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

LiDAR Surveys and Flood Mapping of Tanjay River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
University of San Carlos

APRIL 2017

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

This research project is supported by the Department of Science and Technology (DOST) as part of its Grants-in-Aid Program and is to be cited as:

E. C. Paringit and R. S. Otadoy (eds.) (2017), LiDAR Surveys and Flood Mapping of Tanjay River, Quezon City: University of the Philippines Training Center for Applied Geodesy and Photogrammetry-155pp.

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National Library of the Philippines
ISBN: 978-621-430-190-4

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

CHAPTER 1: OVERVIEW OF THE PROGRAM AND TANJAY RIVER

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

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 San Carlos (USC). USC 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 17 river basins in the Central Visayas Region. The university is located in Cebu City in the province of Cebu.

1.2 Overview of the Tanjay River Basin

The Tanjay River Basin covers the City of Tanjay, and the Municipalities of Pamplona, Sibulan, Amlan and Valencia in the province of Negros Oriental. According to DENR - River Basin Control Office, it has a drainage area of 215 km2 and an estimated 129 million cubic meter (MCM) annual run-off of (RCBO, 2015).

Its main stem, Tanjay River, is part of the river systems in the Negros Island Region. Tanjay River drains to the City of Tanjay, thus the name of the river. Its head waters covers the municipalities of Pamplona and Sibulan. Tanjay City is a 4th class city with a population of 80,532 residing within the city. Pamplona is a 3rd income class municipality and has a population of 37,596 in its territory. Vast agricultural lands can be seen in Tanjay and Pamplona. Sibulan is a 2nd income class municipality with a population of 59,455 according to the 2015 census. Among the areas covered by the Tanjay river basin, Pamplona municipality is the least populated.

Meanwhile, there are communities that live near the river. According to the 2015 national census of NSO, a total of 28,555 locals are residing in the immediate vicinity of the river which are distributed among the eight (8) barangays in Tanjay City and one (1) barangay in Pamplona. Tanjay River plays a vital role on providing irrigation to vast agricultural land mainly used for sugarcane plantation. Also, its riverbed is said to contain high amount of magnetite that can be used for making steel but it is not utilized because mining and quarrying is not allowed along the river. To this day, the local government unit (LGU) of the City of Tanjay is facing accusations from its locals that the recently started dredging project in Tanjay River is just a cover up for black sand mining in the area. The said project aims to remove heavy siltation off the river, its estuaries and part of the adjacent coastline to prevent the impact of flooding.

With regards to climate, the Tanjay river basin area is classified under Type III weather in the Corona climate classification. It experiences dry season from November to April and wet season for the other months of the year. During the wet season, there is high probability that the Tanjay river basin lies in the path of some typhoons that hit the Philippines. Tanjay city is among the areas badly hit by Tropical Storm 'Sendong' (internationally known as Washi) last December 2011, killing at least 38 people in the province (NDRRMC, 2017).

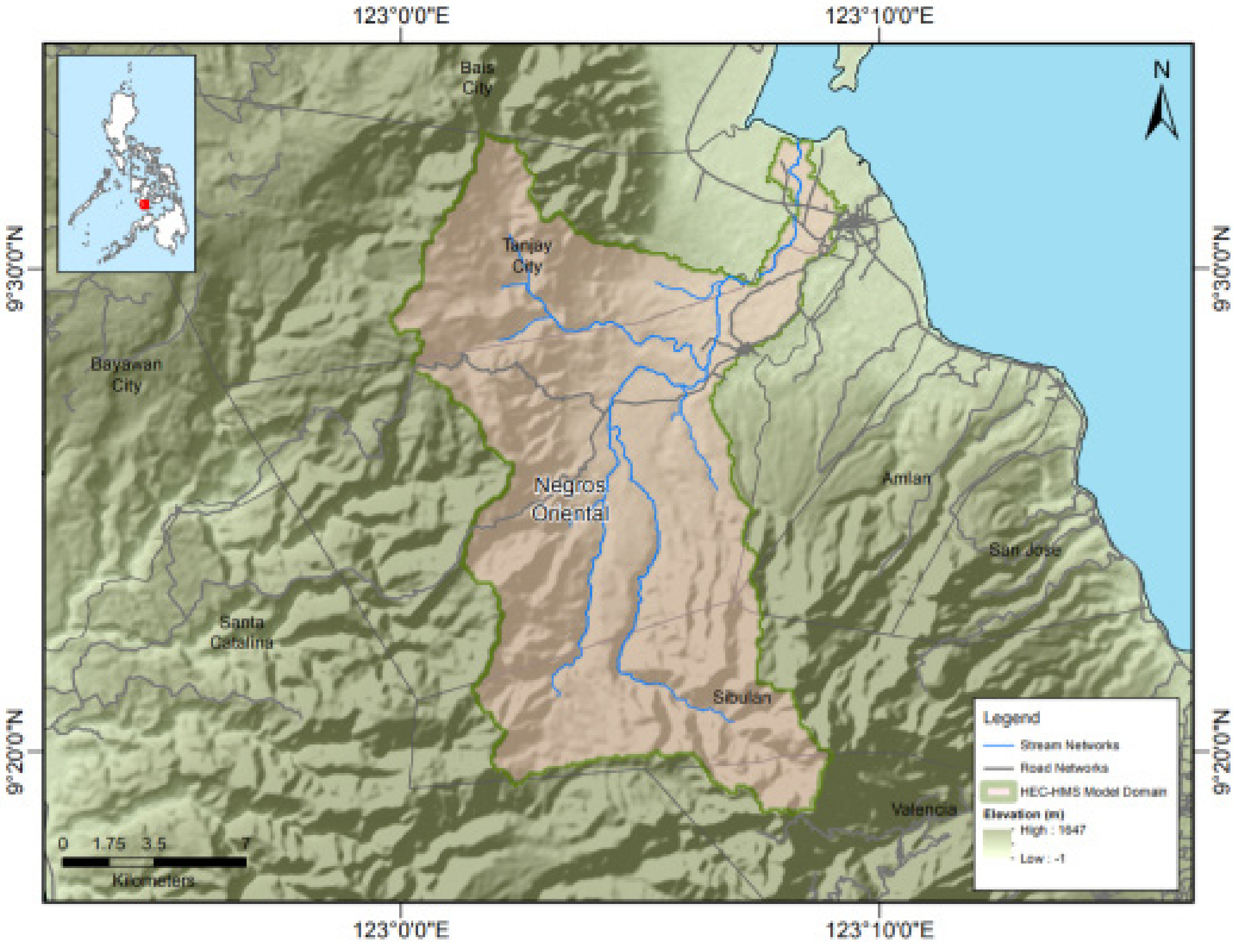

Figure 1. Map of Tanjay River Basin (in brown)

CHAPTER 2: LIDAR ACQUISITION IN TANJAY FLOODPLAIN

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

2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Tanjay Floodplain in Negros Oriental. These missions were planned for 7 lines that run for at most three (3) hours including take-off, landing and turning time. The flight planning parameters for Gemini LiDAR system is found in Table 1. Figure 2 shows the flight plans for Tanjay floodplain survey.

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)
BLK54B	1000	30	50	100	40	115-125	5
BLK54C	700/1000	30	50	100	40	115-125	5

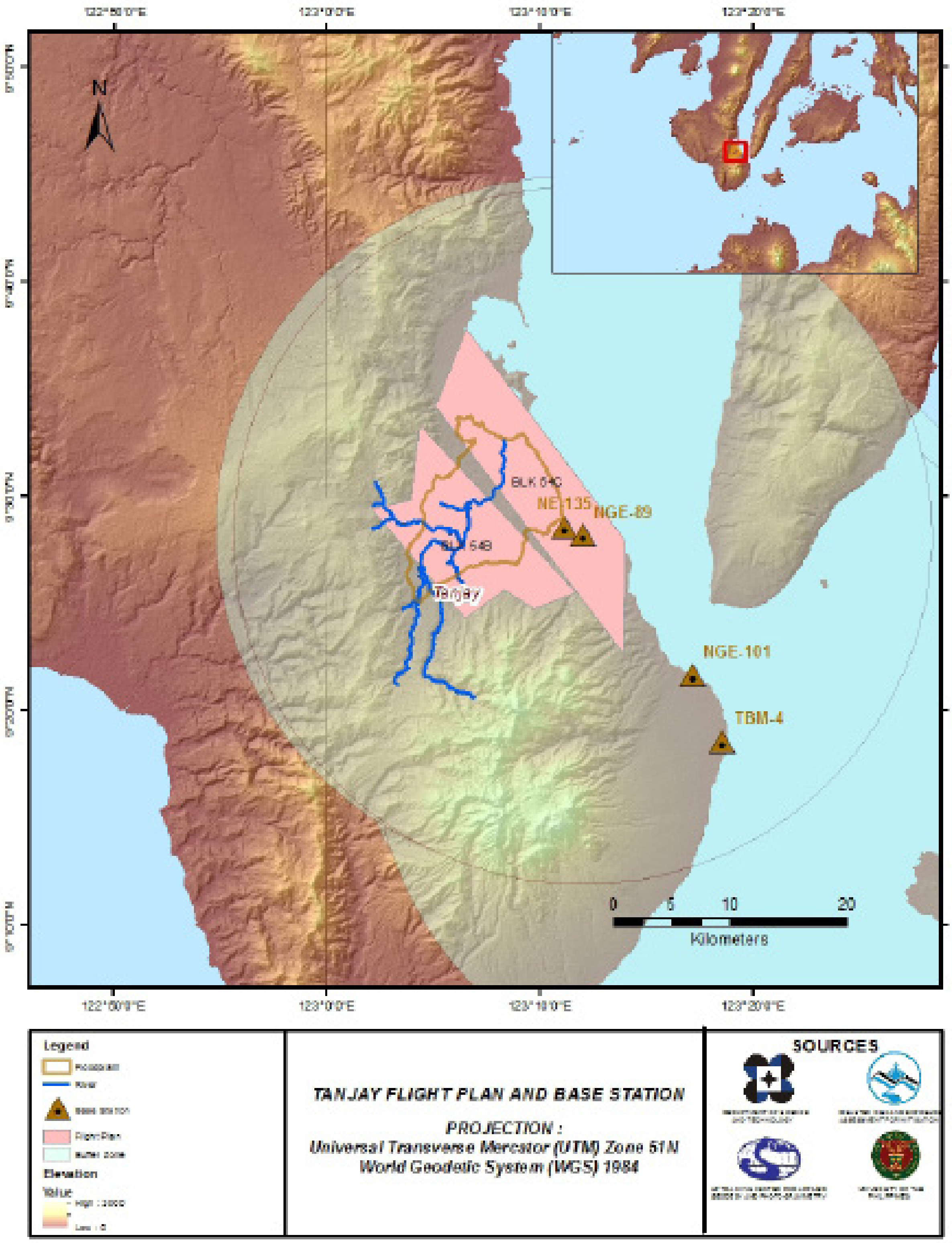

Figure 2. Flight plans and base stations used for Tanjay Floodplain

2.2 Ground Base Station

The project team was able to recover two (2) NAMRIA reference points: NGE-101 and NGE-89 with second (2nd) order accuracy. The team reprocessed one (1) benchmark NE-135 and one (1) NAMRIA reference point TBM-4. The certifications for the base stations are found in Annex 2 while the baseline processing report for the reprocessed point is found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey (September 24-October 6, 2014). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS R8, TRIMBLE SPS 852 and TRIMBLE SPS 985. Flight plans and location of base stations used during the aerial LiDAR acquisition in Tanjay floodplain are shown in Figure 2. The list of LiDAR data acquisition team members are found in Annex 4.

Figure 3 to Figure 6 show the recovered NAMRIA reference points within the area. In addition, Table 2 to Table 5 show the details about the NAMRIA control stations while Table 6 shows the list of all ground control points occupied during the acquisition together with the dates they are utilized during the survey.

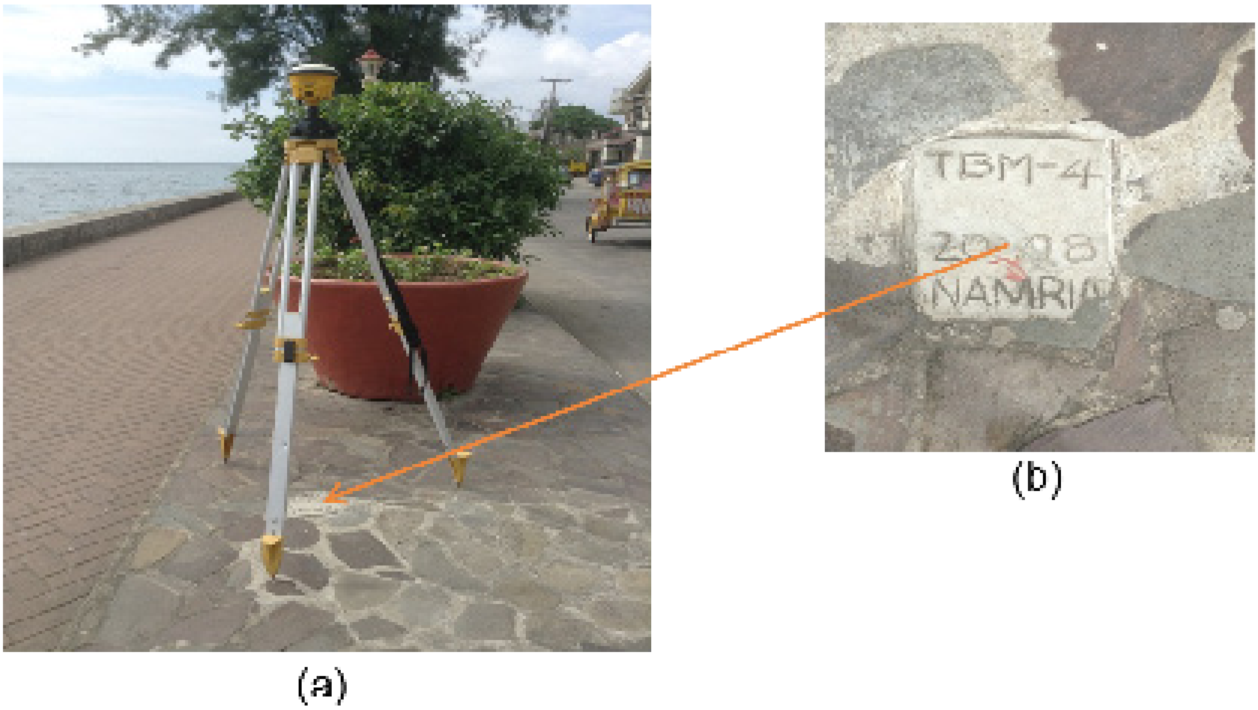

Figure 3. GPS set-up over TBM-4 on top of concrete pathway about 5 meters from the seawall of Dumaguete City's boulevard (a) and NAMRIA reference point TBM-4 (b) as recovered by the field team.

Table 2. Details of the recovered NAMRIA horizontal control point TBM-4 with processed coordinates used as base station for the LiDAR Acquisition.

Station Name	TBM-4	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	9°18'39.58660" North 123°18'28.47112" East 3.712 meters
Grid Coordinates, Philippine Transverse Mercator Zone 1A (PTM Zone 1A PRS 92)	Easting Northing	313960.450 meters 1030039.396 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	9°18'35.66706" North 123°18'33.81248" East 66.241 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 (UTM 51N PRS 92)	Easting Northing	533814.622 meters 1029185.290 meters

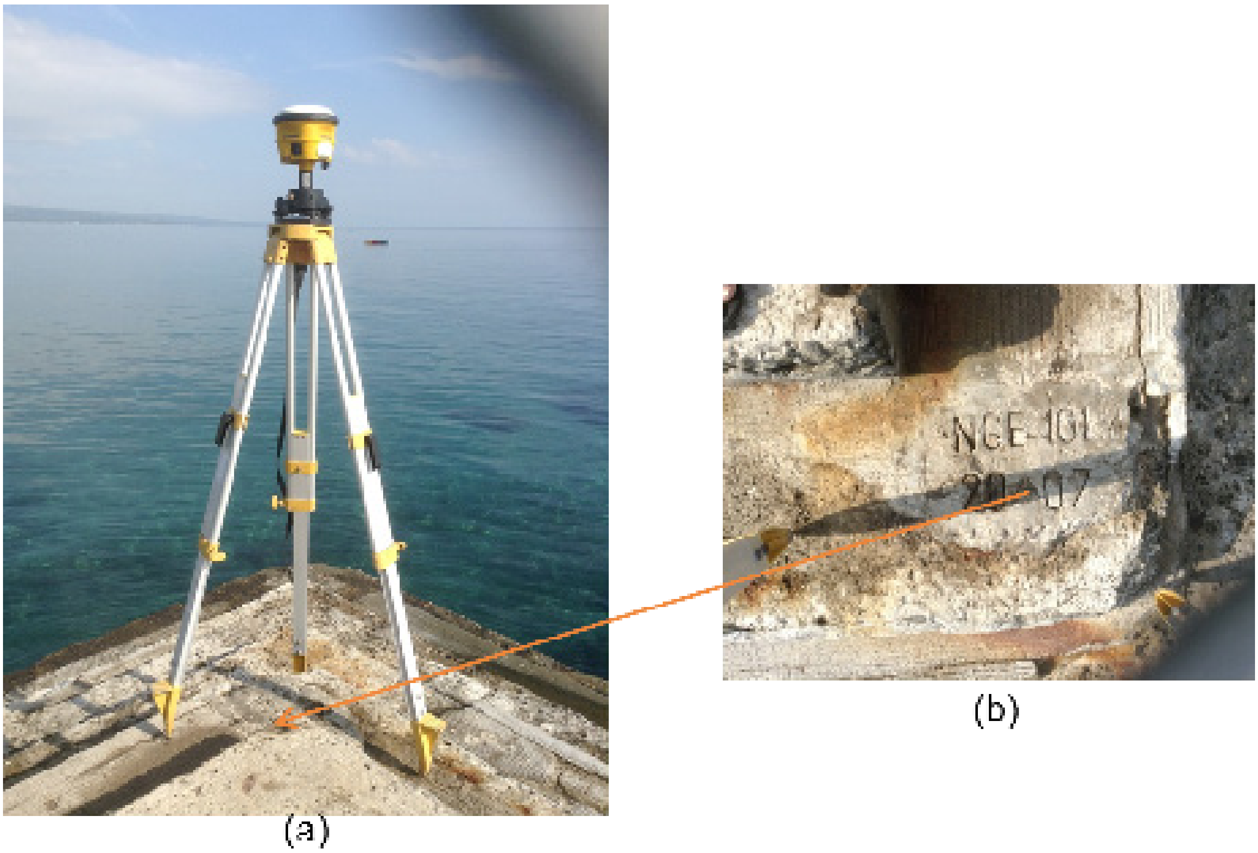

Figure 4. GPS set-up over NGE-101 on the third step from the top flooring of the pier NE corner in barangay Poblacion under the municipality of Sibulan (a) and NAMRIA reference point NGE-101 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point NGE-101 used as base station for the LiDAR Acquisition.

Station Name	NGE-101	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	9°21’46.05028” North 123°17’3.45508” East 2.89700 meters
Grid Coordinates, Philippine Transverse Mercator Zone 1A (PTM Zone 1A PRS 92)	Easting Northing	311516.397 meters 1035718.276 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	9°21’42.11526” North 123°17’8.79199” East 65.25500 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 (UTM 51N PRS 92)	Easting Northing	531340.539 meters 1034845.884 meters

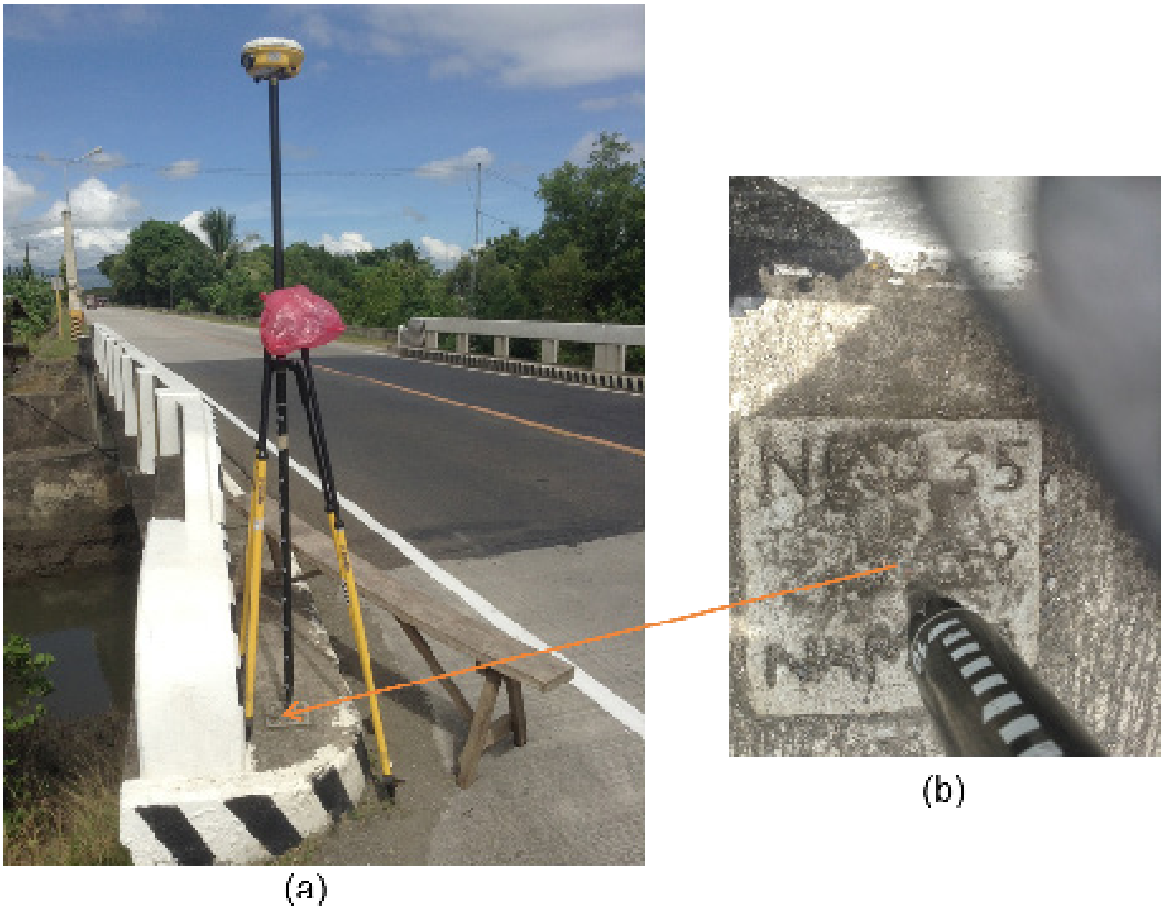

Figure 5. GPS set-up over NE-135 in Busuang Bridge on top of concrete sidewalk in Barangay Bio-os under the municipality of Amlan (a) and NAMRIA reference point NE-135 (b) as recovered by the field team.

Table 4. Details of the recovered NAMRIA horizontal control point NE-135 used as base station for the LiDAR Acquisition.

Station Name	NE-135	
Order of Accuracy	1st	
Relative Error (horizontal positioning)	1:100,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	9°28'39.60020" North 123°11'03.44049" East 5.556 meters
Grid Coordinates Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	300468.479 meters 1048547.710 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	9°28'35.62671" North 123°11'08.76787" East 67.415 meters

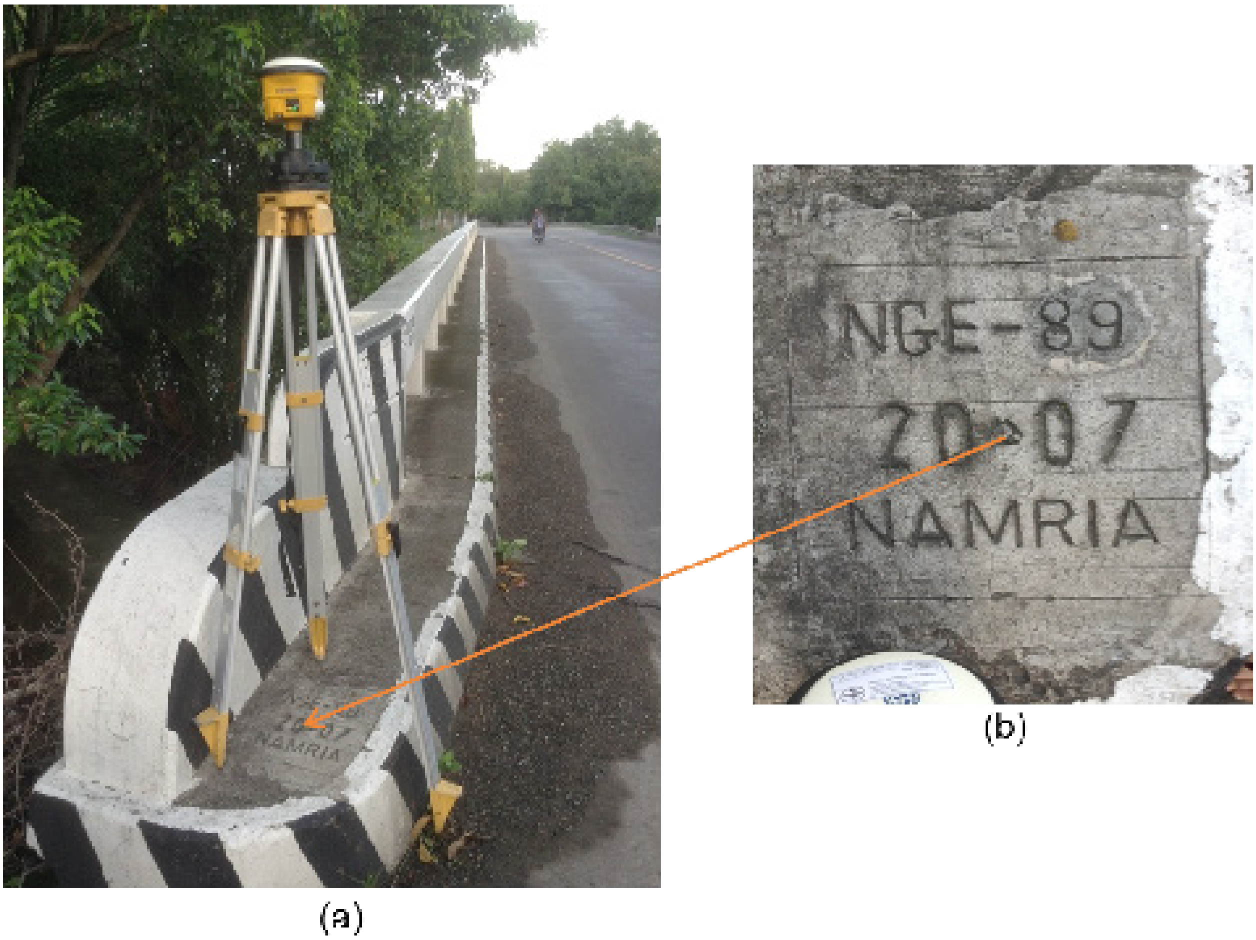

Figure 6. GPS set-up over NGE-89 on the SE corner of Bio-os Bridge in Barangay Bio-os under the municipality of Amlan (a) and NAMRIA reference point NGE-89 (b) as recovered by the field team.

Table 5. Details of the recovered NAMRIA horizontal control point NGE-89 used as base station for the LiDAR Acquisition.

Station Name	**NGE-89**	
Order of Accuracy	**2nd**	
Relative Error (horizontal positioning)	**1 in 50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	9°28’17.93638” North 123°11’53.99321” East 5.29700 meters
Grid Coordinates, Philippine Transverse Mercator Zone 1A (PTM Zone 1A PRS 92)	Easting Northing	302131.943 meters 1047809.850 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	9°28’13.96567” North 123°11’59.32102” East 67.20400 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 (UTM 51N PRS 92)	Easting Northing	521895.196 meters 1046874.129 meters

Table 6. Ground control points used during LiDAR data acquisition

Date Surveyed	Flight Number	Mission Name	Ground Control Points
September 24, 2014	7515G	2BLK56C267B	NGE-101 & T-BM4
September 29, 2014	7524G	2BLK54C272A	NE-135 & NGE-89
October 1, 2014	7528G	2BLK54B274A	NE-135 & NGE-89
October 2, 2014	7530G	2BLK54B56E275A	NE-135 & NGE-101
October 6, 2014	7538G	2BLK54BS279A	NE-135 & NGE-101

2.3 Flight Missions

Five (5) missions were conducted to complete the LiDAR Data Acquisition Tanjay Floodplain, for a total of 14 hours and one minute (14+1) of flying time for RP-C9322. All missions were acquired using the Gemini LiDAR system. Table 7 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 8 presents the actual parameters used during the LiDAR data acquisition.

Table 7. Flight missions for LiDAR data acquisition in Tanjay 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
September 24, 2014	7515	269.96	67.69	23.68	44.01	0	2	53
September 29, 2014	7524	269.96	205.07	48.14	156.93	0	4	11
October 1, 2014	7528	269.96	76.66	34.51	42.15	0	2	29
October 2, 2014	7530	269.96	80.76	24.98	55.78	0	2	23
October 6, 2014	7538	269.96	46.54	22.68	23.68	0	2	5
TOTAL		1349.8	476.72	153.99	322.55	0	14	1

Table 8. Actual parameters used during LiDAR data acquisition.

Date Surveyed	Flight Number	Flying Height (AGL) (m)	Overlap (%)	Field of View	Scan Frequency (kHz)	Speed of Plane (Kts)
September 24, 2014	7515	700	30	50	40	115-125
September 29, 2014	7524	1000	30	50	40	115-125
October 1, 2014	7528	1000	30	40	50	115-125
October 2, 2014	7530	1000	30	40	50	115-125
October 6, 2014	7538	1000	30	40	50	115-125

2.4 Survey Coverage

Tanjay Floodplain is situated within the municipalities of Negros Oriental. The list of municipalities and cities surveyed with at least one (1) square kilometer coverage, is shown in Table 9. The actual coverage of the LiDAR acquisition for Tanjay floodplain is presented in Figure 7.

Table 9. List of municipalities and cities surveyed during Tanjay Floodplain LiDAR survey.

Province	Municipality/City	Area of Municipality/City	Total Area Surveyed	Percentage of Area Surveyed =(Total Area covered/ Area of Municipality)*100
Negros Oriental	Amlan	65.675	38.531	58.670%
	Bacong	26.069	4.789	18.371%
	Bais City	269.219	48.361	17.963%
	Dauin	80.910	0.449	0.555%
	Pamplona	215.091	54.460	25.319%
	San Jose	47.095	30.537	64.842%
	Sibulan	165.361	15.410	9.319%
	Tanjay City	261.009	87.836	33.652%
	Valencia	144.432	11.210	7.762%

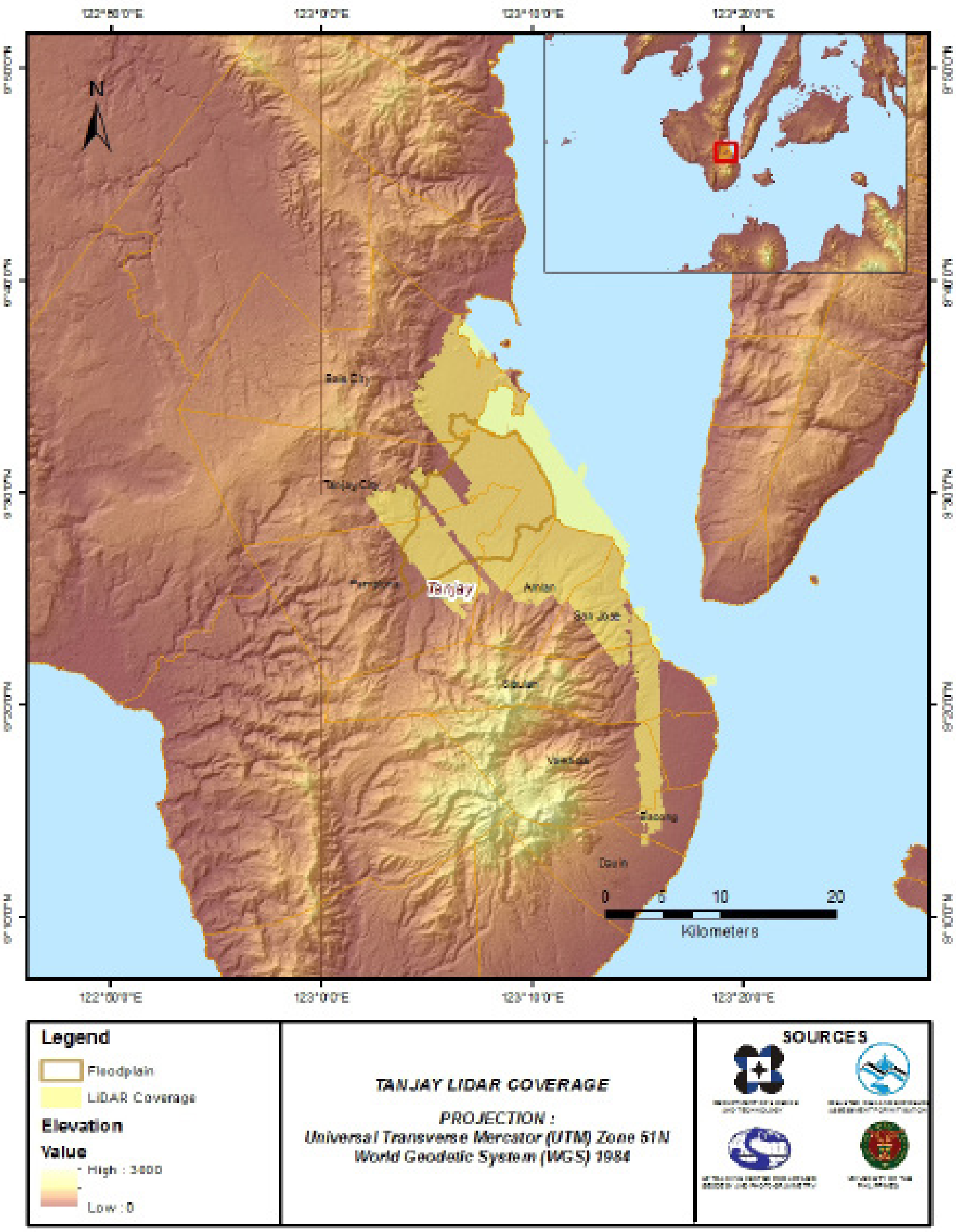

Figure 7. Actual LiDAR data acquisition for Tanjay Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING FOR TANJAY FLOODPLAIN

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

3.1 Overview of 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.

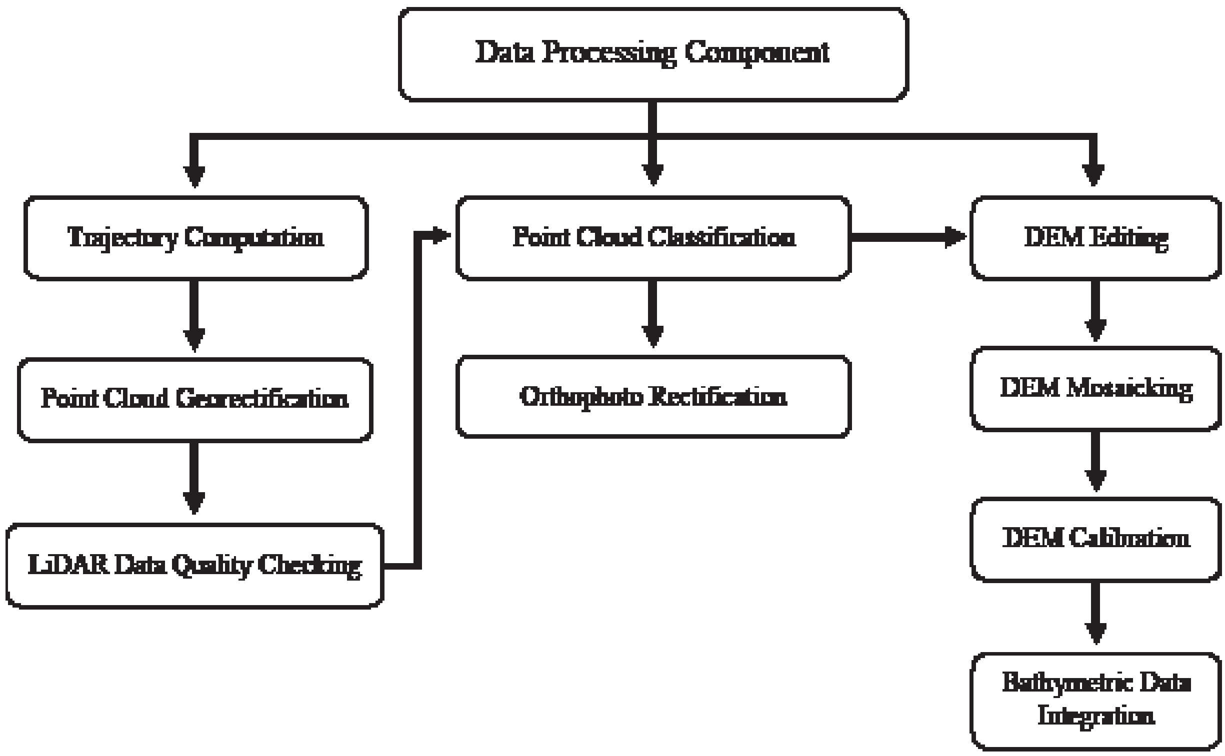

Figure 8. Schematic Diagram for Data Pre-Processing Component

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Tanjay floodplain can be found in Annex 5. Data Transfer Sheets. Missions flown during the first survey conducted on September 2014 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Gemini system while missions acquired during the second survey on January 2016 were flown using Aquarius system and lastly, the third survey was done on May 2016 using the Leica system over Tanjay City, Negros Oriental.

The Data Acquisition Component (DAC) transferred a total of 68.53 Gigabytes of Range data, 0.93 Gigabytes of POS data, and 33.26 Megabytes of GPS base station data, and 27.6 Gigabytes of Image data to the data server from October 20, 2014 up to February 9, 2016 for Optech LiDAR systems while a total of 8.34 Gigabytes of RawLaser data, 600 Megabytes of GNSSIMU data, 235 Megabytes of base station data and 66.3 Gigabytes of RCD30 raw image data were transferred on August 9, 2016 for Leica LiDAR system. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Tanjay was fully transferred on June 21, 2016, as indicated on the Data Transfer Sheets for Tanjay floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 7515G, one of the Tanjay 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 September 21, 2014 00:00AM. The y-axis is the RMSE value for that particular position.

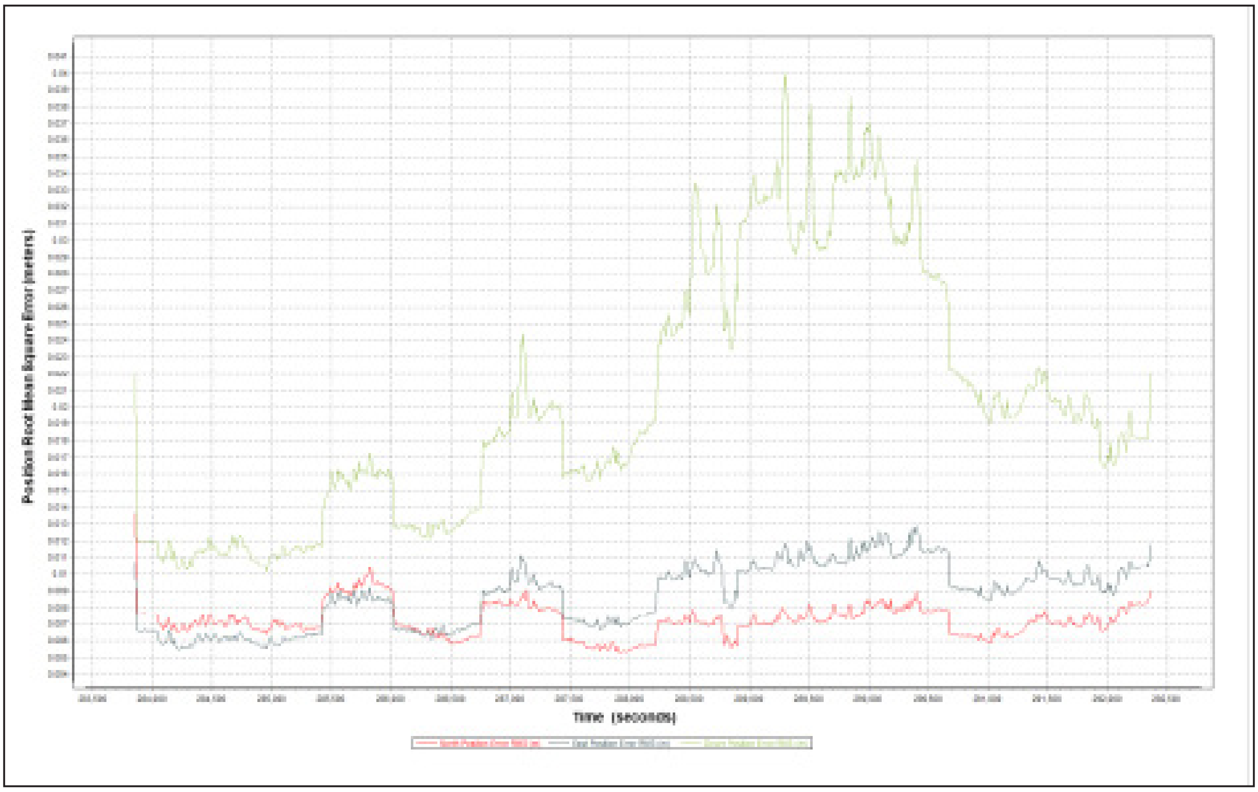

Figure 9. Smoothed Performance Metrics of Tiabanan Flight 7578G.

The time of flight was from 284000 seconds to 292500 seconds, which corresponds to morning of September 24, 2014. 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 1.00 centimeter, the East position RMSE peaks at 1.30 centimeters, and the Down position RMSE peaks at 4.00 centimeters, which are within the prescribed accuracies described in the methodology.

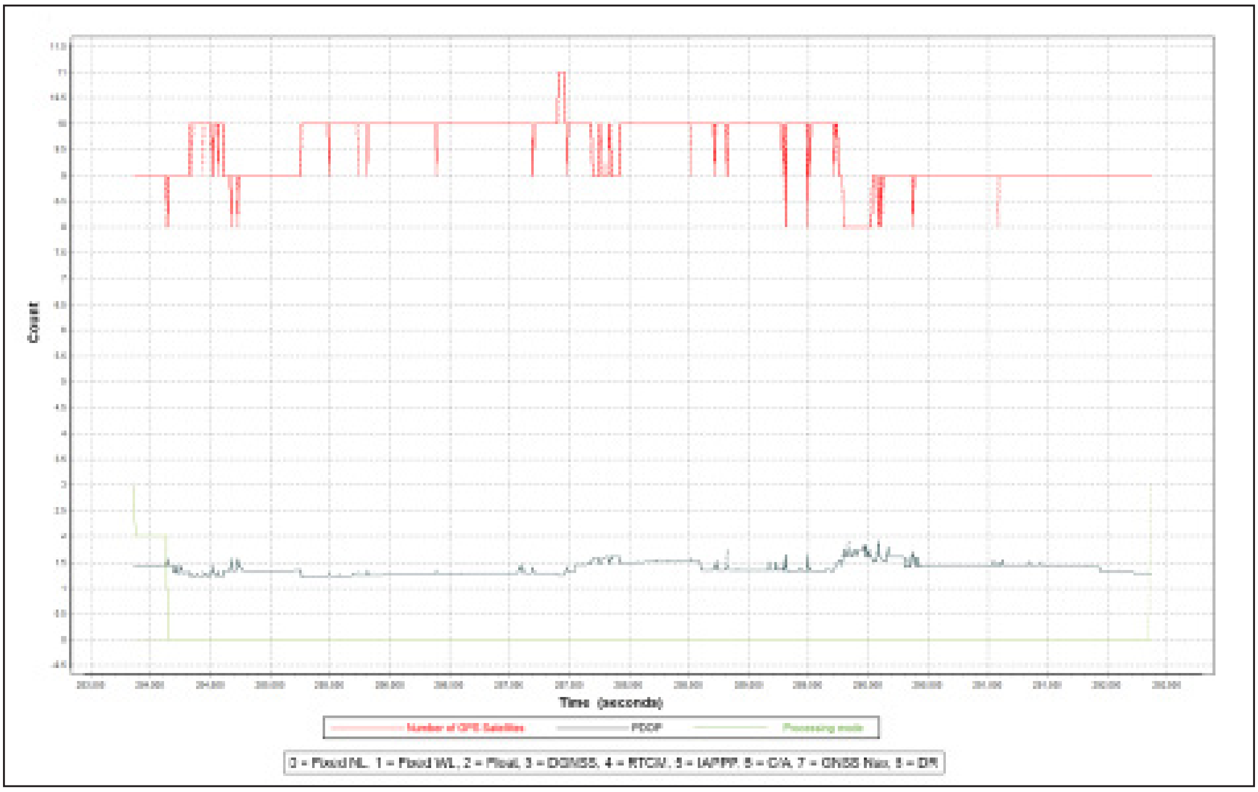

Figure 10. Solution Status Parameters of Tanjay Flight 7515G.

The Solution Status parameters of flight 7515G, one of the Tanjay flights, which indicate 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 7. Most of the time, the number of satellites tracked was between 8 and 11. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode remained at 0 for majority of the survey. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Tanjay flights is shown in Figure 11.

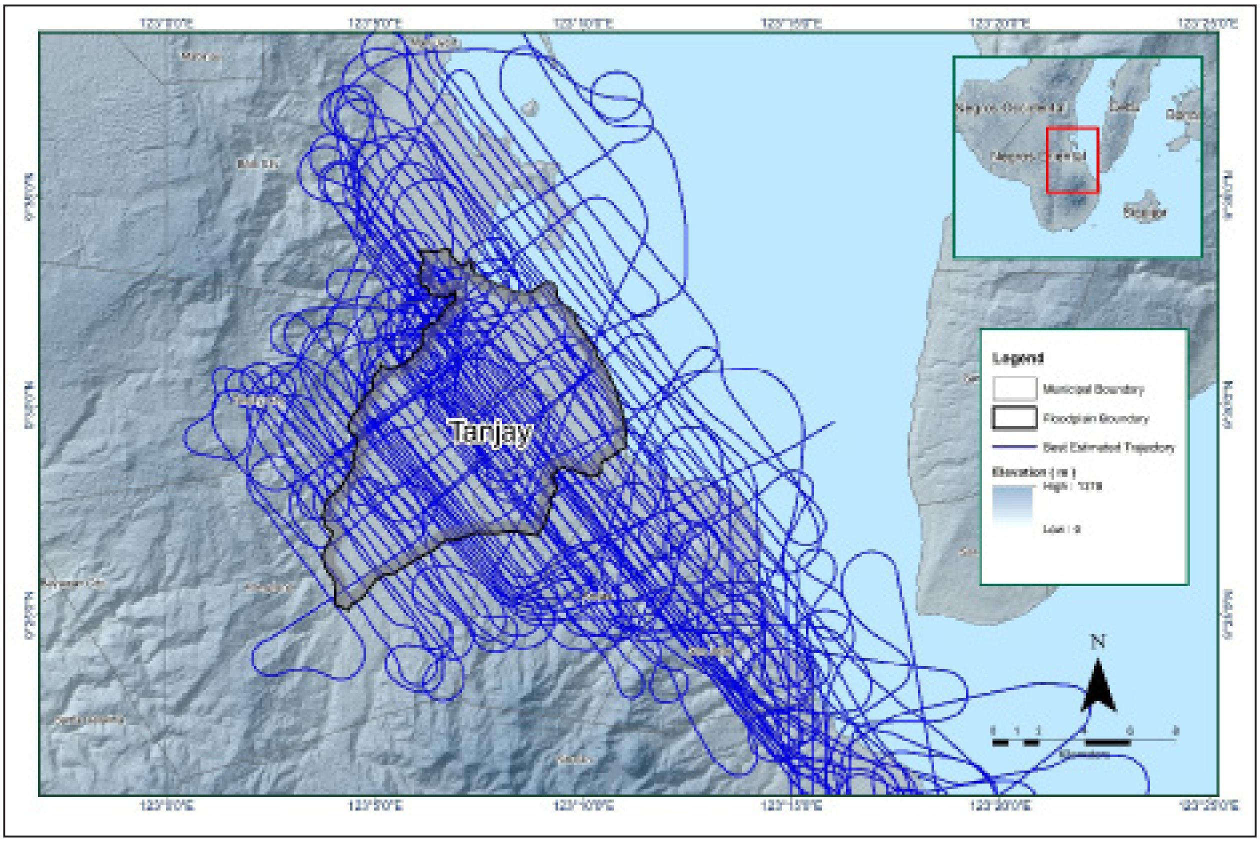

Figure 11. Best estimated trajectory for Tanjay Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 84 flight lines, with each flight line containing one channel, since the Gemini and Aquarius systems both contain one channel only. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Tanjay floodplain are given in Table 10.

Table 10. Self-Calibration Results values for Tanjay flights.

Parameter	Acceptable Value	Computed Value
Boresight Correction stdev	(<0.001degrees)	0.000592
IMU Attitude Correction Roll and Pitch Corrections stdev	(<0.001degrees)	0.000705
GPS Position Z-correction stdev	(<0.01meters)	0.0075

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

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data is shown in Figure 12. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

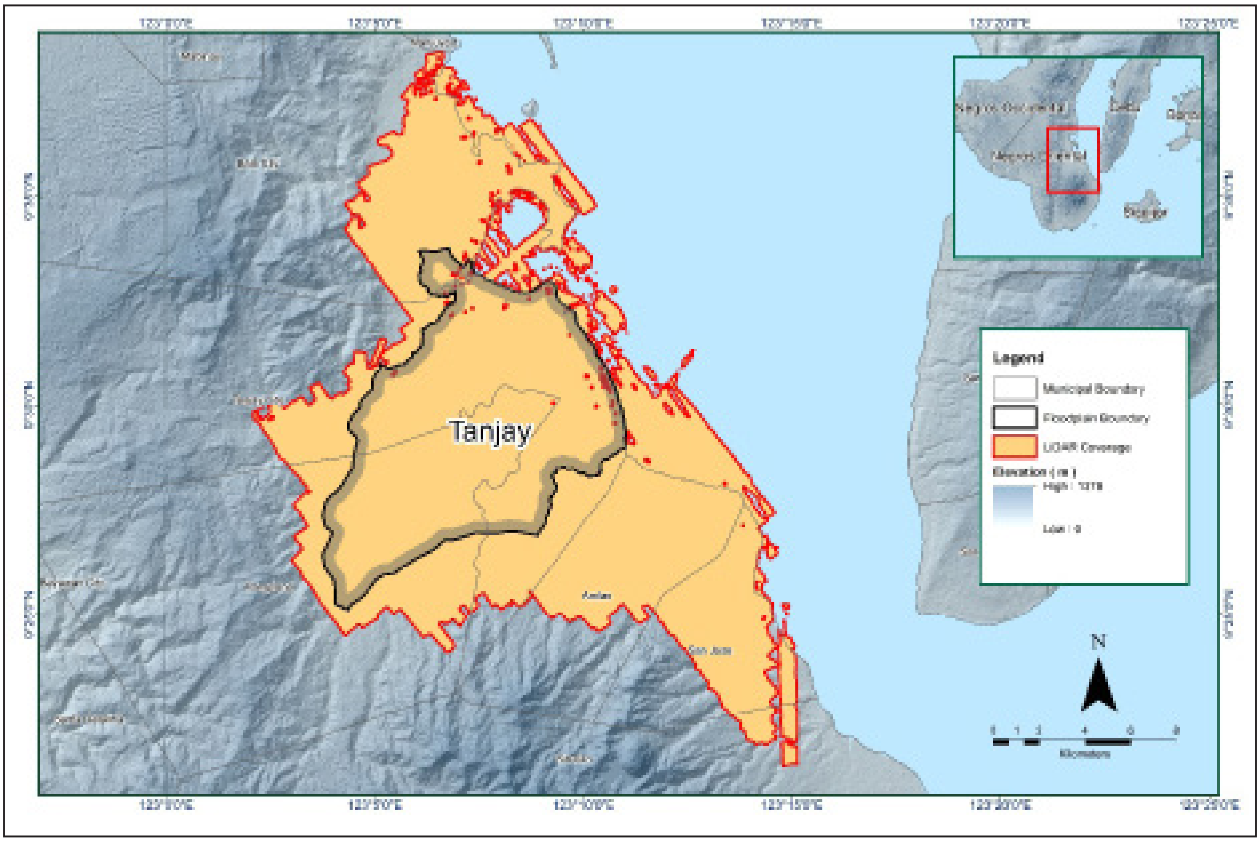

Figure 12. Boundary of the processed LiDAR dataon top of a SAR Elevation Data over Tanjay Floodplain.

The total area covered by the Tanjay missions is 462.30 sq.km that is comprised of eight (8) flight acquisitions grouped and merged into five (5) blocks as shown in Table 11.

Table 11. List of LiDAR blocks for Tanjay Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Dumaguete_Blk54B	7528G	107.54
	7530G	
	7538G	
Dumaguete_Blk54Bsupplement	7538G	42.62
Dumaguete_Blk54C	7515G	185.29
	7524G	
Dumaguete_reflights_Blk54A	10147L	101.63
Dumaguete_reflights_Blk54B	100AC	25.22
TOTAL		462.30 sq.km

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 13. Since the Gemini system employs one channel, we would expect an average value of 1 (blue) for areas where there is limited overlap, and a value of 2 (yellow) or more (red) for areas with three or more overlapping flight lines.

