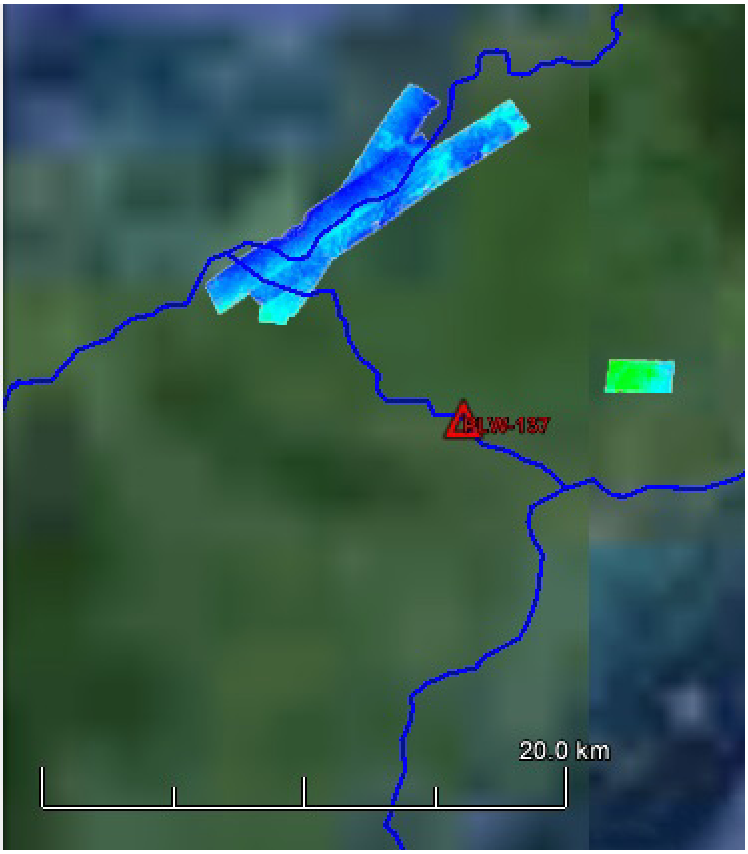


Figure A-7.5. Swath for Flight No. 3173P

Flight No. :	3557G		
Area:	BLK 42 H, L		
Mission Name:	2BLK45HsL335A		
Parameters:	PRF 125	SF 30	FOV 40

LAS/SWATH

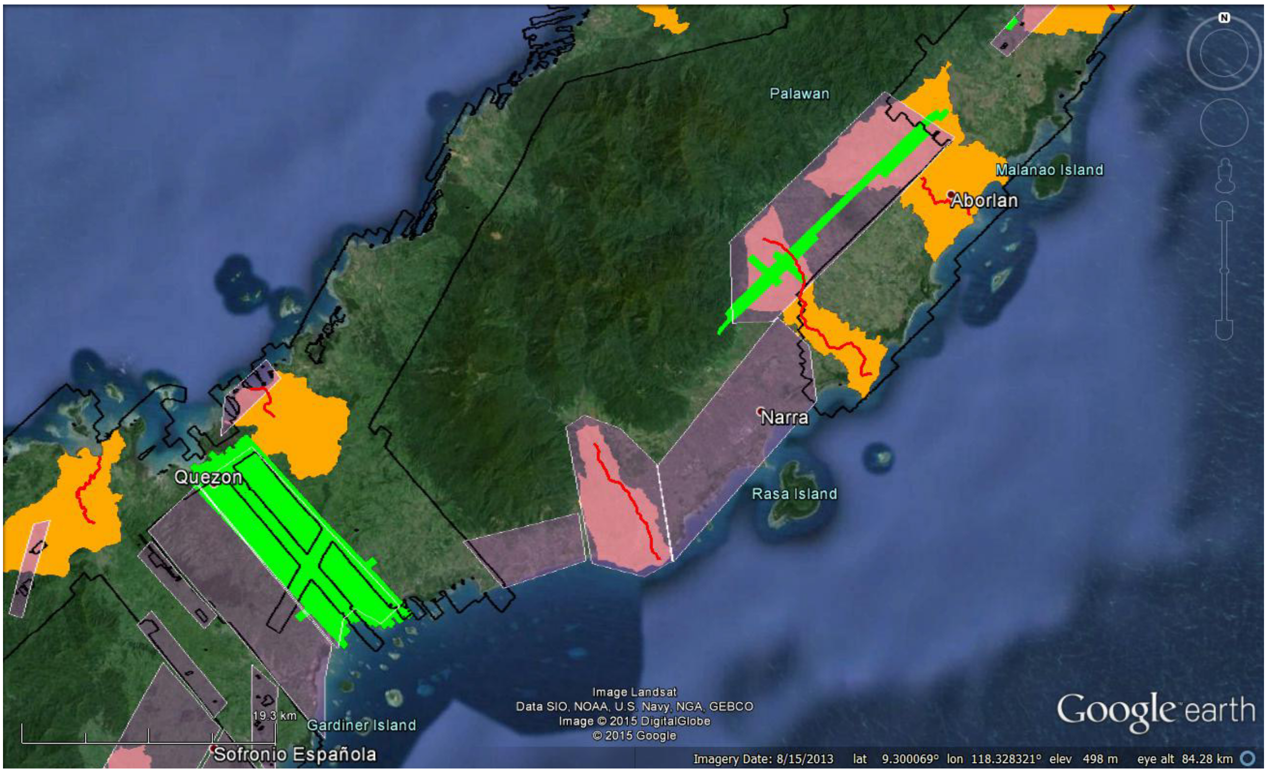


Figure A-7.6. Swath for Flight No. 3557G

Annex 8. Mission Summary Report

Flight Area	West Palawan
Mission Name	Blk42J
Inclusive Flights	3037P
Range data size	31.80 GB
Base data size	1.05 MB
POS	217 MB
Image	45.30 GB
Transfer date	July 13, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	No
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.25
RMSE for East Position (<4.0 cm)	2.50
RMSE for Down Position (<8.0 cm)	4.44
Boresight correction stdev (<0.001deg)	0.000422
IMU attitude correction stdev (<0.001deg)	0.000296
GPS position stdev (<0.01m)	0.0024
Minimum % overlap (>25)	34.23
Ave point cloud density per sq.m. (>2.0)	2.74
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	222
Maximum Height	592.12 m
Minimum Height	50.49 m
Classification (# of points)	
Ground	82,088,710
Low vegetation	48,023,547
Medium vegetation	134,523,291
High vegetation	554,014,637
Building	4,661,408
Orthophoto	Yes
Processed by	Engr. Regis Guhiting, Engr. Chelou Prado, Engr..Krisha Marie Bautista

