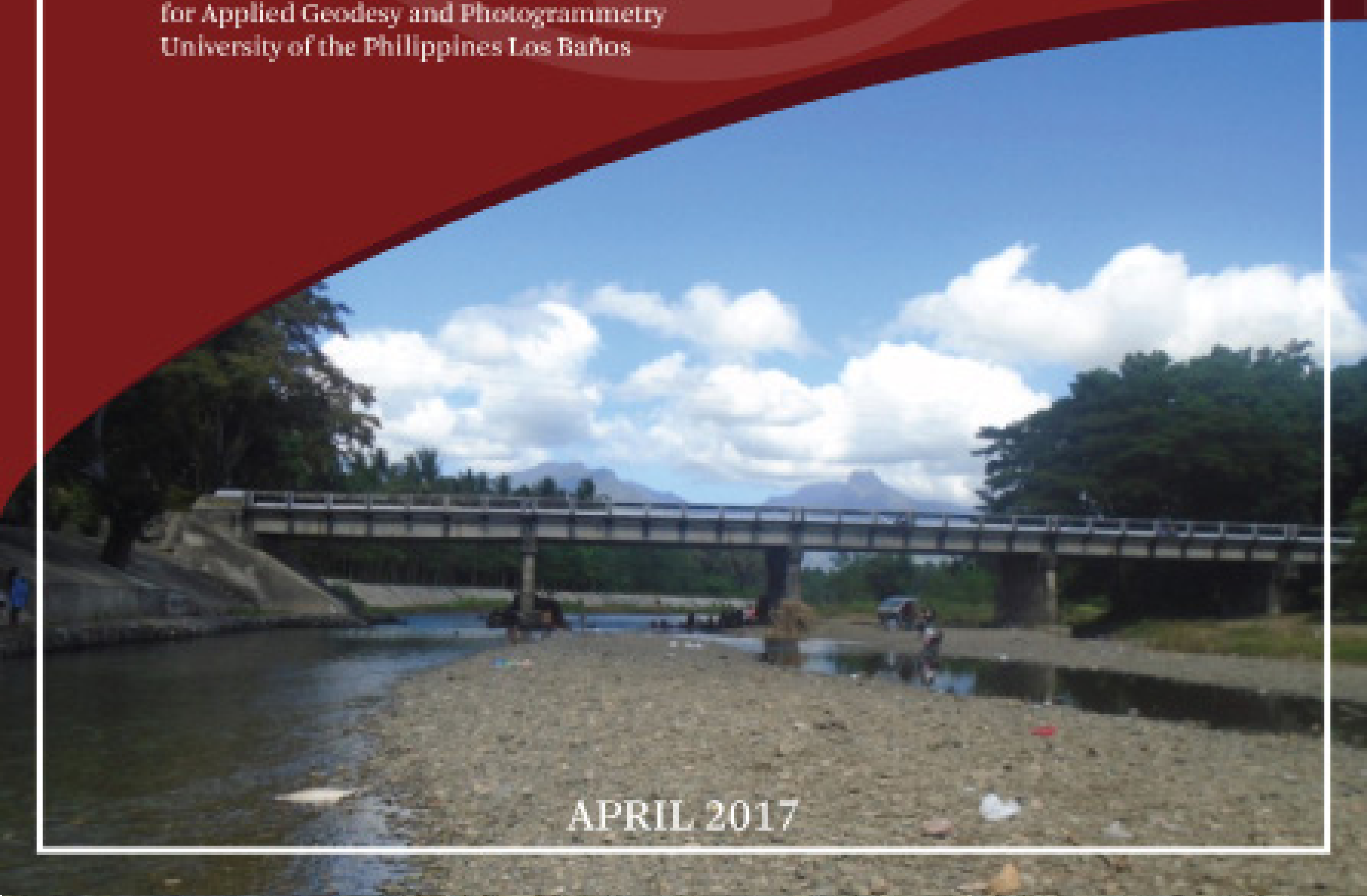
HAZARD MAPPING OF THE PHILIPPINES USING LIDAR (PHIL-LIDAR I)

LiDAR Surveys and Flood Mapping of Tigaplan River

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



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For questions/queries regarding this report, contact:

Asst. Prof. Edwin R. Abucay
Project Leader, Phil-LiDAR 1 Program
University of the Philippines, Los Banos
Los Banos, Laguna, Philippines 4031
E-mail: erabucay@up.edu.ph

Enrico C. Paringit, Dr. Eng.
Program Leader, Phil-LiDAR 1 Program
University of the Philippines Diliman
Quezon City, Philippines 1101
E-mail: ecparingit@up.edu.ph

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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 Baños
UP-TCAGP	University of the Philippines – Training Center for Applied Geodesy and Photogrammetry
UTM	Universal Transverse Mercator
WGS	World Geodetic System

CHAPTER 1: OVERVIEW OF THE PROGRAM AND TIGAPLAN RIVER

Enrico C. Paringit, Dr. Eng., Dr. Edwin R. Abucay, and Engr. Ariel U. Glorioso

1.1 Background of the Phil-LIDAR 1 Program

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

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

The implementing partner university for the Phil-LiDAR 1 Program is the University of the Philippines Los Baños (UPLB). UPLB is in charge of processing LiDAR data and conducting data validation reconnaissance, cross section, bathymetric survey, validation, river flow measurements, flood height and extent data gathering, flood modeling, and flood map generation for the 45 river basins in the Southern Luzon region. The university is located in Los Baños in the province of Laguna.

1.2 Overview of the Tigaplan River Basin

The Tigaplan River Basin is a 104,330-hectare watershed located in Palawan. It covers the barangays of Amos, Aribungos, Barong-barong, Imulnod, Mainit, Pangobilian and Tubtub in the municipality of Brooke's Point. The DENR River Basin Control Office (RBCO) states that the Tigaplan River Basin has a drainage are of 177 km^2 and an estimated 283 cubic meter (MCM) annual run-off (RBCO, 2015).

The main stem of the Tigaplan River Basin, the Tigaplan River, is among the forty-five (45) river systems in Mindoro, Marinduque, Romblon, Palawan (MIMAROPA) Region. It passes through Aribungos, Barong-barong, Imulnod, Mainit, and Tubtub in Brooke's Point municipality.

In terms of geography, the Tigaplan river basin is generally characterized by >50% slope. The soil type in the area is typically Brooke's clay. However, unclassified soils (rough mountain land) and beach sand can also be found in the area. Closed canopy (mature trees covering >50%) is predominantly found in the area followed by cultivated area mixed with brushland/grassland and open canopy (mature trees covering <50%).

Meanwhile, with regards to climate, Climate Type I and III prevails in MIMAROPA and Laguna based on the Modified Corona Classification of climate. This includes the Tigaplan River Basin that is located within the MIMAROPA region. 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.

According to the 2015 national census of PSA, a total of 4,197 persons are residing in Brgy. Barong-barong in the Municipality of Brookes Point, which is within the immediate vicinity of the river. The source of livelihood of the population within the Tigaplan River Basin reflects the economy of the province of Palawan. The economic activities of the communities within the Tigaplan River Basin are primarily agriculture-based. Fishing, tourism, trade, commerce, and mineral extraction are prevalent in the river basin area. (Source: pkp.pcsd.gov.ph/images/ppcprofile/Economic%20Profile.pdf).

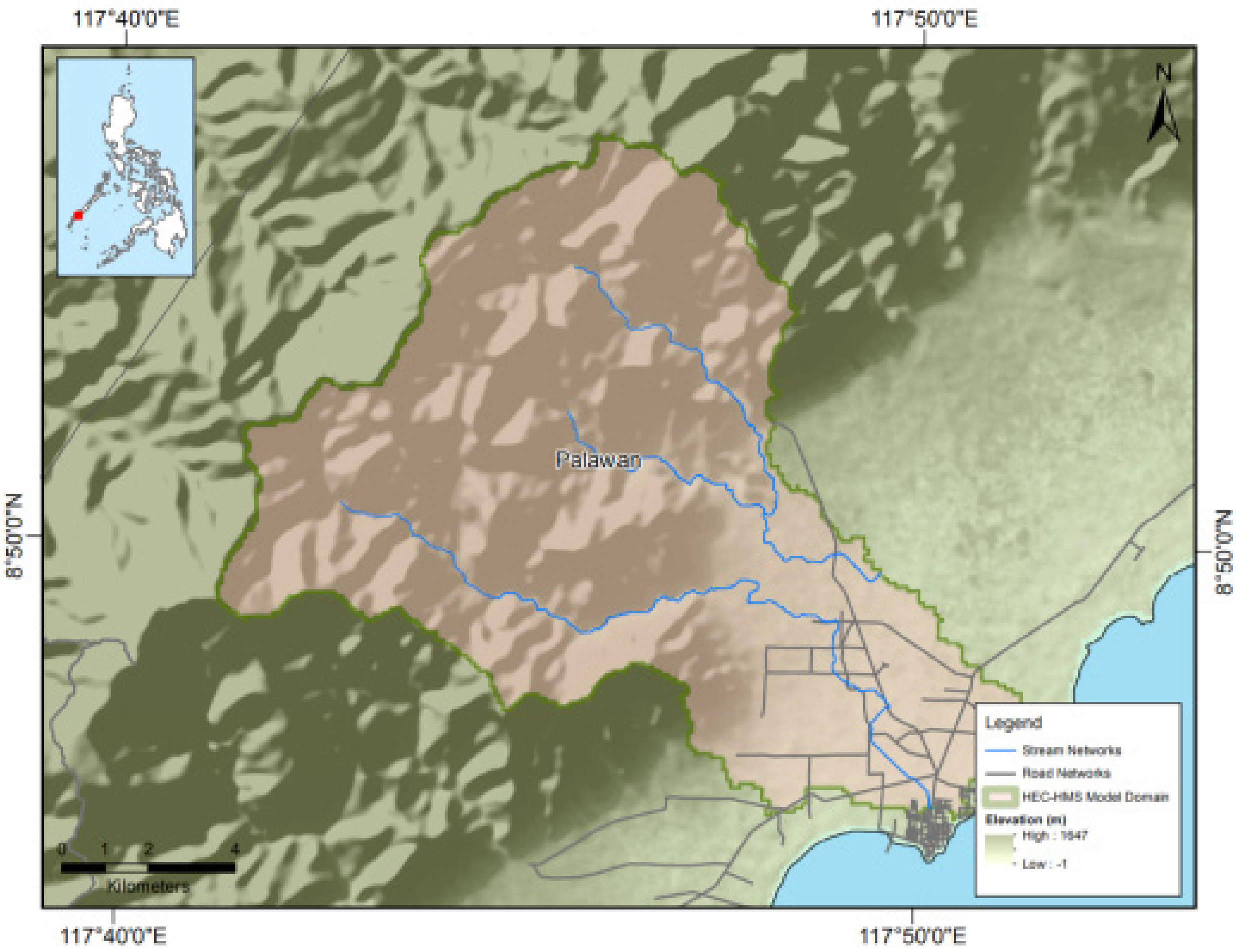


Figure 1. Map of Tigaplan River Basin

In the studies conducted by the Mines and Geosciences Bureau (MGB), some communities within the river basin have flood and landslide susceptibility. Barangays Imulnod and Barong-Barong have low to high flood susceptibility while all other barangays have no flood hazard at all. On the other hand, Amas, Tubtub, Mainit and Aribungos have low to high susceptibilities to landslides. The field surveys conducted by the PHIL-LiDAR 1 validation team showed that there were several notable weather disturbances that caused flooding in 2013 (Auring and Yolanda), 2014 (Seniang), and 2016 (Nina). Heavy rains brought by southwest monsoon also caused flooding in August 2016 affecting Tagusao and Mainit. On November 17, 2016, the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) issued a flood advisory for Tigaplan River and its tributaries due to the moderate to heavy rains brought by the presence of a trough of low pressure area affecting Southern Luzon, Visayas and Mindanao as per NDRRMC report (Source: http://www.ndrrmc.gov.ph/attachments/article/3/General_ Flood_Advisories_as_of_17NOV 016_1700H.pdf).

CHAPTER 2: LIDAR ACQUISITION IN TIGAPLAN FLOODPLAIN

Engr. Louie P. Balicanta, Engr. Christopher Cruz, Lovely Gracia Acuña, Engr. Gerome Hipolito, Ms. Jasmine T. Alviar, and Engr. Brylle Adam G. De Castro

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 Tigaplan floodplain in Palawan. These missions were planned for 15 lines and ran for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameters for the LiDAR system are found in Table 1. Figure 2 shows the flight plan for Tigaplan floodplain.

Table 1. Flight planning parameters for Gemini LiDAR system.

Block Name	Flying Height (AGL)	Overlap (%)	Field of View	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency	Average Speed	Average Turn Time (Minutes)
BLK42eP	800	30	50	125	50	130	5
BLK42eQ	800	30	50	125	50	130	5
BLK42eR	800	30	50	125	50	130	5
BLK42eS	800	30	50	125	50	130	5
BLK42eN	800	30	50	125	50	130	5
BLK42eO	800	30	50	125	50	130	5

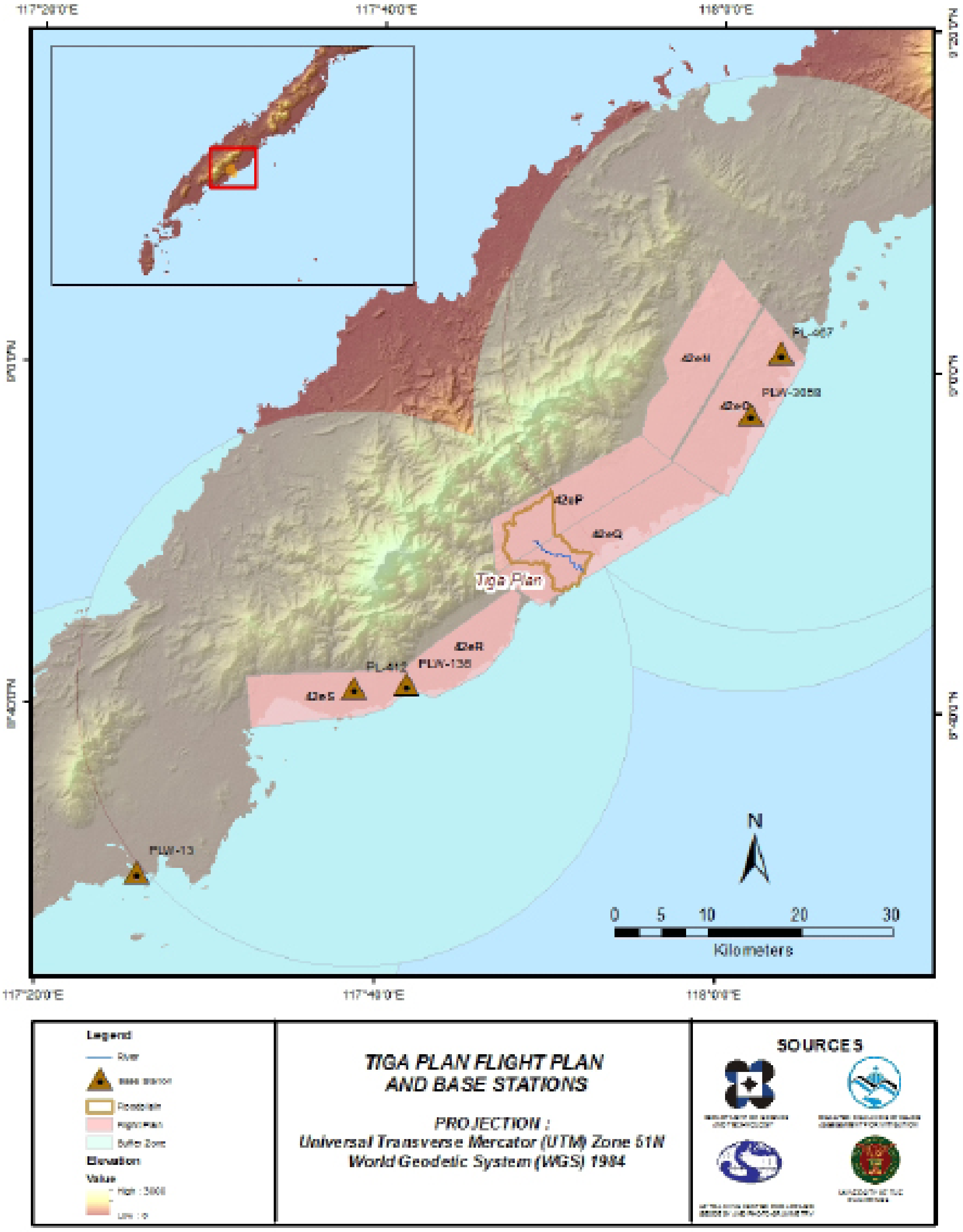


Figure 2. Flight plans and base stations used for Tigaplan Floodplain

2.2 Ground Base Station

The project team was able to recover two (2) NAMRIA horizontal reference points: PLW-13 and PLW-136, which are of second (2nd) order accuracy, and two (2) NAMRIA benchmarks, PL-412 and PL-467. One (1) ground control point (GCP), PLW-3058, was established on a fourth (4th) order NAMRIA control point on an area outside the 30km buffer of NAMRIA reference points. The certifications for the NAMRIA reference points and benchmarks are found in Annex 2, while the baseline processing report for the established GCP is found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey (December 3 to 7, 2015). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 882 and SPS 852. Flight plans and location of base stations used during the aerial LiDAR acquisition in Tigaplan 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 2 to Table 6 show the details about the NAMRIA control stations and established points. Table 7 shows the list of all ground control points occupied during the acquisition together with the corresponding dates of use.

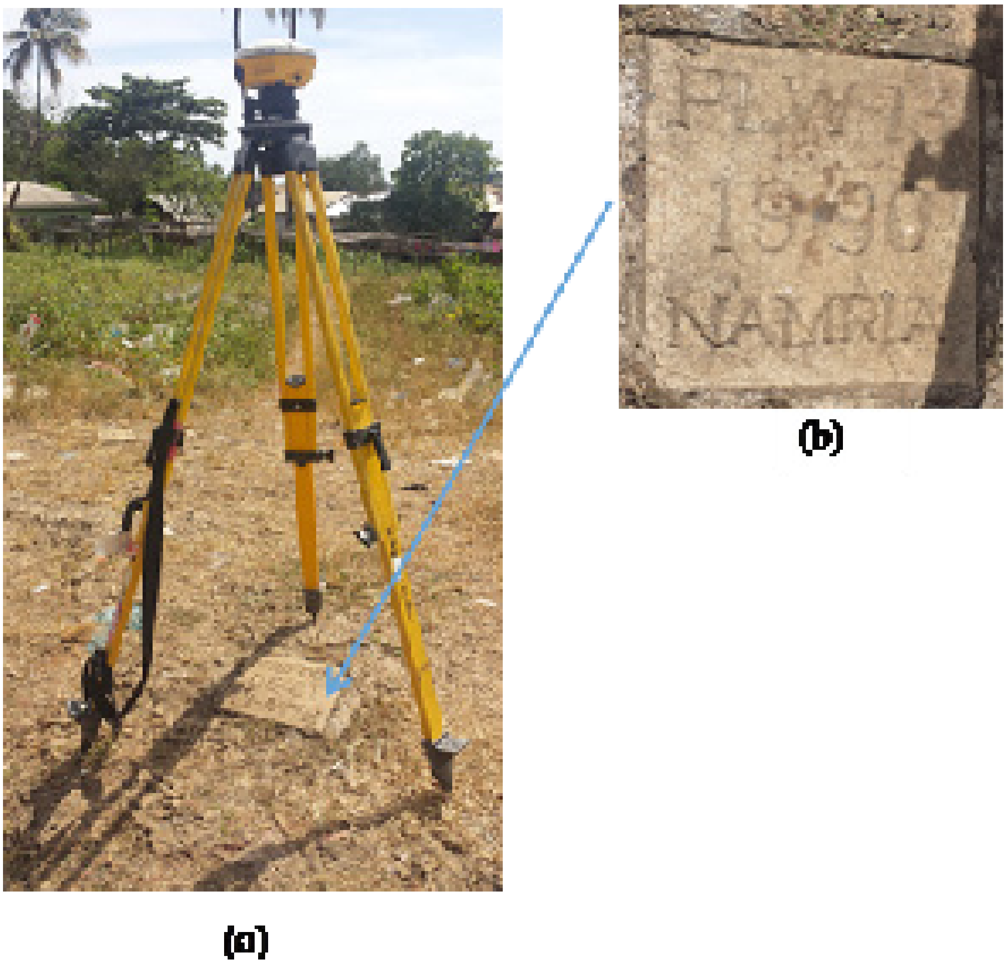


Figure 3. GPS set-up (a) over PLW-13 near the pier in Barangay Rio Tuba and PLW-13 (b) as recovered by the field team.

Table 2. Details of the recovered NAMRIA horizontal control point PLW-13 used as base station for the LiDAR data acquisition.

Station Name	PLW-13	
Order of Accuracy	2nd Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	8° 30' 17.42901" North 117° 25' 55.42672" East -0.25567 meters
Grid Coordinates, Philippine Transverse Mercator Zone 1A (PTM Zone 1A PRS 92)	Easting Northing	382414.126 meters 940540.844 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	8°30 '13.19373" North 117°26'0.86501" East 49.35 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 (UTM 51N PRS 92)	Easting Northing	618656.03 meters 1015326.41 meters

(a)

(b)

Figure 4. GPS set-up over PLW-136 in Malis Elementary School, Brooke's Point Palawan (a) and NAMRIA reference point PLW-136 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point PLW-136 used as base station for the LiDAR data acquisition.

Station Name	**PLW-136**	
Order of Accuracy	**2nd Order**	
Relative Error (horizontal positioning)	**1 in 50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	8° 41' 32.51585 North 117°41' 48.08062" East -2.493 meters
Grid Coordinates, Philippine Transverse Mercator Zone 1A (PTM Zone 1A PRS 92)	Easting Northing	411596.8 meters 961210.738 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	8° 41' 28.25671" North 117° 41' 53.50178" East 47.391 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 (UTM 51N PRS 92)	Easting Northing	576642.18 meters 960851.09 meters

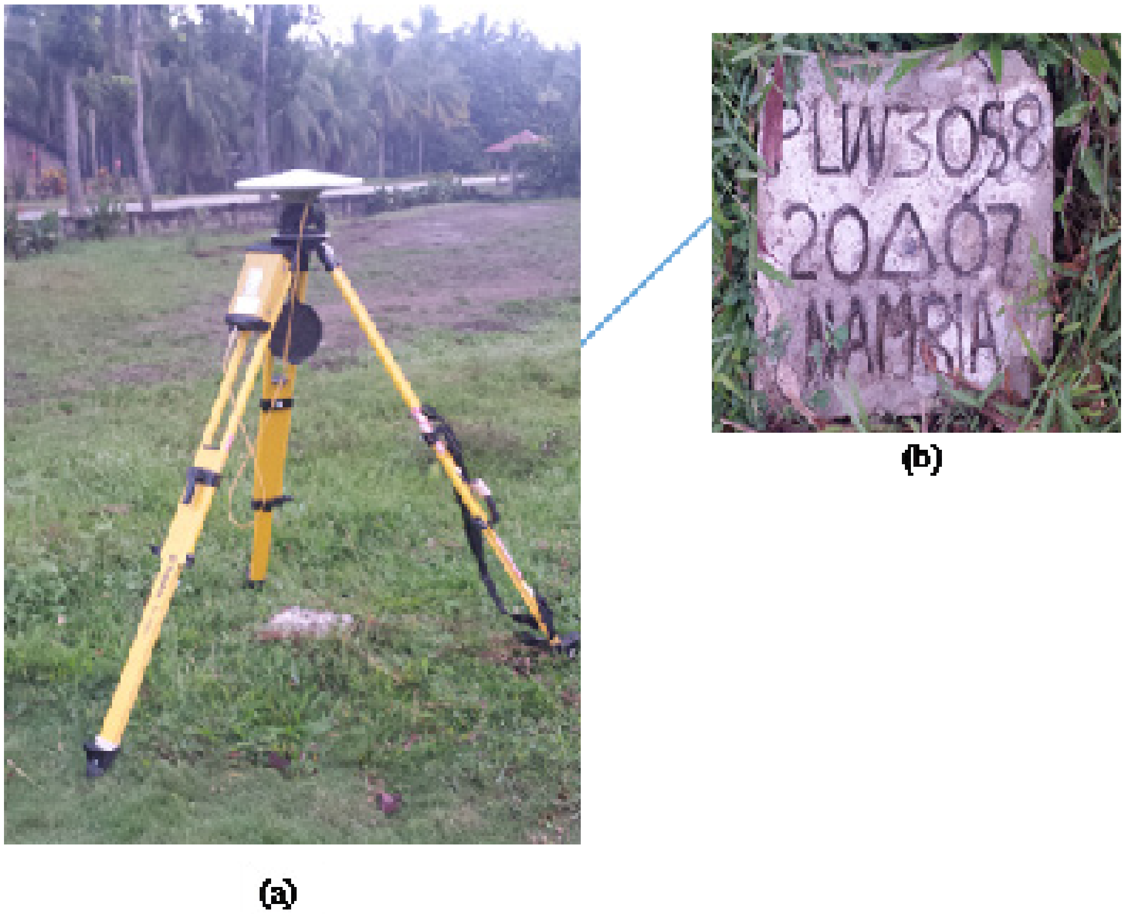


Figure 5. GPS set-up over PLW-3058 on the ground inside Caranasan Elementary School, Espanola, Palawan. (a) and NAMRIA reference point PLW-3058 (b) as recovered by the field team.

Table 4. Details of the recovered NAMRIA horizontal reference point PLW-3058 used as base station for the LiDAR data acquisition with re-processed coordinates.

Station Name	PLW-3058	
Order of Accuracy	2nd Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	8° 57’ 34.41144” North 118° 01’ 39.35193” East -2.979 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	8° 57’ 30.11418” North 118° 01’ 44.74872” East 47.176 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 (UTM 51N PRS 92)	Easting Northing	-47262.005 meters 994023.989 meters

(a)

(b)

Figure 6. GPS set-up over PL-467 at Inogbong Bridge, Bataraza Palawan (a) and PL-467 as recovered by the field team.

Table 5. Details of the NAMRIA vertical reference point PL-467 used as base station for the LiDAR data acquisition with processed coordinates.

Station Name	PL-467	
Order of Accuracy	2nd Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	8° 41’ 12.30540” North 117°38’ 32.43781” East 7.171 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	8° 41’ 08.04286” North 117° 38’ 37.85953” East 56.931 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 (UTM 51N PRS 92)	Easting Northing	-90213.109 meters 964336.926 meters

Table 6. Details of the established NAMRIA vertical control point PL-412 used as base station for the LiDAR data acquisition with re-processed coordinates.

Station Name	PL-412	
Order of Accuracy	2nd Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	9° 01'08.45200" North 118° 03' 21.49607" East -0.337 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	9° 01' 04.14225" North 118° 03' 26.88749" East 49.765 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 (UTM 51N PRS 92)	Easting Northing	-44042.610 meters 1000578.048 meters

Table 7. Ground control points used during LiDAR data acquisition

Date Surveyed	Flight Number	Mission Name	Ground Control Points
December 1, 2015	3565G	2BLK42PQR337A	PL-467, PLW-136
December 2, 2015	3575G	2BLK42OQ339B	PL-412, PLW-3058
December 3, 2015	3581G	2BLK42NPQ341A	PLW-13, PLWW-3058

2.3 Flight Missions

Three (3) missions were conducted to complete LiDAR data acquisition in Tigaplan floodplain, for a total of eleven hours and three minutes (11+3) of flying time for RP-C9022. All missions were acquired using the Gemini LiDAR systems. Table 8 show the total area of actual coverage and the corresponding flying hours per mission while Table 9 presents the actual parameters used during the LiDAR data acquisition.

Table 8. Flight missions for LiDAR data acquisition in Tigaplan 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
December 1, 2015	3565G	343.778	154.05	11.31162	142.73838	--	3	41
December 2, 2015	3575G	298.843	147.603	13.928	133.675	--	3	29
December 3, 2015	3581G	258.319	157.713	30.961	126.752	--	3	53
TOTAL		900.94	459.366	56.201	403.165		11	3

Table 9. Actual parameters used during LiDAR data acquisition.

Flight Number	Flying Height (AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
3565G	800	30	40	125	50	130	5
3575G	800	30	40	125	50	130	5
3581G	800	30	40	125	50	130	5

2.4 Survey Coverage

Tigaplan Floodplain is located on the province of Palawan. The municipalities of Brooke's Point, Sofronio Espanola, and Bataraza 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 10. The actual coverage of the LiDAR acquisition for Tigaplan Floodplain is presented in Figure 7.

Table 10. List of municipalities and cities surveyed in Tigaplan Floodplain LiDAR survey.

Province	Municipality/City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Palawan	Brooke's Point	893.393	295.534	33.08%
	Sofronio Espanola	477.504	66.101	13.84%
	Baltaraza	818.11	11.839	1.45%
Total		2189.01	373.474	17.06%

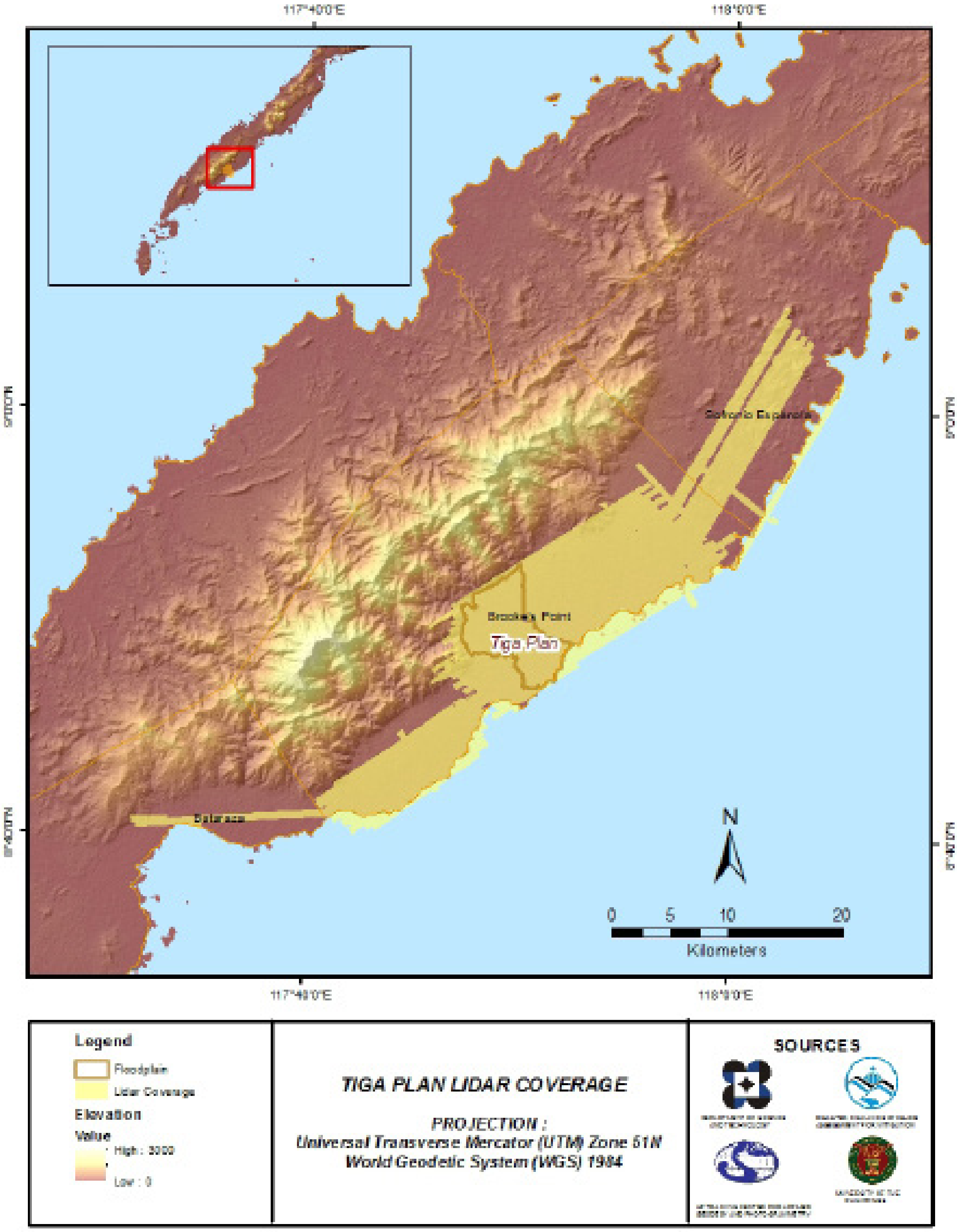


Figure 7. Actual LiDAR data acquisition for Tigaplan Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING FOR TIGAPLAN FLOODPLAIN

Engr. Ma. Rosario Concepcion O. Ang, Engr. John Louie D. Fabila, Engr. Sarah Jane D. Samalburo , Engr. Harmond F. Santos , Engr. Angelo Carlo B. Bongat , Engr. Ma. Ailyn L. Olanda, Engr. Vincent Louise DL. Azucena, Engr. Antonio B. Chua Jr. , Engr. Regis R. Guhiting, Engr. Merven Matthew D. Natino, 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 (Ang, et al., 2014) and further enhanced and updated in Paringit, et al. (2017).

3.1 Overview of 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.

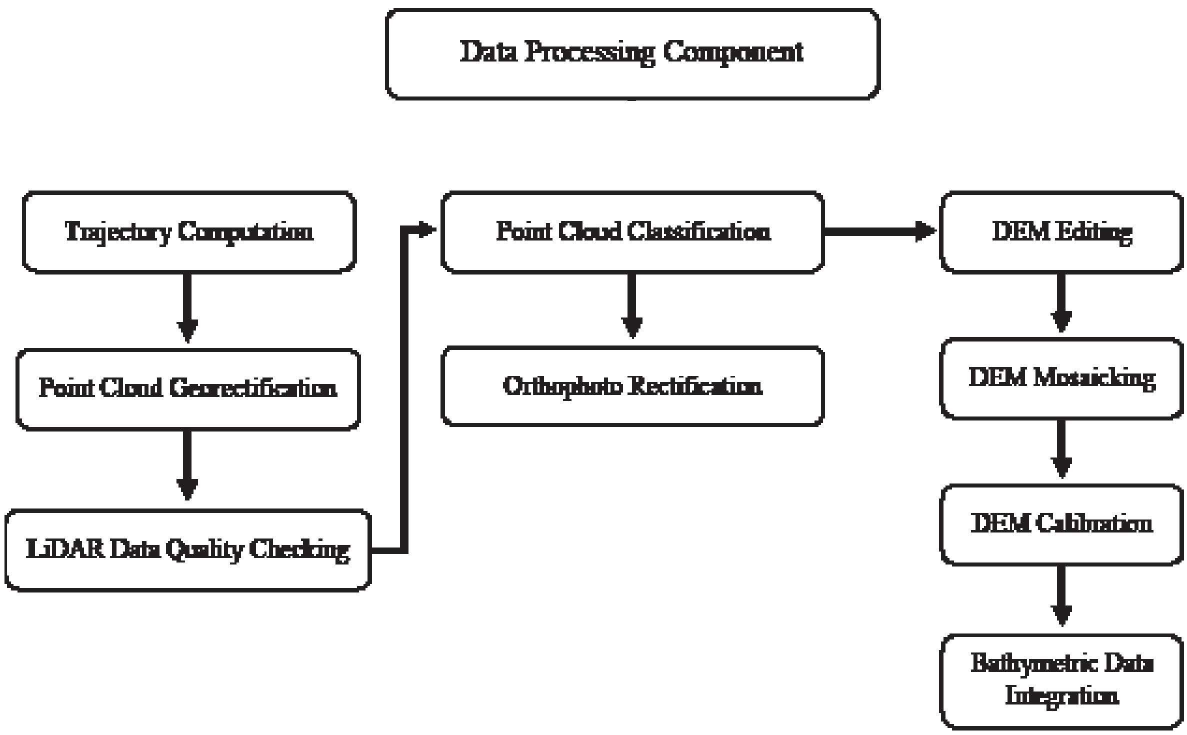


Figure 8. Schematic Diagram for Data Pre-Processing Component

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Tigaplan floodplain can be found in Annex 5. Missions flown during the survey conducted on November 2015 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Gemini system over Brooke's Point, Palawan.

The Data Acquisition Component (DAC) transferred a total of 68.9 Gigabytes of Range data, 0.652 Gigabytes of POS data, 27.61 Megabytes of GPS base station data, and 0 Gigabytes of raw image data to the data server on January 5, 2016. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Tigaplan was fully transferred on January 5, 2016, as indicated on the Data Transfer Sheets for Tigaplan floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 3565G, one of the Tigaplan 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 November 15, 2015 00:00AM. The y-axis is the RMSE value for that particular position.

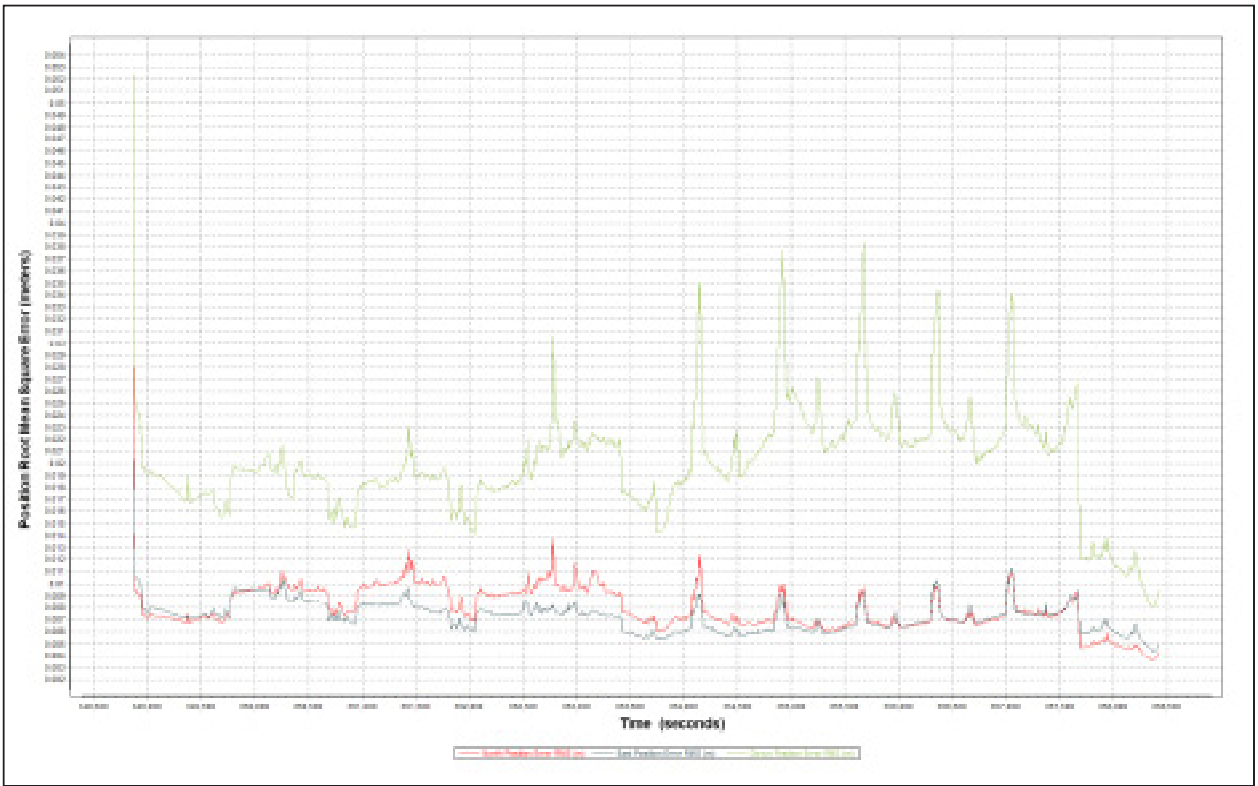


Figure 9. Smoothed Performance Metrics of Tigaplan Flight 3165.

The time of flight was from 348500 seconds to 358500 seconds, which corresponds to morning of November 20, 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 1.40 centimeters, the East position RMSE peaks at 1. 10 centimeters, and the Down position RMSE peaks at 3.80 centimeters, which are within the prescribed accuracies described in the methodology.

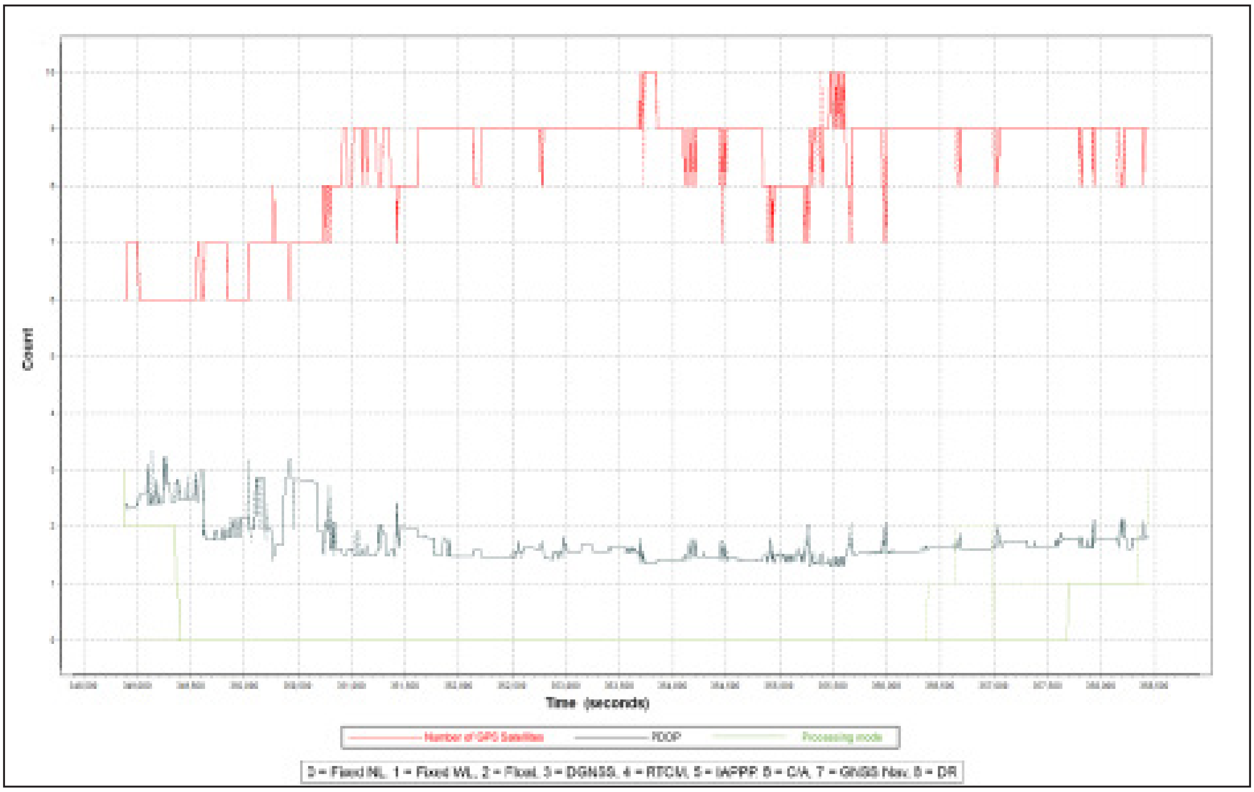


Figure 10. Solution Status Parameters of Tigaplan Flight 3565G.

The Solution Status parameters of flight 3565G, one of the Tigaplan 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 5. Majority of the time, the number of satellites tracked was between 6 and 10. 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 Tigaplan flights is shown in Figure 11.

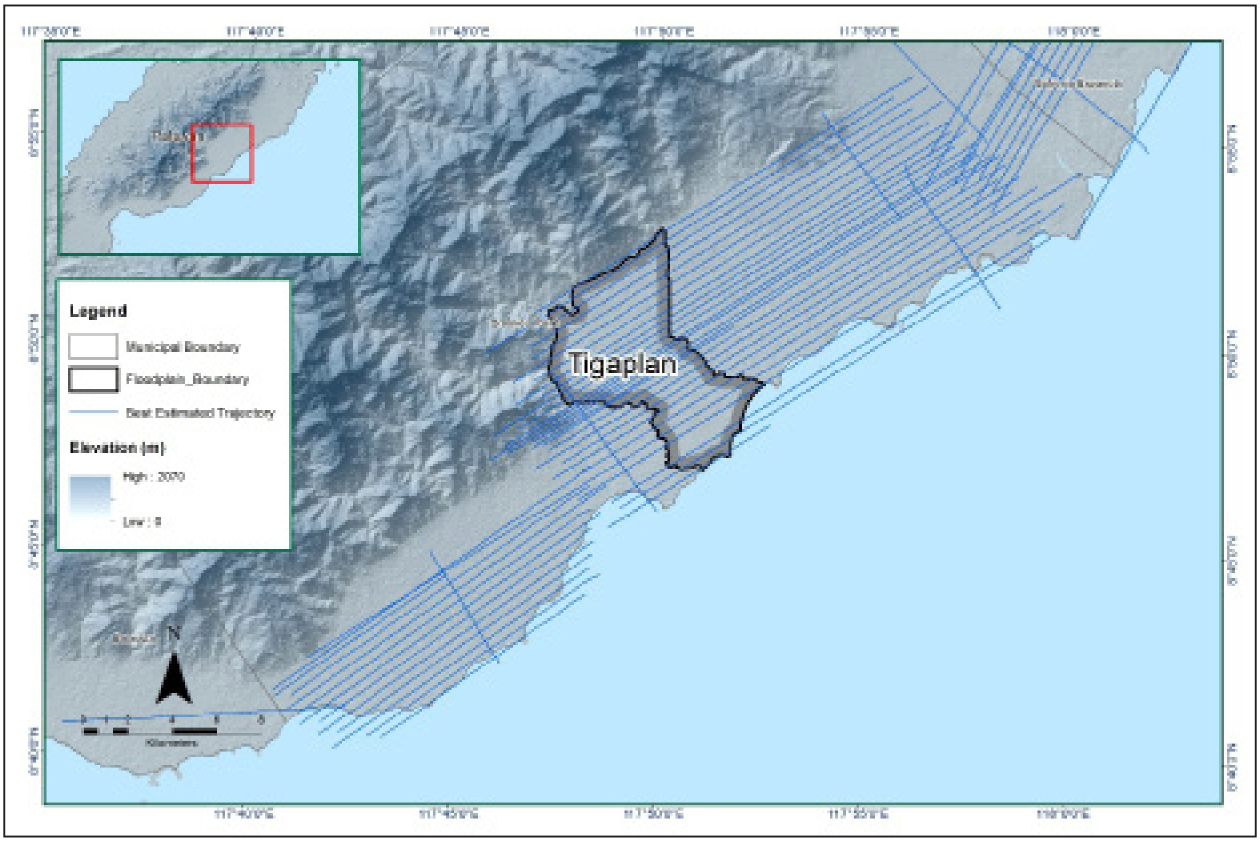


Figure 11. Best Estimated Trajectory for Tigaplan Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 40 flight lines, with each flight line containing one channel, since the Gemini system contains one channel only. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Tigaplan floodplain are given in Table 11.

Table 11. Self-Calibration Results values for Tigaplan flights.

Parameter	Acceptable Value	Value
Boresight Correction stdev	(<0.001degrees)	0.001121
IMU Attitude Correction Roll and Pitch Corrections stdev	(<0.001degrees)	0.000906
GPS Position Z-correction stdev	(<0.01meters)	0.0031

The parameter values did not reach the accuracy standards but the data was still processed. Further calibrations may be done. 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 Tigaplan Floodplain is shown in Figure 12. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

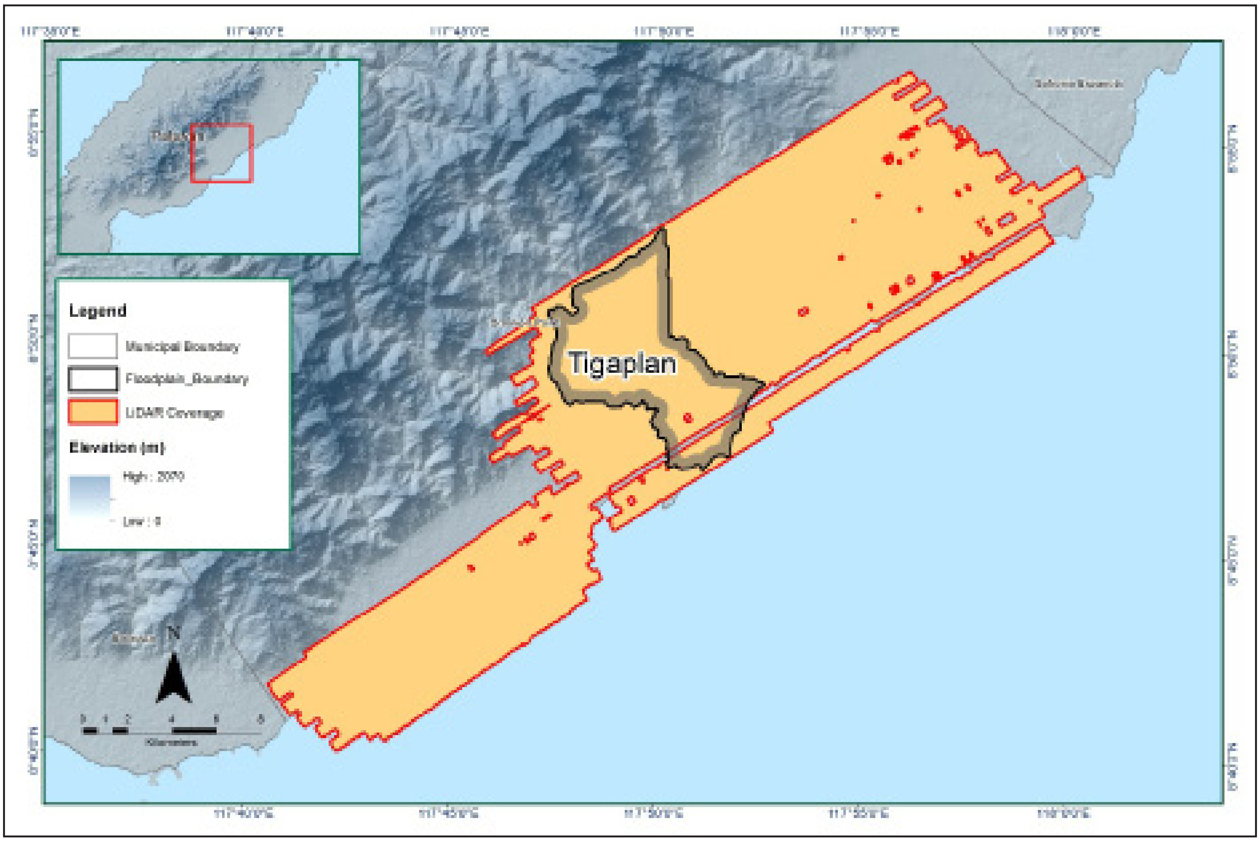


Figure 12. Boundary of the processed LiDAR data over Tigaplan Floodplain

The total area covered by the Tigaplan missions is 304.35 sq.km that is comprised of three (3) flight acquisitions grouped and merged into three (3) blocks as shown in Table 12.

Table 12. List of LiDAR blocks for Tigaplan Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Palawan reflights Blk42eP	3581G	90.49
Palawan reflights Blk42eQ	3565G	137.52
	3575G	
	3581G	
Palawan reflights Blk42eR	3565G	76.34
TOTAL		528.92

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.

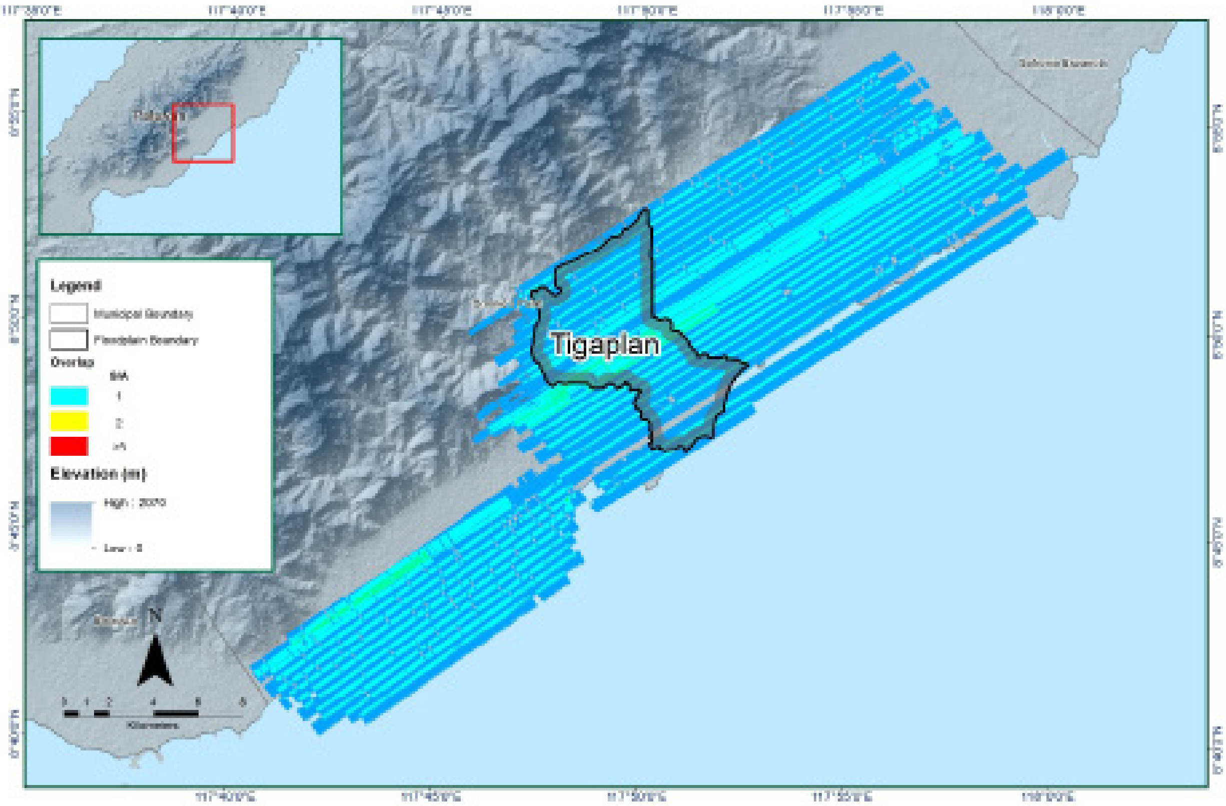


Figure 13. Image of data overlap for Tigaplan Floodplain.