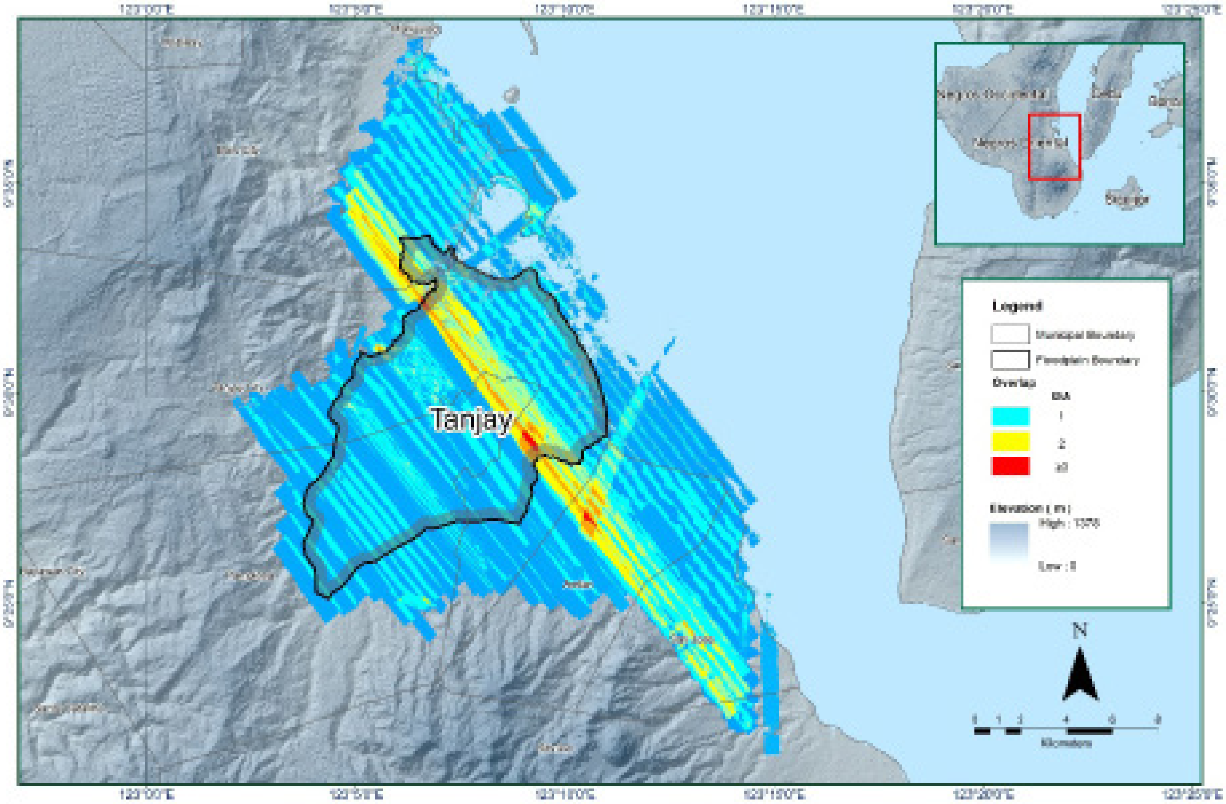

Figure 13. Image of data overlap for Tanjay Floodplain.

The overlap statistics per block for the Tanjay 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 25.93% and 38.72% respectively, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 14. It was determined that all LiDAR data for Tanjay floodplain satisfy the point density requirement, and the average density for the entire survey area is 2.29 points per square meter.

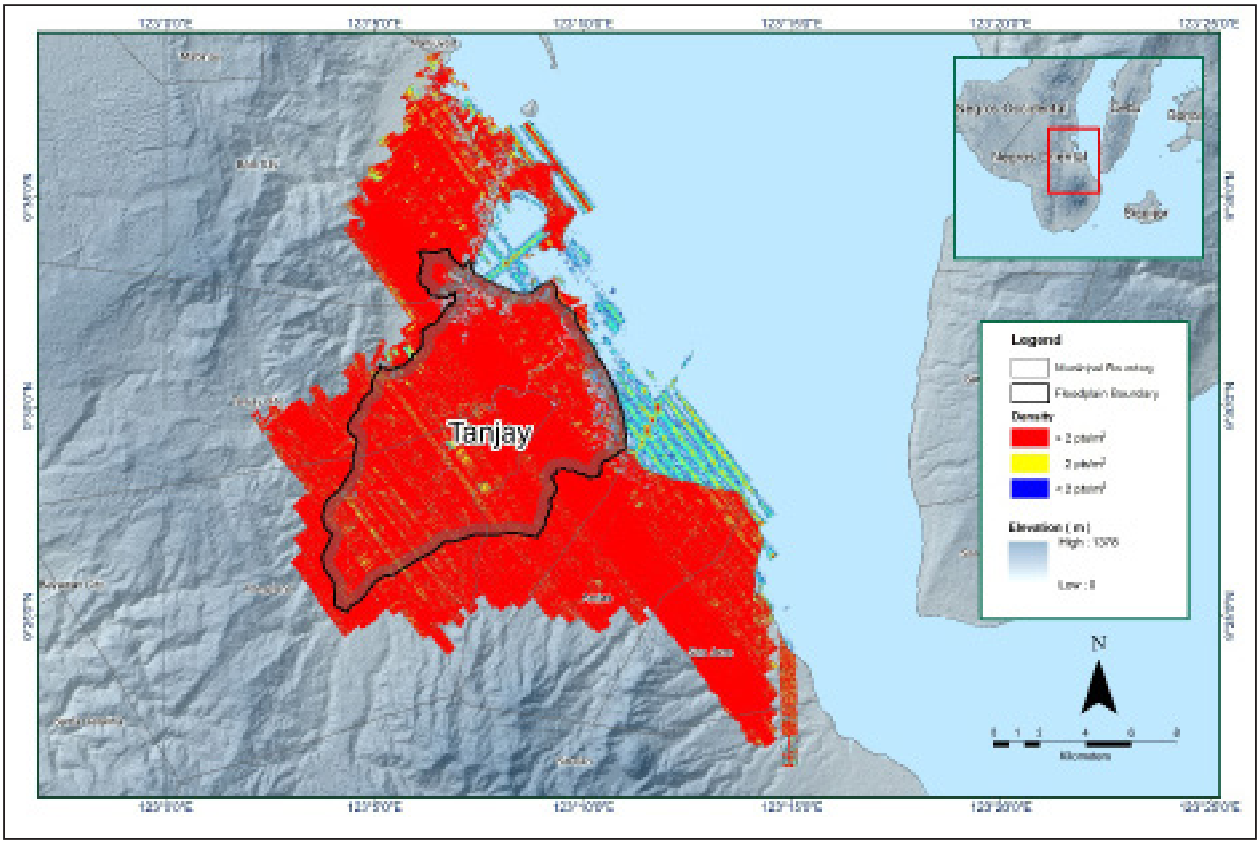

Figure 14. Pulse density map of merged LiDAR data for Tanjay Floodplain.

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.

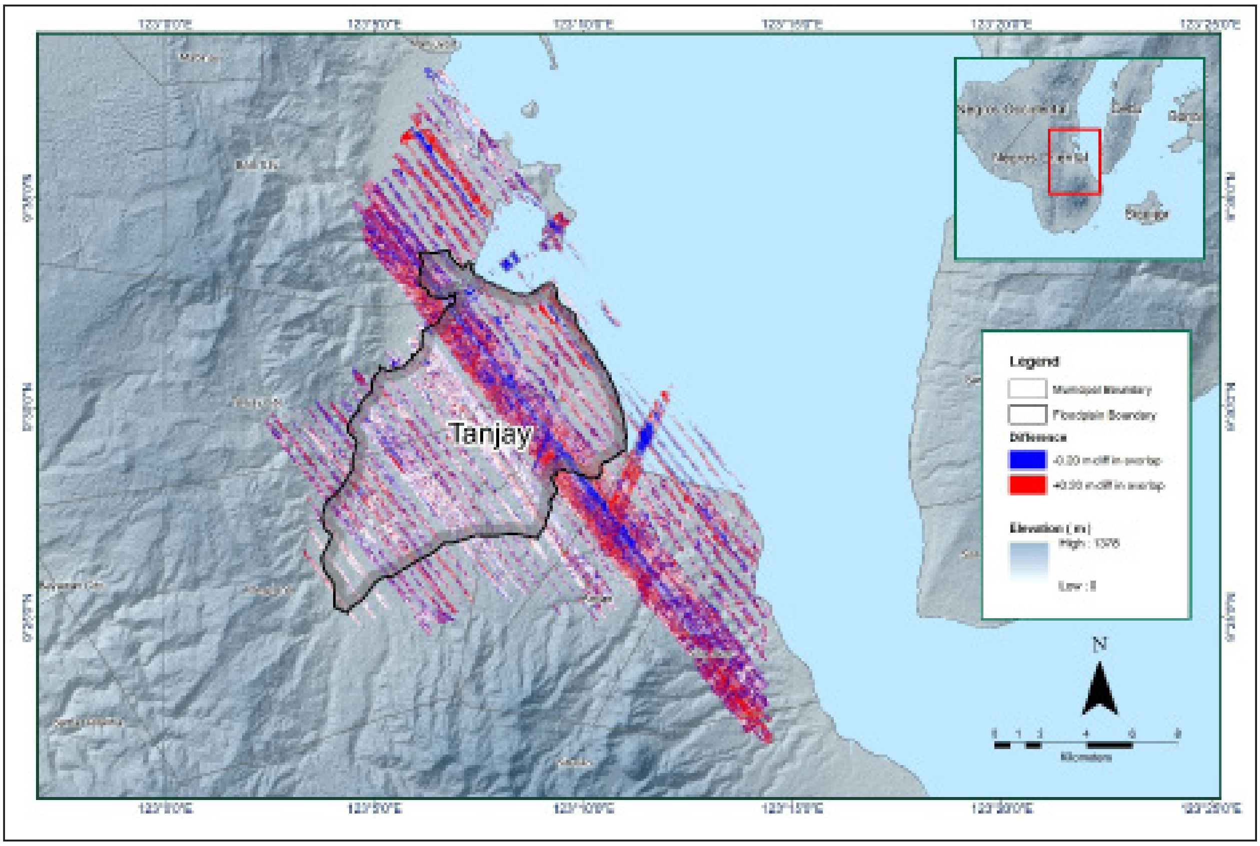

Figure 15. Elevation difference map between flight lines for Tanjay Floodplain.

A screen capture of the processed LAS data from a Tanjay flight 7515G 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 yellow 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.

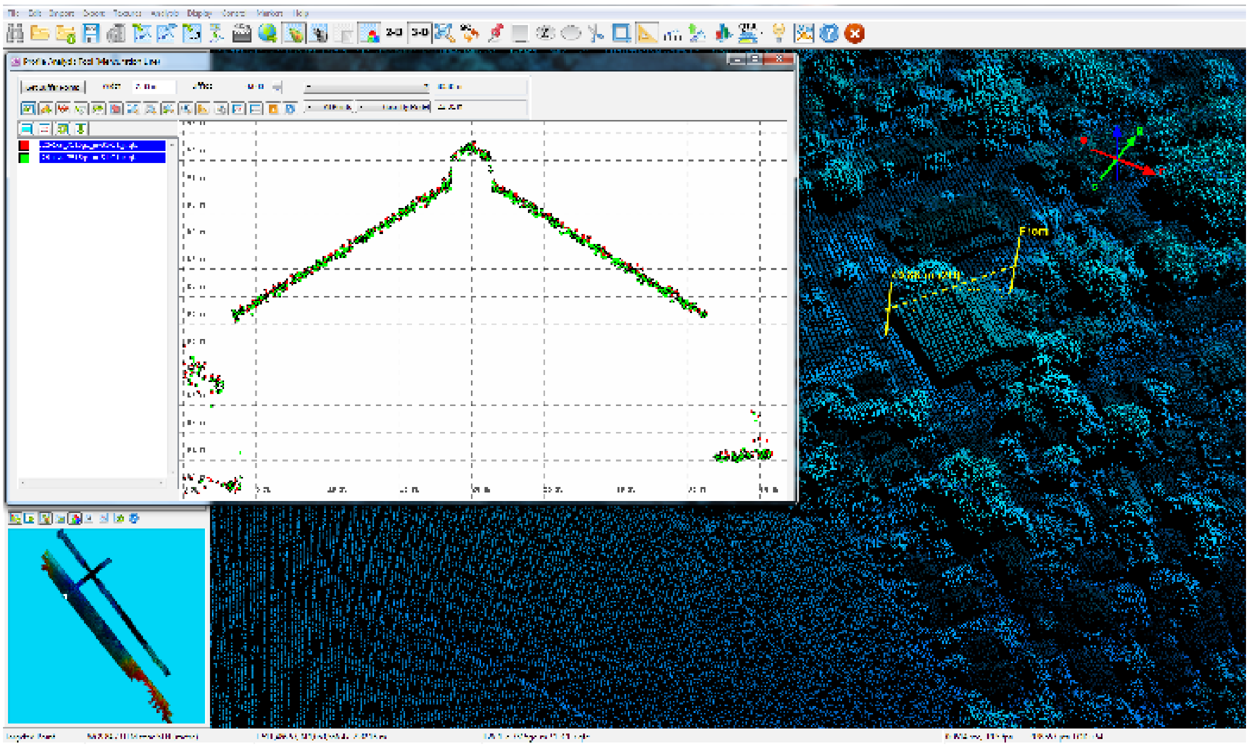

Figure 16. Quality checking for Tanjay Flight 7515G using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 12. Tanjay classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	261,635,751
Low Vegetation	235,807,011
Medium Vegetation	816,870,686
High Vegetation	532,027,546
Building	12,868,099

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Tanjay floodplain is shown in Figure 17. A total of 778 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 12. The point cloud has a maximum and minimum height of 569.20 meters and 55.00 meters respectively.

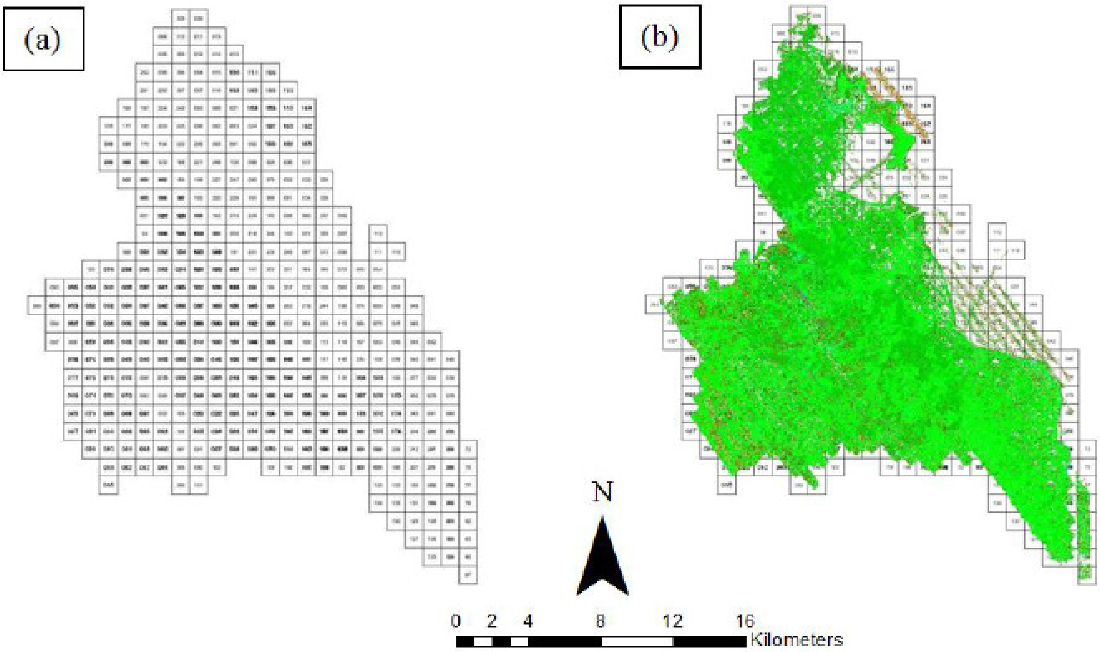

Figure 17. Tiles for Tanjay Floodplain (a) and classification results (b) in TerraScan.

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.

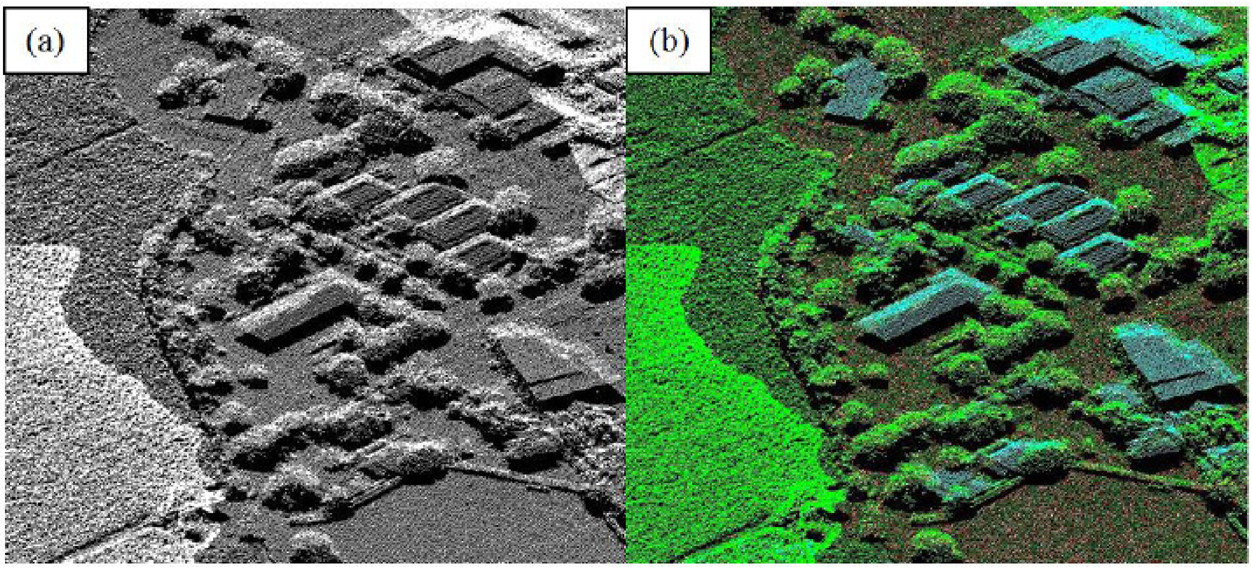

Figure 18. Point cloud before (a) and after (b) classification.

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.

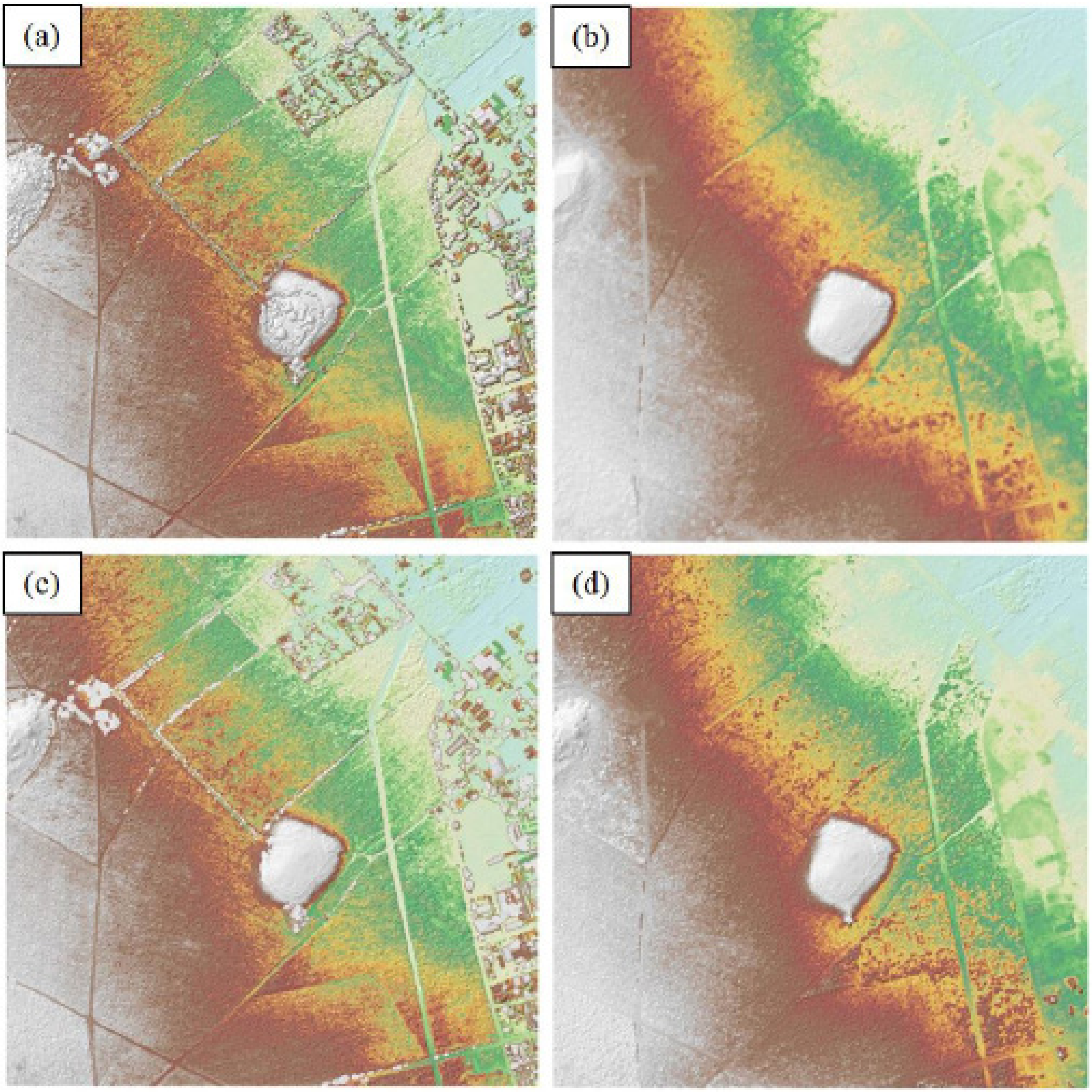

Figure 19. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Tanjay Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 172 1km by 1km tiles area covered by Tanjay floodplain is shown in Figure Figure 20. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Tanjay floodplain has a total of 107.12 sq.km orthophotogaph coverage comprised of 870 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 21.

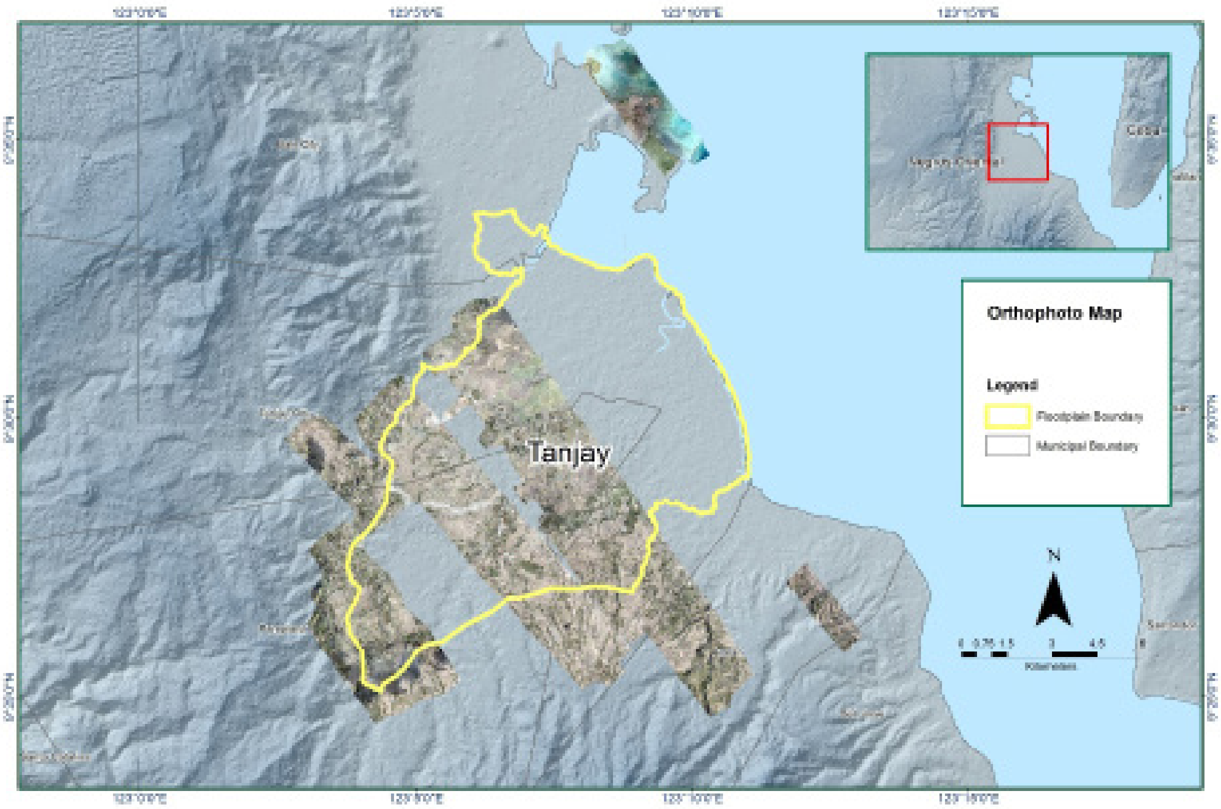

Figure 20. Tanjay Floodplain with available orthophotographs.

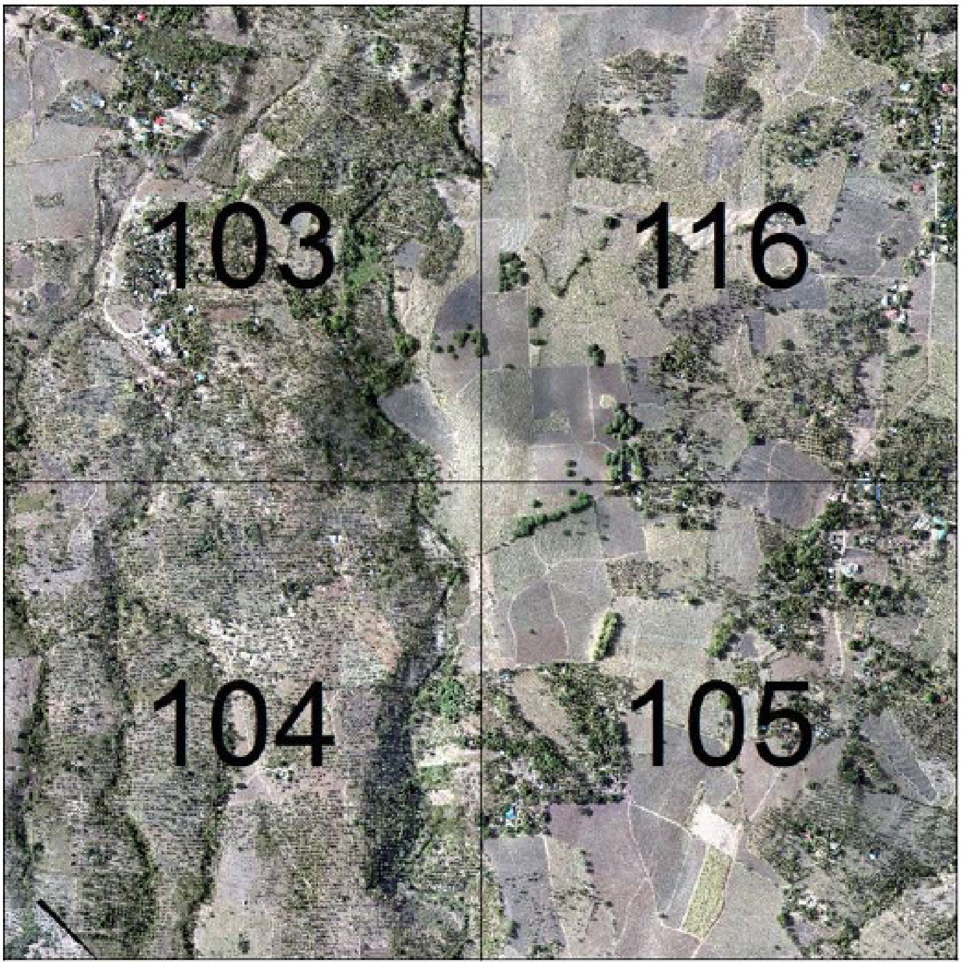

Figure 21. Sample orthophotograph tiles for Tanjay Floodplain.

3.8 DEM Editing and Hydro-Correction

Five (5) mission blocks was processed for Tanjay flood plain. This block is from Dumaguete flight with an area of 462.30 square kilometers. Table 13 shows the name and corresponding area of each block in square kilometers.

Table 13. LiDAR blocks with its corresponding area.

LiDAR Blocks	Area (sq.km)
Dumaguete_Blk54B	107.54
Dumaguete_Blk54Bsupplement	42.62
Dumaguete_Blk54C	185.29
Dumaguete_reflights_Blk54A	101.63
Dumaguete_reflights_Blk54B	25.22
TOTAL	462.30 sq.km

Portions of DTM before and after manual editing are shown in Figure 22. Portions of the DTM of Tanjay with creeks were edited (Figure 22a and Figure 22b). Another is the bridge (Figure 22c) is also considered to be an impedance to the flow of water and has to be removed (Figure 22d) in order to hydrologically correct the river. These are shown in the figure below.

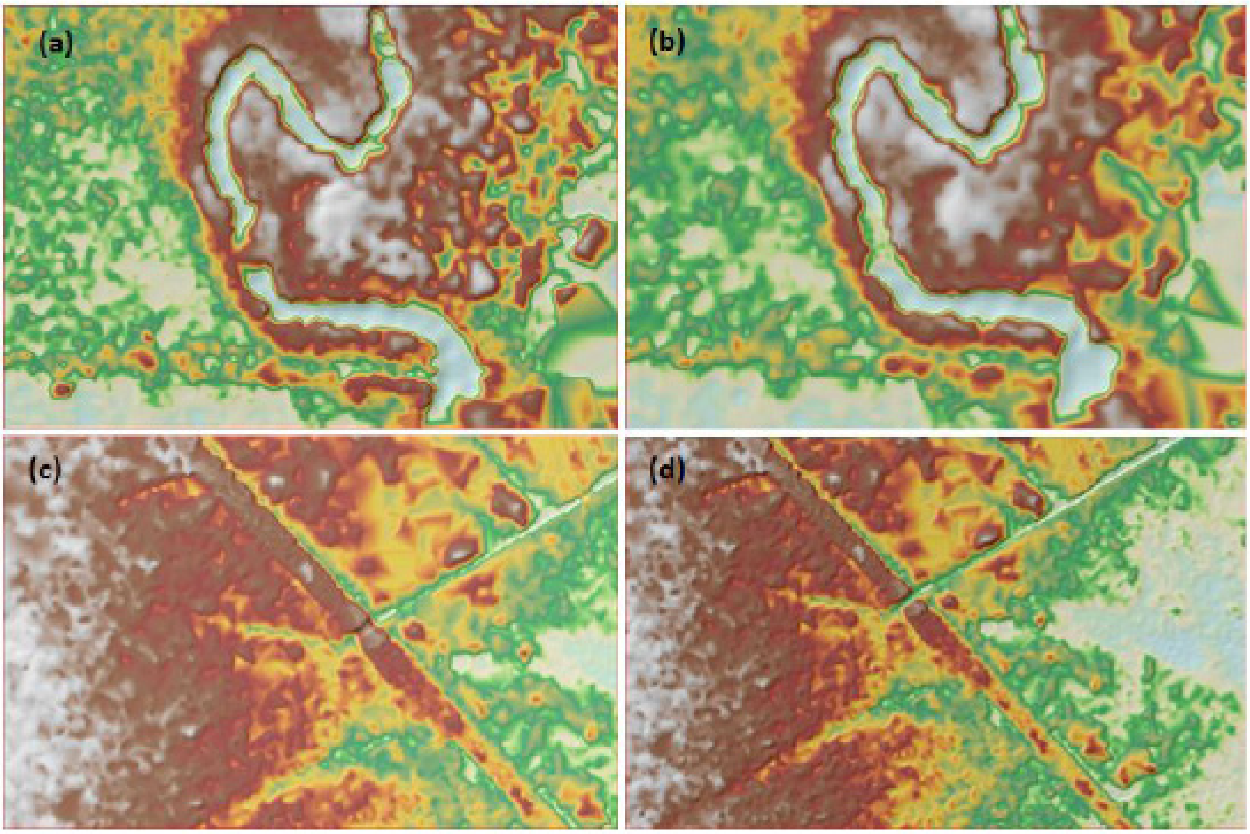

Figure 22. Portions in the DTM of Tanjay Floodplain – (a) before and (b) after editing; (c) before and (d) after bridge removal.

3.9 Mosaicking of Blocks

Dumaguete_Blk54B_supplement was used as the reference block in mosaicking due to the presence of more built up areas. Table 14 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Tanjay floodplain shown in Figure 23. It can be seen that the entire Tanjay floodplain is 90% covered by LiDAR data.

Table 14. Shift Values of each LiDAR Block of Tanjay Floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
Dumaguete_Blk54B	0.00	0.00	0.10
Dumaguete_Blk54B_supplement	0.00	0.00	0.00
Dumaguete_Blk54C	0.00	0.00	0.18
Dumaguete_reflights_Blk54A	0.00	0.00	0.74
Dumaguete_reflights_Blk54B	0.00	0.00	0.46

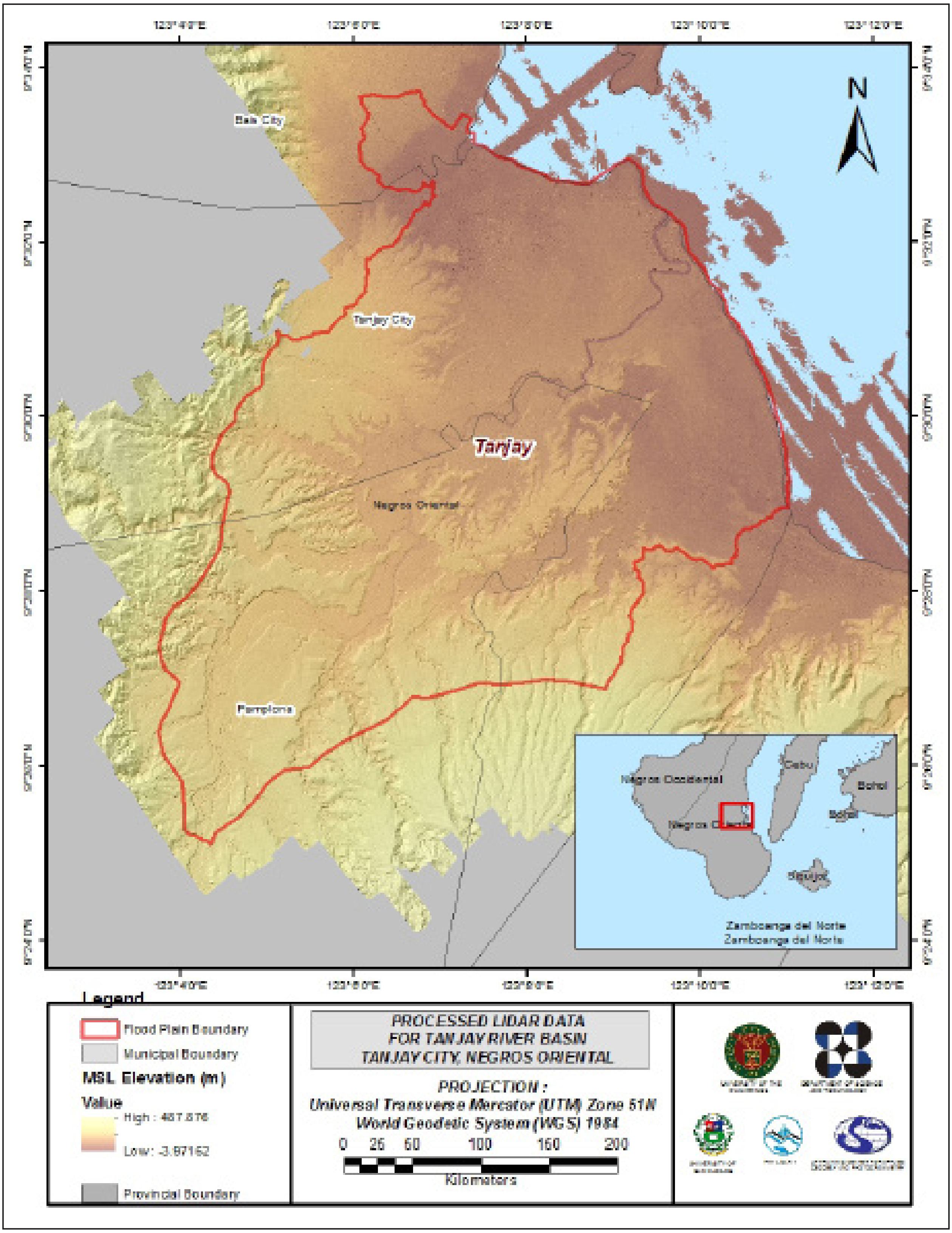

Figure 23. Map of Processed LiDAR Data for Tanjay Floodplain.

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 Tanjay to collect points with which the LiDAR dataset is validated is shown in Figure 24. A total of 14,047 survey points were gathered for all the flood plains within the provinces of Negros Oriental and Negros Occidental wherein the Tanjay floodplain is located. Random selection of 80% of the survey points, resulting to 11,237 points, was used for calibration.

A good correlation between the uncalibrated mosaicked LiDAR DTM and 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 points is 0.35 meters with a standard deviation of 0.18 meters. Calibration of the LiDAR data was done by subtracting the height difference value, 0.35 meters, to the mosaicked LiDAR data. Table 15 shows the statistical values of the compared elevation values between the LiDAR data and calibration data.

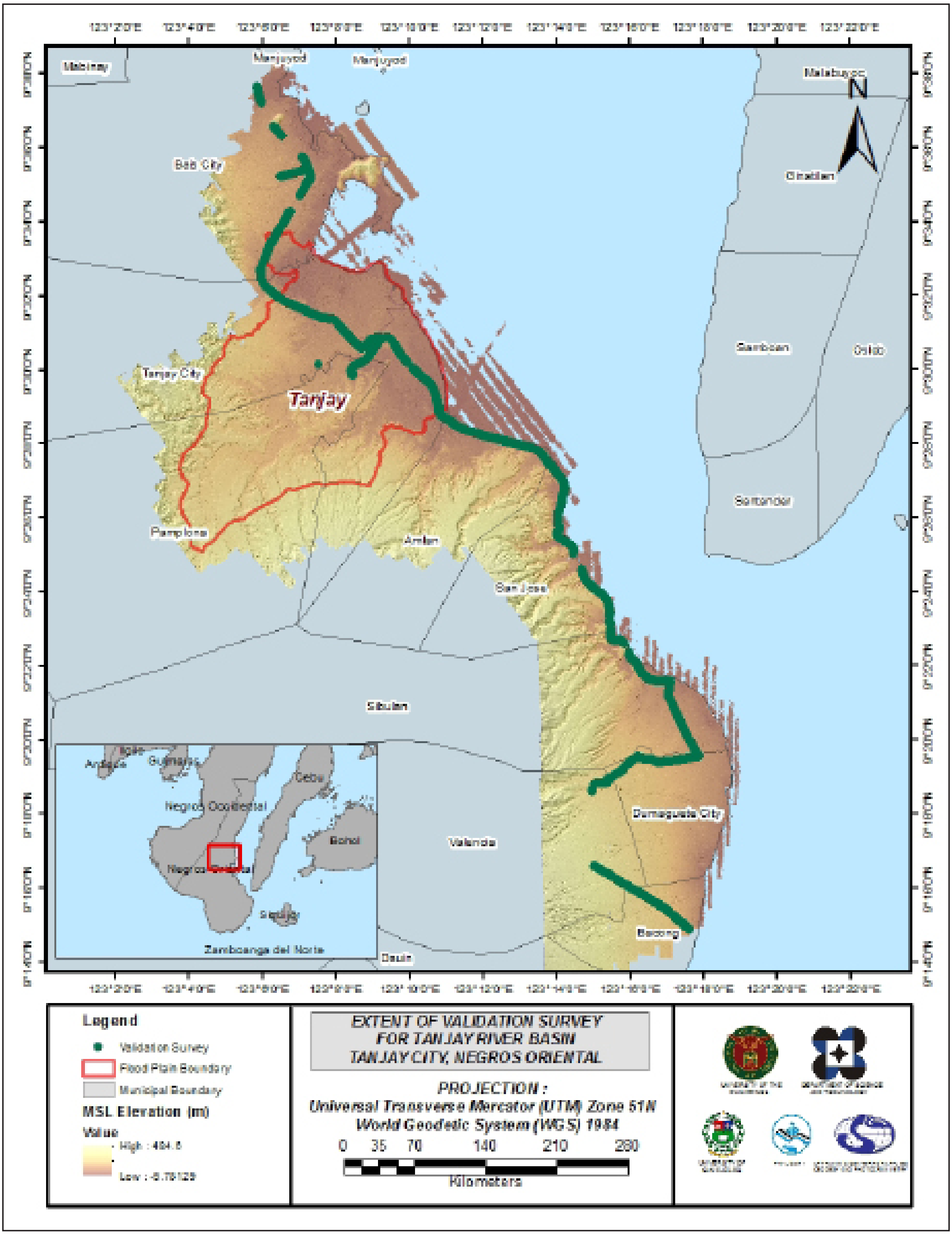

Figure 24. Map of Tanjay Floodplain with validation survey points in green.

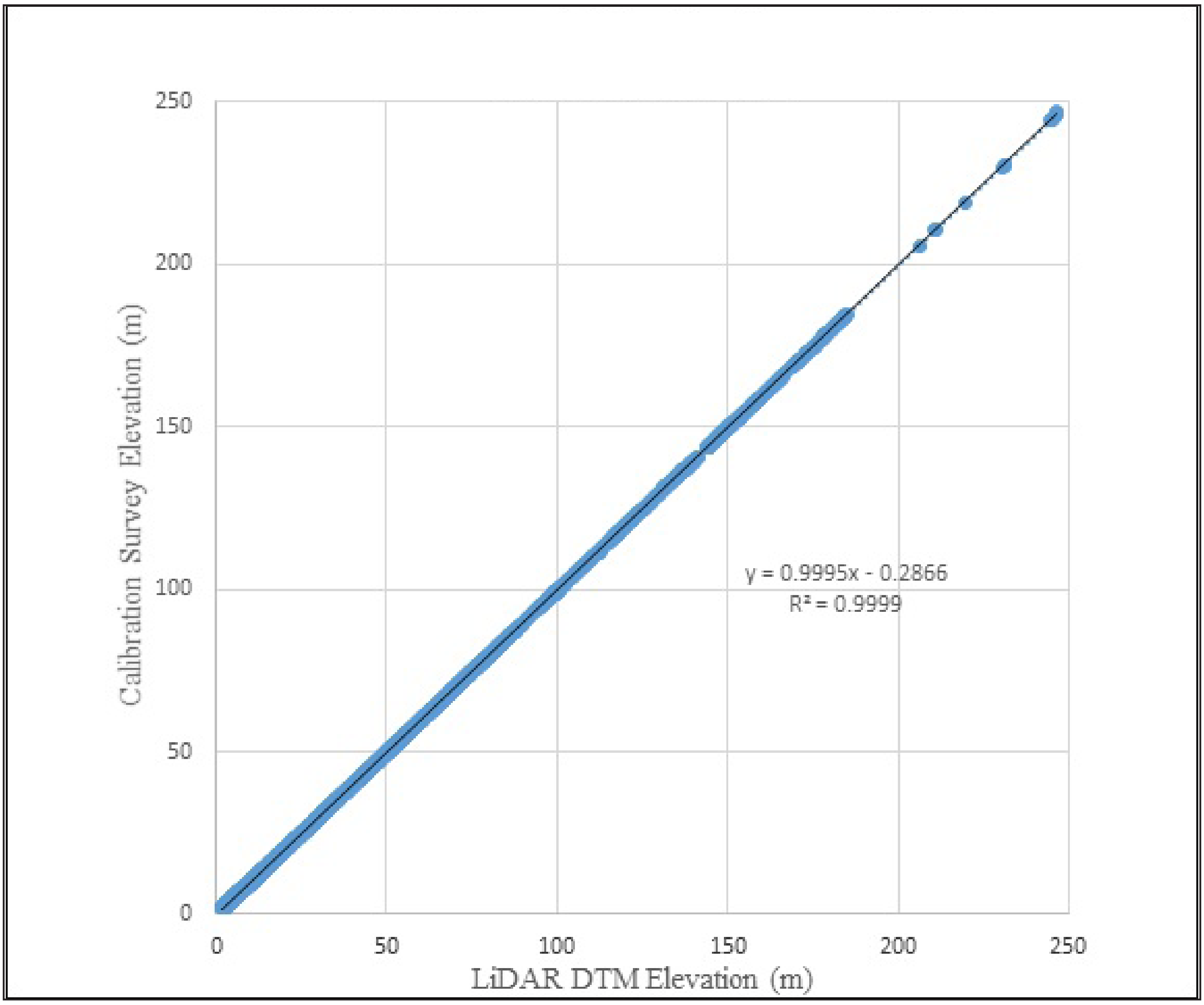

Figure 25. Correlation plot between calibration survey points and LiDAR data.

Table 15. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	0.35
Standard Deviation	0.18
Average	-2.30
Minimum	-0.57
Maximum	0.30

The remaining 20% of the total survey points were intersected to the flood plain, resulting to 138 points, were used for the validation of calibrated Tanjay 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 0.17 meters with a standard deviation of 0.17 meters, as shown in Table 16.

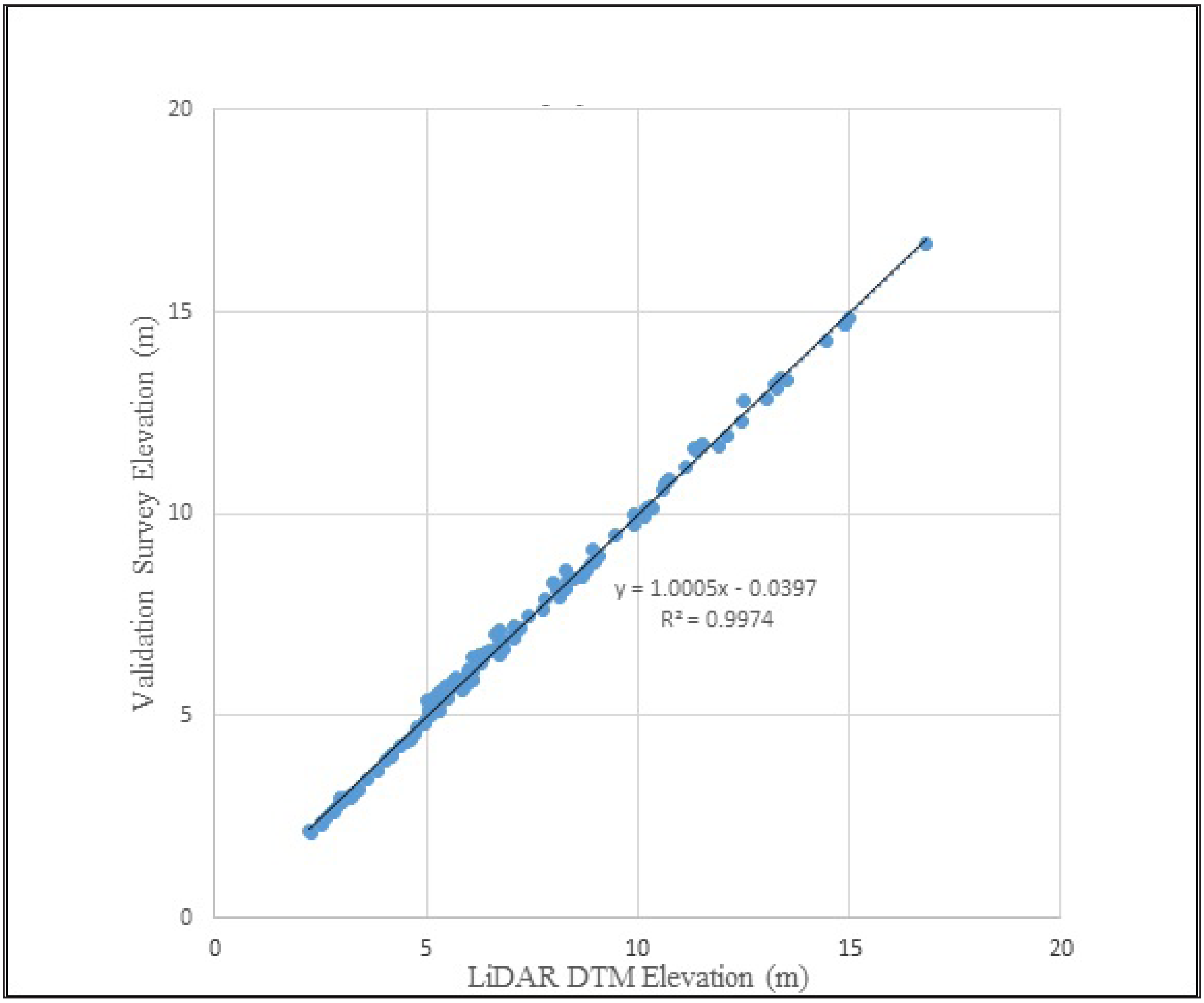

Figure 26. Correlation plot between validation survey points and LiDAR data.

Table 16. Validation Statistical Measures.

Validation Statistical Measures	Value (meters)
RMSE	0.17
Standard Deviation	0.17
Average	-0.04
Minimum	-0.22
Maximum	0.39

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and zigzag data were available for Tanjay with 3,383 bathymetric survey points. The resulting raster surface produced was done by Inverse Distance Weighted interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.0927 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Tanjay integrated with the processed LiDAR DEM is shown in Figure 27.

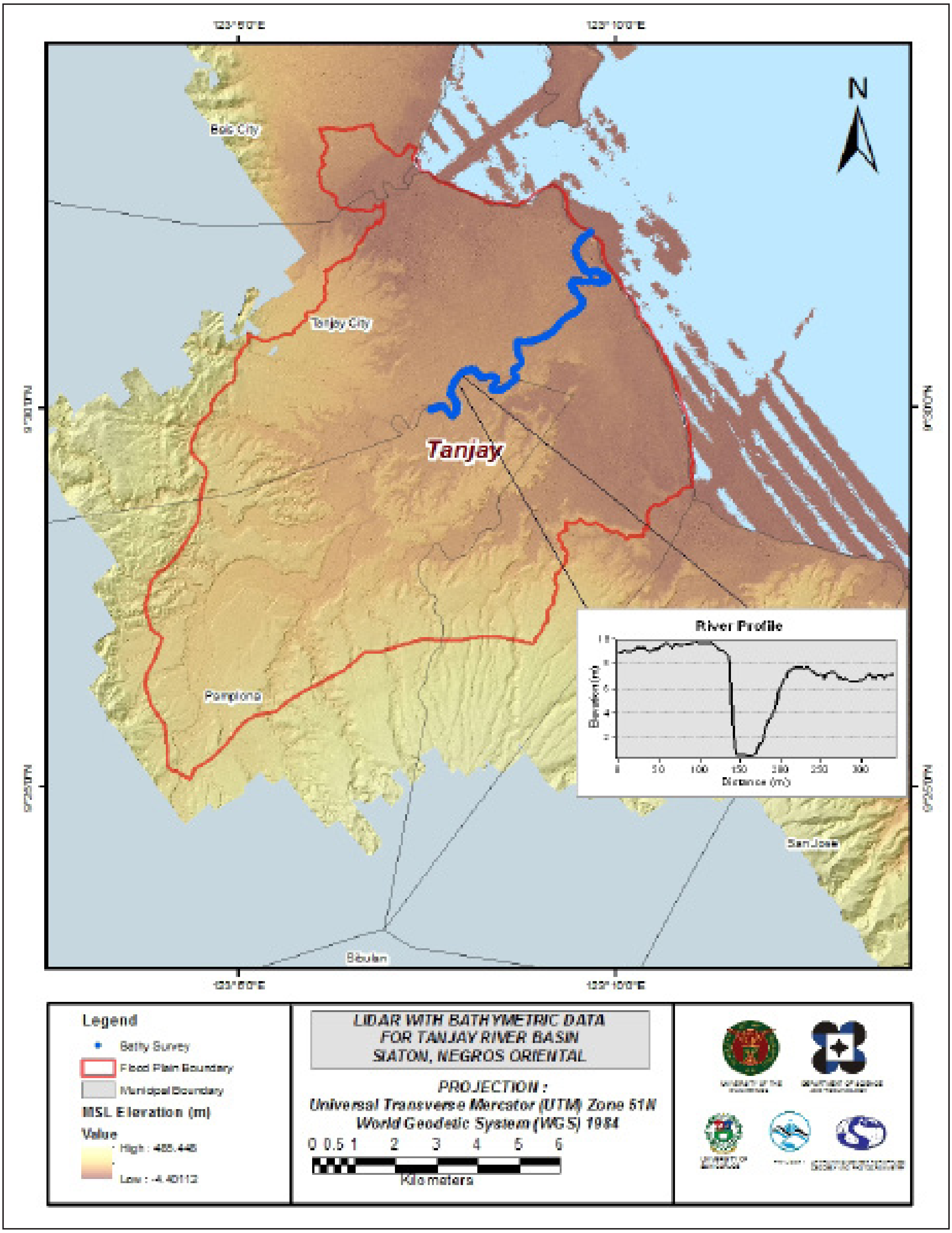

Figure 27. Map of Tanjay Floodplain with bathymetric survey points shown in blue.

3.12 Feature Extraction

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

3.12.1 Quality Checking (QC) of Digitized Features' Boundary

Tanjay floodplain, including its 200 m buffer, has a total area of 125.34 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 1,962 building features, are considered for QC. Figure 28 shows the QC blocks for Tanjay floodplain.

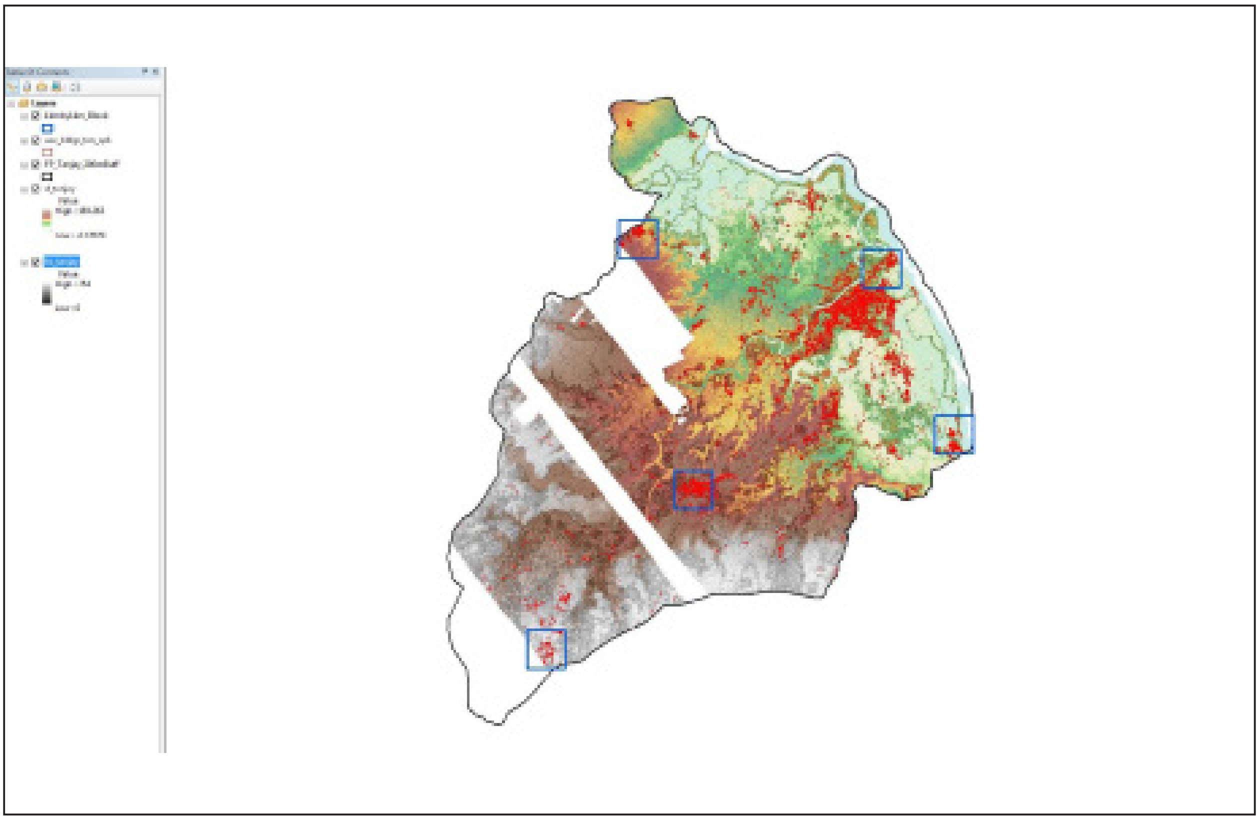

Figure 28. QC blocks for Tanjay building features.