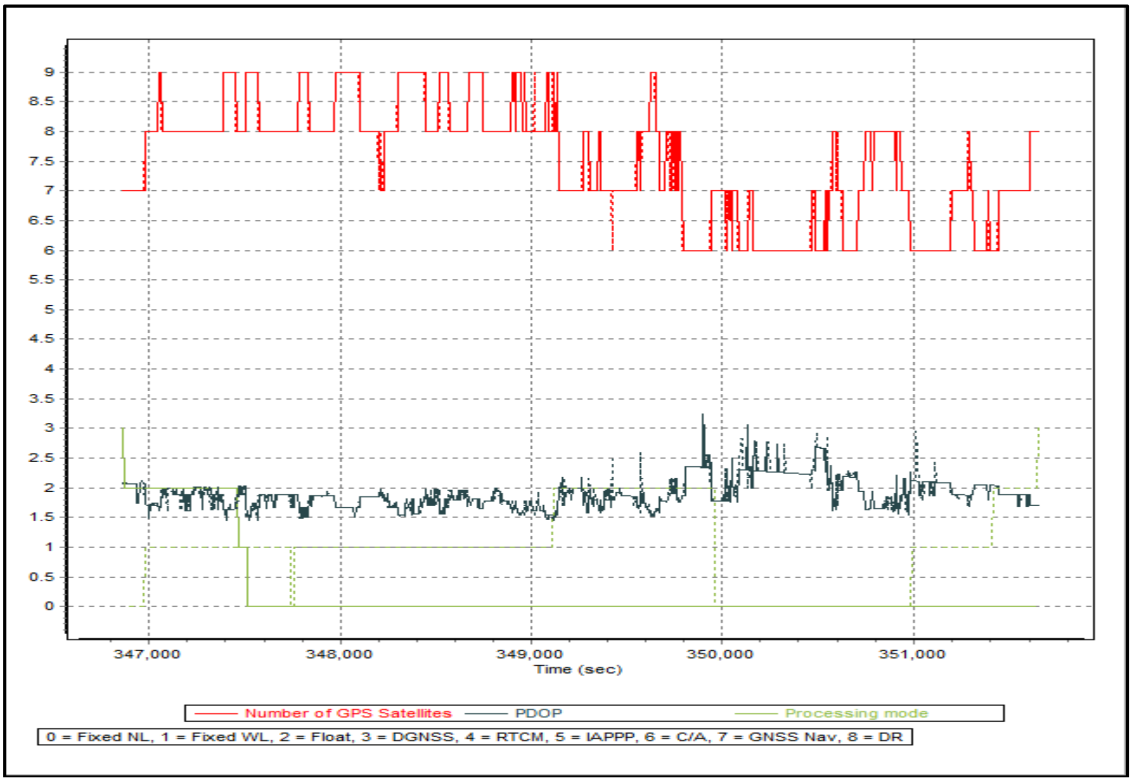


Figure A-8.1. Solution Status

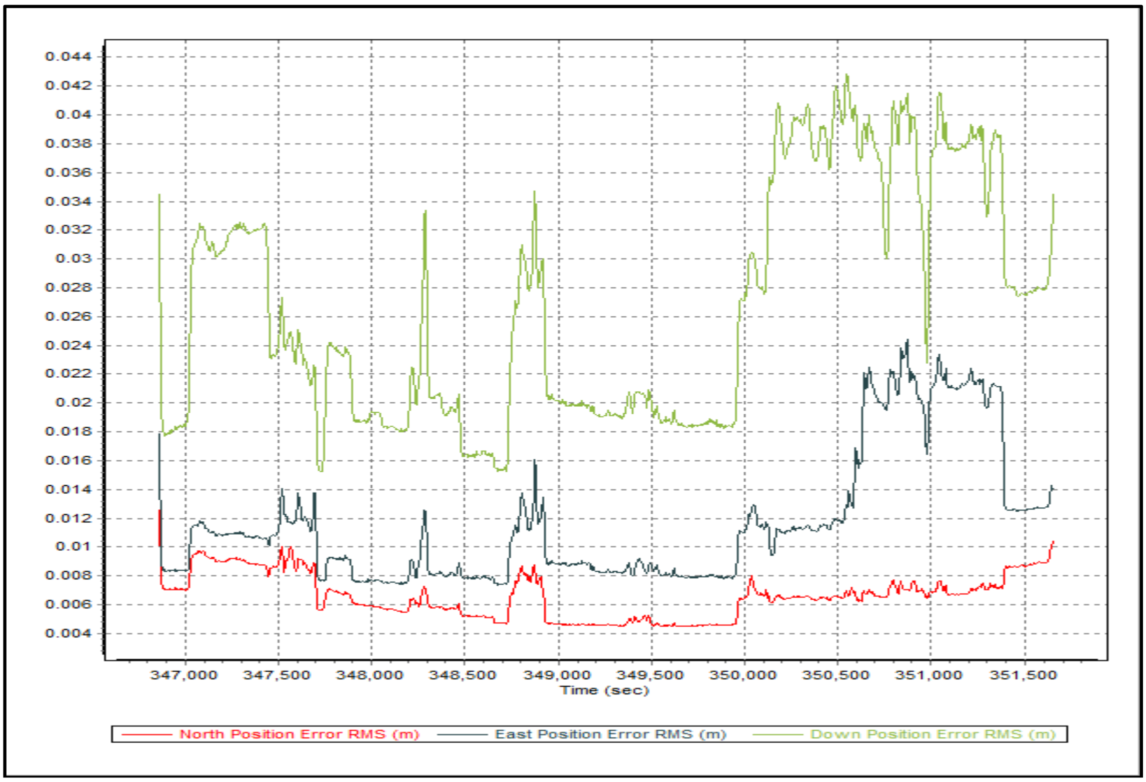


Figure A-8.2. Smoothed Performance Metric Parameters

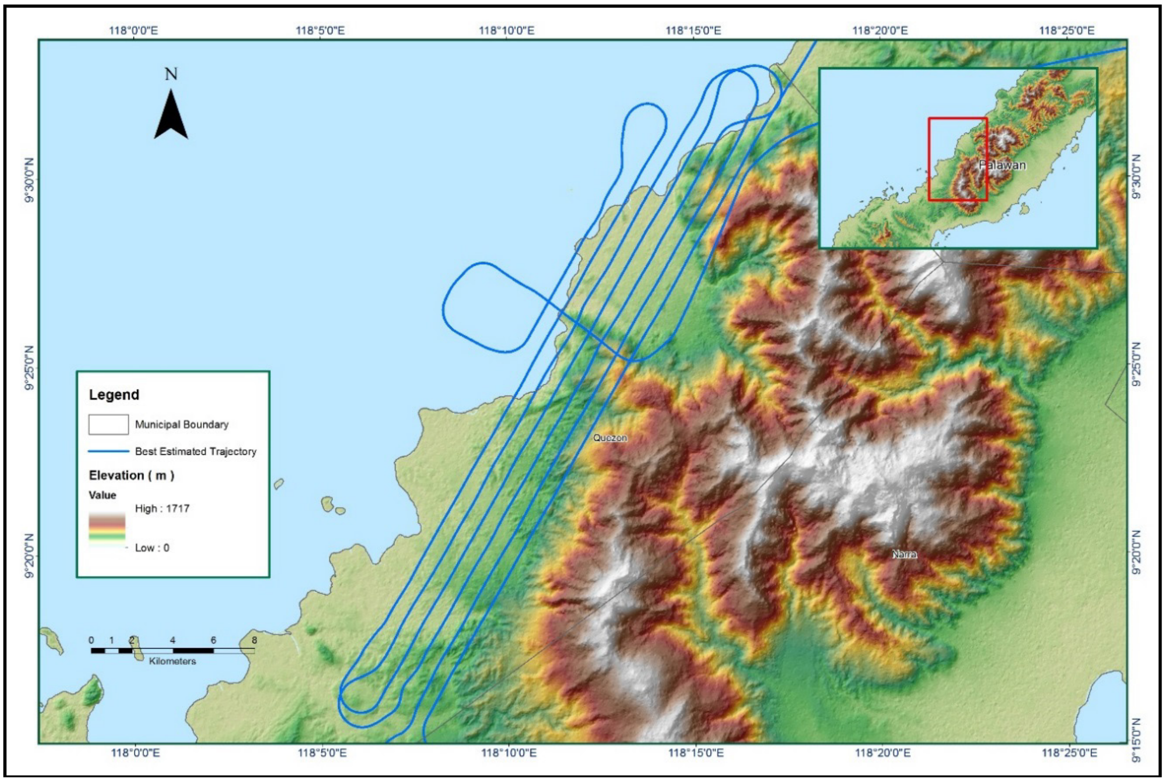


Figure A-8.3. Best Estimated Trajectory

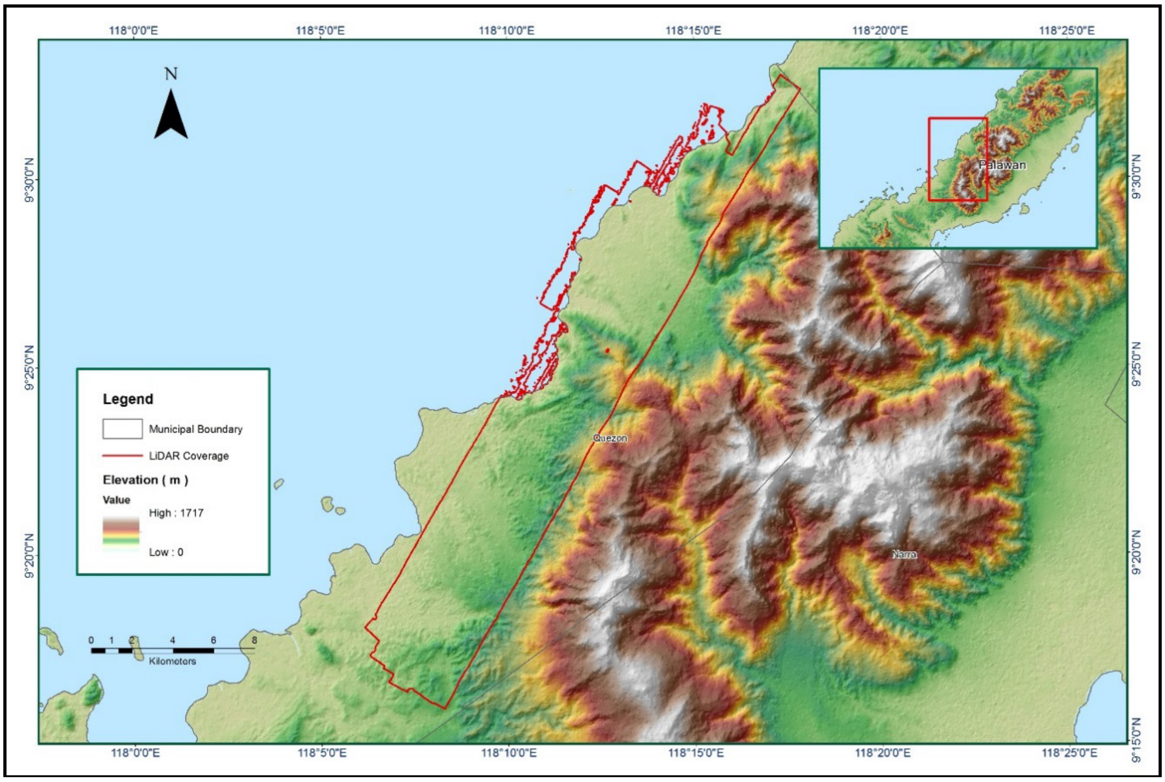


Figure A-8.4. Coverage of LiDAR data

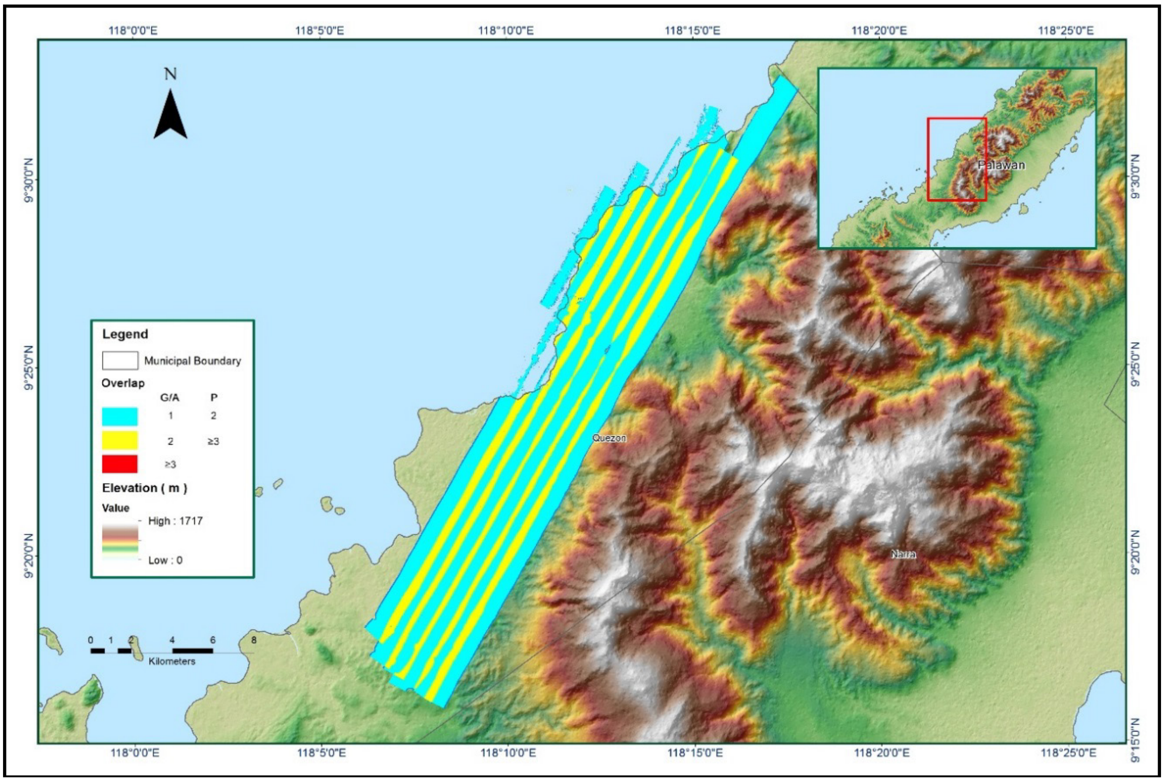


Figure A-8.5. Image of data overlap

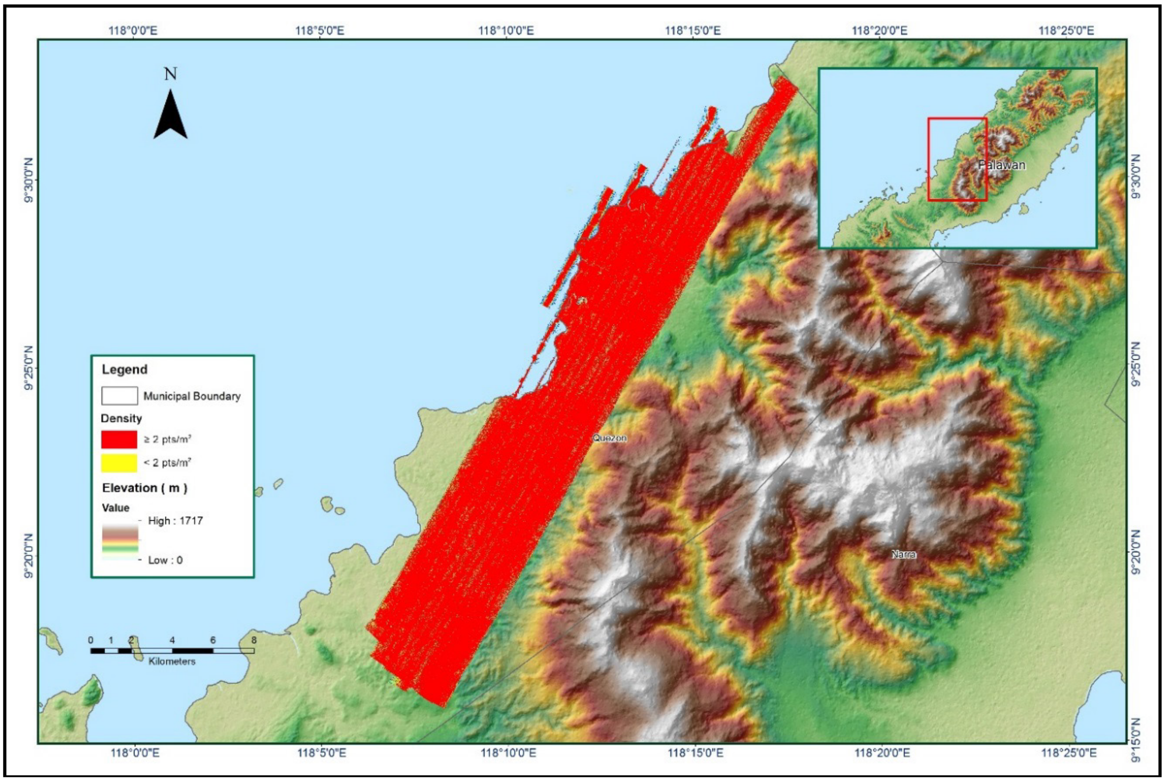


Figure A-8.6. Density map of merged LiDAR data

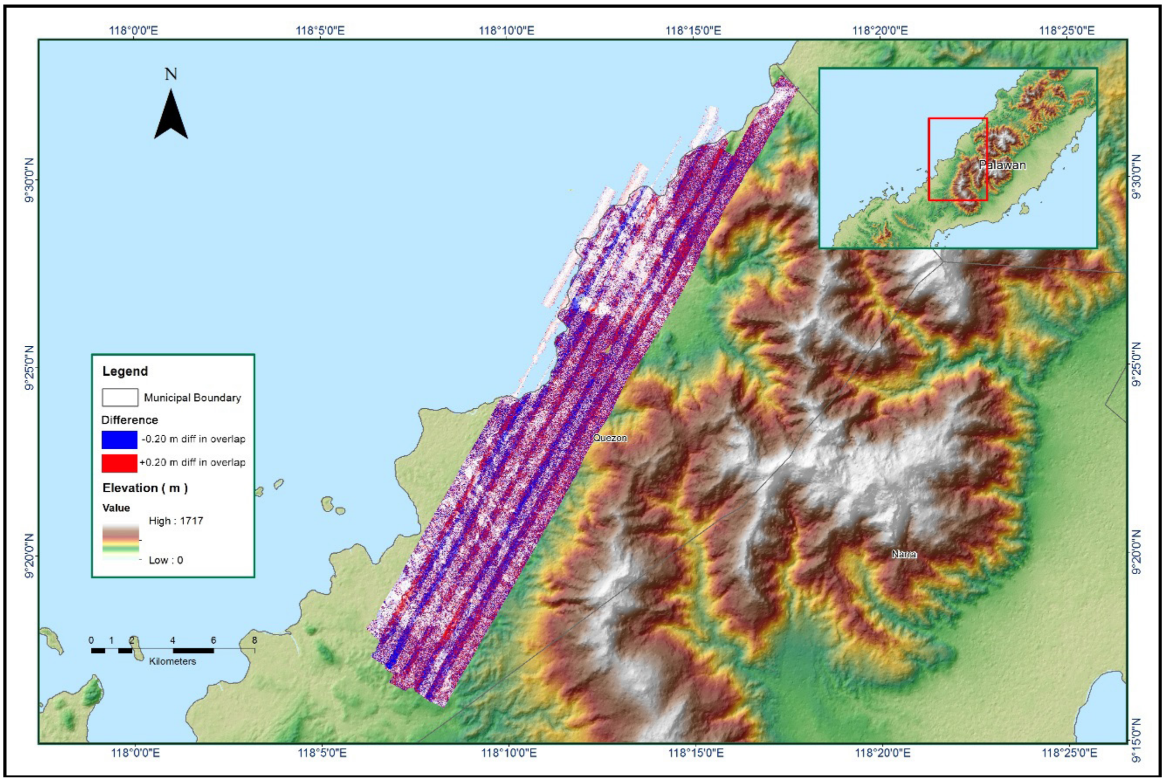


Figure A-8.7. Elevation difference between flight lines

Flight Area	West Palawan
Mission Name	Blk42J_Supplement
Inclusive Flights	3167P
Range data size	7.36 GB
Base data size	11.50 MB
POS	106 MB
Image	4.93 GB
Transfer date	August 5, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.30
RMSE for East Position (<4.0 cm)	1.45
RMSE for Down Position (<8.0 cm)	3.10
Boresight correction stdev (<0.001deg)	0.000650
IMU attitude correction stdev (<0.001deg)	0.000169
GPS position stdev (<0.01m)	0.0019
Minimum % overlap (>25)	19.13
Ave point cloud density per sq.m. (>2.0)	2.04
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	75
Maximum Height	173.82
Minimum Height	42.2
Classification (# of points)	
Ground	30247858
Low vegetation	25978818
Medium vegetation	23892450
High vegetation	60506663
Building	1052914
Orthophoto	No
Processed by	Engr. Sheila-Maye Santillan, Engr. Edgardo Gubatanga, Jr., Alex John Escobido

