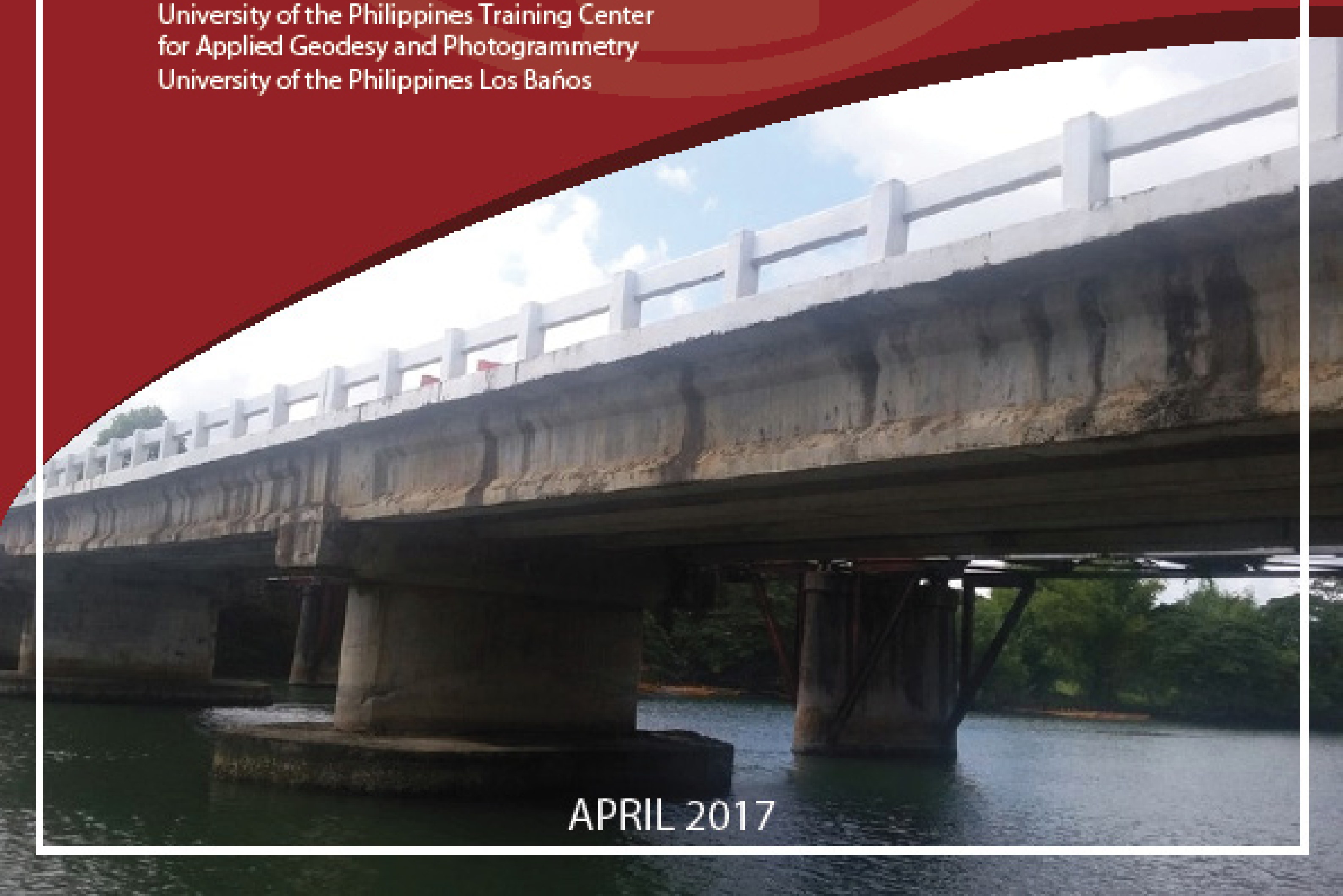
Hazard Mapping of the Philippines Using LIDAR (Phil-LIDAR 1)

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

Enrico C. Paringit, Dr. Eng. and Asst. Prof. Edwin R. Abucay

1.1 Background of the Phil-LIDAR 1 Program

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

Also, the program was aimed at producing an up-to-date and detailed national elevation dataset suitable for 1:5,000 scale mapping, with 50 cm and 20 cm horizontal and vertical accuracies, respectively. These accuracies were achieved through the use of the state-of-the-art Light Detection and Ranging (LiDAR) airborne technology procured by the project through DOST.

The 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 Penal River Basin

The Iwahig Penal River Basin is a 22,859-ha watershed encompassing the City of Puerto Princesa in Palawan. It covers the barangays of Bagong Bayan, Iwahig (Pob.), Montible (Pob.), Napsan, Santa Luica (Pob.), Simpocan, and Inagawan Sub-Colony in Puerto Princesa City. The DENR River Basin Control Office (RBCO) states that the Iwahig Penal River Basin has a drainage are of 213 km^2 and an estimated 341 cubic meter (MCM) annual run-off (RBCO, 2015).

The basin area is predominantly from Cretaceous-Paleogene and Pliocene-Pleistocene. The geologic classification of the remaining areas are Recent, Undifferentiated (Sedimentary & Metamorphic Rocks) as well as Basement Complex (Pre-Jurrasic). Majority of the basin area has gently sloping to steep slopes and elevation range of 10 to more than 300 meters above sea level (masl). The dominant soil in the area include Guimbalaon clay, Taburos clay and Bay clay loam. However large area in basin are still unclassified (rough mountainous land). Closed canopy (mature trees covering >50%) covers almost the entire basin area followed by grassland (grass covering >70%) and crop land mixed with coconut plantation.

With regards to climate, Climate Type I and III prevails in the Iwahig Penal River Basin, as well as 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.

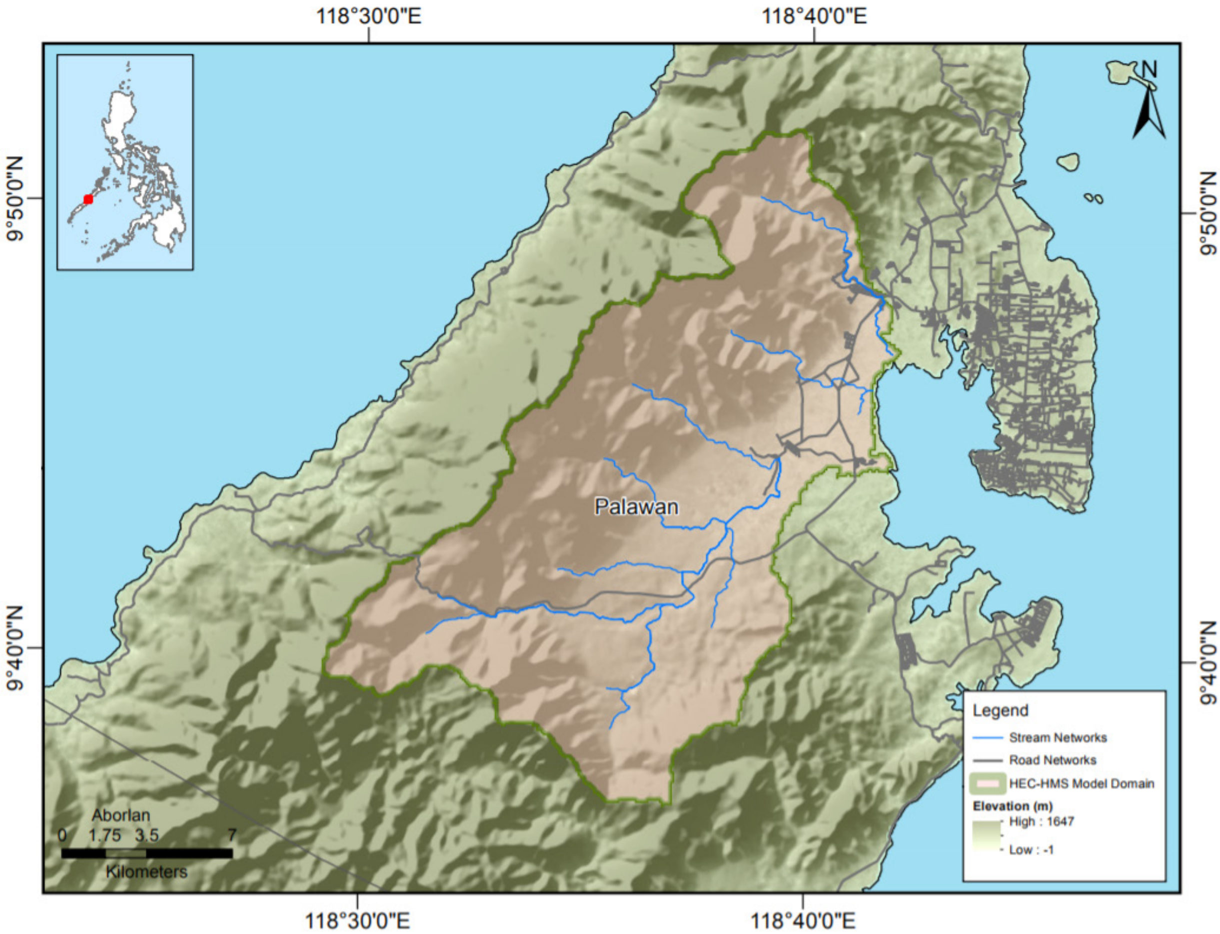

Figure 1. Map of Iwahig Penal River Basin (in brown)

The Iwahig Penal River Basin's main stem, the Iwahig Penal River, is part of the forty-five (45) river systems under the PHIL-LIDAR 1 Program partner State University and College (SUC), the University of the Philippines Los Baños. The Iwahig Penal River passes through the Poblacions of Montible, Iwahig, and portions of Napsan. According to the 2015 national census of PSA, a total of 5,527 persons are residing within Brgy. Iwahig, Puerto Princesa City, Palawan, which is within the immediate vicinity of the river. The people of Iwahig Penal River Basin derives their economy from the same industries within the province of Palawan, which is primarily agriculture-based. The sources of livelihood are 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 the Poblacions of Iwahig and Montible have moderate to high susceptibility to flooding. The field surveys conducted by the PHIL-LiDAR 1 validation team showed that three notable weather disturbance caused flooding in 2007 (Lando), 2013 (Yolanda) and 2014 (Hagibis). On November 4, 2015, the NDRRMC has released the 2nd General Flood Advisory for Region IV-B with several rivers in Palawan including Iwahig Penal River to be likely affected by light to moderate rains and isolated thunderstorms as per NDRRMC report (National Disaster Risk Reduction and Management Council, 2015). In terms of landslides, barangay Simpocan, Bagong Bayan, and Napsan has moderate to high risk of landslides, while Inagawan Sub-Colony has moderate susceptibilities to landslides.

CHAPTER 2: LIDAR DATA ACQUISITION OF THE IWAHIG PENAL 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 Penal Floodplain in Palawan. These missions were planned for 21 lines that run for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameters for the LiDAR system is found in Table 1 and Table 2. Figure 2 shows the flight plan for Iwahig Penal Floodplain.

Table 1. Flight planning parameters for Pegasus LiDAR system.

Block Name	Flying Height (m AGL)	Overlap (%)	Max. Field of View	Pulse Rate Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK 42A	800	30	50	200	30	130	5
BLK 42E	1200	30	50	200	30	130	5
BLK 42F	1500	30	50	200	30	130	5
BLK 42G	1500	30	50	150	30	130	5
BLK 42H	1500	30	50	150	30	130	5

Table 2. Flight planning parameters for Gemini LiDAR system.

Block Name	**Flying Height (m AGL)**	**Overlap (%)**	**Max. Field of View**	**Pulse Rate Frequency (PRF) (kHz)**	**Scan Frequency (Hz)**	**Average Speed (kts)**	**Average Turn Time (Minutes)**
BLK 42eE	800	30	40	200	50	130	5
BLK 42eF	800	30	40	200	50	130	5

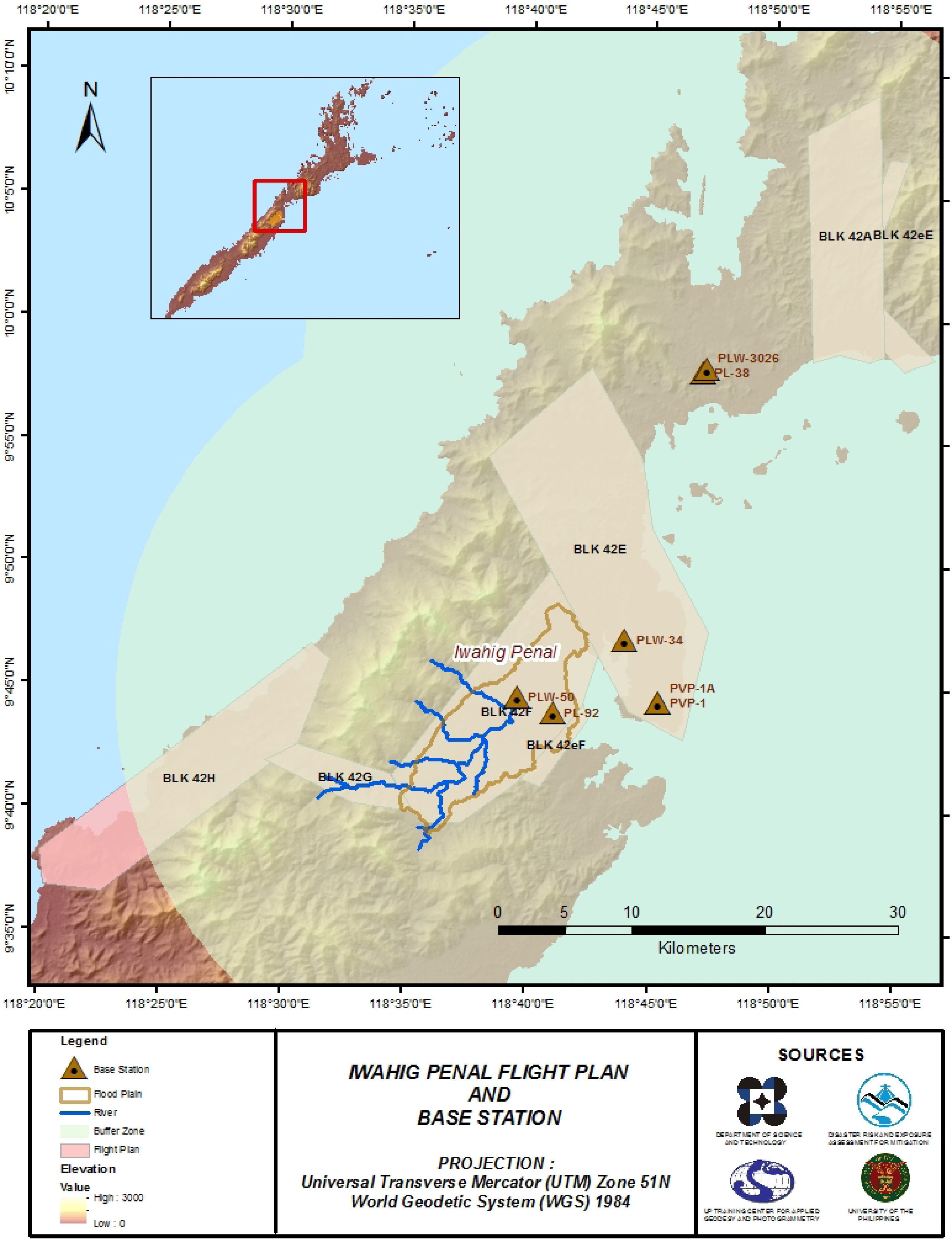
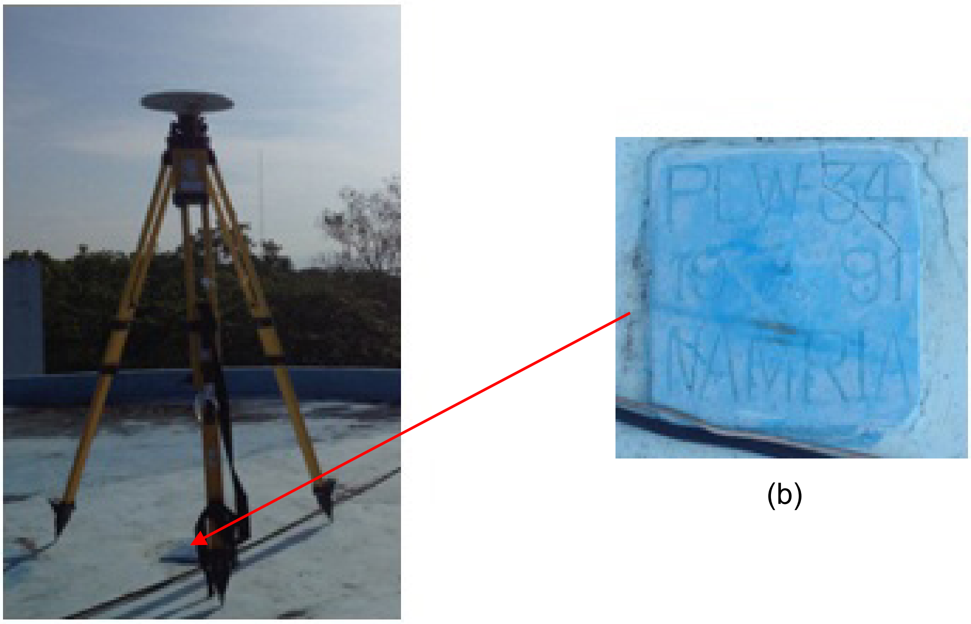


Figure 2. Flight plans used for Iwahig Penal Floodplain

2.2 Ground Base Station

The project team was able to recover two (2) NAMRIA reference points: PLW-34 which is of first (1^{st}) order accuracy, and PLW-50 which is of second (2^{nd}) order accuracy. The project team also re-established ground control point PLW-3026, a NAMRIA reference point of third (3^{rd}) order accuracy. Two (2) NAMRIA benchmarks were recovered, PL-92 and PL-38. These benchmarks were used as vertical reference points and were also established as ground control points. The project team also established two (2) ground control points: PVP-1 and PVP-1A. The certifications for the NAMRIA reference points and benchmarks are found in Annex 2, while the processing reports for the established control points are found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey (May 30-June 8, 2015; November 15, 2015). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 852 and SPS 985. Flight plans and location of base stations used during the aerial LiDAR acquisition in Iwahig Penal floodplain are shown in Figure 2. The list of team members are shown in Annex 4.

Figure 3 to Figure 6 show the recovered NAMRIA reference points within the area, in addition Table 3 to Table 9 show the details about the following NAMRIA control stations and established points, Table 10 shows the list of all ground control points occupied during the acquisition together with the dates they are utilized during the survey.



(b)

(a)

Figure 3. GPS set-up over PLW-34 recovered at the roof deck of the old city hall of Puerto Princesa, Brgy. Sta. Monica, Puerto Princesa City (a) and NAMRIA reference point PLW-34 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point PLW-34 used as base station for the LiDAR Acquisition.

Station Name	PLW-34	
Order of Accuracy	1st	
Relative Error (horizontal positioning)	1:100,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	9°47'4.34346" North
	Longitude	118°43'50.36738" East
	Ellipsoidal Height	53.76200 meters
Grid Coordinates(a)Philippine Transverse Mercator Zone 1A (PTM Zone 1A PRS 92)	Easting	525304.737 meters
	Northing	1081910.004 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9° 46'59.90069" North
	Longitude	118° 43' 55.68915" East
	Ellipsoidal Height	103.89600 meters
Grid Coordinates, Universal Transverse Mercator Zone 50 North (UTM 50N PRS 92)	Easting	689825.58 meters
	Northing	1082009.99 meters

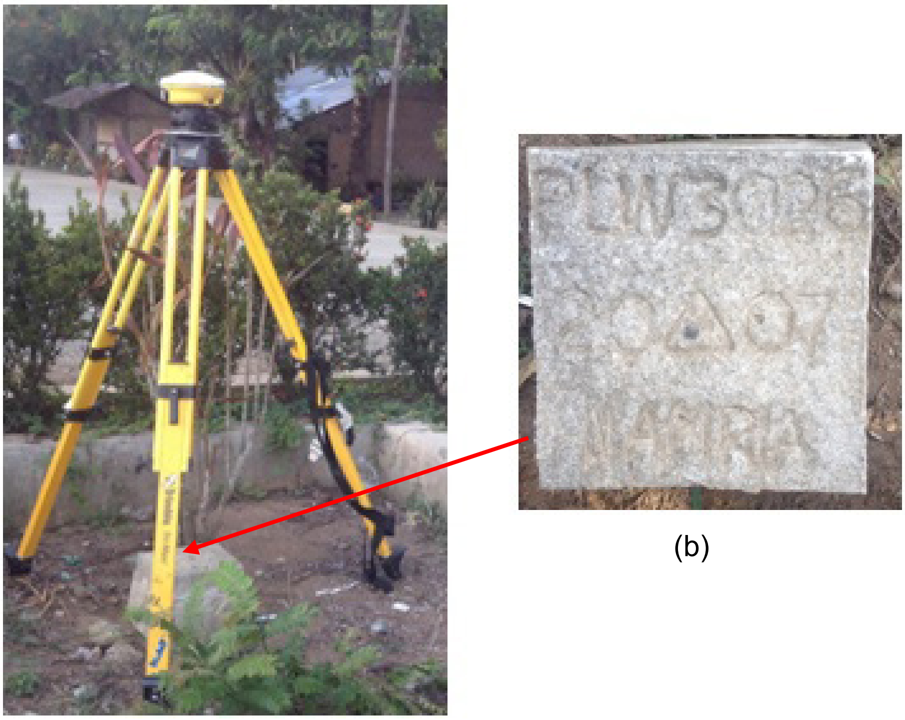
(a)

(b)

Figure 4. GPS set-up over PLW-50 as recovered inside the vicinity of Iwahig Penal Farm in Iwahig, Puerto Princesa City, Palawan (a) and NAMRIA reference point PLW-50 (b) as recovered by the field team.

Table 4. Details of the recovered NAMRIA horizontal control point PLW-50 used as base station for the LiDAR Acquisition.

Station Name	PLW-50	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1:50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	9° 44’ 42.16318” North
	Longitude	118° 39’ 28.02050” East
	Ellipsoidal Height	16.81300 meters
Grid Coordinates, Philippine Transverse Mercator Zone 1A (PTM Zone 1A PRS 92)	Easting	517311.956 meters
	Northing	1077537.527 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9° 44’ 37.72390” North
	Longitude	118° 39’ 33.34598” East
	Ellipsoidal Height	66.85300 meters
Grid Coordinates, Universal Transverse Mercator Zone 50 North (UTM 50N PRS 92)	Easting	681851.72 meters
	Northing	1077601.73 meters



(b)

(a)

Figure 5. GPS set-up over PLW-3026 as recovered at northeast corner of the center island in Salvacion junction, Brgy. Salvacion, Puerto Princesa City (a) and NAMRIA reference point PLW-3026 (b) as recovered by the field team.

Table 5. Details of the recovered NAMRIA horizontal control point PLW-3026 used as base station for the LiDAR Acquisition with reprocessed coordinates.

Station Name	PLW-3026	
Order of Accuracy	1st	
Relative Error (horizontal positioning)	1:100,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	9°58’03.41442” North
	Longitude	118°47’09.05751” East
	Ellipsoidal Height	57.363 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9°58’07.89863” North
	Longitude	118°47’03.75221” East
	Ellipsoidal Height	7.504 meters
Grid Coordinates, Universal Transverse Mercator Zone 50 North (UTM 50N PRS 92)	Easting	695610.418 meters
	Northing	1102427.869 meters

Figure 6. GPS set-up over PVP-1 located on the ground beside Puerto Princesa Airport Fire Station (a) and reference point PVP-1 (b) as recovered by the field team.

Table 6. Details of the recovered horizontal control point PVP-1 used as base station for the LiDAR Acquisition established coordinate.

Station Name	PVP-1	
Order of Accuracy	1st	
Relative Error (horizontal positioning)	1:100,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	9° 44' 31.66247" North
	Longitude	118° 45' 13.60677" East
	Ellipsoidal Height	17.172 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9° 44' 27.23233" North
	Longitude	118° 45' 18.93228" East
	Ellipsoidal Height	61.835 meters
Grid Coordinates, Universal Transverse Mercator Zone 50 North (UTM 50N WGS84)	Easting	692547.525 meters
	Northing	1077290.373 meters

Table 7. Details of the recovered NAMRIA vertical control point PL-38 with processed coordinates used as base station for the LiDAR Acquisition with established coo.

Station Name	PL-38	
Order of Accuracy	1st	
Relative Error (horizontal positioning)	1:100,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	8° 57’ 59.62464” North
	Longitude	118° 46’ 56.29975” East
	Ellipsoidal Height	7.756 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9° 57’ 55.14081” North
	Longitude	118° 47’ 01.60525” East
	Ellipsoidal Height	57.615 meters
Grid Coordinates, Universal Transverse Mercator Zone 50 North (UTM 50N PRS 92)	Easting	685384.782 meters
	Northing	1102172.433 meters

Table 8. Details of the recovered NAMRIA bench mark point PL-92 with processed coordinates used as base station for the LiDAR Acquisition.

Station Name	PL-92	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1:50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	9° 44’ 4.01581” North
	Longitude	118° 40’ 58.28065” East
	Ellipsoidal Height	8.218 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9° 43’ 59.58138” North
	Longitude	118° 41’ 3.60701” East
	Ellipsoidal Height	58.344 meters
Grid Coordinates, Universal Transverse Mercator Zone 50 North (UTM 50N WGS84)	Easting	684769.426 meters
	Northing	1076375.505 meters

Table 9. Details of the recovered NAMRIA horizontal control point PVP-1A used as base station for the LiDAR Acquisition.

Station Name	PVP-1A	
Order of Accuracy	1st	
Relative Error (horizontal positioning)	1:100,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	9° 44’ 32.50133” North
	Longitude	118° 45’ 13.64985” East
	Ellipsoidal Height	17.110 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9° 44’ 28.07113” North
	Longitude	118° 45’ 18.97534” East
	Ellipsoidal Height	67.394 meters
Grid Coordinates, Universal Transverse Mercator Zone 50 North (UTM 50N WGS84)	Easting	692548.704 meters
	Northing	1077290.373 meters

Table 10. Ground Control Points used during LiDAR Data Acquisition

Date Surveyed	Flight Number	Mission Name	Ground Control Points
30-May-15	2989P	1BLK42E150A	PLW-34
4-Jun-15	3009P	1BLK42F155A	PLW-34
6-Jun-15	3017P	1BLK42A157A	PLW-34, PLW-3026
8-Jun-15	3025P	1BLK42GH159A	PL-92, PLW-50
8-Jun-15	3027P	1BLK42FS159B	PL-38, PLW-3026
15-Nov-15	3493G	2BLK42EF319A	PVP-1, PVP1A

2.3 Flight Missions

Six (6) missions were conducted to complete the LiDAR Data Acquisition in Iwahig Penal Floodplain, for a total of twenty hours and thirty-three minutes (20+33) of flying time for RP-C9022. All missions were acquired using the Pegasus and Gemini LiDAR system. 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 Penal Floodplain.

Date Surveyed	Flight Number	Flight Plan Area (km2)	Surveyed Area (km2)	Area Surveyed within the Floodplain (km2)	Area Surveyed Outside the Floodplain (km2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
30-May-15	2989P	213.38	239.59	0.98	232.22	808	4	6
4-Jun-15	3009P	137.45	177.63	94.09	79.07	362	2	59
6-Jun-15	3017P	100.65	178.62	NA	175.55	791	4	23
8-Jun-15	3025P	153.75	191.64	1.79	191.19	388	3	7
8-Jun-15	3027P	137.45	116.39	21.84	88.29	287	2	13
15-Nov-15	3493G	45.23	71.47	20.15	51.32	NA	3	45
TOTAL		787.91	975.34	138.85	836.49	2636	20	33

Table 12. Actual Parameters used during LiDAR Data Acquisiton

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
2989P	1200, 800	30	50	200	25	130	5
3009P	1200	30	50	200	25	130	5
3017P	900	30	50	200	25	130	5
3025P	1500	30	50	150	30	130	5
3027P	1000	30	50	200	25	130	5
3493G	1000, 850	30	26, 50	100, 125	50, 40	130	5

2.4. Survey Coverage

Iwahig Penal floodplain is located in the province of Palawan with majority of the floodplain situated within the municipality of Puerto Princesa City. Municipalities of Puerto Princesa City and Aborlan are mostly covered by the survey. 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 Iwahig Penal floodplain is presented in Figure 7.

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

Province	Municipality/City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Palawan	Aborlan	645.11	19.24	3%
	Puerto Princesa City	2186.36	721.97	33%
TOTAL		2831.47	741.21	26.18%

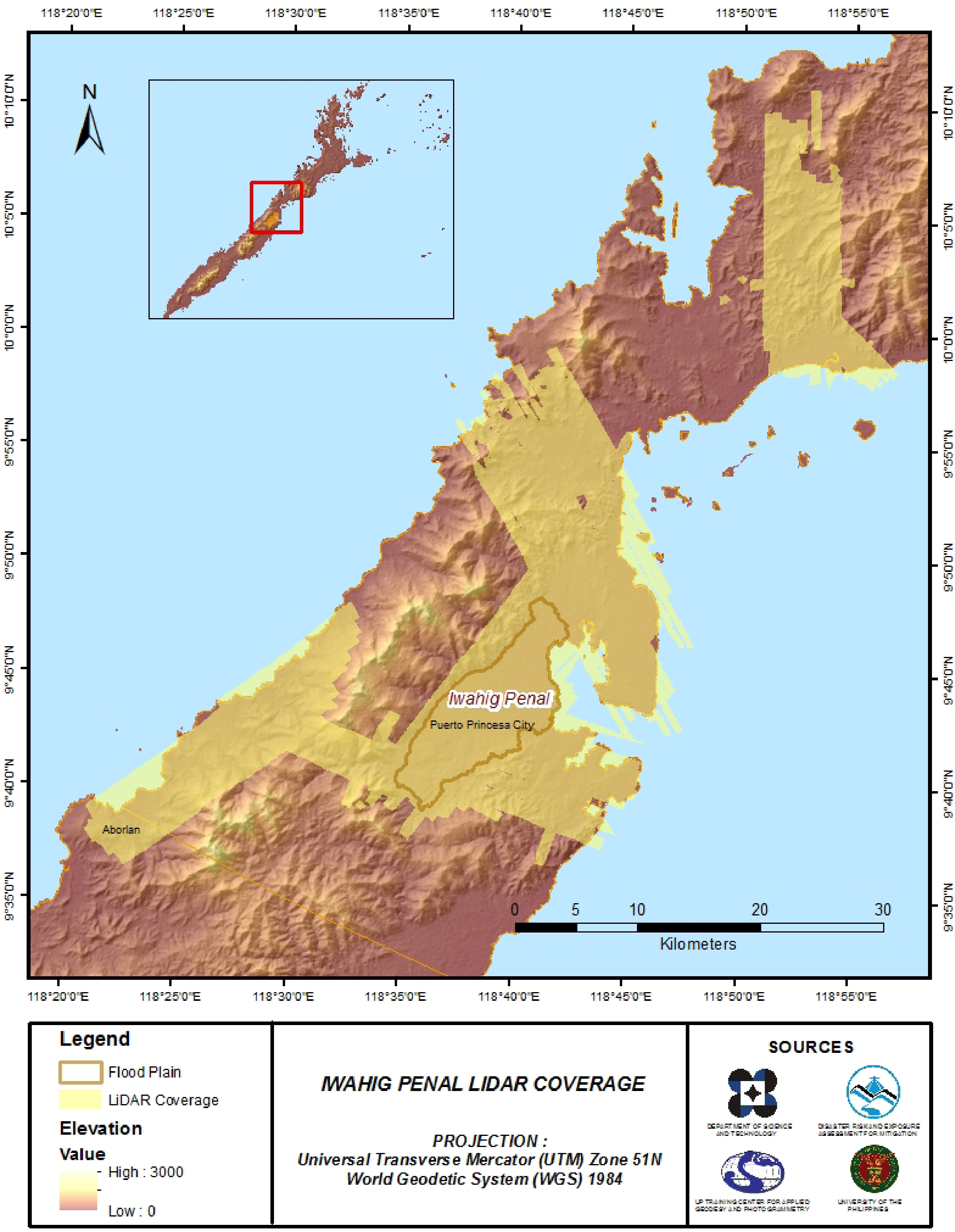


Figure 7. Actual LiDAR survey coverage for Iwahig Penal Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE IWAHIG PENAL FLOODPLAIN

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

3.1 Overview of the LIDAR Data Pre-Processing

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

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

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

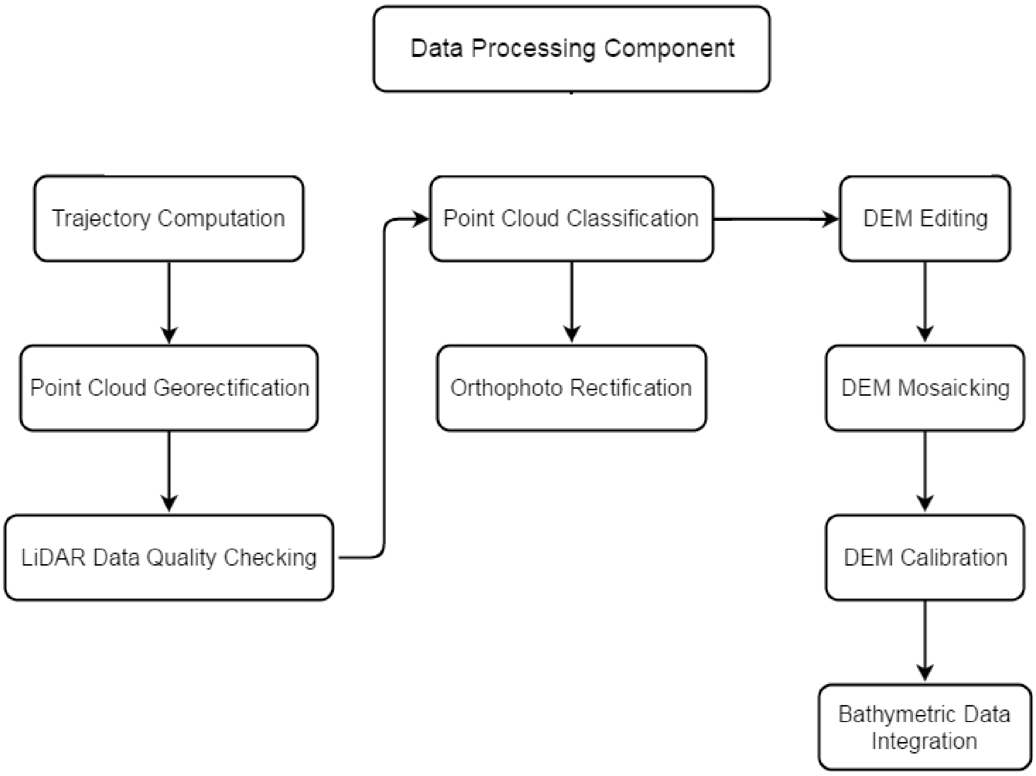


Figure 8. Schematic Diagram for Data Pre-Processing Component

3.2 Transmittal of Acquired LiDAR Data

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

The Data Acquisition Component (DAC) transferred a total of 111.80 Gigabytes of Range data, 1.21 Gigabytes of POS data, 41.22 Megabytes of GPS base station data, and 185.97 Gigabytes of raw image data to the data server on June 23, 2015 for the first survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Iwahig Penal was fully transferred on December 2, 2015, as indicated on the Data Transfer Sheets for Iwahig Penal floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 3009P, one of the Iwahig Penal flights, which is the North, East, and Down position RMSE values are shown in Figure 9. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on June 4, 2015 00:00AM. The y-axis is the RMSE value for that particular position.

Figure 9. Smoothed Performance Metrics of Iwahig Penal Flight 3009P.

The time of flight was from 349,100 seconds to 357,100 seconds, which corresponds to morning of June 4, 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 9 shows that the North position RMSE peaks at 1.10 centimeters, the East position RMSE peaks at 1.60 centimeters, and the Down position RMSE peaks at 3.20 centimeters, which are within the prescribed accuracies described in the methodology.

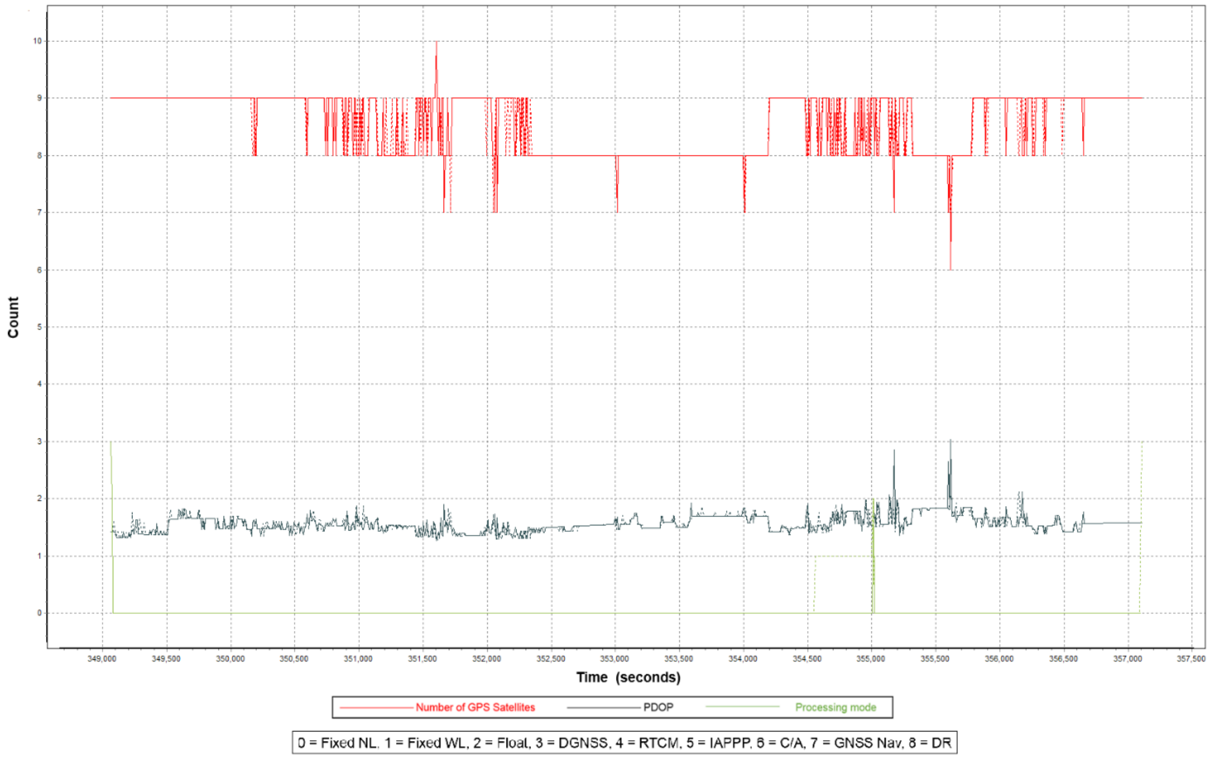


Figure 10. Solution Status Parameters of Iwahig Penal Flight 3009P.

The Solution Status parameters of flight 3009P, one of the Iwahig Penal flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 10. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Majority of the time, the number of satellites tracked was between 6 and 9. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode stayed at the value of 0 for majority of the survey with some peaks up to 2 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 Penal flights is shown in Figure 11.

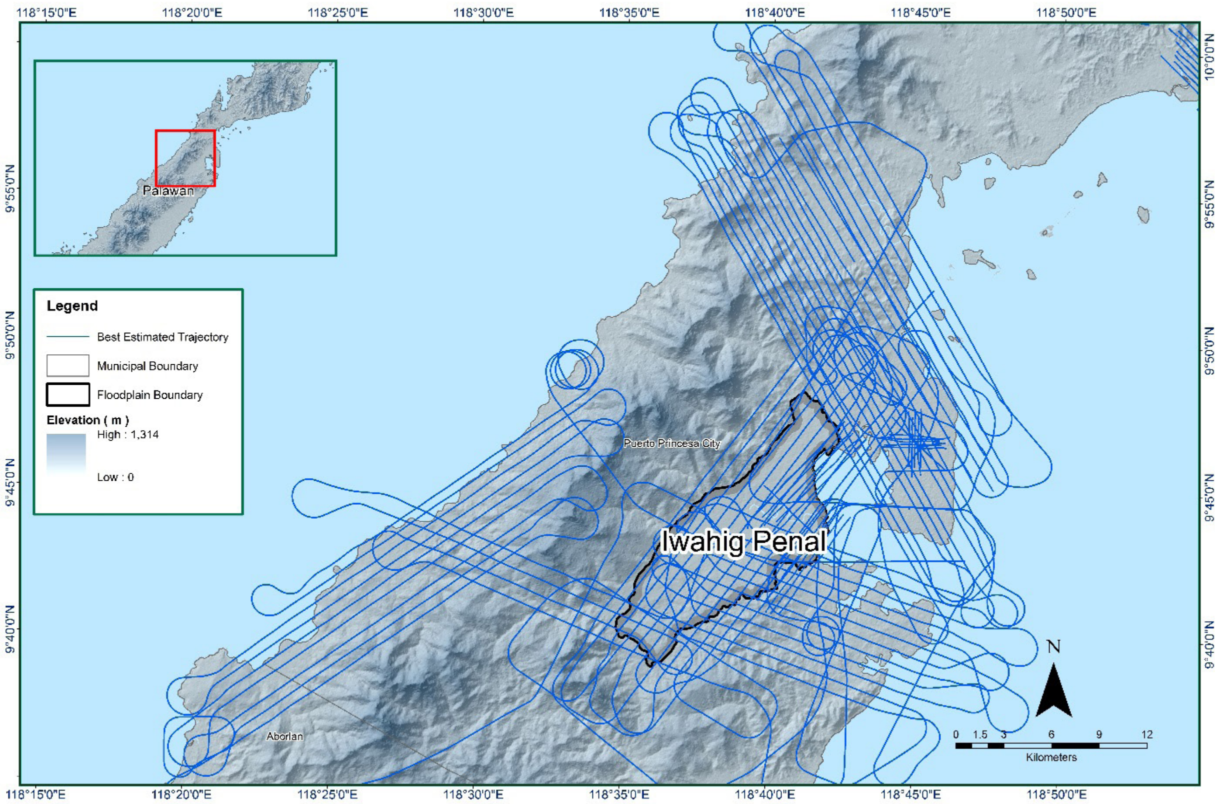


Figure 11. Best Estimated Trajectory for Iwahig Penal Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 78 flight lines, with each flight line containing one channel and two channels, respectively, since the Gemini system contains one channel and Pegasus system contains two channels. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Iwahig Penal floodplain are given in Table 14.

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

Parameter	Computed Value
Boresight Correction stdev (<0.001degrees)	0.000338
IMU Attitude Correction Roll and Pitch Corrections stdev (<0.001degrees)	0.000921
GPS Position Z-correction stdev (<0.01meters)	0.0090

The optimum accuracy is obtained for all Iwahig Penal 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 Penal Floodplain is shown in Figure 12. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

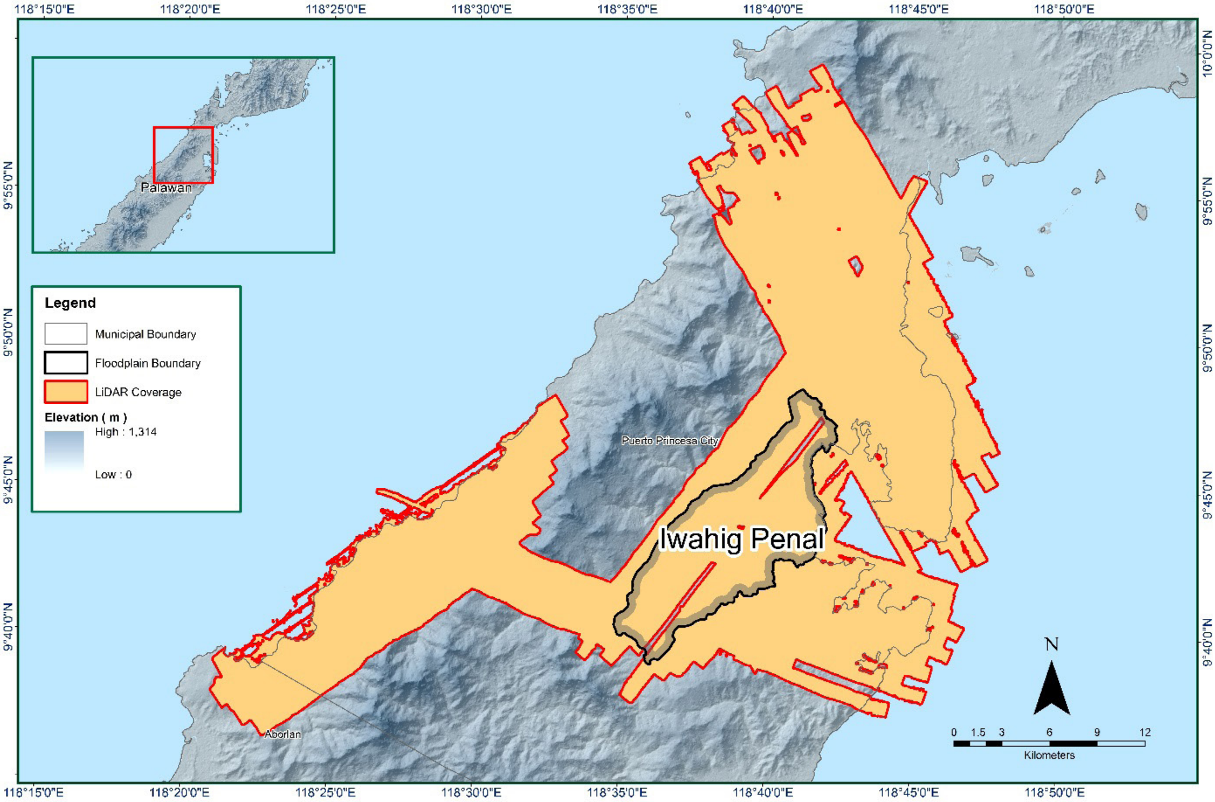


Figure 12. Boundary of the processed LiDAR data over Iwahig Penal Floodplain

The total area covered by the Iwahig Penal missions is 807.67 sq.km that is comprised of six (6) flight acquisitions grouped and merged into seven (7) blocks as shown in Table 15.

Table 15. List of LiDAR blocks for Iwahig Penal Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Palawan_Blk42E	2989P	268.13
	3017P	
Palawan_Blk42F	3009P	168.72
Palawan_Blk42F_additional	3027P	16.03
Palawan_Blk42F_supplement	3009P	121.93
Palawan_Blk42G	3025P	52.24
Palawan_Blk42H	3025P	146.16
Palawan_reflights_Blk42eF	3493G	34.36
TOTAL		807.67 sq.km

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 13. Since the Gemini 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.

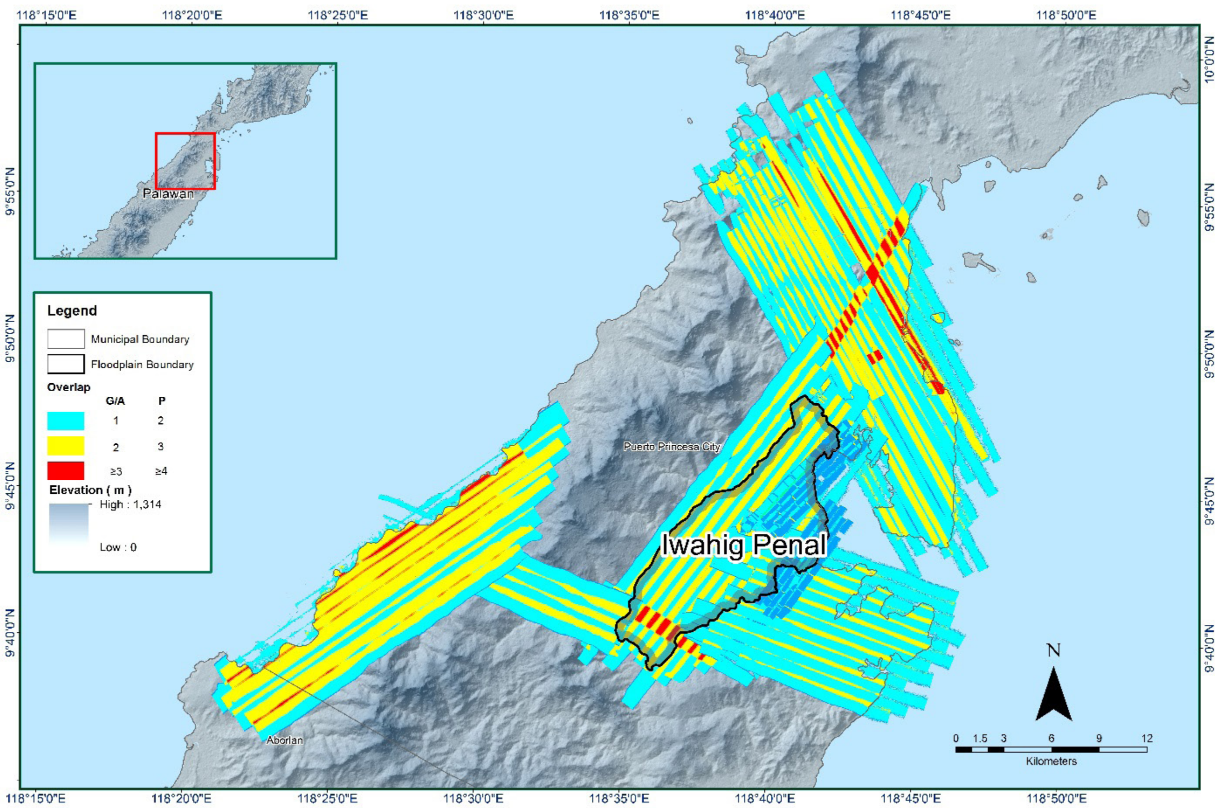


Figure 13. Image of data overlap for Iwahig Penal Floodplain.

The overlap statistics per block for the Iwahig Penal 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 27.59% and 66.84% respectively, which passed the 25% requirement.

The pulsa 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 14. It was determined that all LiDAR data for Iwahig Penal floodplain satisfy the point density requirement, and the average density for the entire survey area is 3.49 points per square meter.

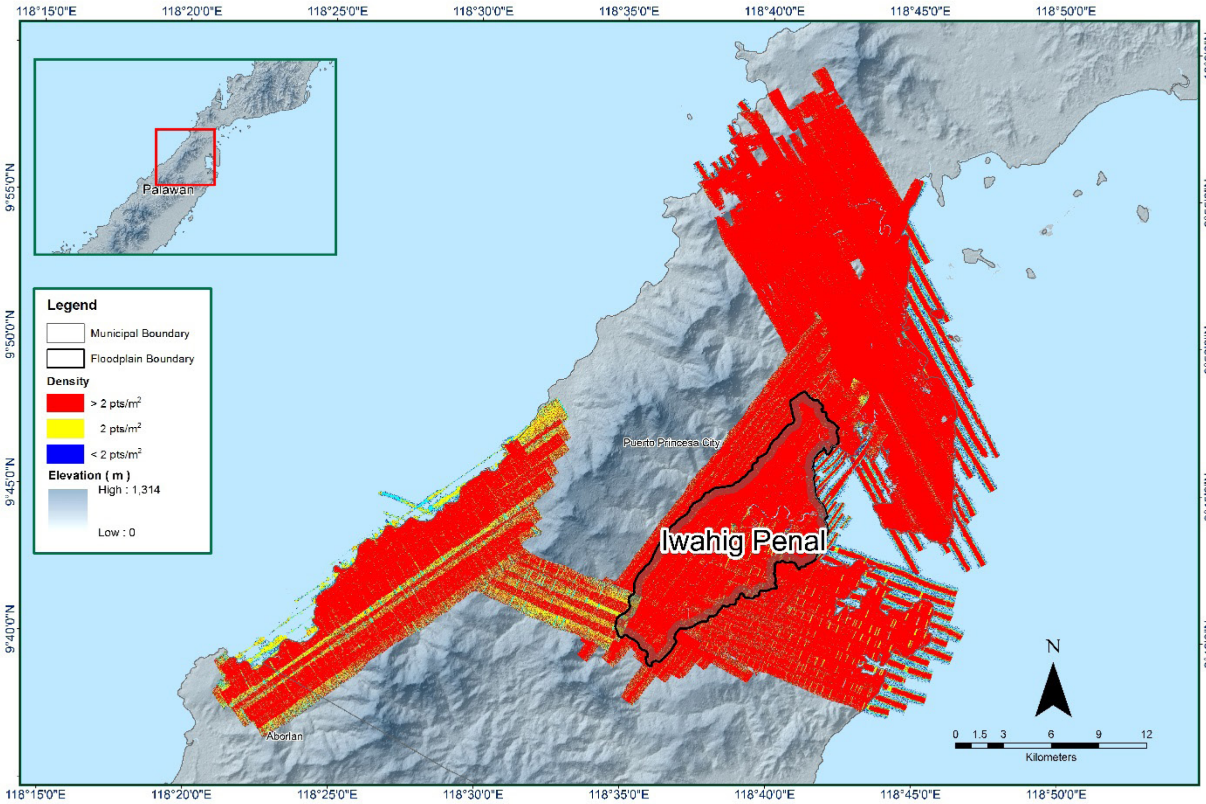


Figure 14. Pulse density map of merged LiDAR data for Iwahig Penal Floodplain.

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

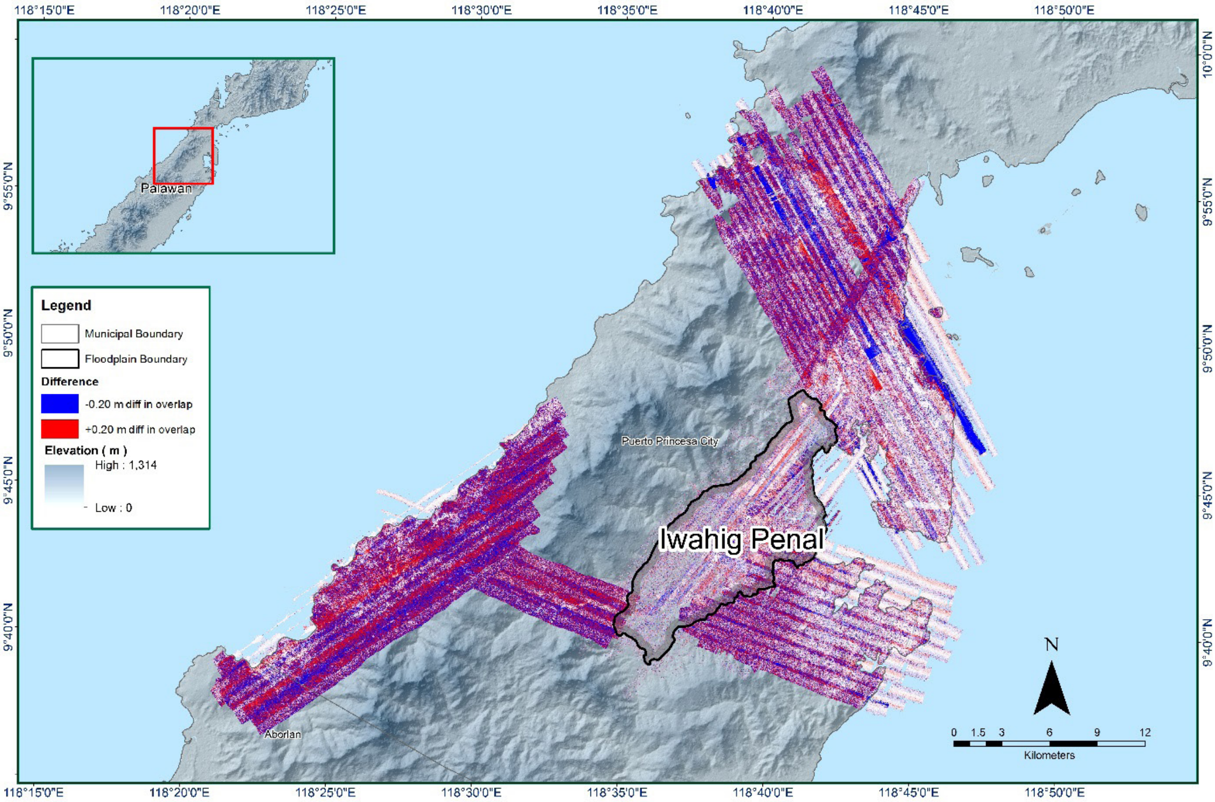


Figure 15. Elevation difference map between flight lines for Iwahig Penal Floodplain.

A screen capture of the processed LAS data from Iwahig Penal flight 3009P loaded in QT Modeler is shown in Figure 16. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed red line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

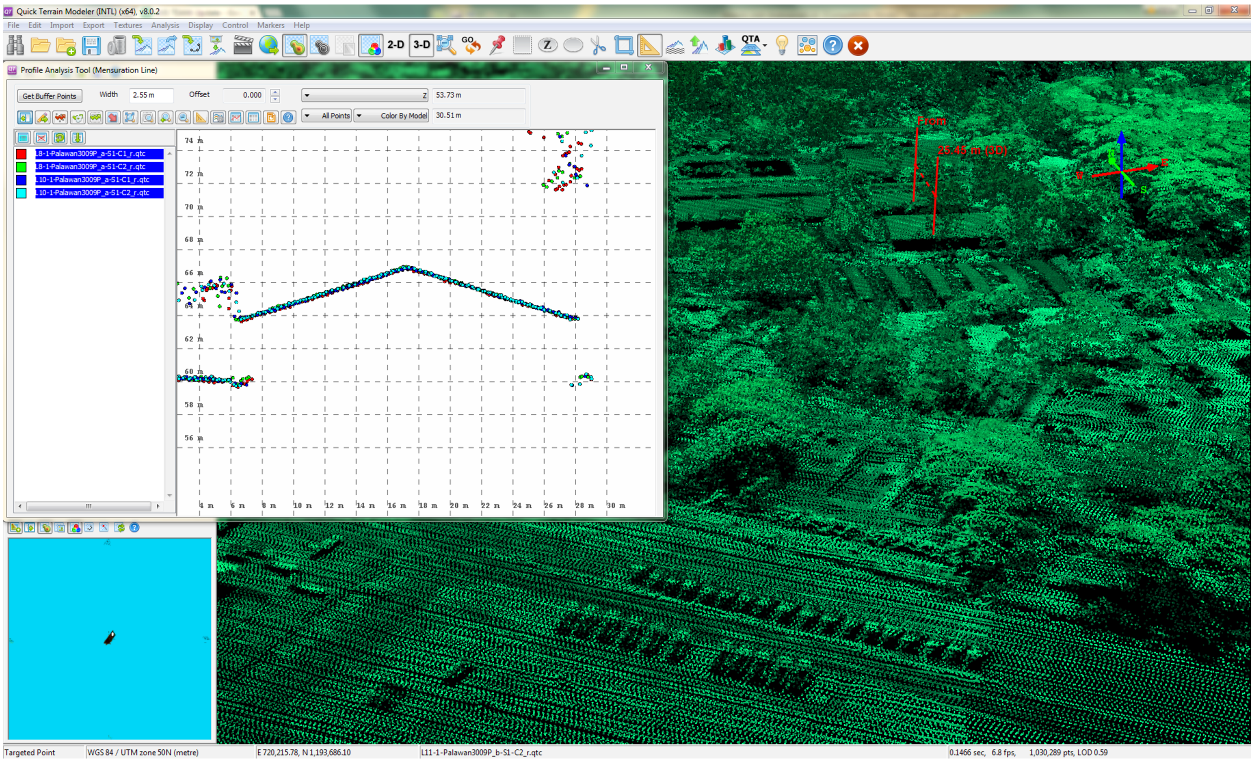


Figure 16. Quality checking for Iwahig Penal flight 3009P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 16. Iwahig Penal classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	577,778,678
Low Vegetation	316,059,250
Medium Vegetation	709,001,073,
High Vegetation	3,581,230,146
Building	49,387,623

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Iwahig Penal floodplain is shown in Figure 17. A total of 1,127 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 899.45 meters and 40.76 meters respectively.