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

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

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Tanjay	99.34	99.49	92.46	PASSED

3.12.2 Height Extraction

Height extraction was done for 12,050 building features in Tanjay floodplain. Of these building features, 246 were filtered out after height extraction, resulting to 11,804 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 12.48 m.

3.12.3 Feature Attribution

In attribution, combination of participatory mapping and actual field validation was done. Representatives from LGU were invited to assist in the determination of the features. The remaining unidentified features were then validated on the field.

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

Table 18. Building Features Extracted for Tanjay Floodplain.

Facility Type	No. of Features
Residential	11,352
School	120
Market	11
Agricultural/Agro-Industrial Facilities	40
Medical Institutions	8
Barangay Hall	16
Military Institution	2
Sports Center/Gymnasium/Covered Court	11
Telecommunication Facilities	3
Transport Terminal	0
Warehouse	23
Power Plant/Substation	2
NGO/CSO Offices	1
Police Station	0
Water Supply/Sewerage	0
Religious Institutions	30
Bank	5
Factory	0
Gas Station	8
Fire Station	0
Other Government Offices	17
Other Commercial Establishments	154
Total	**11,804**

Table 19. Total Length of Extracted Roads for Tanjay Floodplain.

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Tanjay	56.35	24.04	18.56	12.55	0.00	111.50

Table 20. Number of Extracted Water Bodies for Tanjay Floodplain.

Floodplain	Water Body Type					Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Tanjay	5	0	0	0	0	5

A total of 11 bridges and culverts over small channels that are part of the river network were also extracted for the floodplain.

3.12.4 Final Quality Checking of Extracted Features

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

Figure 25 shows the Digital Surface Model (DSM) of Tanjay floodplain overlaid with its ground features.

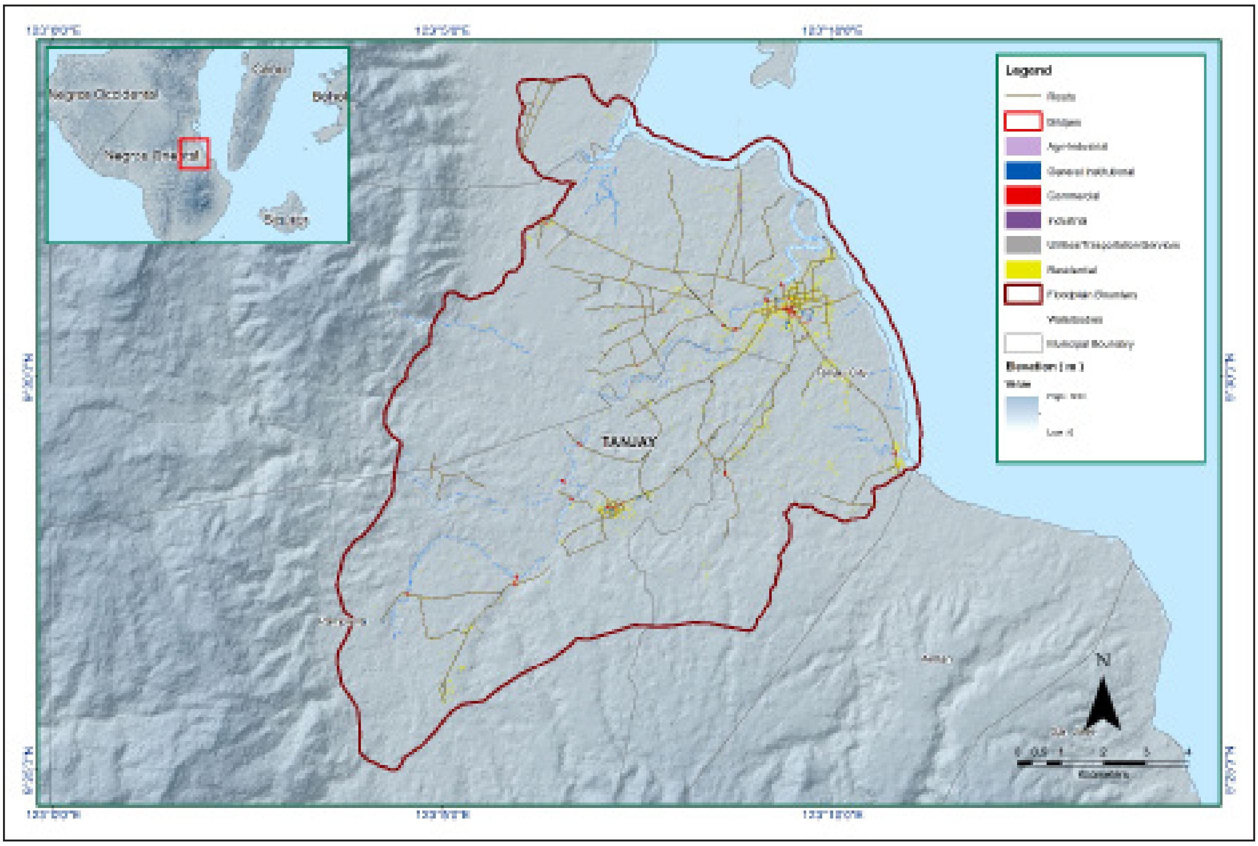

Figure 29. Extracted features for Tanjay Floodplain.

CHAPTER 4: DATA VALIDATION SURVEY AND MEASUREMENTS IN THE TANJAY RIVER BASIN

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

4.1 Summary of Activities

The Data Validation and Bathymetry Component (DVBC) conducted field survey in Tanjay River on January 26 – February 10, 2016 with the following scope of work: reconnaissance; control survey for the establishment of a control point; cross-section survey in Barangay Malalangsi, Pamplona, Negros Oriental for AWLS deployment; LiDAR Validation of about 84 km; and bathymetric survey from Brgy. Novallas down to the mouth of the river in Brgy. San Isidro, both in the City of Tanjay with an approximate length of 10.40 km using Ohmex™ Single Beam Echo Sounder and Trimble® SPS 852 GNSS PPK survey technique as shown in Figure 30.

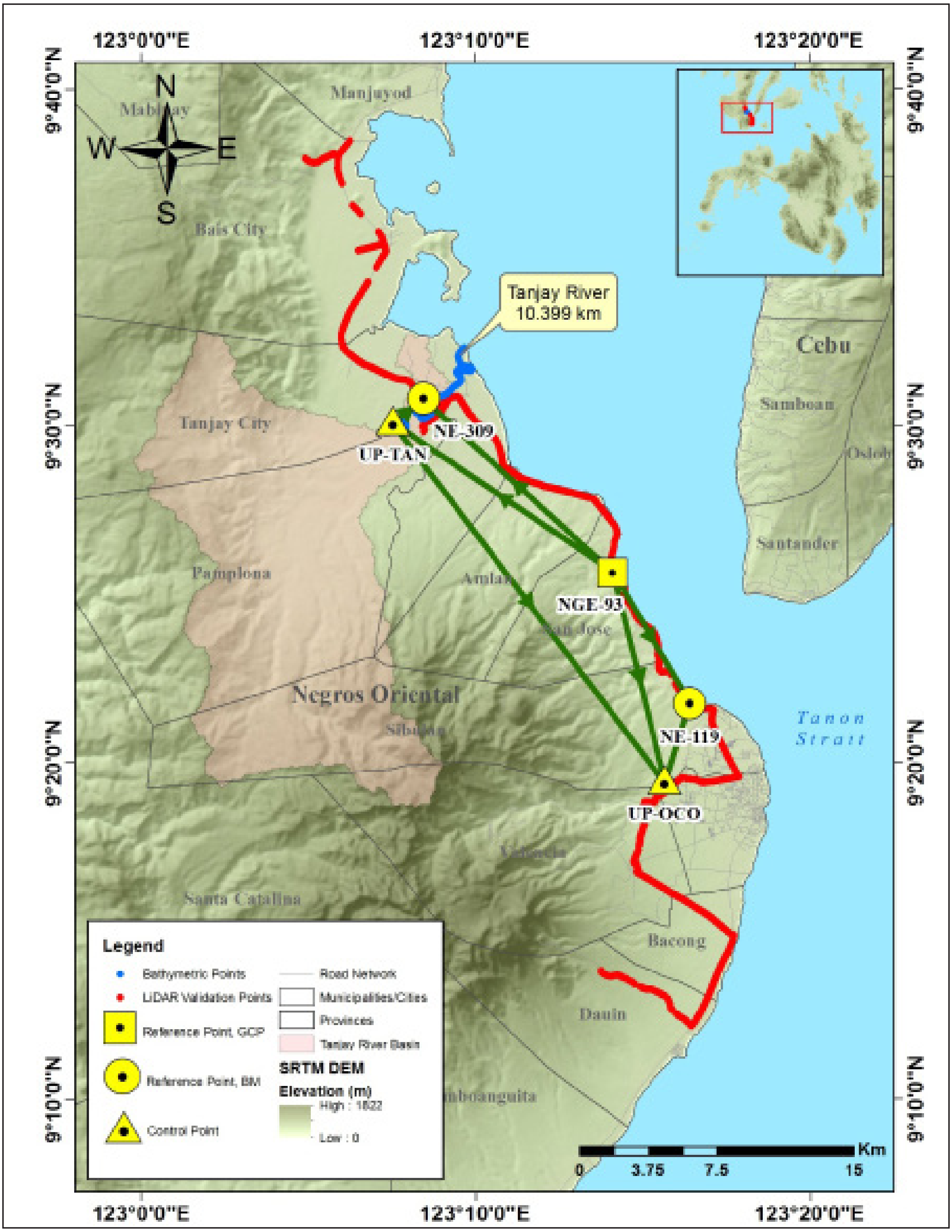

Figure 30. Tanjay River Survey Extent

4.2 Control Survey

The GNSS network used for Tanjay River Basin is composed of three (3) loops established on February 1, 2016 occupying the following reference points: NE-119, a first-order BM, in Brgy. Campaclan, Municipality of Sibulan; and NGE-93, a second-order GCP, in Brgy. Jilocon, Municipality of San Jose.

A NAMRIA control point, NE-309 located in Brgy. San Jose, Tanjay City, was also occupied and used as a marker alongside with another two (2) control points that were established in the area: UP-TAN in Brgy. Novallas, City of Tanjay and UP-OCO in Brgy. Calabnugn, Municipality of Sibulan.

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

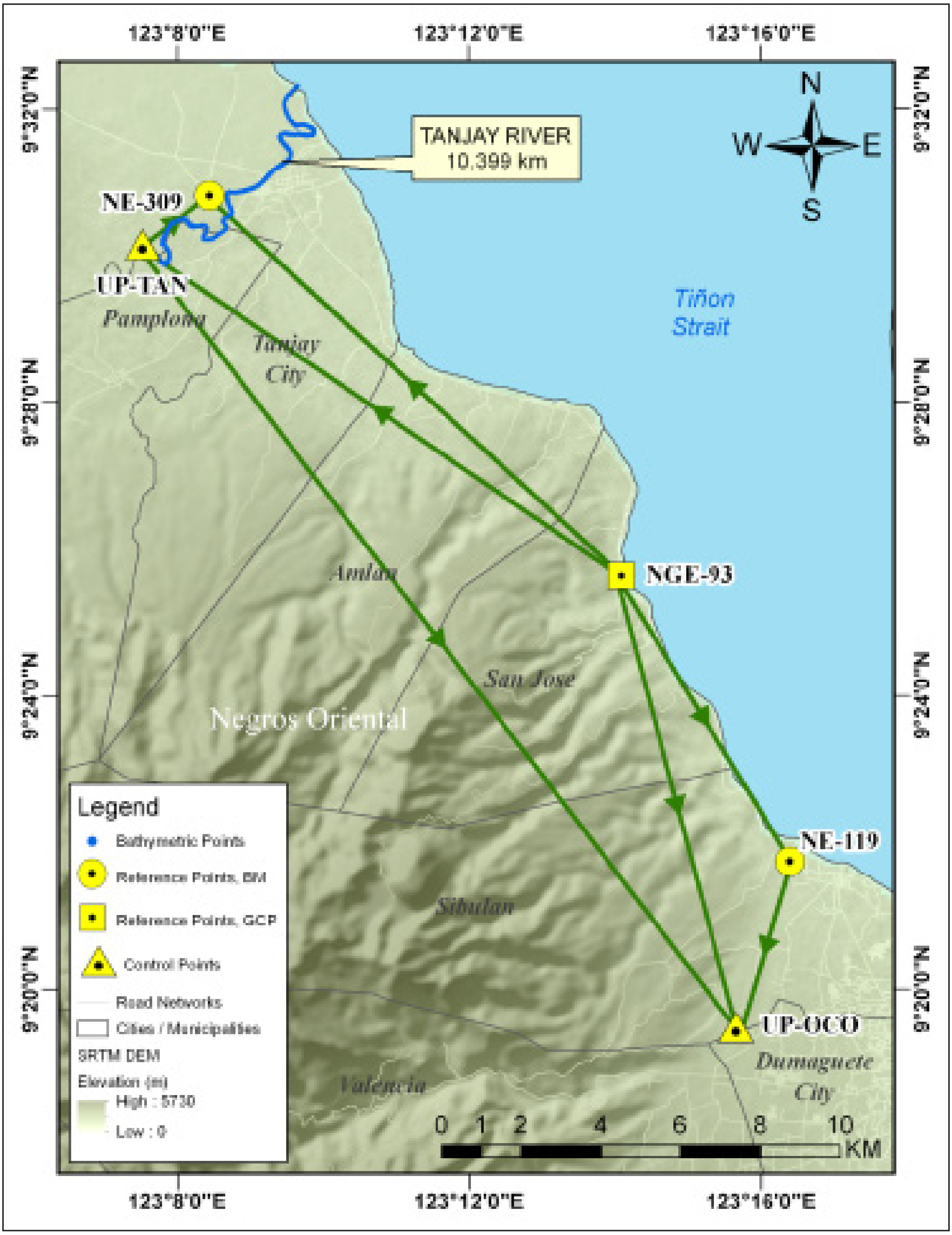

Figure 31. GNSS Network of Tanjay River field survey

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

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (Meter)	Elevation in MSL (Meter)	Date Established
NE-119	1st order, BM	-	-	71.085	7.414	2008
NGE-93	2nd order, GCP	9°25'38.28279"	123°14'05.68141"	66.238	-	2007
NE-309	Used as Marker	-	-	-	-	2008
UP-TAN	Established	-	-	-	-	February 2016
UP-OCO	Established	-	-	-	-	February 2016

The GNSS set up made in the location of the reference and control points are exhibited are shown in Figure 32 to Figure 36.

Figure 32. GNSS receiver setup, Trimble® SPS 882, at NE-119 at the approach of Ocoy Bridge in Brgy. Campaclan, Municipality of Sibulan, Negros Oriental

Figure 33. GNSS receiver set-up, Trimble® SPS 852, at NGE-93 in Brgy. Jilocon, Municipality of San Jose, Negros Oriental

Figure 34. GNSS base set up, Trimble® SPS 855, at NE-309, a BM used as a marker, located on top of a rock along Western Nautical Highway in Brgy. San Jose, City of Tanjay, Negros Oriental

Figure 35. GNSS receiver set up, Trimble® SPS 855, at UP-TAN, an established control point located in Brgy. Novallas, Tanjay City, Negros Oriental

Figure 36. GNSS receiver set-up, Trimble® SPS 882 at control point UP-OCO near the abutment of Sibulan Bridge Brgy. Calabnugan, Municipality of Sibulan, Negros Oriental

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 Tanjay River Basin is summarized in Table 22 generated by TBC software.

Table 22. Baseline Processing Report for Tanjay 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)
NGE-93 --- NE-119 (B18)	02-01-2016	Fixed	0.006	0.016	149°32'32"	8342.974	4.857
NGE-93 --- UP-TAN (B20)	02-01-2016	Fixed	0.004	0.012	304°44'59"	14612.993	8.626
NGE-93 --- NE-309 (B19)	02-01-2016	Fixed	0.005	0.015	312°46'57"	14070.135	3.586
NGE-93 --- UP-OCO (B17)	02-01-2016	Fixed	0.004	0.014	165°50'22"	11697.257	50.653
NE-119 --- UP-OCO (B14)	02-01-2016	Fixed	0.008	0.022	198°14'36"	4369.643	45.844
UP-TAN --- NE-309 (B7)	02-01-2016	Fixed	0.004	0.015	53°50'00"	2080.683	-5.061
UP-TAN --- UPOCO (B16)	02-01-2016	Fixed	0.005	0.018	142°53'54"	24658.100	42.034

As shown in Table 22, a total of seven (7) baselines were processed and all of them passed the required accuracy set by the project.

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 23 to Table 25 for the complete details.

The five (5) control points, NE-119, NGE-93, NE-309, UP-TAN and UP-OCO were occupied and observed simultaneously to form a GNSS loop. Elevation value of NE-119 and coordinates of point NGE-93 were held fixed during the processing of the control points as presented in Table 23. Through these reference points, the coordinates and elevation of the unknown control points will be computed.

Table 23. Control Point Constraints

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
NE-119	Grid				Fixed
NGE-93	Local	Fixed	Fixed		
Fixed = 0.000001(Meter)					

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 24. The fixed control points NE-119 and NGE-93 have no values for elevation error and grid errors, respectively.

Table 24. Adjusted Grid Coordinates

Point ID	Easting	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
NE-119	530021.363	0.018	1034916.542	0.009	7.414	?	e
NGE-93	525789.116	?	1042102.575	?	2.470	0.063	LL
NE-309	515460.124	0.014	1051648.501	0.007	6.010	0.082	
UP-TAN	513781.484	0.011	1050420.498	0.006	11.014	0.075	
UP-OCO	528657.161	0.012	1030767.083	0.008	53.120	0.070	

The network is fixed at reference point NGE-93 with known coordinates, and NE-119 with known elevation. As shown in Table 24, the standard errors (xe and ye) of NE-119 are 1.80 cm and 0.90 cm; NE-309 with 1.40 cm and 0.70 cm; UP-TAN with 1.10 cm and 0.60 cm; and UP-OCO with 1.20 and 0.80 cm, respectively.

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

a. NE-119

horizontal accuracy	=	√((1.80)² + (0.90)²
	=	√ (3.24 + 0.81)
	=	2.01 cm < 20 cm
vertical accuracy	=	Fixed

b. NGE-93

horizontal accuracy	=	Fixed
vertical accuracy	=	6.30 < 10 cm

c. NE-309

horizontal accuracy	=	√((1.40)² + (0.70)²
	=	√ (1.96 + 0.49)
	=	1.57 cm < 20 cm
vertical accuracy	=	8.20 cm < 10 cm

d. UP-TAN

horizontal accuracy	=	√((1.10)² + (0.60)²
	=	√ (1.21 + 0.36)
	=	1.25 cm < 20 cm
vertical accuracy	=	7.50 cm < 10 cm

e. UP-OCO

horizontal accuracy	=	√((1.20)² + (0.80)²
	=	√ (1.44 + 0.64)
	=	1.44 cm < 20 cm
vertical accuracy	=	7.0 cm < 10 cm

Following the given formula, the horizontal and vertical accuracy result of the two occupied control points are within the required precision.

Table 25. Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
NE-119	N9°21'44.19653"	E123°16'24.28145"	71.085	0.063	
NGE-93	N9°25'38.28279"	E123°14'05.68141"	66.238	?	LLh
NE-309	N9°30'49.29191"	E123°08'27.09882"	69.810	0.055	
UP-TAN	N9°30'09.32752"	E123°07'32.02420"	74.861	0.046	
UP-OCO	N9°19'29.11816"	E123°15'39.45442"	116.909	0.051	

The corresponding geodetic coordinates of NAMRIA established reference points, NGE-93, NE-119, and NE-309 are within the required accuracy as shown in Table 25. 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 26.

Table 26. 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)
NE-119	1st order, BM	9°21' 44.19653"	123°16' 24.28145"	71.085	1034916.543	530021.363	7.414
NGE-93	2nd order, GCP	9°25' 38.28279"	123°14' 05.68141"	66.238	1042102.575	525789.116	2.47
NE-309	Used as marker	9°30' 49.29191"	123°08' 27.09882"	69.81	1051648.501	515460.125	6.01
UP-TAN	Established	9°30' 09.32752"	123°07' 32.02420"	74.861	1050420.498	513781.485	11.014
UP-OCO	Established	9°19' 29.11816"	123°15' 39.45442"	116.909	1030767.084	528657.161	53.12

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

Since there is no bridge located in the upstream of Tanjay River, cross-section survey was conducted at the upstream flow measurement and sensors deployment site identified by USC located in Barangay Malalangsi, Pamplona, Negros Oriental using a GNSS receiver, Trimble® SPS 882, in PPK survey technique as shown in Figure 37.

Figure 37. The deployment site of rain gauge and flow meter for Tanjay River

The cross-sectional line length of the deployment site is about 89.42 m with 80 cross-sectional points acquired using UP-TAN as the GNSS base station. The water surface elevation acquired on February 3, 2015 is 4.88 meters above MSL. The location map and cross-section diagram are illustrated in Figure 38 and Figure 39.

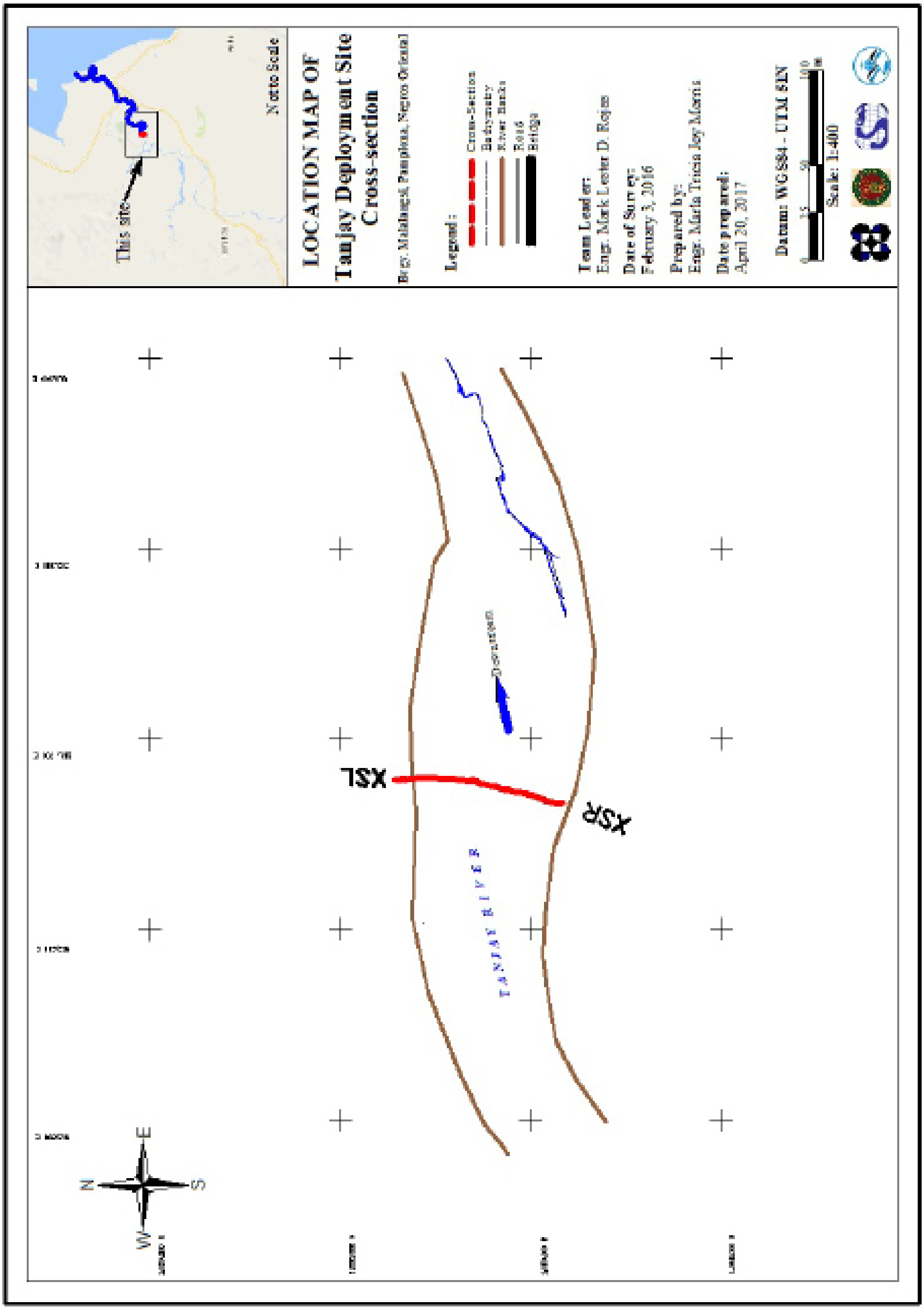

Figure 38. Location map of Tiabanan River cross-section survey

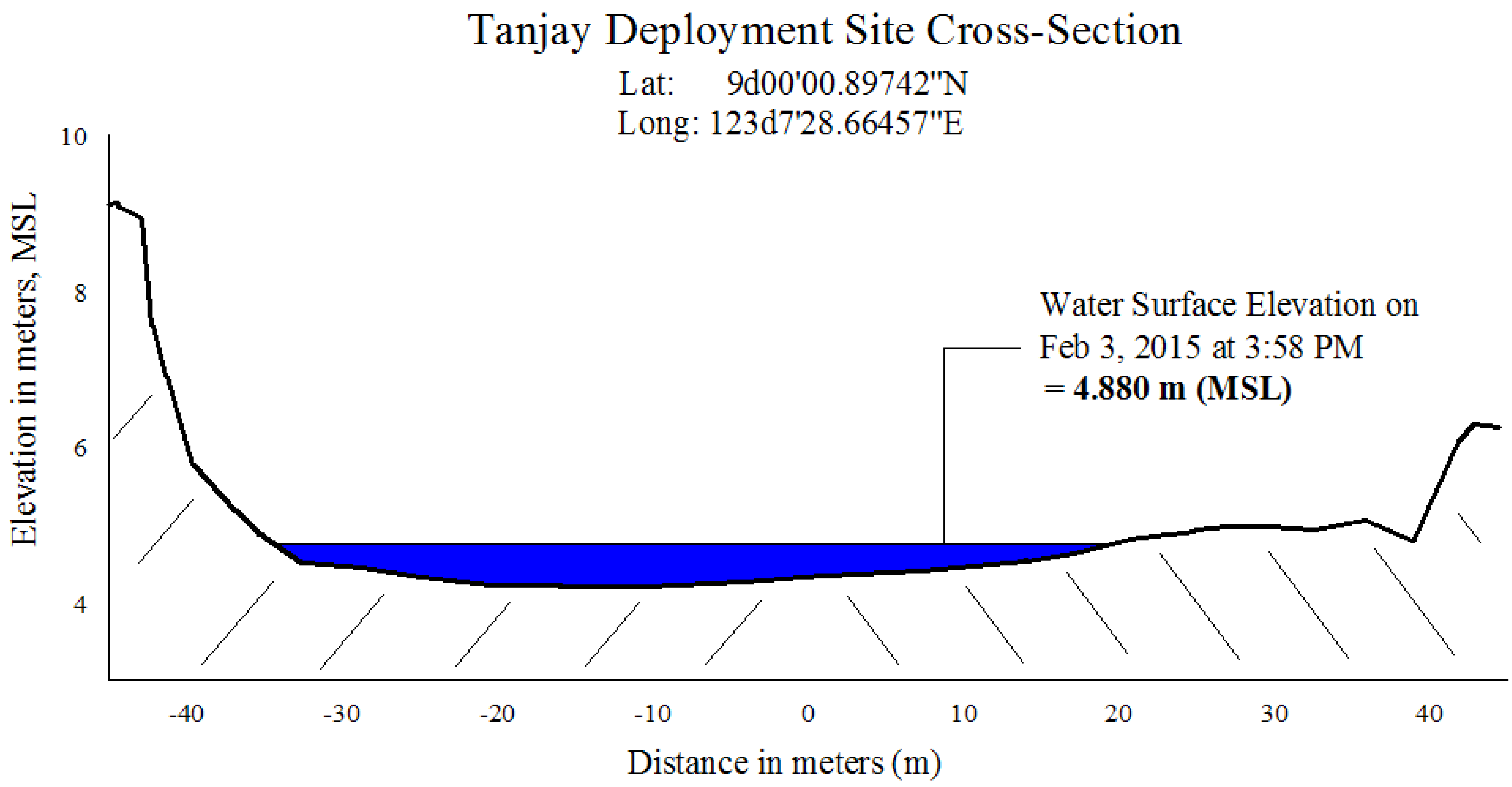

Figure 39. Tanjay River Cross-section Diagram

Water-level marking for Tanjay River was to be conducted by partner Higher Education Institution (HEI), University of San Carlos, using instruments like digital level and total station.

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on February 4, 2016 using a survey-grade GNSS Rover receiver, Trimble® SPS 855, mounted on a pole which was attached to the side of vehicle as shown in Figure 40. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The antenna height was 2.10 m and measured from the ground up to the bottom of notch of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with UP-TAN occupied as the GNSS base stations in the conduct of the survey.

Figure 40. Validation points acquisition survey set-up

The survey started from Ocoy Bridge in Brgy. Campaclan in the Municipality of Sibulan going norht towards to the boundary of Bais City and Manjuyod via Western Nautical Highway. This route aims to cut flight strips perpendicularly. It gathered 6,460 points with approximate length of 84 km. UP-TAN was used as GNSS base for the entire extent validation points acquisition survey, as drawn in a map in Figure 41.

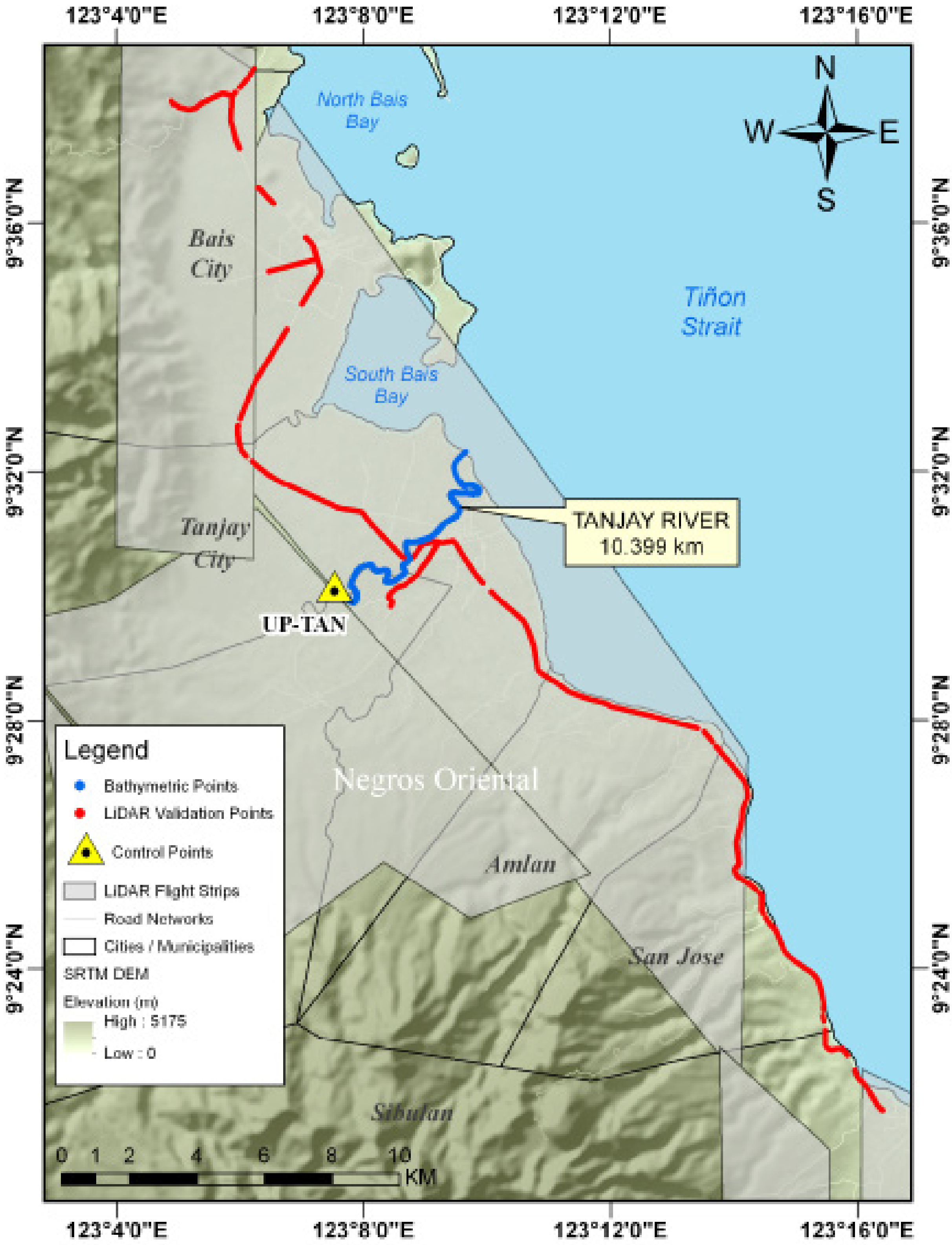

Figure 41. LiDAR Validation points acquisition survey for Tanjay River Basin

4.7 Bathymetric Survey

Bathymetric survey was executed on February 2 to 4, 2016 using a Trimble® SPS 882 in GNSS PPK survey technique and Ohmex™ single beam echo sounder, as illustrated in Figure C-13A. The extent of the survey is from the upstream in Brgy. Novallas. Tanjay City with coordinates 9d29’57.59153”N, 123d07’32.67934”E, down to the mouth of the river in Brgy. San Isidro, Tanjay City with coordinates 9d32’18.84073”N, 123d09’40.38784”E, as shown in the map in Figure 42.

On February 2, the survey covered 5.361 km that started from Brgy. San Isidro (9d30’42.88509”N, 123d08’42.60784”E) down to the mouth of the river in Bgry. San Isidro. On February 3, the survey covered two separate segments of the river: the first segment is 1.594 km from Brgy. Novallas (9d29’57.59153”N, 123d07’32.67934”E) going downstream towards the same barangay (9d30’09.49212”N, 123d07’48.06549”E) with 1.594 km and the second segment is 2.235 from Brgy. San Jose (9d30’23.62081”N, 123d08’12.34002”E) going downstream towards Brgy. Isidro (9d30’45.28943”N, 123d08’41.98273”E). Both days utilized continuous topo mode while doing bathymetry by rubber boat with installed Ohmex™ single beam echo sounder. On the last day, February 4, the survey used manual bathymetry to include shallow part of the river. The survey covered 1.209 km that started from Brgy. Novallas (9d30’11.11491”N, 123d07’48.63641”E) going downstream towards Brgy. San Jose (9d30’23.47581”N, 123d08’13.88459”E). The control point UP-TAN was used as the GNSS base station throughout this survey.

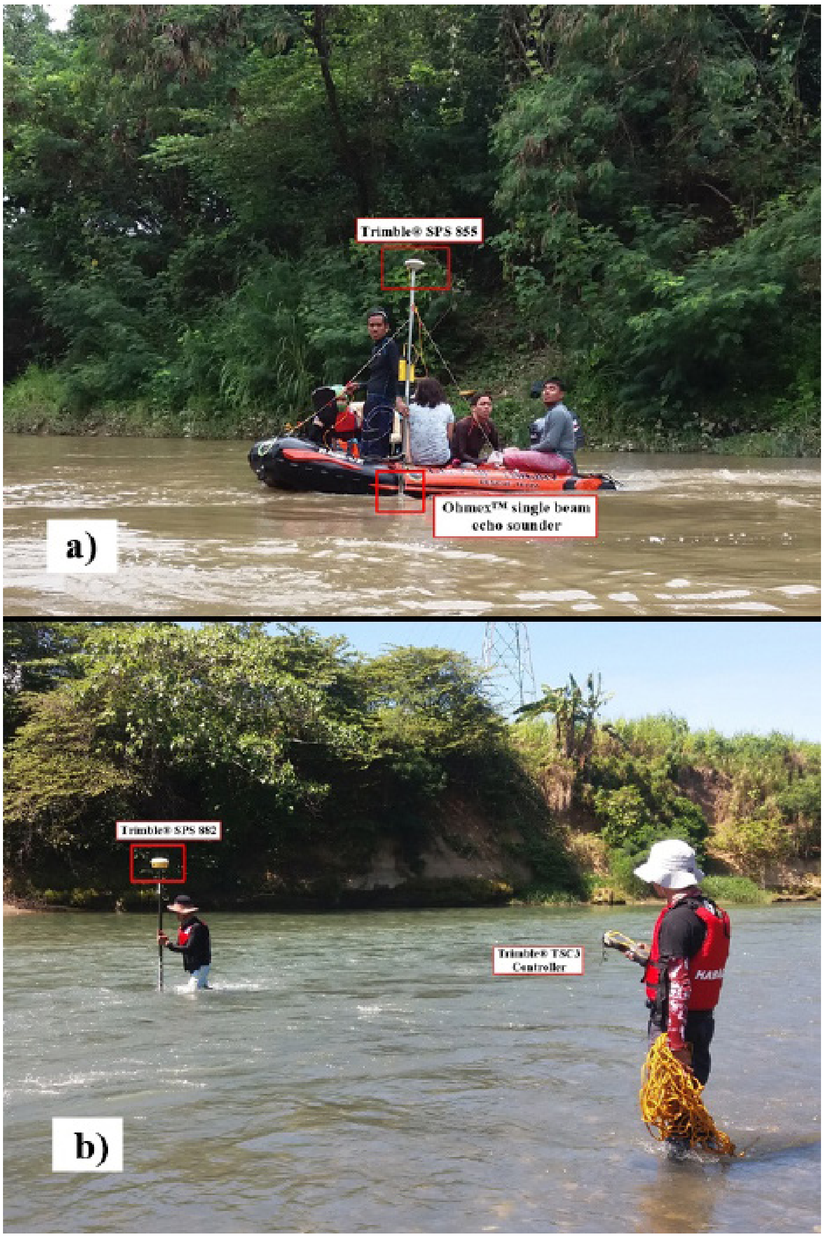

Figure 42. Bathymetric survey of ABSD at Tanjay River using a Hi-Target™ GNSS Rover Receiver

The bathymetric survey gathered a total of 11,110 points covering 10.399 km of the river traversing the ff. barangays from the upstream - Brgy. Novallas, Brgy. San Isdiro and Brgy. San Jose, as shown in the map in Figure 43.

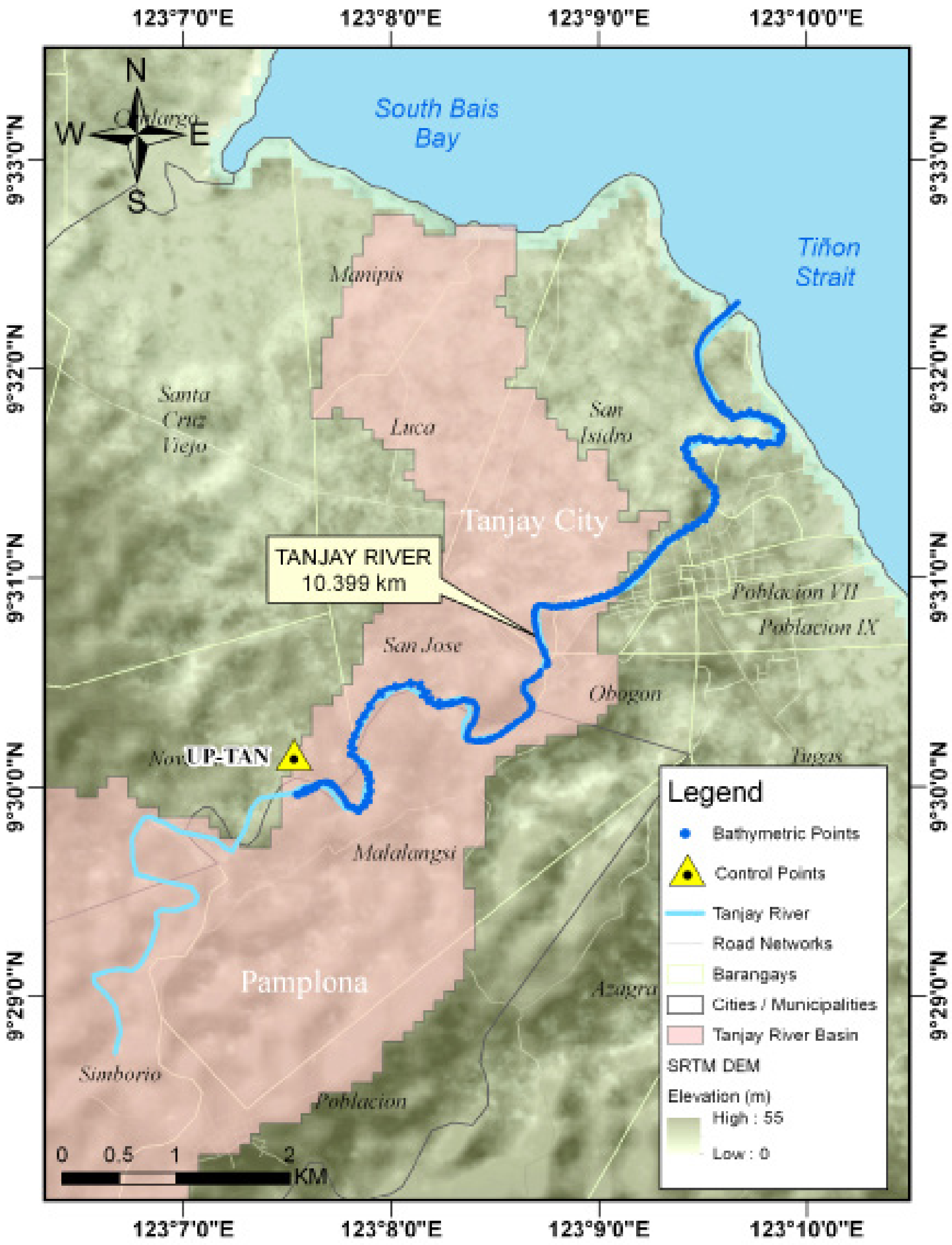

Figure 43. Bathymetric survey of Tanjay River

A CAD drawing was also produced to illustrate the riverbed profile of Tanjay River. As shown in Figure 44, the highest and lowest elevation has a 9.5-meter difference. The highest elevation observed was 3.649 m above MSL located in Brgy. Novallas while the lowest was 5.856 m below MSL located in Brgy. San Jose, both in Tanjay City.

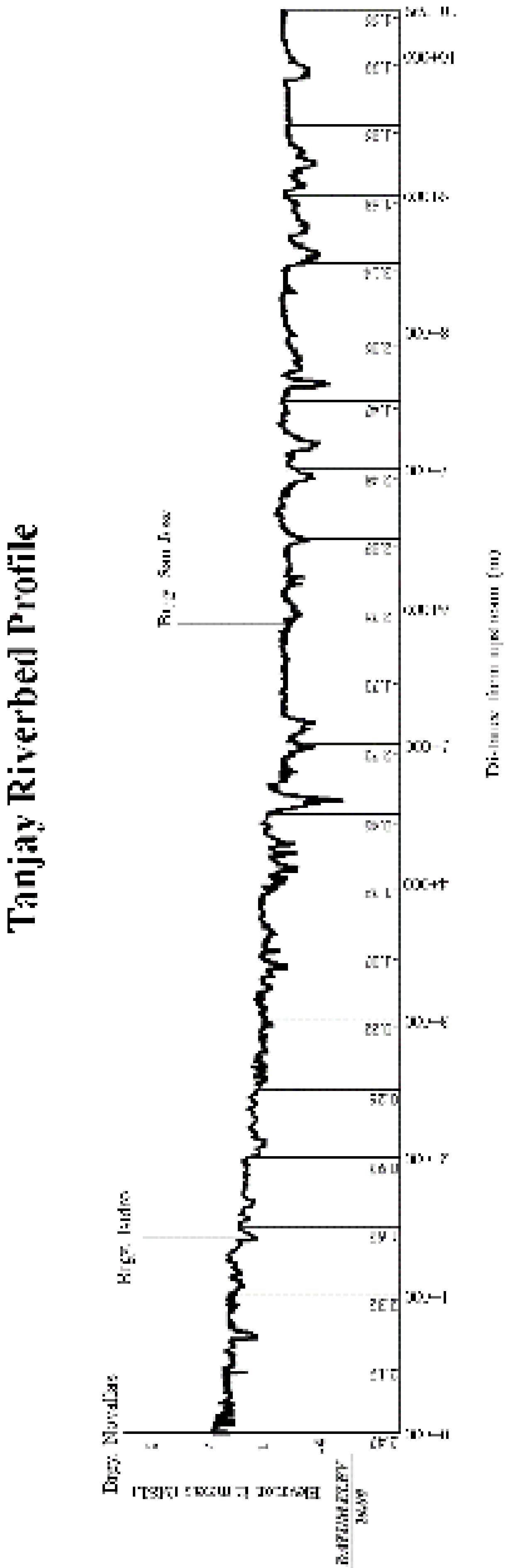

Figure 44. Tanjay riverbed profile

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, Pauline Racoma

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 data that affect the hydrologic cycle of the Tanjay 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 Tanjay River Basin were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from an automatic rain gauge installed by the Department of Science and Technology Advanced Science and Technology Institute (DOST ASTI). The rain gauge was installed in the Negros Oriental State University in the Municipality of Pamplona with geographic coordinates of 9.46223°N and 123.10881°E. The location of the rain gage in the watershed in presented in Figure 45.

The total precipitation data used for calibration is 3.4 mm. The rainfall event was used started at 4:00 in the morning and ended at 5:30 in the morning on April 16, 2017 (Figure 48).

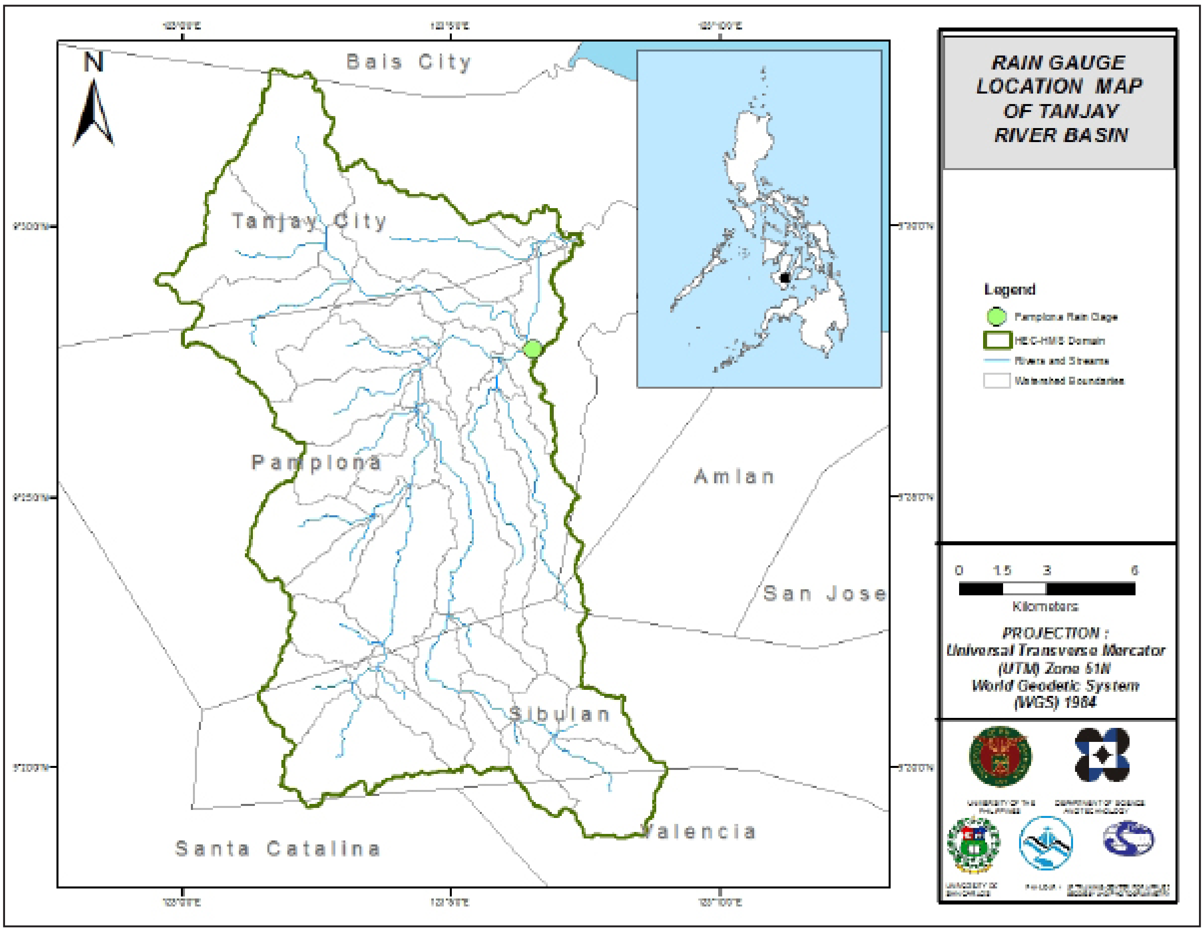

Figure 45. The location map of Tanjay HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Brgy. Novallas (9.50008° N and 123.124°E). It gives the relationship between the observed water levels and outflow of the watershed at this location.

For Brgy. Novallas, the rating curve is expressed as $y = 5E - 12e^{5.3167x}$ as shown in Figure 47.

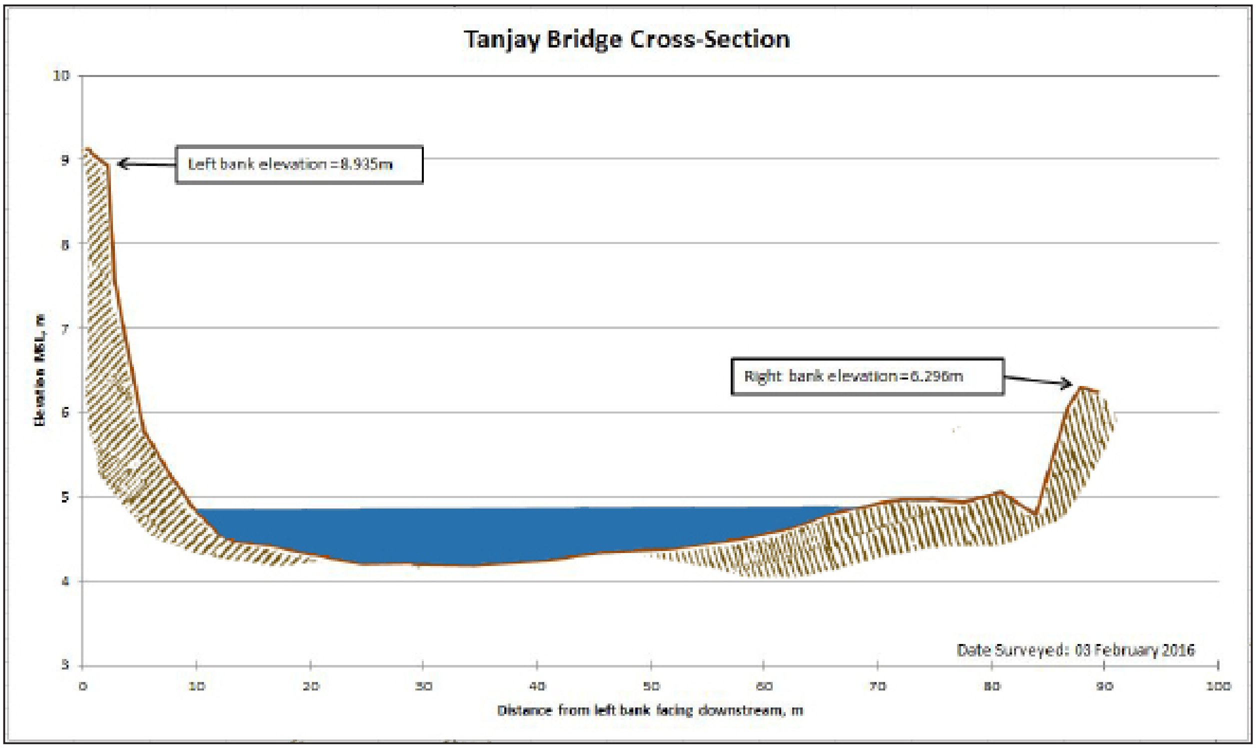

Figure 46. Cross-Section Plot of Tanjay Bridge

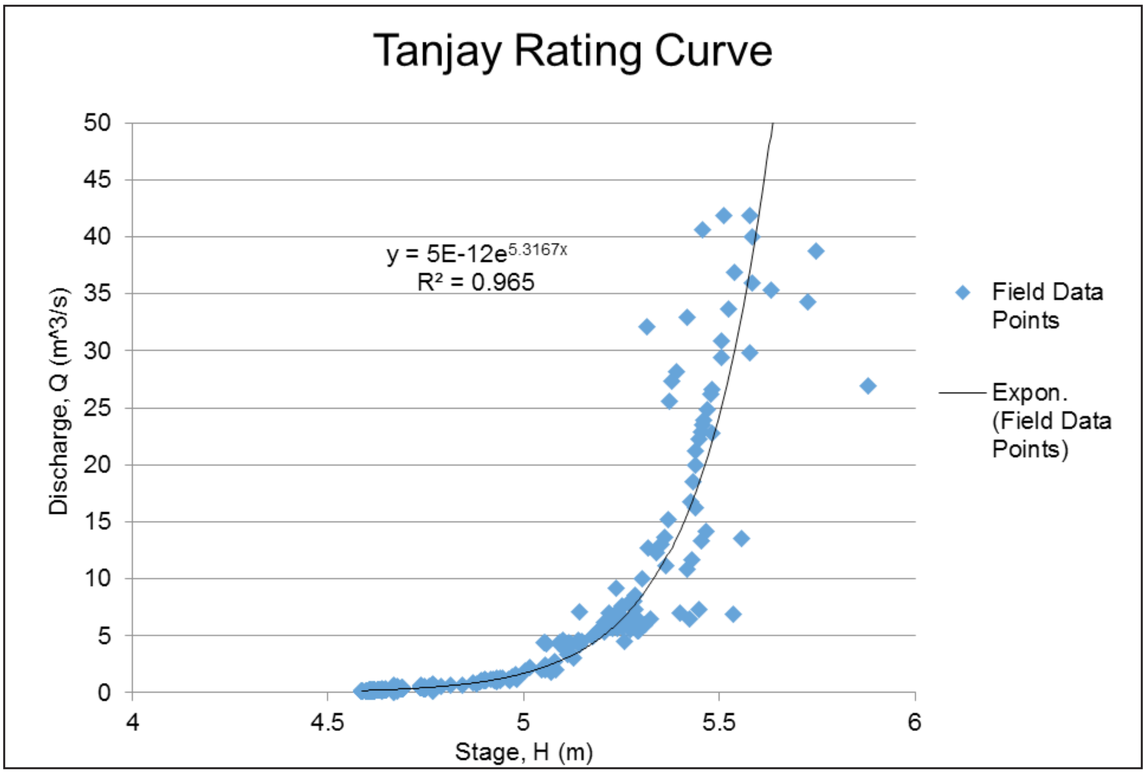

Figure 47. Rating curve at Brgy. Novallas in Tanjay River

This rating curve equation was used to compute the river outflow at Brgy. Novallas for the calibration of the HEC-HMS model shown in Figure 48. Peak discharge is 41.864 m3/s at 14:00, April 2, 2017.

