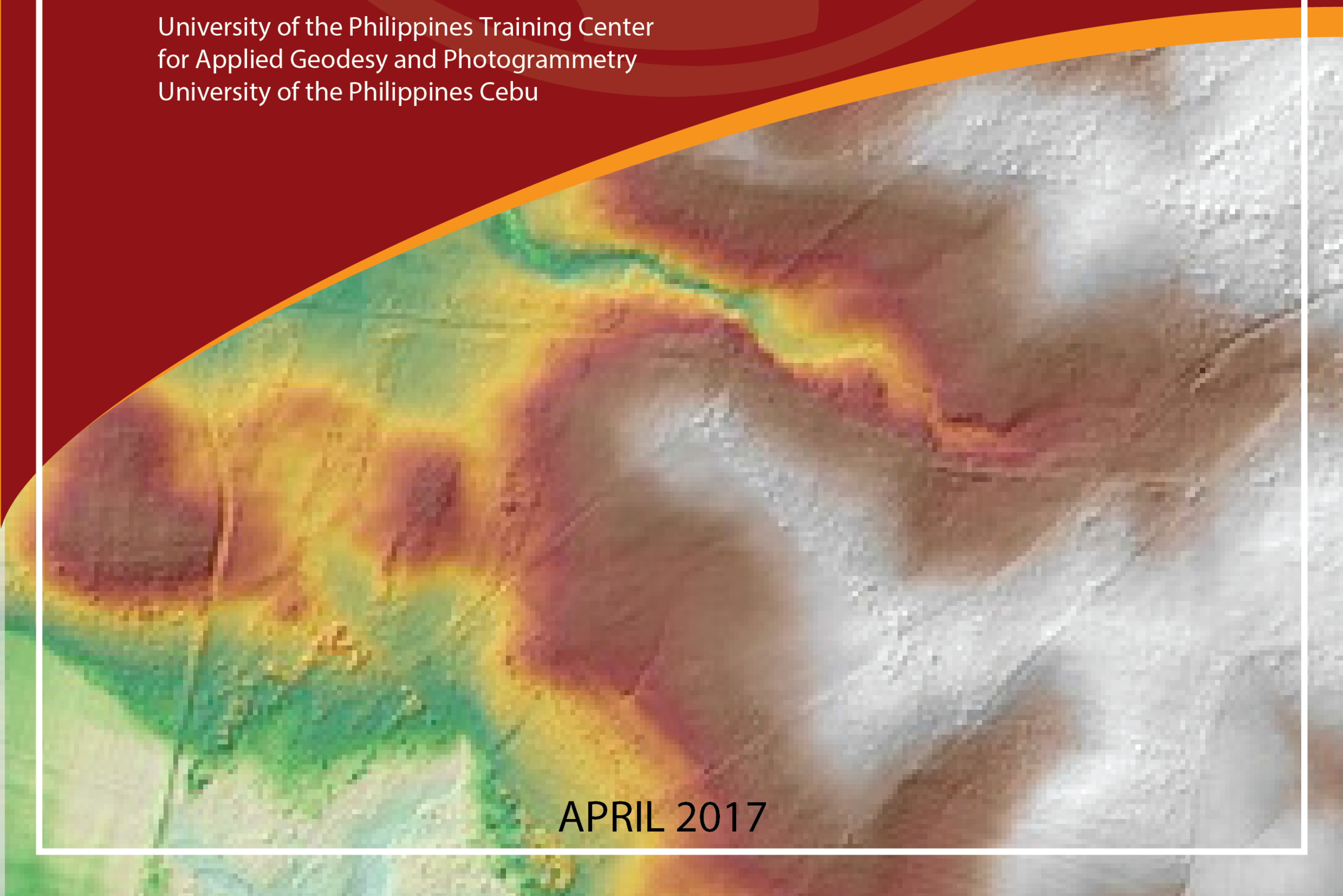
Hazard Mapping of the Philippines Using LIDAR (Phil-LIDAR 1)

LiDAR Surveys and Flood Mapping of Grande River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
University of the Philippines Cebu



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LIST OF ACRONYMS AND ABBREVIATIONS

AAC	Asian Aerospace Corporation
Ab	abutment
ALTM	Airborne LiDAR Terrain Mapper
ARG	automatic rain gauge
AWLS	Automated Water Level Sensor
BA	Bridge Approach
BM	benchmark
CAD	Computer-Aided Design
CN	Curve Number
CSRS	Chief Science Research Specialist
DAC	Data Acquisition Component
DEM	Digital Elevation Model
DENR	Department of Environment and Natural Resources
DOST	Department of Science and Technology
DPPC	Data Pre-Processing Component
DREAM	Disaster Risk and Exposure Assessment for Mitigation [Program]
DRRM	Disaster Risk Reduction and Management
DSM	Digital Surface Model
DTM	Digital Terrain Model
DVBC	Data Validation and Bathymetry Component
FMC	Flood Modeling Component
FOV	Field of View
GiA	Grants-in-Aid
GCP	Ground Control Point
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center - River Analysis System
HC	High Chord
IDW	Inverse Distance Weighted [interpolation method]
IMU	Inertial Measurement Unit
kts	knots
LAS	LiDAR Data Exchange File format
LC	Low Chord
LGU	local government unit
LiDAR	Light Detection and Ranging
LMS	LiDAR Mapping Suite
m AGL	meters Above Ground Level
MCM	
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
RCBO	River Basin Control Office
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 GRANDE RIVER

Enrico C. Paringit, Dr. Eng. and Jonnifer Sinogaya, PhD.

1.1 Background of the Phil-LiDAR 1 Program

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

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

The implementing partner university for the Phil-LiDAR 1 Program is the University of the Philippines Cebu (UPC). UPC 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 22 river basins in the Western Visayas Region. The university is located in Cebu City in the province of Cebu.

1.2 Overview of the Grande River Basin

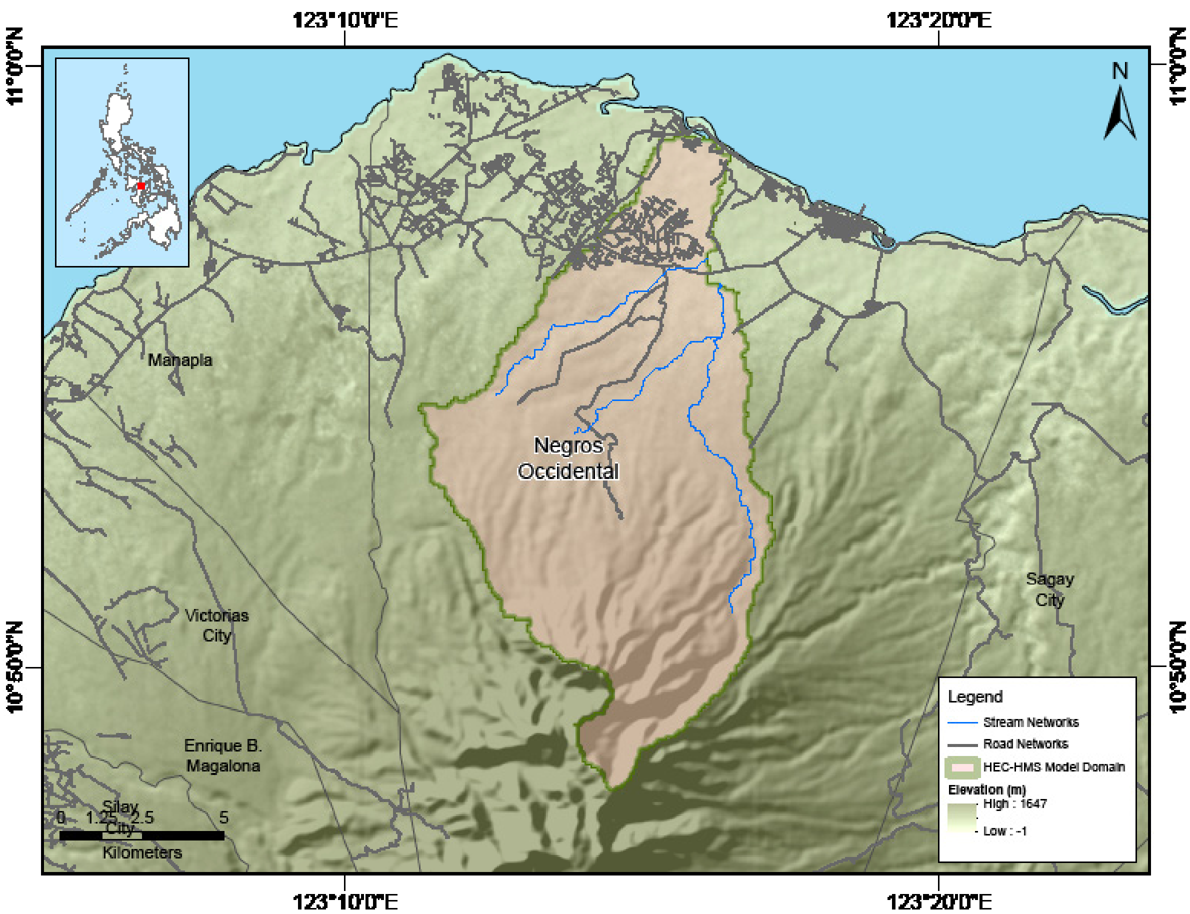

Figure 1. Map of Grande River Basin (in brown)

Grande River Basin is located in the province of Negros Occidental located at the north of Negros Island. The floodplain and drainage area of 92.57 km^2 and 78.22 km^2, respectively, covers Cadiz City. The estimated annual run-off is 155 million cubic meters (MCM). The floodplain is 100% covered with LiDAR data which compromises 3 blocks. The LiDAR data was calibrated then mosaicked with an RMSE of -0.05 and then bathy burned. The bathymetry survey conducted reached a total length of 7.72 km starting from Daga Bridge, Daga, Cadiz City up to the river mouth with 7803 points surveyed. There are 9035 buildings, 263.51km roads, 409 waterbodies and 10 bridges digitized based from the LiDAR data. Feature Extraction Attribution was conducted and among the building features, 8795 of them are Residential, 128 are schools and 14 are Medical Institutions.

Its main stem, the Grande River, is part of the river systems in Negros Island Region. The 2010 census of National Statistics Office stated that there is a total of 25,492 people residing in the immediate vicinity of the river which is distributed among the barangays of Luna and Daga. Sand and gravel deposits are quarried by the locals and serve as a source of income. The recent flood event occurred on October 11, 2013 due to Typhoon Santi in which agricultural damages incurred from heavy rainfall.

The flood hazard map produced for the Grande River Basin covers the 19.42 km2, 24.53 km2, 27.25 km2 for the 5-year, 25-year, and 100-year rainfall return period in Cadiz City which affects 9 barangays. A flood depth validation was conducted using 181 randomly generated points which is spread throughout the 6 ranges namely 0m-0.2m, 0.21m-0.5m, 0.51m-1m, 1.01m-2m, 2.10m-5m, 5m+ depth using the 25-yr rainfall flood depth map. It yielded a 0.723 m RMSE.

A rating curve was developed at Trozo Bridge, Cadiz City, Negros Occidental, which shows the relationship between the observed water levels at Trozo Bridge and outflow of the watershed at this location. This rating curve equation, expressed as Q=1.3234e0.3596x, was used to compute the river outflow at Trozo Bridge for the calibration of the HEC-HMS model. The resulting outflow was used to simulate the flooded areas using HEC-RAS. The simulated model will be an integral part in determining the real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website.

CHAPTER 2: LIDAR DATA ACQUISITION IN GRANDE 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 Grande floodplain in Negros Occidental. These missions were planned for 14 lines and ran for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameters for the LiDAR system are found in Table 1 and Table 2. Figure 2 shows the flight plan and base station for Grande floodplain.

Table 1. Flight planning parameters for Aquarius LiDAR system

Block Name	Flying Height (AGL)	Overlap (%)	Field of View	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency	Average Speed	Average Turn Time (Minutes)
BLK44 D	600	30	36	70	50	120	5
BLK 44 E	600	30	36	70	50	120	5

Table 2. 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)
BLK44 D	1800	30	40	200	50	130	5
BLK44 E	1800	30	40	200	50	130	5
BLK44 H	1800	30	50	200	40	130	5

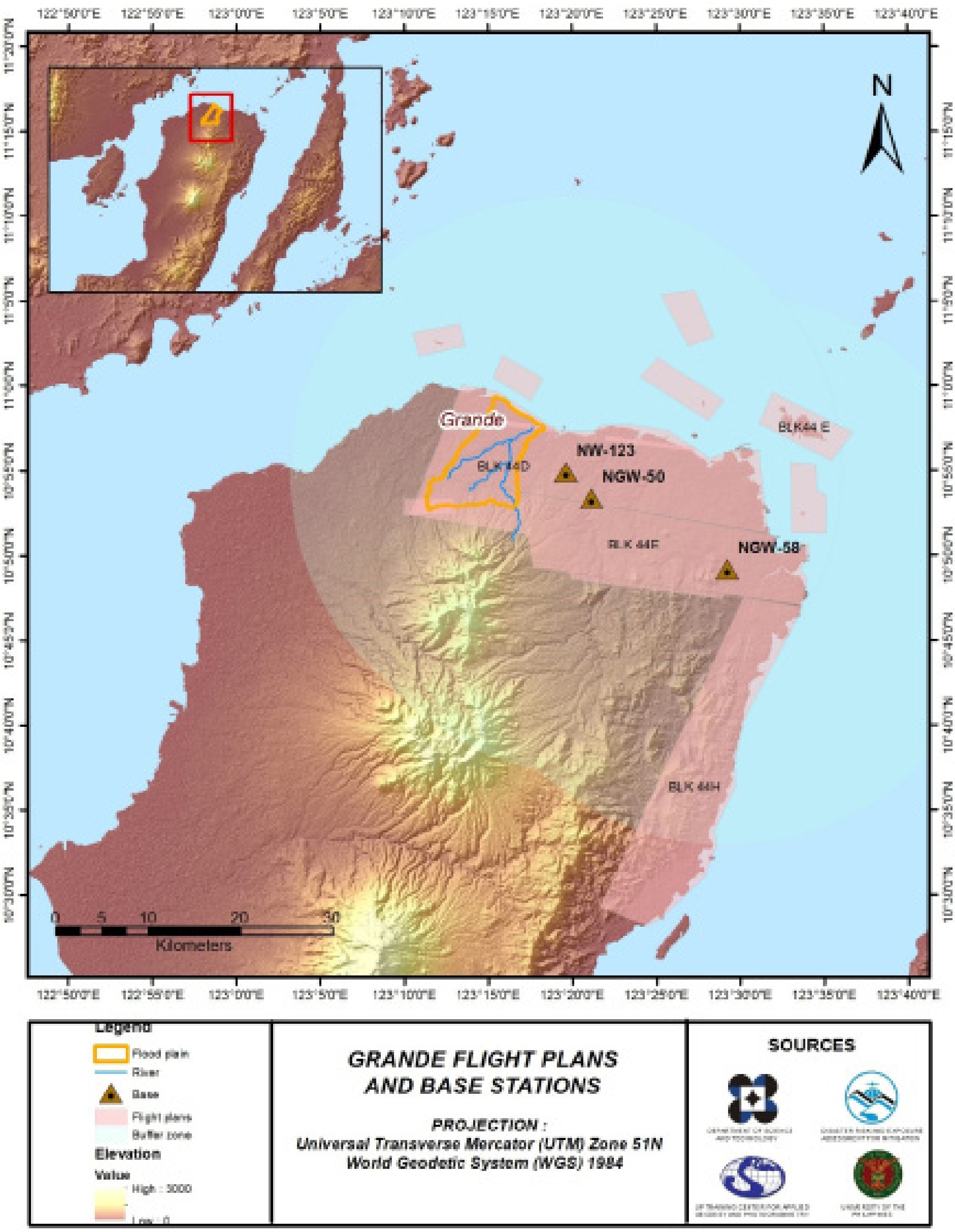

Figure 2. Flight plan used for Grande floodplain.

2.2 Ground Base Station

The project team was able to recover three (3) NAMRIA reference points: NGW-50 and NGW-58, which are of second (2nd) order accuracy. The team also reprocessed one (1) benchmark NW-123. This benchmark was used as vertical reference points and was also established as ground control points. The certification for the NAMRIA reference points and benchmarks are found in Annex E while the baseline processing reports for the established control points are found in Annex F. These were used as base stations during flight operations for the entire duration of the survey (April to May 2014 and April to May 2016). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 852 and SPS 985. Flight plans and location of base stations used during the aerial LiDAR acquisition in Grande floodplain are shown in Figure 2.

Figure 3 to Figure 5 shows the recovered NAMRIA control station within the area, in addition Table 3 to Table 5 show the details about the following NAMRIA control stations and established points, Table 6 shows the list of all ground control points occupied during the acquisition with the corresponding dates of utilization.

Figure 3. GPS set-up over NGW-50 in Sagay, Negros Occidental (a) NAMRIA reference point NGW-50 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point ZGN-138 used as base station for the LiDAR

Station Name	NGW-50	
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	810° 53’ 26.84456” 123° 21’ 06.66798” 15.386 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting	538465.927 m
	Northing	1204272.594 m

Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	10° 53' 26.84456" North 123° 21' 06.66798" East 15.386 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting	538452.463 meters
	Northing	1203851.077 meters

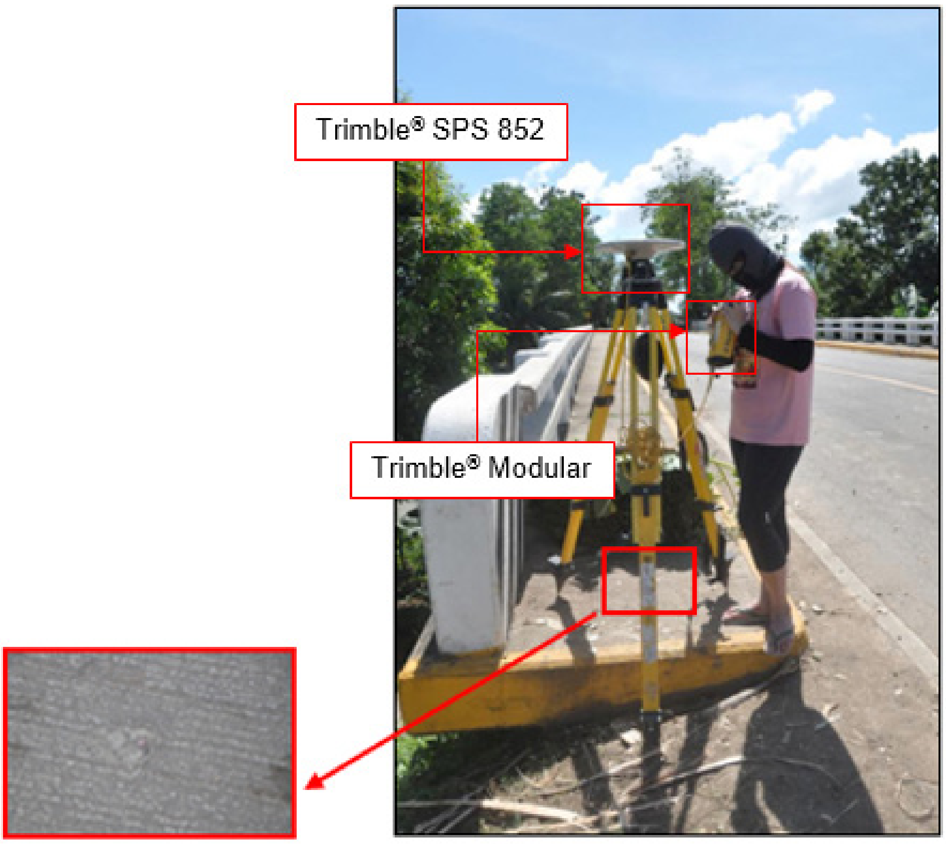

Figure 4. GPS set-up over NGW-58 in Brgy. Jonobjonob, Sitio Labarca, Escalante, Negros Occidental. It is on top of embedded benchmark NW-100.

Table 4. Details of the recovered NAMRIA horizontal control point NGW-58 used as base station for the LiDAR Acquisition.

Station Name	NGW-58	
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	10° 49' 16.43235" 123° 29' 11.51295" 8.72200 m
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	553202.195 m 1196599.363 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	10° 49' 12.14178" 123° 29' 16.71871" 68.25600 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	553,183.57 1,196,180.53

Figure 5. GPS set-up over NW-123 in Cadiz, Negros Occidental going to San Carlos, along the national road (a) and NAMRIA reference point NW-123 (b) as recovered by the field team.

Table 5. Details of the recovered NAMRIA horizontal control point NW-123 used as base station for the LiDAR Acquisition.

Station Name	NW-123	
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	10° 54’ 55.44193” 123° 19’ 39.85851” 29.402 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	8° 12’ 40.63408” North 123° 0’ 24.56923”East 75.58 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRD 1992)	Easting Northing	535814.201 meters 1206569.167 meters

Table 6. Ground control points used during LiDAR data acquisition

Date Surveyed	Flight Number	Mission Name	Ground Control Points
May 1, 2014	1411P	1BLK44D121A	NGW-50 and NGW-58
May 2, 2014	1415P	1BLK44H122A	NGW-50 and NGW-58
April 24, 2016	8457AC	3BLK44EDS115A	NGW-50 and NW-123

2.3 Flight Missions

Three (3) missions were conducted to complete LiDAR data acquisition in Grande floodplain, for a total of 12 hours and 3 minutes (12+03) of flying time for RP-C9022 and RP-C9322. All missions were acquired using the Aquarius and Pegasus LiDAR systems. 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. Ground control points used during LiDAR data acquisition

Date Sur-veyed	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
May 1, 2014	1411P	584.55	358.76	59.40	299.36	519	3	47
May 2, 2014	1415P	501.27	405.08	21.83	281.97	686	4	23
April 24, 2016	8457AC	53.08	64.14	7.58	56.56	NA	3	53
Total		1138.90	827.98	88.81	637.89	1205	12	03

Table 8. Actual parameters used during LiDAR data acquisition.

Date Surveyed	Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (kHz)	Scan Fre-quency (Hz)	Speed of Plane (Kts)	Average Turn Time (Minutes)
May 1, 2014	1411P	1200	30	40	200	50	120	5
May 2, 2014	1415P	1200	30	40	200	50	120	5
April 24, 2016	8457AC	500	60	40	50	40	125	5

2.4 Survey Coverage

Grande floodplain is located in the province of Negros Occidental with majority of the floodplain situated within the municipality of Cadiz City. Municipalities of Sagay City and Cadiz City are mostly covered by the survey. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 9. The actual coverage of the LiDAR acquisition for Grande floodplain is presented in Figure 6.

Table 9. List of Municipalities/Cities Surveyed in Negros Occidental

Province	Municipality	Area of Municipality/ City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Negros Occidental	Sagay City	304.62	191.07	63%
	Cadiz City	516.18	238.88	46%
	Escalante City	193.4	49.59	26%
	Toboso	118.52	19.16	16%
	Calatrava	344.54	40.81	12%
	Manapala	99.18	4.56	5%
	San Carlos City	408.97	3.28	1%

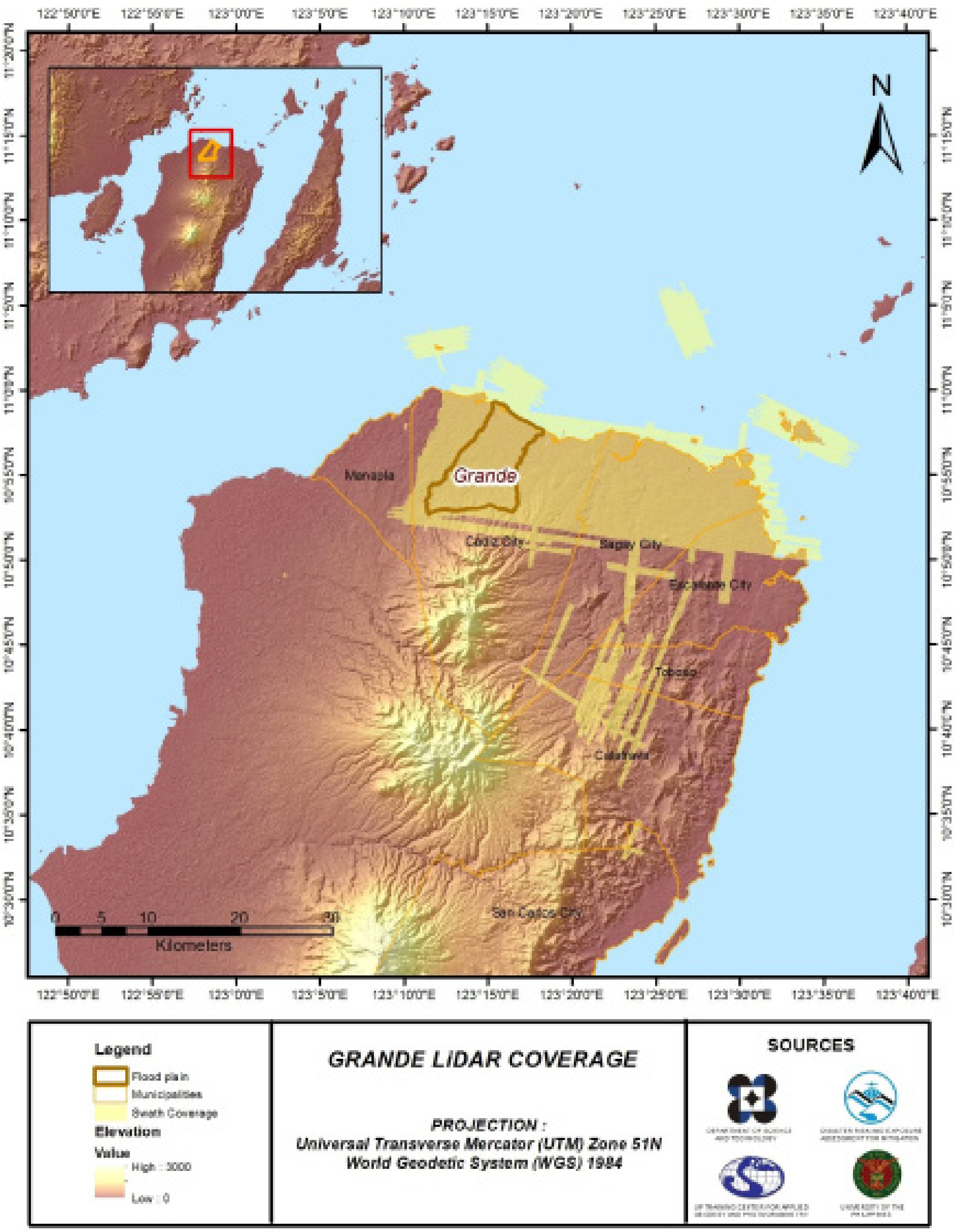

Figure 6. Actual LiDAR survey coverage for Grande floodplain.