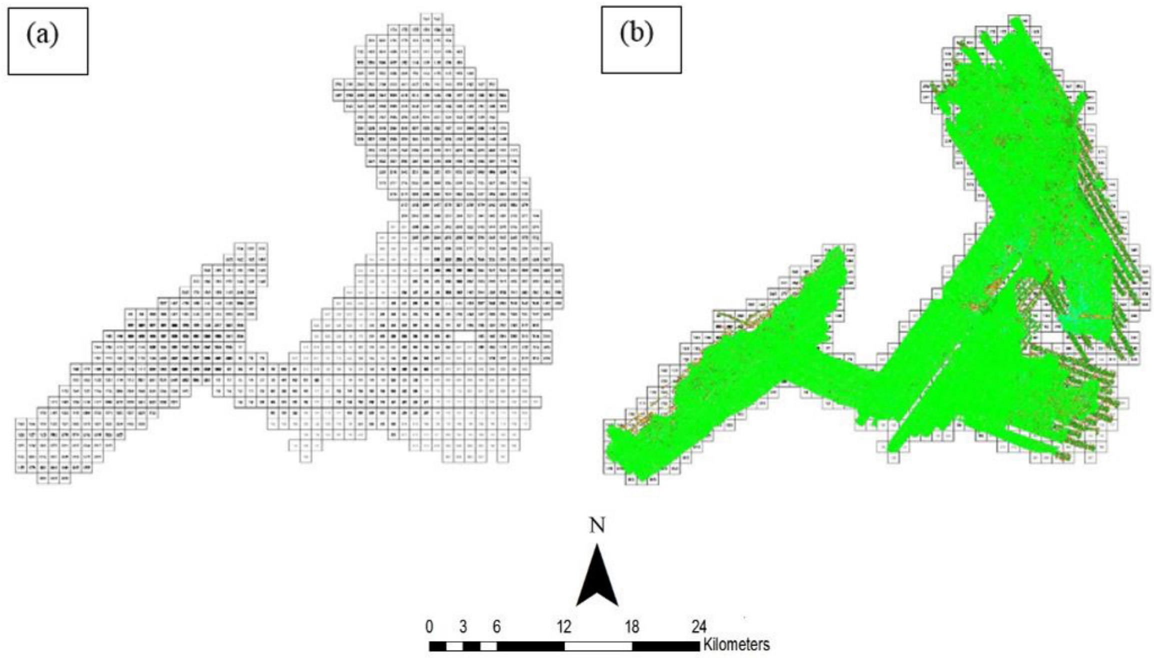


Figure 17. Tiles for Iwahig Penal Floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 18. 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.

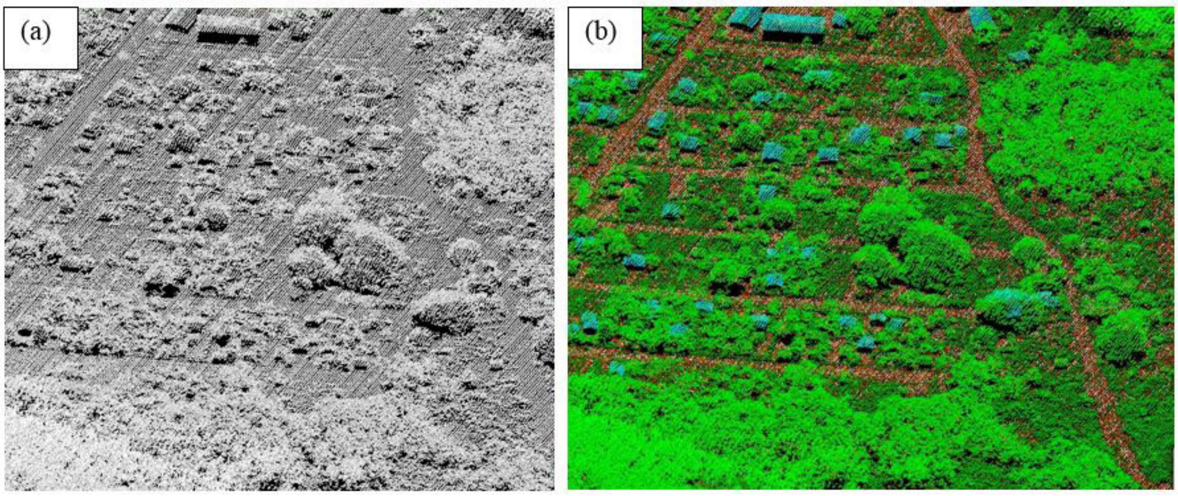


Figure 18. Point cloud before (a) and after (b) classification.

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

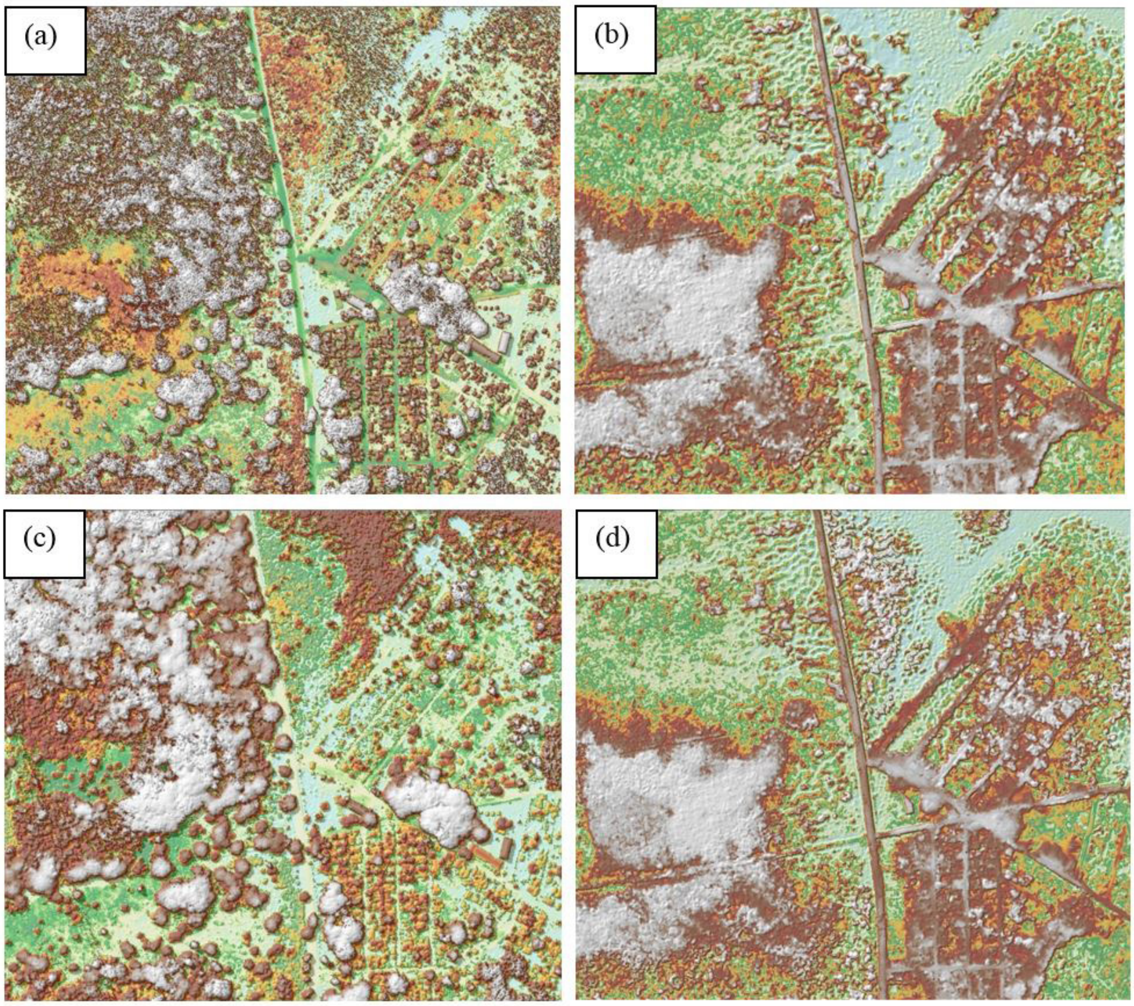


Figure 19. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Iwahig Penal Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 1,027 1km by 1km tiles area covered by Iwahig Penal floodplain is shown in Figure 20. 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 Penal floodplain has a total of 593.13 sq.km orthophotogaph coverage comprised of 2,263 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 21.

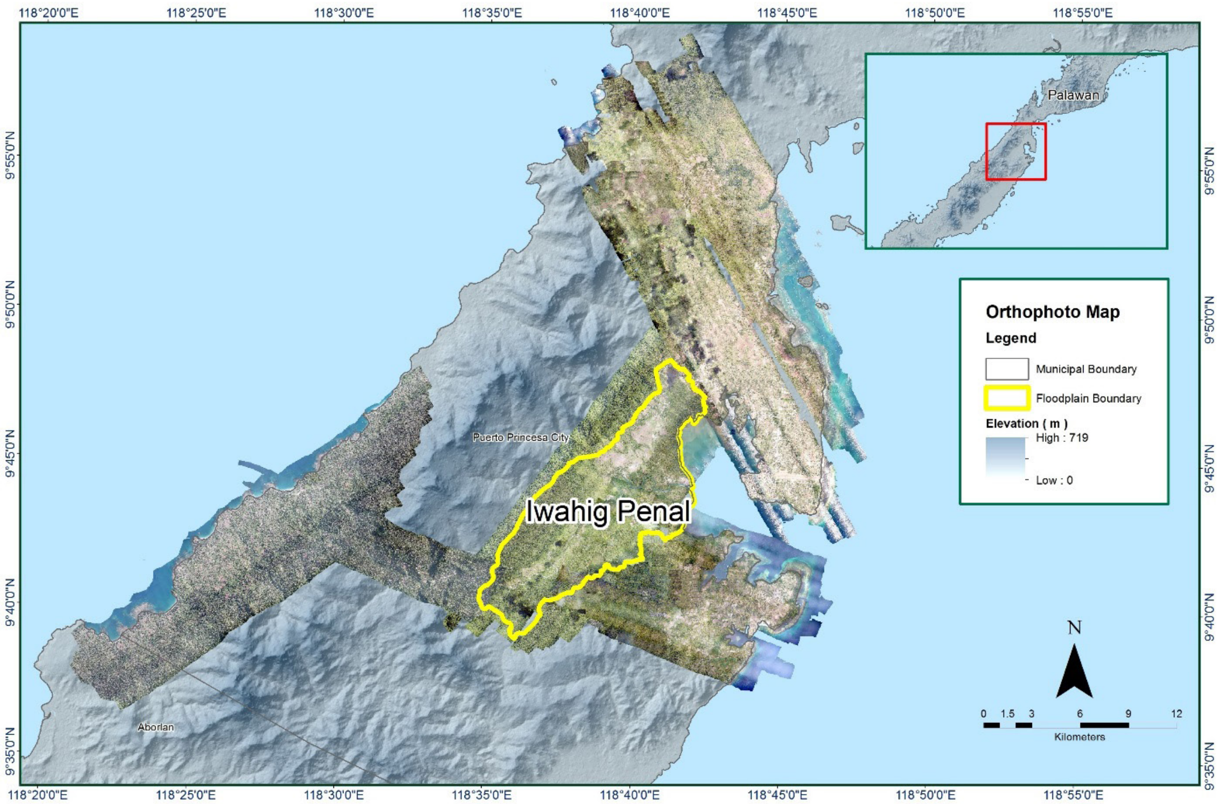


Figure 20. Iwahig Penal Floodplain with available orthophotographs.

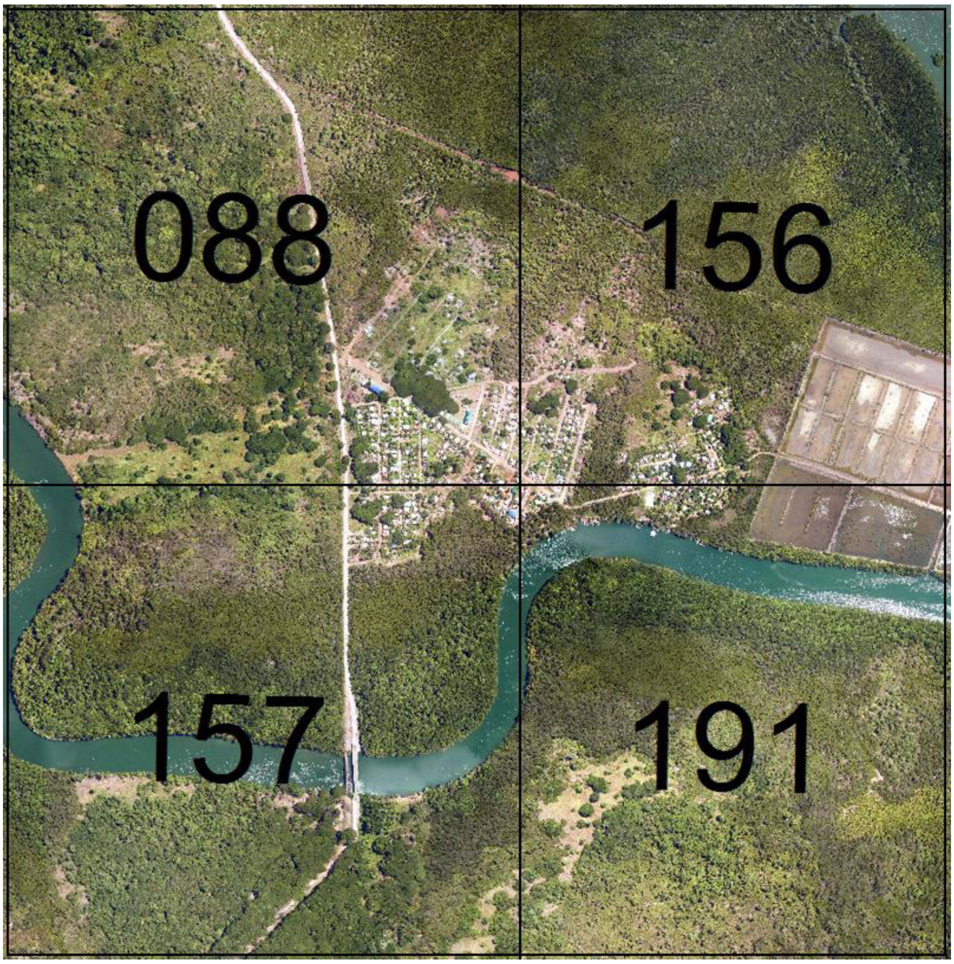


Figure 21. Sample orthophotograph tiles for Iwahig Penal Floodplain.

3.8 DEM Editing and Hydro-Correction

Seven (7) mission blocks were processed for Iwahig Penal flood plain. These blocks are composed of Palawan and Palawan_reflights blocks with a total area of 807.67 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_Blk42E	268.13
Palawan_Blk42F	168.72
Palawan_Blk42F_additional	16.03
Palawan_Blk42F_supplement	121.93
Palawan_Blk42G	52.24
Palawan_Blk42H	146.16
Palawan_reflights_Blk42eF	34.46
TOTAL	807.67 sq.km

Portions of DTM before and after manual editing are shown in Figure 22. The bridge (Figure 22a) is also considered to be an impedance to the flow of water along the river and has to be removed (Figure 22b) in order to hydrologically correct the river. A part of the profile of the waterway (Figure 22c) was elevated and has to be interpolated (Figure 22d) to allow the correct flow of water. Also, data gap (Figure 22c) has been filled to complete the surface (Figure 22d).

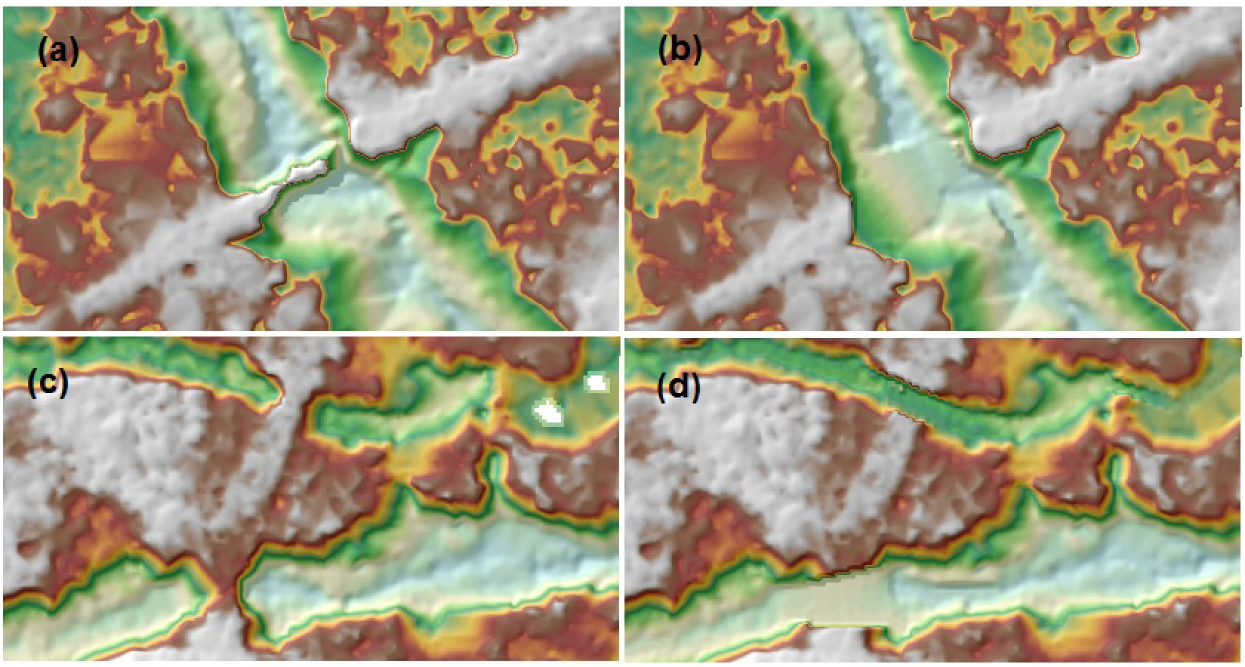


Figure 22. Portions in the DTM of Iwahig Penal Floodplain – a bridge before (a) and after (b) manual editing; and a block in the water way and data gaps before (c) and after (d) removal and filling.

3.9 Mosaicking of Blocks

Palawan_Blk42Aa was used as the reference block at the start of mosaicking because it was the first block mosaicked to the larger DTM of West Coast Palawan. Upon inspection of the blocks mosaicked for the Iwahig Penal floodplain, it was concluded that the elevation of all blocks for this river basin needed adjustment. Table 18 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Iwahig Penal floodplain is shown in Figure 23. It can be seen that the entire Iwahig Penal floodplain is 100% covered by LiDAR data.

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

Mission Blocks	Shift Values (meters)		
	x	y	z
Palawan_Blk42E	0.00	0.00	-0.13
Palawan_Blk42F (left)	-0.24	-0.25	-0.10
Palawan_Blk42F (right)	-0.26	1.52	-0.10
Palawan_Blk42F_additional	-0.04	0.95	0.06
Palawan_Blk42F_supplement	0.01	0.97	-0.09
Palawan_Blk42G	0.00	0.00	0.54
Palawan_Blk42H	0.00	0.00	-0.07
Palawan_reflights_Blk42eF	0.02	1.01	-0.10
Palawan_Blk42E	0.00	0.00	-0.13

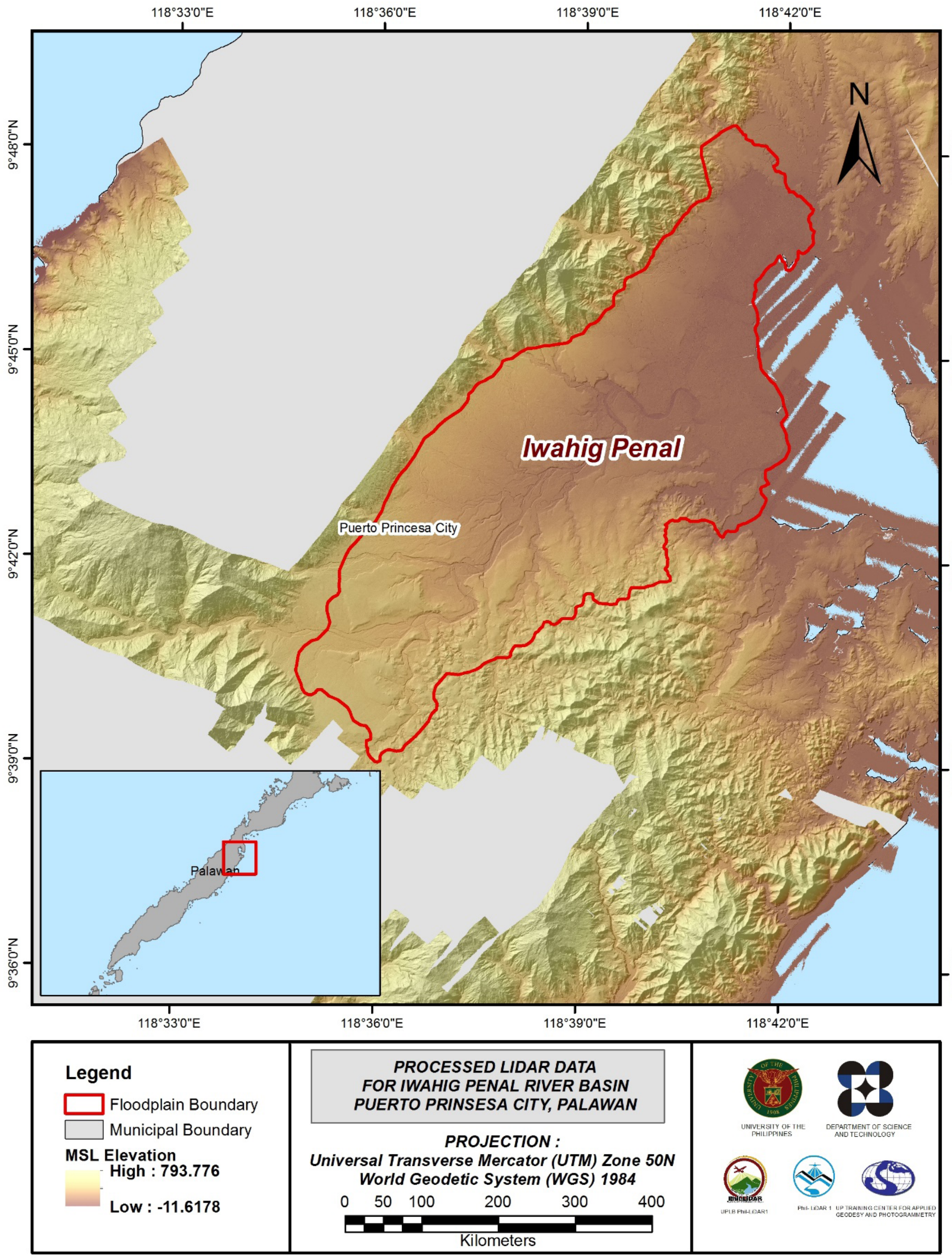


Figure 23. Map of Processed LiDAR Data for Iwahig Penal Floodplain.

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 Penal to collect points with which the LiDAR dataset is validated is shown in Figure 24. A total of 1,103 survey points were used for calibration and validation of Iwahig Penal LiDAR data. Random selection of 80% of the survey points, resulting to 883 points, was used for calibration.

A good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values is shown in Figure 25. 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 10.74 meters with a standard deviation of 0.20 meters. Calibration of Iwahig Penal LiDAR data was done by adding the height difference value, 10.74 meters, to Iwahig Penal mosaicked LiDAR data. Table 19 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

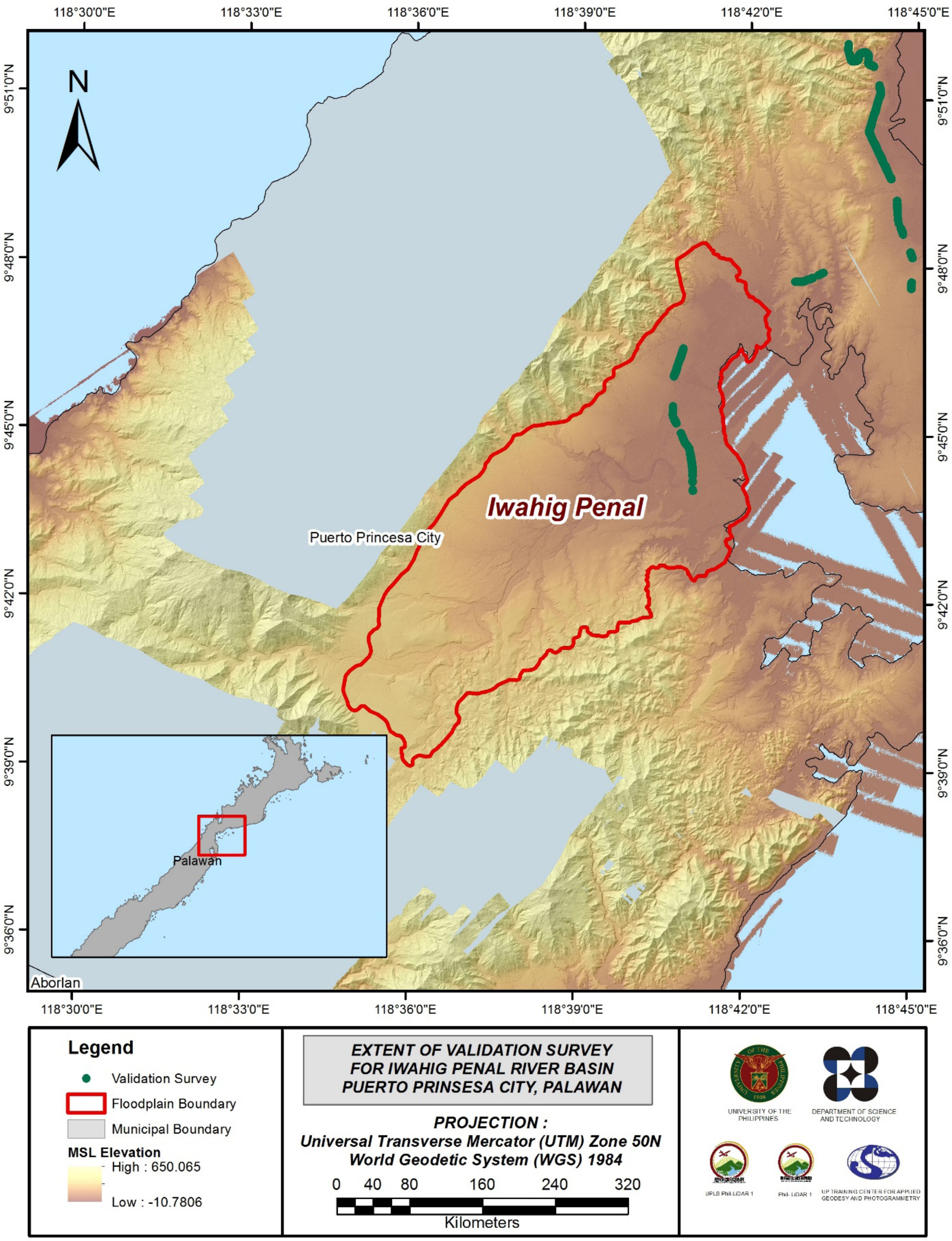


Figure 24. Map of Iwahig Penal Floodplain with validation survey points in green.

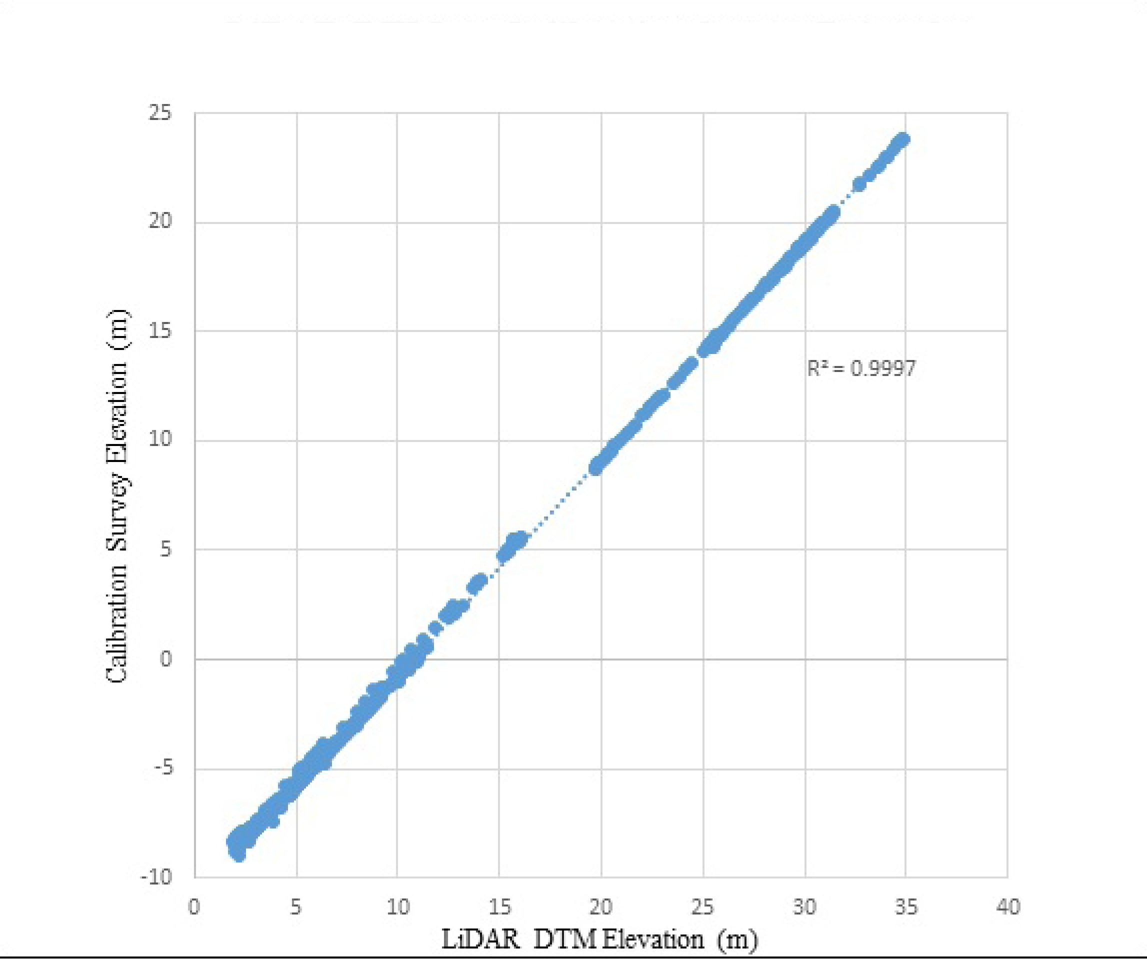


Figure 25. Correlation plot between calibration survey points and LiDAR data

Table 19. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	10.74
Standard Deviation	0.20
Average	10.74
Minimum	10.34
Maximum	11.14

A total of 220 survey points lie within Iwahig Penal flood plain and were used for the validation of the calibrated Iwahig Penal 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 26. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.20 meters with a standard deviation of 0.20 meters, as shown in Table 20.

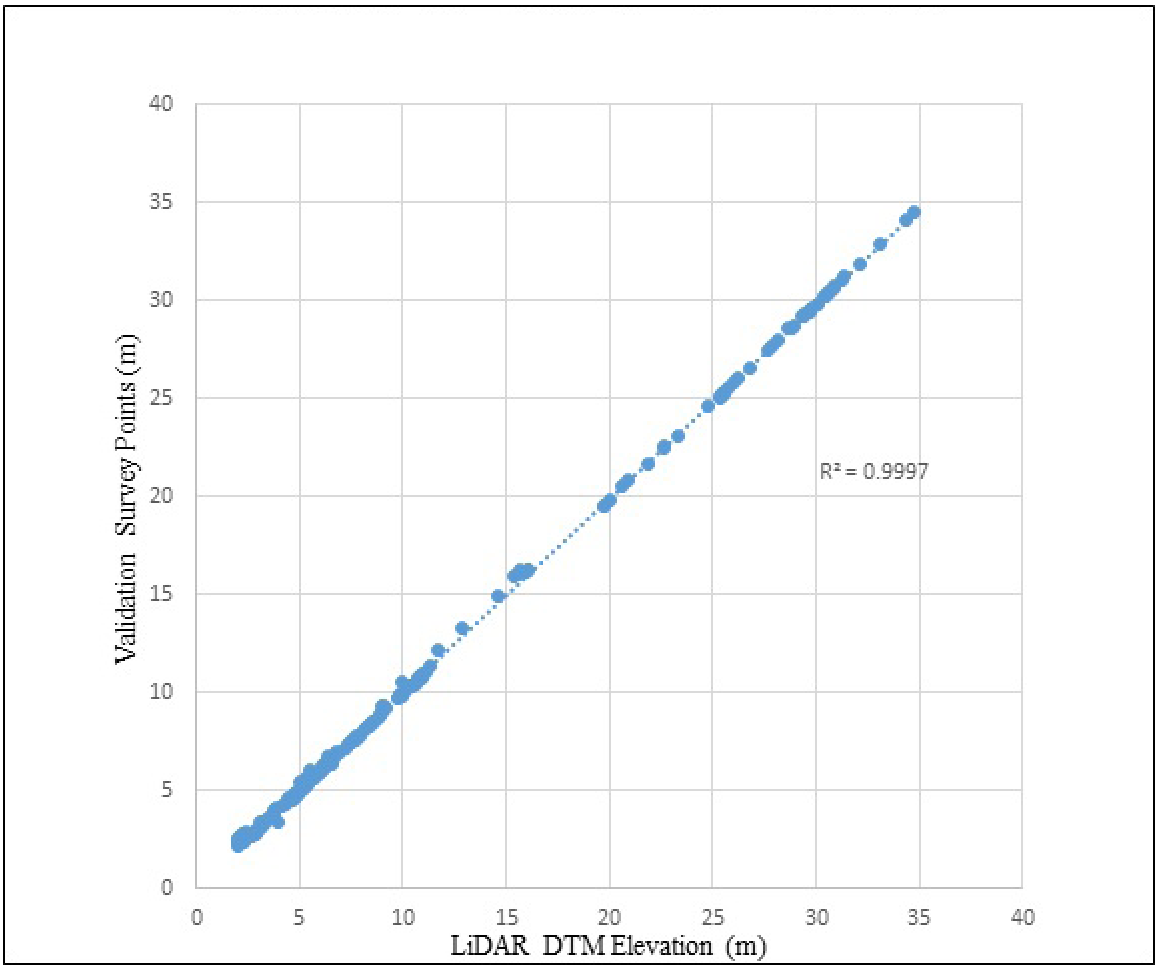


Figure 26. Correlation plot between validation survey points and LiDAR data.

Table 20. Validation Statistical Measures.

Validation Statistical Measures	Value (meters)
RMSE	0.20
Standard Deviation	0.20
Average	-0.002
Minimum	-0.40
Maximum	0.40

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and zigzag data were available for Iwahig Penal with 9,153 bathymetric survey points. The resulting raster surface produced was done by Inverse Distance Weighted (IDW) interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.07 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Iwahig Penal integrated with the processed LiDAR DEM is shown in Figure 27.

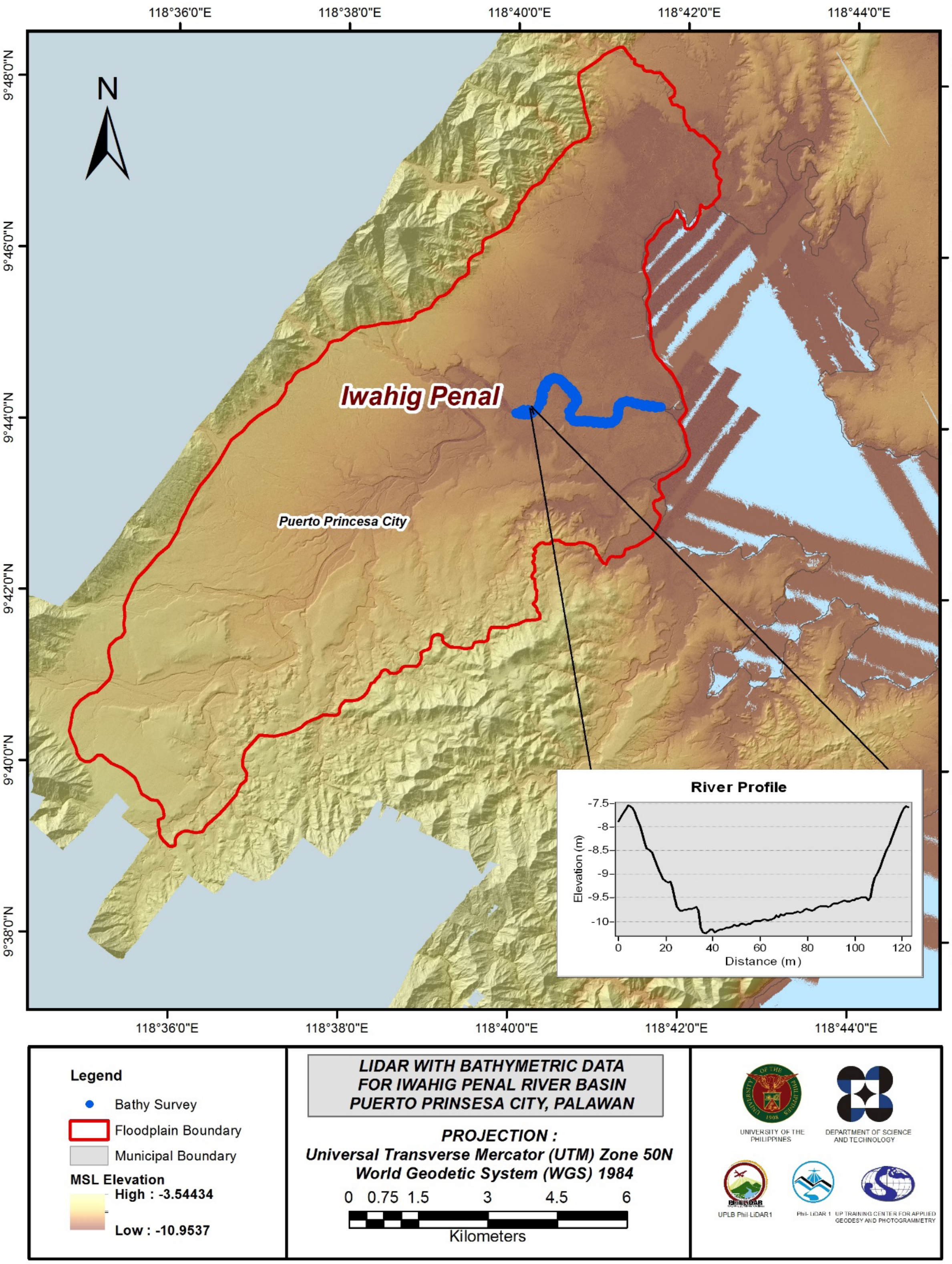


Figure 27. Map of Iwahig Penal Floodplain with bathymetric survey points shown in blue.

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

Engr. Louie P. Balicanta, Engr. Joemarie S. Caballero, Ms. Patrizcia Mae. P. dela Cruz, Engr. Kristine Ailene B. Borromeo Ms. Jeline M. Amante, Marie Angelique R. Estipona, Charie Mae V. Manliguez, Engr. Janina Jupiter, Vie Marie Paola M. Rivera

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

4.1 Summary of Activities

AB Surveying and Development (ABSD) conducted a field survey in Iwahig Penal River on November 25-26, 28, 2015 and December 8, 2015 with the following scope: reconnaissance; control survey; cross-section and as-built survey at Iwahig Penal Bridge in Brgy. Iwahig, Puerto Princesa City, Palawan; and bathymetric survey from its upstream in down to the mouth of the river located in Brgy. Iwahig, Puerto Princesa City, Palawan, with an approximate length of 4.14 km using Hi-Target™ Echo Sounder. 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 Penal River Basin area. The entire survey extent is illustrated in Figure 28.

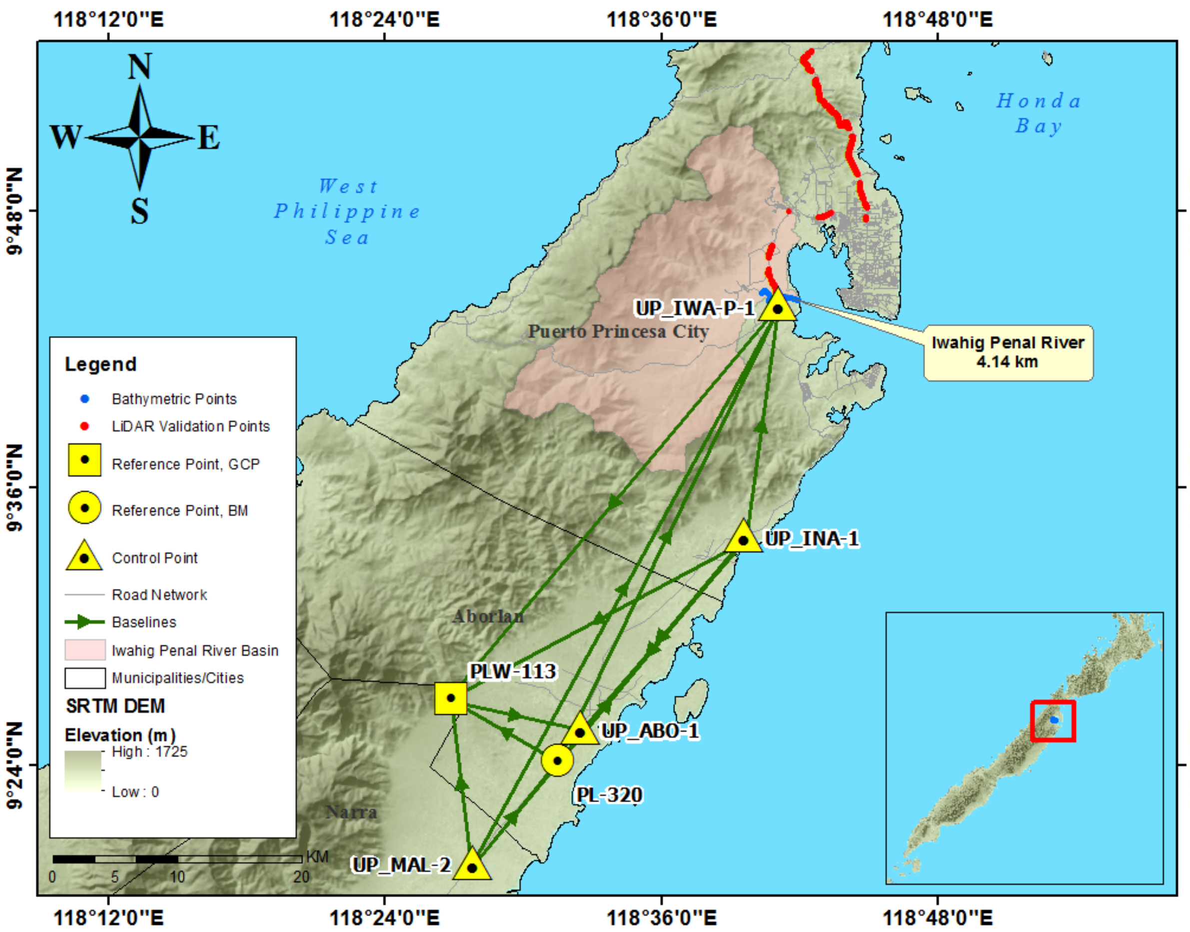


Figure 28. Iwahig Penal River Survey Extent

4.2 Control Survey

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

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

The summary of reference and control points and its location is summarized in Table 21 while GNSS network established is illustrated in Figure 29.

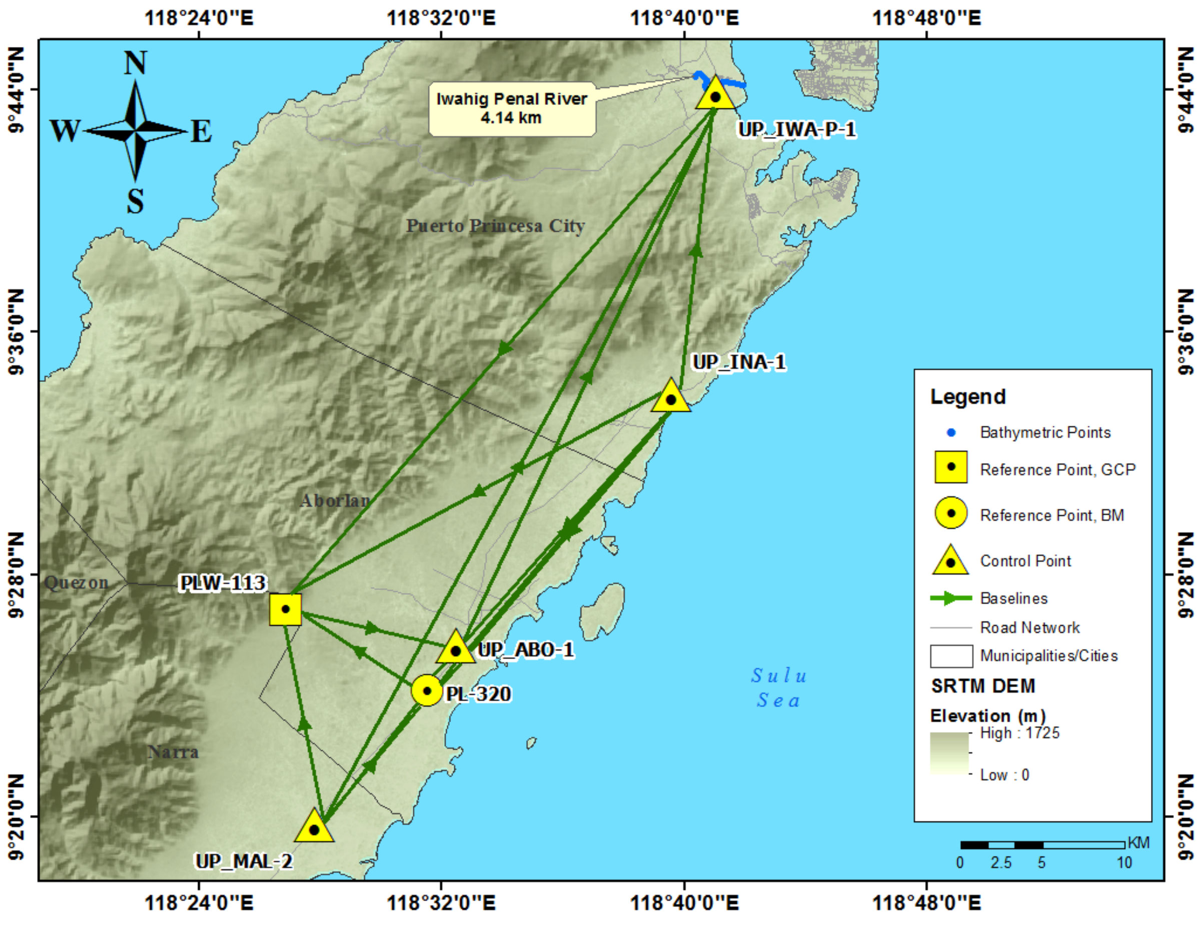


Figure 29. GNSS Network covering Iwahig River

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

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

The GNSS set-ups on recovered reference points and established control points in Iwahig Penal River are shown from Figure 30 to Figure 35.

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

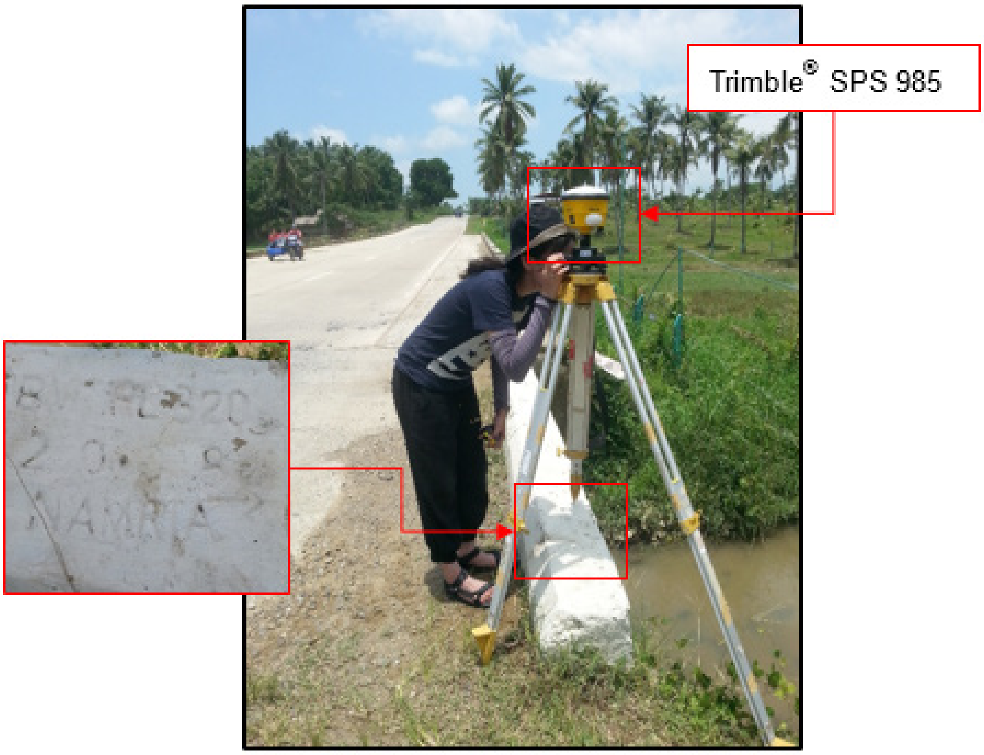


Figure 31. GNSS receiver set up, Trimble® SPS 985, at PL-320, located on top of a culvert headwall along the National Road in Brgy. Ramon Magsaysay, Aborlan, Province of Palawan

Figure 32. GNSS receiver set up, Trimble® SPS 882, at UP_MAL-2, located at the approach of Malatgao Bridge in Brgy. Tinagong Dagat, Narra, Province of Palawan

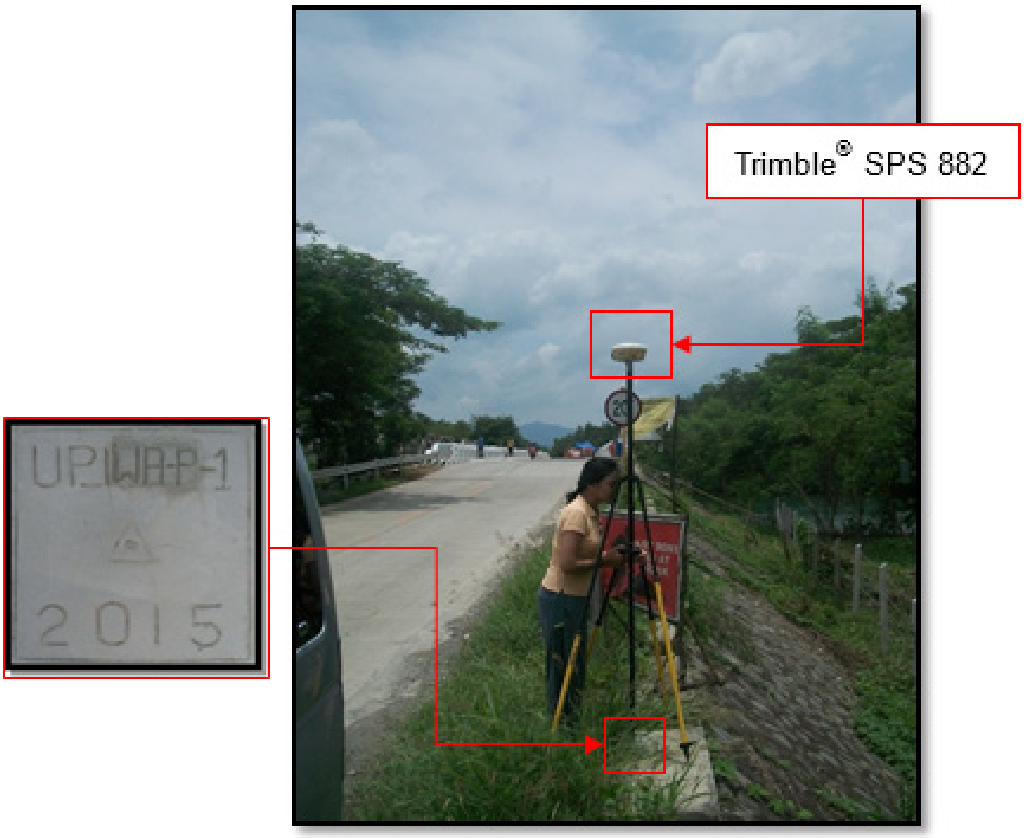


Figure 33. GNSS receiver set up, Trimble® SPS 982, at UP_IWA-P-1, located at the approach of Iwahig Penal Bridge in Brgy. Iwahig, Puerto Princesa City, Palawan

Figure 34. GNSS receiver set-up, Trimble® SPS 852, at UP_ABO-1, an established control point, beside the approach of Aborlan Bridge in Brgy. Gogognan, Aborlan, Palawan

Figure 35. GNSS receiver set up, Trimble® SPS 882, at UP_INA-1, located beside the approach of Inagauan Bridge in Brgy. Inagauan Sub-Colony, Puerto Princesa City, Palawan

4.3 Baseline Processing

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

Table 22. Baseline Processing Report for Iwahig Penal 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-113 --- UP_ABO-1	8-25-2016	Fixed	0.009	0.023	101°59'15"	10513.593	-85.092
UP_IWA-P-1 --- PLW-113	8-25-2016	Fixed	0.004	0.024	219°26'55"	40874.066	88.833
PL-320 --- PLW- 113	8-25-2016	Fixed	0.018	0.029	300°01'31"	9832.467	86.391
PL-320 --- UP_IWA-P-1	8-25-2016	Fixed	0.004	0.018	205°34'21"	40449.118	2.530
UP_MAL-2 --- PL- 320	8-25-2016	Fixed	0.010	0.021	220°02'59"	10578.751	9.435
UP_INA-1 --- UP_ABO-1	8-25-2016	Fixed	0.008	0.025	220°15'41"	20085.570	2.974
UP_INA-1 --- PLW-113	8-25-2016	Fixed	0.005	0.025	240°32'45"	26716.978	88.012
UP_INA-1 --- PL-320	8-25-2016	Fixed	0.010	0.019	219°14'35"	23320.185	1.618
UP_INA-1 --- UP_IWA-P-1	8-25-2016	Fixed	0.005	0.019	188°21'15"	18624.653	0.847
UP_MAL-2 --- UP_INA-1	8-25-2016	Fixed	0.005	0.014	39°28'10"	33898.188	-11.058
UP_MAL-2 --- UP_IWA-P-1	8-25-2016	Fixed	0.024	0.024	208°33'52"	50759.890	11.894
UP_MAL-2 --- PLW-113	8-25-2016	Fixed	0.005	0.021	352°31'24"	13129.154	76.935

As shown Table 22 a total of twelve (12) baselines were processed with coordinate and elevation values of UP_IWA-P-1 and the coordinate values of PLW-113 held fixed. All of them passed the required accuracy.

4.4 Network Adjustment

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

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

Where:

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

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

The six (6) control points, PLW-113, PL-320, UP-MAL-2, UP-IWA-P-1, UP_ABO-1, and UP_INA-1 were occupied and observed simultaneously to form a GNSS loop. The coordinates and elevation of UP_IWA-P-1 and the coordinates of PLW-113 were held fixed during the processing of the control points as presented in Table 23. Through these reference points, the coordinates and elevations 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-113	Global	Fixed	Fixed		
UP_IWA-P-1	Grid				Fixed
UP_IWA-P-1	Global	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. All fixed control points have no values for grid errors and elevation error.

Table 24. Adjusted Grid Coordinates

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

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

PL-320
horizontal accuracy = √((1.3)² + (0.8)²
= √ (1.69 + 0.64)
= 2.33 < 20 cm
vertical accuracy = 4.9 < 10 cm

PLW-113
horizontal accuracy = Fixed
vertical accuracy = Fixed

UP_ABO-1
horizontal accuracy = √((1.8)² + (1.6)²
= √ (3.24 + 2.56)
= 5.8 < 20 cm
vertical accuracy = 8.0 < 10 cm

UP_INA-1
horizontal accuracy = √((0.9)² + (0.7)²
= √ (0.81 + 0.49)
= 1.30 < 20 cm
vertical accuracy = 4.7 < 10 cm

UP_IWA-P-1
horizontal accuracy = Fixed
vertical accuracy = Fixed

UP_MAL-2
horizontal accuracy = √((1.2)² + (0.9)²
= √ (1.44 + 0.81)
= 2.25 < 20 cm
vertical accuracy = 4.7 < 10 cm

Following the given formula, the horizontal and vertical accuracy result of the six (6) occupied control points are within the required precision.

Table 25. Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
PL-320	N9°24'10.67926"	E118°31'31.30061"	58.025	0.049	
PLW-113	N9°26'50.78624"	E118°26'52.23491"	144.388	0.054	LL
UP_ABO-1	N9°25'39.66712"	E118°32'29.34660"	59.322	0.080	
UP_INA-1	N9°33'58.62160"	E118°39'34.84567"	56.382	0.047	
UP_IWA-P-1	N9°43'58.38961"	E118°41'03.58218"	55.529	?	LLe
UP_MAL-2	N9°19'47.08511"	E118°27'48.23731"	67.449	0.047	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 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 UTM Zone 50N)					
		Latitude	Longitude	Ellipsoidal Height (Meter)	Northing (m)	Easting (m)	BM Ortho (m)
PLW-113	2nd order, GCP	9° 26' 50.78624" N	118° 26' 52.23491" E	144.388	1044650.284	658953.945	93.784
PL-320	1st order, BM	9° 24' 10.67926" N	118° 31' 31.30061" E	58.025	1039767.829	667487.736	7.089
UP_MAL-2	Established	9° 19' 47.08536" N	118° 27' 48.23703" E	67.449	1031641.078	660716.408	16.469
UP_IWA-P-1	Established	9° 43' 58.38961" N	118° 41' 03.58218" E	55.529	1076338.886	684768.852	5.044
UP_ABO-1	Established	9° 25' 39.66712" N	118° 32' 29.34660" E	59.322	1042509.427	669246.54	8.415
UP_INA-1	Established	9° 33' 58.62160" N	118° 39' 34.84567" E	56.382	1057898.445	682153.657	5.672

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

Cross-section and as-built surveys were conducted on November 26, 2015 at the downstream side of Iwahig Penal Bridge in Brgy. Iwahig, City of Puerto Princesa as shown in Figure 36. A Horizon® Total Station was utilized for this survey as shown in Figure 37.