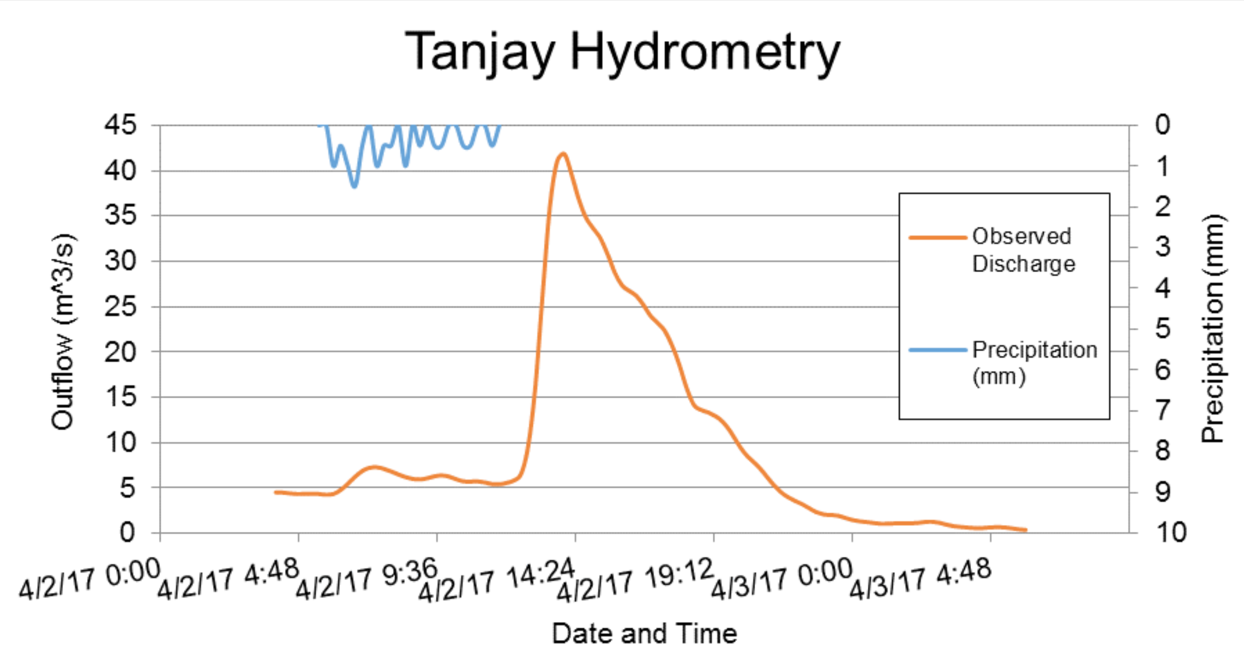

Figure 48. Rainfall and outflow data at Brgy. Novallas used for modeling

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Dumaguete Point Gauge. This station chosen based on its proximity to the Tiabanan watershed. Tiabanan extreme values for this watershed were computed based on a 35-year record, shown in Table 27.

Table 27. RIDF values for Dumaguete Point 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	16.2	24.8	30.6	39.7	50	55.3	63.4	69.1	76
5	21.8	33.6	42.3	57.1	76.5	87.3	100	109.5	116.5
10	25.6	39.4	50	68.6	94	108.5	124.3	136.3	143.3
15	27.7	42.7	54.3	75.1	103.9	120.5	138	151.4	158.4
20	29.1	45	57.4	79.7	110.8	128.9	147.5	162	169
25	30.3	46.8	59.7	83.2	116.1	135.3	154.9	170.2	177.2
50	33.8	52.3	66.9	94	132.5	155.2	177.6	195.3	202.4
100	37.2	57.7	74.1	104.8	148.8	174.9	200.2	220.2	227.3

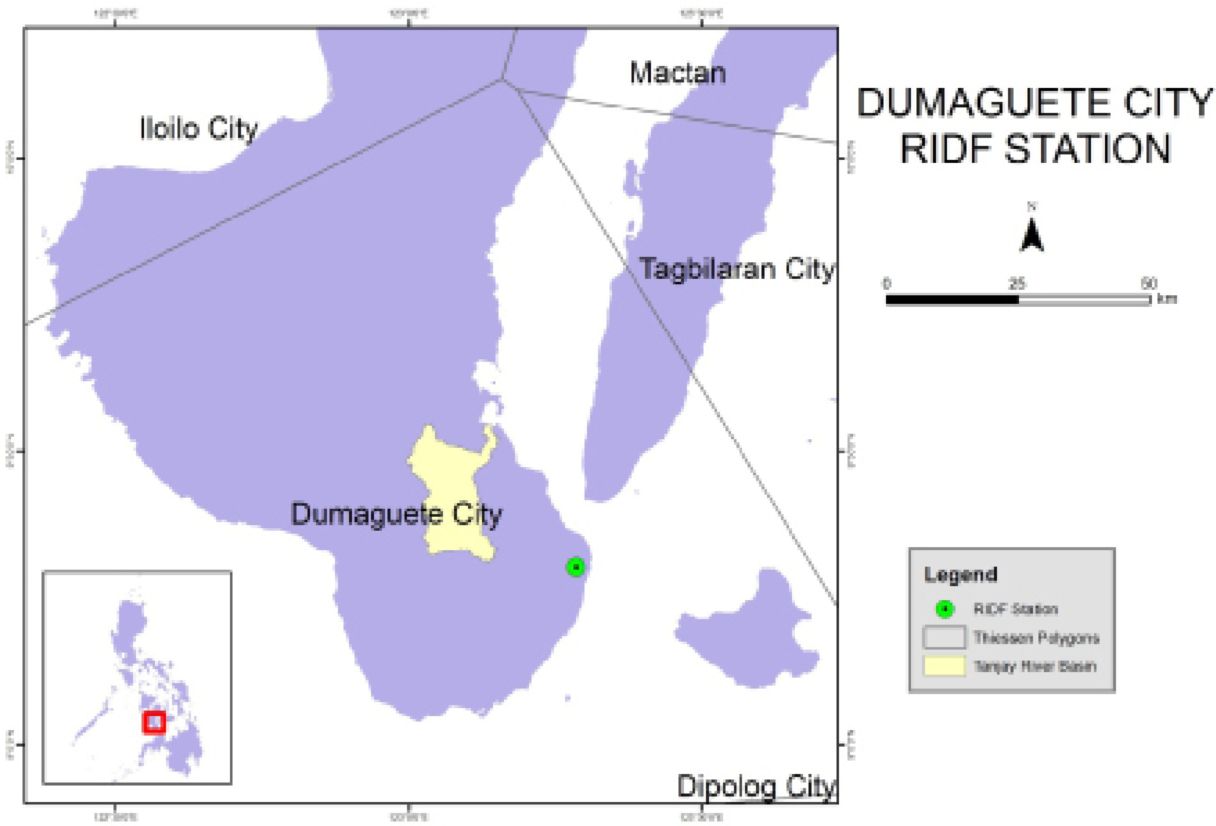

Figure 49. Location of Dumaguete Point RIDF Station relative to Tanjay River Basin

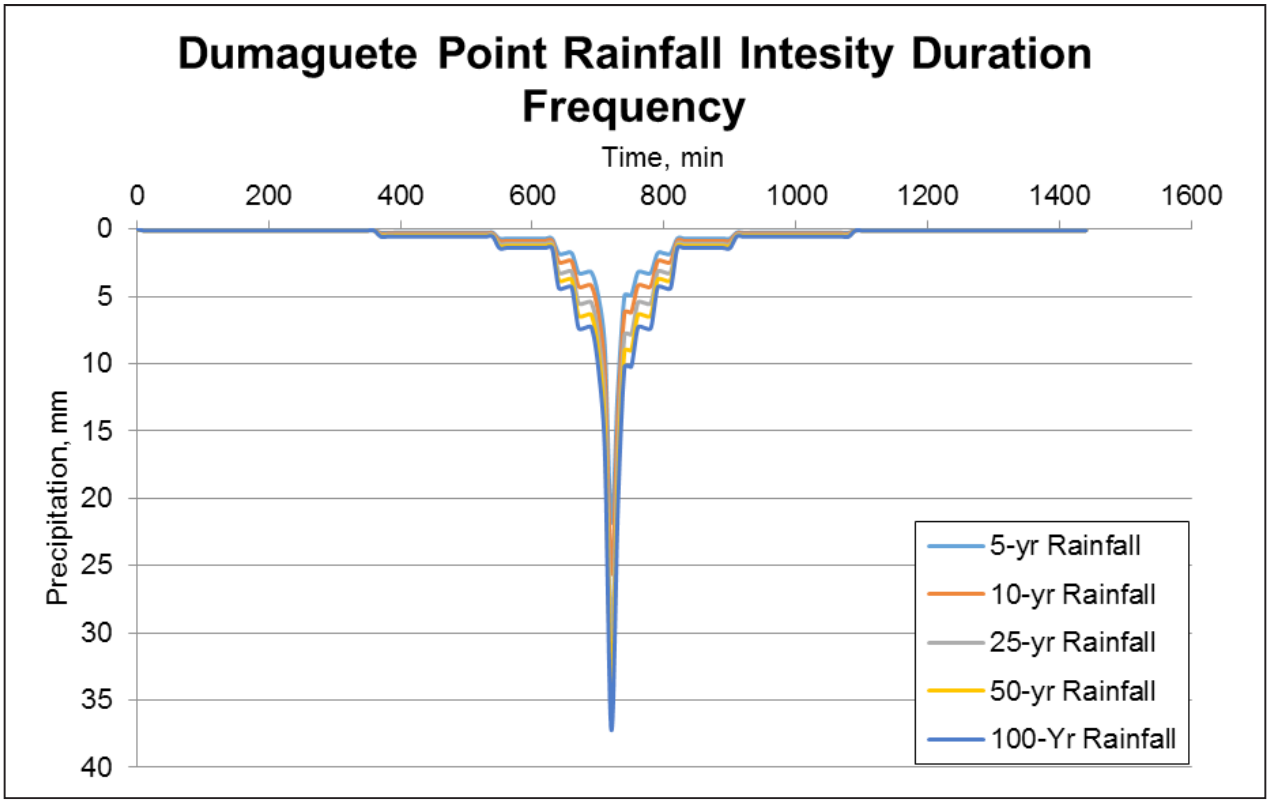

Figure 50. Synthetic storm generated for a 24-hr period rainfall for various return periods.

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 Tanjay River Basin are shown in Figure 51 and Figure 52, respectively.

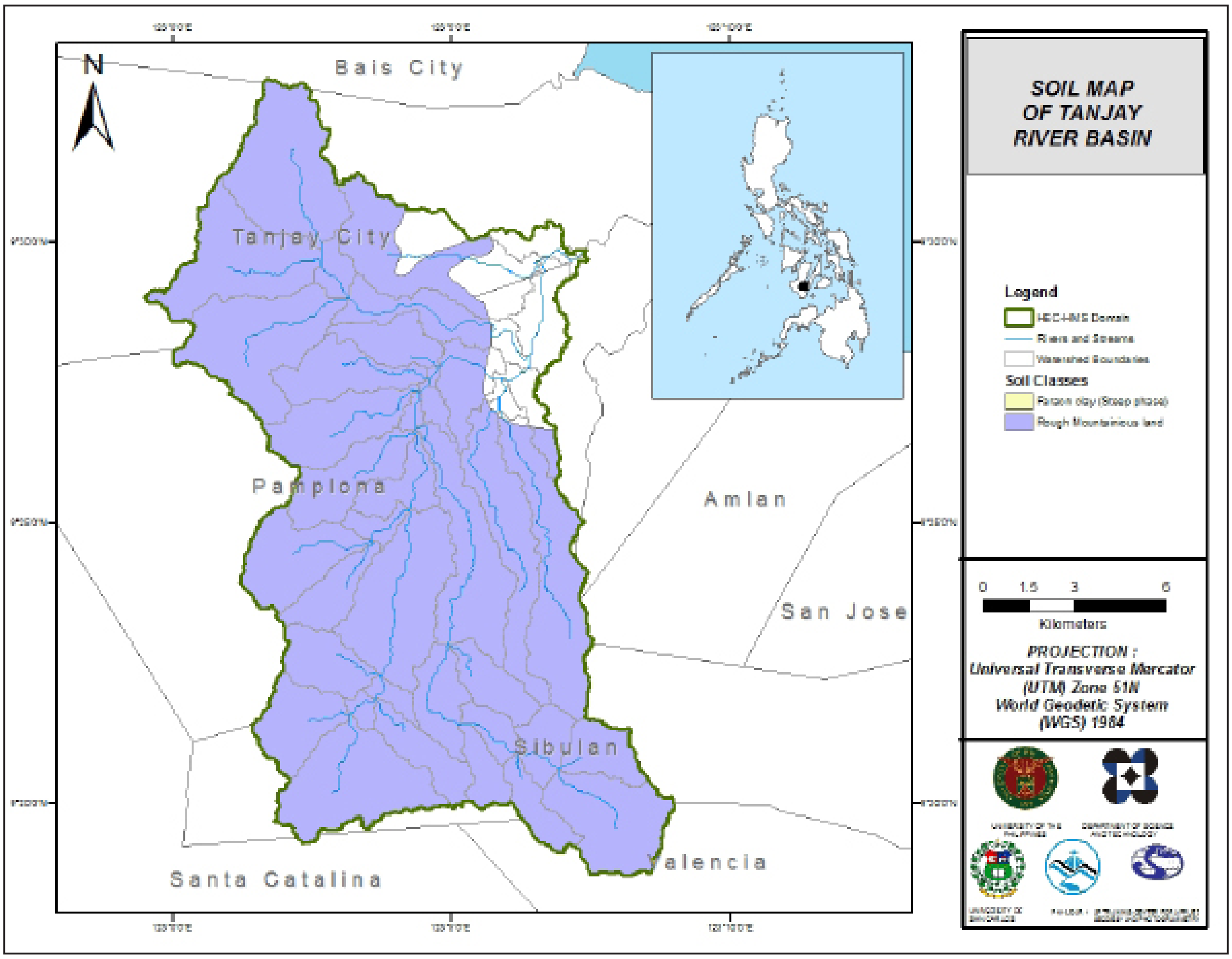

Figure 51. Soil map of the Tanjay River Basin used for the estimation of the CN parameter. (Source: DA)

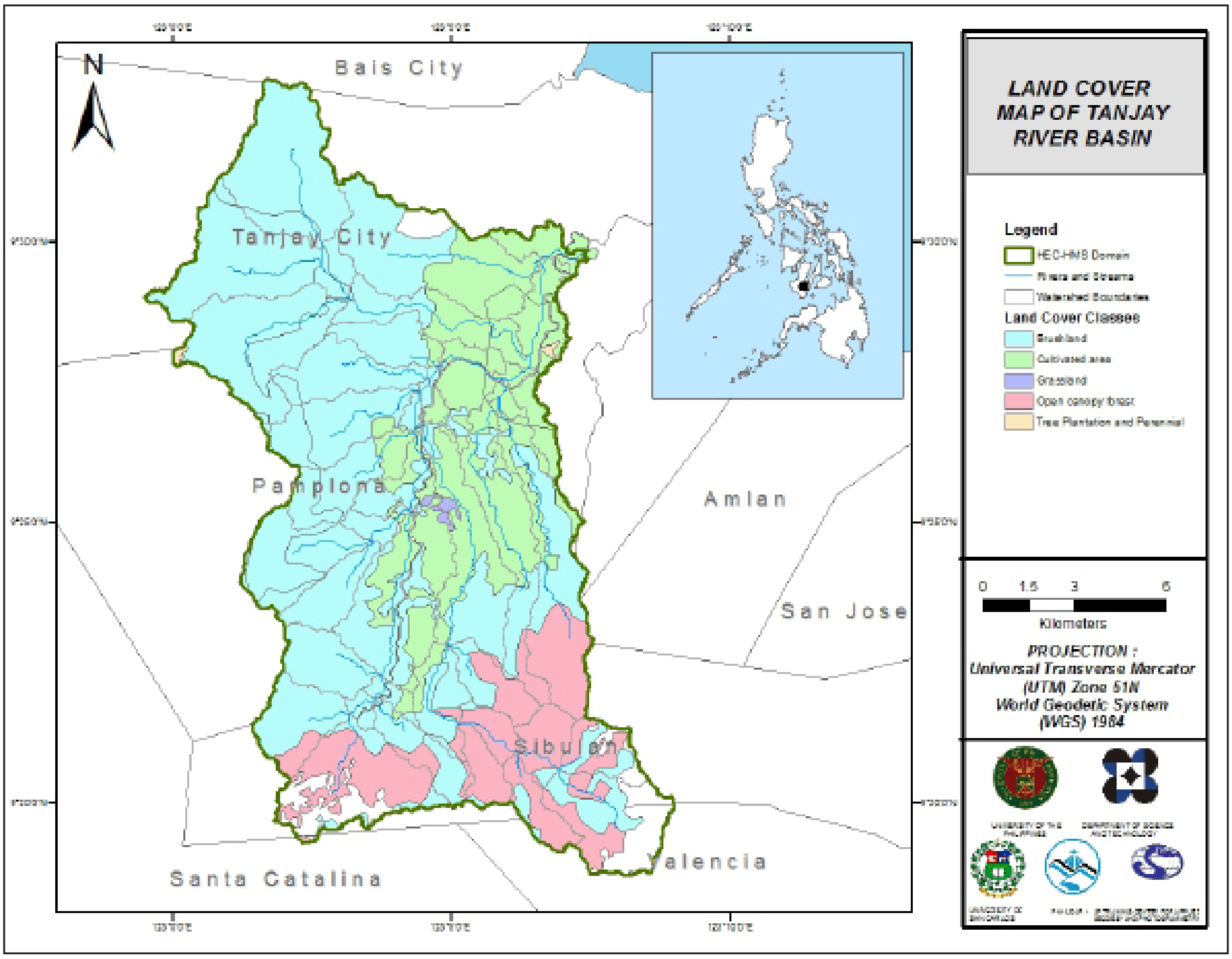

Figure 52. Land cover map of Tiabanan River Basin used for the estimation of the Curve Number (CN) and the watershed lag parameters of the rainfall-runoff model. (Source: NAMRIA)

For the Tanjay river basin, two (2) soil classes were identified. The Tanjay river basin is largely rough mountainous land with a very small portion of Faraon clay (steep phase). Moreover, five (5) land cover classes were identified. Most of the Tanjay river basin is brushland, cultivated area and open canopy forest, with patches of grassland and tree plantation and perennial land cover.

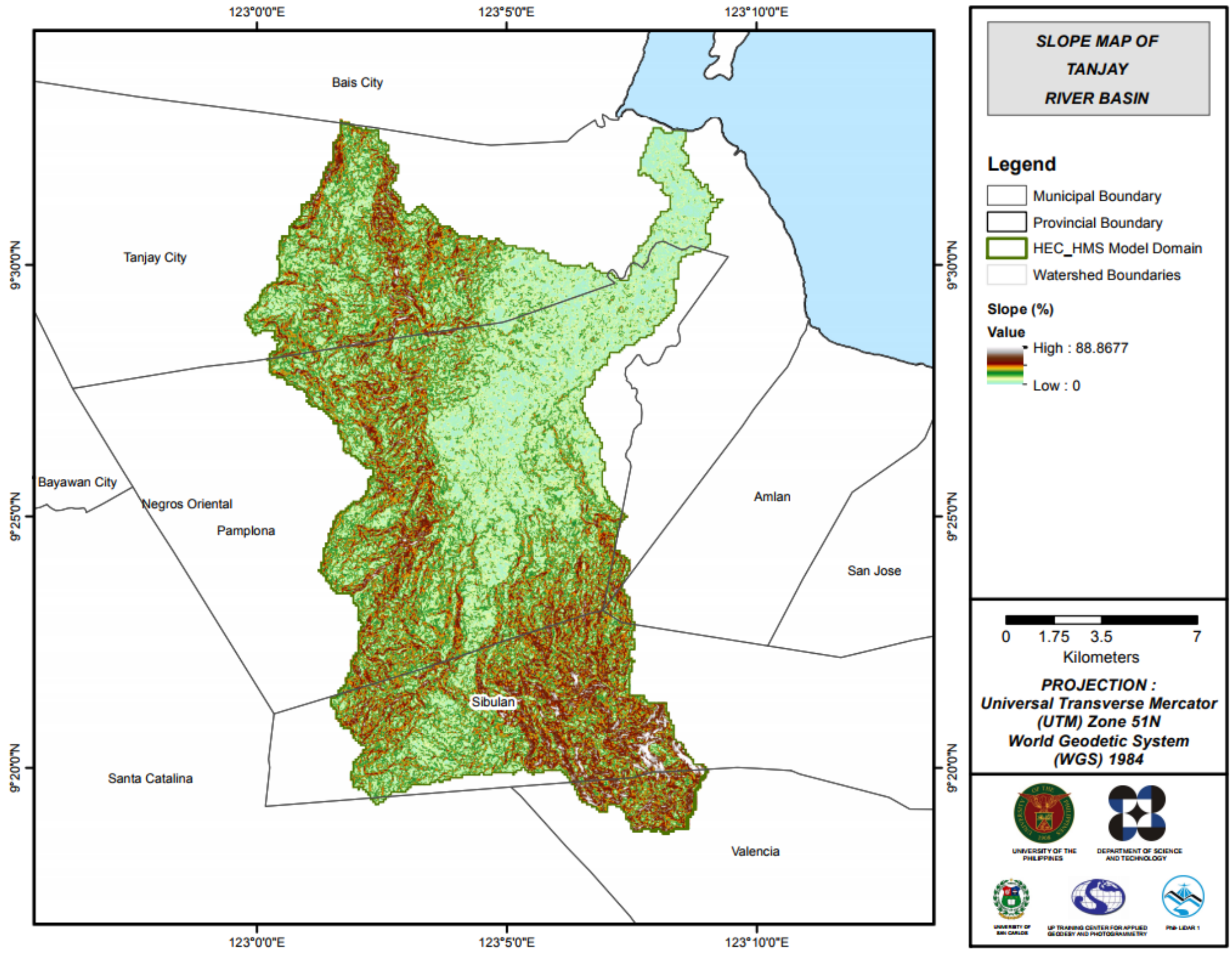

Figure 53. Slope map of Tanjay River Basin

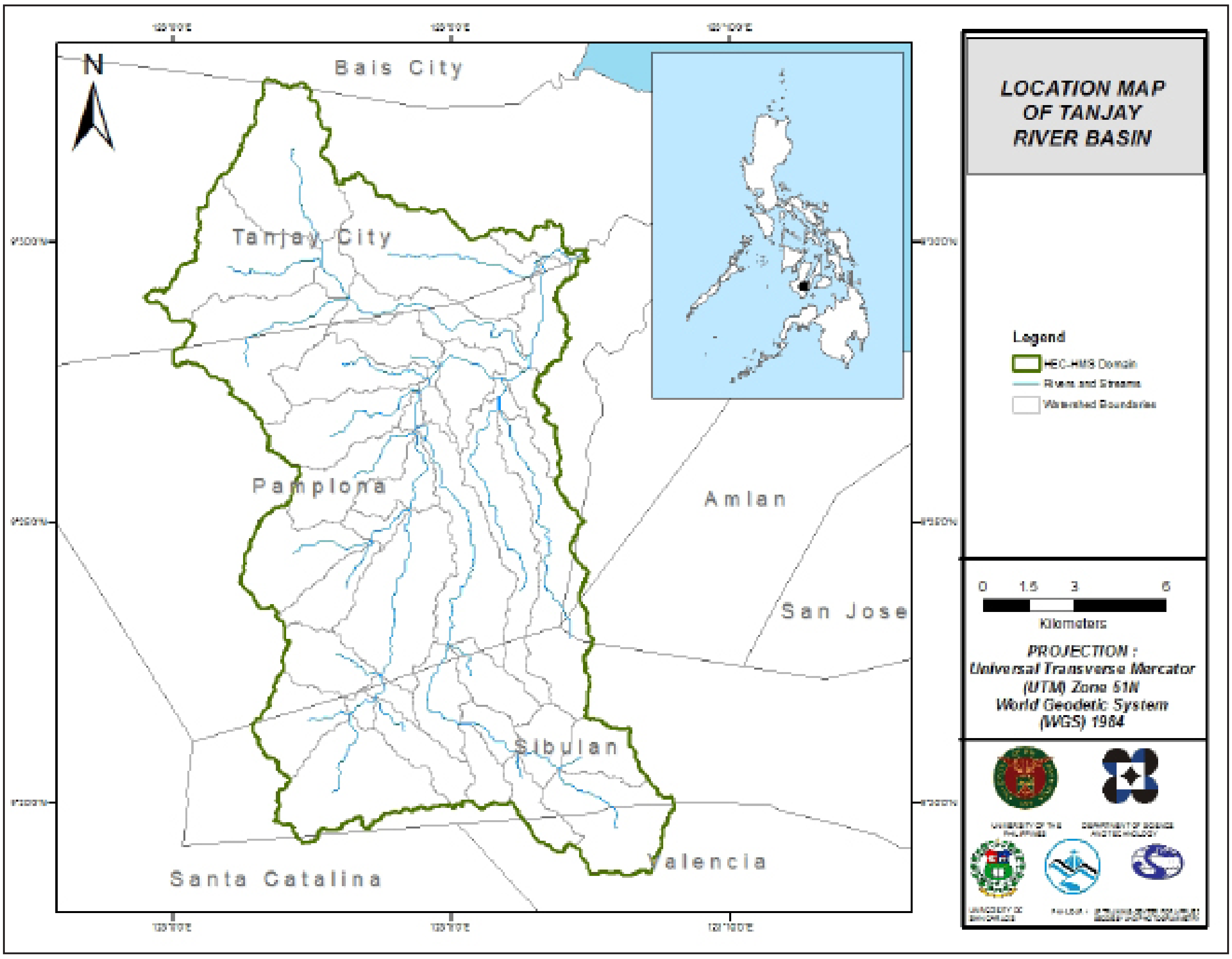

Figure 54. Stream Delineation Map of the Tanjay River Basin

The Tanjay basin model comprises 41 sub basins, 21 reaches, and 21 junctions. The main outlet is outlet 1. This basin model is illustrated in Figure 54. The basins were identified based on soil and land cover characteristic of the area. Precipitation was taken from an installed rain gauge near and inside the river basin. Finally, it was calibrated using the data from actual discharge flow gathered in the Brgy. Novallas, Tanjay City.

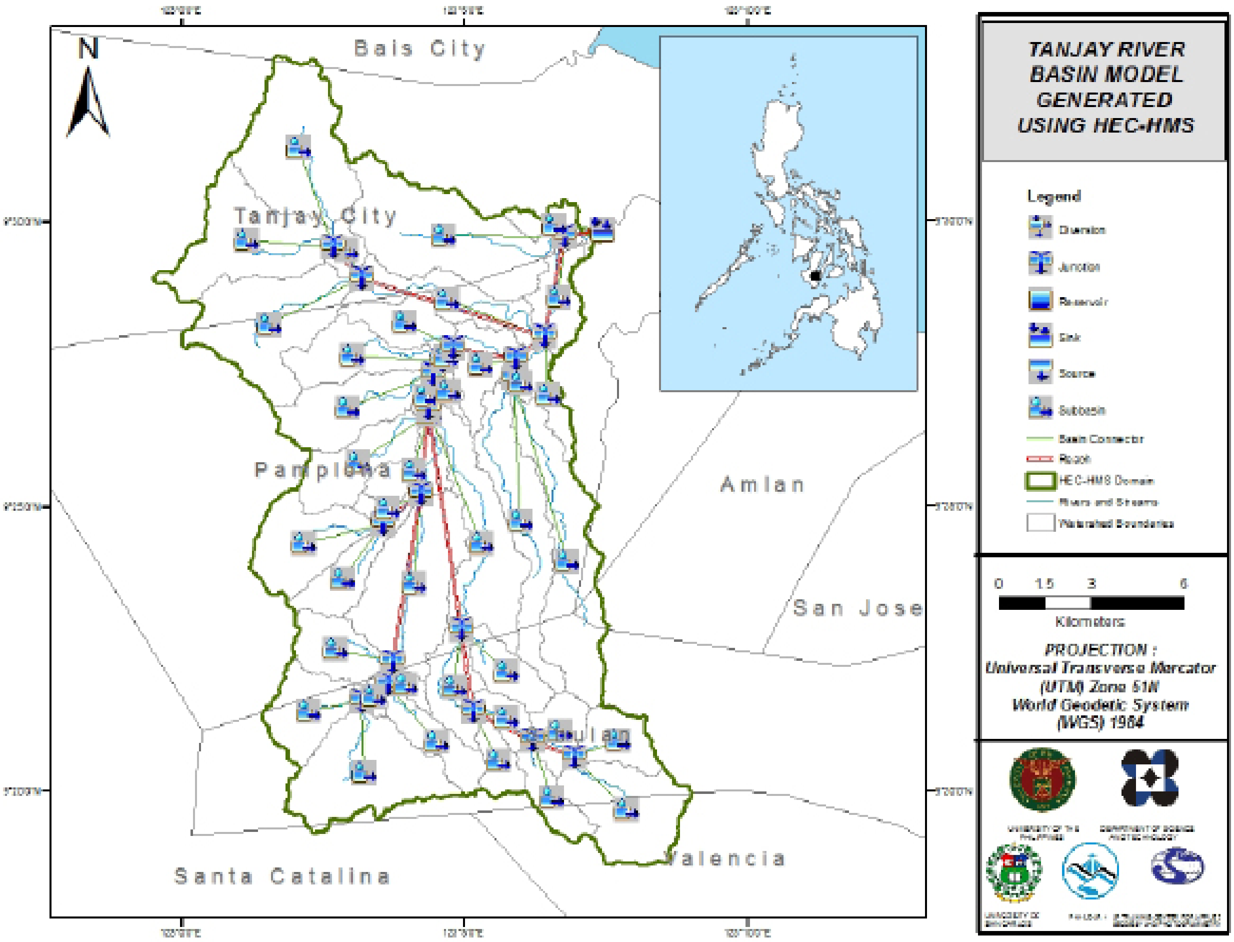

Figure 55. HEC-HMS generated Tanjay River Basin Model.

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.

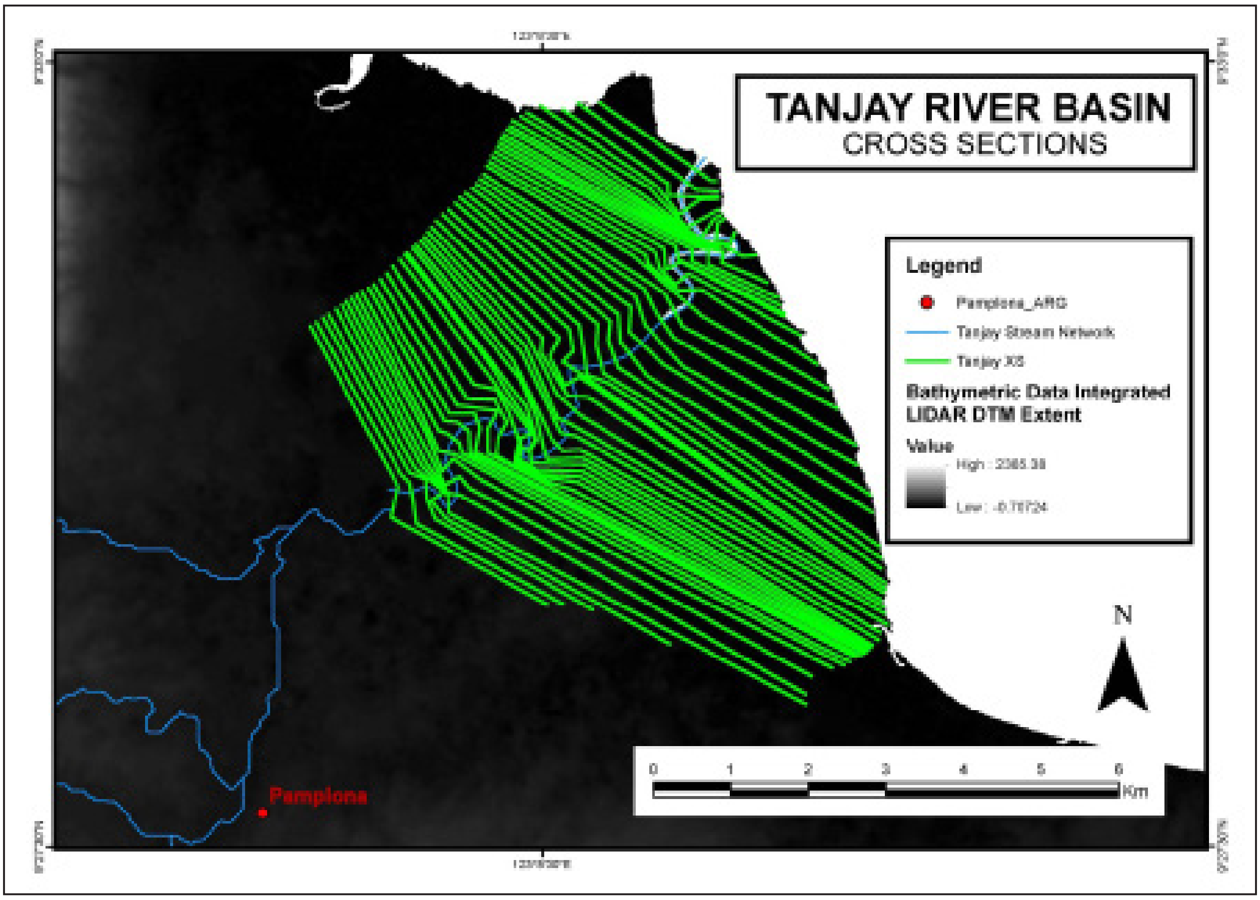

Figure 56. River cross-section of Tanjay River generated through Arcmap HEC GeoRAS tool

5.5 Flo 2D Model

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

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

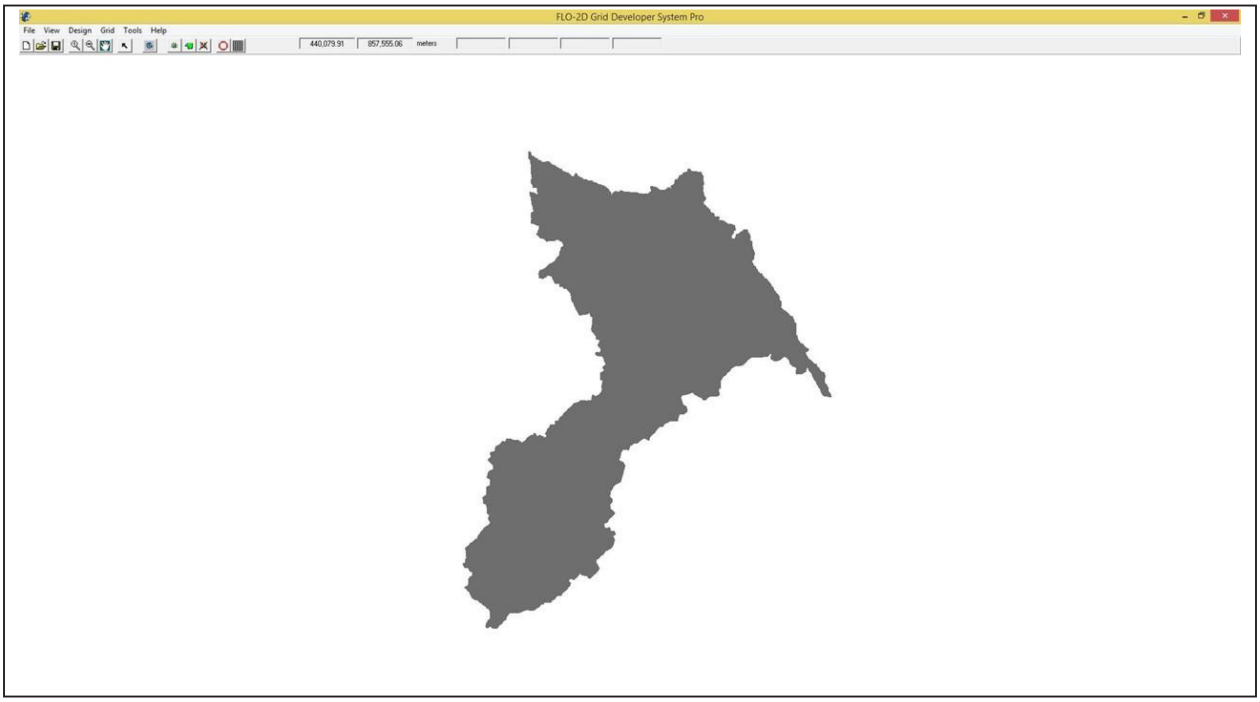

Figure 57. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 37.13159 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 59,257,600.00 m2.

There is a total of 25,804,147.61 m3 of water entering the model. Of this amount, 15,335,512.63 m3 is due to rainfall while 10,468,634.99 m3 is inflow from other areas outside the model. 5,170,802.50 m3 of this water is lost to infiltration and interception, while 6,666,076.01 m3 is stored by the flood plain. The rest, amounting up to 13,967,282.79 m3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Tanjay HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 58 shows the comparison between the two discharge data.

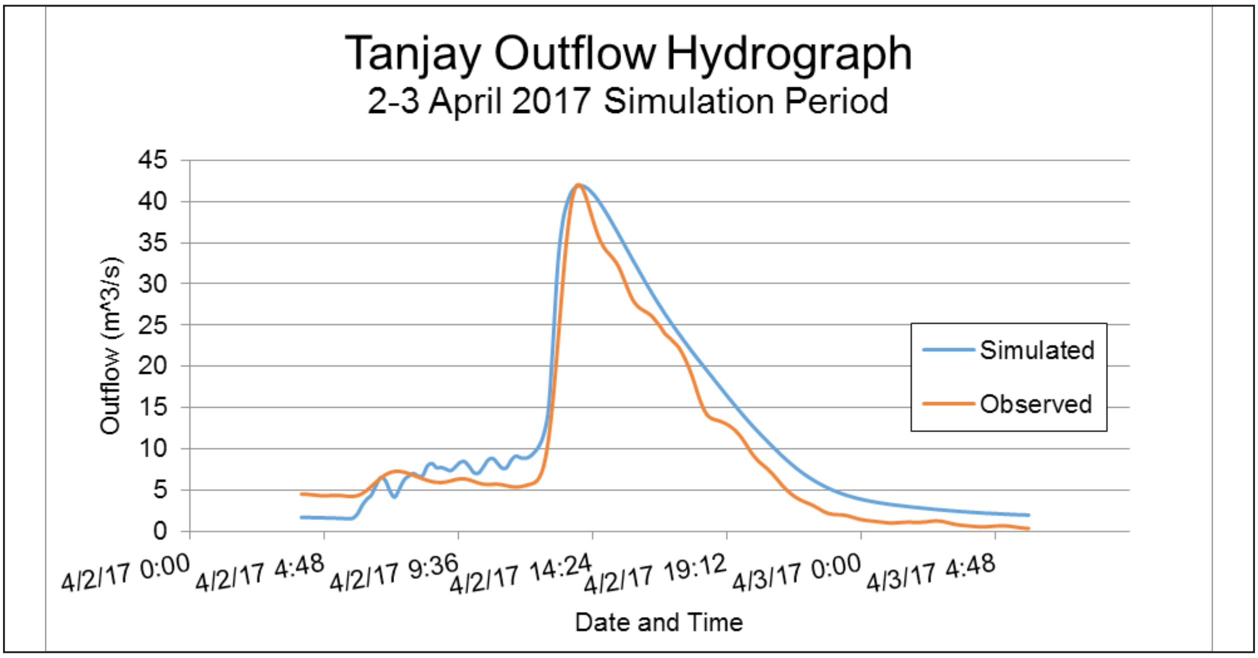

Figure 58. Outflow Hydrograph of Tanjay produced by the HEC-HMS model compared with observed outflow.

Enumerated in Table 28 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 28. Range of calibrated values for Tiabanan Watershed

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	0.42-14.40
			Curve Number	47.28-99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	10-100
			Storage Coefficient (hr)	0.16-136.48
	Baseflow	Recession	Recession Constant	0.03-0.83
			Ratio to Peak	0.00001-
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.0000334

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 values range from 0.42 to 14.40mm means that there is minimal to average amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 65 to 90 for curve number is advisable for Philippine watersheds depending on the soil and land cover of the area (M. Horritt, personal communication, 2012). The curve number for Tanjay River is 47.28 to 99 since its watershed is mostly clay and mountainous land.

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 0.16 to 136.48 minutes 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 0.00001 to 0.0000334 indicates that the basin will quickly go back to its original discharge. Ratio to peak of 0.00001 to 0.00011 indicates a steep receding limb of the outflow hydrograph.

Manning's roughness coefficient of 0.025 corresponds to the common roughness in Tanjay, which is determined to be brushland, cultivated areas and canopy forests (Brunner, 2010).

Table 29. Summary of the Efficiency Test of Tanjay HMS Model

Accuracy measure	Value
RMSE	2.9393
r2	0.9846
NSE	0.9260
PBIAS	-21
RSR	0.2721

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 2.9393.

The Pearson correlation coefficient (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 0.9846.

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 0.9260.

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 -21.

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 0.2721.

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 59) show the Tanjay outflow using the Dumaguete Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-, 10-, 25-, 50-, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAG-ASA) data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a uniform duration of 24 hours and varying return periods.

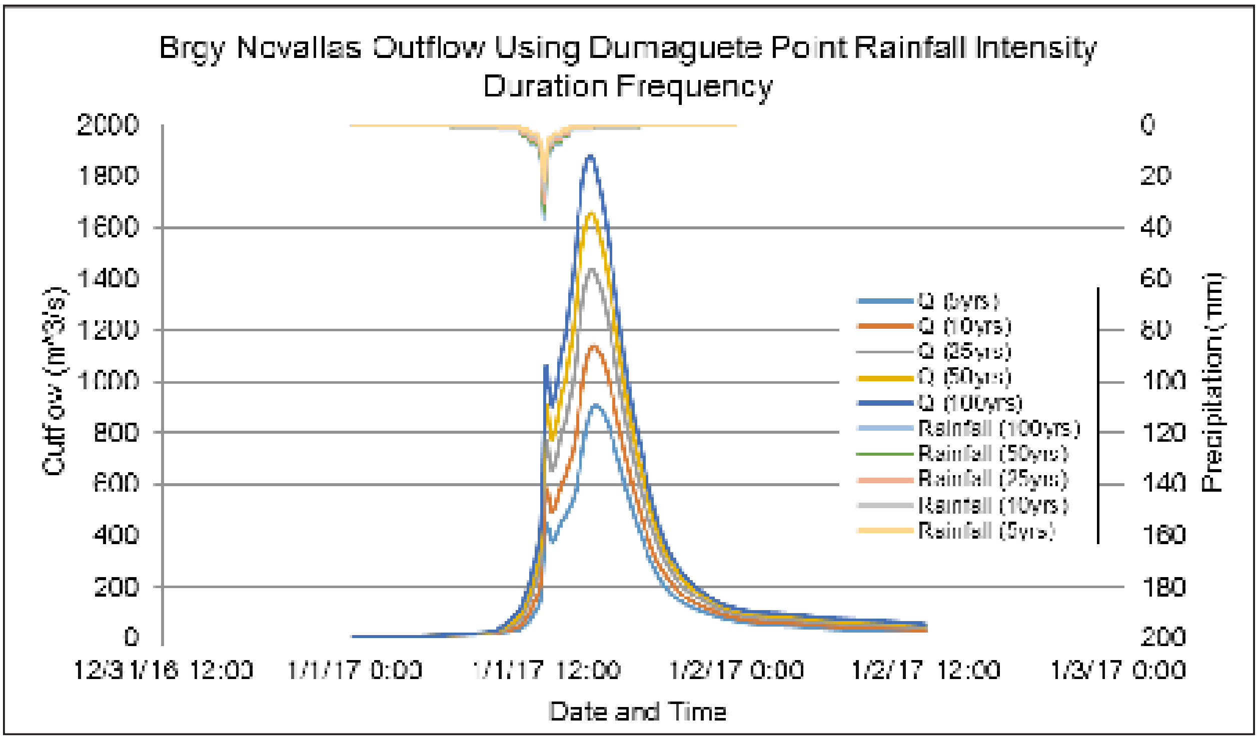

Figure 59. Outflow hydrograph at Brgy. Novallas, Tanjay City generated using Dumaguete Point RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of the Tanjay River discharge using the Dumaguete Point Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 30.

Table 30. Peak values of the Tiabanan HECHMS Model outflow using the Dumaguete RIDF

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	116.5	21.800	905.072	3 hours, 10 minutes
10-Year	143.3	25.600	1,140.262	3 hours, 10 minutes
25-Year	177.2	30.300	1,438.765	3 hours
50-Year	202.4	33.800	1,658.065	3 hours
100-Year	227.3	37.200	1,877.947	3 hours

5.8 River Analysis Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. For this publication, only a sample output map river was to be shown. The sample generated map of Tanjay River using the calibrated event flow is shown in Figure 59.

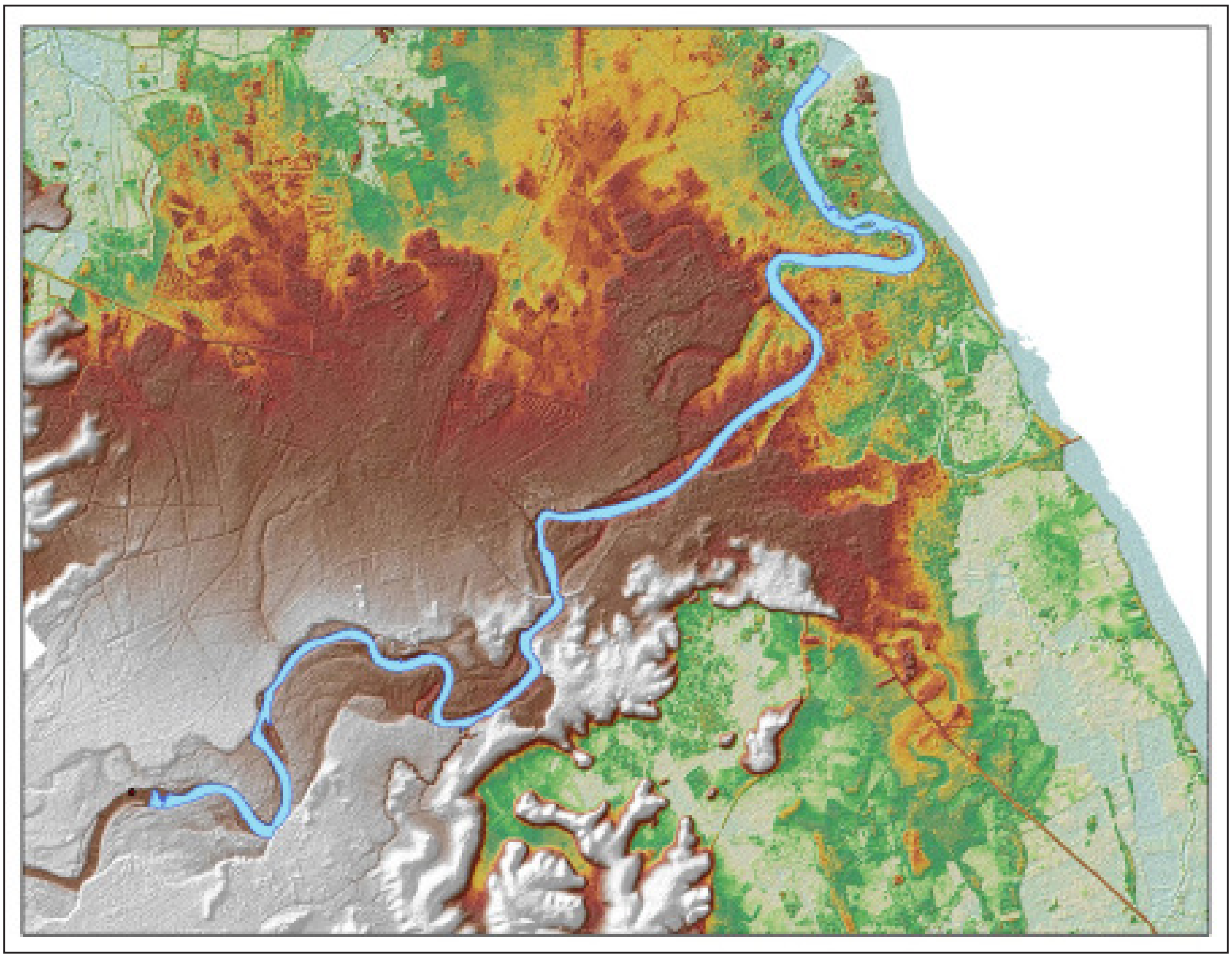

Figure 60. Sample output of Tanjay RAS Model

5.9 Flood Hazard and Flow Depth Map

The resulting hazard and flow depth maps have a 10m resolution. Figure 62 to Figure 67 shows the 5-, 25-, and 100-year rain return scenarios of the Tanjay floodplain. The floodplain, with an area of ________ sq. km., covers __ municipalites/ cities namely _______. Table 33 shows the percentage of area affected by flooding per municipality.