CHAPTER 3: LIDAR DATA PROCESSING FOR GRANDE 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

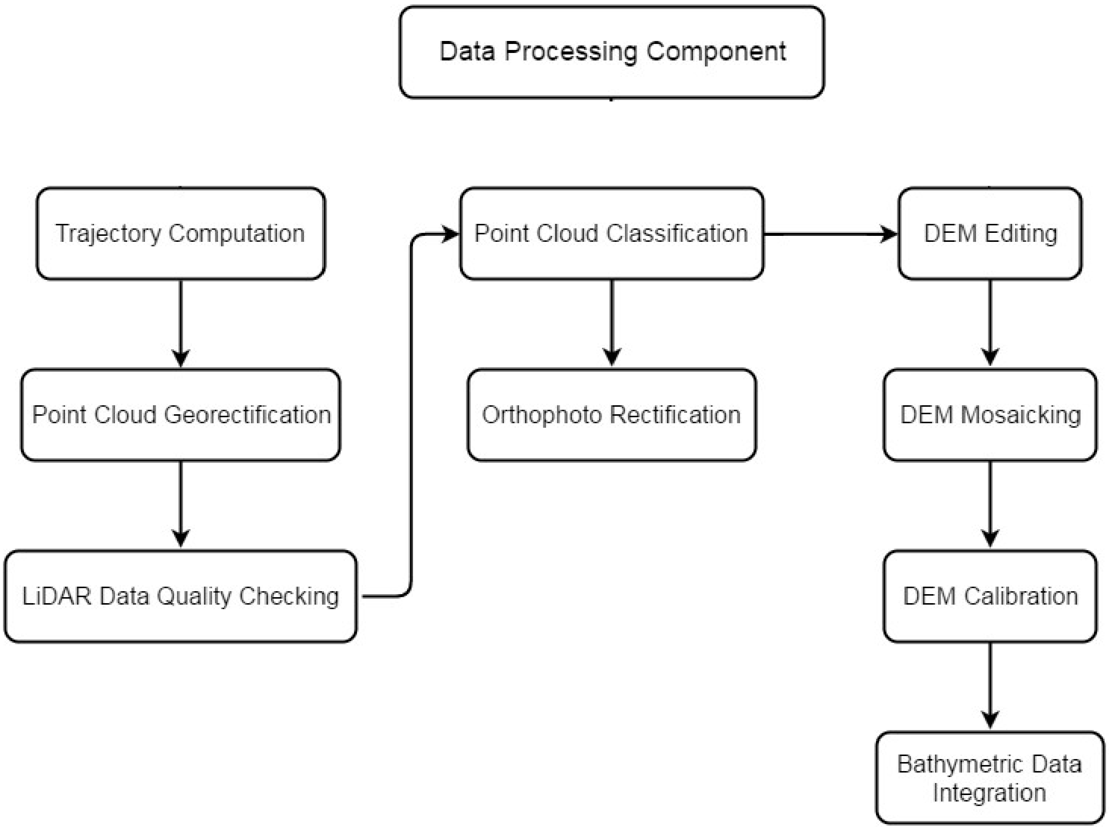

Figure 7. Schematic Diagram for Data Pre-Processing Component

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

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

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

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Grande floodplain can be found in Annex H. Missions flown during the first survey conducted on April 2014 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus system while missions flow during the second survey on April 2016 were flown using the Aquarius system over Cadiz, Negros Occidental. The Data Acquisition Component (DAC) transferred a total of 54.74 Gigabytes of Range data, 728 Megabytes of POS data, 107.88 Megabytes of GPS base station data, and 71.1 Gigabytes of raw image data to the data server on June 4, 2014 for the first survey and May 20, 2016 for the second survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Grande was fully transferred on May 20, 2016, as indicated on the Data Transfer Sheets for Grande floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 8457A, one of the Grande flights, which is the North, East, and Down position RMSE values are shown in Figure 8. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on April 24, 2016 00:00AM. The y-axis is the RMSE value for that particular position.

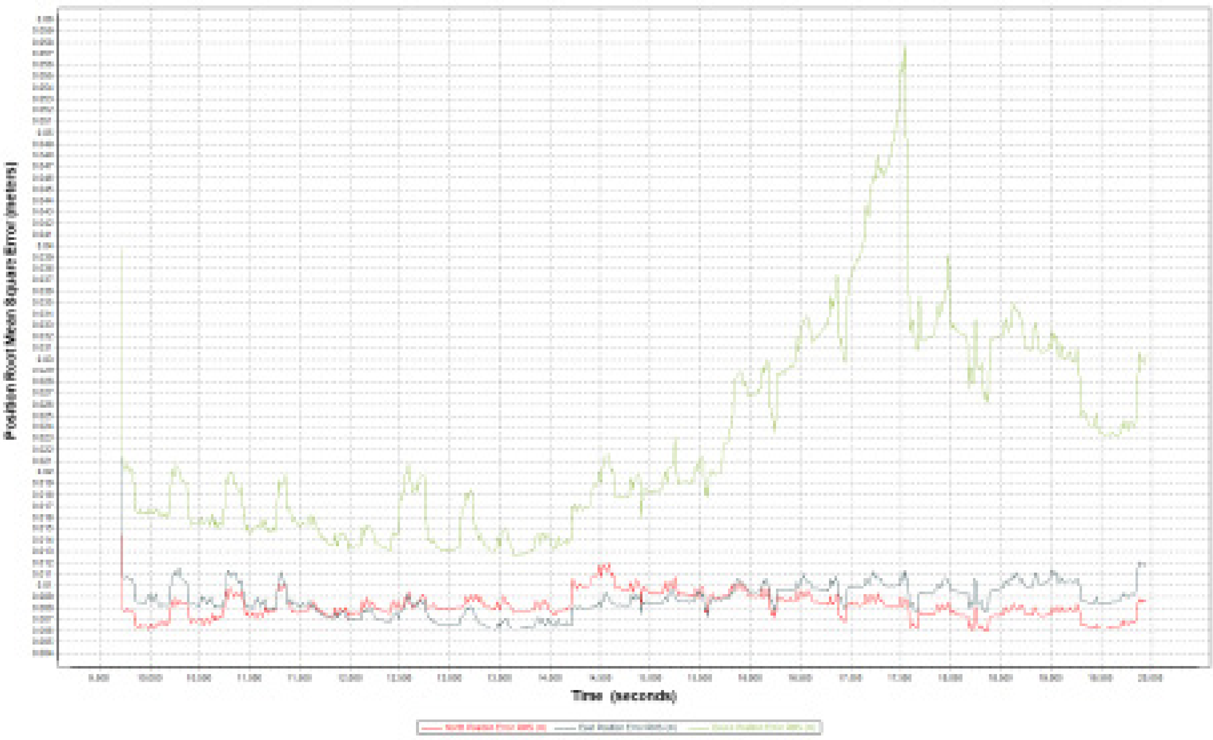

Figure 8. Smoothed Performance Metrics of a Grande Flight 8457A.

The time of flight was from 9700 seconds to 20000 seconds, which corresponds to afternoon of April 24, 2016. 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 1.04 centimeters, the East position RMSE peaks at 1. 26 centimeters, and the Down position RMSE peaks at 2.51 centimeters, which are within the prescribed accuracies described in the methodology.

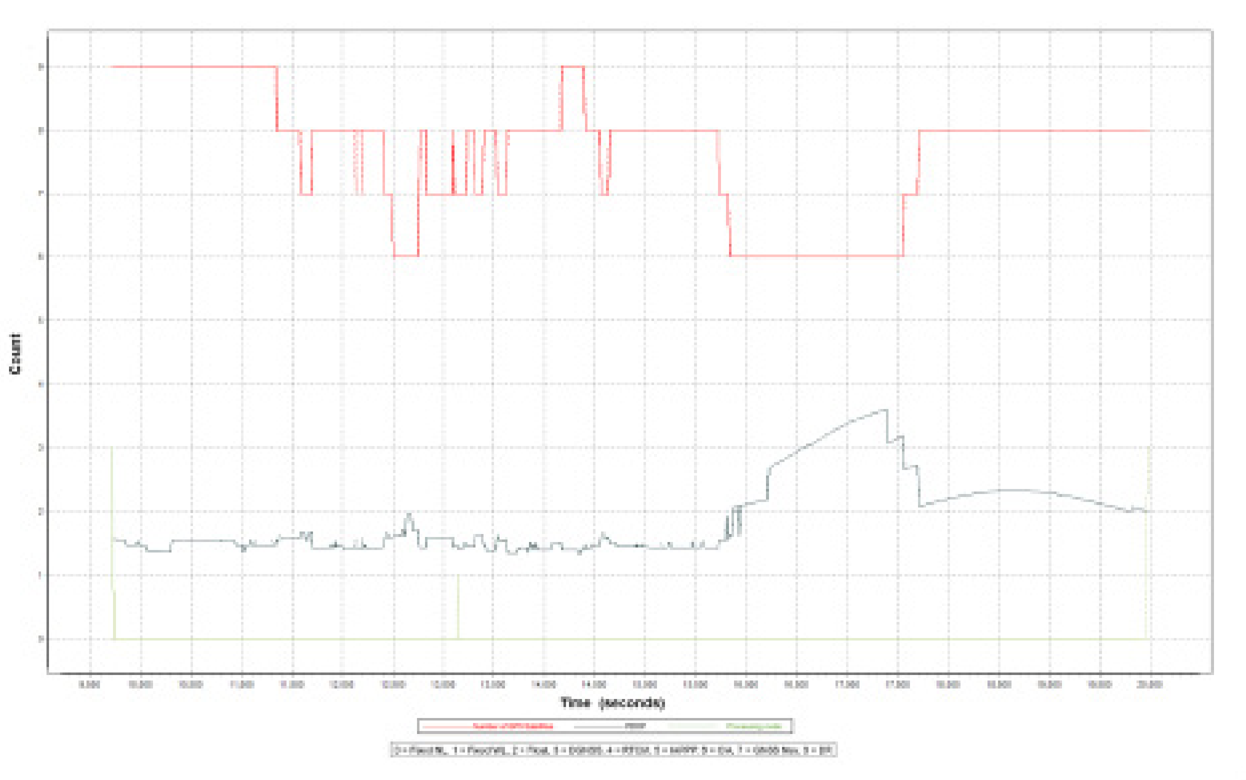

Figure 9. Solution Status Parameters of Grande Flight 8457A.

The Solution Status parameters of flight 8457A, one of the Grande flights, which indicate the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 9. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Most of the time, the number of satellites tracked was between 6 and 9. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode remained at 0 for majority of the survey with some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Grande flights is shown in Figure 10.

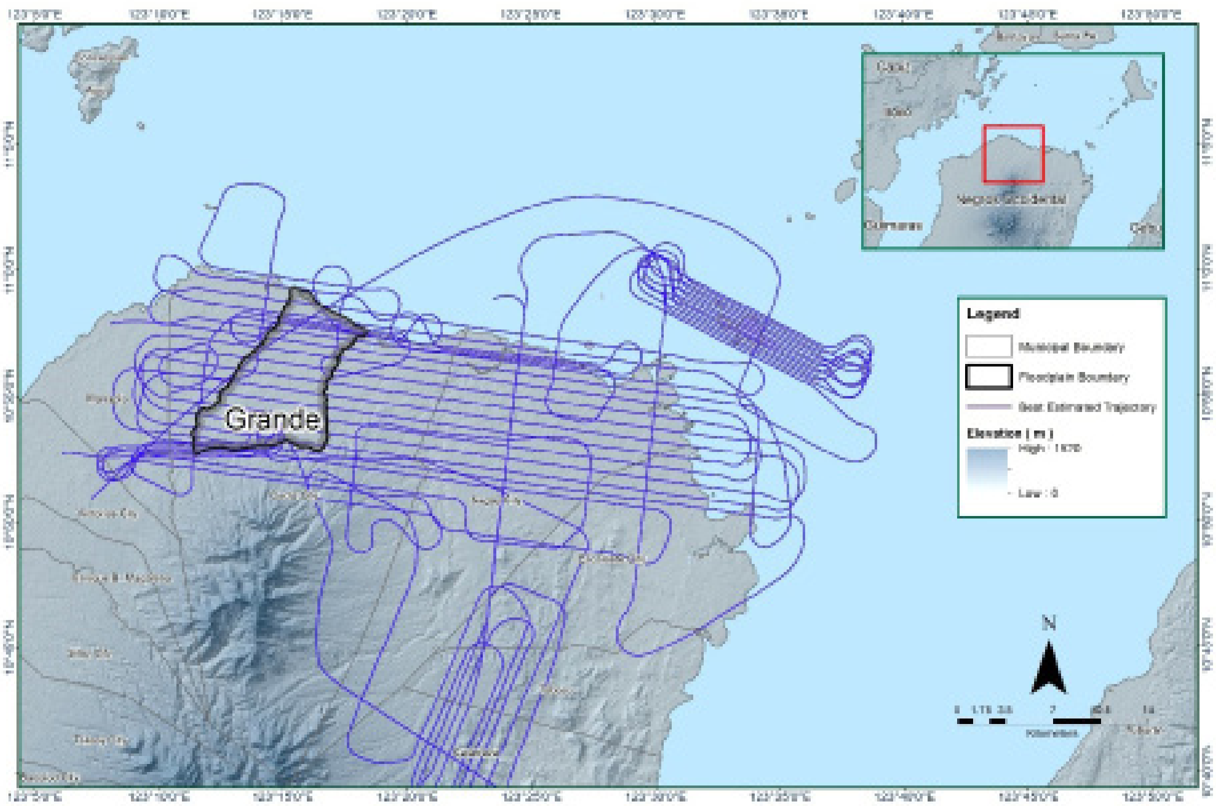

Figure 10. Best estimated trajectory for Grande floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 27 flight lines, with each flight line containing two channels for Pegasus system and one channel for Aquarius system. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Grande floodplain are given in Table 10.

Table 10. Self-Calibration Results values for Grande flights

Parameter	Computed Value
Boresight Correction stdev (<0.001degrees)	0.000446
IMU Attitude Correction Roll and Pitch Corrections stdev (<0.001degrees)	0.005774
GPS Position Z-correction stdev (<0.01meters)	0.0134

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

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data is shown in Figure 11. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

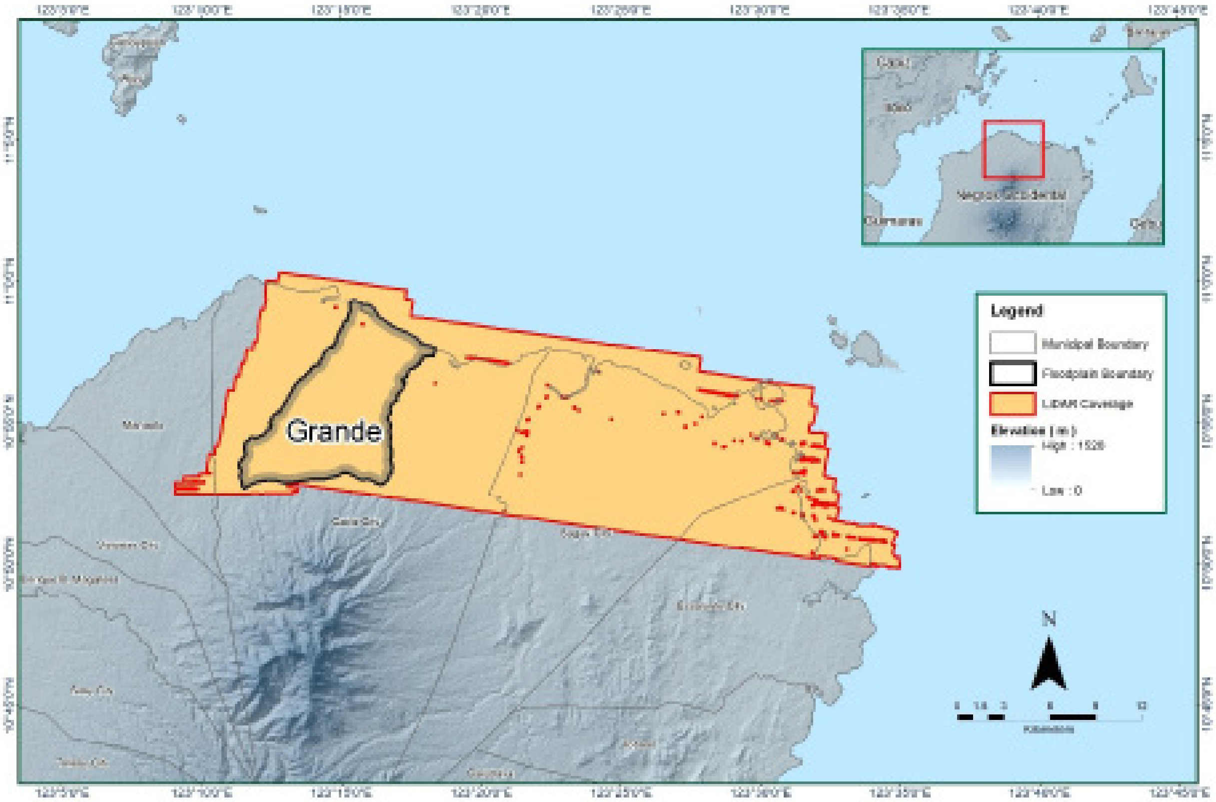

Figure 11. Boundary of the processed LiDAR data on top of a SAR Elevation Data over Grande Floodplain.

The total area covered by the Grande missions is 499.98 sq.km that is comprised of three (3) flight acquisitions grouped and merged into three (3) blocks as shown in Table 11.

Table 11. List of LiDAR blocks for Grande floodplain

LiDAR Blocks	Flight Numbers	Area (sq. km)
Negros_Blk44D	1411P	475.20
	1435P	
Bacolod_Blk44C	8457A	9.49
Bacolod_Blk44D	8457A	15.29
TOTAL		499.98 sq.km

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 12. Since the Aquarius system employs one channel, we would expect an average value of 1 (blue) for areas where there is limited overlap, and a value of 2 (yellow) or more (red) for areas with three or more overlapping flight lines. While for the Pegasus system which employs two channels, we would expect an average value of 2 (blue) for areas where there is limited overlap and a value of 3 (yellow) or more (red) for areas with three or more overlapping flight lines.

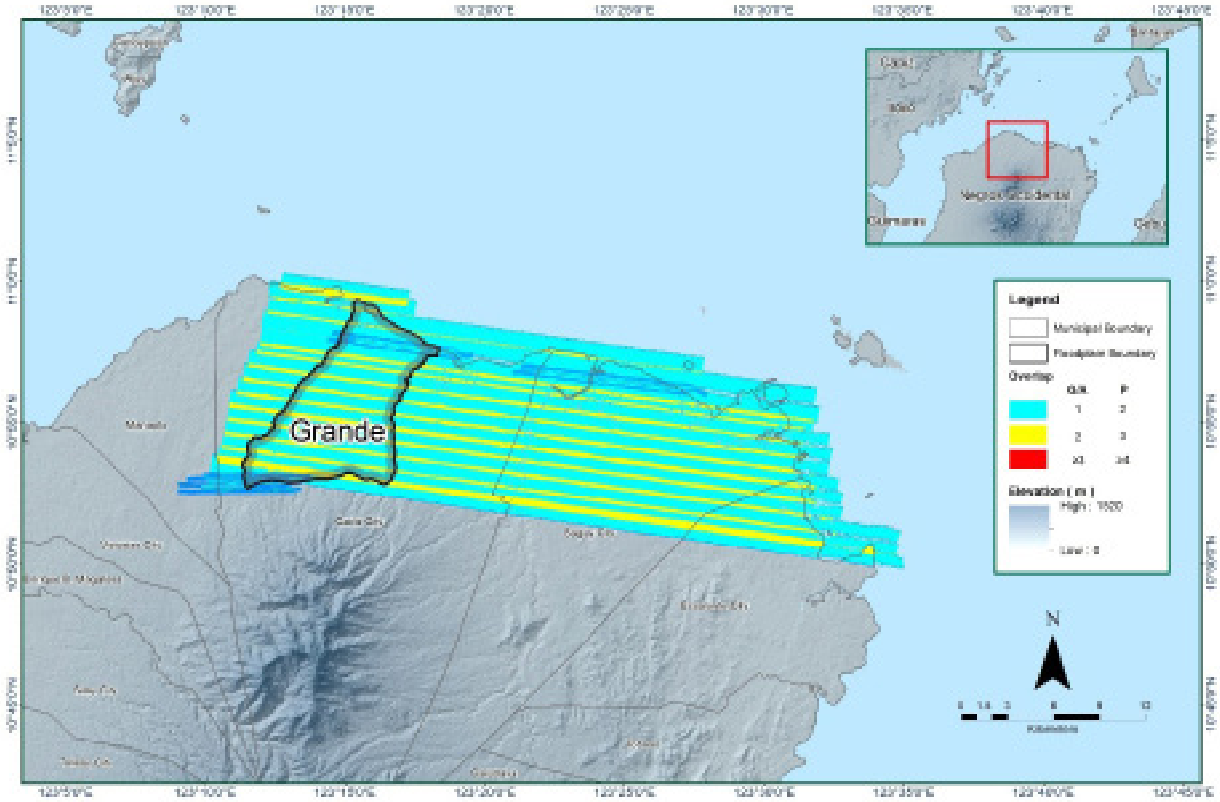

Figure 12. Image of data overlap for Grande floodplain.

The overlap statistics per block for the Grande 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 25.50% and 30.10% 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 13. It was determined that all LiDAR data for Grande floodplain satisfy the point density requirement, and the average density for the entire survey area is 2.95 points per square meter.

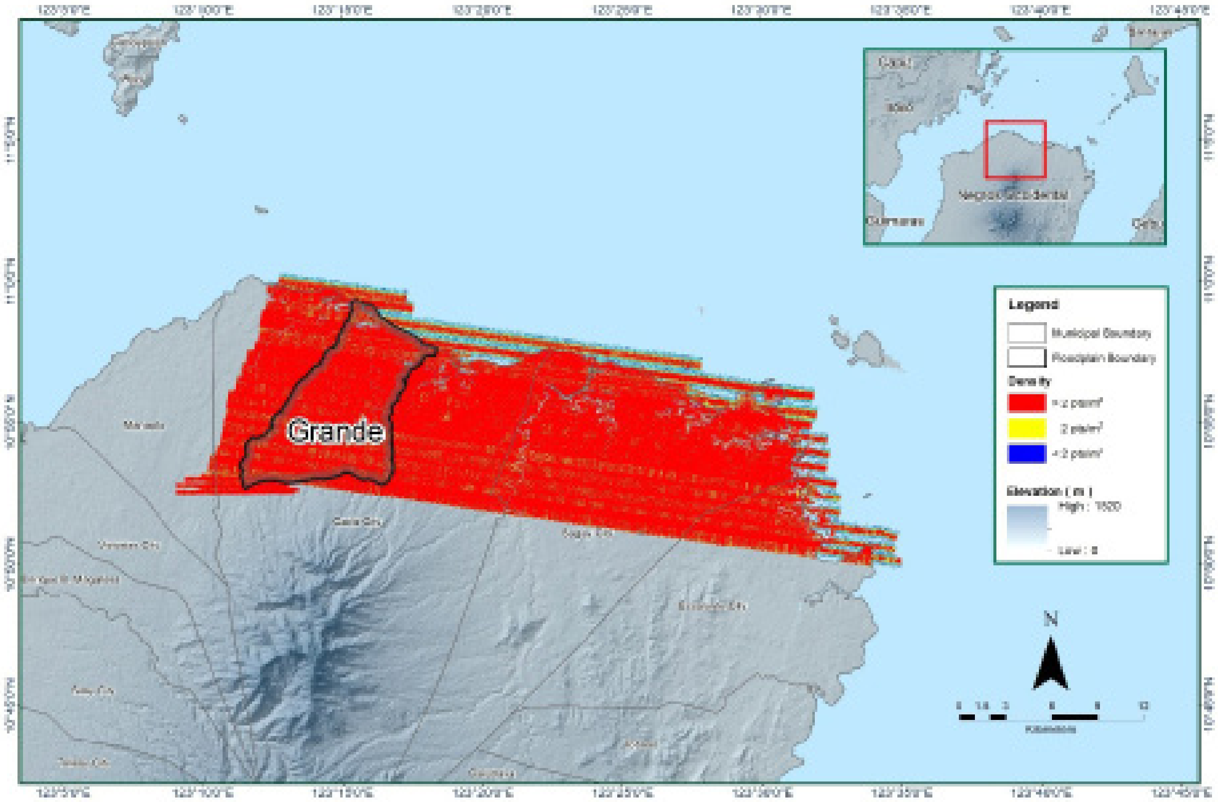

Figure 13. Pulse density map of merged LiDAR data for Grande floodplain.