The overlap statistics per block for the Tigaplan 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 28.71% and 37.47% respectively, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 14. It was determined that all LiDAR data for Tigaplan floodplain satisfy the point density requirement, and the average density for the entire survey area is 5.02 points per square meter.

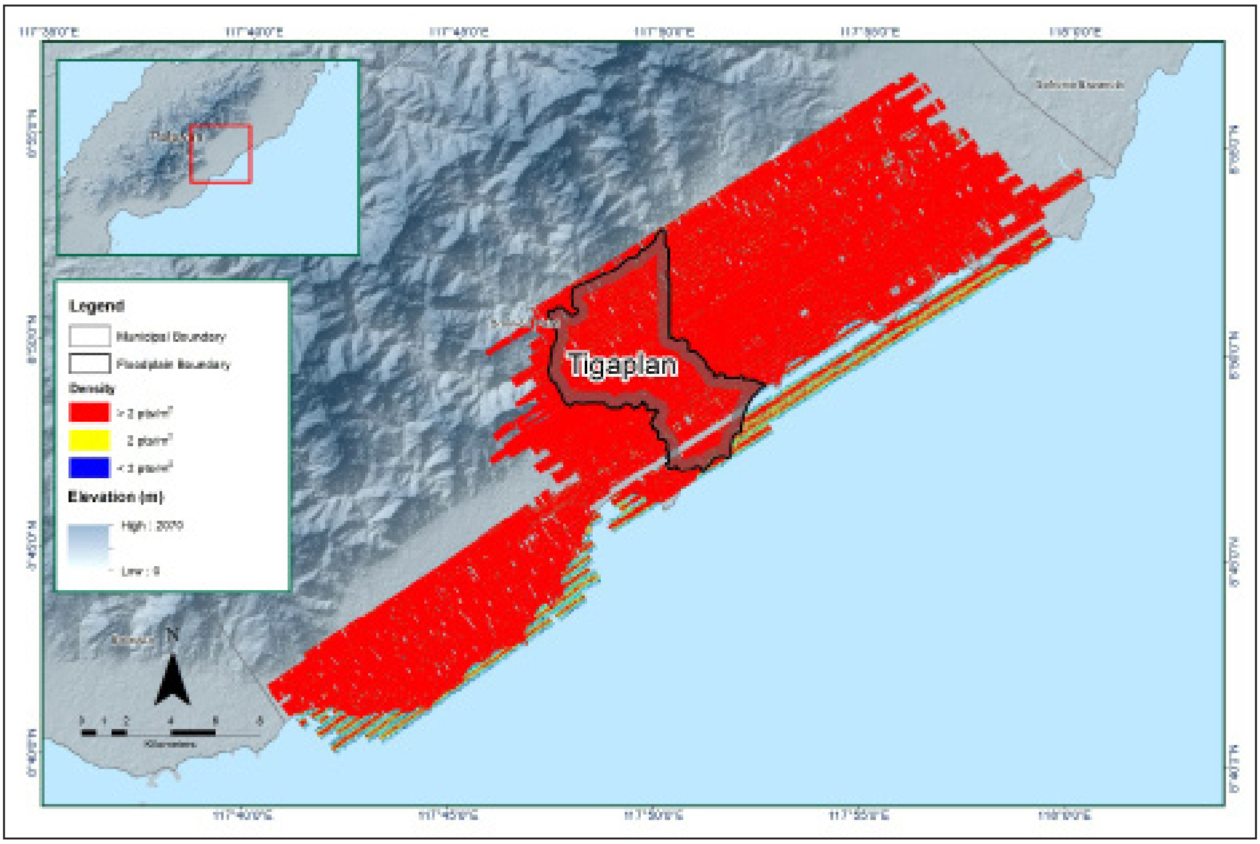


Figure 14. Pulse density map of merged LiDAR data for Tigaplan Floodplain.

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.

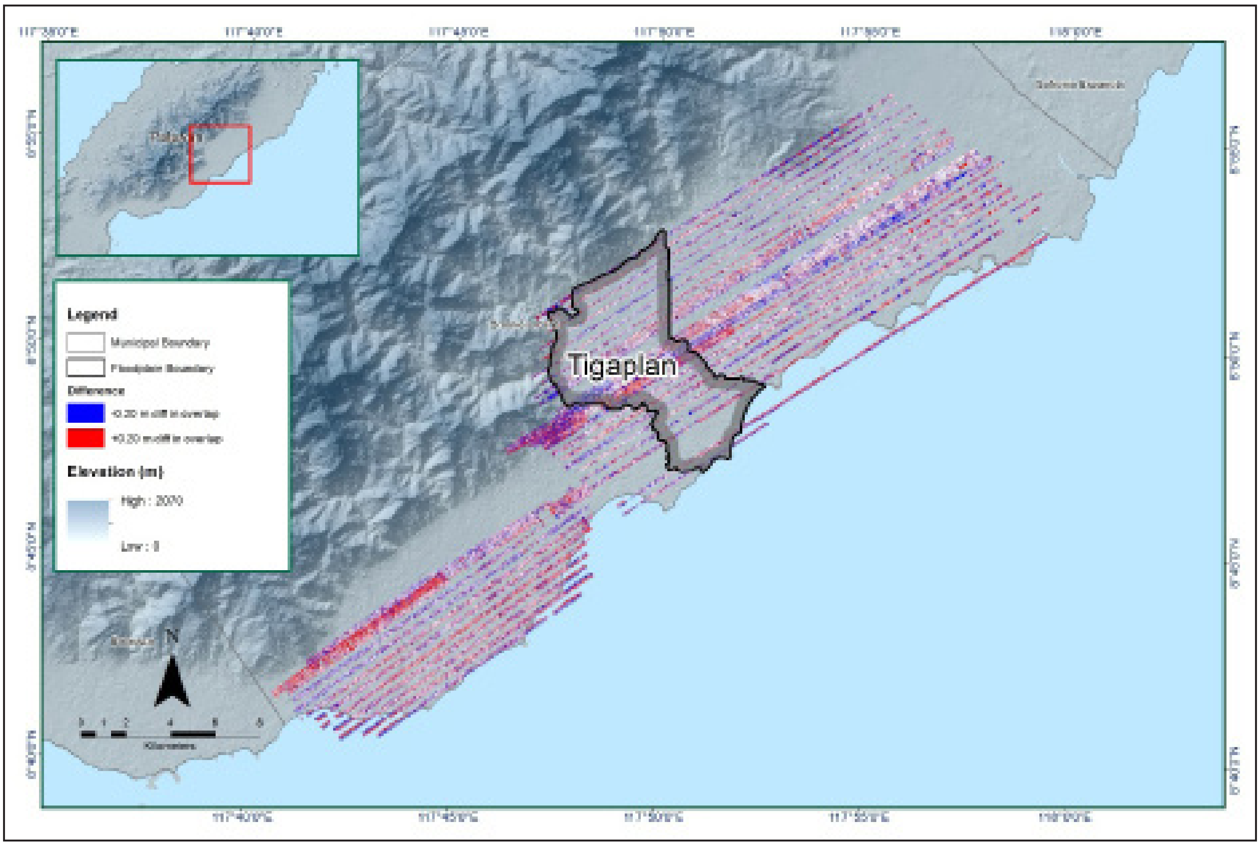


Figure 15. Elevation difference map between flight lines for Tigaplan Floodplain.

A screen capture of the processed LAS data from a Tigaplan flight 3565G 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.

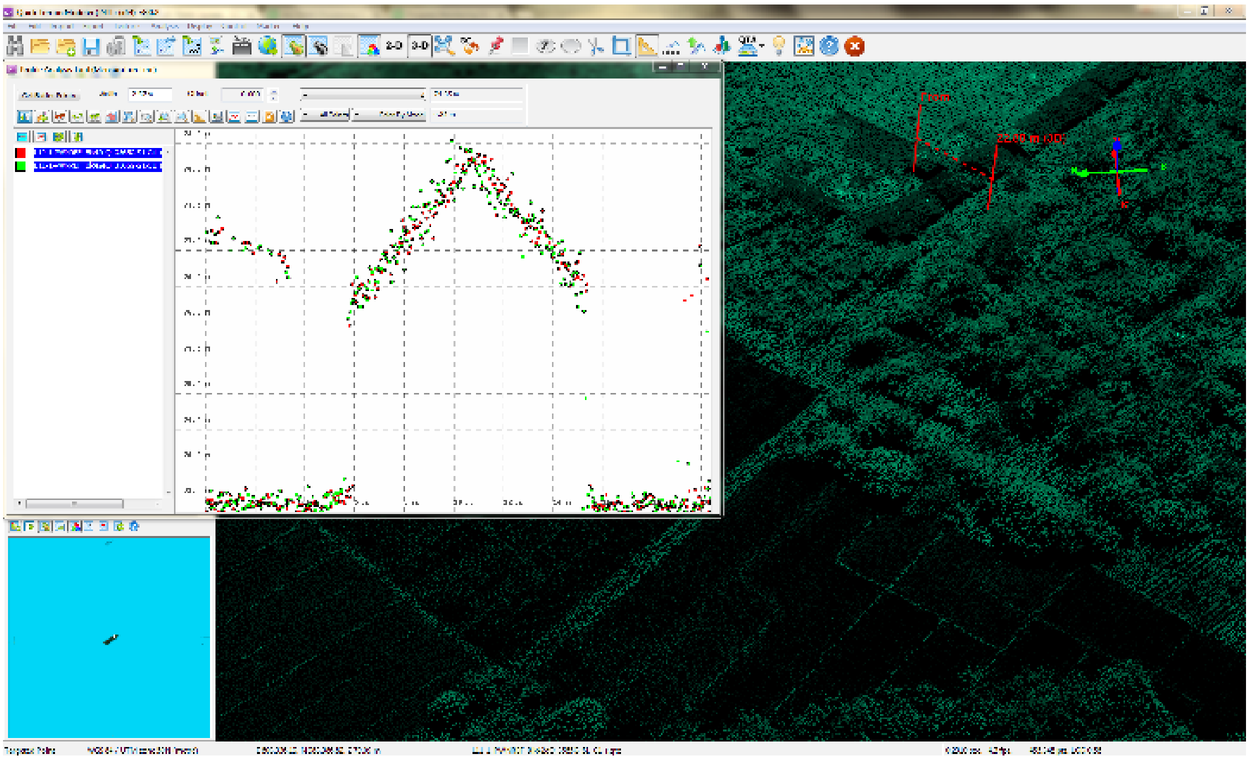


Figure 16. Quality checking for Tigaplan flight 3565G using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 13. Tigaplan classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	135,600,434
Low Vegetation	166,307,003
Medium Vegetation	670,931,515
High Vegetation	469,691,130
Building	4,277,294

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Tigaplan floodplain is shown in Figure 17. A total of 479 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 13. The point cloud has a maximum and minimum height of 760.59 meters and 42.06 meters respectively.

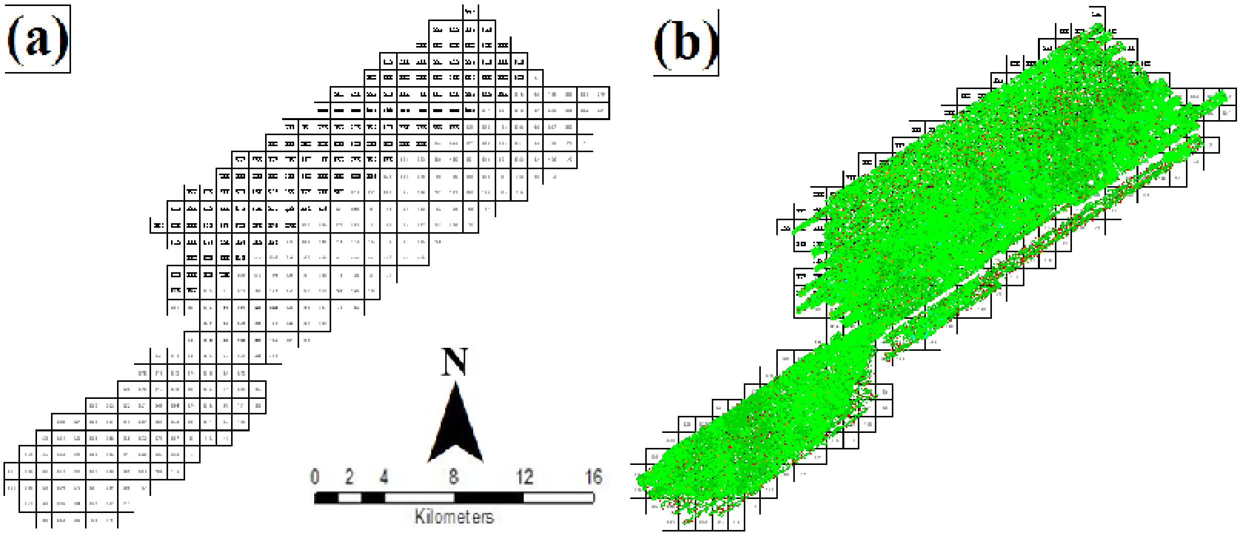


Figure 17. Tiles for Tigaplan Floodplain (a) and classification results (b) in TerraScan.

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.

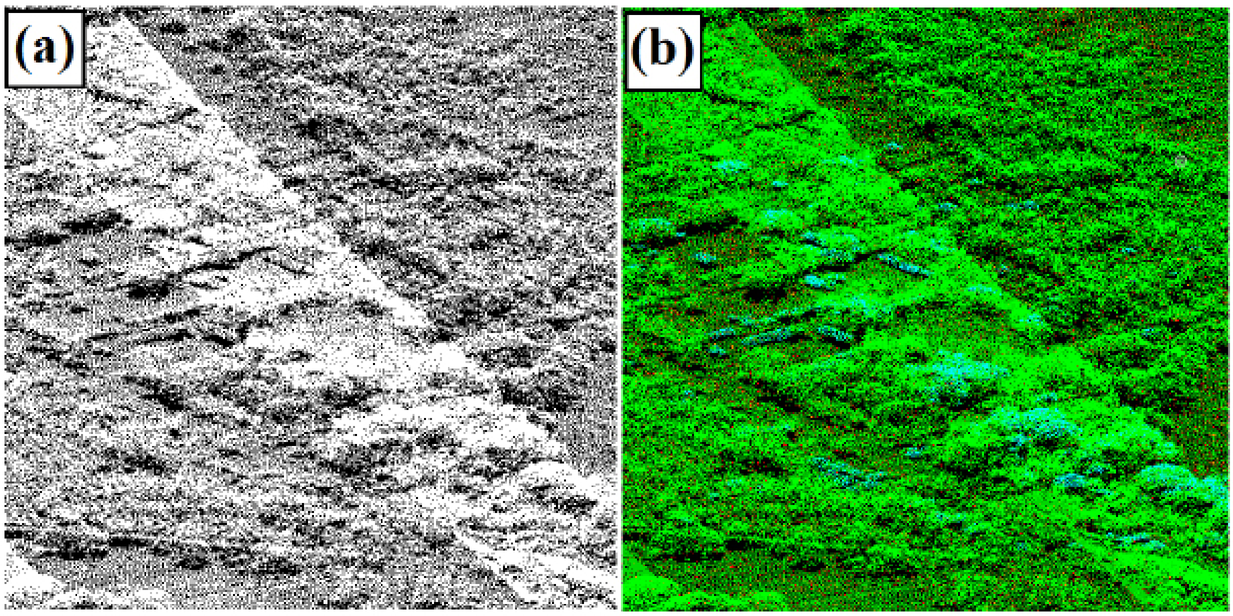


Figure 18. Point cloud before (a) and after (b) classification.

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.

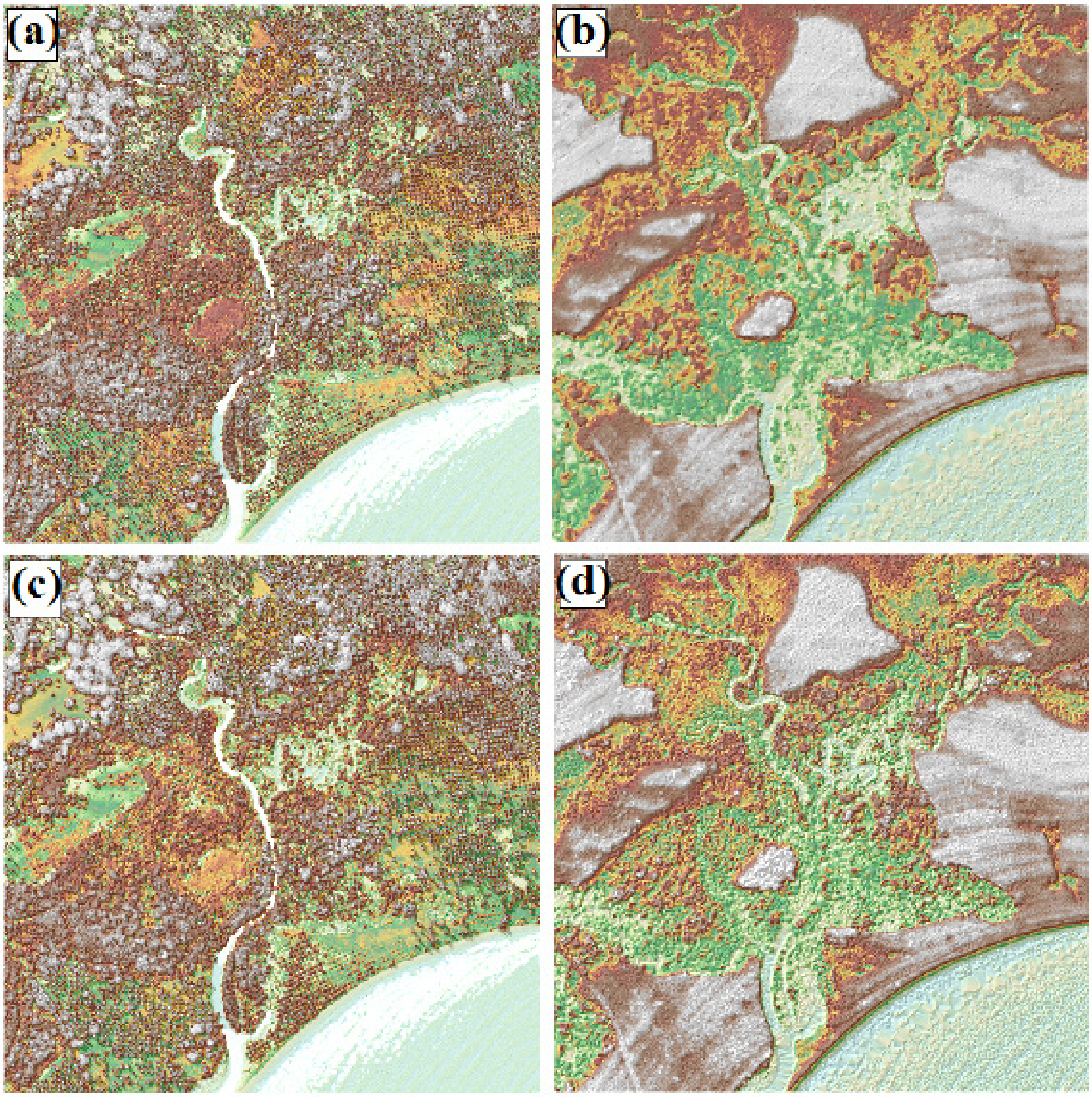


Figure 19. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Tigaplan Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

There are no available orthophotographs for the Tigaplan floodplain.

3.8 DEM Editing and Hydro-Correction

Three (3) mission blocks were processed for Tigaplan floodplain. These blocks are composed of Palawan_ reflight blocks with a total area of 304.35 square kilometers. Table 14 shows the name and corresponding area of each block in square kilometers.

Table 14. LiDAR blocks with its corresponding area.

LiDAR Blocks	Area (sq.km)
Palawan_Reflight_Blk42eP	90.49
Palawan_Reflight_Blk42eQ	137.52
Palawan_Reflight_Blk42eR	76.34
TOTAL	304.35 sq.km

DTM before and after manual editing are shown in Figure 22. The data gap (Figure 22a) has been filled to complete the surface (Figure 22b) to allow the correct flow of water. A part of the profile of the waterway (Figure 22c) was elevated and has to be interpolated (Figure 22d).

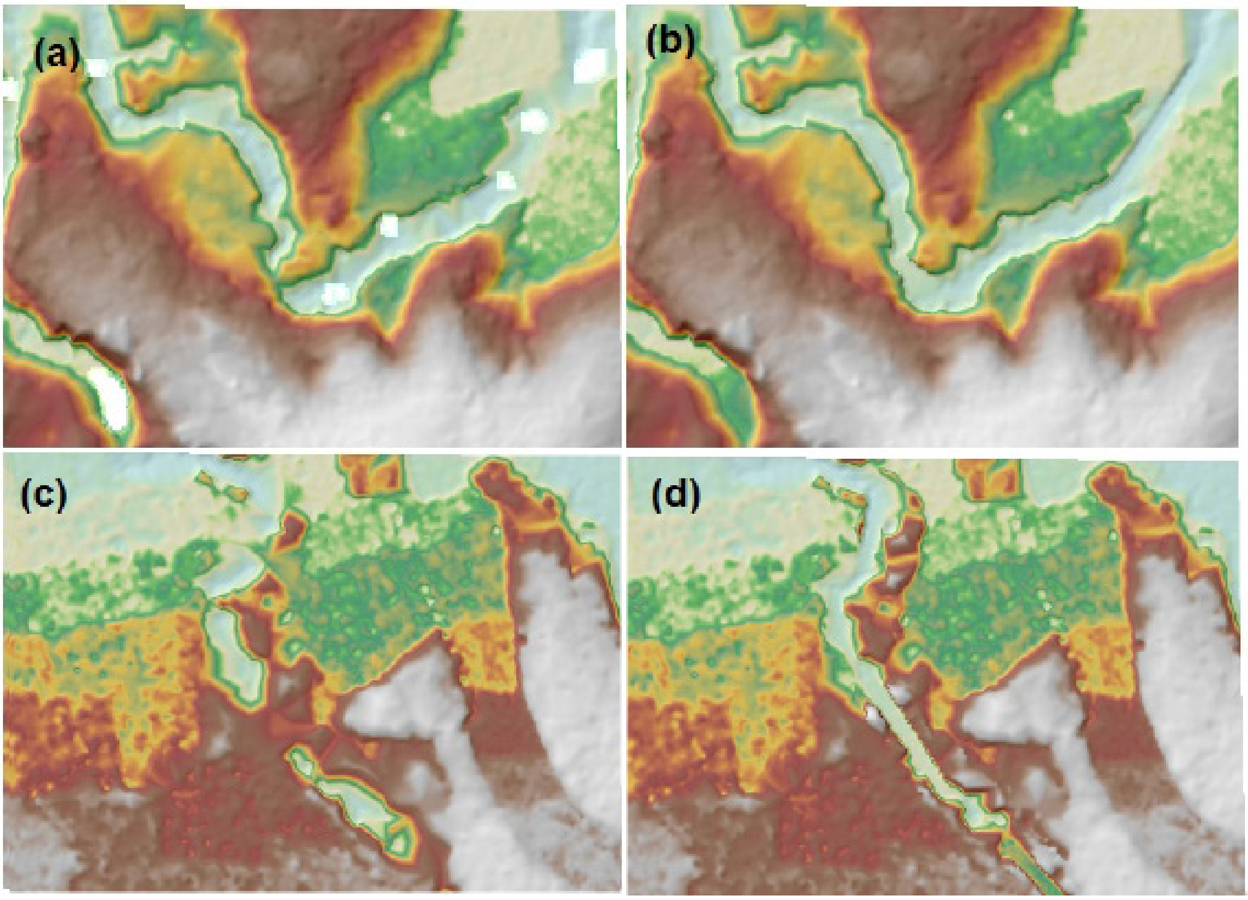


Figure 20. Portions in the DTM of Tigaplan Floodplain – data gaps before (a) and after (b) filling; an elevated part of the waterway before (a) and after (b) manual editing.

3.9 Mosaicking of Blocks

Palawan Block 42AB 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 Tigaplan floodplain, it was concluded that the elevation of the DTM for all of the blocks needed adjustment before merging. Table 15 hows the shift values applied to the LiDAR block during mosaicking.

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

Table 15. Shift Values of each LiDAR Block of Tigaplan Floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
Palawan_Reflight_Blk42eP	0.00	0.00	6.60
Palawan_Reflight_Blk42eQ	0.00	0.00	5.73
Palawan_Reflight_Blk42eR	0.00	0.00	6.22

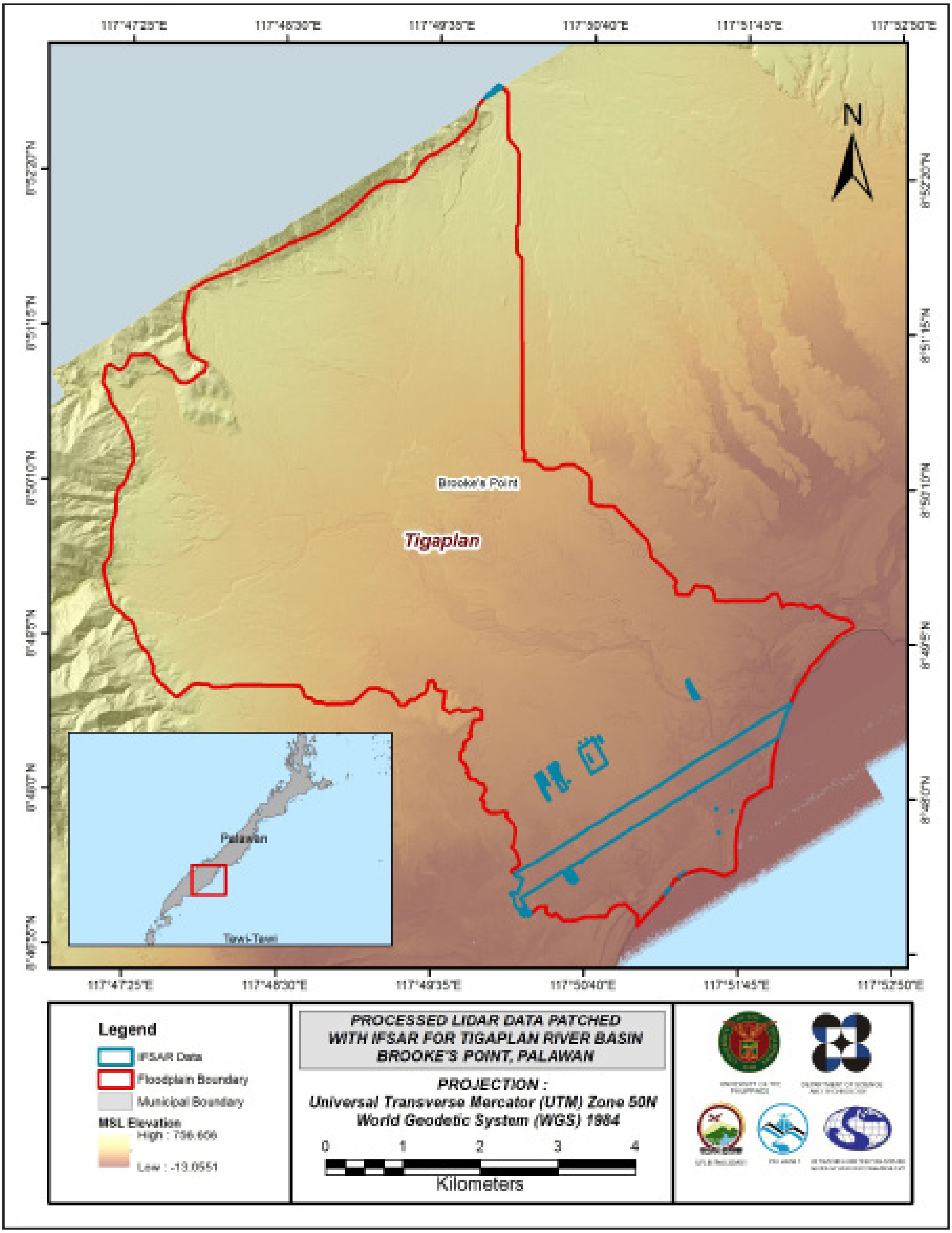


Figure 21. Map of Processed LiDAR Data for Tigaplan Floodplain.

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 Tigaplan to collect points with which the LiDAR dataset is validated is shown in Figure 24. A total of 4,785 survey points were used for calibration and validation of Tigaplan LiDAR data. Random selection of 80% of the survey points, resulting to 3,828 points, was used for calibration.

The 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 10.16 meters with a standard deviation of 0.20 meters. Calibration of Tigaplan LiDAR data was done by adding the height difference value, 10.16 meters, to Tigaplan mosaicked LiDAR data. Table 16 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

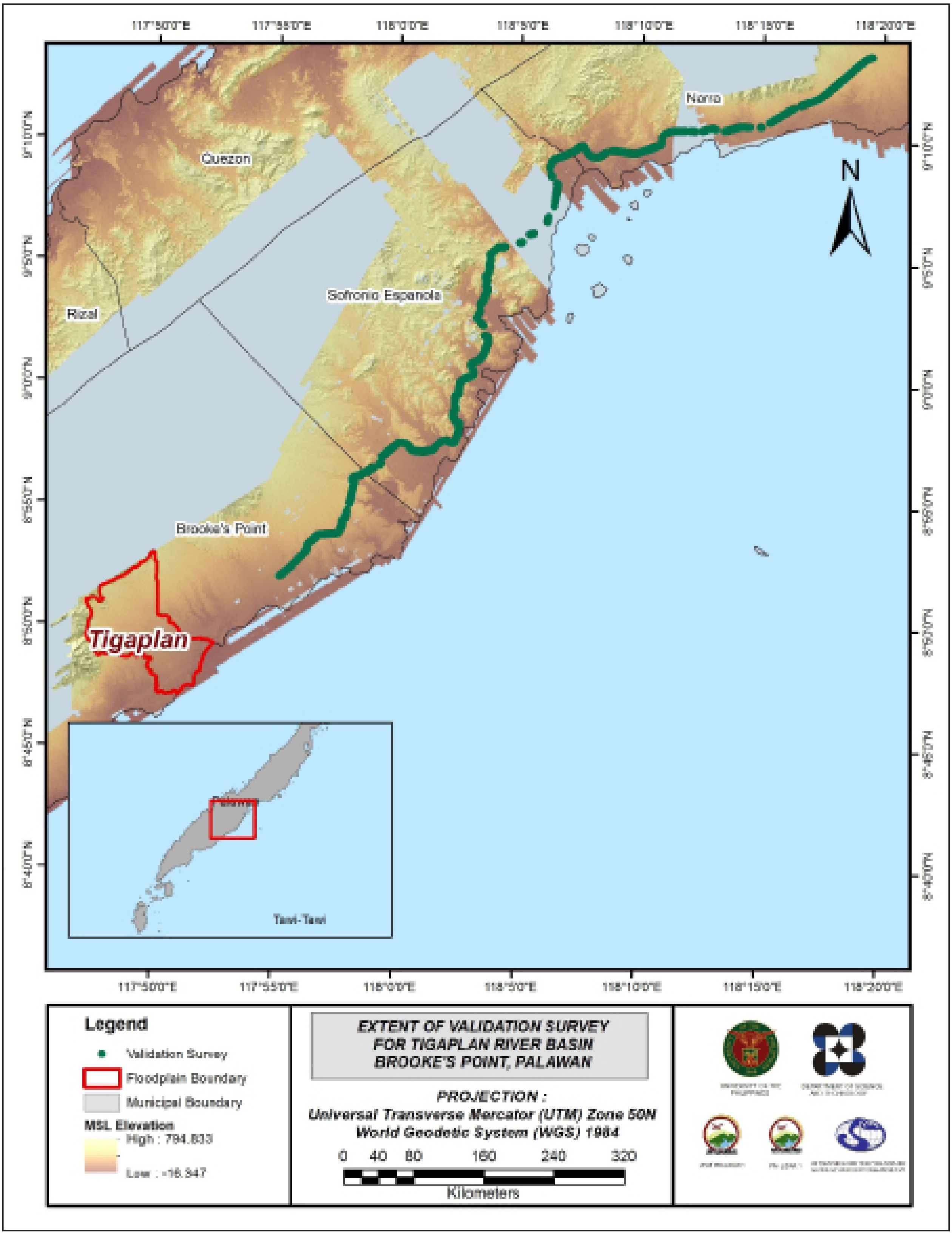


Figure 22. Map of Tigaplan Floodplain with validation survey points in green.

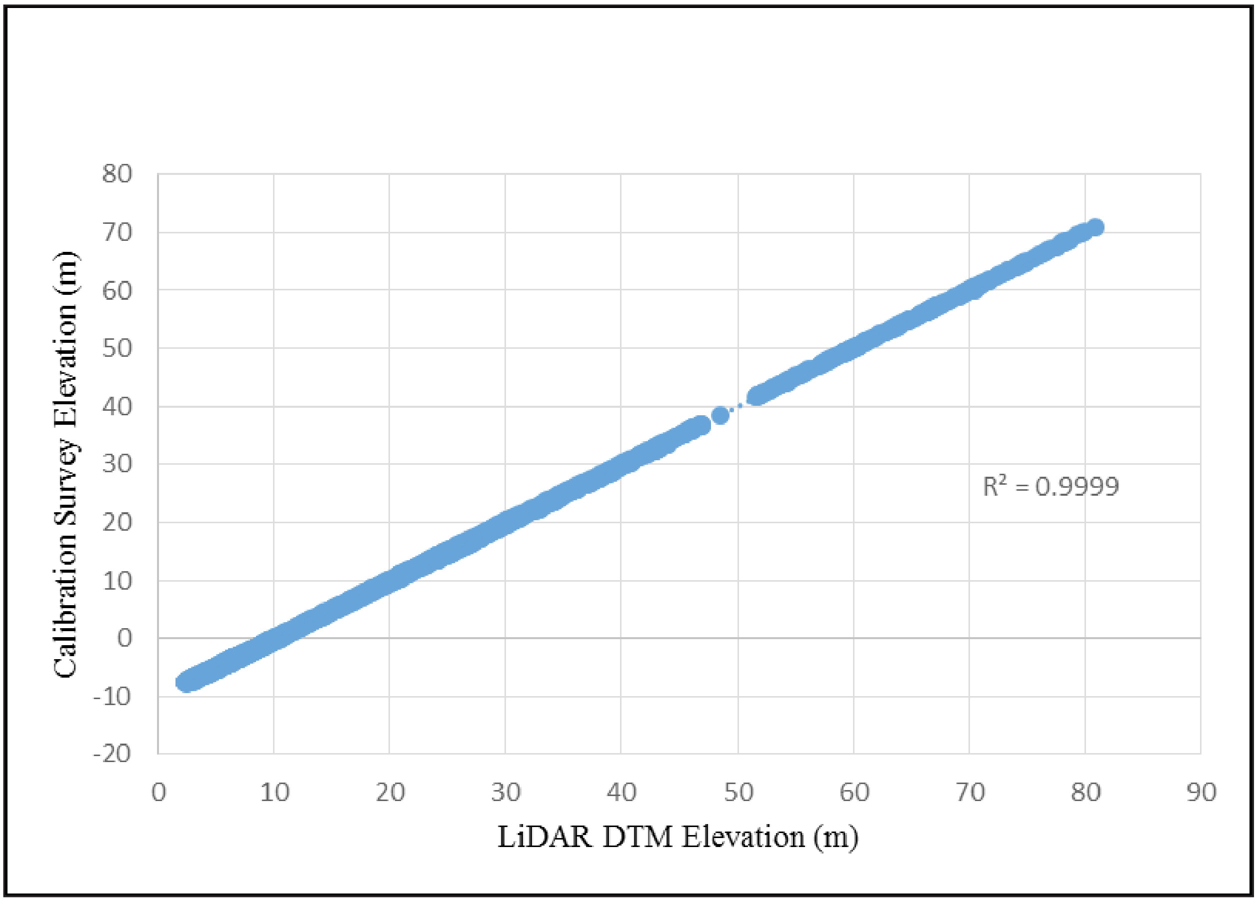


Figure 23. Correlation plot between calibration survey points and LiDAR data.

Table 16. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	10.16
Standard Deviation	0.20
Average	10.16
Minimum	9.77
Maximum	10.55

The remaining 20% of the total survey points, resulting to 528, were used for the validation of calibrated Tigaplan 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 17.

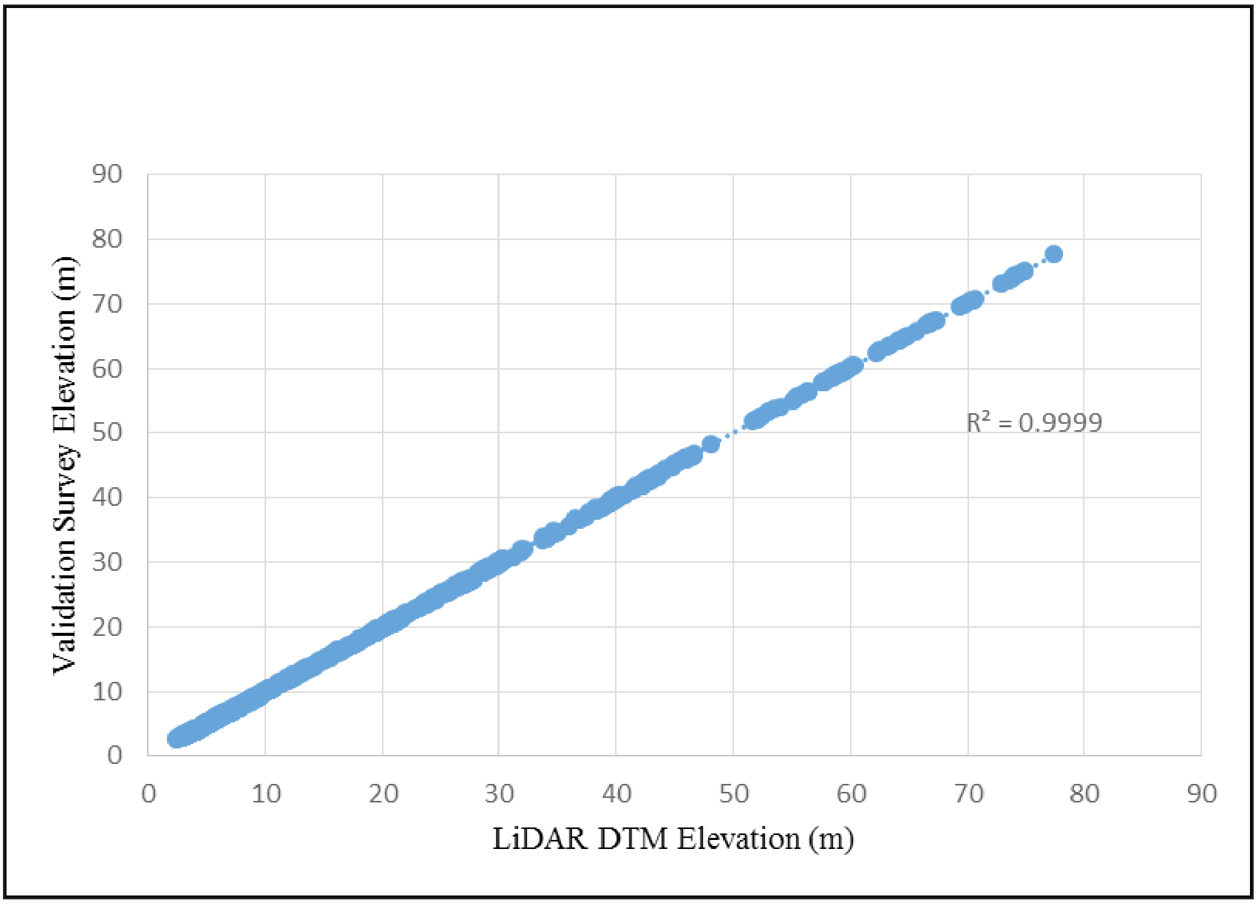


Figure 24. Correlation plot between validation survey points and LiDAR data.

Table 17. Validation Statistical Measures.

Validation Statistical Measures	Value (meters)
RMSE	0.20
Standard Deviation	0.20
Average	-0.001
Minimum	-0.40
Maximum	0.40

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathymetric data integration, only cross section was available for Tigaplan with a total of 2,020 survey points. The resulting raster surface produced was done by Kernel Interpolation with Barrier method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.38 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Tigaplan integrated with the processed LiDAR DEM is shown in Figure 27.

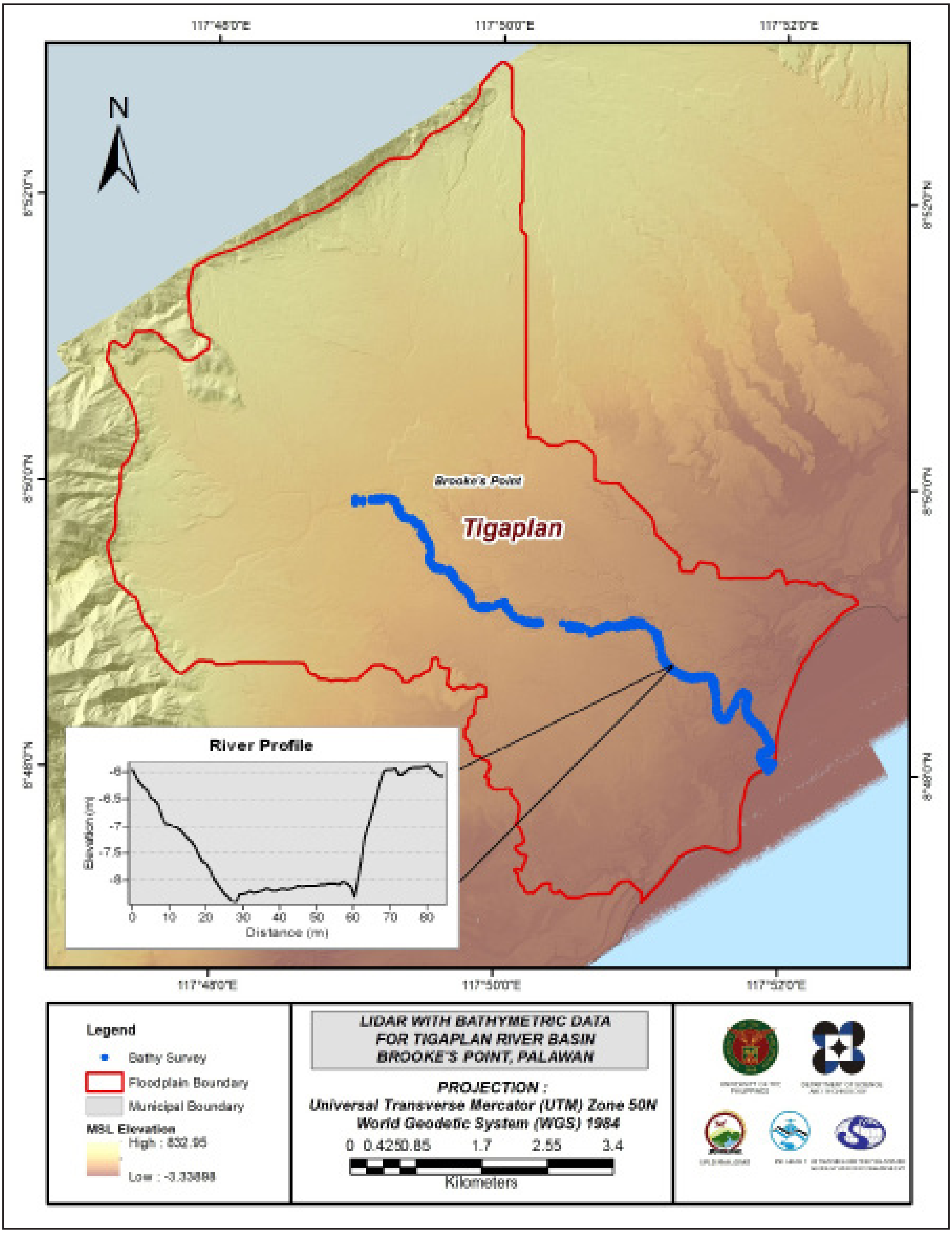


Figure 25. Map of Tigaplan Floodplain with bathymetric survey points shown in blue.

CHAPTER 4: DATA VALIDATION SURVEY AND MEASUREMENTS IN THE TIGAPLAN 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, and 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 Tigaplan River on November 30, 2015 and February 2 to 5, and 8, 2016 with the following scope: reconnaissance; cross-section, bridge as-built and water level marking in MSL of Tigaplan Bridge and manual bathymetric survey from the mouth of the river in Brgy. Barong-Barong to the upstream in Brgy. Imulnod in the Municipality of Brookes Point, Palawan. Random checking points for the contractor's cross-section and bathymetry data were gathered by DVC 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 Tigaplan River Basin area. The entire survey extent is illustrated in Figure 28.

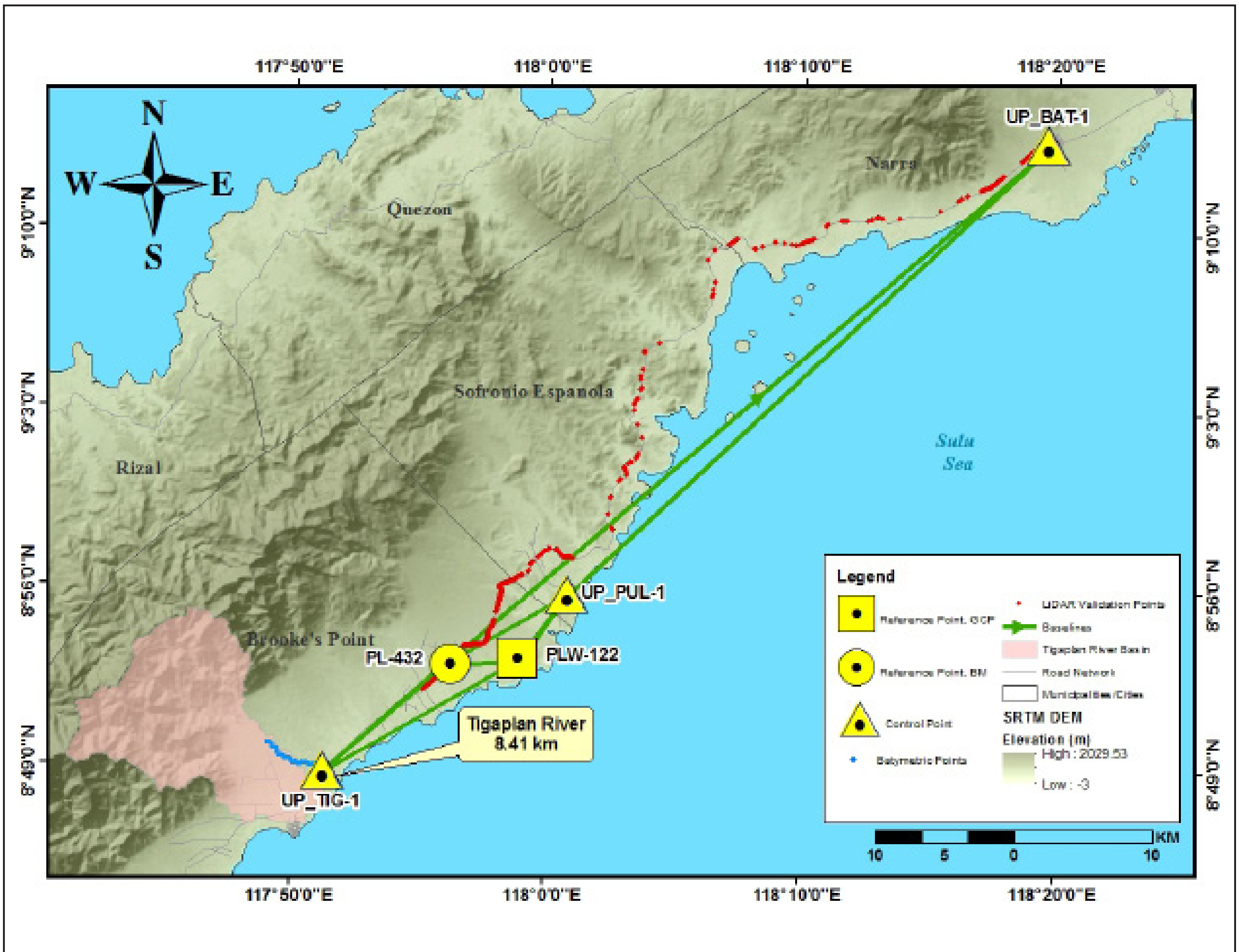


Figure 26. Tigaplan River Survey Extent

4.2 Control Survey

The GNSS network used for Tigaplan River is composed of two (2) loops established on August 23, 2016 occupying the following reference points: PLW-122, a second-order GCP, in Brgy. Calasaguen, Brookes Point, Palawan and PL-432, a first-order BM, in Brgy. Maasin, Brookes Point, Palawan.

Three (3) control points established in the area by ABSD were also occupied: UP_BAT-1 at the approach of Batang-batang Bridge in Brgy. Batang-batang, Narra, Province of Palawan, UP_PUL-1 at the approach of Pulot Bridge in Brgy. Pulot Shore, Sofronio Española, Palawan, and UP_TIG-1 located at the approach of Tigaplan Bridge in Brgy. Barong-barong, Brookes Point, Palawan.

The summary of references and control points and its location is summarized in Table 18 while the GNSS network established is illustrated in Figure 29.

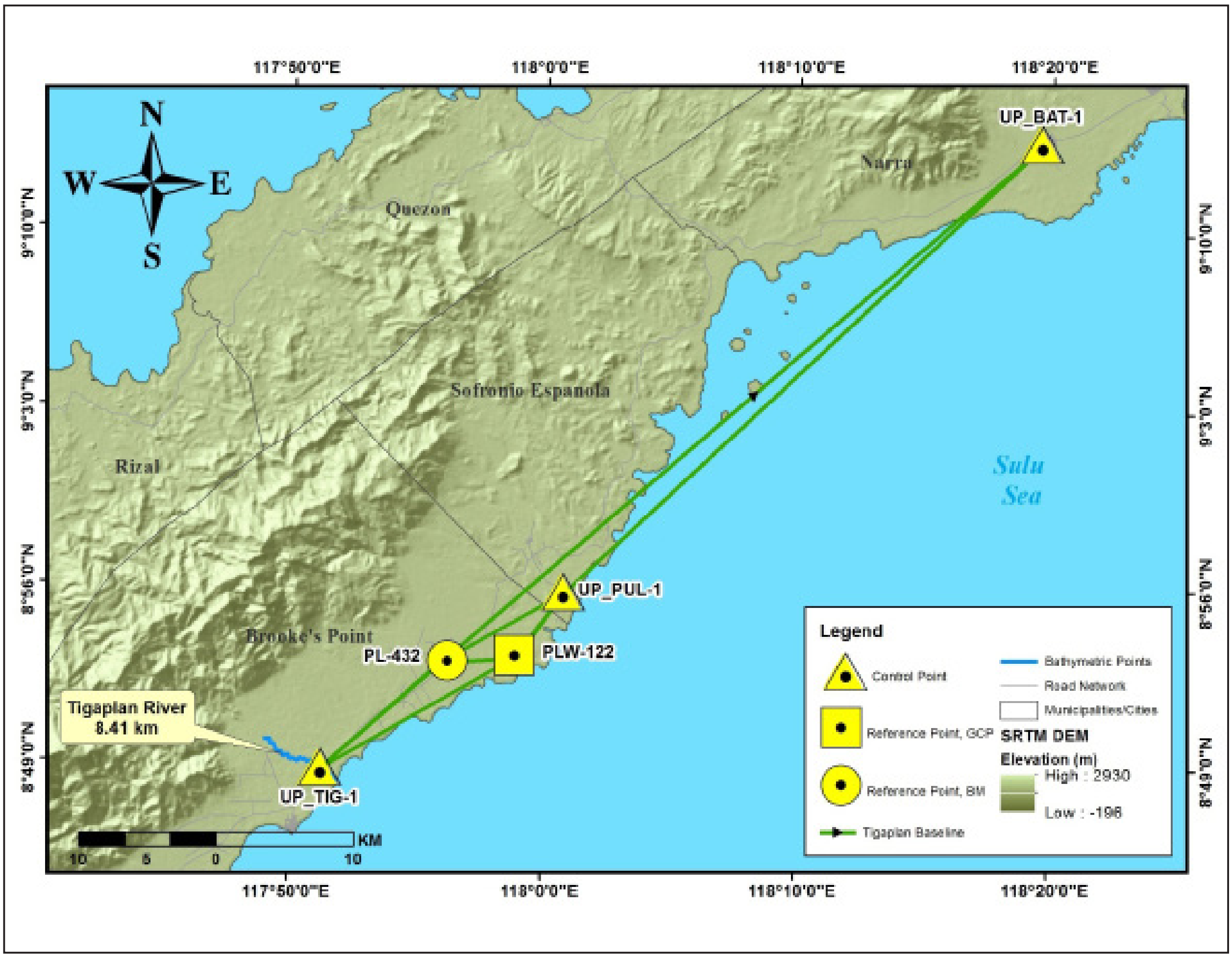


Figure 27. GNSS Network covering Tigaplan River

Table 18. List of reference and control points used during the survey in Tigaplan River (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (Meter)	Elevation in MSL (Meter)	Date Established
PLW-122	2nd order, GCP	8°53'15.04059"N	117°58'54.93380"E	62.283	0.061	2007
PL-432	1st order, BM	8°53'00.38663"N	117°56'15.64298"E	68.495	0.042	2008
UP_BAT-1	Established	9°13'36.17513"	118°19'28.44057"E	99.128	48.319	12-07-15
UP_PUL-1	Established	8°56'59.82715"N	117°59'27.45211"E	61.711	0.064	12-17-15
UP_TIG-1	Established	8°48'46.72587"N	117°51'10.83488"E	60.057	0.086	11-30-15

The GNSS set-ups on recovered reference points and established control points in Tigaplan River are shown from Figure 28 to Figure 32.