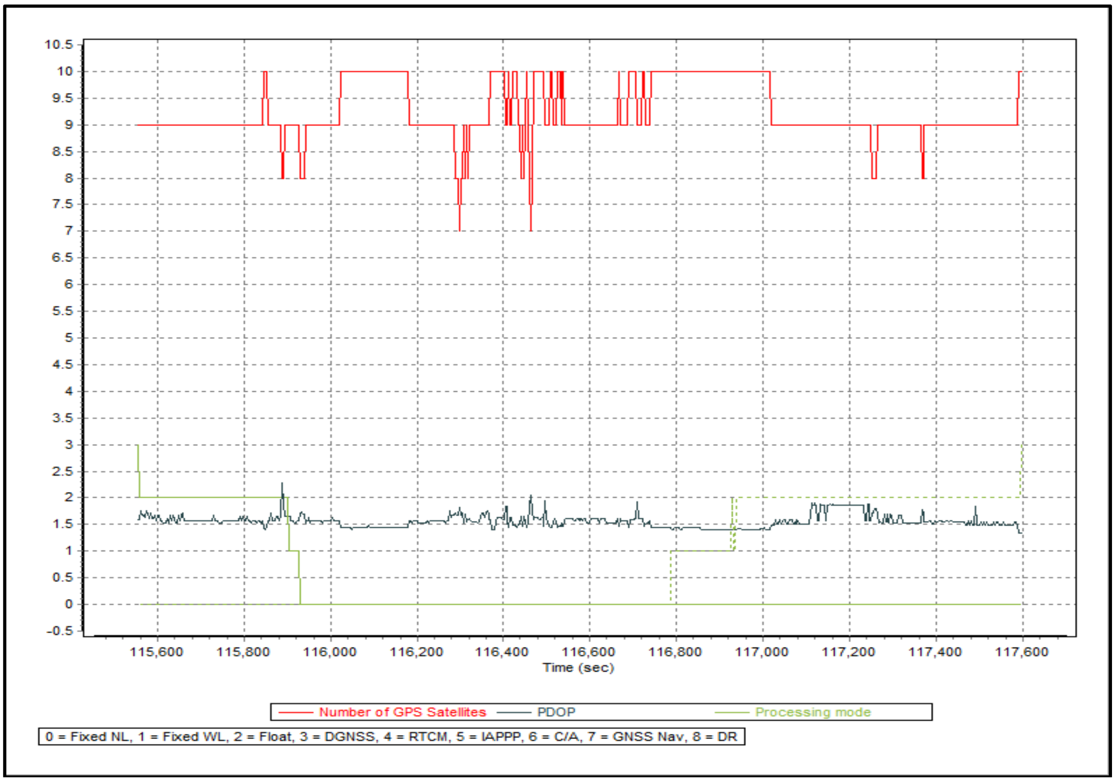


Figure A-8.8. Solution Status

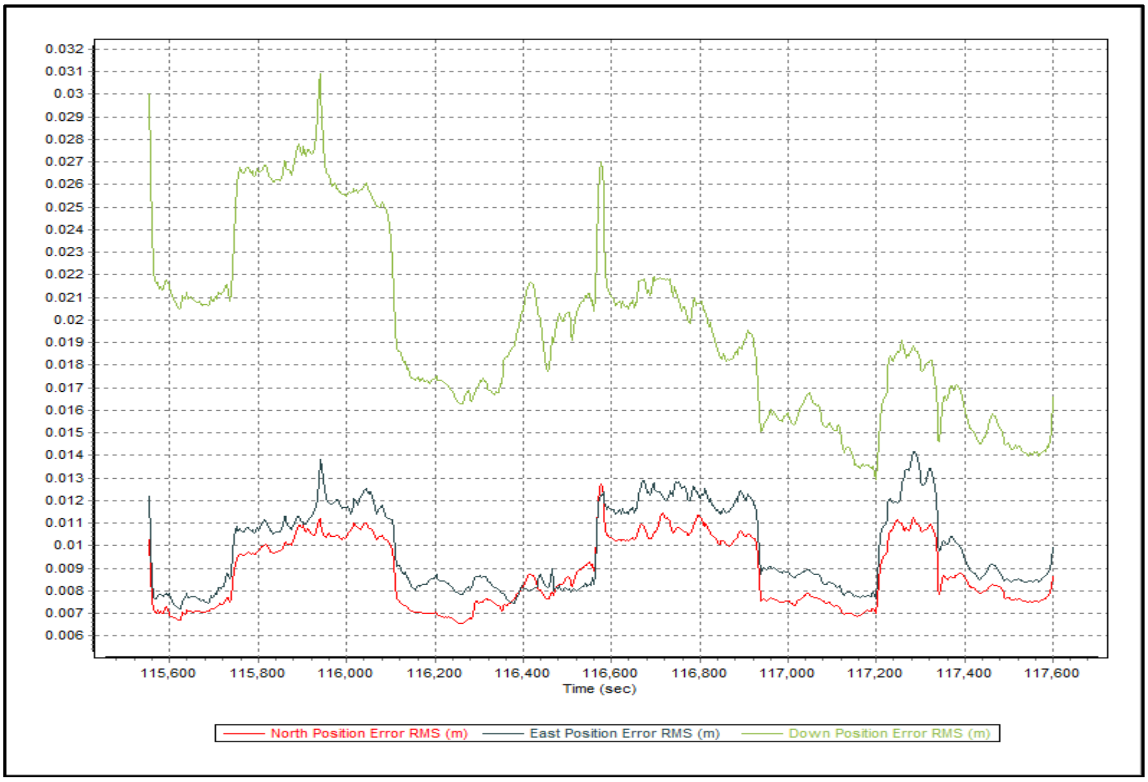


Figure A-8.9. Smoothed Performance Metric Parameters

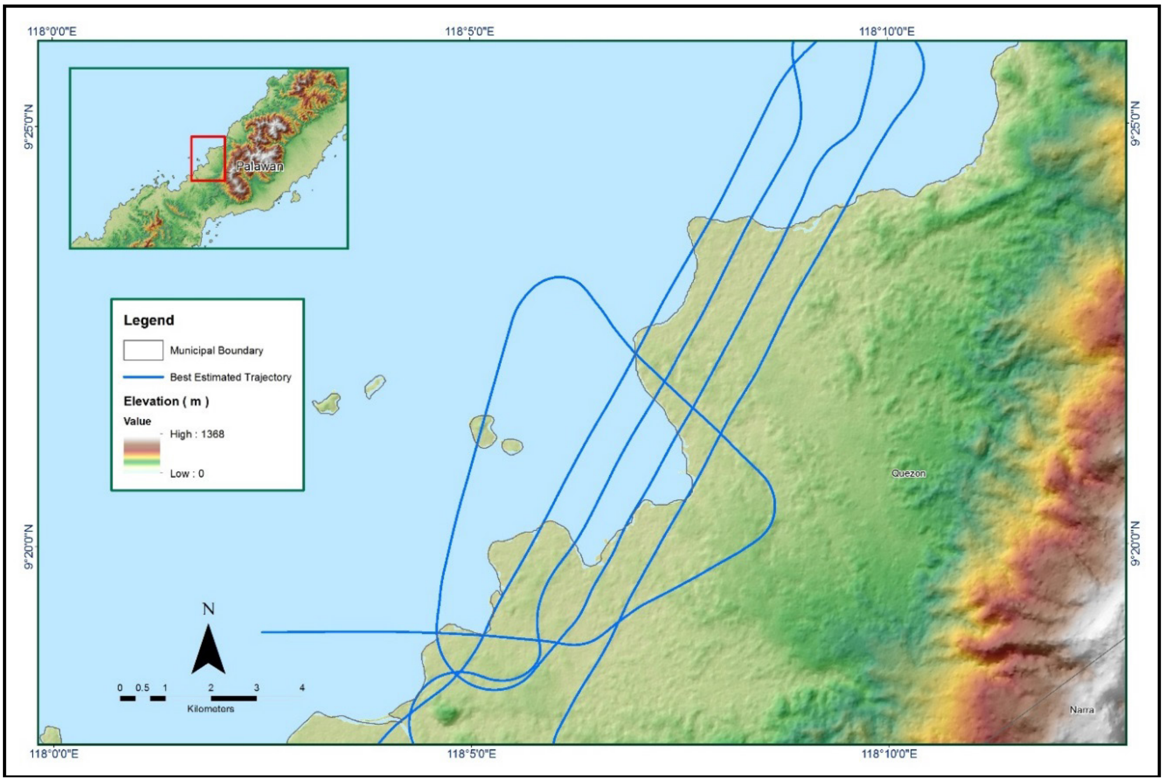


Figure A-8.10. Best Estimated Trajectory

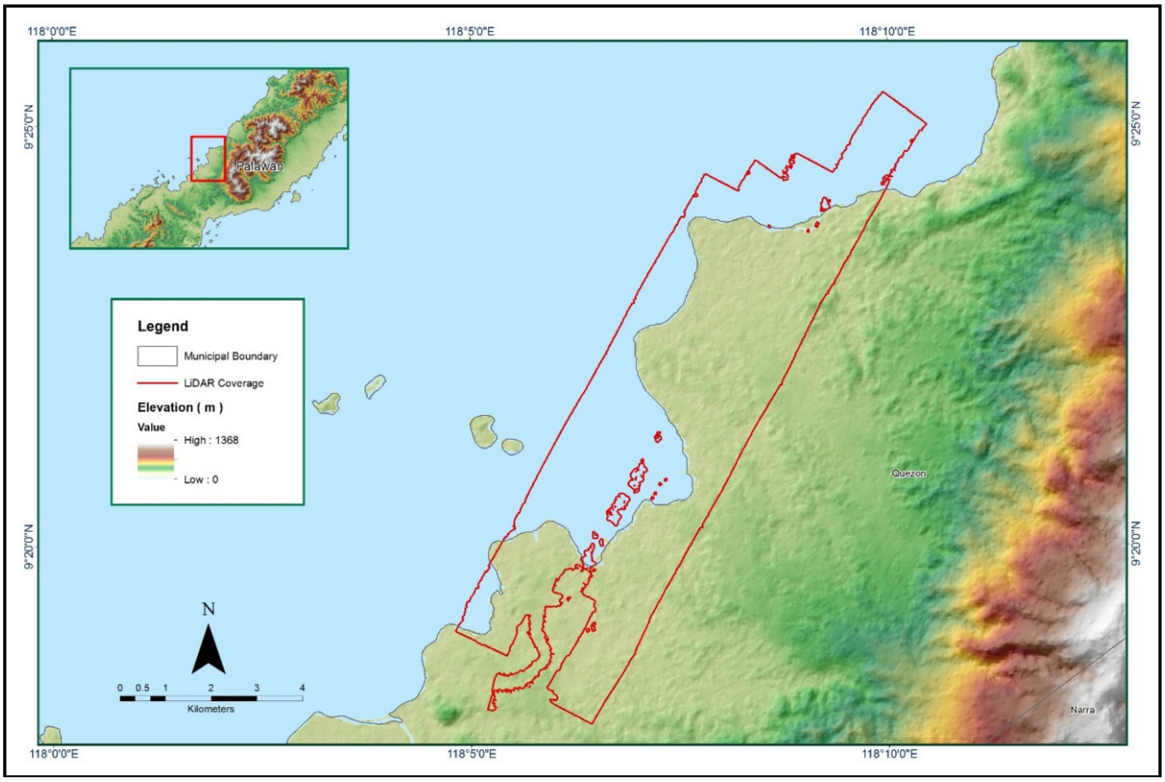


Figure A-8.11. Coverage of LiDAR data

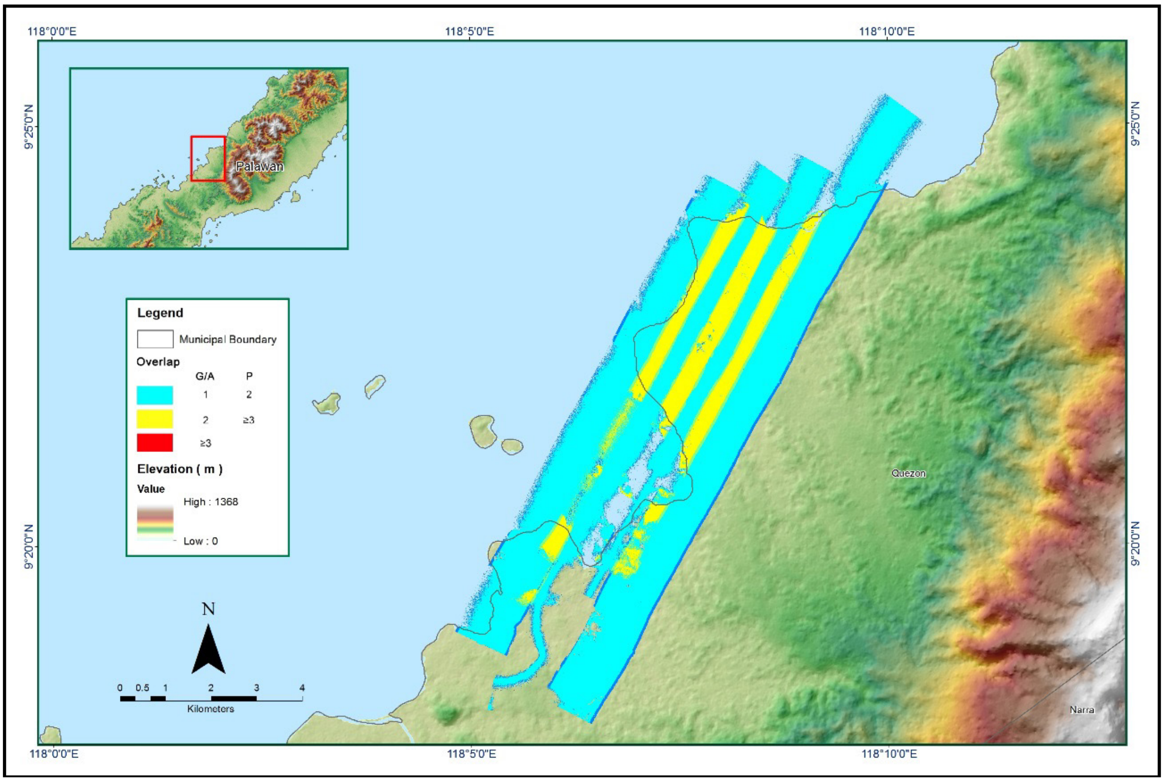


Figure A-8.12. Image of data overlap

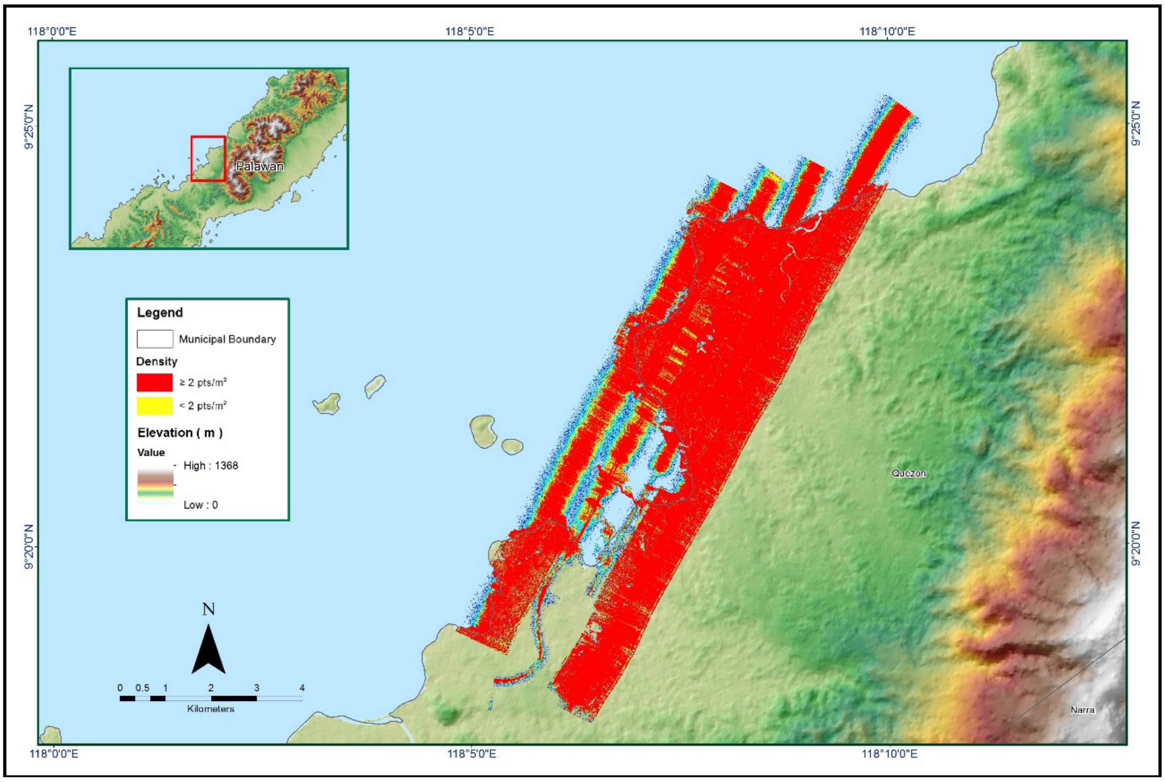


Figure A-8.13. Density map of merged LiDAR data

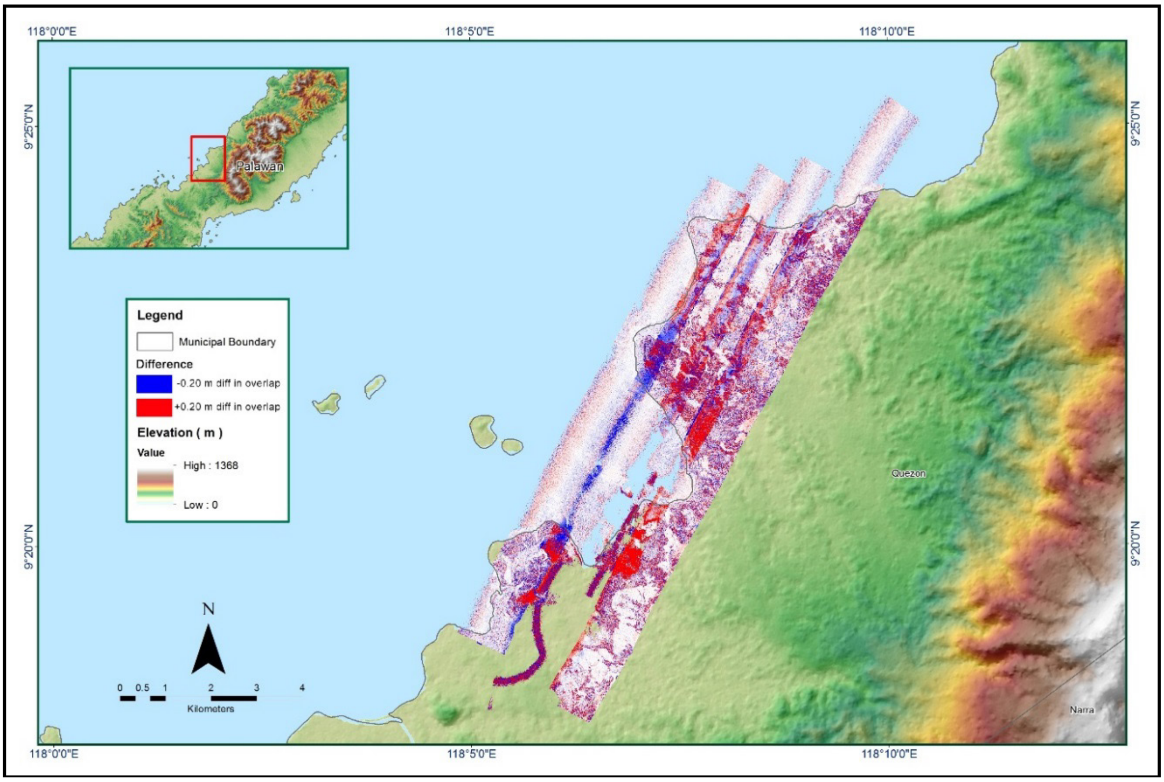


Figure A-8.14. Elevation difference between flight lines

Flight Area	West Palawan
Mission Name	Blk42K
Inclusive Flights	3039P
Range data size	17.50 GB
Base data size	3.90 MB
POS	167 MB
Image	20.40 GB
Transfer date	July 13, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	2.20
RMSE for East Position (<4.0 cm)	2.30
RMSE for Down Position (<8.0 cm)	3.20
Boresight correction stdev (<0.001deg)	0.000133
IMU attitude correction stdev (<0.001deg)	0.000101
GPS position stdev (<0.01m)	0.0011
Minimum % overlap (>25)	24.56
Ave point cloud density per sq.m. (>2.0)	2.43
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	314
Maximum Height	385.37
Minimum Height	42.2
Classification (# of points)	
Ground	172405687
Low vegetation	100371279
Medium vegetation	215300963
High vegetation	478171928
Building	9800683
Orthophoto	Yes
Processed by	Engr. Regis Guhiting, Engr. Merven Matthew Natino, Kathryn Claudyn Zarate