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

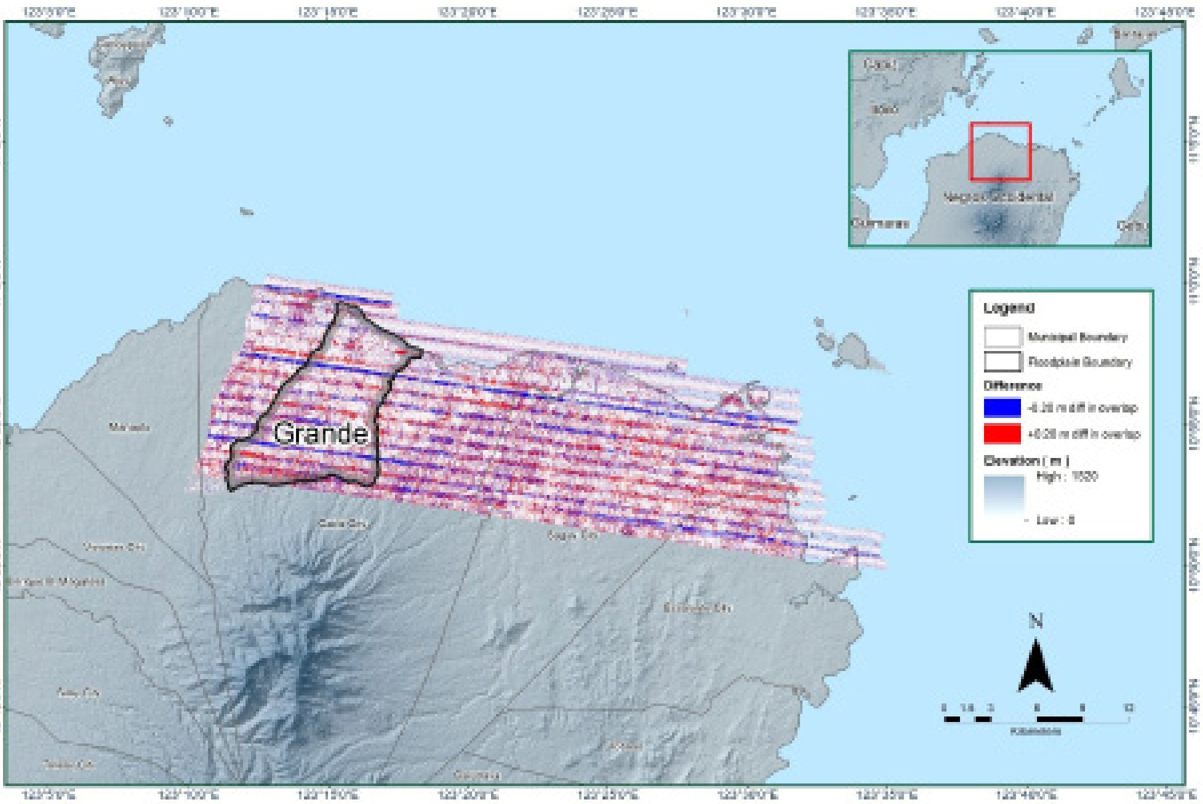

Figure 14. Elevation difference map between flight lines for Grande Floodplain.

A screen capture of the processed LAS data from a Grande flight 8457A loaded in QT Modeler is shown in Figure 15. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed 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.

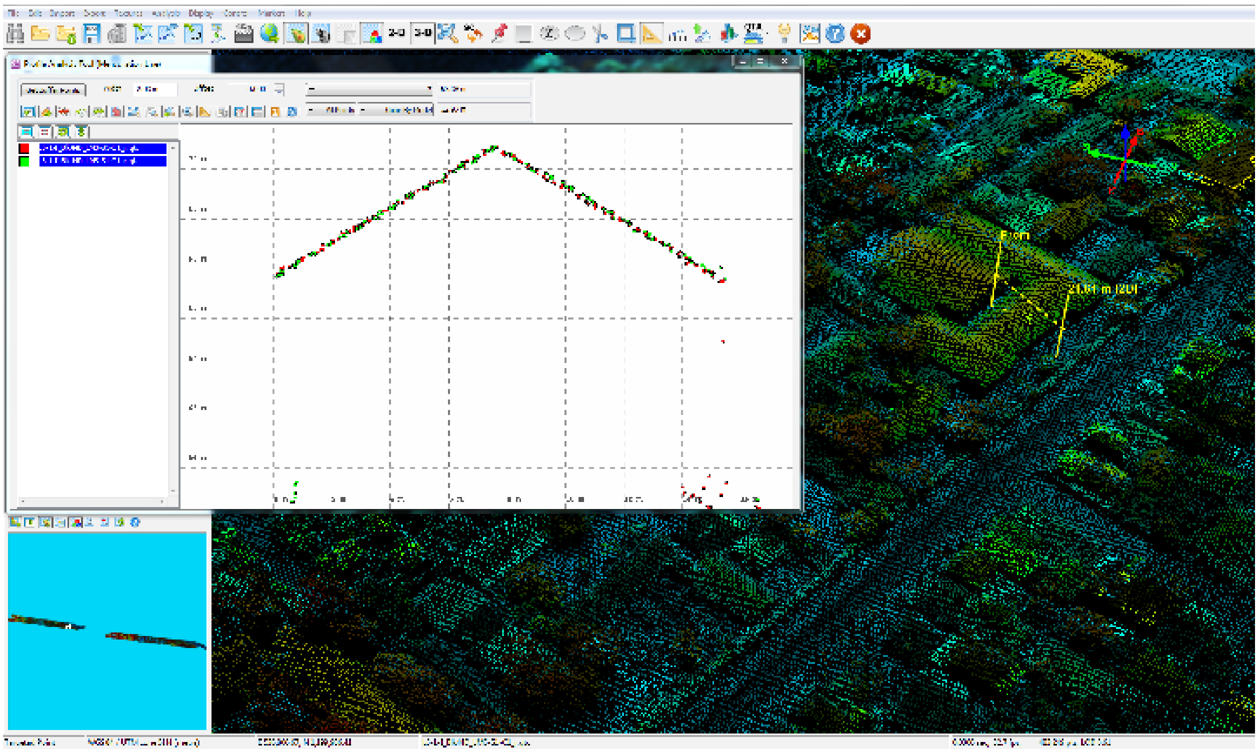

Figure 15. Quality checking for a Grande flight 8457A using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 12. Grande classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	408,768,359
Low Vegetation	344,838,163
Medium Vegetation	481,141,291
High Vegetation	133,822,096
Building	11,653,157

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Grande floodplain is shown in Figure 16. A total of 618 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 395.70 meters and 50.84 meters respectively.

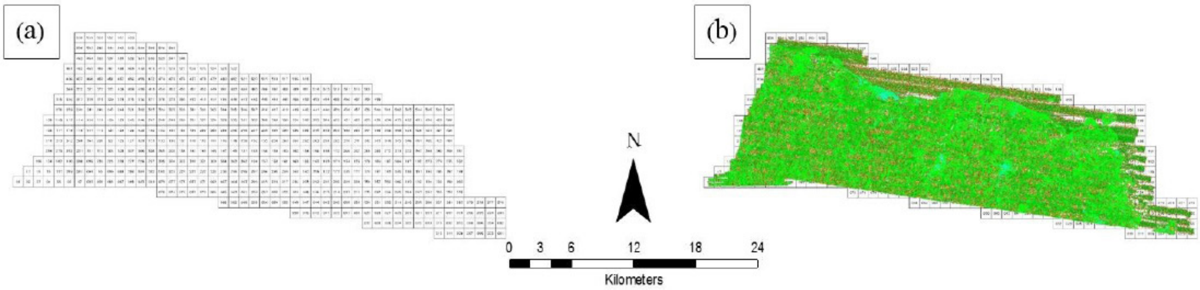

Figure 16. Tiles for Grande floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 17. The ground points are in orange, 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.

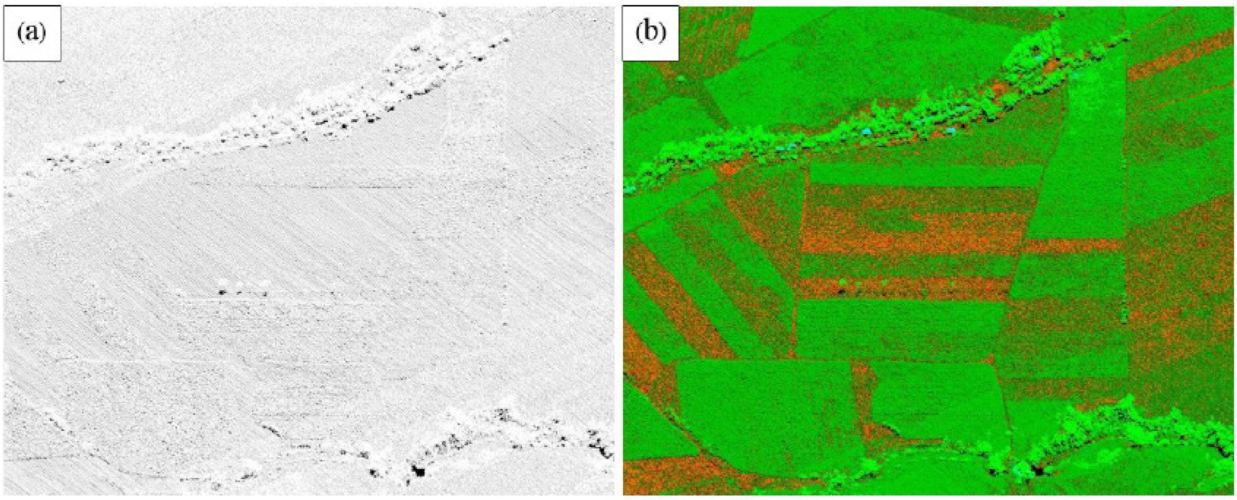

Figure 17. Point cloud before (a) and after (b) classification.

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

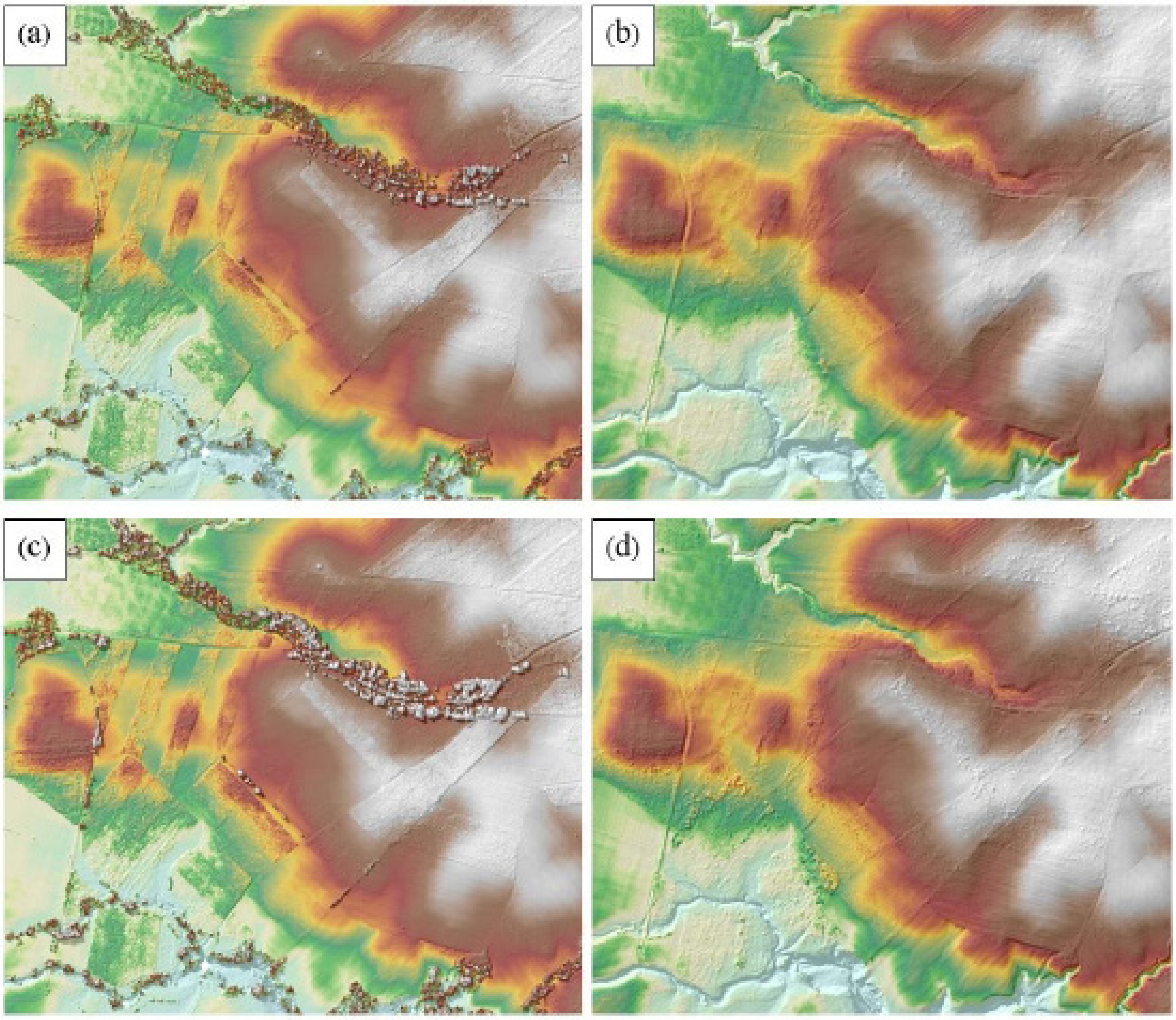

Figure 18. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Grande floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 385 1km by 1km tiles area covered by Grande floodplain is shown in Figure 19. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Grande floodplain has a total of 300.85 sq.km orthophotogaph coverage comprised of 497 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 20.

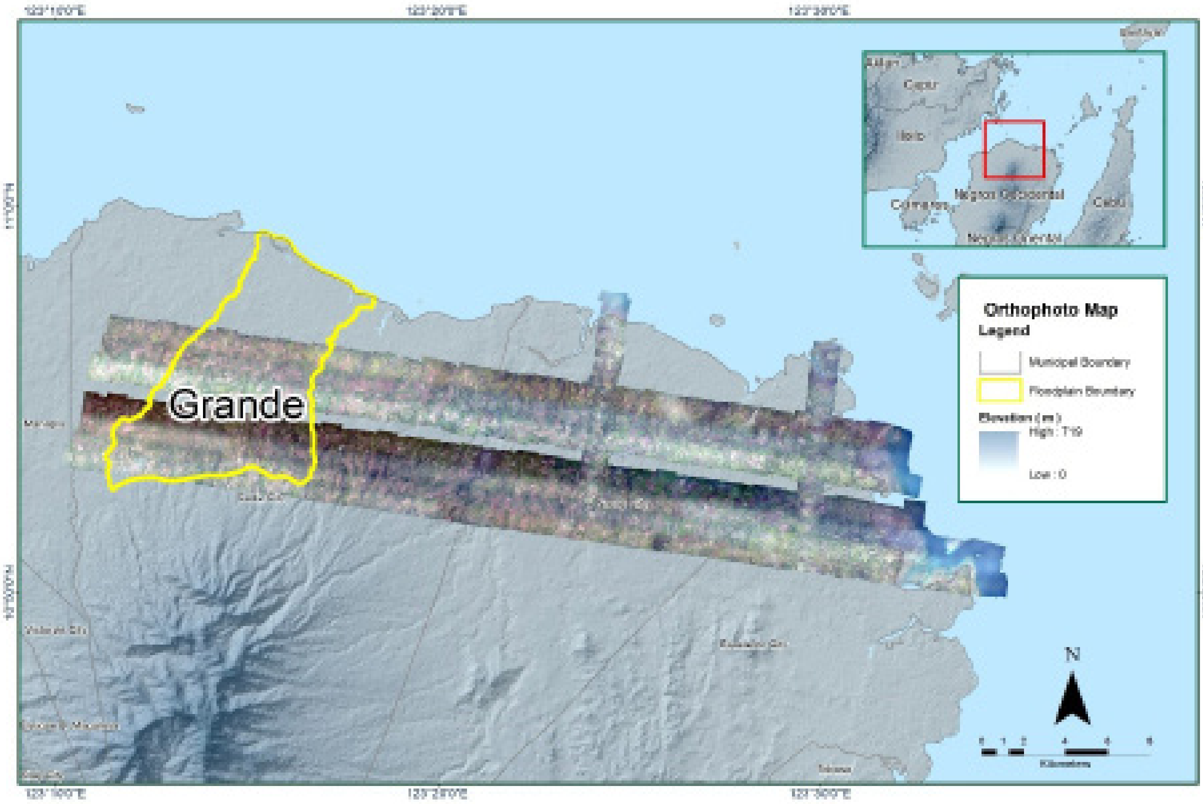

Figure 19. Grande floodplain with available orthophotographs

Figure 20. Sample orthophotograph tiles for Grande floodplain.

3.8 DEM Editing and Hydro - Correction

The 385 1km by 1km tiles area covered by Grande floodplain is shown in Figure 19. After tie point selection Three (3) mission blocks were processed for Grande flood plain. These blocks are composed of Negros and Bacolod blocks with a total area of 499.98 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)
Negros_Blk44D	475.20
Bacolod_Blk44C	9.49
Bacolod_Blk44D	15.29
TOTAL	499.98 sq.km

Portions of DTM before and after manual editing are shown in Figure 21. It shows that the paddy field (Figure 21a) has been misclassified and removed during classification process and has to be retrieved to complete the surface (Figure 21b). The bridges (Figure 21c) would be an impedance to the flow of water along the river and have to be removed (Figure 21d) in order to hydrologically correct the river. Another example is a road that has been misclassified (Figure 21e) and has to be retrieved through manual editing (Figure 21f).

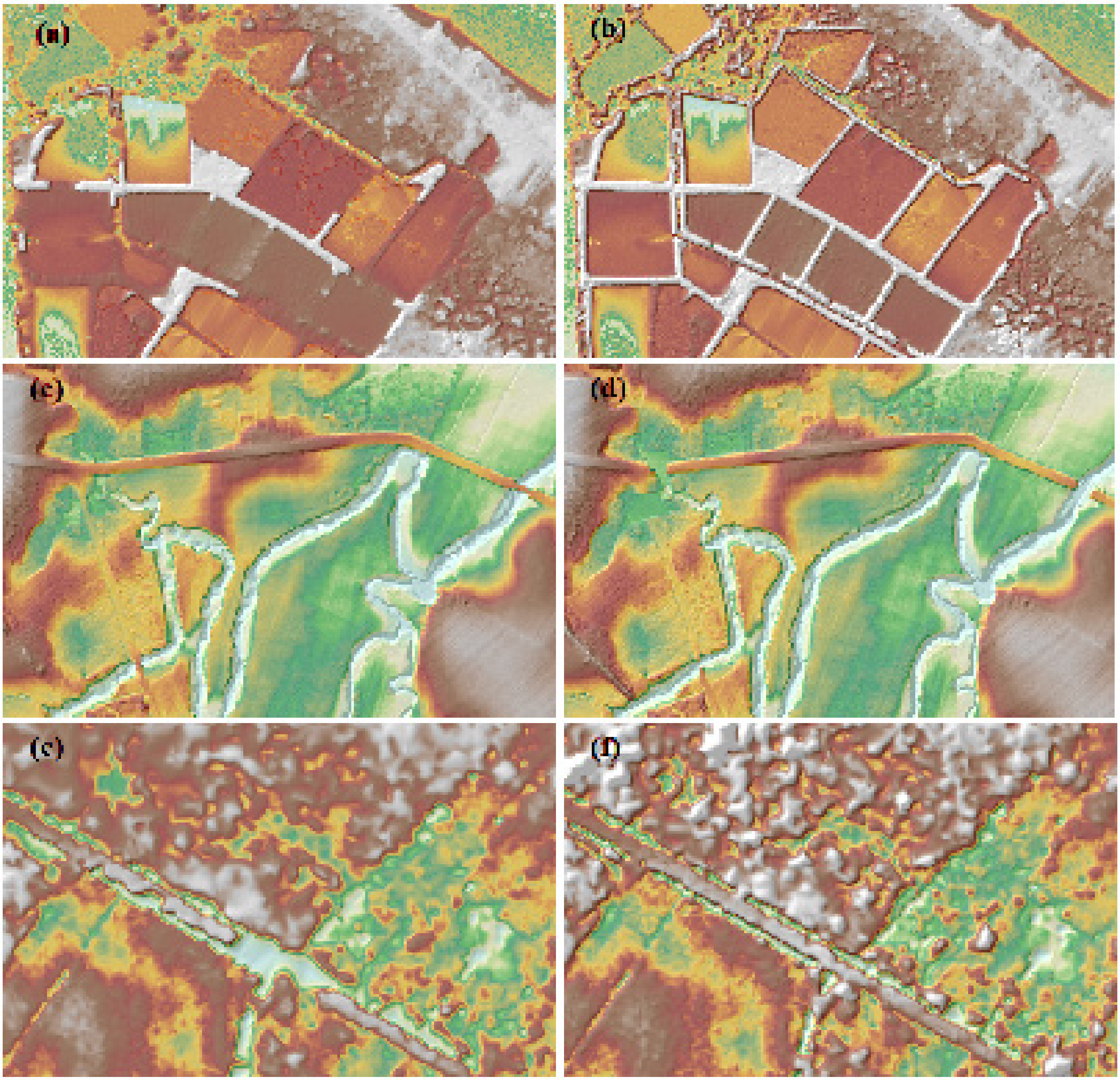

Figure 21. Portions in the DTM of Grande floodplain – a paddy field before (a) and after (b) data retrieval; bridges before (c) and after (d) manual editing; and a road before (e) and after (f) data retrieval.

3.9 Mosaicking of Blocks

Negros_Blk44AB was used as the reference block at the start of mosaicking because it was referred to a base station with an acceptable order of accuracy. Table 14 shows the area of each LiDAR block and the shift values applied during mosaicking.

Mosaicked LiDAR DTM for Grande floodplain is shown in Figure 22. It can be seen that the entire Grande floodplain is 100% covered by LiDAR data.

Table 14. Shift Values of each LiDAR Block of Grande floodplain.