Table 31. Municipalities affected in Tanjay floodplain

City / Municipality	Total Area	Area Flooded	% Flooded

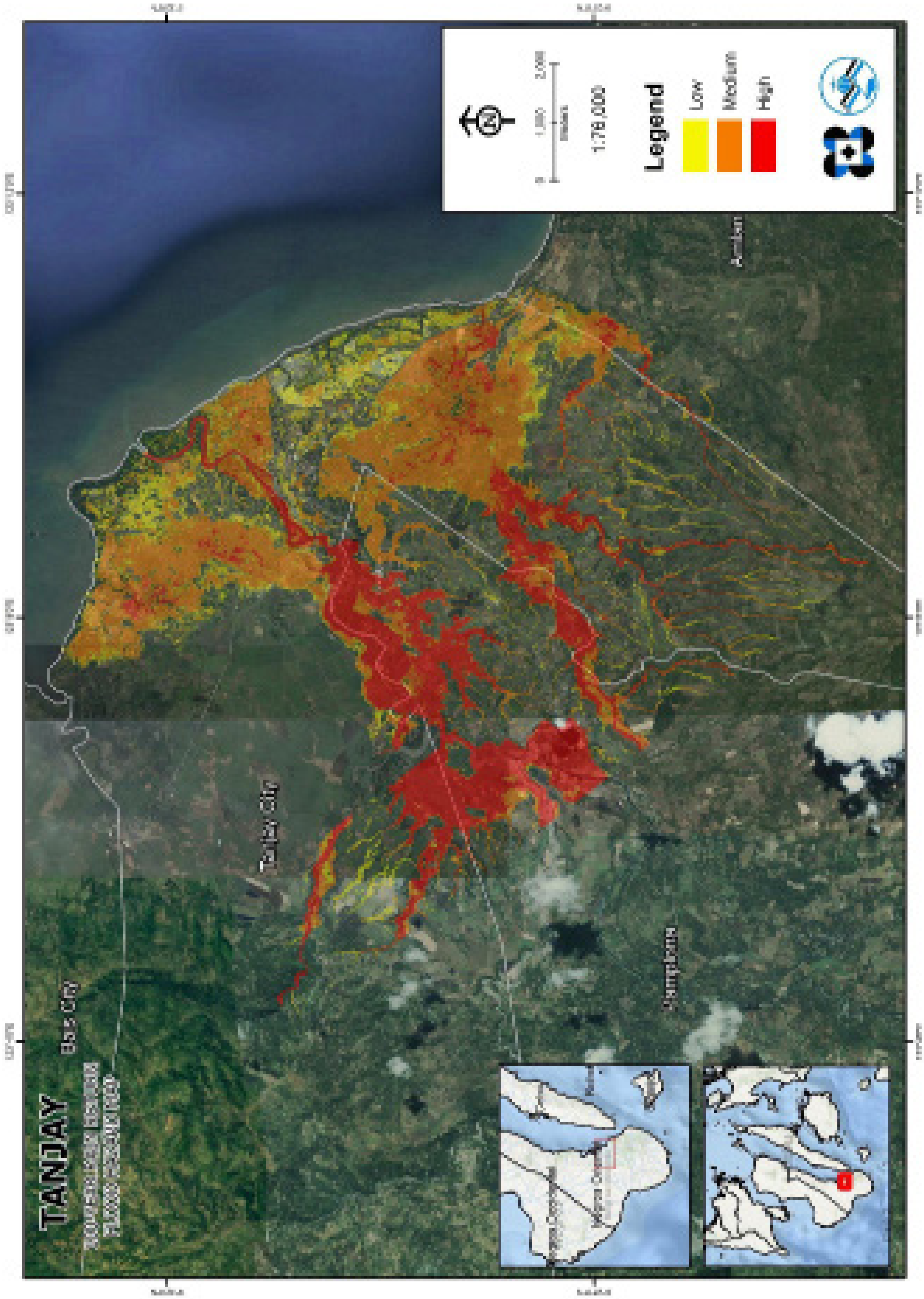

Figure 61. 100-year Flood Hazard Map for Tanjay Floodplain overlaid in Google Earth imagery

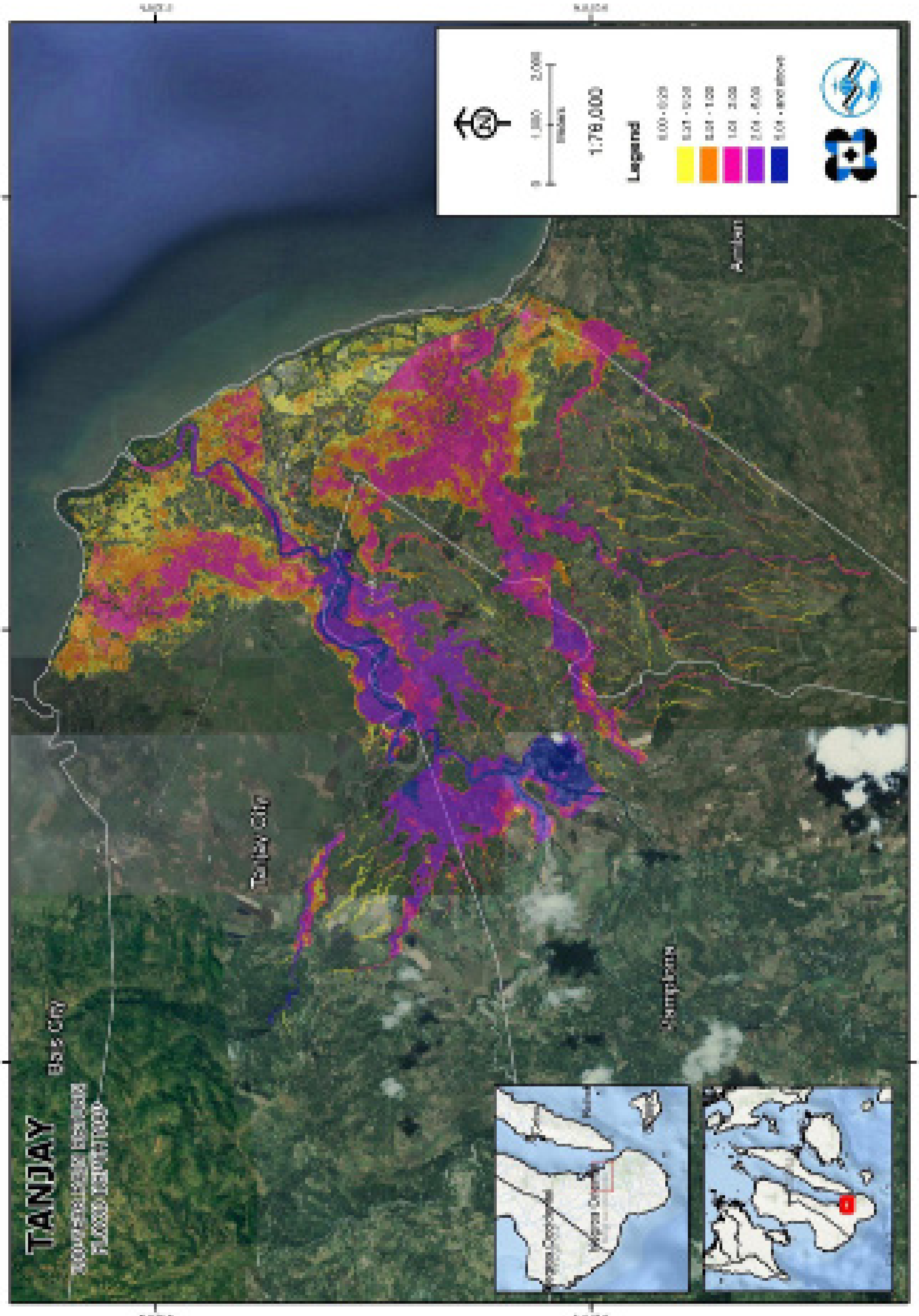

Figure 62. 100-year Flow Depth Map for Tanjay Floodplain overlaid in Google Earth imagery

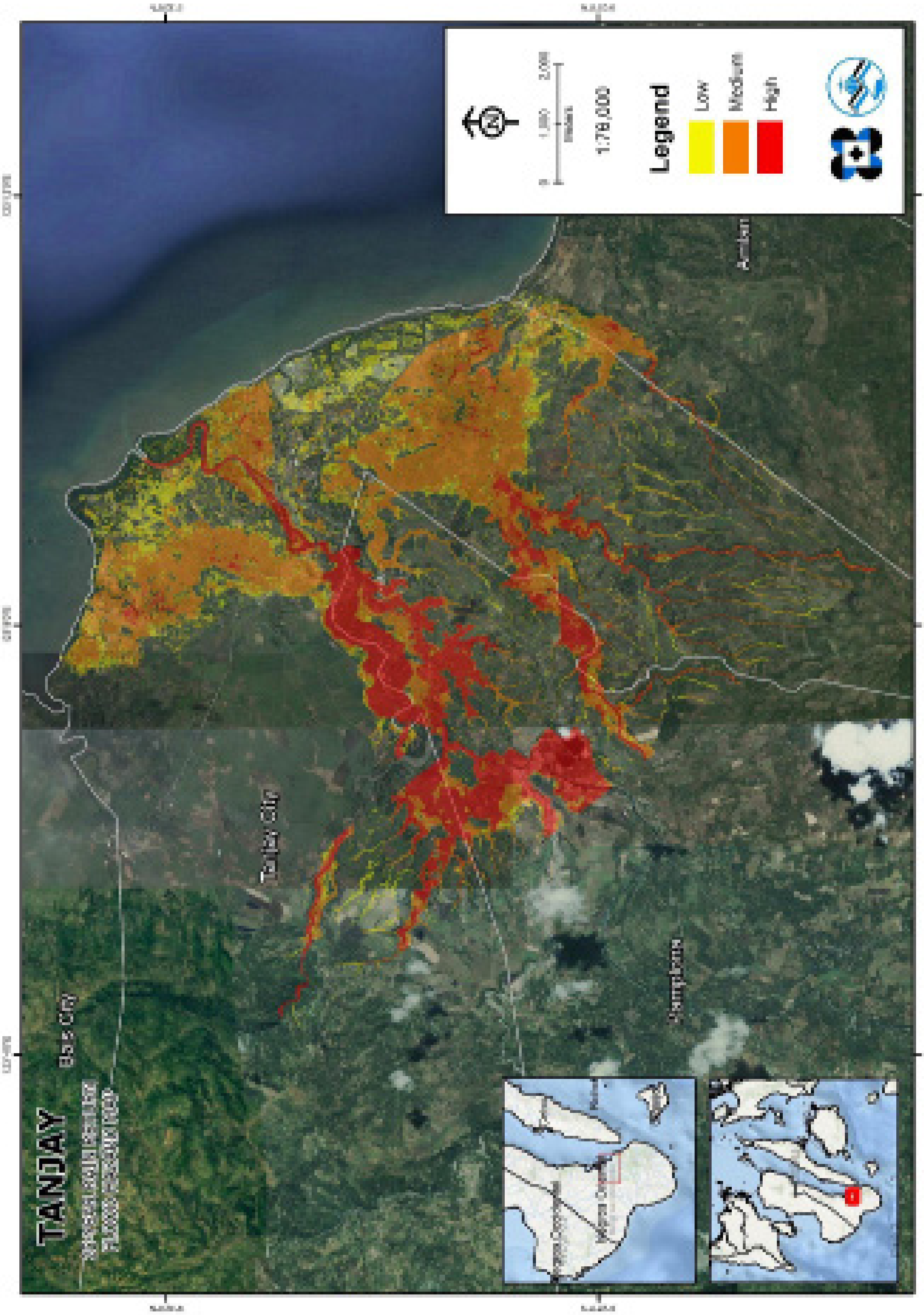

Figure 63. 25-year Flood Hazard Map for Tanjay Floodplain overlaid in Google Earth imagery

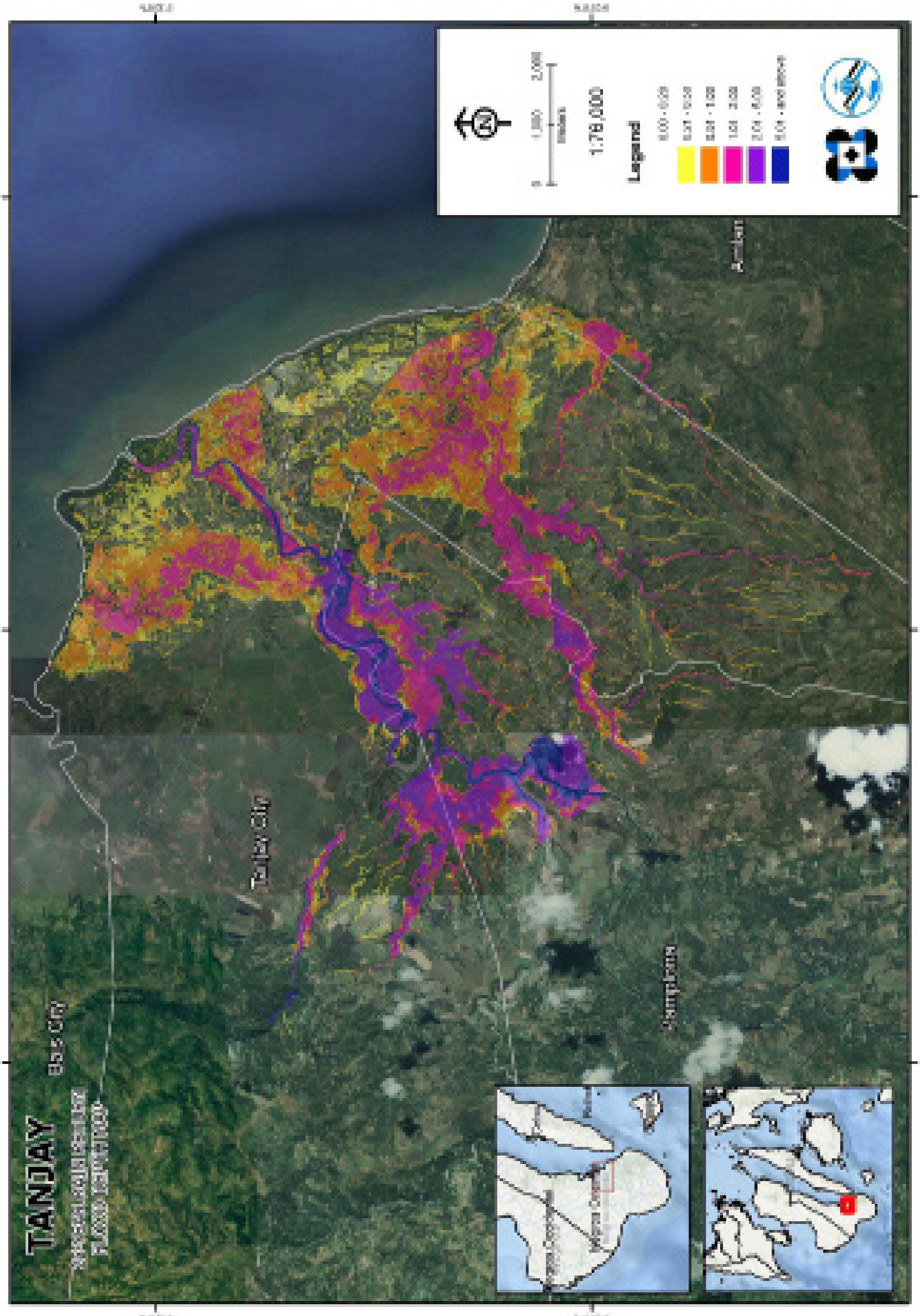

Figure 64. 25-year Flow Depth Map for Tanjay Floodplain overlaid in Google Earth imagery

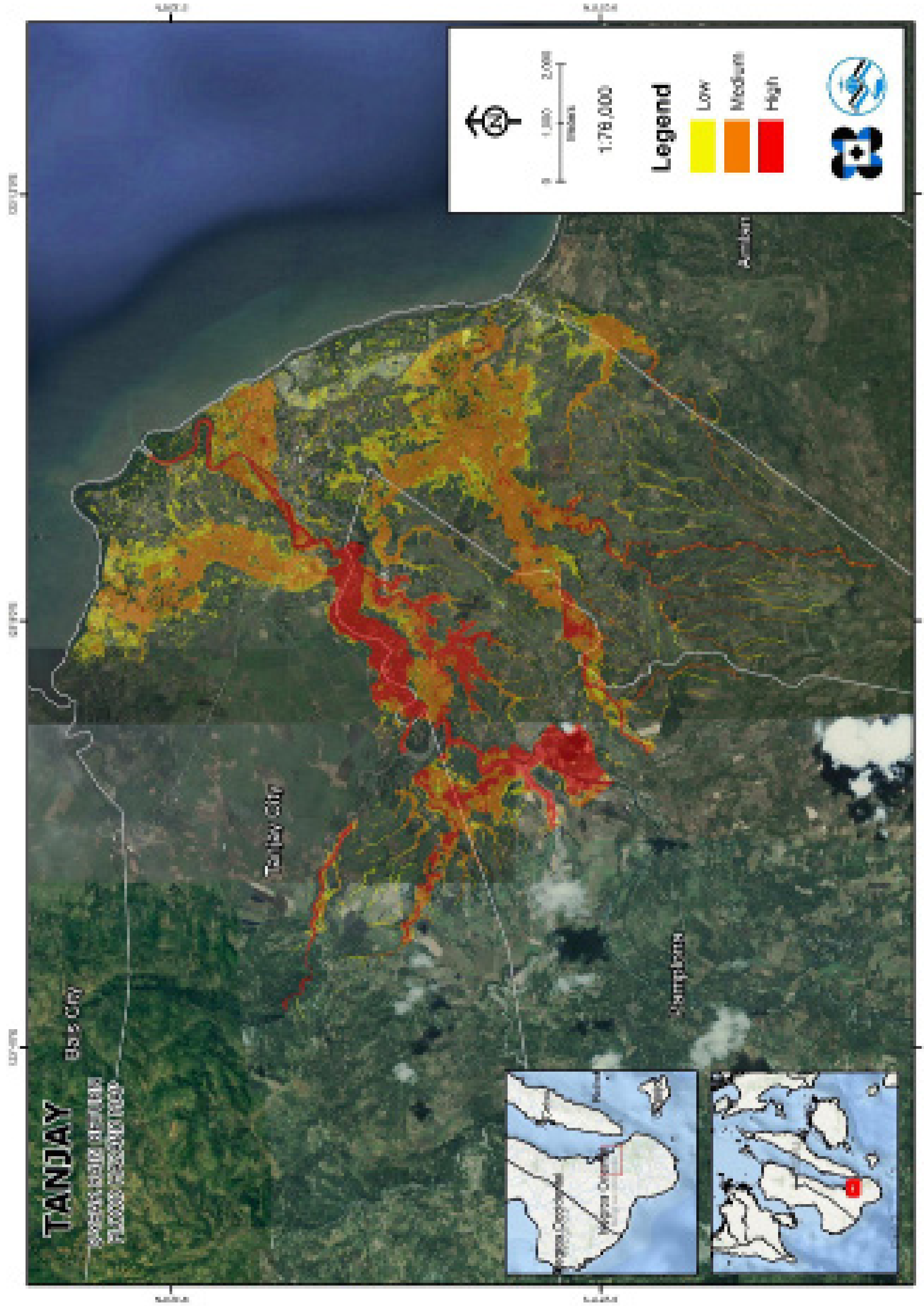

Figure 65. 5-year Flood Hazard Map for Tanjay Floodplain overlaid in Google Earth imagery

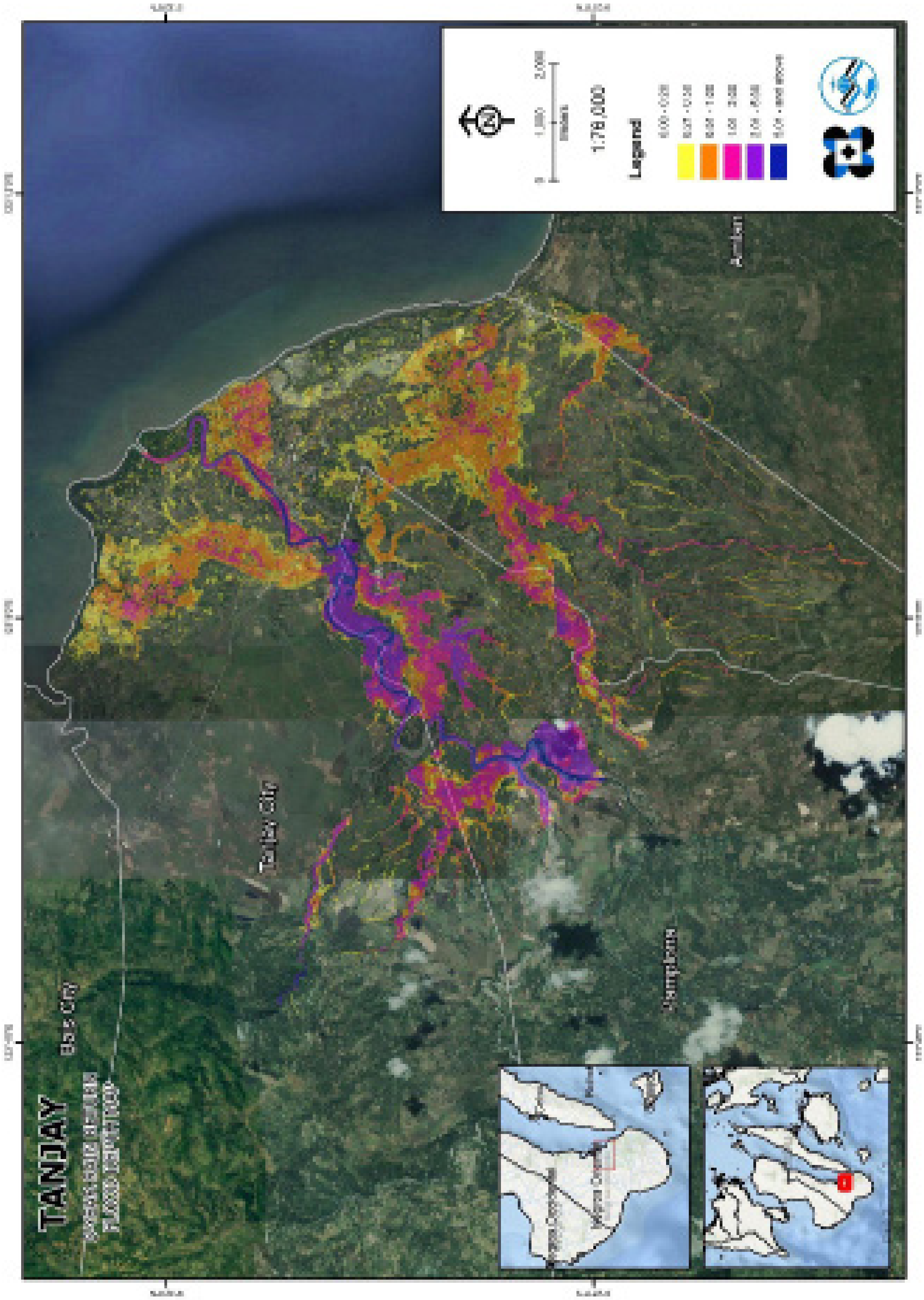

Figure 66. 5-year Flow Depth Map for Tanjay Floodplain overlaid in Google Earth imagery

5.10 Inventory of Areas Exposed to Flooding

Affected barangays in the Tanjay river basin, grouped by municipality, are listed below. For the said basin, three municipalities consisting of 27 barangays are expected to experience flooding when subjected to 5-yr rainfall return period.

For the 5-year return period, 3.496% of the municipality of Amplan with an area of 59.2 sq. km. will experience flood levels of less 0.20 meters. 0.346% of the area will experience flood levels of 0.21 to 0.50 meters while 0.549%, 0.219%, and 0.05% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, and 2.01 to 5 meters, respectively. Listed in Table 32 and shown in Figure 67 are the affected areas in square kilometres by flood depth per barangay.

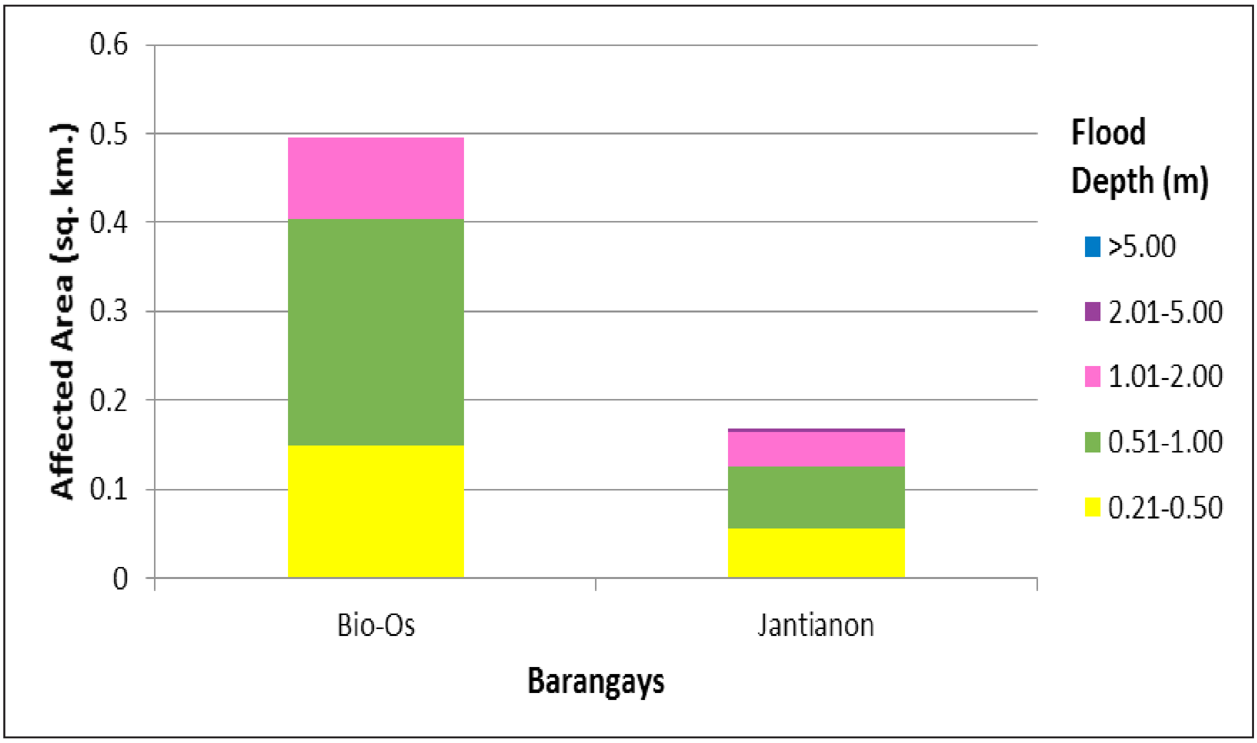

Figure 67. Affected Areas in Amlan, Negros Oriental during 5-Year Rainfall Return Period

Table 32. Affected Areas in Amlan, Negros Oriental during 5-Year Rainfall Return Period

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Amlan (in sq. km.)	
	Bio-Os	Jantianon
0.03-0.20	0.59	1.48
0.21-0.50	0.15	0.056
0.51-1.00	0.26	0.069
1.01-2.00	0.09	0.039
2.01-5.00	0	0.0031
> 5.00	0	0

For the municipality of Pamplona, with an area of 222.7 sq. km., 5.32% will experience flood levels of less 0.20 meters. 0.537% of the area will experience flood levels of 0.21 to 0.50 meters while 0.805%, 1.1%, 1%, and 0.26% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 33 and shown in Figure 68 are the affected areas in square kilometres by flood depth per barangay.

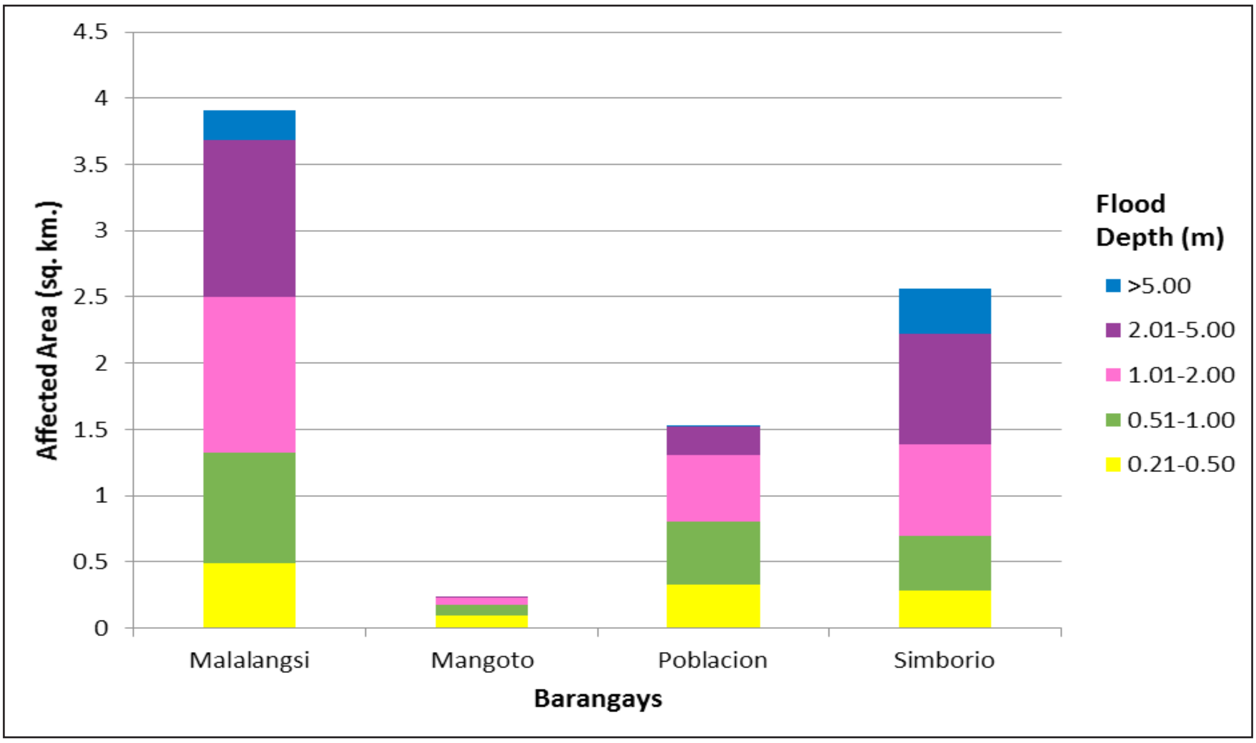

Figure 68. Affected Areas in Pamplona, Negros Oriental during 5-Year Rainfall Return Period

Table 33. Affected Areas in Pamplona, Negros Oriental during 5-Year Rainfall Return Period

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Pamplona (in sq. km.)			
	Malalangsi	Mangoto	Poblacion	Simborio
0.03-0.20	3.91	1.89	3.88	2.19
0.21-0.50	0.49	0.093	0.33	0.28
0.51-1.00	0.83	0.082	0.47	0.41
1.01-2.00	1.18	0.054	0.51	0.7
2.01-5.00	1.18	0.0087	0.21	0.83
> 5.00	0.23	0	0.0032	0.34

For the municipality of Pamplona, with an area of 228.2 sq. km., 17.13% will experience flood levels of less 0.20 meters. 3.214% of the area will experience flood levels of 0.21 to 0.50 meters while 3.436%, 1.715%, 0.464%, and 0.15% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 34 and Table 35 and shown in Figure 69 are the affected areas in square kilometres by flood depth per barangay.

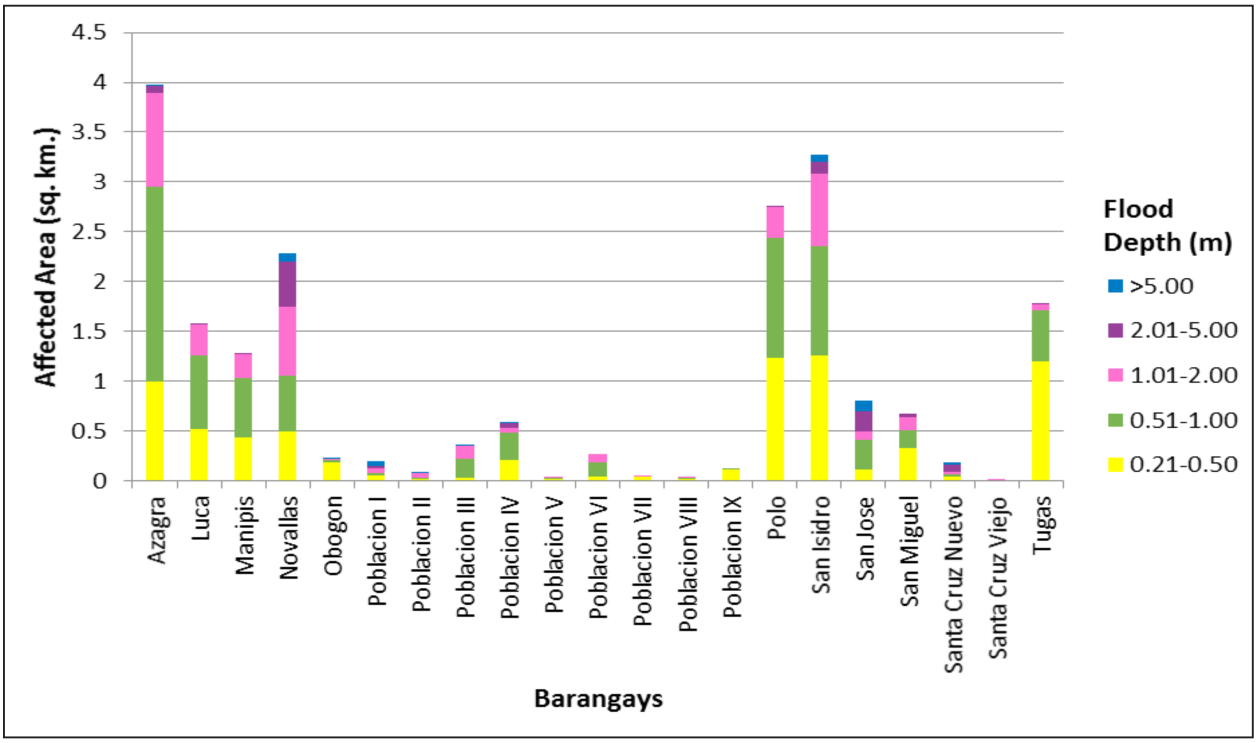

Figure 69. Affected Areas in Tanjay City, Negros Oriental during 5-Year Rainfall Return Period

Table 34. Affected Areas in Tanjay City, Negros Oriental during 5-Year Rainfall Return Period

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Tanjay City (in sq. km.)									
	Azagra	Luca	Manipis	Novallas	Obogon	Poblacion I	Poblacion II	Poblacion III	Poblacion IV	Poblacion V
0.03-0.20	7.12	0.94	0.64	5.83	0.7	0.24	0.08	0.014	0.24	0.064
0.21-0.50	0.99	0.52	0.44	0.49	0.18	0.055	0.014	0.032	0.21	0.02
0.51-1.00	1.95	0.73	0.6	0.56	0.027	0.018	0.017	0.19	0.27	0.012
1.01-2.00	0.94	0.32	0.23	0.69	0.0081	0.048	0.047	0.13	0.055	0.0027
2.01-5.00	0.076	0.0007	0.0002	0.46	0.0022	0.031	0.0027	0.002	0.047	0
> 5.00	0.0031	0	0	0.08	0.0026	0.036	0.0039	0.0069	0.0061	0

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Tanjay City (in sq. km.)										
	Poblacion VI	Poblacion VII	Poblacion VIII	Poblacion IX	Polo	San Isidro	San Jose	San Miguel	Santa Cruz Nuevo	Santa Cruz Viejo	Tugas
0.03-0.20	0.061	0.38	0.21	0.64	6.94	3.08	0.18	7.34	0.94	0.061	3.39
0.21-0.50	0.036	0.037	0.021	0.11	1.24	1.26	0.12	0.33	0.035	0.0019	1.19
0.51-1.00	0.15	0.0081	0.009	0.0051	1.2	1.1	0.29	0.18	0.025	0.0007	0.51
1.01-2.00	0.082	0.00029	0.0002	0	0.32	0.73	0.085	0.13	0.031	0.0003	0.068
2.01-5.00	0	0	0	0	0.0041	0.12	0.21	0.036	0.067	0	0.0004
> 5.00	0	0	0	0	0	0.07	0.11	0	0.025	0	0

For the 25-year return period, 3.23% of the municipality of Amplan with an area of 59.2 sq. km. will experience flood levels of less 0.20 meters. 0.348% of the area will experience flood levels of 0.21 to 0.50 meters while 0.48%, 0.53%, and 0.02% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, and 2.01 to 5 meters, respectively. Listed in Table 36 and shown in Figure 70 are the affected areas in square kilometres by flood depth per barangay.

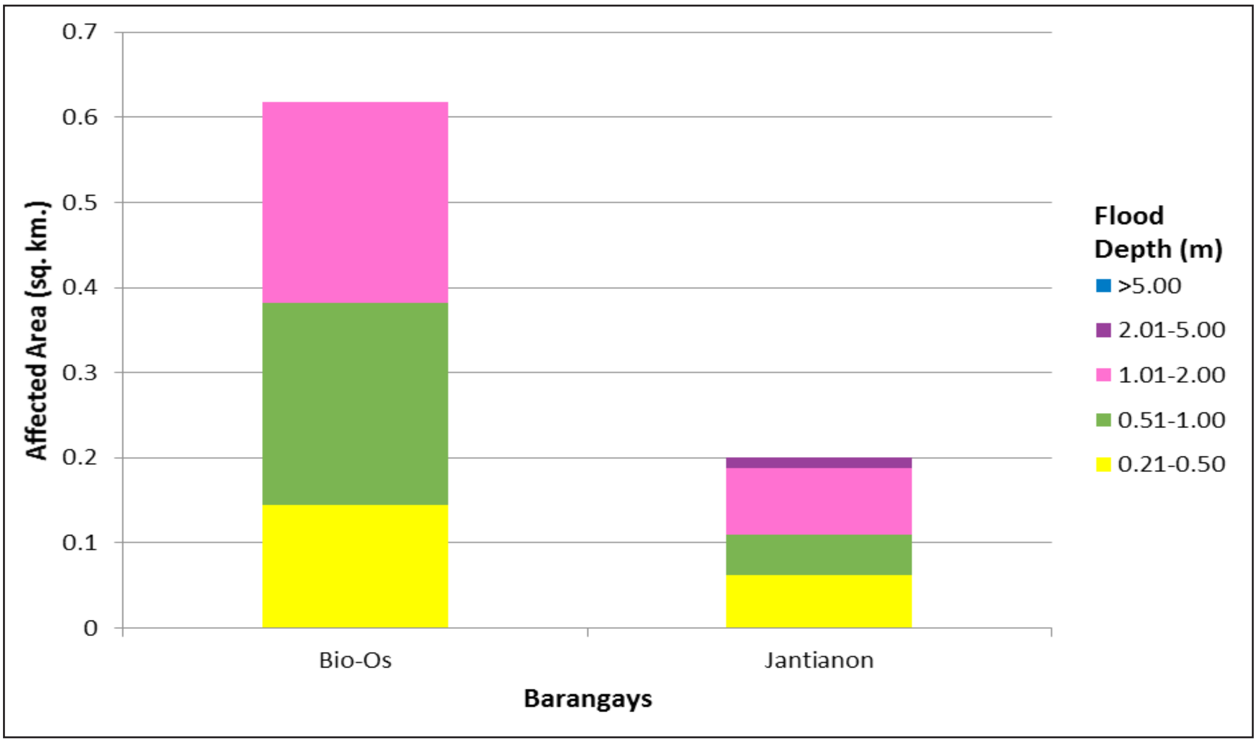

Figure 70. Affected Areas in Amlan, Negros Oriental during 25-Year Rainfall Return Period

Table 35. Affected Areas in Amlan, Negros Oriental during 25-Year Rainfall Return Period

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Amlan (in sq. km.)	
	Bio-Os	Jantianon
0.03-0.20	0.46	1.45
0.21-0.50	0.14	0.062
0.51-1.00	0.24	0.047
1.01-2.00	0.24	0.078
2.01-5.00	0	0.013
> 5.00	0	0

For the municipality of Pamplona, with an area of 222.7 sq. km., 4.83% will experience flood levels of less 0.20 meters. 0.345% of the area will experience flood levels of 0.21 to 0.50 meters while 0.631%, 1.1%, 1.58%, and 0.53% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 37 and shown in Figure 71 are the affected areas in square kilometres by flood depth per barangay.

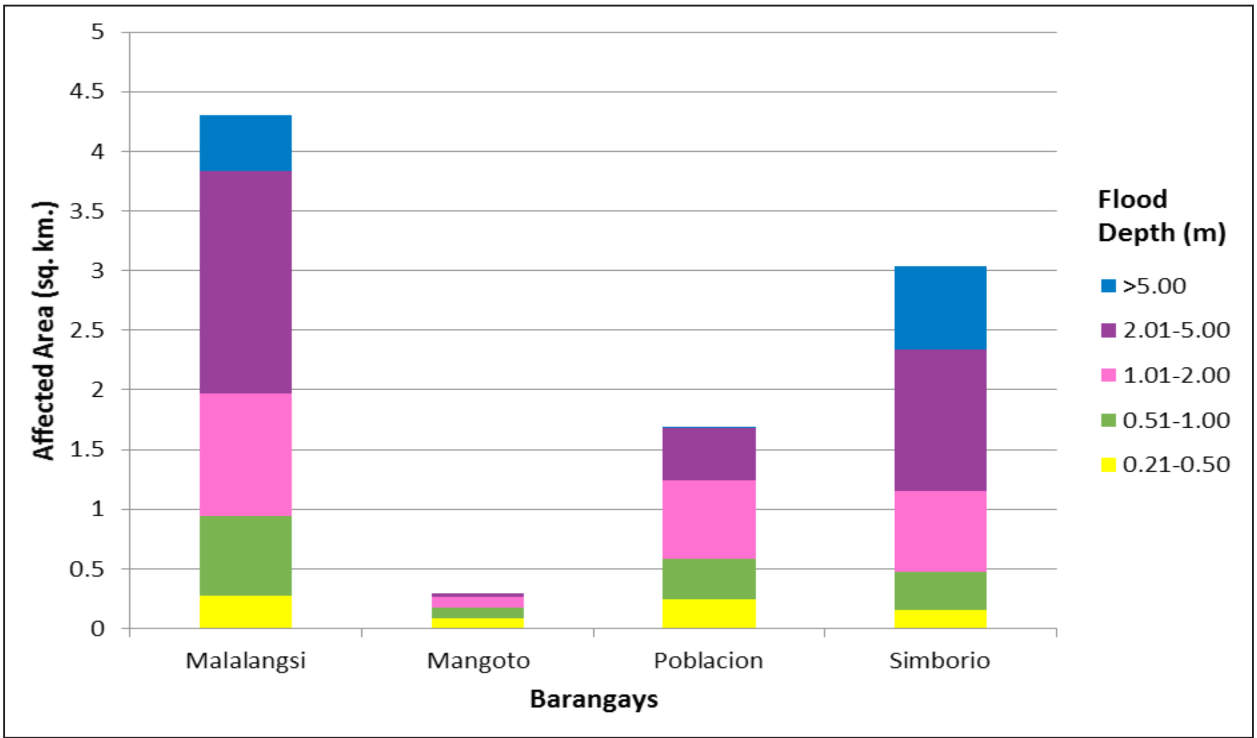

Figure 71. Affected Areas in Pamplona, Negros Oriental during 25-Year Rainfall Return Period

Table 36. Affected Areas in Pamplona, Negros Oriental during 25-Year Rainfall Return Period

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Pamplona (in sq. km.)			
	Malalangsi	Mangoto	Poblacion	Simborio
0.03-0.20	3.51	1.82	3.71	1.72
0.21-0.50	0.27	0.086	0.25	0.16
0.51-1.00	0.66	0.094	0.33	0.31
1.01-2.00	1.03	0.086	0.66	0.68
2.01-5.00	1.86	0.033	0.44	1.19
> 5.00	0.47	0	0.016	0.7

For the municipality of Pamplona, with an area of 228.2 sq. km., 14.38% will experience flood levels of less 0.20 meters. 2.65% of the area will experience flood levels of 0.21 to 0.50 meters while 3.84%, 4%, 1%, and 0.22% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 38 and Table 39, and shown in Figure 72 are the affected areas in square kilometres by flood depth per barangay.

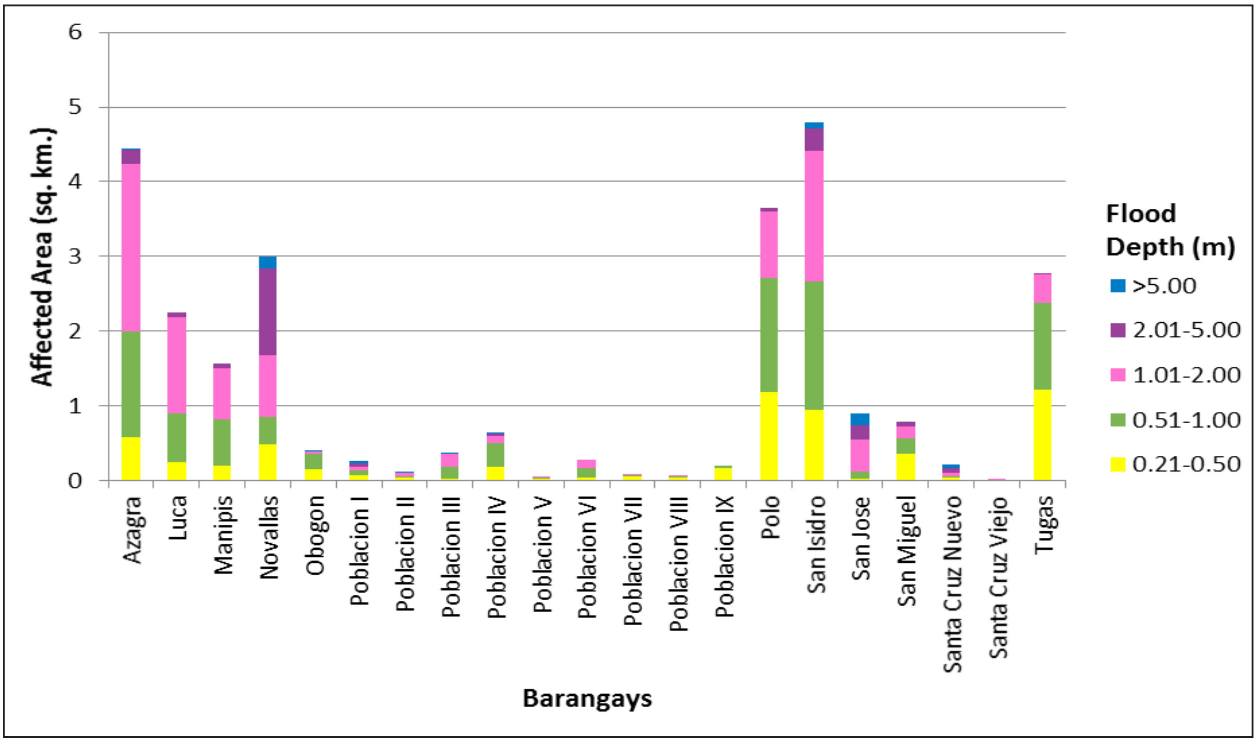

Figure 72. Affected Areas in Tanjay City, Negros Oriental during 25-Year Rainfall Return Period

Table 37. Affected Areas in Tanjay City, Negros Oriental during 25-Year Rainfall Return Period

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Tanjay City (in sq. km.)									
	Azagra	Luca	Manipis	Novallas	Obogon	Poblacion I	Poblacion II	Poblacion III	Poblacion IV	Poblacion V
0.03-0.20	6.65	0.27	0.35	5.12	0.53	0.17	0.057	0.011	0.18	0.053
0.21-0.50	0.58	0.25	0.2	0.48	0.15	0.073	0.034	0.02	0.18	0.025
0.51-1.00	1.43	0.65	0.62	0.36	0.21	0.068	0.015	0.16	0.33	0.017
1.01-2.00	2.23	1.28	0.68	0.82	0.018	0.038	0.051	0.17	0.083	0.0042
2.01-5.00	0.2	0.07	0.061	1.16	0.0069	0.049	0.0046	0.0022	0.047	0
> 5.00	0.005	0	0	0.17	0.0027	0.037	0.0039	0.0071	0.0069	0

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Tanjay City (in sq. km.)										
	Poblacion VI	Poblacion VII	Poblacion VIII	Poblacion IX	Polo	San Isidro	San Jose	San Miguel	Santa Cruz Nuevo	Santa Cruz Viejo	Tugas
0.03-0.20	0.054	0.35	0.18	0.56	6.05	1.56	0.089	7.22	0.9	0.053	2.41
0.21-0.50	0.031	0.059	0.03	0.17	1.18	0.94	0.026	0.36	0.034	0.0088	1.21
0.51-1.00	0.13	0.011	0.017	0.019	1.53	1.72	0.087	0.2	0.023	0.0014	1.16
1.01-2.00	0.12	0.00046	0.013	0	0.89	1.76	0.43	0.17	0.04	0.0007	0.37
2.01-5.00	0	0	0	0	0.045	0.3	0.2	0.068	0.073	0	0.0054
> 5.00	0	0	0	0	0	0.077	0.16	0	0.044	0	0

For the 100-year return period, 3.08% of the municipality of Amplan with an area of 59.2 sq. km. will experience flood levels of less 0.20 meters. 0.304% of the area will experience flood levels of 0.21 to 0.50 meters while 0.49%, 0.7%, and 0.044% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, and 2.01 to 5 meters, respectively. Listed in Table 40 and shown in Figure 73 are the affected areas in square kilometres by flood depth per barangay.

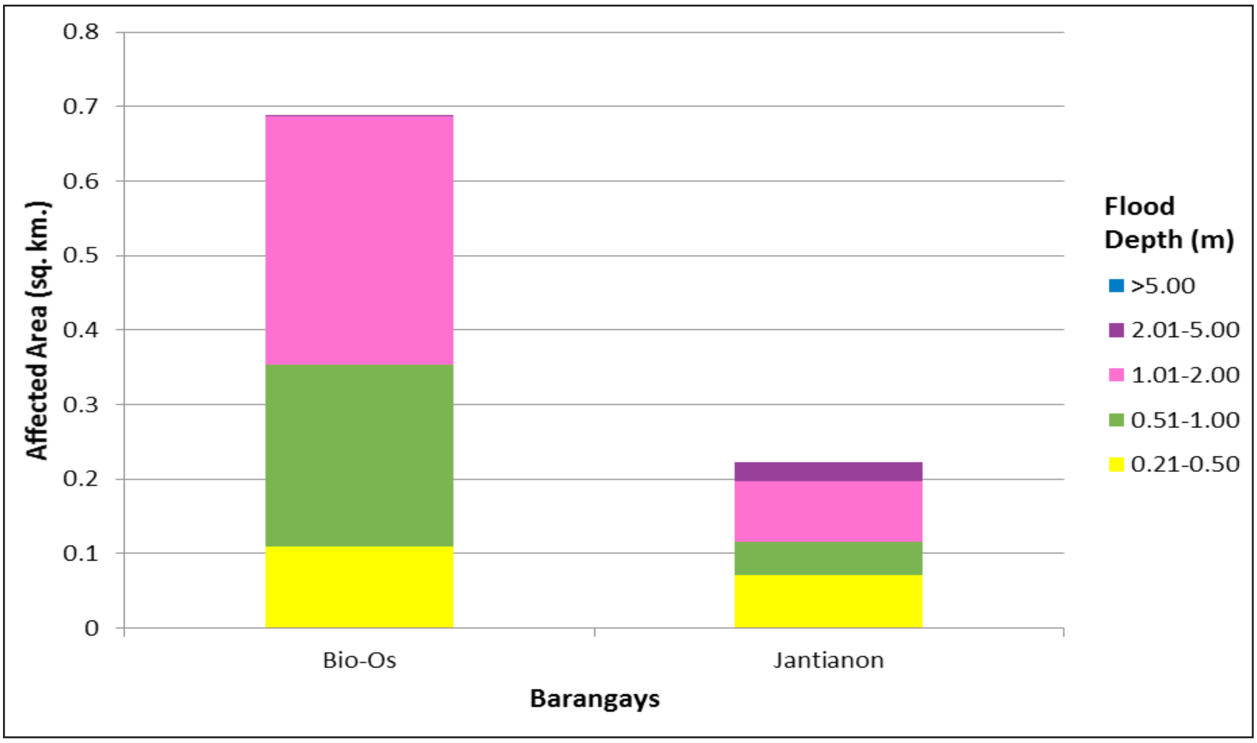

Figure 73. Affected Areas in Amlan, Negros Oriental during 100-Year Rainfall Return Period

Table 38. Affected Areas in Amlan, Negros Oriental during 100-Year Rainfall Return Period

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Amlan (in sq. km.)	
	Bio-Os	Jantianon
0.03-0.20	0.39	1.43
0.21-0.50	0.11	0.071
0.51-1.00	0.24	0.045
1.01-2.00	0.33	0.081
2.01-5.00	0.0002	0.026
> 5.00	0	0

For the municipality of Pamplona, with an area of 222.7 sq. km., 4.62% will experience flood levels of less 0.20 meters. 0.278% of the area will experience flood levels of 0.21 to 0.50 meters while 0.435%, 0.9%, 1.92%, and 0.88% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 41 and shown in Figure 74 are the affected areas in square kilometres by flood depth per barangay.

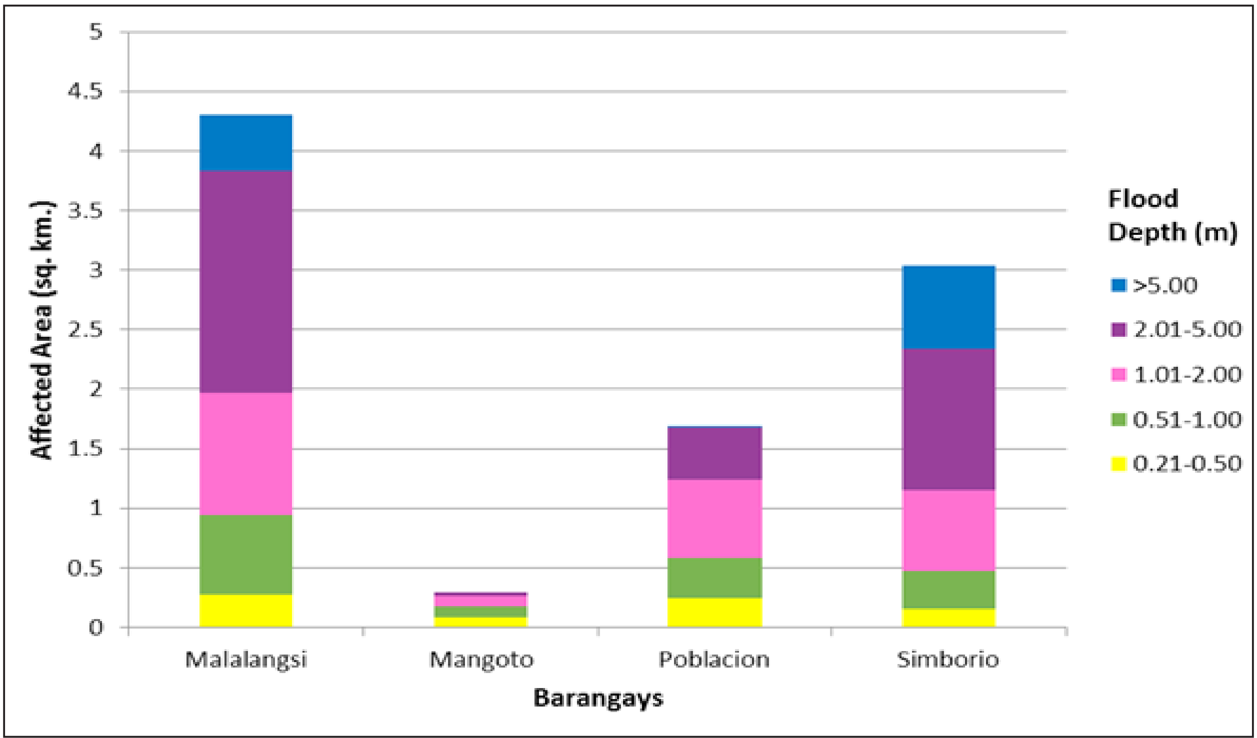

Figure 74. Affected Areas in Pamplona, Negros Oriental during 100-Year Rainfall Return Period

Table 39. Affected Areas in Pamplona, Negros Oriental during 100-Year Rainfall Return Period

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Pamplona (in sq. km.)			
	Malalangsi	Mangoto	Poblacion	Simborio
0.03-0.20	3.3	1.78	3.63	1.56
0.21-0.50	0.21	0.091	0.23	0.083
0.51-1.00	0.47	0.077	0.26	0.16
1.01-2.00	0.72	0.12	0.64	0.53
2.01-5.00	2.3	0.054	0.51	1.41
> 5.00	0.8	0	0.14	1.02

For the municipality of Pamplona, with an area of 228.2 sq. km., 13.21% will experience flood levels of less 0.20 meters. 2.38% of the area will experience flood levels of 0.21 to 0.50 meters while 3.33%, 4.98%, 1.85%, and 0.356% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 42 and Table 43, and shown in Figure 75 are the affected areas in square kilometres by flood depth per barangay.