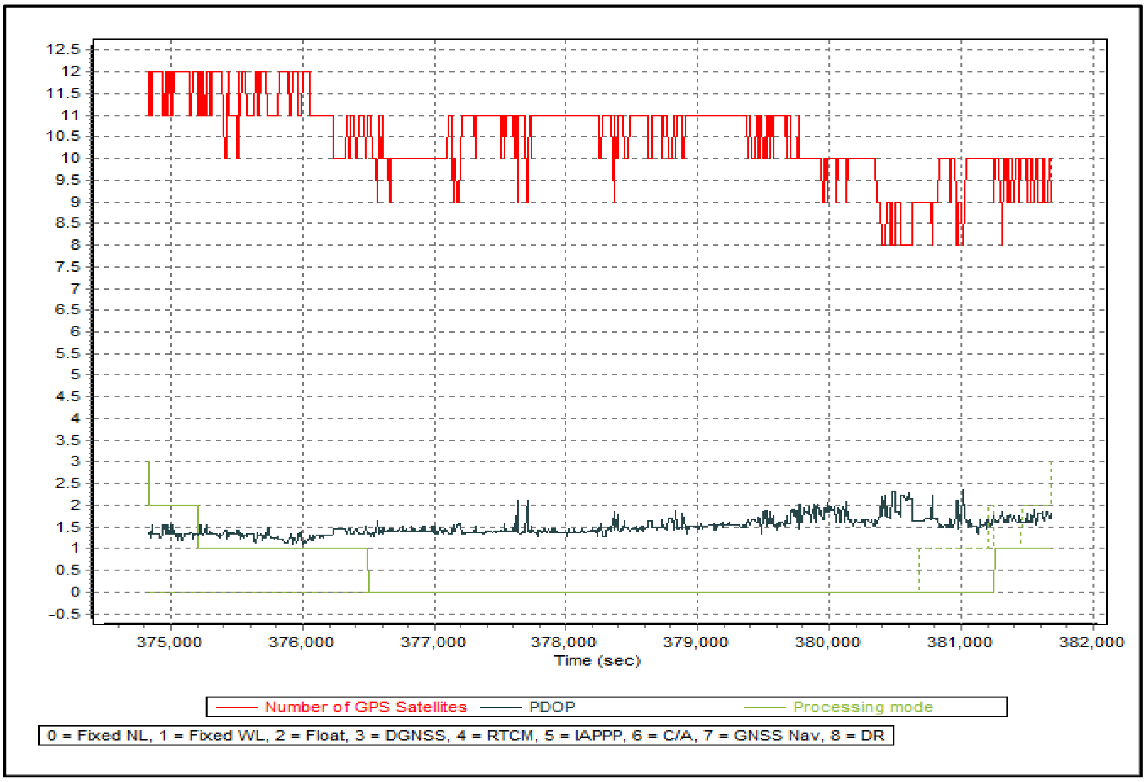


Figure A-8.15. Solution Status

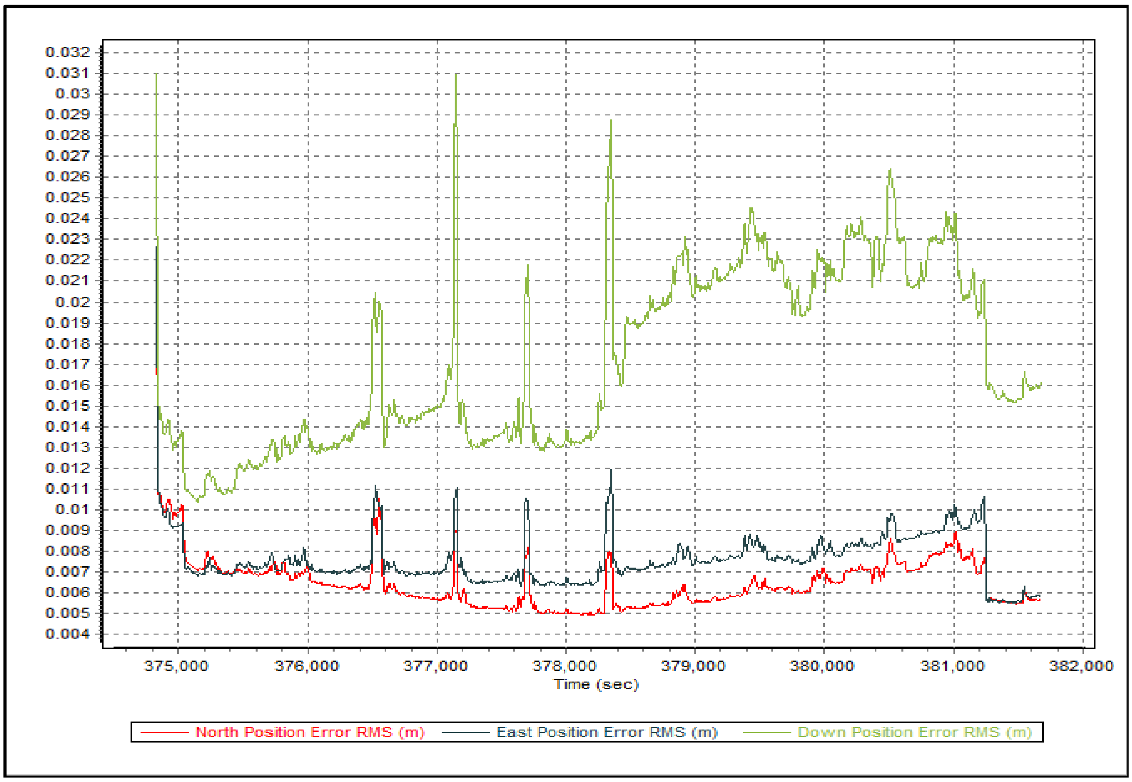


Figure A-8.16. Smoothed Performance Metric Parameters

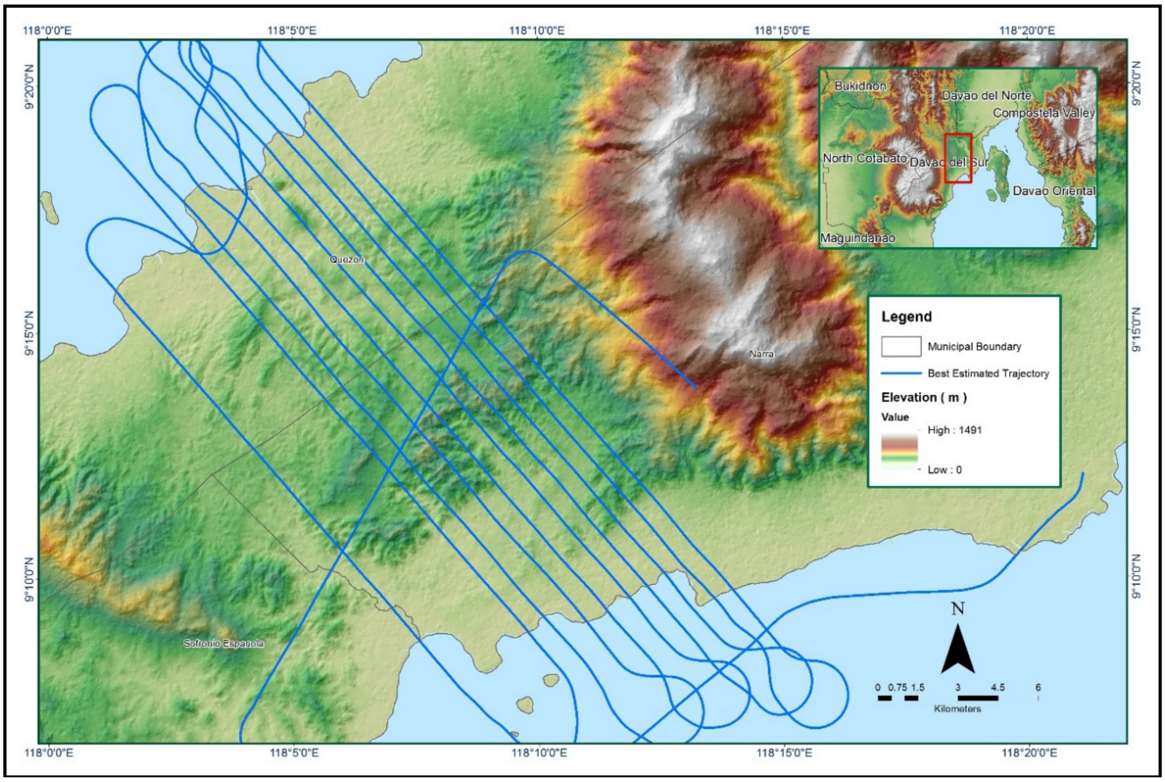


Figure A-8.17. Best Estimated Trajectory

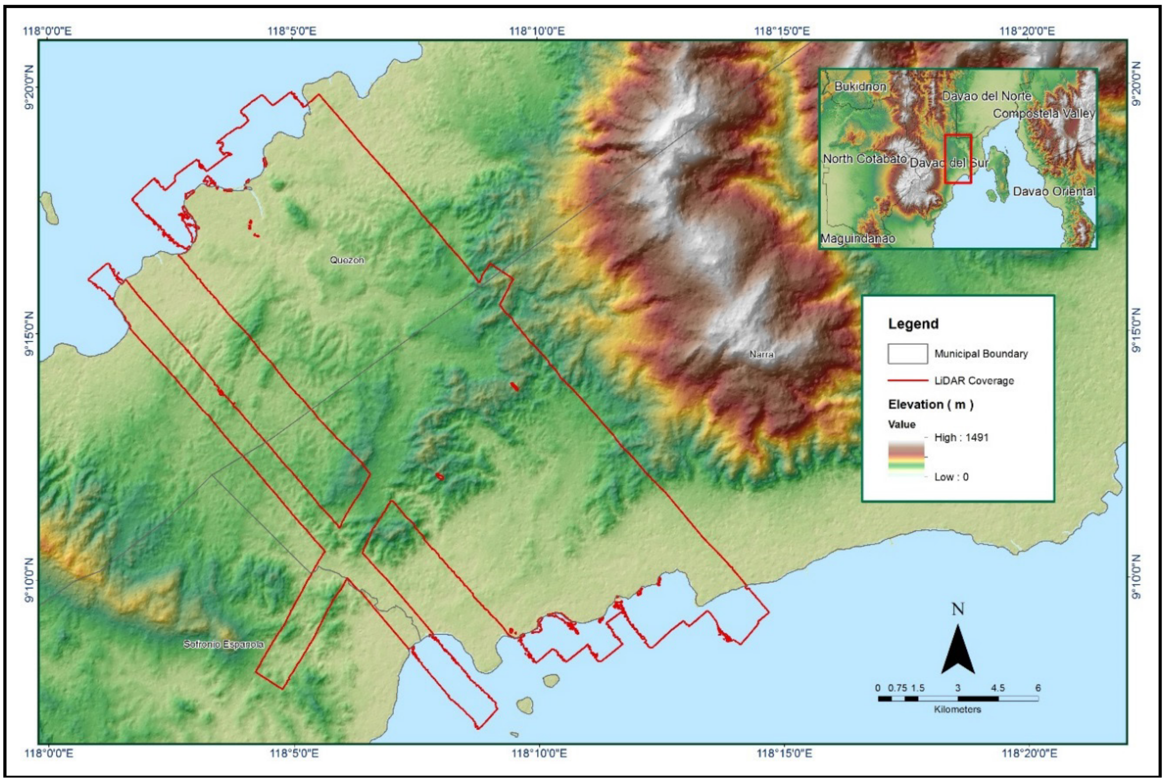


Figure A-8.18. Coverage of LiDAR data

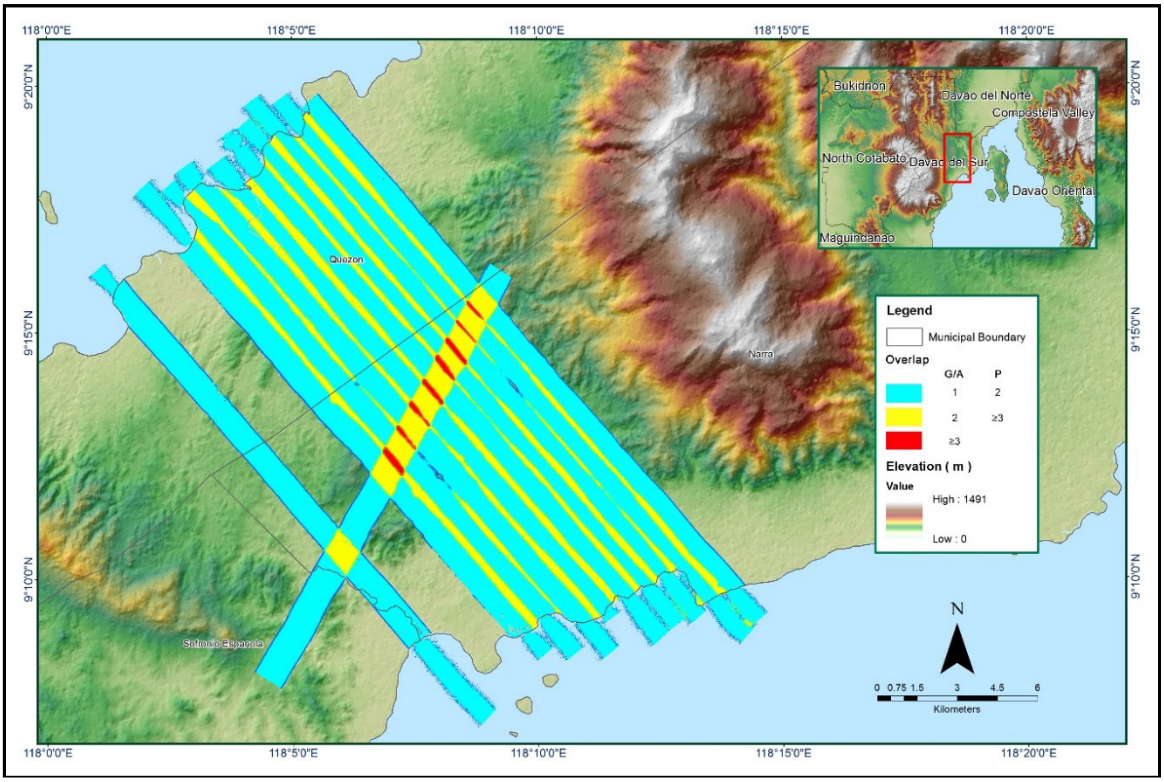


Figure A-8.19. Image of data overlap

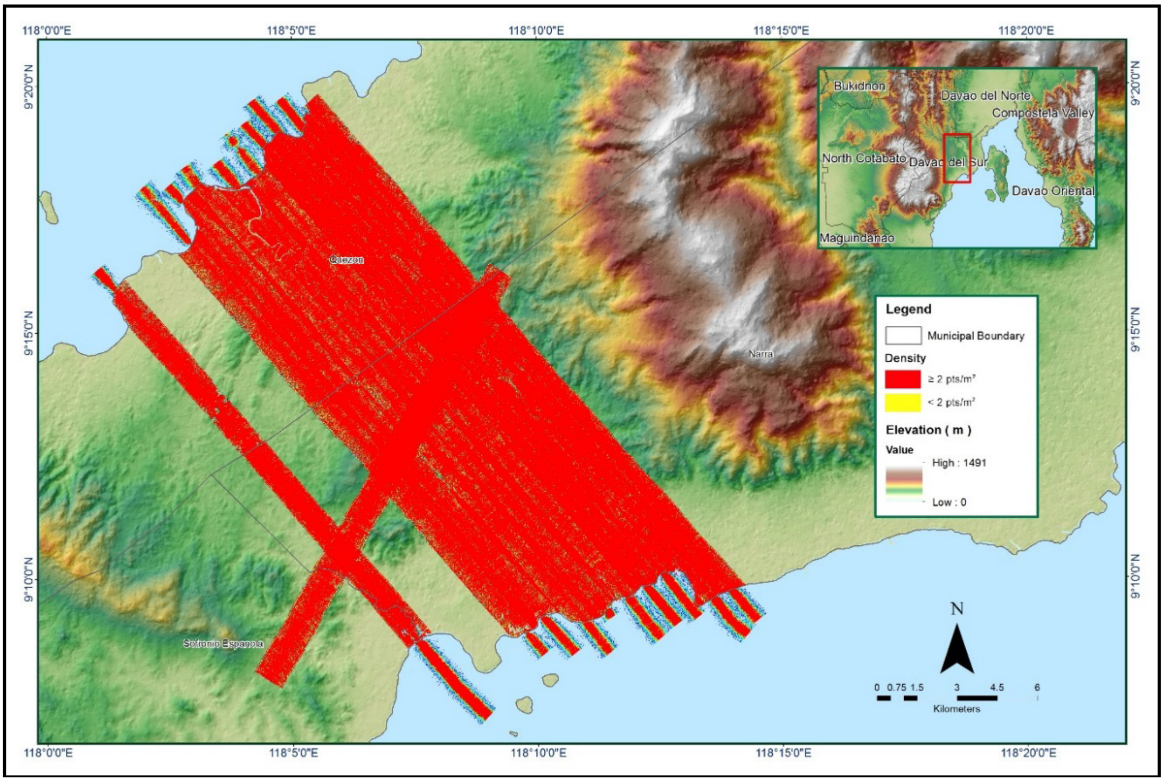


Figure A-8.20. Density map of merged LiDAR data

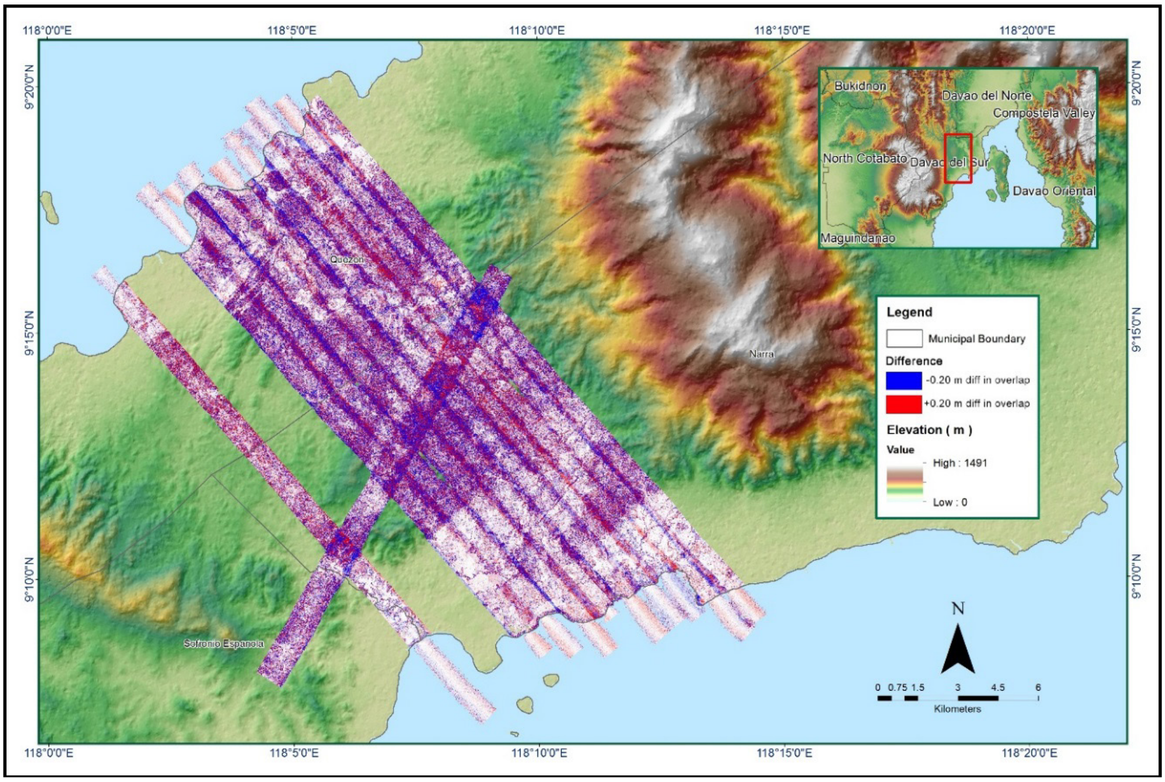


Figure A-8.21. Elevation difference between flight lines

Flight Area	West Palawan
Mission Name	Blk42K_Supplement
Inclusive Flights	3173P
Range data size	3.33 GB
Base data size	1.19 MB
POS	63.20 MB
Image	NA
Transfer date	August 5, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.35
RMSE for East Position (<4.0 cm)	1.55
RMSE for Down Position (<8.0 cm)	2.30
Boresight correction stdev (<0.001deg)	0.000150
IMU attitude correction stdev (<0.001deg)	0.000138
GPS position stdev (<0.01m)	0.0065
Minimum % overlap (>25)	15.01
Ave point cloud density per sq.m. (>2.0)	2.09
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	44
Maximum Height	160.1
Minimum Height	41.91
Classification (# of points)	
Ground	15549849
Low vegetation	7859839
Medium vegetation	18519062
High vegetation	53305508
Building	831612
Orthophoto	No
Processed by	Engr. Analyn Naldo, Engr. Antonio Chua Jr, Ryan Nicholai Dizon