Mission Blocks	**Shift Values (meters)**		
	x	**y**	**z**
Negros_Blk44D	0.00	0.00	0.66
Bacolod_Blk44C	0.00	0.00	1.55
Bacolod_Blk44D	0.00	0.00	1.66

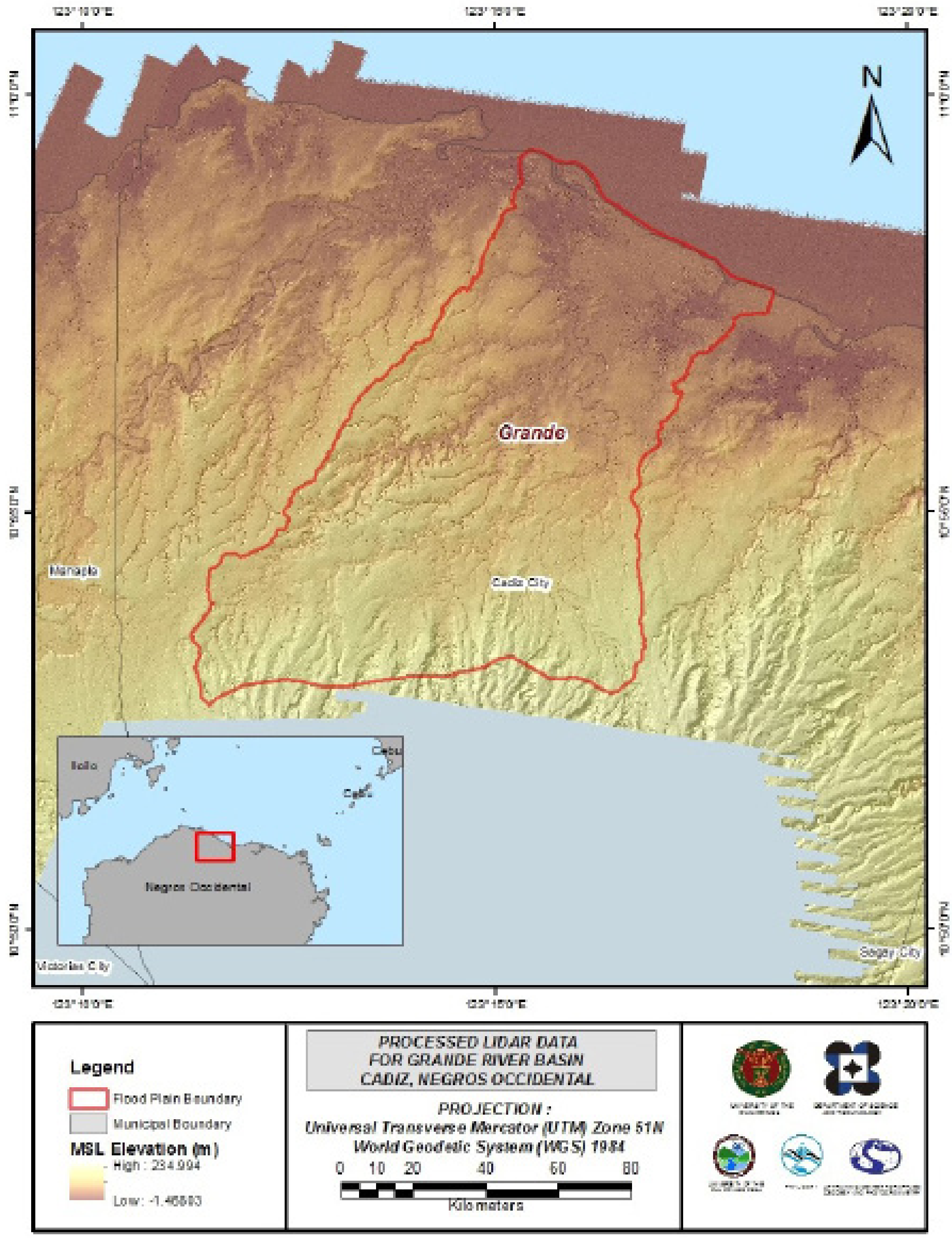

Figure 22. Map of Processed LiDAR Data for Grande Flood Plain.

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 the Negros Island to collect points with which the LiDAR dataset is validated is shown in Figure 23. A total of 39,705 points were gathered for all the floodplains within the Negros Island wherein the Grande is located. Random selection of 80% of the survey points, resulting to 31,385 points, were used for calibration.

A good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values is shown in Figure 24. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration elevation values is 0.94 meters with a standard deviation of 0.15 meters. Calibration of Grande LiDAR data was done by subtracting the height difference value, 0.94 meters, to the mosaicked LiDAR data for Grande. Table 15 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

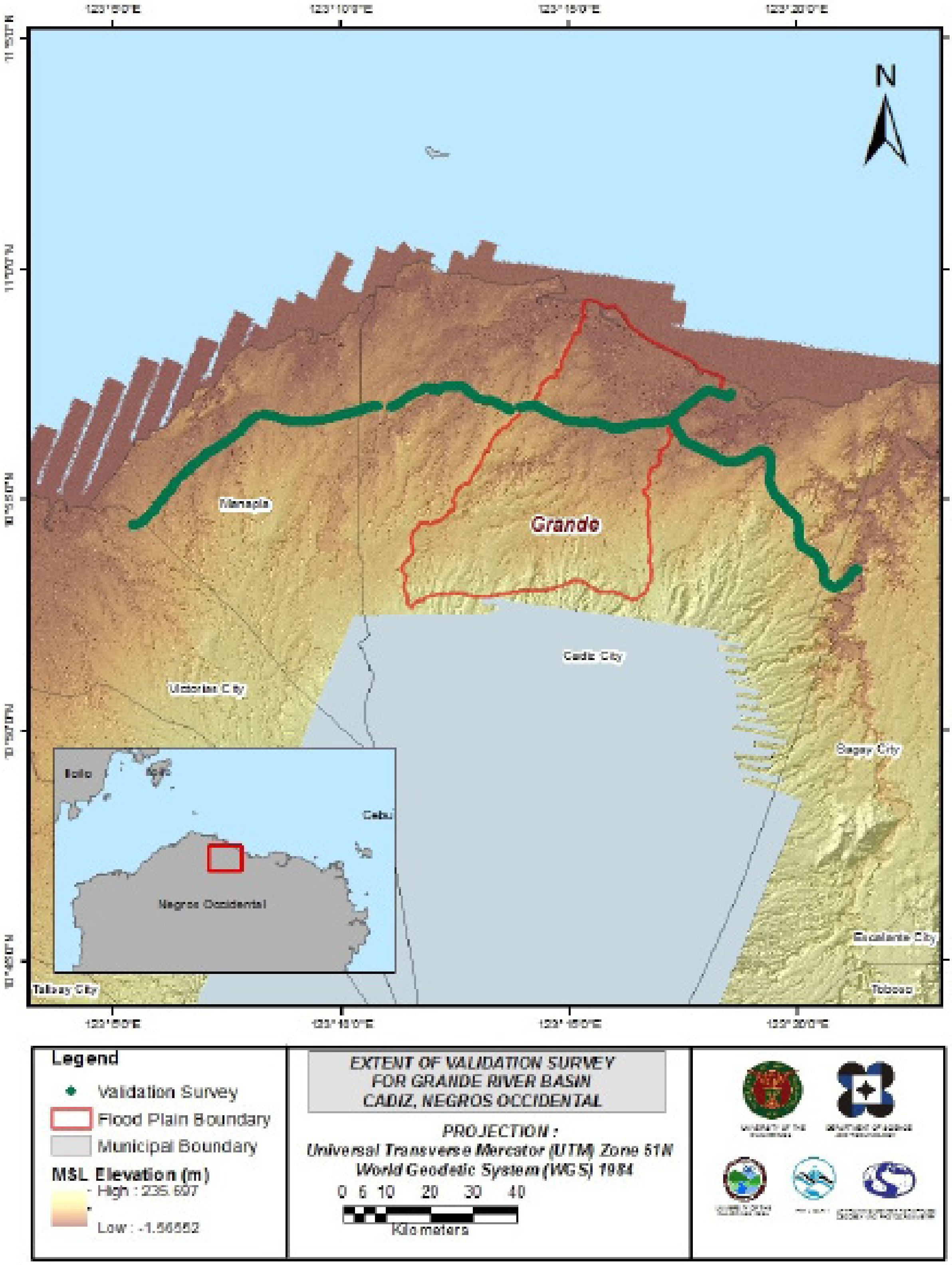

Figure 23. Map of Grande Flood Plain with validation survey points in green.

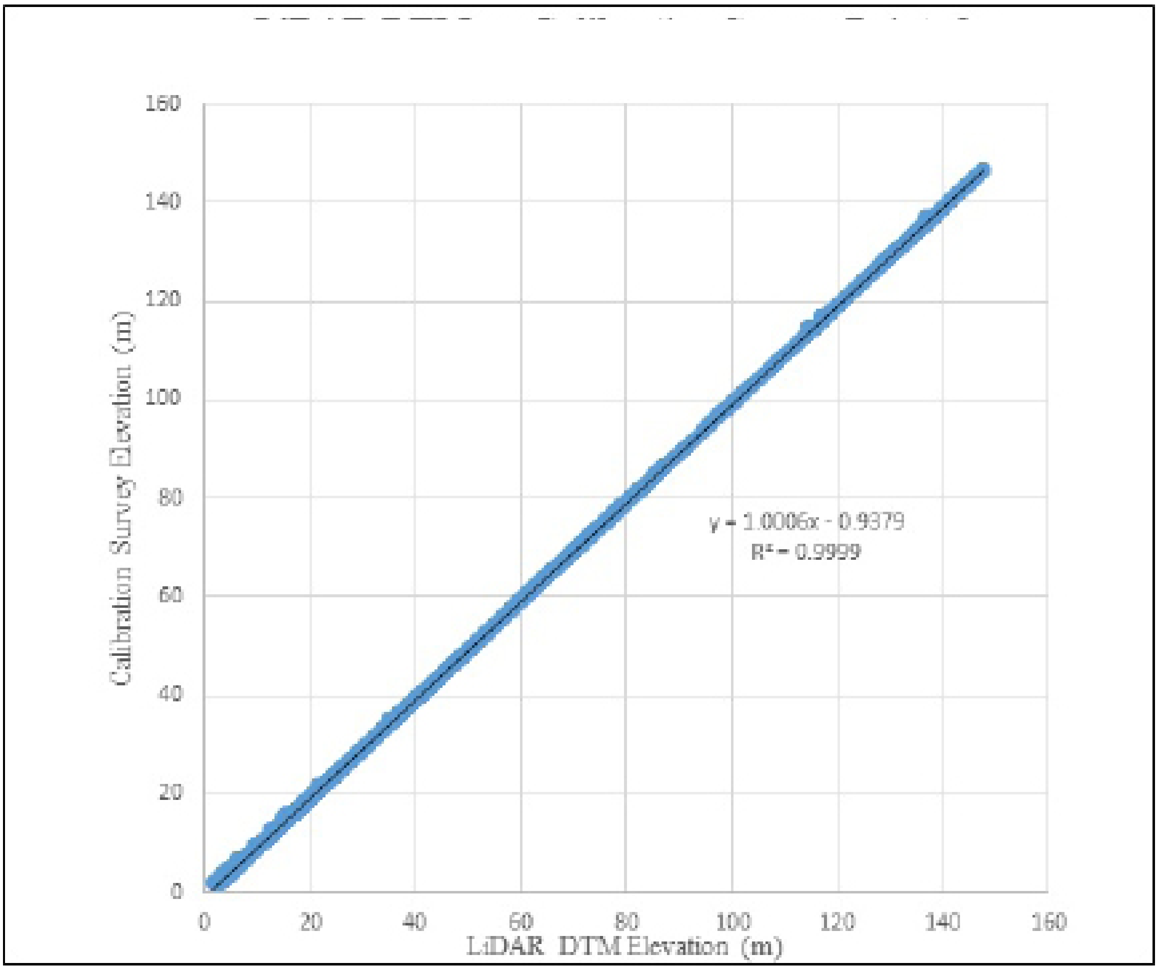

Figure 24. Correlation plot between calibration survey points and LiDAR data.

Table 15. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	0.94
Standard Deviation	0.15
Average	-0.93
Minimum	-1.21
Maximum	0.89

A total of 192 survey points that are within Grande flood plain were used for the validation of the calibrated Grande 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 25. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.09 meters with a standard deviation of 0.08 meters, as shown in Table 16.

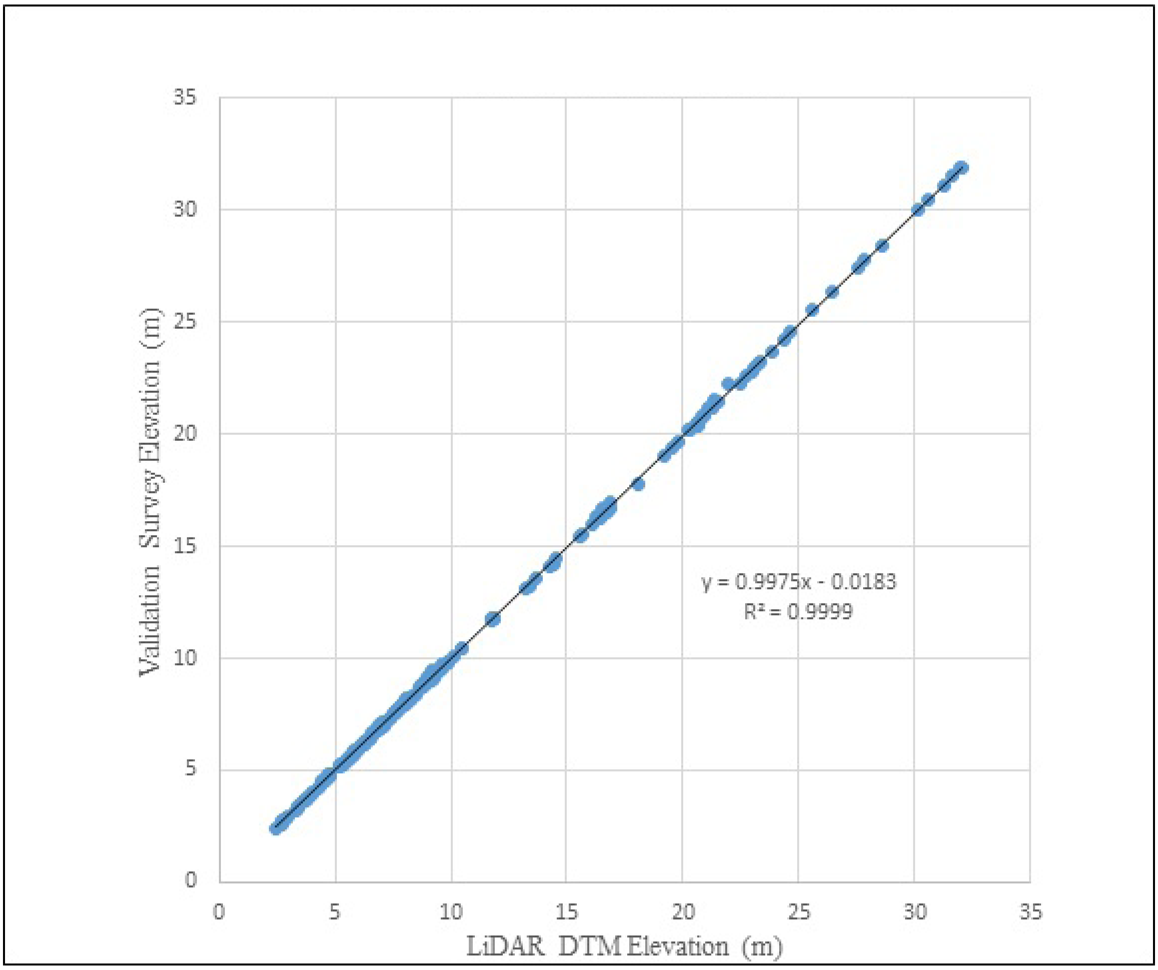

Figure 25. Correlation plot between validation survey points and LiDAR data.

Table 16. Validation Statistical Measures.

Validation Statistical Measures	Value (meters)
RMSE	0.09
Standard Deviation	0.08
Average	-0.05
Minimum	-0.23
Maximum	0.25

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, only centerline data was available for Grande with 7,802 bathymetric survey points. The resulting raster surface produced was done by Inverse Distance Weighted (IDW) interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.07 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Grande integrated with the processed LiDAR DEM is shown in Figure 26.

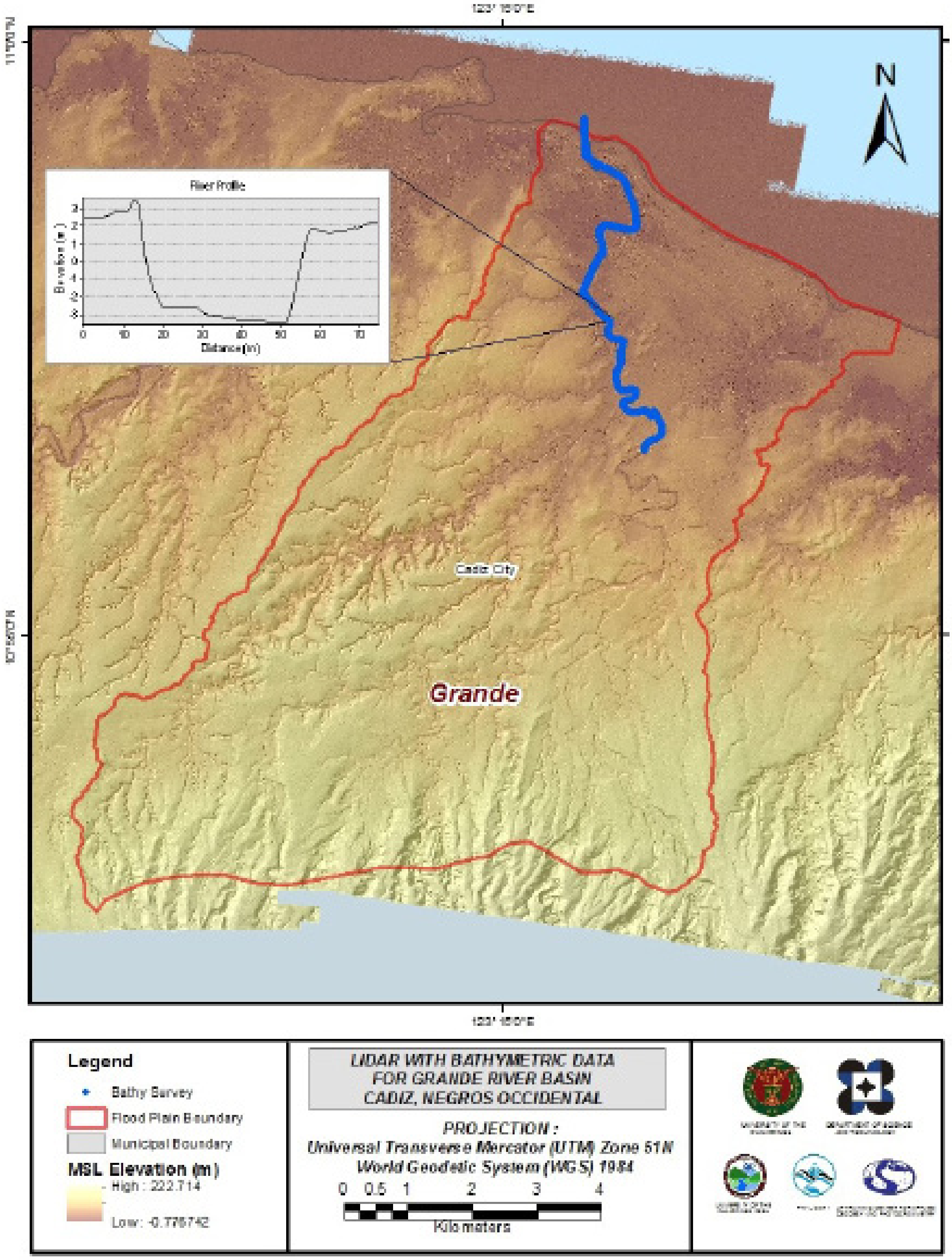

Figure 26. Map of Grande Flood Plain with bathymetric survey points shown in blue.

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 of Digitized Features ' Boundary

Grande floodplain, including its 200 m buffer, has a total area of 87.07 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 1254 building features, are considered for QC. Figure 27 shows the QC blocks for Grande floodplain.

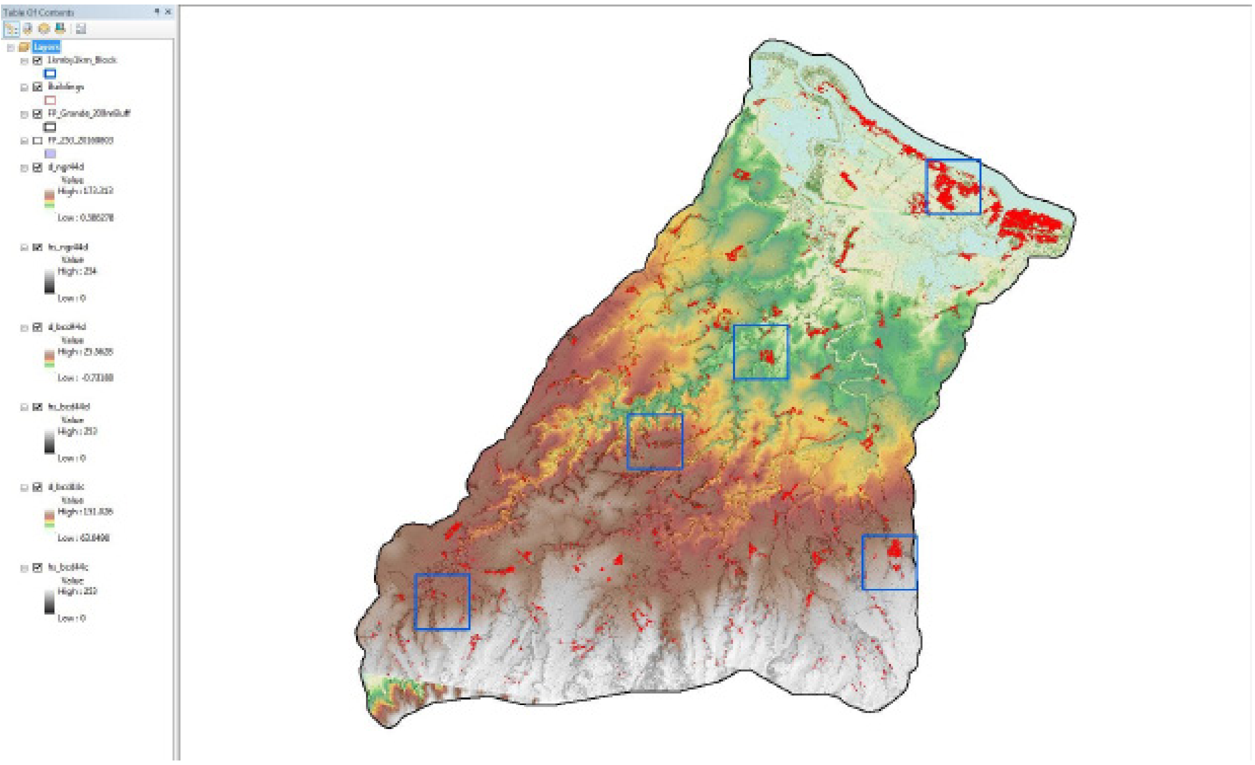

Figure 27. QC blocks for Grande building features.

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

Table 17. Quality Checking Ratings for Grande Building Features.

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Grande	100.00	100.00	99.68	PASSED

3.12.b2 Height Extraction

Height extraction was done for 9,122 building features in Grande floodplain. Of these building features, 87 was filtered out after height extraction, resulting 9,035 buildings with height attributes. The lowest building height is at 2.0 m, while the highest building is at 10.29 m.

3.12.3 Feature Attribution

The feature attribution survey was conducted through a participatory community-based mapping in coordination with the Local Government Units of the Municipality/City. The research associates of Phil-LiDAR 1 team visited local barangay units and interviewed key local personnel and officials who possessed expert knowledge of their local environments to identify and map out features.

Maps were displayed on a laptop and were presented to the interviewees for identification. The displayed map includes the orthophotographs, Digital Surface Models, existing landmarks, and extracted feature shapefiles. Physical surveys of the barangay were also done by the Phil-LiDAR 1 team every after interview for validation. The number of days by which the survey was conducted was dependent on the number of features and number of barangays included in the flood plain of the river basin.

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 Grande Floodplain.

Facility Type	No. of Features
Residential	8,795
School	128
Market	7
Agricultural/Agro-Industrial Facilities	5
Medical Institutions	14
Barangay Hall	3
Military Institution	16
Sports Center/Gymnasium/Covered Court	3
Telecommunication Facilities	3
Transport Terminal	7
Warehouse	0
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	5
Water Supply/Sewerage	0
Religious Institutions	13
Bank	2
Factory	0
Gas Station	1
Fire Station	0
Other Government Offices	5
Other Commercial Establishments	33
N/A	1
Total	9,035

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

FLOODPLAIN	Road Network Length (km)					Total
	Barangay Road	City/ Municipal Road	Provincial Road	National Road	Others	
Grande	228.34	21.80	0.00	13.37	0.00	263.51

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

Floodplain	Water Body Type					Total
	Rivers/ Streams	Lakes/ Ponds	Sea	Dam	Fish Pen	
Grande	306	0	0	0	103	409

A total of 10 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 28 shows the Digital Surface Model (DSM) of Grande floodplain overlaid with its ground features.