Figure 36. Iwahig Penal Bridge facing upstream

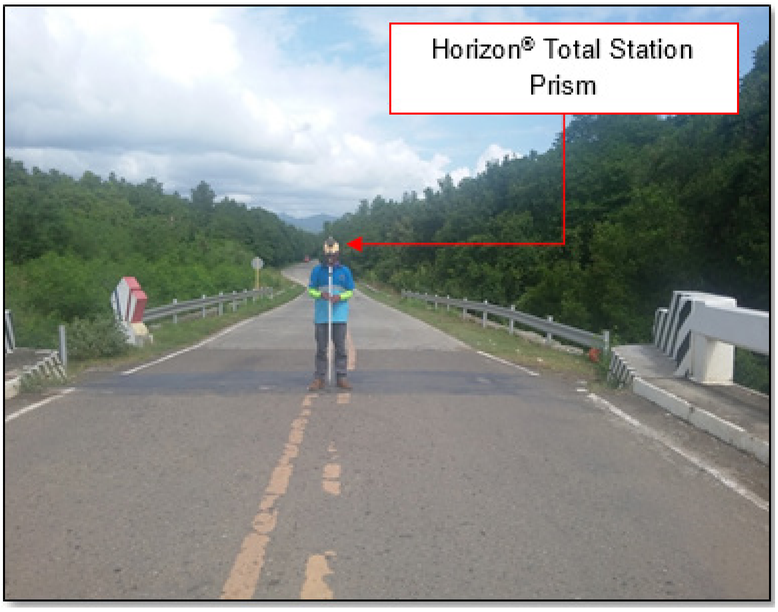


Figure 37. As-built survey of Iwahig Penal Bridge

The cross-sectional line of Iwahig Penal Bridge is about 178 m with forty (40) cross-sectional points using the control points UP_IWA-P-1 and UP_IWA-P-2 as the GNSS base stations. The cross-section diagram, location map, and the bridge data form are shown in Figure 38 to Figure 40. Gathering of random points for the checking of ABSD's bridge cross-section and bridge points data was performed by DVBC on August 26, 2016 using a survey grade GNSS Rover receiver attached to a 2-m pole.

Linear square correlation (R^2) 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 R^2 value must be within 0.85 to 1. An R^2 approaching 1 signifies a strong correlation between the vertical (elevation values) of the two datasets. A computed R^2 value of 0.953 and 0.989 for the bridge cross-section and bridge points data, respectively, were obtained by comparing the data of the contractor and DVBC; signifying a strong correlation between the two (2) datasets.

In addition to the Linear Square Correlation, Root Mean Square (RMSE) analysis is also performed in order to assess the difference in elevation between the DVBC checking points and the contractor's. The RMSE value should only have a maximum radial distance of 5 m and the difference in elevation within the radius of 5 meters should not be beyond 0.50 m. For the bridge cross-section data, a computed value of 0.098 was acquired while a computed value of 0.073 was acquired for the bridge points data. The computed R^2 and RMSE values are within the accuracy requirement of the program.

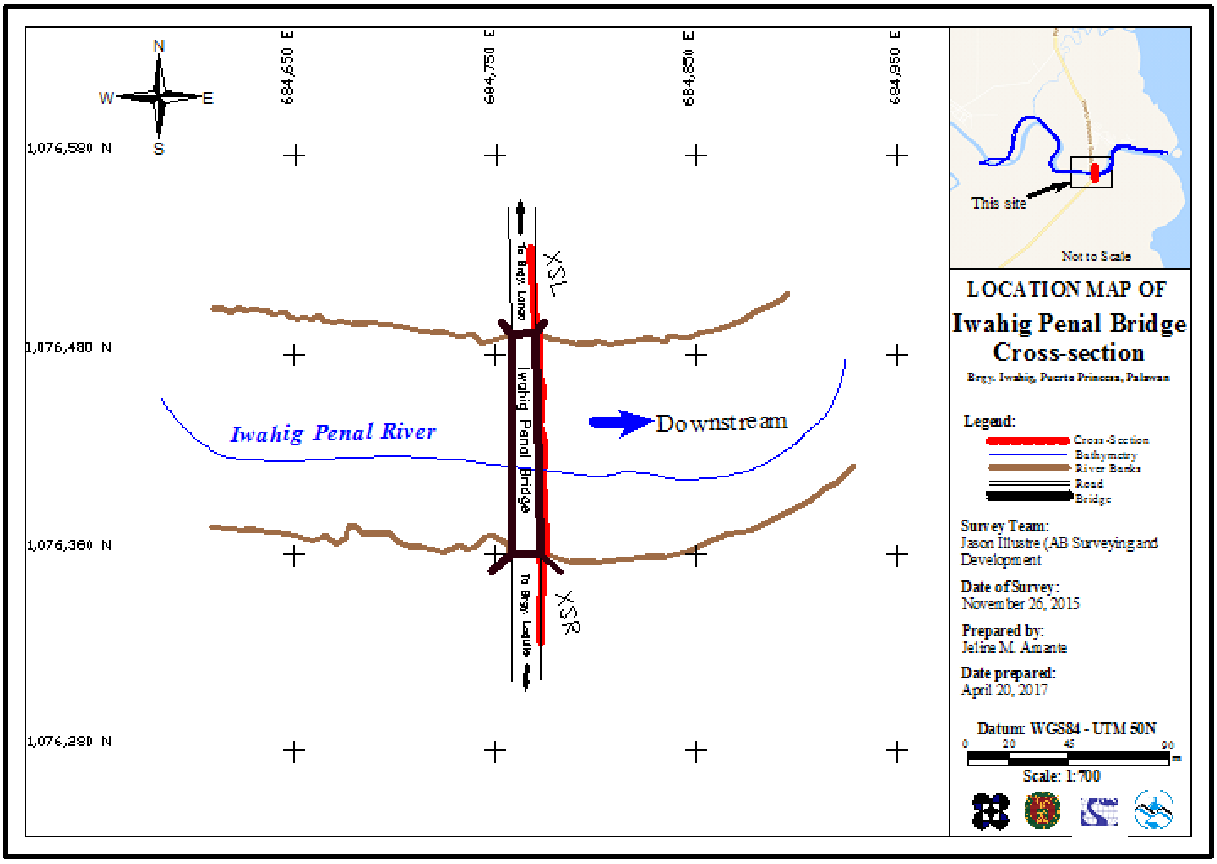


Figure 38. Location Map of Iwahig Penal Bridge River Cross-Section survey

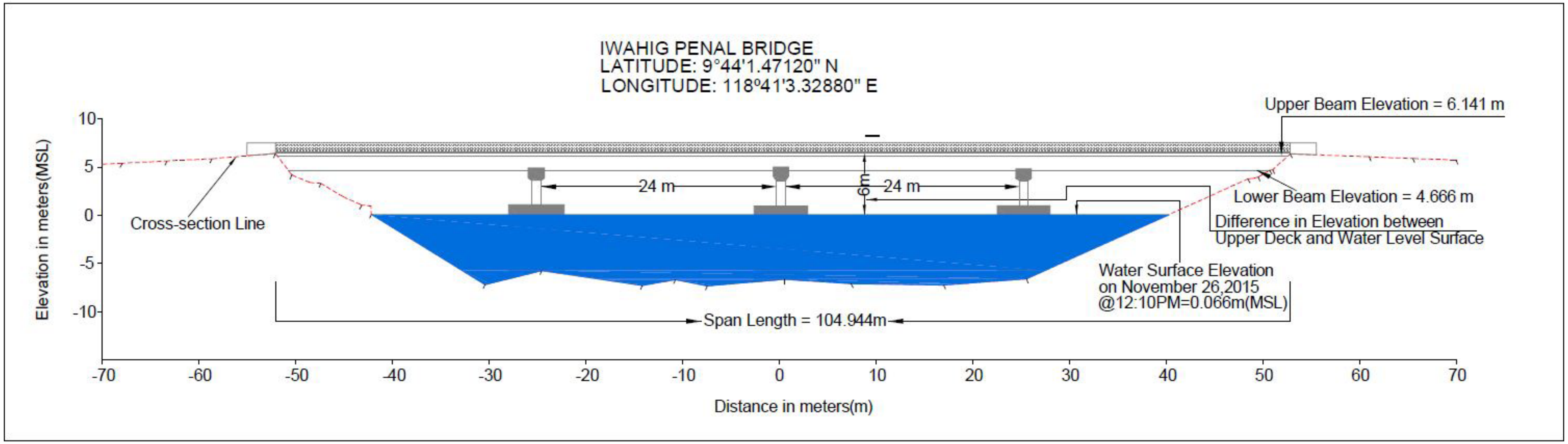


Figure 39. Iwahig Penal Bridge cross-section diagram

Bridge Data Form

Bridge Name: Iwahig Penal Bridge

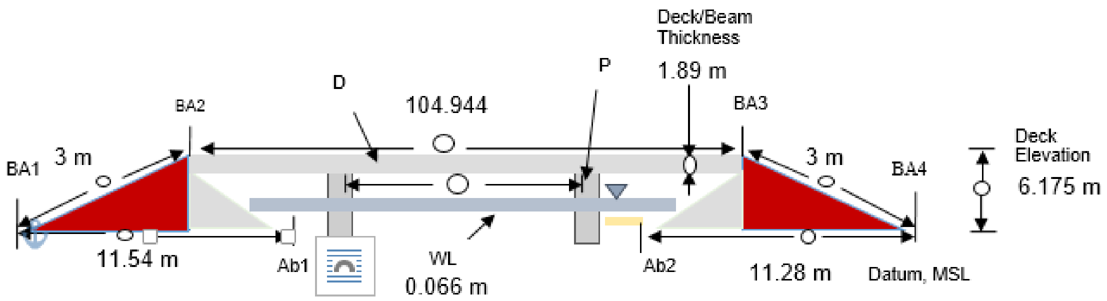
River Name: Iwahig Penal River
Location (Brgy, City, Region): Brgy. Iwahig, Puerto Princesa City, Palawan

Survey Team: Jayson Illustre, Dante Rabago
Date and Time: November 26, 2015, 12:10 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 m	
2. BA2-BA3	104.944 m	
3. BA3-BA4	3 m	
4. BA1-Ab1	11.54 m	
5. Ab2-BA4	11.28 m	
6. Deck/beam thickness	1.89 m	
7. Deck elevation	6.175m	

Note: Observer should be facing downstream

Figure 40. Bridge as-built form of Iwahig Penal Bridge

Water surface elevation of Iwahig Penal River was determined by a Horizon® Total Station on November 26, 2015 at 12:10 PM at Iwahig Penal Bridge area with a value of 0.066 m in MSL as shown in Figure 39. This was translated into marking on the bridge's pier as shown in Figure 41. The marking will serve as reference for flow data gathering and depth gauge deployment of the partner HEI responsible for Iwahig Penal River, the University of the Philippines Los Baños.

Figure 41. Water-level markings on Iwahig Penal Bridge

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted by DVBC on August 25, 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 42. It was secured with cable ties and ropes to ensure that it was horizontally and vertically balanced. The antenna height was 2.590 m and measured from the ground up to the bottom of the quick release of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with PLW-48, a second-order GCP occupied for the survey of Bacungan River located north east of Iwahig Penal River, occupied as the GNSS base station in the conduct of the survey.

Figure 42. Validation points acquisition survey set-up for Iwahig Penal River

The survey started from Brgy. Iwahig, City of Puerto Princesa, Palawan going north east along the national high way, covering five (5) barangays in the City of Puerto Princesa and ended in Brgy. Bacungan, City of Puerto Princesa, Palawan. The survey gathered a total of 2,941 points with approximate length of 20.40 km using PLW-48 as GNSS base station for the entire extent of validation points acquisition survey as illustrated in the map in Figure 43. Reception of satellite signals were poor due to the heavy canopy along the roads, hence, 20% of the surveyed area has no data.

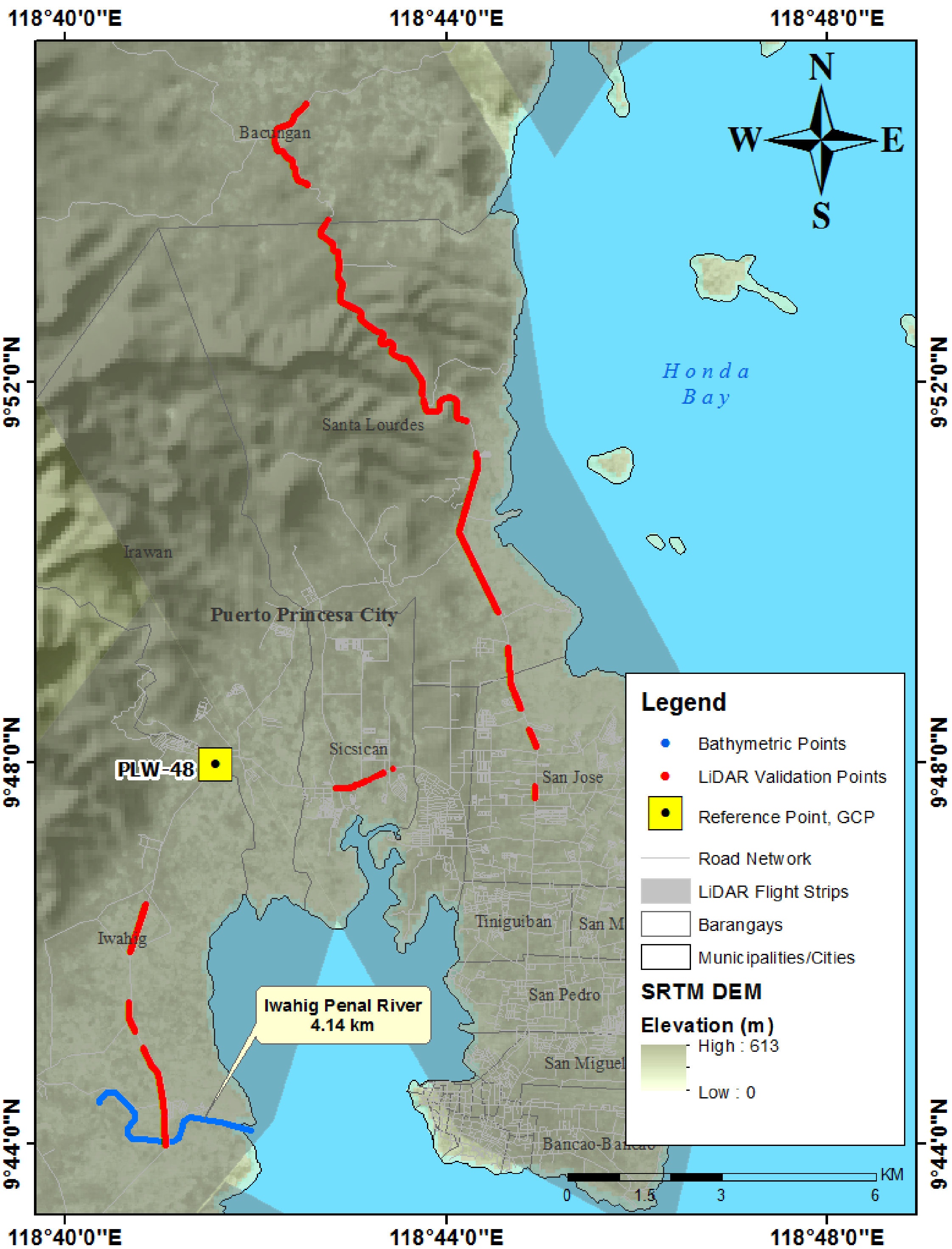


Figure 43. Validation point acquisition survey of Iwahig Penal River Basin area

4.7 Bathymetric Survey

Bathymetric survey was executed on November 28, 2015 using a Hi-Target™ Echo Sounder as seen in Figure 44. The survey started in Brgy. Iwahig, City of Puerto Princesa, Palawan with coordinates 9° 44’ 7.78642”N, 118° 40’ 0.82704”E and ended at the mouth of the river in Brgy. Iwahig, City of Puerto Princesa, Palawan as well, with coordinates 9° 44’ 12.93219”N, 118° 41’ 44.33532”E. The control point UP_IWA-P-2 was used as GNSS base station all throughout the entire survey.

Figure 44. Bathymetric survey of ABSD at Iwahig Penal River using Hi-Target™ Echo Sounder

Gathering of random points for the checking of ABSD’s bathymetric data was performed by DVBC on August 27, 2016 using a survey grade GNSS Rover receiver attached to a boat (Figure 45).

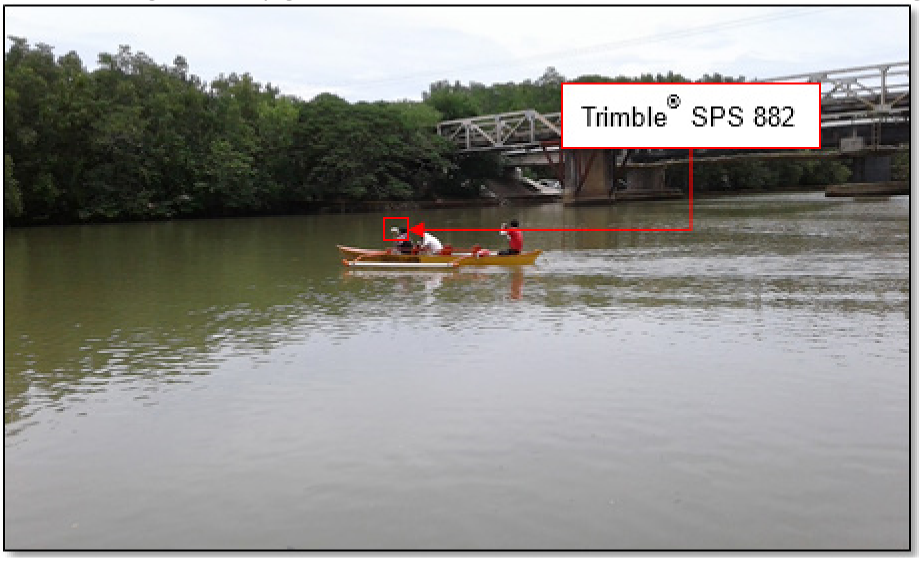


Figure 45. Gathering of random bathymetric points along Iwahig Penal River

The bathymetric survey for Iwahig Penal River gathered a total of 58,941 points covering 4.72 km of the river traversing Brgy. Iwahig in the City of Puerto Princesa (Figure 46).

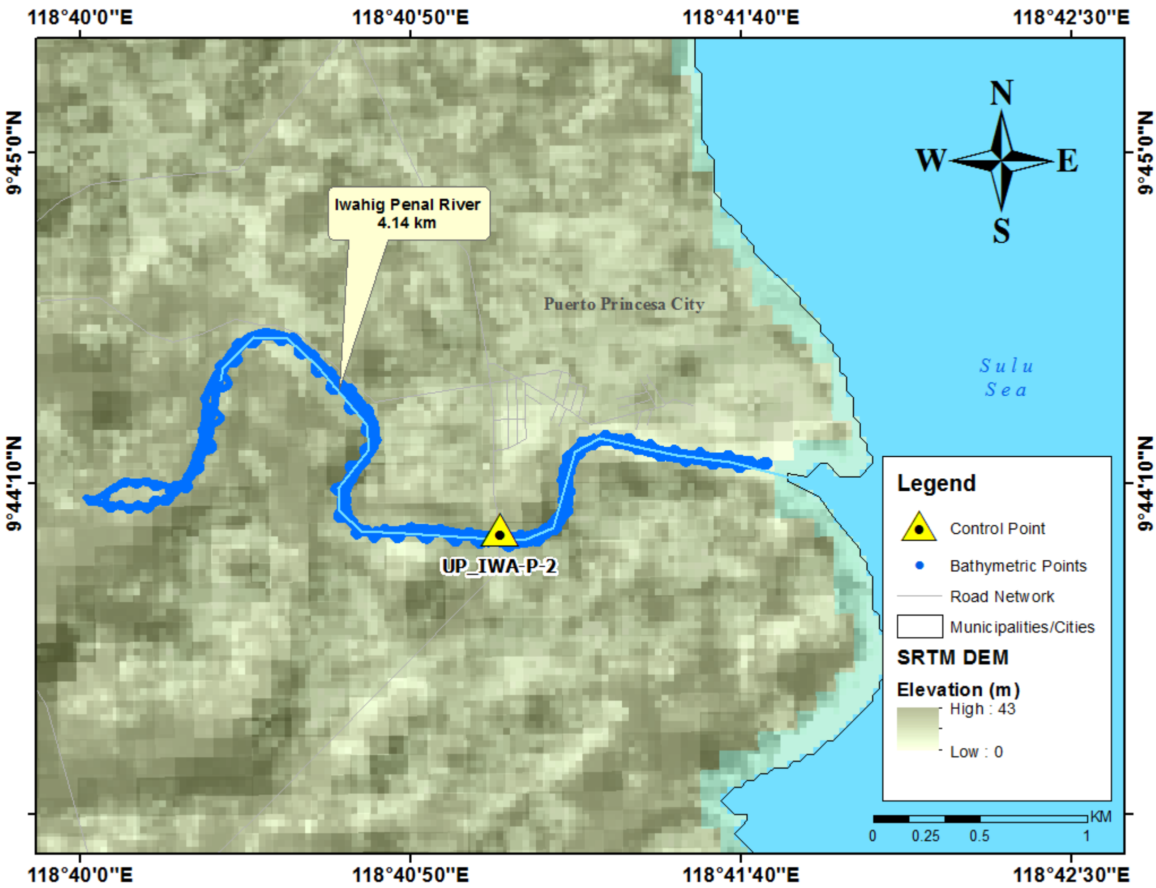


Figure 46. Bathymetric survey of Iwahig Penal River

Linear square correlation (R^2) and RMSE analysis were also performed on the two (2) datasets. A computed R^2 value of 0.888 and 0.724 for the centerline and zigzag line bathymetric data, respectively, were acquired which is within the 0.85 to 1 required range for R^2 value. Additionally, an RMSE values of 2.227 and 0.961 for the centerline and zigzag line bathymetric data, respectively, were obtained. Both the computed R^2 and RMSE values are within the accuracy required by the program; however, the computed R^2 value for the zigzag line bathymetric data is below the required range for R^2 due to the change of river profile and bathymetry during the quality checking. A map showing the DVBC bathymetric checking points is shown in Figure 47 and Figure 48.

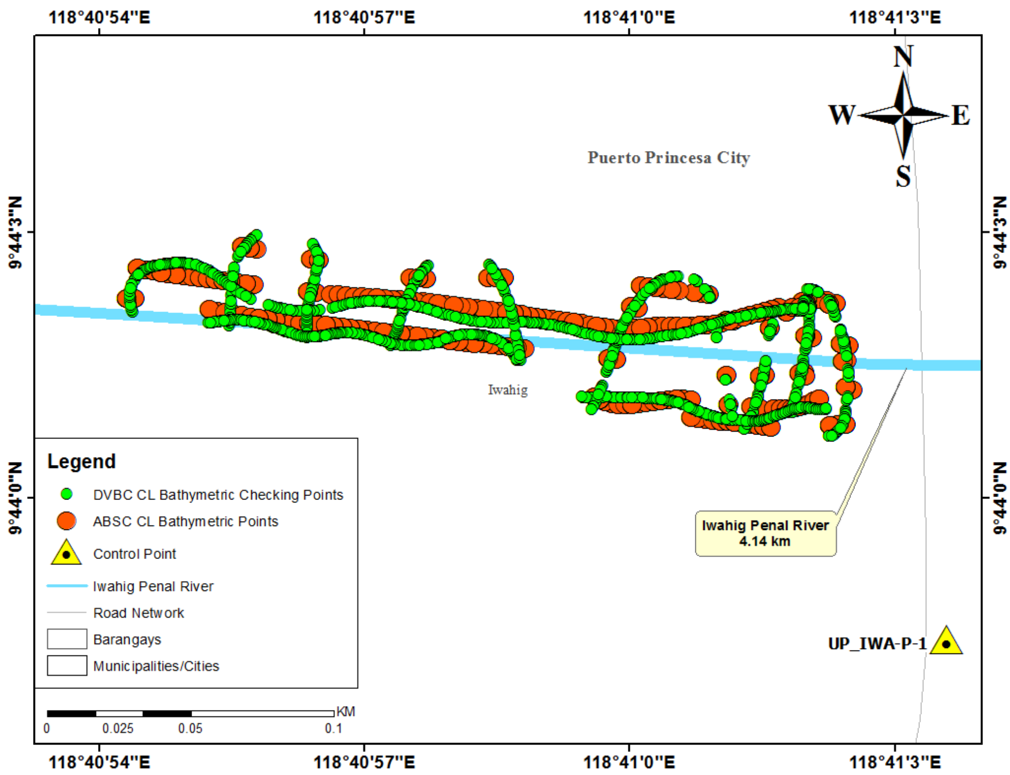


Figure 47. Quality checking points gathered along Iwahig Penal River by DVBC (center line)

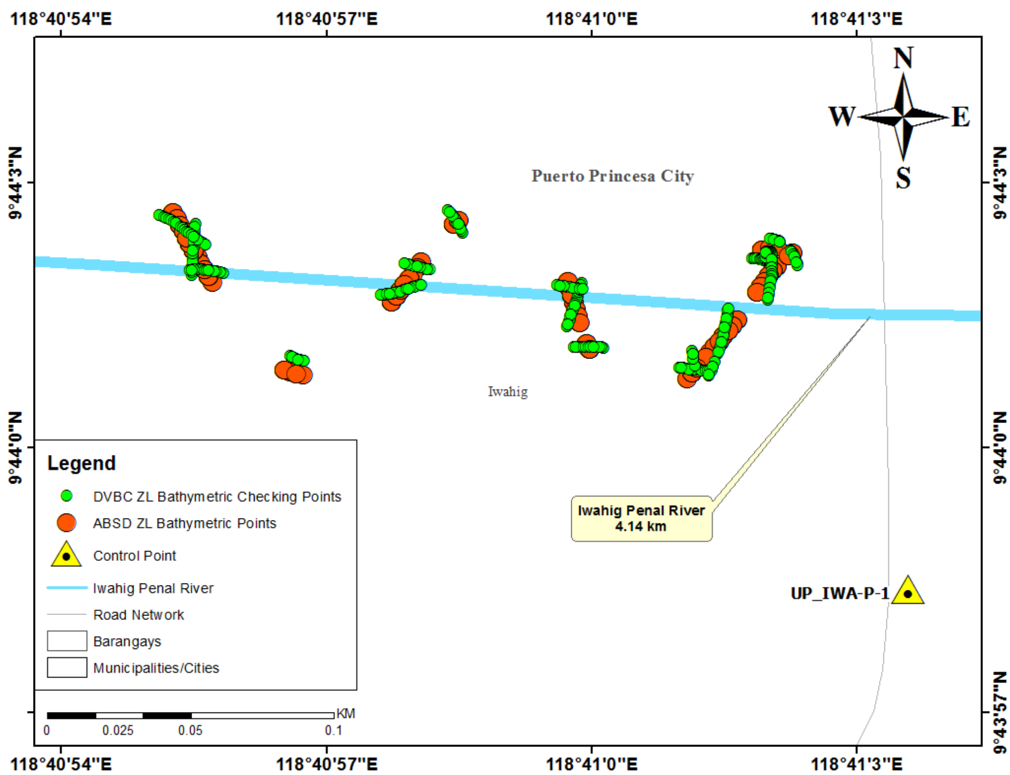


Figure 48. Quality checking points gathered along Iwahig Penal River by DVBC (zigzag line)

A CAD drawing was also produced to illustrate the riverbed profile of Iwahig Penal River. As shown in Figure 49, the highest and lowest elevation has a 6-m difference. The highest elevation observed was -1.225 m below MSL located in Brgy. Iwahig, City of Puerto Princesa while the lowest was -11.405 m below MSL located in Brgy. Iwahig, City of Puerto Princesa as well.

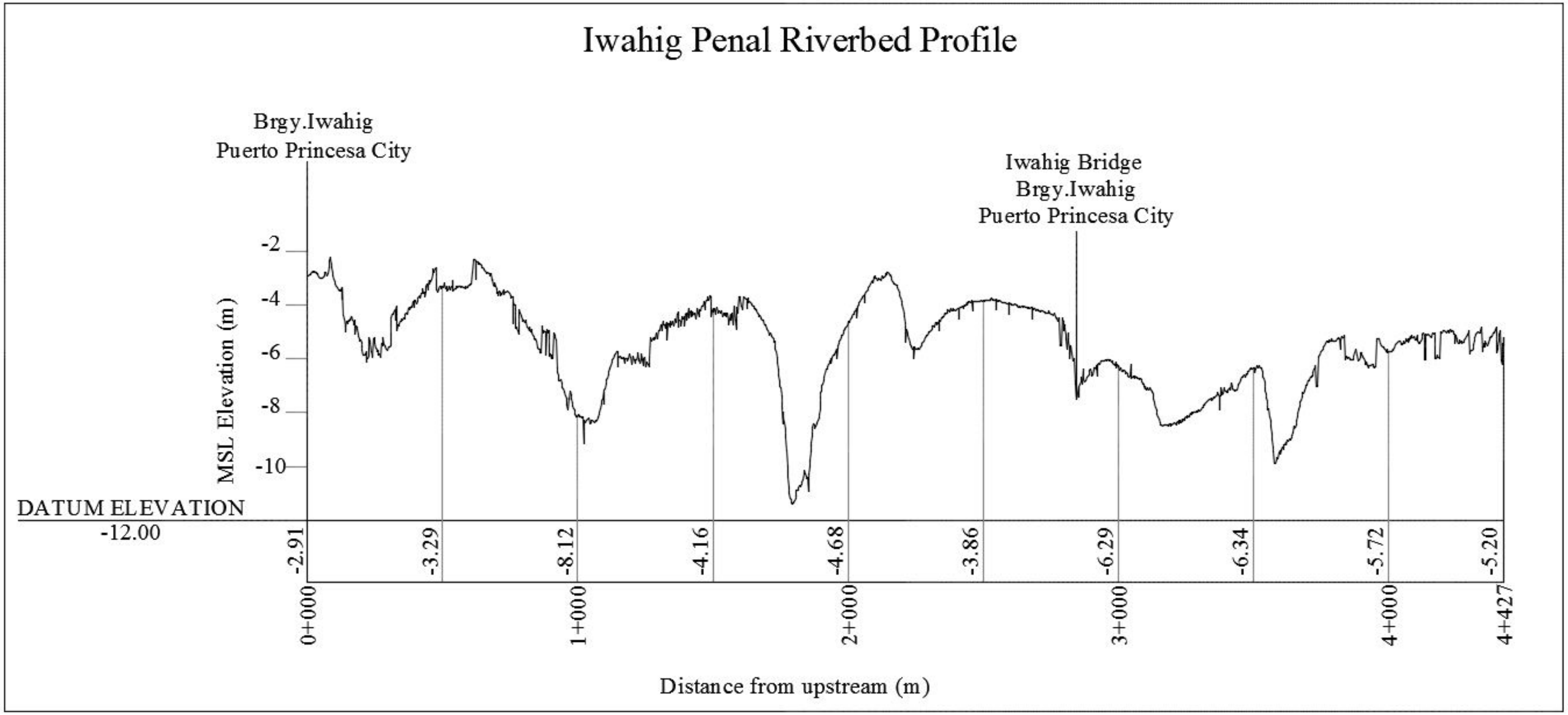


Figure 49. Iwahig Penal Riverbed Profile

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, Gillian Katherine L. Inciong, Gemmalyn E. Magnaye, Leendel Jane D. Punzalan, Sarah Joy A. Acepcion, Ivan Marc H. Escamos, Allen Roy C. Roberto, and Jan Martin C. Magcale

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

5.1 Data used in Hydrologic Modeling

No gathered rainfall data for Iwahig Penal 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 Princesa Rain Gauge computed by PAGASA

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	10 mins	20 mins	30 mins	1 hr	2 hrs	3 hrs	6 hrs	12 hrs	24 hrs
2	14.8	22	27.3	36.2	49.8	58.8	75.1	88	104.1
5	21.3	31.9	39.7	52.3	73	86.9	112.8	135.4	156.4
10	25.6	38.5	48	63	88.4	105.5	137.8	166.8	191.1
15	28.1	42.2	52.6	69	97	116	151.9	184.5	210.6
20	29.8	44.7	55.9	73.3	103.1	123.4	161.7	196.8	224.3
25	31.1	46.7	58.4	76.5	107.8	129.1	169.3	206.4	234.9
50	35.2	52.9	66.1	86.5	122.2	146.5	192.7	235.8	267.3
100	39.2	59	73.7	96.4	136.5	163.8	216	265	299.6

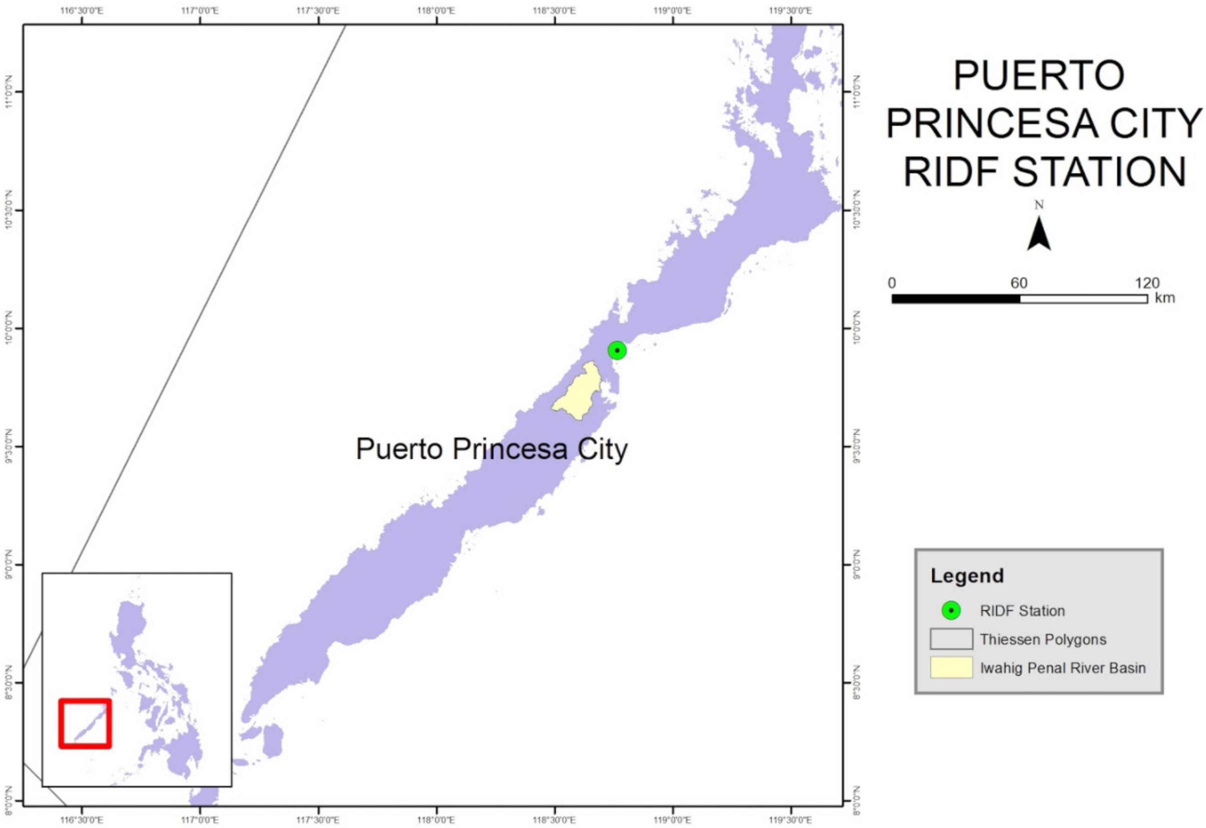


Figure 50. Location of Puerto Prinsesa RIDF relative to Iwahig Penal River Basin

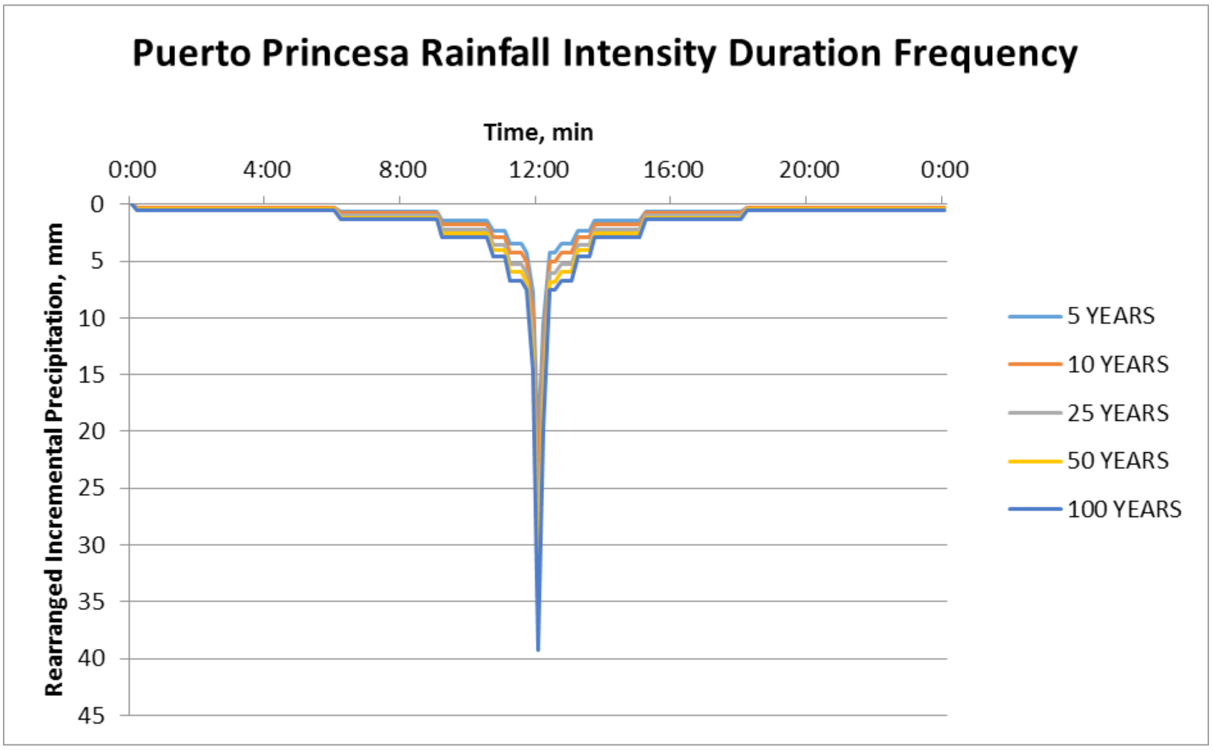


Figure 51. Synthetic storm generated for a 24-hr period rainfall for various return periods.

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 Penal River Basin are shown in Figure 52 and Figure 53, respectively.

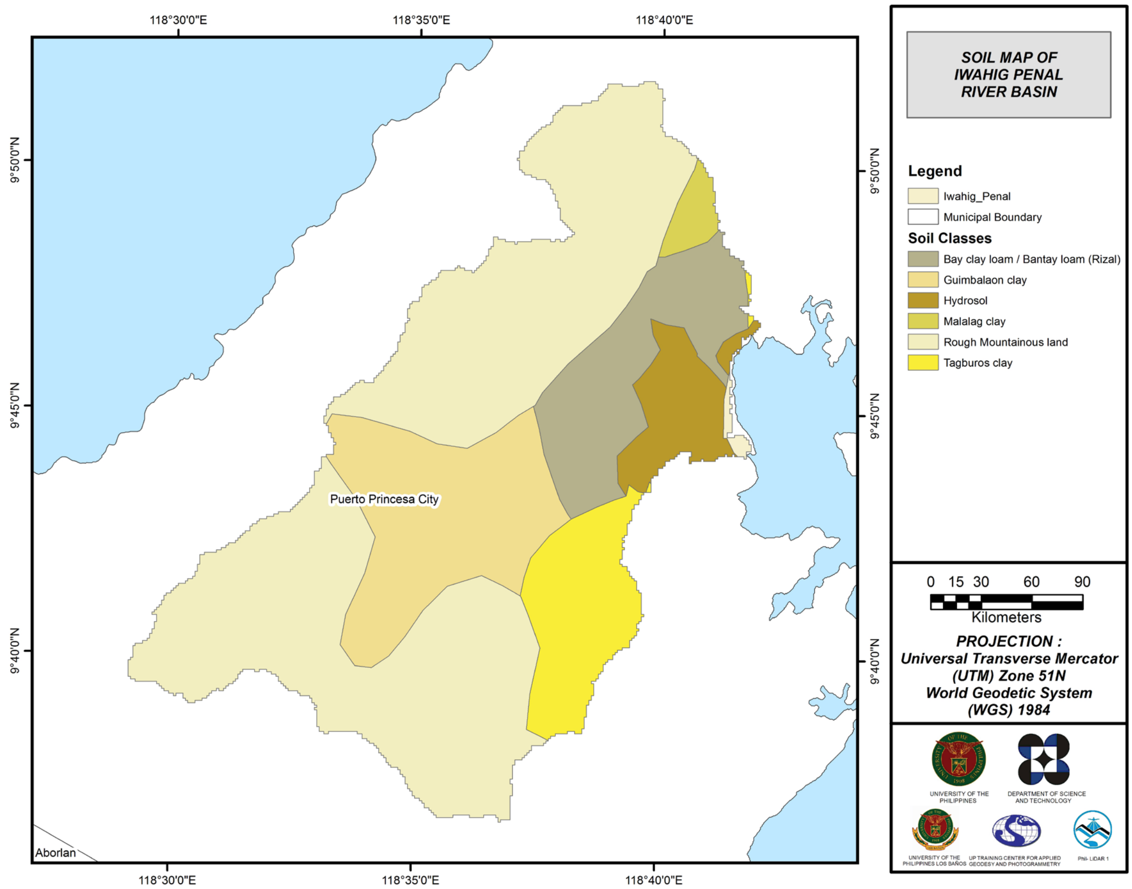


Figure 52. Soil map of Iwahig Penal River Basin used for the estimation of the CN parameter. (Source: DA)

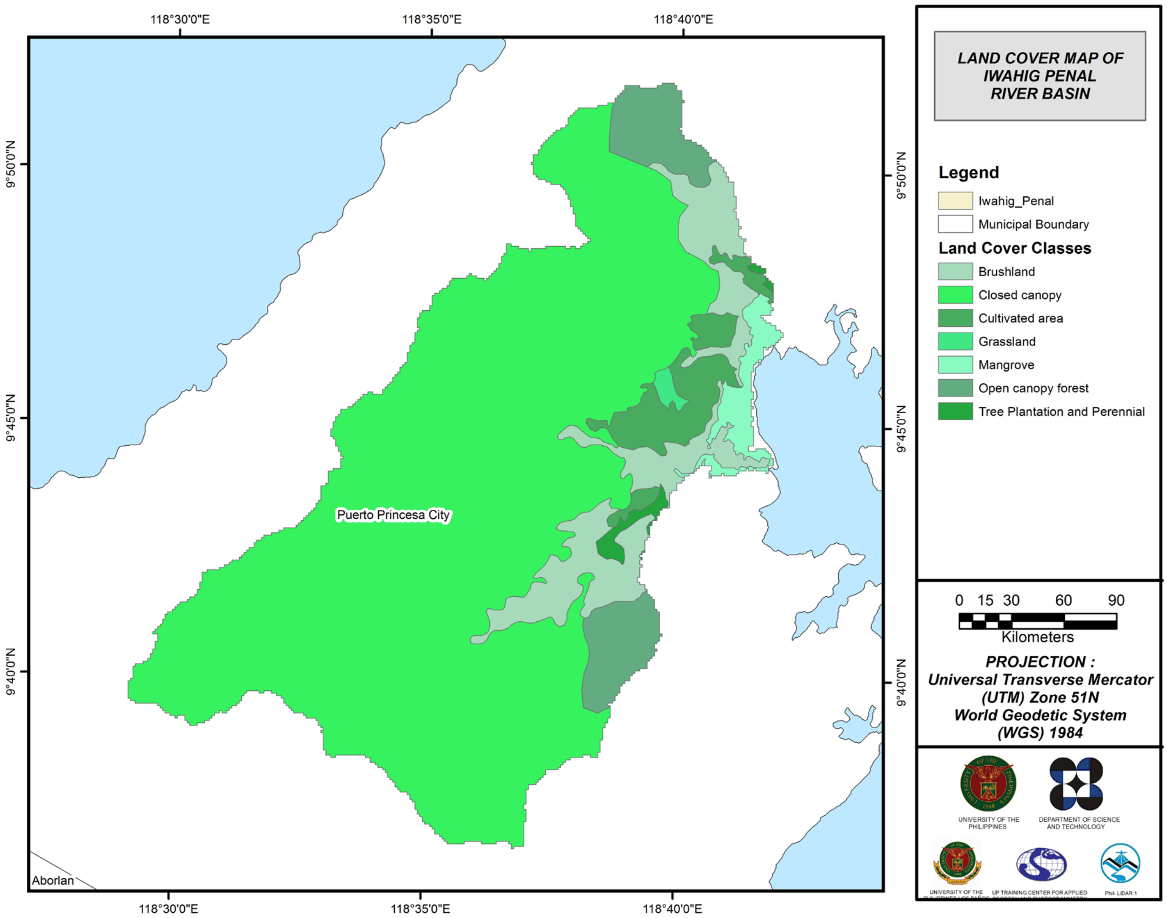


Figure 53. Land cover map of Iwahig Penal River Basin used for the estimation of the CN and watershed lag parameters of the rainfall-runoff model. (Source: NAMRIA)

For Iwahig river basin, the six (6) soil classes identified were rough mountainous land, Guimbalaon clay, Bay clay loam/ Bantal loam (Rizal), Tagburos clay, hydrosol, and Malalag clay. The seven (7) land cover types identified were largely closed canopy, followed by brushland, cultivated area, grassland, mangrove, open canopy forest, and tree plantation and perennial land cover.

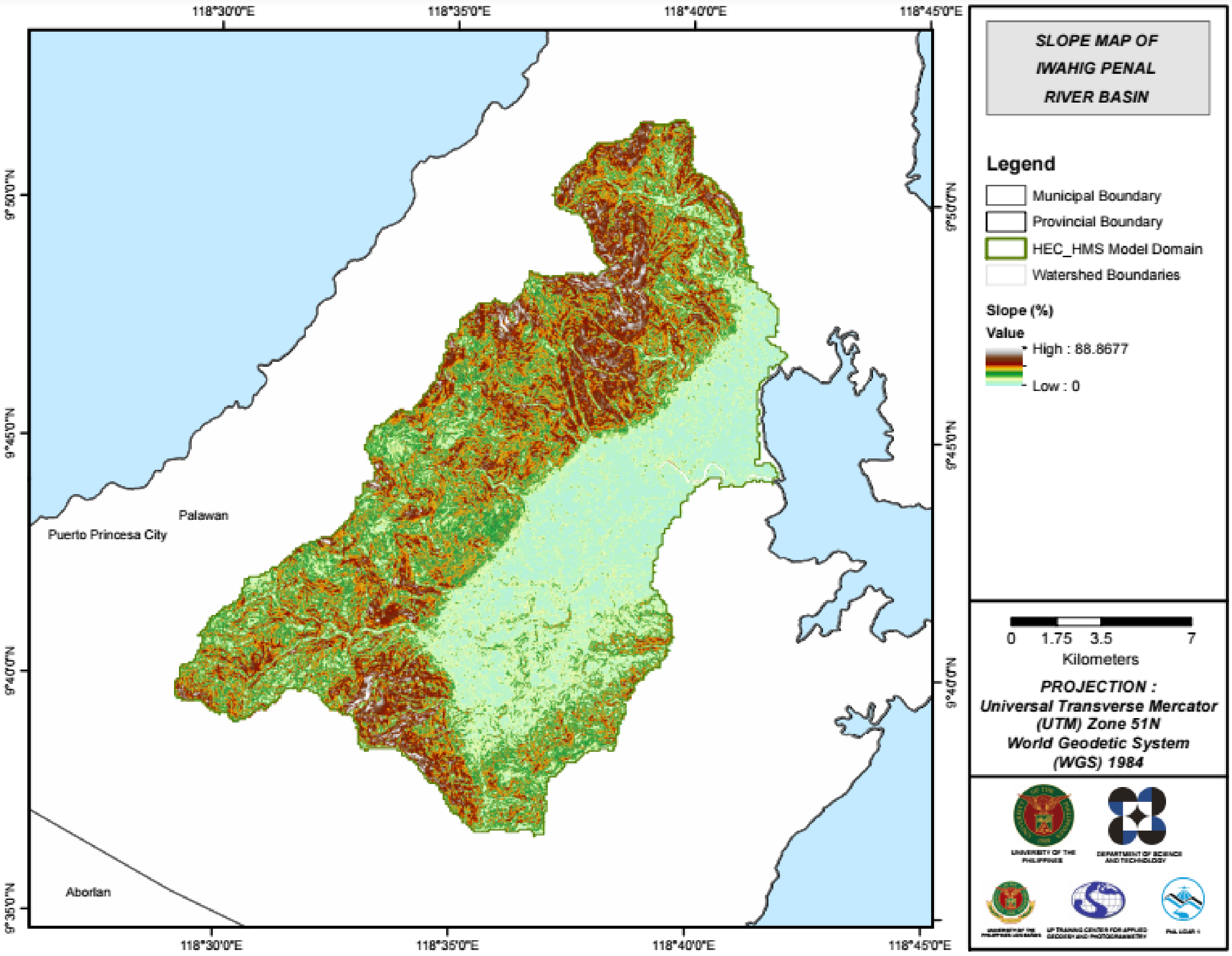


Figure 54. Slope map of Iwahig Penal River Basin

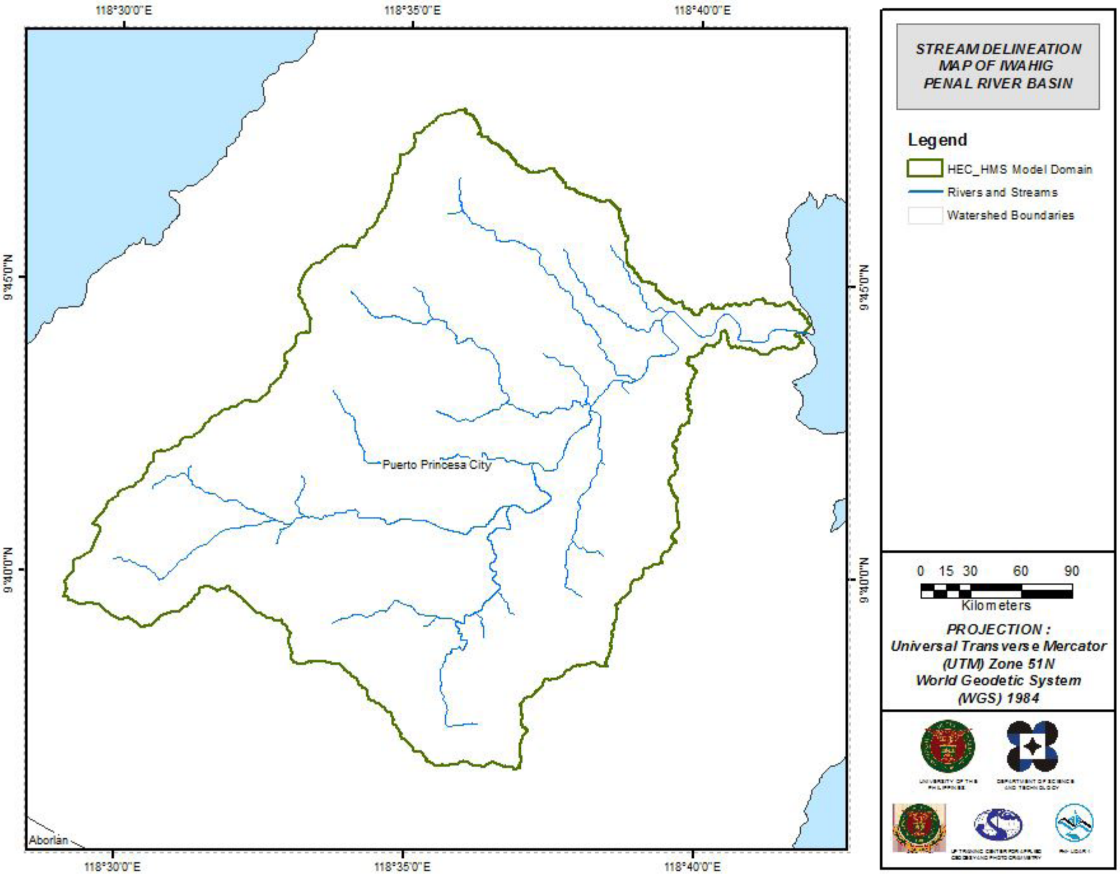


Figure 55. Stream delineation map of Iwahig Penal River Basin

Using SAR-based DEM, the Iwahig Penal basin was delineated and further subdivided into subbasins. The model consists of __ sub basins, __ reaches, and __ junctions. The main outlet is labelled as ____. 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 Penal 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.

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

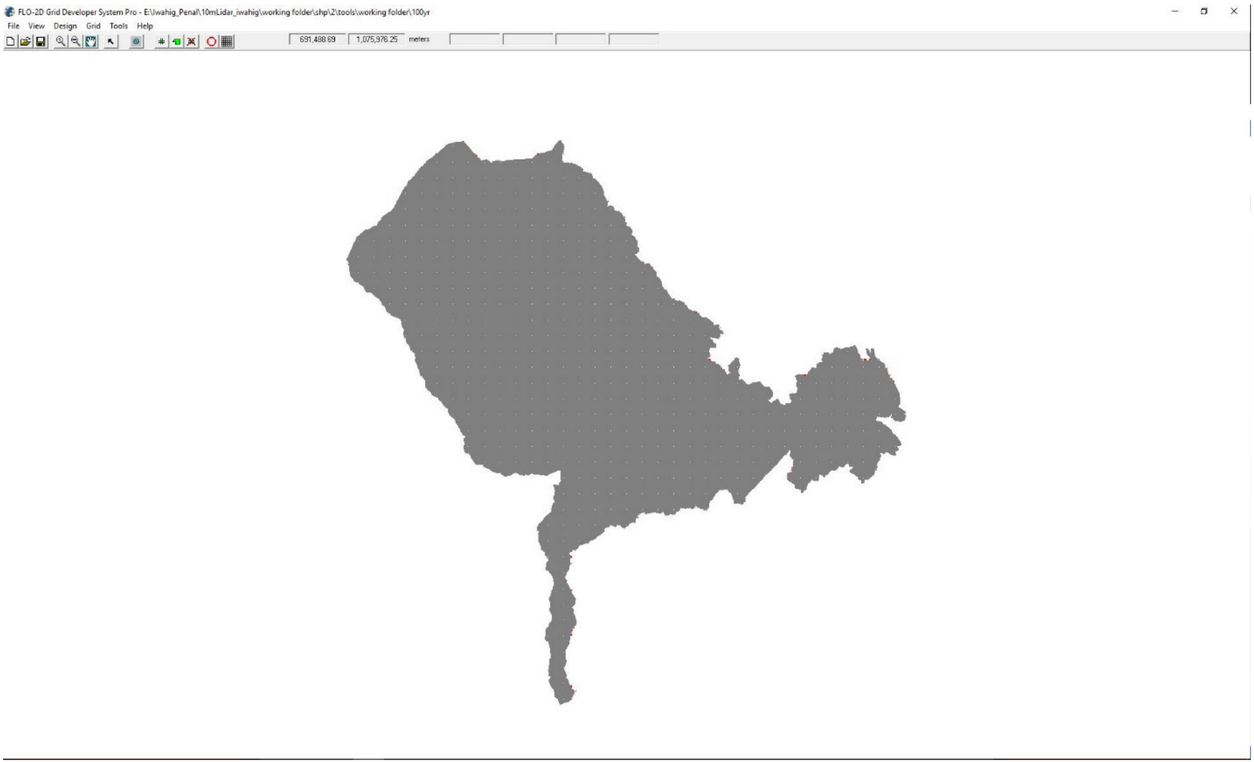


Figure 58. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 18.94794 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 25071600.00 m2.

There is a total of 52313784.09 m3 of water entering the model. Of this amount, 7651063.31 m3 is due to rainfall while 44662720.77 m3 is inflow from other areas outside the model. 2249784.75 m3 of this water is lost to infiltration and interception, while 1922415.40 m3 is stored by the flood plain. The rest, amounting up to 8758927.27 m3, is outflow.

5.6 HEC-HMC Model Values (Uncalibrated)

Enumerated in Table 28 are the range of values of the parameters in the model.

Table 28. Range of calibrated values for Iwahig Penal River Basin

Hydrologic Element	Calculation Type	Method	Parameter	Range of Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	
			Curve Number	
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	
			Storage Coefficient (hr)	

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 Penal River using the calibrated HMS base flow is shown in Figure 59.

Figure 59. Sample output of Iwahig Penal 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 Penal floodplain are shown in Figure 60 to Figure 61. The floodplain, with an area of 195.21 sq. km., covers one municipality named Puerto Princesa City. Table 29 shown the percentage of area affected by flooding per municipality.