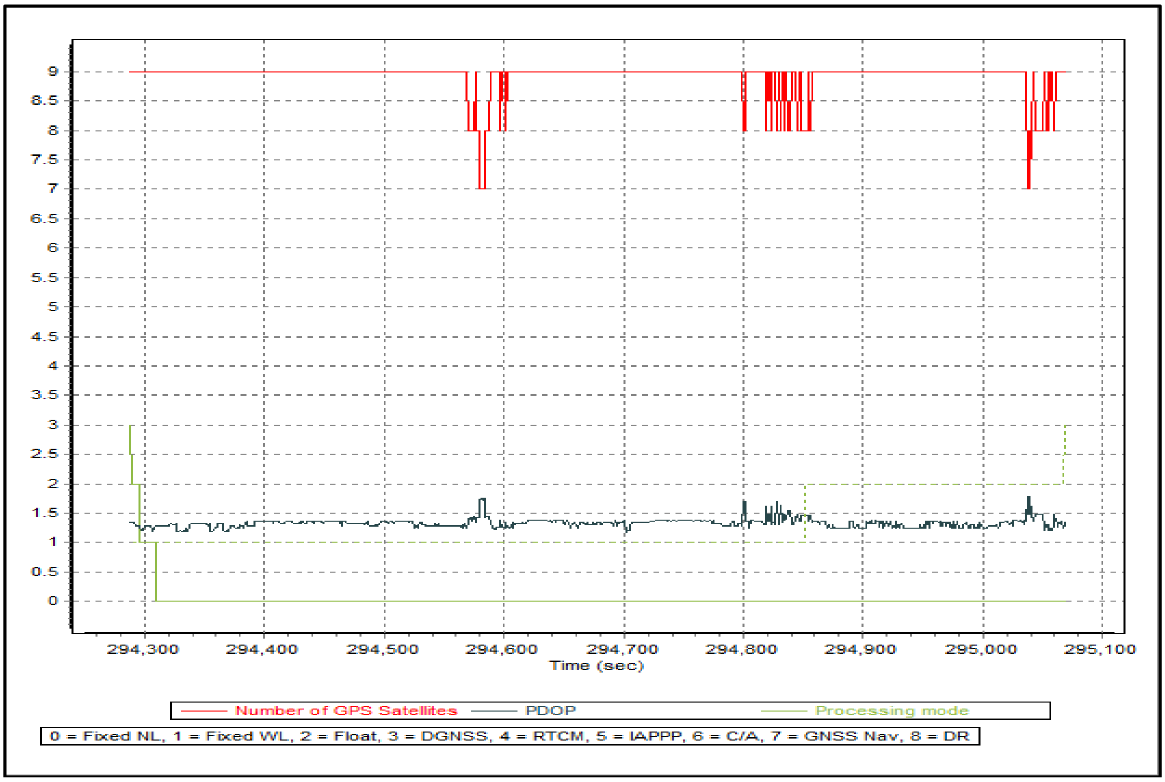


Figure A-8.22. Solution Status

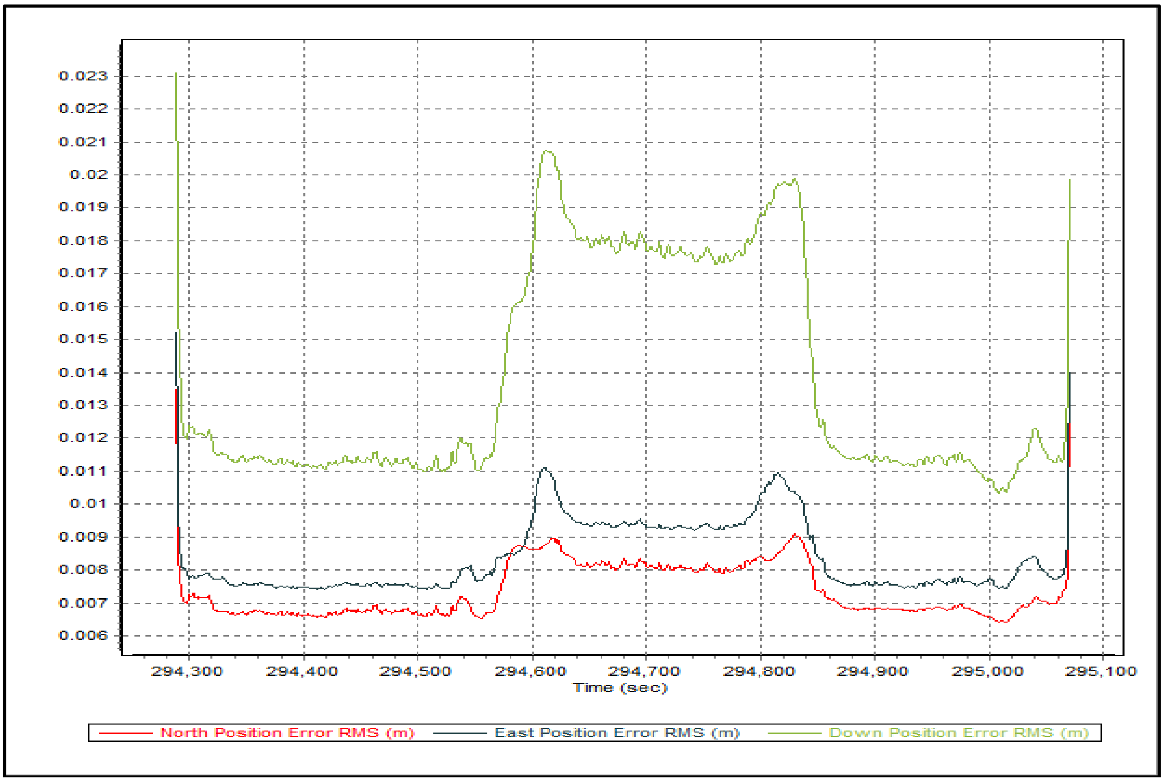


Figure A-8.23. Smoothed Performance Metric Parameters

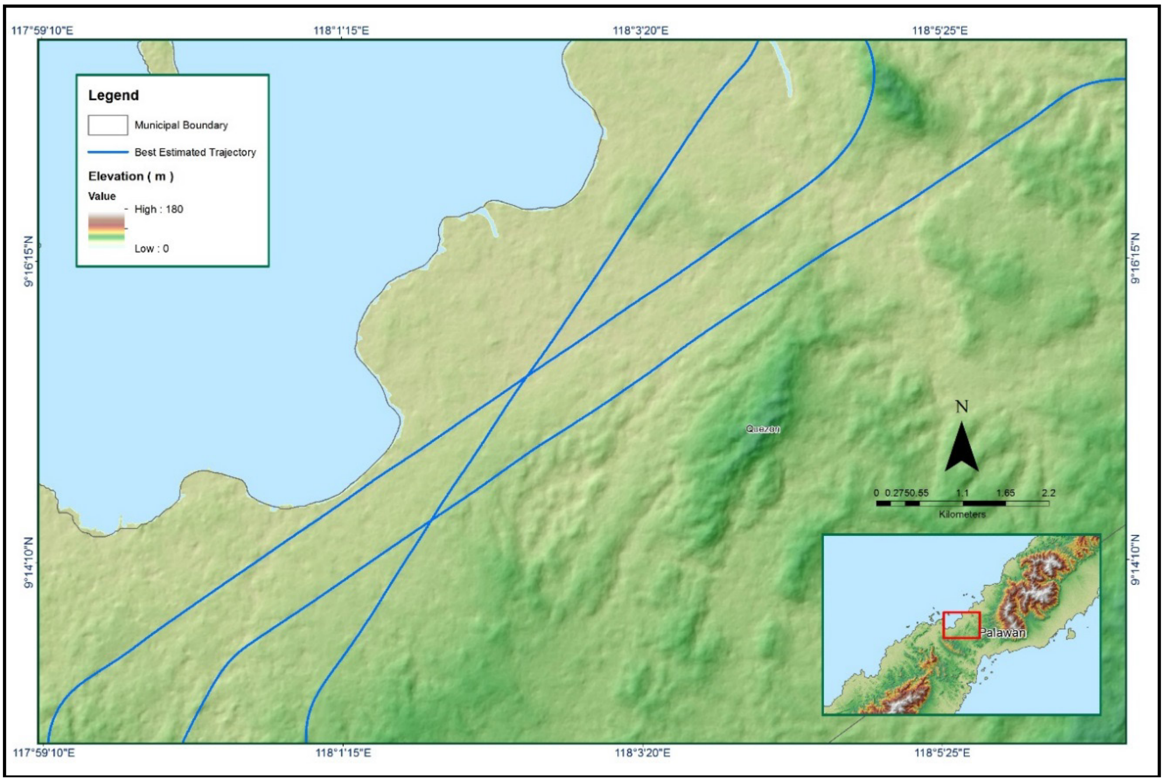


Figure A-8.24. Best Estimated Trajectory

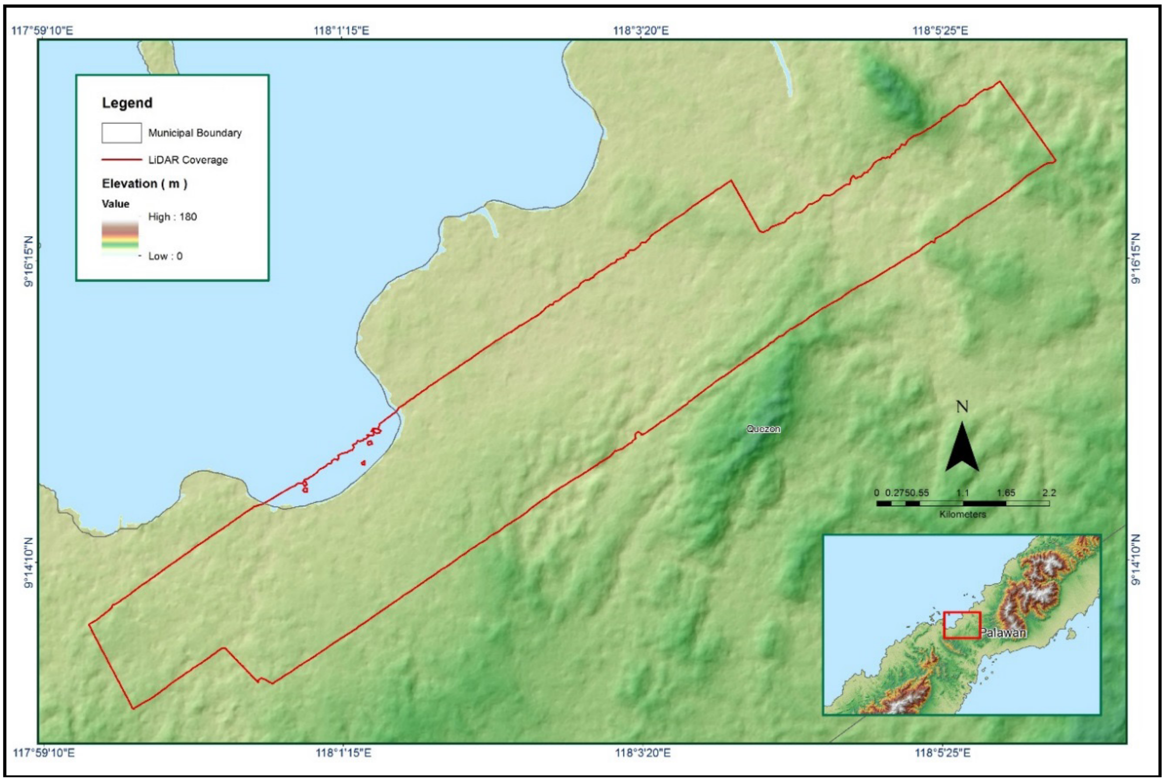


Figure A-8.25. Coverage of LiDAR data

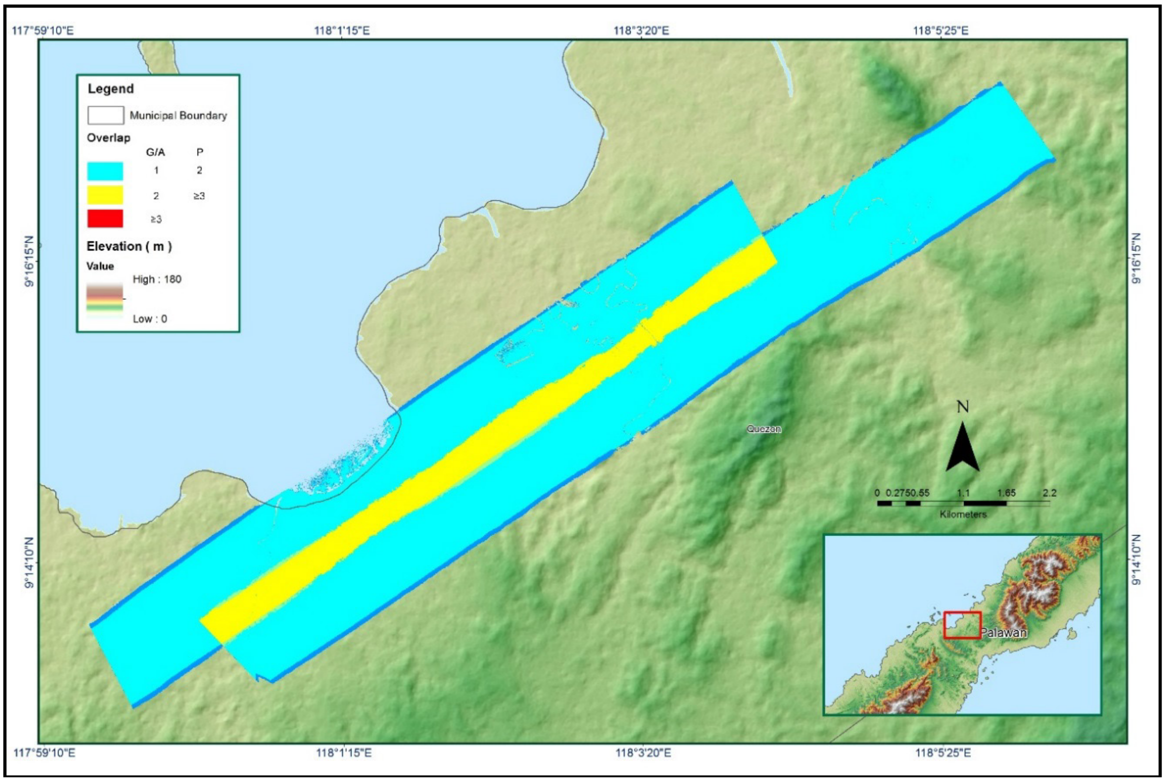


Figure A-8.26. Image of data overlap

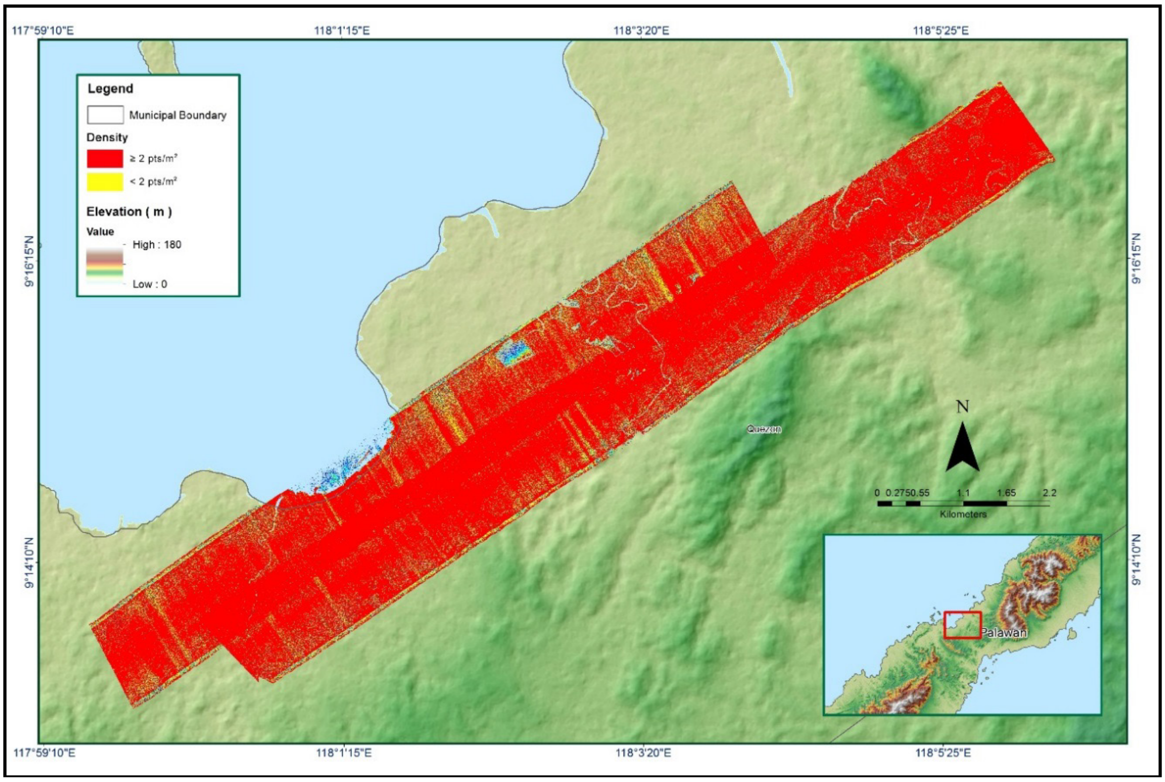


Figure A-8.27. Density map of merged LiDAR data

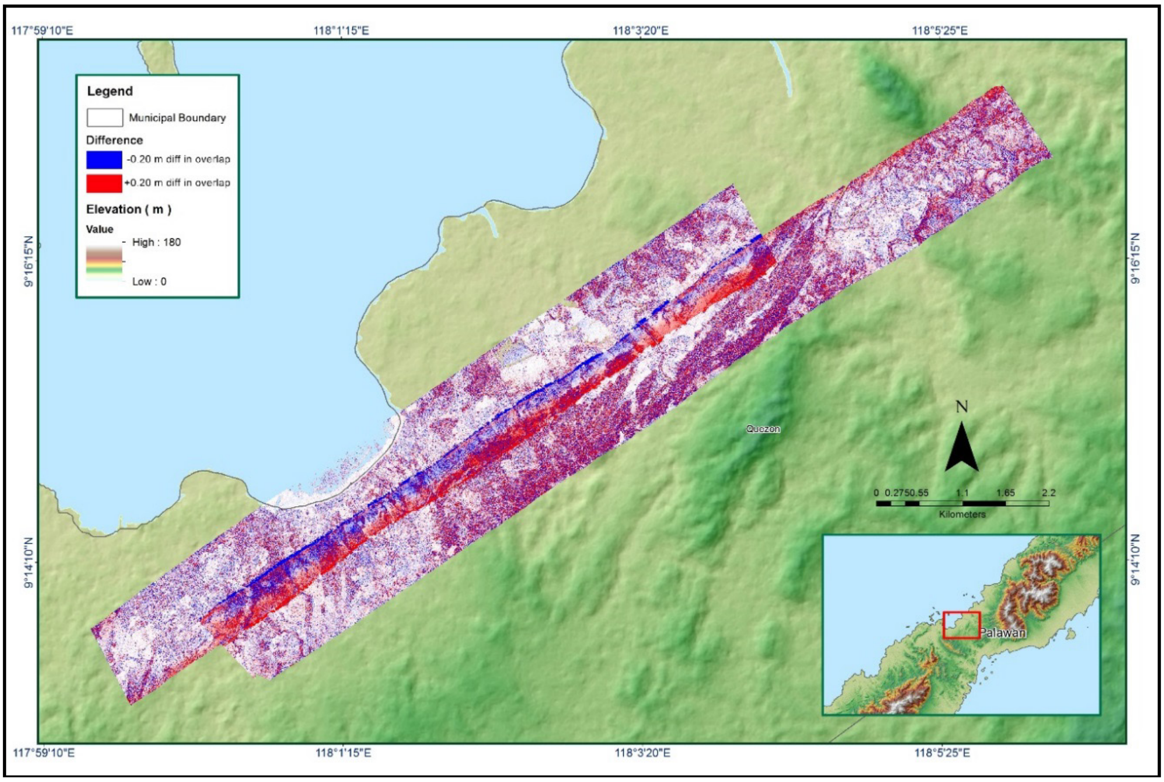


Figure A-8.28. Elevation difference between flight lines

Flight Area	Palawan Reflights
Mission Name	Blk42KS
Inclusive Flights	3557G
Range data size	19 GB
Base data size	4.3 MB
POS	195 MB
Image	NA
Transfer date	January 4, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.58
RMSE for East Position (<4.0 cm)	1.76
RMSE for Down Position (<8.0 cm)	5.91
Boresight correction stdev (<0.001deg)	0.000595
IMU attitude correction stdev (<0.001deg)	0.009918
GPS position stdev (<0.01m)	0.0299
Minimum % overlap (>25)	47.72%
Ave point cloud density per sq.m. (>2.0)	4.72
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	141
Maximum Height	349.78 m
Minimum Height	51.71 m
Classification (# of points)	
Ground	52,717,743
Low vegetation	31,158,820
Medium vegetation	150,647,188
High vegetation	177,824,464
Building	1,093,772.00
Ortophoto	No
Processed by	Engr. Analyn Naldo, Engr. Velina Angela Bemida, Jovy Narisma