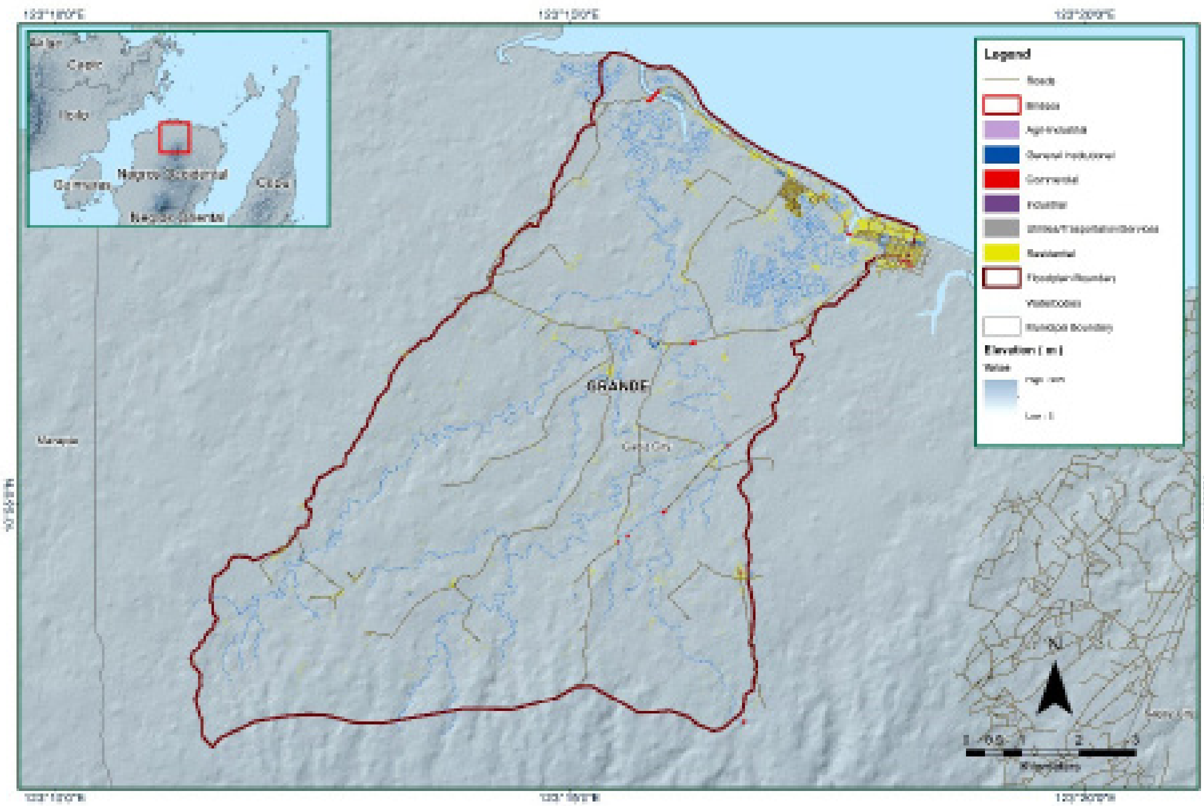

Figure 28. Extracted features for Grande floodplain.

CHAPTER 4: SURVEY AND MEASUREMENTS IN THE GRANDE RIVER BASIN

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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).

4.1 Summary of Activities

The Data Validation and Bathymetry Component (DVBC) conducted a field survey in Grande River from December 4 to 16, 2014 with the following scope of work: reconnaissance survey to determine the viability of traversing the planned routes for bathymetric survey; courtesy call to the barangays near the survey area for information dissemination of the team's activities and to ask for a boat and local aide's assistance; control survey for the establishment of a control point; cross-section; bridge as-built and water level marking in MSL of Troso Bridge piers; ground validation data acquisition survey of about 71.47 km; and bathymetric survey from Troso Bridge in Brgy. Bayabas, Sitio Troso, Cadiz City, Negros Occidental down to Brgy. Daga, Cadiz City, Negros Occidental with an estimated length of 7.6 km using an Ohmex™ Single Beam Echo Sounder integrated with a roving GNSS receiver, Trimble® SPS 882 utilizing GNSS PPK survey technique.

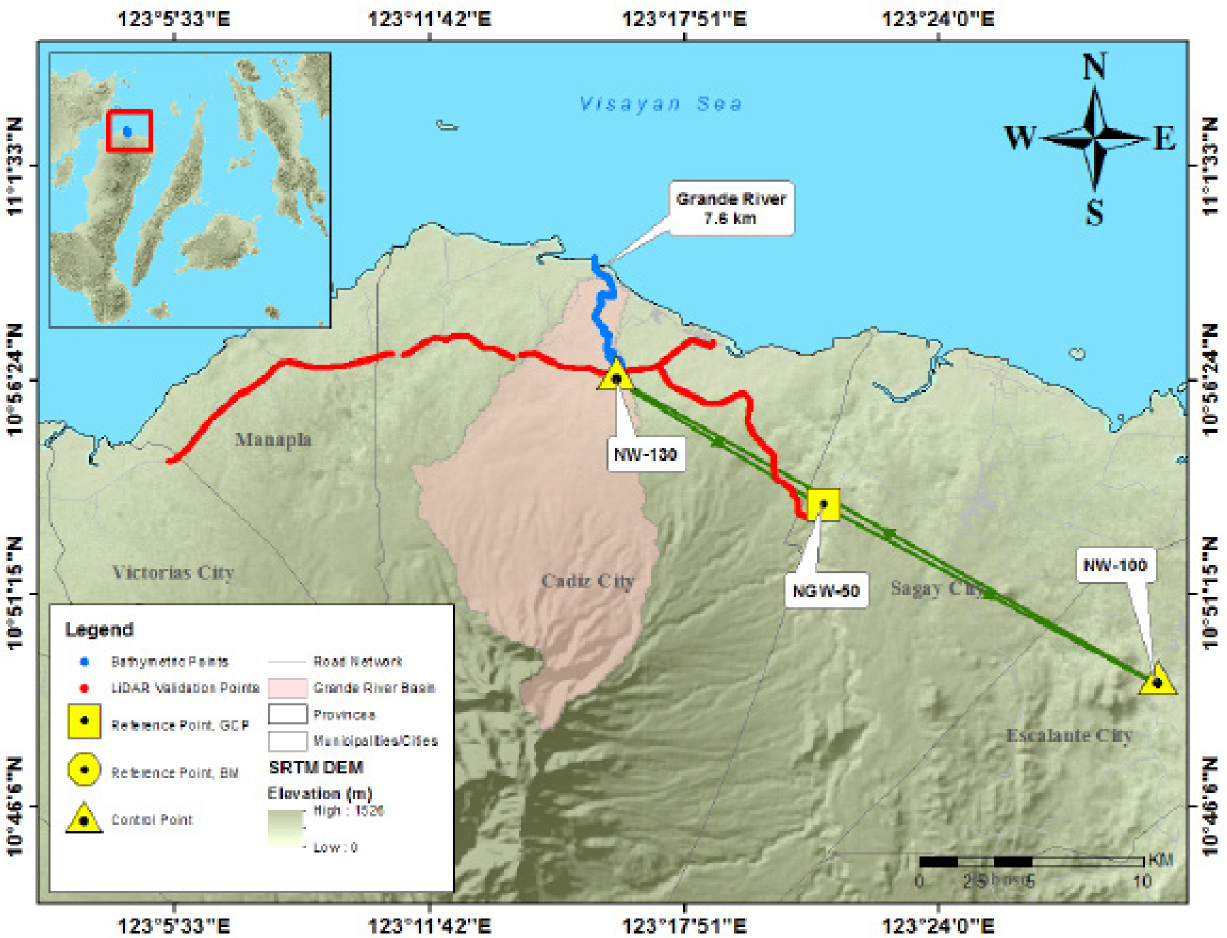


Figure 29. Grande River survey extent

4.2 Control Survey

The GNSS network used for Grande River survey is composed of a single loop established on September 9, 2014 occupying the following reference points: NGW-50, a second order GCP in Brgy. Paraiso, Sagay City; and NW-100, a first order BM in Brgy. Jonobjonob, Escalante City, Negros Occidental.

The point NW-130, a NAMRIA established control point, along the approach of Trozo Bridge in Brgy. Daga, Cadiz City, was also occupied to use by the DVBC survey team as marker during the survey.

The summary of reference and control points is shown in Table C-1, while the GNSS network established is illustrated in Figure 30.

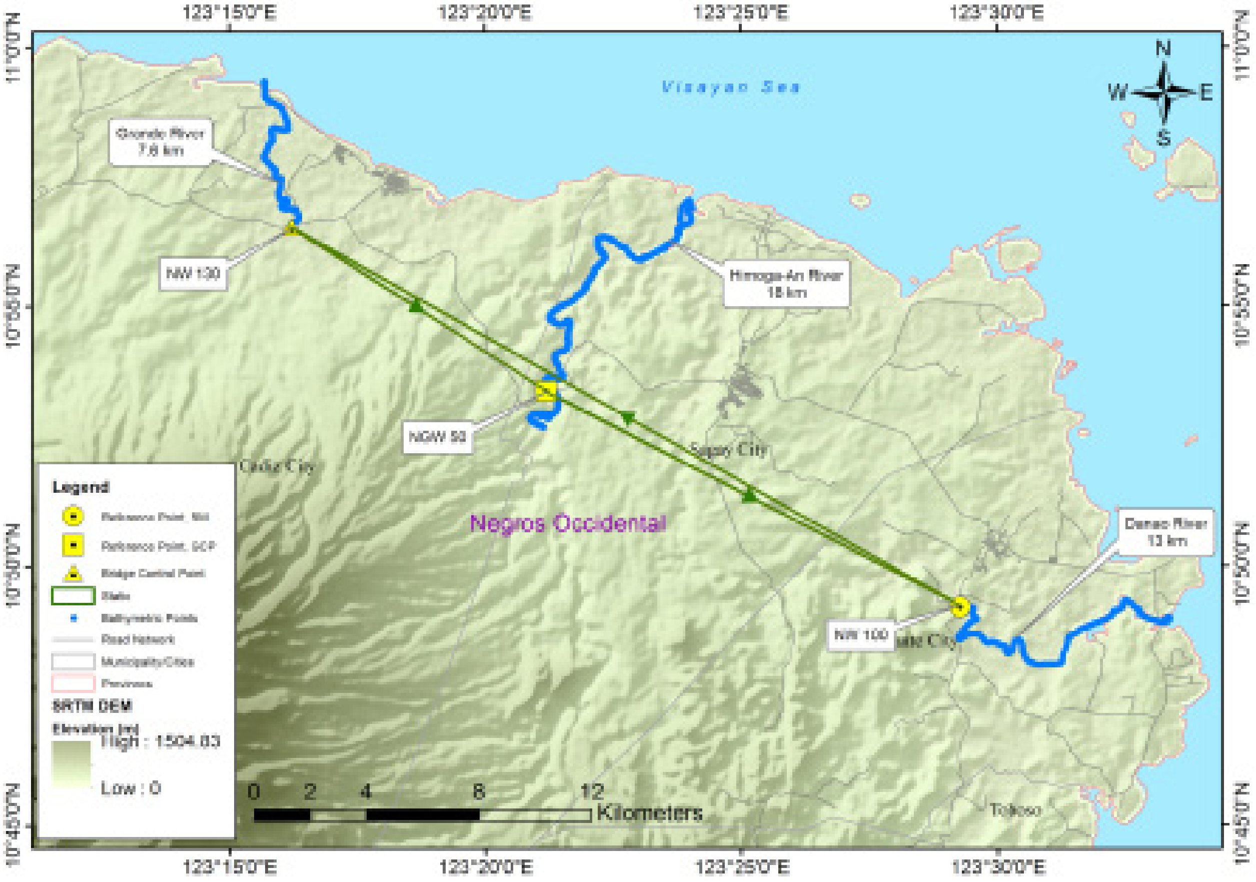


Figure 30. GNSS network of Grande River field survey

Table 21. List of references and control points occupied in Negros Occidental survey (Source: UP-TCAGP, NAMRIA)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (m)	MSL Elevation (m)	Date Established
NGW-50	2nd order, GCP	10°53'22.52478"	123°21'11.86863"	74.422	13.0512	2013
NW-100	1st order, BM	-	-	68.325	7.2272	2007
NW-130	Used as Marker	-	-	-	-	2017

The GNSS set-ups on recovered reference points and established control points in Grande River are shown in Figure 31 to Figure 33.

Figure 31. GNSS base receiver setup, Trimble® SPS 852, at NGW-50 in Himoga-An Bridge, Brgy. Paraiso, Sagay City, Negros Occidental

Figure 32. GNSS base receiver setup, Trimble® SPS 852, at NW-100 in Grande Bridge, Brgy. Jonobjonob, Escalante City, Negros Occidental

Figure 33. GNSS base receiver setup, Trimble® SPS 852, over NW-130 in Troso Bridge, Brgy. Daga, Cadiz City, Negros Occidental

4.3 Baseline Processing

The GNSS baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/- 20 cm and +/- 10 cm requirement, respectively. In 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. The Baseline processing result of control points in Grande River Basin is summarized in Table 22, as generated by TBC software.

Table 22. Baseline Processing Report for Grande River Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
NGW 50 --- NW 130 (B4)	09-11-2014	Fixed	0.005	0.008	302°49'33"	10801.487	-2.613
NW 130 --- NW 100 (B5)	9-11-2014	Fixed	0.185	0.037	119°37'31"	27388.571	-3.542
NGW 50 --- NW 100 (B6)	9-11-2014	Fixed	0.004	0.006	117°34'16"	16614.558	-6.178

4.4 Network Adjustment

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

$\sqrt{((Xe)^2+(Ye)^2)}$ <20cm and $Ze<10\ cm$

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 26 for complete details.

The three control points, NGW-50, NW-100, and NW-130 were occupied and observed simultaneously to form a GNSS loop. Coordinates of NGW-50; and elevation value of NW-100 were held fixed during the processing of the control points as presented in Table 23.

Table 23. Control Point Constraints

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
NGW 50	Global	Fixed	Fixed	Fixed	
Fixed = 0.000001 (Meter)					

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 24. The fixed control NGW-50 has no values for and elevation error yet. An offset of 0.0188 m between geoid (EGM2008) and MSL values of the benchmark NW-100 from September 10 to 24, 2014 was applied for referring the elevation of the control points to MSL.

Table 24. Adjusted Grid Coordinates

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
NGW 50	538610.026	?	1203793.905	?	13.070	?	LLh
NW 100	553341.183	0.013	1196123.819	0.007	7.170	0.020	
NW 130	529529.956	0.017	1209636.397	0.008	10.639	0.024	

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

NGW-50
horizontal accuracy = Fixed
vertical accuracy = Fixed

NW-100
horizontal accuracy = $\sqrt{((1.3)^2 + (0.7)^2}$
= $\sqrt{(1.69 + 0.49)}$
= 1.48 < 20 cm
vertical accuracy = 2.0 cm < 10 cm

NW-130
horizontal accuracy = $\sqrt{((1.7)^2 + (0.8)^2}$
= $\sqrt{(2.89 + 0.64)}$
= 1.88 < 20 cm
vertical accuracy = 2.4 cm < 10 cm

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

Table 25. Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
NGW 50	N10°53'22.52478"	E123°21'11.86863"	74.422	?	LLh
NW 130	N10°56'33.04992"	E123°16'12.93293"	71.819	0.024	
NW 100	N10°49'12.14033"	E123°29'16.71793"	68.325	0.020	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 26. Based on the result of the computation, the equation 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)
NGW-50	2nd order, GCP	10°53'22.52478 "N	123°21'11.86863 "E	74.422	1203793.905	538610.026	13.051
NW-100	1st order BM	10°49'12.14033 "N	123°29'16.71793 "E	68.325	1196123.819	553341.183	7.227
NW-130	Used as Marker	10°56'33.04992 "N	123°16'12.93293 "E	71.819	1209636.397	529529.956	10.643

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

Cross-section and bridge as-built surveys were conducted on September 16 and 17, 2014 along the downstream side of Troso Bridge in Brgy. Bayabas, Cadiz City using a GNSS receiver Trimble® SPS 882 utilizing GNSS PPK survey technique as shown in Figure 34.

Figure 34. Cross-section survey at Troso Bridge in Cadiz City

The cross-sectional line is about 83.28 m with 86 points acquired using NW-130 as GNSS base station. The location map, cross-section diagram, and bridge as-built form are shown in Figure 35 to Figure 37, respectively.

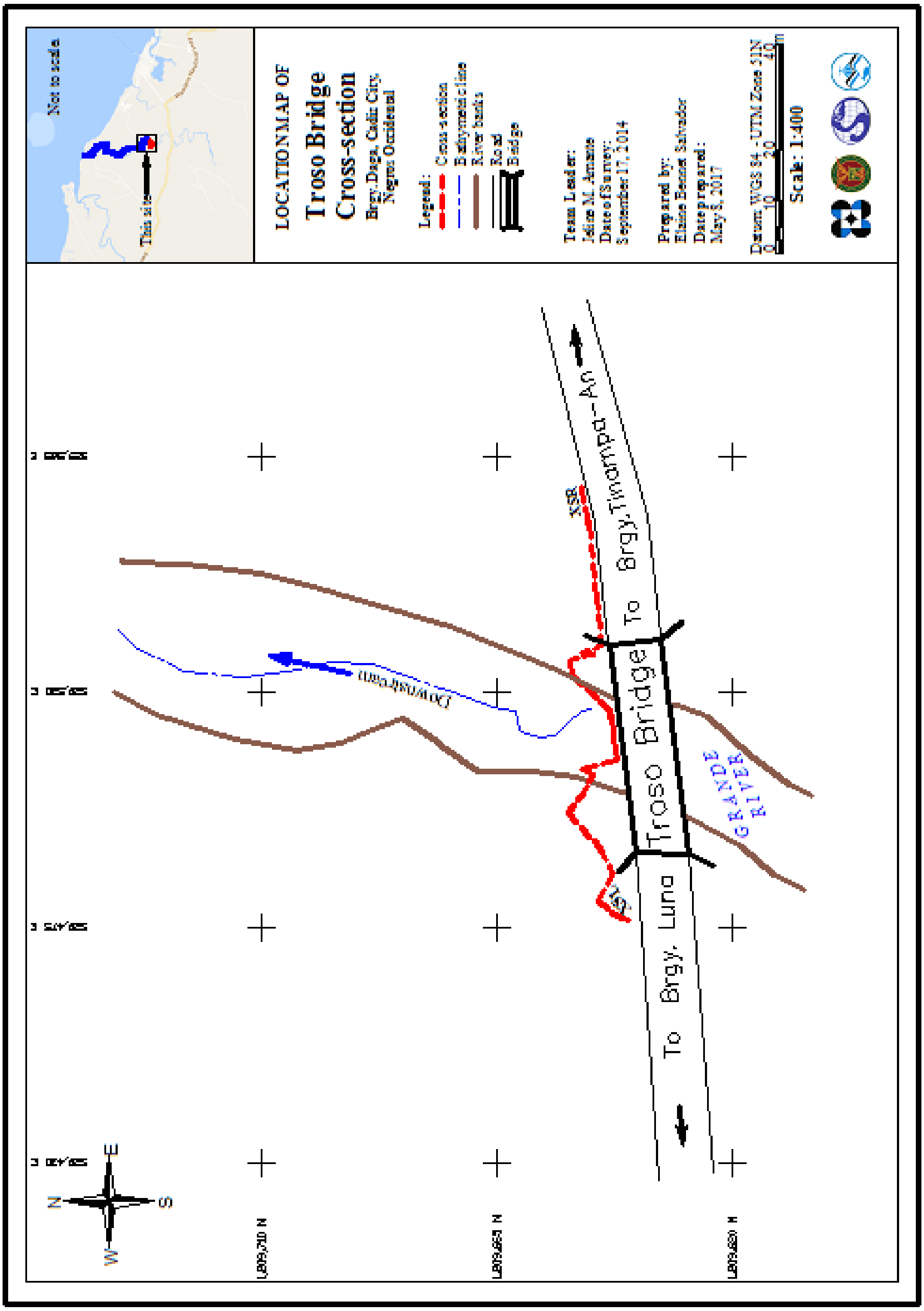


Figure 35. Troso Bridge location map

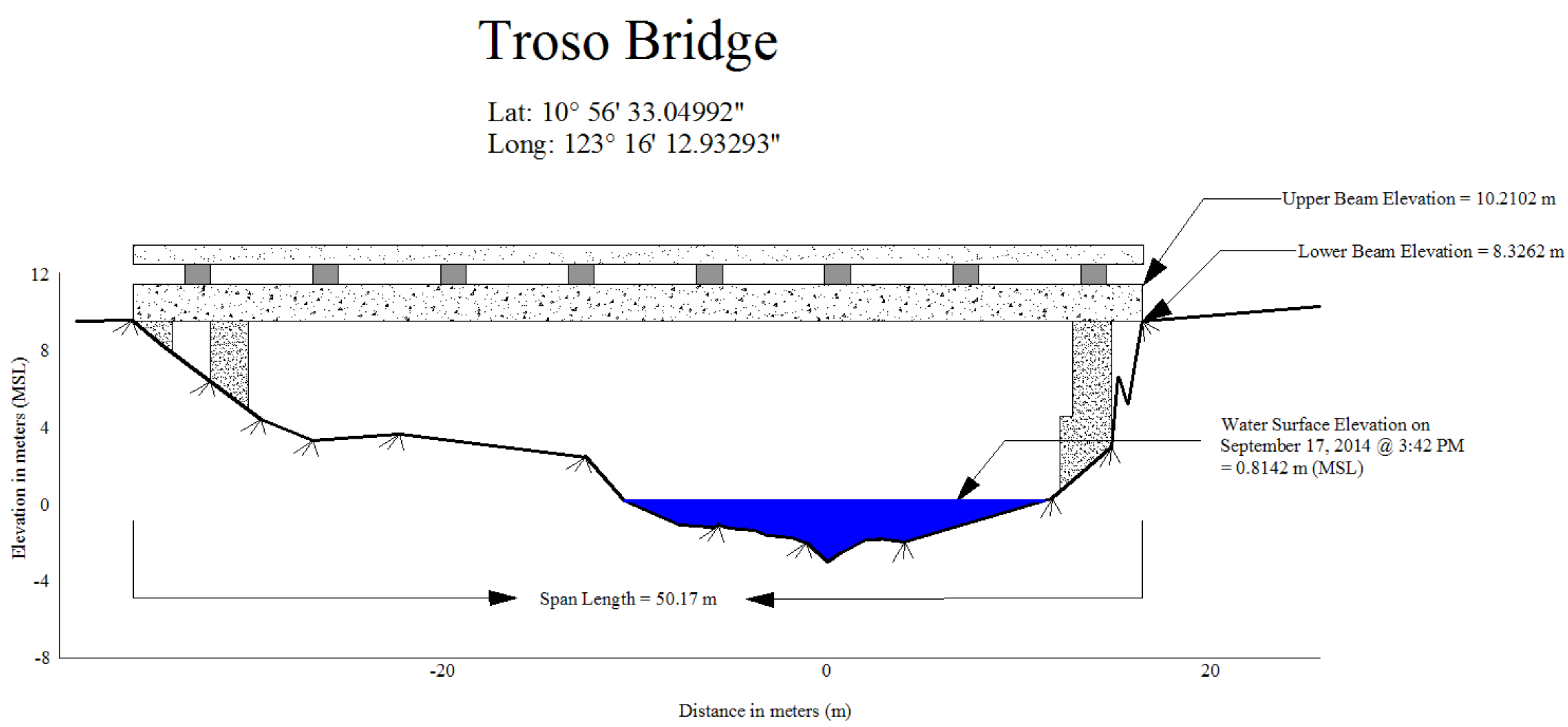


Figure 36. Troso Bridge cross-section diagram

Bridge Data Form

Bridge Name: Troso Bridge — **Date:** September 16 & 17, 2014

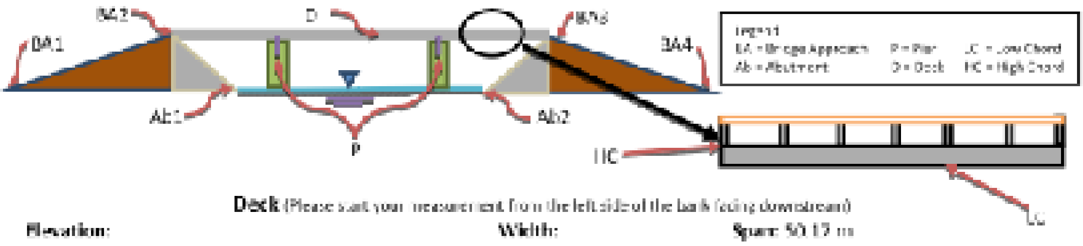
River Name: Grande River — **Time:** 2: 00 PM

Location (Brgy, City, Region): Cadiz City, Negros Occidental

Survey Team: Negros Occidental Survey Team

Flow condition: low normal high — **Weather Condition:** fair ____ rainy

Latitude: 10d56'33.04592" N **Longitude:** 123d16'12.93293" E



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

Elevation: **Width:** **Span:** 50.12 m

	Station	High Chord Elevation	Low Chord Elevation
1		10.2108 m	8.3262 m
2			
3			
4			
5			

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

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	**0**	9.0012 m	**BA3**	80.84 m	10.6342 m
BA2	30.67 m	10.5992 m	**BA4**	n/a	n/a

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

	Station (Distance from BA1)	Elevation
Ab1	32.35 m	2.9152 m
Ab2	76.56 m	4.3632 m

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

Shape: circular **Number of Piers:** 2 **Height of column footing:** ____________

	Station (Distance from BA1)	Elevation	Pier Width
Pier 1	36.5	10.6232	
Pier 2	76.57	10.6242	
Pier 3			
Pier 4			
Pier 5			
Pier 6			

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

Figure 37. Troso Bridge Data Form

The water surface elevation of Grande River on the left and right banks was acquired using a GNSS receiver Trimble® SPS 882 in GNSS PPK survey technique on September 17, 2014 at 3:42 PM with a value of about 0.8142 m above MSL. The resulting data was used to mark the piers of Troso Bridge as show in Figure 38. The markings on the bridge piers shall serve as a reference for flow data gathering and depth gauge deployment of UP Cebu PHIL-LIDAR 1.