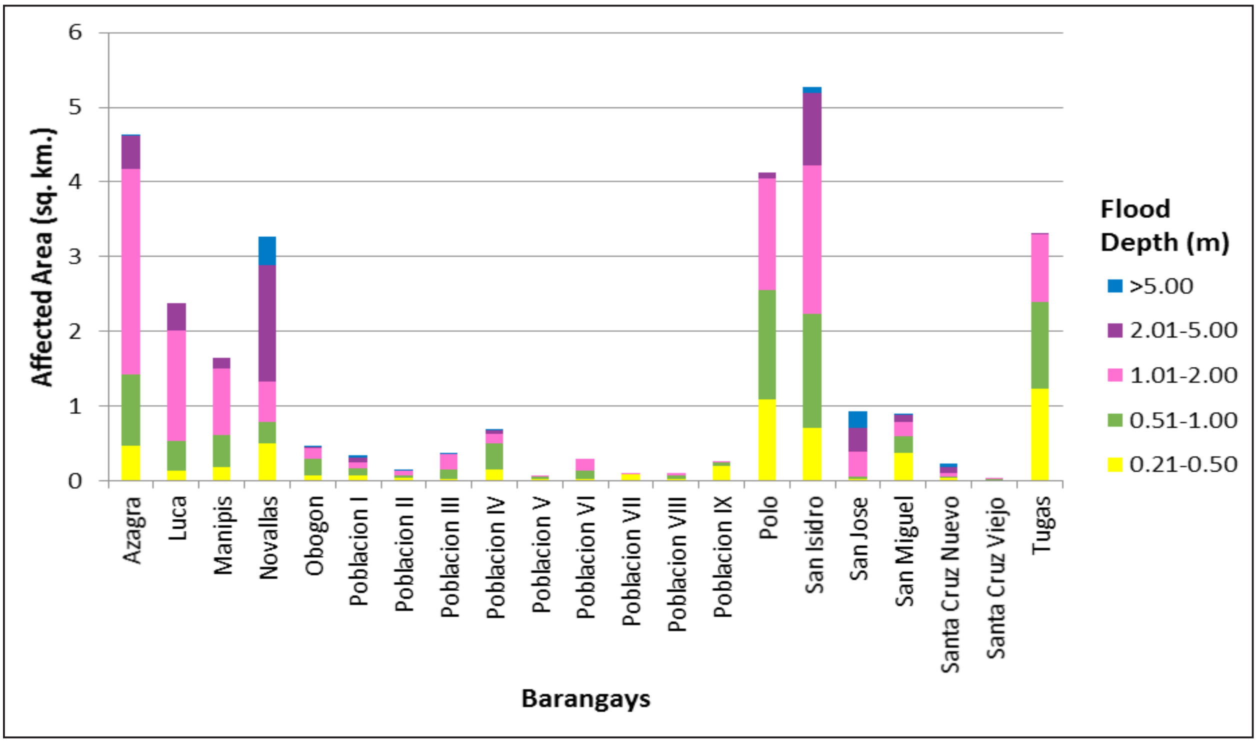

Figure 75. Affected Areas in Tanjay City, Negros Oriental during 100-Year Rainfall Return Period

Table 40. Affected Areas in Tanjay City, Negros Oriental during 100-Year Rainfall Return Period

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Tanjay City (in sq. km.)									
	Azagra	Luca	Manipis	Novallas	Obogon	Poblacion I	Poblacion II	Poblacion III	Poblacion IV	Poblacion V
0.03-0.20	6.47	0.13	0.26	4.84	0.47	0.088	0.027	0.0081	0.14	0.036
0.21-0.50	0.46	0.13	0.18	0.51	0.077	0.062	0.036	0.014	0.14	0.026
0.51-1.00	0.95	0.4	0.44	0.28	0.21	0.11	0.039	0.13	0.36	0.03
1.01-2.00	2.76	1.47	0.88	0.53	0.15	0.078	0.051	0.21	0.13	0.0065
2.01-5.00	0.44	0.38	0.15	1.57	0.0095	0.059	0.0074	0.0027	0.046	0
> 5.00	0.0064	0	0	0.38	0.0029	0.037	0.004	0.0074	0.0083	0

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Tanjay City (in sq. km.)										
	Poblacion VI	Poblacion VII	Poblacion VIII	Poblacion IX	Polo	San Isidro	San Jose	San Miguel	Santa Cruz Nuevo	Santa Cruz Viejo	Tugas
0.03-0.20	0.048	0.33	0.14	0.51	5.56	1.09	0.066	7.14	0.89	0.046	1.86
0.21-0.50	0.029	0.078	0.028	0.2	1.09	0.7	0.016	0.38	0.035	0.014	1.22
0.51-1.00	0.11	0.014	0.036	0.041	1.47	1.53	0.038	0.22	0.019	0.0032	1.17
1.01-2.00	0.14	0.00087	0.031	0.00049	1.48	1.98	0.33	0.18	0.046	0.0011	0.89
2.01-5.00	0	0	0	0	0.086	0.97	0.32	0.094	0.078	0	0.014
> 5.00	0	0	0	0	0	0.085	0.22	0.0005	0.055	0	0

Among the barangays in the municipality of Amlan, Jantianon is projected to have the highest percentage of area that will experience flood levels at 2.79%. Meanwhile, Bio-Os posted the second highest percentage of area that may be affected by flood depths at 1.83%.

Among the barangays in the municipality of Pamplona, Malalangsi is projected to have the highest percentage of area that will experience flood levels at 3.51%. Meanwhile, Poblacion posted the second highest percentage of area that may be affected by flood depths at 2.42%.

Among the barangays in the city of Tanjay, Azagra is projected to have the highest percentage of area that will experience flood levels at 4.86%. Meanwhile, Polo posted the second highest percentage of area that may be affected by flood depths at 4.25%.

Moreover, the generated flood hazard maps for the Tanjay Floodplain were used to assess the vulnerability of the educational and medical institutions in the floodplain. Using the flood depth units of PAG-ASA for hazard maps - “Low”, “Medium”, and “High” - the affected institutions were given their individual assessment for each Flood Hazard Scenario (5 yr, 25 yr, and 100 yr).

Table 41. Area covered by each warning level with respect to the rainfall scenario

Warning Level	Area Covered in sq. km.		
	5 year	25 year	100 year
Low	8.87	7.12	6.33
Medium	14.50	17.95	17.34
High	6.42	12.17	16.80
TOTAL	**29.79**	**37.24**	**40.47**

Of the 22 identified Education Institutions in the Tanjay Floodplain, 3 schools were assessed to be exposed to Low level flooding during a 5 year scenario, while 3 schools were also assessed to be exposed to Medium level flooding in the same scenario. In the 25 year scenario, 4 schools were assessed to be exposed to low level flooding, while 6 schools were assessed to be exposed to medium level flooding in the same scenario. In the 100 year scenario, 3 schools were assessed to be exposed to low level flooding, while 8 schools were assessed to be exposed to medium level flooding in the same scenario. The list of educational institutions exposed to flooding in the Tanjay floodplain is found in Annex 12.

Of the 5 identified Medical Institutions in the Tanjay Floodplain, 1 medical institution was assessed to be exposed to Low level flooding during a 25 year scenario. In the 100 year scenario, 2 medical institutions were assessed ot be exposed to low level flooding. The list of medical or health institutions exposed to flooding in the Tanjay floodplain is found in Annex 13.

5.11 Flood Validation

Survey was done along the floodplain of Tanjay River to validate the generated flood maps. The team gathered secondary data regarding flood occurrence in the area. Ground validation points were acquired as well as the other necessary details like date of occurrence, name of typhoon and actual flood depth.

During validation conducted last July 21 to 22, 2016, the team was assisted by the local Disaster Risk Reduction and Management representative from the Municipality of Tanjay. Residents along the floodplain were interviewed of the historical flood events they experiences.

Actual flood depth acquired from the ground validation were then computed and compared to the flood depth simulated by the model. An RMSE value of 2.45 was obtained.

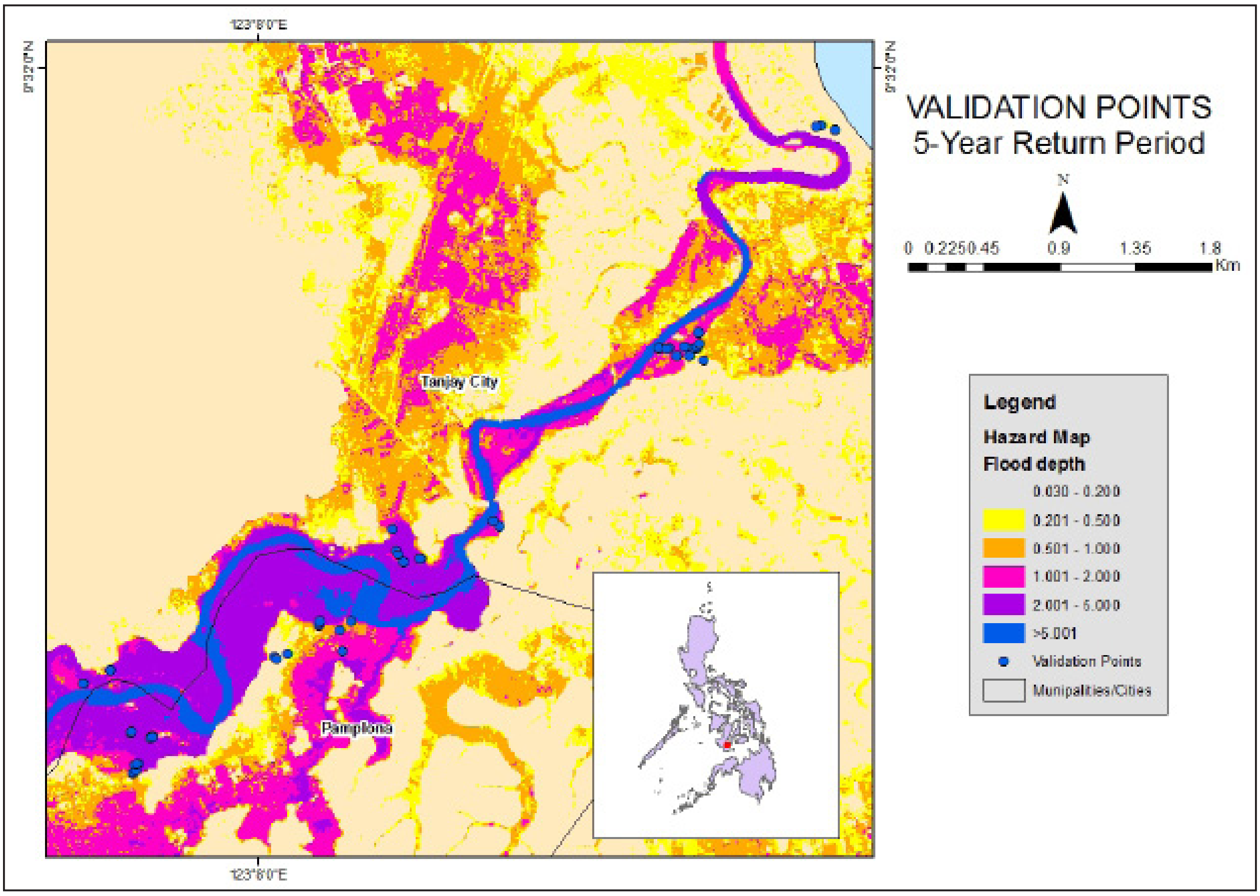

Figure 76. Tanjay River Basin Flood Validation Points

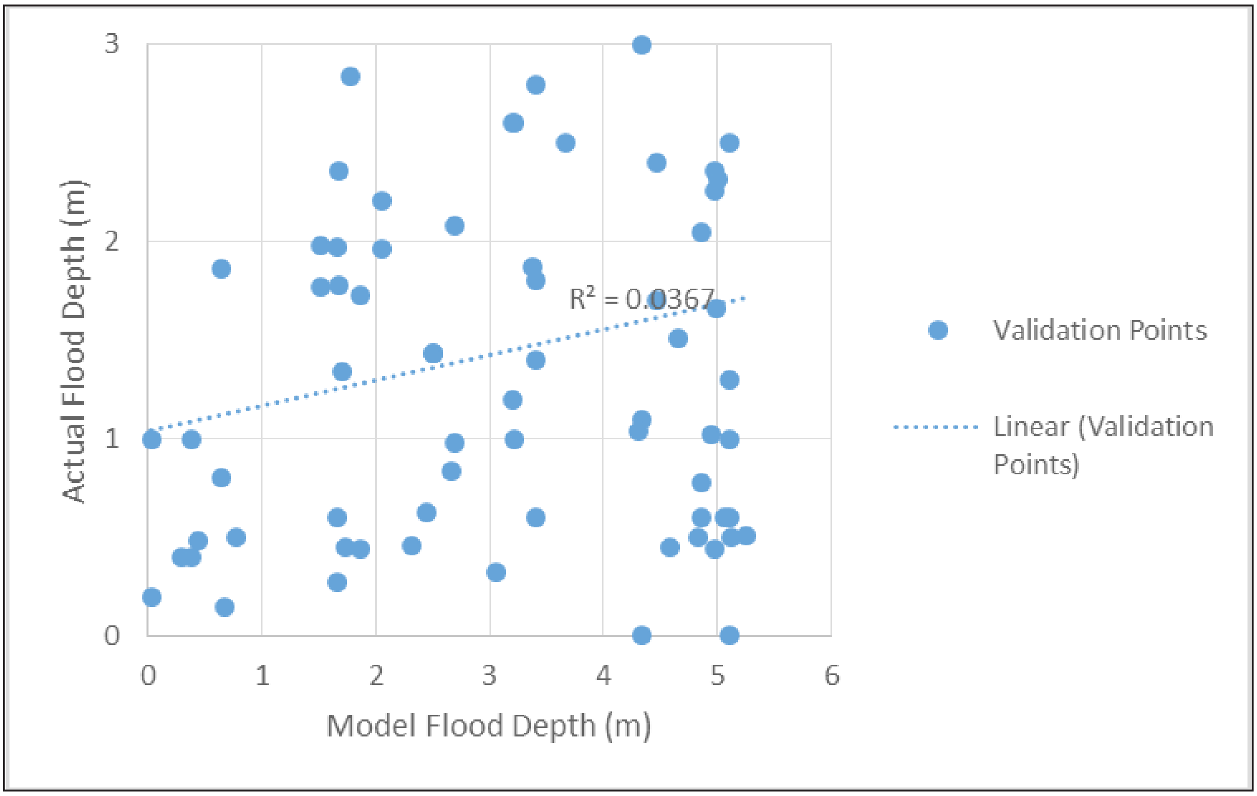

Figure 77. Flood map depth vs. actual flood depth

Table 42. Actual flood vs simulated flood depth at different levels in the Tanjay 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	1	0	1	0	1	1	4
0.21-0.50	0	3	1	3	5	1	13
0.51-1.00	1	1	1	1	7	4	15
1.01-2.00	0	0	1	6	13	1	21
2.01-5.00	0	0	0	2	14	1	17
> 5.00	0	0	0	0	1	0	1
Total	2	4	4	12	41	8	71

Table 43. Summary of the Accuracy Assessment in the Tanjay River Basin Survey

	No. of Points	%
Correct	25	35.21
Overestimated	40	56.34
Underestimated	6	8.45
Total	71	100.00

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Annex 1. Optech Technical Specification of the Gemini Sensor

1. GEMINI SENSOR

2. PARAMETERS AND SPECIFICATIONS OF THE GEMINI SENSOR

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

Annex 2. NAMRIA Certificates of Reference Points Used

1. 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**	Barangay:	**IPILAN**		
Municipality:	**PUERTO PRINCESA CITY (CAPITAL)**	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:	**85.64700 m.**
		PTM / PRS92 Coordinates			
Northing:	**1015530.347 m.**	Easting:	**453844.056 m.**	Zone:	**1A**
		UTM / PRS92 Coordinates			
Northing:	**1,015,326.41**	Easting:	**618,656.93**	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

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	-26.465
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

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:	gpt 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

2

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	35.993 m	Height	35.834 m	Height	85.647 m

To:	qzt 2				
Grid		Local		Global	
Easting	597450.975 m	Latitude	N9°10'57.93286"	Latitude	N9°10'53.56686"
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	0.0000238932

23

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

22

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

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°26'00.86501"
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

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	2.595

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

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	49.766 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

Annex 4. The LiDAR Survey Team Composition

Data Acquisition Component Sub -Team	Designation	Name	Agency / Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	ENGR. CZAR JAKIRI SARMIENTO	UP-TCAGP
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 Tanjay 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-Jan-15	3049P	1BLK42S18SA	Pegasus	980	na	7	192	31	352	15.3	29.3	15.2	1KB	1KB	70/57	na	Z:\DAC\RAW DATA
30-Jan-15	3073P	1BLK42S171A	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	1.64	na	11.6	256	2.11	1020/661	38.5	108	9.43	1KB	1KB	95	na	Z:\DAC\RAW DATA
8-Jul	3145P	1BLK42GRT189A	Pegasus	752	na	5.41	194	166	101	14.8	NA	11.9	1KB	1KB	179/96	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
13-Jul	3161P	1BLK42LM193A	Pegasus	1.51	477/407	9.82	214	29.7	559	26.8	67.6	4.26	1KB	1KB	216	na	Z:\DAC\RAW DATA
13-Jul	3165P	1BLK42LM194A	Pegasus	1.5	na	13.5	236	35.4	295	26.9	na	11.5	1KB	1KB	na	na	Z:\DAC\RAW DATA
13-Jul	3167P	1BLK42JB194B	Pegasus	320	na	3.65	195	4.93	2	7.36	11	11.5	1KB	1KB	109/120	NA	Z:\DAC\RAW DATA
15-Jul	3179P	1BLK42KS196A	Pegasus	550	9978	2.73	63.2	na	na	3.33	7.6	1.15	1KB	1KB	11	NA	Z:\DAC\RAW DATA

Received from

Name
Position PA
Signature

Received by

Name AC Bongat
Position SSRP
Signature 8/5/2015

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	
* transferred twice 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	160	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	2BLK42DQ339B	GEMINI	NA	734	530	218	na	na	22.3	na	12.1	1KB	1KB	24/22/30/53/50/48/51	NA	Z:\DAC\RAW DATA
28-Nov-15	3581	2BLK42NPQ341A	GEMINI	NA	872	484	232	na	na	21.2	na	8.55	1KB	NA	24/22/21/27/30/53/50/48/51	NA	Z:\DAC\RAW DATA
30-Nov-15	3585	2BLK42Nv342A	GEMINI	NA	1080	558	234	na	na	23	na	5.29	1KB	1KB	24/22/21/28/27/30/53/50/48/51	NA	Z:\DAC\RAW DATA
30-Nov-15	3593	2BLK42TwEwF344A	GEMINI	NA	1343	523	227	na	na	20.9	na	11.4	1KB	1KB	53/50/48/17	NA	Z:\DAC\RAW DATA
1-Dec-15	3595	2BLK42US344B	GEMINI	NA	253	387	156	na	na	17.4	na	11.4	1KB	1KB	17/16	NA	Z:\DAC\RAW DATA

Received from

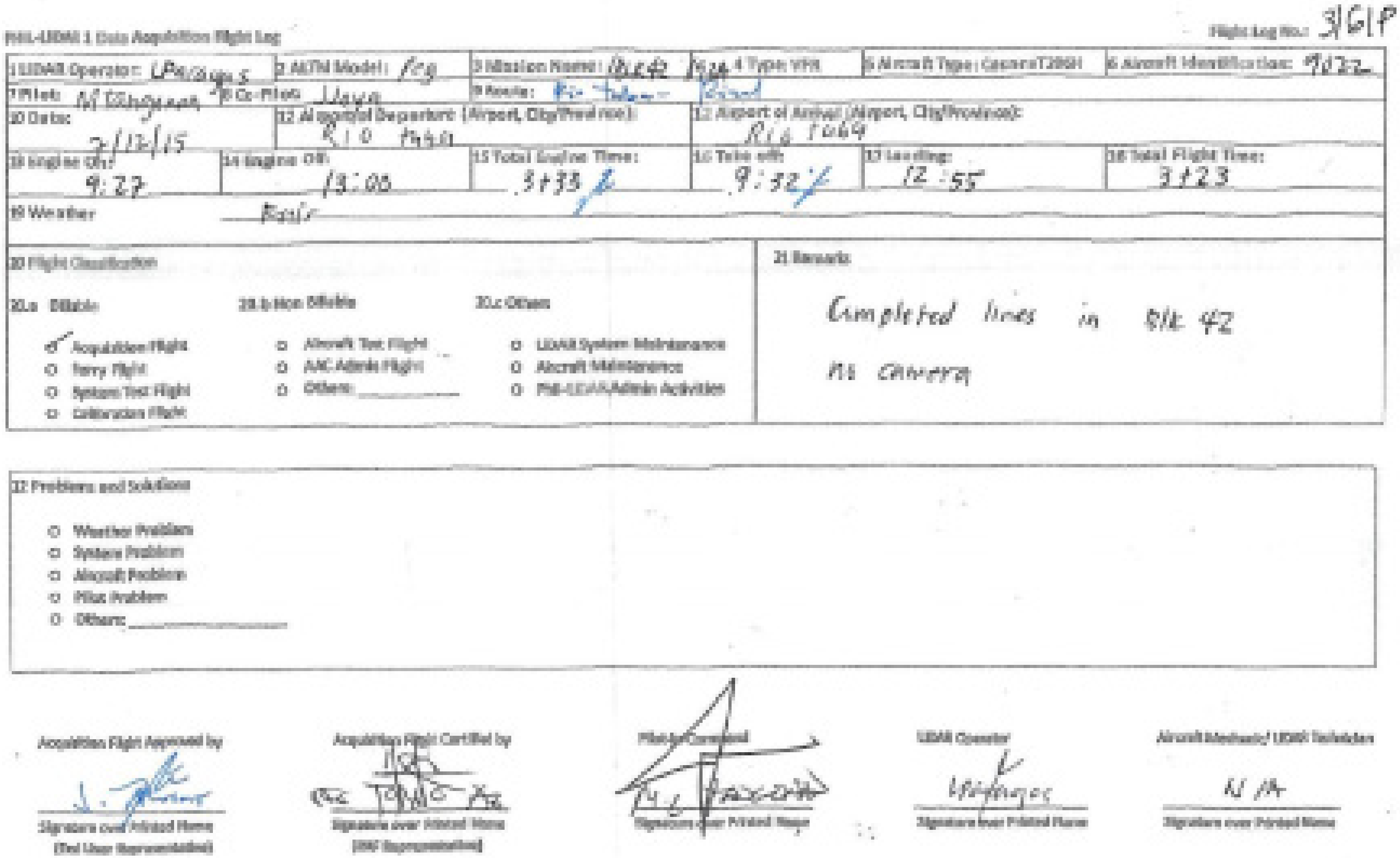
Name C. Joaquin
Position
Signature

Received by

Name AC Bongat
Position SSRS
Signature 1/5/2016

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: CesnnaT206H
6 Aircraft Identification: 9122
7 Pilot: M Tangonan
8 Co-Pilot: J Maya
10 Date: 7/13/15
12 Airport of Departure (Airport, City/Province): Rio Tuba
12 Airport of Arrival (Airport, City/Province): Rio Tuba
13 Engine On: 9:22
14 Engine Off: 13:00
15 Total Engine Time: 3+38
16 Take off: 9:32
17 Landing: 12:55
18 Total Flight Time: 3+23
19 Weather: Fair

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

21 Remarks
Completed 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
(End User Representative)

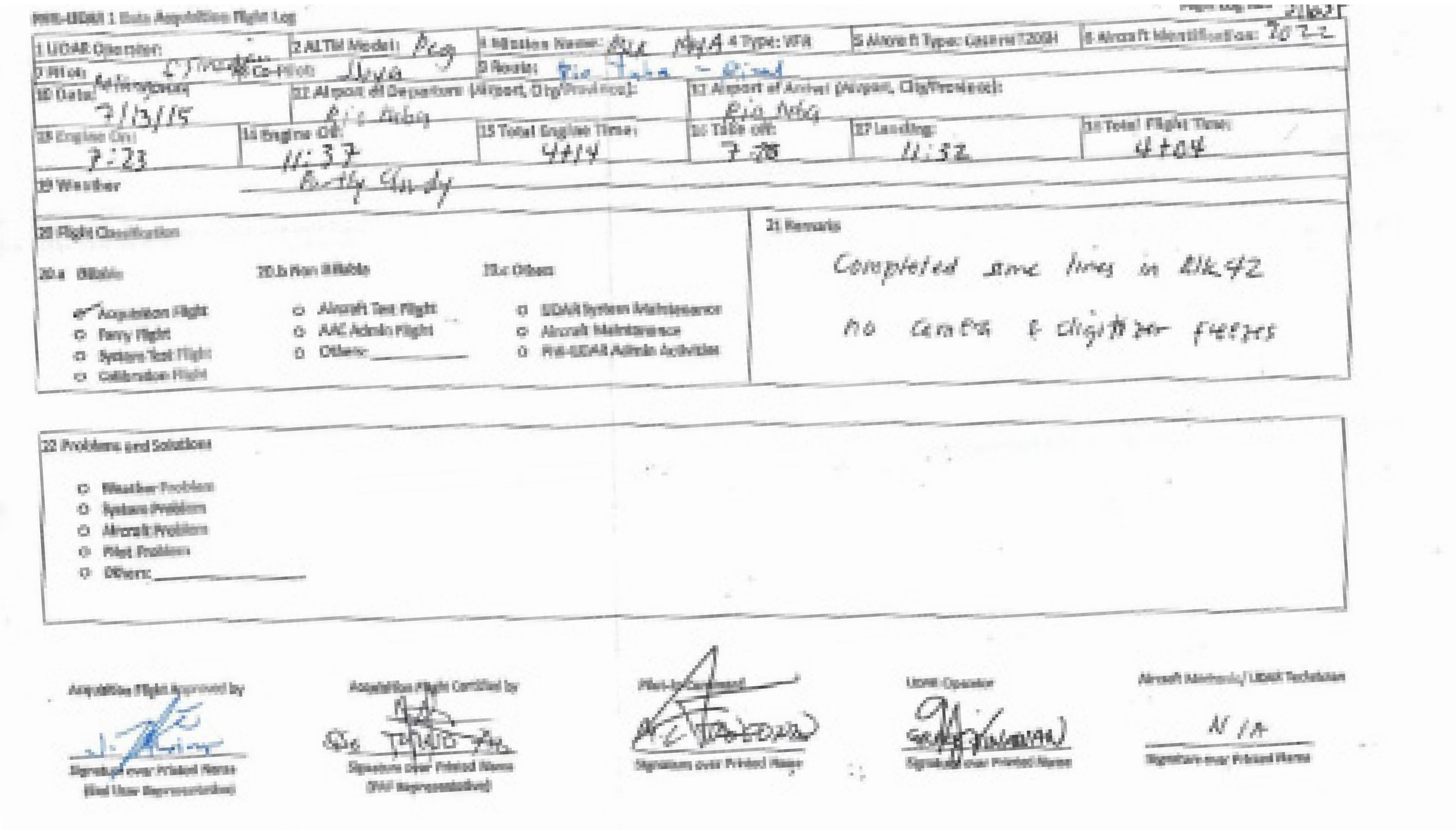
Acquisition Flight Certified by
Signature over Printed Name
(PAF Representative)

Pilot-in-Command
Signature over Printed Name

LIDAR Operator
Signature over Printed Name

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

2. Flight Log for 1BLK42LM194A Mission


PHIL-LIDAR 1 Data Acquisition Flight Log

1 LiDAR Operator:	2 ALTM Model: Peg	3 Mission Name: BLK 42A	4 Type: VFR	5 Aircraft Type: Cessna T206H	6 Aircraft Identification: 9022
7 Pilot:	8 Co-Pilot:	9 Route: Rio Tuba - Bind			
10 Date: 7/13/15		12 Airport of Departure (Airport, City/Province): Rio Tuba		13 Airport of Arrival (Airport, City/Province): Rio Tuba	
13 Engine On: 7:23	14 Engine Off: 11:37	15 Total Engine Time: 4+14	16 Take off: 7:28	17 Landing: 11:32	18 Total Flight Time: 4+04
19 Weather	Partly Cloudy				

20 Flight Classification

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

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

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

21 Remarks

Completed 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)

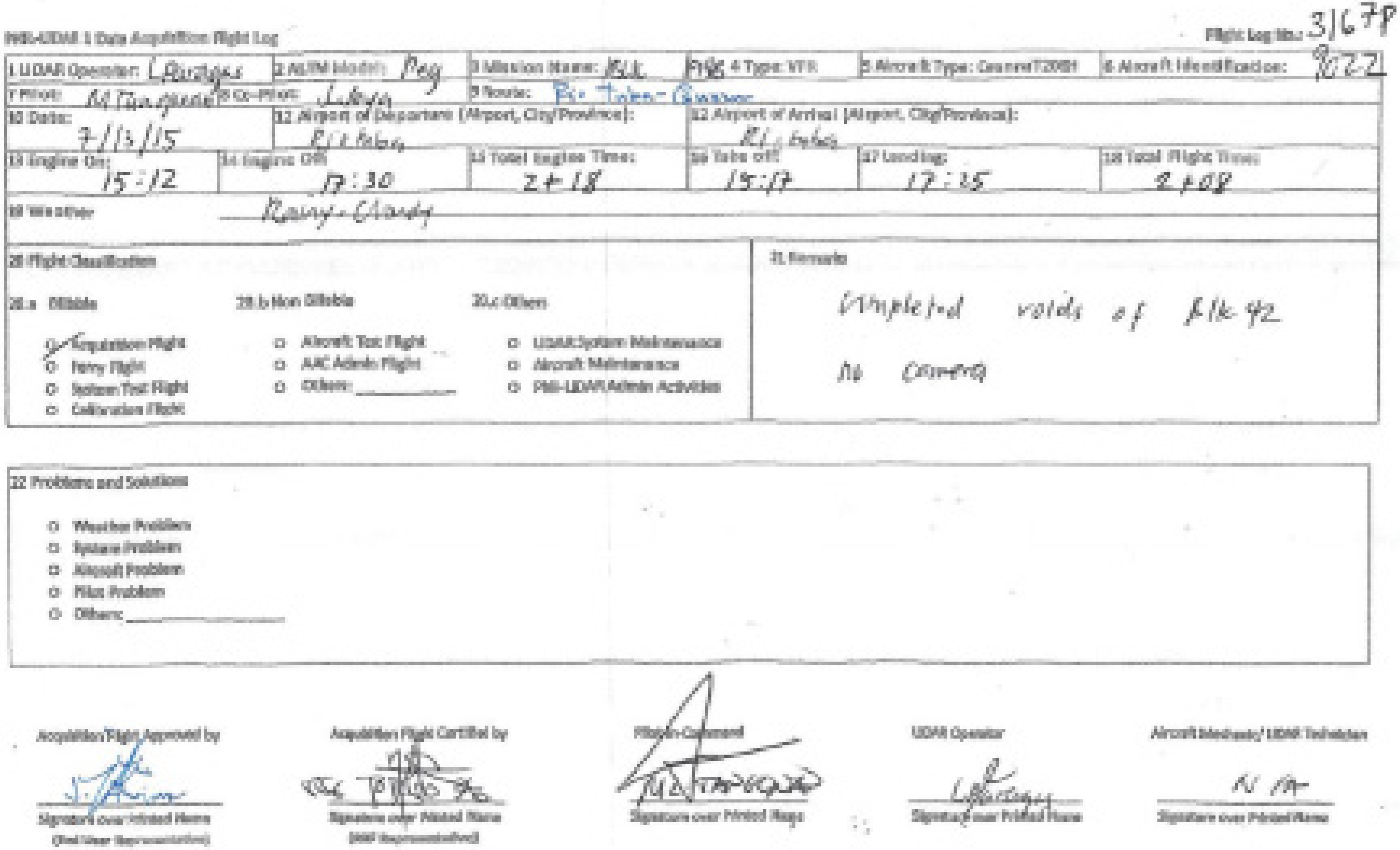
Acquisition Flight Certified by — Signature over Printed Name (PAF Representative)

Pilot-in-Command — Signature over Printed Name

LiDAR Operator — Signature over Printed Name

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

3. Flight Log for 1BLK42JS194B Mission


PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 3167P

1 LIDAR Operator: L Paragas	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:			
10 Date: 7/13/15	12 Airport of Departure (Airport, City/Province):		12 Airport of Arrival (Airport, City/Province):		
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
- 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 voids of 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 (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

4. Flight Log for 2BLK42Ov339A Mission

Data Acquisition Flight Log — Flight Log No.: 35736

1 LIDAR Operator: M.CE BALIGUAS	2 ALTM Model: GEM	3 Mission Name: 2BLK42Ov339A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9022
7 Pilot: A. LIM	8 Co-Pilot: R. LACCO	9 Route: RTH - RTH			
10 Date: Dec. 5, 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: 0700 H	17 Landing: 1043 H	18 Total Flight Time: 3+43
19 Weather: Cloudy					

20 Flight Classification

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

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

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

21 Remarks

Surveyed BLK42D and covered voids over west coast

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator	Aircraft Mechanic/ Technician
G. Hipolito	A2C [illegible] PAF	A. LIM	MCE BALIGUAS	G. ANTONIO
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

Annex 7. Flight Status

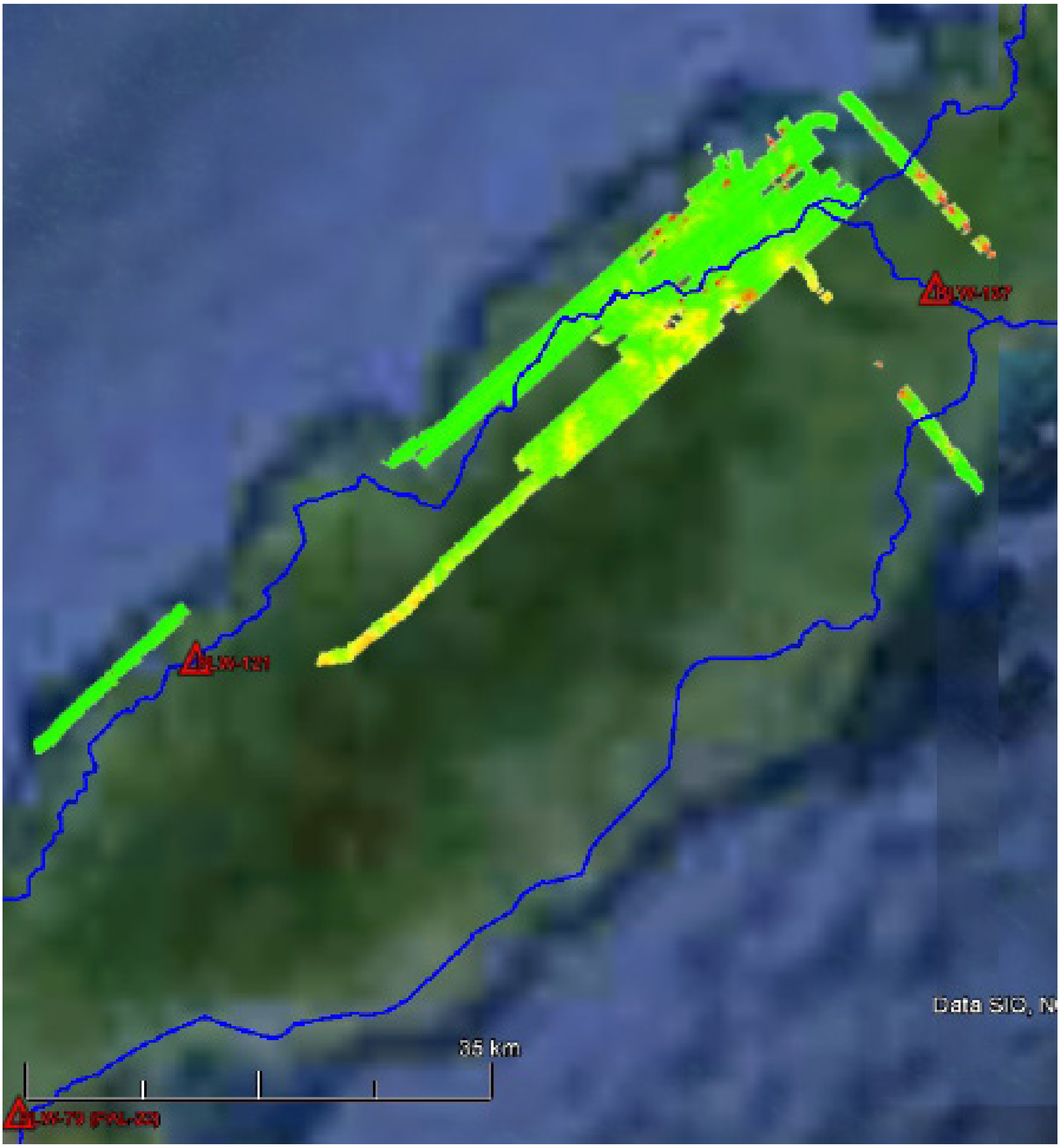
FLIGHT STATUS REPORT
Tanjay FLOODPLAIN
(July 11-13 & December 5, 2015)

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

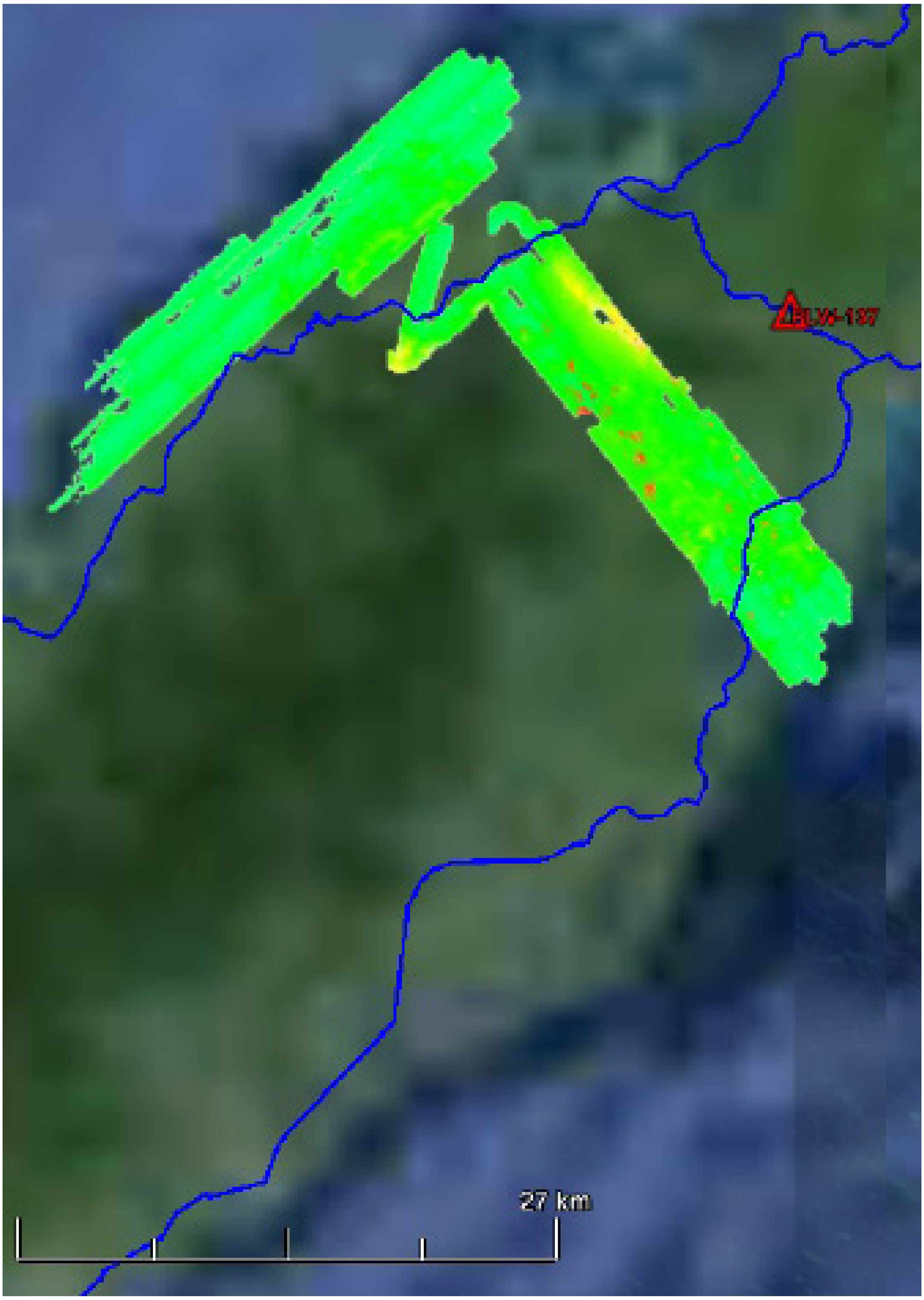
FLIGHT LOG NO.	3161P	
AREA:	BLOCK 42LM	
MISSION NAME:	1BLK42LM193A	PRF: 200
	Scan Freq: 30 Hz	Scan Angle: 25 deg
SURVEY COVERAGE:		

LAS



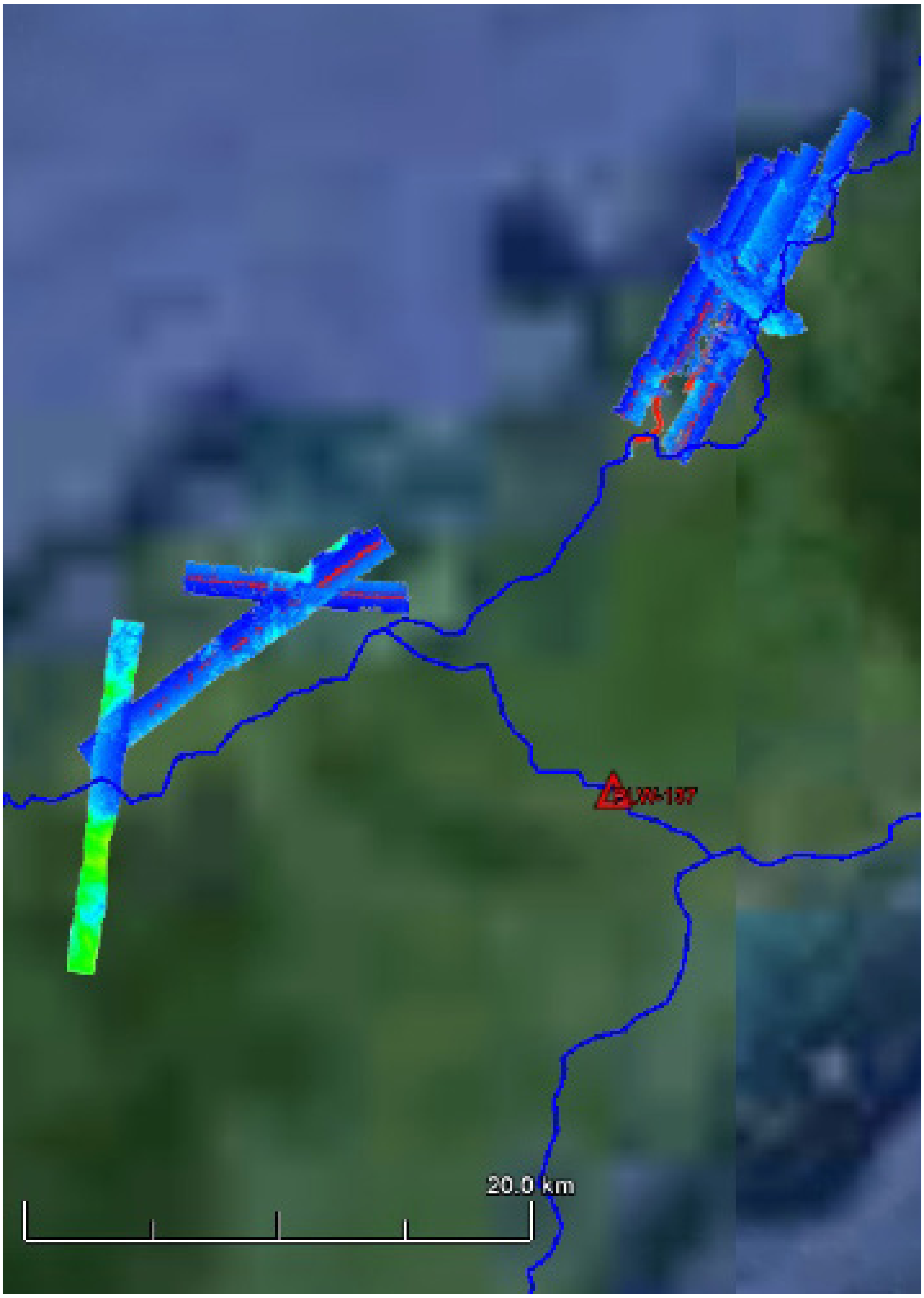
FLIGHT LOG NO.	3165P	
AREA:	BLOCK 42LM	
MISSION NAME:	1BLK42LM194A	PRF: 200
	Scan Freq: 30 Hz	Scan Angle: 25 deg
SURVEY COVERAGE:		

LAS

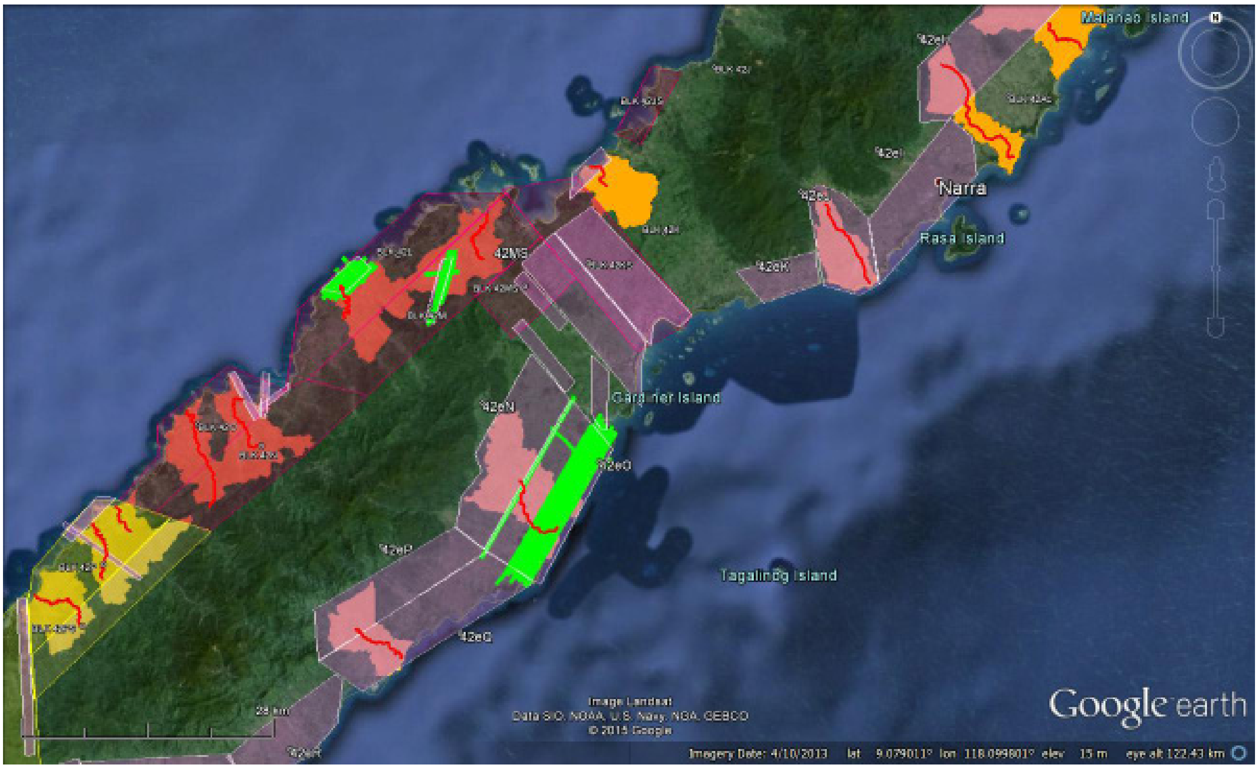


FLIGHT LOG NO.	3167P	
AREA:	BLOCK 42JS	
MISSION NAME:	1BLK42JS194B	PRF: 200
	Scan Freq: 30 Hz	Scan Angle: 25 deg
SURVEY COVERAGE:		