Table 29. Municipalities affected in Iwahig Penal Floodplain

Municipality	Total Area	Area Flooded	% Flooded
Puerto Princesa City	2186.36	195.11	8.92

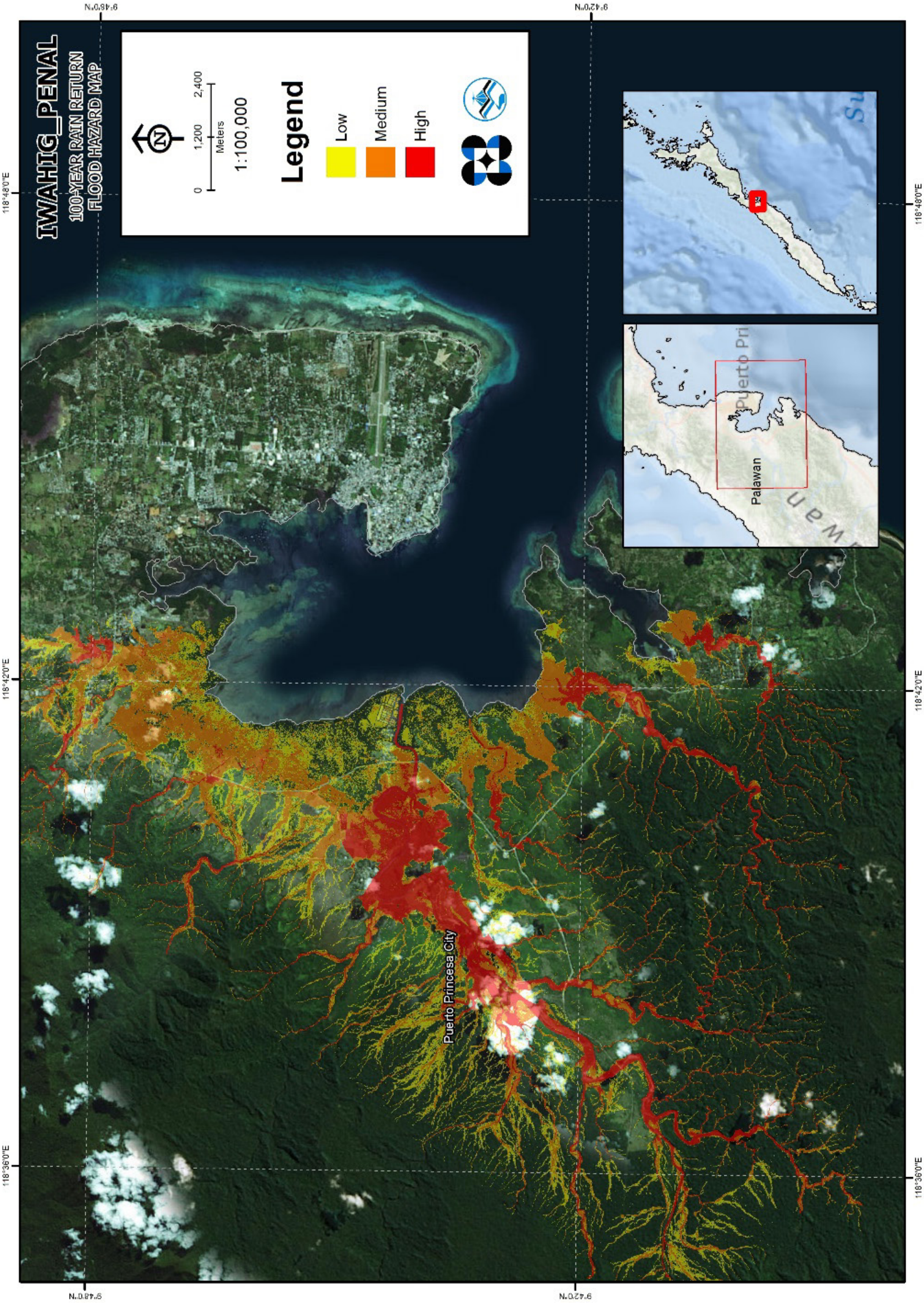


Figure 60. 100-year Flood Hazard Map for Iwahig Penal Floodplain overlaid on Google Earth imagery

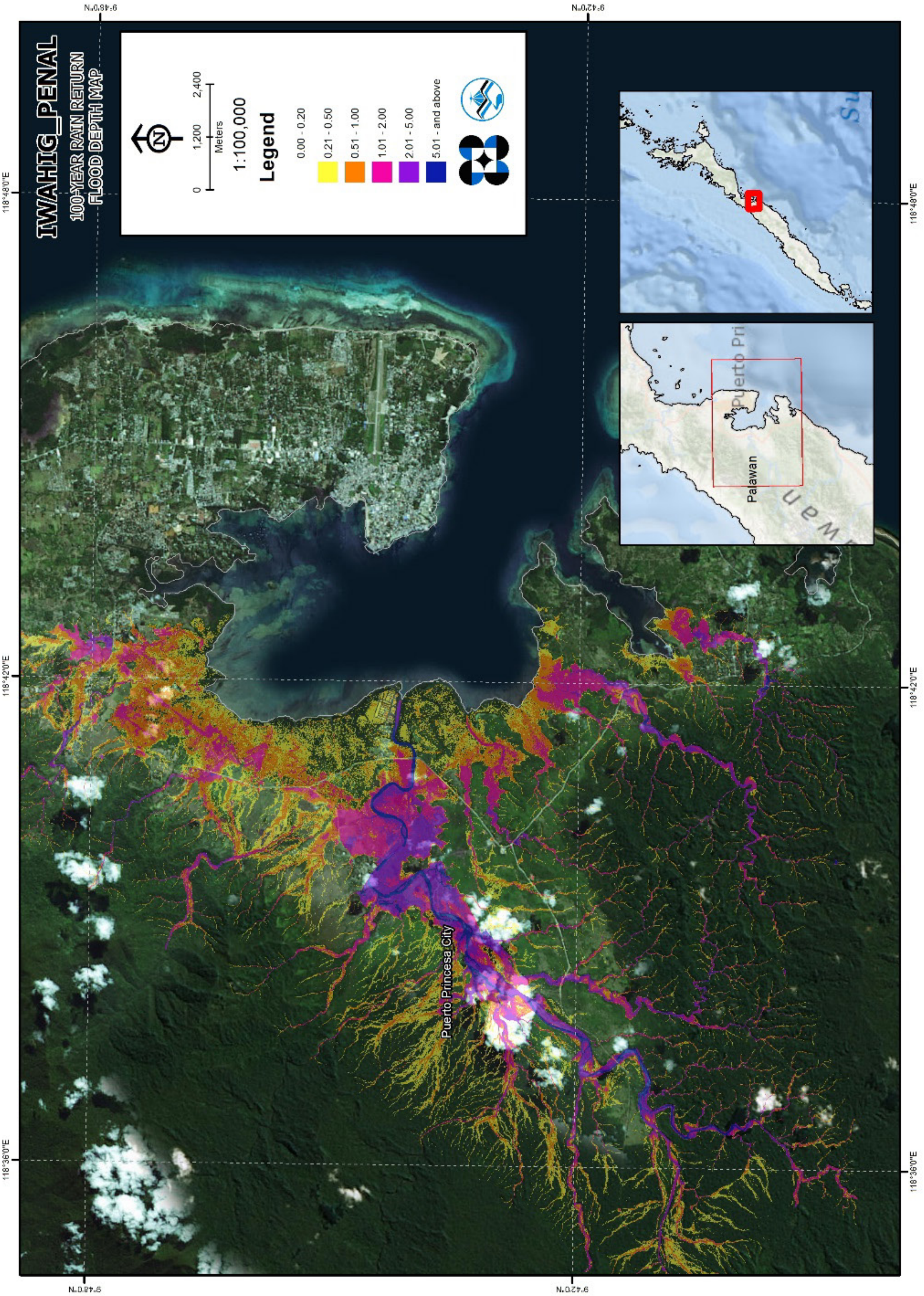


Figure 61. 100-year Flow Depth Map for Iwahig Penal Floodplain overlaid on Google Earth imagery

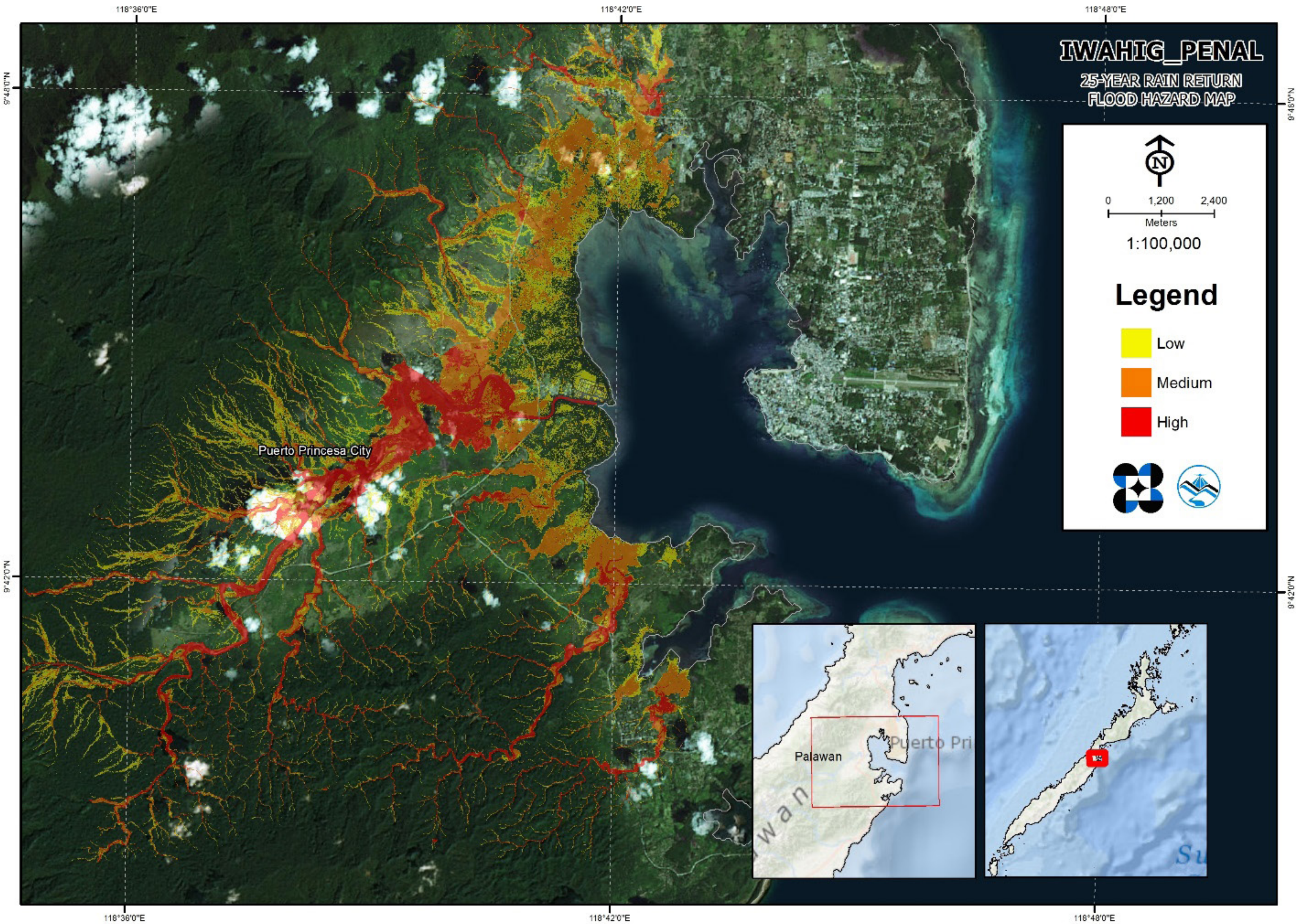


Figure 62. 25-year Flood Hazard Map for Iwahig Penal Floodplain overlaid on Google Earth imagery

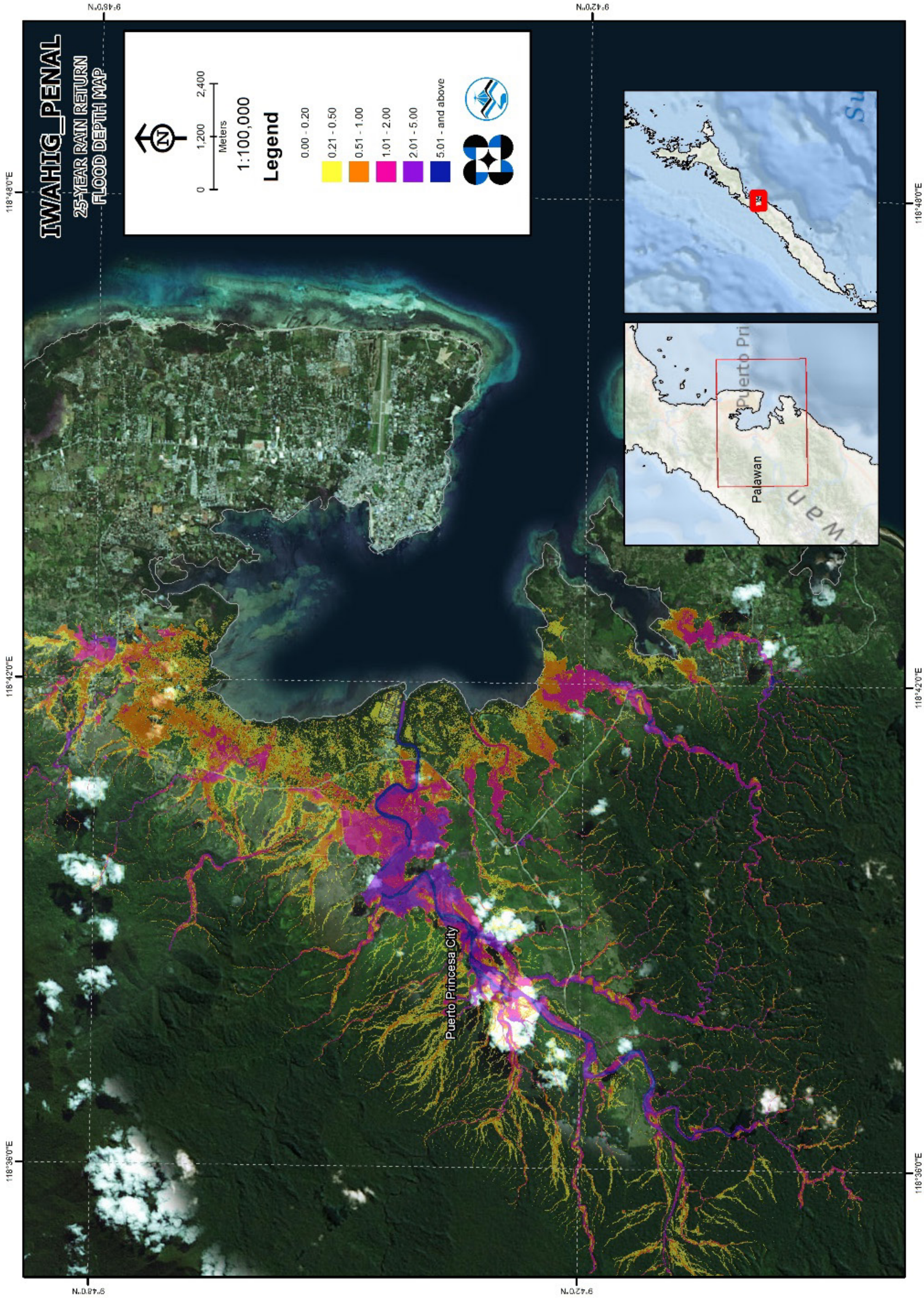


Figure 63. 25-year Flow Depth Map for Iwahig Penal Floodplain overlaid on Google Earth imagery

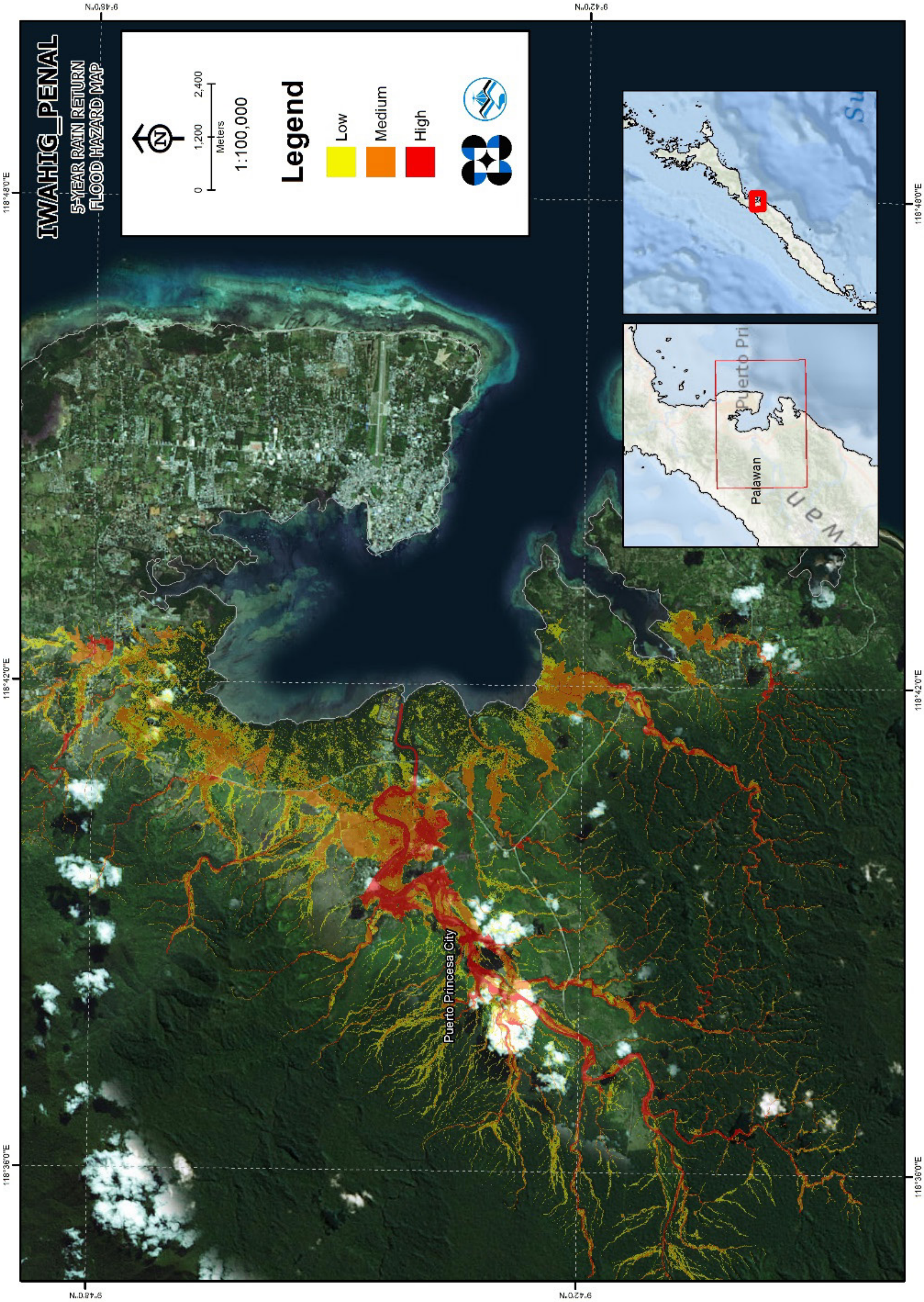


Figure 64. 5-year Flood Hazard Map for Iwahig Penal Floodplain overlaid on Google Earth imagery

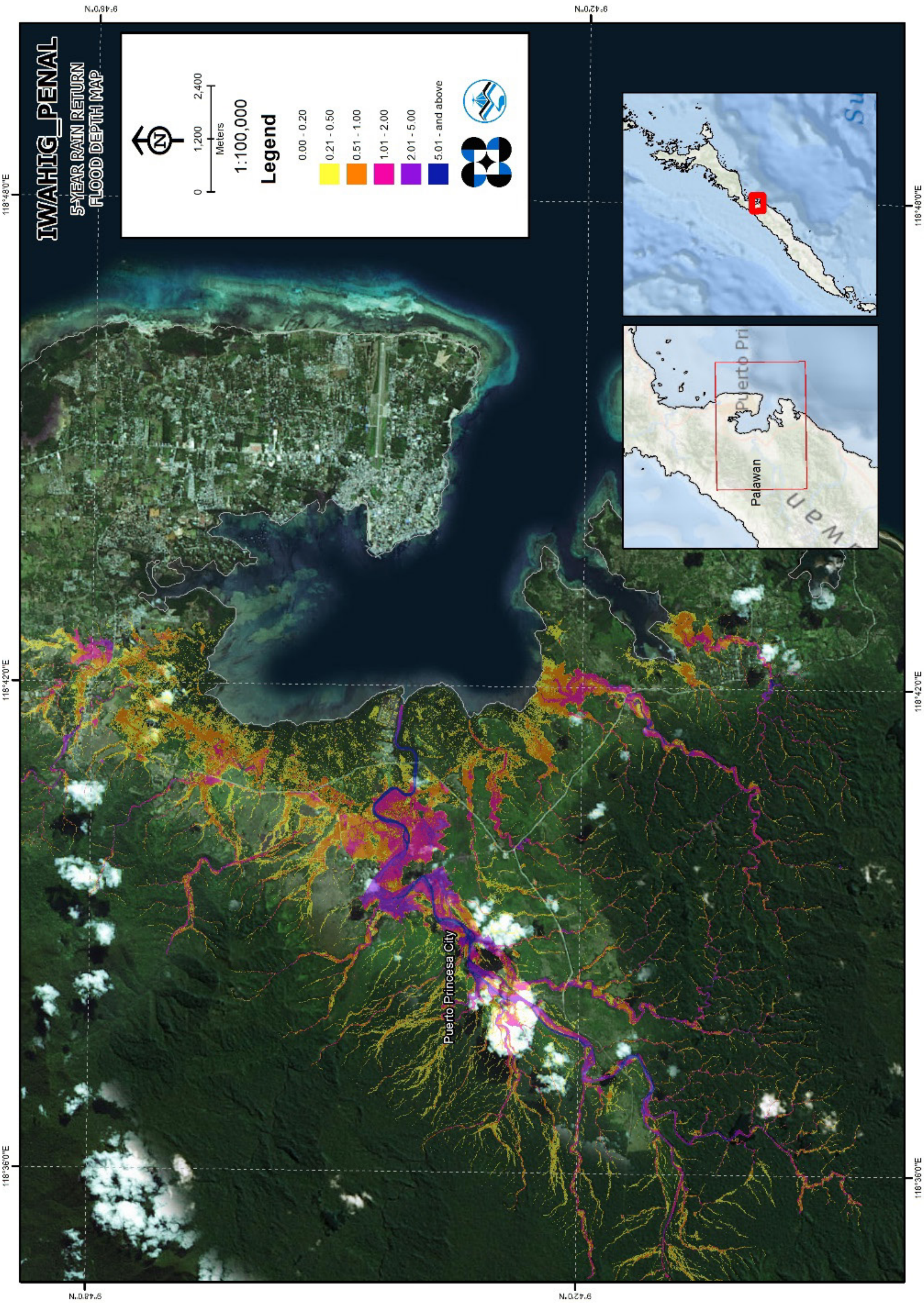


Figure 65. 5-year Flood Depth Map for Iwahig Penal Floodplain overlaid on Google Earth imagery

5.9 Inventory of Areas Exposed to Flooding

Listed below are the barangays affected by the Iwahig Penal River Basin, grouped accordingly by municipality. For the said basin, one (1) municipality consisting of 9 barangays are expected to experience flooding when subjected to a 5-year rainfall return period.

For the 5-year return period, 7.16% of the municipality of Puerto Princesa City with an area of 2186.36 sq. km. will experience flood levels of less 0.20 meters, while 0.73% of the area will experience flood levels of 0.21 to 0.50 meters; 0.52%, 0.32%, 0.15%, and 0.03% 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 Puerto Princesa City in square kilometers by flood depth per barangay.

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

Affected Area (sq. km.) by flood depth (in m.)	Area of affected barangays in Puerto Princesa City (in sq. km.)								
	Inagawan Sub-Colony	Irawan	Iwahig	Luzviminda	Montible	Santa Lucia	Sicsican	Simpocan	Tagburos
0.03-0.20	0.45	5.21	48.99	1.1	56.67	35.58	1.98	0.19	6.43
0.21-0.50	0.024	1.3	7.67	0.21	4.56	1.83	0.28	0.0033	0.17
0.51-1.00	0.025	0.76	5.81	0.31	2.34	1.9	0.17	0.0012	0.12
1.01-2.00	0.017	0.34	3.42	0.11	1.7	1.32	0.064	0.0001	0.06
2.01-5.00	0.0039	0.12	1.61	0.0033	1.12	0.38	0.03	0.0001	0.016
> 5.00	0	0.0088	0.48	0	0.22	0.038	0	0	0.0005

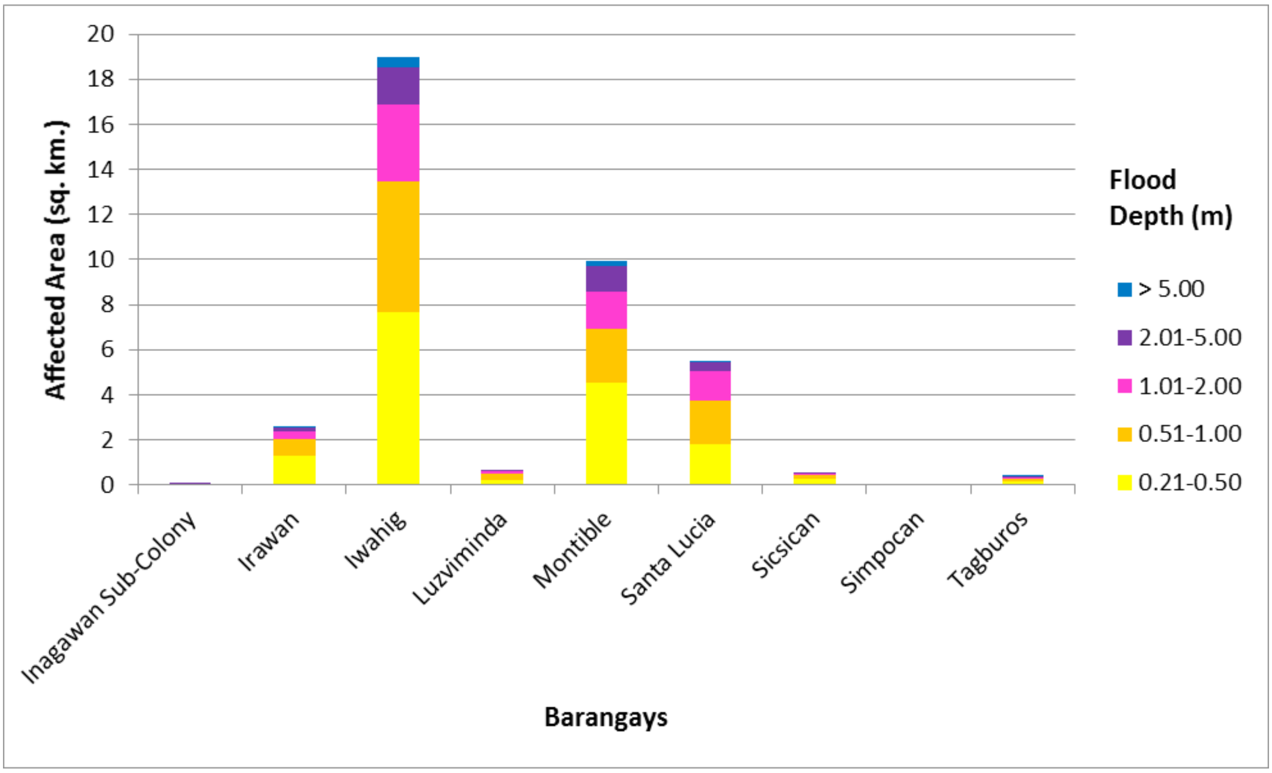


Figure 66. Affected areas in Puerto Princesa City, Palawan during a 5-Year Rainfall Return Period.

For the 25-year return period, 6.72% of the municipality of Puerto Princesa City with an area of 2186.36 sq. km. will experience flood levels of less 0.20 meters, while 0.81% of the area will experience flood levels of 0.21 to 0.50 meters; 0.62%, 0.48%, 0.25%, and 0.05% 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 areas affected in Puerto Princesa City in square kilometers by flood depth per barangay.

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

Affected Area (sq. km.) by flood depth (in m.)	Area of affected barangays in Puerto Princesa City (in sq. km.)								
	Inagawan Sub-Colony	Irawan	Iwahig	Luzviminda	Montible	Santa Lucia	Sicsican	Simpocan	Tagburos
0.03-0.20	0.44	4.22	44.2	1.03	53.87	34.77	1.81	0.19	6.36
0.21-0.50	0.022	1.47	8.24	0.12	5.54	1.79	0.28	0.0036	0.19
0.51-1.00	0.026	1.31	6.88	0.26	2.84	1.8	0.27	0.0018	0.14
1.01-2.00	0.026	0.57	5.28	0.31	2.25	1.96	0.11	0.0002	0.087
2.01-5.00	0.0057	0.16	2.76	0.017	1.72	0.65	0.05	0.0001	0.025
> 5.00	0	0.012	0.63	0	0.39	0.065	0	0	0.0011

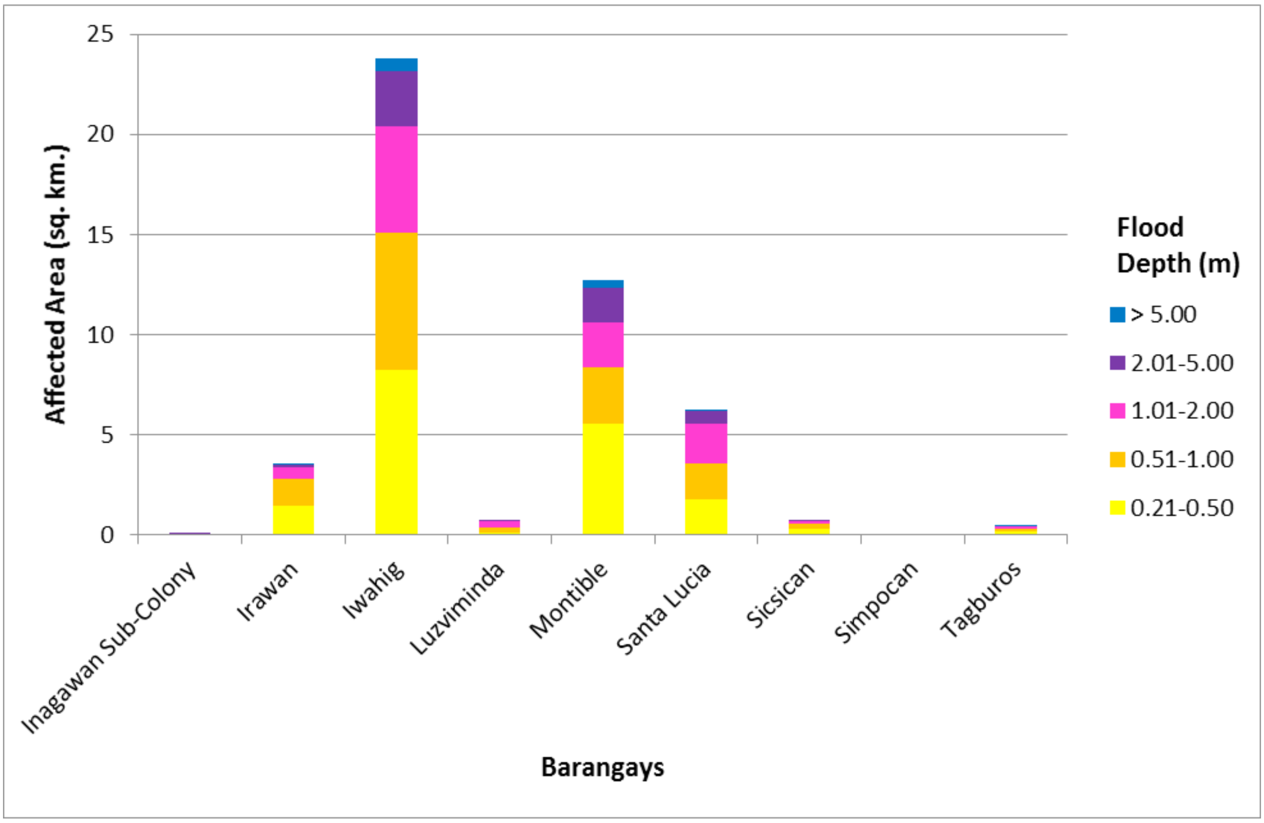


Figure 67. Affected areas in Puerto Princesa City, Palawan during a 25-Year Rainfall Return Period.

For the 100-year return period, 6.47% of the municipality of Puerto Princesa City with an area of 2186.36 sq. km. will experience flood levels of less 0.20 meters, while 0.84% of the area will experience flood levels of 0.21 to 0.50 meters; 0.66%, 0.56%, 0.33%, and 0.07% 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 Puerto Princesa City in square kilometers by flood depth per barangay.

Table 32. Affected areas in Puerto Princesa City, Palawan during a 100-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Area of affected barangays in Puerto Princesa City (in sq. km.)								
	Inagawan Sub-Colony	Irawan	Iwahig	Luzviminda	Montible	Santa Lucia	Sicsican	Simpocan	Tagburos
0.03-0.20	0.43	3.73	41.63	1	52.06	34.31	1.74	0.19	6.32
0.21-0.50	0.02	1.4	8.46	0.11	6.06	1.81	0.25	0.004	0.2
0.51-1.00	0.027	1.58	7.4	0.2	3.21	1.68	0.29	0.0021	0.14
1.01-2.00	0.03	0.8	6.01	0.36	2.53	2.18	0.18	0.0002	0.11
2.01-5.00	0.0083	0.2	3.67	0.071	2.22	0.97	0.054	0.0001	0.031
> 5.00	0	0.017	0.83	0	0.53	0.088	0	0	0.0014

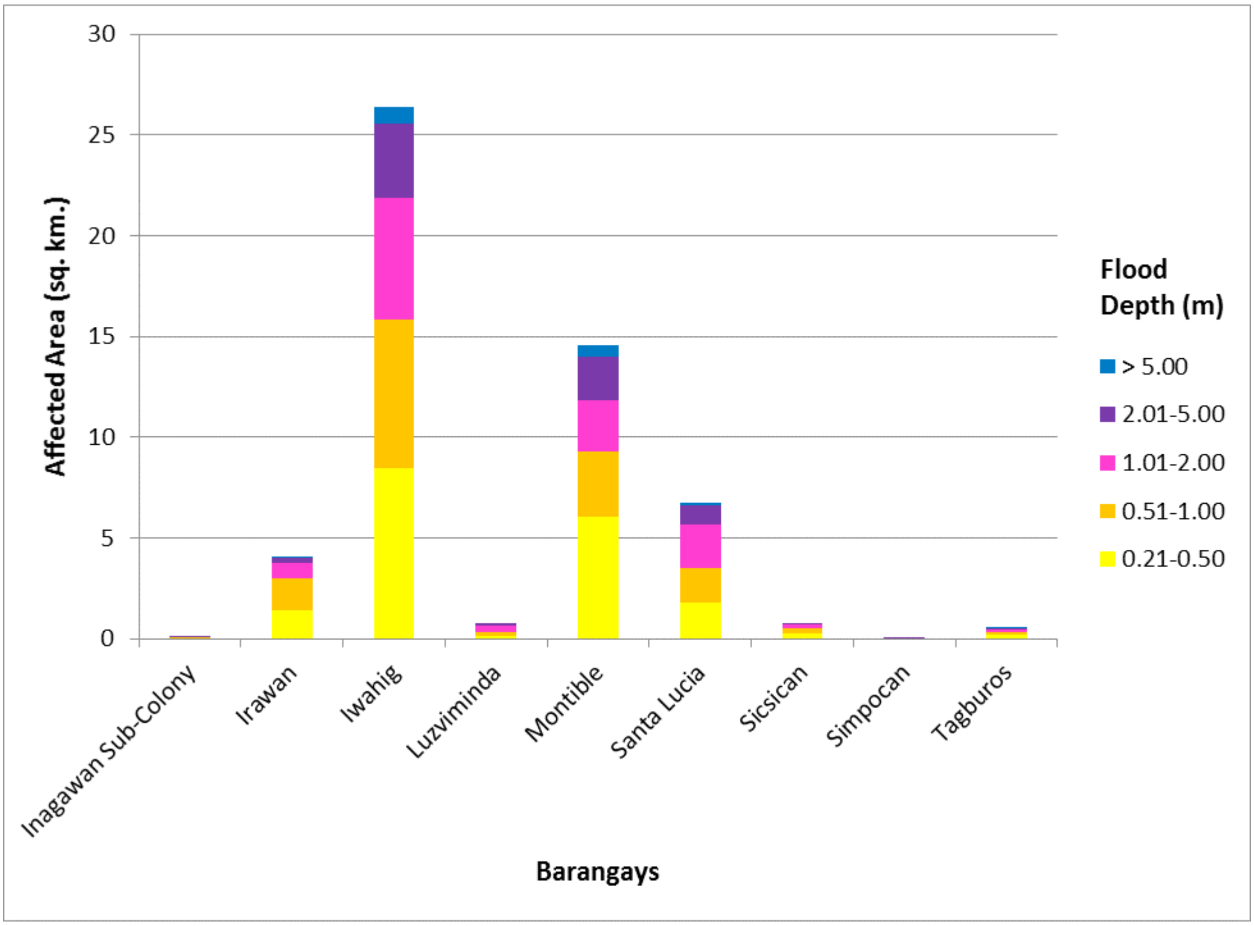


Figure 68. Affected areas in Puerto Princesa City, Palawan during a 100-Year Rainfall Return Period.

Among the barangays in the municipality of Puerto Princesa City, Iwahig is projected to have the highest percentage of area that will experience flood levels of at 3.11%. On the other hand, Montible posted the percentage of area that may be affected by flood depths of at 3.05%.

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 70.

The flood validation consists of 129 points randomly selected all over the Iwahig Penal floodplain. Comparing it with the flood depth map of the nearest storm event, the map has an RMSE value of 0.42m. Table 33 shows a contingency matrix of the comparison.

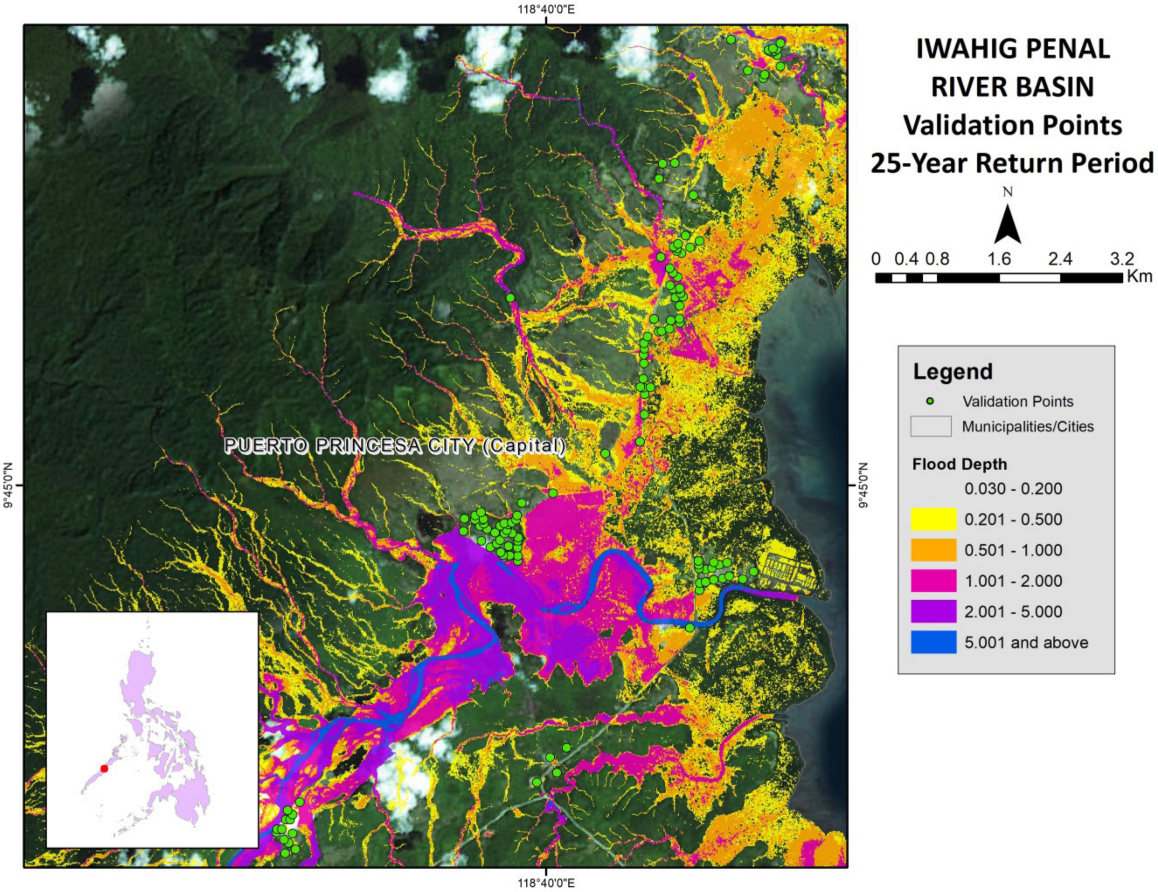


Figure 69. Validation points for 25-year Flood Depth Map of Iwahig Penal Floodplain

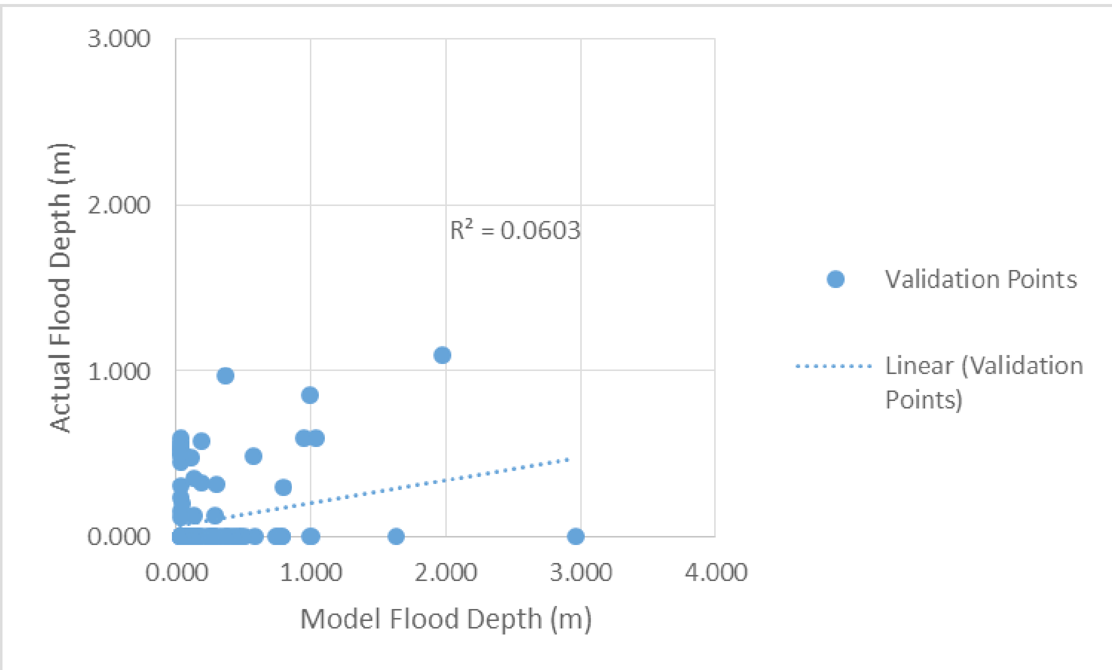


Figure 70. Flood map depth vs. actual flood depth

Table 33. Actual flood vs simulated flood depth at different levels in the Iwahig Penal 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	78	18	8	1	1	0	106
0.21-0.50	9	1	2	0	0	0	12
0.51-1.00	6	1	2	1	0	0	10
1.01-2.00	0	0	0	1	0	0	1
2.01-5.00	0	0	0	0	0	0	0
> 5.00	0	0	0	0	0	0	0
Total	93	20	12	3	1	0	129

The overall accuracy generated by the flood model is estimated at 63.57% with 82 points correctly matching the actual flood depths. In addition, there were 30 points estimated one level above and below the correct flood depths while there were 14 points and 2 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 16 points were underestimated in the modelled flood depths of Iwahig Penal. Table 34 depicts the summary of the Accuracy Assessment in the Iwahig Penal River Basin Survey.

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

	No. of Points	%
Correct	82	63.57
Overestimated	31	24.03
Underestimated	16	12.40
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.

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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

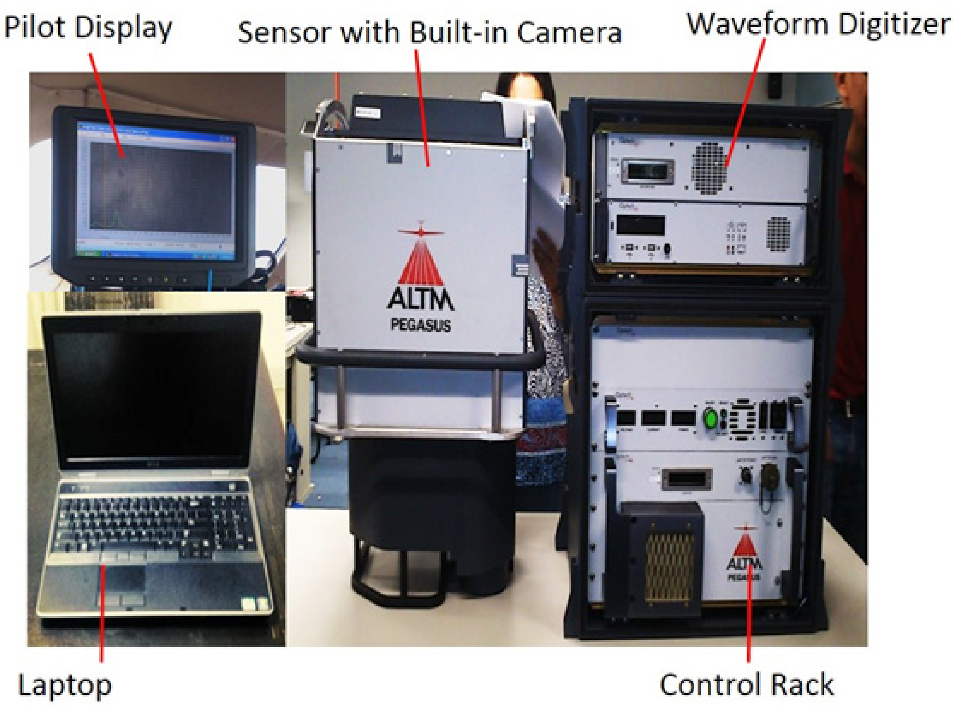

Figure A-1.1 Pegasus Sensor

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)

Parameter	Specification
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

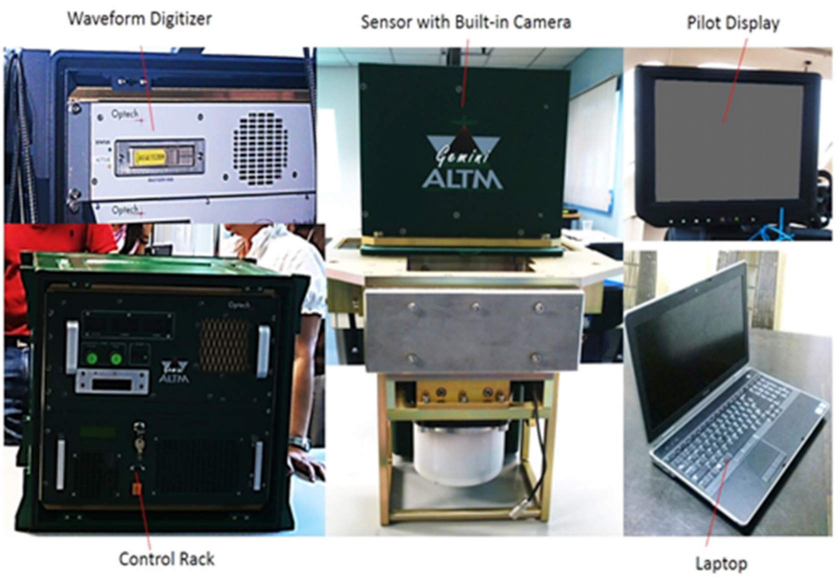

Figure A-1.1 Gemini Sensor

Table A-1.1 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

Parameter	Specification
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

PL-34

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

June 15, 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-34**
Order: **1st**

Island: **LUZON**	Barangay: **STA. MONICA**	
Municipality: **PUERTO PRINCESA CITY (CAPITAL)**	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **9° 47' 4.34346"**	Longitude: **118° 43' 50.36738"**	Ellipsoidal Hgt: **53.76200 m.**
	WGS84 Coordinates	
Latitude: **9° 46' 59.90069"**	Longitude: **118° 43' 55.68915"**	Ellipsoidal Hgt: **103.89600 m.**
	PTM / PRS92 Coordinates	
Northing: **1081910.004 m.**	Easting: **525304.737 m.**	Zone: **1A**
	UTM / PRS92 Coordinates	
Northing: **1,082,009.99**	Easting: **689,825.58**	Zone: **50**

Location Description

PLW-34
From the wharf of Philippine Ports Authority in Puerto Princesa city, travel eastward on a 2 wheel drive vehicle, along Rizal street up to the National highway for 1.80 kilometers. Turn turn left, travel Northwest along the national highway for 5.50 kilometers up to the cemented road that leads to the City Hall. Turn left and travel alonf the cemented road for 0.75 kilometers up to the station. Station is located on top of the roof deck of the city Mayor's office. Station mark is 4" copper nail with cross cut on top centered in a 30 cm square cement patty, protruding about 1 cm on the semi-circle shaped concrete roofed deck of Puerto Princesa City Hall.

Requesting Party: **UP-DREAM**
Purpose: **Reference**
OR Number: **8084005 I**
T.N.: **2015-1264**

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

9906152015132303

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

CIP/4701/12/09/814

Figure A-2.1. PL-34

PL-92

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

June 23, 2015

CERTIFICATION

To whom it may concern:

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

Province: **PALAWAN**
Station Name: **PL-92**

Island: **PALAWAN**	Municipality: **PUERTO PRINCESA CITY**	Barangay: **IWAHIG (POB.)**
Elevation: **6.5072 +/- 0.03 m.**	Order: **1st Order**	Datum: **Mean Sea Level**
Latitude:	Longitude:	

Location Description

PL-92

From Puerto Princesa travel south along the National Highway towards Aborlan located at Iwahig Bridge. Mark is the head of 4" copper nail, drilled on hole and set flushed on a cement putty with inscription "PL-92 2008 NAMRIA". The station is located in Brgy. Iwahig along aborlan.

Requesting Party: **UP-DREAM**
Purpose: **Reference**
OR Number: **8083538 I**
T.N.: **2015-1344**

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

9906232015114626

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.2. PL-92

PLW-50

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-50**	
	Order: **2nd**	
Island: **LUZON**	Barangay: **IWAHIG**	
Municipality: **PUERTO PRINCESA CITY (CAPITAL)**	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **9° 44' 42.16318"**	Longitude: **118° 39' 28.02050"**	Ellipsoidal Hgt: **16.81300 m.**
	WGS84 Coordinates	
Latitude: **9° 44' 37.72390"**	Longitude: **118° 39' 33.34598"**	Ellipsoidal Hgt: **66.85300 m.**
	PTM / PRS92 Coordinates	
Northing: **1077537.527 m.**	Easting: **517311.956 m.**	Zone: **1A**
	UTM / PRS92 Coordinates	
Northing: **1,077,601.73**	Easting: **681,851.72**	Zone: **50**

Location Description

PLW-50
From Puerto Princesa City Proper, travel along the National Highway S bound, until reaching Iwahig Penal Farm at about 15 km. The station is located inside the vicinity of Iwahig Penal Farm, situated at the base of the fountain 20 m. NW of Administration Building and 50 m W of Iwahig Elem. School. Station mark is a brass plate 10" in diameter with inscription "Corps of Engineers, U.S. Army Survey control mark circle station".

Requesting Party: **UP-DREAM**
Purpose: **Reference**
OR Number: **8083538 I**
T.N.: **2015-1337**

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

9906232015114335

Figure A-2.3. PLW-50

PLW-3026

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-3026**	
	Order: **3rd**	
Island: **LUZON**	Barangay: **SALVACION**	
Municipality: **PUERTO PRINCESA CITY (CAPITAL)**	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **9° 58' 7.89691"**	Longitude: **118° 47' 3.75351"**	Ellipsoidal Hgt: **7.58909 m.**
	WGS84 Coordinates	
Latitude: **9° 58' 3.41268"**	Longitude: **118° 47' 9.05885"**	Ellipsoidal Hgt: **57.44800 m.**
	PTM / PRS92 Coordinates	
Northing: **1102299.607 m.**	Easting: **531180.701 m.**	Zone: **1A**
	UTM / PRS92 Coordinates	
Northing: **1,102,427.82**	Easting: **695,610.46**	Zone: **50**

Location Description

PLW-3026
From Puerto Princesa, travel N via PPC-Roxas National Highway up to Sabang junction in Brgy. Salvacion. Station is located on the N corner of the center island. Mark is the head of 4" copper nail flushed in a cement putty 25cm x 25cm x 120cm embedded 1 m on the ground with inscriptions "PLW-3026 2007 NAMRIA."