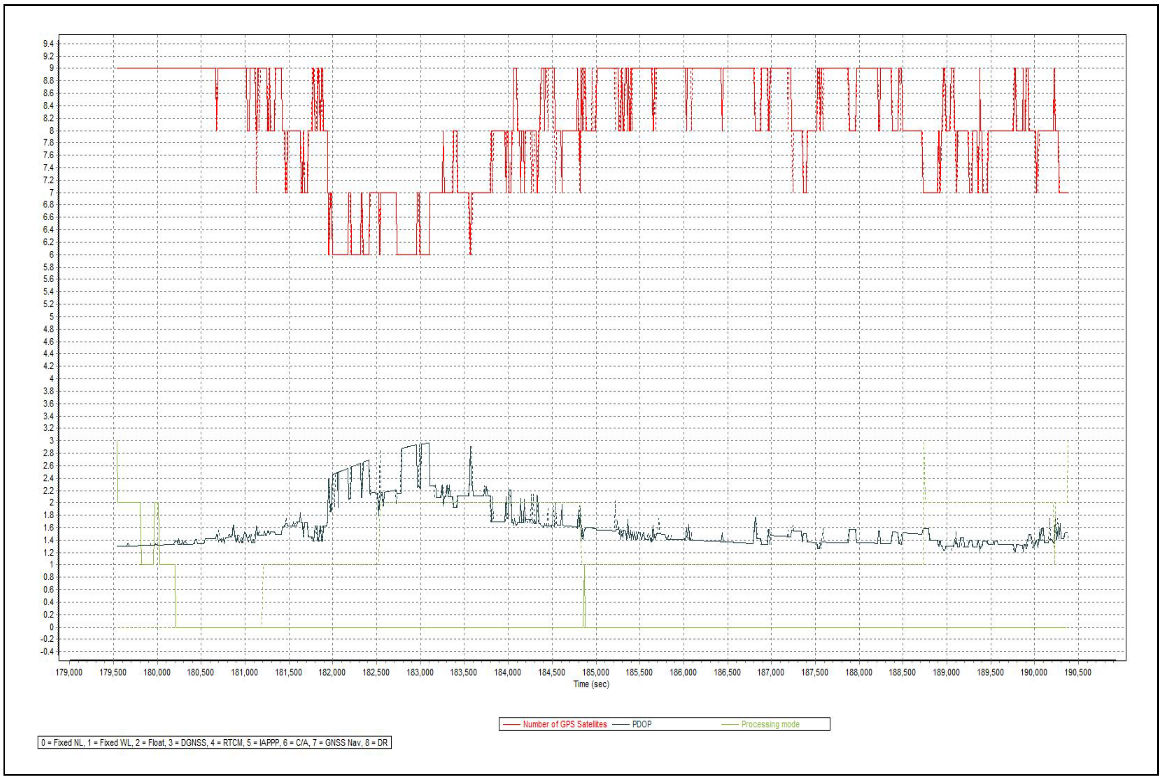


Figure A-8.29. Solution Status

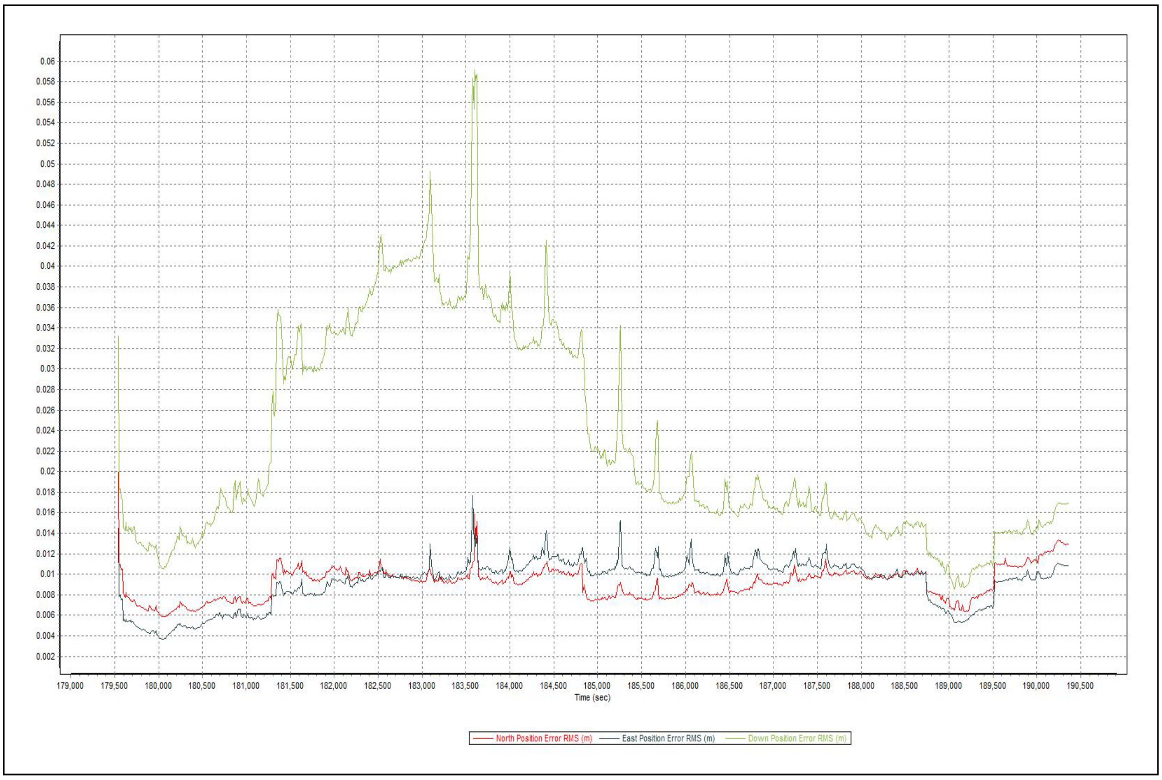


Figure A-8.30. Smoothed Performance Metric Parameters

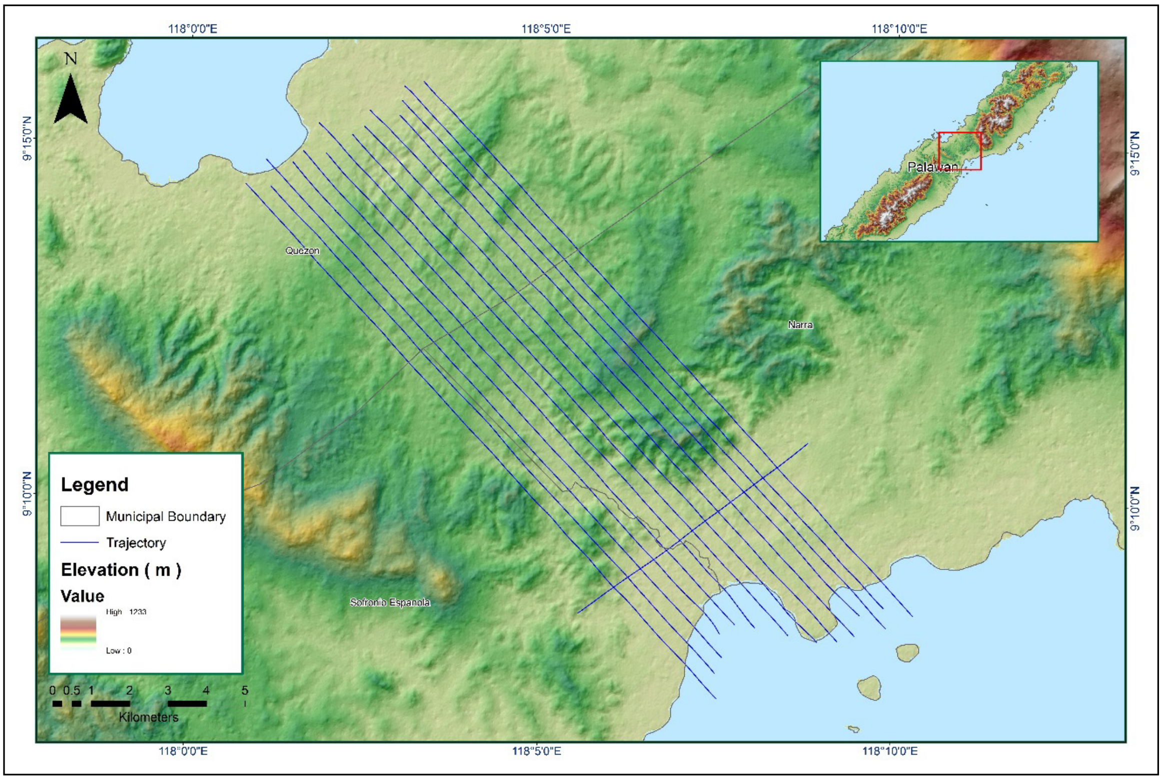


Figure A-8.31. Best Estimated Trajectory

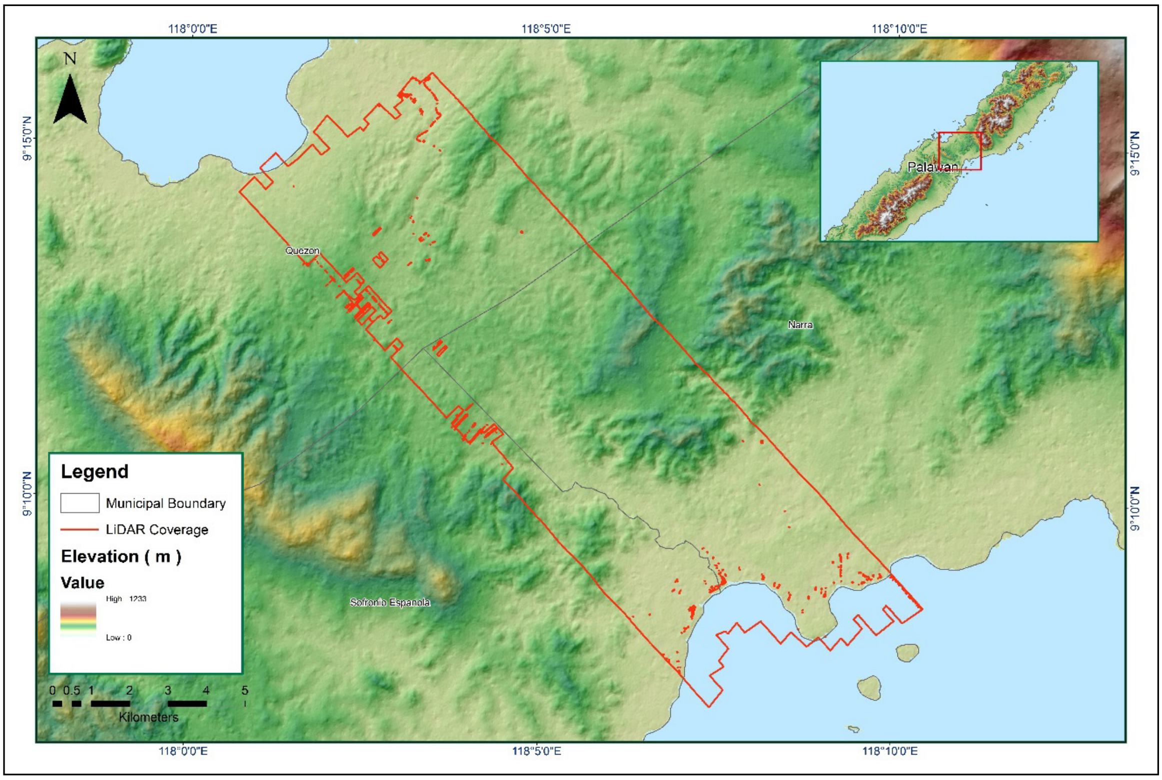


Figure A-8.32. Coverage of LiDAR data

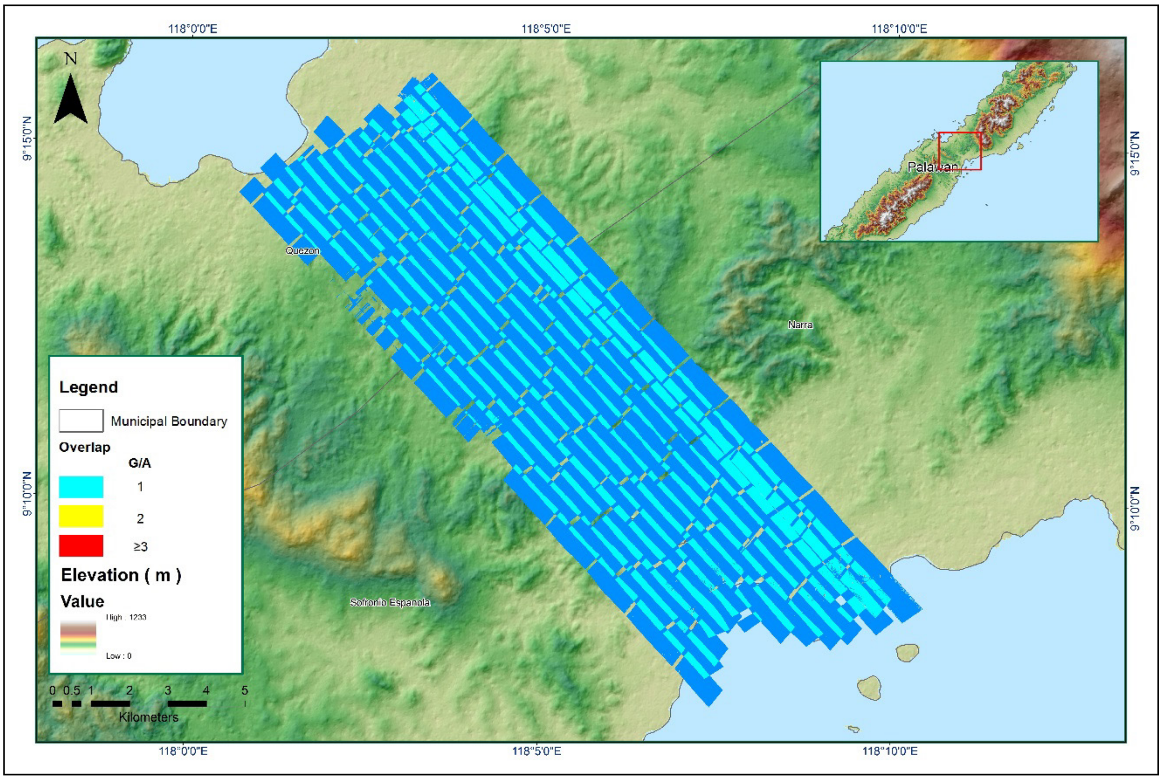


Figure A-8.33. Image of data overlap

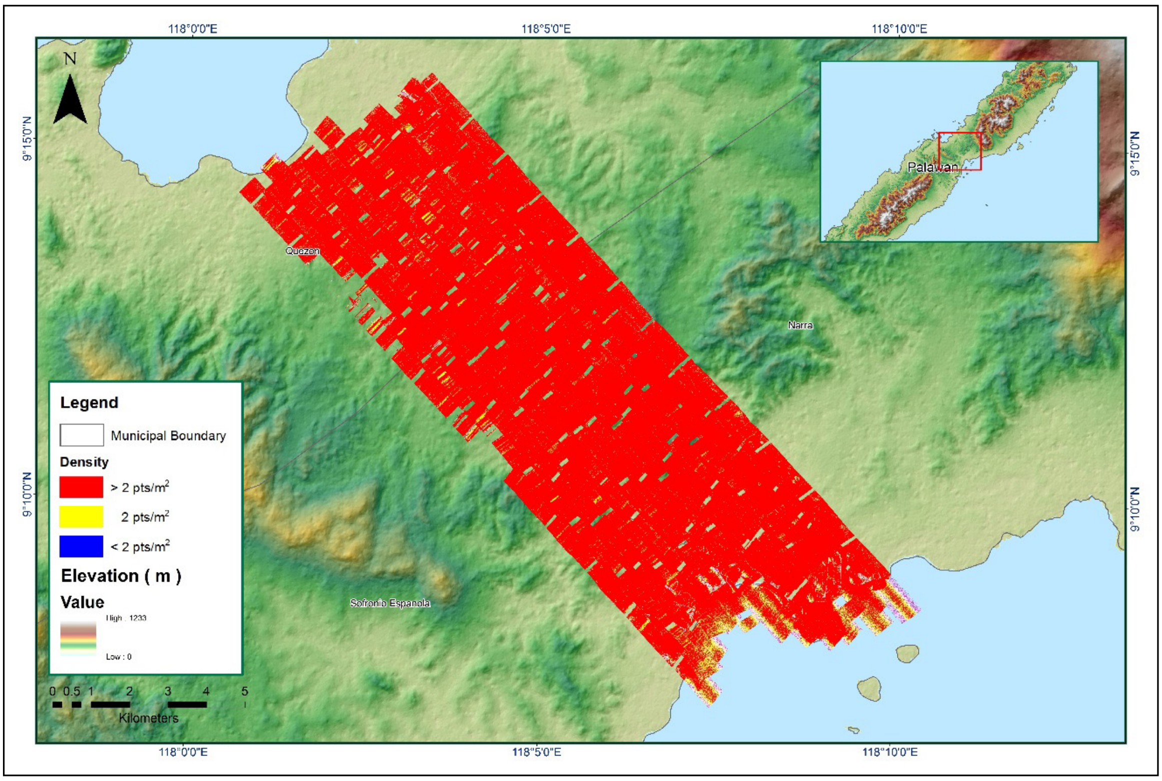


Figure A-8.34. Density Map of merged LiDAR data

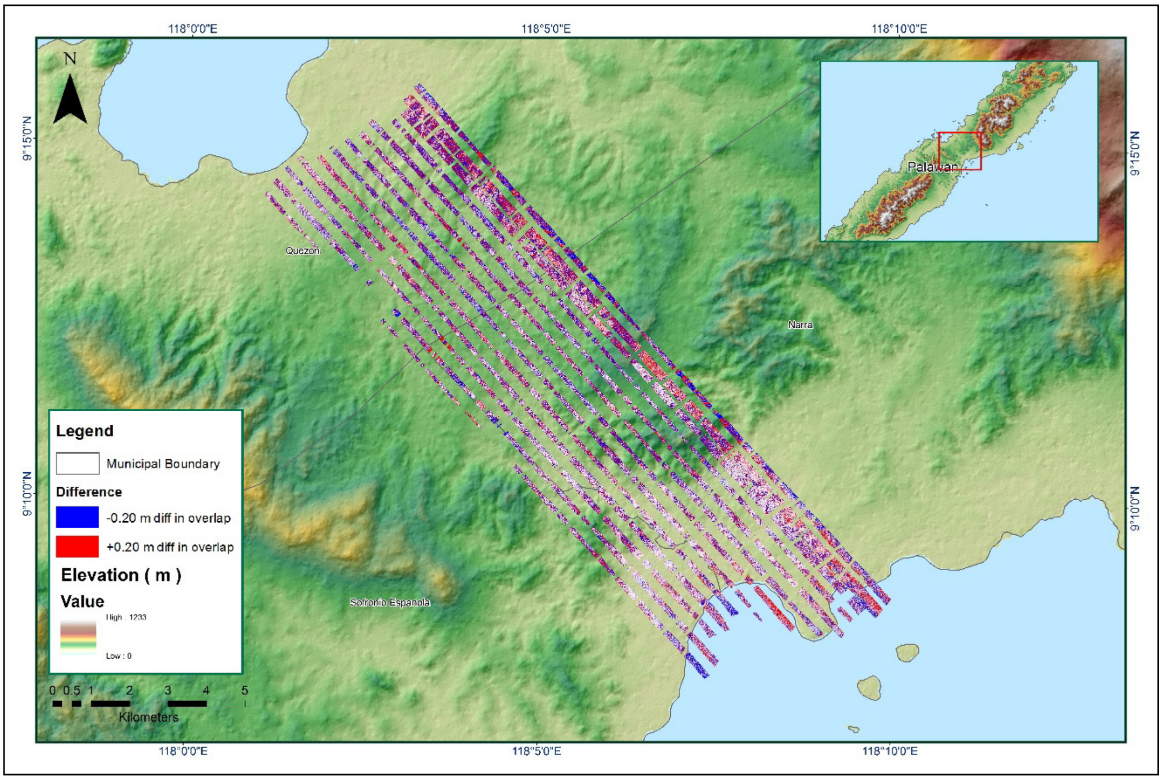


Figure A-8.35. Elevation Difference Between flight lines

Annex 9. Iwahig Model Basin Parameters

Table A-9.1 Iwahig Model Basin Parameters

Subbasin	SCS CURVE NUMBER LOSS			CLARK UNIT HYDROGRAPH TRANSFORM	
	Initial Abstraction (mm)	Curve Number	Imperviousness (%)	Time of Concentration (HR)	Storage Coefficient (HR)
W1020	13.75	48	0	0.62915	6.0057
W1030	13.75	48	0	1.438	1.5919
W460	13.75	48	0	3.6799	3.3326
W480	10.198	55.463	0	2.042	4.3426
W490	13.75	48	0	2.6609	3.7104
W500	10.017	55.905	0	2.2735	7.7918
W510	10.55	54.623	0	4.7744	3.4029
W520	13.75	48	0	2.0851	5.1551
W530	13.75	48	0	3.1587	1.9938
W550	13.361	48.731	0	3.3471	5.4624
W560	4.4959	73.855	0	3.8738	6.322
W570	10.076	55.76	0	1.6064	2.6216
W580	10.003	55.939	0	1.6543	2.6999
W590	13.75	48	0	3.0928	5.0474
W600	9.7279	56.626	0	1.2961	2.1153
W610	9.3433	57.614	0	1.7844	2.9121
W620	10.084	55.742	0	1.396	2.2782
W630	8.45	60	0	0.34193	0.55804
W640	13.75	48	0	3.6472	5.9523
W650	9.1305	58.175	0	1.7352	2.8318
W660	13.75	48	0	3.256	5.3137
W670	13.694	48.117	0	3.4477	5.6266
W680	4.65	73	0	1.1742	1.9162
W690	8.5428	59.785	0	0.68075	1.111
W700	10.35	55	0	0.98428	1.6064
W720	10.35	55	0	1.9307	1.0268
W730	13.75	48	0	3.4355	3.151
W740	13.75	48	0	4.4918	5.6067
W750	10.35	55	0	1.2231	7.3306
W760	8.7797	59.126	0	0.85126	1.9961
W770	10.099	55.705	0	0.44794	1.3893
W780	10.35	55	0	1.1493	0.73103
W790	13.75	48	0	2.4694	1.8756
W800	11.313	52.889	0	3.0912	4.0301
W810	13.75	48	0	2.5525	5.0449
W820	10.35	55	0	1.1781	4.1657
W830	10.35	55	0	1.466	1.9227

Subbasin	SCS CURVE NUMBER LOSS			CLARK UNIT HYDROGRAPH TRANSFORM	
	Initial Abstraction (mm)	Curve Number	Imperviousness (%)	Time of Concentration (HR)	Storage Coefficient (HR)
W840	13.75	48	0	2.1305	2.3925
W850	13.75	48	0	3.0392	3.477
W860	13.75	48	0	1.2717	4.96
W870	13.75	48	0	1.3686	2.0754
W880	13.75	48	0	1.7665	2.2335
W890	13.75	48	0	3.0697	2.8829
W900	13.75	48	0	1.6478	5.0097
W920	2.1124	85.739	0	0.9754	2.6893
W930	3.2819	79.465	0	1.24	2.0236
W970	2.6117	82.943	0	1.2217	4.3886
W980	7.7022	62.248	0	2.6891	2.3469

Annex 10. Iwahig Model Reach Parameters

Table A-10.1 Iwahig Model Reach Parameters

Reach Number	MUSKINGUM CUNGE CHANNEL ROUTING			
	Length (M)	Slope (M/M)	Shape	Side Slope (xH:1V)
R1000	2144.2	0.00937	Trapezoid	1
R1050	534.26	0.016322	Trapezoid	1
R130	459.71	0.093451	Trapezoid	1
R140	4641.7	0.031668	Trapezoid	1
R160	4321.3	0.003484	Trapezoid	1
R20	110.71	0.008222	Trapezoid	1
R200	2455.1	0.02932	Trapezoid	1
R210	2427.2	0.005883	Trapezoid	1
R220	2424.1	0.012151	Trapezoid	1
R230	968.41	0.065728	Trapezoid	1
R260	1322	0.022411	Trapezoid	1
R270	188.99	0.018121	Trapezoid	1
R290	581.84	0.072347	Trapezoid	1
R300	1940.2	0.007625	Trapezoid	1
R330	1575.4	0.11299	Trapezoid	1
R350	2666.2	0.081388	Trapezoid	1
R360	2268.2	0.008561	Trapezoid	1
R380	3397.5	0.019842	Trapezoid	1
R390	748.7	0.007232	Trapezoid	1
R400	2390.7	0.010176	Trapezoid	1
R430	1280.5	0.007625	Trapezoid	1
R70	1537.3	0.053526	Trapezoid	1
R80	3654.3	0.015047	Trapezoid	1
R90	2106.5	0.01237	Trapezoid	1
R950	2377.4	0.001547	Trapezoid	1

Annex 11. Iwahig Flood Validation Data

Table A-11.1 Iwahig Flood Validation Data

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event	Date	Rain Return/ Scenario
	Latitude	Longitude						
1	9.231877	118.1212	0.03	0	-0.03			25-Year
2	9.232184	118.1213	0.03	0	-0.03			25-Year
3	9.233461	118.1204	0.03	0	-0.03			25-Year
4	9.233797	118.1209	0.03	0	-0.03			25-Year
5	9.23437	118.1224	0.03	0	-0.03			25-Year
6	9.234786	118.1229	0.03	0	-0.03			25-Year
7	9.23527	118.123	0.03	0	-0.03			25-Year
8	9.235733	118.1231	0.03	0	-0.03			25-Year
9	9.236555	118.1231	0.03	0	-0.03			25-Year
10	9.238153	118.1233	0.03	0	-0.03			25-Year
11	9.239361	118.1209	0.03	0	-0.03			25-Year
12	9.23992	118.1204	0.03	0	-0.03			25-Year
13	9.240331	118.1209	0.03	0	-0.03			25-Year
14	9.240478	118.121	0.03	0	-0.03			25-Year
15	9.241207	118.1207	0.03	0	-0.03			25-Year
16	9.246001	118.1211	2.24	0	-2.24			25-Year
17	9.246253	118.1247	0.03	0	-0.03			25-Year
18	9.24635	118.125	0.03	0	-0.03			25-Year
19	9.246383	118.1214	1.16	0	-1.16			25-Year
20	9.247115	118.1251	0.03	0	-0.03			25-Year
21	9.247198	118.121	1.69	0	-1.69			25-Year
22	9.248257	118.1203	4.33	0	-4.33			25-Year
23	9.250095	118.0378	0.03	0	-0.03			25-Year
24	9.250395	118.0382	0.03	0	-0.03			25-Year
25	9.250998	118.0392	0.1	0	-0.1			25-Year
26	9.251334	118.0387	0.06	0	-0.06			25-Year
27	9.25135	118.0361	0.12	0	-0.12			25-Year
28	9.251706	118.0396	0.13	0	-0.13			25-Year
29	9.251769	118.04	0.05	0	-0.05			25-Year
30	9.254312	118.1197	0.94	0	-0.94			25-Year