Figure 28. GNSS base set up, Trimble® SPS 852, at PLW-122, located in an open lot beside the house of Ms. Liza Jamili in Brgy. Calasaguen, Brookes Point, Province of Palawan

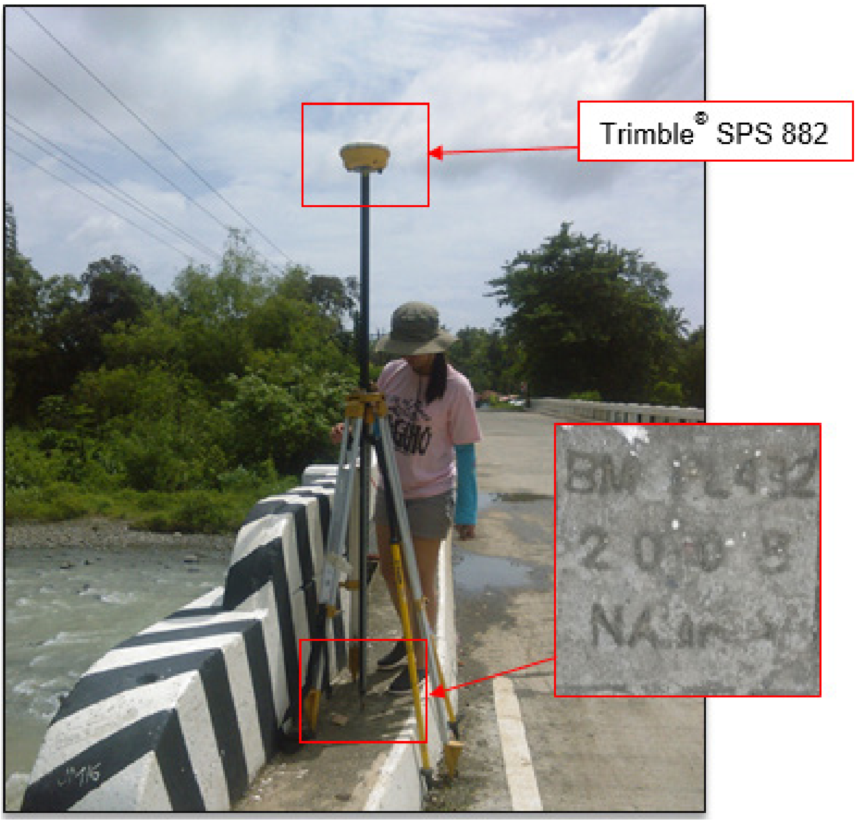


Figure 29. GNSS receiver set up, Trimble® SPS 882, at PL-432, located at the approach of Maasin Bridge in Brgy. Maasin, Brookes Point, Province of Palawan

Figure 30. GNSS receiver set up, Trimble® SPS SPS 882, at UP_BAT-1, located near the approach of Batang-batang Bridge in Brgy. Princesa Urduja, Narra, Province of Palawan

Figure 31. GNSS receiver set up, Trimble® SPS 985, at UP_PUL-1, located at the approach of Pulot Bridge, In Brgy. Pulot Shore, Sofronio Española, Province of Palawan

Figure 32. GNSS receiver set up, Trimble® SPS 985, at UP_TIG-1, located at the approach of Tigaplan Bridge in Brgy. Tigaplan, Brookes Point, Province of Palawan

4.3 Baseline Processing

GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/- 20 cm and +/- 10 cm requirement, respectively. In case where one or more baselines did not meet all of these criteria, masking is performed. Masking is done by removing/masking portions of these baseline data using the same processing software. It is repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, resurvey is initiated. Baseline processing result of control points in Tigaplan River Basin is summarized in Table 19 generated by TBC software.

Table 19. Baseline Processing Report for Tigaplan River Static Survey
(Source: NAMRIA, UP-TCAGP)

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
UP_PUL-1 --- UP_BAT-1	8-23-2016	Fixed	0.034	0.034	230°10'32"	27770.125	-37.471
PL-432 --- UP_BAT-1	8-23-2016	Fixed	0.024	0.024	228°16'42"	57014.957	-30.624
UP_TIG-1 --- UP_PUL-1	8-23-2016	Fixed	0.019	0.019	45°02'06"	21441.510	1.686
UP_TIG-1 --- PL-432	8-23-2016	Fixed	0.026	0.026	50°04'25"	12144.165	8.381
PLW-122 --- UP_PUL-1	8-23-2016	Fixed	0.012	0.012	8°11'07"	6977.113	-0.582
PLW-122 --- PL-432	8-23-2016	Fixed	0.020	0.020	264°43'06"	4887.669	6.201

As shown in Table 19, a total of six (6) baselines were processed with coordinate and ellipsoidal height values of PLW-122 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 form:

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

Where:

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

for each control point. See the Network Adjustment Report shown in Table 20 to Table 22 for complete details.

The five (5) control points, PL-432, PLW-122, UP-BAT-1, UP_PUL-1, and UP-TIG-1 were occupied and observed simultaneously to form a GNSS loop. The coordinates and ellipsoidal height of PLW-122 were held fixed during the processing of the control points as presented in Table 20. Through these reference points, the coordinates and ellipsoidal height of the unknown control points were computed.

Table 20. Control Point Constraints

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
PLW-122	Global	Fixed	Fixed		
UP_BAT-1	Grid				Fixed
UP_BAT-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 21.

Table 21. Adjusted Grid Coordinates

Point ID	Easting	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
PLW-122	607965.609	?	982558.716	?	11.971	0.061	LL
PL-432	603101.186	0.014	982096.040	0.014	18.317	0.042	
UP_BAT-1	645509.020	?	1020187.067	?	48.319	?	LLe
UP_PUL-1	608940.379	0.010	989465.589	0.008	11.454	0.064	
UP_TIG-1	593808.679	0.017	974282.799	0.017	10.210	0.086	

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

a. PLW-122

horizontal accuracy = Fixed

vertical accuracy = Fixed

b. PL-432

horizontal accuracy = $\sqrt{((1.4)^2 + (1.4)^2}$

= $\sqrt{(1.96 + 1.96)}$

= $1.98 < 20$ cm

vertical accuracy = $4.2 < 10$ cm

c. UP_BAT-1

horizontal accuracy = Fixed

vertical accuracy = Fixed

d. UP_PUL-1

horizontal accuracy = $\sqrt{((1.0)^2 + (0.8)^2}$

= $\sqrt{(1.0 + 0.64)}$

= $1.28 < 20$ cm

vertical accuracy = $6.4 < 10$ cm

e. UP_TIG-1

horizontal accuracy = $\sqrt{((1.7)^2 + (1.7)^2}$

= $\sqrt{(2.89 + 2.89)}$

= $2.40 < 20$ cm

vertical accuracy = $8.6 < 10$ cm

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

Table 22. Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
PLW-122	N8°53'15.04059"	E117°58'54.93380"	62.283	0.061	LL
PL-432	N8°53'00.38663"	E117°56'15.64298"	68.495	0.042	
UP_BAT-1	N9°13'36.17513"	E118°19'28.44057"	99.128	?	LLe
UP_PUL-1	N8°56'59.82715"	E117°59'27.45211"	61.711	0.064	
UP_TIG-1	N8°48'46.72587"	E117°51'10.83488"	60.057	0.086	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 22. Based on the result of the computation, the accuracy condition is satisfied; hence, the required accuracy for the program was met.

The summary of reference and control points used is indicated in Table 23.

Table 23. Reference and control points used and its location (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing	Easting	MSL Elevation (m)
PLW-122	2nd order, GCP	N8°53' 15.04059"	E117°58' 54.93380"	85.647	982558.716	607965.609	0.061
PL-432	1st order, BM	N8°53' 00.38663"	E117°56' 15.64298"	63.739	982096.040	603101.186	0.042
UP_BAT-1	Established	N9°13' 36.17513"	E118°19' 28.44057"	48.751	1020187.067	645509.020	48.319
UP_PUL-1	Established	N8°56' 59.82715"	E117°59' 27.45211"	52.045	989465.589	608940.379	0.064
UP_TIG-1	Established	N8°48' 46.72587"	E117°51' 10.83488"	48.192	974282.799	593808.679	0.086

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

Cross-section and as-built surveys were conducted on November 30, 2015 at the upstream side of Tigaplan Bridge in Brgy. Tigaplan, Municipality of Brookes Point as shown in Figure 33. A Horizon® Total Station (HTS-585 ARX) was utilized for this survey as shown in Figure 34.

Figure 33. Tigaplan Bridge facing downstream

Figure 34. As-built survey of Tigaplan Bridge

The cross-sectional line of Tigaplan Bridge is about 139.954 m with sixty-three (63) cross-sectional points using the control points UP_TIG-1 and UP_TIG-2 as the GNSS base stations. The location map, cross-section diagram, and the bridge data form are shown in Figure 35 to Figure 37.

Gathering of random points for the checking of ABSD's bridge cross-section and bridge points data was performed by DVBC on August 25, 2016 using a survey grade GNSS Rover receiver attached to a 2-m pole. Linear square correlation (R2) and RMSE analysis were performed on the two (2) datasets. The linear square coefficient range is determined to ensure that the submitted data of the contractor is within the accuracy standard of the project which is ±20 cm and ±10 cm for horizontal and vertical, respectively. The R2 value must be within 0.85 to 1. An R2 approaching 1 signifies a strong correlation between the vertical (elevation values) of the two datasets. A computed R2 value of 0.9339 was obtained was obtained by comparing the data of the contractor and DVBC; signifying a strong correlation between the two (2) datasets.

In addition to the Linear Square correlation, Root Mean Square (RMSE) analysis is also performed in order to assess the difference in elevation between the DVBC checking points and the contractor's. The RMSE value should only have a maximum radial distance of 5 m and the difference in elevation within the radius of 5 meters should not be beyond 0.50 m. For the bridge cross-section data, a computed value of 0.1005 with a radial maximum radial distance of 7.2515 which exceeds the allowable 5 meters. However, since the checking points were gathered on the paved area of the bridge, the value has been deemed acceptable.

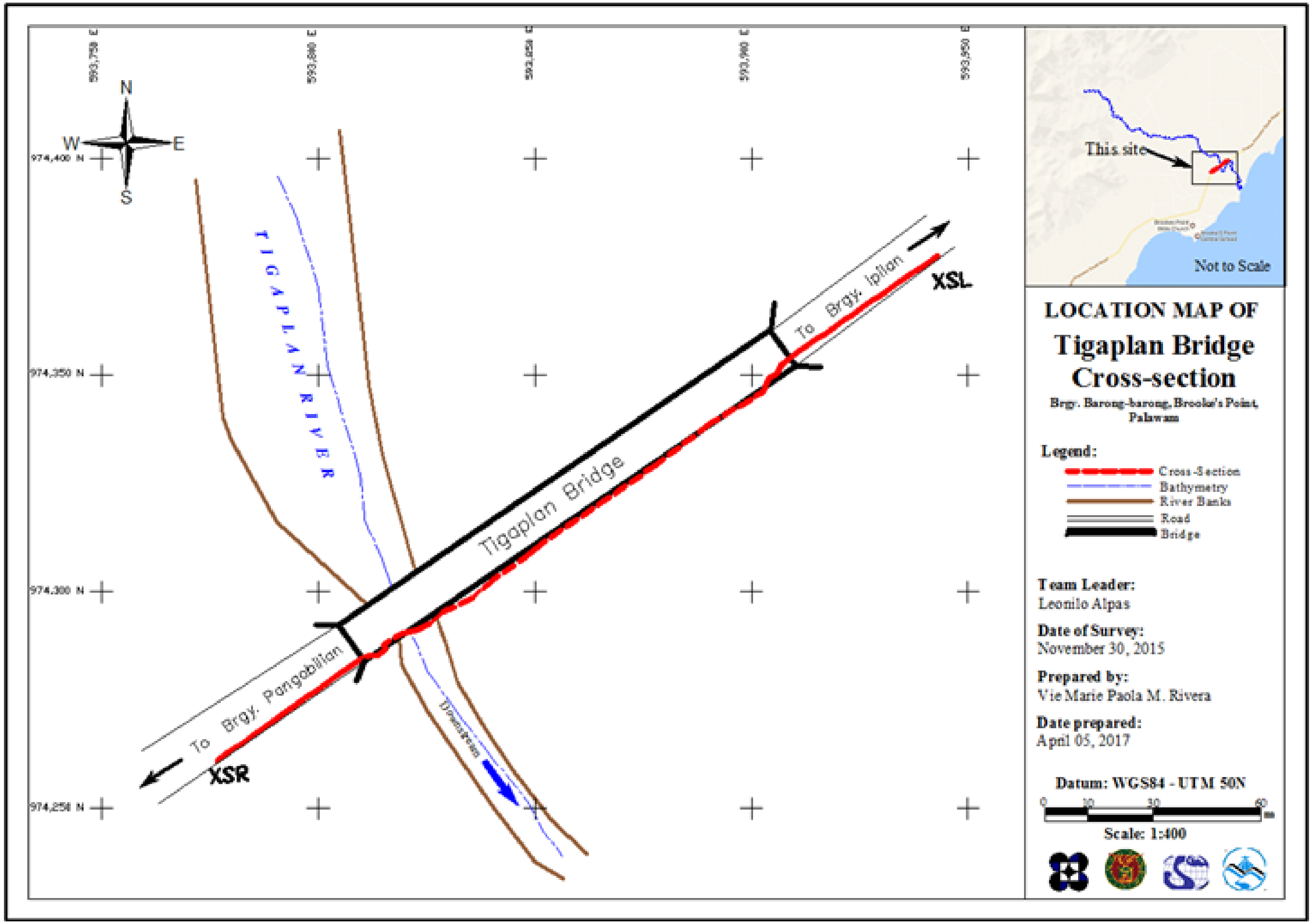


Figure 35. Location map of Tigaplan Bridge River cross-section survey

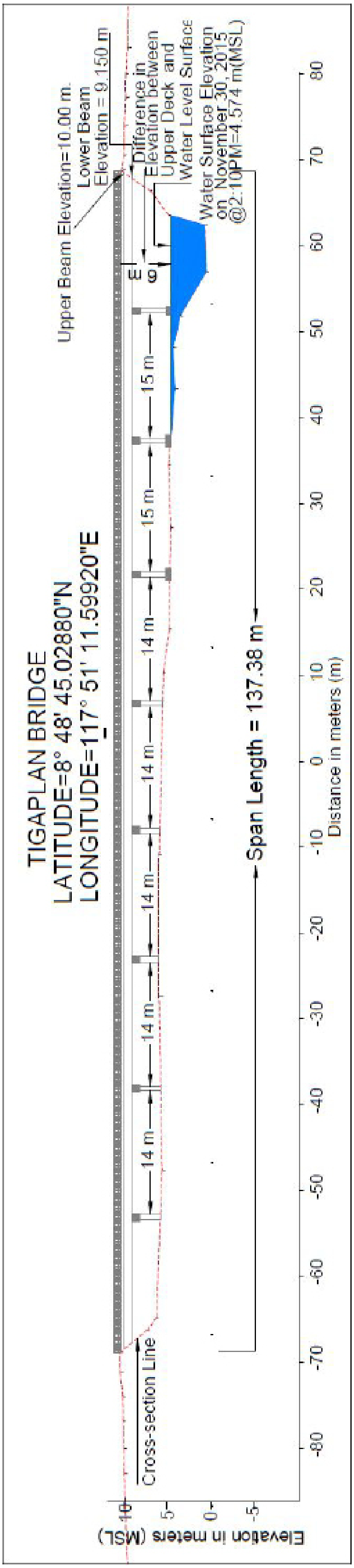


Figure 36. Tigaplan Bridge cross-section diagram

Bridge Data Form

Bridge Name: TIGA PLAN BRIDGE

River Name: TIGA PLAN RIVER

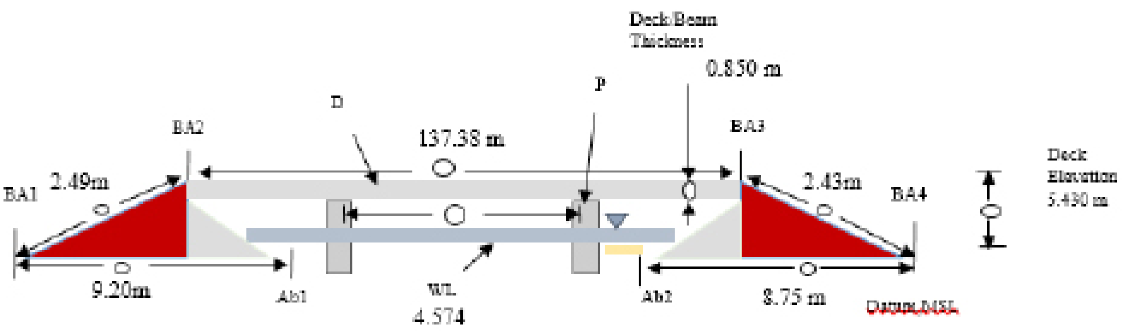
Location (Brgy,City,Region): Brgy. Barong-Barong, Municipality of Brooke's Point, Palawan

Survey Team: Nilo Alpas, Arnel Nemenzo
Date and Time: November 30, 2015, 2:10 pm

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	2.49 m	
2. BA2-BA3	137.38 m	
3. BA3-BA4	2.43 m	
4. BA1-Ab1	9.20 m	
5. Ab2-BA4	8.75 m	
6. Deck/beam thickness	0.850 m	
7. Deck elevation	5.430 m	

Note: Observer should be facing downstream

Figure 37. Bridge as-built form of Tigaplan Bridge

Water surface elevation of Tigaplan River was determined by a Horizon® Total Station on November 30, 2015 at 2:10 pm at Tigaplan Bridge area with a value of 4.574 m in MSL as shown in Figure 36. This was translated into marking on the bridge's pier as shown in Figure 38. The marking will serve as reference for flow data gathering and depth gauge deployment of the partner HEI responsible for Tigaplan River, the University of the Philippines Los Baños.

Figure 38. Water-level markings on Tigaplan Bridge

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted by DVBC from August 16-28, 2016 using a survey grade GNSS Rover receiver, Trimble® SPS 985, mounted on a range pole which was attached on the side of the vehicle as shown in Figure 39. It was secured with cable ties and ropes to ensure that it was horizontally and vertically balanced. The antenna height was 1.361 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-122 occupied as the GNSS base station in the conduct of the survey.

Figure 39. Validation points acquisition survey set-up for Tigaplan River

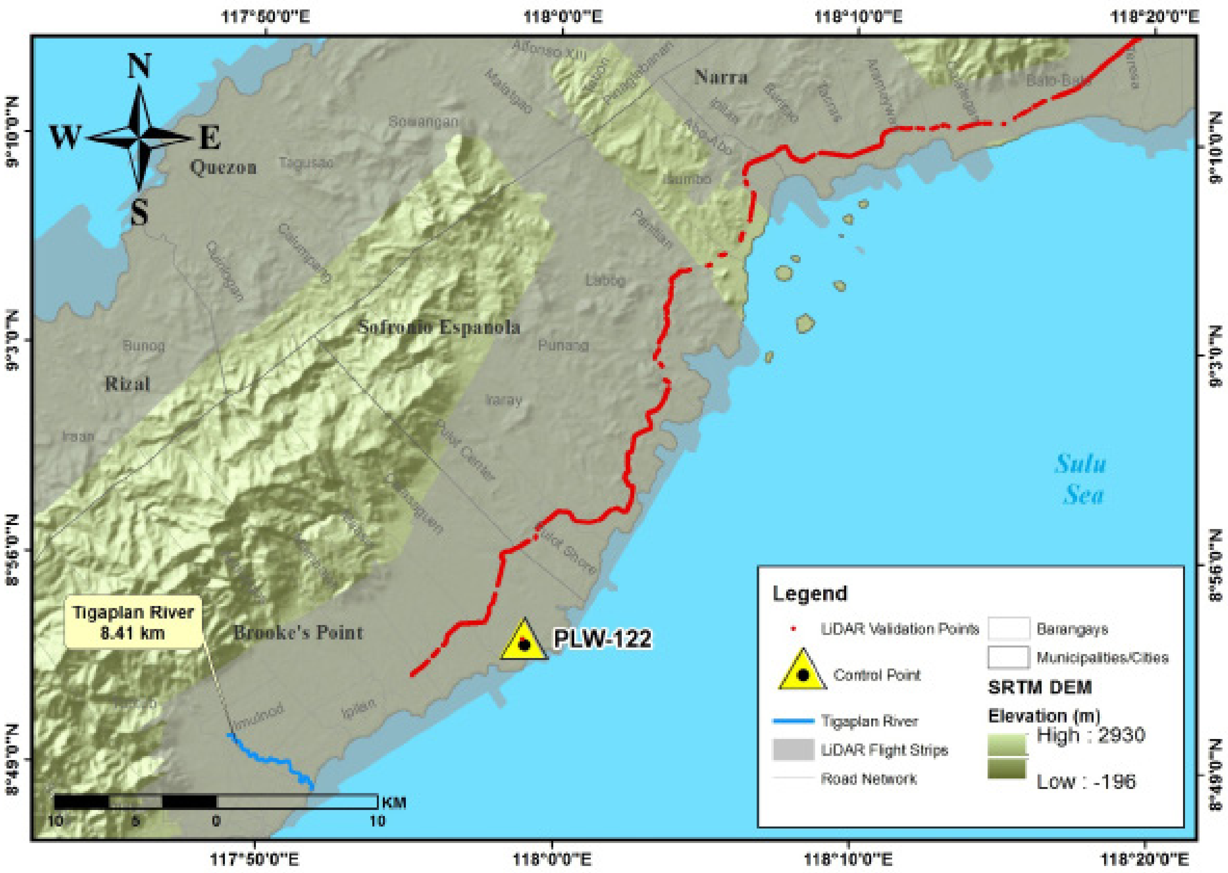


Figure 40. Validation point acquisition survey of Tigaplan River Basin

4.7 Bathymetric Survey

Bathymetric survey was executed from February 2 to 5, 2016 using a Horizon™ Total Station as illustrated in Figure 41. The survey started from the mouth of the river in Brgy. Barong-barong in Municipality of Brookes Point, Palawan with coordinates 8°48'4.73774"N, 117°51'58.22918"E and ended at the upstream of the river in Brgy. Imulnod, Municipality of Quezon as well, with coordinates 8°49'53.86069"N, 117°49'0.11115"E. The control points UP_TIG-1 and UP_TIG-2 were used as GNSS base stations all throughout the entire survey.

No bathymetric checking points were gathered for Tigaplan River due to heavy rains which rendered the river unnavigable, both on foot and by boat during the time of quality checking.

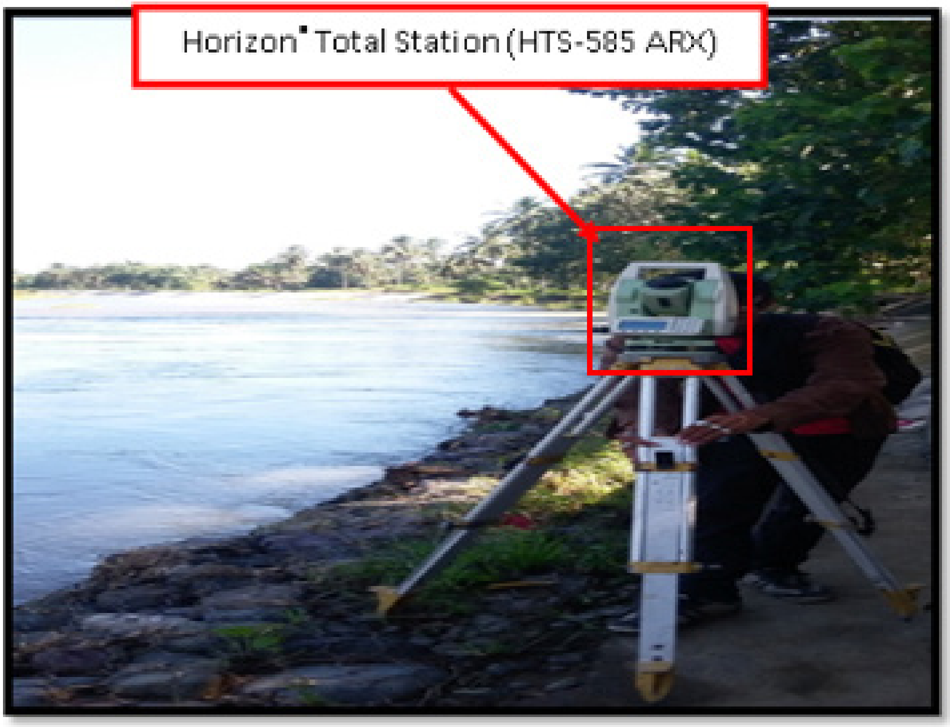


Figure 41. Bathymetric survey of ABSD at Tigaplan River using a Hi-Target™ GNSS Rover Receiver

The bathymetry points covered an estimated total length of 8.41 km gathered starting from the mouth of the river at Barangay Barong-barong down to the upstream of the river in Brgy. Imulnod as shown in Figure 42.

Figure 42. Bathymetric survey of Tigaplan River

A CAD drawing was also produced to illustrate the riverbed profile of Tigaplan River. As shown in Figure 43, the highest and lowest elevation has a 22-m difference. The highest elevation observed was 22.38 m above MSL located in Brgy. Imulnod, Municipality of Brookes Point while the lowest was 0.160 m above MSL located in Brgy. Pangobilian, Municipality of Brookes Point.

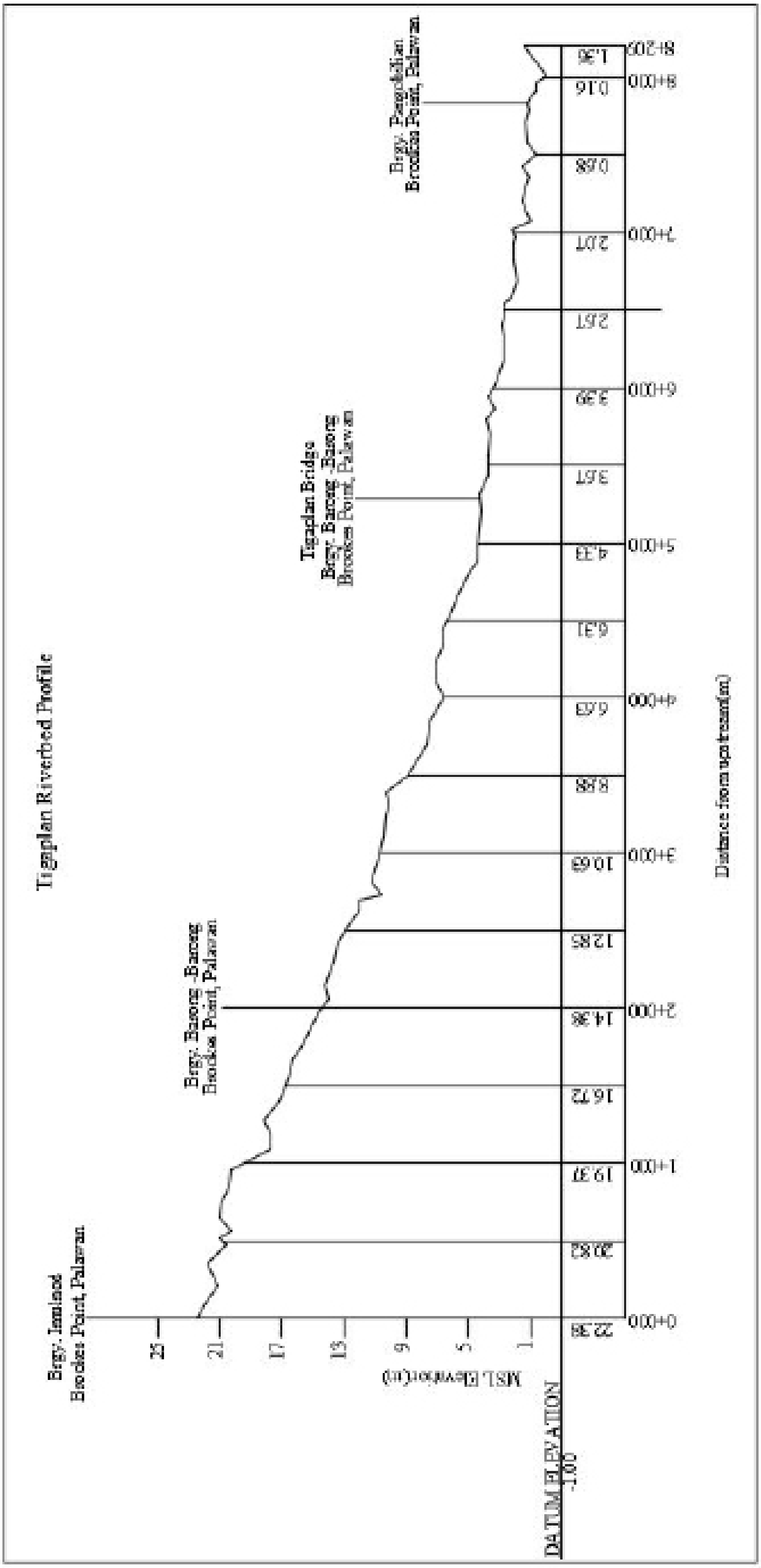


Figure 43. Tigaplan riverbed profile

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

5.1.1 Hydrometry and Rating Curves

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

5.1.2 Precipitation

Precipitation data was taken from a portable rain gauge deployed on a strategic location within the riverbasin (8.794922˚ N, 117.83381˚ E). The location of the rain gauge is seen in Figure 44.

The total precipitation for this event is 29.60 mm. It has a peak rainfall of 10.40 mm on February 24, 2017 at 6:15 am. The lag time between the peak rainfall and discharge is 6 hour and 10 minutes, as seen in Figure 47.

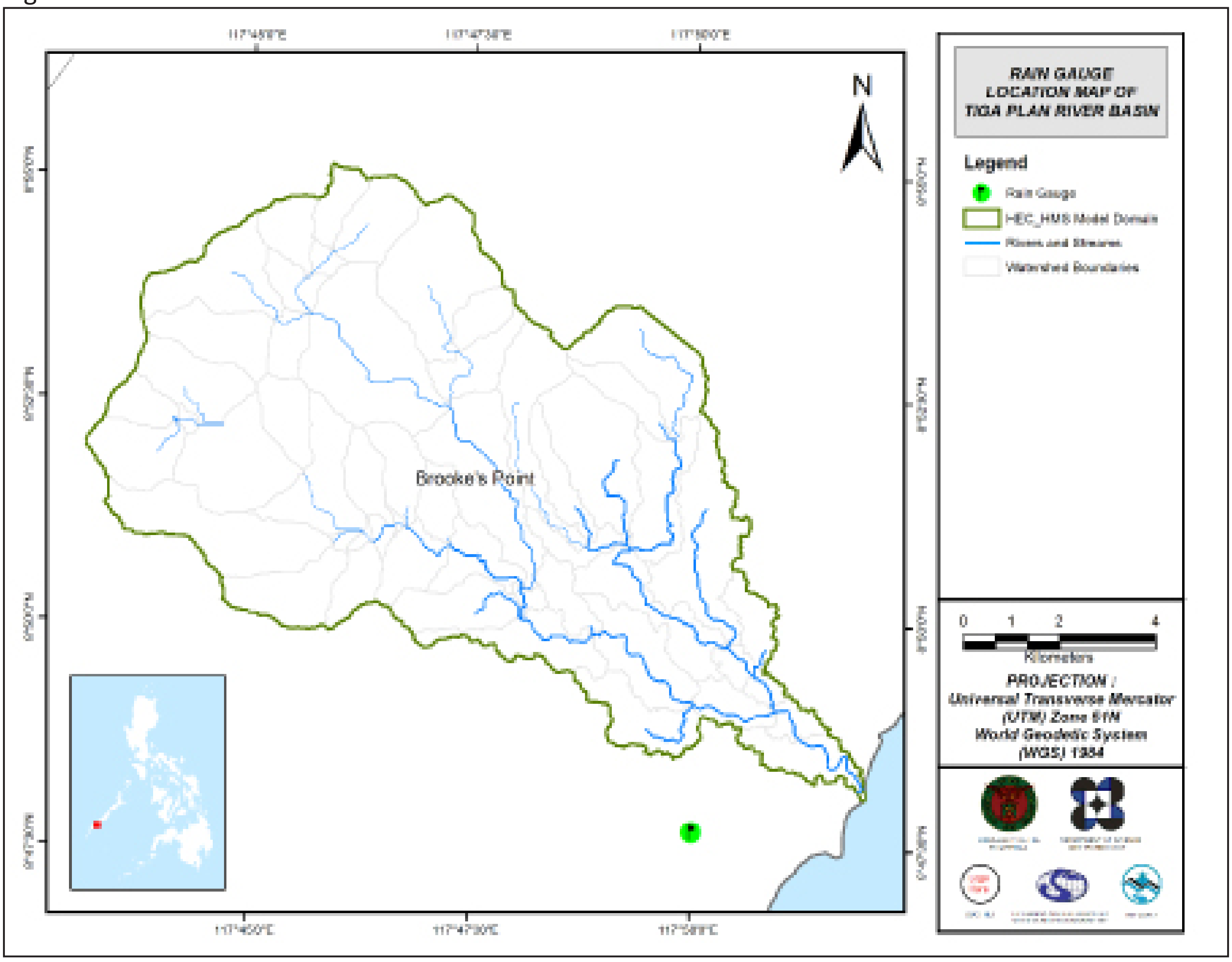


Figure 44. The location map of Tigaplan HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Tigaplan Bridge, Brooke's Point, Palawan (8.812764° N, 117.853500° E). It gives the relationship between the observed water levels from the Tigaplan Bridge and outflow of the watershed at this location using Bankfull Method in Manning's Equation.

For Tigaplan Bridge, the rating curve is expressed as Q = 59.838x2 -443.28x +820.97 as shown in Figure 46.

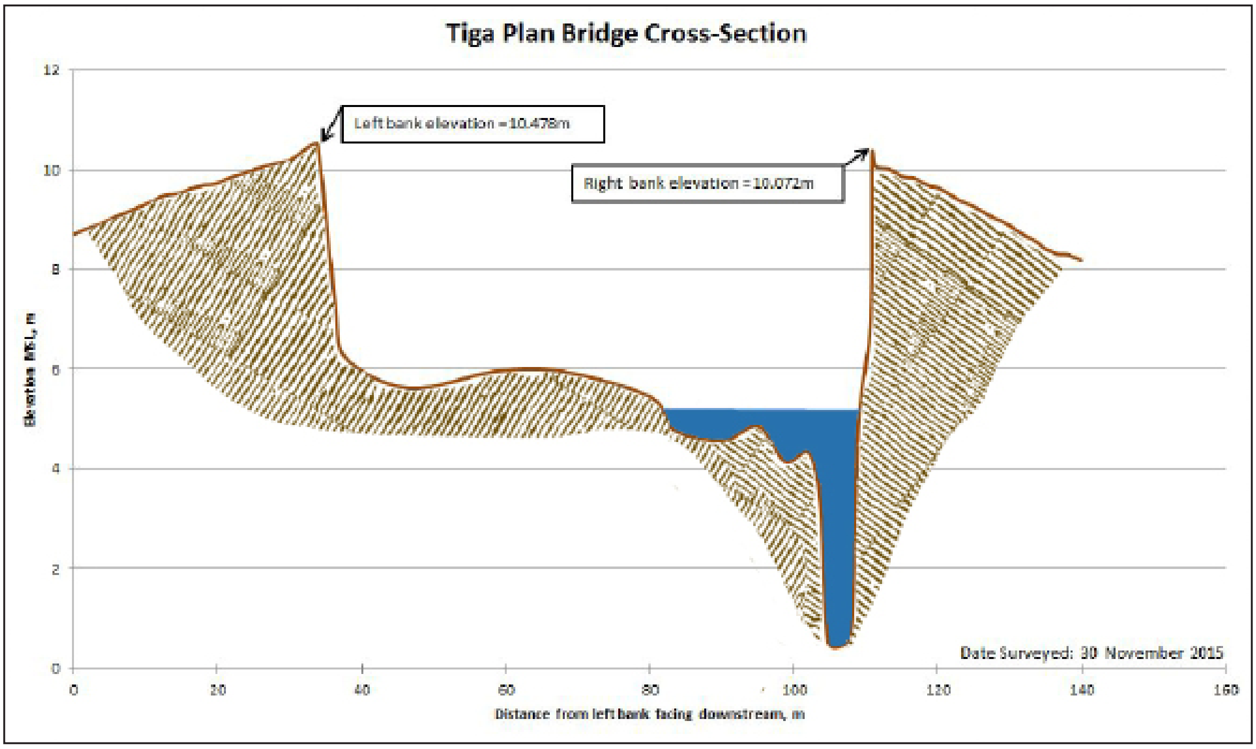


Figure 45. Cross-Section Plot of Tigaplan Bridge

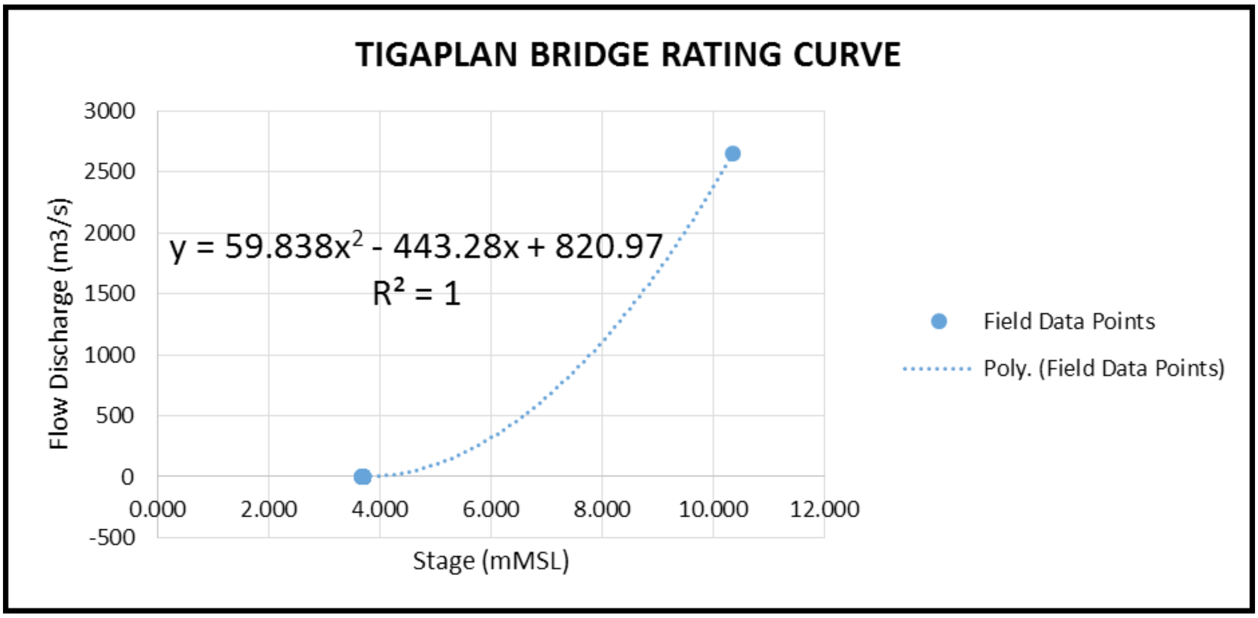


Figure 46. Rating curve at Tigaplan Bridge, Brooke's Point, Palawan

For the calibration of the HEC-HMS model, shown in Figure 47, actual flow discharge during a rainfall event was collected in the Tigaplan bridge. Peak discharge is 46.70 cu.m/s on February 24, 2017 at 12:25 pm.

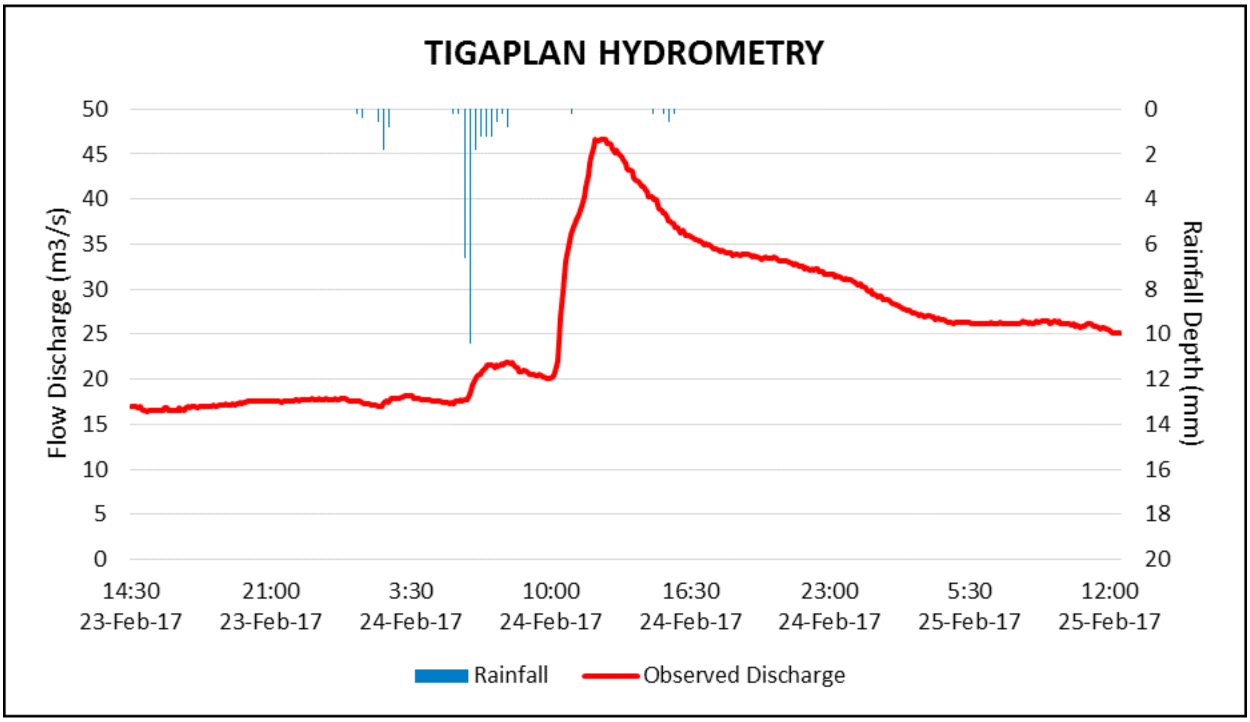


Figure 47. Rainfall and outflow data at Tigaplan River Basin used for modeling

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the 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 Tigaplan watershed. The extreme values for this watershed were computed based on a 58-year record, with the computed extreme values shown in Table 24.

Table 24. values for Romblon 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	22.7	35.5	36.3	50.2	68.2	80.1	104.1	125.7	150.8
5	27.9	45.5	53.8	74.2	103.4	122.5	159.7	192.9	226.7
10	34.2	52.1	65.4	90.1	126.7	150.6	196.5	237.3	276.9
15	37.8	57.4	71.9	99	139.8	166.4	217.3	262.4	305.3
20	40.3	61	76.5	105.3	149	177.5	231.9	280	325.1
25	42.2	63.9	80	110.1	156.1	186	243.1	293.5	340.4
50	48.1	72.6	90.9	125	178	212.3	277.6	335.2	387.5
100	54	81.2	101.6	139.8	199.7	238.4	311.8	376.6	434.3

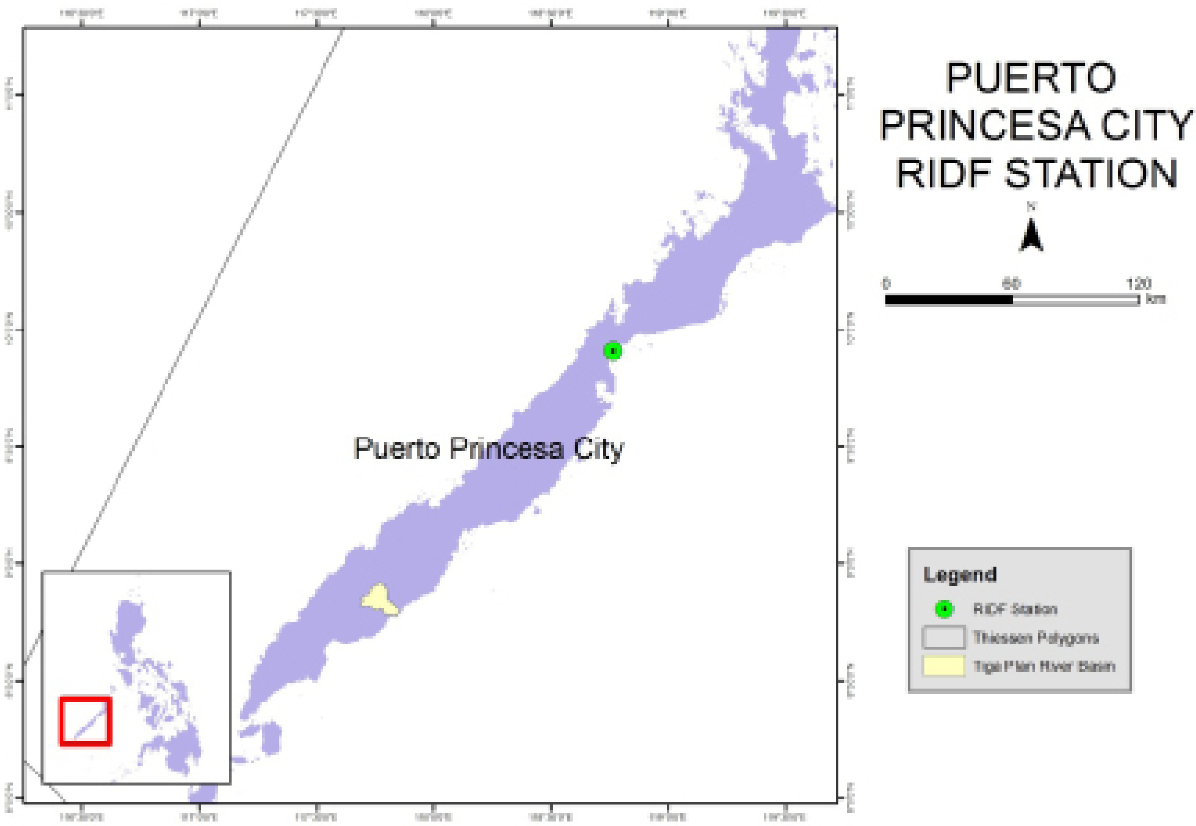


Figure 48. Location of Puerto Princesa RIDF relative to Tigaplan River Basin

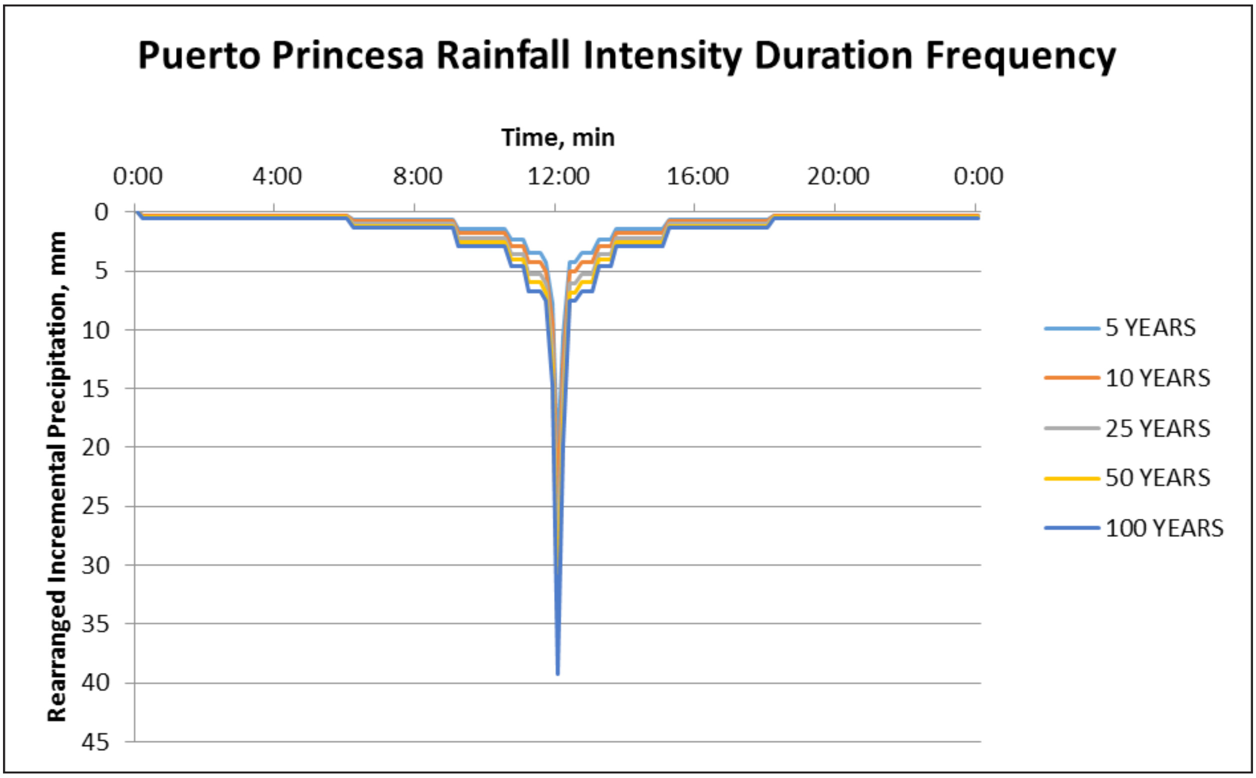


Figure 49. Synthetic storm generated for a 24-hr period rainfall for various return periods.

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 Tigaplan River Basin are shown in Figure 50 and Figure 51, respectively.

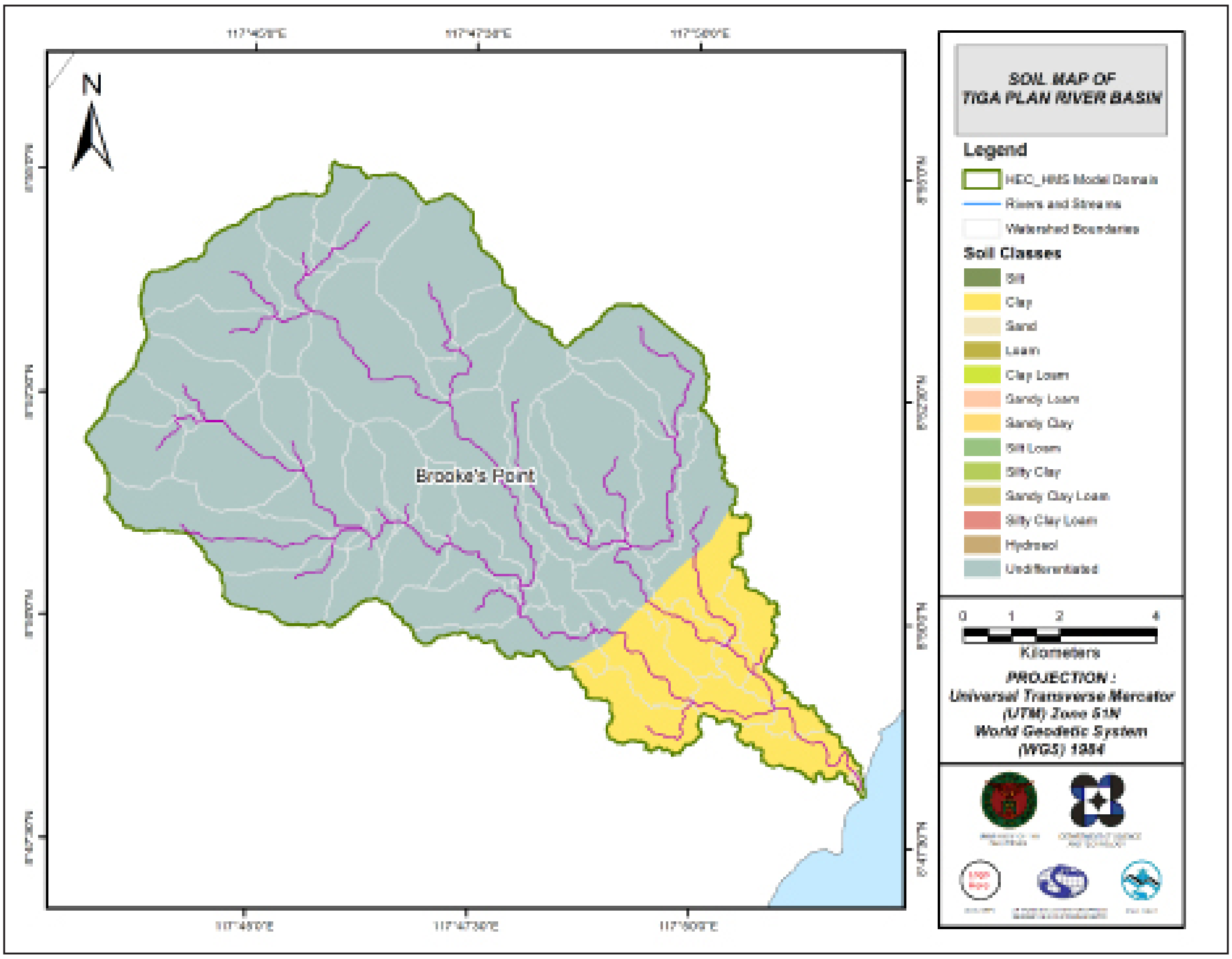


Figure 50. Soil map of Tigaplan River Basin used for the estimation of the CN parameter. (Source: DA)

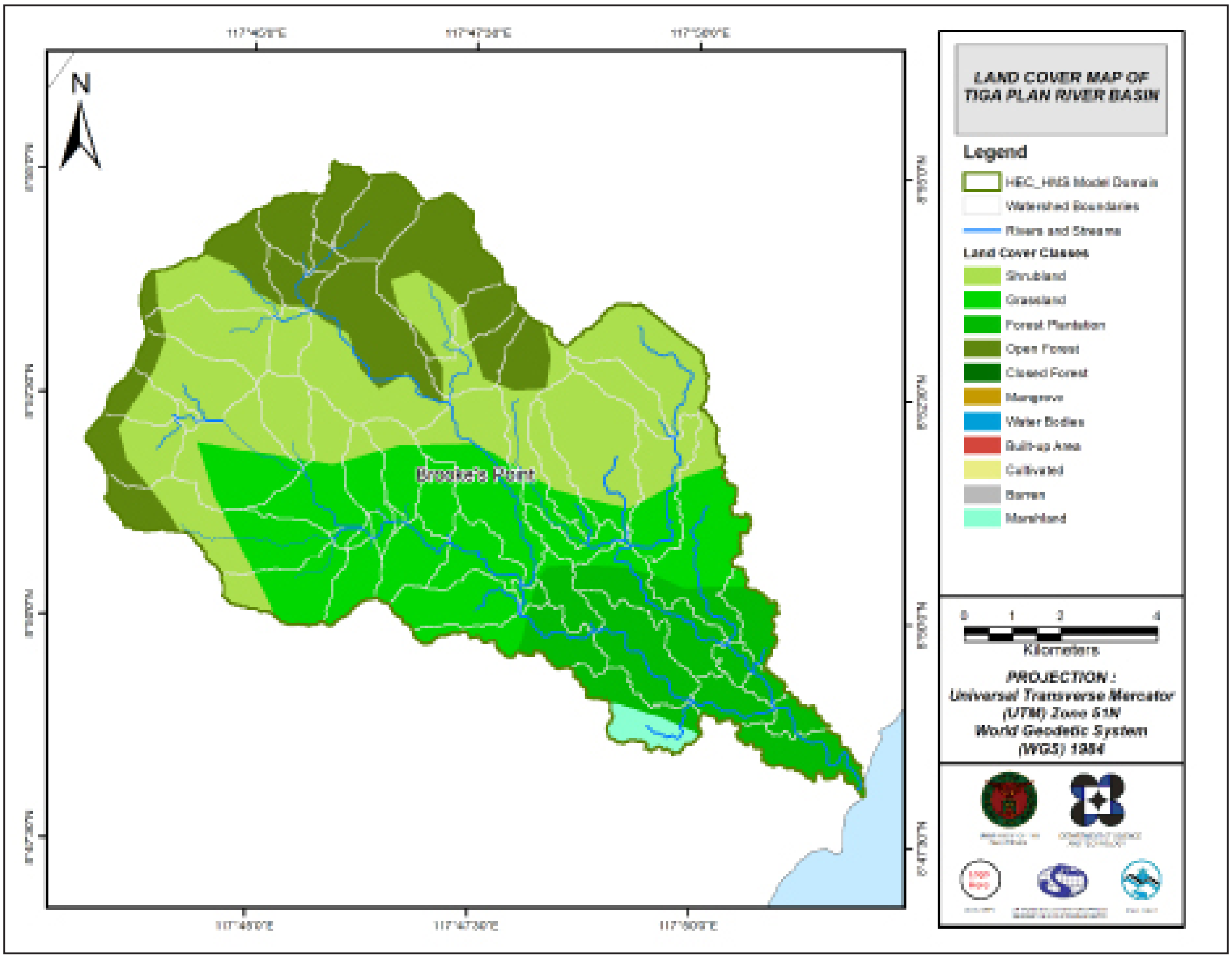


Figure 51. Land cover map of Tigaplan River Basin used for the estimation of the CN and watershed lag parameters of the rainfall-runoff model. (Source: NAMRIA)

For Tigaplan river basin, the two (w) soil classes identified were clay and undifferentiated soil. The five (5) land cover types identified were open forest, shrubland, grassland, forest plantation, and marshland.