Requesting Party: **UP-DREAM**
Purpose: **Reference**
OR Number: **8083538 I**
T.N.: **2015-1338**

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

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

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Branch : 421 Barraca St. San Nicolas, 1010 Manila, Philippines, Tel. No. (632) 241-3494 to 98
www.namria.gov.ph

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

CIP/4701/12/09/814

Figure A-2.4 PLW-3026

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

Vector Components (Mark to Mark)

From:	PLW-34				
Grid		Local		Global	
Easting	689825.571 m	Latitude	N9°47'04.34346"	Latitude	N9°46'59.90069"
Northing	1082009.987 m	Longitude	E118°43'50.36738"	Longitude	E118°43'55.68915"
Elevation	53.466 m	Height	53.762 m	Height	103.896 m

To:	PLW-3026				
Grid		Local		Global	
Easting	695610.418 m	Latitude	N9°58'07.89863"	Latitude	N9°58'03.41442"
Northing	1102427.869 m	Longitude	E118°47'03.75221"	Longitude	E118°47'09.05751"
Elevation	7.024 m	Height	7.504 m	Height	57.363 m

Vector					
ΔEasting	5784.847 m	NS Fwd Azimuth	16°06'56"	ΔX	-3460.453 m
ΔNorthing	20417.882 m	Ellipsoid Dist.	21220.288 m	ΔY	-5939.795 m
ΔElevation	-46.442 m	ΔHeight	-46.258 m	ΔZ	20076.102 m

Standard Errors

Vector errors:					
σ ΔEasting	0.002 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.004 m
σ ΔNorthing	0.001 m	σ Ellipsoid Dist.	0.001 m	σ ΔY	0.006 m
σ ΔElevation	0.007 m	σ ΔHeight	0.007 m	σ ΔZ	0.002 m

Figure A-3.1. Baseline Processing Report - A

Vector Components (Mark to Mark)

From:	PLW-3026				
Grid		Local		Global	
Easting	695610.414 m	Latitude	N9°58'07.89864"	Latitude	N9°58'03.41443"
Northing	1102427.869 m	Longitude	E118°47'03.75205"	Longitude	E118°47'09.05735"
Elevation	7.058 m	Height	7.537 m	Height	57.396 m

To:	PL-38				
Grid		Local		Global	
Easting	695384.782 m	Latitude	N9°57'59.62464"	Latitude	N9°57'55.14081"
Northing	1102172.433 m	Longitude	E118°46'56.29975"	Longitude	E118°47'01.60525"
Elevation	7.275 m	Height	7.756 m	Height	57.615 m

Vector					
ΔEasting	-225.631 m	NS Fwd Azimuth	221°45'49"	ΔX	177.646 m
ΔNorthing	-255.436 m	Ellipsoid Dist.	340.793 m	ΔY	148.044 m
ΔElevation	0.217 m	ΔHeight	0.219 m	ΔZ	-250.329 m

Standard Errors

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

Figure A-3.2. Baseline Processing Report - B

Vector Components (Mark to Mark)

From:	PLW 50				
Grid		Local		Global	
Easting	23307.331 m	Latitude	N9°44'42.16318"	Latitude	N9°44'37.72390"
Northing	1080218.190 m	Longitude	E118°39'28.02050"	Longitude	E118°39'33.34598"
Elevation	16.338 m	Height	16.813 m	Height	66.853 m

To:	PL 92				
Grid		Local		Global	
Easting	26049.752 m	Latitude	N9°44'04.01581"	Latitude	N9°43'59.58138"
Northing	1079008.192 m	Longitude	E118°40'58.28065"	Longitude	E118°41'03.60701"
Elevation	7.859 m	Height	8.218 m	Height	58.344 m

Vector					
ΔEasting	2742.421 m	NS Fwd Azimuth	113°04'19"	ΔX	-2504.878 m
ΔNorthing	-1209.998 m	Ellipsoid Dist.	2990.326 m	ΔY	-1153.405 m
ΔElevation	-8.479 m	ΔHeight	-8.595 m	ΔZ	-1156.451 m

Standard Errors

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

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000048259		
Y	-0.0000079489	0.0000161587	
Z	-0.0000016287	0.0000033073	0.0000011240

Figure A-3.3. Baseline Processing Report – C

Vector Components (Mark to Mark)

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

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

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

Standard Errors

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

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000000874		
Y	-0.0000000471	0.0000002060	
Z	-0.0000000153	0.0000000347	0.0000000449

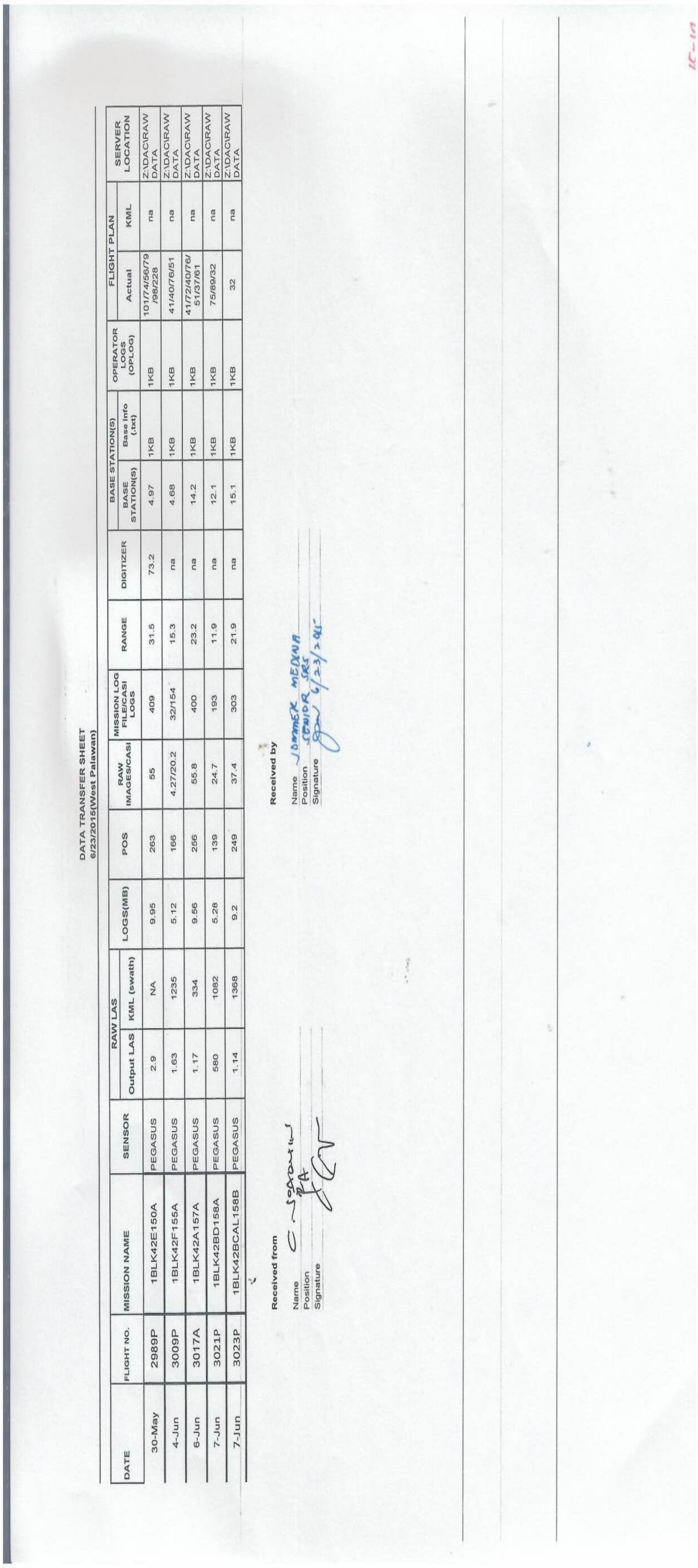
Figure A-3.4. Baseline Processing Report – D

Annex 4. The LiDAR Survey Team Composition

Table A-4.1 LiDAR Survey Team Composition

Data Acquisition Component Sub -Team	Designation	Name	Agency / Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	ENGR. LOUIE BALICANTA	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUÑA	UP-TCAGP
		LOVELYN ASUNCION	UP-TCAGP
FIELD TEAM			
LiDAR Operation	Senior Science Research Specialist (SSRS)	JASMINE ALVIAR	UP-TCAGP
	SSRS	GEROME HIPOLITO	UP-TCAGP
	Research Associate (RA)	LARAH KRISELLE PARAGAS	UP-TCAGP
	RA	MARY CATHERINE ELIZABETH BALIGUAS	UP-TCAGP
	RA	JONATHAN ALMALVEZ	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	GRACE SINADJAN	UP-TCAGP
	RA	JERIEL PAUL ALAMBAN	UP-TCAGP
	RA	IRO NIEL ROXAS	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. PRADYUMNA DAS RAMIREZ	PHILIPPINE AIR FORCE (PAF)
		ATC2 JUNMAR PARANGUE	PAF
	Pilot	CAPT. MARK TANGONAN	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. ALBERT PAUL LIM	AAC
		CAPT. RANDY LAGCO	AAC

Annex 5. Data Transfer Sheets



DATA TRANSFER SHEET
6/23/2015(West Palawan)

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS Output LAS	RAW LAS KML (swath)	LOGS(MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S) BASE STATION(S)	BASE STATION(S) Base Info (.txt)	OPERATOR LOGS (OPLOG)	FLIGHT PLAN Actual	FLIGHT PLAN KML	SERVER LOCATION
30-May	2989P	1BLK42E150A	PEGASUS	2.9	NA	9.95	263	55	409	31.5	73.2	4.97	1KB	1KB	101/74/56/79/99/228	na	Z:\DAC\RAW DATA
4-Jun	3009P	1BLK42F155A	PEGASUS	1.63	1235	5.12	166	4.27/20.2	32/154	15.3	na	4.68	1KB	1KB	41/40/76/51	na	Z:\DAC\RAW DATA
6-Jun	3017A	1BLK42A157A	PEGASUS	1.17	334	9.56	256	55.8	400	23.2	na	14.2	1KB	1KB	41/72/40/76/51/37/61	na	Z:\DAC\RAW DATA
7-Jun	3021P	1BLK42BD158A	PEGASUS	580	1082	5.28	139	24.7	193	11.9	na	12.1	1KB	1KB	75/89/32	na	Z:\DAC\RAW DATA
7-Jun	3023P	1BLK42BCAL158B	PEGASUS	1.14	1368	9.2	249	37.4	303	21.9	na	15.1	1KB	1KB	32	na	Z:\DAC\RAW DATA

Received from
Name
Position
Signature

Received by
Name
Position SENIOR SRS
Signature 6/23/2015

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

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	7.46	187	33.9	246	15.1	NA	7.06	1KB	1KB	14/28	na	Z:\DAC\RAW DATA
8-Jun-15	3027P	1BLK42FS159B	Pegasus	652	175	5.26	133	16.8	146	13.5	30.2	5.15	1KB	1KB	24	na	Z:\DAC\RAW DATA
11-Jun	3037P	1BLK42IJ162A	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	37/62/85/71	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: [signature]

Received by
Name: JOIDA PRIETO 7/13/15
Position: SSRS
Signature: [signature]

15-1

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

DATA TRANSFER SHEET
palawan 12/2/15

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	
15-Nov-15	3493P	2BLK42EF319A	GEMINI	NA	300	611	208	NA	NA	13.2	NA	5.16	0KB	1KB	8/67	NA	Z:\DAC\RAW DATA
16-Nov-15	3497P	2BLK42DisI320A	GEMINI	NA	384	616	220	NA	NA	17.4	NA	7.61	0KB	1KB	22	NA	Z:\DAC\RAW DATA
16-Nov-15	3499P	2BLK42isI320B	GEMINI	NA	593	517	112	NA	NA	9.16	NA	7.61	0KB	1KB	14/15/16	NA	Z:\DAC\RAW DATA
18-Nov-15	3505P	2BLK42AEs322A	GEMINI	NA	438	737	222	NA	NA	17.5	NA	8.09	0KB	1KB	22/21/16	NA	Z:\DAC\RAW DATA
18-Nov-15	3507P	2BLK42isIAs322B	GEMINI	NA	728	734	180	NA	NA	13.2	NA	8.09	0KB	1KB	16/22	NA	Z:\DAC\RAW DATA

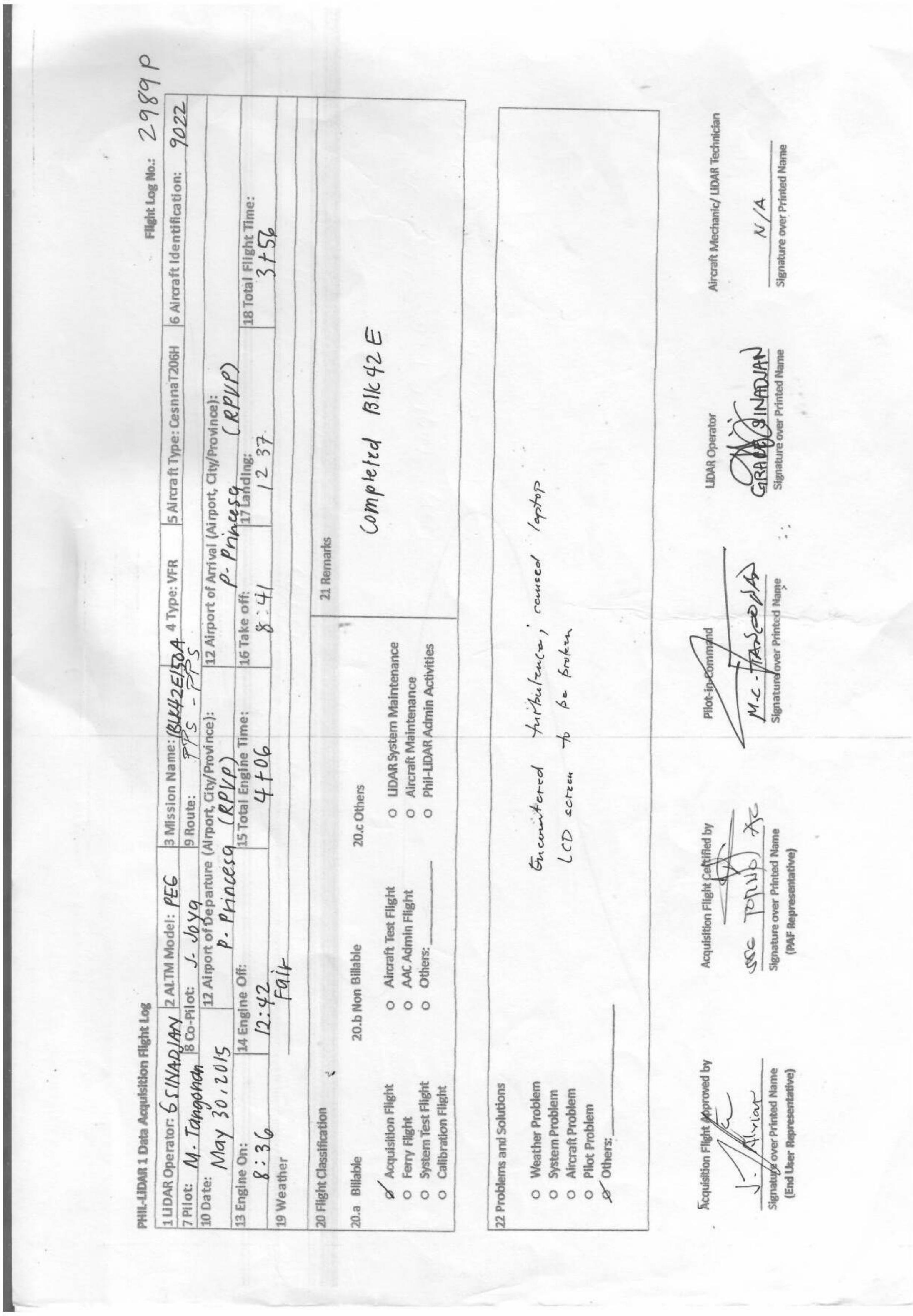
Received from
Name
Position
Signature

Received by
Name AC Bongat
Position
Signature 12/8/15

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

Annex 6. Flight Logs

1. Flight Log for 1BLK42E150A Mission



PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 2989P

1 LIDAR Operator: G SINADJAN	2 ALTM Model: PEG	3 Mission Name: 1BLK42E150A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9022
7 Pilot: M. Tangonan	8 Co-Pilot: J. Joyo	9 Route: PPS - PPS			
10 Date: May 30, 2015	12 Airport of Departure (Airport, City/Province): P. Princesa (RPVP)		12 Airport of Arrival (Airport, City/Province): P. Princesa (RPVP)		
13 Engine On: 8:36	14 Engine Off: 12:42	15 Total Engine Time: 4+06	16 Take off: 8:41	17 Landing: 12:37	18 Total Flight Time: 3+56
19 Weather: Fair					

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 BLK42E

22 Problems and Solutions
- o Weather Problem
- o System Problem
- o Aircraft Problem
- o Pilot Problem
- ✓ Others: Encountered turbulence; caused laptop LCD screen to be broken

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

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

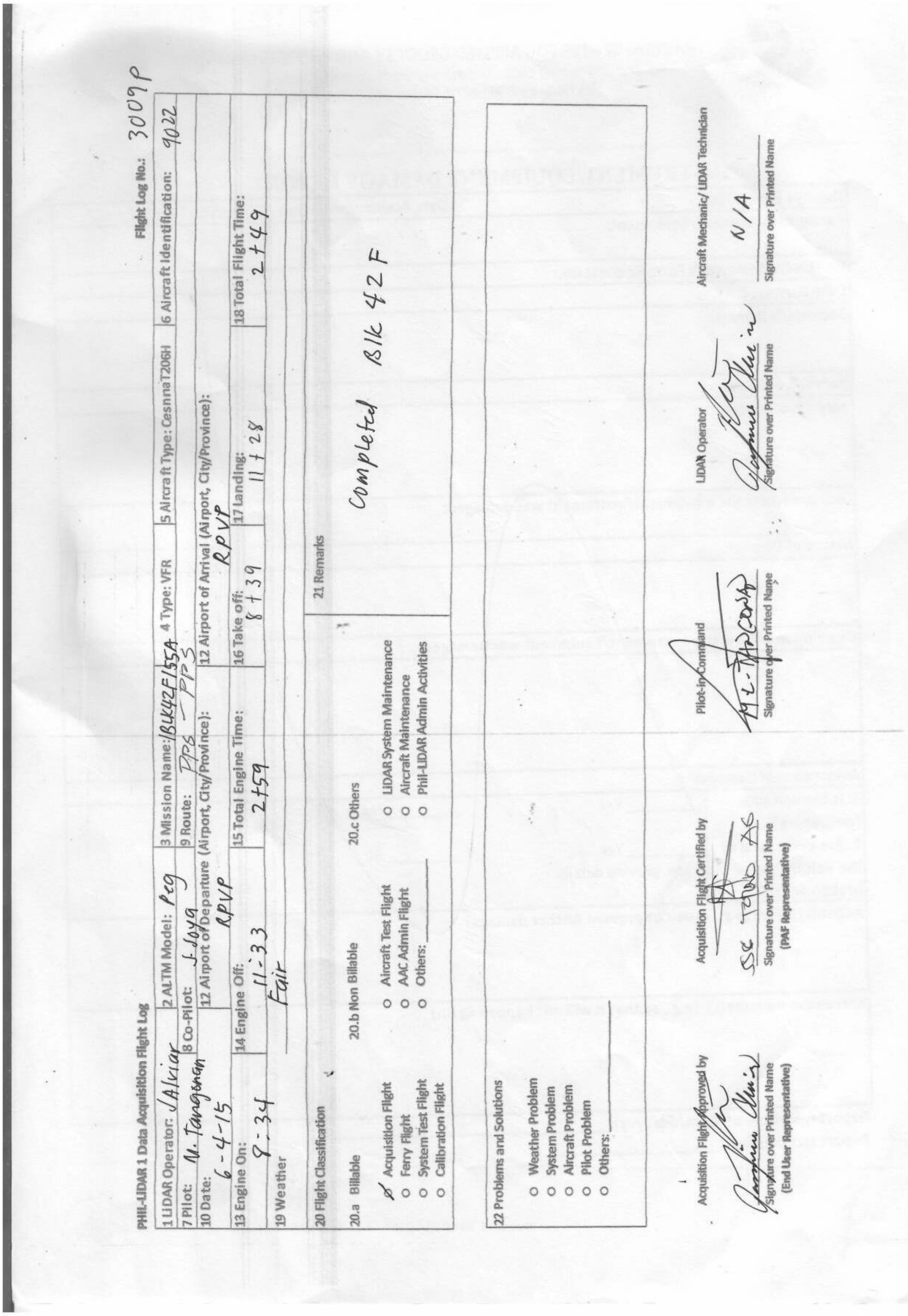
Pilot-in-Command: M.C. TANGONAN — Signature over Printed Name

LIDAR Operator: GRACE SINADJAN — Signature over Printed Name

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

Figure A-6.1. Flight Log for 1BLK42E150A Mission

2. Flight Log for 1BLK42F155A Mission



PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 3009P

1 LIDAR Operator: J Alviar	2 ALTM Model: Peg	3 Mission Name: 1BLK42F155A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9022
7 Pilot: M. Tangonan	8 Co-Pilot: J. Joya	9 Route: PPS - PPS			
10 Date: 6-4-15	12 Airport of Departure (Airport, City/Province): RPVP		12 Airport of Arrival (Airport, City/Province): RPVP		
13 Engine On: 8:34	14 Engine Off: 11:33	15 Total Engine Time: 2+59	16 Take off: 8+39	17 Landing: 11+28	18 Total Flight Time: 2+49
19 Weather: Fair					

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 42F

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 TONO AS — Signature over Printed Name (PAF Representative)

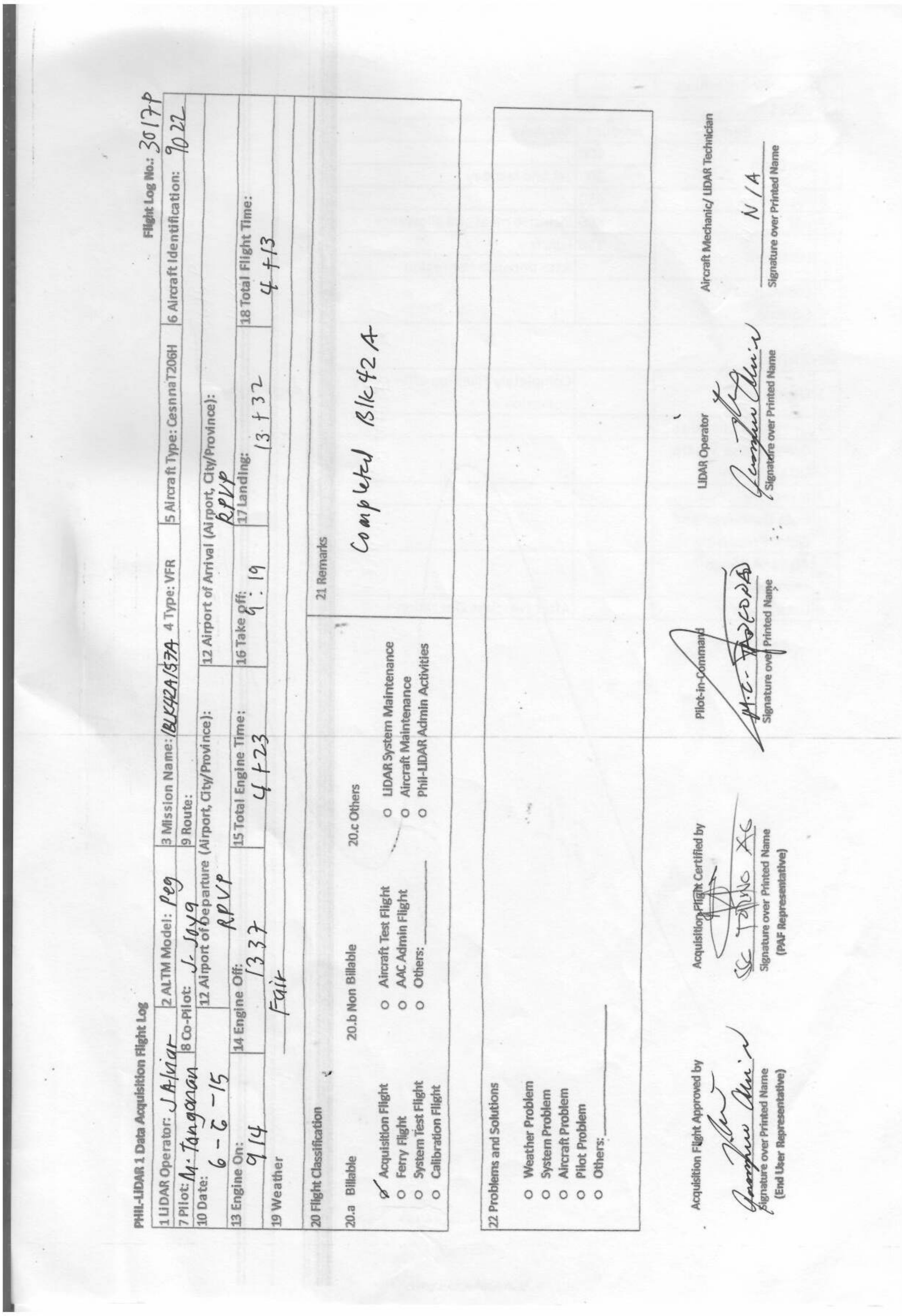
Pilot-in-Command — Signature over Printed Name

LIDAR Operator — Signature over Printed Name

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

Figure A-6.2. Flight Log for 1BLK42F155A Mission

3. Flight Log for 1BLK42A157A Mission



PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 3017P

1 LiDAR Operator: J. Alviar
2 ALTM Model: Peg
3 Mission Name: 1BLK42A157A
4 Type: VFR
5 Aircraft Type: CesnnaT206H
6 Aircraft Identification: 9022

7 Pilot: M. Tangonan
8 Co-Pilot: J. Jaya
9 Route:

10 Date: 6-6-15
12 Airport of Departure (Airport, City/Province): RPVP
12 Airport of Arrival (Airport, City/Province): RPVP

13 Engine On: 914
14 Engine Off: 1337
15 Total Engine Time: 4+23
16 Take off: 9:19
17 Landing: 13+32
18 Total Flight Time: 4+13

19 Weather: Fair

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 Blk42A

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

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

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

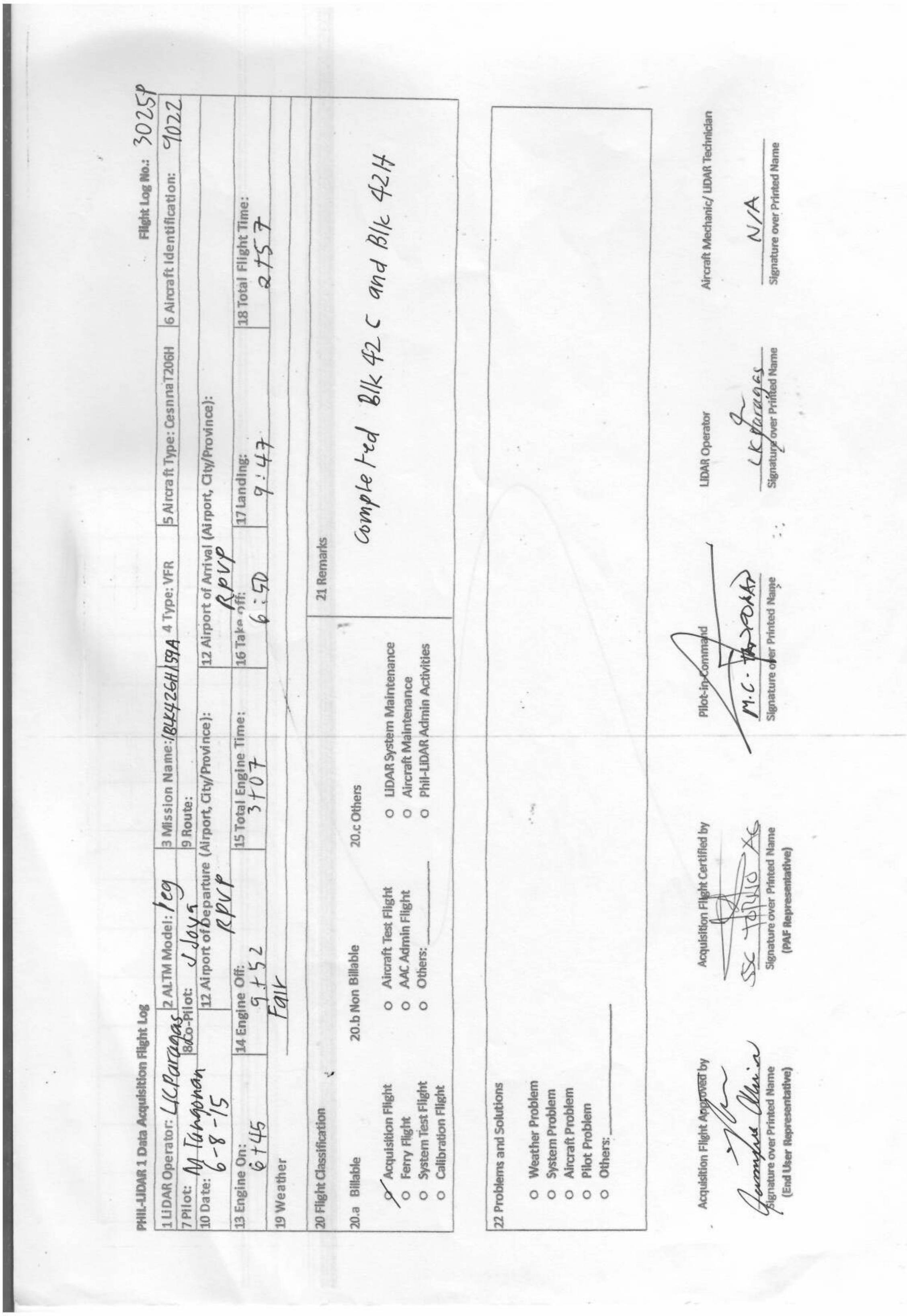
Pilot-in-Command — Signature over Printed Name

LIDAR Operator — Signature over Printed Name

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

Figure A-6.3. Flight Log for 1BLK42A157A Mission

4. Flight Log for 1BLK42GH159A Mission


PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 3025P

1 LIDAR Operator: LK Paragas	2 ALTM Model: Peg	3 Mission Name: 1BLK42GH159A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9022
7 Pilot: M Tangonan	8 Co-Pilot: J Joya	9 Route:			
10 Date: 6-8-15	12 Airport of Departure (Airport, City/Province): RPVP		12 Airport of Arrival (Airport, City/Province): RPVP		
13 Engine On: 6+45	14 Engine Off: 9+52	15 Total Engine Time: 3+07	16 Take off: 6:50	17 Landing: 9:47	18 Total Flight Time: 2+57
19 Weather: Fair					

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

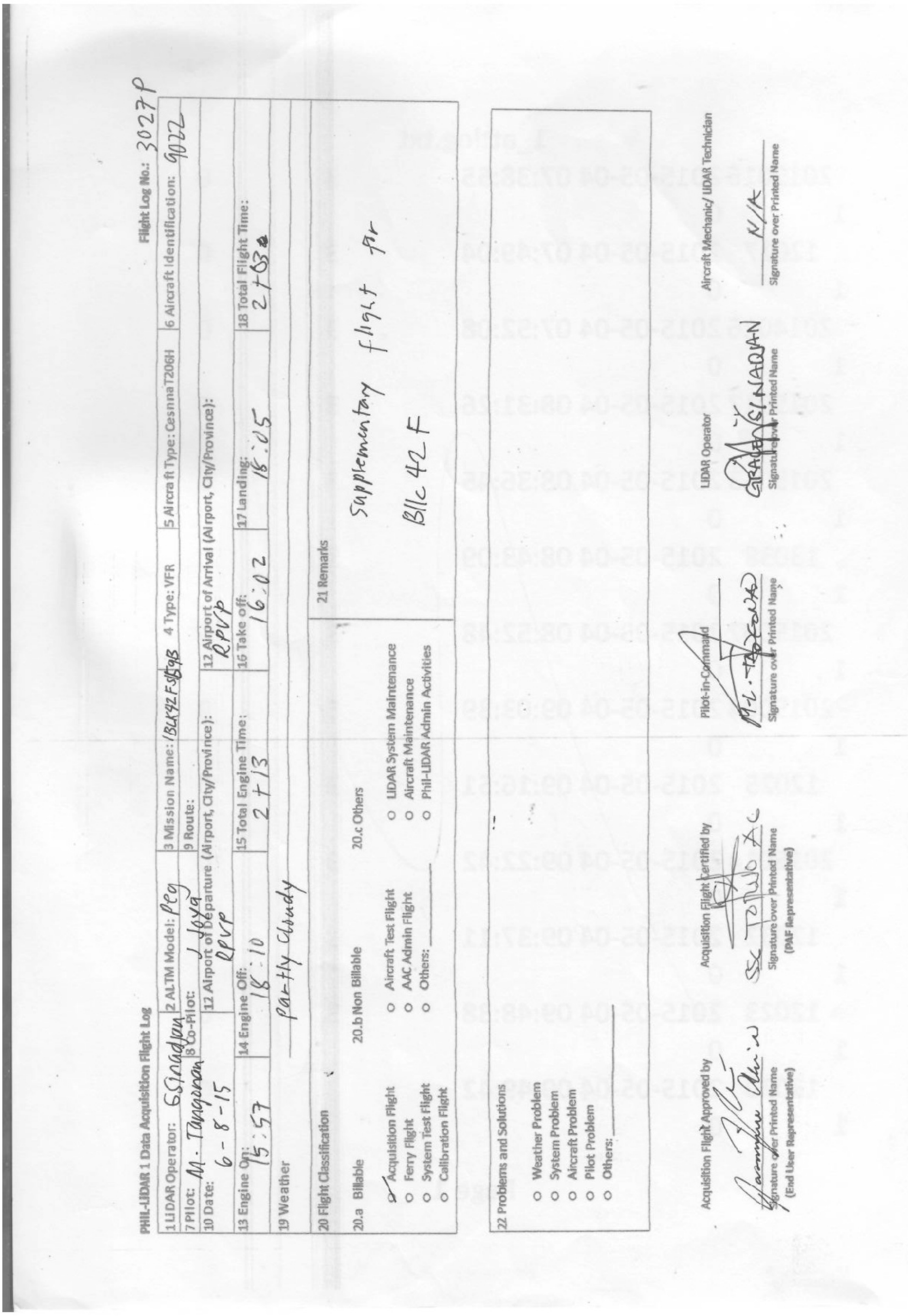
Completed Blk 42C and Blk 42H

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	LIDAR Operator	Aircraft Mechanic/ LIDAR Technician
[signature]	SC Tolulo XG	M.C. Tangonan	LK Paragas	N/A
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

Figure A-6.4. Flight Log for 1BLK42GH159A Mission

5. Flight Log for 1BLK42FS159B Mission



Flight Log No.: 3027P

PHIL-LIDAR 1 Data Acquisition Flight Log

1 LIDAR Operator: G. Sinadjan	2 ALTM Model: Peg	3 Mission Name: 1BLK42FS159B	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9022
7 Pilot: M. Tangonan	8 Co-Pilot: J. Joya	9 Route:			
10 Date: 6-8-15	12 Airport of Departure (Airport, City/Province): RPVP		12 Airport of Arrival (Airport, City/Province): RPVP		
13 Engine On: 15:57	14 Engine Off: 18:10	15 Total Engine Time: 2+13	16 Take off: 16:02	17 Landing: 18:05	18 Total Flight Time: 2+03
19 Weather	Partly cloudy				

20 Flight Classification

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

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

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

21 Remarks

Supplementary flight for Blk 42F

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 — SSC Topuo AC — Signature over Printed Name (PAF Representative)

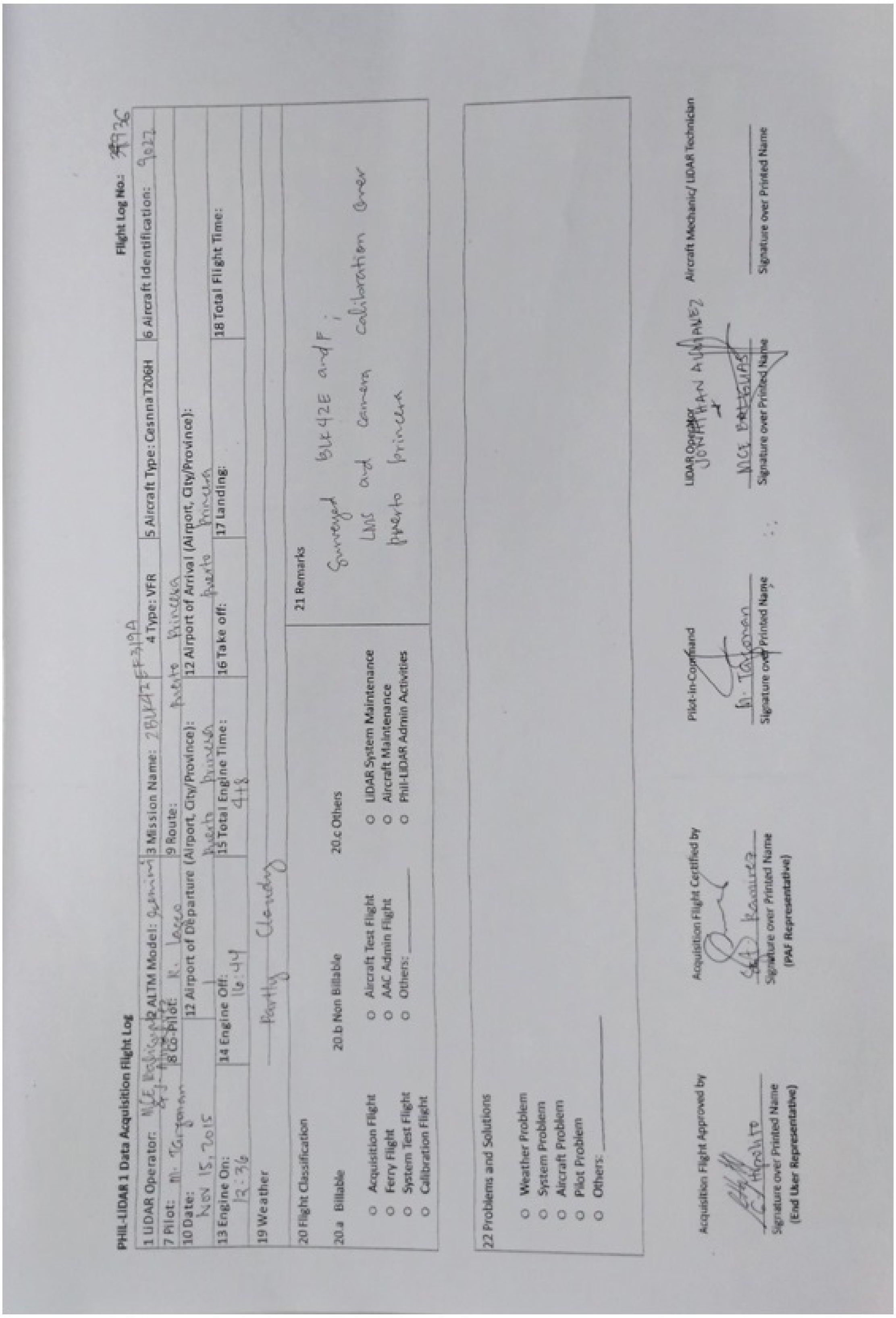
Pilot-in-Command — M.L. Tangonan — Signature over Printed Name

LIDAR Operator — Grace Sinadjan — Signature over Printed Name

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

Figure A-6.5 Flight Log for 1BLK42FS159B Mission

6. Flight Log for 2BLK42EF319A Mission



PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: [illegible]

1 LIDAR Operator: [illegible]	2 ALTM Model: Gemini	3 Mission Name: 2BLK42EF319A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9022
7 Pilot: M. Tangonan	8 Co-Pilot: [illegible]	9 Route: Puerto Princesa			
10 Date: Nov 15, 2015	12 Airport of Departure (Airport, City/Province): Puerto Princesa		12 Airport of Arrival (Airport, City/Province): Puerto Princesa		
13 Engine On: 12:36	14 Engine Off: 16:44	15 Total Engine Time: 4+8	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather	Partly Cloudy				

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

Surveyed BLK42E and F; LMS and camera calibration over Puerto Princesa

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: Signature over Printed Name

Aircraft Mechanic/ LIDAR Technician: Signature over Printed Name

Figure A-6.6 Flight Log for 2BLK42EF319A Mission

Annex 7. Flight Status Report

IWAHIG PENAL FLOODPLAIN
(May 30-June 8; November 15, 2015)

FLIGHT NO.	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
2989P	BLK 42E	1BLK42E150A	G. Sinadjan	30-May-15	Data acquired in BLK 42E
3009P	BLK 42F	1BLK42F155A	J. Alviar	4-June-15	Completed BLK 42F but experienced Fms No Commerror towards end of flight
3017P	BLK 42A	1BLK42A157A	J. Alviar	6-June-15	Data acquired in BLK 42A
3025P	BLK 42G & 42H	1BLK42GH159A	L. Paragas	8-June-15	Surveyed BLK 42G and BLK 42H
3027P	BLK 42FS	1BLK42FS159B	G. Sinadjan	8-June-15	Surveyed voids in BLK 42F, extended area to BLK 42FS
3493G	BLK42 eE & 42eF	2BLK42EF319A	MCE Baliguas JM Almalvez	15-Nov-15	Calibration flight; covered voids and gaps on RBs

LAS/SWATH BOUNDARIES PER MISSION FLIGHT
FLIGHT LOG NO. 2989P Scan Freq: 30 Hz
AREA: BLOCK 42E Scan Angle: 25 deg
MISSION NAME: 1BLK42E150A PRF: 200 kHz

SURVEY COVERAGE:

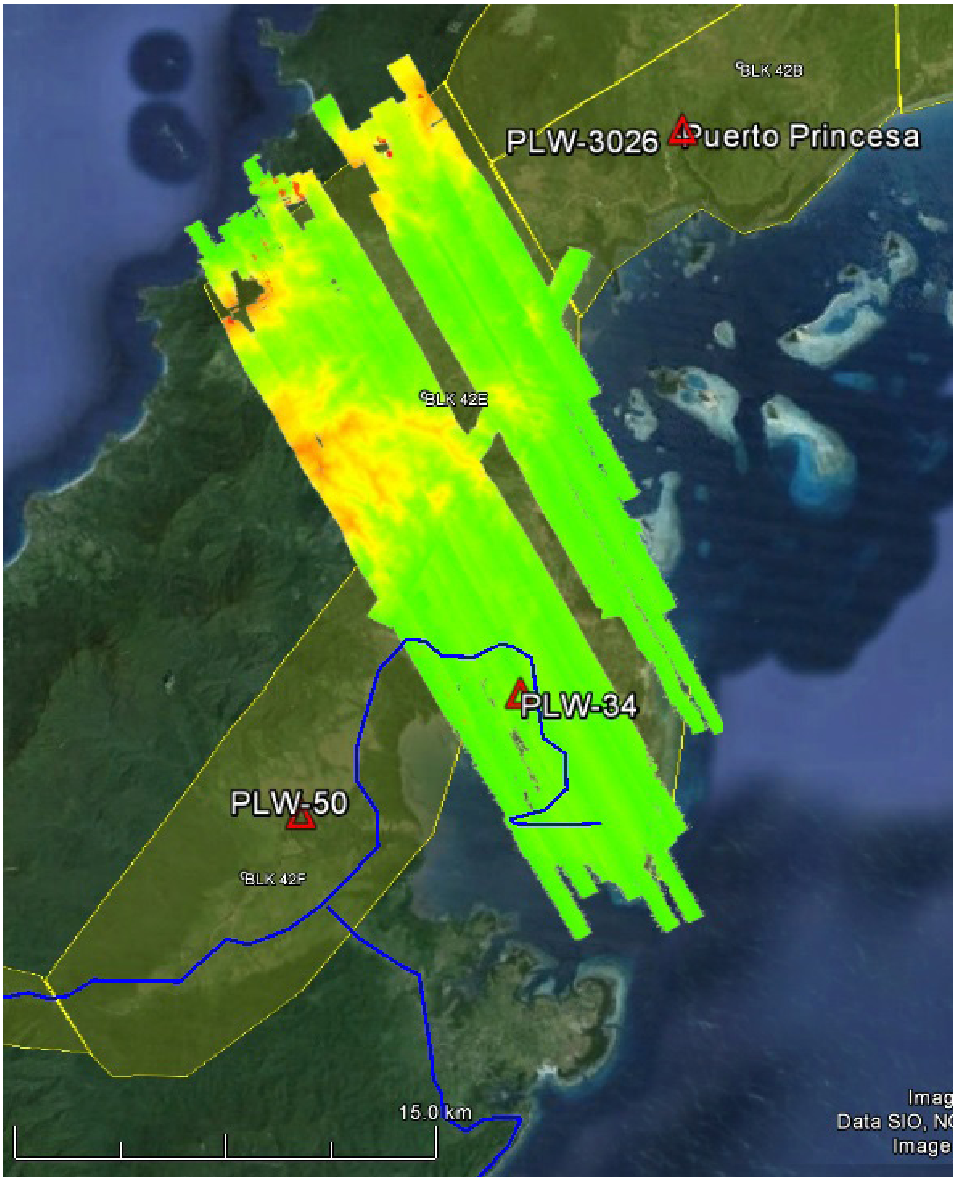


Figure A-7.1. Swath for Flight No. 2989P

FLIGHT LOG NO. 3009P Scan Freq: 30 Hz
AREA: BLOCK 42F Scan Angle: 25 deg
MISSION NAME: 1BLK42F155A PRF: 200 kHz

SURVEY COVERAGE:

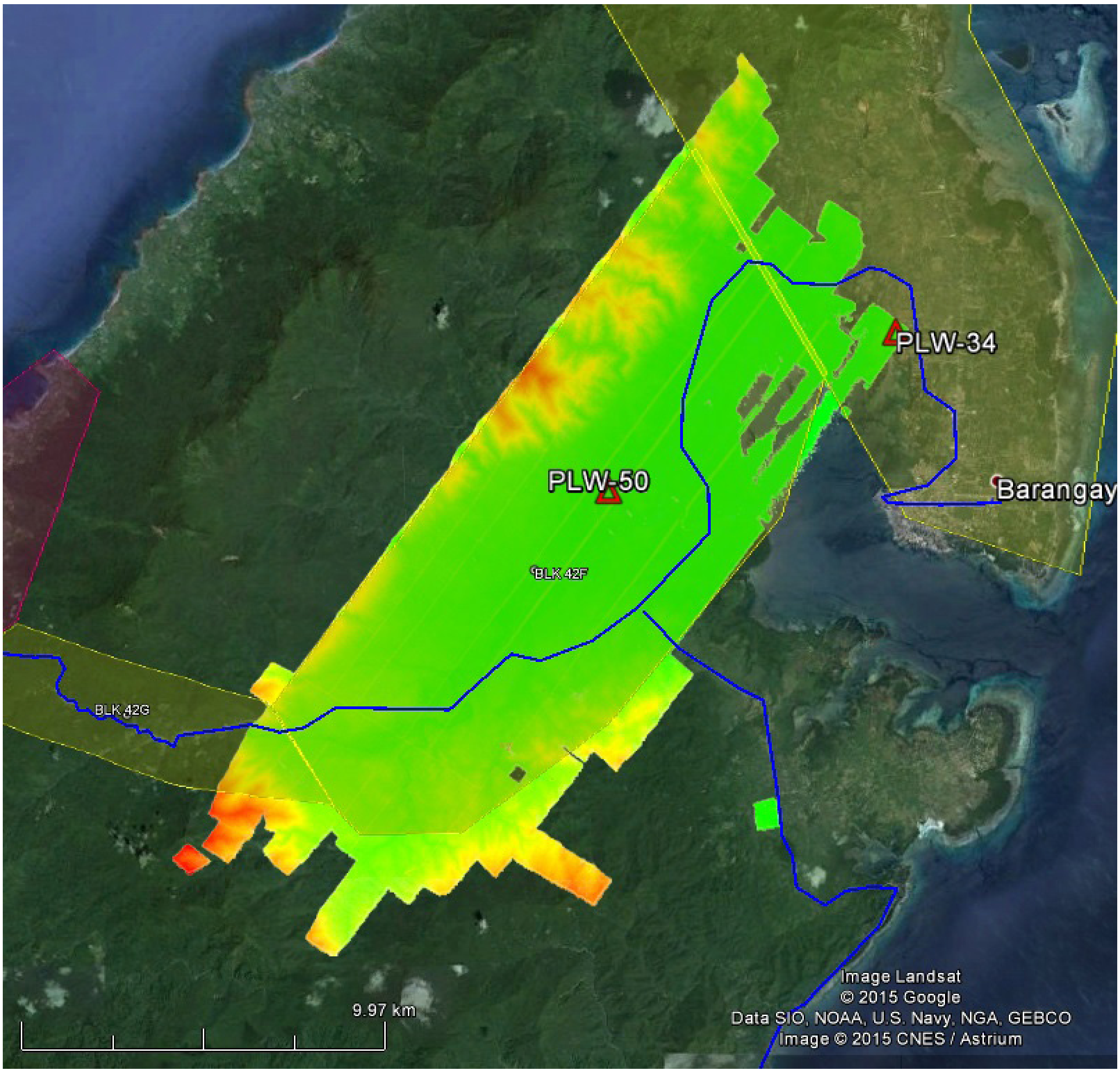


Figure A-7.2. Swath for Flight No. 3009P

FLIGHT LOG NO. 3017P Scan Freq: 30 Hz
AREA: BLOCK 42A Scan Angle: 25 deg
MISSION NAME: 1BLK42A157A PRF: 200 kHz

SURVEY COVERAGE:

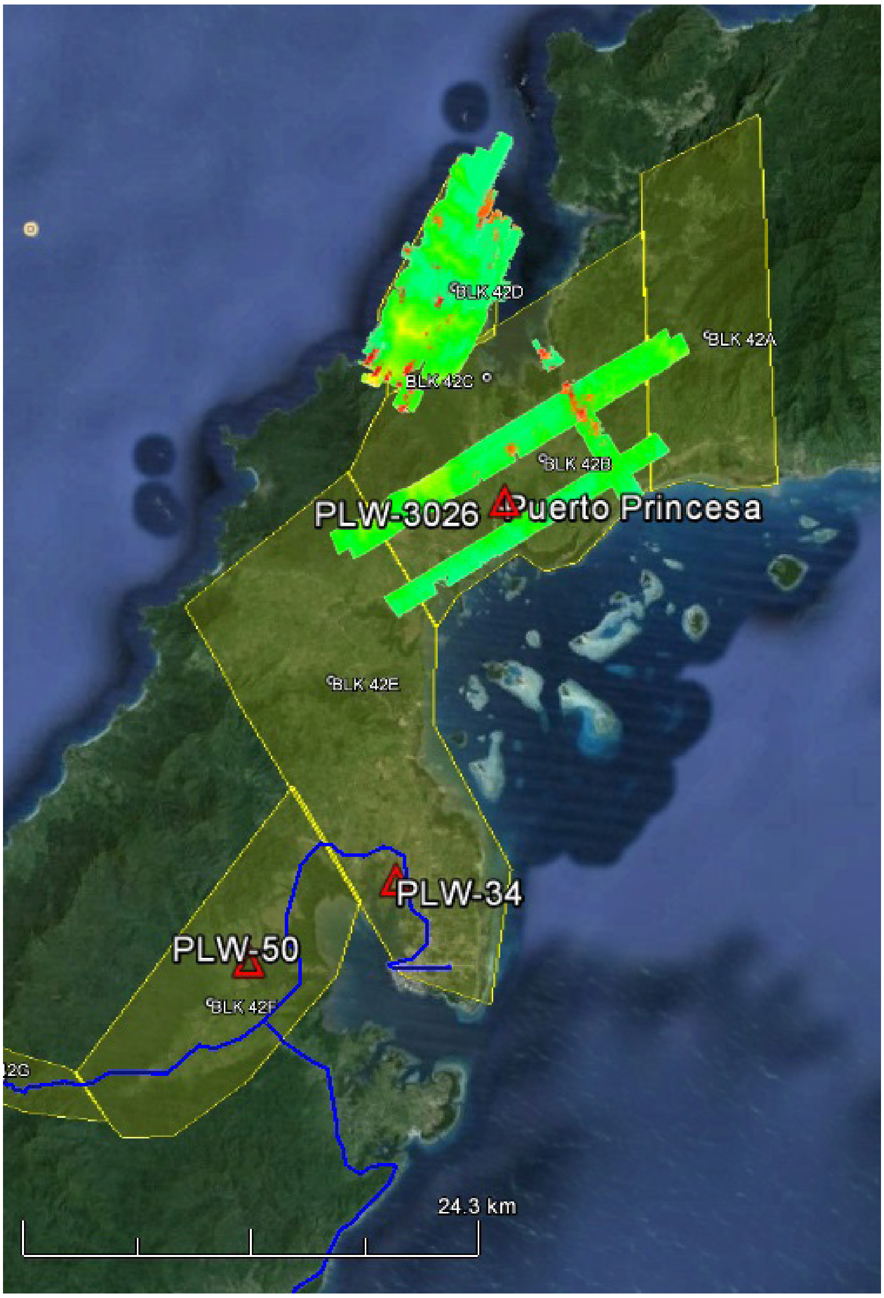


Figure A-7.4. Swath for Flight No. 3017P

FLIGHT LOG NO. 3025P
AREA: BLOCK 42G & 42H
MISSION NAME: 1BLK42GH159A
Scan Freq: 30 Hz
Scan Angle: 25 deg
PRF: 150 kHz

SURVEY COVERAGE:

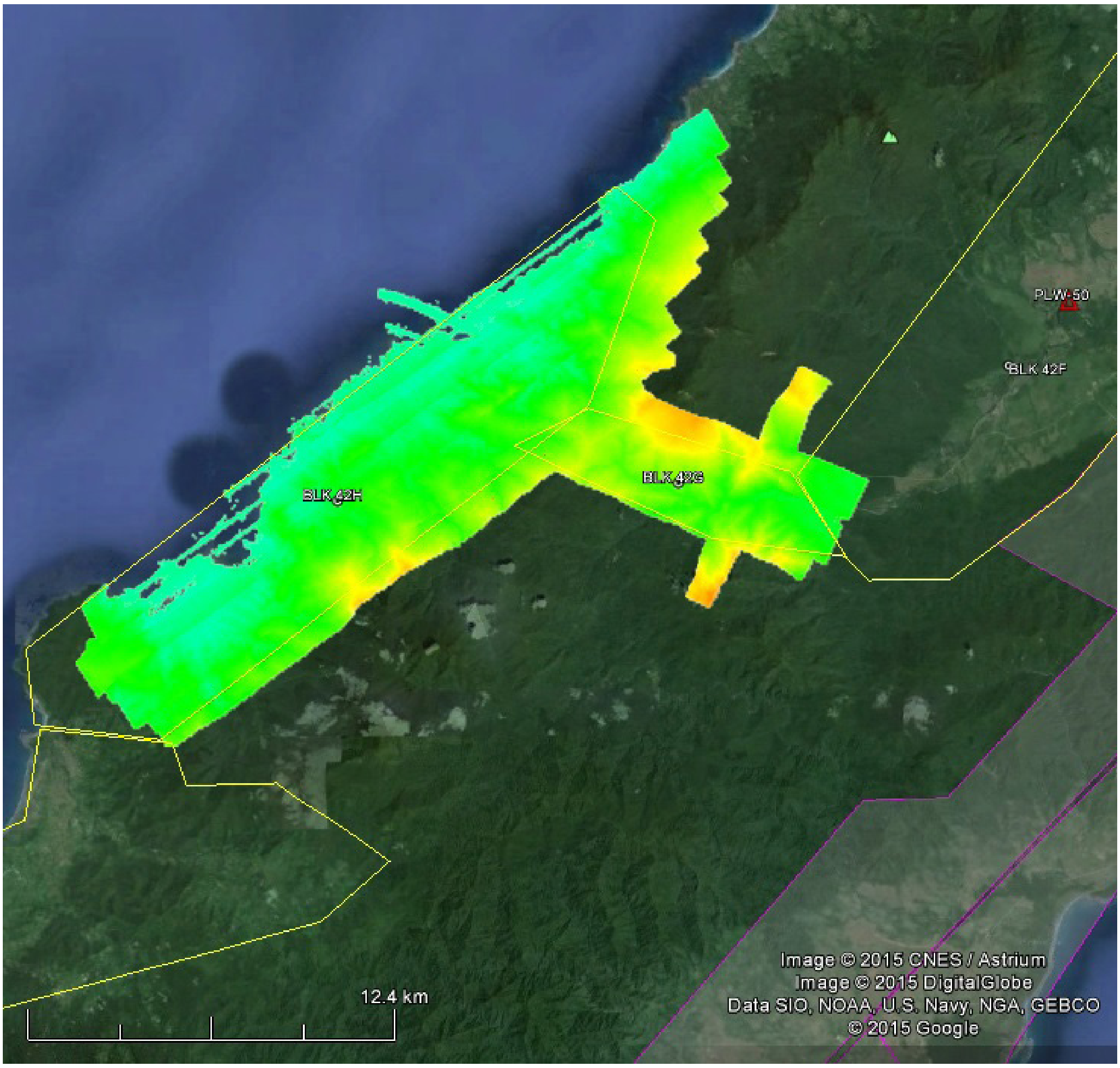


Figure A-7.5. Swath for Flight No. 3025P

FLIGHT LOG NO. 3027P
AREA: BLOCK 42F & 42FS
MISSION NAME: 2BLK42EF319A

Scan Freq: 30 Hz
Scan Angle: 25 deg
PRF: 200 kHz

SURVEY COVERAGE:

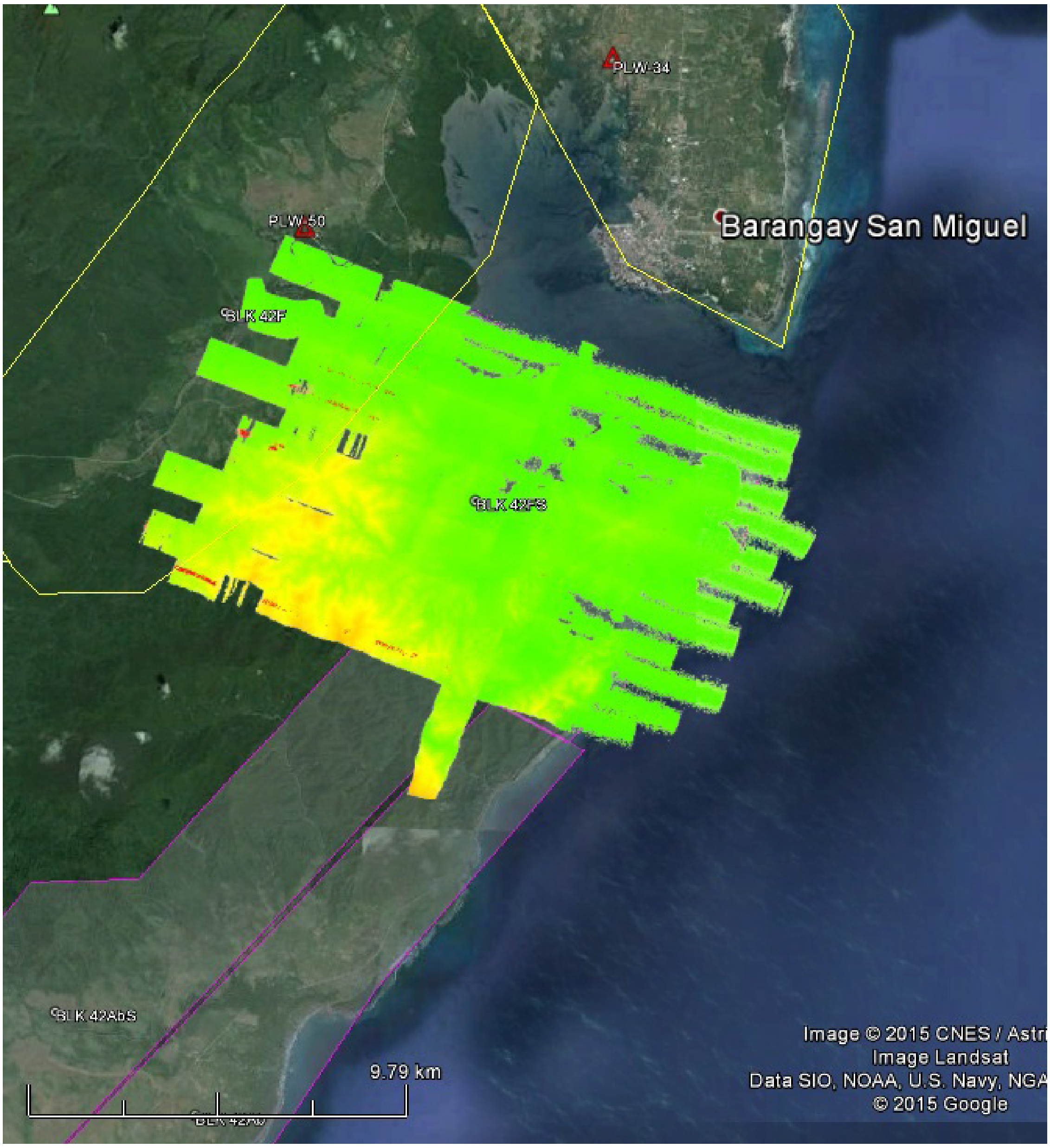


Figure A-7.6. Swath for Flight No. 3027P

FLIGHT LOG NO. 3493G
AREA: BLOCK 42eE & 42eF
MISSION NAME: 2BLK42EF319A
Scan Freq: 50 Hz
Scan Angle: 40 deg
PRF: 200 kHz

SURVEY COVERAGE:

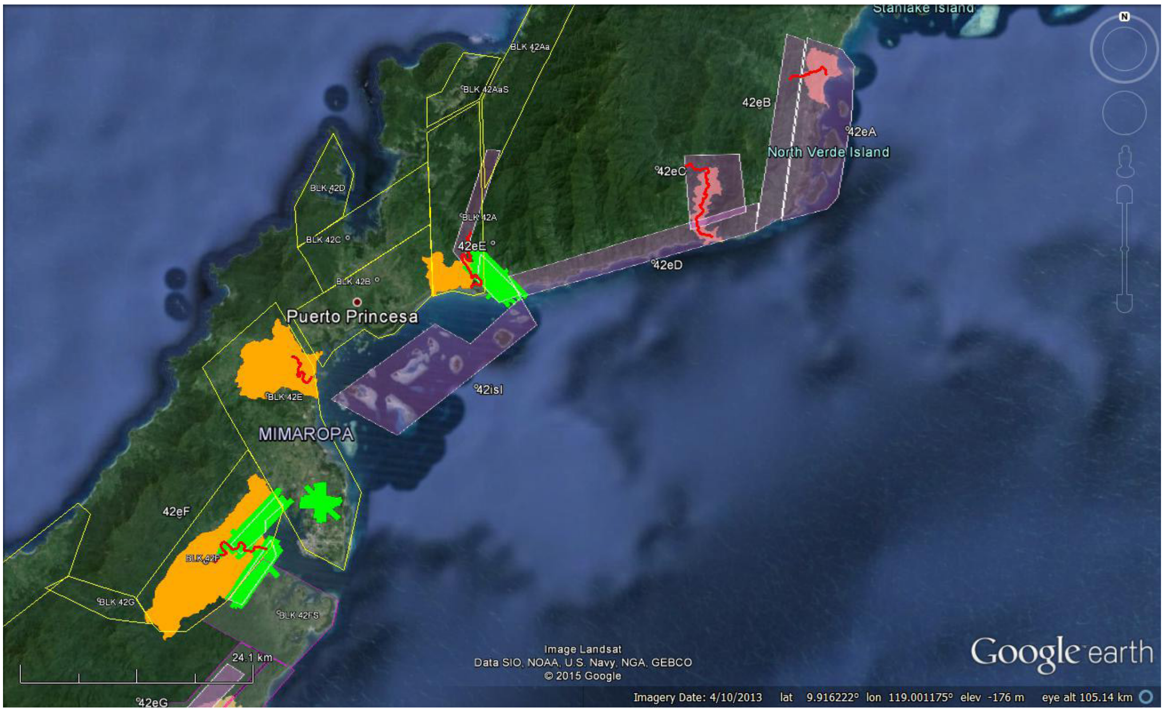


Figure A-7.7. Swath for Flight No. 3493G

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Blk42E

Flight Area	West Palawan
Mission Name	Block 42E
Inclusive Flights	2989P & 3017P
Range data size	54.70 GB
Base data size	19.17 MB
POS	519 MB
Image	110.80 GB
Transfer date	June 23, 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)	2.60
RMSE for East Position (<4.0 cm)	2.60
RMSE for Down Position (<8.0 cm)	4.30
Boresight correction stdev (<0.001deg)	0.000203
IMU attitude correction stdev (<0.001deg)	0.147257
GPS position stdev (<0.01m)	0.0025
Minimum % overlap (>25)	45.87
Ave point cloud density per sq.m. (>2.0)	4.49
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	353
Maximum Height	899.45 m
Minimum Height	49.6 m
Classification (# of points)	
Ground	364,978,265
Low vegetation	181,902,193
Medium vegetation	383,273,014
High vegetation	1,344,953,370
Building	33,880,796
Orthophoto	Yes
Processed by	Engr. Irish Cortez, Engr. Abigail Joy Ching, Engr. Chelou Prado, Engr. Ma. Ailyn Olanda, Engr. Krisha Marie Bautista