Figure 38. (A) Marking of bridge pier and (B) Water Level Mark at the pier of Troso Bridge

4.4 Validation Points Acquisition Survey

A validation points acquisition survey was conducted on September 13, 2014 using a survey-grade GNSS rover receiver Trimble® SPS 882 mounted on a pole, which was attached in front of the vehicle (see Figure 38). It was secured with a steel rod and cable ties to ensure that it was horizontally and vertically balanced. The antenna height was measured from the ground up to the bottom of the notch of the GNSS rover receiver. Points were gathered along concrete roads of Victorias City - Sagay City national highway, including a portion of national roads and Villena St. in Cadiz City proper, so that data to be acquired will have a relatively minimal change in elevation and observing vehicle speed of 10 to 20 kph. Cutting across the flight strips of the Data Acquisition Component (DAC) with the aid of available topographic maps and Google Earth™ images. Gathered data were processed using Trimble® Business Center Software.

The GNSS base station was set up over NW 130, in Troso Bridge, Brgy. Bayabas, Sitio Troso, Cadiz City gathered validation points. The ground validation line is approximately 71.47 km in length from Himoga-An Bridge, Sagay City to Brgy. VI Manapla with 4,649 points. Figure 38 shows the ground validation survey result.

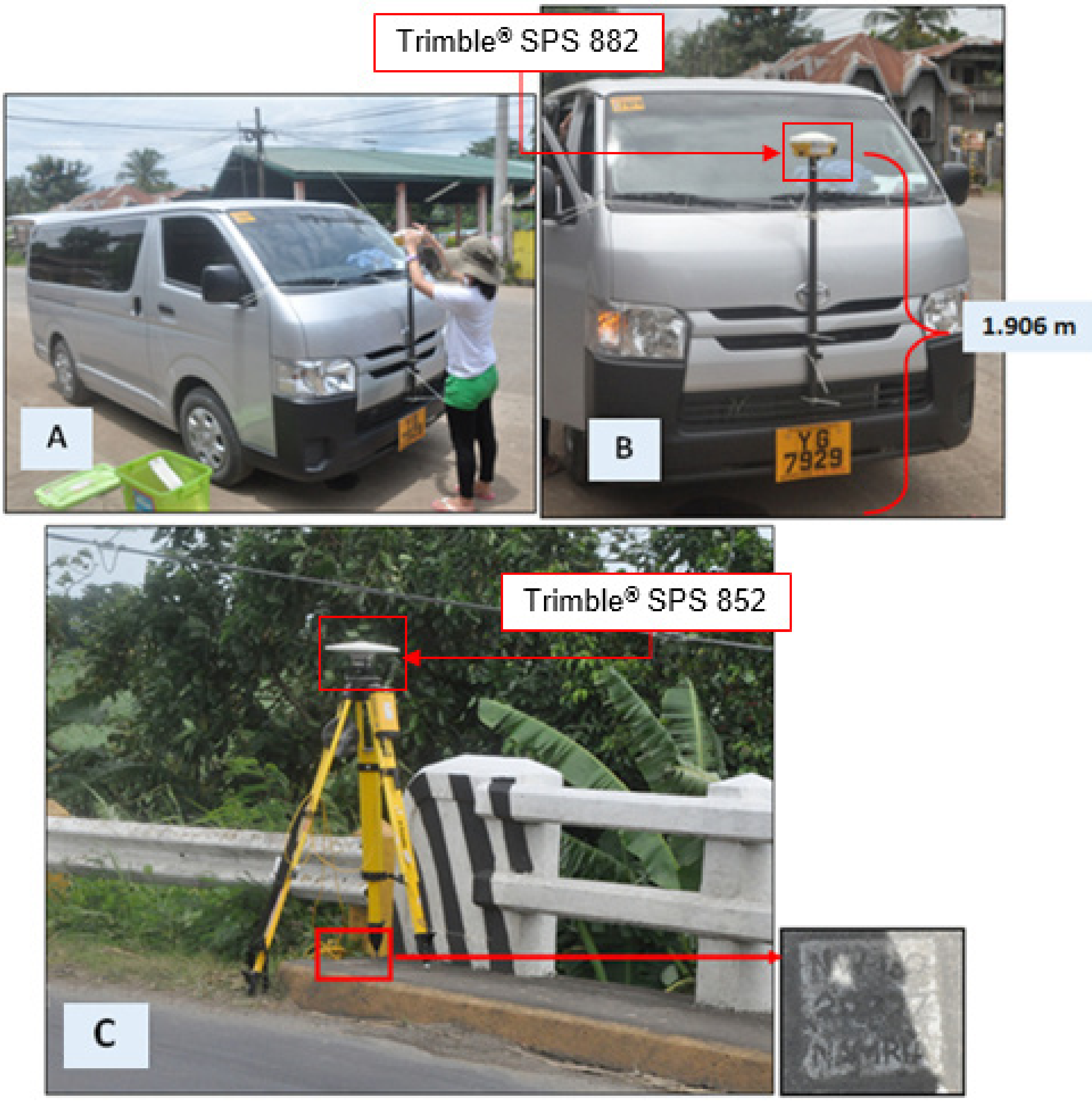


Figure 39. (A) GNSS Receiver Trimble® SPS 882 installation prior the validation points acquisition survey; (B) Final set up of GNSS Receiver with antenna height measured from the ground up to the bottom of the notch of the GNSS rover receiver and (C) Occupied base station, NW-130 in Troso Bridge, Cadiz City

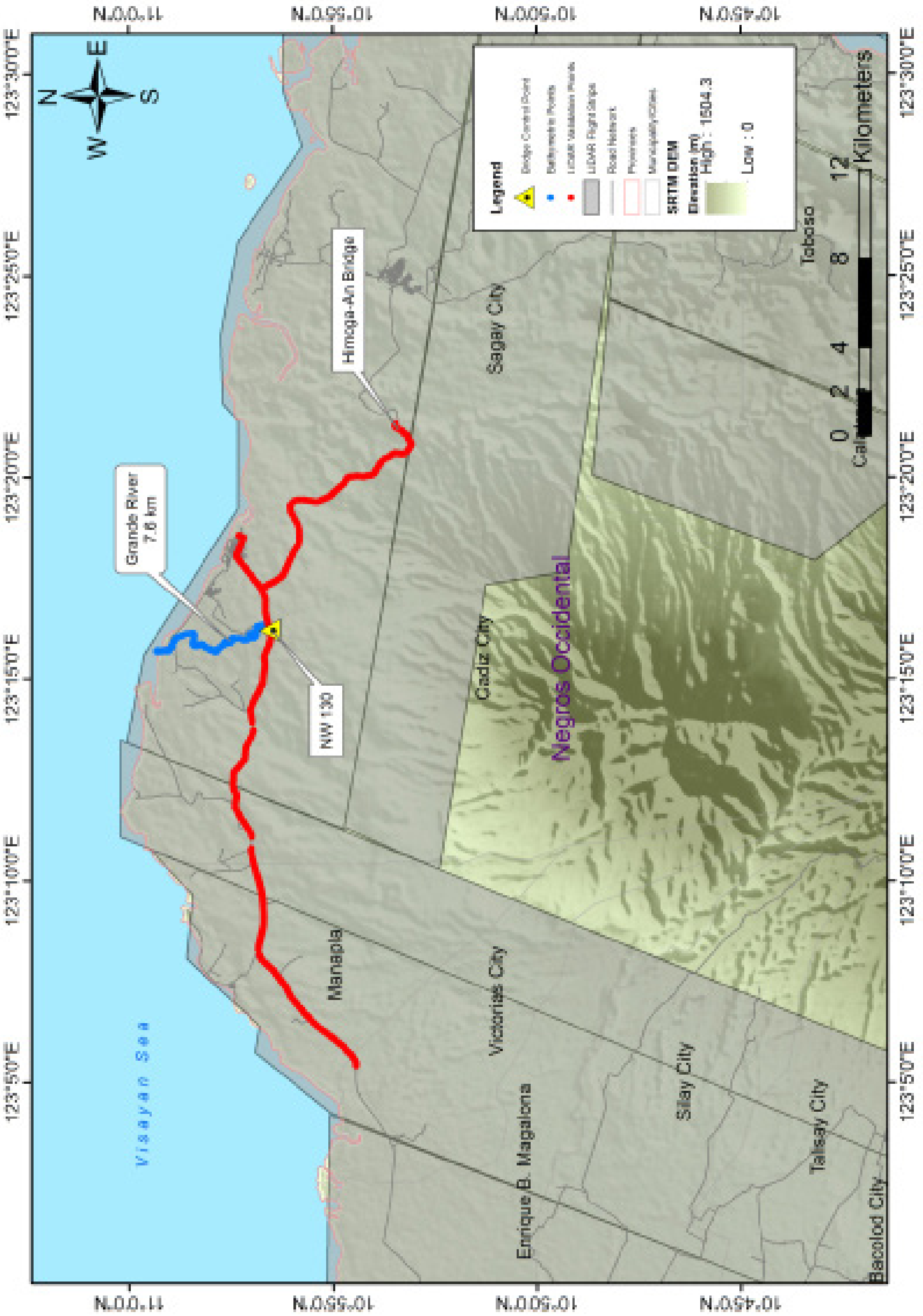


Figure 40. Validation points acquisition survey from Himoga-An Bridge to Brgy. VI Manapla

4.7 Bathymetric Survey

A validation points acquisition survey was conducted on September 13, 2014 using a survey-grade GNSS rover receiver Trimble® SPS 882 mounted on a pole, which was attached in front of the vehicle (see Figure 38). It was secured with a steel rod and cable ties to ensure that it was horizontally and vertically balanced. The antenna height was measured from the ground up to the bottom of the notch of the GNSS rover receiver. Points were gathered along concrete roads of Victorias City - Sagay City national highway, including a portion of national roads and Villena St. in Cadiz City proper, so that data to be acquired will have a relatively minimal change in elevation and observing vehicle speed of 10 to 20 kph. Cutting across the flight strips of the Data Acquisition Component (DAC) with the aid of available topographic maps and Google Earth™ images. Gathered data were processed using Trimble® Business Center Software.

Figure 41. Bathymetric survey along Grande River

Bathymetric line is approximately 7.6 km in length with 15,639 points acquired using NW-130 as GNSS base station covering Brgy. Daga, and Brgy. Luna, Cadiz City as shown in Figure 42.

Figure 42. Bathymetric survey along Grande River

A CAD drawing was also produced to illustrate the Grande riverbed profile as shown in Figure 43, the lowest elevation was recorded at -6.0998 m in MSL, about 1.5 km downstream of Troso Bridge, and the highest elevation is -0.287 m in MSL, located near Troso Bridge.

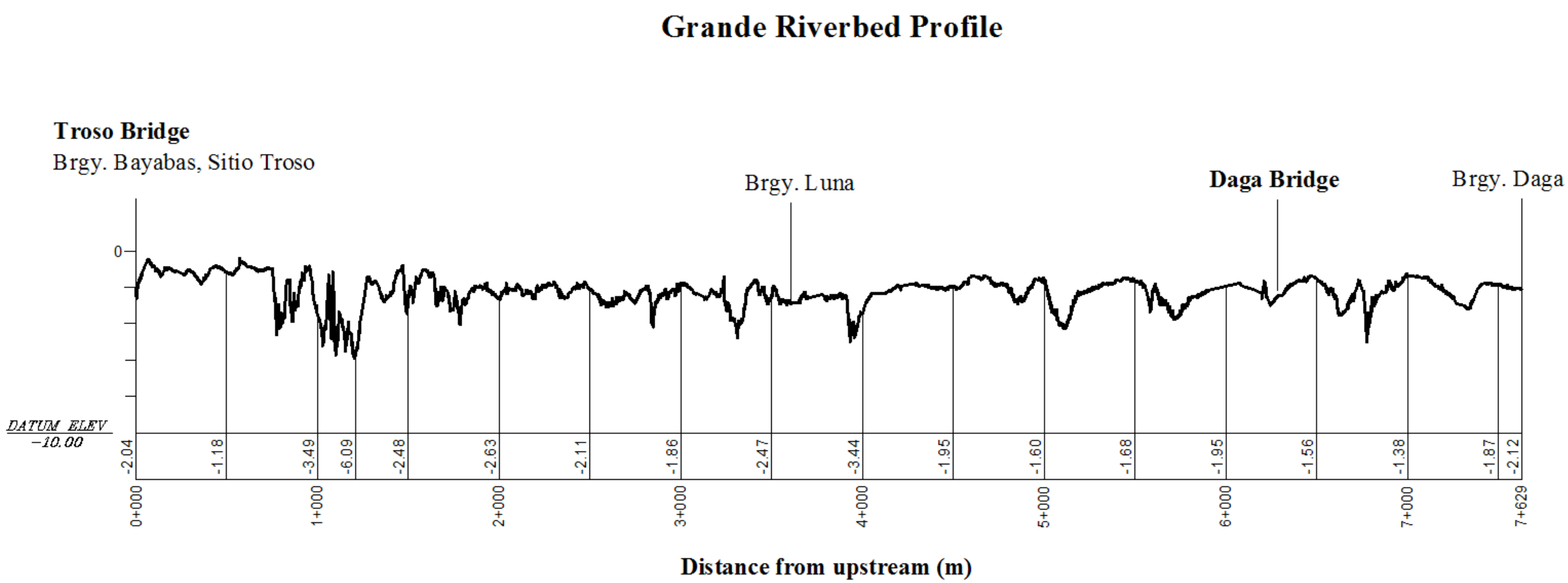


Figure 43. Riverbed profile of Grande River

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, Narvin Clyd Tan, and Marvin Arias

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

5.1 Data used for Hydrologic Mapping

5.1.1 Hydrometry and Rating Curves

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

5.1.2 Precipitation

Precipitation data was taken from an automatic rain gauge (ARG) deployed by the UP Cebu Flood Modeling Component (FMC) team. The ARG was installed at Brgy. Andres, Cadiz City, Negros Occidental (Figure 1). The precipitation data collection started from January 14, 2017 at 9:00 AM to January 17, 2017 at 15:25 with 5 minutes recording interval.

The total precipitation for this event in Brgy Andres ARG was 64.6 mm. It has a peak rainfall of 3.2 mm. on January 14, 2017 at 9:15 in the morning. The lag time between the peak rainfall and discharge is 8 hours and 35 minutes.

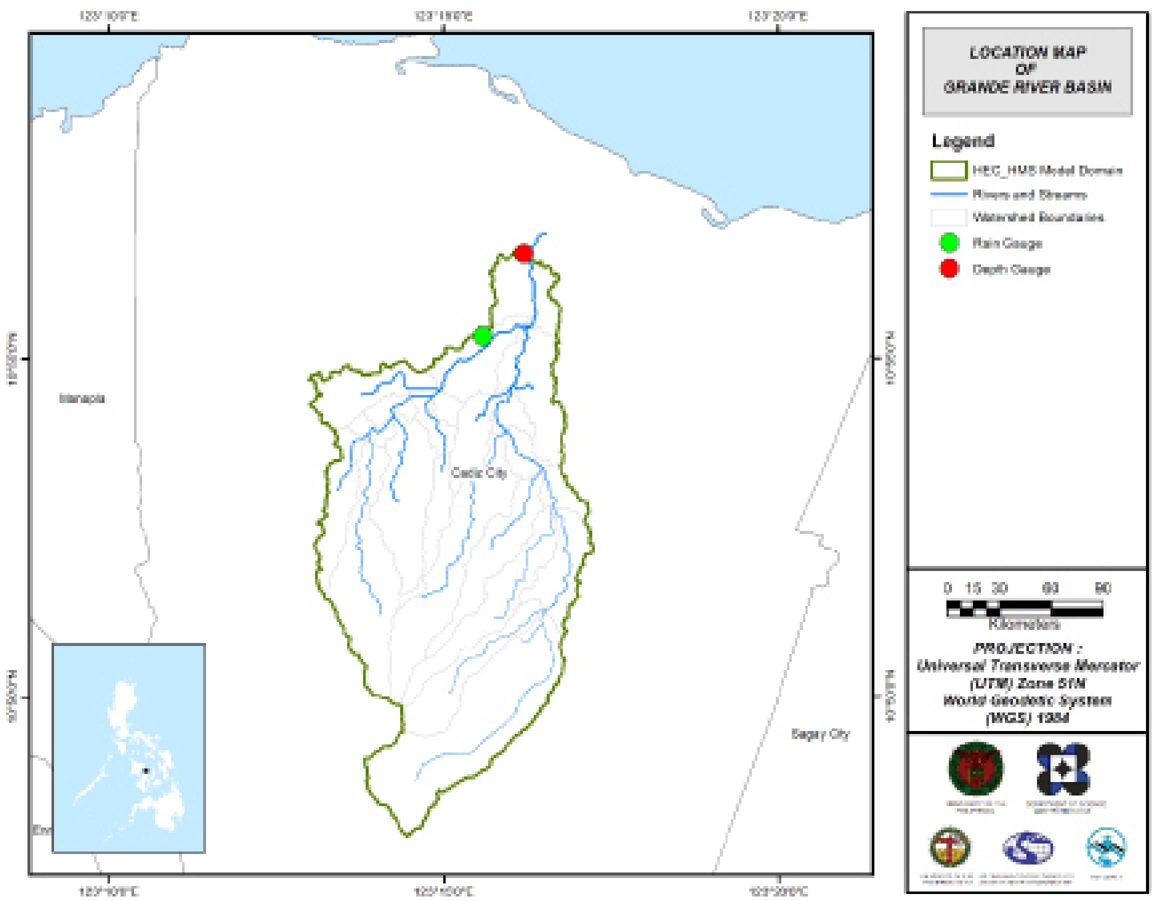


Figure 44. The location map of Grande HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

A rating curve was computed using the prevailing cross-section (Figure 45) at Trozo Bridge, Cadiz City, Negros Occidental (10°56'33.13"N, 123°16'12.37"E) to establish the relationship between the observed water levels at Grande Bridge (H) and outflow (Q) of the watershed at this location. For Trozo Bridge, the rating curve is expressed as Q = 1.3234e0.3596x as shown in Figure 46.

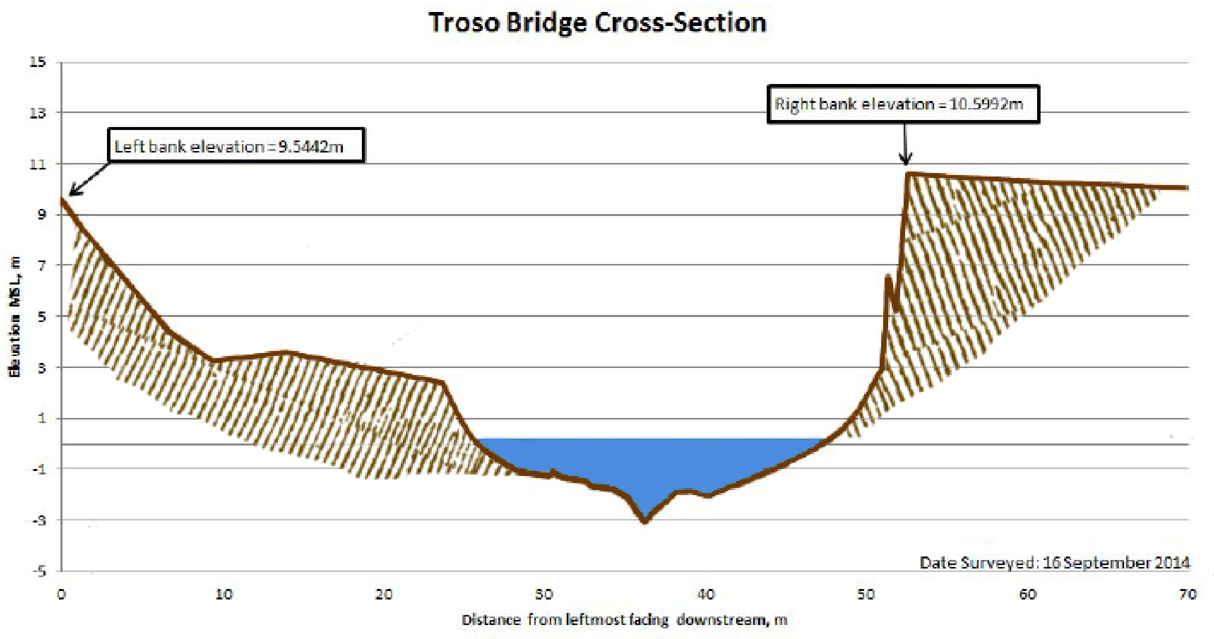


Figure 45. Cross-Section Plot of Trozo Bridge

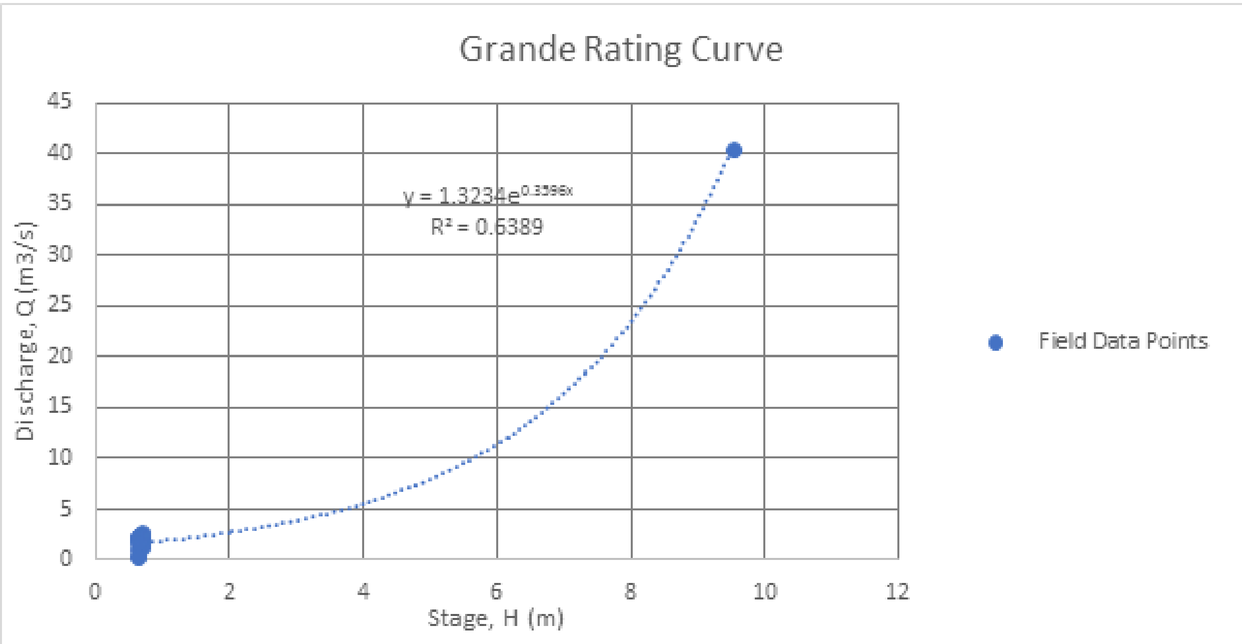


Figure 46. Rating Curve at Trozo Bridge, Cadiz City

This rating curve equation was used to compute the river outflow at Trozo Bridge for the calibration of the HEC-HMS model shown in Figure 47. The total rainfall for this event is 64.6mm and the peak discharge is 25.26 m3at 1:50 PM, January 16, 2017.