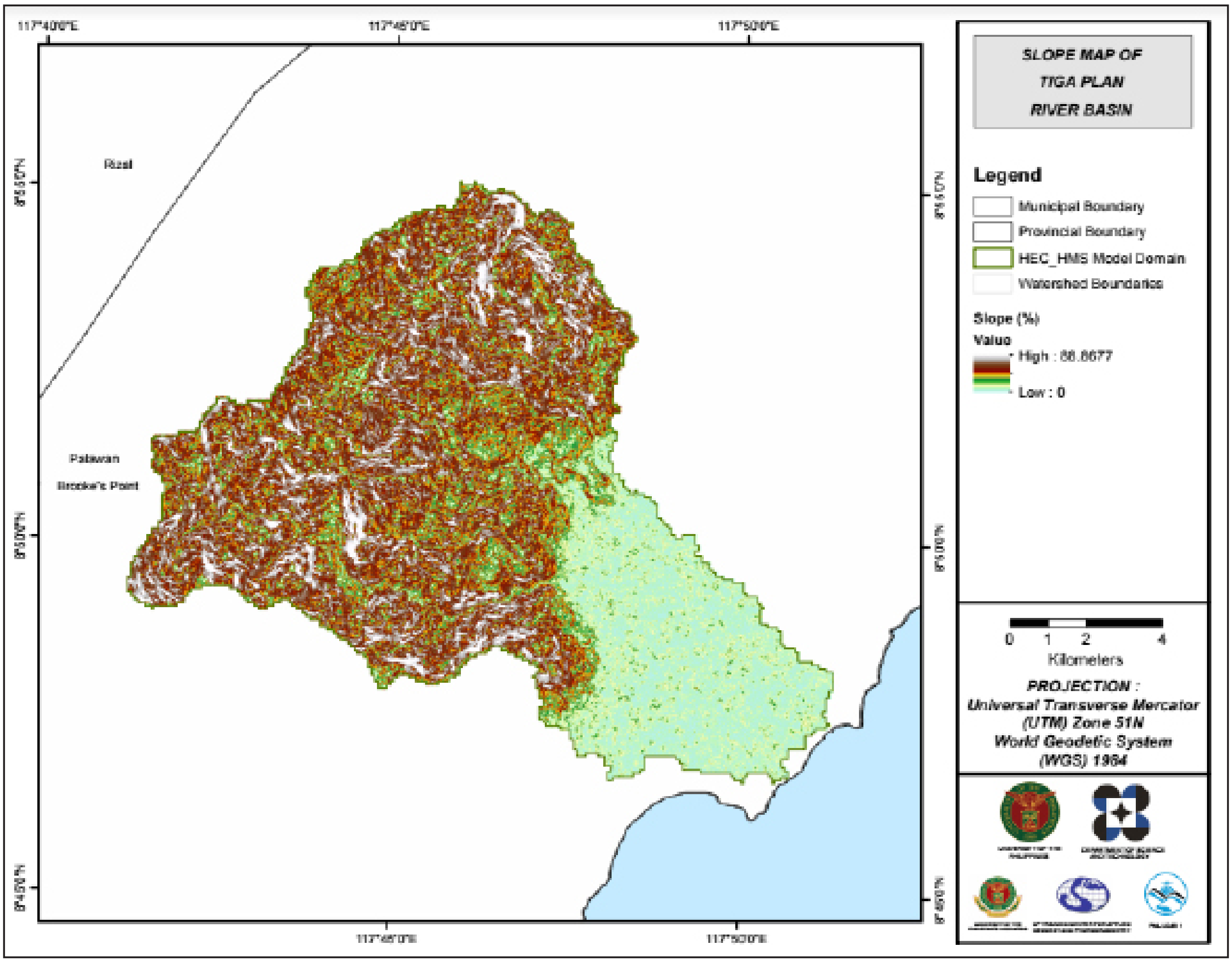


Figure 52. Slope map of Tigaplan River Basin

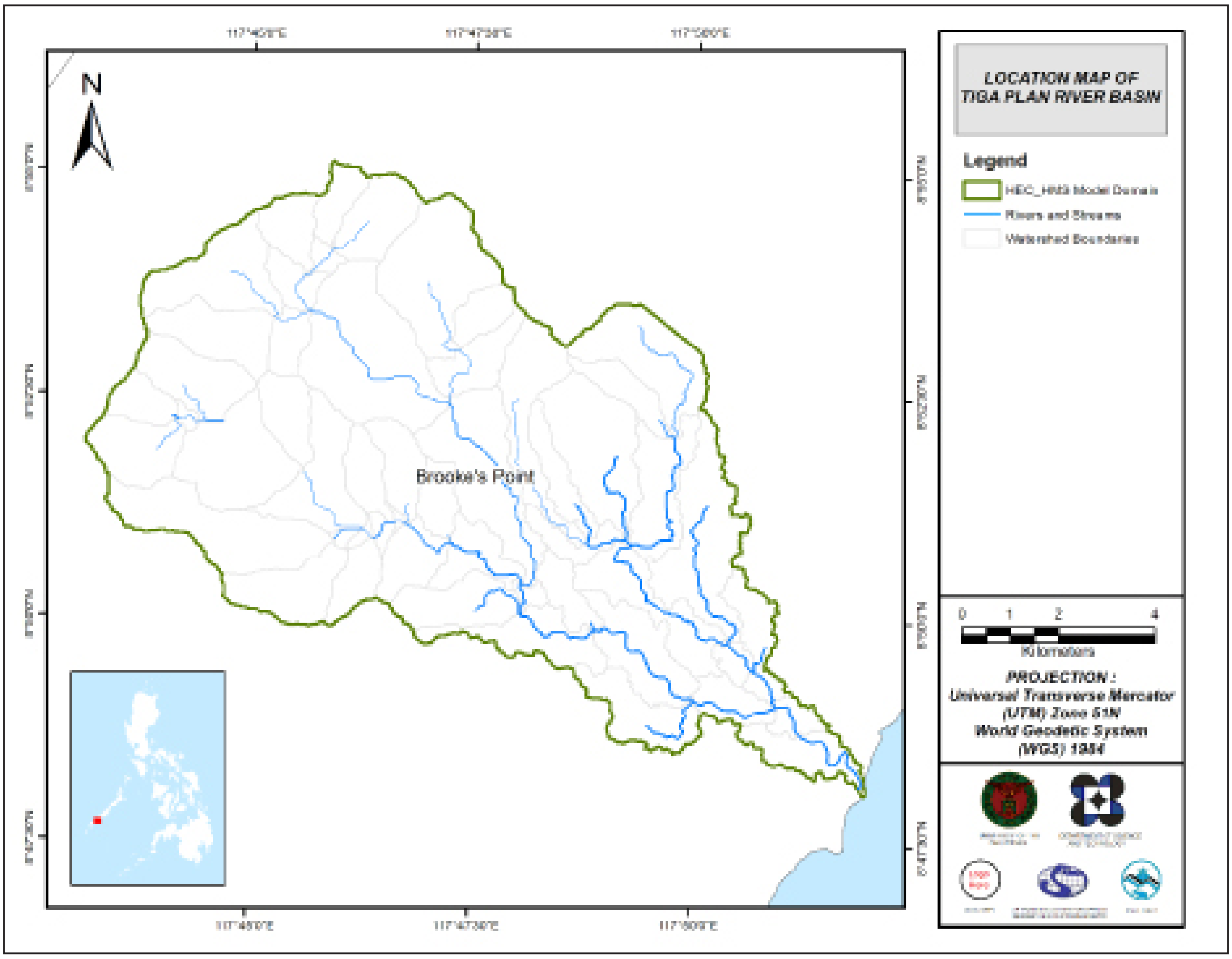


Figure 53. Stream Delineation Map of the Tigaplan River Basin

Using SAR-based DEM, the Tigaplan basin was delineated and further subdivided into subbasins. The model consists of 54 sub basins, 27 reaches, and 27 junctions. The main outlet is at Tigaplan Bridge. This is illustrated in Figure 54.

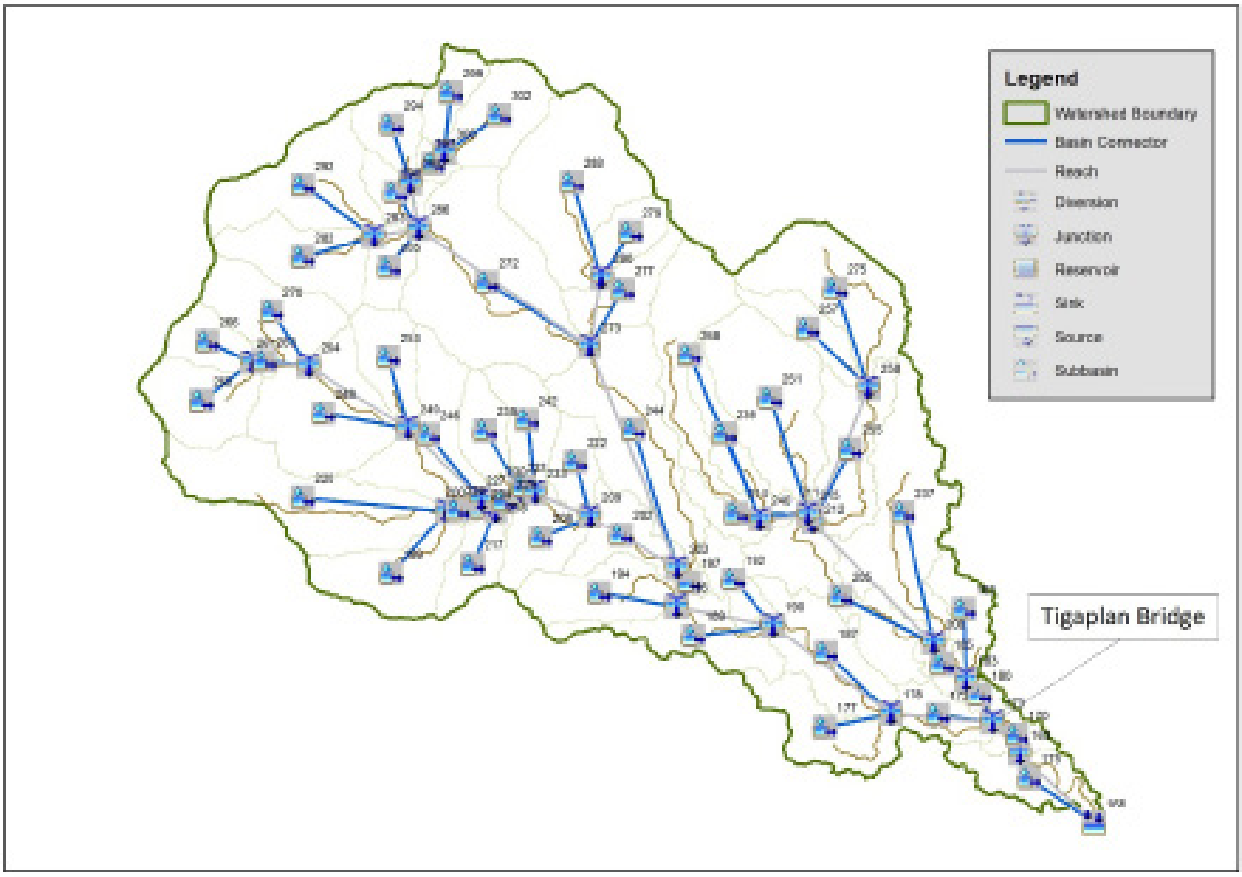


Figure 54. HEC-HMS generated Tigaplan River Basin Model.

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.

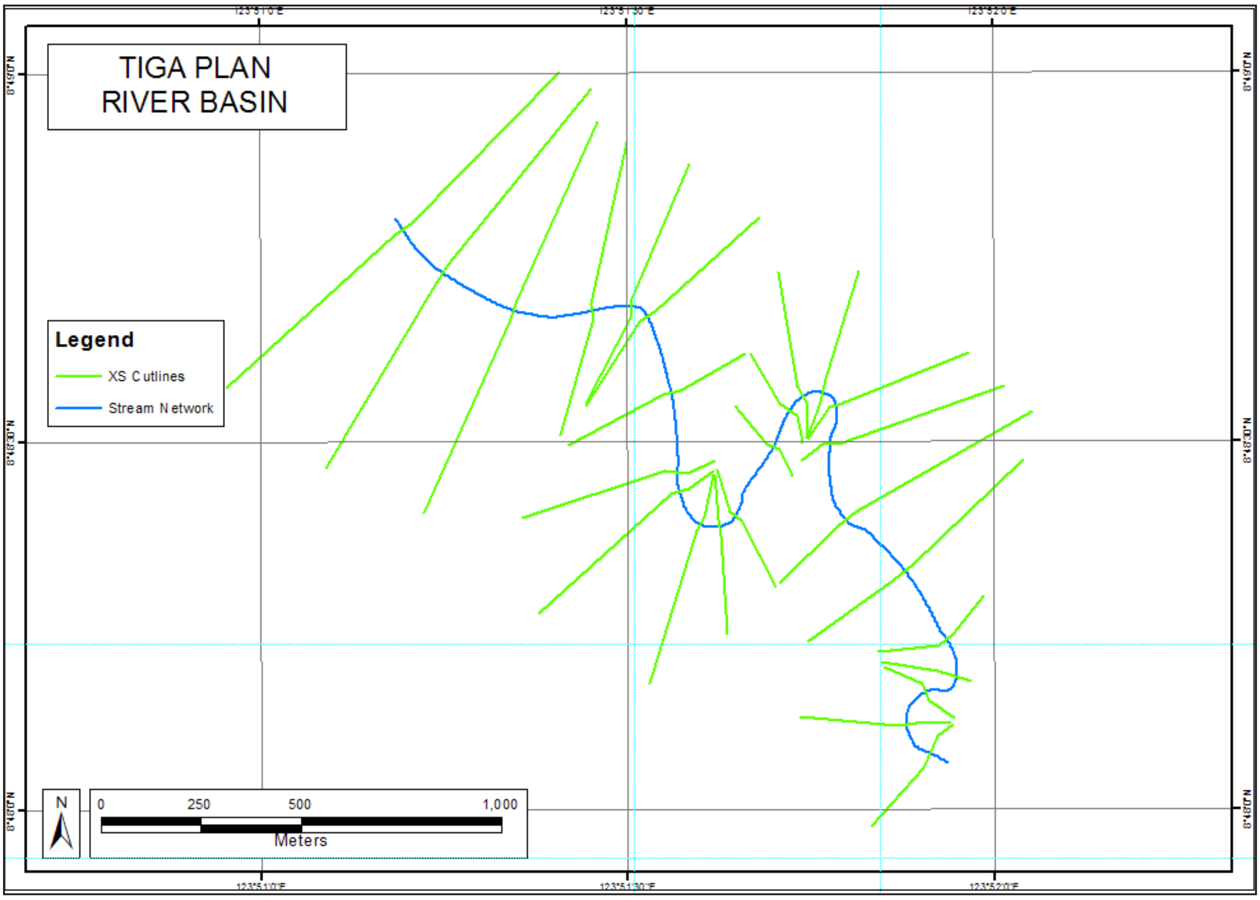


Figure 55. River cross-section of Tigaplan River generated through Arcmap HEC GeoRAS tool

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

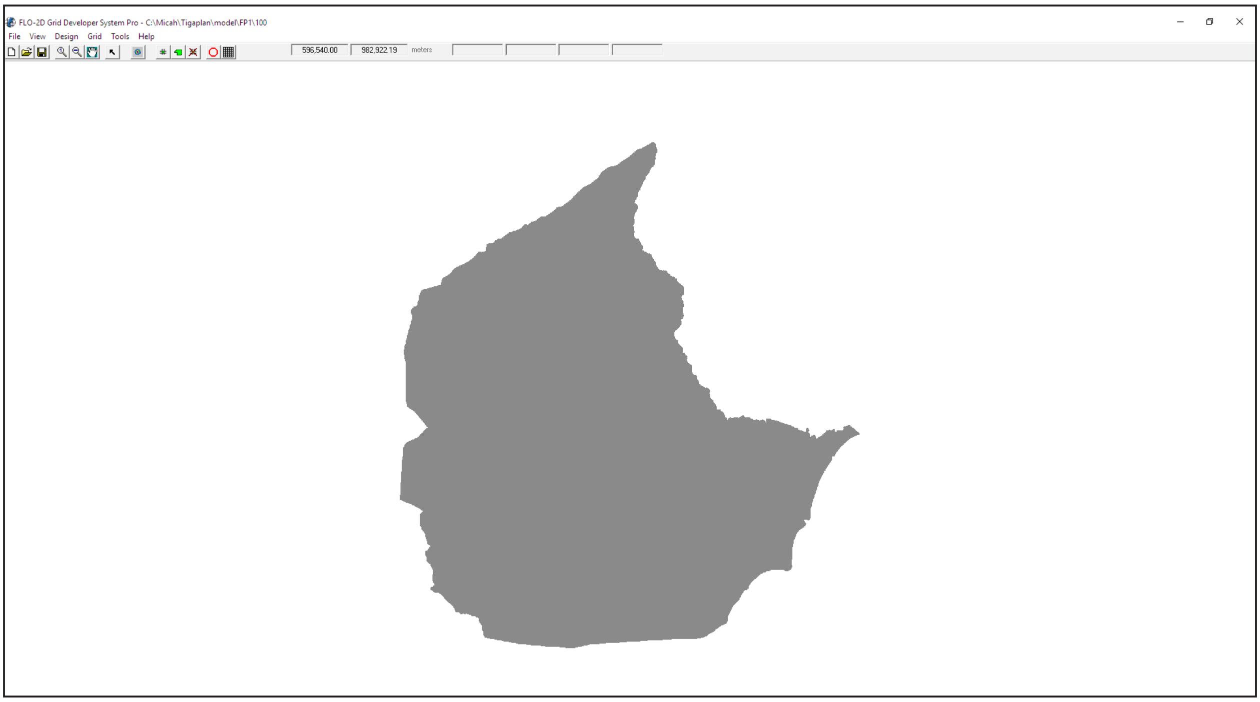


Figure 56. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 84.26050 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 70 915 400.00 m2.

There is a total of 46 018 599.25 m3 of water entering the model. Of this amount, 20 057 354.39 m3 is due to rainfall while 25 961 244.87 m3 is inflow from other areas outside the model. 8 151 507.50 m3 of this water is lost to infiltration and interception, while 3 912 435.95 m3 is stored by the flood plain. The rest, amounting up to 33 954 672.96 m3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Tigaplan HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 57 shows the comparison between the two discharge data.

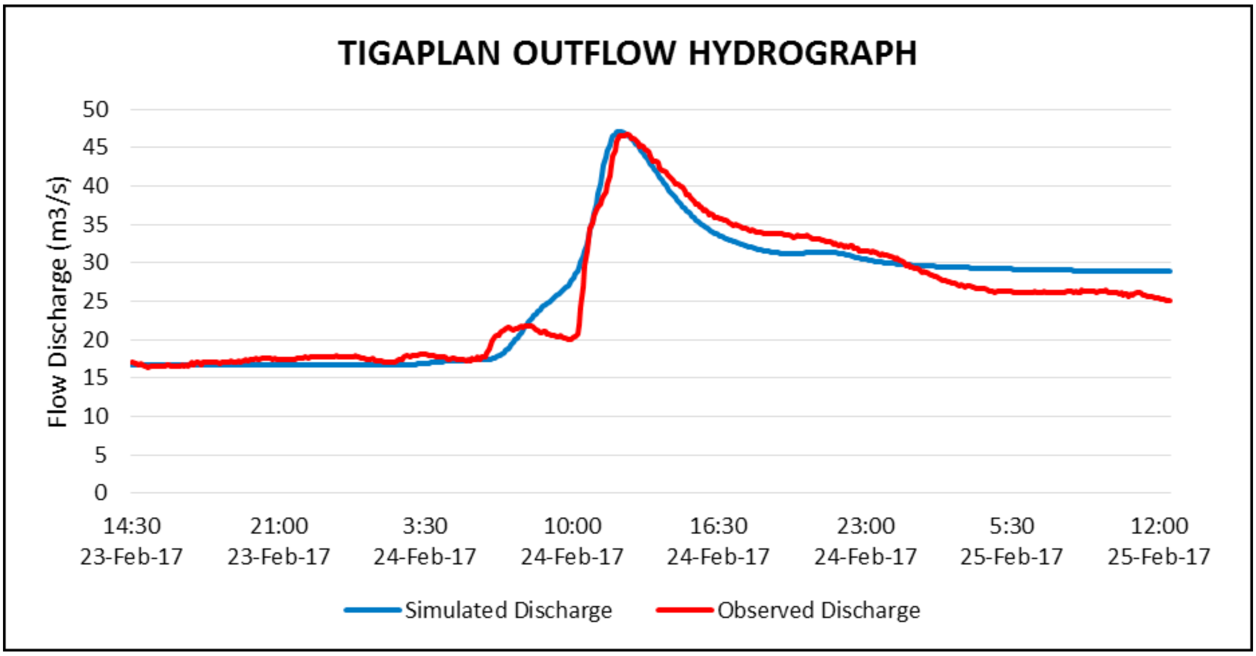


Figure 57. Outflow Hydrograph of Tigaplan produced by the HEC-HMS model compared with observed outflow.

Enumerated in Table 25 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 25. Range of calibrated values for Tigaplan River Basin

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	0.4 - 3
			Curve Number	60 - 99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.6 - 10
			Storage Coefficient (hr)	0.5 - 8
	Baseflow	Recession	Recession Constant	1
			Ratio to Peak	0.5
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.11

Initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as initial abstraction decreases. The range of values from 0.4 to 3mm means that there is a minimal amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 60 to 99 for curve number is advisable for Philippine watersheds depending on the soil and land cover of the area (M. Horritt, personal communication, 2012).

Time of concentration and storage coefficient are the travel time and index of temporary storage of runoff in a watershed. The range of calibrated values from 0.5 hours to 10 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant of 1 indicates that the basin is unlikely to quickly go back to its original discharge and instead, will be higher. Ratio to peak of 0.5 indicates an average slope of receding limb of the outflow hydrograph.

Manning's roughness coefficient of 0.11 is relatively high compared to the common roughness of watersheds (Brunner, 2010)

Table 26. Summary of the Efficiency Test of Tigaplan HMS Model

Accuracy measure	Value
RMSE	2.172
r2	0.966
NSE	0.930
PBIAS	-1.044
RSR	0.264

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 2.172.

The Pearson correlation coefficient (r2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.966.

The Nash-Sutcliffe (E) method was also used to assess the predictive power of the model. Here the optimal value is 1. The model attained an efficiency coefficient of 0.930.

A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate bias towards over-prediction. Again, the optimal value is 0. In the model, the PBIAS is -1.044.

The Observation Standard Deviation Ratio, RSR, is an error index. A perfect model attains a value of 0 when the error in the units of the valuable a quantified. The model has an RSR value of 0.264.

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

5.7.1 Hydrograph using the Rainfall Runoff Model

The summary graph (Figure 58) shows the Tigaplan outflow using the Puerto Princesa Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

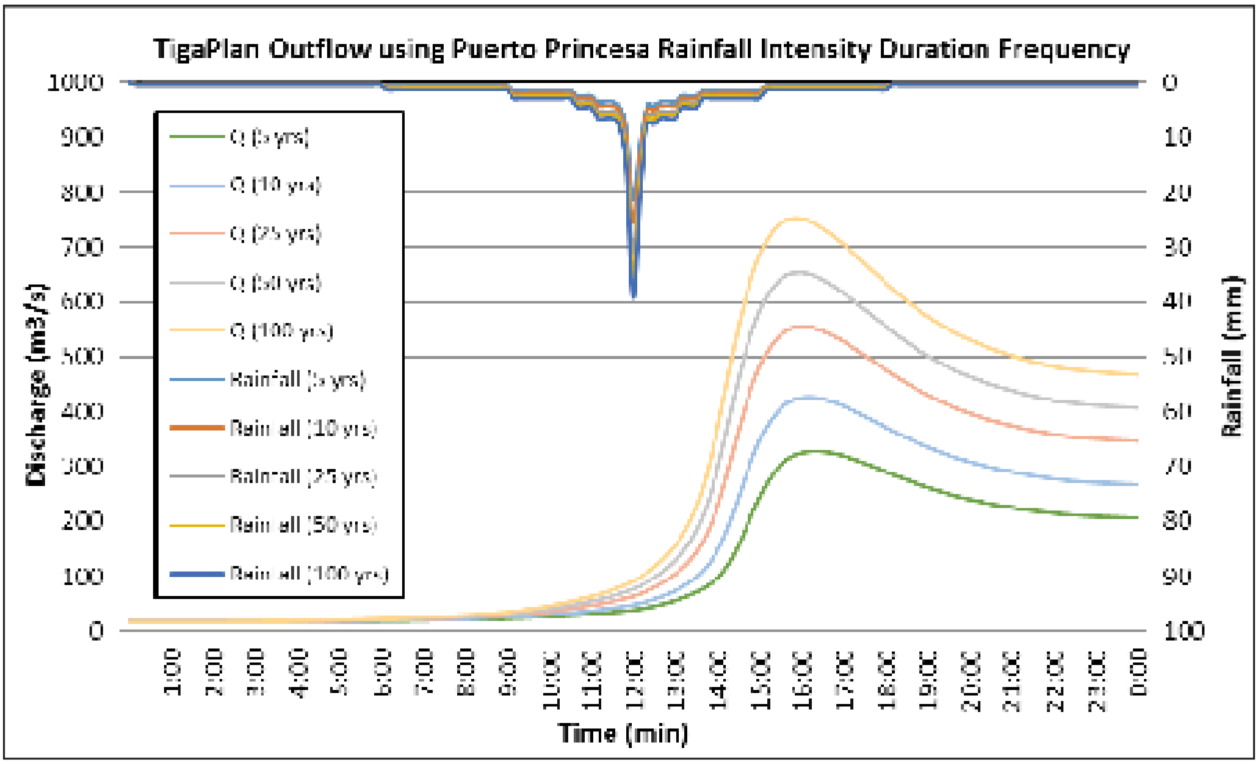


Figure 58. Outflow hydrograph at Tigaplan Station generated using Puerto Princesa RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow, time to peak and lag time of the Tigaplan discharge using the Puerto Princesa Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 27.

Table 27. Peak values of the Tigaplan HECHMS Model outflow using the Romblon RIDF 24-hour values

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak	Lag Time
5-Year	156.40	21.30	328.160	4 hours 20 minutes	-
10-Year	191.10	25.60	426.630	4 hours 10 minutes	-
25-Year	234.90	31.10	555.995	4 hours	-
50-Year	267.30	35.20	653.817	4 hours	-
100-Year	299.60	39.20	752.759	3 hours 50 minutes	-

5.8 River Analysis Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM/ Phil-LiDAR 1 website. The sample map of Tigaplan River using the HMS base flow is shown on Figure 59.

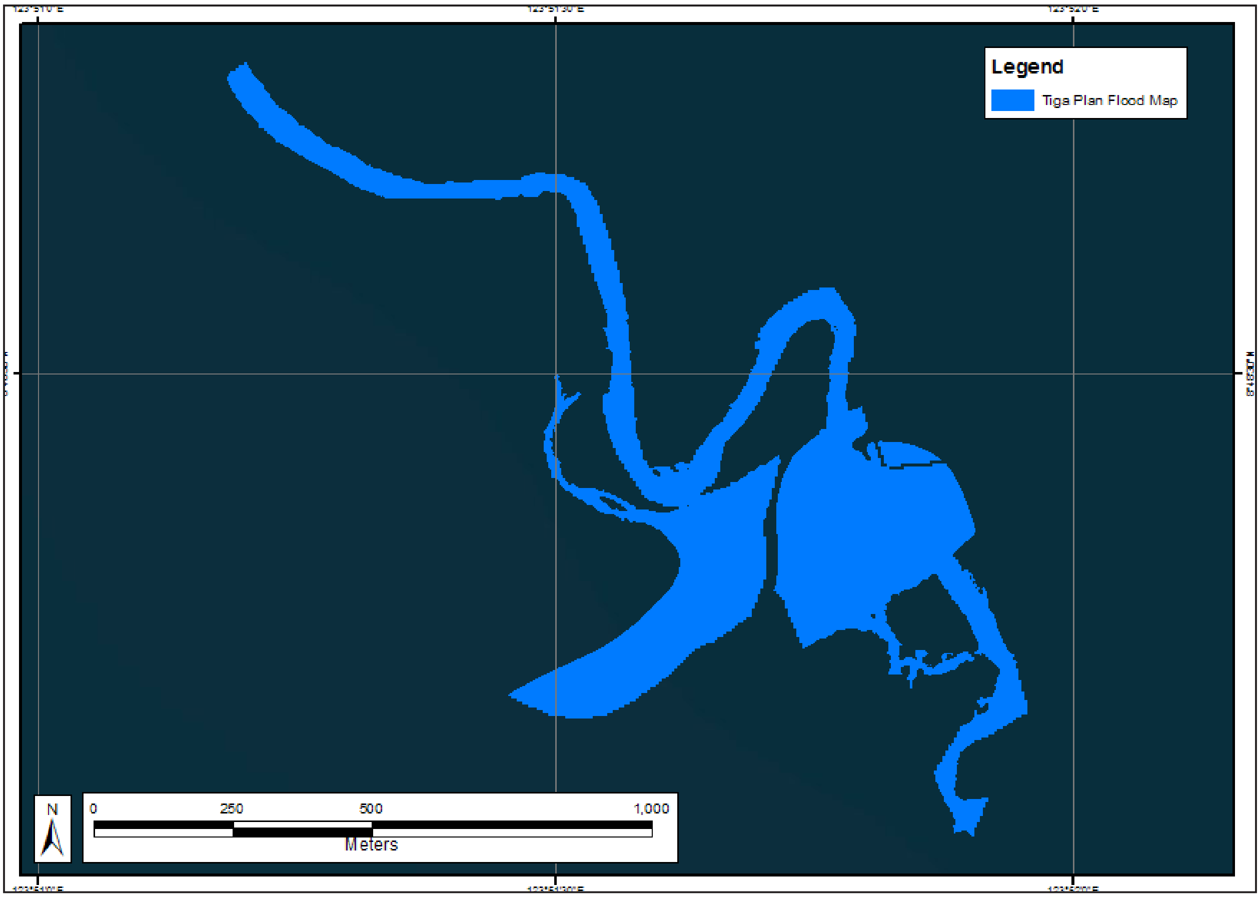


Figure 59. Sample output of Tigaplan RAS Model

5.9 Flood Hazard and Flow Depth Map

The resulting hazard and flow depth maps for 5-, 25-, and 100-year rain return scenarios of the Tiga Plan floodplain are shown in Figure 60 to Figure 65. The floodplain, with an area of 102.16 sq. km., covers one municipality namely Brooke's Point. Table 28 shows the percentage of area affected by flooding per municipality.

Table 28. Municipalities affected in Tigaplan Floodplain

City / Municipality	Total Area	Area Flooded	% Flooded
Brooke's Point	893.39	102.10	11.43

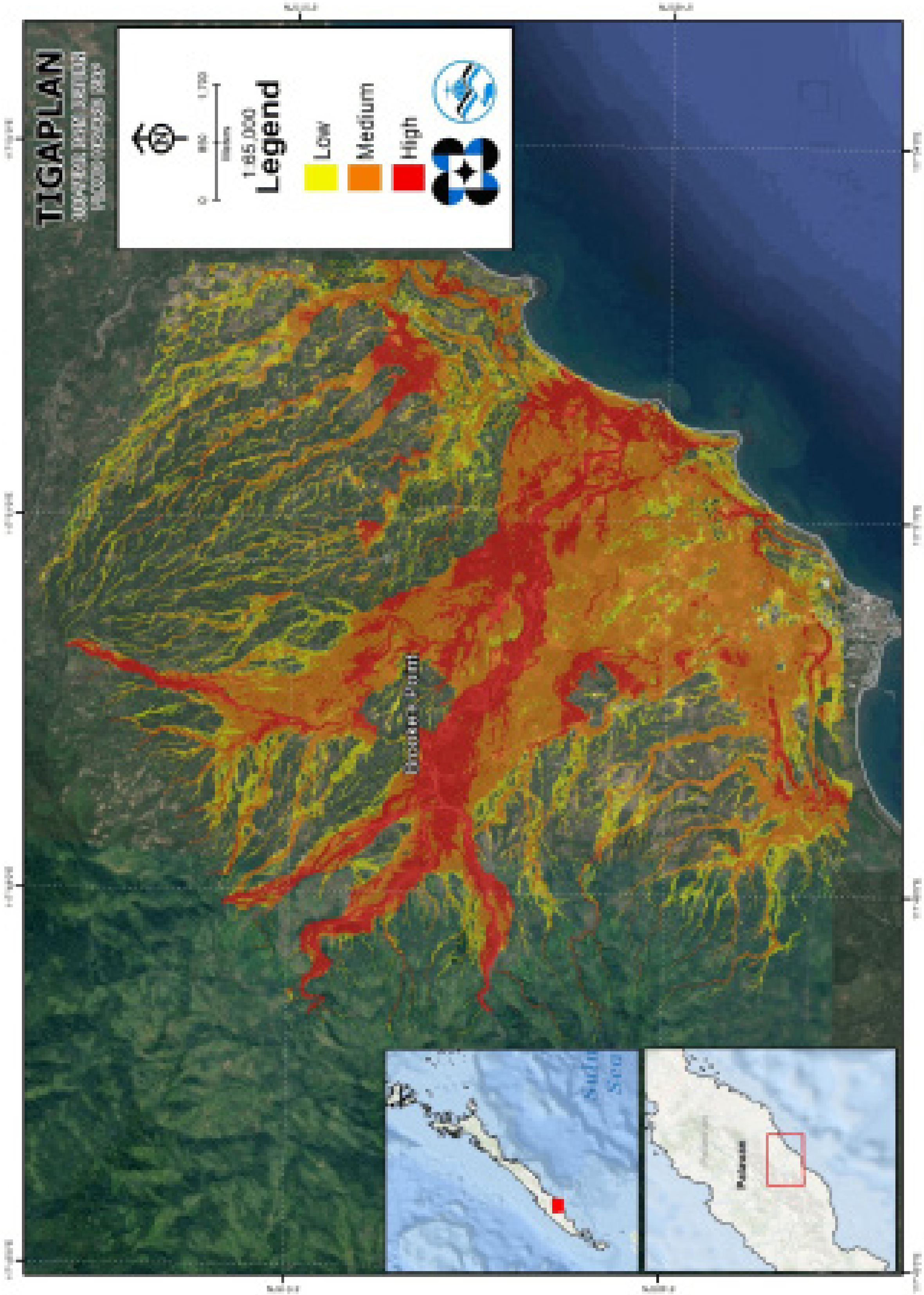


Figure 60. 100-year Flood Hazard Map for Tigaplan Floodplain overlaid in Google Earth imagery

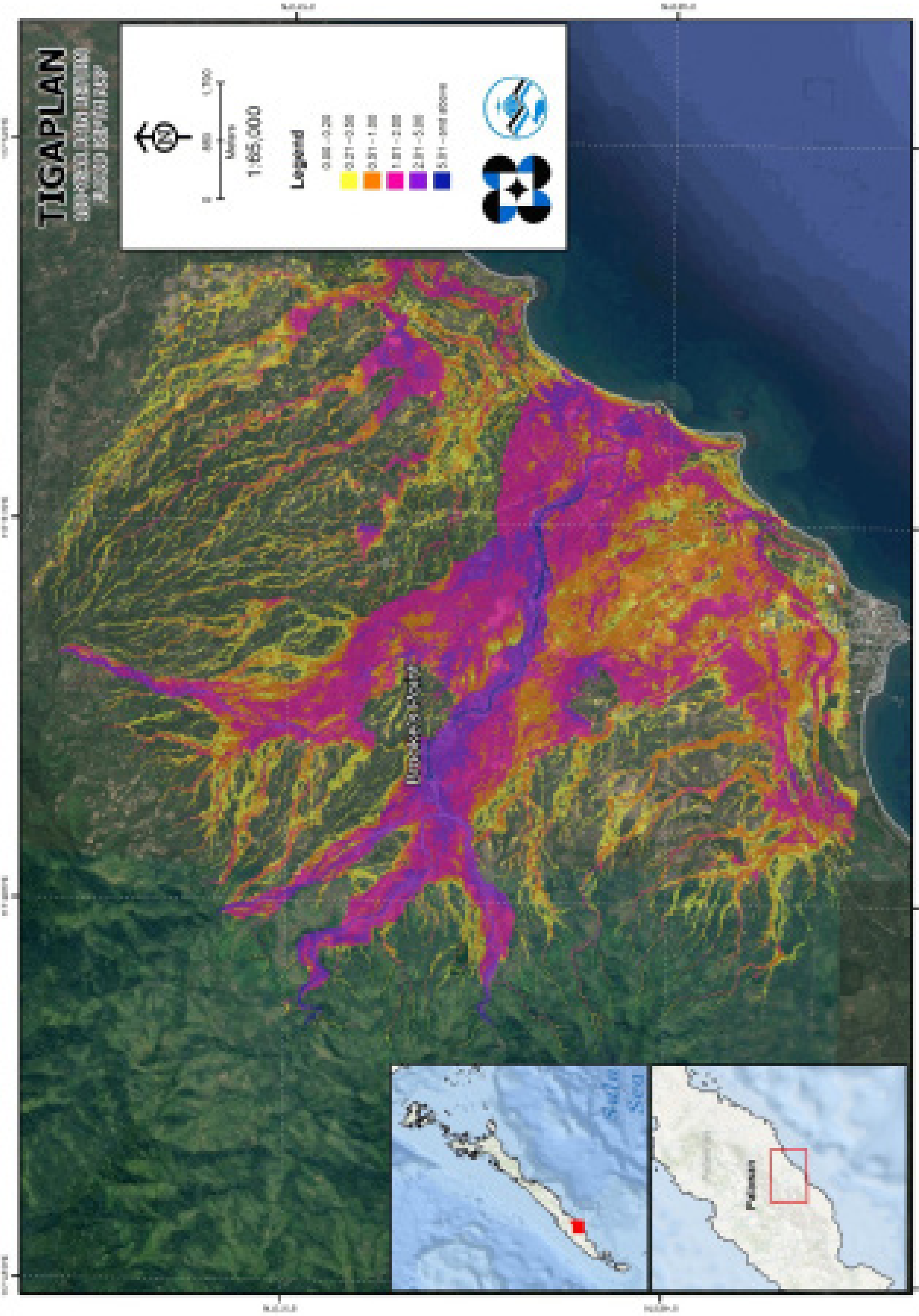


Figure 61. 100-year Flow Depth Map for Tigaplan Floodplain overlaid in Google Earth imagery

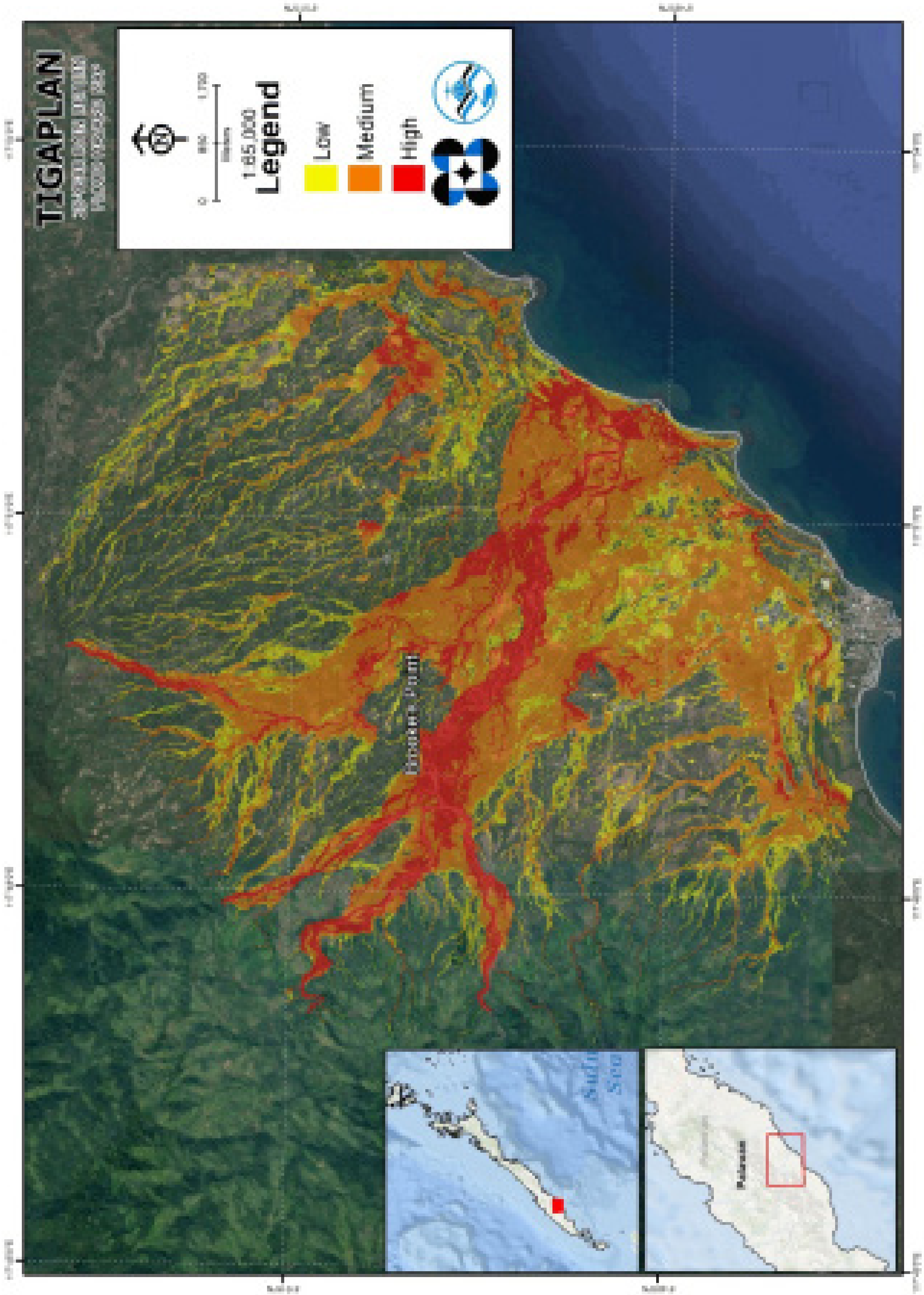


Figure 62. 25-year Flood Hazard Map for Tigaplan Floodplain overlaid in Google Earth imagery

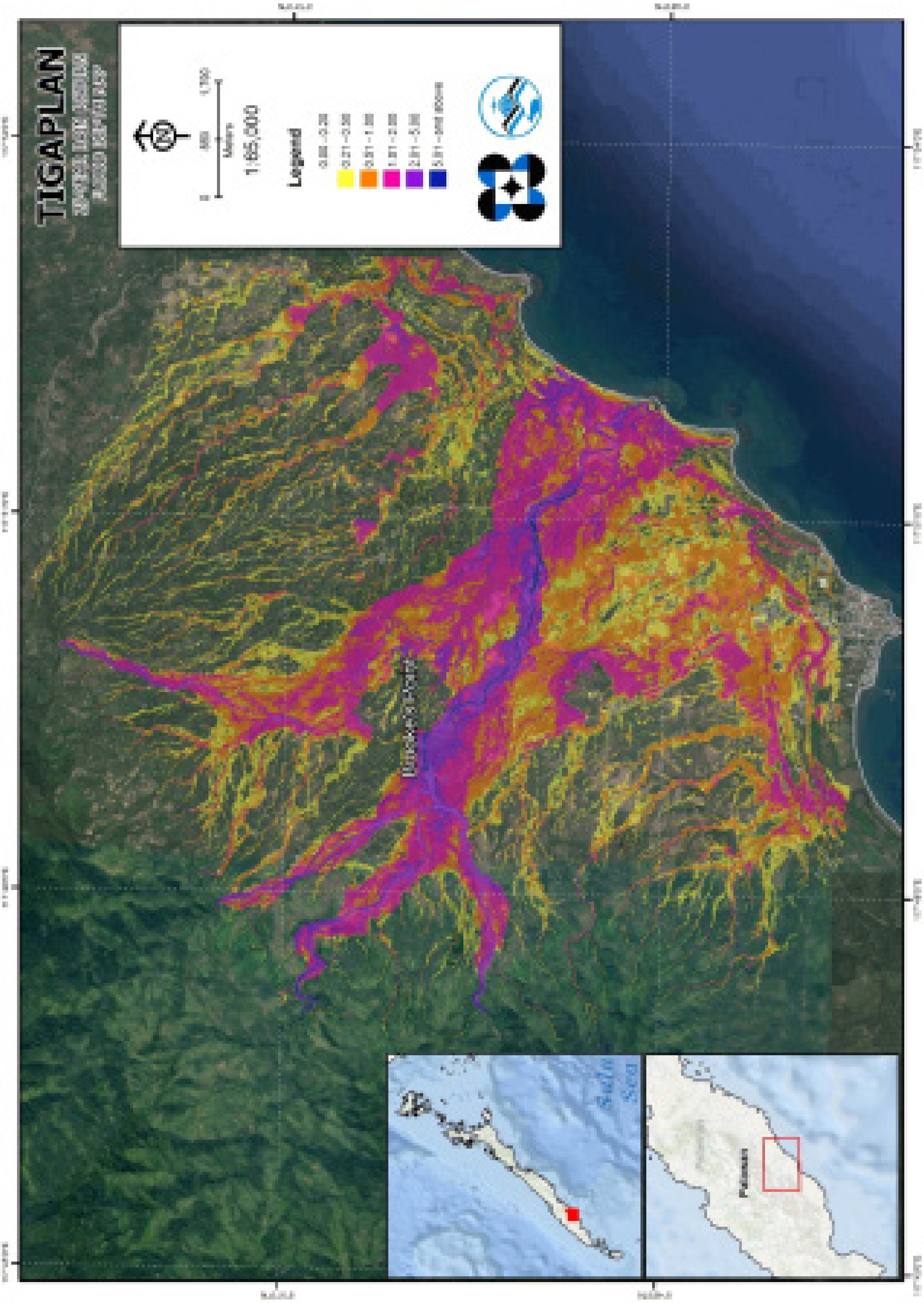


Figure 63. 25-year Flow Depth Map for Tigaplan Floodplain overlaid in Google Earth imagery

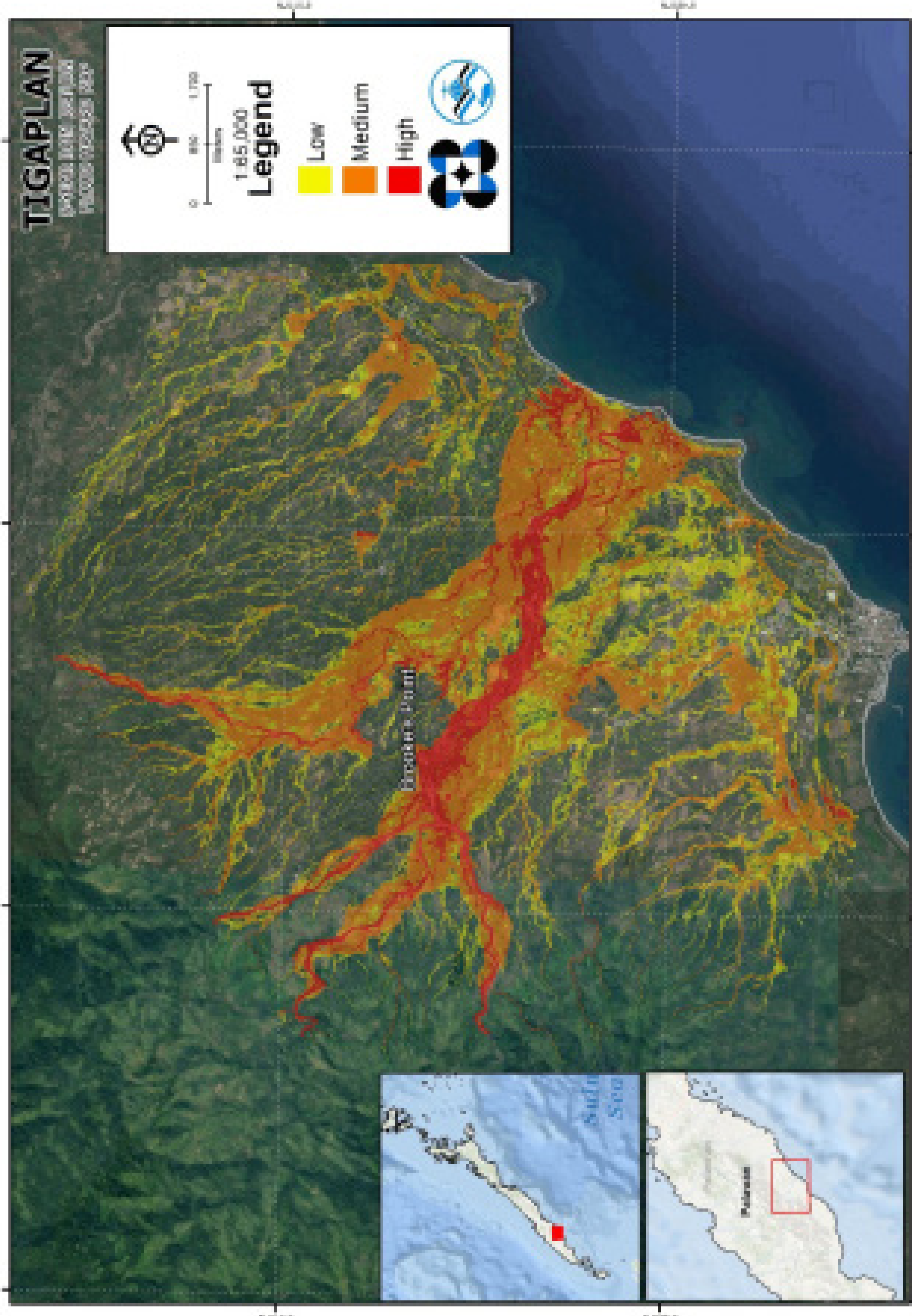


Figure 64. 5-year Flood Hazard Map for Tigaplan Floodplain overlaid in Google Earth imagery

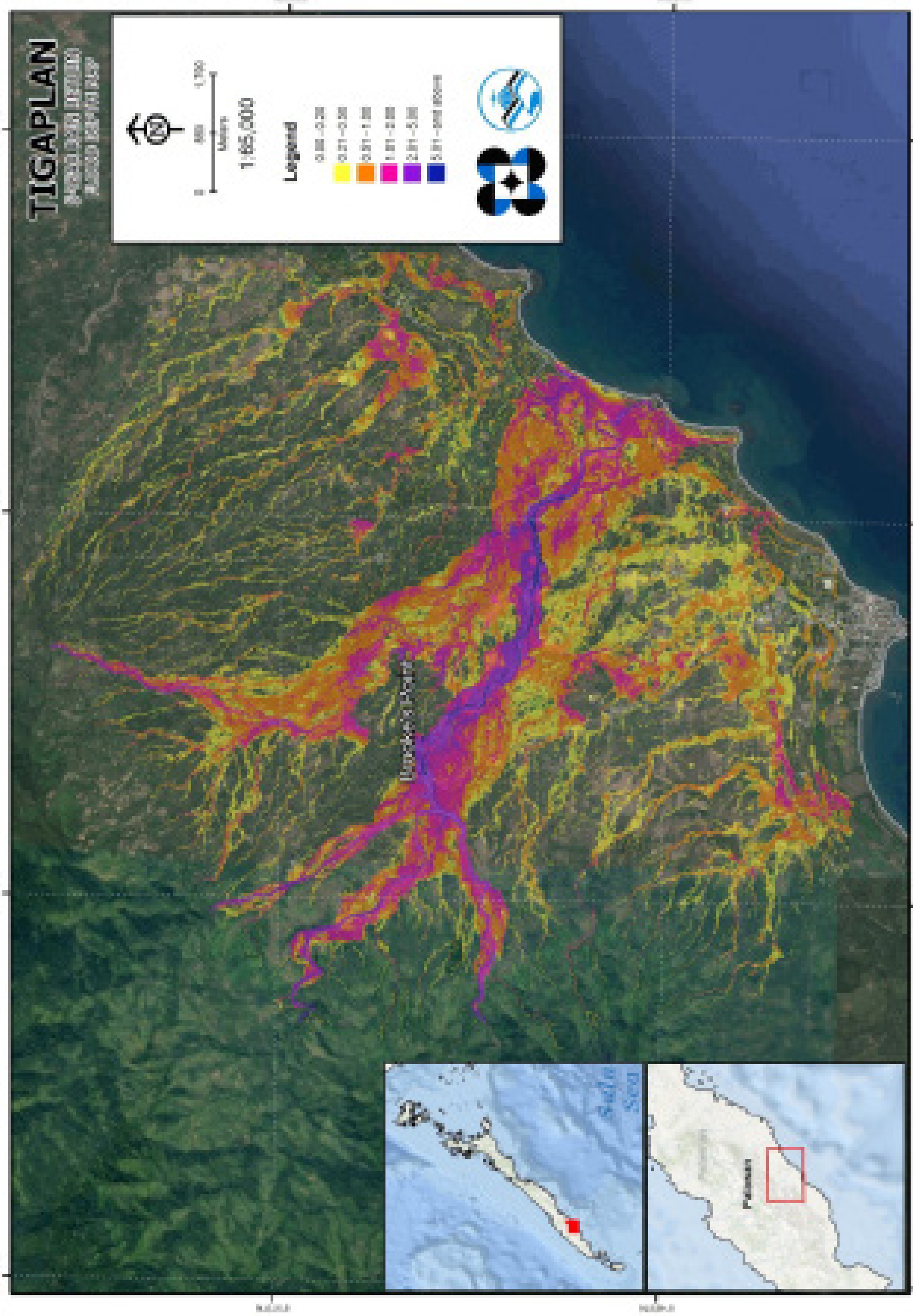


Figure 65. 5-year Flow Depth Map for Tigaplan Floodplain overlaid in Google Earth imagery

5.10 Inventory of Areas Exposed to Flooding

Listed below are the barangays affected by the Tiga Plan 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, 7.22% of the municipality of Brooke's Point with an area of 893.39 sq. km. will experience flood levels of less 0.20 meters, while 1.62% of the area will experience flood levels of 0.21 to 0.50 meters; 1.51%, 0.82%, 0.26%, and 0.02% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 t0 5 meters, and more than 5 meters respectively. Table 29 and Figure 66 depict the areas affected in Brooke's Point in square kilometers by flood depth per barangay.