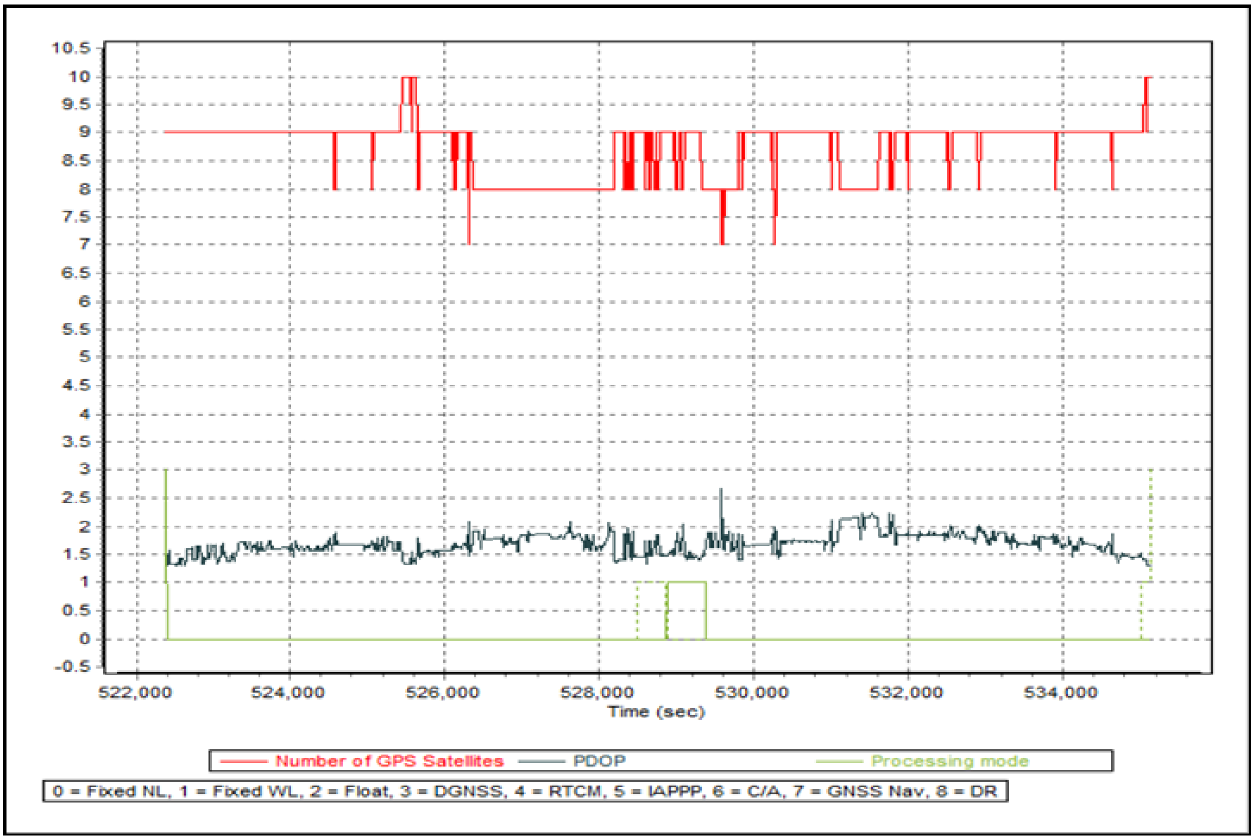


Figure A-8.1. Solution Status

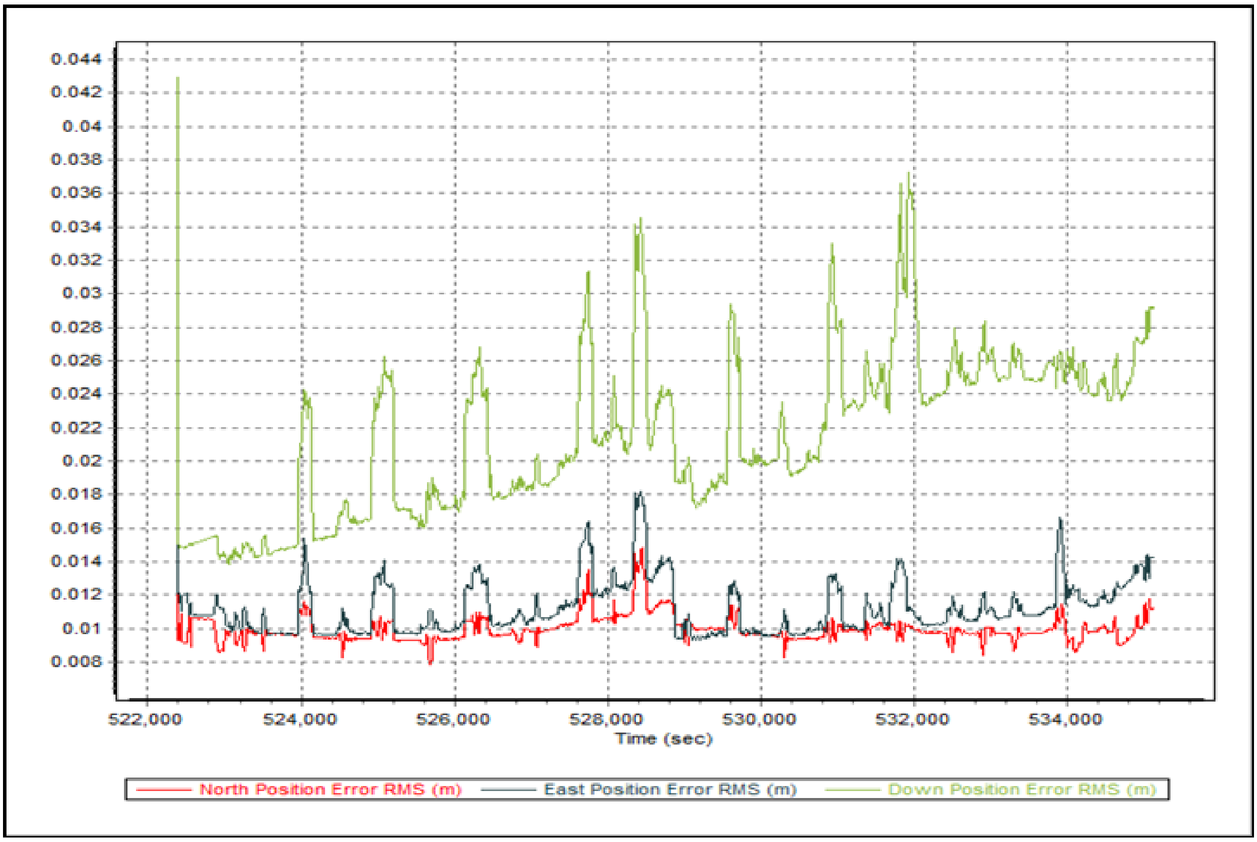


Figure A-8.2. Smoothed Performance Metrics Parameters

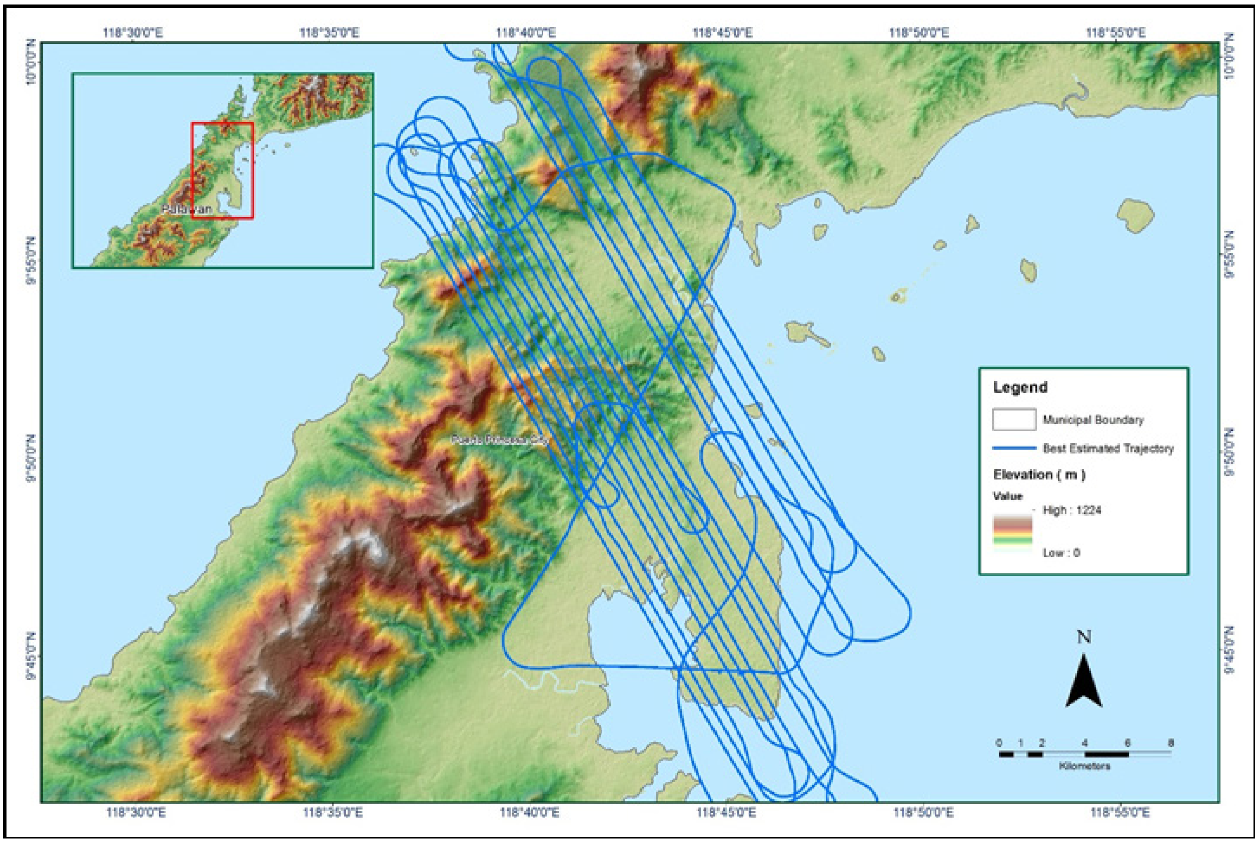


Figure A-8.3. Best Estimated Trajectory

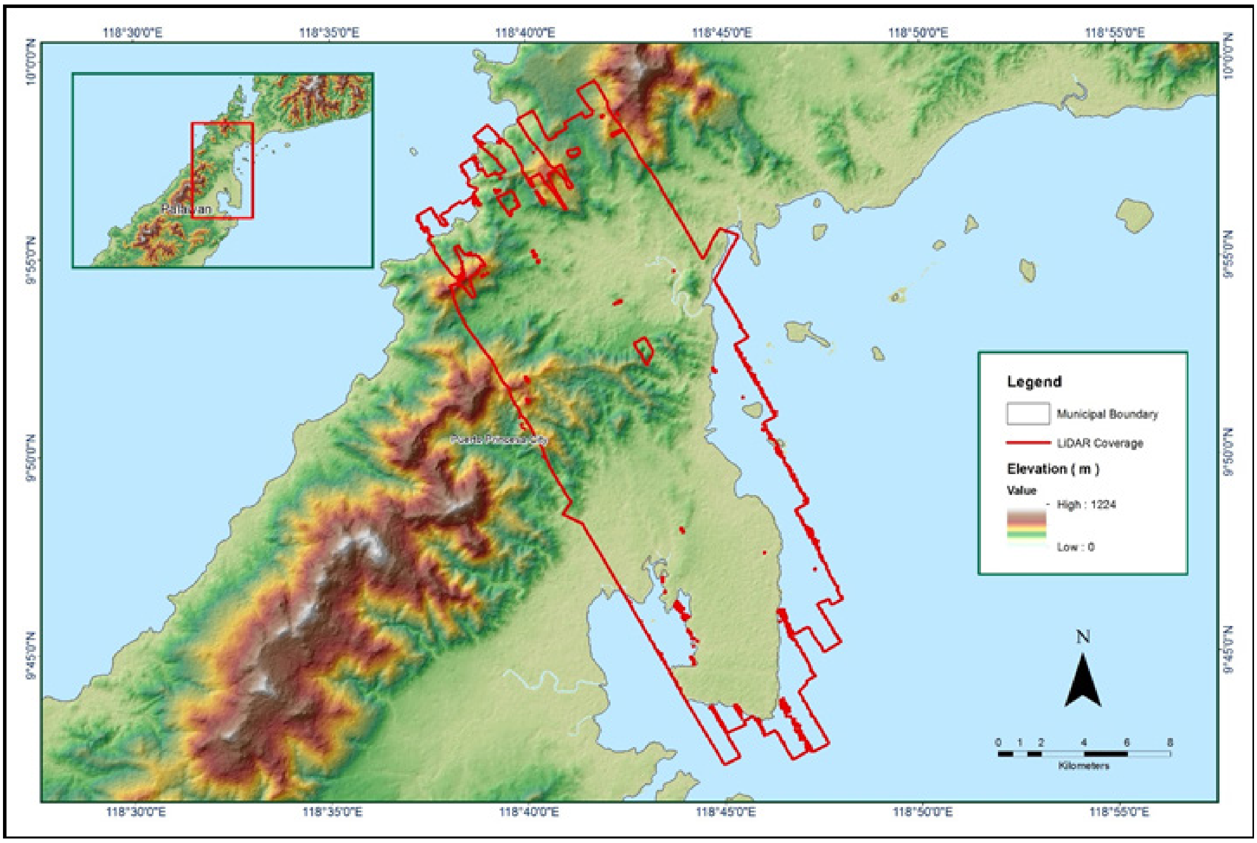


Figure A-8.4. Coverage of LiDAR data

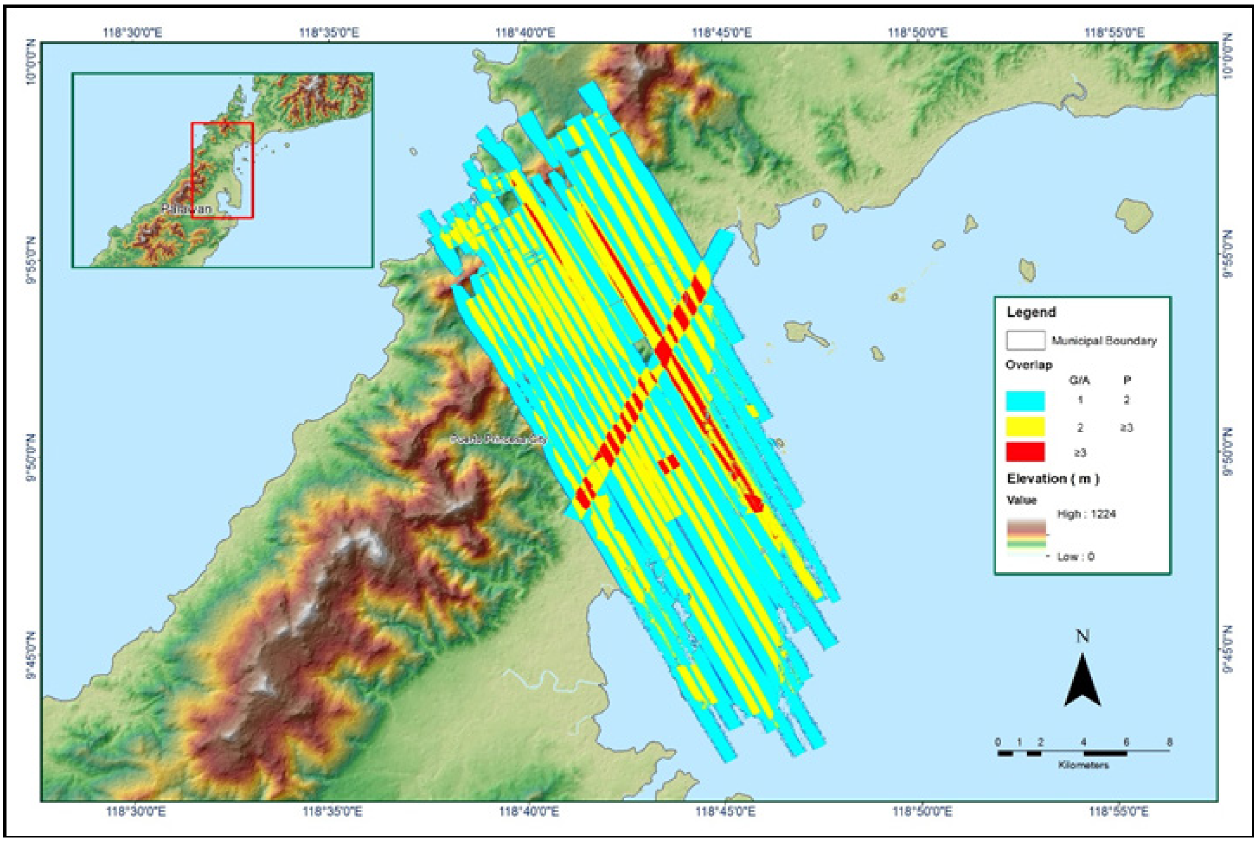


Figure A-8.5. Image of Data Overlap

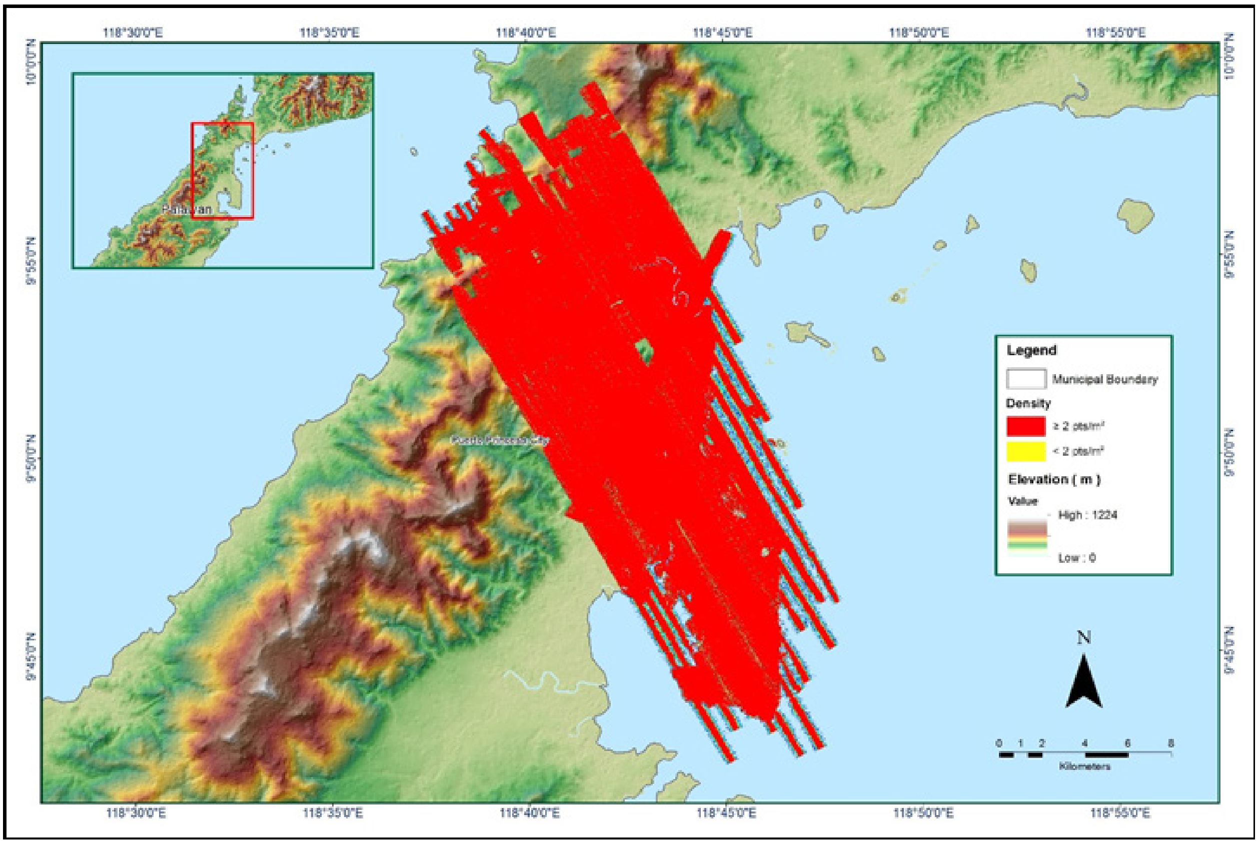


Figure A-8.6. Density map of merged LiDAR data

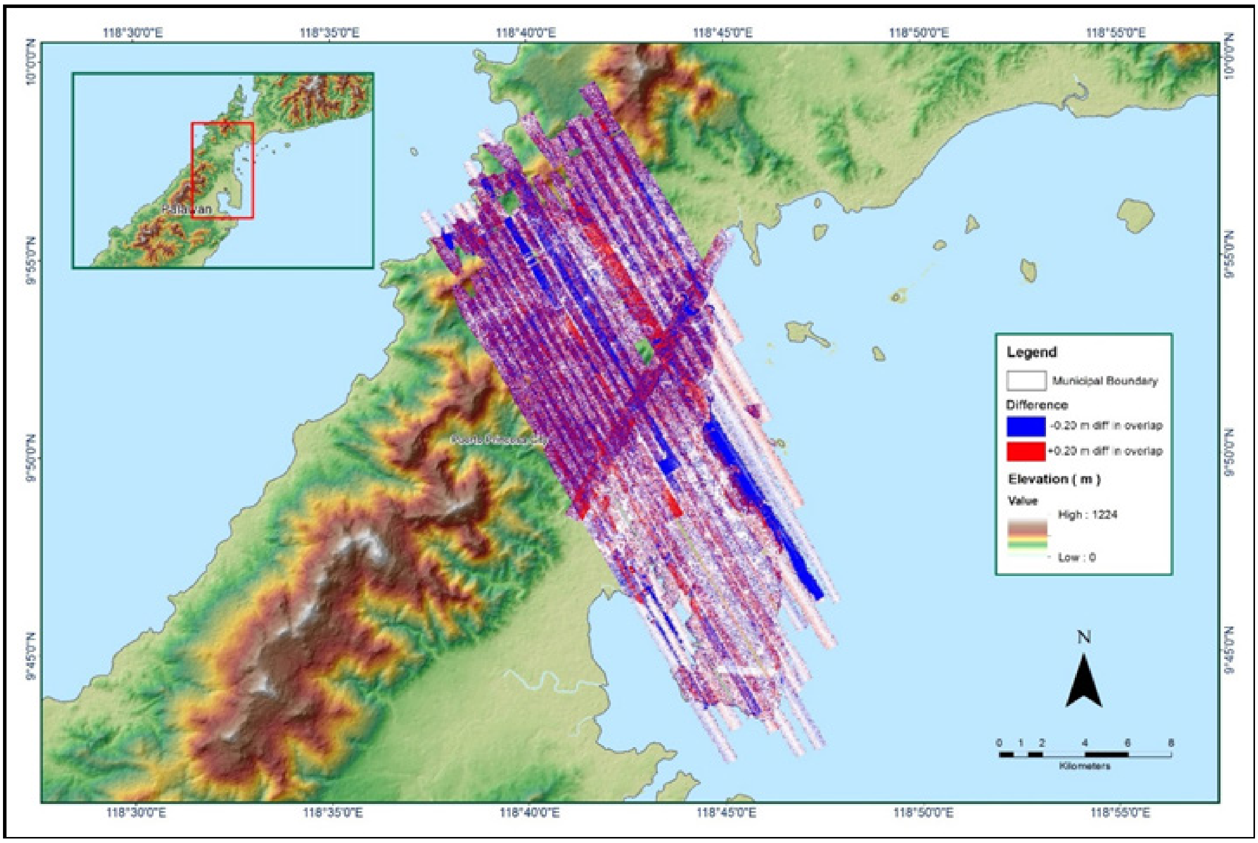


Figure A-8.7. Elevation difference between flight lines

Table A-8.2. Mission Summary Report for Mission Block 42F

Flight Area	West Palawan
Mission Name	Block 42F
Inclusive Flights	3009P
Range data size	15.30 GB
Base data size	4.68 MB
POS	166 MB
Image	20.20 GB
Transfer date	June 23, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	No
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.15
RMSE for East Position (<4.0 cm)	1.70
RMSE for Down Position (<8.0 cm)	3.30
Boresight correction stdev (<0.001deg)	0.000338
IMU attitude correction stdev (<0.001deg)	0.0.000398
GPS position stdev (<0.01m)	0.0090
Minimum % overlap (>25)	44.84
Ave point cloud density per sq.m. (>2.0)	3.39
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	226
Maximum Height	747.07 m
Minimum Height	40.72 m
Classification (# of points)	
Ground	69,752,138
Low vegetation	38,547,071
Medium vegetation	95,837,395
High vegetation	802,342,004
Building	7,334,249
Orthophoto	Yes
Processed by	Engr. Jommer Medina, Engr. Edgardo Gubatanga, Jr., Maria Tamsyn Malabanan

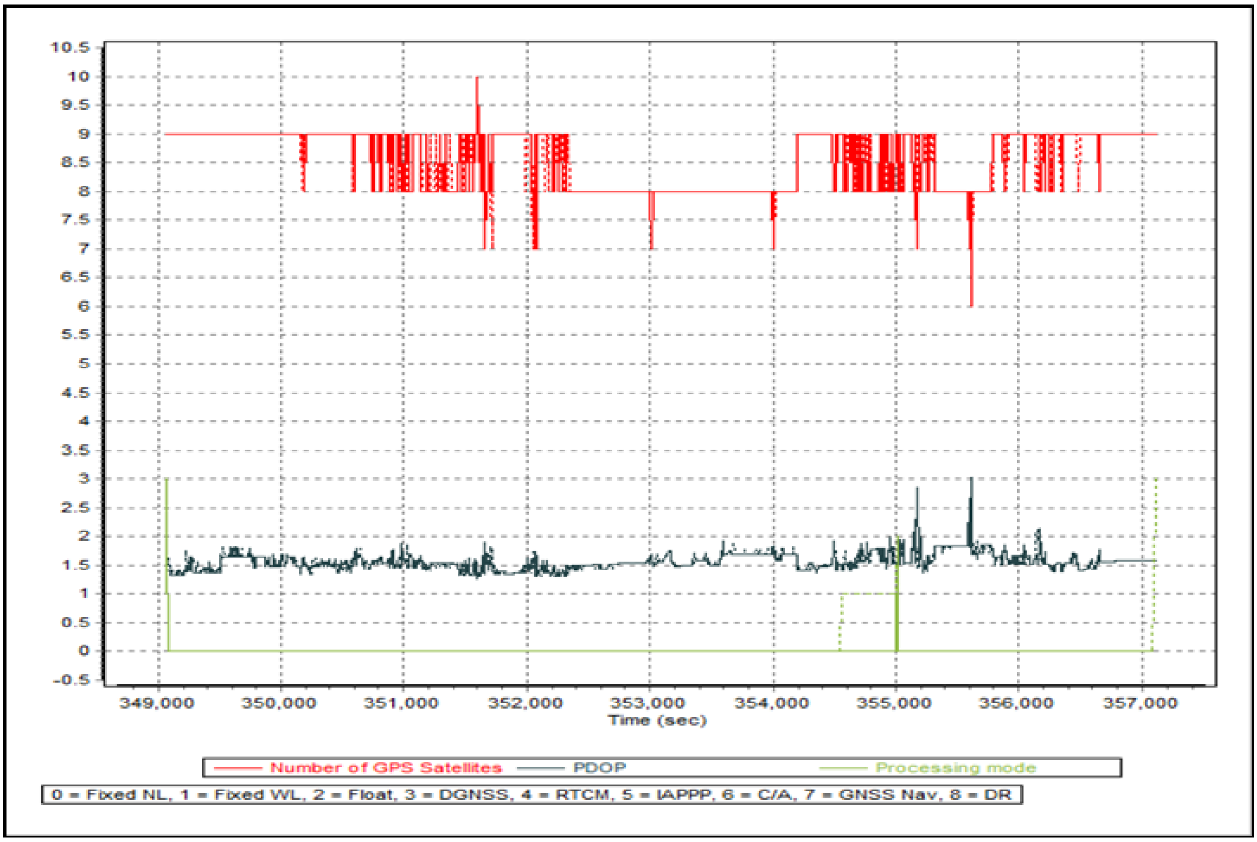


Figure A-8.8. Solution Status Parameters

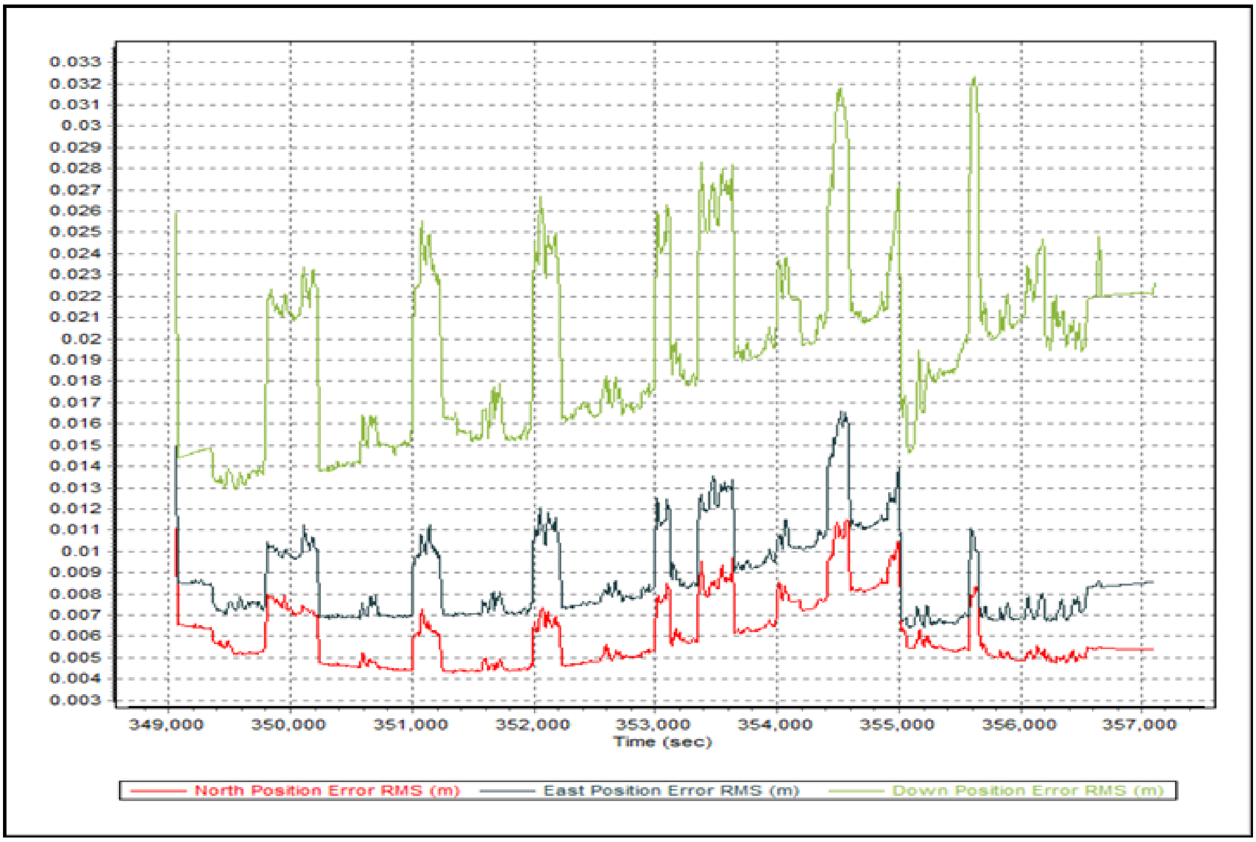


Figure A-8.9. Smoothed Performance Metrics Parameters

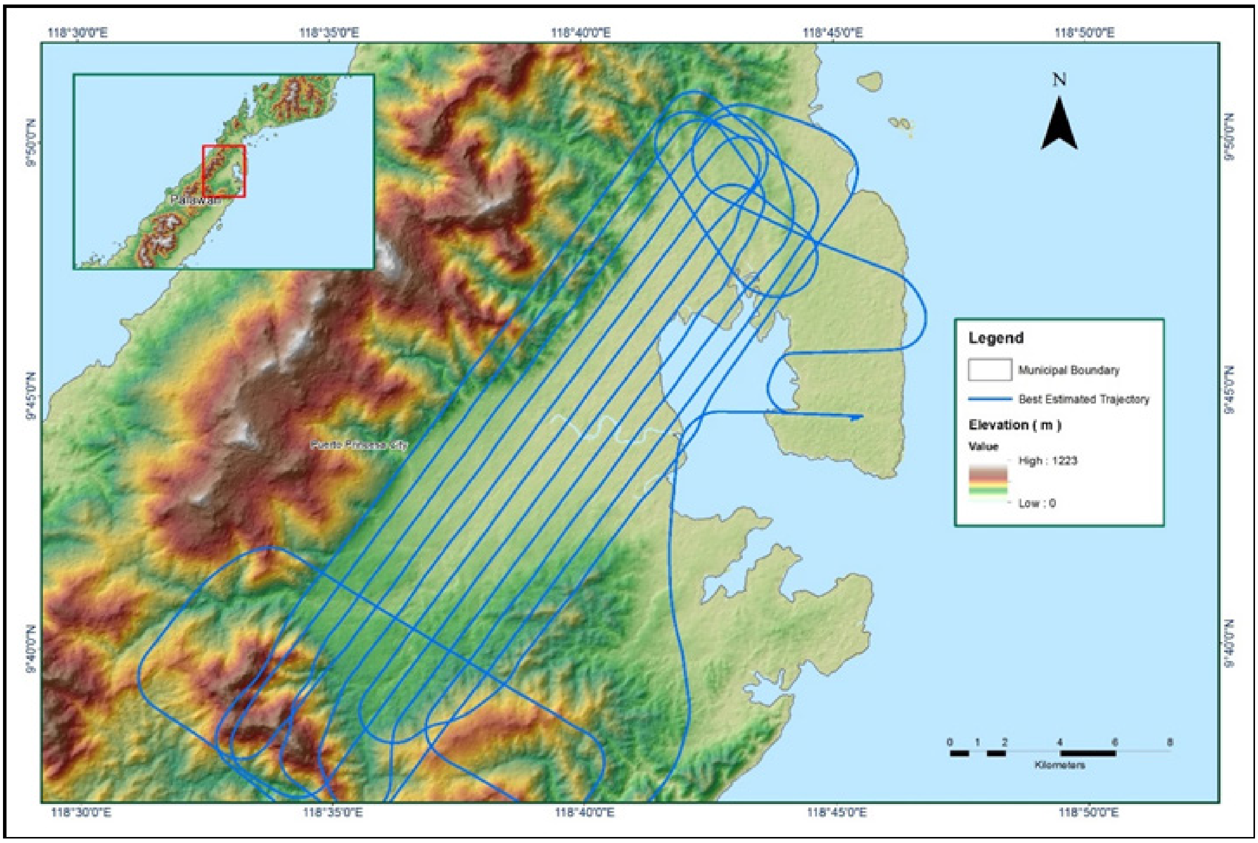


Figure A-8.10. Best Estimated Trajectory

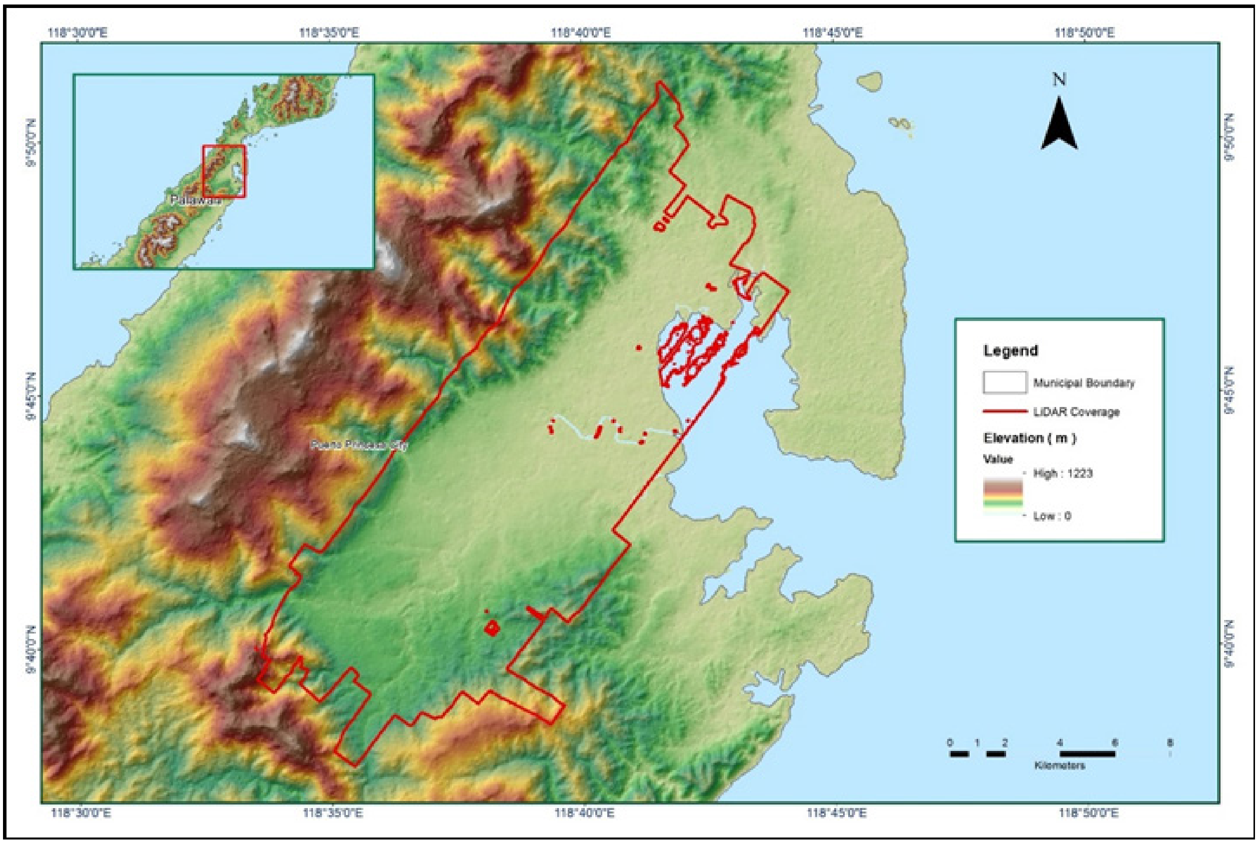


Figure A-8.11. Coverage of LiDAR data

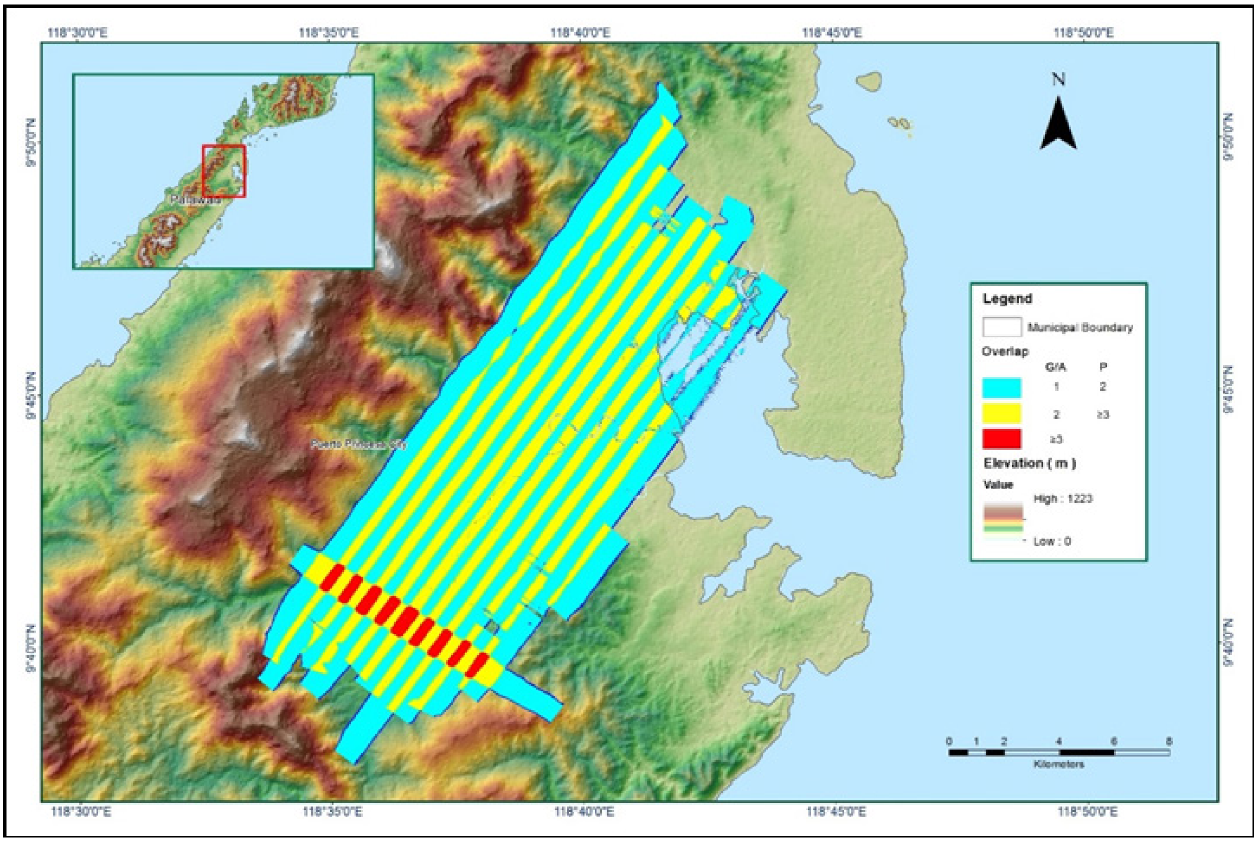


Figure A-8.12. Image of Data Overlap

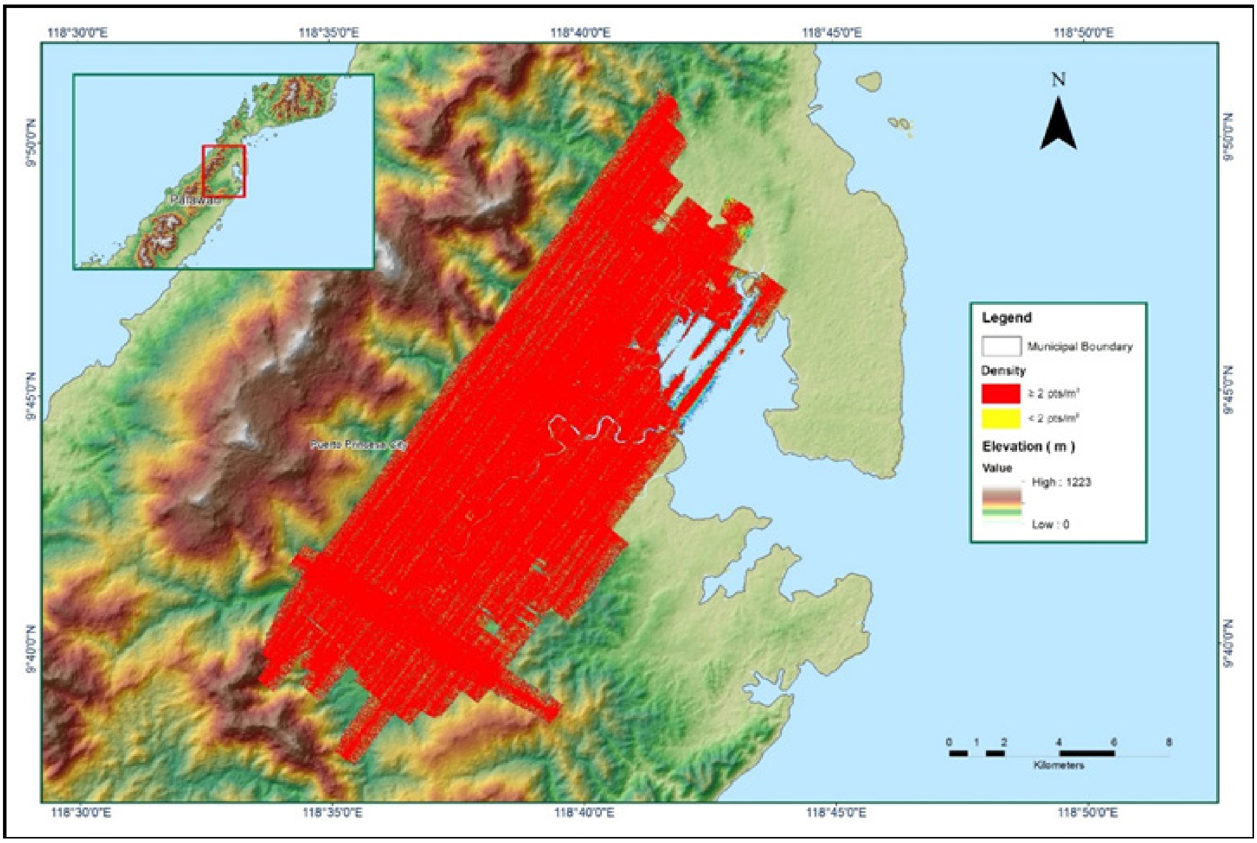


Figure A-8.13. Density map of merged LiDAR data

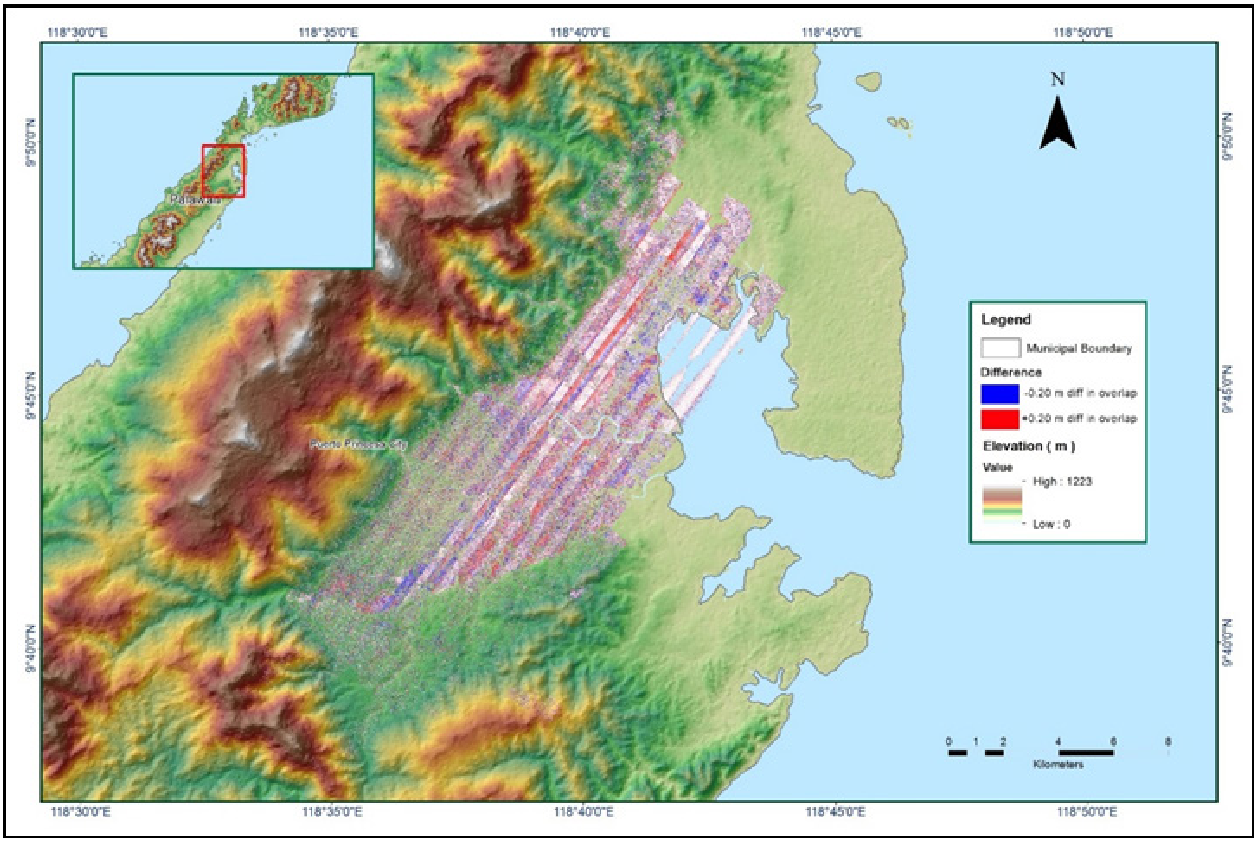


Figure A-8.14. Elevation difference between flight lines

Table A-8.3. Mission Summary Report for Mission Block 42F additional

Flight Area	West Palawan
Mission Name	Block 42F additional
Inclusive Flights	3049P
Range data size	18.30 GB
Base data size	16.30 MB
POS	162 MB
Image	31 GB
Transfer date	August 5, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.90
RMSE for East Position (<4.0 cm)	2.40
RMSE for Down Position (<8.0 cm)	5.40
Boresight correction stdev (<0.001deg)	0.000310
IMU attitude correction stdev (<0.001deg)	0.0.000769
GPS position stdev (<0.01m)	0.0091
Minimum % overlap (>25)	5.98
Ave point cloud density per sq.m. (>2.0)	3.83
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	29
Maximum Height	470.33 m
Minimum Height	86.25 m
Classification (# of points)	
Ground	3,026,483
Low vegetation	1,012,737
Medium vegetation	6,591,902
High vegetation	111,349,189
Building	108,282
Orthophoto	Yes
Processed by	Engr. Kenneth Solidum, Aljon Rie Araneta, Alex John Escobido