LAS



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



ANNEX 8. Mission Summary Reports

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

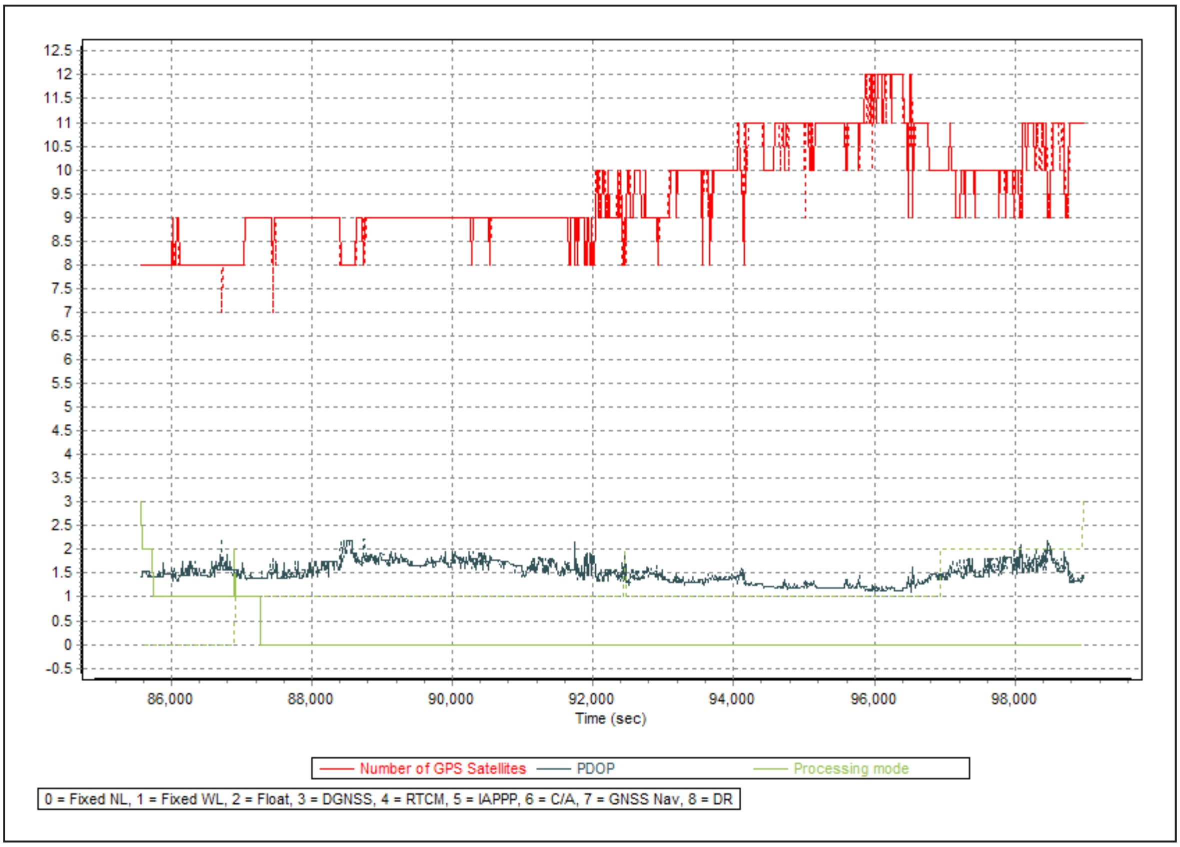


Figure A-8.1. Solution Status

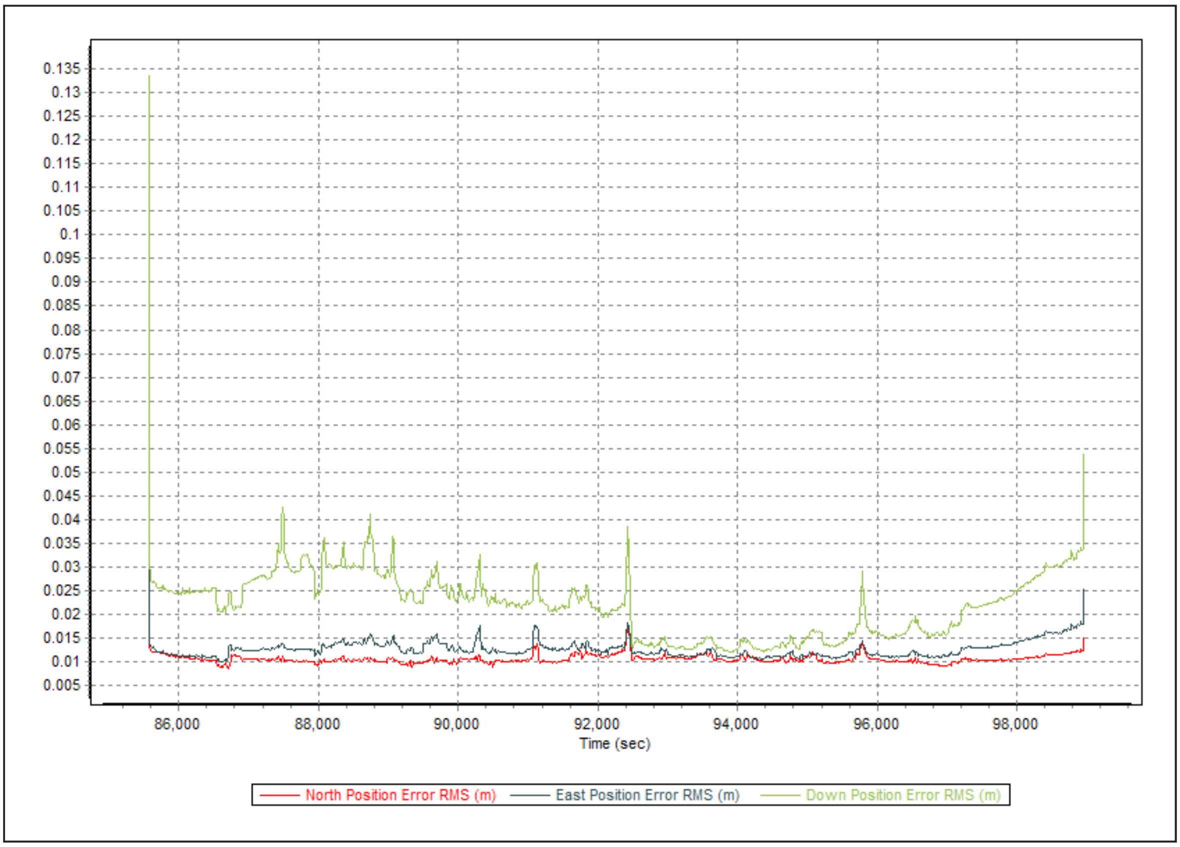


Figure A-8.2. Smoothed Performance Metric Parameters

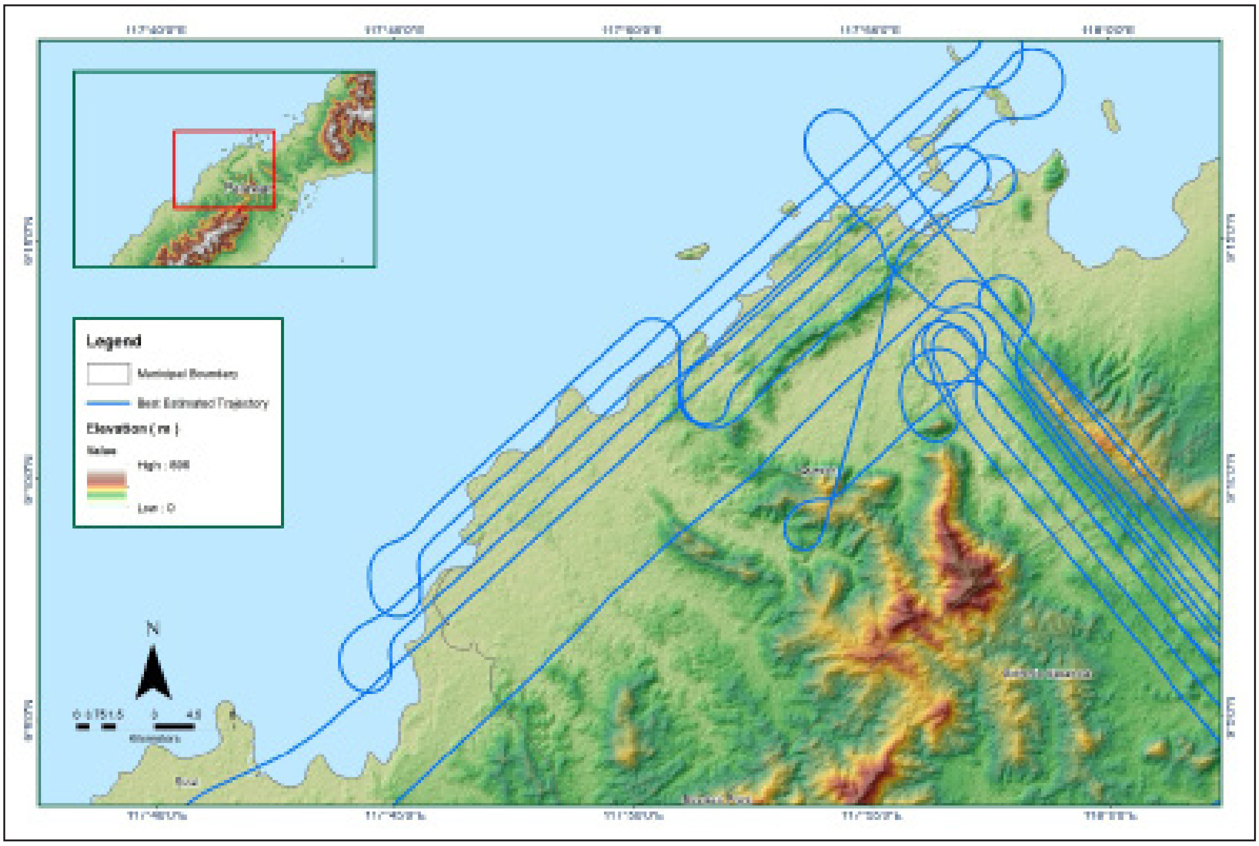


Figure A-8.3. Best Estimated Trajectory

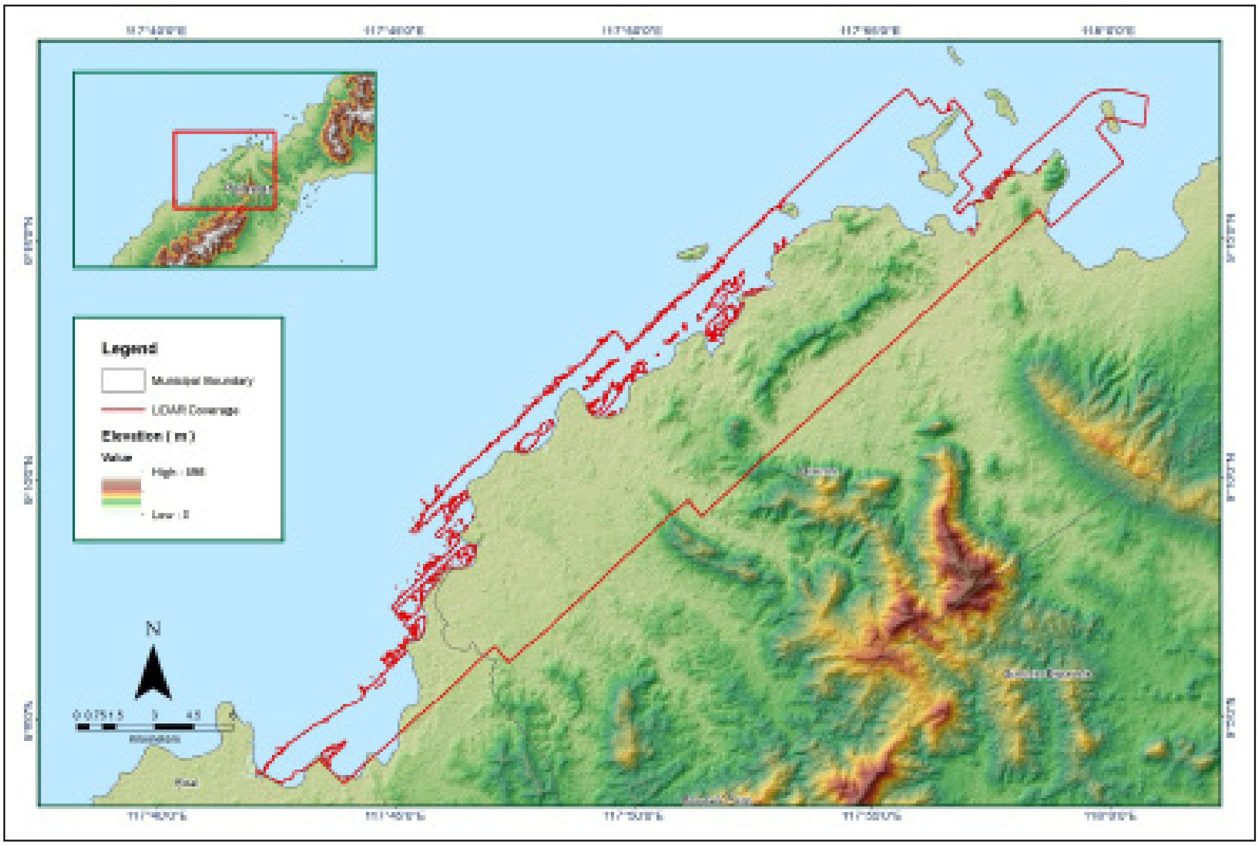


Figure A-8.4. Coverage of LiDAR data

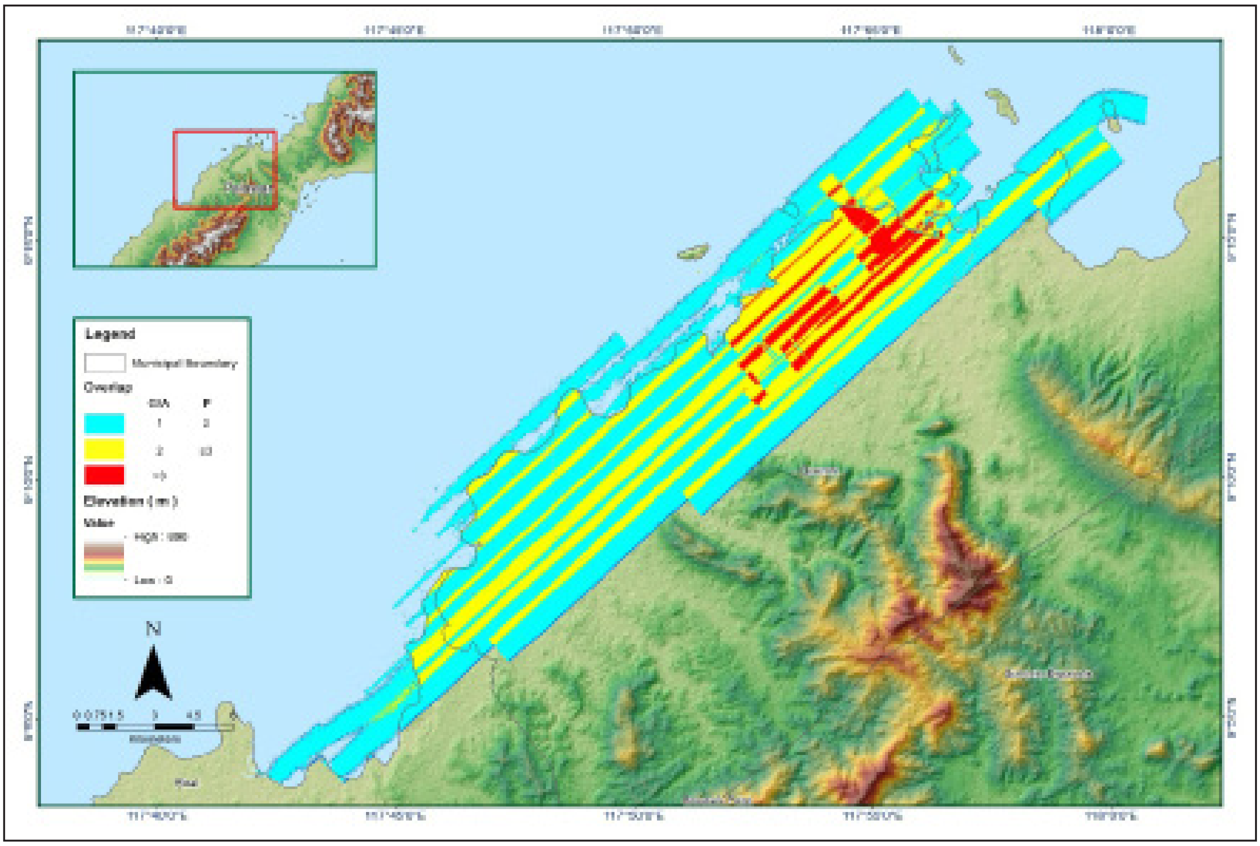


Figure A-8.5. Image of data overlap

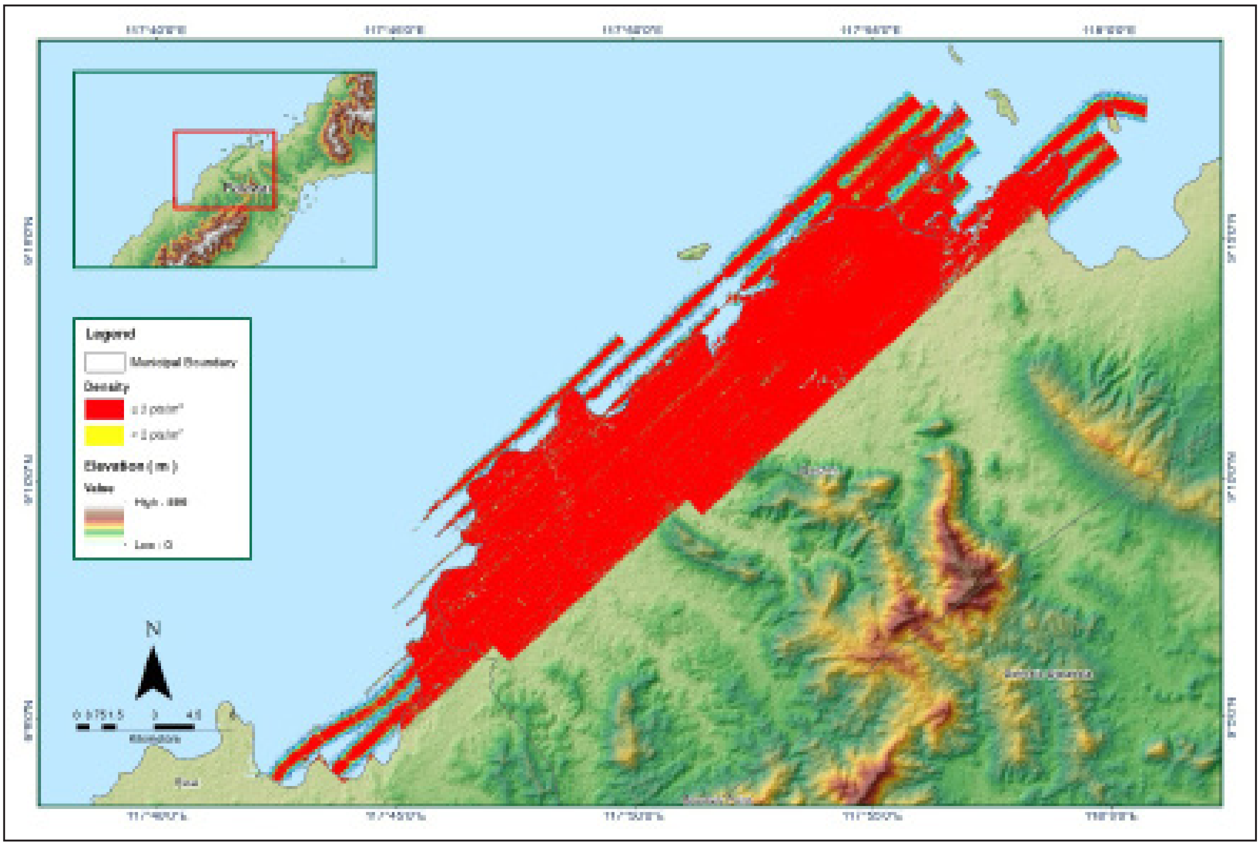


Figure A-8.6. Density map of merged LiDAR data

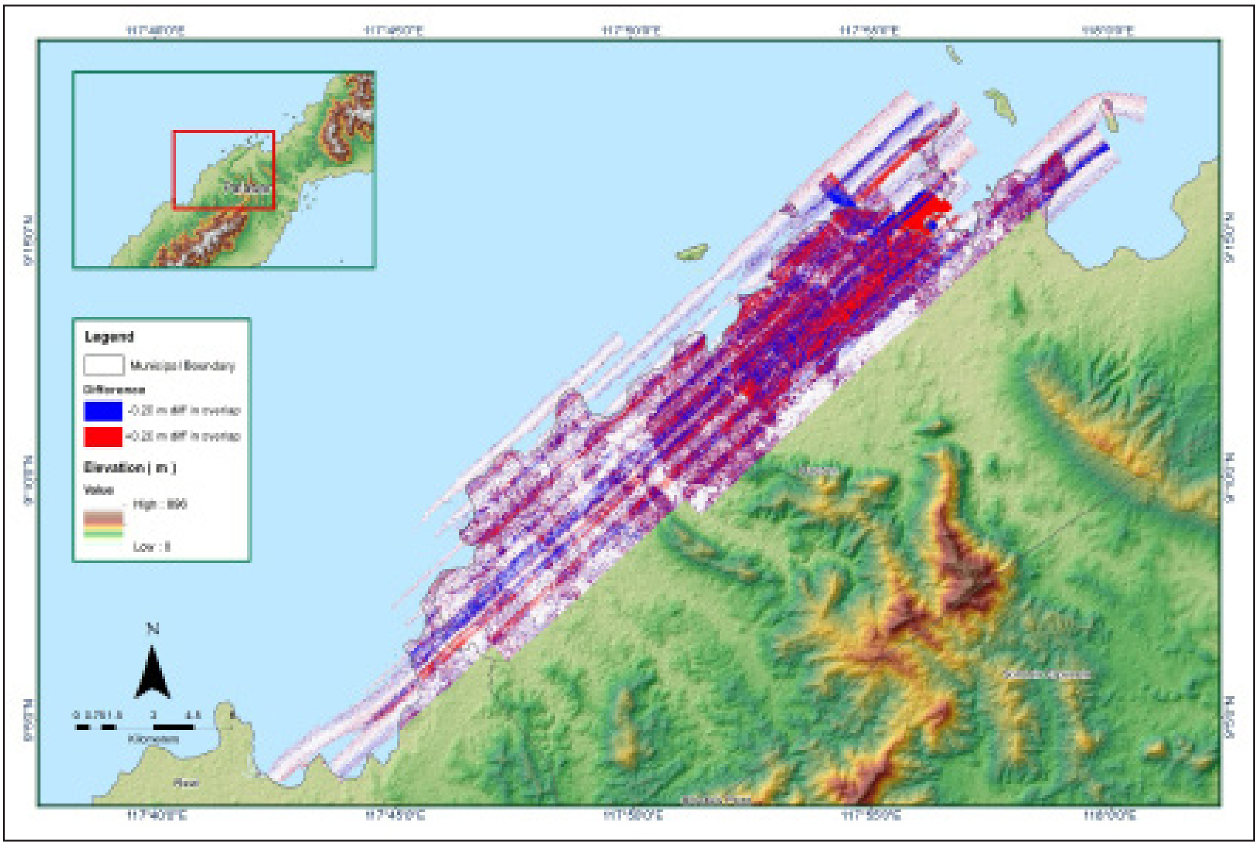


Figure A-8.7. Elevation difference between flight lines

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

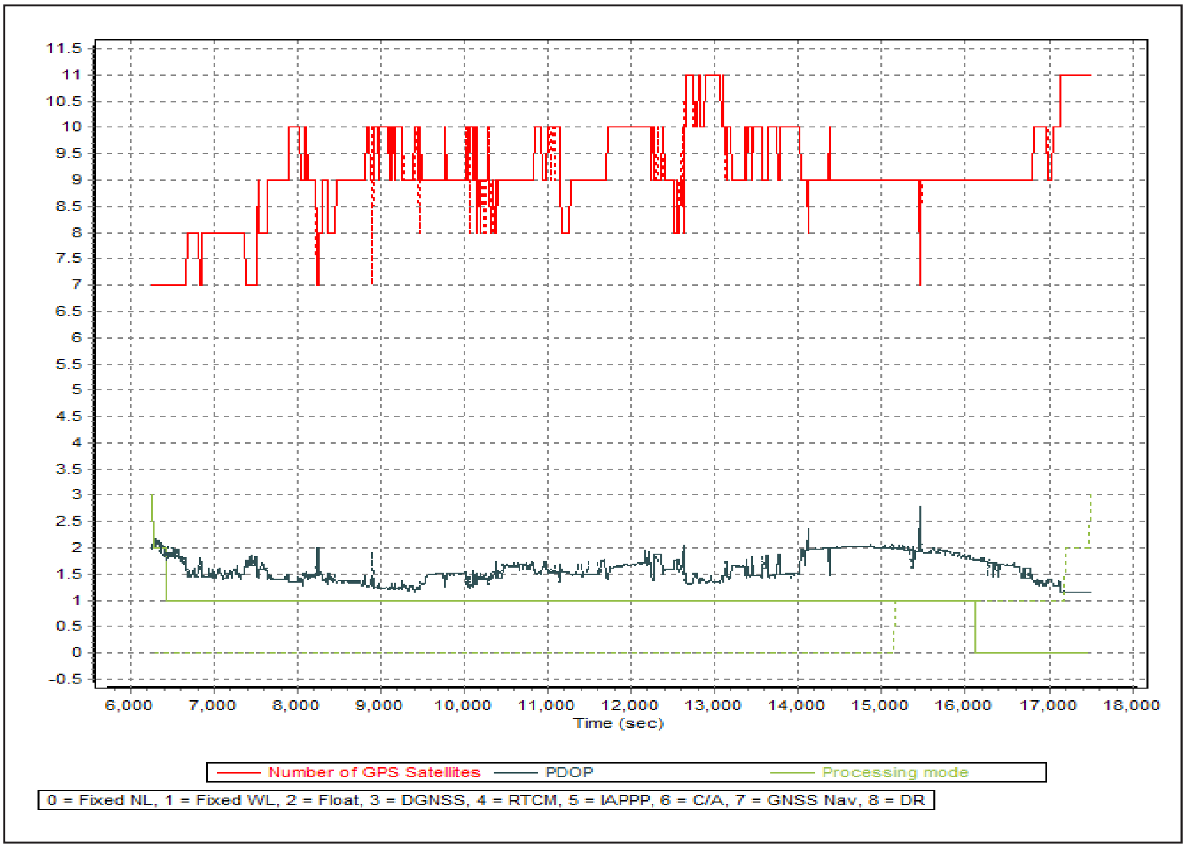


Figure A-8.8. Solution Status

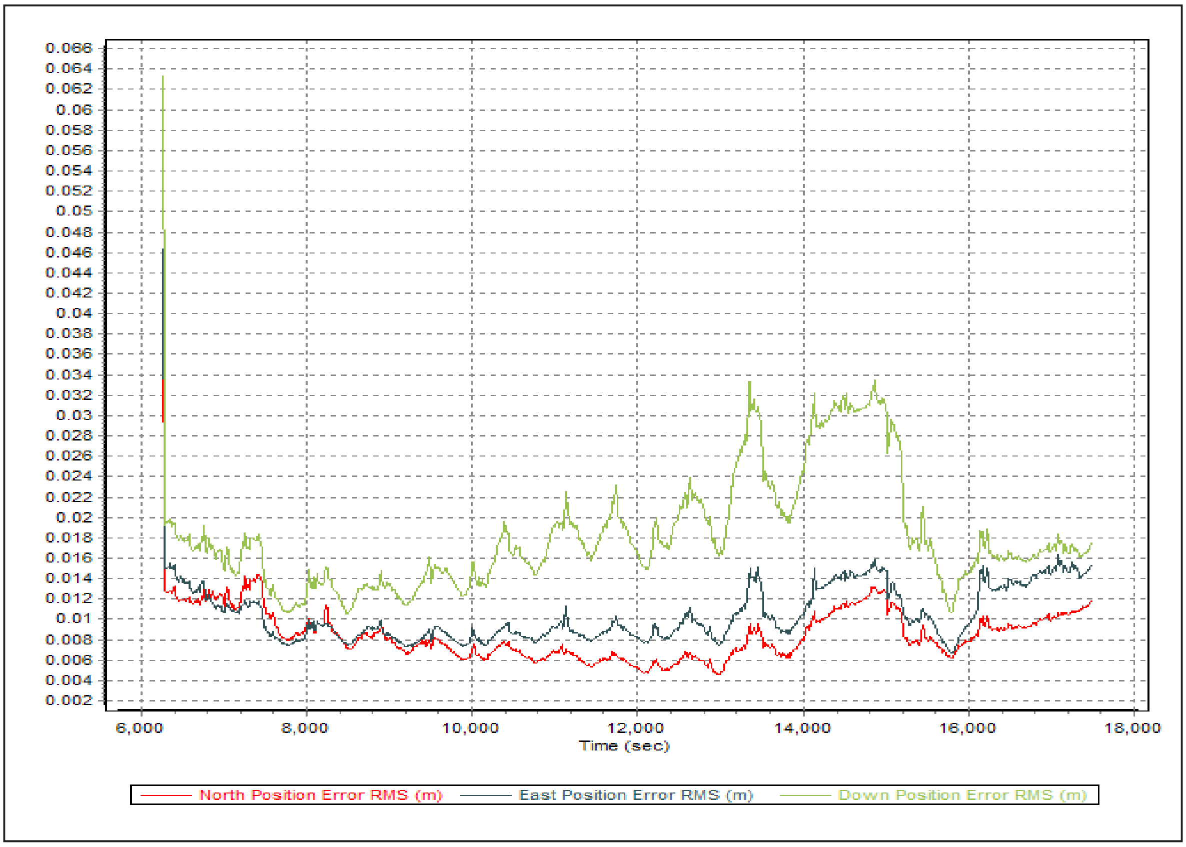


Figure A-8.9. Smoothed Performance Metric Parameters

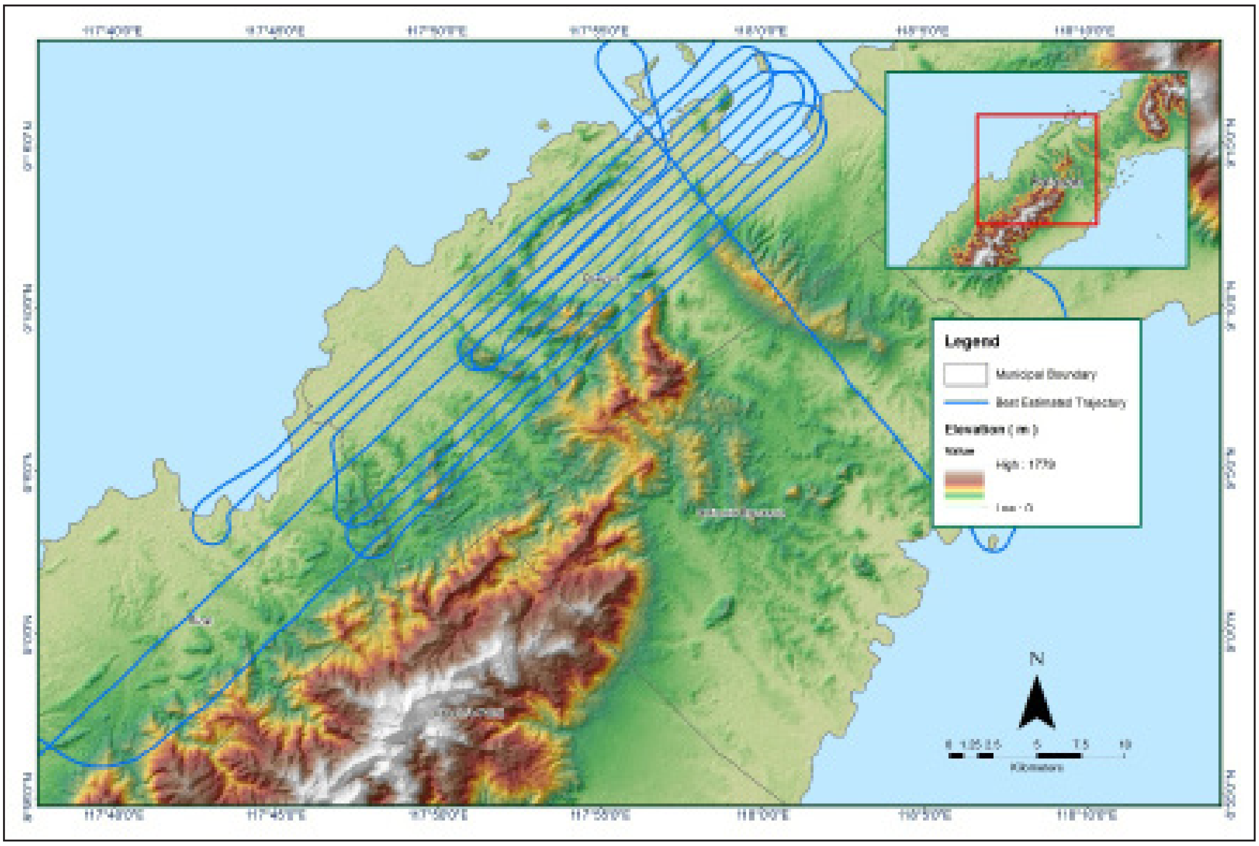


Figure A-8.10. Best Estimated Trajectory

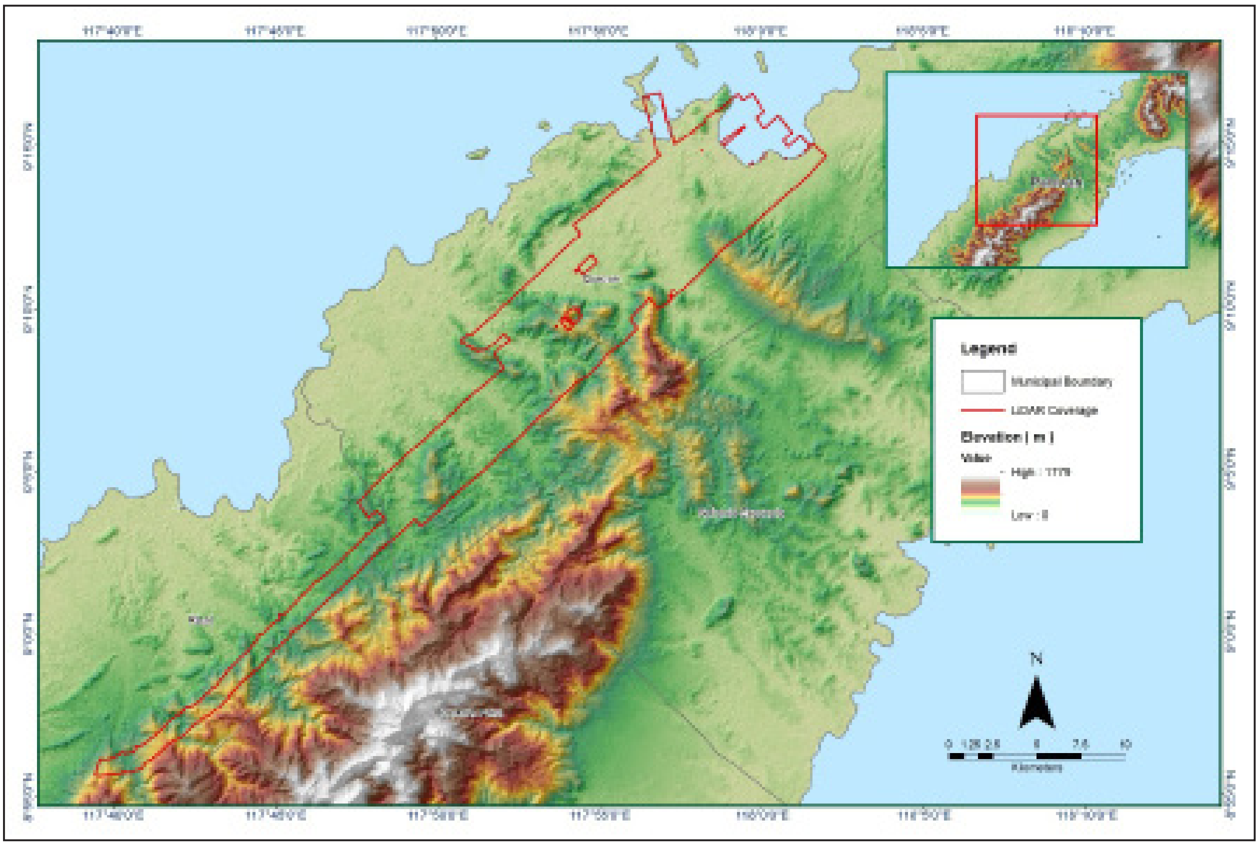


Figure A-8.11. Coverage of LiDAR data

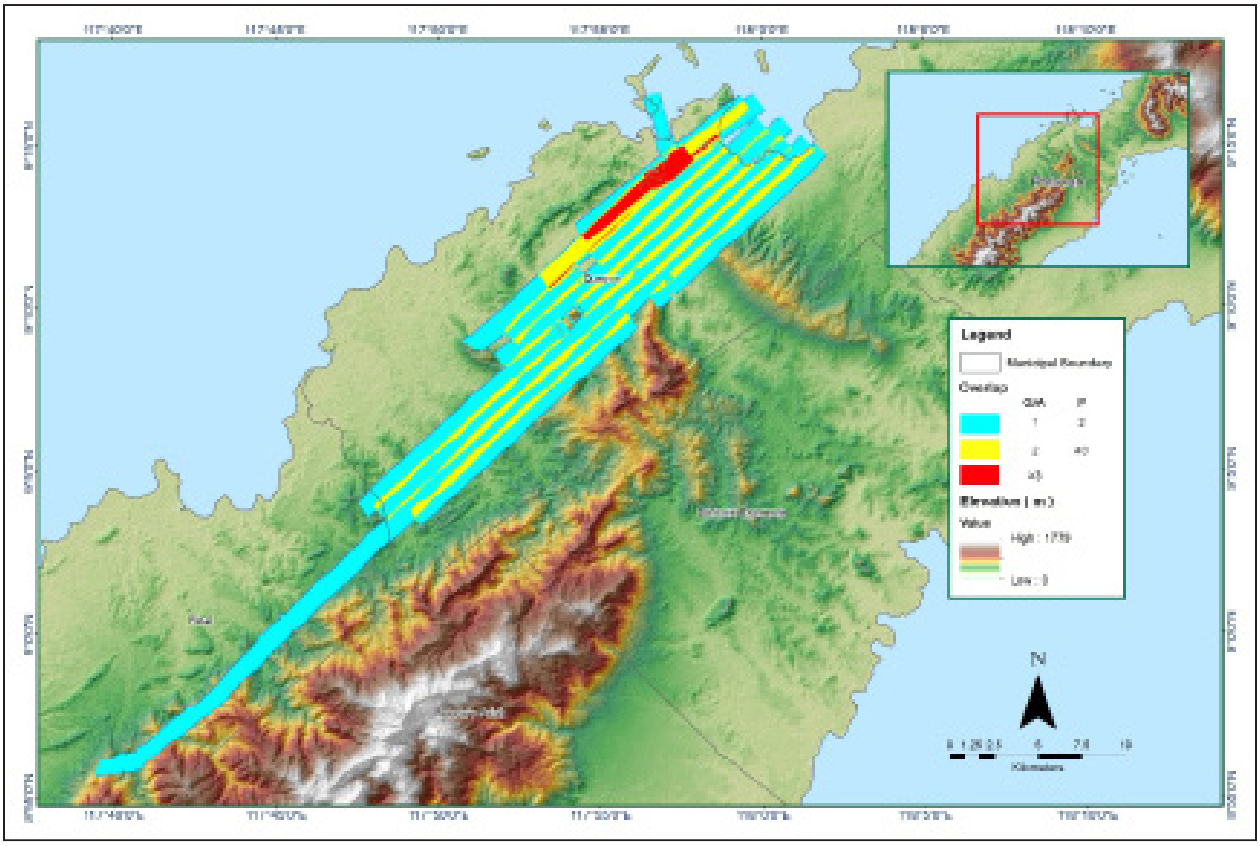


Figure A-8.12. Image of data overlap

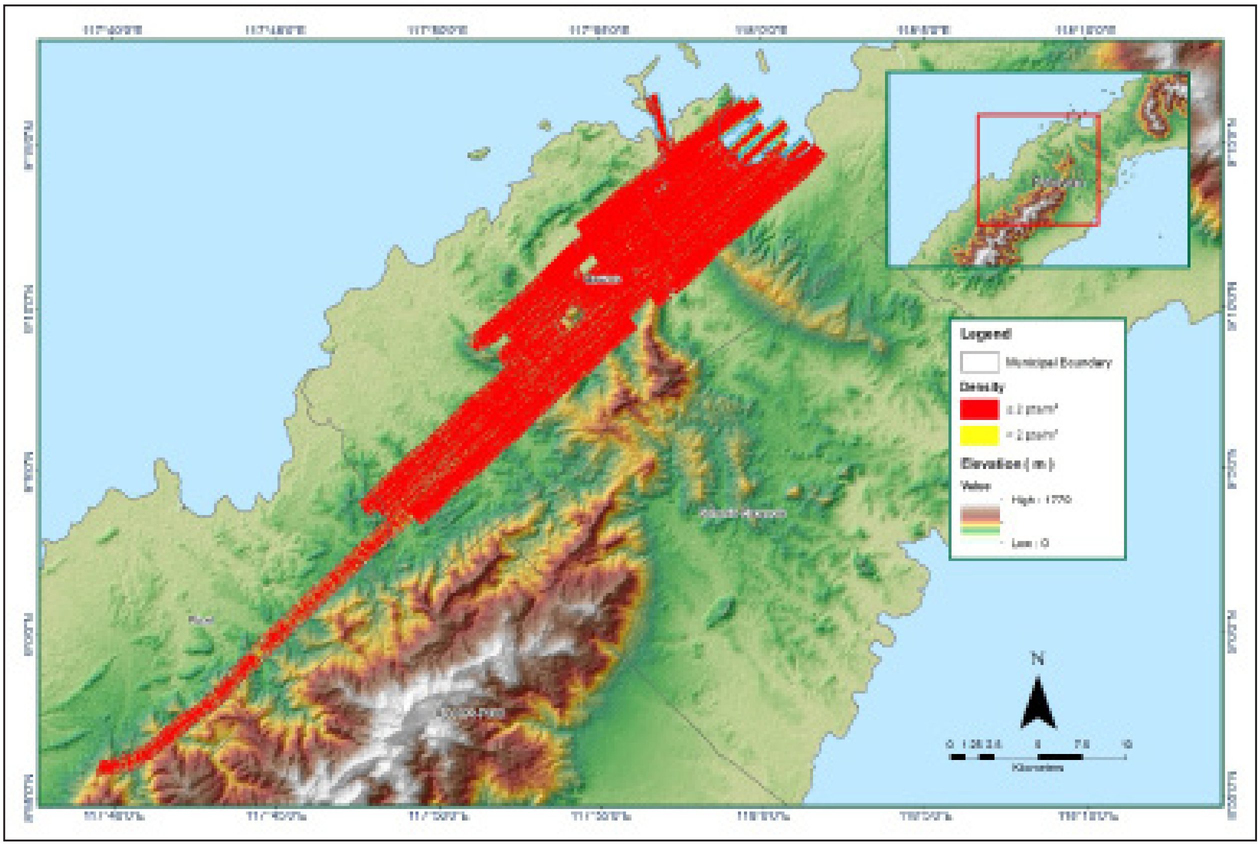


Figure A-8.13. Density map of merged LiDAR data

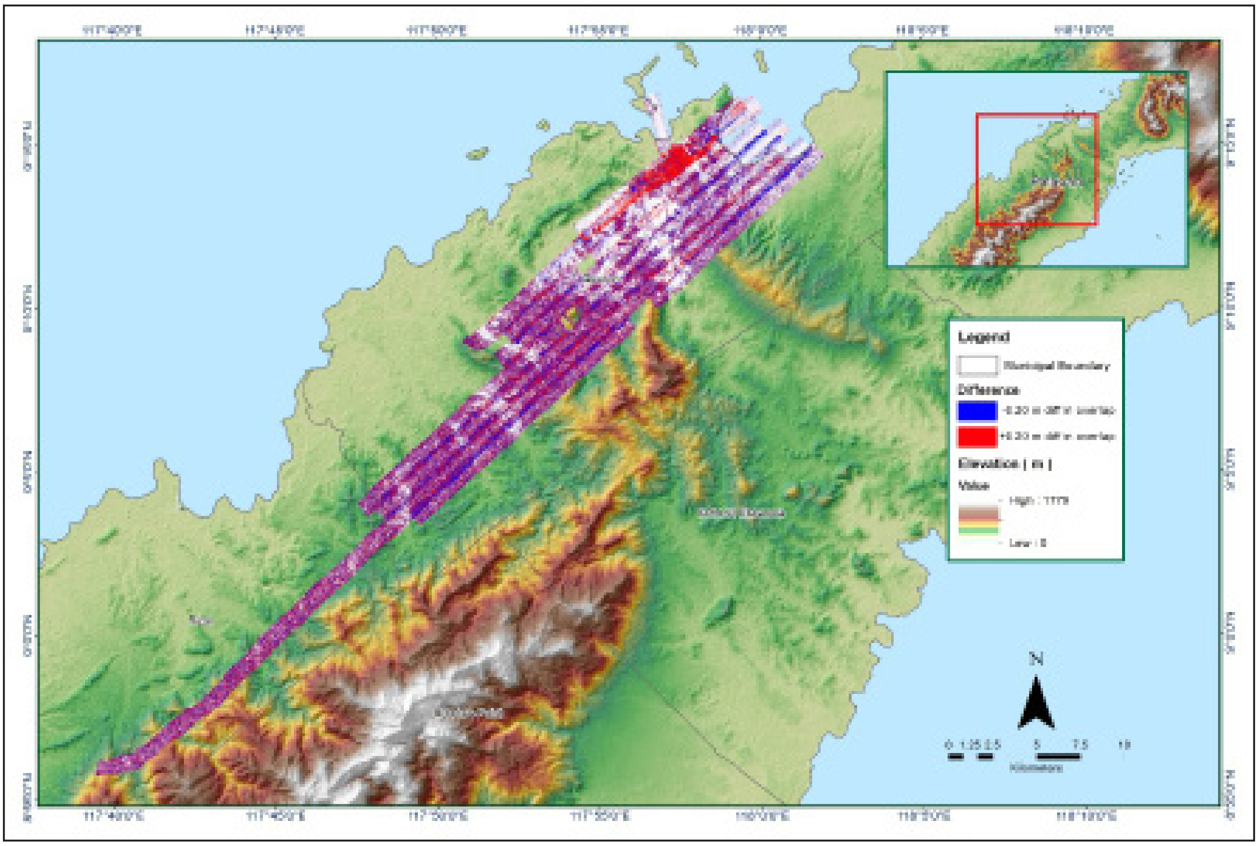


Figure A-8.14. Elevation difference between flight lines

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

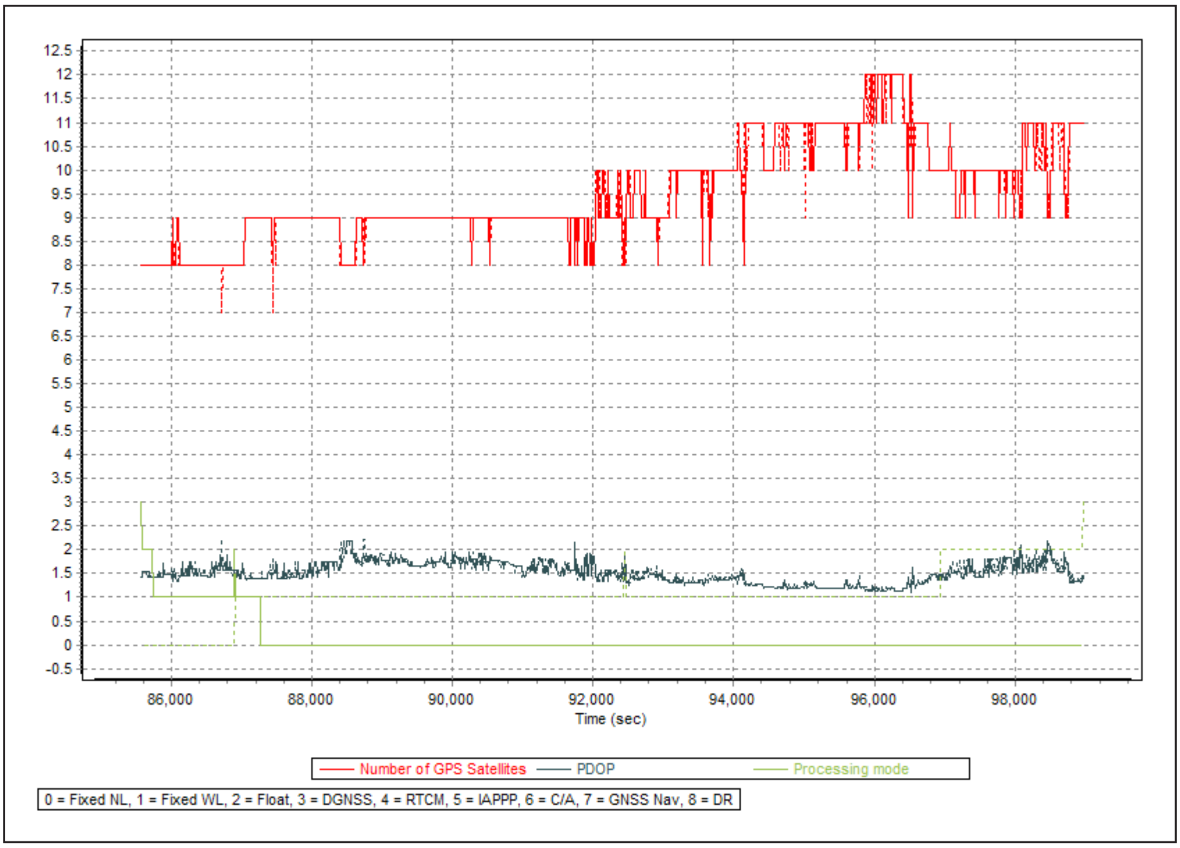


Figure A-8.15. Solution Status

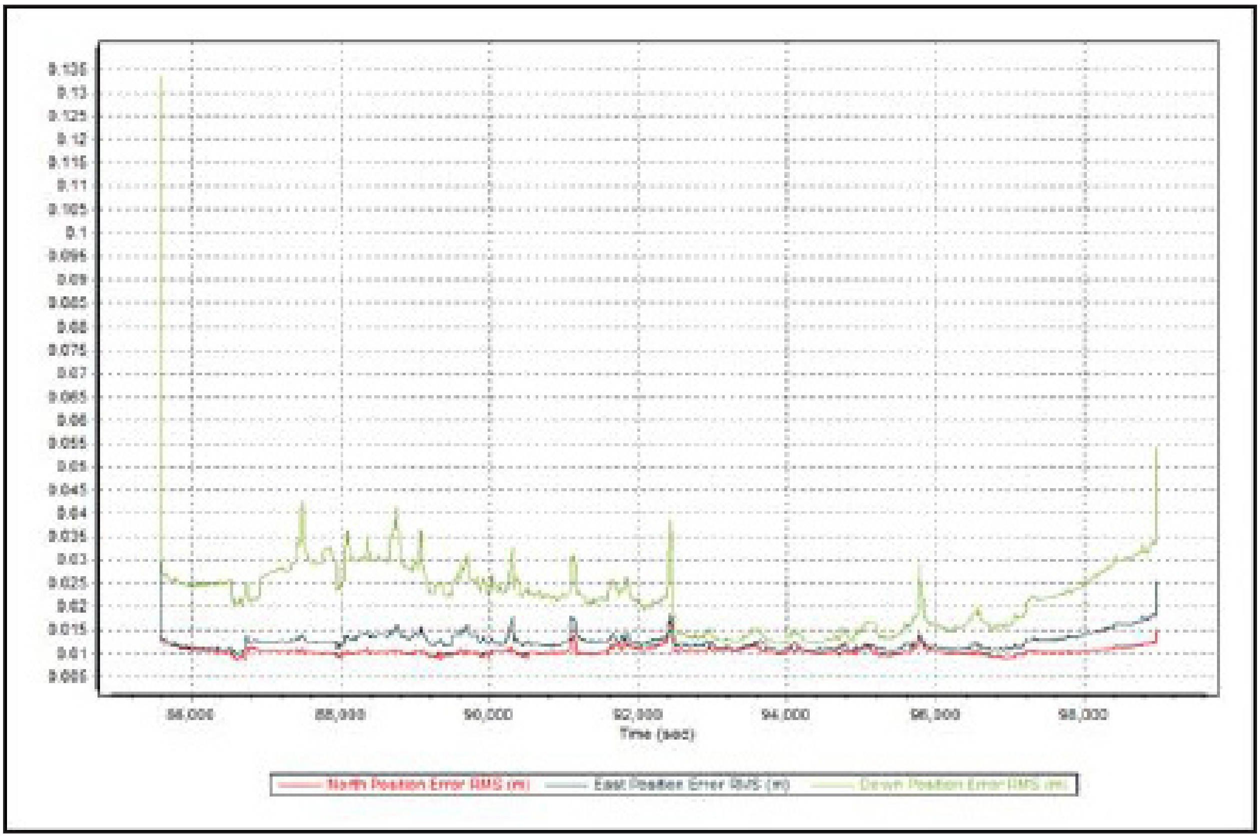


Figure A-8.16. Smoothed Performance Metric Parameters

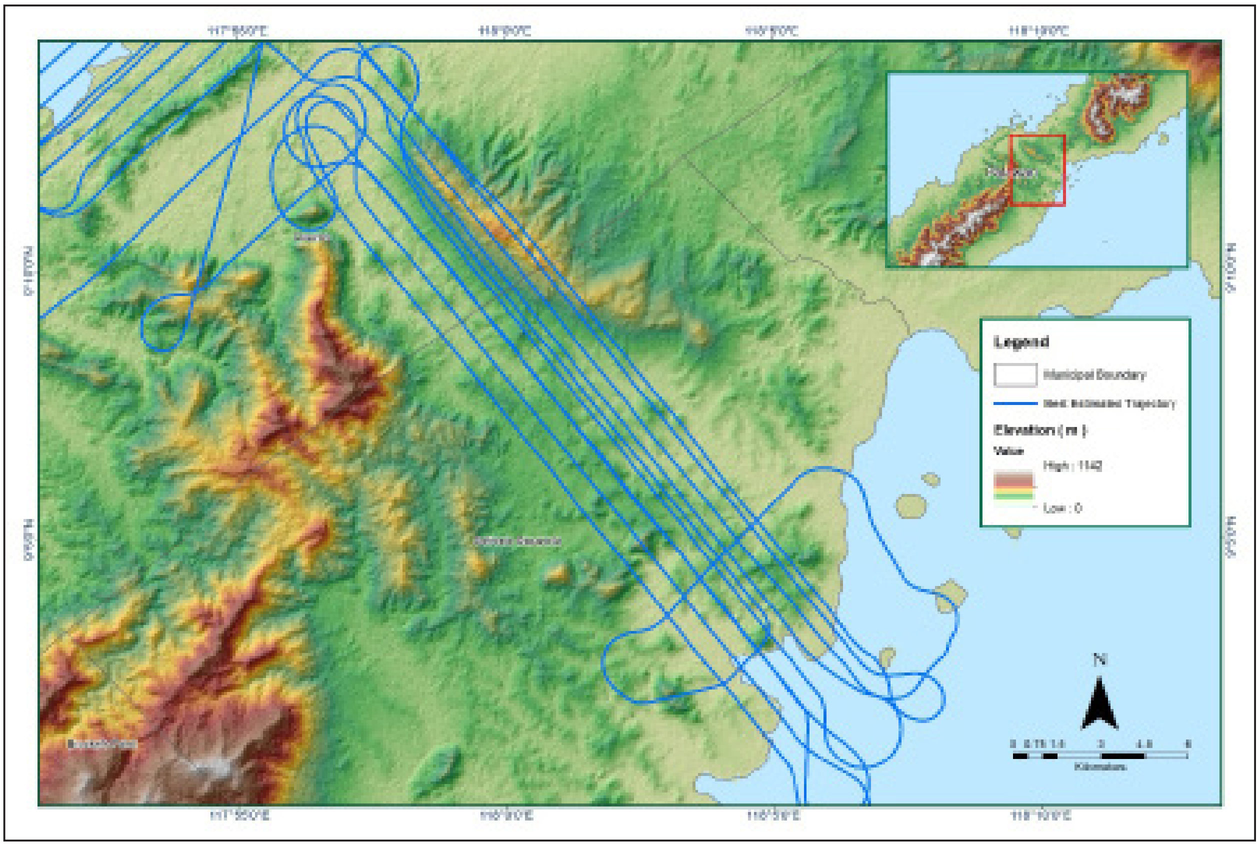


Figure A-8.17. Best Estimated Trajectory

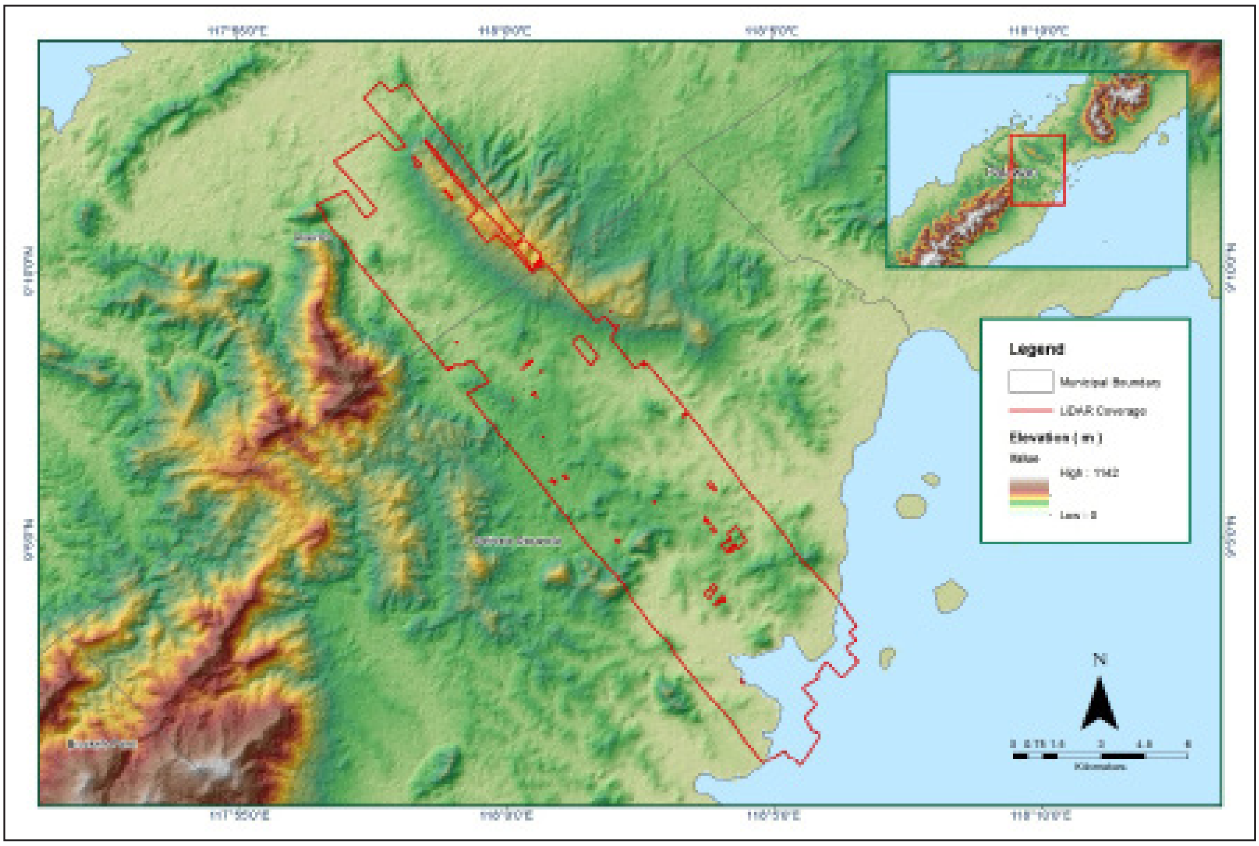


Figure A-8.18. Coverage of LiDAR data