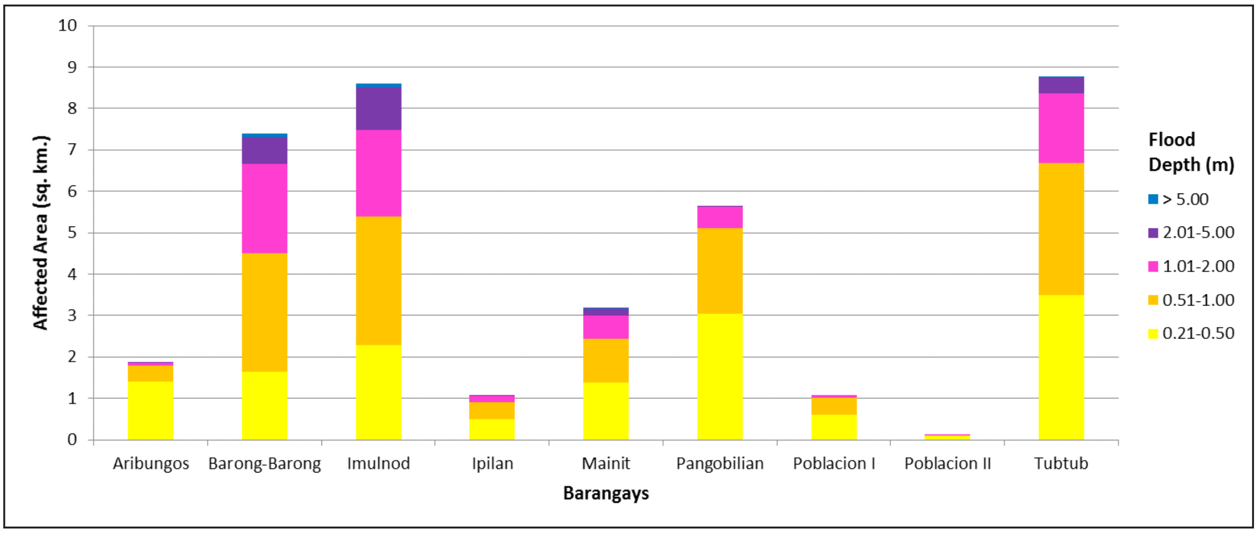


Figure 66. Affected areas in Brooke's Point, Palawan during a 5-Year Rainfall Return Period.

Table 29. Affected areas in Brooke's Point, Palawan during a 5-Year Rainfall Return Period

Affected area (sq.km.) by flood depth (in m.)	Affected Barangays in Brooke's Point								
	Aribungos	Barong-Barong	Imulnod	Ipilan	Mainit	Pangobilian	Poblacion I	Poblacion II	Tubtub
0.03-0.20	10	5.34	9.9	2.24	8.57	4.6	1.43	0.79	21.6
0.21-0.50	1.4	1.65	2.29	0.5	1.38	3.04	0.6	0.078	3.5
0.51-1.00	0.4	2.86	3.1	0.4	1.05	2.08	0.42	0.022	3.18
1.01-2.00	0.06	2.16	2.09	0.15	0.56	0.52	0.069	0.0091	1.7
2.01-5.00	0.0089	0.64	1.05	0.0047	0.18	0.019	0	0	0.39
> 5.00	0	0.077	0.069	0	0.0004	0	0	0	0.013

For the 25-year return period, 6.15% of the municipality of Brooke's Point with an area of 893.39 sq. km. will experience flood levels of less 0.20 meters, while 1.55% of the area will experience flood levels of 0.21 to 0.50 meters; 1.71%, 1.57%, 0.42%, and 0.03% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 t0 5 meters, and more than 5 meters respectively. Table 30 and Figure 67 depict the areas affected in Brooke's Point in square kilometers by flood depth per barangay.

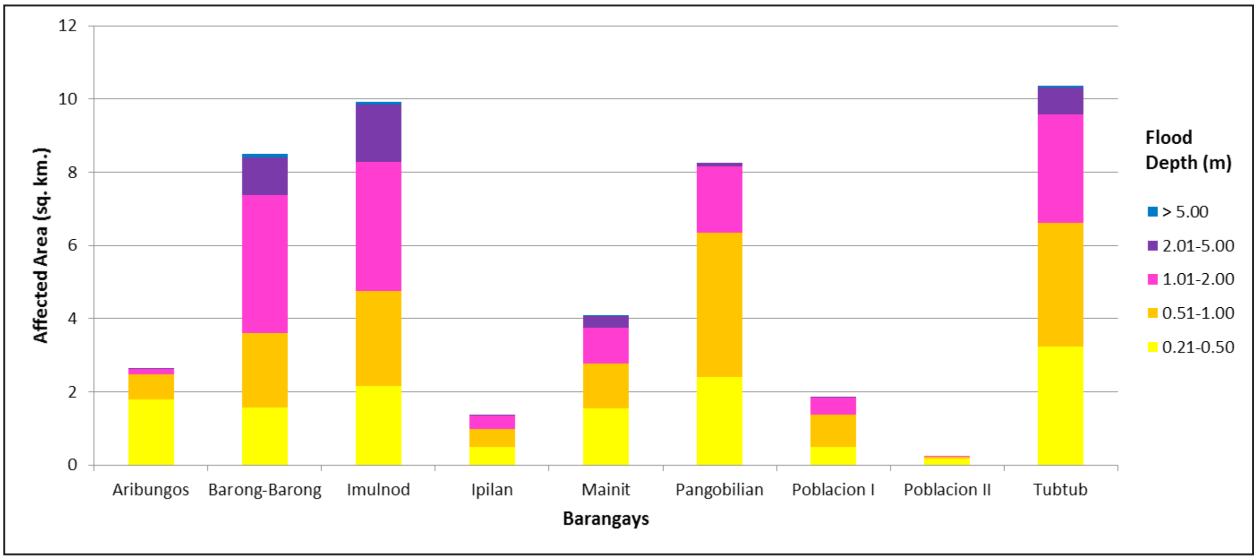


Figure 67. Affected areas in Brooke's Point, Palawan during a 25-Year Rainfall Return Period.

Table 30. Affected areas in Brooke's Point, Palawan during a 25-Year Rainfall Return Period

Affected area (sq.km.) by flood depth (in m.)	Affected Barangays in Brooke's Point								
	Aribungos	Barong-Barong	Imulnod	Ipilan	Mainit	Pangobilian	Poblacion I	Poblacion II	Tubtub
0.03-0.20	9.23	4.24	8.56	1.93	7.67	2	0.68	0.64	20.01
0.21-0.50	1.8	1.56	2.16	0.48	1.54	2.41	0.5	0.17	3.25
0.51-1.00	0.69	2.04	2.59	0.49	1.23	3.94	0.88	0.053	3.37
1.01-2.00	0.14	3.78	3.52	0.36	0.99	1.8	0.46	0.031	2.95
2.01-5.00	0.013	1.03	1.56	0.024	0.32	0.1	0.0002	0	0.75
> 5.00	0	0.093	0.091	0	0.0044	0	0	0	0.042

For the 100-year return period, 5.63% of the municipality of Brooke's Point with an area of 893.39 sq. km. will experience flood levels of less 0.20 meters, while 1.49% of the area will experience flood levels of 0.21 to 0.50 meters; 1.73%, 1.97%, 0.60%, and 0.03% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 t0 5 meters, and more than 5 meters respectively. Table 31 and Figure 68 depict the areas affected in Brooke's Point in square kilometers by flood depth per barangay.

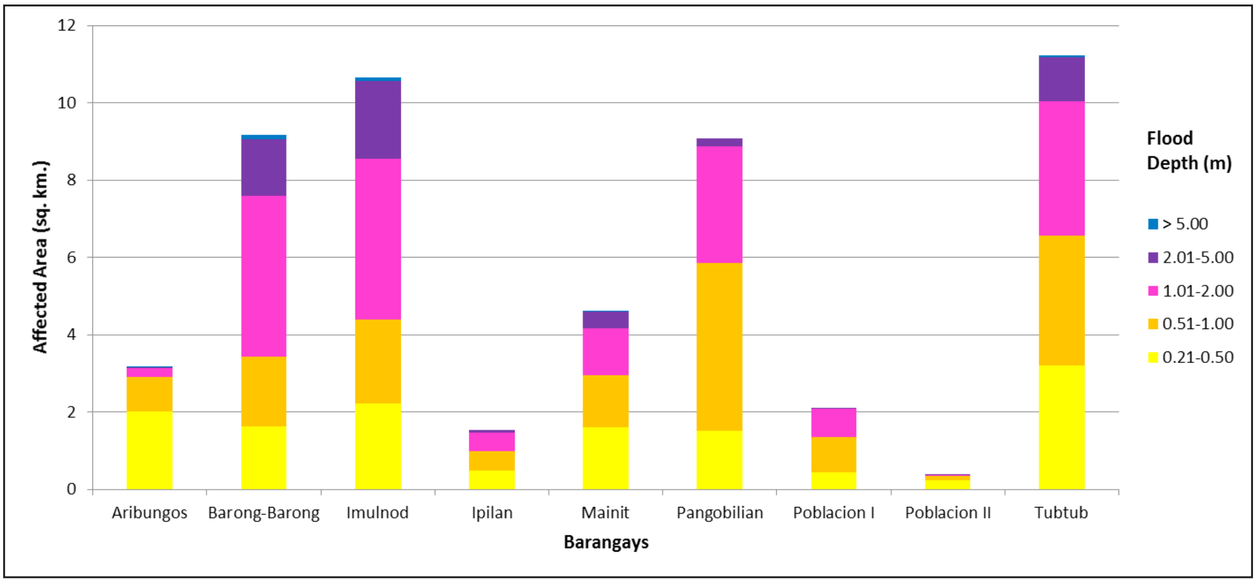


Figure 68. Affected areas in Brooke's Point, Palawan during a 100-Year Rainfall Return Period.

Table 31. Affected areas in Brooke's Point, Palawan during a 100-Year Rainfall Return Period

Affected area (sq.km.) by flood depth (in m.)	Affected Barangays in Brooke's Point								
	Aribungos	Barong-Barong	Imulnod	Ipilan	Mainit	Pangobilian	Poblacion I	Poblacion II	Tubtub
0.03-0.20	8.71	3.58	7.84	1.75	7.14	1.19	0.42	0.51	19.14
0.21-0.50	2.01	1.62	2.21	0.48	1.61	1.52	0.43	0.24	3.21
0.51-1.00	0.9	1.81	2.17	0.51	1.33	4.34	0.93	0.096	3.35
1.01-2.00	0.23	4.18	4.17	0.48	1.23	3.02	0.73	0.046	3.49
2.01-5.00	0.02	1.46	2	0.077	0.43	0.19	0.011	0.0033	1.13
> 5.00	0.0002	0.099	0.11	0	0.007	0	0	0	0.057

Among the barangays in the municipality of Brooke's Point, Tubtub is projected to have the highest percentage of area that will experience flood levels of at 3.40%. On the other hand, Imulnod posted the percentage of area that may be affected by flood depths of at 2.07%.

5.11 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 consisted of 131 points randomly selected all over the Tigaplan floodplain (Figure 69). Comparing it with the flood depth map of the nearest storm event, the map has an RMSE value of 0.81m. Table 32 shows a contingency matrix of the comparison.

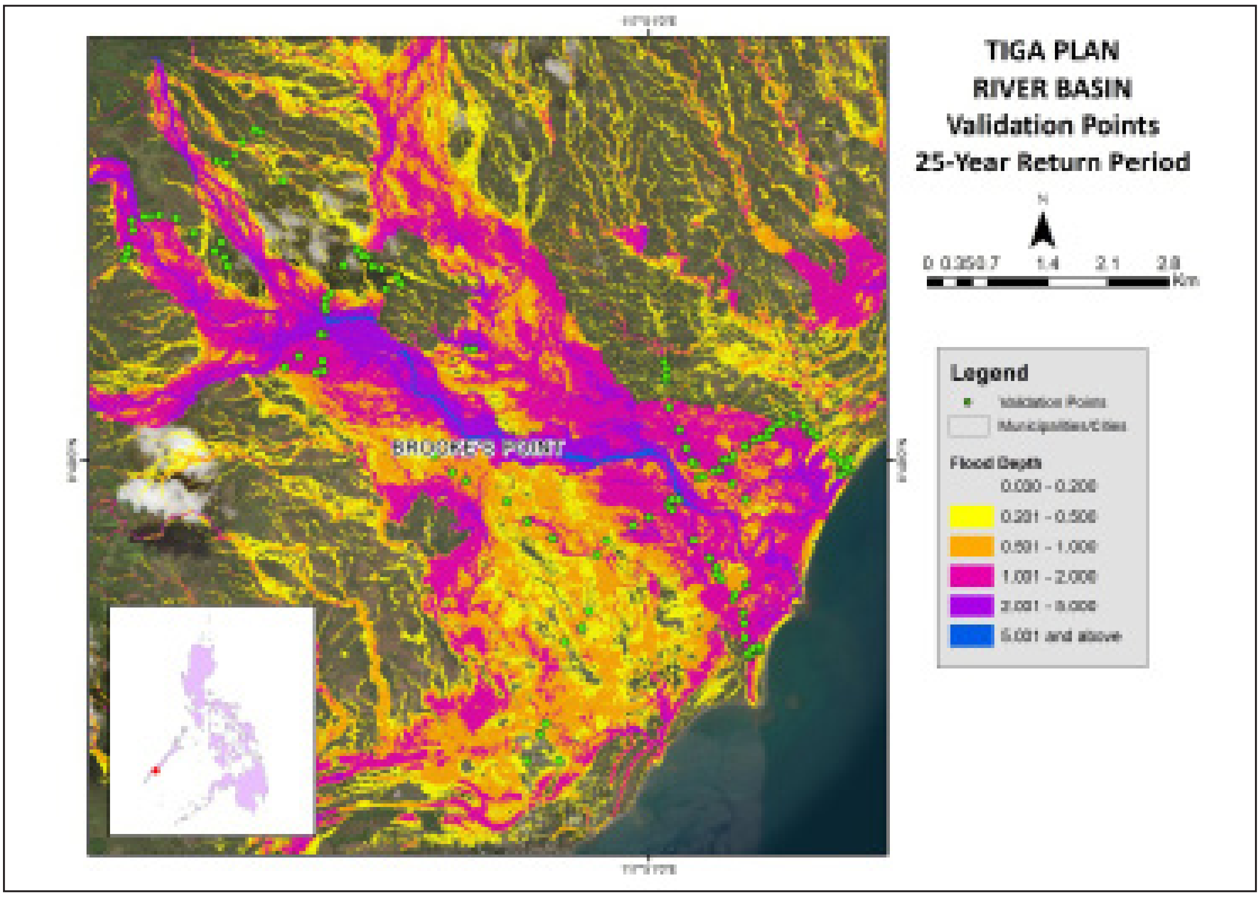


Figure 69. Validation points for 25-year Flood Depth Map of Tigaplan Floodplain

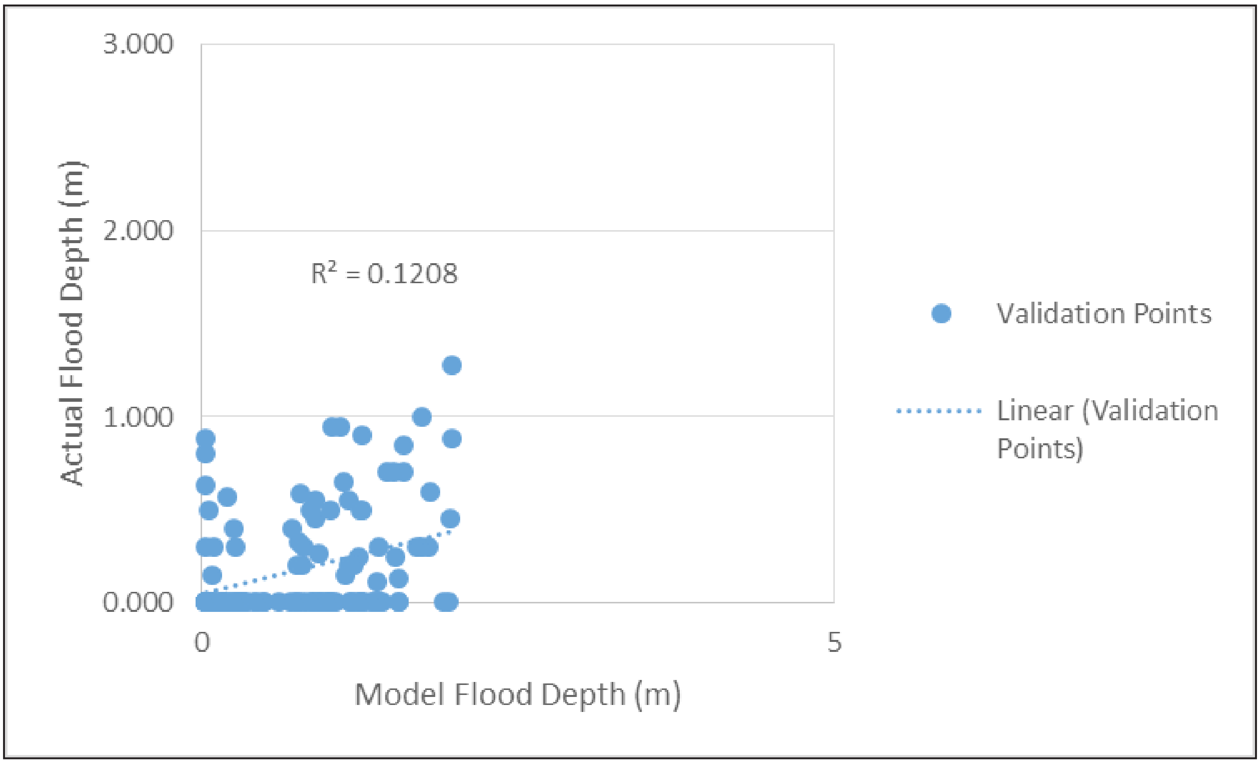


Figure 70. Flood map depth vs. actual flood depth

Table 32. Actual flood vs simulated flood depth at different levels in the Tigaplan 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	32	14	16	29	0	0	91
0.21-0.50	3	2	6	10	0	0	21
0.51-1.00	4	0	2	12	0	0	18
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	39	16	24	52	0	0	131

The overall accuracy generated by the flood model is estimated at 28.24% with 37 points correctly matching the actual flood depths. In addition, there were 35 points estimated one level above and below the correct flood depths while there were 30 points and 29 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 4 points were overestimated while a total of 7 points were underestimated in the modelled flood depths of Tigaplan. Table 33 depicts the summary of the Accuracy Assessment in the Tigaplan River Basin Survey.

Table 33. Summary of the Accuracy Assessment in the Tigaplan River Basin Survey

	No. of Points	%
Correct	37	28.24
Overestimated	87	66.41
Underestimated	7	5.34
Total	131	100.00

REFERENCES

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

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

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

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

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

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

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

ANNEXES

Annex 1. Optech Technical Specification of the Sensor

1. GEMINI SENSOR

Figure A-1.1. Parameters and Specification of Gemini Sensor

2. PARAMETERS AND SPECIFICATIONS OF THE GEMINI SENSOR

Table A-1.1. Parameters and Specification of Gemini Sensor

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

Annex 2. NAMRIA Certificates of Reference Points Used

1. PLW-137

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

December 02, 2015

CERTIFICATION

To whom it may concern:

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

Province: **PALAWAN**
Station Name: **PLW-137**
Order: **2nd**

Island: **LUZON**
Municipality: **PUERTO PRINCESA CITY (CAPITAL)**
Barangay: **IPILAN**
MSL Elevation:

PRS92 Coordinates

Latitude: 9° 11' 2.95304"	Longitude: 118° 4' 48.04729"	Ellipsoidal Hgt: 35.83359 m.

WGS84 Coordinates

Latitude: 9° 10' 58.60442"	Longitude: 118° 4' 53.42391"	Ellipsoidal Hgt: 85.64706 m.

PTM / PRS92 Coordinates

Northing: 1015530.347 m.	Easting: 453844.056 m.	Zone: 1A

UTM / PRS92 Coordinates

Northing: 1,015,326.41	Easting: 618,656.63	Zone: 50

Location Description

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

Requesting Party: UP DREAM
Purpose: Reference
OR Number: 8088735 I
T.N.: 2015-3959

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.1. PLW-137

Annex 3. Baseline Processing Report of Reference Points Used

1. QZT-1

Project information		Coordinate System	
Name:	C:\Users\Windows User\Documents \Business Center - HCE\PLW 137 QZT 1 QZT 2.vce	Name:	UTM
Size:	271 KB	Datum:	PRS 92
Modified:	7/24/2015 6:13:47 PM (UTC:8)	Zone:	50 North (117E)
Time zone:	Taipei Standard Time	Geoid:	EGMPH
Reference number:		Vertical datum:	
Description:			

Baseline Processing Report

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
plw 137 --- qzt 1 (B1)	plw 137	qzt 1	Fixed	0.005	0.011	269°40'42"	21218.741	-26.466
plw 137 --- qzt 2 (B2)	plw 137	qzt 2	Fixed	0.018	0.037	269°35'56"	21211.522	-28.970

Acceptance Summary

Processed	Passed	Flag	Fail
2	2	0	0

plw 137 - qzt 1 (7:23:34 AM-1:08:19 PM) (S1)

Baseline observation:	plw 137 --- qzt 1 (B1)
Processed:	7/24/2015 6:14:51 PM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.005 m
Vertical precision:	0.011 m
RMS:	0.005 m
Maximum PDOP:	2.209
Ephemeris used:	Broadcast
Antenna model:	NGS Absolute
Processing start time:	7/13/2015 7:23:34 AM (Local: UTC+8hr)
Processing stop time:	7/13/2015 1:08:19 PM (Local: UTC+8hr)
Processing duration:	05:44:45
Processing interval:	5 seconds

1

Figure A-3.1. Baseline Processing Report - A

Vector Components (Mark to Mark)

From:	plw 137				
Grid		Local		Global	
Easting	618656.024 m	Latitude	N9°11'02.95363"	Latitude	N9°10'58.60442"
Northing	1015326.411 m	Longitude	E118°04'48.04733"	Longitude	E118°04'53.42391"
Elevation	35.893 m	Height	35.834 m	Height	85.647 m

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

Vector					
ΔEasting	-21212.540 m	NS Fwd Azimuth	269°40'42"	ΔX	18740.467 m
ΔNorthing	-182.904 m	Ellipsoid Dist.	21218.741 m	ΔY	9950.677 m
ΔElevation	-25.857 m	ΔHeight	-26.496 m	ΔZ	-128.040 m

Standard Errors

Vector errors:					
σ ΔEasting	0.002 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.003 m
σ ΔNorthing	0.001 m	σ Ellipsoid Dist.	0.002 m	σ ΔY	0.005 m
σ ΔElevation	0.006 m	σ ΔHeight	0.006 m	σ ΔZ	0.001 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000094504		
Y	-0.0000117410	0.0000274170	
Z	-0.0000021534	0.0000044403	0.0000015882

Figure A-3.2. Baseline Processing Report - B

2. QZT-2

Vector Components (Mark to Mark)

From:	plw 137				
Grid		Local		Global	
Easting	618656.024 m	Latitude	N8°11'02.95363"	Latitude	N8°10'58.60442"
Northing	1015326.411 m	Longitude	E118°04'48.04733"	Longitude	E118°04'53.42391"
Elevation	35.893 m	Height	35.834 m	Height	85.647 m

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

Vector					
ΔEasting	-21205.048 m	NS Fwd Azimuth	269°35'56"	ΔX	18732.854 m
ΔNorthing	-212.303 m	Ellipsoid Dist.	21211.522 m	ΔY	9949.197 m
ΔElevation	-28.333 m	ΔHeight	-28.970 m	ΔZ	-157.483 m

Standard Errors

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

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0001228363		
Y	-0.0001285827	0.0002649111	
Z	-0.0000183105	0.0000652757	0.0000238832

Figure A-3.3. Baseline Processing Report - C

Processing style

Elevation mask:	10.0 deg
Auto start processing:	Yes
Start automatic ID numbering:	AUTO0001
Continuous vectors:	No
Generate residuals:	Yes
Antenna model:	Automatic
Ephemeris type:	Automatic
Frequency:	Multiple Frequencies
Processing interval:	Use all data
Force float:	No

Acceptance Criteria

Vector Component	Flag	Fail
Horizontal Precision >	0.050 m + 1.000 ppm	0.100 m + 1.000 ppm
Vertical Precision >	0.100 m + 1.000 ppm	0.200 m + 1.000 ppm

plw 137 - qzt 2 (1:21:54 PM-5:50:14 PM) (S2)

Baseline observation:	plw 137 --- qzt 2 (B2)
Processed:	7/24/2015 6:16:02 PM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.018 m
Vertical precision:	0.037 m
RMS:	0.004 m
Maximum PDOP:	1.717
Ephemeris used:	Broadcast
Antenna model:	NGS Absolute
Processing start time:	7/13/2015 1:21:54 PM (Local: UTC+8hr)
Processing stop time:	7/13/2015 5:50:14 PM (Local: UTC+8hr)
Processing duration:	04:28:20
Processing interval:	5 seconds

Figure A-3.4. Baseline Processing Report - D

3. PL-3058

Baseline Processing Report

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
PLW3058 --- PLW13 (B1)	PLW13	PLW3058	Fixed	0.007	0.024	52°27'10"	82603.650	-2.693

Acceptance Summary

Processed	Passed	Flag	Fail
1	1	0	0

PLW3058 - PLW13 (7:29:44 AM-1:02:54 PM) (S1)

Baseline observation:	PLW3058 --- PLW13 (B1)
Processed:	1/8/2016 5:57:30 PM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.007 m
Vertical precision:	0.024 m
RMS:	0.005 m
Maximum PDOP:	2.036
Ephemeris used:	Broadcast
Antenna model:	NGS Absolute
Processing start time:	12/7/2015 7:30:04 AM (Local: UTC+8hr)
Processing stop time:	12/7/2015 1:02:54 PM (Local: UTC+8hr)
Processing duration:	05:32:50
Processing interval:	5 seconds

1

Figure A-3.5. Baseline Processing Report - E

Vector Components (Mark to Mark)

From:	PLW13				
Grid		Local		Global	
Easting	-113741.490 m	Latitude	N8°30'17.42900"	Latitude	N8°30'13.19373"
Northing	944471.057 m	Longitude	E117°25'56.42676"	Longitude	E117°26'00.86801"
Elevation	1.573 m	Height	-0.256 m	Height	49.360 m

To:	PLW3068				
Grid		Local		Global	
Easting	-47262.005 m	Latitude	N8°57'34.41144"	Latitude	N8°57'30.11418"
Northing	994023.989 m	Longitude	E118°01'39.35193"	Longitude	E118°01'44.74872"
Elevation	-3.131 m	Height	-2.948 m	Height	47.207 m

Vector					
ΔEasting	66479.484 m	NS Fwd Azimuth	52°27'10"	ΔX	-54449.908 m
ΔNorthing	49552.932 m	Ellipsoid Dist.	82603.650 m	ΔY	-37251.543 m
ΔElevation	-4.704 m	ΔHeight	-2.693 m	ΔZ	49706.933 m

Standard Errors

Vector errors:					
σ ΔEasting	0.003 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.006 m
σ ΔNorthing	0.002 m	σ Ellipsoid Dist.	0.003 m	σ ΔY	0.011 m
σ ΔElevation	0.012 m	σ ΔHeight	0.012 m	σ ΔZ	0.003 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000356543		
Y	-0.0000566784	0.0001191653	
Z	-0.0000106477	0.0000187894	0.0000078497

Figure A-3.6. Baseline Processing Report - F

4. PL-412

Baseline Processing Report

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
PLW-3058 --- PL-412 (B1)	PLW-3058	PL-412	Fixed	0.005	0.018	25°22'54"	7278.148	2.612
PLW-3058 --- PL-412 (B2)	PLW-3058	PL-412	Fixed	0.009	0.034	25°22'54"	7278.131	2.585

Acceptance Summary

Processed	Passed	Flag	Fail
2	2	0	0

PLW-3058 - PL-412 (1:37:59 PM-6:11:54 PM) (S1)

Baseline observation:	PLW-3058 --- PL-412 (B1)
Processed:	1/4/2016 2:09:04 PM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.005 m
Vertical precision:	0.018 m
RMS:	0.026 m
Maximum PDOP:	2.957
Ephemeris used:	Broadcast
Antenna model:	NGS Absolute
Processing start time:	12/5/2015 1:38:29 PM (Local: UTC+8hr)
Processing stop time:	12/5/2015 6:11:54 PM (Local: UTC+8hr)
Processing duration:	04:33:25
Processing interval:	5 seconds

1

Figure A-3.7. Baseline Processing Report - G

Vector Components (Mark to Mark)

From:	PLW-3058				
Grid		Local		Global	
Easting	-47262.004 m	Latitude	N8°57'34.41133"	Latitude	N8°57'30.11407"
Northing	994023.986 m	Longitude	E118°01'39.35197"	Longitude	E118°01'44.74876"
Elevation	-3.131 m	Height	-2.948 m	Height	47.207 m

To:	PL-412				
Grid		Local		Global	
Easting	-44042.610 m	Latitude	N9°01'08.45200"	Latitude	N9°01'04.14225"
Northing	1000578.048 m	Longitude	E118°03'21.49607"	Longitude	E118°03'26.88749"
Elevation	-0.491 m	Height	-0.337 m	Height	49.768 m

Vector					
ΔEasting	3219.394 m	NS Fwd Azimuth	25°22'54"	ΔX	-2271.764 m
ΔNorthing	6554.062 m	Ellipsoid Dist.	7278.148 m	ΔY	-2371.208 m
ΔElevation	2.640 m	ΔHeight	2.612 m	ΔZ	6495.211 m

Standard Errors

Vector errors:					
σ ΔEasting	0.002 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.005 m
σ ΔNorthing	0.002 m	σ Ellipsoid Dist.	0.002 m	σ ΔY	0.008 m
σ ΔElevation	0.009 m	σ ΔHeight	0.009 m	σ ΔZ	0.002 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000235182		
Y	-0.0000361146	0.0000644168	
Z	-0.0000060329	0.0000098915	0.0000055951

Figure A-3.8. Baseline Processing Report - H

Annex 4. The LiDAR Survey Team Composition

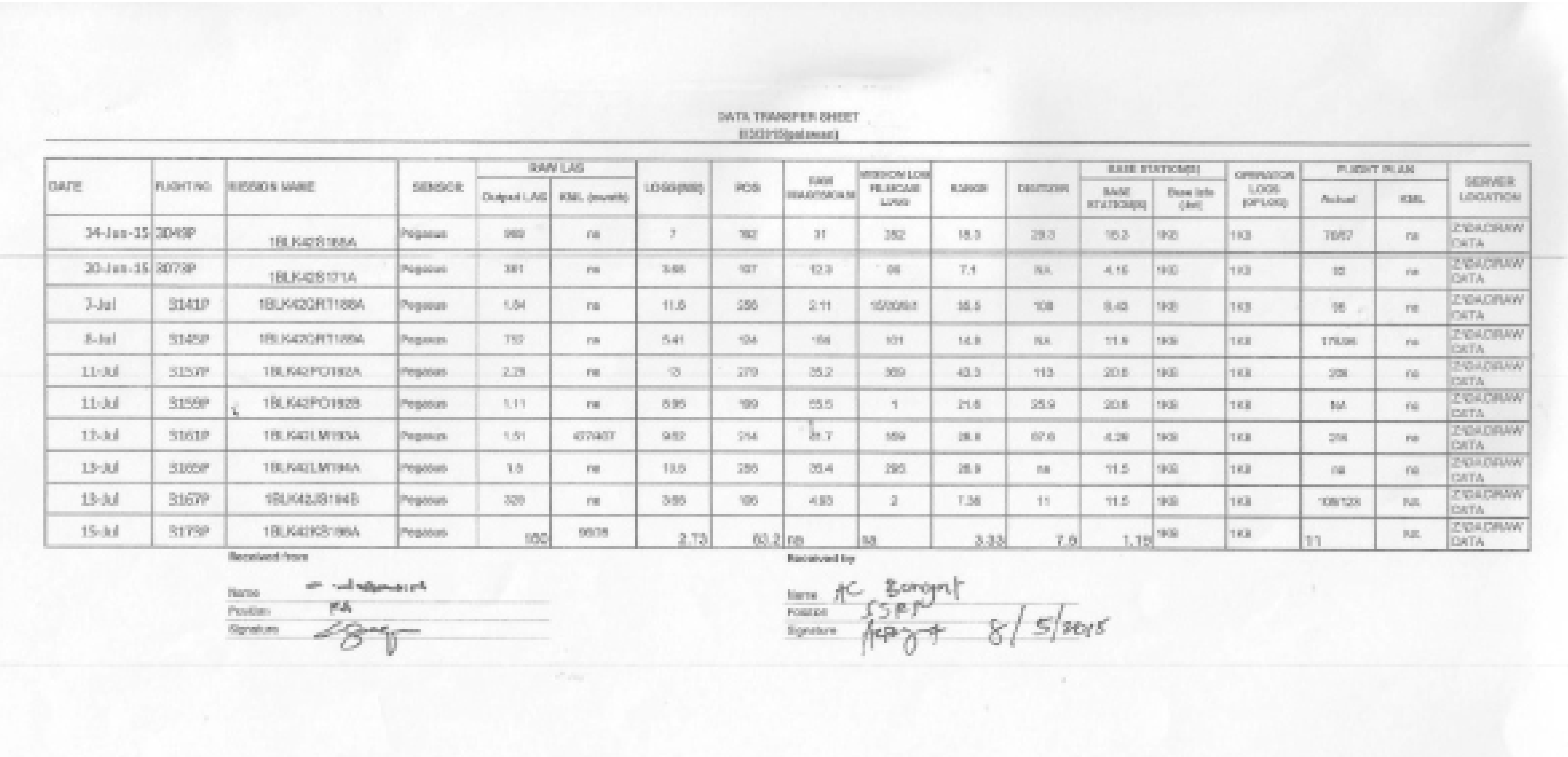
Table A-4.1. LiDAR Survey Team Composition

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. CZAR JAKIRI SARMIENTO	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUÑA	UP-TCAGP
		ENGR. LOVELYN ASUNCION	UP-TCAGP

FIELD TEAM

LiDAR Operation	Senior Science Research Specialist (SSRS)	JASMINE ALVIAR	UP-TCAGP
	Research Associate (RA)	ENGR. GEROME B.HIPOLITO	UP-TCAGP
	RA	ENGR. LARAH KRISELLE PARAGAS	UP-TCAGP
	RA	GRACE SINADJAN	UP-TCAGP
	RA	MARY CATHERINE ELIZABETH BALIGUAS	UP-TCAGP
	RA	JONATHAN ALMALVEZ	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	JERIEL PAUL ALAMBAN, GEOL.	UP-TCAGP
	RA	ENGR. IRO NIEL ROXAS	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. ARIES TORNO	PHILIPPINE AIR FORCE (PAF)
		AT2C JUNMAR PARANGUE	PAF
	Pilot	CAPT. MARK TANGONAN	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. ALBERT PAUL LIM	AAC
		CAPT. JUSTINE JOYA	AAC
		CAPT. RANDY LAGCO	AAC

Annex 5. Data Transfer Sheet For Tigaplan Floodplain



DATA TRANSFER SHEET

[illegible]

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	
24-Jun-15	3049P	1BLK42B188A	Pegasus	989	na	7	192	31	282	18.3	29.3	15.2	1KB	1KB	70/57	na	Z:\DAC\RAW DATA
30-Jun-15	3073P	1BLK42B171A	Pegasus	381	na	3.66	107	12.3	66	7.1	NA	4.15	1KB	1KB	55	na	Z:\DAC\RAW DATA
7-Jul	3141P	1BLK42GRT188A	Pegasus	1.84	na	11.6	286	2.11	10/20/84	36.3	108	8.43	1KB	1KB	56	na	Z:\DAC\RAW DATA
8-Jul	3145P	1BLK42GRT189A	Pegasus	750	na	5.41	104	156	101	14.8	NA	11.8	1KB	1KB	176/86	na	Z:\DAC\RAW DATA
11-Jul	3157P	1BLK42PO192A	Pegasus	2.28	na	13	279	35.2	369	43.3	113	20.8	1KB	1KB	208	na	Z:\DAC\RAW DATA
11-Jul	3159P	1BLK42PO192B	Pegasus	1.11	na	8.95	189	55.5	1	21.6	25.9	20.8	1KB	1KB	NA	na	Z:\DAC\RAW DATA
12-Jul	3161P	1BLK42LM193A	Pegasus	1.51	477/407	9.82	214	28.7	559	28.8	67.6	4.26	1KB	1KB	208	na	Z:\DAC\RAW DATA
13-Jul	3165P	1BLK42LM194A	Pegasus	1.5	na	13.6	286	35.4	295	28.8	na	11.5	1KB	1KB	na	na	Z:\DAC\RAW DATA
13-Jul	3167P	1BLK42JB194B	Pegasus	320	na	3.66	106	4.83	2	7.38	11	11.5	1KB	1KB	108/120	NA	Z:\DAC\RAW DATA
15-Jul	3175P	1BLK42KS196A	Pegasus	550	98/78	2.73	63.2	na	na	3.33	7.6	1.15	1KB	1KB	11	NA	Z:\DAC\RAW DATA

Received from

Name [illegible]
Position PA
Signature [signature]

Received by

Name AC Bongat
Position SSRP
Signature [signature] 8/5/2015

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

DATA TRANSFER SHEET
PALAWAN 12/17/15

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
20-Nov-15	3565	2BLK42PQR337A	GEMINI	NA	92	536	202	na	na	25.4	na	6.96	1KB	1KB	22/24/22/48/51	NA	Z:\DAC\RAW DATA
21-Nov-15	3571	2BLK42Tv338A	GEMINI	NA	171	370	180	na	na	14.6	na	640	1KB	1KB	22/24/22/48/51	NA	Z:\DAC\RAW DATA
26-Nov-15	3573	2BLK42Dv339A	GEMINI	NA	484	1	227	na	na	19.7	na	12.1	1KB	1KB	24/22/48/53/51/30	NA	Z:\DAC\RAW DATA
27-Nov-15	3575	2BLK42OQ339B	GEMINI	NA	734	530	218	na	na	22.3	na	12.1	1KB	1KB	24/22/30/53/50/48/51	NA	Z:\DAC\RAW DATA
28-Nov-15	3581	2BLK42NPQ341A	GEMINI	NA	872	484	232	na	na	21.2	na	8.55	1KB	NA	24/22/21/27/30/53/50/48/51	NA	Z:\DAC\RAW DATA
30-Nov-15	3585	2BLK42Nv342A	GEMINI	NA	1080	558	234	na	na	23	na	5.29	1KB	1KB	24/22/21/28/27/30/53/50/48/51	NA	Z:\DAC\RAW DATA
30-Nov-15	3593	2BLK42TwEwF344A	GEMINI	NA	1343	523	227	na	na	20.9	na	11.4	1KB	1KB	53/50/48/17	NA	Z:\DAC\RAW DATA
1-Dec-15	3595	2BLK42US344B	GEMINI	NA	253	387	156	na	na	17.4	na	11.4	1KB	1KB	17/16	NA	Z:\DAC\RAW DATA

* transferred twice

Received from

Name C. J [illegible]
Position
Signature

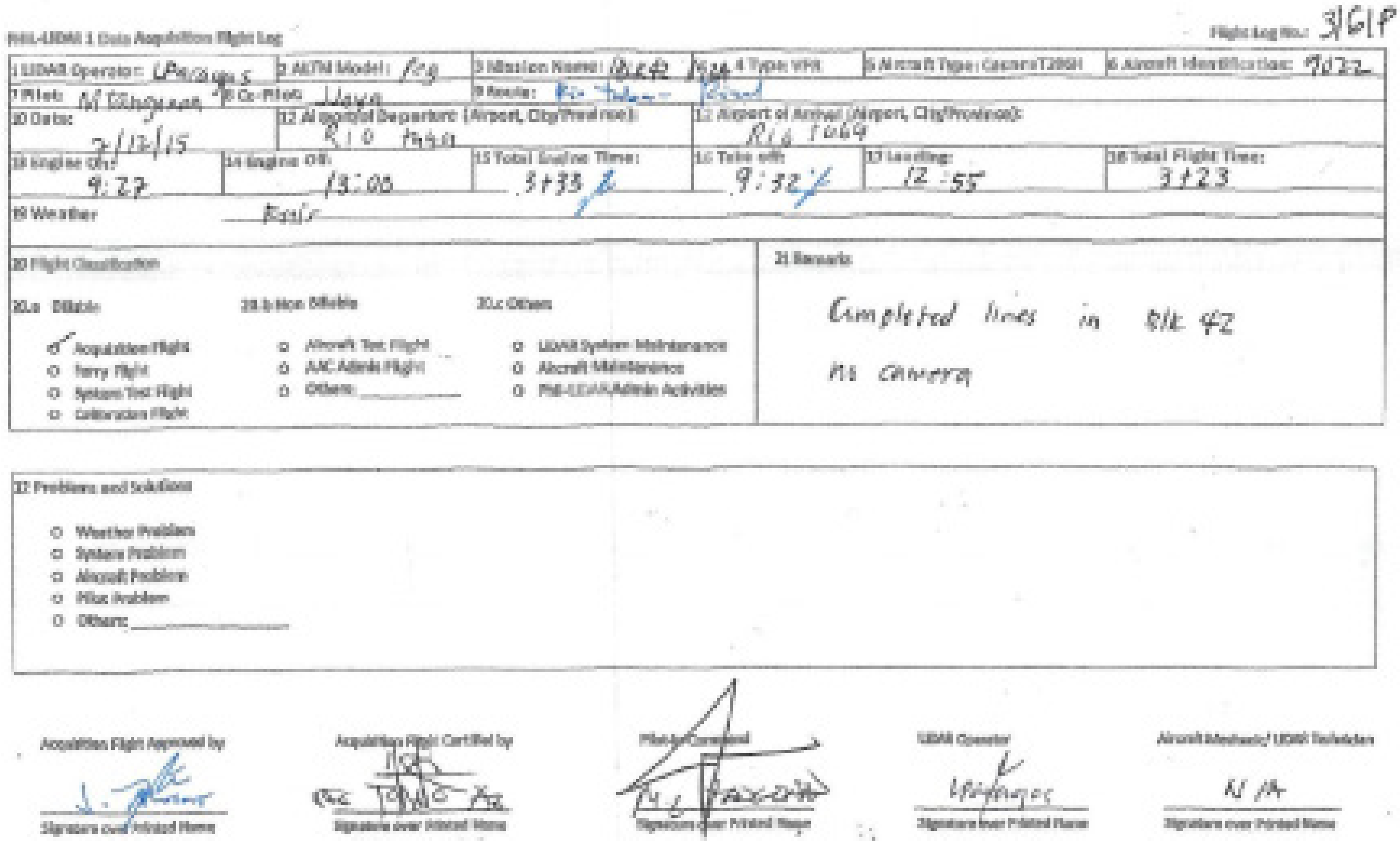
Received by

Name AC Bongat
Position SSRS
Signature [illegible] 1/5/2016

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

Annex 6. Flight Logs

1. Flight Log for 1BLK42LM193A Mission



PHIL-LIDAR 1 Data Acquisition Flight Log — Flight Log No.: 3161P

1 LIDAR Operator: LParagas | 2 ALTM Model: Peg | 3 Mission Name: 1BLK42 | 4 Type: VFR | 5 Aircraft Type: Cessna T206H | 6 Aircraft Identification: 9022
7 Pilot: | 8 Co-Pilot: | 9 Route:
10 Date: 7/12/15 | 12 Airport of Departure (Airport, City/Province): | 12 Airport of Arrival (Airport, City/Province):
13 Engine On: 9:22 | 14 Engine Off: 13:08 | 15 Total Engine Time: 3+33 | 16 Take off: 9:32 | 17 Landing: 12:55 | 18 Total Flight Time: 3+23
19 Weather

20 Flight Classification
20.a Billable: ✓ Acquisition Flight; Ferry Flight; System Test Flight; Calibration Flight
20.b Non Billable: Aircraft Test Flight; AAC Admin Flight; Others
20.c Others: LIDAR System Maintenance; Aircraft Maintenance; Phil-LIDAR Admin Activities

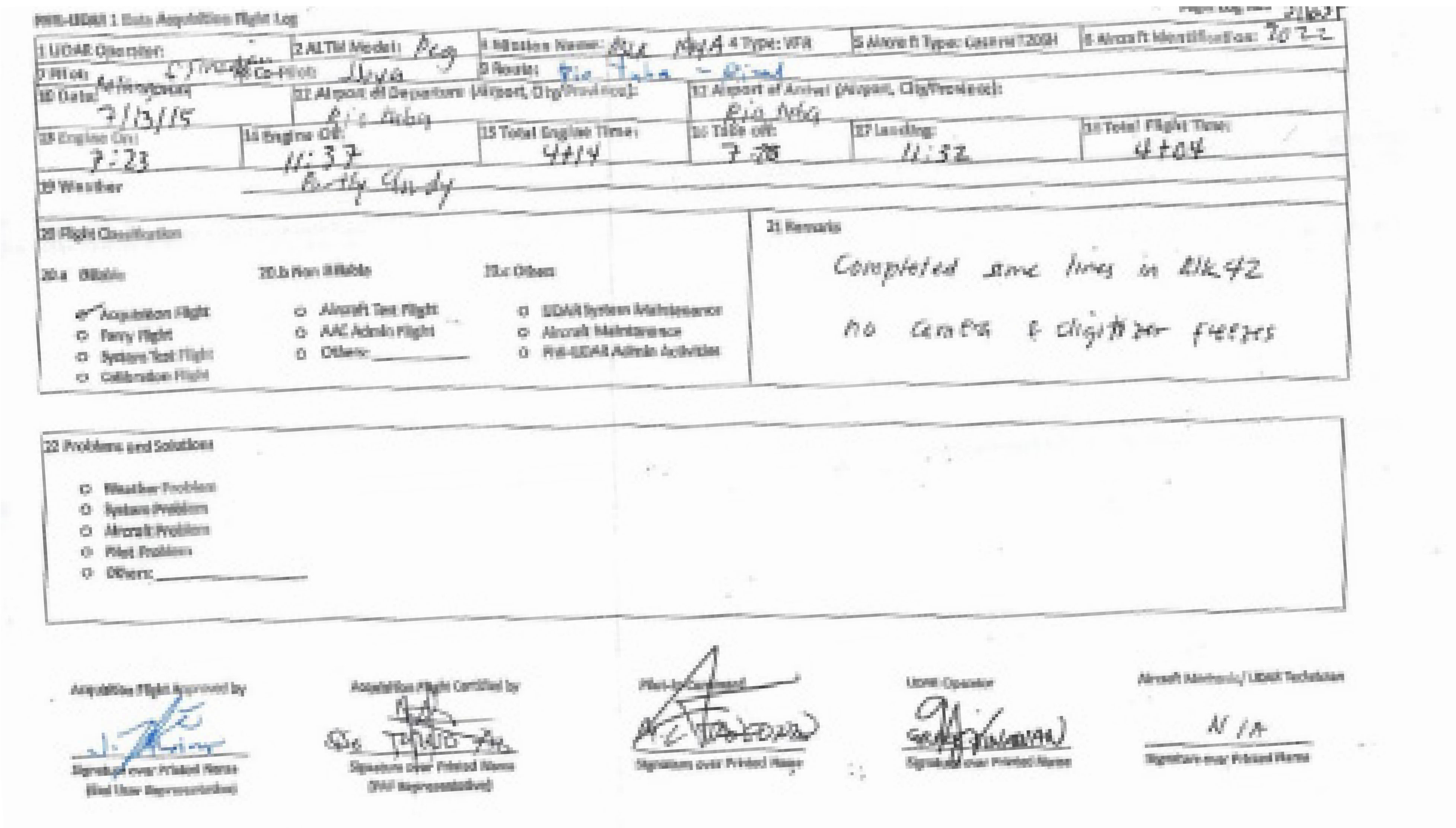
21 Remarks: Completed lines in BLK 42 No camera

22 Problems and Solutions: Weather Problem; System Problem; Aircraft Problem; Pilot Problem; Others

Acquisition Flight Approved by — Signature over Printed Name
Acquisition Flight Certified by — Signature over Printed Name
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-6.1. Flight Log for Mission 1BLK42LM193A

2. Flight Log for 1BLK42LM194A Mission



PHIL-LIDAR 1 Data Acquisition Flight Log

1 LiDAR Operator: | 2 ALTM Model: | 3 Mission Name: | 4 Type: VFR | 5 Aircraft Type: Cessna T206H | 6 Aircraft Identification:

7 Pilot: | 8 Co-Pilot: | 9 Route:

10 Date: 7/13/15 | 12 Airport of Departure (Airport, City/Province): | 13 Airport of Arrival (Airport, City/Province):

13 Engine On: 7:23 | 14 Engine Off: 11:37 | 15 Total Engine Time: 4+14 | 16 Take off: | 17 Landing: 11:32 | 18 Total Flight Time: 4+04

19 Weather

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 some lines in BLK42

no camera & digitizer freezes

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)

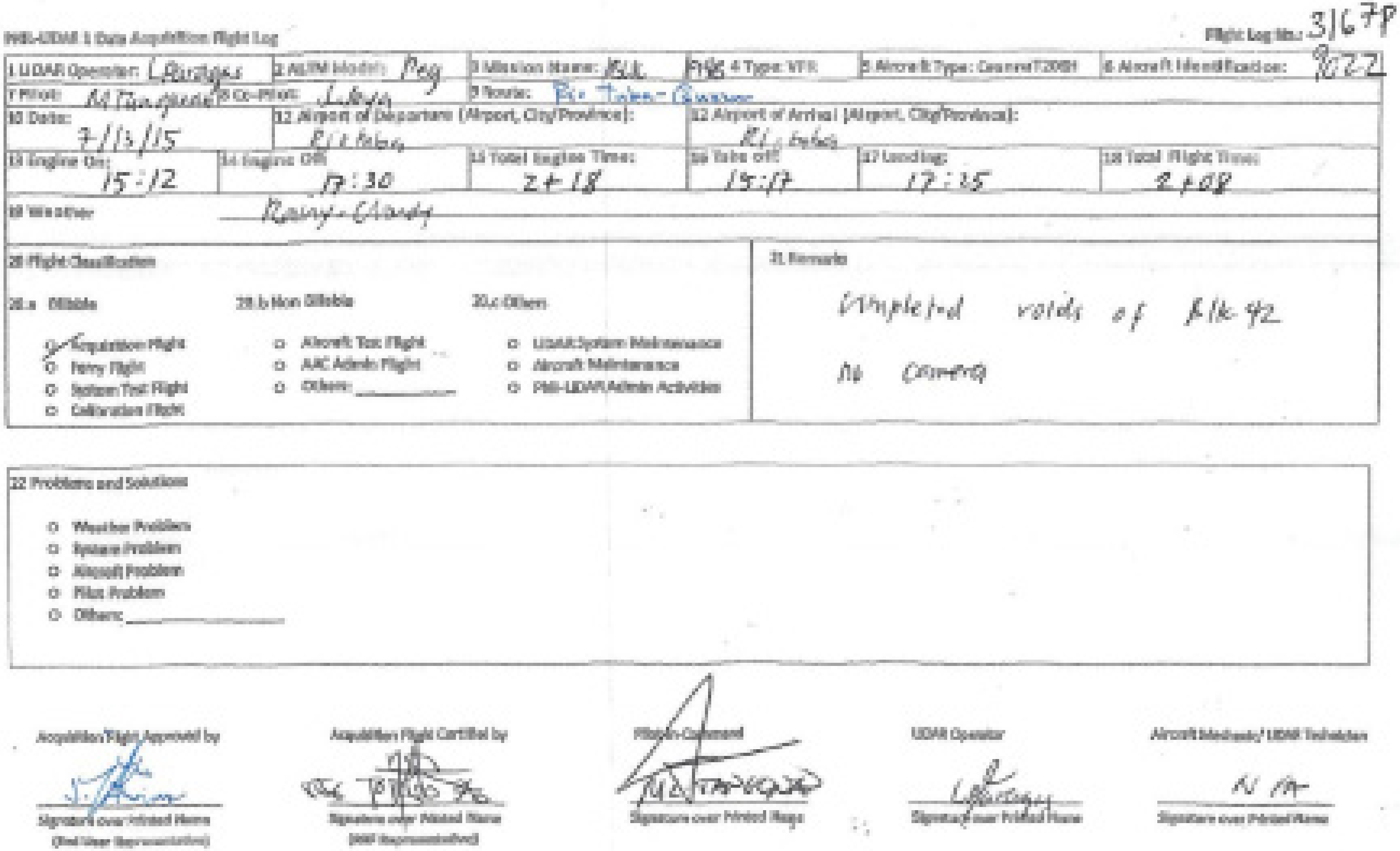
Pilot-in-Command — Signature over Printed Name

LiDAR Operator — Signature over Printed Name

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

Figure A-6.2. Flight Log for Mission LK42LM194A

3. Flight Log for 1BLK42JS194B Mission


PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 3167P

1 LIDAR Operator: L Burgos	2 ALTM Model: Peg	3 Mission Name: BLK	4 Type: VFR	5 Aircraft Type: Cessna T206H	6 Aircraft Identification: 9022
7 Pilot: M Tangonan	8 Co-Pilot: J Loyola	9 Route: R. Tubo - Quezon			
10 Date: 7/13/15	12 Airport of Departure (Airport, City/Province): R. Tubo		12 Airport of Arrival (Airport, City/Province): R. Tubo		
13 Engine On: 15:12	14 Engine Off: 17:30	15 Total Engine Time: 2+18	16 Take off: 15:17	17 Landing: 17:25	18 Total Flight Time: 2+08
19 Weather	Rainy - Cloudy				