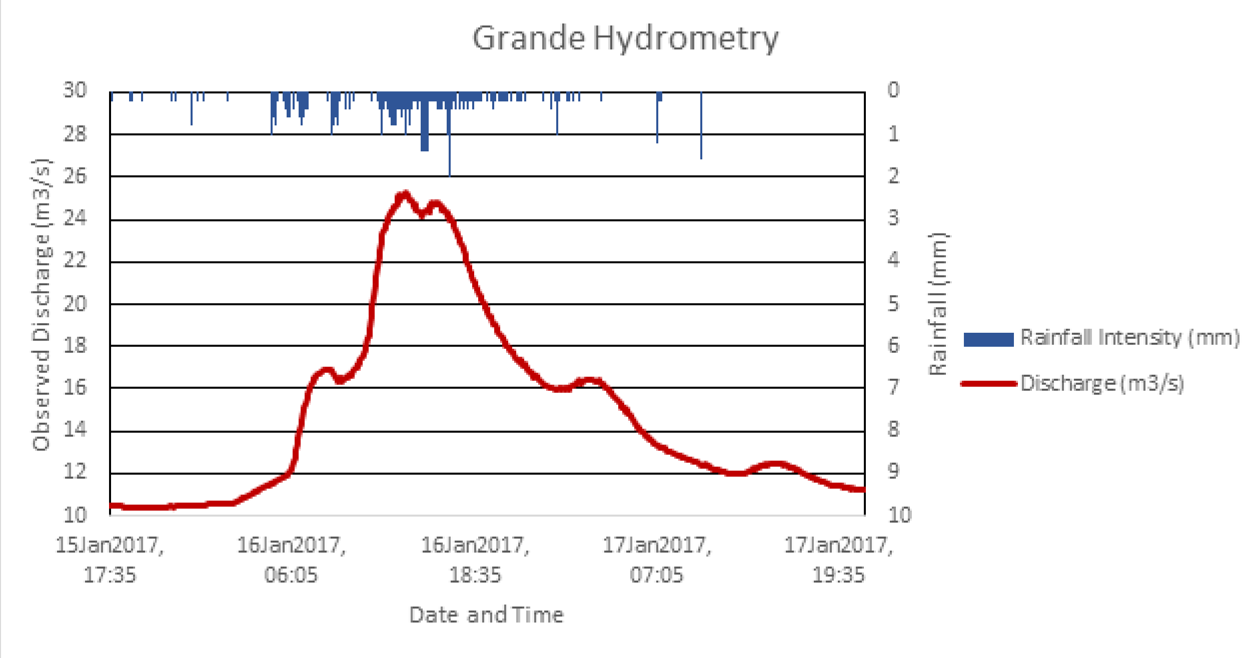


Figure 47. Rainfall and outflow data at Grande used for modeling.

5.2 RIDF Station

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

Table 27. RIDF values for Iloilo 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
5	28.7	39.4	48	59.4	74.9	90	114.7	131.7	165.2
10	33.9	45.6	55.6	68.1	85	103.6	133.6	155.4	198.9
25	40.5	53.5	65.3	79.2	97.6	120.8	157.6	185.3	241.5
50	45.4	59.4	72.4	87.3	107	133.5	175.3	207.4	273.1
100	50.3	65.2	79.5	95.4	116.4	146.2	193	229.4	304.5

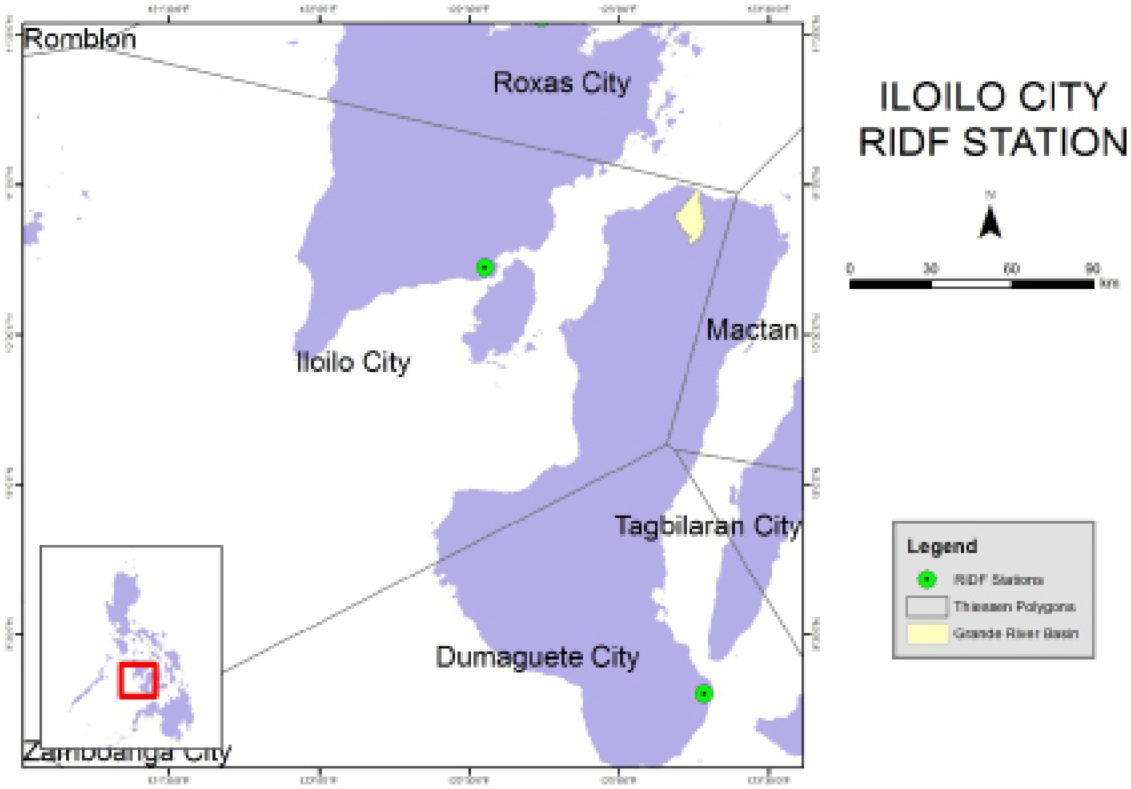


Figure 48. Location of Iloilo RIDF station relative to Grande River Basin

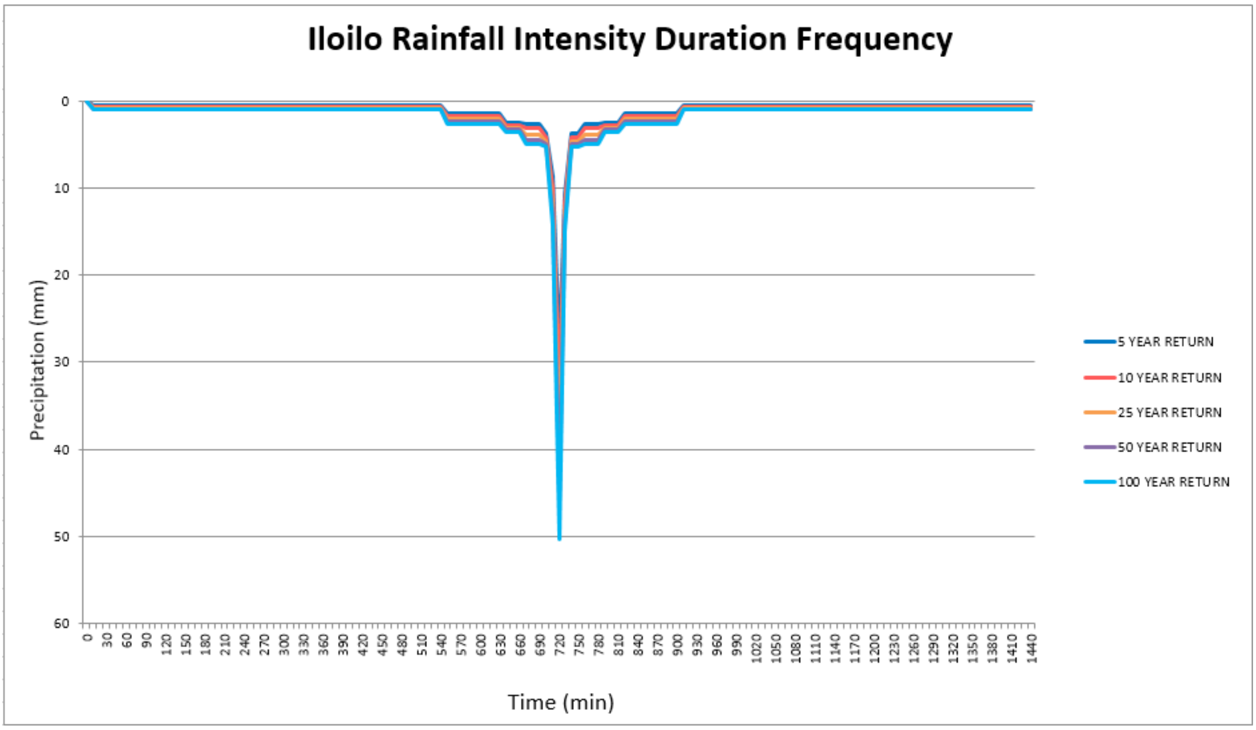


Figure 49. Synthetic storm generated for a 24-hr period rainfall for various return periods

5.3 HMS Model

The soil shapefile was taken on 2004 from the Bureau of Soils; this is under the Department of Environment and Natural Resources Management. The land cover shape file is from the National Mapping and Resource Information Authority (NAMRIA). The soil and land cover of the Grande River Basin are shown in Figures 50 and 51, respectively.

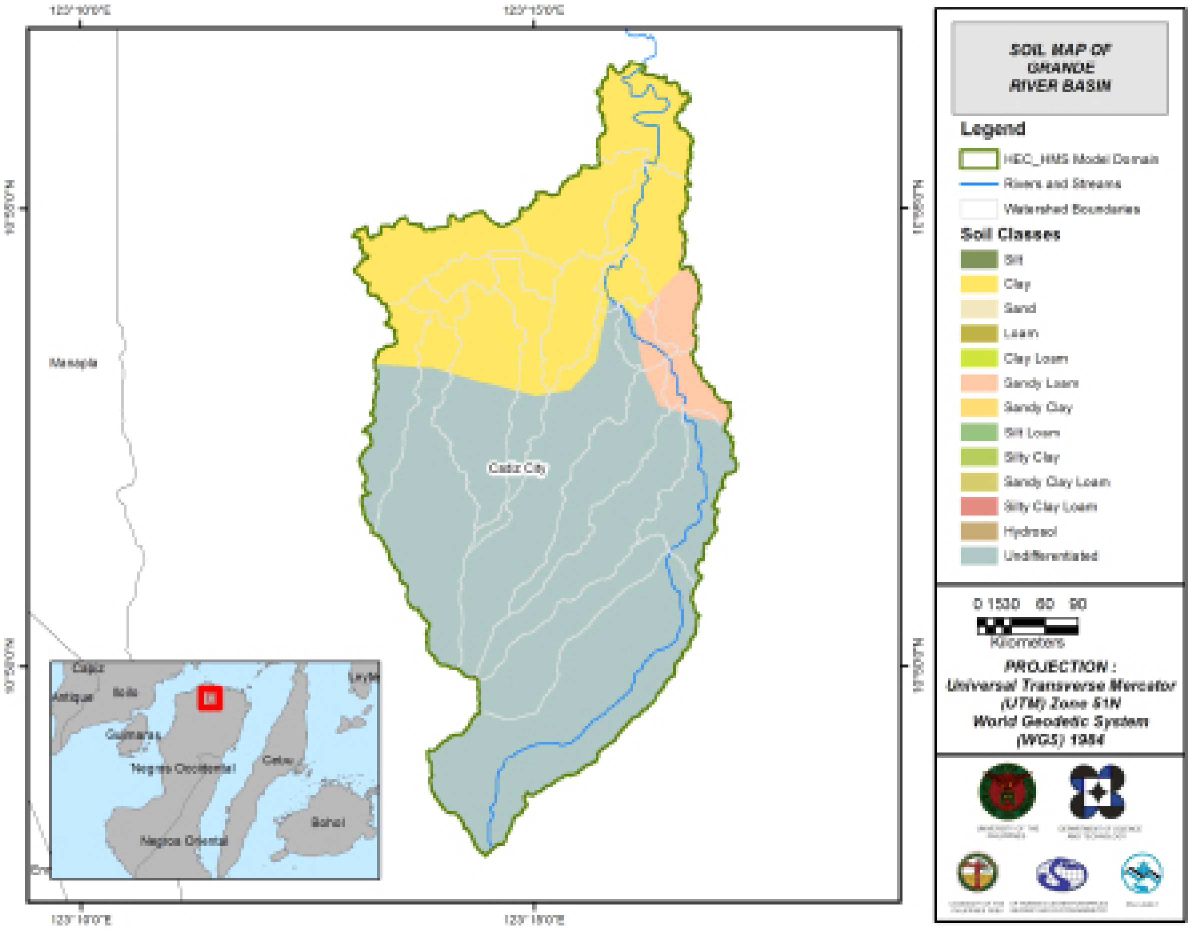


Figure 50. The soil map of the Grande River Basin

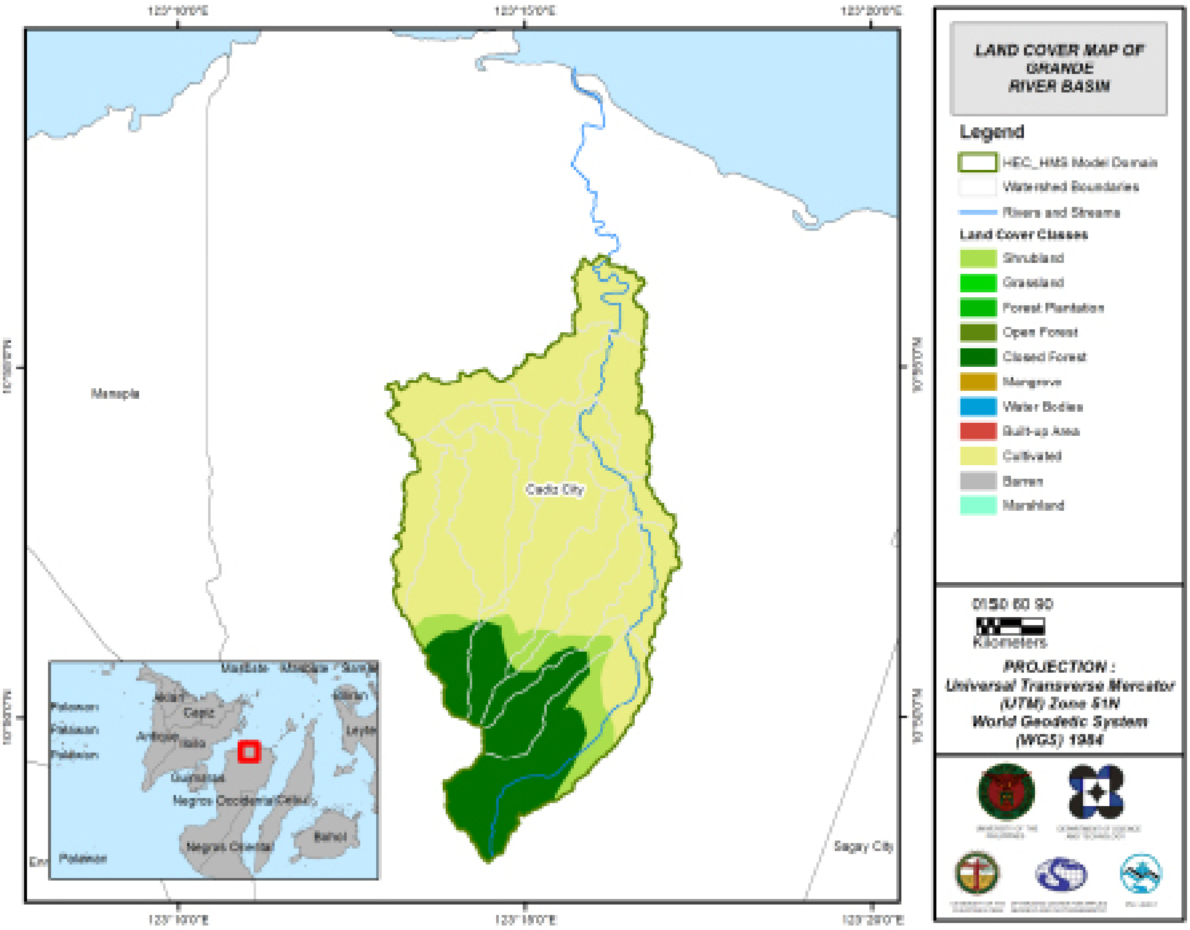


Figure 51. The land cover map of the Grande River Basin

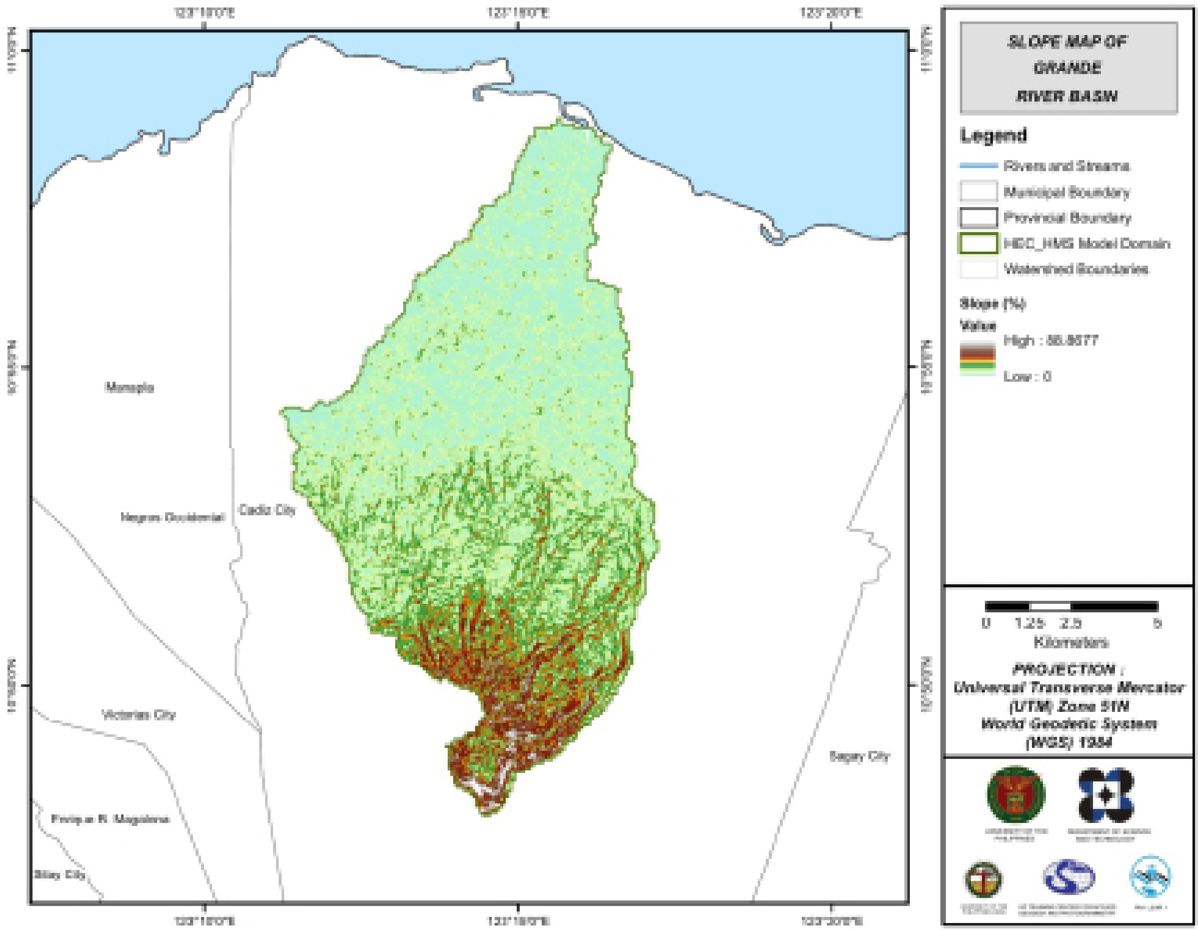


Figure 52. Slope map of the Grande River Basin

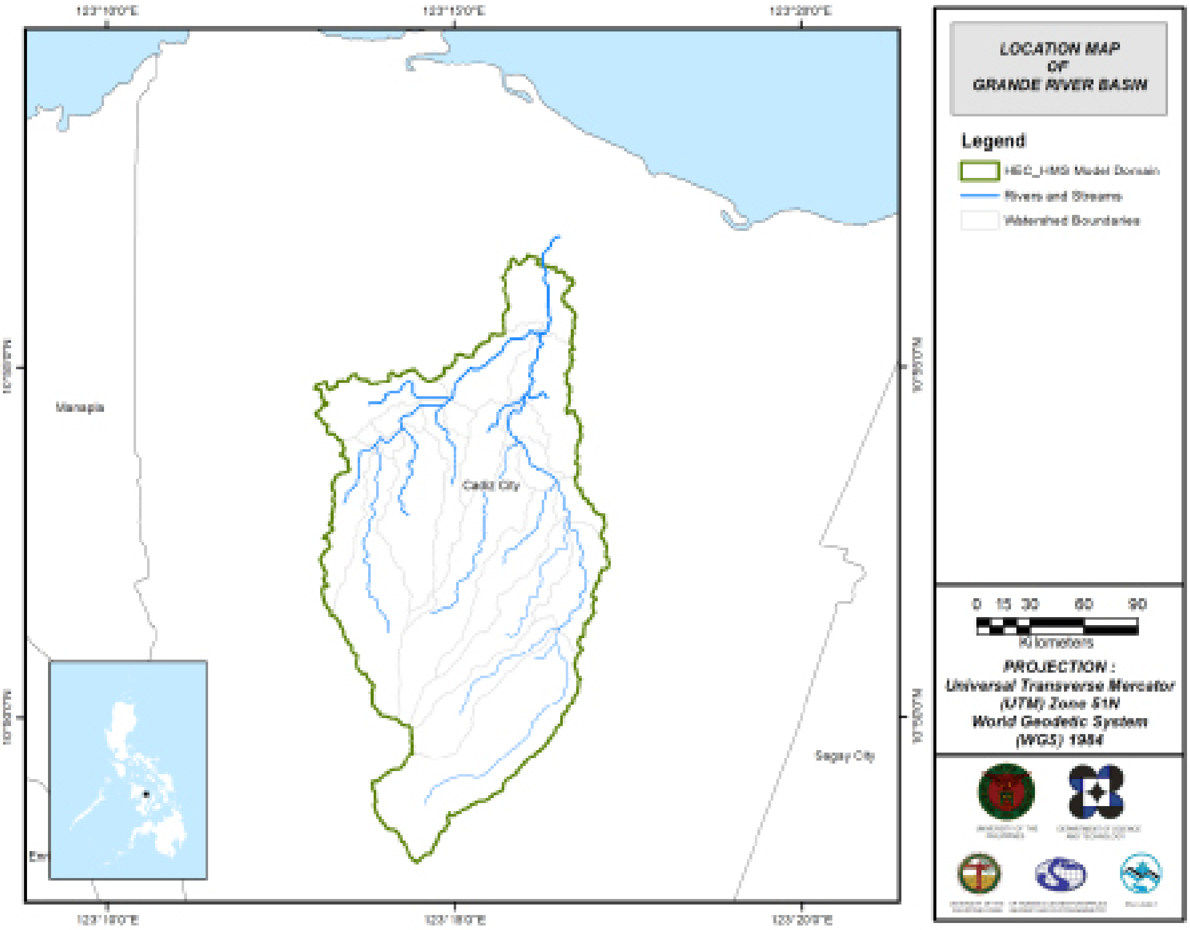


Figure 53. Stream delineation map of Bago river basin

For Grande, three soil classes were identified. These are sandy loam, clay, and undifferentiated soil. Moreover, three land cover classes were identified. These are shrubland, closed forest, and cultivated areas.

Using the SAR-based DEM, the Grande basin was delineated and further subdivided into sub-basins. The model consists of 21 sub basins, 11 reaches, and 10 junctions as shown in Figure 54. The main outlet is at Trozo Bridge.