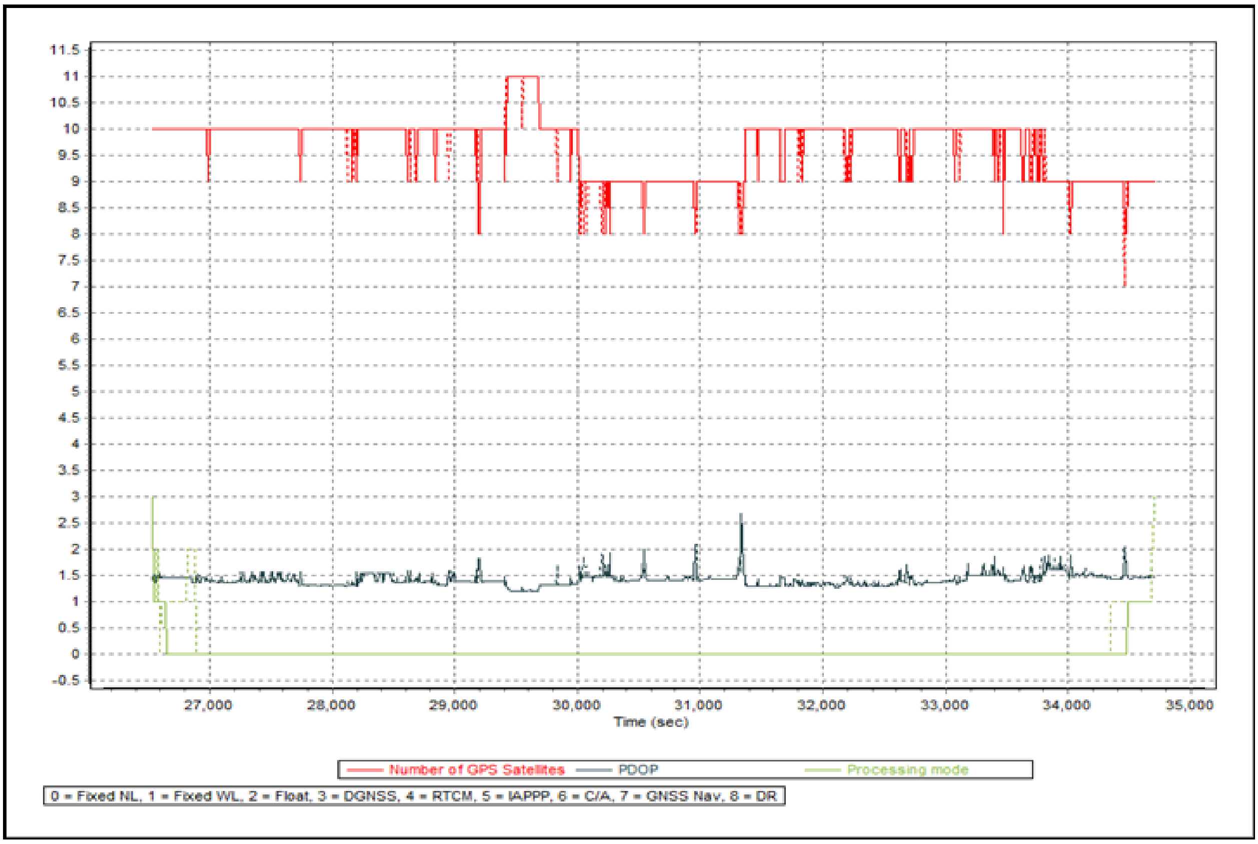


Figure A-8.15. Solution Status

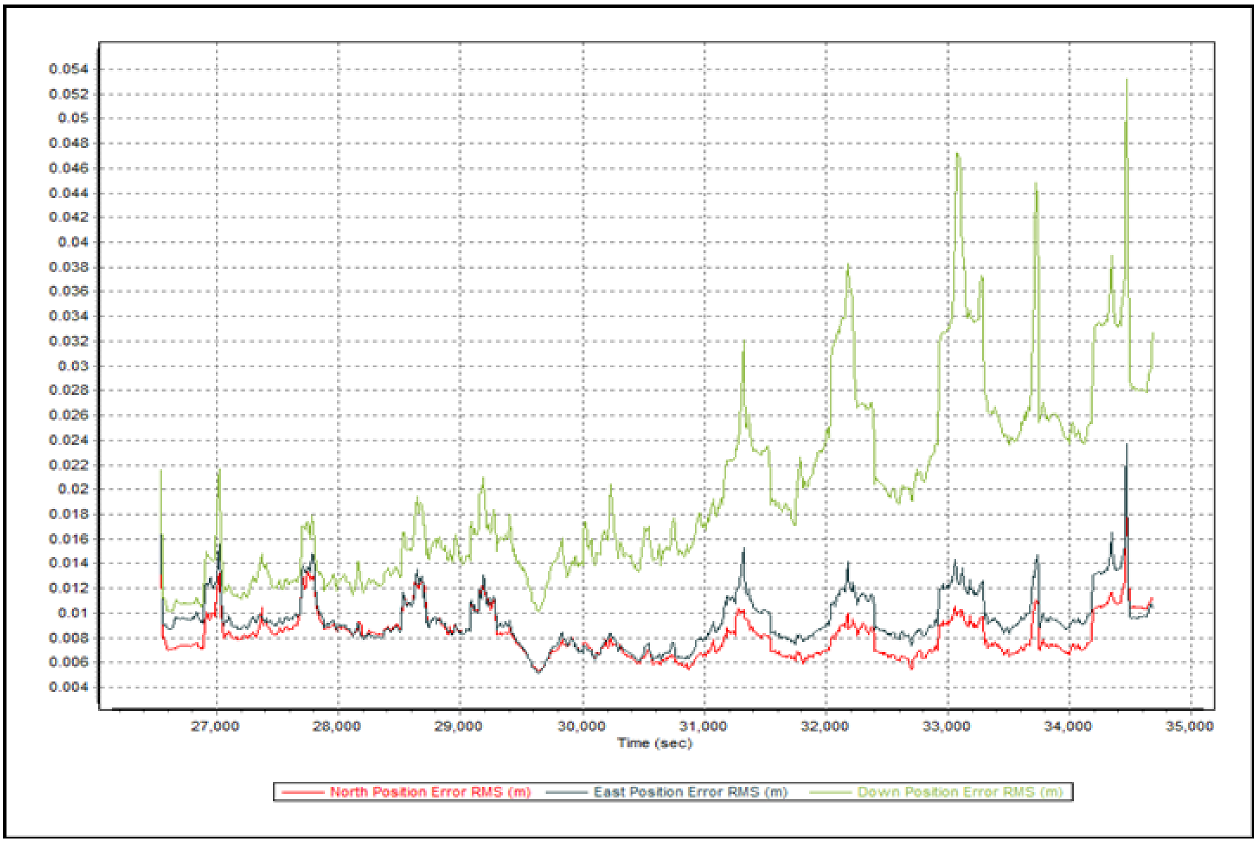


Figure A-8.16. Smoothed Performance Metric Parameters

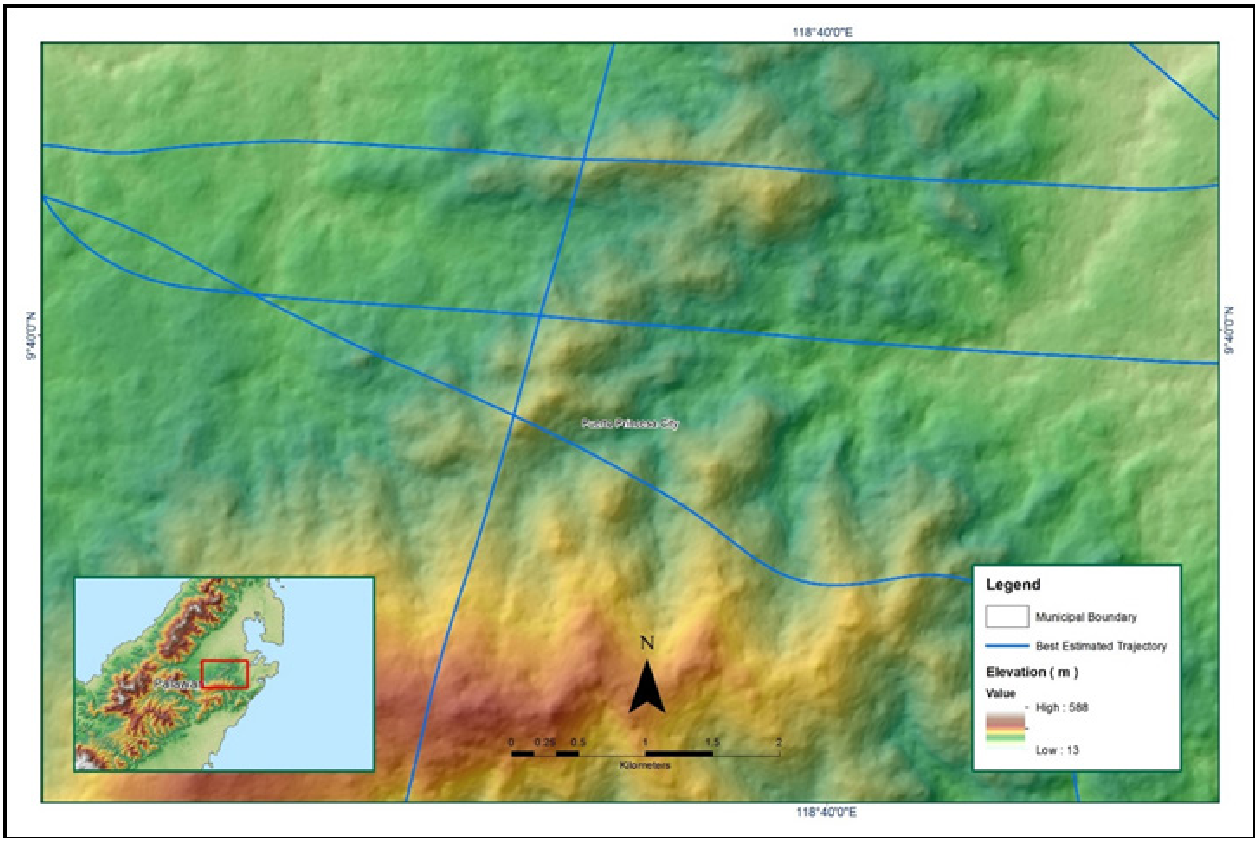


Figure A-8.17. Best Estimated Trajectory

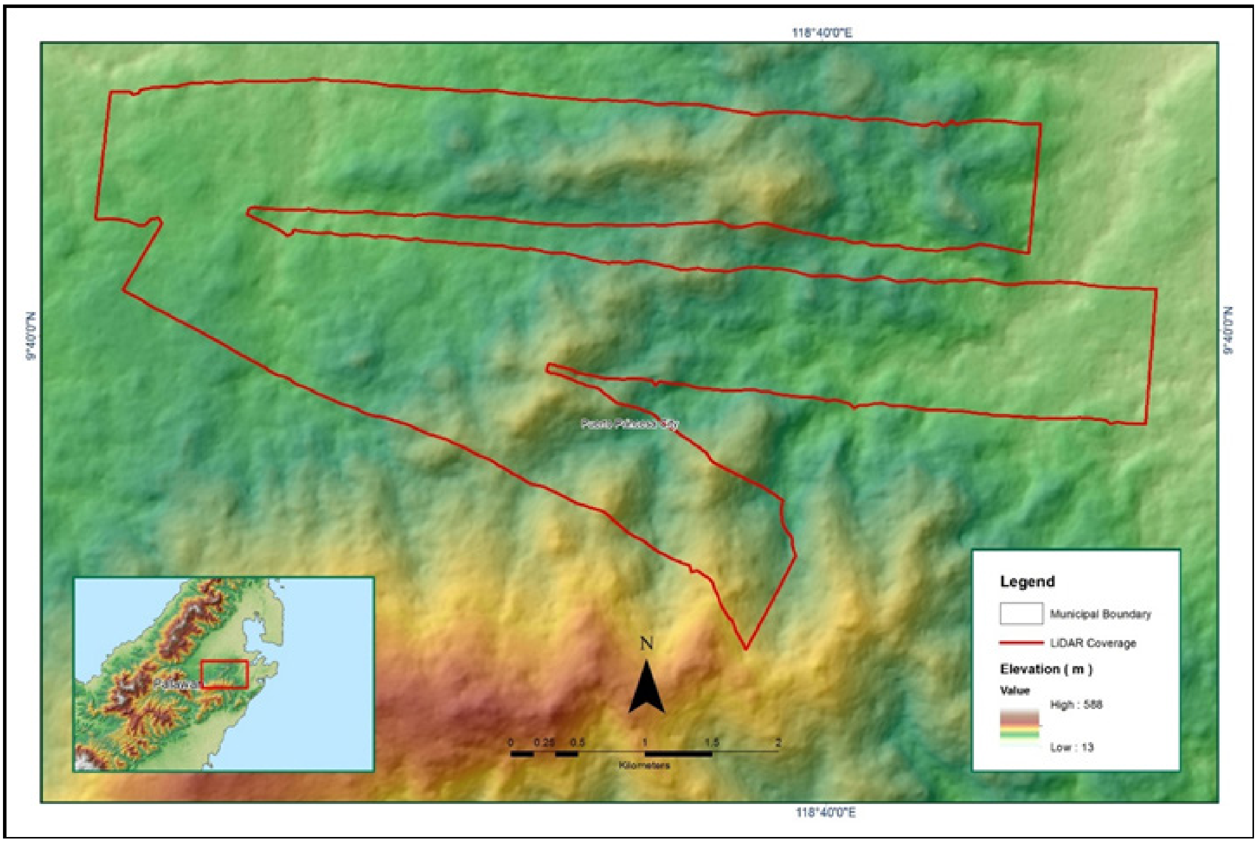


Figure A-8.18. Coverage of LiDAR data

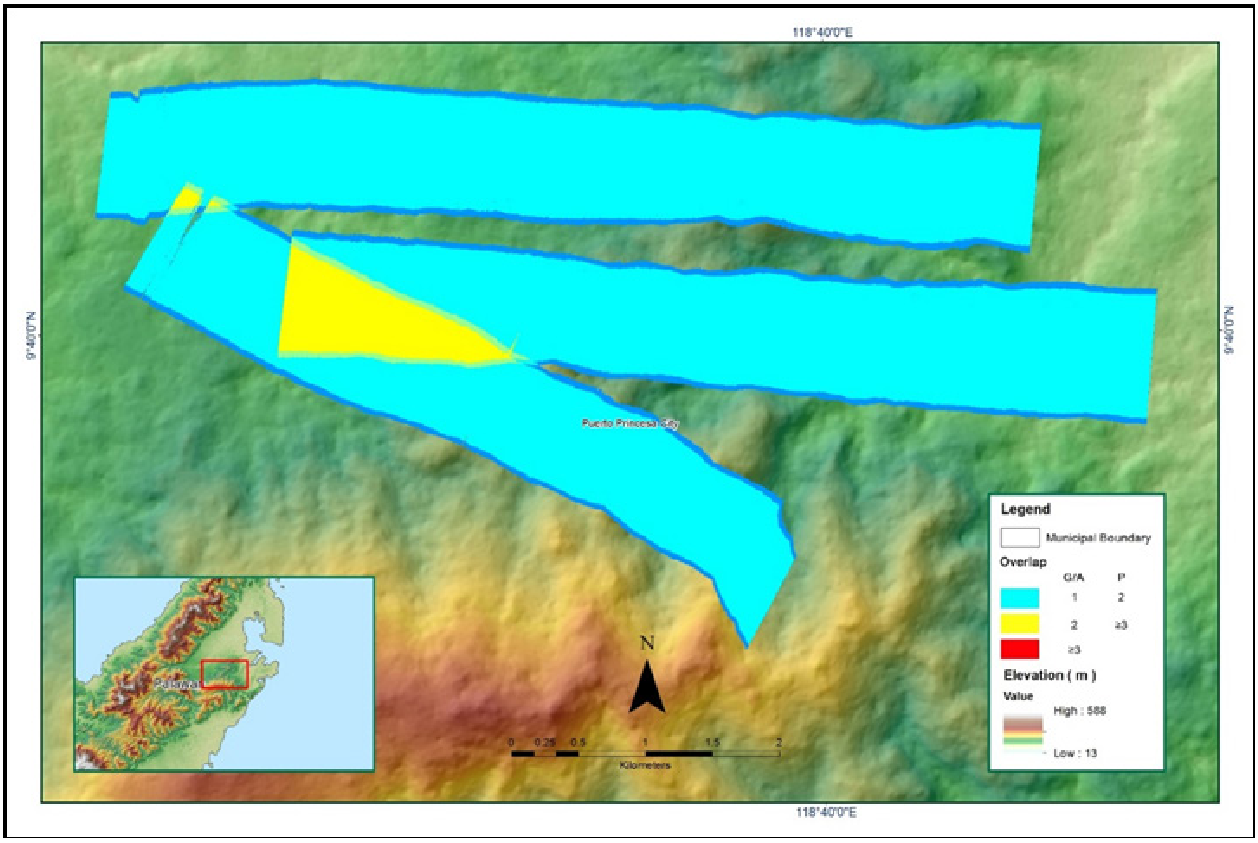


Figure A-8.19. Image of Data Overlap

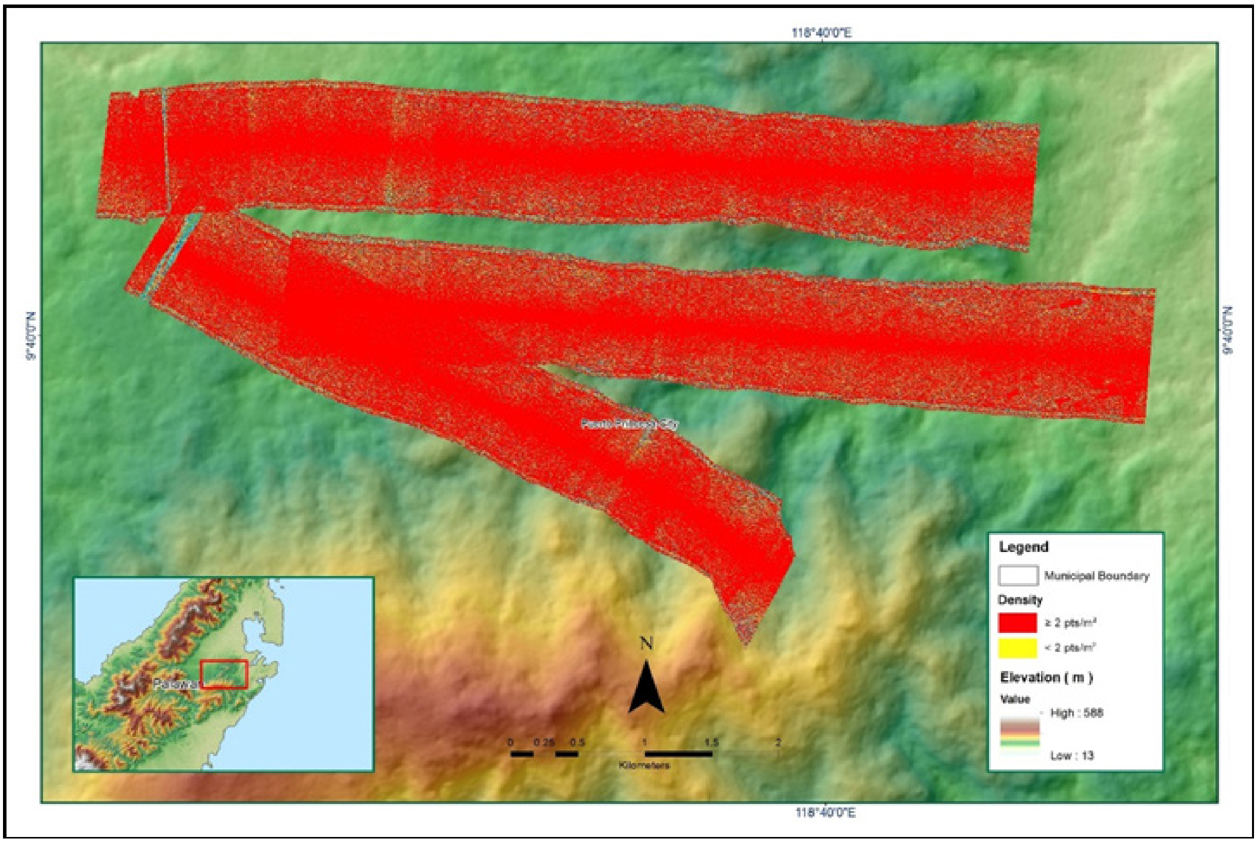


Figure A-8.20. Density map of merged LiDAR data

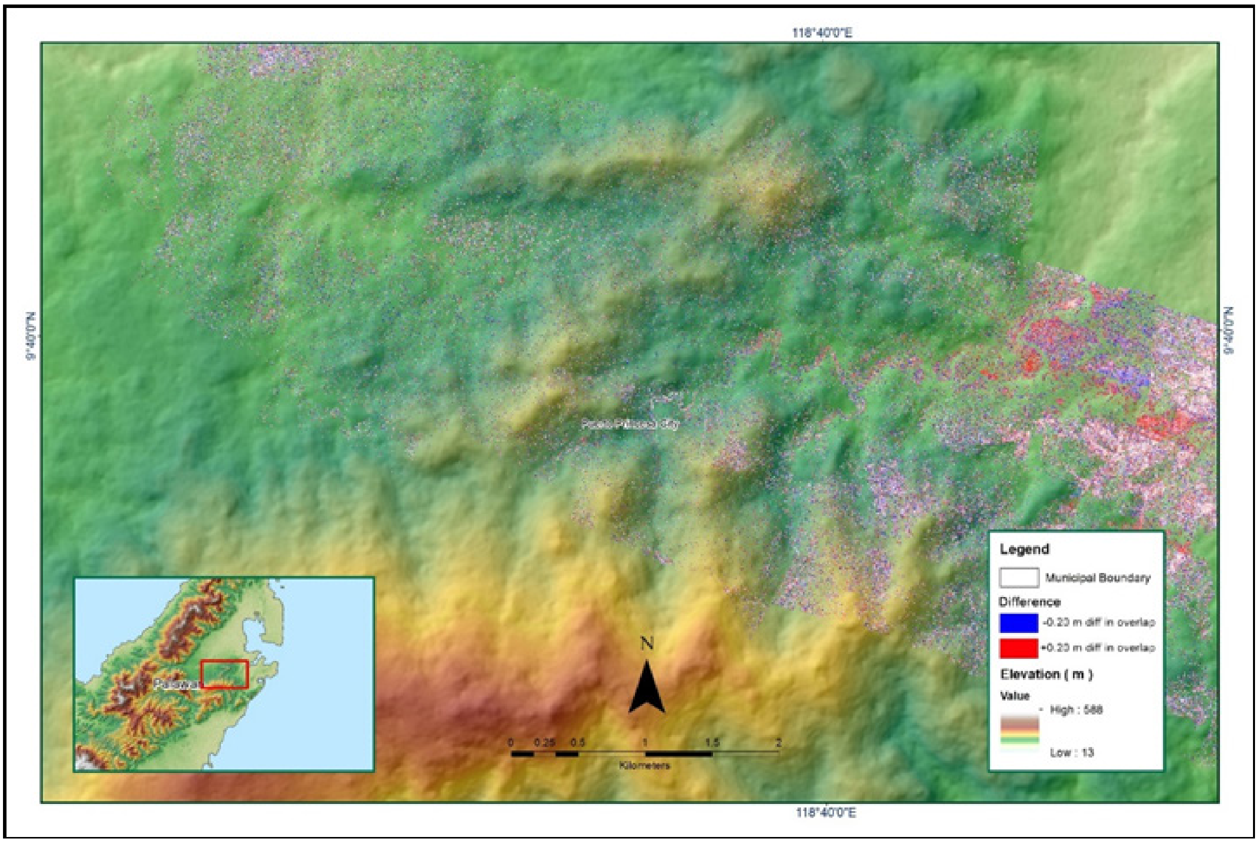


Figure A-8.21. Elevation difference between flight lines

Table A-8.4. Mission Summary Report for Mission Block 42F Supplement

Flight Area	West Palawan
Mission Name	Block 42F Supplement
Inclusive Flights	3027P
Range data size	13.50 GB
Base data size	5.15 MB
POS	133 MB
Image	16.80 GB
Transfer date	July 13, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	3.00
RMSE for East Position (<4.0 cm)	3.10
RMSE for Down Position (<8.0 cm)	5.20
Boresight correction stdev (<0.001deg)	0.000145
IMU attitude correction stdev (<0.001deg)	0.003565
GPS position stdev (<0.01m)	0.0073
Minimum % overlap (>25)	20.74
Ave point cloud density per sq.m. (>2.0)	3.19
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	171
Maximum Height	467.88 m
Minimum Height	50.6 m
Classification (# of points)	
Ground	79,600,032
Low vegetation	58,934,925
Medium vegetation	103,102,233
High vegetation	468,922,708
Building	2,674,290
Orthophoto	Yes
Processed by	Engr. Jommer Medina, Engr. Velina Angela Bemida, Engr. Mark Sueden Lyle Magtalas

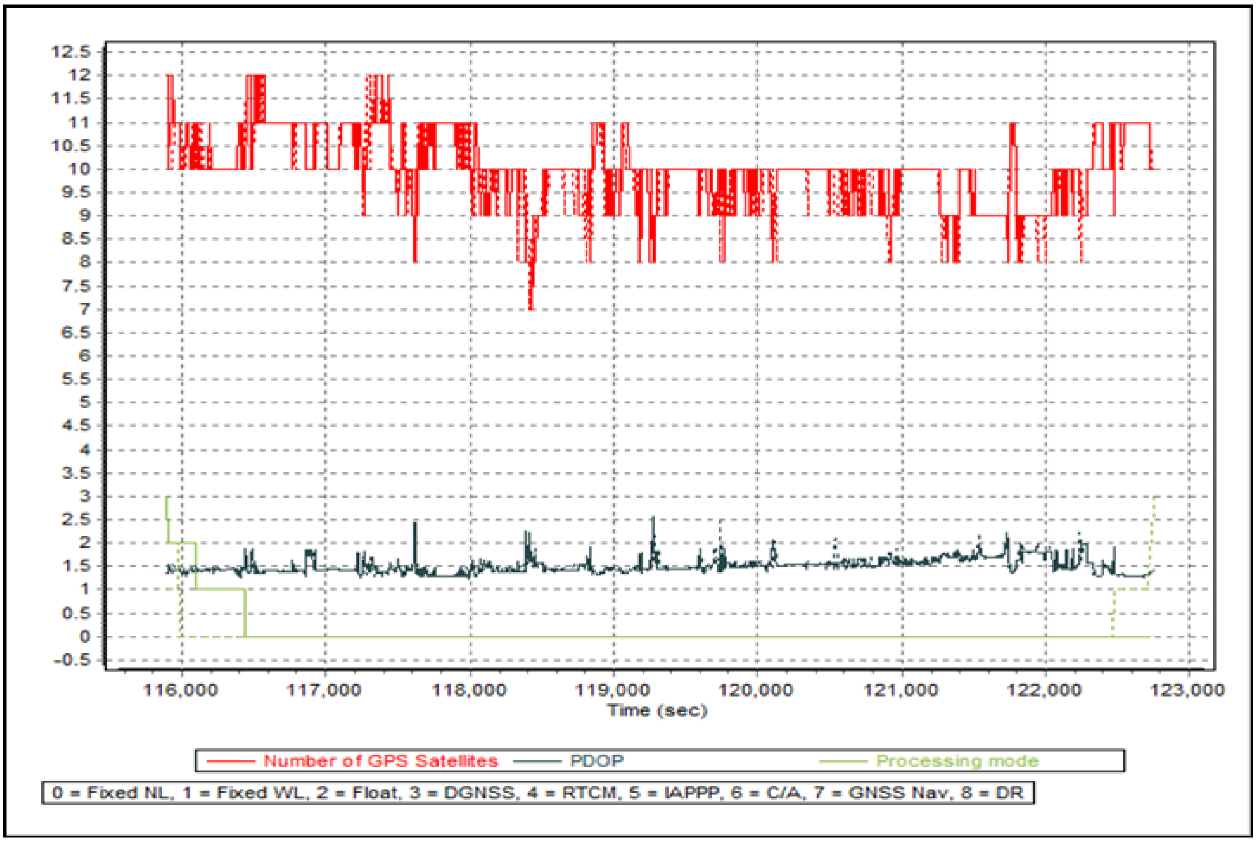


Figure A-8.22. Solution Status

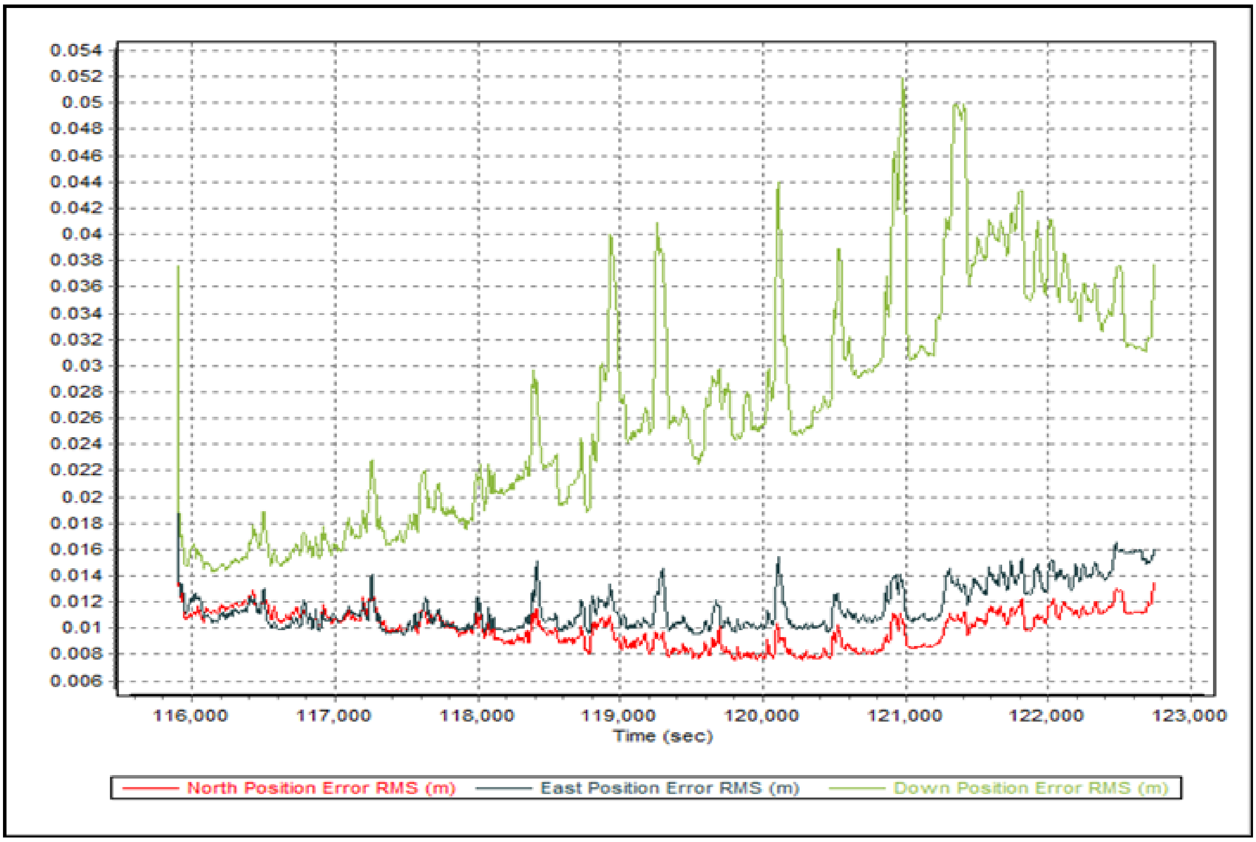


Figure A-8.23. Smoothed Performance Metric Parameters

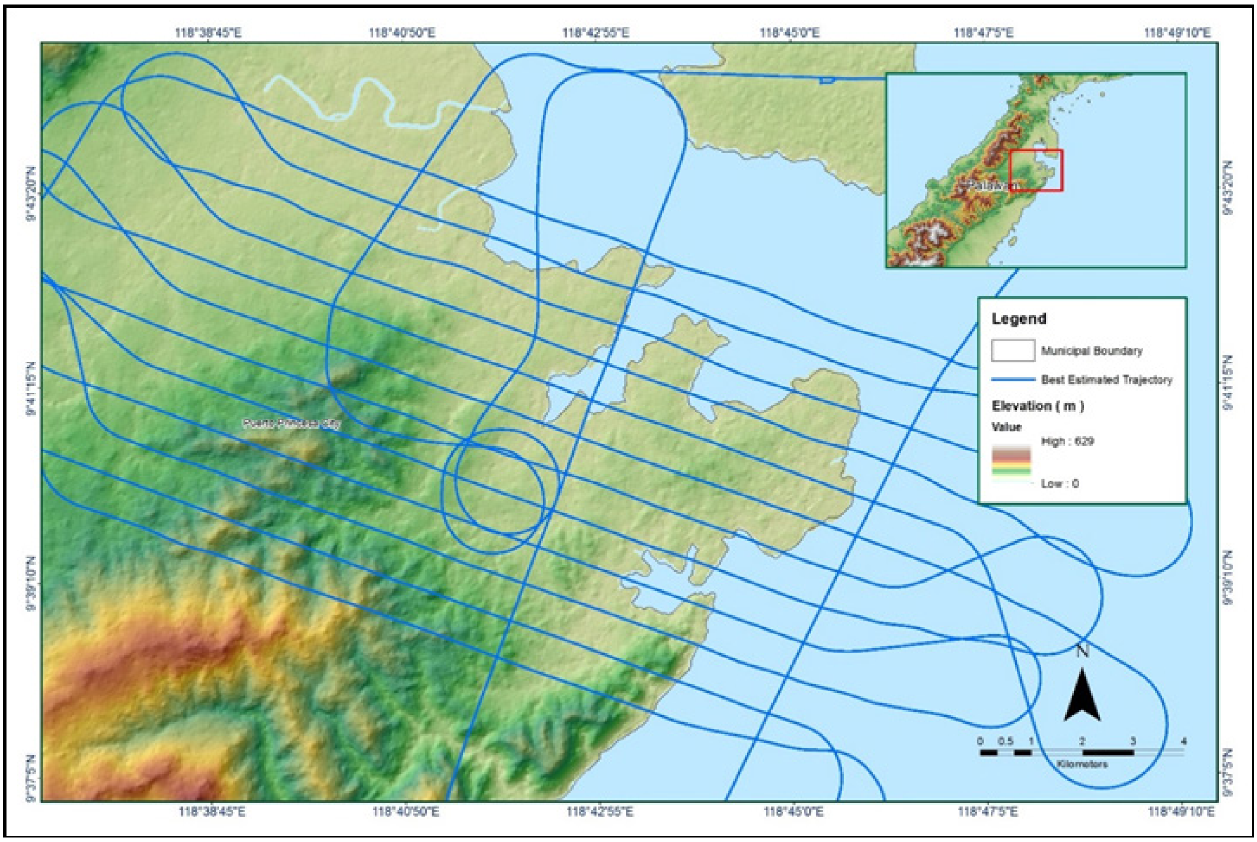


Figure A-8.24. Best Estimated Trajectory

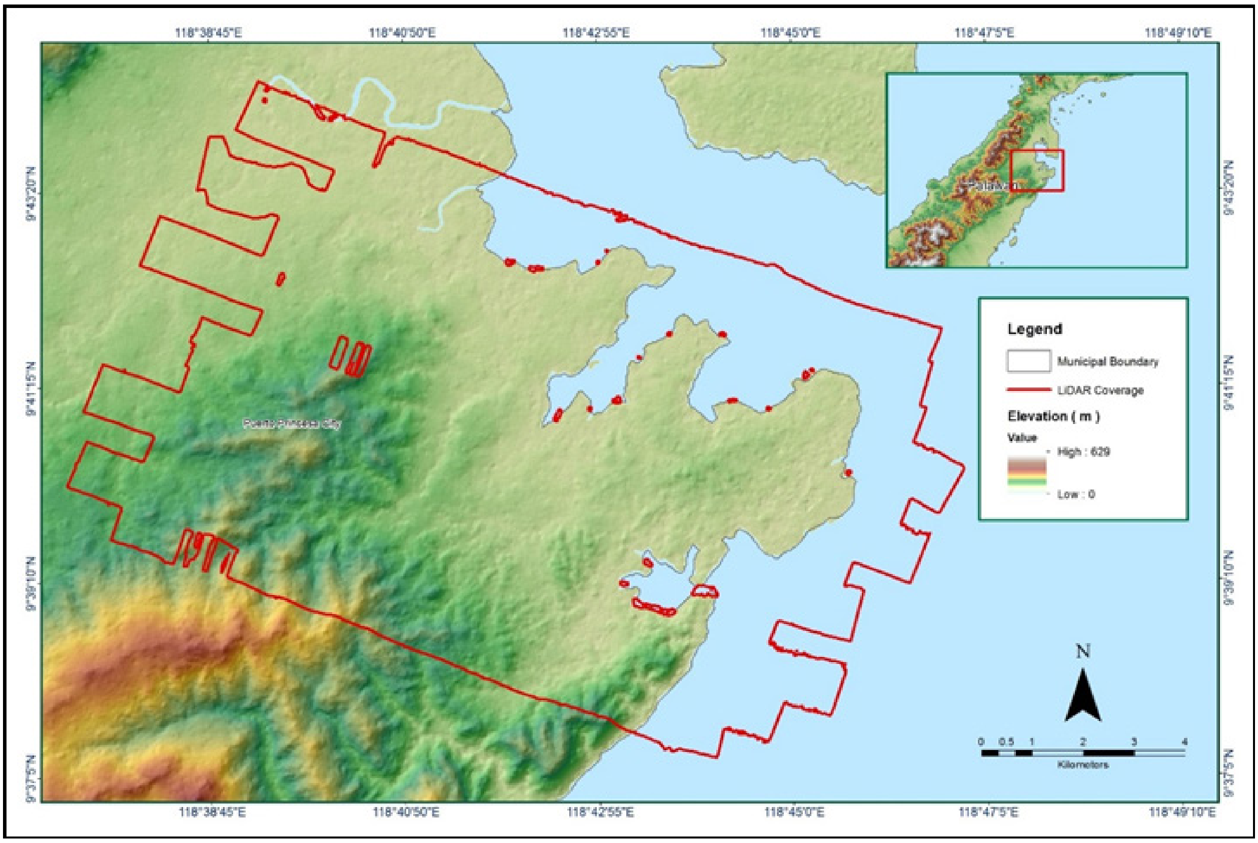


Figure A-8.25. Coverage of LiDAR data

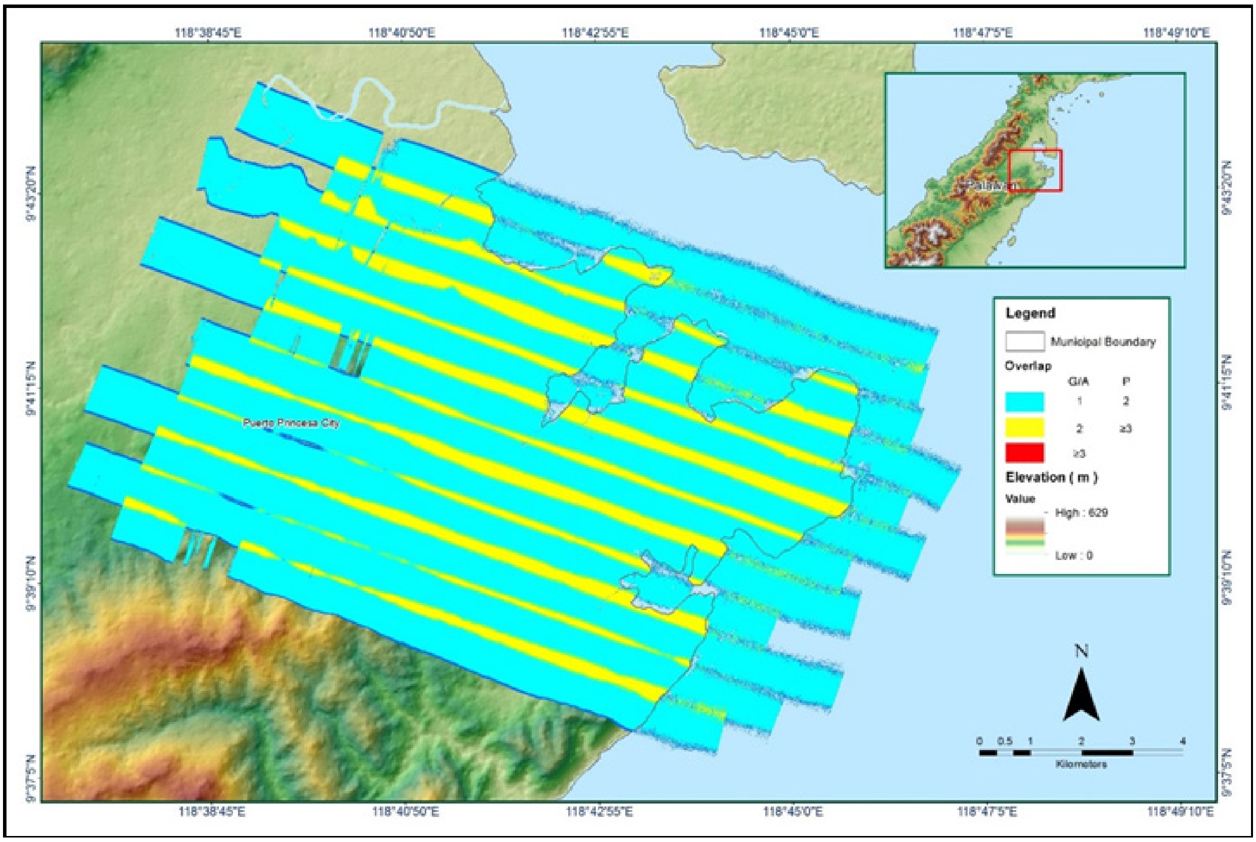


Figure A-8.26. Image of Data Overlap

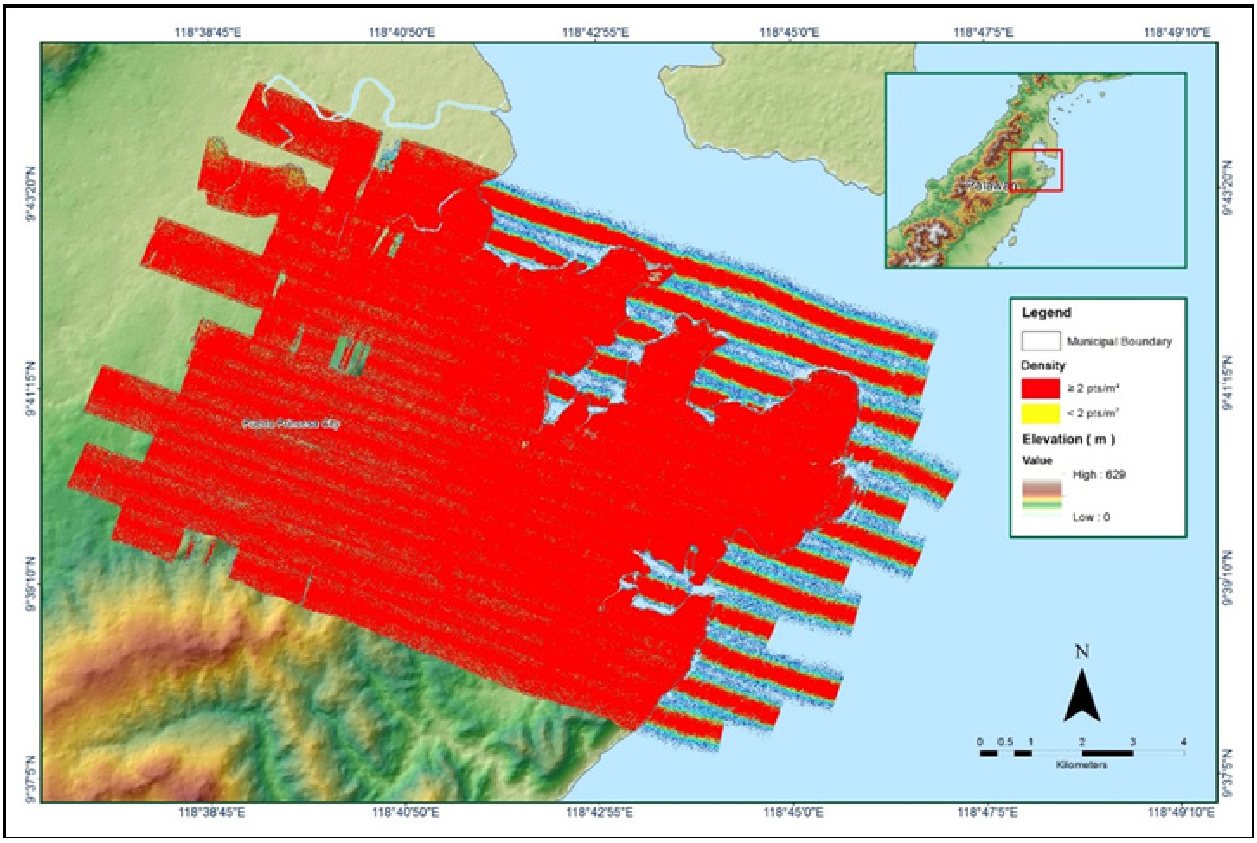


Figure A-8.27. Density map of merged LiDAR data

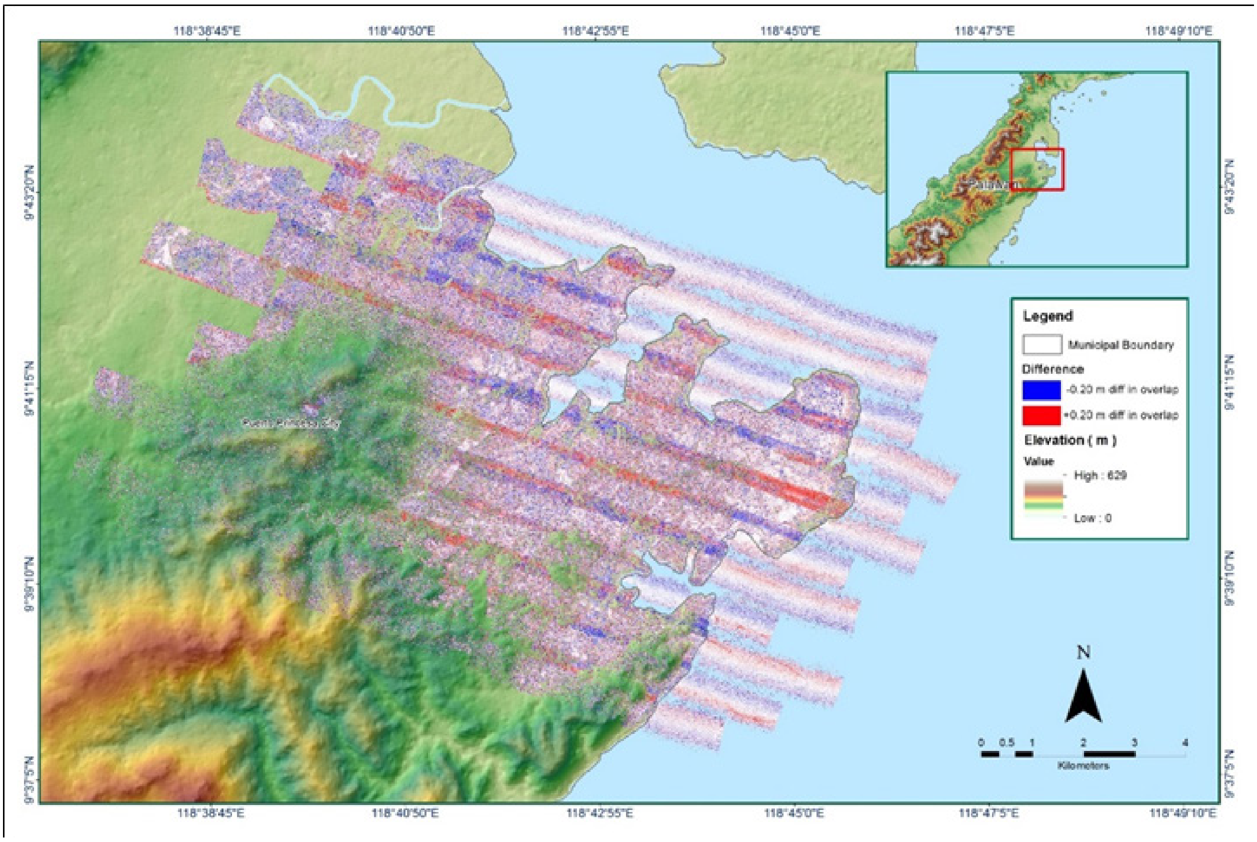


Figure A-8.28. Elevation difference between flight lines

Table A-8.5. Mission Summary Report for Mission Block 42G

Flight Area	West Palawan
Mission Name	Block 42G
Inclusive Flights	3025P
Range data size	15.10 GB
Base data size	7.06 MB
POS	187 MB
Image	33.90 GB
Transfer date	July 13, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.65
RMSE for East Position (<4.0 cm)	1.80
RMSE for Down Position (<8.0 cm)	3.33
Boresight correction stdev (<0.001deg)	0.001061
IMU attitude correction stdev (<0.001deg)	0.000245
GPS position stdev (<0.01m)	0.0027
Minimum % overlap (>25)	32.93
Ave point cloud density per sq.m. (>2.0)	2.14
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	82
Maximum Height	880.82 m
Minimum Height	50.95 m
Classification (# of points)	
Ground	10,718,001
Low vegetation	4,007,625
Medium vegetation	13,781,517
High vegetation	192,991,892
Building	575,371
Orthophoto	Yes
Processed by	Engr. Angelo Carlo Bongat, Aljon Rie Araneta, Alex John Escobido

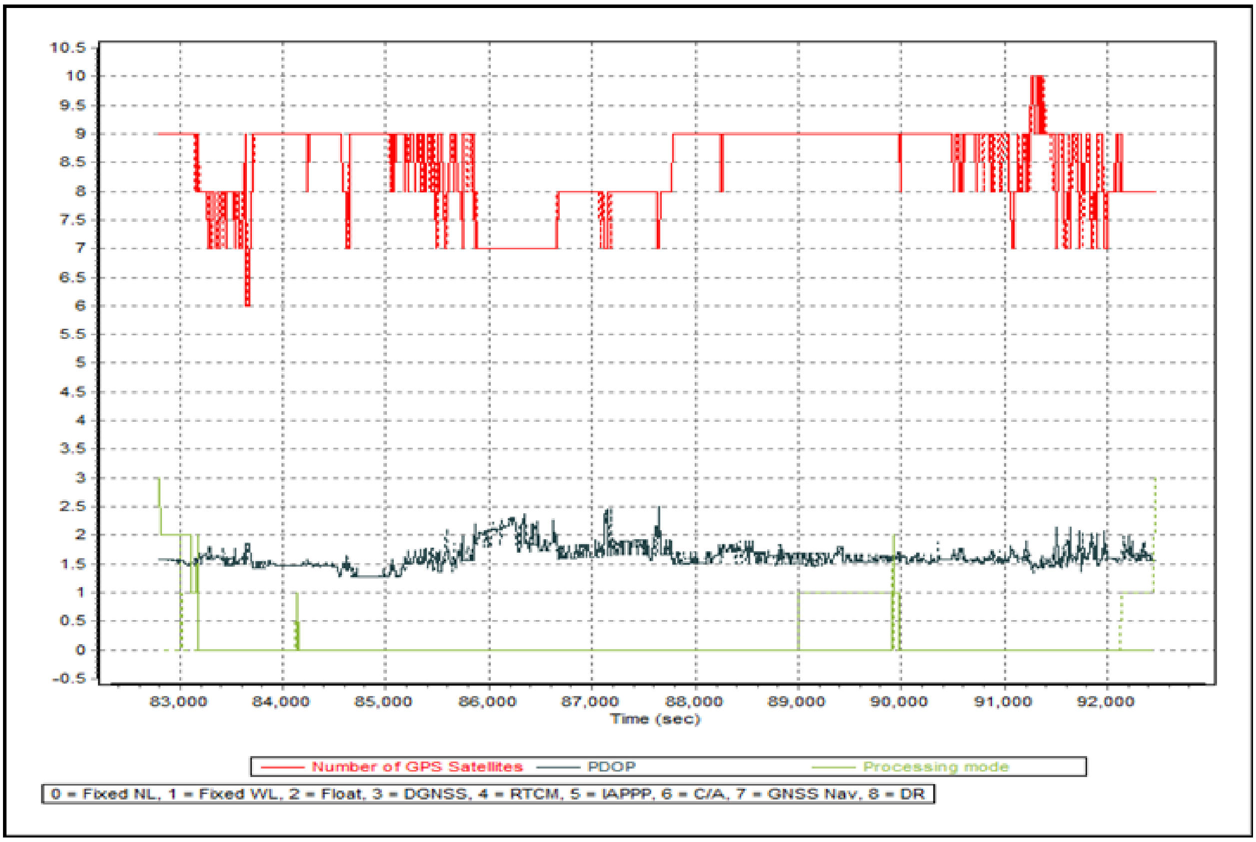


Figure A-8.29. Solution Status

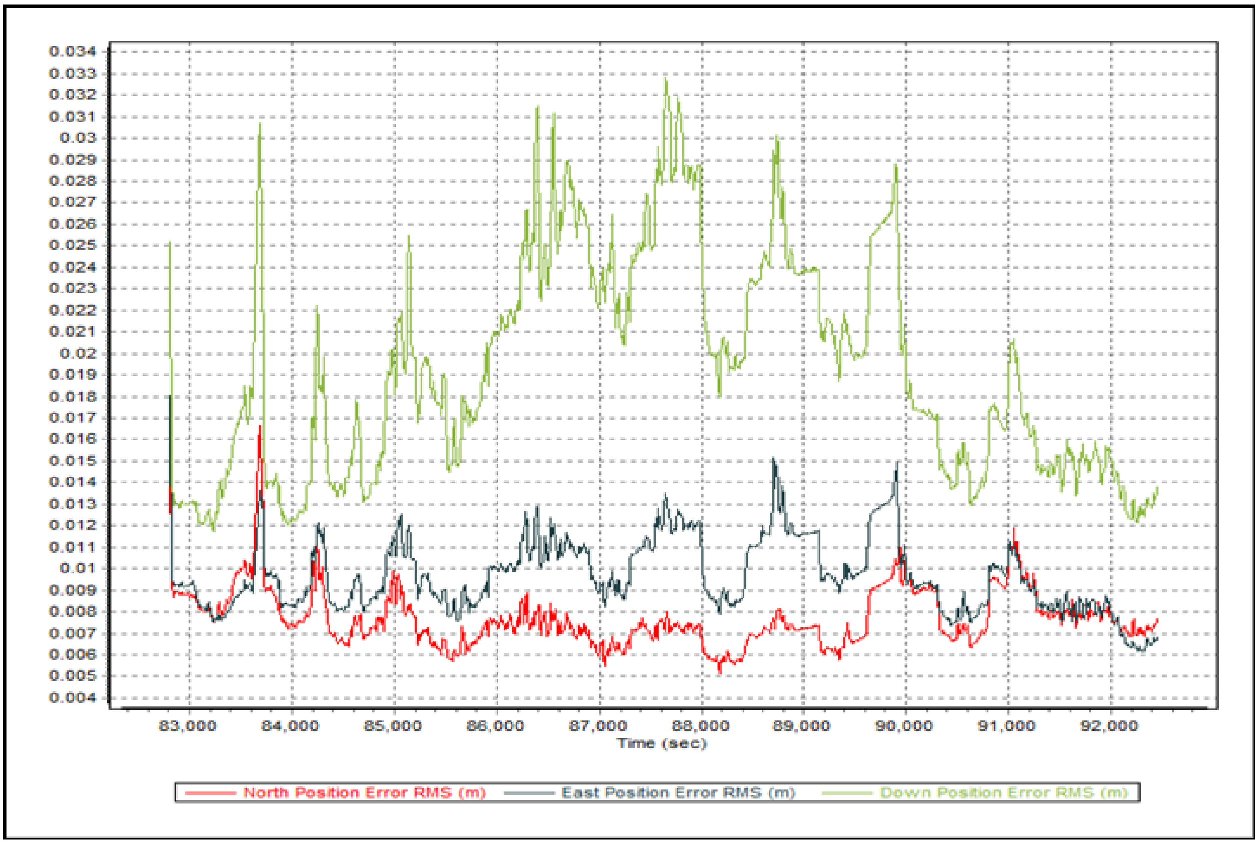


Figure A-8.30. Smoothed Performance Metric Parameters

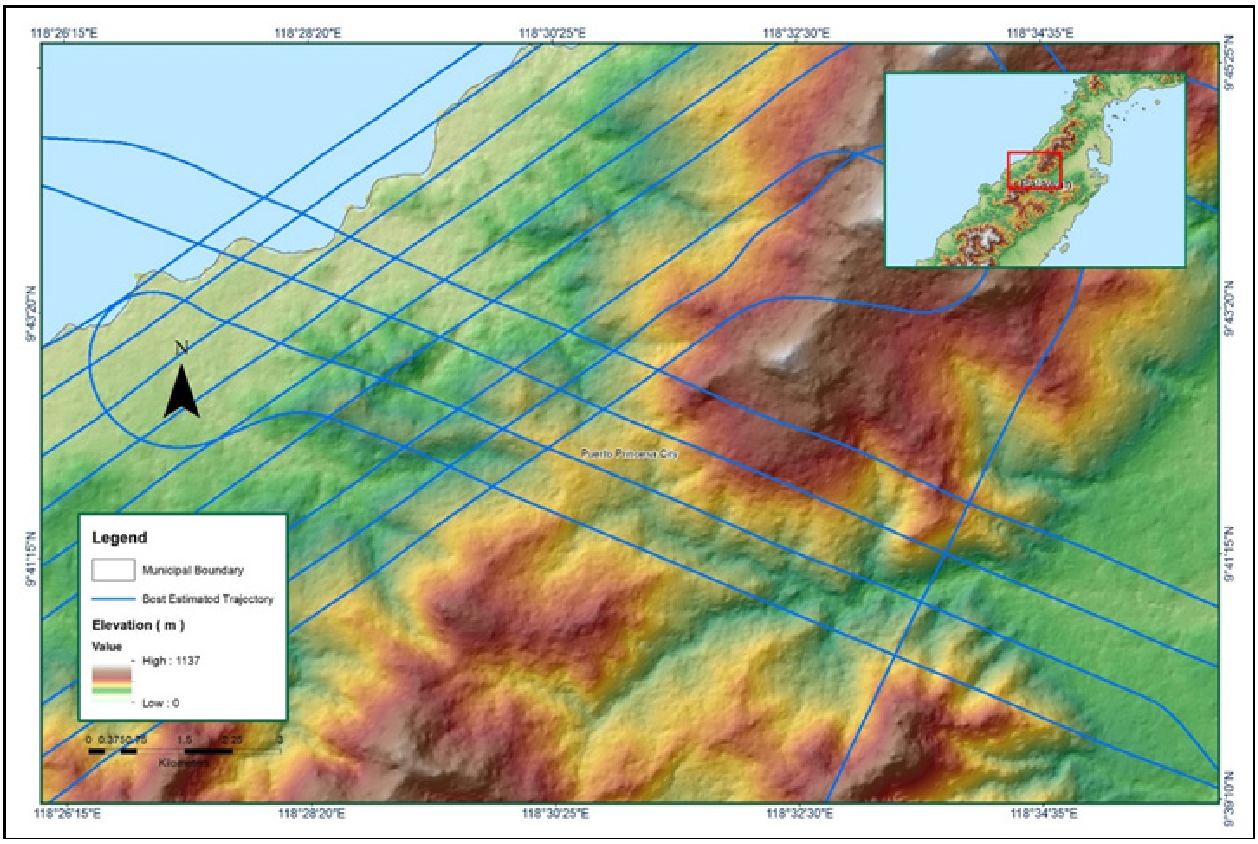


Figure A-8.31. Best Estimated Trajectory

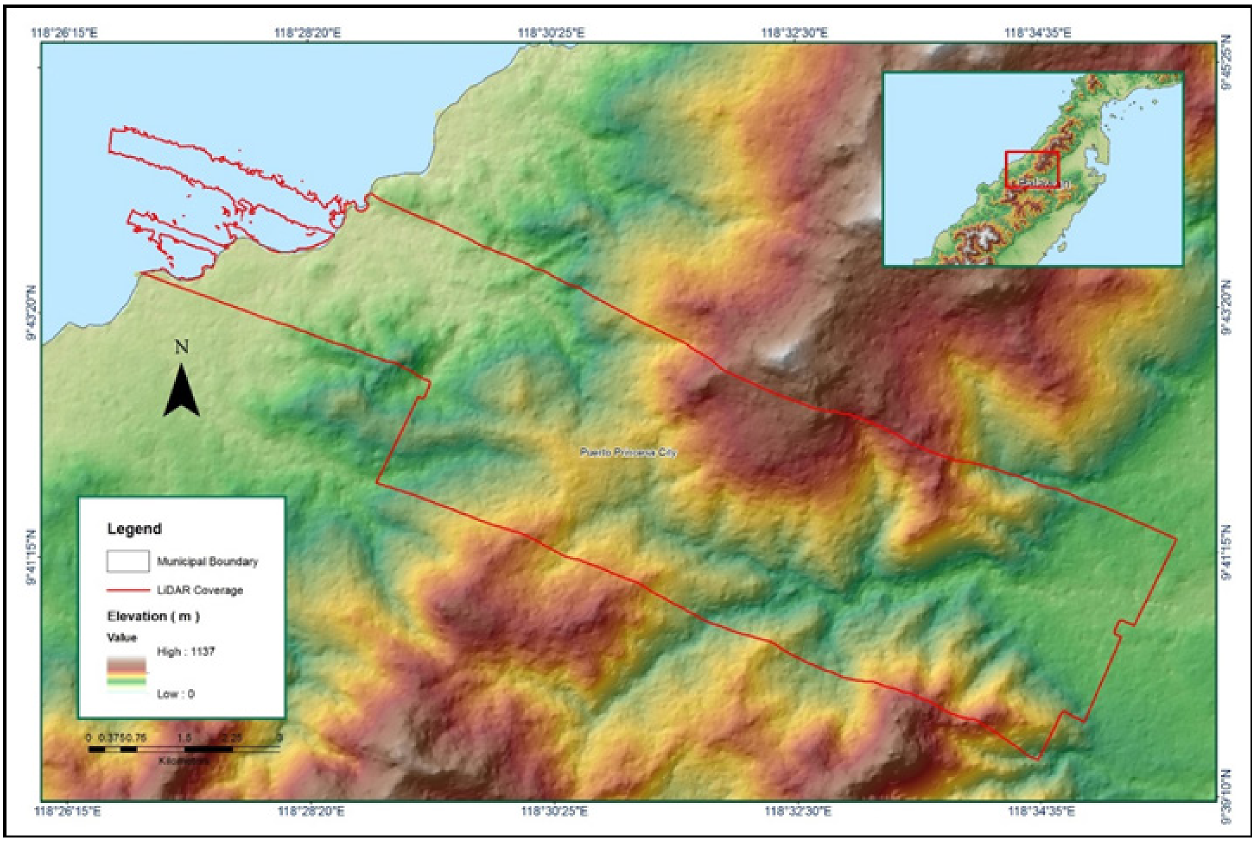


Figure A-8.32. Coverage of LiDAR data

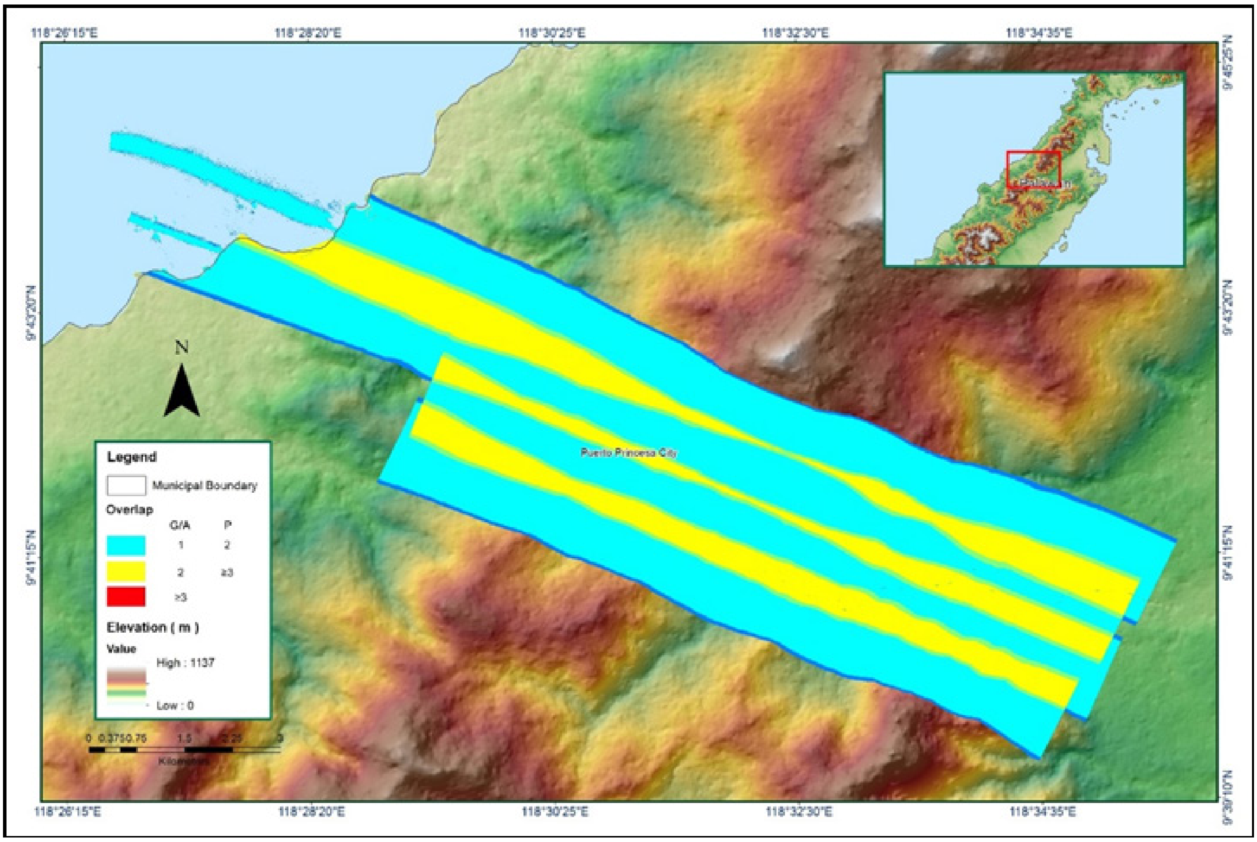


Figure A-8.33. Image of Data Overlap

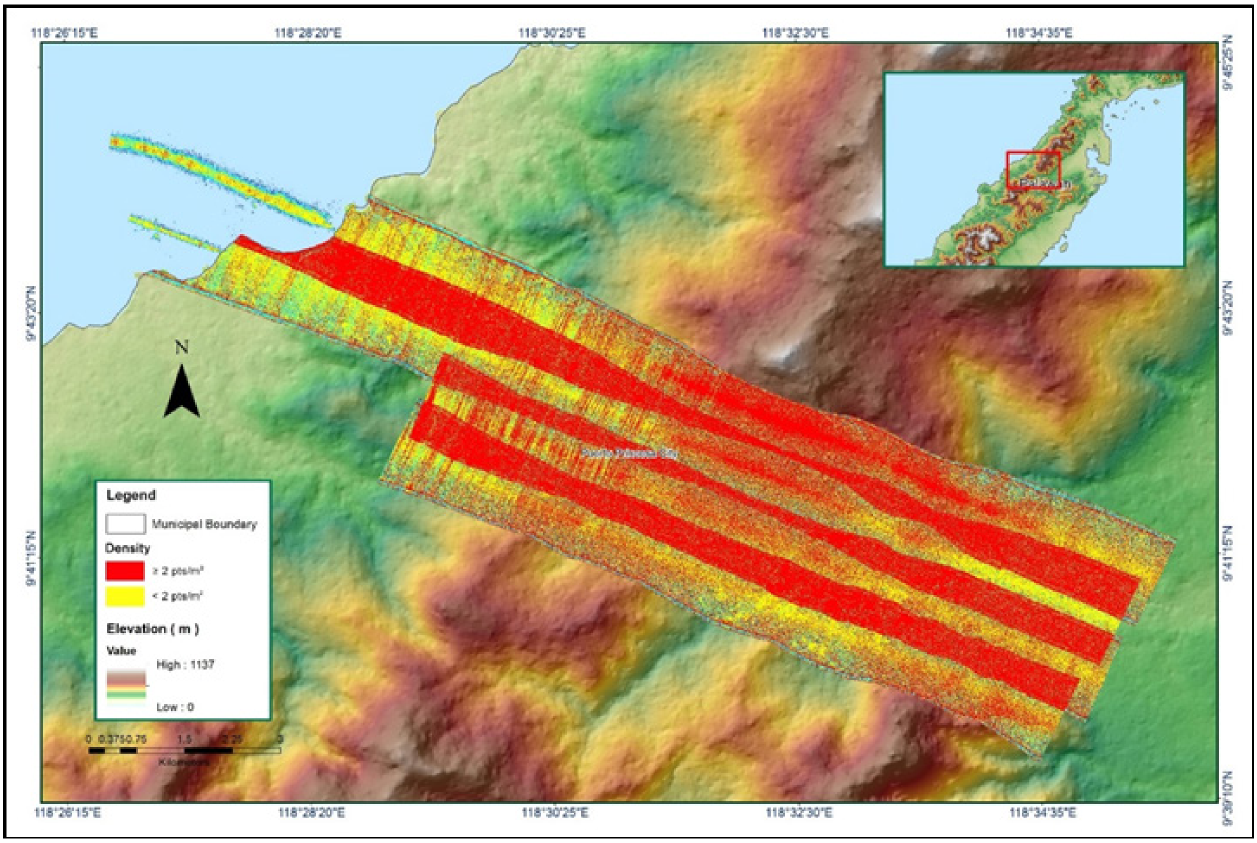


Figure A-8.34. Density map of merged LiDAR data

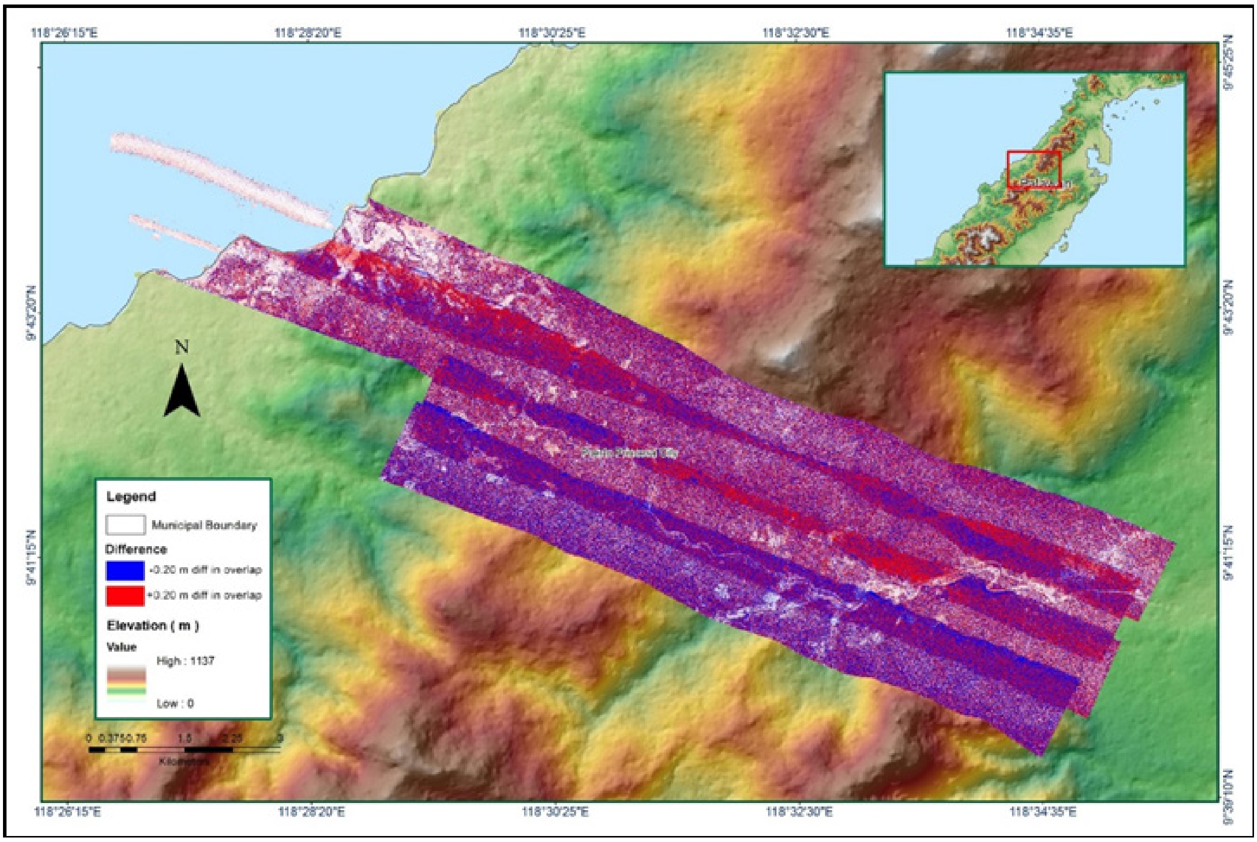


Figure A-8.35. Elevation difference between flight lines

Table A-8.6. Mission Summary Report for Mission Block 42H

Flight Area	West Palawan
Mission Name	Block 42H
Inclusive Flights	3025P
Range data size	15.10 GB
Base data size	7.06 MB
POS	187 MB
Image	33.90 GB
Transfer date	July 13, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.65
RMSE for East Position (<4.0 cm)	1.80
RMSE for Down Position (<8.0 cm)	3.33
Boresight correction stdev (<0.001deg)	0.000263
IMU attitude correction stdev (<0.001deg)	0.000178
GPS position stdev (<0.01m)	0.0018
Minimum % overlap (>25)	66.84
Ave point cloud density per sq.m. (>2.0)	2.53
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	201
Maximum Height	773.89 m
Minimum Height	42.6 m
Classification (# of points)	
Ground	44,067,195
Low vegetation	28,315,647
Medium vegetation	70,851,585
High vegetation	556,344,047
Building	4,499,893
Orthophoto	Yes
Processed by	Engr. Angelo Carlo Bongat, Engr. Antonio Chua Jr, Engr Melissa Fernandez