20 Flight Classification

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

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

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

21 Remarks

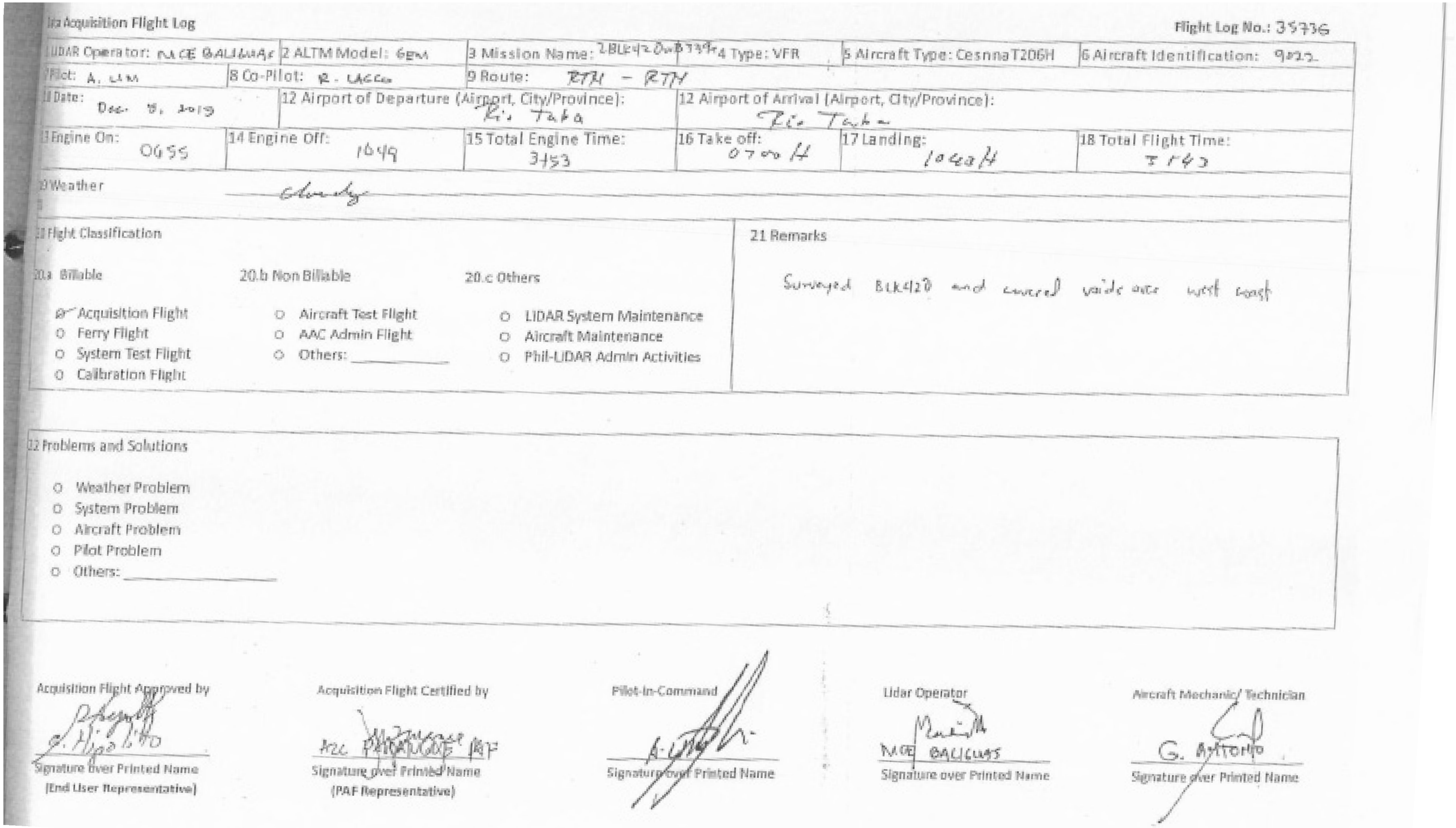
Completed voids of Blk 42
No camera

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	LIDAR Operator	Aircraft Mechanic/ LIDAR Technician
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	N/A Signature over Printed Name

Figure A-6.3. Flight Log for Mission LK42LM194A

4. Flight Log for 2BLK42Ov339A Mission


1 a Acquisition Flight Log

Flight Log No.: 35736

1 LiDAR Operator: MJCE BALIGUAS	2 ALTM Model: Gem	3 Mission Name: 2BLK42Ov339A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9022
7 Pilot: A. LIM	8 Co-Pilot: R. LACCO	9 Route: RTH - RTH			
10 Date: Dec. 8, 2019	12 Airport of Departure (Airport, City/Province): Rio Tuba		12 Airport of Arrival (Airport, City/Province): Rio Tuba		
13 Engine On: 0655	14 Engine Off: 1049	15 Total Engine Time: 3+53	16 Take off: 0700H	17 Landing: 1040H	18 Total Flight Time: 3+40
19 Weather: Cloudy					

20 Flight Classification

20.a Billable
- Acquisition Flight (checked)
- Ferry Flight
- System Test Flight
- Calibration Flight

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

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

21 Remarks

Surveyed BLK42D and covered voids over west coast

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

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

Acquisition Flight Certified by: [signature] A2C Pagatpatan PAF — Signature over Printed Name (PAF Representative)

Pilot-in-Command: [signature] A. Lim — Signature over Printed Name

Lidar Operator: [signature] MJCE Baliguas — Signature over Printed Name

Aircraft Mechanic/ Technician: [signature] G. Antonio — Signature over Printed Name

Figure A-6.4. Flight Log for Mission 2BLK42Ov339A

Annex 7. Flight Status

FLIGHT STATUS REPORT
Tigaplan FLOODPLAIN
(July 11-13 & December 5, 2015)

Table A-7.1. Flight Status Report

FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
3161P	BLK 42LM	1BLK42LM193A	L. Paragas	July 12, 2015	Surveyed BLK 42L and BLK 42M
3165P	BLK 42LM	1BLK42LM194A	G. Sinadjan	July 13, 2015	Surveyed remaining areas In BLK 42L and BLK 42M
3167P	BLK 42JS	1BLK42JS194B	L. Paragas	July 13, 2015	Surveyed remaining gap in BLK 42J
3573	BLK42 eO; L,M voids	2BLK42Ov339A	MCE Baliguas	05-Dec-15	Surveyed BLK42eO and west voids (BLK42L,M)

LAS/SWATH BOUNDARIES PER MISSION FLIGHT

FLIGHT LOG NO.	3161P	
AREA:	BLOCK 42LM	
MISSION NAME:	1BLK42LM193A	PRF: 200
	Scan Freq: 30 Hz	Scan Angle: 25 deg
SURVEY COVERAGE:		

LAS

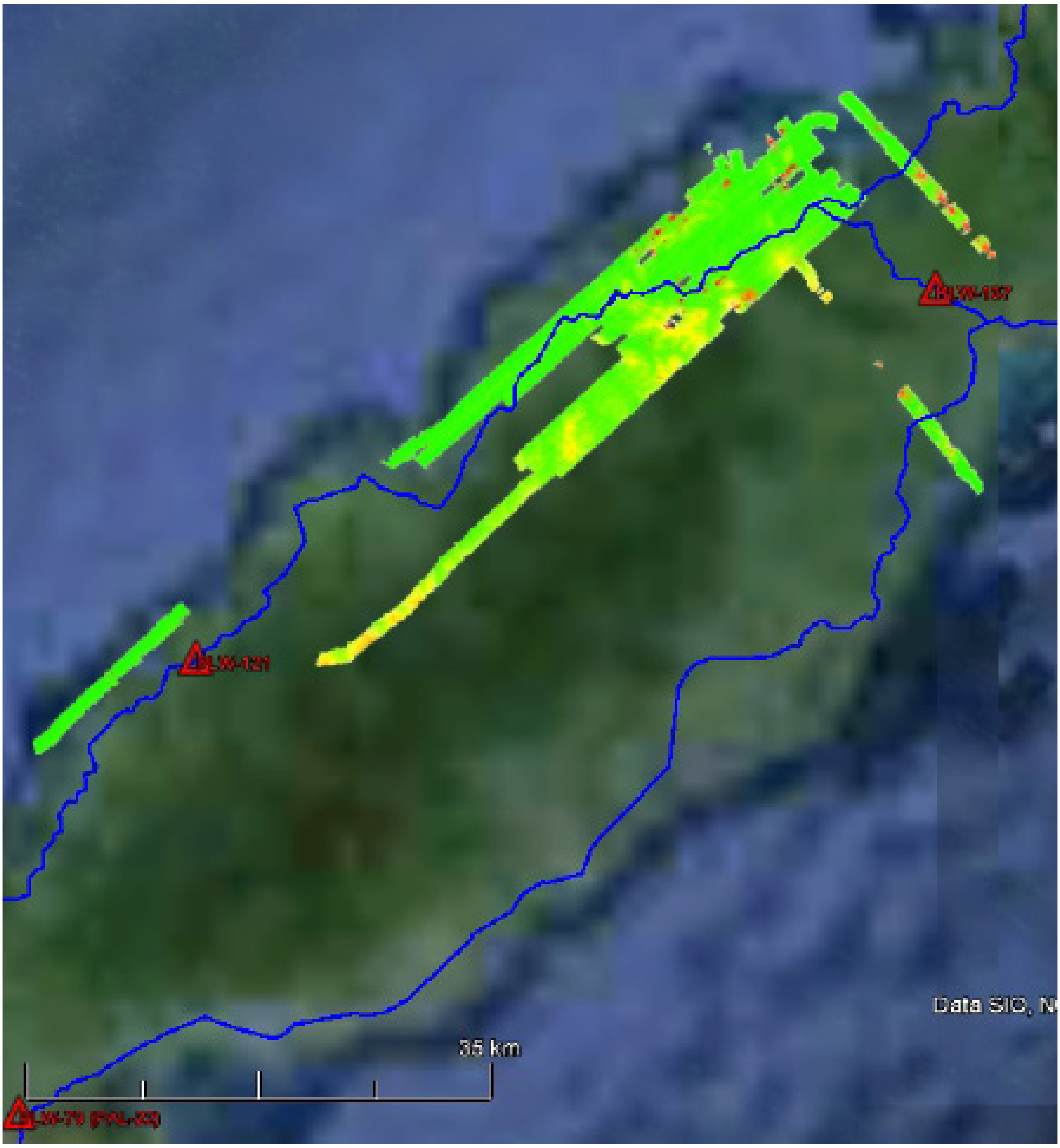


Figure A-7.1. Swath for Flight No. 3161P

FLIGHT LOG NO.	3165P	
AREA:	BLOCK 42LM	
MISSION NAME:	1BLK42LM194A	PRF: 200
	Scan Freq: 30 Hz	Scan Angle: 25 deg
SURVEY COVERAGE:		

LAS

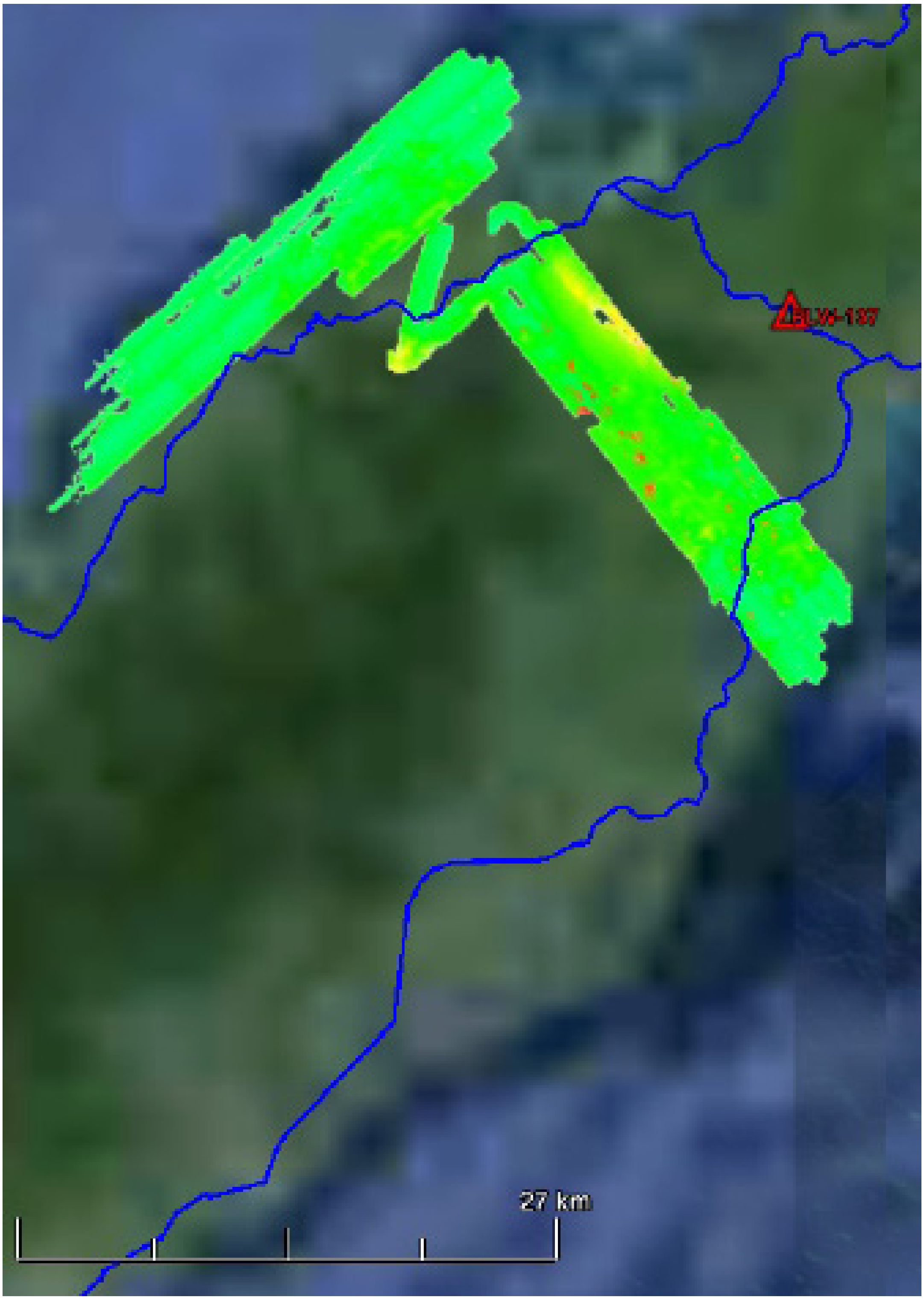


Figure A-7.2. Swath for Flight No. 3165P

FLIGHT LOG NO.	3167P	
AREA:	BLOCK 42JS	
MISSION NAME:	1BLK42JS194B	PRF: 200
	Scan Freq: 30 Hz	Scan Angle: 25 deg
SURVEY COVERAGE:		

LAS

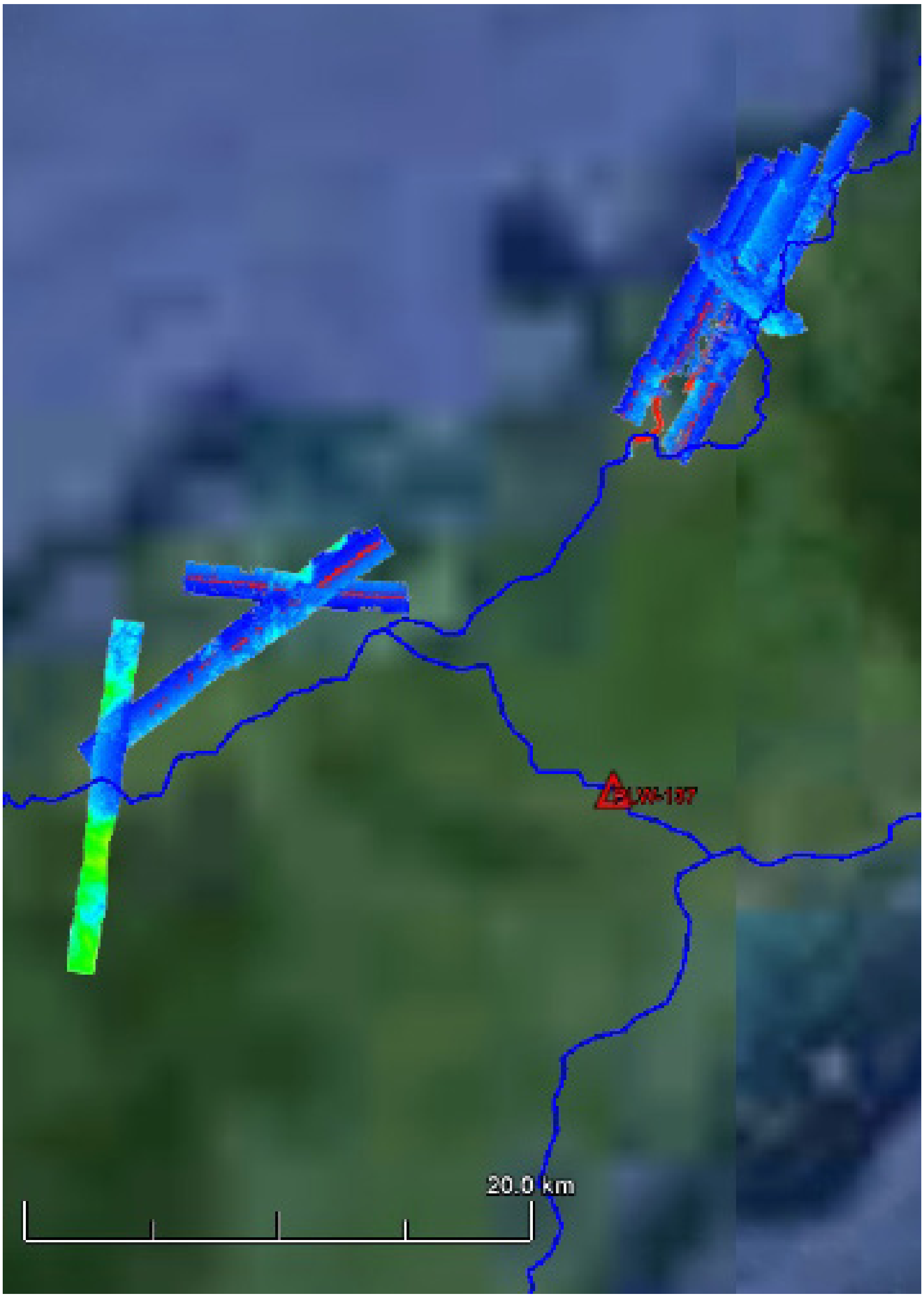


Figure A-7.3. Swath for Flight No. 3167P

FLIGHT NO.	3573
AREA:	BLK 42 EO, 42LKM VOIDS
MISSION NAME:	2BLK42OV339A
TOTAL AREA SURVEYED:	111.657 SQ KM

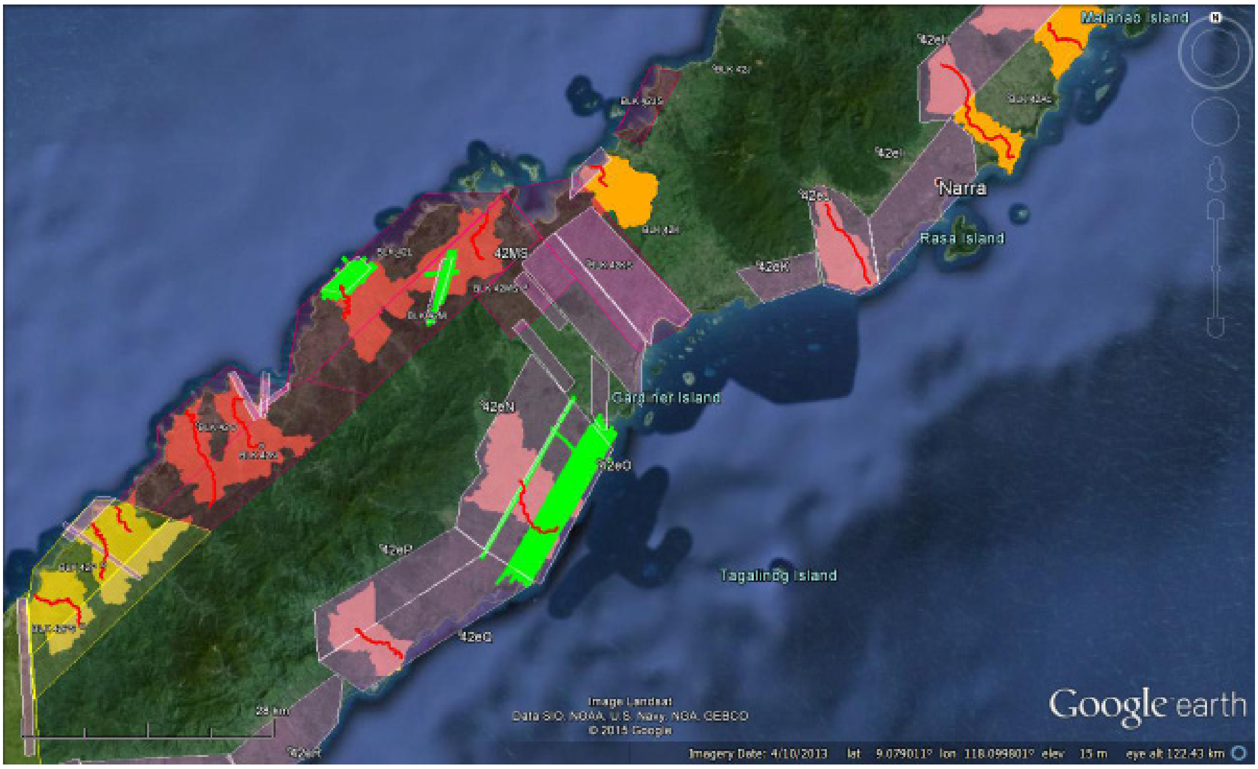


Figure A-7.4. Swath for Flight No. 3573P

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Blk 42L

Flight Area	Davao Oriental
Mission Name	Blk 42L
Inclusive Flights	3161P & 3165P
Range data size	57.70 GB
POS	469 MB
Image	78.10 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)	1.80
RMSE for East Position (<4.0 cm)	2.60
RMSE for Down Position (<8.0 cm)	1.35
Boresight correction stdev (<0.001deg)	0.000188
IMU attitude correction stdev (<0.001deg)	0.000512
GPS position stdev (<0.01m)	0.0015
Minimum % overlap (>25)	41.20
Ave point cloud density per sq.m. (>2.0)	2.92
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	286
Maximum Height	330.22
Minimum Height	35.92
Classification (# of points)	
Ground	156485701
Low vegetation	131781027
Medium vegetation	193453766
High vegetation	471929280
Building	7313285
Orthophoto	No
Processed by	Engr. Regis Guhiting, Engr. Melanie Hingpit, Ryan Nicholai Dizon

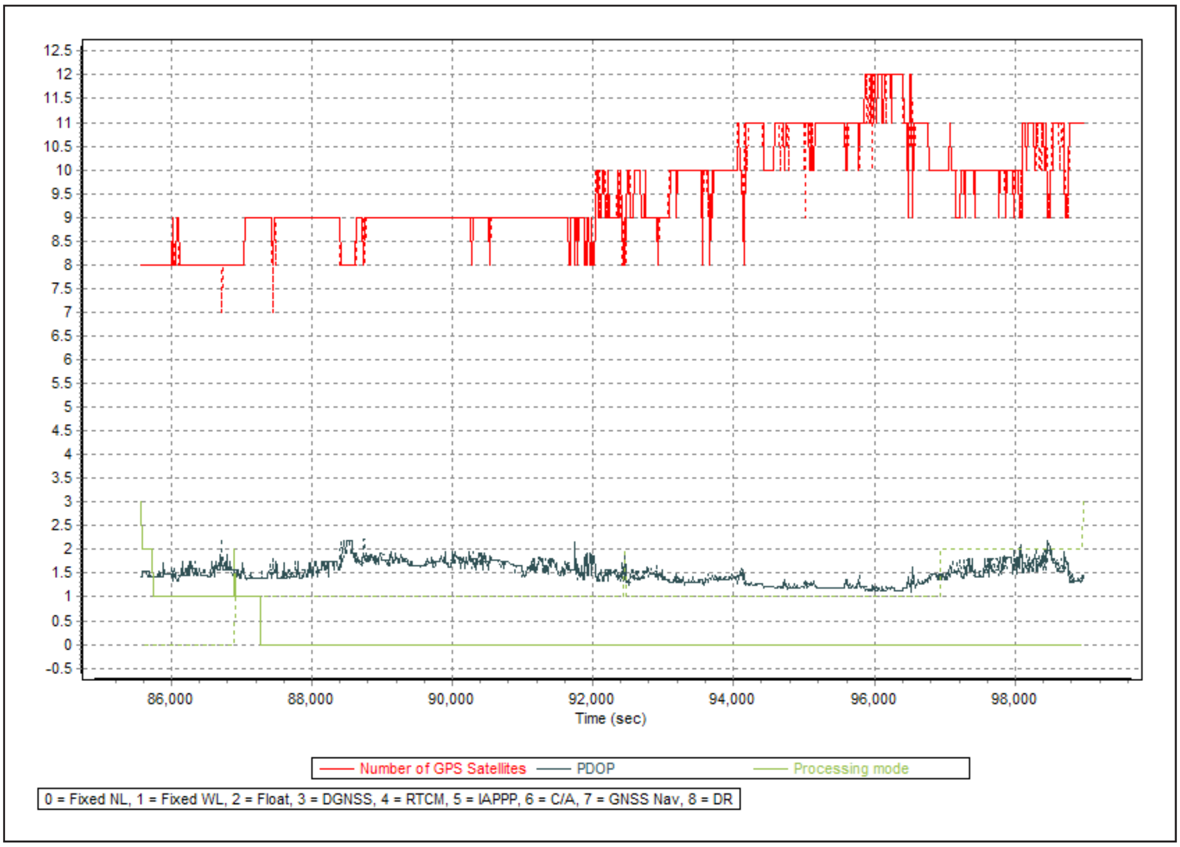


Figure A-8.1. Solution Status

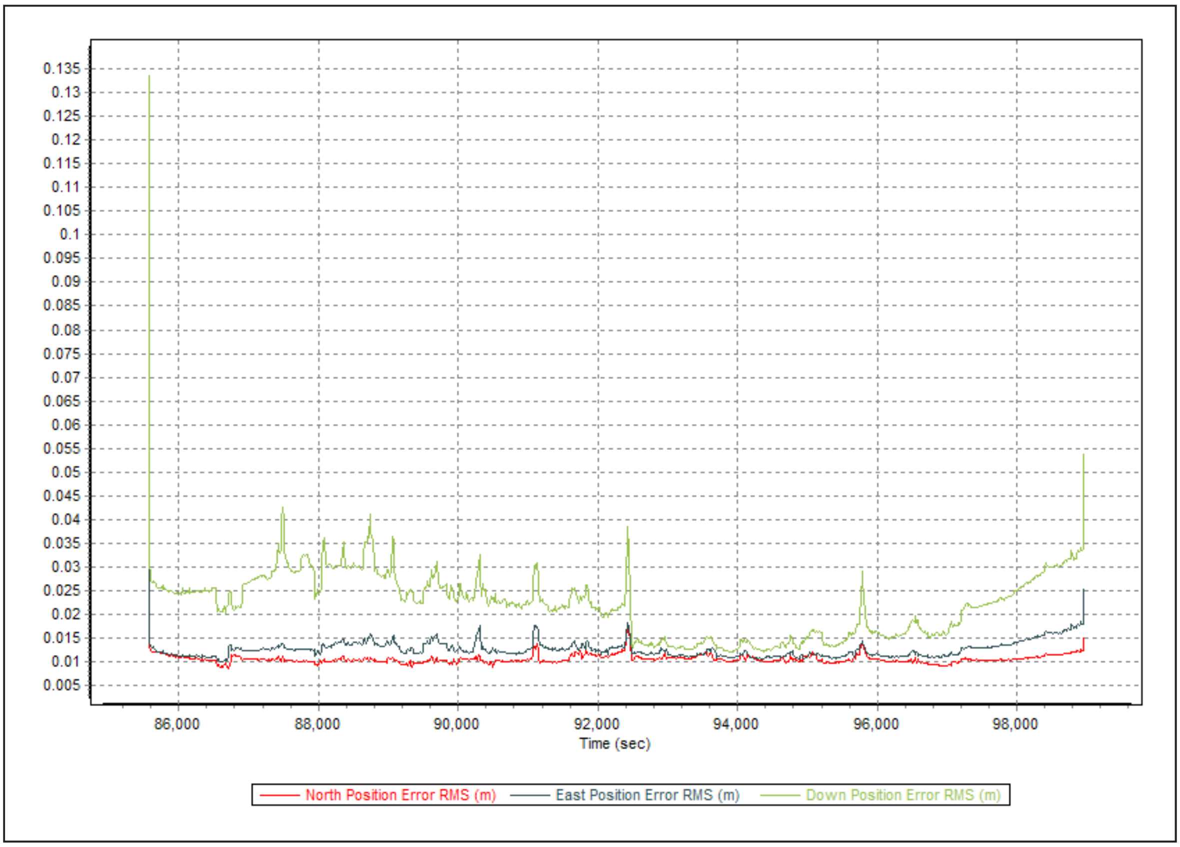


Figure A-8.2. Smoothed Performance Metric Parameters

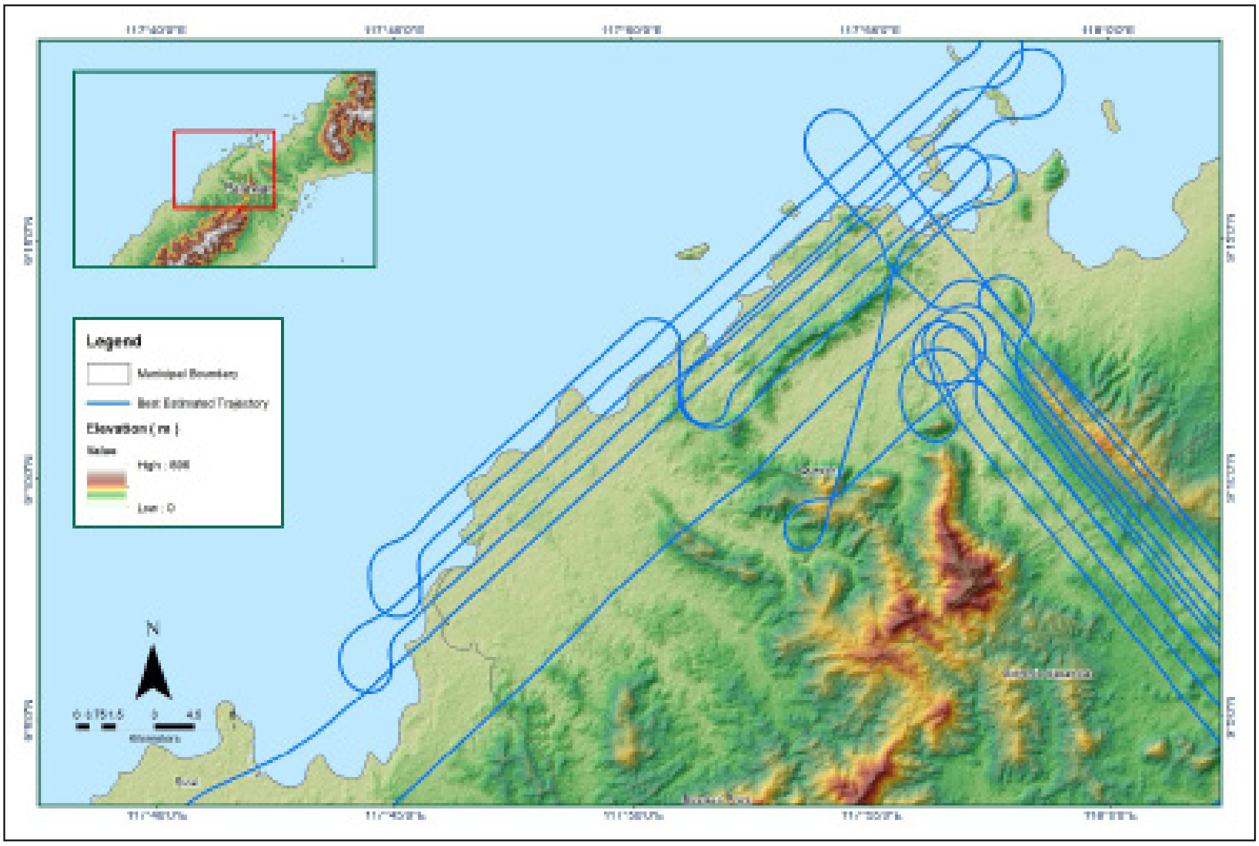


Figure A-8.3. Best Estimated Trajectory

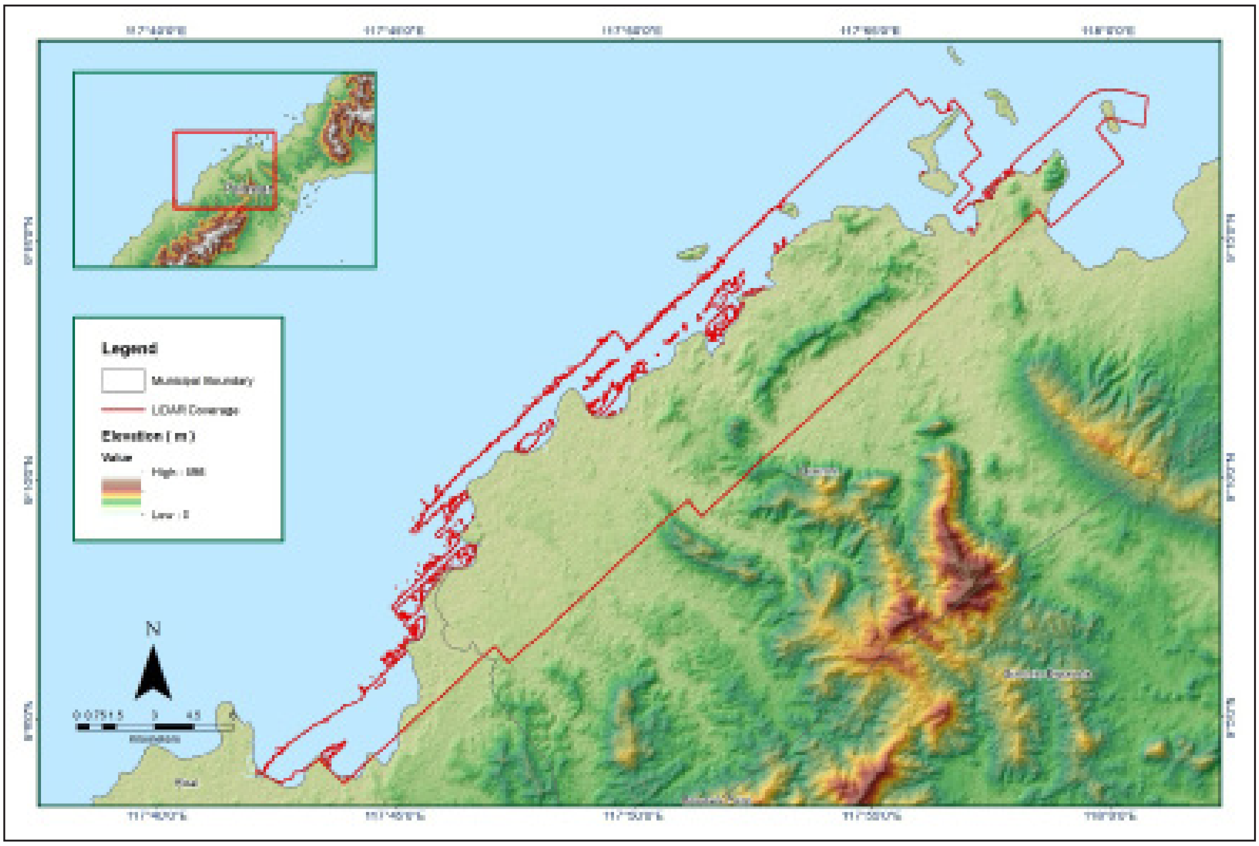


Figure A-8.4. Coverage of LiDAR data

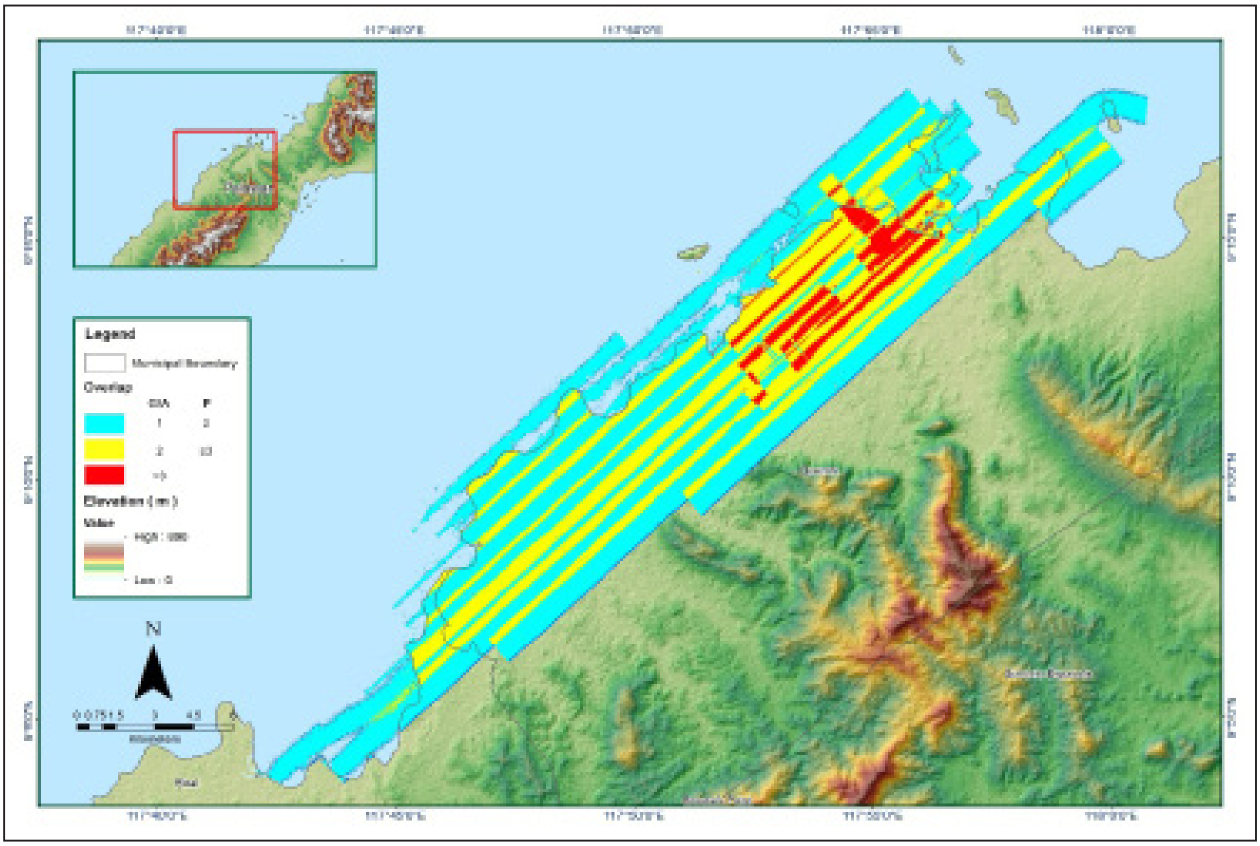


Figure A-8.5. Image of data overlap

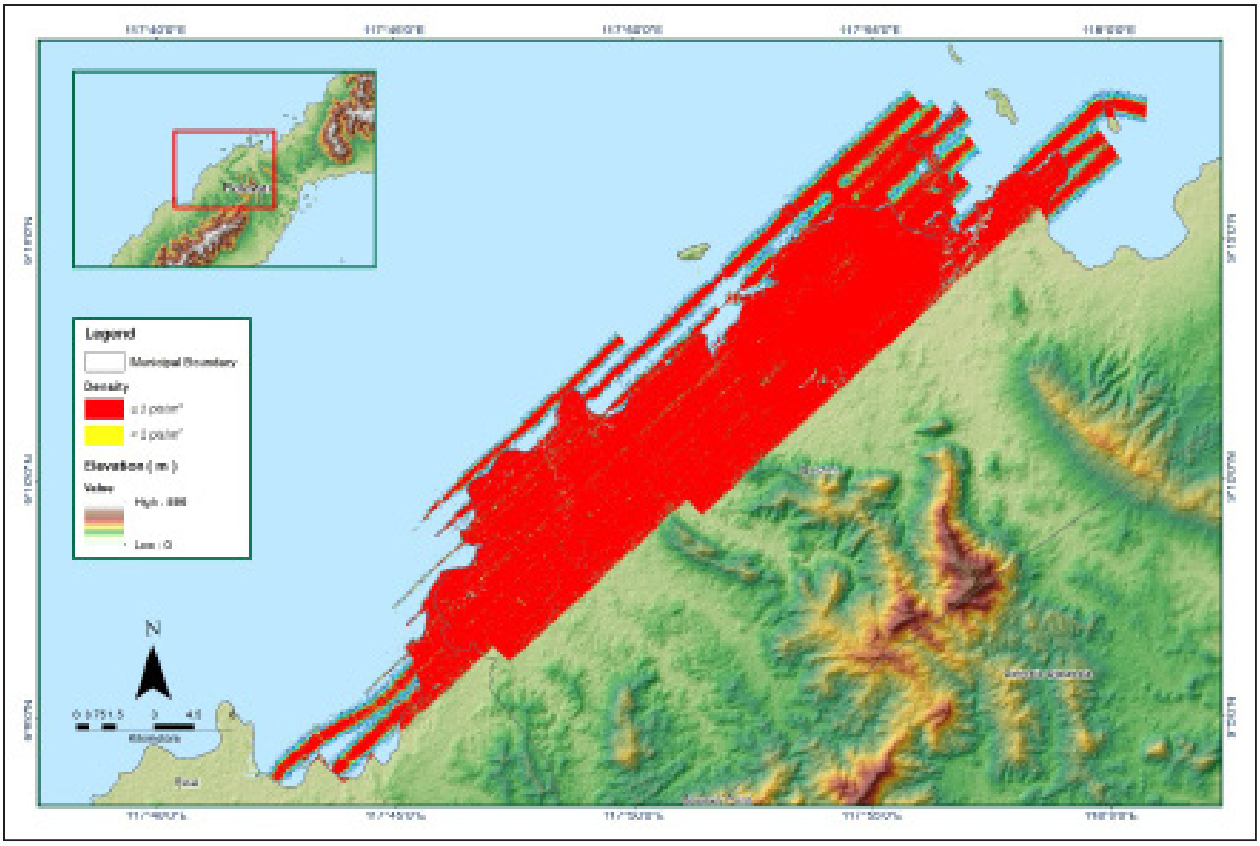


Figure A-8.6. Density map of merged LiDAR data

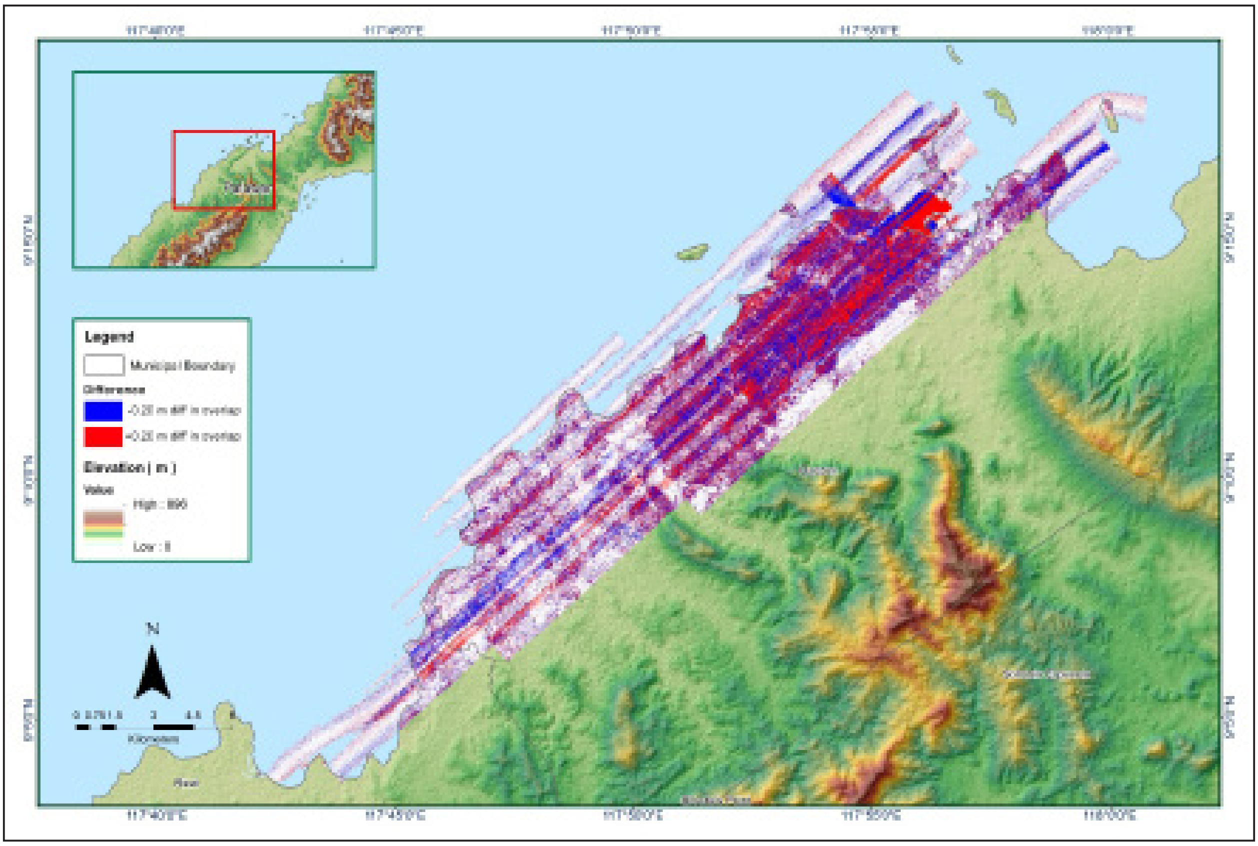


Figure A-8.7. Elevation difference between flight lines

Table A-8.2. Mission Summary Report for Mission Blk 42M

Flight Area	Davao Oriental
Mission Name	Blk 42M
Inclusive Flights	3161P, 3165P & 3167P
Range data size	65.06 GB
POS	575 MB
Image	83.03 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)	4.00
RMSE for East Position (<4.0 cm)	4.60
RMSE for Down Position (<8.0 cm)	6.40
Boresight correction stdev (<0.001deg)	0.000283
IMU attitude correction stdev (<0.001deg)	0.000320
GPS position stdev (<0.01m)	0.0020
Minimum % overlap (>25)	33.01
Ave point cloud density per sq.m. (>2.0)	2.99
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	287
Maximum Height	577.26
Minimum Height	41
Classification (# of points)	
Ground	125649379
Low vegetation	76720115
Medium vegetation	157777193
High vegetation	708301440
Building	9606648
Orthophoto	No
Processed by	Engr. Regis Guhiting, Aljon Rei Araneta, Engr. Mark Sueden Lyle Magtalas