31	9.254429	118.0436	0.05	0	-0.05			25-Year
32	9.254571	118.0418	0.03	0	-0.03			25-Year
33	9.25571	118.118	0.03	0	-0.03			25-Year
34	9.254775	118.0435	0.04	0	-0.04			25-Year
35	9.254798	118.0446	0.04	0	-0.04			25-Year
36	9.255024	118.0438	0.06	0	-0.06			25-Year
37	9.256376	118.1163	0.03	0	-0.03			25-Year
38	9.255707	118.0449	0.03	0	-0.03			25-Year
39	9.255861	118.045	0.04	0	-0.04			25-Year
40	9.256079	118.0463	0.03	0	-0.03			25-Year
41	9.256258	118.0465	0.03	0	-0.03			25-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event	Date	Rain Return/ Scenario
	Latitude	Longitude						
42	9.256543	118.0473	0.03	0.5	0.47		Aug 16 2017	25-Year
43	9.256977	118.0497	0.03	0.5	0.47		Aug 16 2017	25-Year
44	9.257086	118.049	0.15	0.5	0.35		Aug 16 2017	25-Year
45	9.257458	118.0499	0.89	0.3	-0.59		Aug 16 2017	25-Year
46	9.257687	118.0499	2.01	0.4	-1.61		Aug 16 2017	25-Year
47	9.257695	118.0492	1.17	0.4	-0.77		Aug 16 2017	25-Year
48	9.258222	118.0496	1.17	0.2	-0.97		Aug 16 2017	25-Year
49	9.258562	118.0564	2.28	1	-1.28		Aug 16 2017	25-Year
50	9.258589	118.0562	2.44	1.35	-1.09		Aug 16 2017	25-Year
51	9.258683	118.0503	2.09	0.5	-1.59		Aug 16 2017	25-Year
52	9.259726	118.0561	2.39	2.6	0.21		Aug 16 2017	25-Year
53	9.259855	118.0564	2.34	2.6	0.26		Aug 16 2017	25-Year
54	9.260193	118.0583	0.03	0.6	0.57		Aug 16 2017	25-Year
55	9.26044	118.0583	0.13	0.6	0.47		Aug 16 2017	25-Year
56	9.260752	118.058	1.12	1.2	0.08		Aug 16 2017	25-Year
57	9.261329	118.0568	1.28	1.8	0.52		Aug 16 2017	25-Year
58	9.263341	118.0541	2.17	0.8	-1.37		Aug 16 2017	25-Year
59	9.270141	118.064	0.03	0	-0.03			25-Year
60	9.271417	118.0649	0.03	0	-0.03			25-Year
61	9.273917	118.0681	0.03	0	-0.03			25-Year
62	9.277882	118.0971	0.03	0.9	0.87		Aug 16 2017	25-Year
63	9.278761	118.0898	0.03	0	-0.03			25-Year
64	9.278527	118.0715	0.03	0	-0.03			25-Year
65	9.278994	118.0866	4.46	0	-4.46			25-Year
66	9.279072	118.0886	0.03	0	-0.03			25-Year
67	9.279211	118.086	0.03	0	-0.03			25-Year
68	9.279323	118.0869	0.03	0	-0.03			25-Year
69	9.27956	118.098	0.03	0	-0.03			25-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event	Date	Rain Return/ Scenario
	Latitude	Longitude						
70	9.279415	118.0856	0.03	0	-0.03			25-Year
71	9.27967	118.0734	1.22	0	-1.22			25-Year
72	9.280008	118.085	0.03	0	-0.03			25-Year
73	9.279853	118.0729	1.49	0	-1.49			25-Year
74	9.28001	118.0728	1.62	0	-1.62			25-Year
75	9.280264	118.0845	1.41	0	-1.41			25-Year
76	9.280232	118.0726	1.53	0	-1.53			25-Year
77	9.280449	118.0726	1.39	0	-1.39			25-Year
78	9.280664	118.0847	3.55	0	-3.55			25-Year
79	9.280837	118.071	2.29	0.18	-2.11		Aug 16 2017	25-Year
80	9.28086	118.0718	1.33	0	-1.33			25-Year
81	9.281127	118.0839	3.11	0.6	-2.51		Aug 16 2017	25-Year
82	9.281037	118.0728	4.18	1.95	-2.23		Aug 16 2017	25-Year
83	9.281152	118.0729	3.76	1.95	-1.81		Aug 16 2017	25-Year
84	9.281992	118.0829	0.03	0	-0.03			25-Year
85	9.283893	118.0816	0.03	0	-0.03			25-Year
86	9.285799	118.0766	0.03	0	-0.03			25-Year
87	9.285894	118.0776	0.03	0	-0.03			25-Year
88	9.286668	118.077	0.14	0	-0.14			25-Year
89	9.288171	118.0767	0.03	0	-0.03			25-Year
90	9.288596	118.0767	0.03	0	-0.03			25-Year
91	9.290321	118.0762	0.05	0	-0.05			25-Year
92	9.291019	118.0764	0.03	0	-0.03			25-Year
93	9.291604	118.0778	0.03	0.5	0.47		Aug 16 2017	25-Year
94	9.293044	118.0773	0.12	1	0.88		Aug 16 2017	25-Year
95	9.294115	118.0773	0.06	0	-0.06			25-Year
96	9.294654	118.1012	0.03	0	-0.03			25-Year
97	9.295196	118.1022	0.03	0	-0.03			25-Year
98	9.296064	118.1025	0.03	0	-0.03			25-Year
99	9.296495	118.1036	0.03	0	-0.03			25-Year
100	9.296321	118.0774	0.55	1	0.45		Aug 16 2017	25-Year
101	9.29862	118.1048	0.03	0	-0.03			25-Year
102	9.299166	118.1049	0.03	0	-0.03			25-Year
103	9.300792	118.1261	0.32	0	-0.32			25-Year
104	9.300601	118.1022	0.03	0	-0.03			25-Year
105	9.301432	118.1059	0.03	0	-0.03			25-Year
106	9.301848	118.1258	0.47	0	-0.47			25-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event	Date	Rain Return/ Scenario
	Latitude	Longitude						
107	9.303171	118.1254	0.03	0	-0.03			25-Year
108	9.303207	118.1114	0.03	0	-0.03			25-Year
109	9.303531	118.1254	0.03	0	-0.03			25-Year
110	9.303359	118.1078	0.03	0	-0.03			25-Year
111	9.303596	118.1242	0.03	0	-0.03			25-Year
112	9.303694	118.1208	0.03	0	-0.03			25-Year
113	9.30385	118.1258	0.03	0	-0.03			25-Year
114	9.303862	118.1101	0.03	0	-0.03			25-Year
115	9.304118	118.1175	0.03	0	-0.03			25-Year
116	9.304616	118.1275	0.03	0	-0.03			25-Year
117	9.305112	118.1206	0.03	0	-0.03			25-Year
118	9.305327	118.1275	0.03	0	-0.03			25-Year
119	9.305184	118.1137	0.44	0	-0.44			25-Year
120	9.305397	118.1285	0.03	0	-0.03			25-Year
121	9.305876	118.122	0.03	0	-0.03			25-Year
122	9.307794	118.1291	0.03	0	-0.03			25-Year
123	9.307675	118.1172	0.03	0	-0.03			25-Year
124	9.308524	118.1296	0.03	0	-0.03			25-Year
125	9.30846	118.1235	0.03	0	-0.03			25-Year
126	9.310456	118.1165	0.03	0	-0.03			25-Year
127	9.311891	118.1166	0.03	0	-0.03			25-Year
128	9.31381	118.1183	0.18	0	-0.18			25-Year
129	9.314132	118.1208	0.11	0	-0.11			25-Year

Annex 12. Phil-LiDAR 1 UPLB Team Composition

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