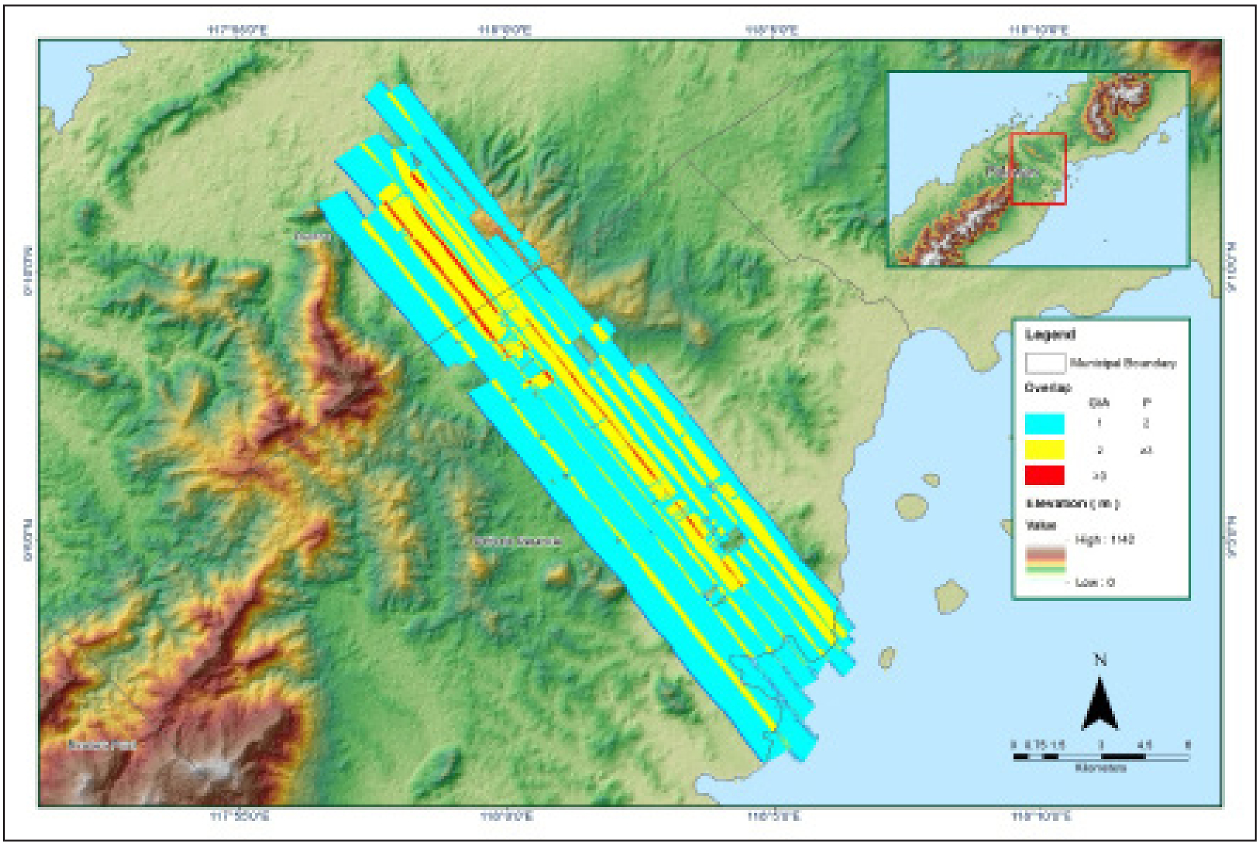


Figure A-8.19. Image of data overlap

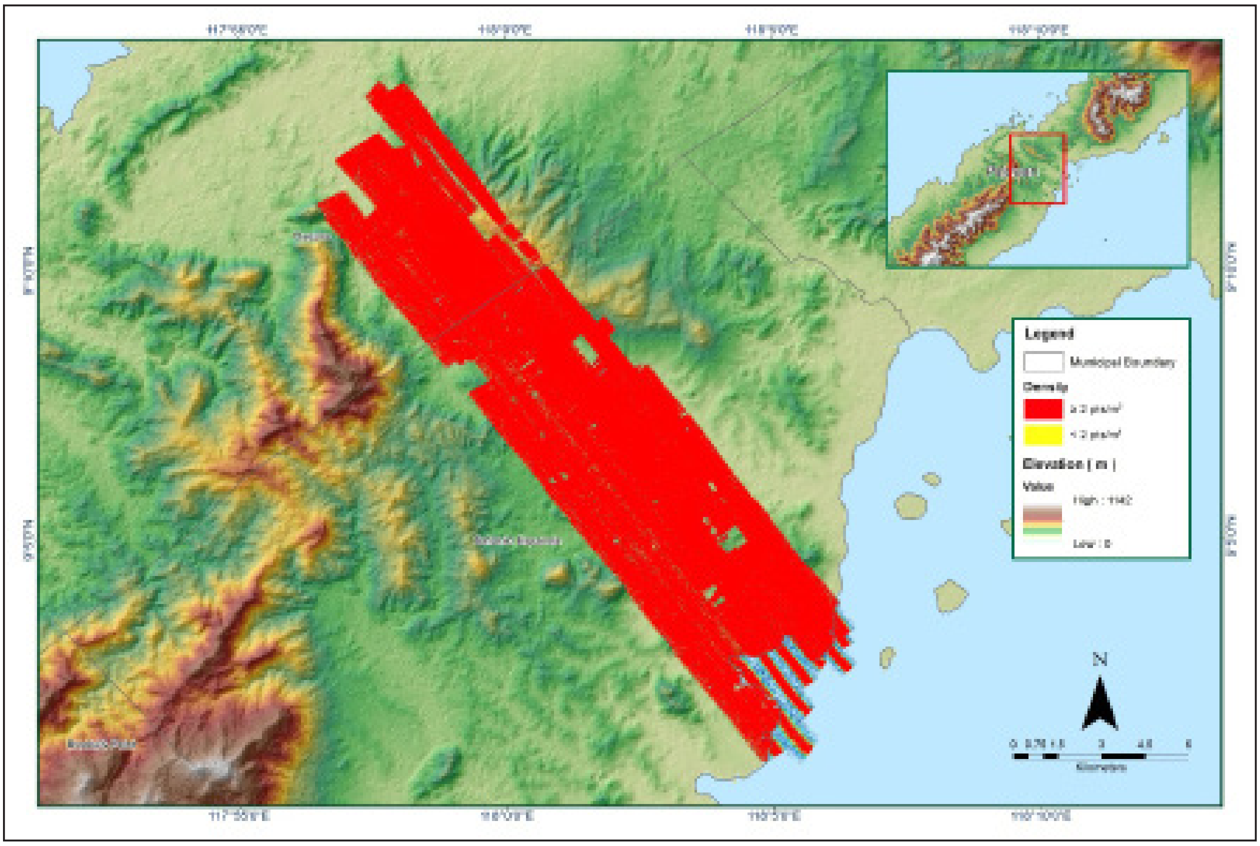


Figure A-8.20. Density map of merged LiDAR data

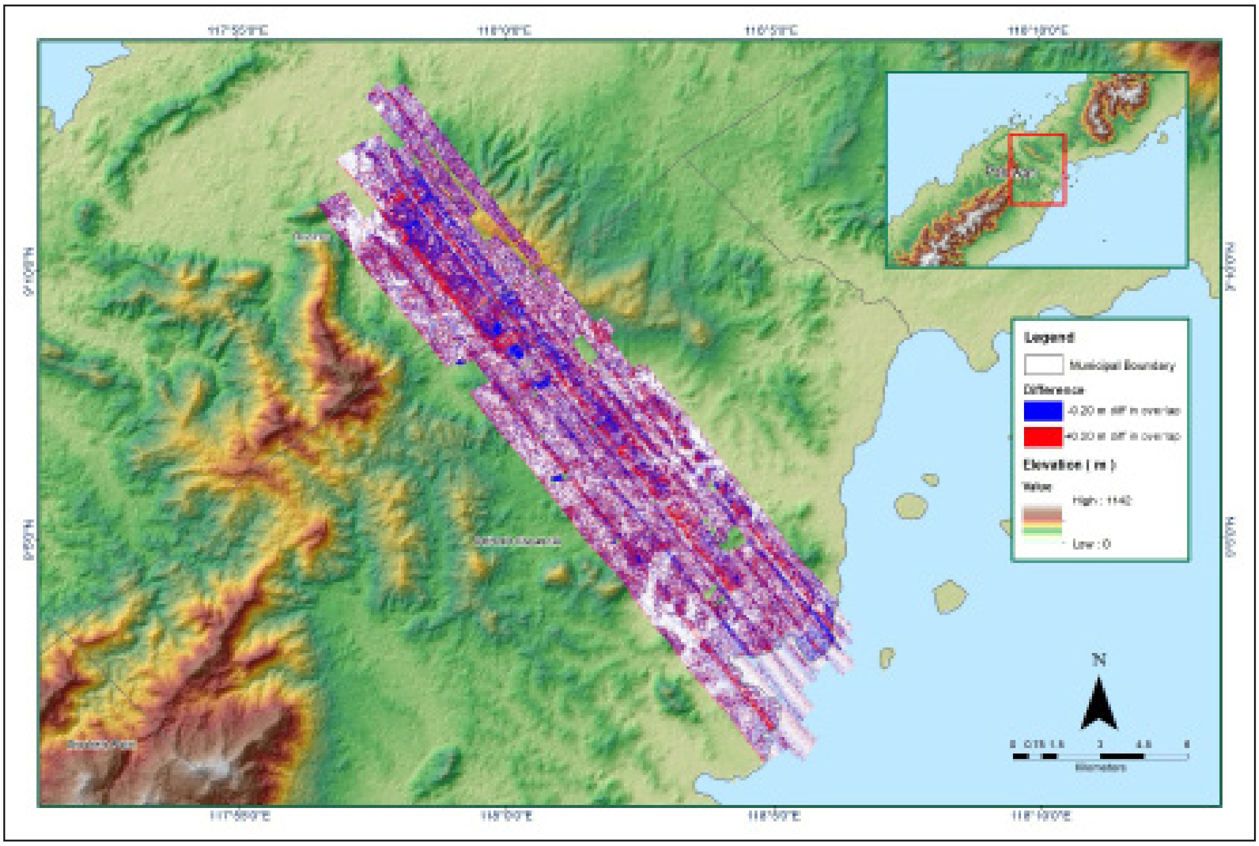


Figure A-8.21. Elevation difference between flight lines

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

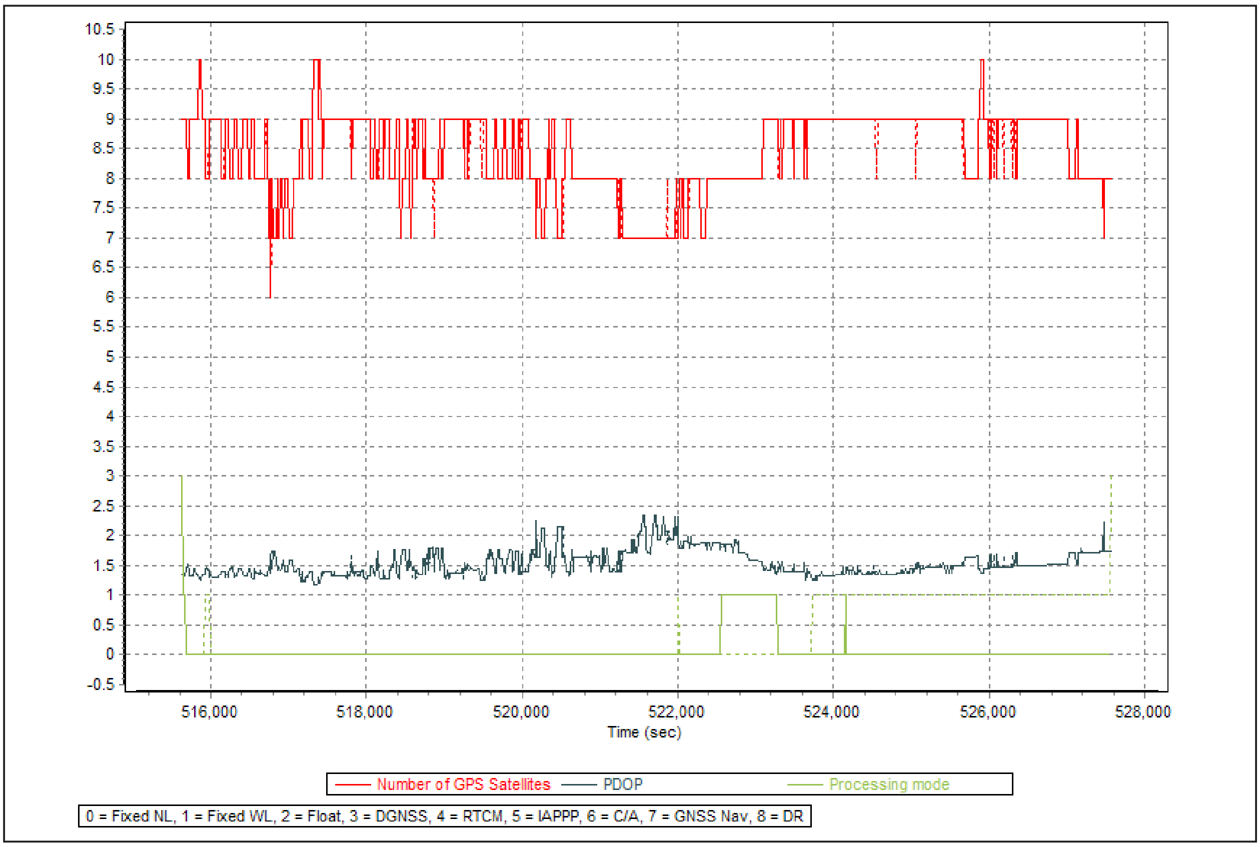


Figure A-8.22. Solution Status

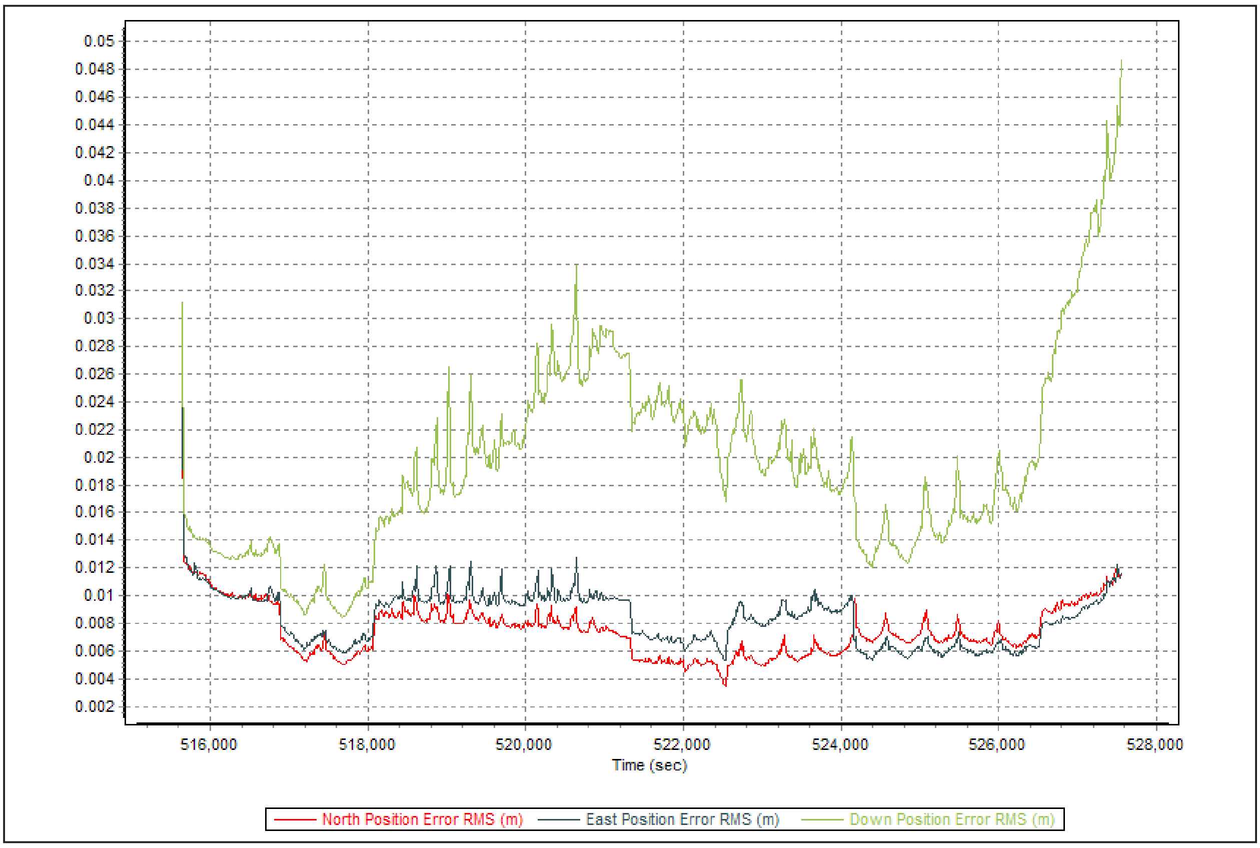


Figure A-8.23. Smoothed Performance Metric Parameters

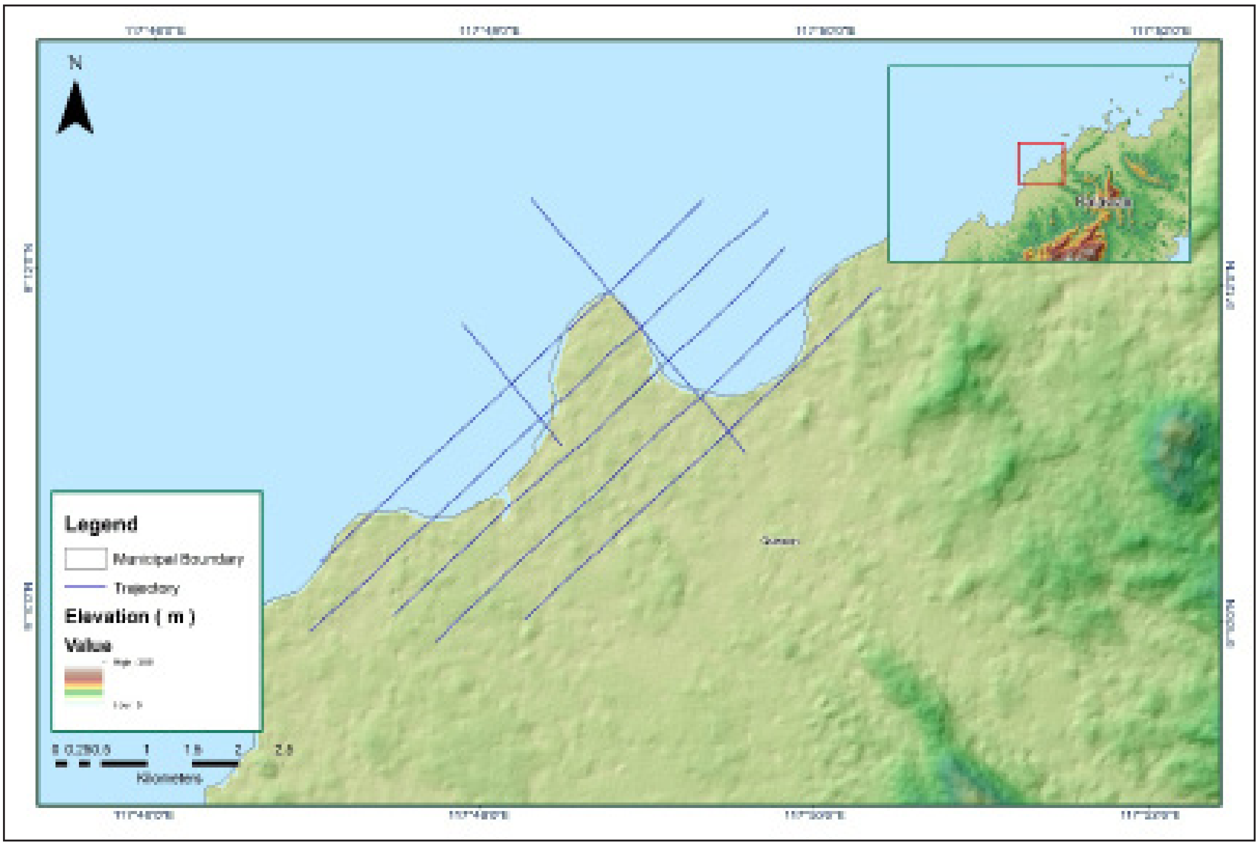


Figure A-8.24. Best Estimated Trajectory

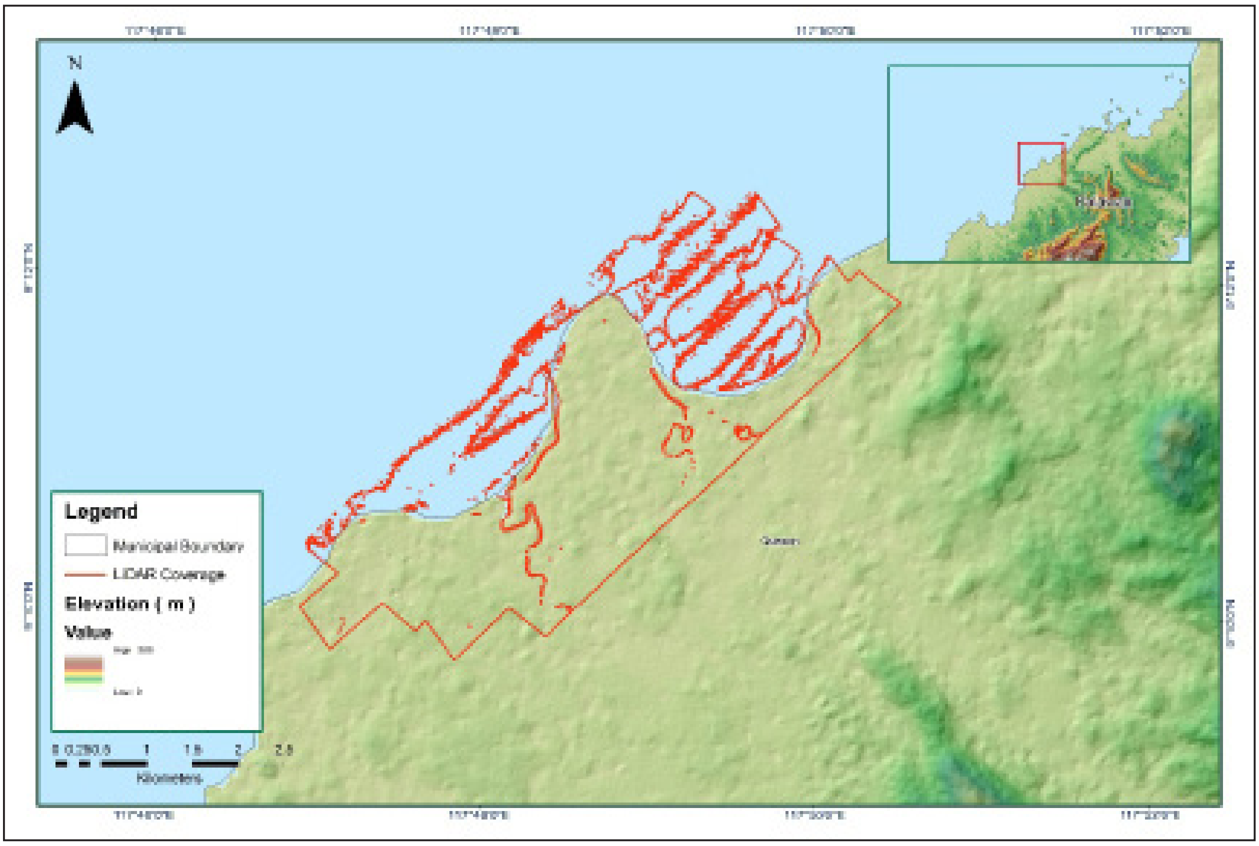


Figure A-8.25. Coverage of LiDAR data

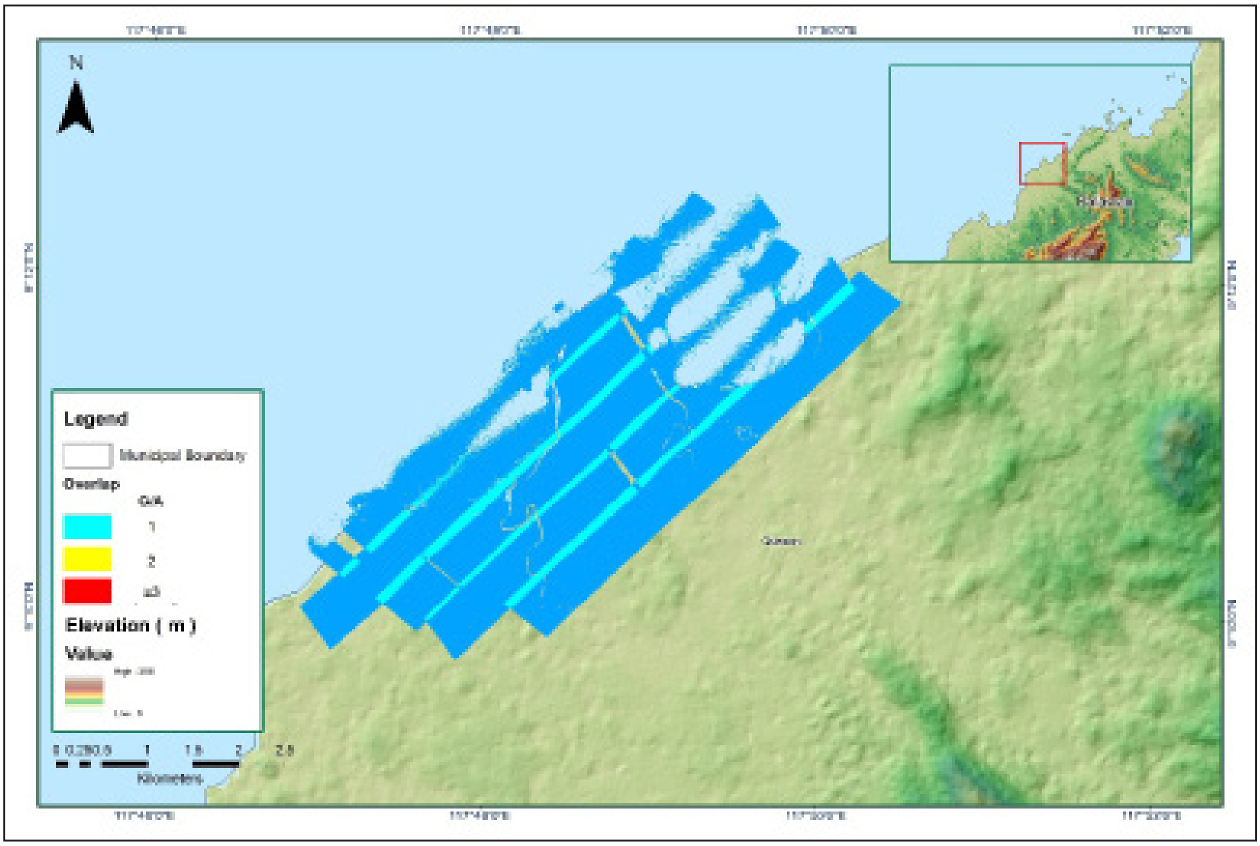


Figure A-8.26. Image of data overlap

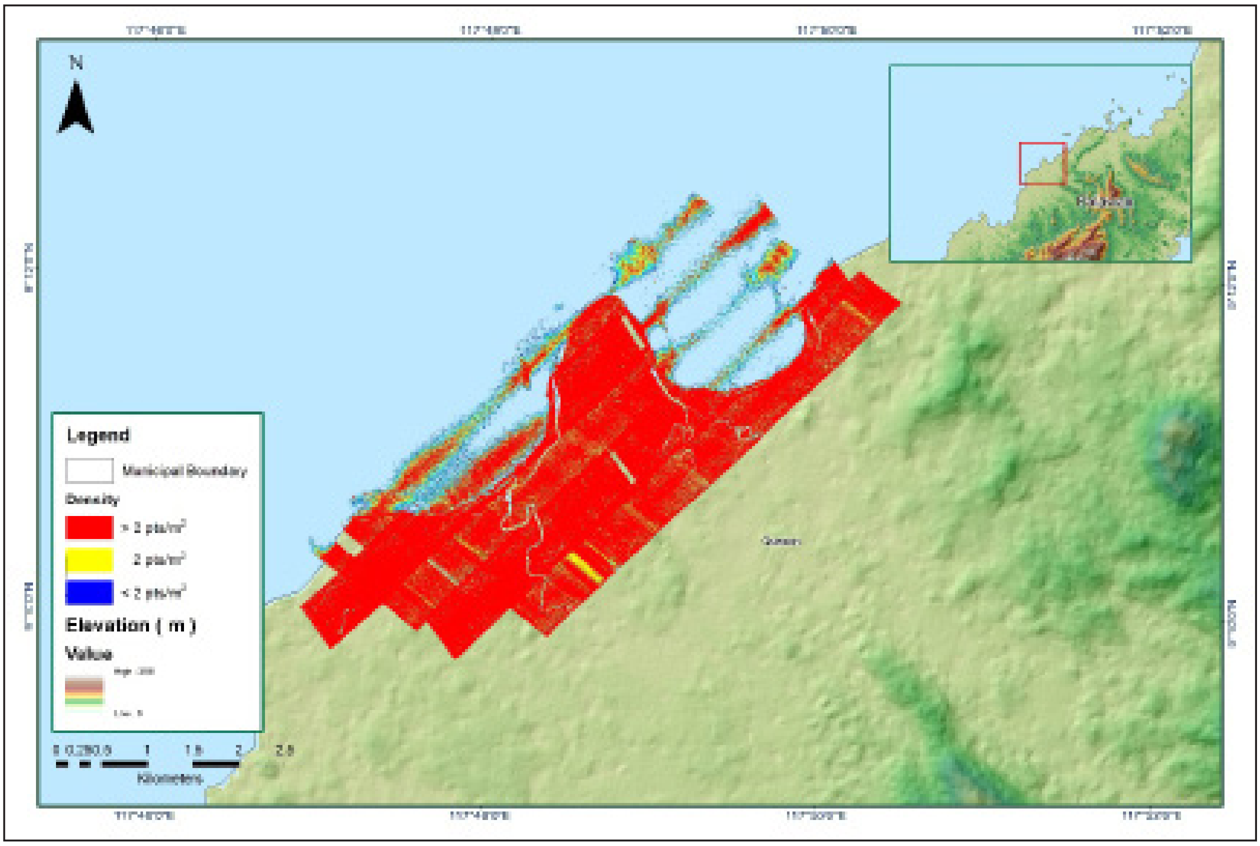


Figure A-8.27. Density map of merged LiDAR data

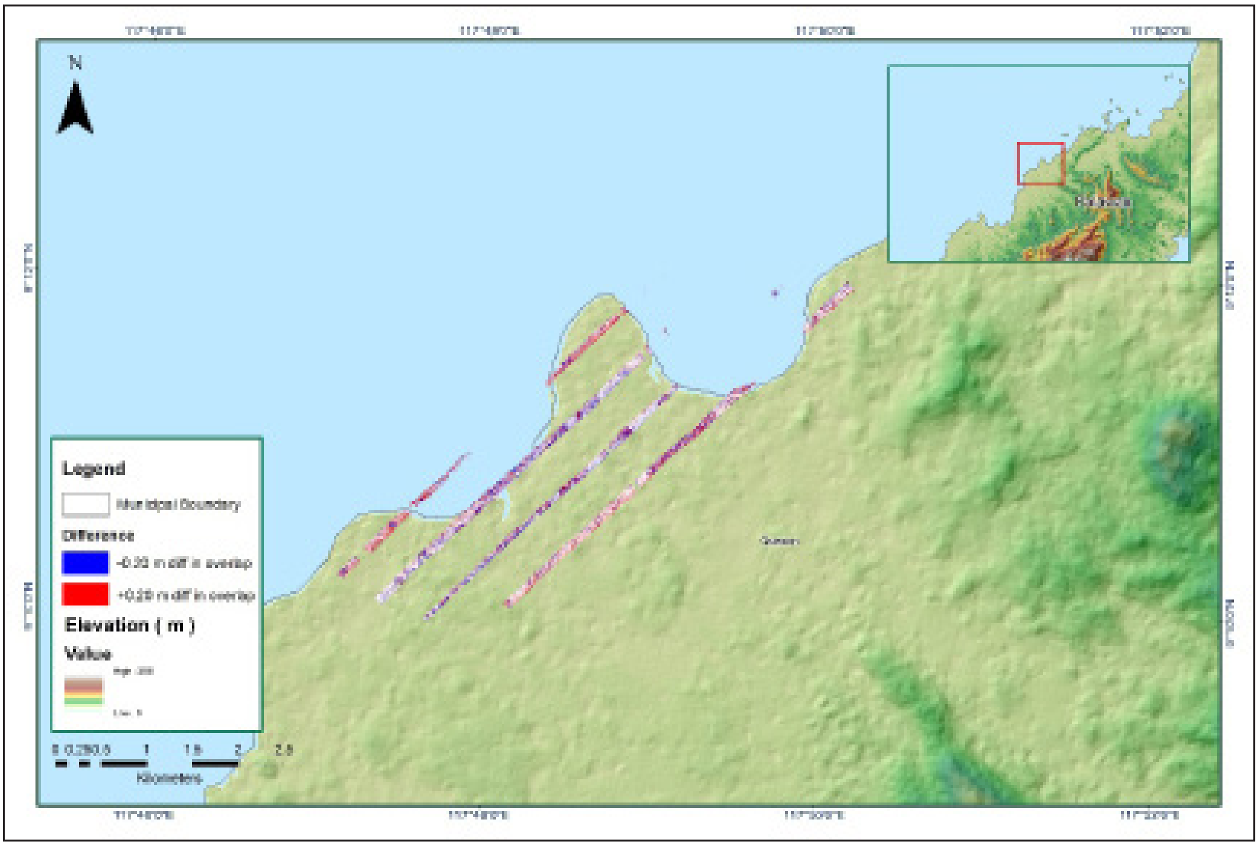


Figure A-8.28. Elevation difference between flight lines

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

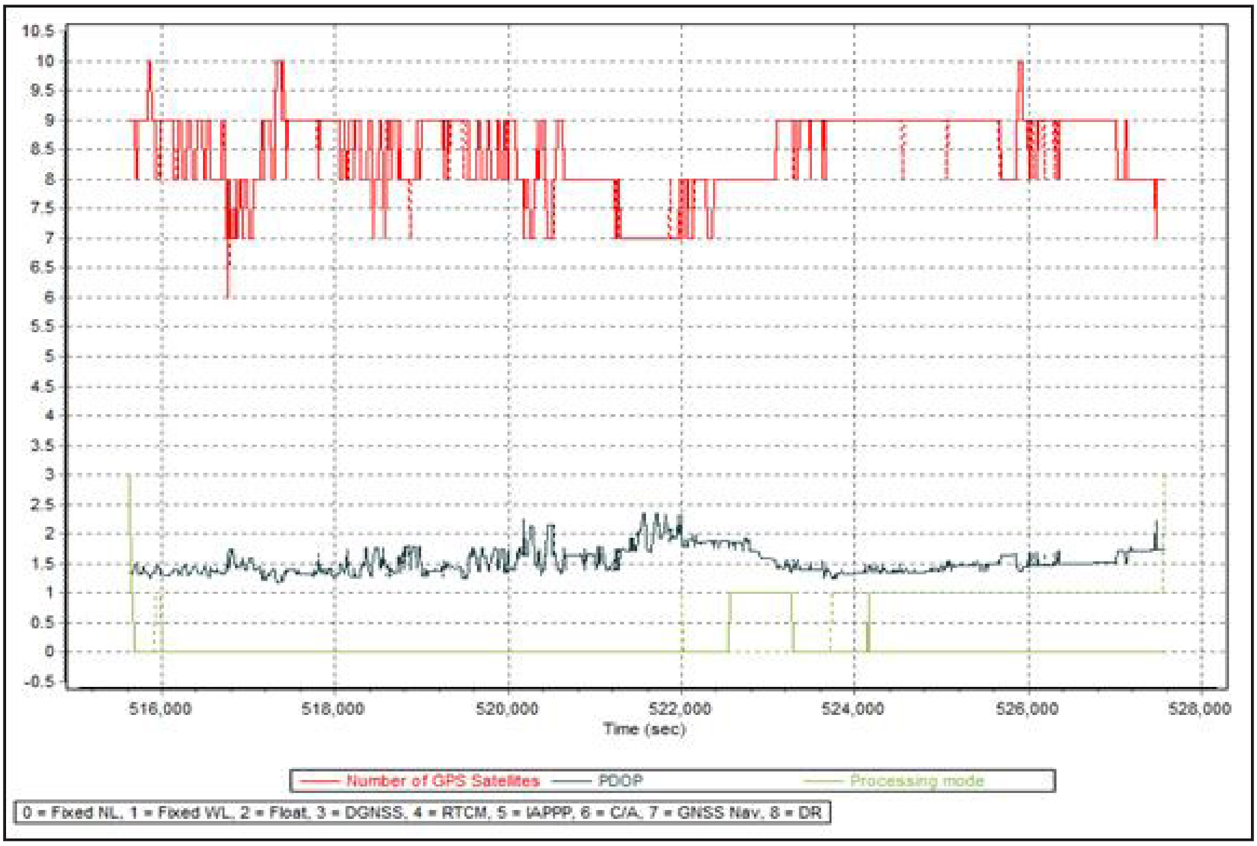


Figure A-8.29. Solution Status

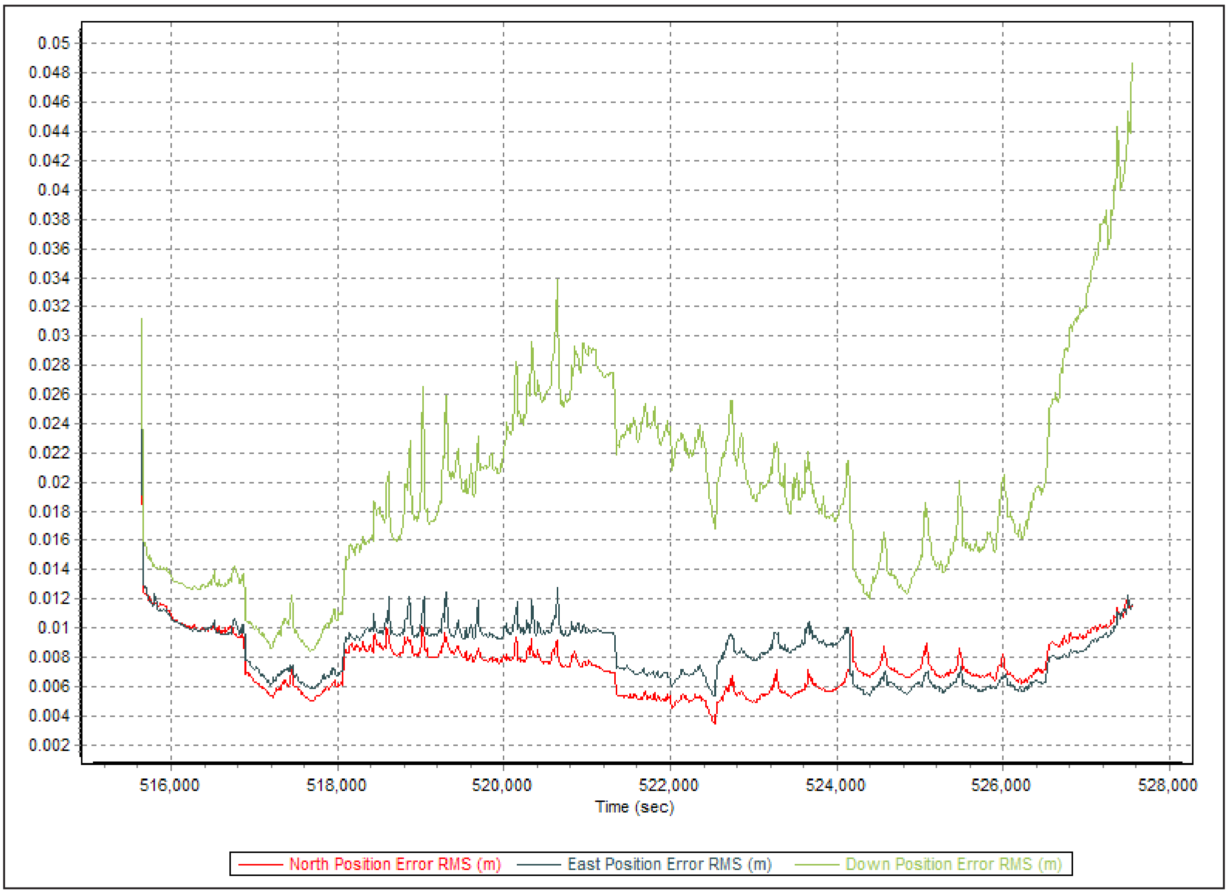


Figure A-8.30. Smoothed Performance Metric Parameters

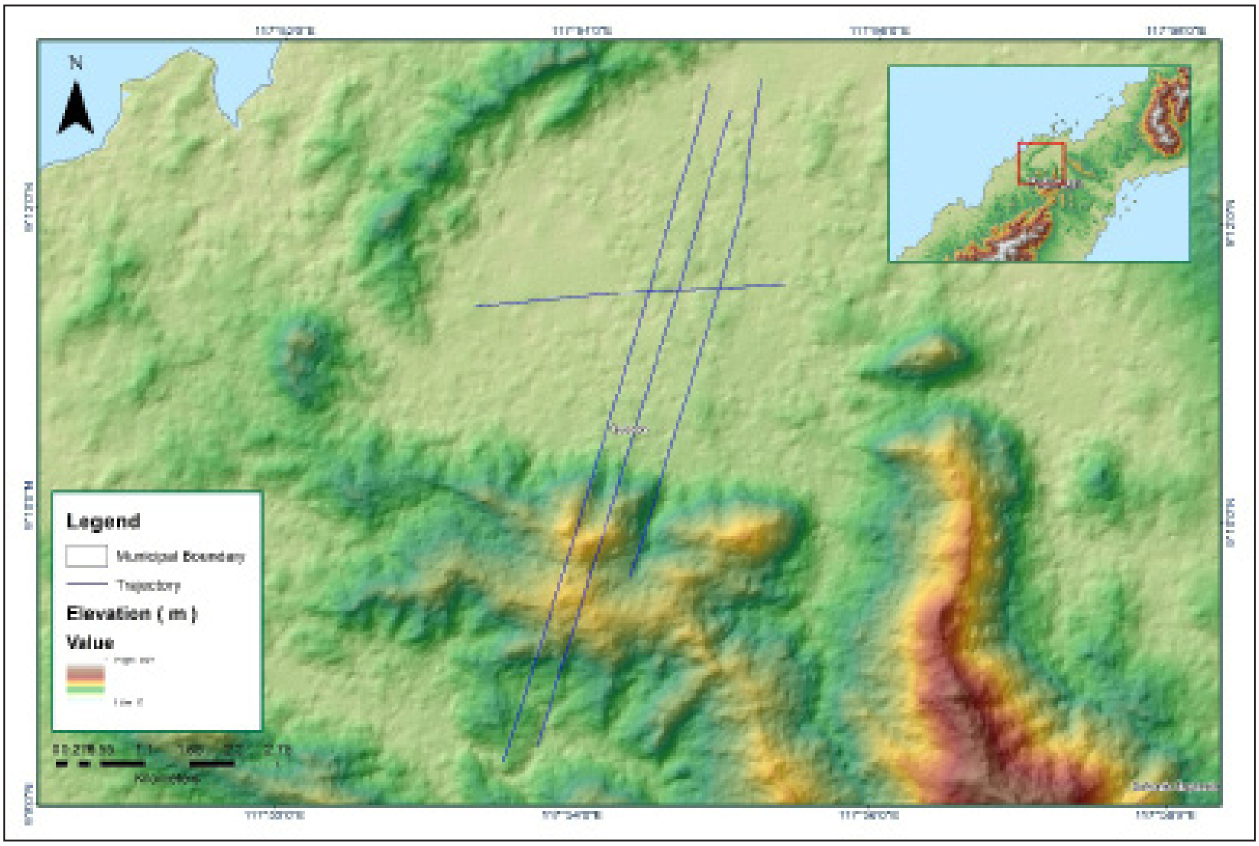


Figure A-8.31. Best Estimated Trajectory

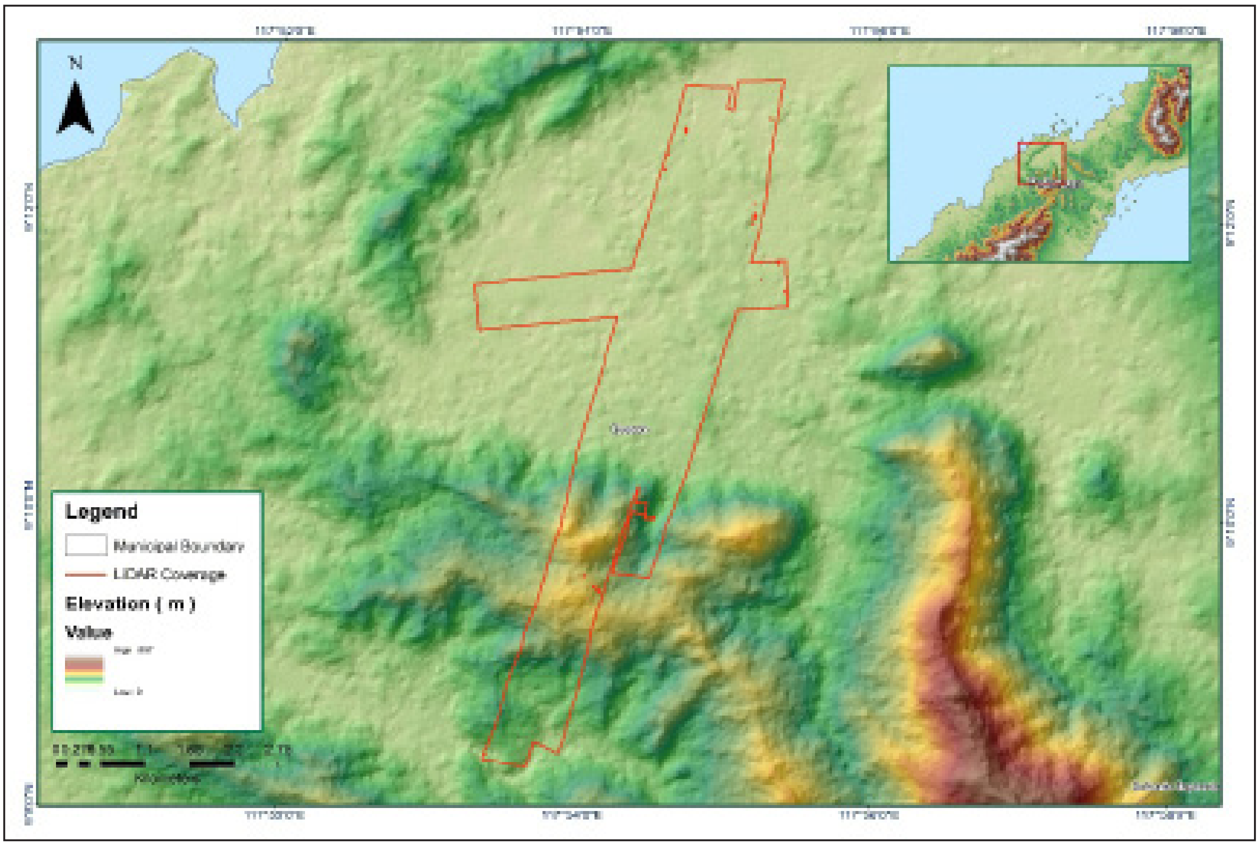


Figure A-8.32. Coverage of LiDAR data

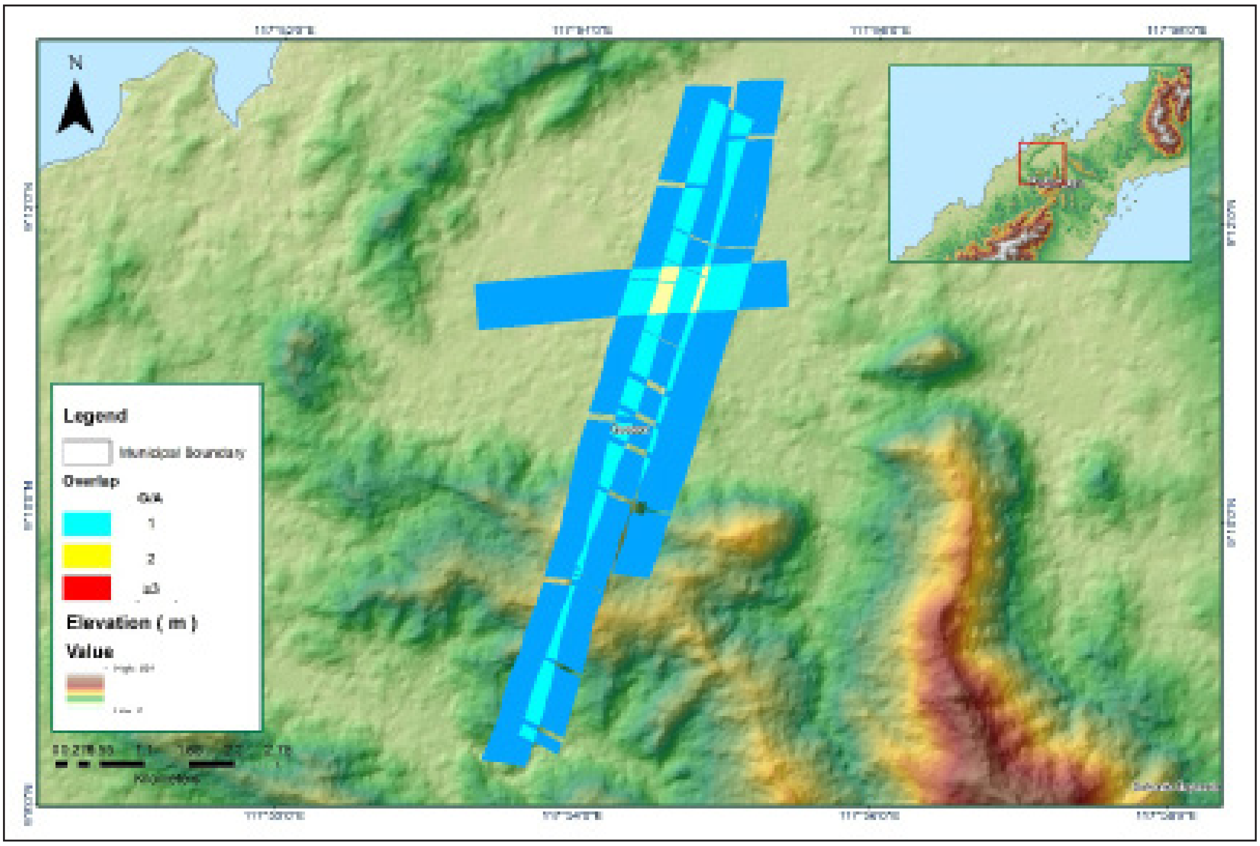


Figure A-8.33. Image of data overlap

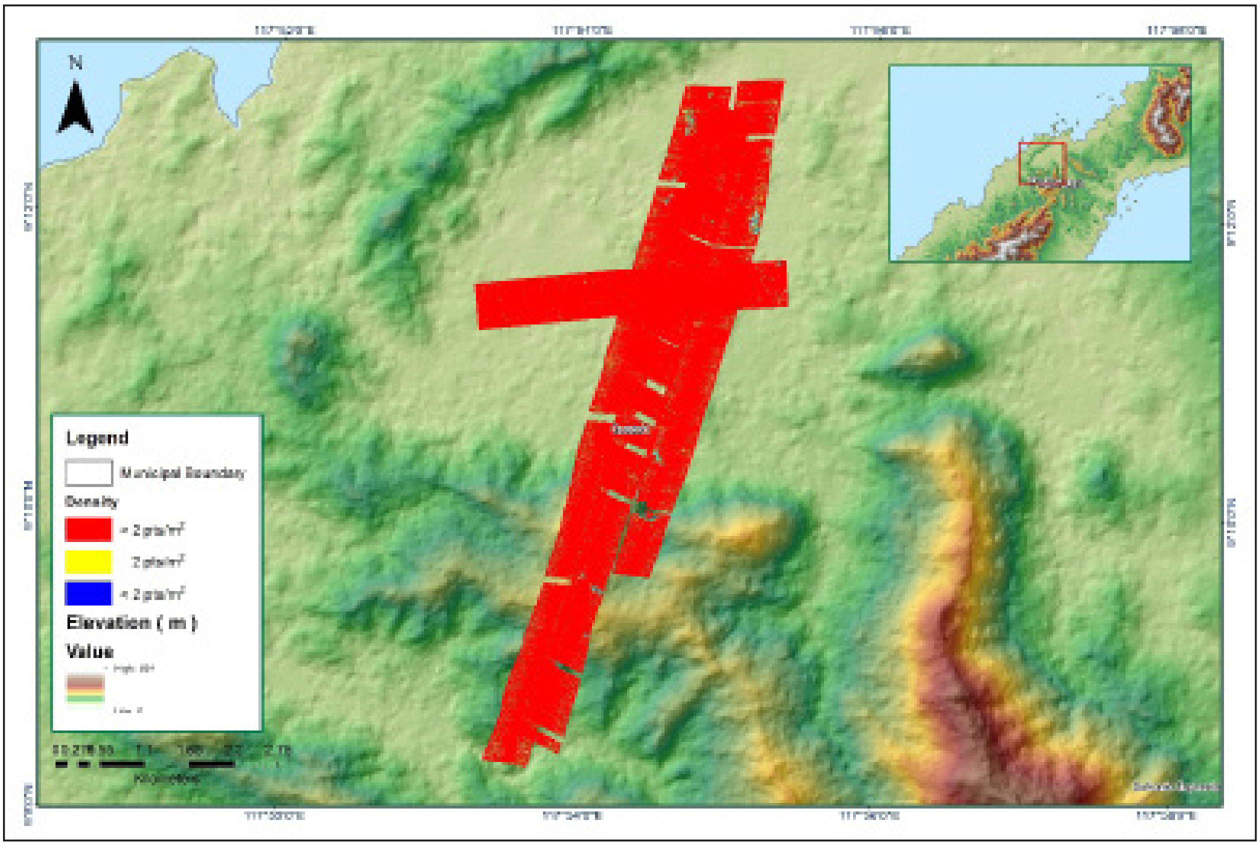


Figure A-8.34. Density map of merged LiDAR data

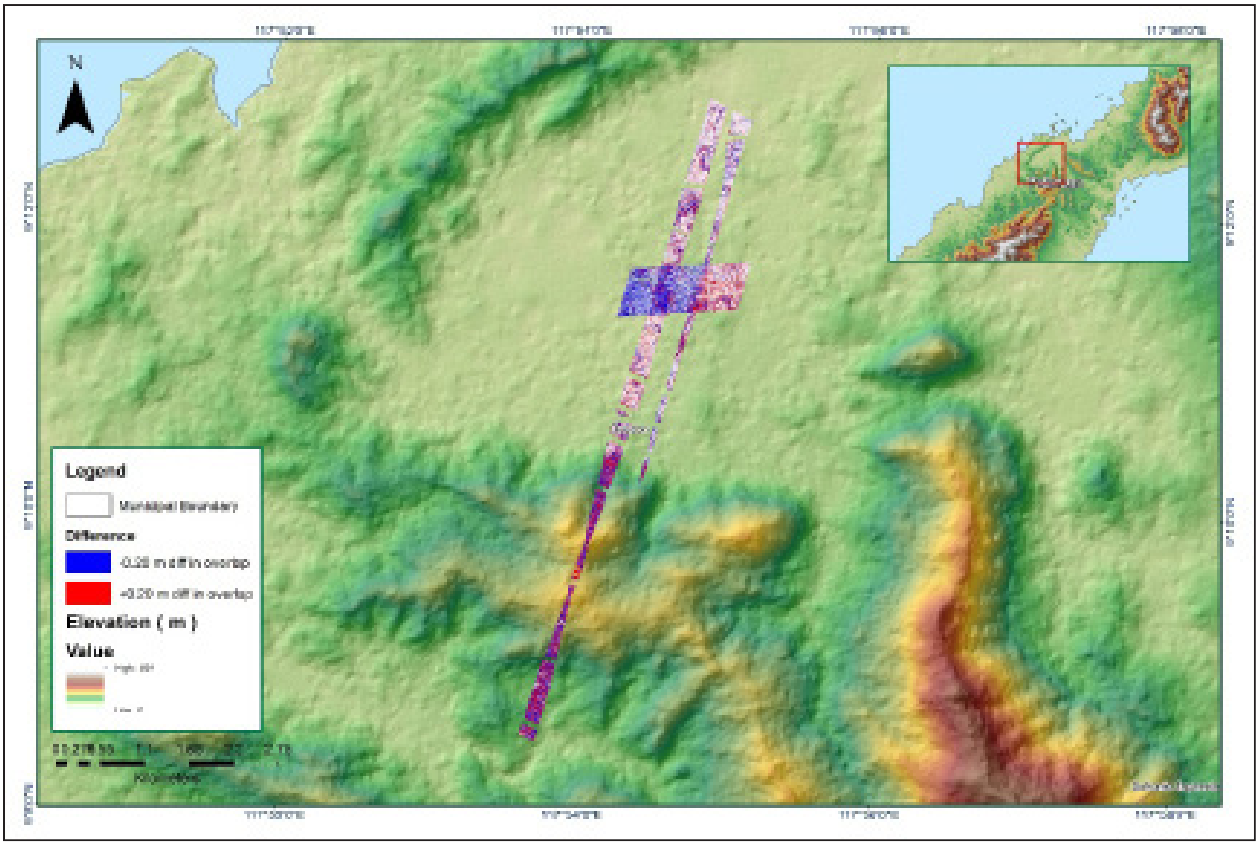


Figure A-8.35. Elevation difference between flight lines

Annex 9. Tanjay 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. Tanjay 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. Tanjay 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