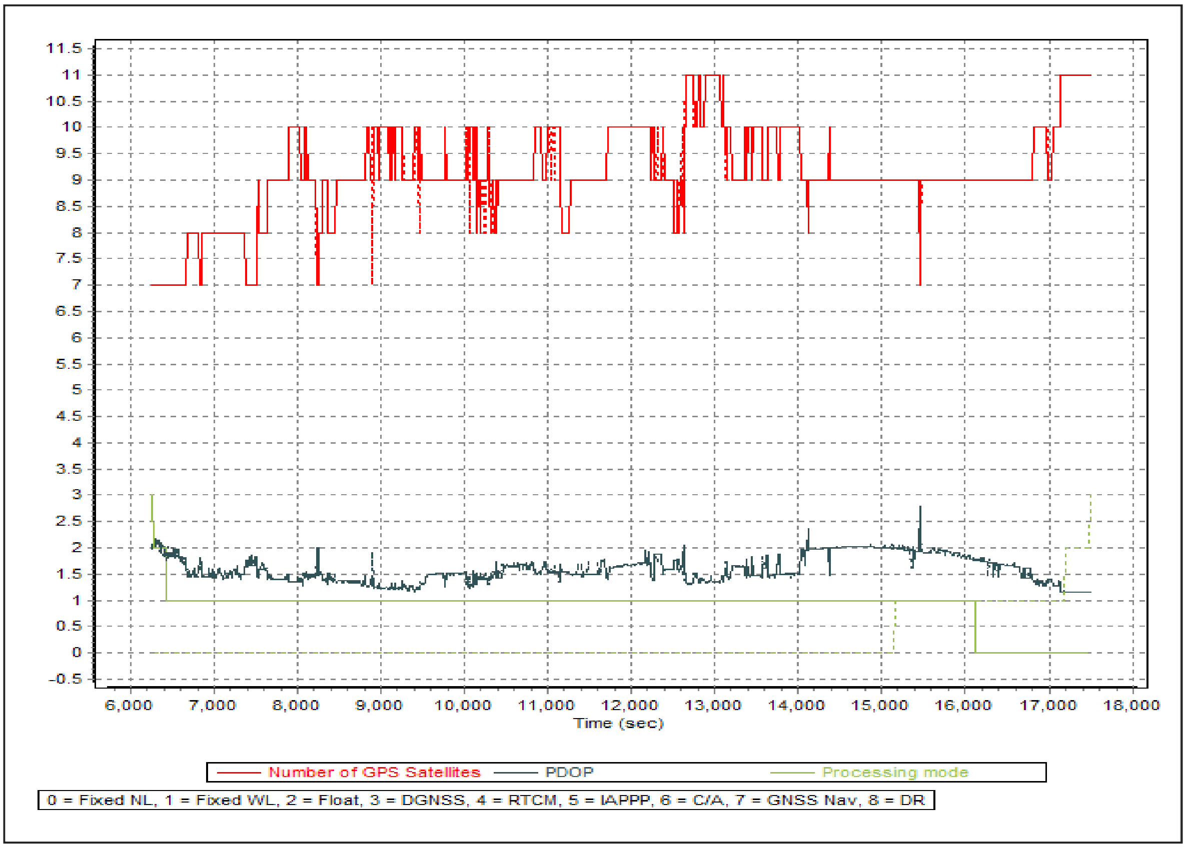


Figure A-8.8. Solution Status

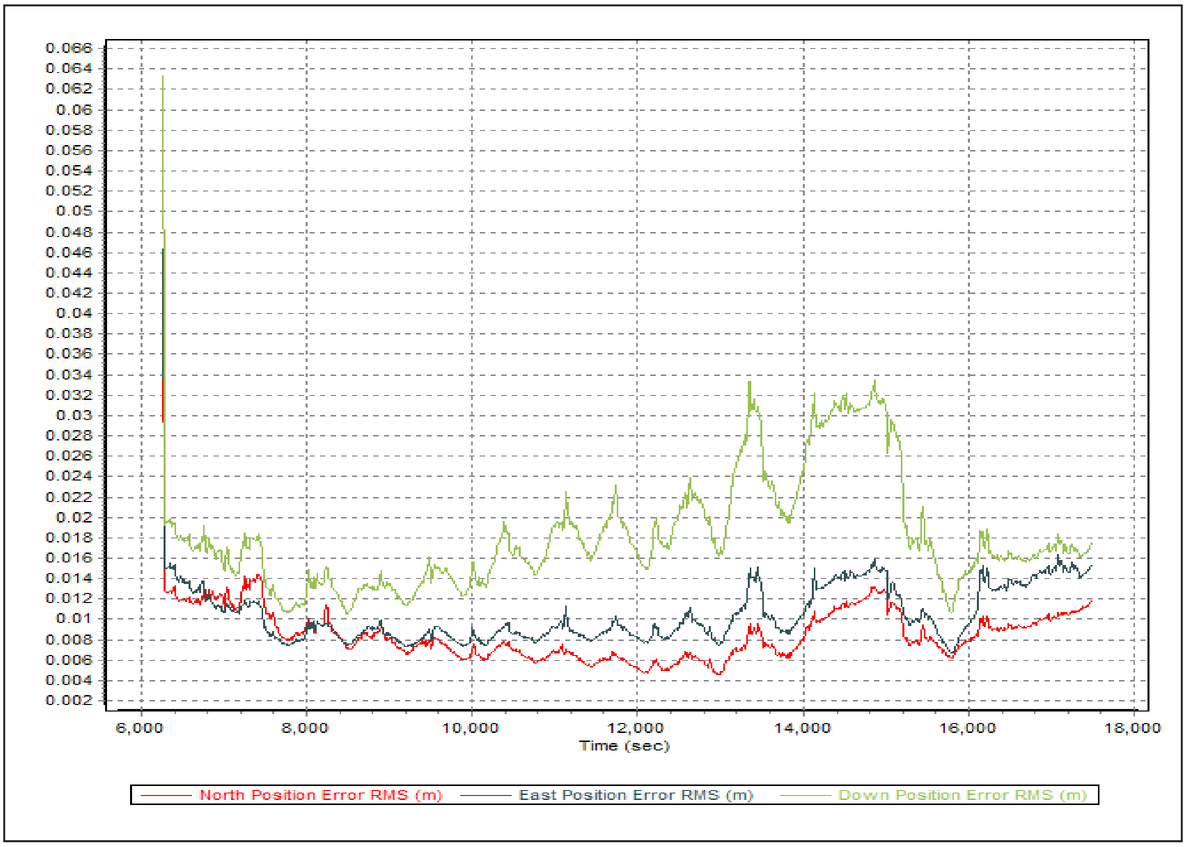


Figure A-8.9. Smoothed Performance Metric Parameters

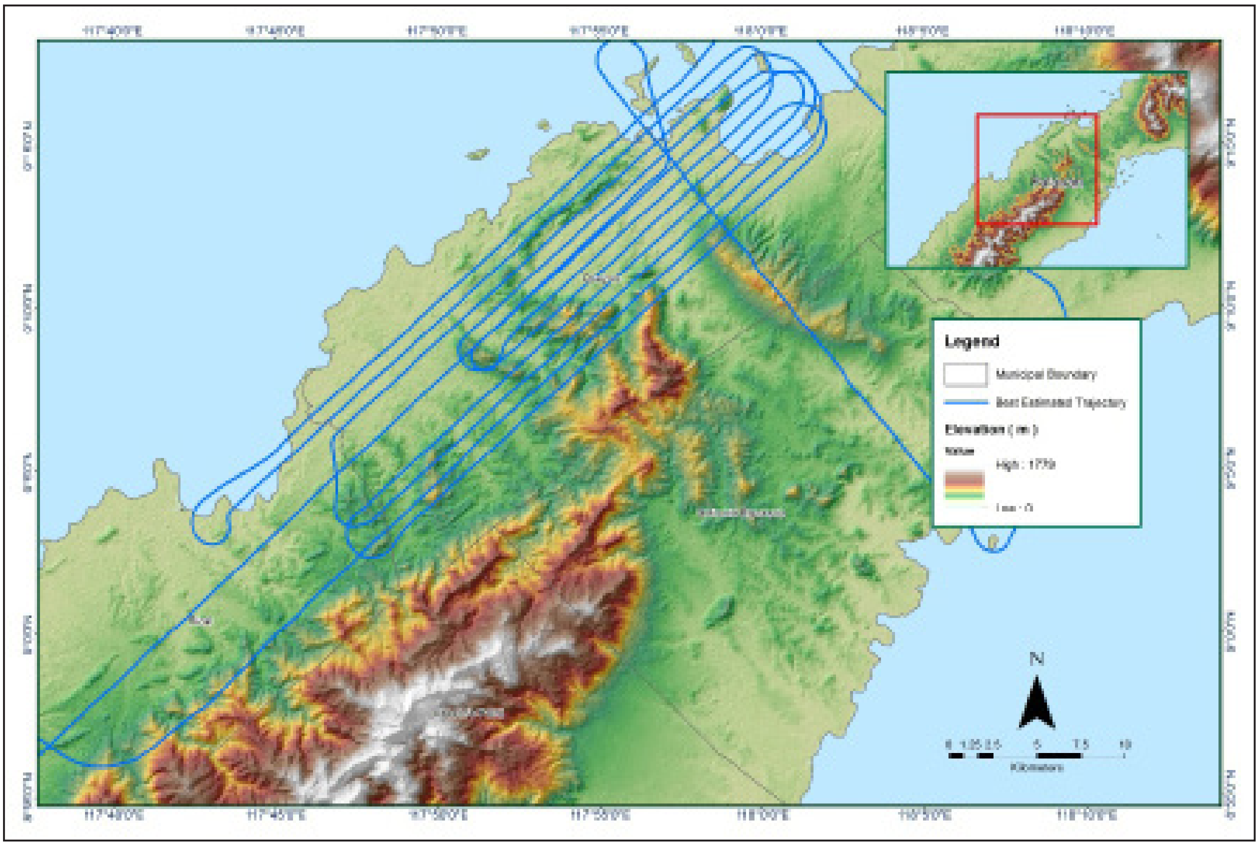


Figure A-8.10. Best Estimated Trajectory

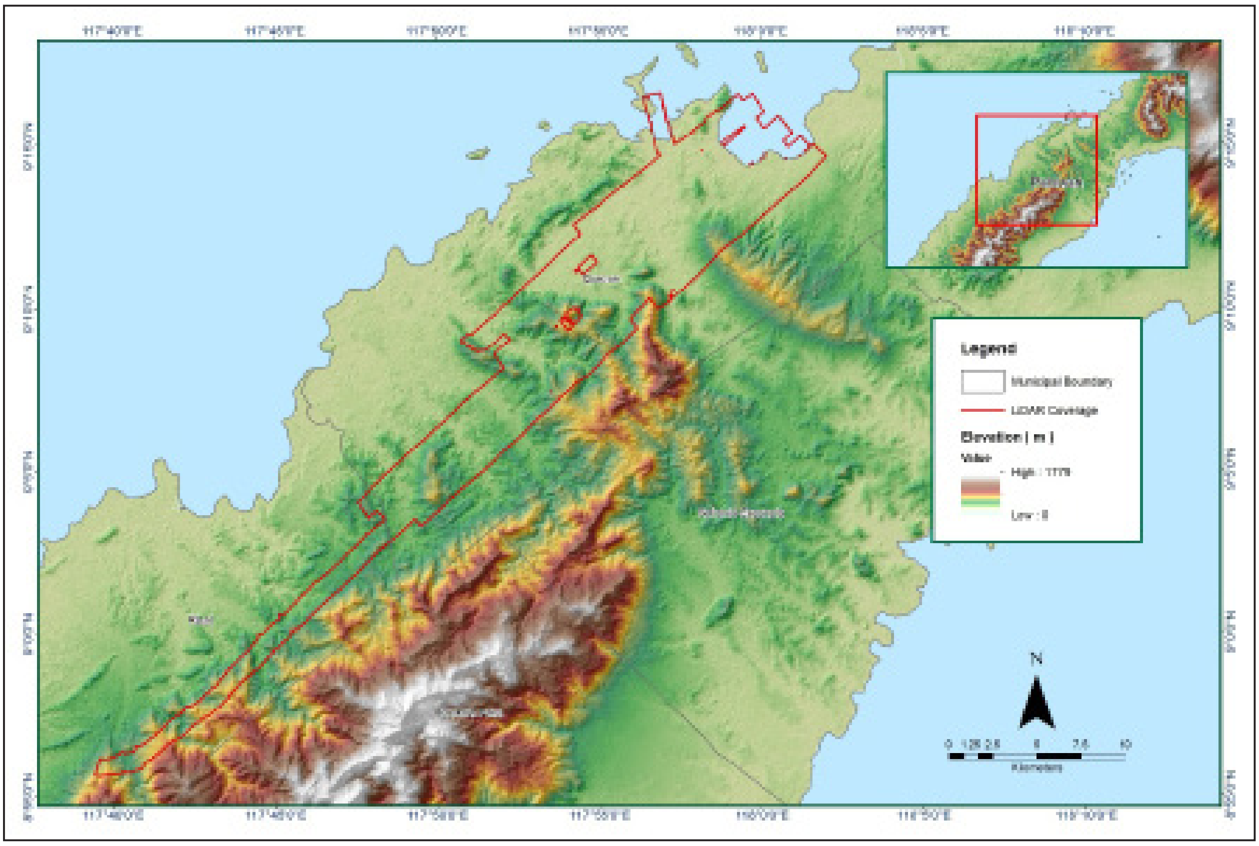


Figure A-8.11. Coverage of LiDAR data

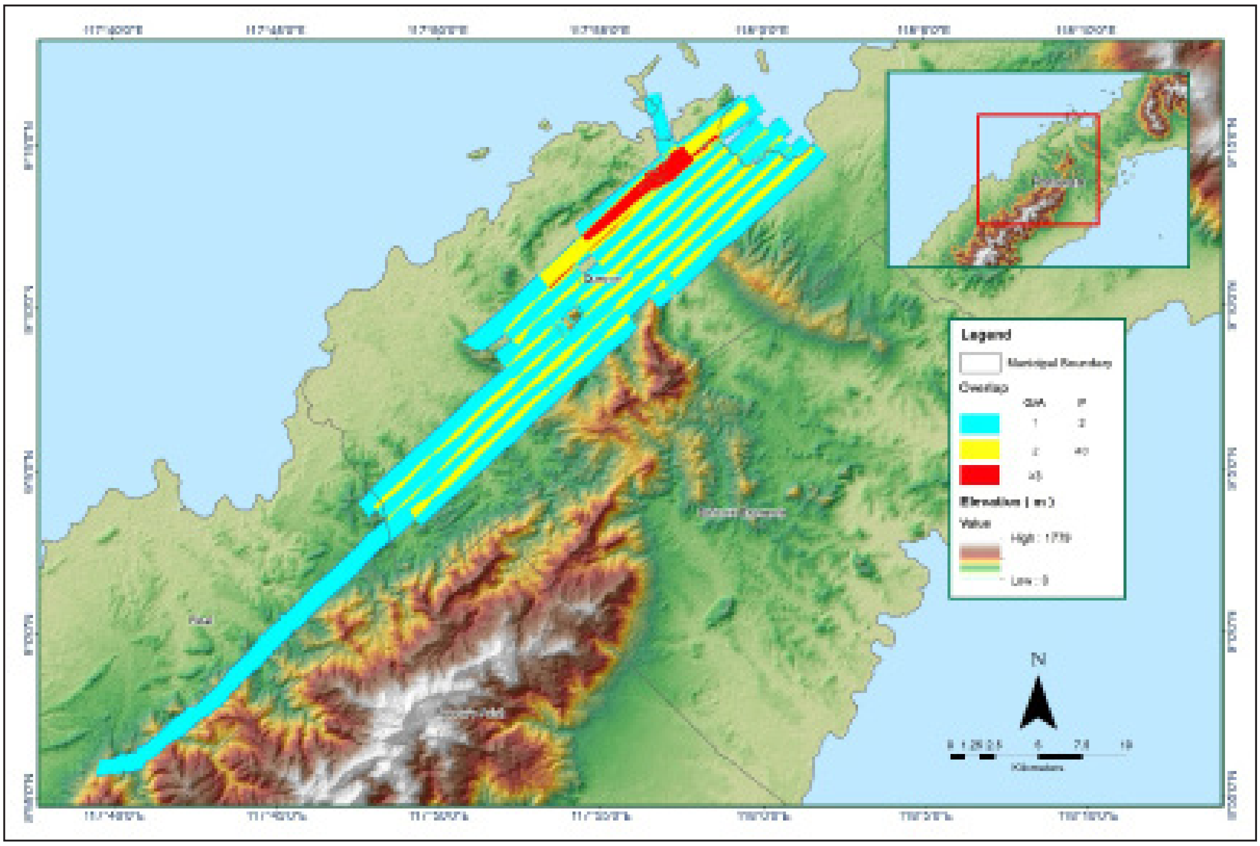


Figure A-8.12. Image of data overlap

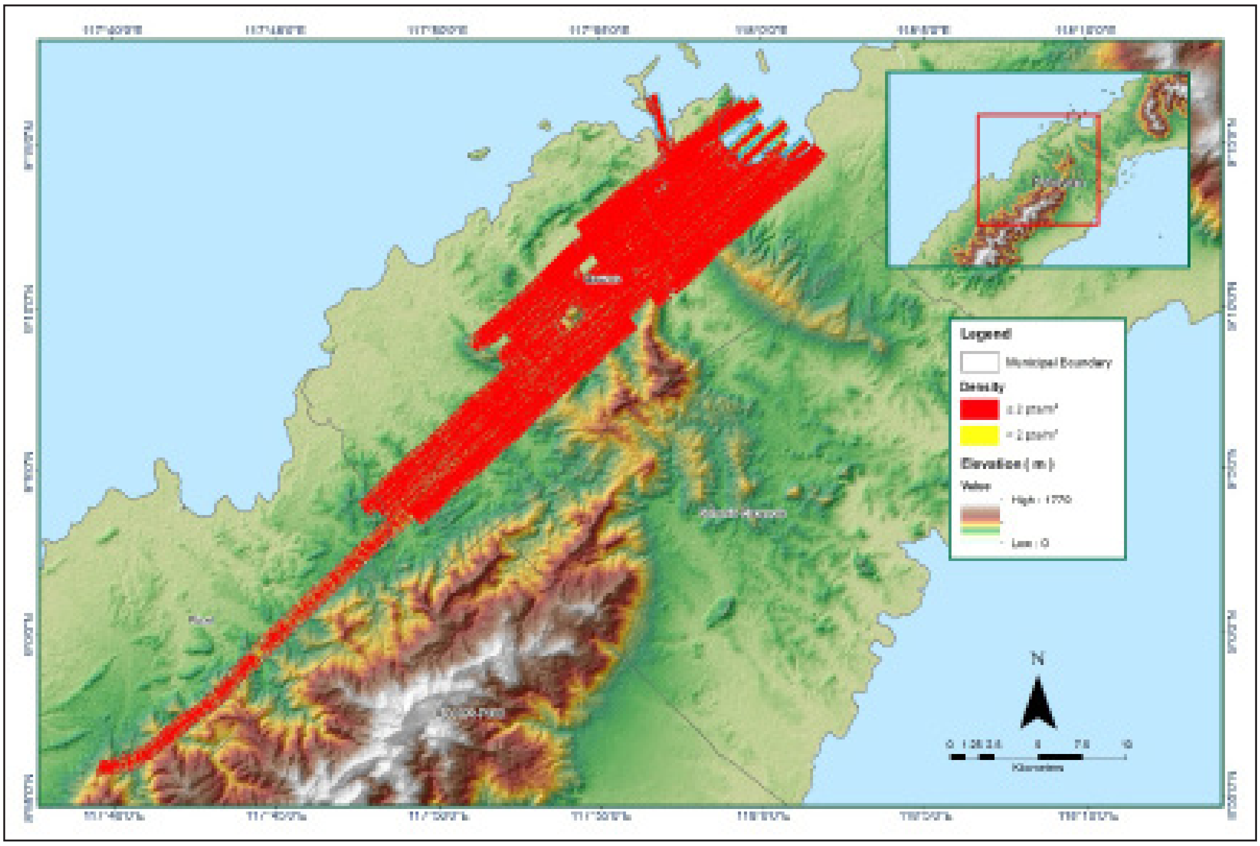


Figure A-8.13. Density map of merged LiDAR data

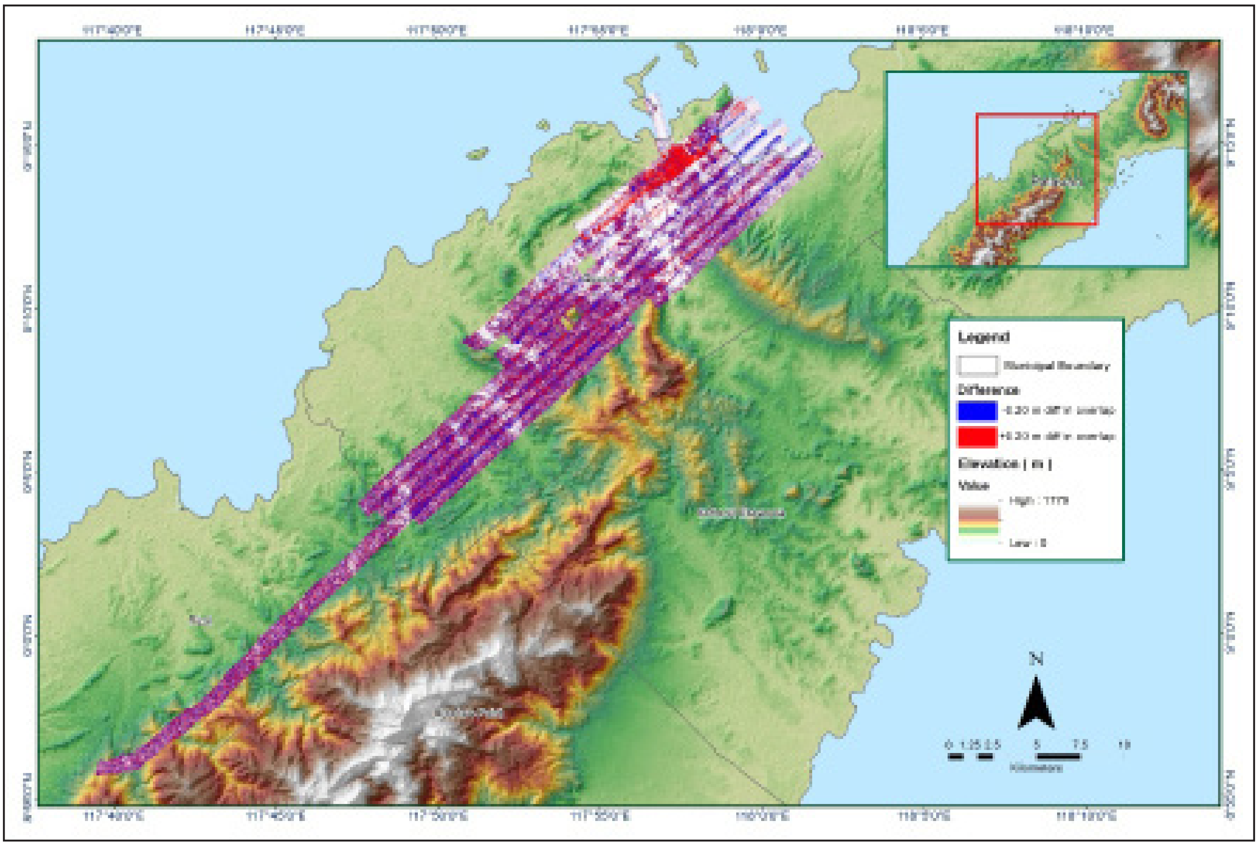


Figure A-8.14. Elevation difference between flight lines

Table A-8.3. Mission Summary Report for Mission Block 42M Supplement

Flight Area	Davao Oriental
Mission Name	Block 42M Supplement
Inclusive Flights	3165P
Range data size	28.90 GB
POS	255 MB
Image	36.40 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)	1.80
RMSE for East Position (<4.0 cm)	2.60
RMSE for Down Position (<8.0 cm)	1.35
Boresight correction stdev (<0.001deg)	0.000219
IMU attitude correction stdev (<0.001deg)	0.000122
GPS position stdev (<0.01m)	0.0014
Minimum % overlap (>25)	32.96
Ave point cloud density per sq.m. (>2.0)	4.12
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	174
Maximum Height	557.25
Minimum Height	43.67
Classification (# of points)	
Ground	115711792
Low vegetation	86033359
Medium vegetation	230045374
High vegetation	215206848
Building	3094395
Orthophoto	No
Processed by	Engr. Regis Guhiting, Engr. Velina Angela Bemida, Engr. Krisha Marie Bautista

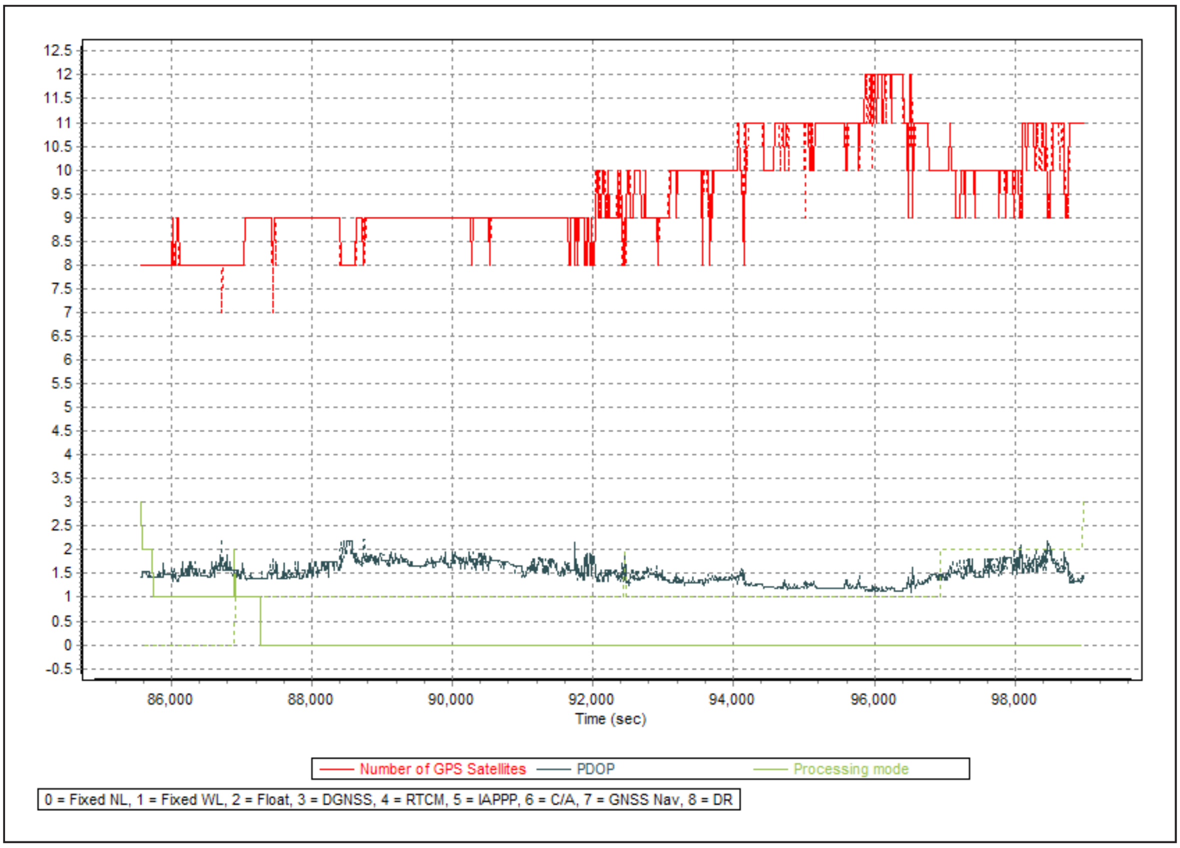


Figure A-8.15. Solution Status

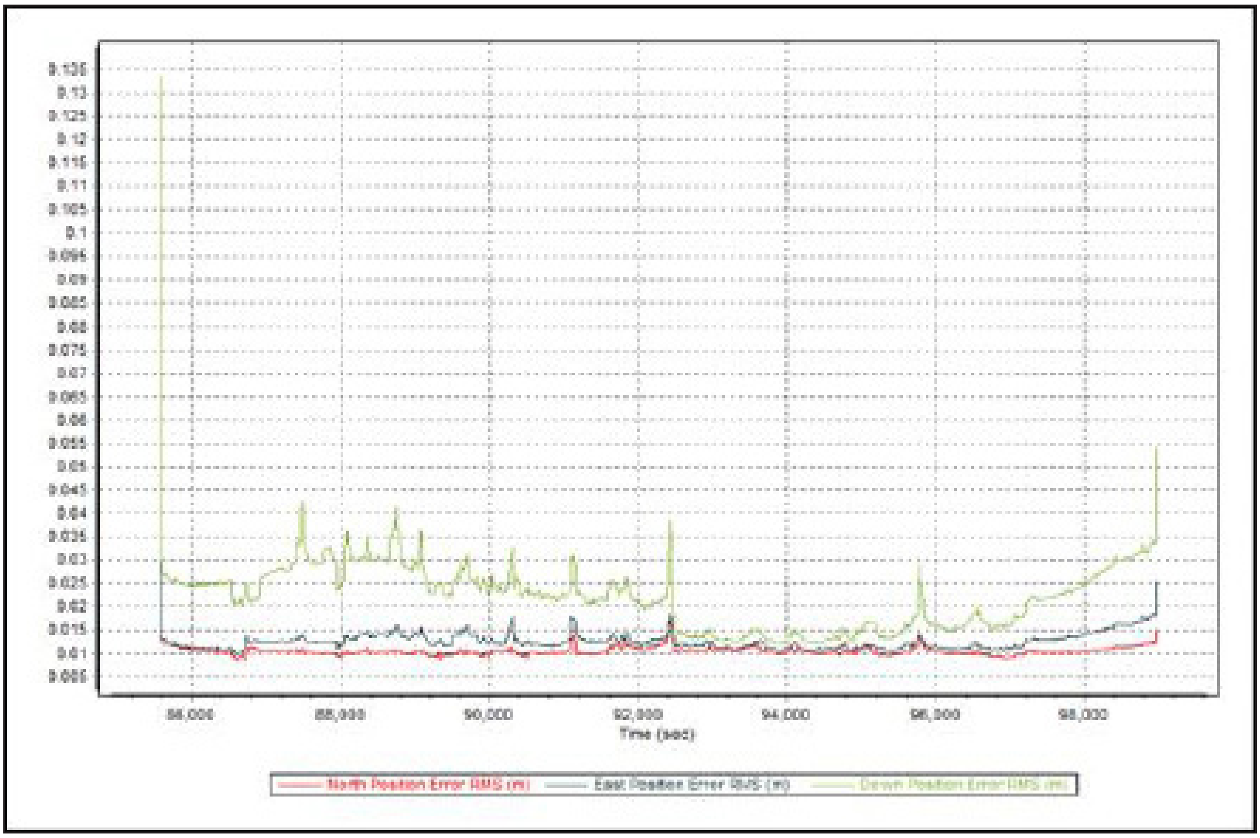


Figure A-8.16. Smoothed Performance Metric Parameters

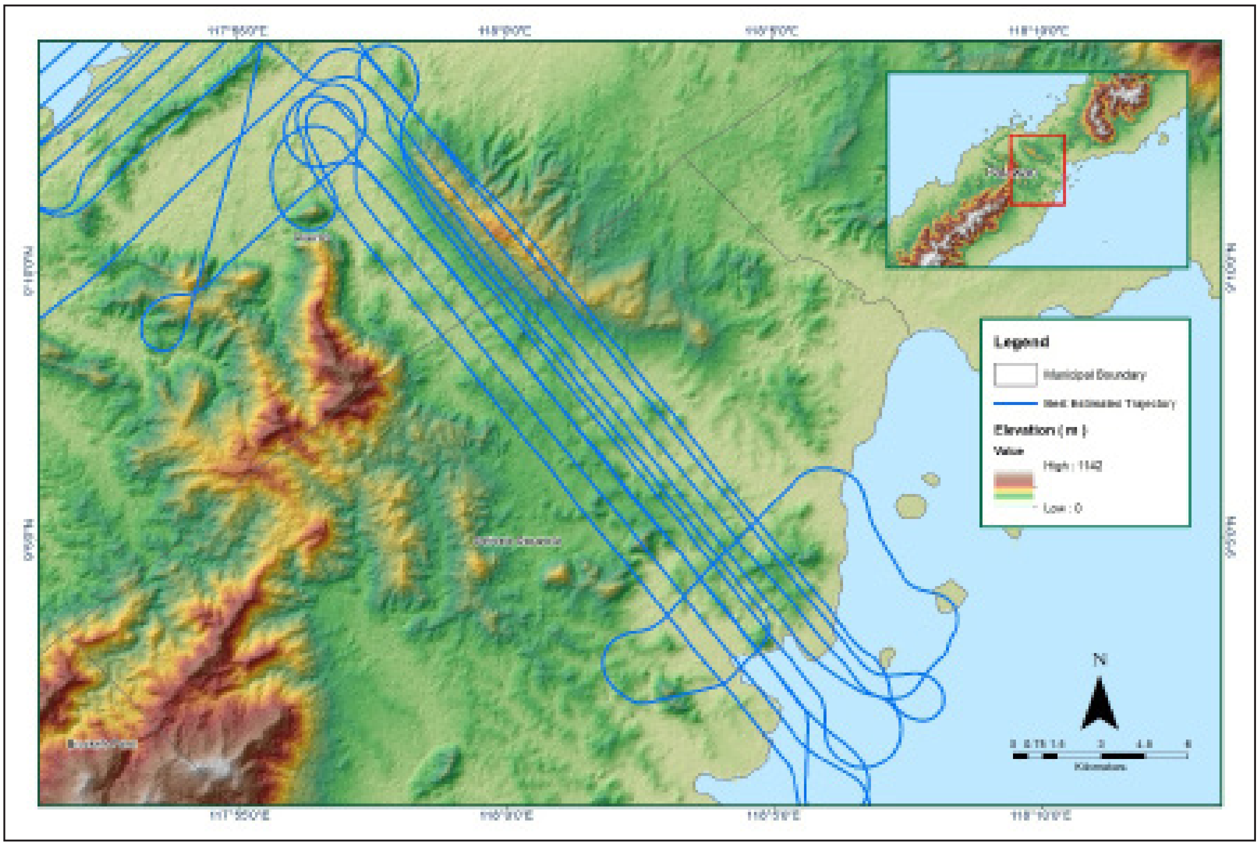


Figure A-8.17. Best Estimated Trajectory

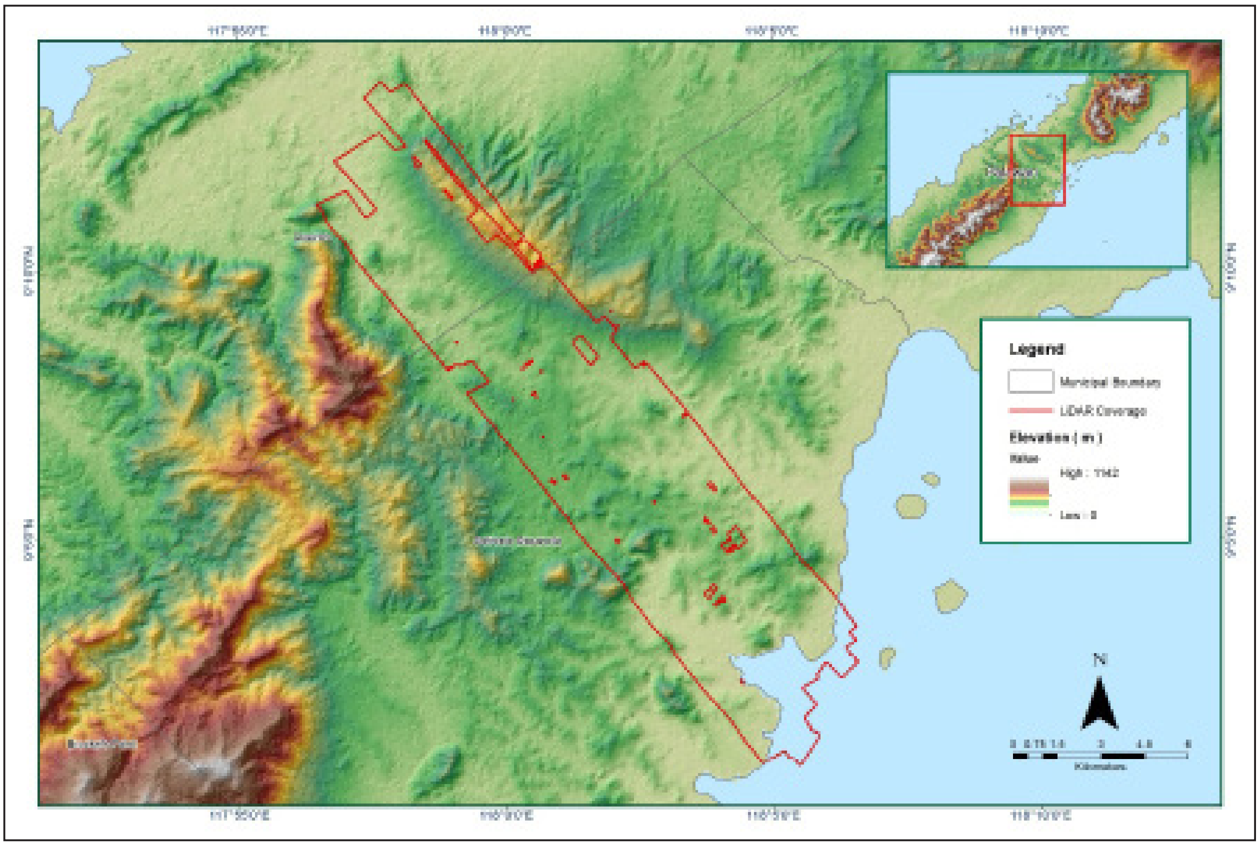


Figure A-8.18. Coverage of LiDAR data

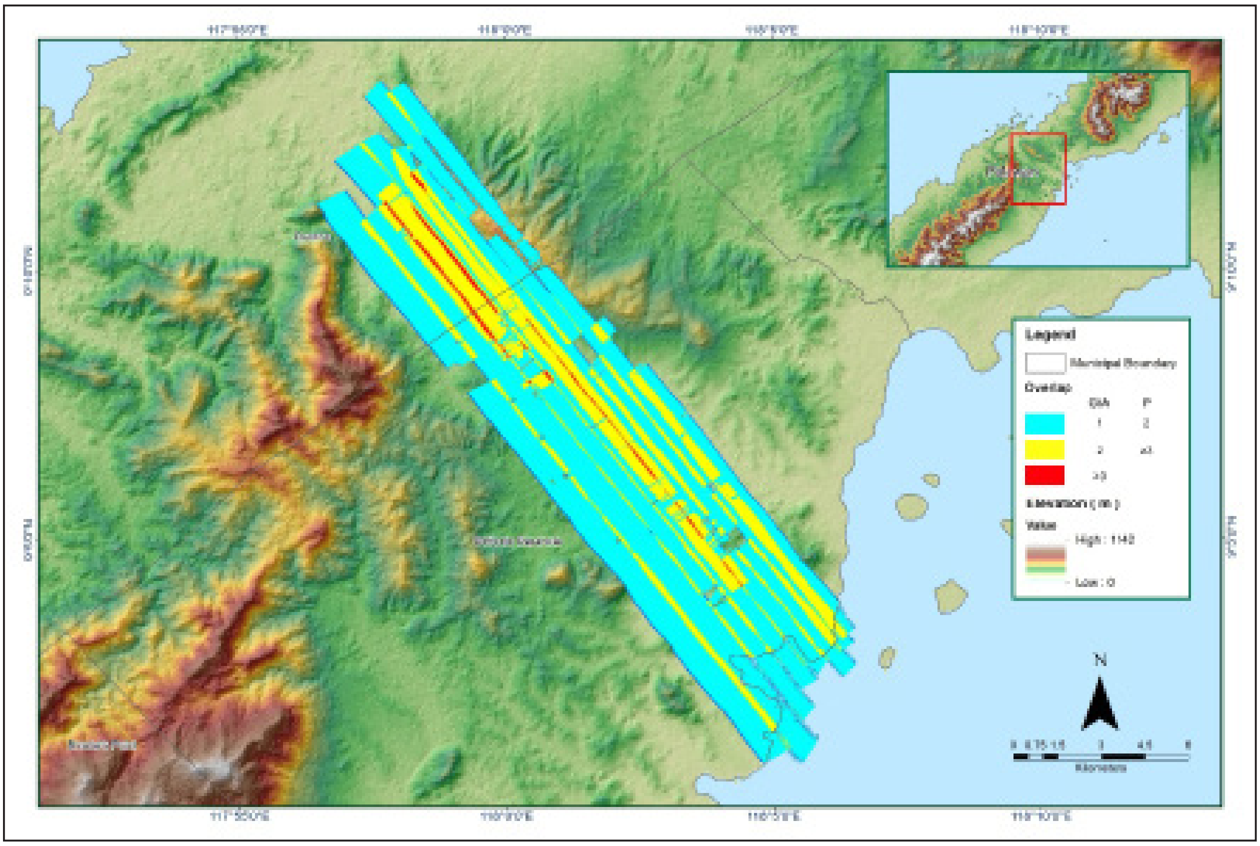


Figure A-8.19. Image of data overlap

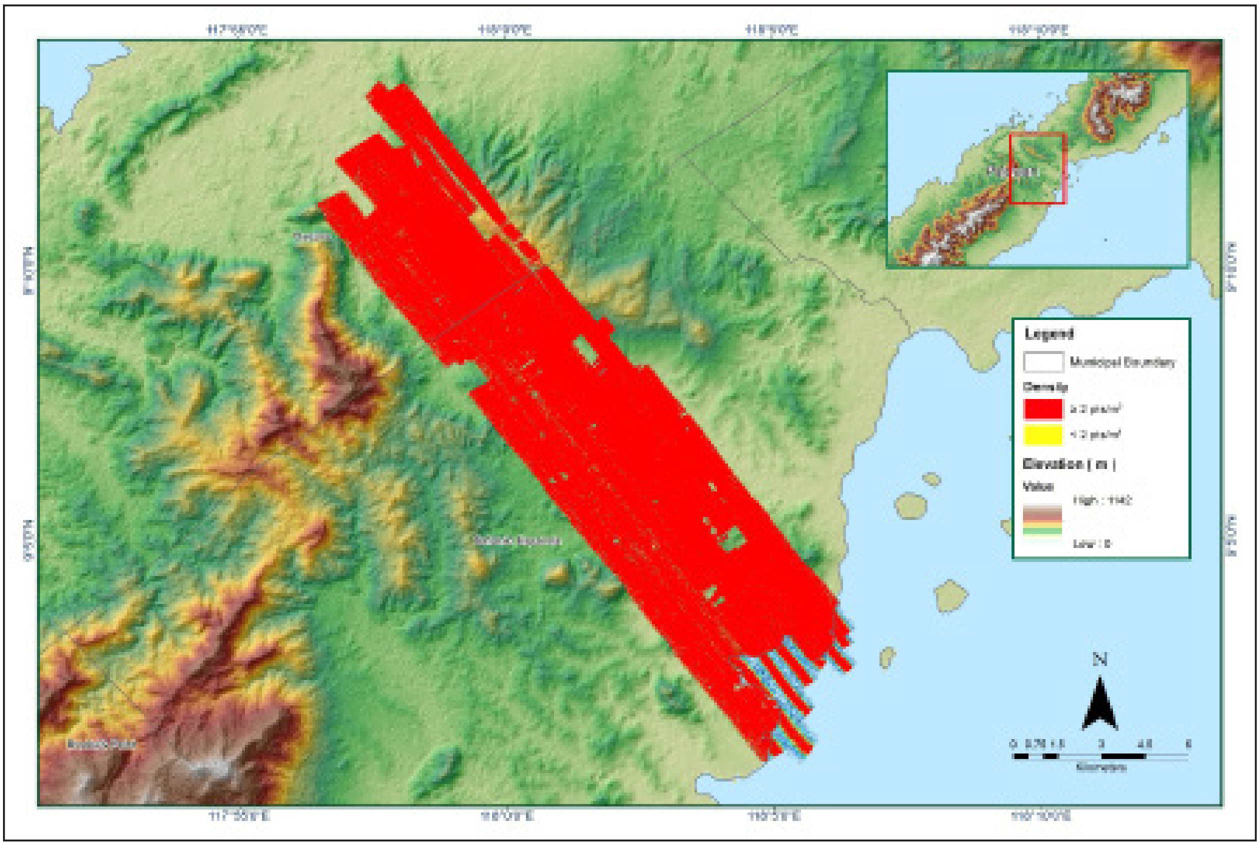


Figure A-8.20. Density map of merged LiDAR data

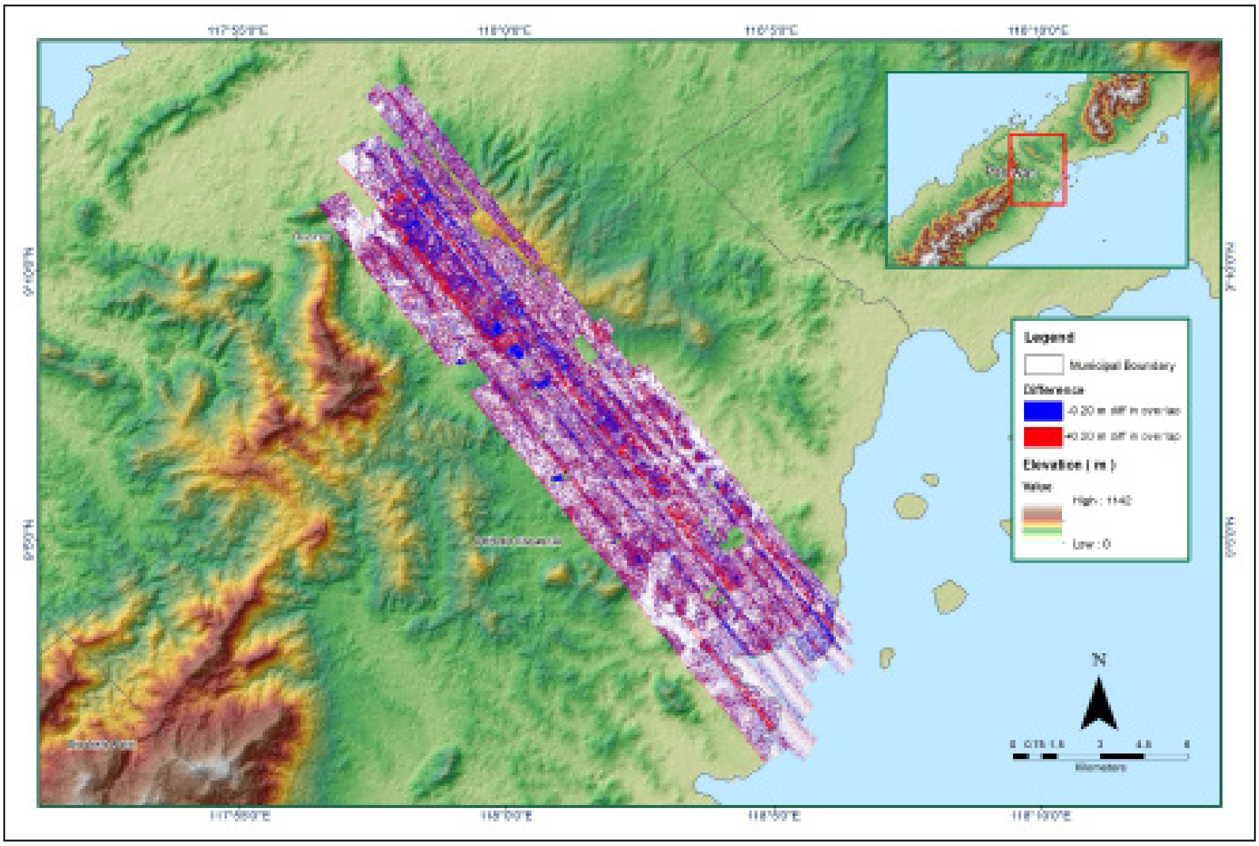


Figure A-8.21. Elevation difference between flight lines

Table A-8.4. Mission Summary Report for Mission Blk42L

Flight Area	Davao Oriental
Mission Name	Blk42L
Inclusive Flights	3573G
Range data size	19.7 GB
Base data size	12.1 MB
POS	227 MB
Image	NA
Transfer date	January 5, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.01
RMSE for East Position (<4.0 cm)	1.28
RMSE for Down Position (<8.0 cm)	3.39
Boresight correction stdev (<0.001deg)	NA
IMU attitude correction stdev (<0.001deg)	NA
GPS position stdev (<0.01m)	NA
Minimum % overlap (>25)	10.06%
Ave point cloud density per sq.m. (>2.0)	3.34
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	30
Maximum Height	108.79 m
Minimum Height	41.08 m
Classification (# of points)	
Ground	4,394,990
Low vegetation	4,891,248
Medium vegetation	12,105,160
High vegetation	14,375,481
Building	63,603
Ortophoto	No
Processed by	Engr. Regis Guhiting, Engr. Christy Lubiano, Kathryn Claudyn Zarate