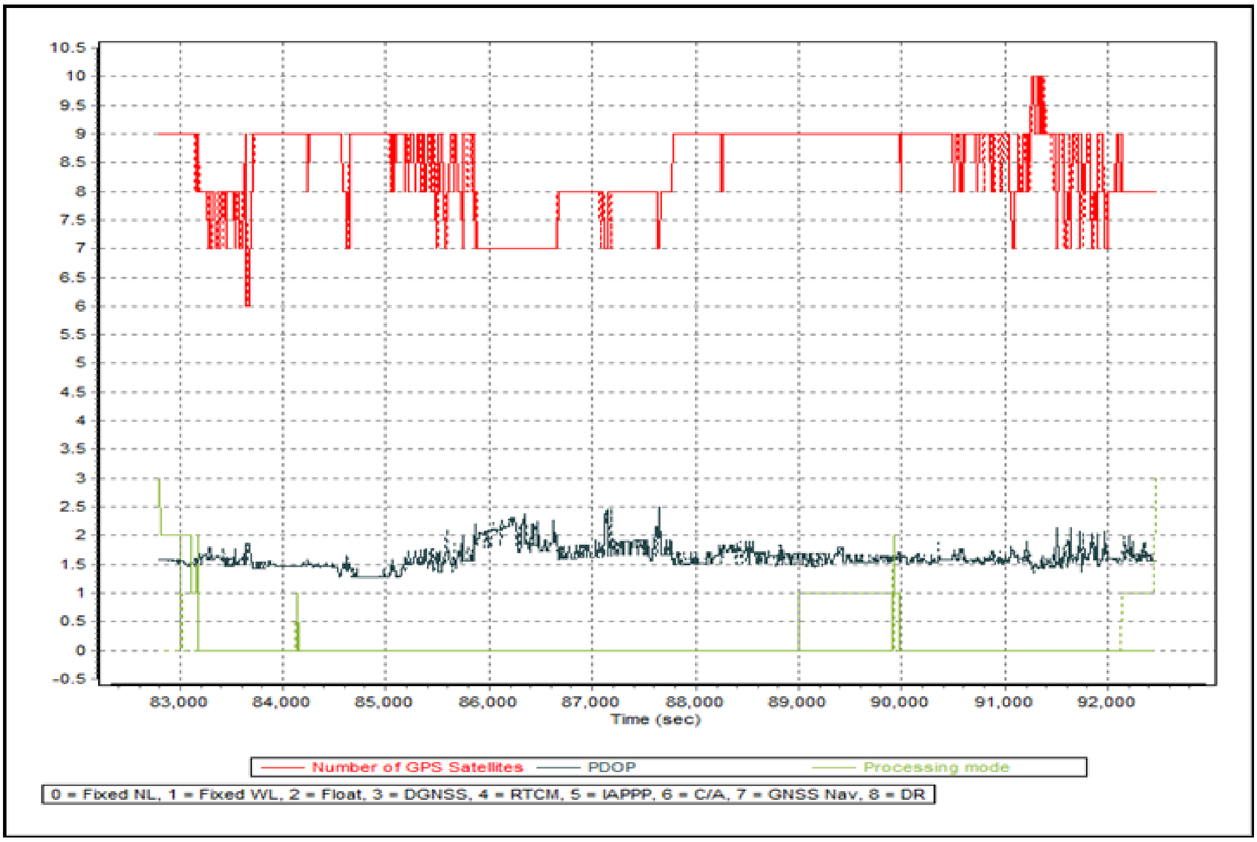


Figure A-8.36. Solution Status

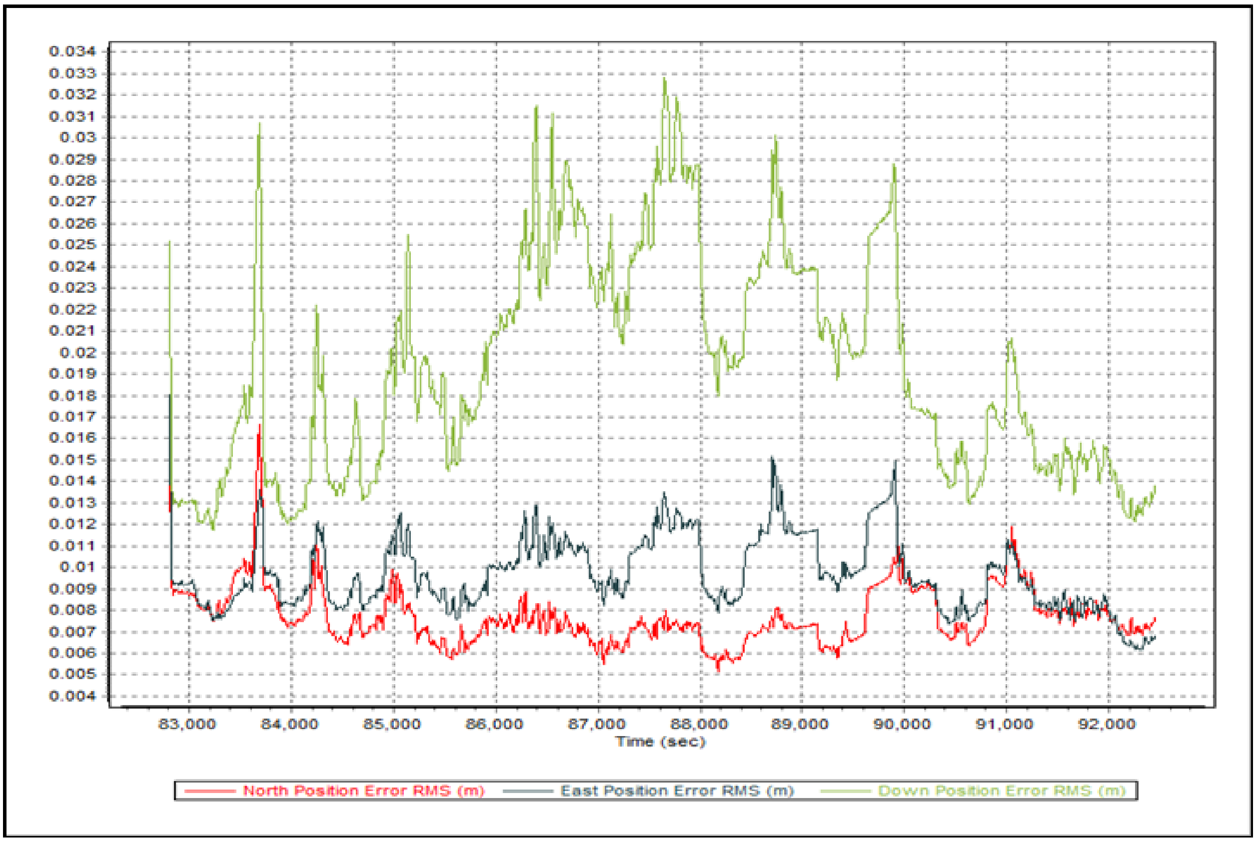


Figure A-8.37. Smoothed Performance Metric Parameters

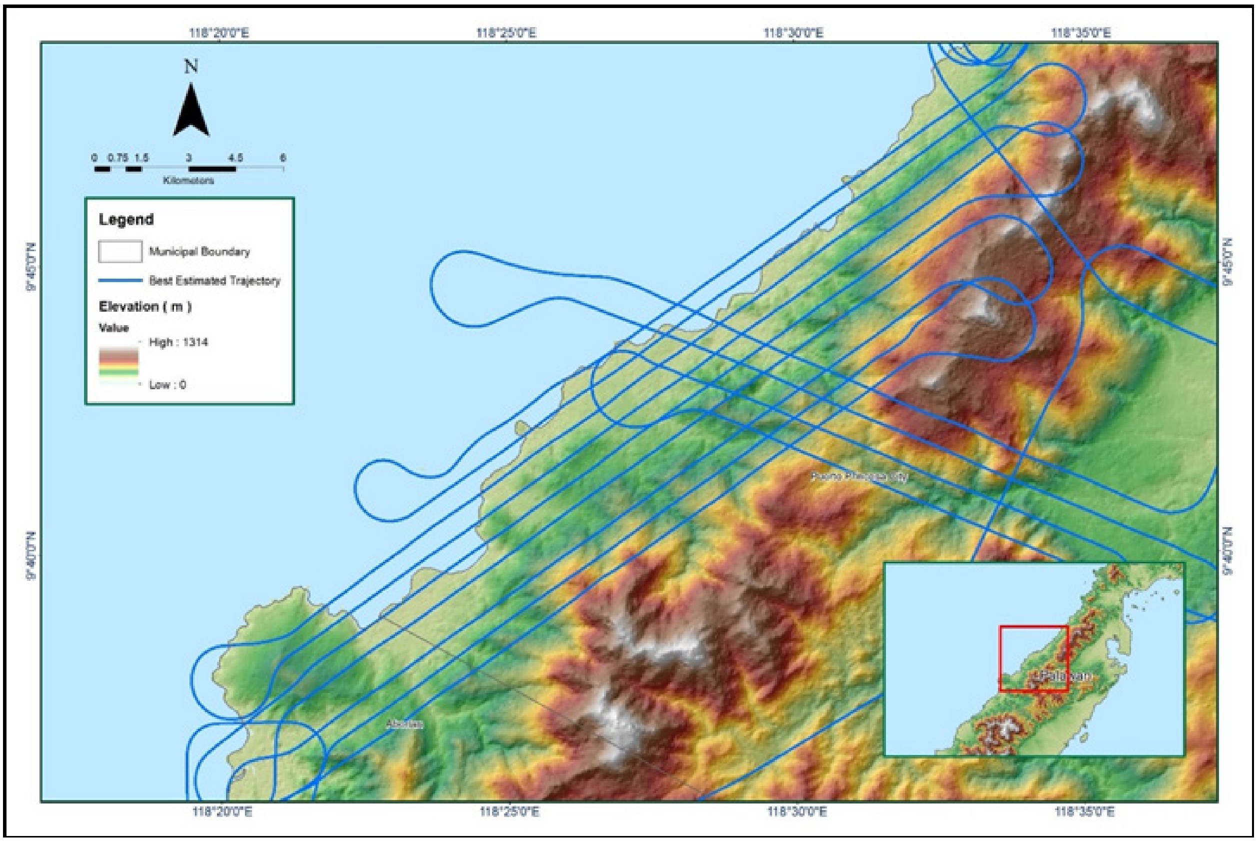


Figure A-8.38. Best Estimated Trajectory

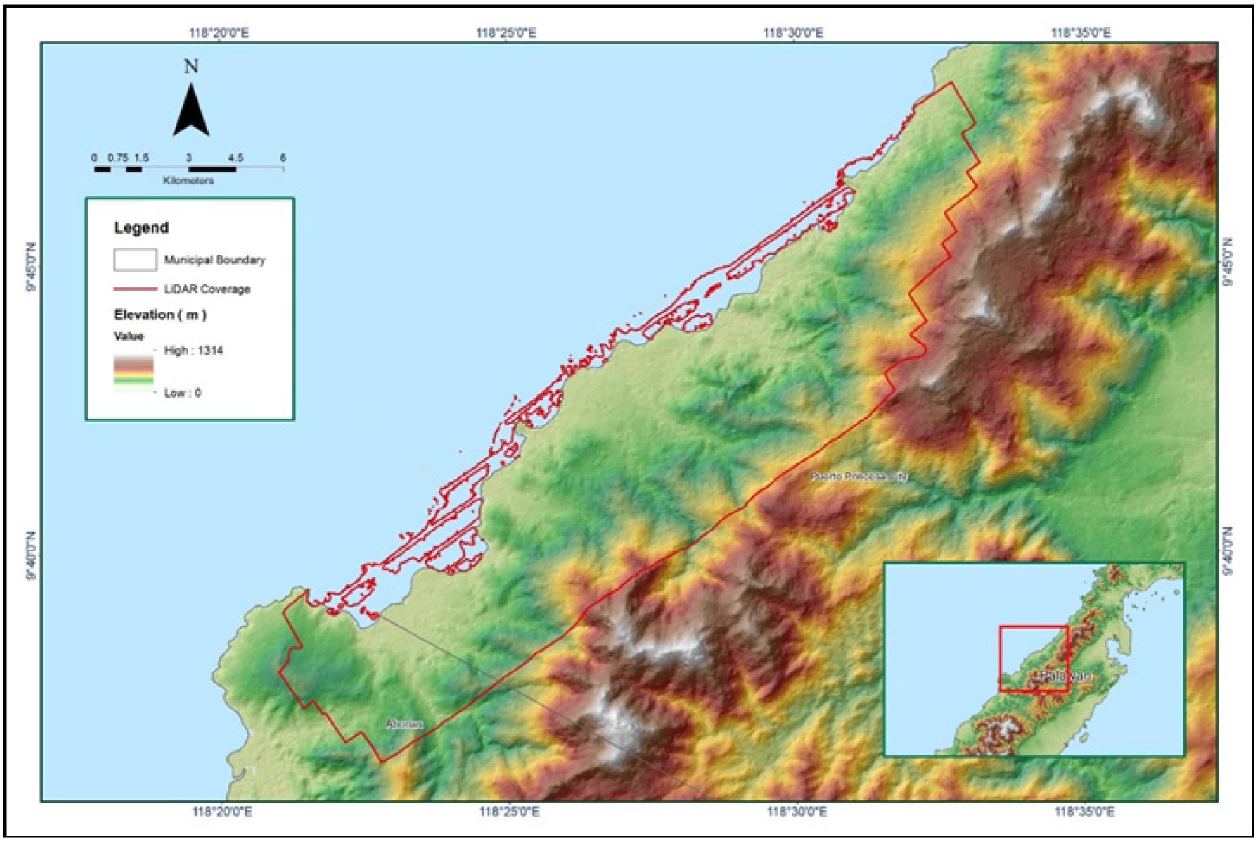


Figure A-8.39. Coverage of LiDAR data

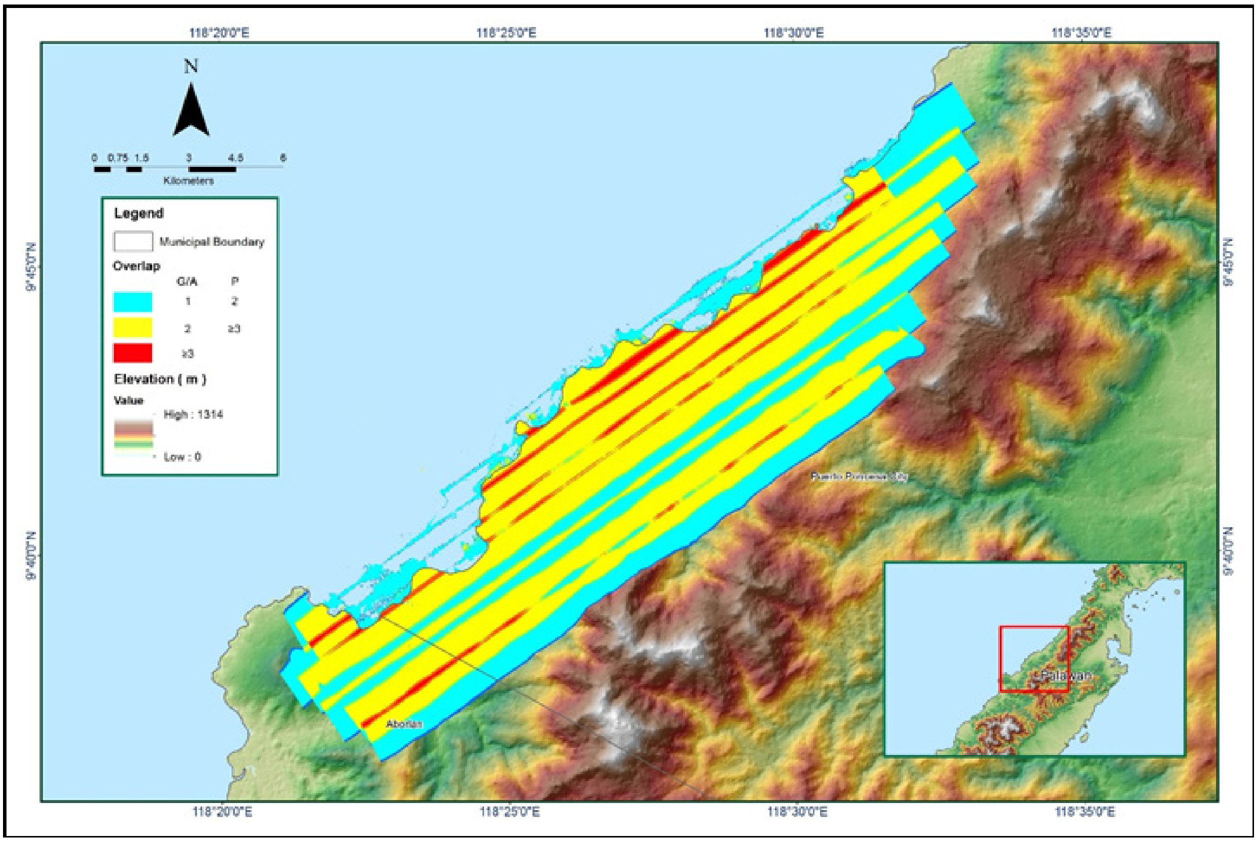


Figure A-8.40. Image of Data Overlap

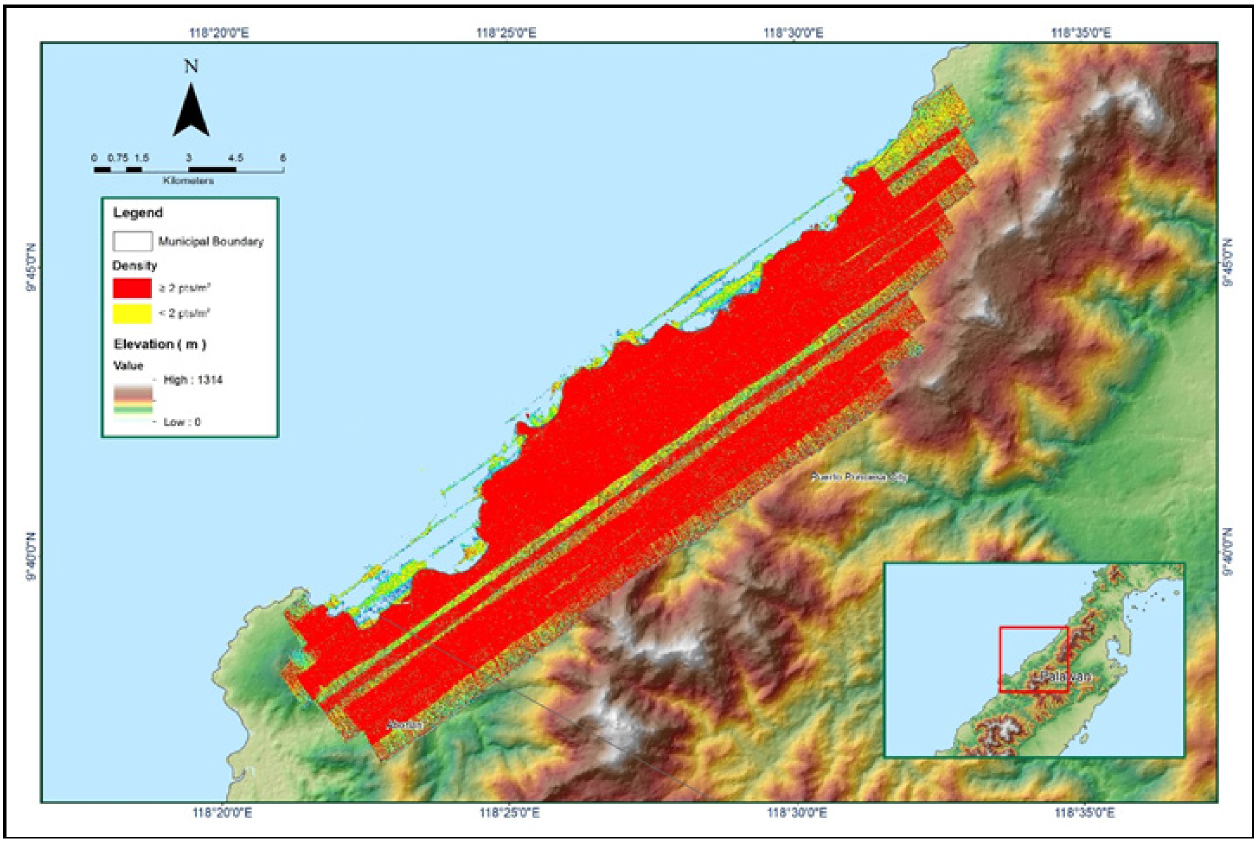


Figure A-8.41. Density map of merged LiDAR data

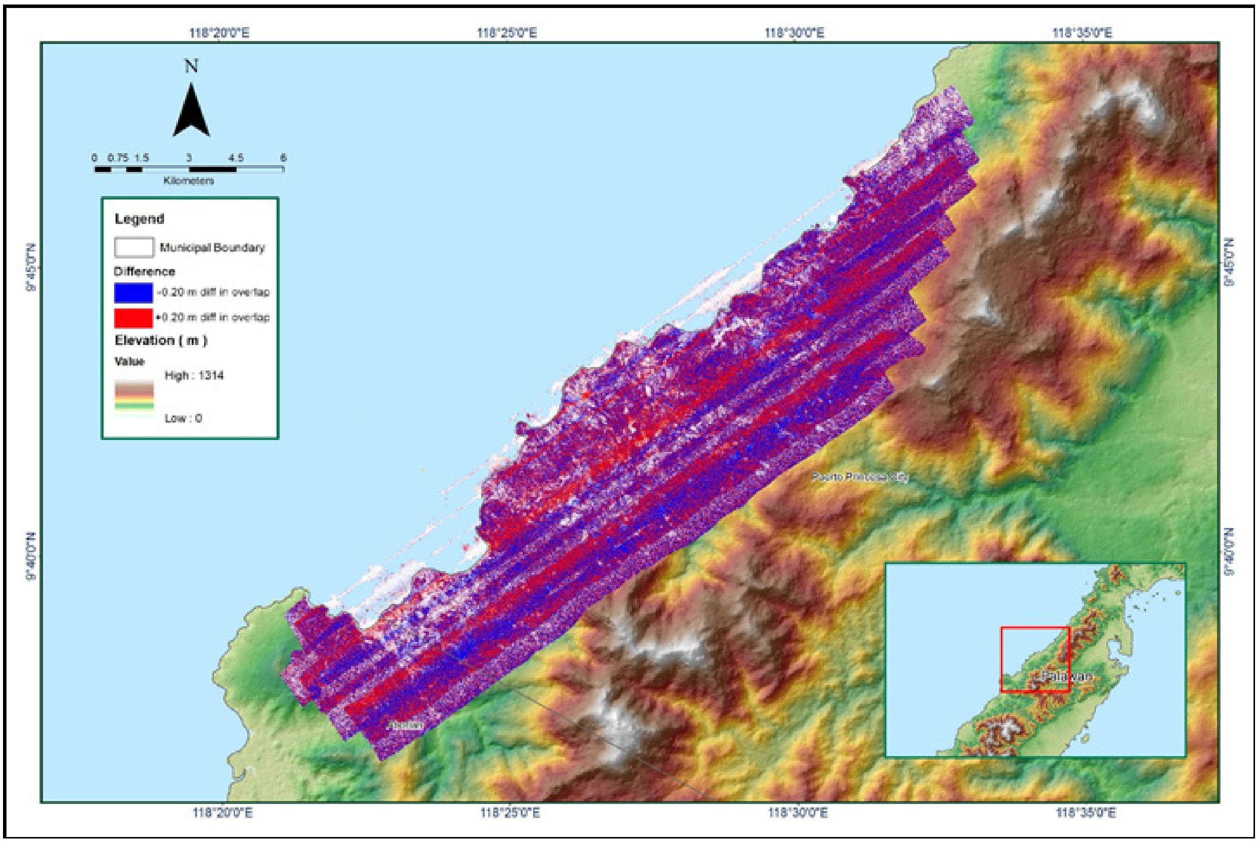


Figure A-8.42. Elevation difference between flight lines

Table A-8.7. Mission Summary Report for Mission Blk42eF

Flight Area	Palawan Reflights
Mission Name	Blk42eF
Inclusive Flights	3493G
Range data size	13.2 GB
Base data size	5.16 MB
POS	208 MB
Image	NA
Transfer date	December 8, 2015
Solution Status	
Number of Satellites (>6)	No
PDOP (<3)	No
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.31
RMSE for East Position (<4.0 cm)	1.20
RMSE for Down Position (<8.0 cm)	3.37
Boresight correction stdev (<0.001deg)	NA
IMU attitude correction stdev (<0.001deg)	NA
GPS position stdev (<0.01m)	NA
Minimum % overlap (>25)	27.59%
Ave point cloud density per sq.m. (>2.0)	4.59
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	65
Maximum Height	346.68 m
Minimum Height	50.95 m
Classification (# of points)	
Ground	5,610,349
Low vegetation	3,297,932
Medium vegetation	34,851,941
High vegetation	103,148,691
Building	293,863
Ortophoto	No
Processed by	Engr. Regis Guhiting, Engr. Velina Angela Bemida, Engr. Melissa Fernandez

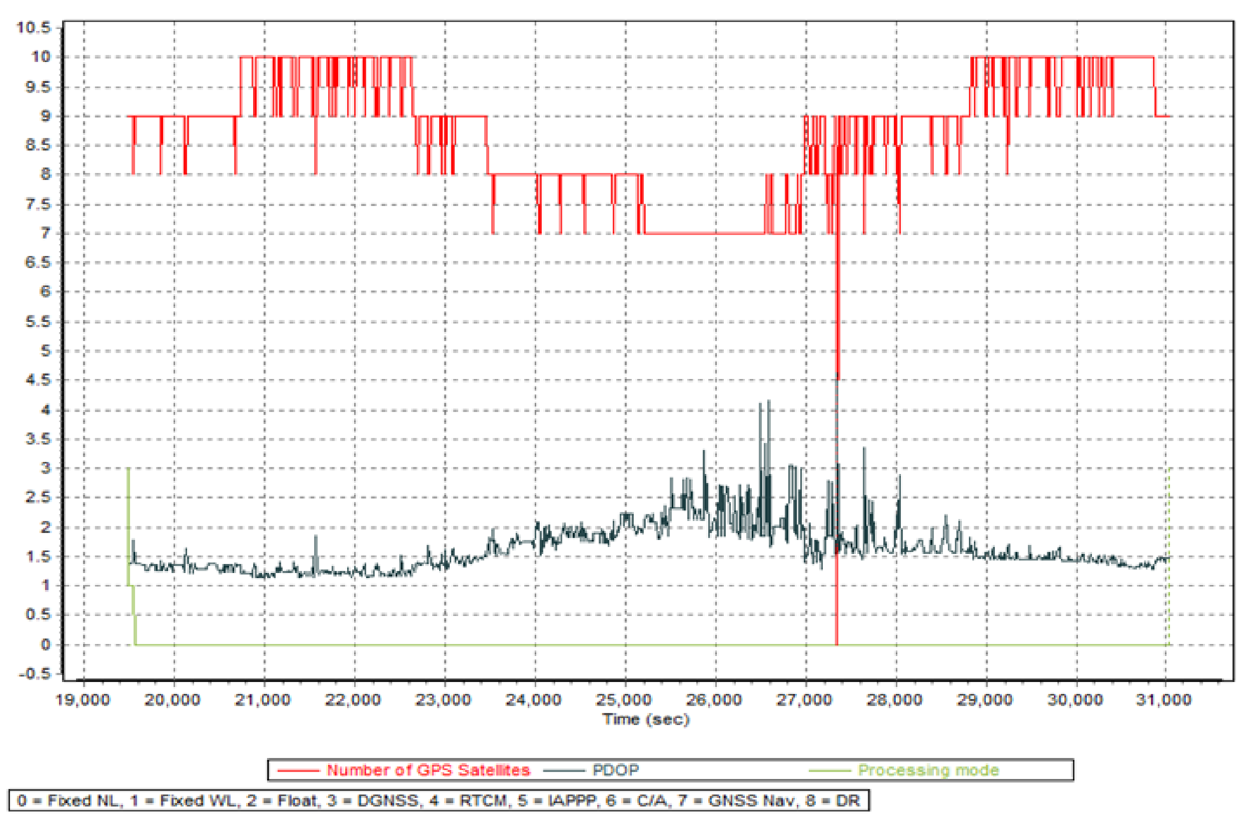


Figure A-8.43. Solution Status

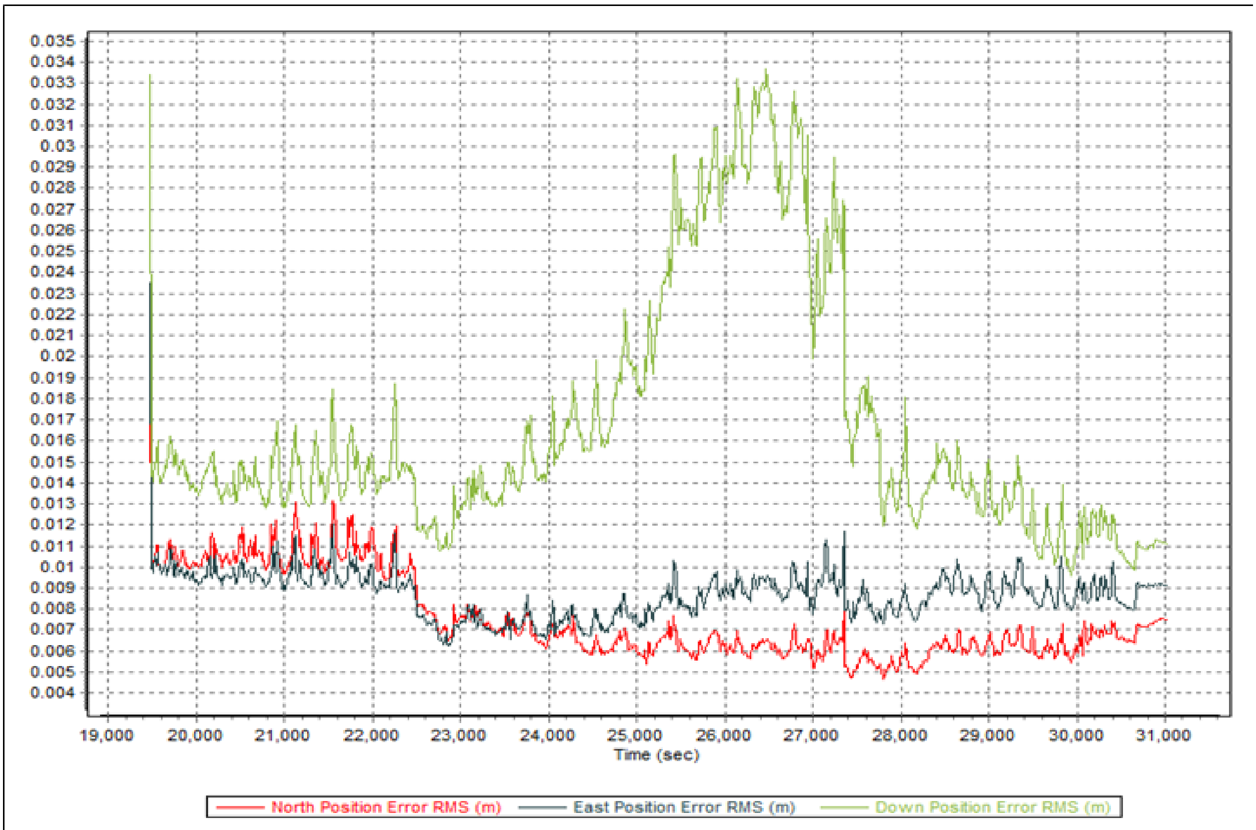


Figure A-8.44. Smoothed Performance Metric Parameters

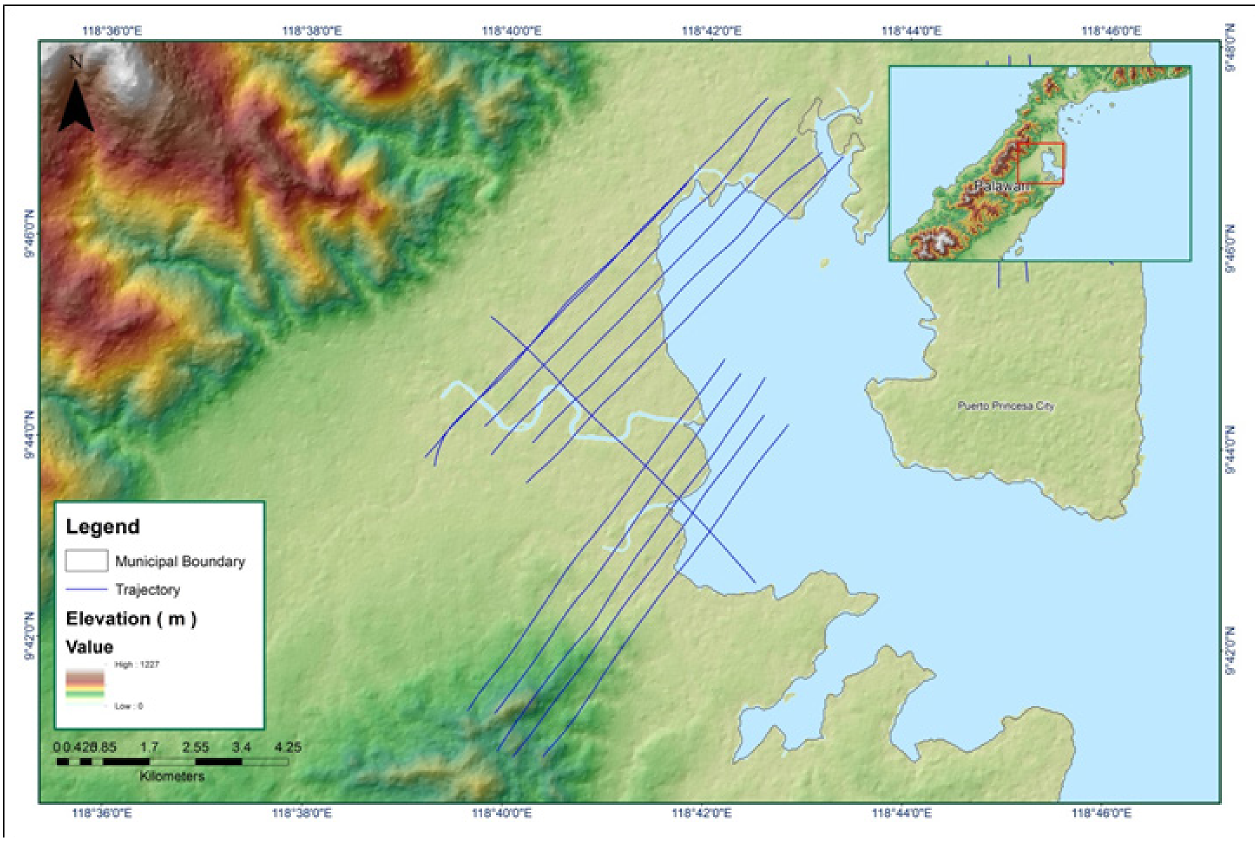


Figure A-8.45. Best Estimated Trajectory

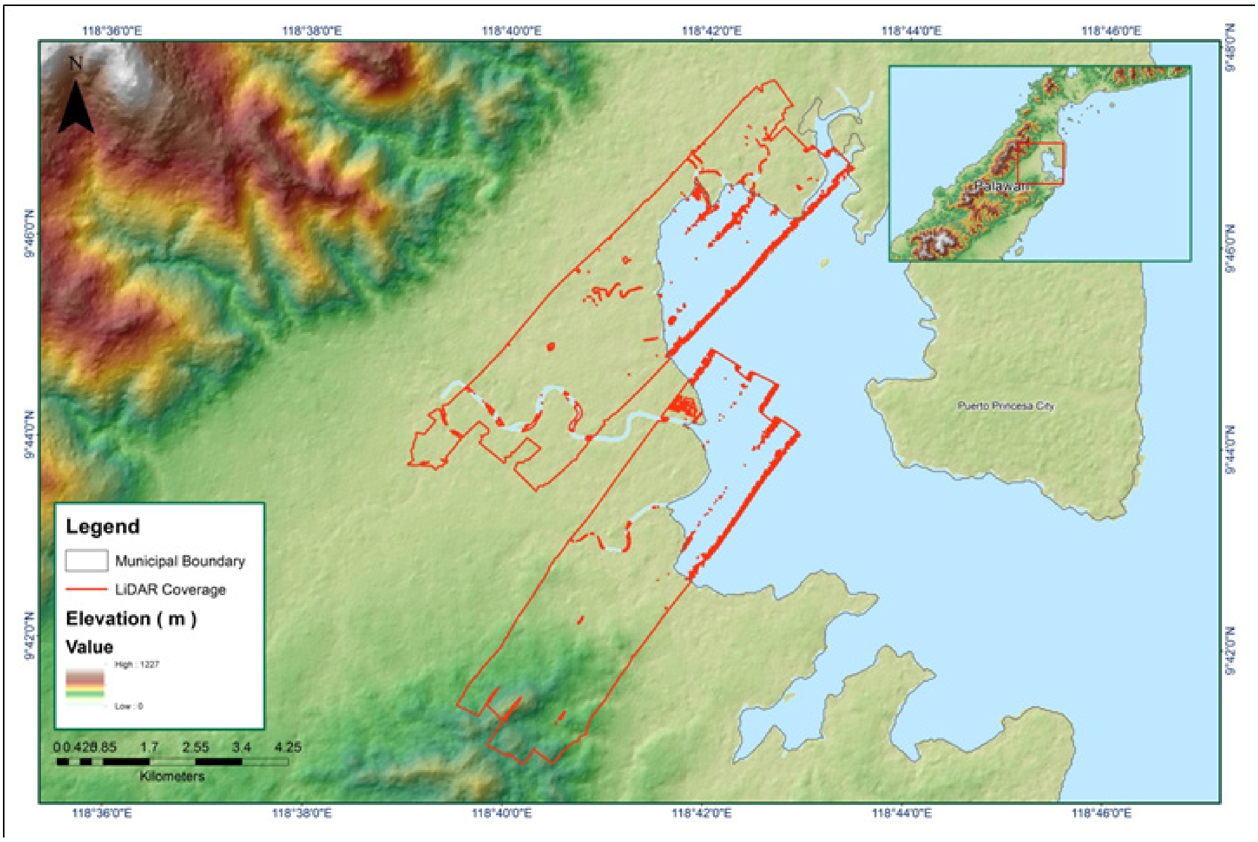


Figure A-8.46. Coverage of LiDAR data

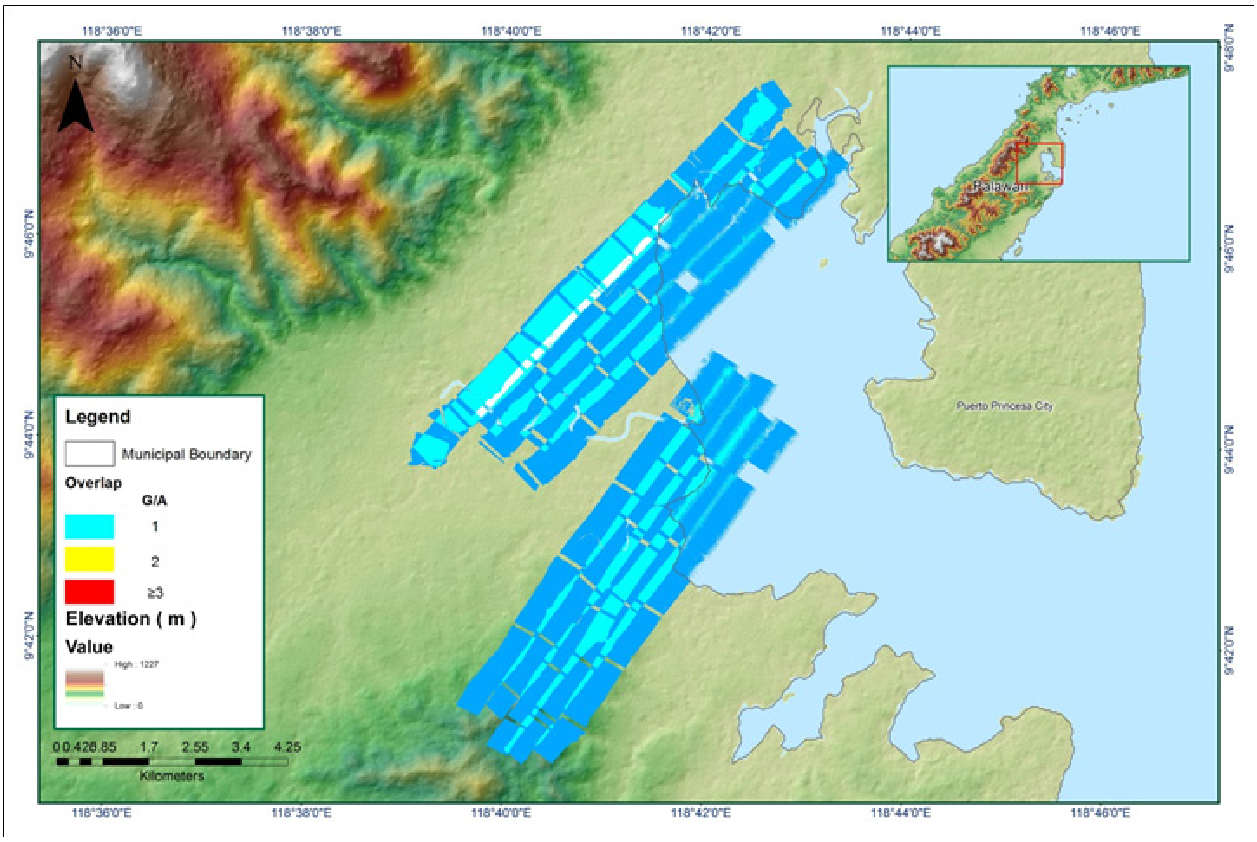


Figure A-8.47. Image of Data Overlap

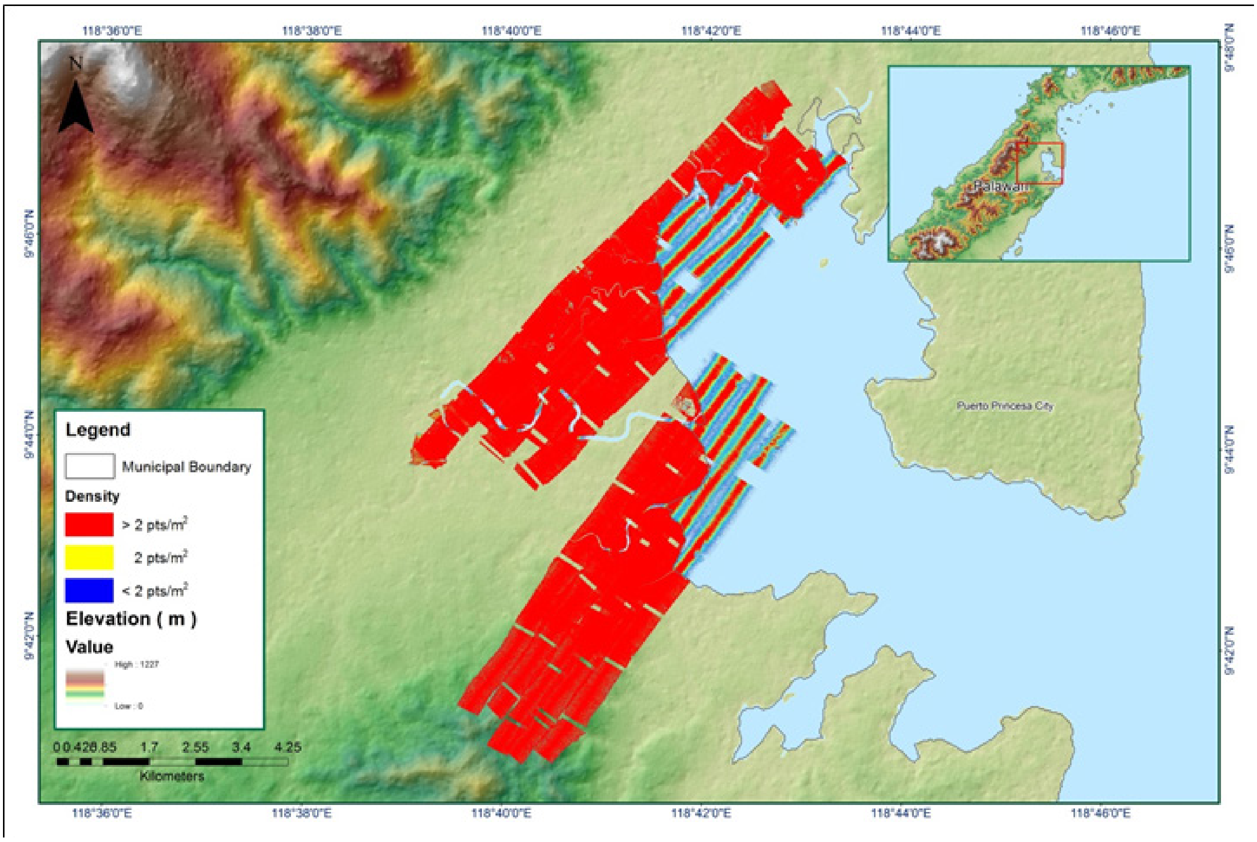


Figure A-8.48. Density map of merged LiDAR data

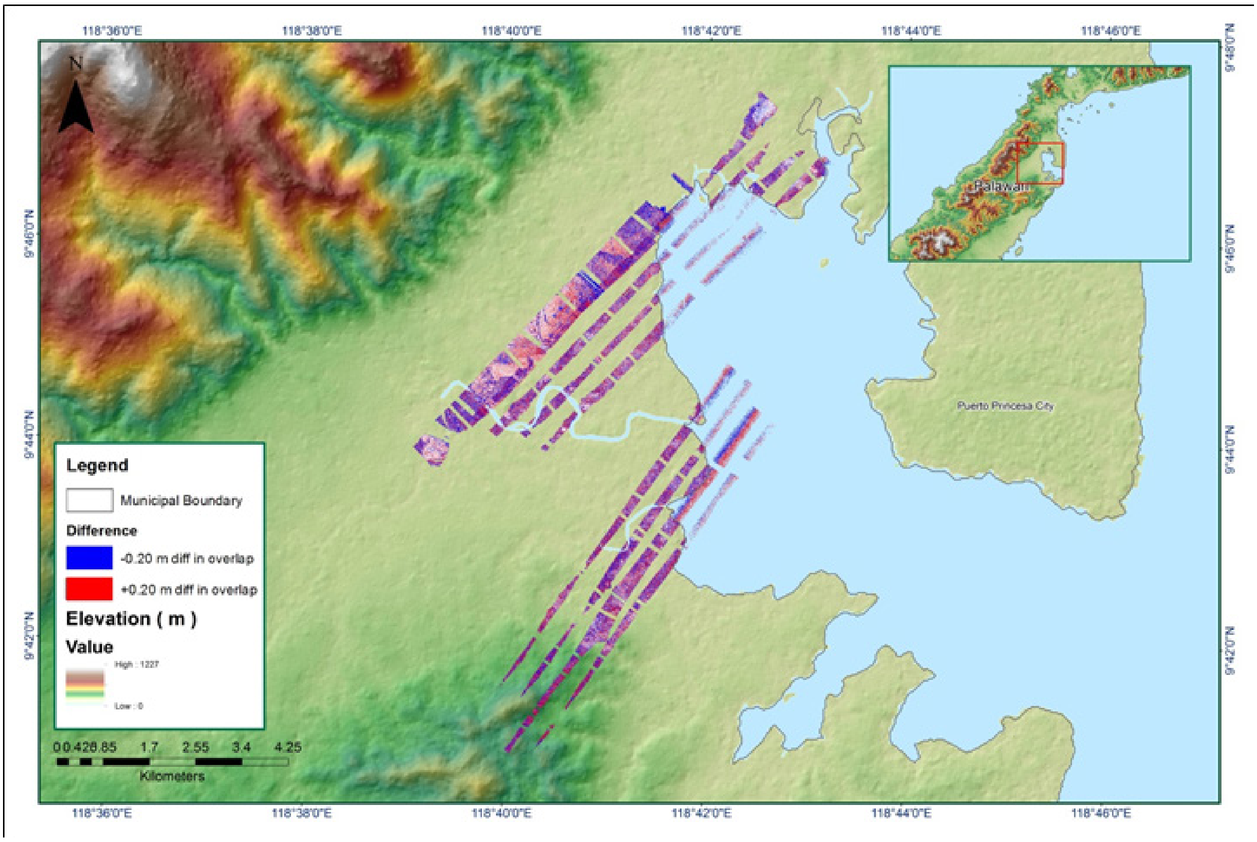


Figure A-8.49. Elevation difference between flight lines

Annex 9. Iwahig Penal Model Basin Parameters

Table A-9.1 Iwahig Penal Model Basin Parameters

Annex 10. Iwahig Penal Model Reach Parameters

Table A-10.1 Iwahig Penal Model Reach Parameters

Annex 11. Iwahig Penal Flood Validation Data

Table A-11.1 Iwahig Penal Flood Validation Data

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event	Date	Rain Return/ Scenario
	Latitude	Longitude						
1	9.706878	118.6362	0.03	0	-0.03			25-Year
2	9.707342	118.6374	0.33	0	-0.33			25-Year
3	9.708109	118.6366	0.03	0	-0.03			25-Year
4	9.708496	118.6361	0.03	0	-0.03			25-Year
5	9.709176	118.6371	0.39	0	-0.39			25-Year
6	9.709337	118.6351	0.03	0	-0.03			25-Year
7	9.709685	118.6352	0.03	0	-0.03			25-Year
8	9.709699	118.6358	0.14	0	-0.14			25-Year
9	9.710835	118.6363	0.04	0	-0.04			25-Year
10	9.71084	118.6367	0.03	0	-0.03			25-Year
11	9.711398	118.637	0.03	0	-0.03			25-Year
12	9.711905	118.6365	2.96	0	-2.96			25-Year
13	9.712898	118.6379	0.8	0.3	-0.5		1996	25-Year
14	9.715197	118.6656	0.04	0	-0.04			25-Year
15	9.716324	118.668	0.03	0	-0.03			25-Year
16	9.718098	118.6671	0.03	0	-0.03			25-Year
17	9.719254	118.6691	0.37	0	-0.37			25-Year
18	9.733264	118.6835	0.03	0	-0.03			25-Year
19	9.737666	118.6846	0.14	0	-0.14			25-Year
20	9.738504	118.6847	0.03	0.12	0.09	Yolanda	Nov. 2013	25-Year
21	9.738644	118.6853	0.13	0.13	0	Yolanda	Nov. 2013	25-Year
22	9.738886	118.6863	0.3	0	-0.3			25-Year
23	9.738886	118.6863	0.3	0.32	0.02	Lando	Nov. 2007	25-Year
24	9.738957	118.6897	0.03	0.24	0.21	Yolanda	Nov. 2013	25-Year
25	9.739058	118.6873	0.03	0.16	0.13	Yolanda	Nov. 2013	25-Year
26	9.739298	118.6881	0.29	0.13	-0.16	Yolanda	Nov. 2013	25-Year
27	9.739835	118.6909	0.19	0.33	0.14		2009	25-Year
28	9.740117	118.6853	0.03	0.5	0.47		Oct. 2011	25-Year
29	9.740117	118.6853	0.06	0.5	0.44		Oct. 2011	25-Year
30	9.740226	118.6846	0.13	0.35	0.22		2010	25-Year
31	9.740256	118.6861	0.15	0	-0.15			25-Year
32	9.740648	118.6845	0.11	0	-0.11			25-Year
33	9.740661	118.6869	0.03	0.31	0.28	Rainfall/ High Tide	2016	25-Year
34	9.740895	118.6878	0.11	0	-0.11			25-Year
35	9.740939	118.6863	0.15	0	-0.15			25-Year
36	9.741112	118.6634	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						
37	9.741112	118.6845	0.03	0	-0.03			25-Year
38	9.7417	118.6634	0.03	0	-0.03			25-Year
39	9.741738	118.6624	0.03	0	-0.03			25-Year
40	9.741771	118.6617	0.06	0	-0.06			25-Year
41	9.742104	118.6614	0.1	0	-0.1			25-Year
42	9.742655	118.6634	0.08	0	-0.08			25-Year
43	9.742687	118.6601	0.03	0	-0.03			25-Year
44	9.742805	118.6623	0.03	0	-0.03			25-Year
45	9.743105	118.6609	0.03	0	-0.03			25-Year
46	9.743452	118.6591	0.03	0	-0.03			25-Year
47	9.743444	118.6634	0.04	0	-0.04			25-Year
48	9.74352	118.6613	0.03	0	-0.03			25-Year
49	9.743845	118.6634	0.04	0	-0.04			25-Year
50	9.744318	118.6627	0.06	0	-0.06			25-Year
51	9.744329	118.6618	0.17	0	-0.17			25-Year
52	9.744412	118.6607	0.03	0	-0.03			25-Year
53	9.744575	118.657	0.04	0	-0.04			25-Year
54	9.74472	118.6621	0.03	0	-0.03			25-Year
55	9.74484	118.6598	0.03	0	-0.03			25-Year
56	9.745168	118.659	0.03	0	-0.03			25-Year
57	9.745222	118.6613	0.05	0	-0.05			25-Year
58	9.745365	118.6623	0.04	0	-0.04			25-Year
59	9.745464	118.6594	0.03	0	-0.03			25-Year
60	9.745508	118.6618	0.18	0	-0.18			25-Year
61	9.745592	118.6627	0.04	0	-0.04			25-Year
62	9.745864	118.6592	0.08	0	-0.08			25-Year
63	9.745915	118.6584	0.03	0	-0.03			25-Year
64	9.745914	118.6632	0.03	0	-0.03			25-Year
65	9.746016	118.6594	0.06	0	-0.06			25-Year
66	9.746031	118.6571	0.07	0	-0.07			25-Year
67	9.746438	118.6584	0.03	0	-0.03			25-Year
68	9.746429	118.6633	0.75	0	-0.75			25-Year
69	9.746785	118.6591	0.08	0	-0.08			25-Year
70	9.747898	118.6638	0.03	0	-0.03			25-Year
71	9.749017	118.6675	0.19	0.58	0.39	Hagibis	June 2014	25-Year
72	9.753682	118.6736	0.04	0.53	0.49	Hagibis	June 2014	25-Year
73	9.755057	118.6777	1.63	0	-1.63			25-Year
74	9.758238	118.6781	0.48	0	-0.48			25-Year
75	9.760633	118.6782	0.78	0	-0.78			25-Year
76	9.761368	118.678	0.03	0	-0.03			25-Year
77	9.761405	118.6789	0.28	0	-0.28			25-Year
78	9.76147	118.6777	0.18	0	-0.18			25-Year

Annex 12. Phil-LiDAR 1 UPLB Team Composition

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

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