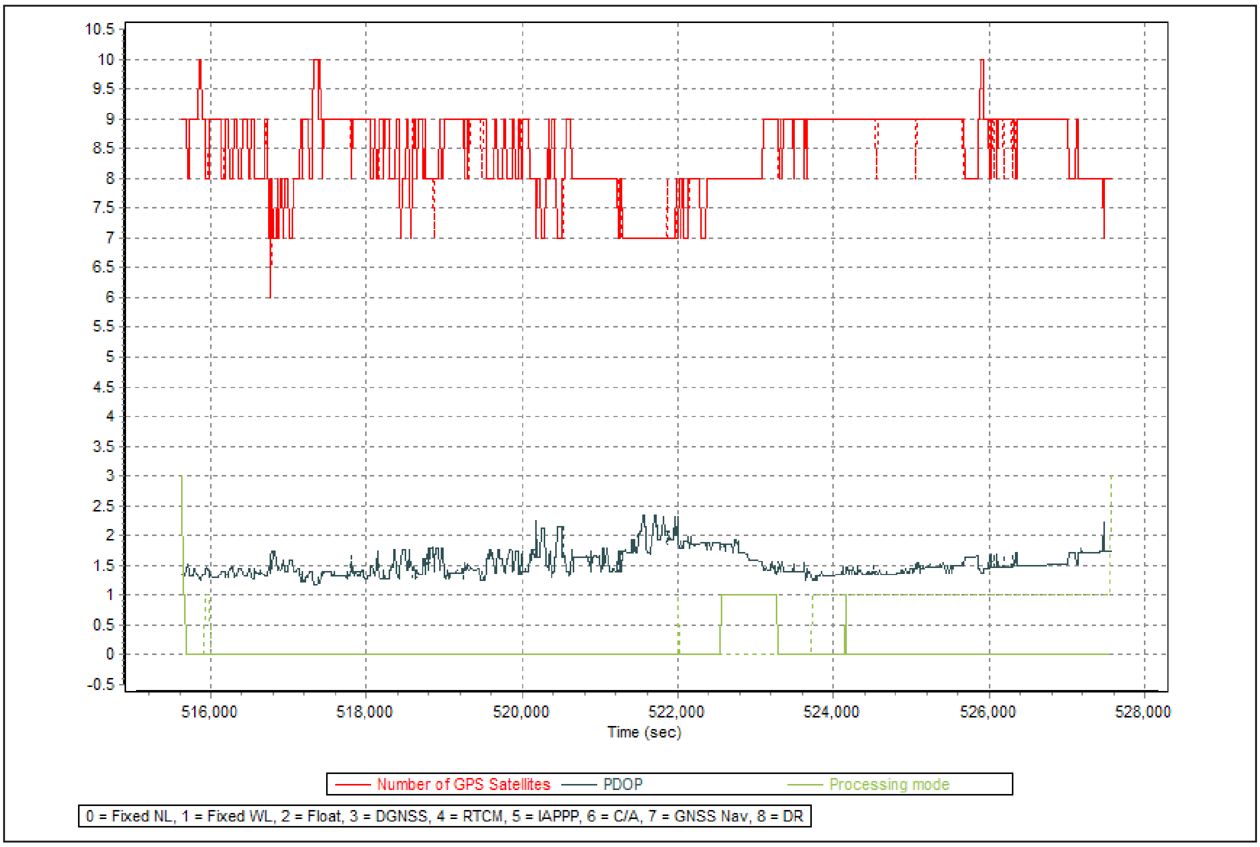


Figure A-8.22. Solution Status

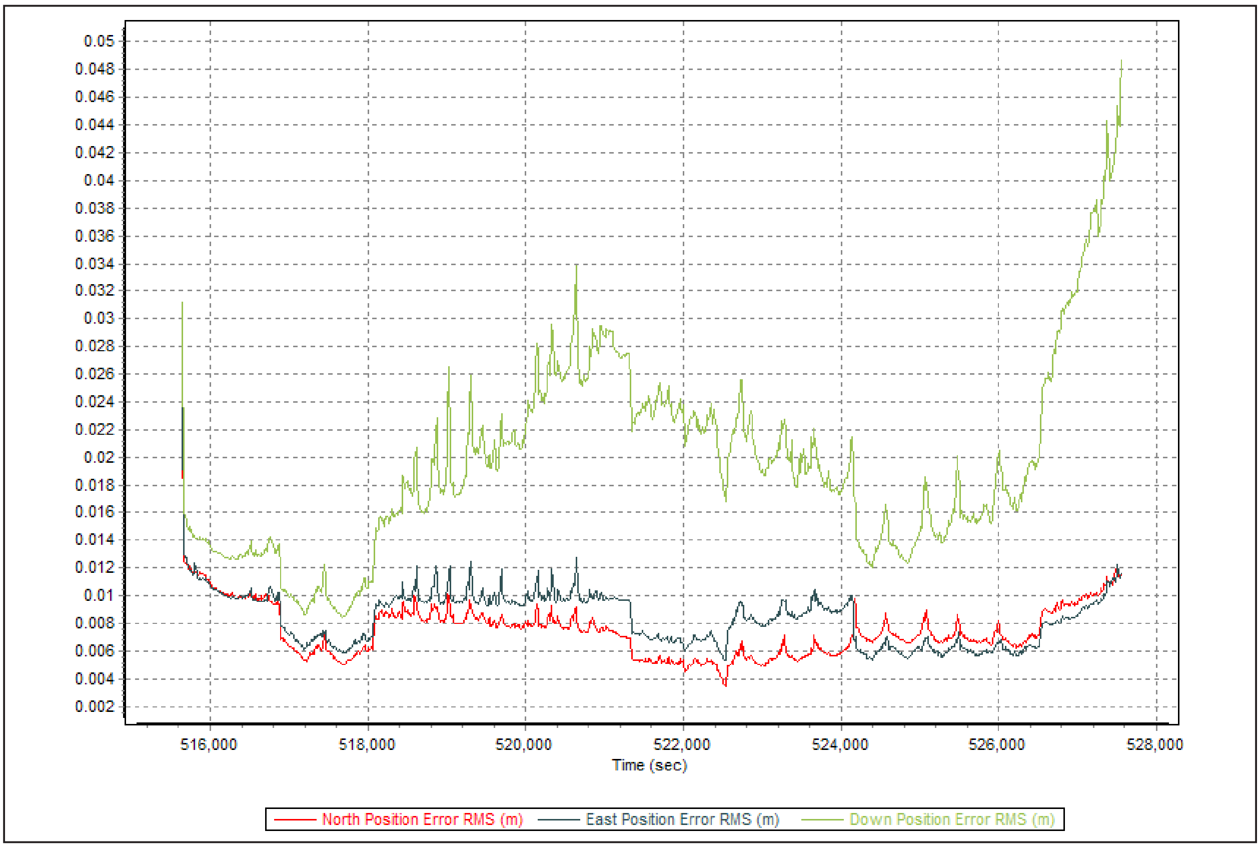


Figure A-8.23. Smoothed Performance Metric Parameters

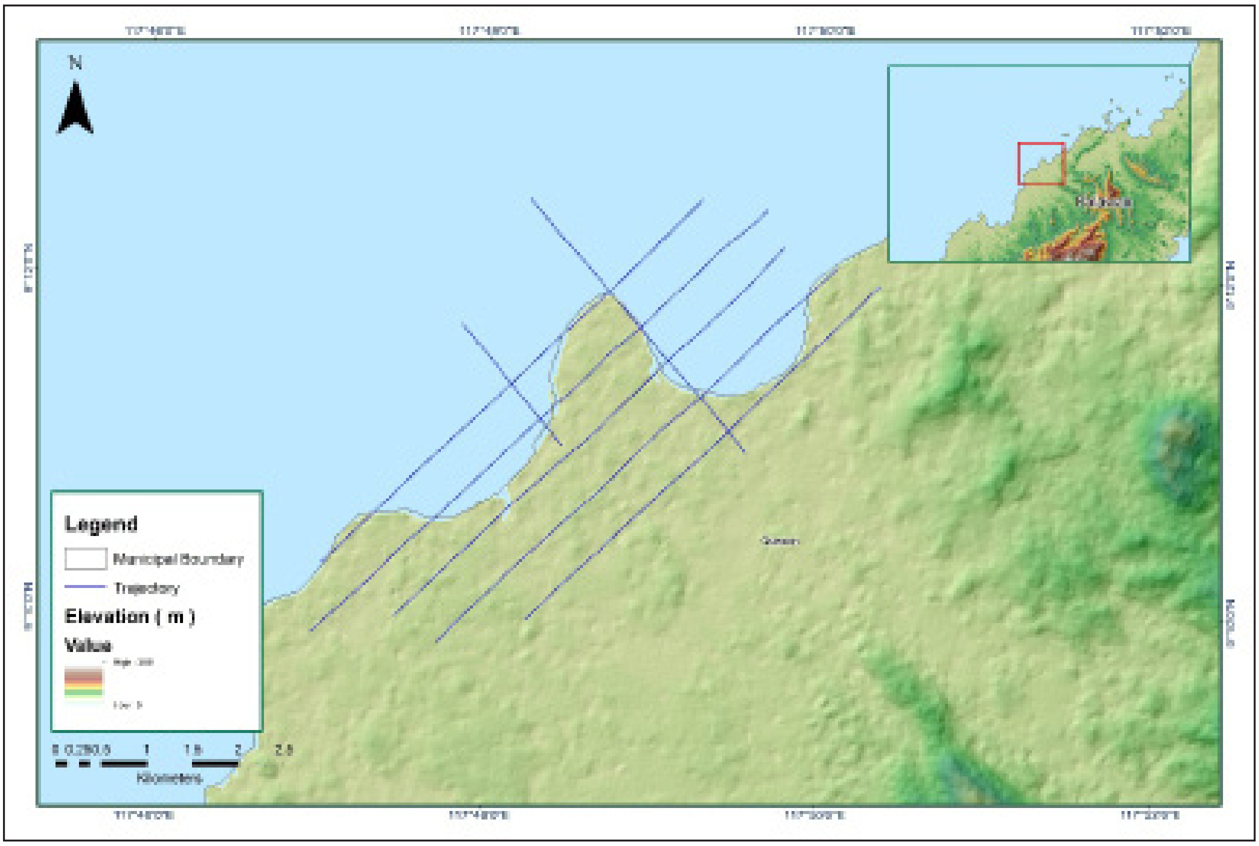


Figure A-8.24. Best Estimated Trajectory

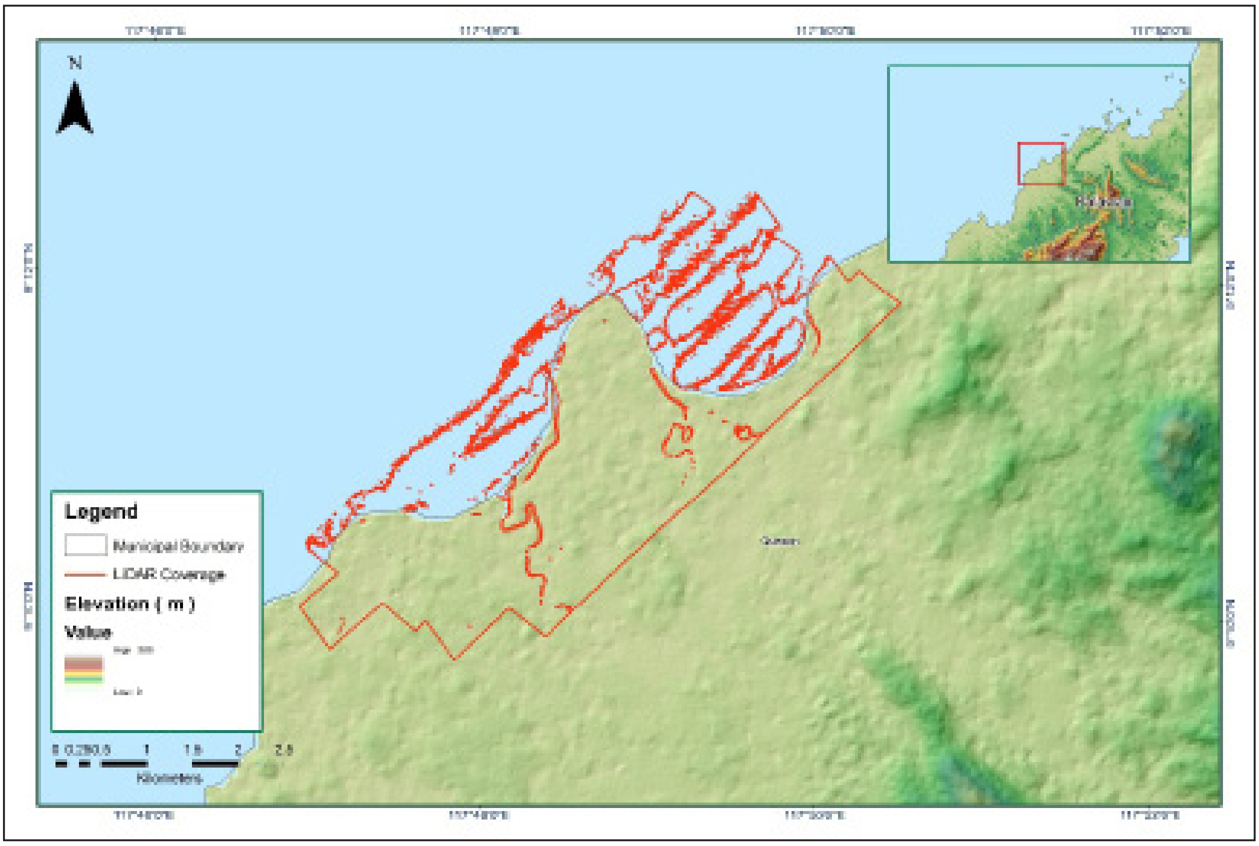


Figure A-8.25. Coverage of LiDAR data

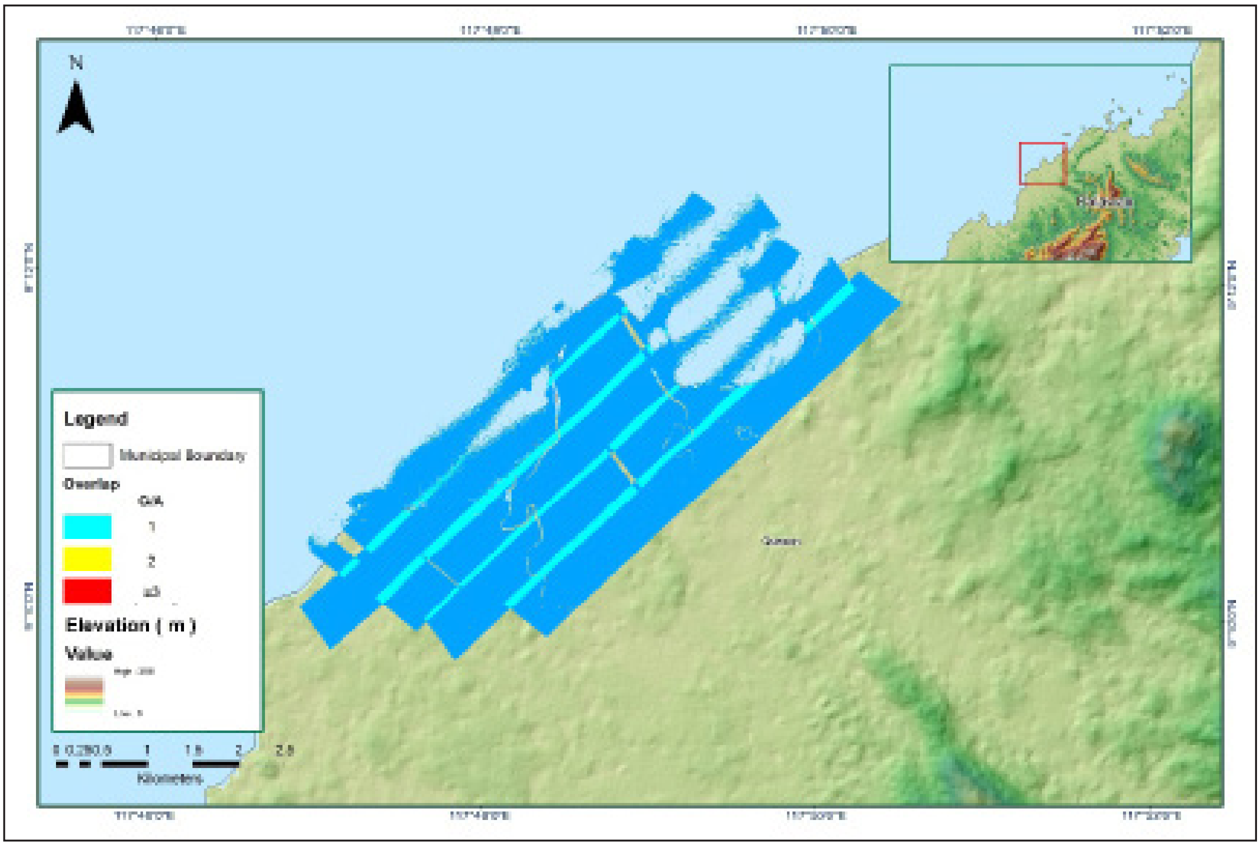


Figure A-8.26. Image of data overlap

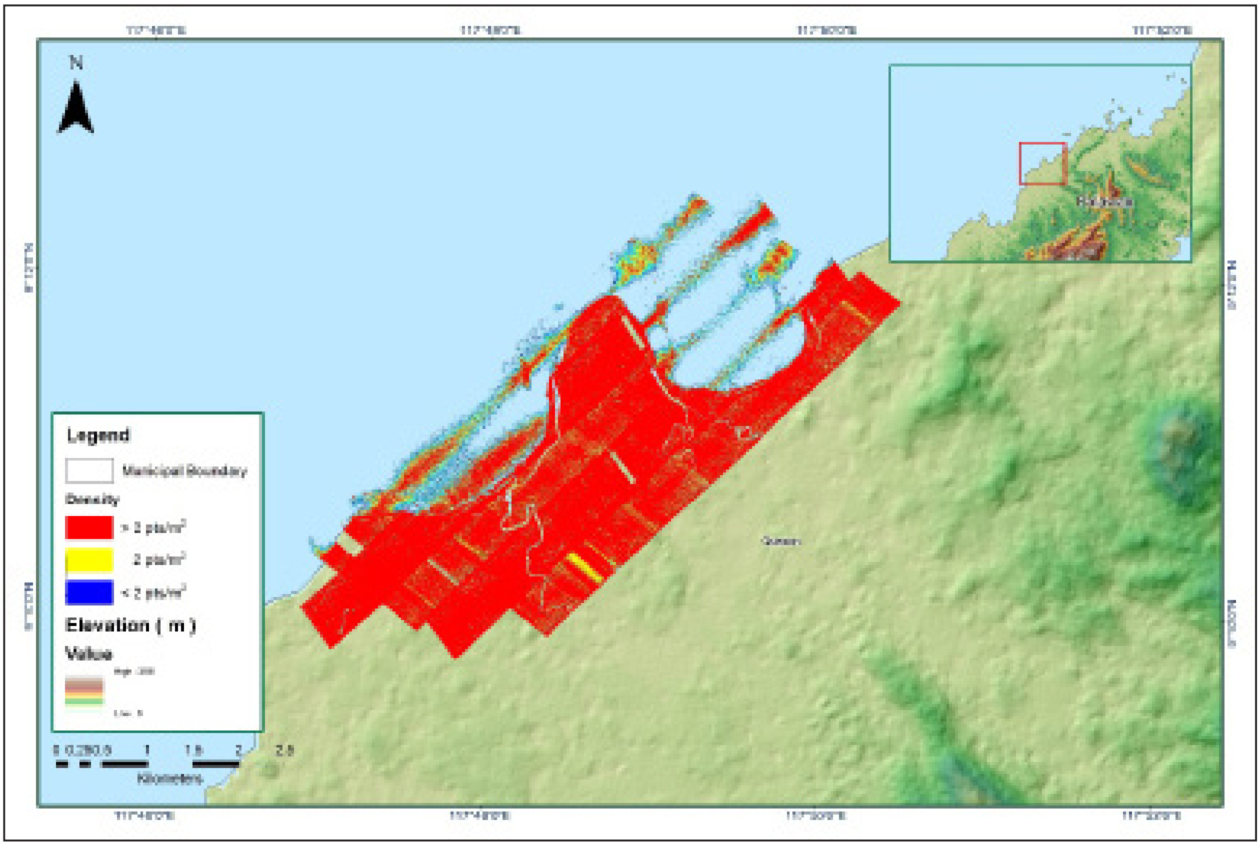


Figure A-8.27. Density map of merged LiDAR data

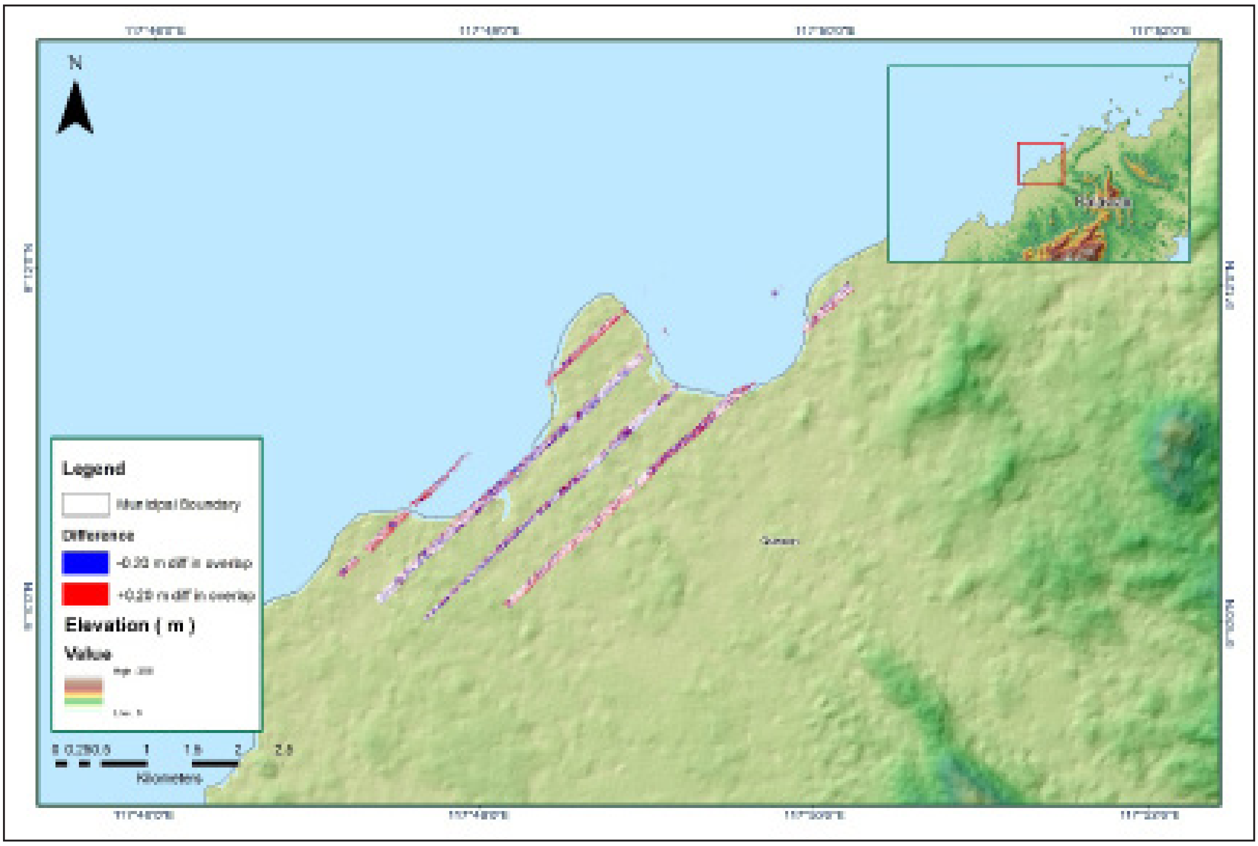


Figure A-8.28. Elevation difference between flight lines

Table A-8.5 Mission Summary Report for Mission Blk42M

Flight Area	Davao Oriental
Mission Name	Blk42M
Inclusive Flights	3573G
Range data size	19.7 GB
Base data size	12.1 MB
POS	227 MB
Image	NA
Transfer date	January 5, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.01
RMSE for East Position (<4.0 cm)	1.28
RMSE for Down Position (<8.0 cm)	3.39
Boresight correction stdev (<0.001deg)	NA
IMU attitude correction stdev (<0.001deg)	NA
GPS position stdev (<0.01m)	NA
Minimum % overlap (>25)	21.52%
Ave point cloud density per sq.m. (>2.0)	4.81
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	28
Maximum Height	501.22 m
Minimum Height	46.40 m
Classification (# of points)	
Ground	4,105,596
Low vegetation	4,982,741
Medium vegetation	17,233,950
High vegetation	25,902,556
Building	353,805
Ortophoto	No
Processed by	Engr. Regis Guhiting, Engr. Merven Matthew Natino, Engr. Elainne Lopez

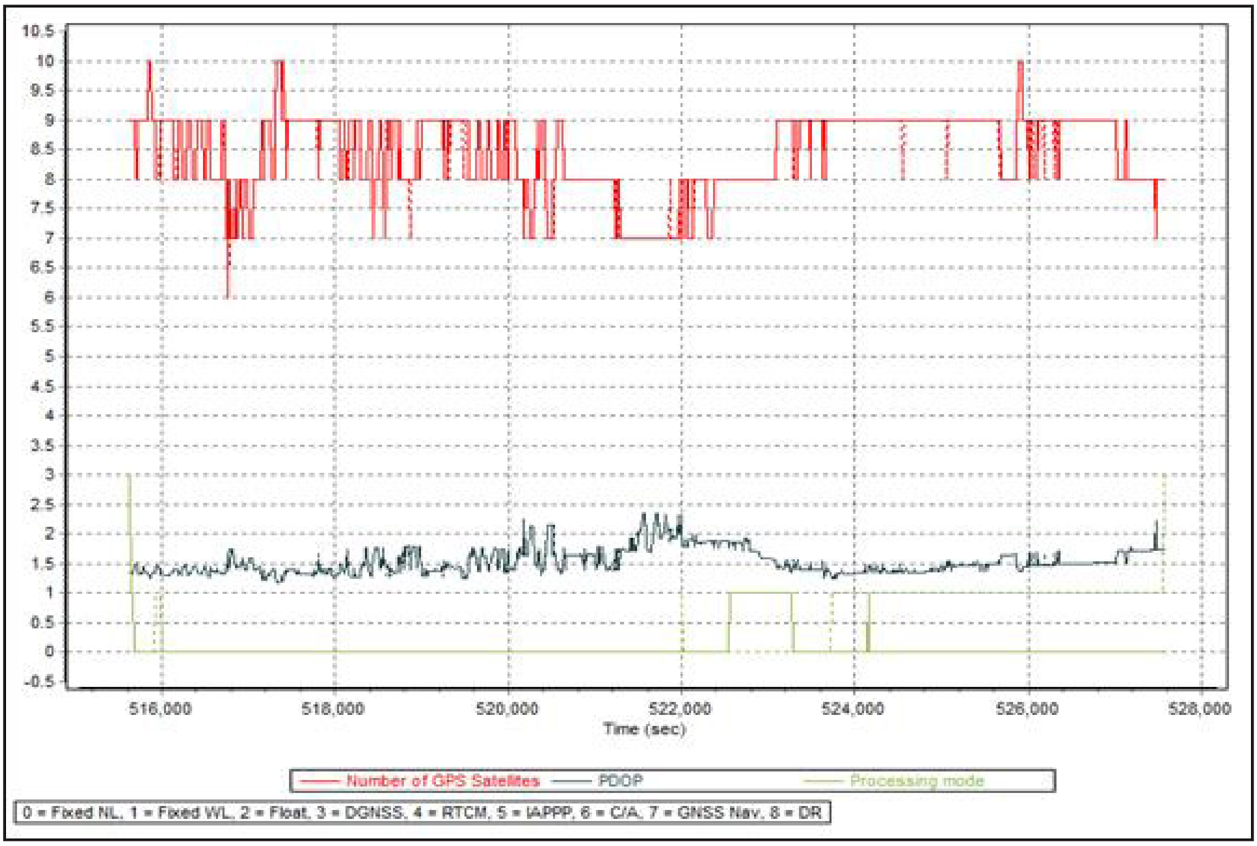


Figure A-8.29. Solution Status

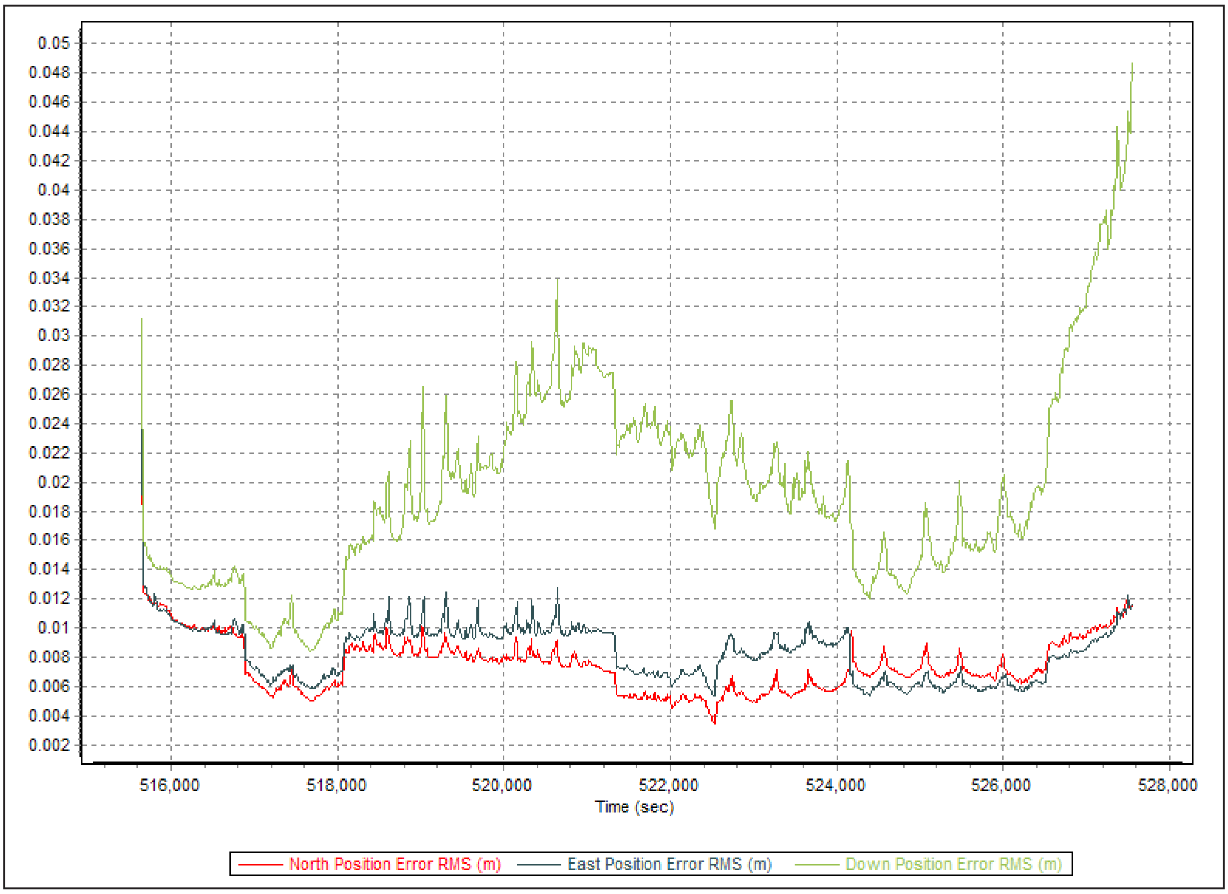


Figure A-8.30. Smoothed Performance Metric Parameters

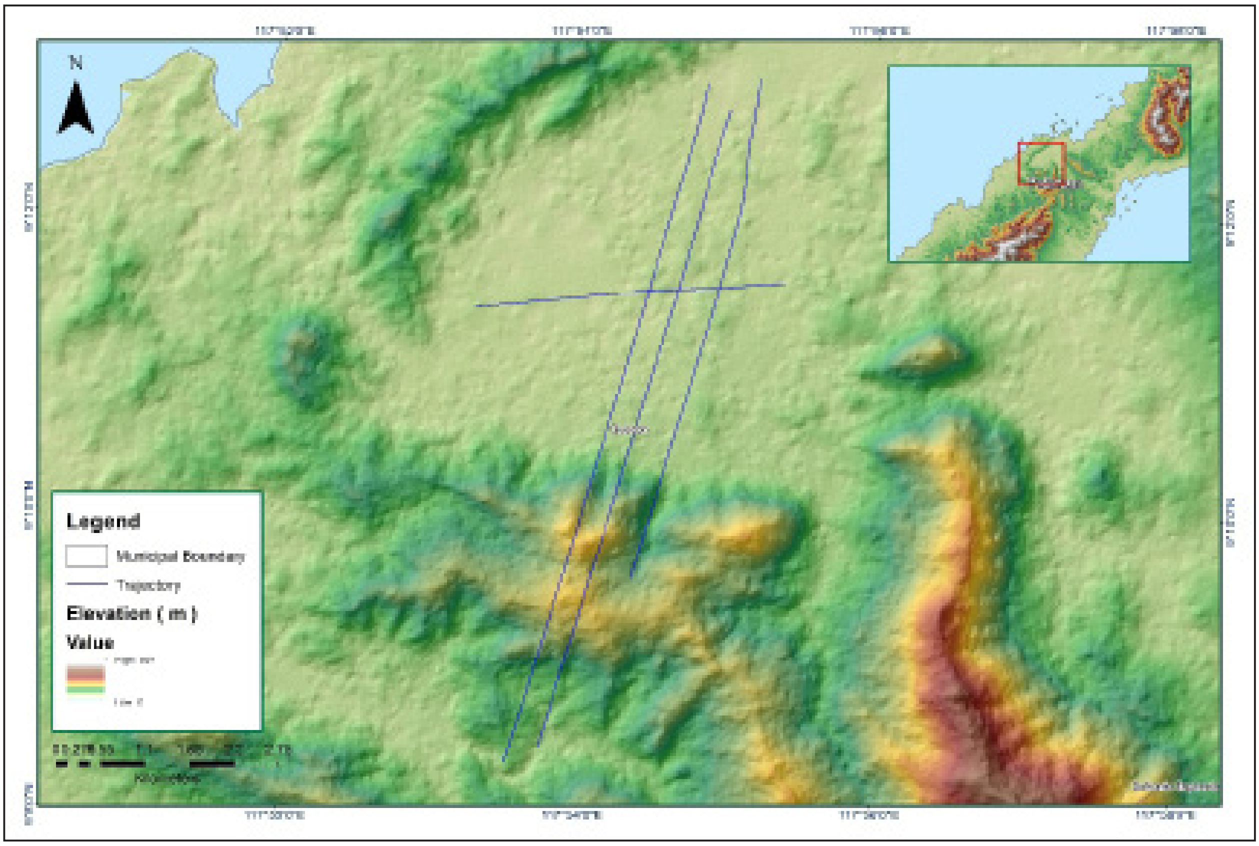


Figure A-8.31. Best Estimated Trajectory

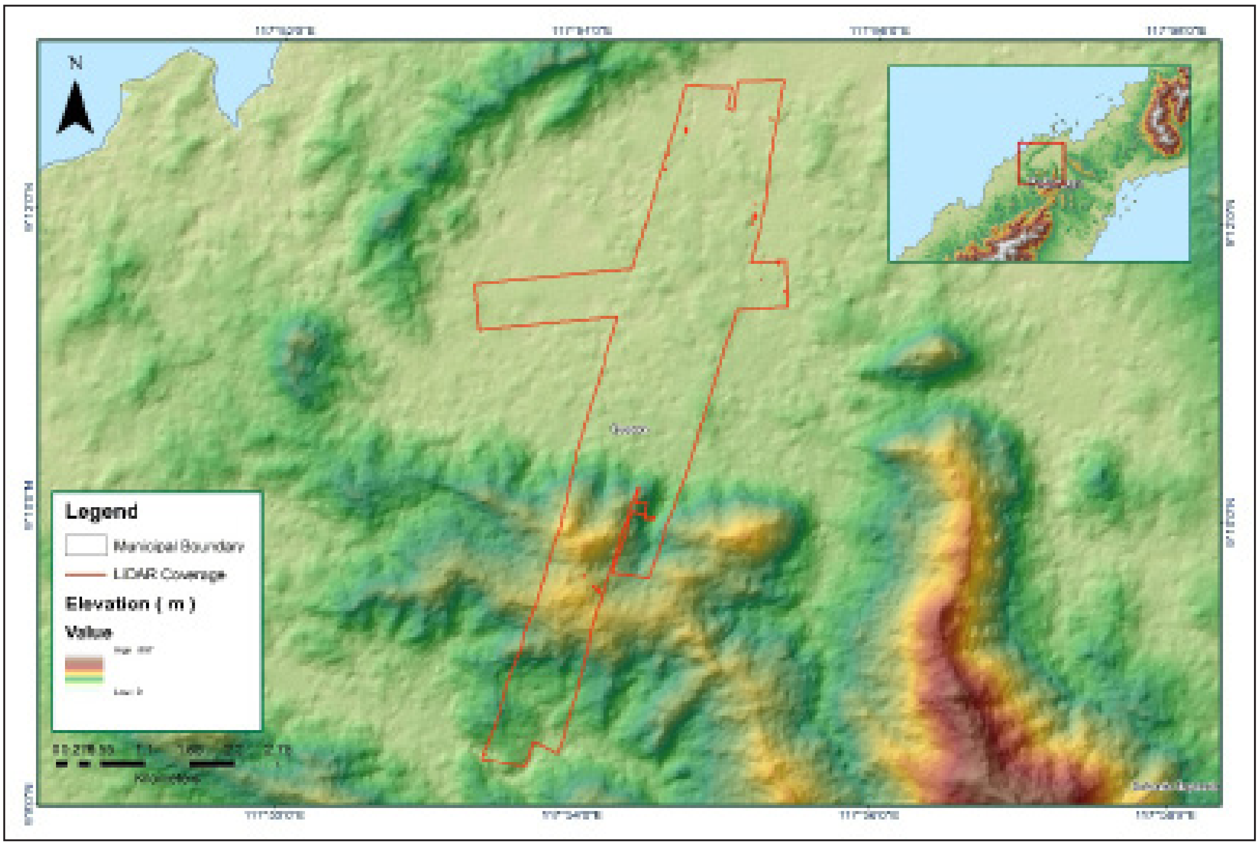


Figure A-8.32. Coverage of LiDAR data

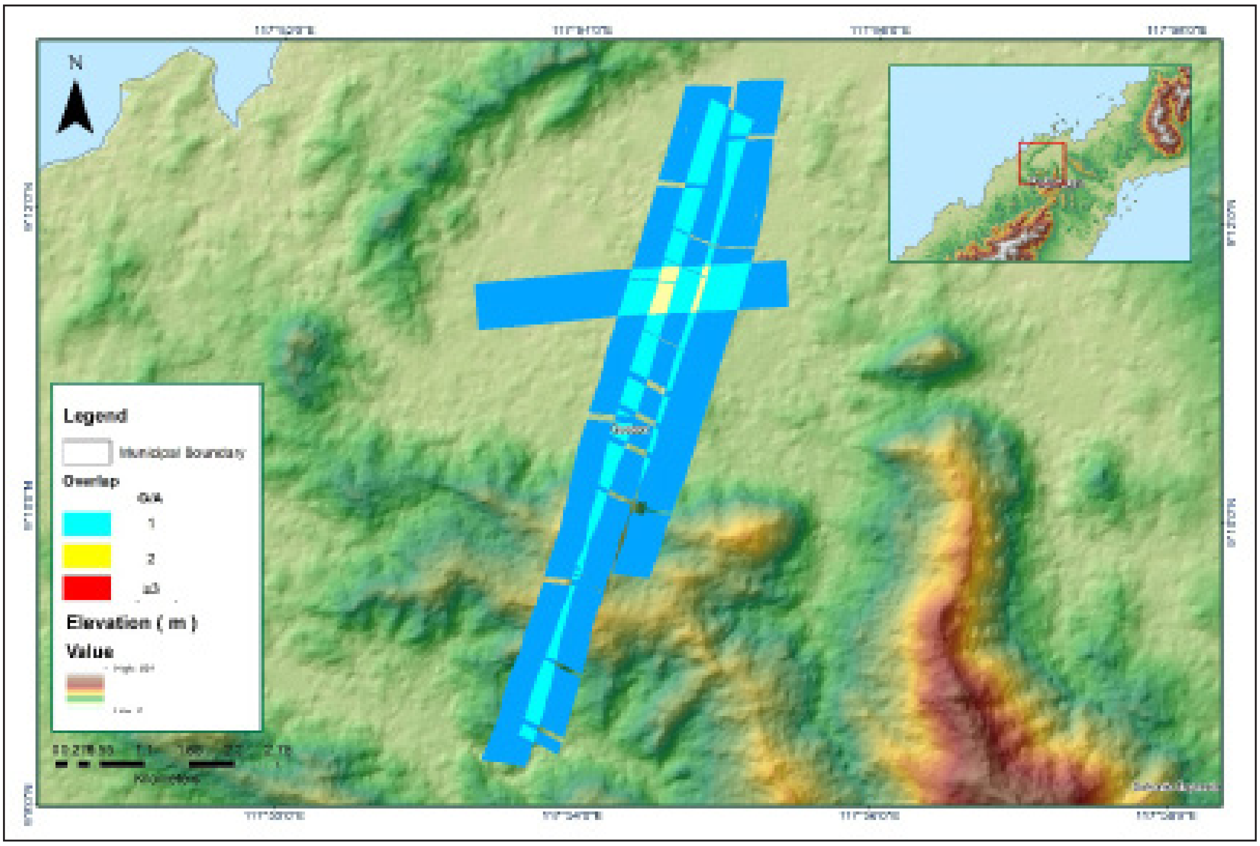


Figure A-8.33. Image of data overlap

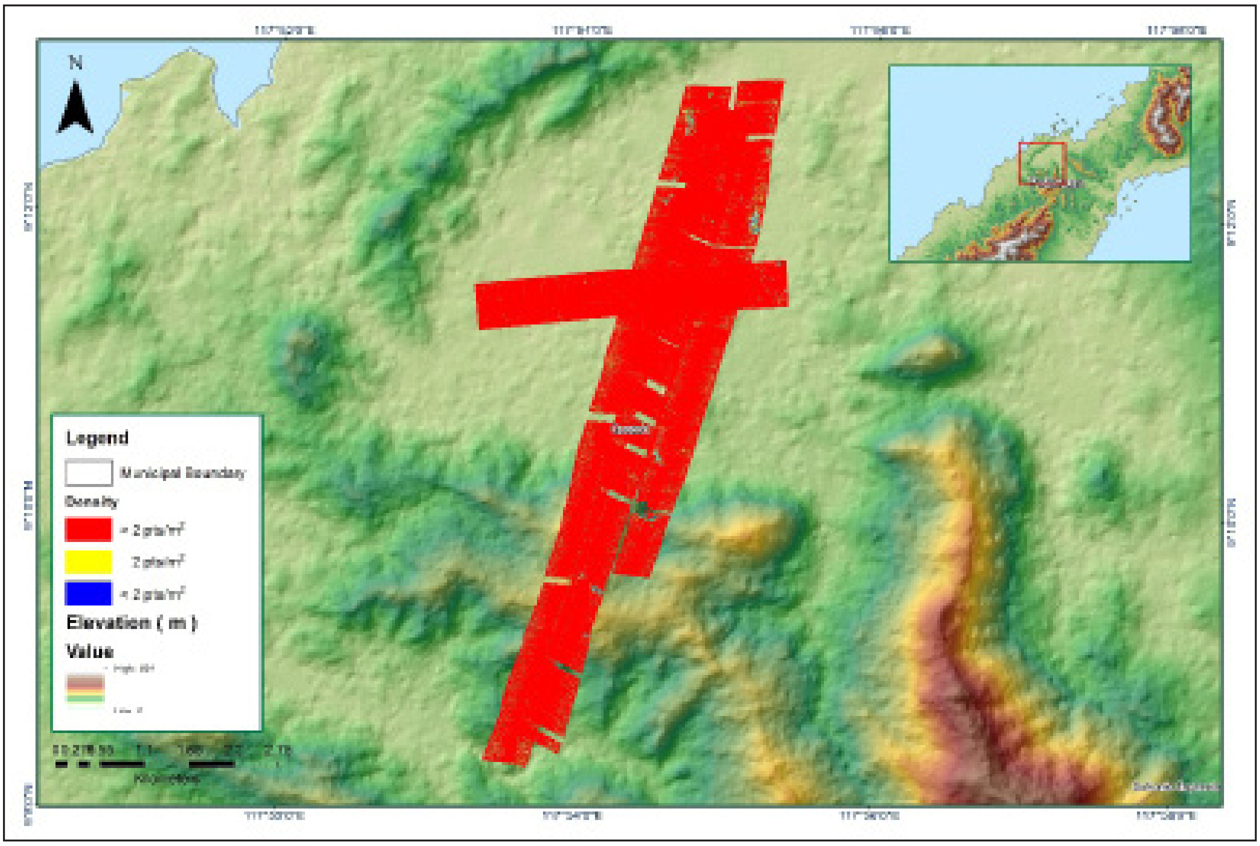


Figure A-8.34. Density map of merged LiDAR data

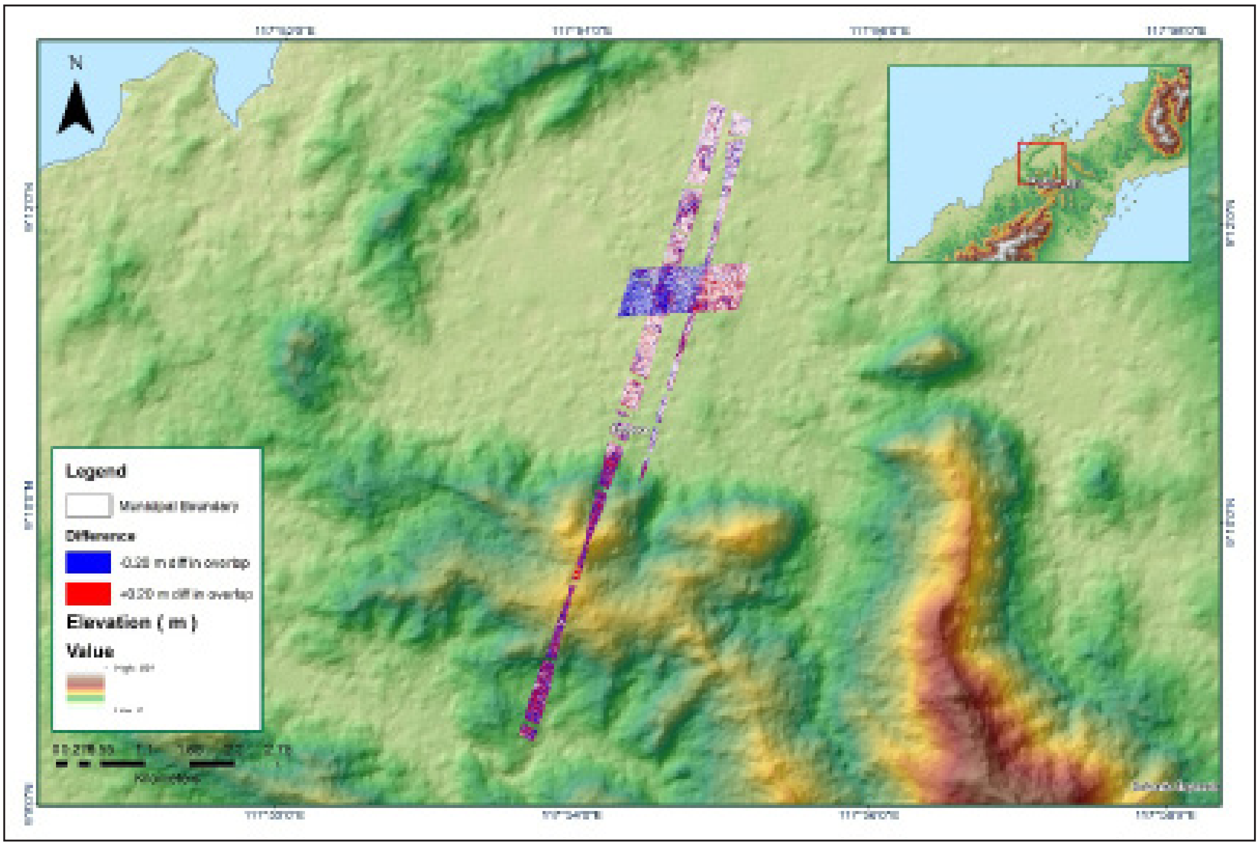


Figure A-8.35. Elevation difference between flight lines

Annex 9. Tigaplan Model Basin Parameters

Table A-9.1 Tigaplan Model Basin Parameters

Sub-basin	SCS Curve Number Loss			Clark Unit Hydrograph Transform				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Discharge (M3/S)	Recession Constant	Ratio to Peak
W1000	1.5500	89.0000	0.0	1.1615	1.8956	0.0059207	1.0000	0.5000
W1010	1.6729	88.3605	0.0	0.9410	1.5358	0.0862861	1.0000	0.5000
W1020	1.5500	89.0000	0.0	0.8828	1.4407	0.0123481	1.0000	0.5000
W1040	1.5500	89.0000	0.0	1.4879	2.4283	0.0856990	1.0000	0.5000
W1050	1.8745	87.1386	0.0	1.2347	2.0150	0.14217	1.0000	0.5000
W1060	1.6504	88.4992	0.0	0.8553	1.3959	0.0704358	1.0000	0.5000
W1070	1.2801	47.9710	0.0	2.9146	0.7031	0.18555	0.6403	0.2134
W1080	1.5500	89.0000	0.0	0.6174	1.0076	0.10396	1.0000	0.5000
W1090	3.5500	78.0000	0.0	0.8496	1.3866	0.0811532	1.0000	0.5000
W1100	4.2793	74.7971	0.0	2.1297	3.4756	0.49233	1.0000	0.5000
W1110	0.7906	40.6230	0.0	2.9093	3.2605	0.11585	0.4356	0.4612
W1120	3.8909	76.5479	0.0	1.4763	2.4092	0.18502	1.0000	0.5000
W1130	0.7752	37.3080	0.0	0.3853	0.6657	0.0080682	1.0000	0.3201
W1140	3.0814	80.4744	0.0	0.6189	1.0100	0.0942840	1.0000	0.5000
W1150	1.3551	42.7190	0.0	1.5779	1.6960	0.0943643	0.4444	0.3137
W1160	0.7906	40.2240	0.0	2.5035	1.2278	0.0191970	0.6533	0.3151
W1170	0.8320	36.7850	0.0	1.8778	1.3792	0.0887748	0.6667	0.1423
W1180	1.9244	34.8290	0.0	2.2465	0.9896	0.10047	1.0000	0.2092
W1190	2.2046	36.7400	0.0	1.5049	1.6270	0.25279	0.6533	0.4612
W1200	2.2116	36.7250	0.0	1.9417	0.9538	0.0223480	1.0000	0.5309
W1210	2.6408	35.3410	0.0	2.7027	2.6347	0.26788	1.0000	0.4612
W1220	1.1106	36.1550	0.0	2.8202	1.5689	0.0532659	0.6667	0.3137
W1230	0.9761	40.0800	0.0	1.6193	1.1991	0.0898485	0.6533	0.5304

Sub-basin	SCS Curve Number Loss			Clark Unit Hydrograph Transform				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Discharge (M3/S)	Recession Constant	Ratio to Peak
W1240	2.6353	42.5270	0.0	1.3244	4.7893	0.13995	0.4268	0.3137
W1250	1.7970	52.9400	0.0	0.9067	2.1674	0.0771843	0.2904	0.3137
W1260	3.6218	40.3150	0.0	0.8062	2.9118	0.0766123	1.0000	0.4612
W1270	1.2515	38.3560	0.0	1.3541	0.4321	0.0039688	0.4444	0.3305
W1280	1.0602	36.3960	0.0	1.1870	1.2936	0.0130355	0.6667	0.5438
W1290	2.1266	35.2980	0.0	1.1780	0.9381	0.10840	0.4444	0.3075
W1300	2.6361	36.2380	0.0	1.3348	2.3747	0.0089061	0.6667	0.3137
W1310	4.0338	35.1000	0.0	1.3963	1.3936	0.14015	0.2963	0.4612
W1320	1.8075	35.1000	0.0	1.1121	4.0486	0.0814743	0.6667	0.4612
W1330	7.8717	61.7353	0.0	0.8962	1.4626	0.0935765	1.0000	0.5000
W1340	1.0448	60.6580	0.0	1.2228	1.3012	0.0992965	0.2963	0.2134
W1350	0.9213	37.0390	0.0	3.0959	1.5083	0.21451	0.2963	0.2092
W1360	1.7955	35.9720	0.0	1.3264	1.4399	0.0826233	0.4444	0.3075
W1370	1.8135	36.0200	0.0	1.5190	0.5061	0.0011189	0.9929	0.6918
W1380	2.5919	36.3030	0.0	0.9797	5.3348	0.11493	0.9750	0.4612
W1390	2.1237	35.2040	0.0	3.0315	2.2392	0.0998584	0.6667	0.4612
W1400	2.2402	35.2780	0.0	5.6509	1.8828	0.20799	1.0000	0.4612
W1410	7.9246	61.5769	0.0	1.8018	2.9405	0.3335639	1.0000	0.5000
W1420	2.6878	35.9720	0.0	1.3389	2.2173	0.19649	0.6533	0.4612
W1440	1.5500	89.0000	0.0	1.1855	1.9347	0.0534866	1.0000	0.5000
W1450	0.7906	41.0450	0.0	2.6045	1.2773	0.0286801	1.0000	0.2134
W1490	1.5500	89.0000	0.0	1.4869	2.4266	0.0474255	1.0000	0.5000
W1500	1.5500	89.0000	0.0	1.2453	2.0323	0.0256395	1.0000	0.5000
W720	0.2831	97.8193	0.0	0.7310	1.1930	0.0255943	1.0000	0.5000
W730	1.7357	87.9762	0.0	1.1308	1.8455	0.0796128	1.0000	0.5000

Sub-basin	SCS Curve Number Loss			Clark Unit Hydrograph Transform				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Discharge (M3/S)	Recession Constant	Ratio to Peak
W740	0.2609	97.9869	0.0	0.9187	1.4993	0.0528093	1.0000	0.5000
W750	0.1000	99.0000	0.0	0.5803	0.9471	0.0055745	1.0000	0.5000
W760	3.4094	78.8361	0.0	0.9949	1.6237	0.0731803	1.0000	0.5000
W770	3.0363	80.7052	0.0	1.3862	2.2623	0.0783283	1.0000	0.5000
W780	1.0138	92.6074	0.0	1.7681	2.8856	0.11460	1.0000	0.5000
W790	3.5500	78.0000	0.0	1.0212	1.6665	0.0976909	1.0000	0.5000
W800	2.6936	82.5018	0.0	1.6534	2.6983	0.0312390	1.0000	0.5000
W810	3.1536	80.1078	0.0	1.8776	3.0643	0.0297990	1.0000	0.5000
W820	2.7771	82.0566	0.0	0.7897	1.2888	0.16364	1.0000	0.5000
W830	1.5500	89.0000	0.0	1.2233	1.9964	0.0840282	1.0000	0.5000
W840	2.7310	82.3018	0.0	1.3481	2.2001	0.17349	1.0000	0.5000
W850	3.4310	78.7306	0.0	0.6857	1.1191	0.0445705	1.0000	0.5000
W860	1.6784	88.3272	0.0	1.0431	1.7023	0.0847407	1.0000	0.5000
W870	1.8953	87.0145	0.0	1.2386	2.0214	0.0176516	1.0000	0.5000
W880	2.1649	85.4359	0.0	1.7766	2.8994	0.13898	1.0000	0.5000
W890	1.5500	89.0000	0.0	1.3269	2.1655	0.0410332	1.0000	0.5000
W910	0.7906	41.0450	0.0	4.2012	0.9487	0.10725	1.0000	0.2134
W920	0.7879	41.0450	0.0	0.9959	0.7297	0.0065780	1.0000	0.4635
W930	3.2504	79.6220	0.0	0.9118	1.4880	0.13594	1.0000	0.5000
W940	1.5500	89.0000	0.0	1.2299	2.0071	0.0833659	1.0000	0.5000
W950	0.7906	41.0450	0.0	2.9939	1.4913	0.0011189	1.0000	0.3137
W960	1.5500	89.0000	0.0	0.6186	1.0096	0.0092573	1.0000	0.5000
W970	1.7612	37.6950	0.0	4.5675	3.4294	0.17544	1.0000	0.4612
W980	1.1800	41.0450	0.0	2.2059	2.3606	0.0755787	1.0000	0.3137
W990	2.5319	83.3779	0.0	1.0905	1.7797	0.16204	1.0000	0.5000

Annex 10. Tigaplan Model Reach Parameters

Table A-10.1 Tigaplan Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R10	Automatic Fixed Interval	428.85	.0009653472	0.04	Trapezoid	25	1
R100	Automatic Fixed Interval	1378.8	0.0015816	0.04	Trapezoid	25	1
R120	Automatic Fixed Interval	1812.4	.0001736929	0.04	Trapezoid	25	1
R140	Automatic Fixed Interval	1161.5	.0005999673	0.04	Trapezoid	25	1
R1460	Automatic Fixed Interval	964.97	0.0032622	0.0177436	Trapezoid	25	1
R1510	Automatic Fixed Interval	781.84	0.0027876	0.04	Trapezoid	25	1
R160	Automatic Fixed Interval	1099.8	0.0098976	0.04	Trapezoid	25	1
R170	Automatic Fixed Interval	1508.5	0.0038805	0.04	Trapezoid	25	1
R190	Automatic Fixed Interval	525.98	.0008847450	0.0251335	Trapezoid	25	1
R200	Automatic Fixed Interval	1612.1	0.0031537	0.04	Trapezoid	25	1
R230	Automatic Fixed Interval	1873.1	0.0021249	0.04	Trapezoid	25	1
R240	Automatic Fixed Interval	297.99	0.0018675	0.0379094	Trapezoid	25	1
R250	Automatic Fixed Interval	155.56	0.0280264	0.04	Trapezoid	25	1
R280	Automatic Fixed Interval	543.14	0.0073662	0.04	Trapezoid	25	1
R290	Automatic Fixed Interval	278.99	.0004121149	0.04	Trapezoid	25	1
R300	Automatic Fixed Interval	1150.2	0.0030558	0.04	Trapezoid	25	1
R330	Automatic Fixed Interval	1338.4	0.0066740	0.04	Trapezoid	25	1
R360	Automatic Fixed Interval	2503.1	0.0027164	0.0252184	Trapezoid	25	1
R390	Automatic Fixed Interval	2281.9	0.0021650	0.04	Trapezoid	25	1
R40	Automatic Fixed Interval	1247.8	.0007935551	0.04	Trapezoid	25	1
R410	Automatic Fixed Interval	536.27	0.0143893	0.0251807	Trapezoid	25	1
R440	Automatic Fixed Interval	791.84	0.0051836	0.0376477	Trapezoid	25	1
R470	Automatic Fixed Interval	1742.0	0.0072586	0.0376477	Trapezoid	25	1

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R490	Automatic Fixed Interval	1223.3	0.0044130	0.0196349	Trapezoid	25	1
R50	Automatic Fixed Interval	568.70	0.0028584	0.04	Trapezoid	25	1
R500	Automatic Fixed Interval	708.70	0.0225090	0.0915195	Trapezoid	25	1
R520	Automatic Fixed Interval	531.42	0.0285070	0.0261333	Trapezoid	25	1
R550	Automatic Fixed Interval	575.27	0.0011709	0.0256107	Trapezoid	25	1
R560	Automatic Fixed Interval	3257.1	0.0043169	0.0167323	Trapezoid	25	1
R570	Automatic Fixed Interval	560.42	0.0054502	0.0167323	Trapezoid	25	1
R580	Automatic Fixed Interval	6185.1	0.0174284	0.04	Trapezoid	25	1
R620	Automatic Fixed Interval	1552.0	0.0044565	0.0113825	Trapezoid	25	1
R630	Automatic Fixed Interval	184.85	0.0071433	0.0113957	Trapezoid	25	1
R650	Automatic Fixed Interval	2590.5	0.0037092	0.0165998	Trapezoid	25	1
R680	Automatic Fixed Interval	1918.5	0.0122503	0.0113825	Trapezoid	25	1
R70	Automatic Fixed Interval	2445.5	0.0010603	0.04	Trapezoid	25	1
R90	Automatic Fixed Interval	2390.4	0.0011305	0.04	Trapezoid	25	1

Annex 11. Tigaplan Field Validation Data

Table A-11.1 Tigaplan Field Validation Data

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event	Date	Rain Return / Scenario
	Lat	Long						
1	9.169963	117.9542	3.31	0	-3.31	Auring	Jan. 2013	25-Year
2	9.176879	117.9553	0.38	0	-0.38	Auring	Jan. 2013	25-Year
3	9.181001	117.9547	0.73	0	-0.73	Auring	Jan. 2013	25-Year
4	9.184241	117.9552	0.1	0	-0.1	Auring	Jan. 2013	25-Year
5	9.185909	117.9542	0.26	0	-0.26	Auring	Jan. 2013	25-Year
6	9.18739	117.9514	0.03	0	-0.03	Auring	Jan. 2013	25-Year
7	9.190405	117.9528	1.13	0	-1.13	Auring	Jan. 2013	25-Year
8	9.190614	117.9518	0.03	0	-0.03	Auring	Jan. 2013	25-Year
9	9.192088	117.9537	0.38	0	-0.38	Auring	Jan. 2013	25-Year
10	9.203641	117.9479	0.63	0.45	-0.18	Auring	Jan. 2013	25-Year
11	9.20419	117.9452	0.68	0.3	-0.38	Auring	Jan. 2013	25-Year
12	9.20456	117.9448	0.77	0.3	-0.47	Auring	Jan. 2013	25-Year
13	9.205213	117.947	0.79	0.45	-0.34	Auring	Jan. 2013	25-Year
14	9.206009	117.9493	0.05	1	0.95	Habagat	Aug. 2016	25-Year
15	9.207884	117.9545	0.03	0	-0.03	Auring	Jan. 2013	25-Year
16	9.208102	117.9551	0.03	0	-0.03	Auring	Jan. 2013	25-Year
17	9.2082	117.9538	0.58	0	-0.58	Auring	Jan. 2013	25-Year
18	9.209885	117.9583	0.03	0	-0.03	Auring	Jan. 2013	25-Year
19	9.210411	117.9414	1.1	0	-1.1	Auring	Jan. 2013	25-Year
20	9.210577	117.9367	0.03	0	-0.03	Auring	Jan. 2013	25-Year
21	9.211216	117.9365	0.03	0	-0.03	Auring	Jan. 2013	25-Year
22	9.211802	117.9605	0.05	0	-0.05	Auring	Jan. 2013	25-Year
23	9.211841	117.9415	0.55	0.75	0.2	Auring	Jan. 2013	25-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event	Date	Rain Return / Scenario
	Lat	Long						
24	9.213006	117.9409	1.39	1.45	0.06	Auring	Jan. 2013	25-Year
25	9.213808	117.9607	0.03	0	-0.03	Auring	Jan. 2013	25-Year
26	9.213846	117.963	0.06	0	-0.06	Auring	Jan. 2013	25-Year
27	9.213793	117.9403	0.03	0	-0.03	Auring	Jan. 2013	25-Year
28	9.214027	117.94	0.03	0	-0.03	Auring	Jan. 2013	25-Year
29	9.214607	117.9625	0.03	0	-0.03	Auring	Jan. 2013	25-Year
30	9.216639	117.9657	0.03	0	-0.03	Auring	Jan. 2013	25-Year
31	9.216436	117.9392	0.03	0	-0.03	Auring	Jan. 2013	25-Year
32	9.21689	117.9668	0.63	0	-0.63	Auring	Jan. 2013	25-Year
33	9.21715	117.9678	0.03	0	-0.03	Auring	Jan. 2013	25-Year
34	9.216984	117.9393	0.03	0	-0.03	Auring	Jan. 2013	25-Year
35	9.217749	117.9385	0.03	0.28	0.25	Auring	Jan. 2013	25-Year
36	9.217912	117.9295	0.03	2.5	2.47	Auring	Jan. 2013	25-Year
37	9.218182	117.9394	0.55	1	0.45	Auring	Jan. 2013	25-Year
38	9.218443	117.9376	0.39	0.45	0.06	Auring	Jan. 2013	25-Year
39	9.219191	117.9368	0.14	0.93	0.79	Auring	Jan. 2013	25-Year
40	9.219363	117.9379	0.4	1.3	0.9	Auring	Jan. 2013	25-Year
41	9.219946	117.9766	0.83	0	-0.83	Auring	Jan. 2013	25-Year
42	9.219413	117.9352	0.2	0	-0.2	Auring	Jan. 2013	25-Year
43	9.219448	117.9365	0.58	0.93	0.35	Auring	Jan. 2013	25-Year
44	9.219813	117.9359	0.08	0.9	0.82	Auring	Jan. 2013	25-Year
45	9.219862	117.939	1.42	2.3	0.88	Auring	Jan. 2013	25-Year
46	9.219801	117.9335	0.28	1.45	1.17	Auring	Jan. 2013	25-Year
47	9.220411	117.9761	2.26	0	-2.26	Auring	Jan. 2013	25-Year
48	9.219815	117.9317	0.67	1.3	0.63	Auring	Jan. 2013	25-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event	Date	Rain Return / Scenario
	Lat	Long						
49	9.219963	117.9353	0.07	0.6	0.53	Auring	Jan. 2013	25-Year
50	9.220101	117.9358	0.35	0.9	0.55	Auring	Jan. 2013	25-Year
51	9.220115	117.9349	0.21	1	0.79	Auring	Jan. 2013	25-Year
52	9.220247	117.9328	0.31	2.5	2.19	Auring	Jan. 2013	25-Year
53	9.221248	117.9781	0.91	0	-0.91	Auring	Jan. 2013	25-Year
54	9.222384	117.9306	0.79	1.5	0.71	Auring	Jan. 2013	25-Year
55	9.224556	117.9311	0.89	1.5	0.61	Auring	Jan. 2013	25-Year
56	9.224728	117.9303	0.65	2	1.35	Auring	Jan. 2013	25-Year
57	9.224838	117.9285	0.21	2.3	2.09	Auring	Jan. 2013	25-Year
58	9.227606	117.9269	0.44	0	-0.44	Auring	Jan. 2013	25-Year
59	9.229517	117.9318	0.86	0.68	-0.18	Auring	Jan. 2013	25-Year
60	9.230366	117.9323	0.03	0.4	0.37	Auring	Jan. 2013	25-Year
61	9.234723	117.935	0.03	0	-0.03	Auring	Jan. 2013	25-Year
62	9.235637	117.9358	0.03	0	-0.03	Auring	Jan. 2013	25-Year

Annex 12. Phil-LiDAR 1 UPLB Team Composition

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

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

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

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

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

Information Systems Analyst
Jan Martin C. Magcale

Project Assistants
Daisili Ann V. Pelegrina
Athena Mercado
Kaye Anne A. Matre
Randy P. Porciocula