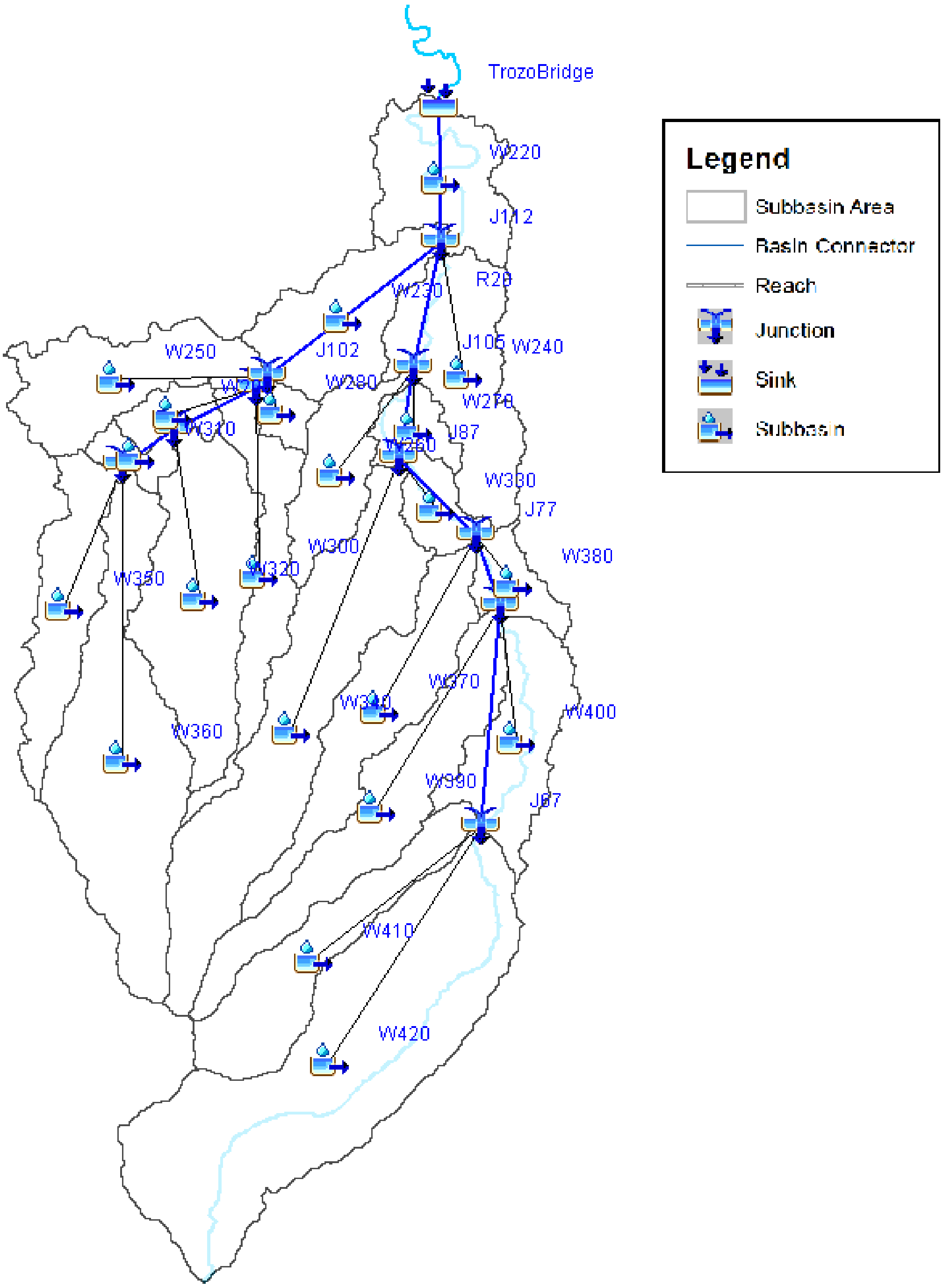


Figure 54. The Grande river basin model generated using HEC-HMS

5.4 Cross-section Data

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

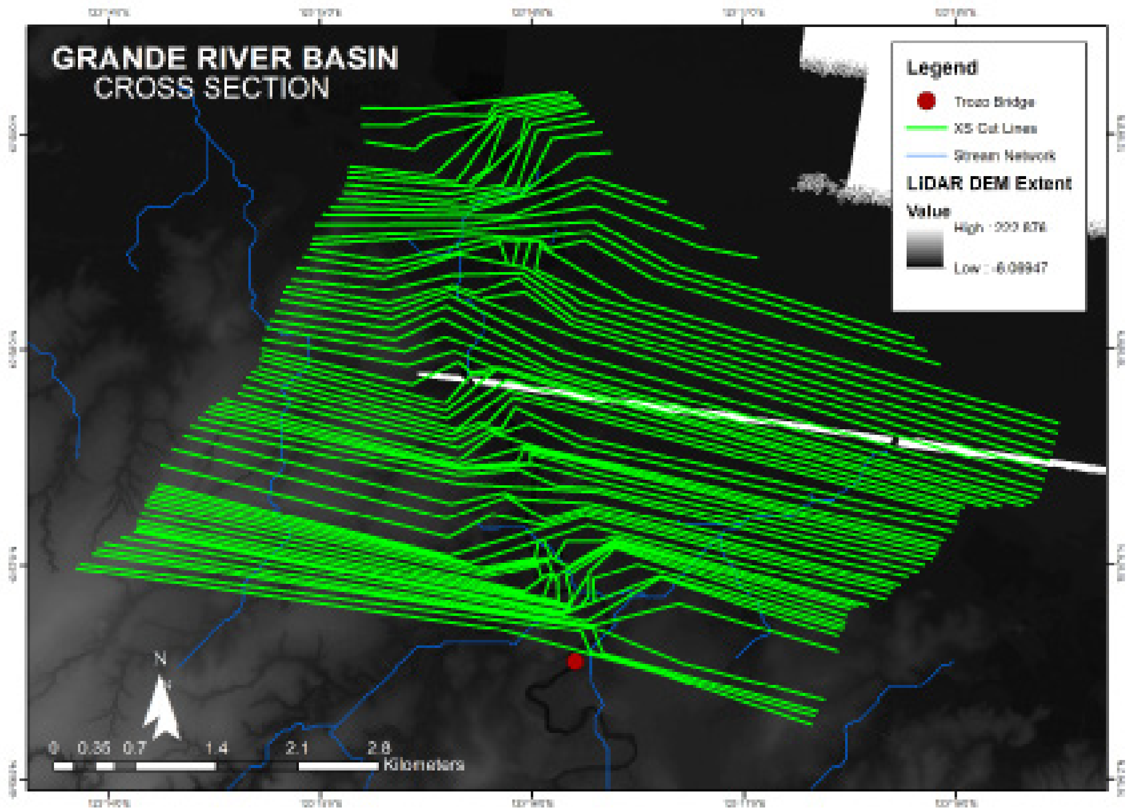


Figure 55. River cross-section of Grande River generated through Arcmap HEC GeoRAS tool

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 meters by 10 meters 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 south of the model to the northeast, following the main channel. As such, boundary elements in those particular regions of the model are assigned as inflow and outflow elements respectively.

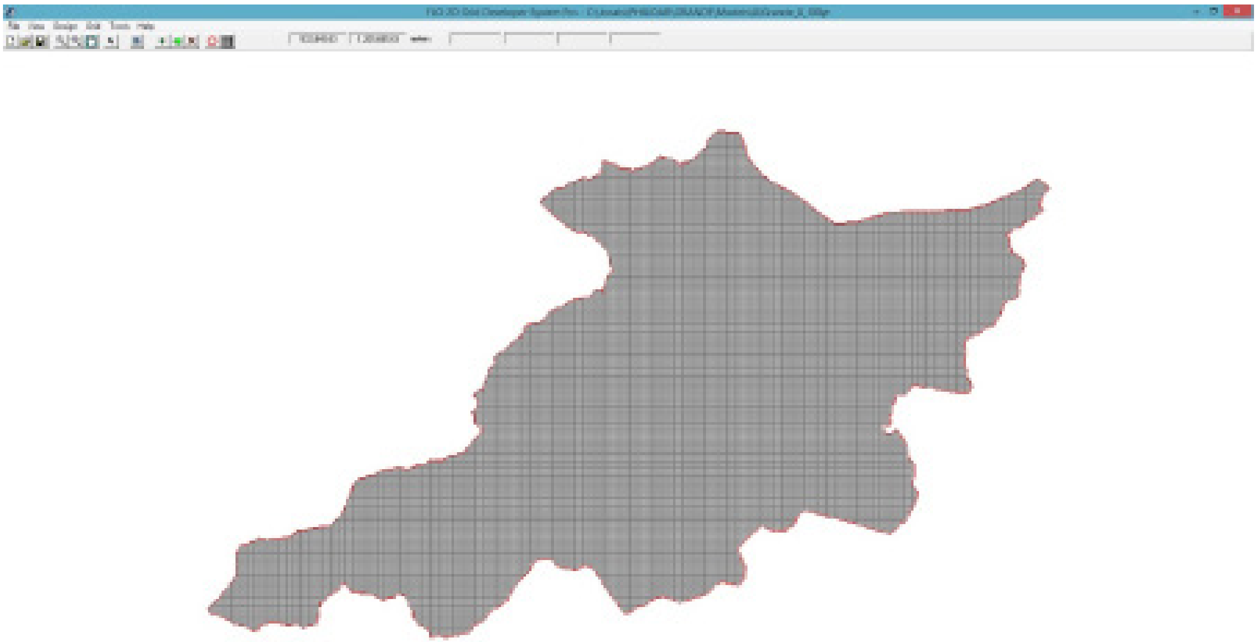


Figure 56. Screenshot of sub-catchment with the computational area to be modeled in FLO-2D Grid Developer System Pro (FLO-2D GDS Pro)

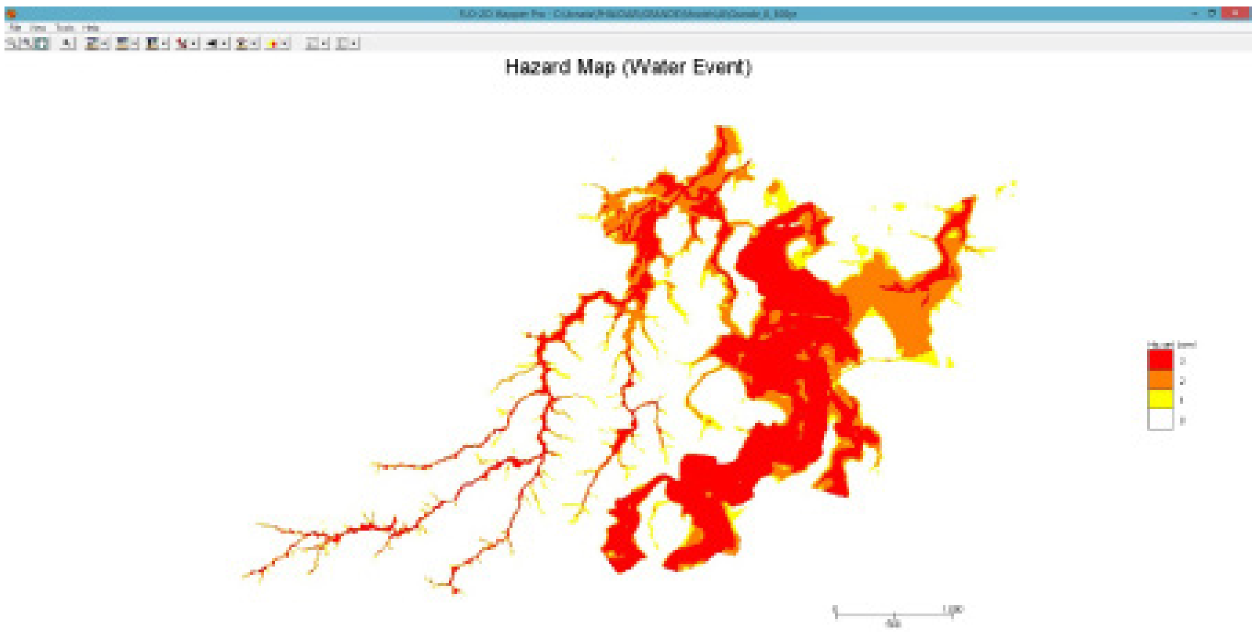


Figure 57. Generated 100-year rain return hazard map from FLO-2D Mapper

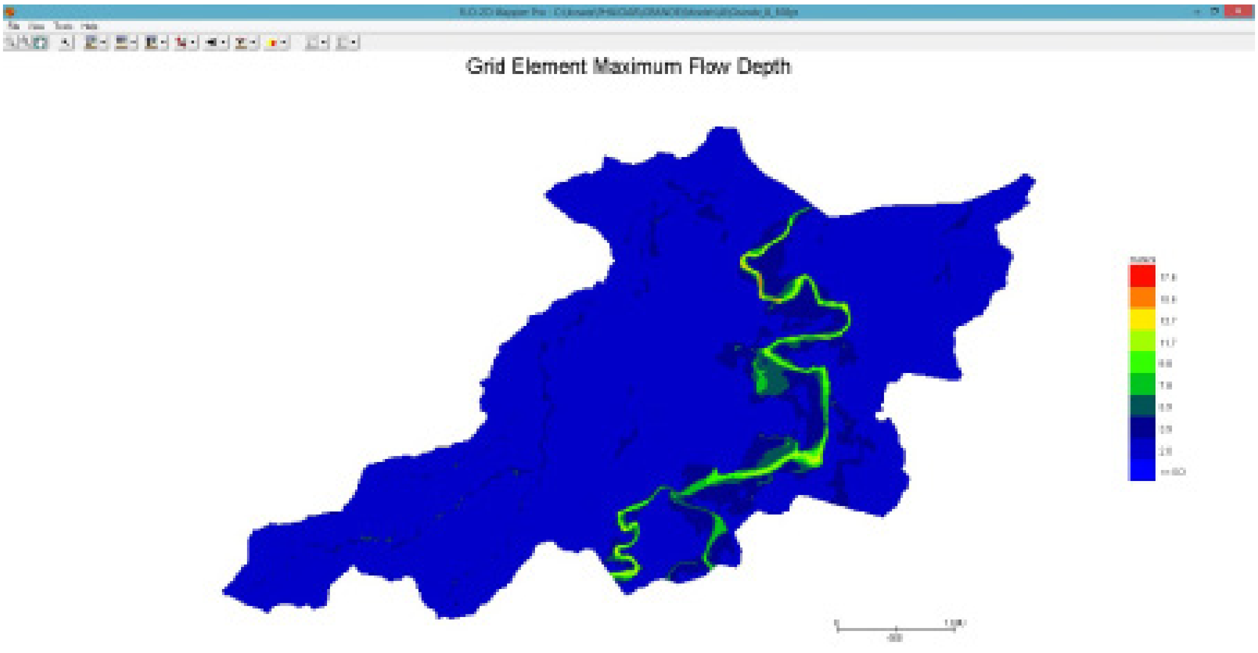


Figure 58. Generated 100-year rain return flow depth map from FLO-2D Mapper

5.6 Results of HMS Calibration

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

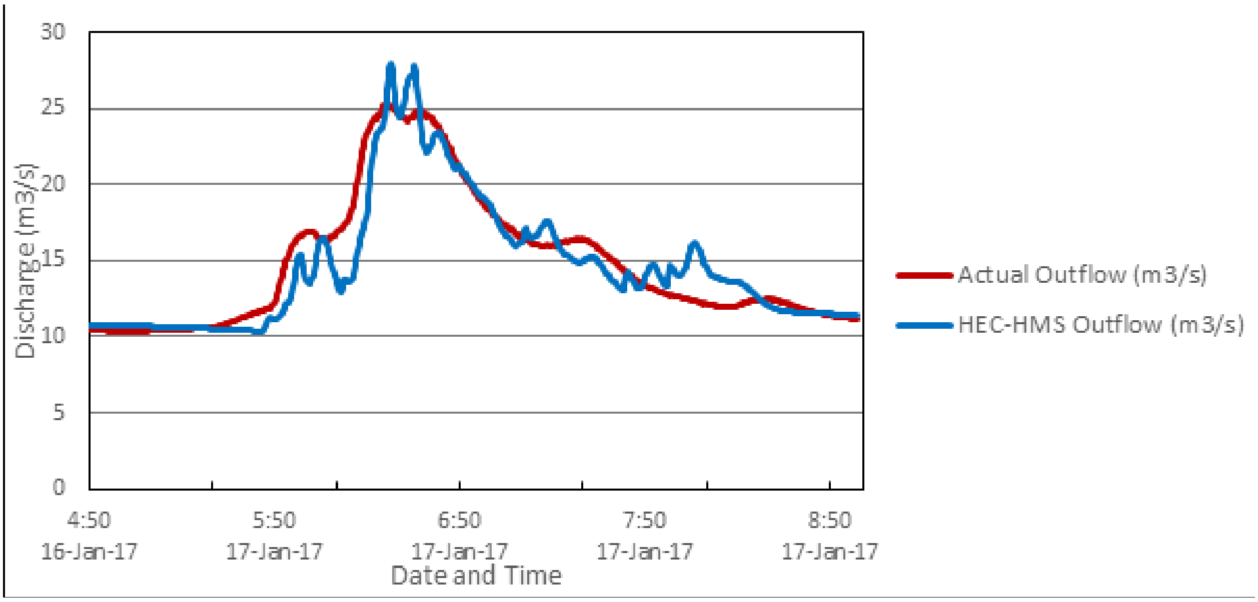


Figure 59. Outflow Hydrograph of Grande produced by the HEC-HMS model compared with observed outflow

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 Grande River Basin

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	6.6-95.1
			Curve Number	52.7-99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.03-0.14
			Storage Coefficient (hr)	0.16-0.72
	Baseflow	Recession	Recession Constant	0.81-1
			Ratio to Peak	0.14
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.06-0.34

Initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as initial abstraction decreases. The range of values from 6.6 mm to 95.1 mm 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 52.7 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). For Grande, the basin mostly consists of closed forest, shrublands, and cultivated areas, and the soil consists of clay, sandy loam, and undifferentiated soil.

Time of concentration and storage coefficient are the travel time and index of temporary storage of runoff in a watershed. The range of calibrated values from 0.03 hours to 0.136 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant of 1 indicates that the basin is unlikely to quickly go back to its original discharge and instead, will be higher. Ratio to peak of 0.14 indicates a lower receding limb of the outflow hydrograph.

Manning’s roughness coefficient of 0.06-0.34 corresponds to the common roughness of Philippine watersheds. Grande river basin is determined to be cultivated with mature row crops (Brunner, 2010).

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

Accuracy Measure	Value
RMS Error	1.5
r2	0.94
NSE	0.88
RSR	0.35
PBIAS	1.53

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 1.5 (m3/s).

The Pearson correlation coefficient (r2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.9441.

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 0.88.

A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate bias towards over-prediction. Again, the optimal value is 0. In the model, the PBIAS is 1.53.

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 0.35.

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 60) shows the Grande outflow using the Iloilo Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAG-ASA) data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods from 165.2m3 in a 5-year return period to 304.5m3 for a 100-year return period.

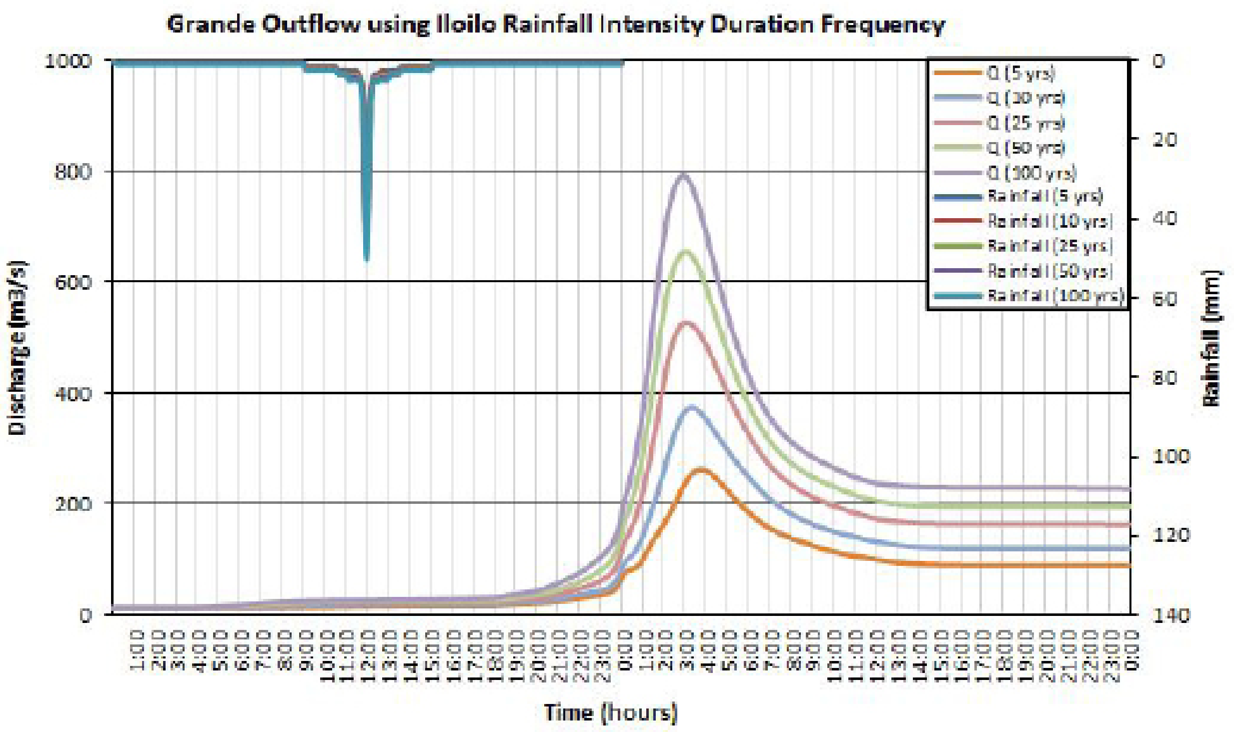


Figure 60. Outflow hydrograph at Grande Station generated using Iloilo RIDF simulated in HEC-HMS

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

Table 30. Peak values of the Grande HEC-HMS Model outflow using the Iloilo RIDF

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	165.2	28.7	261.69	1 hour, 55 minutes
10-Year	198.9	33.9	374.1	1 hour, 40 minutes
25-Year	241.5	40.5	525.9	1 hour, 35 minutes
50-Year	273.1	45.4	654.51	1 hour, 30 minutes
100-Year	304.5	50.3	790.92	1 hour, 30 minutes

5.8 River Analysis Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. The sample generated map of Grande River using the calibrated HMS event flow is shown in Figure 61.

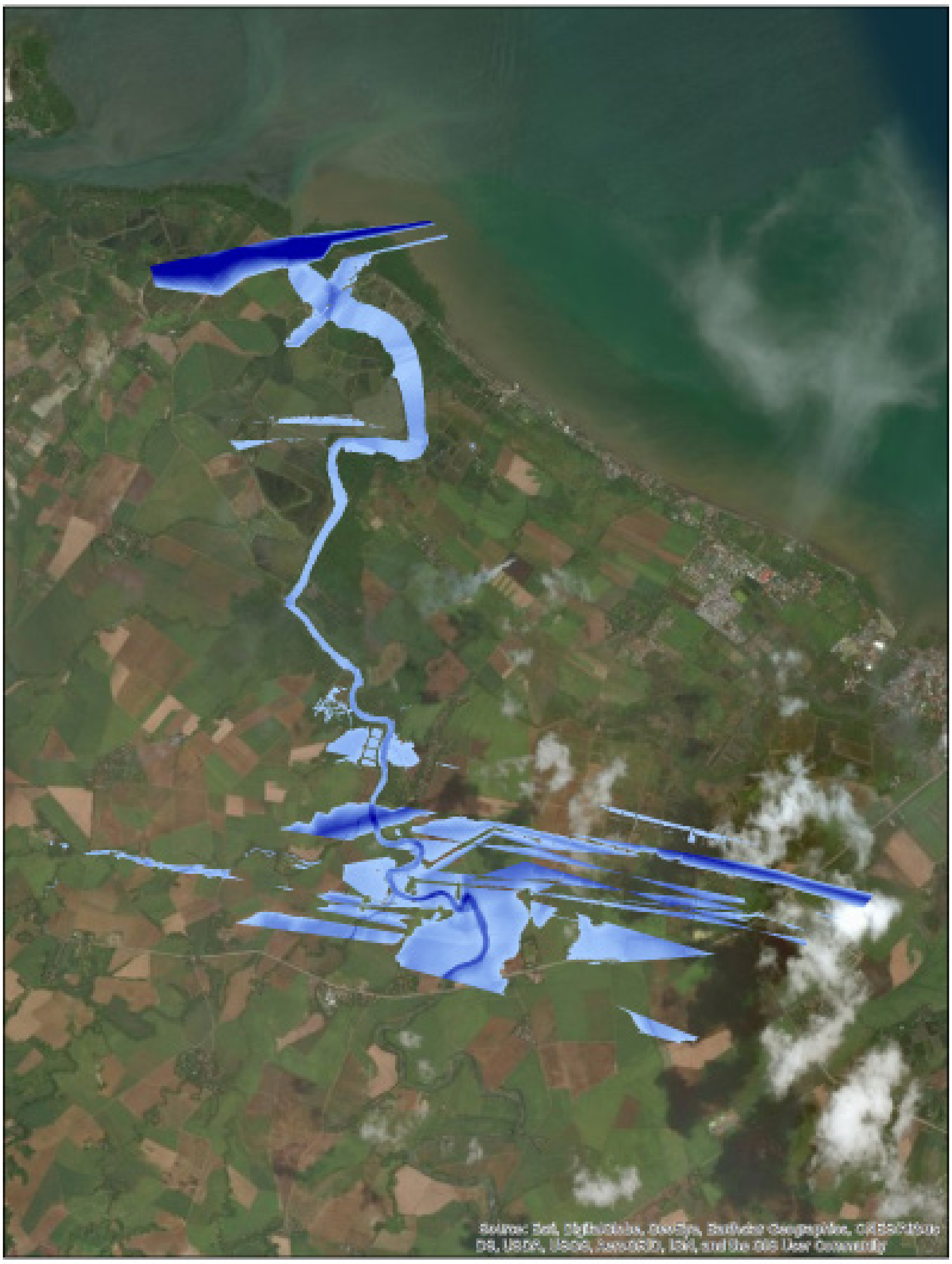


Figure 61. Sample output of Grande RAS Model

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 Grande floodplain. The floodplain, with an area of 83.59 sq.km., covers one municipality namely, Grande City.

Table 31. Municipalities affected in the Grande Floodplain

Municipality	Total Area	Area Flooded	% Flooded
Grande City	526.16	83.51	15.87

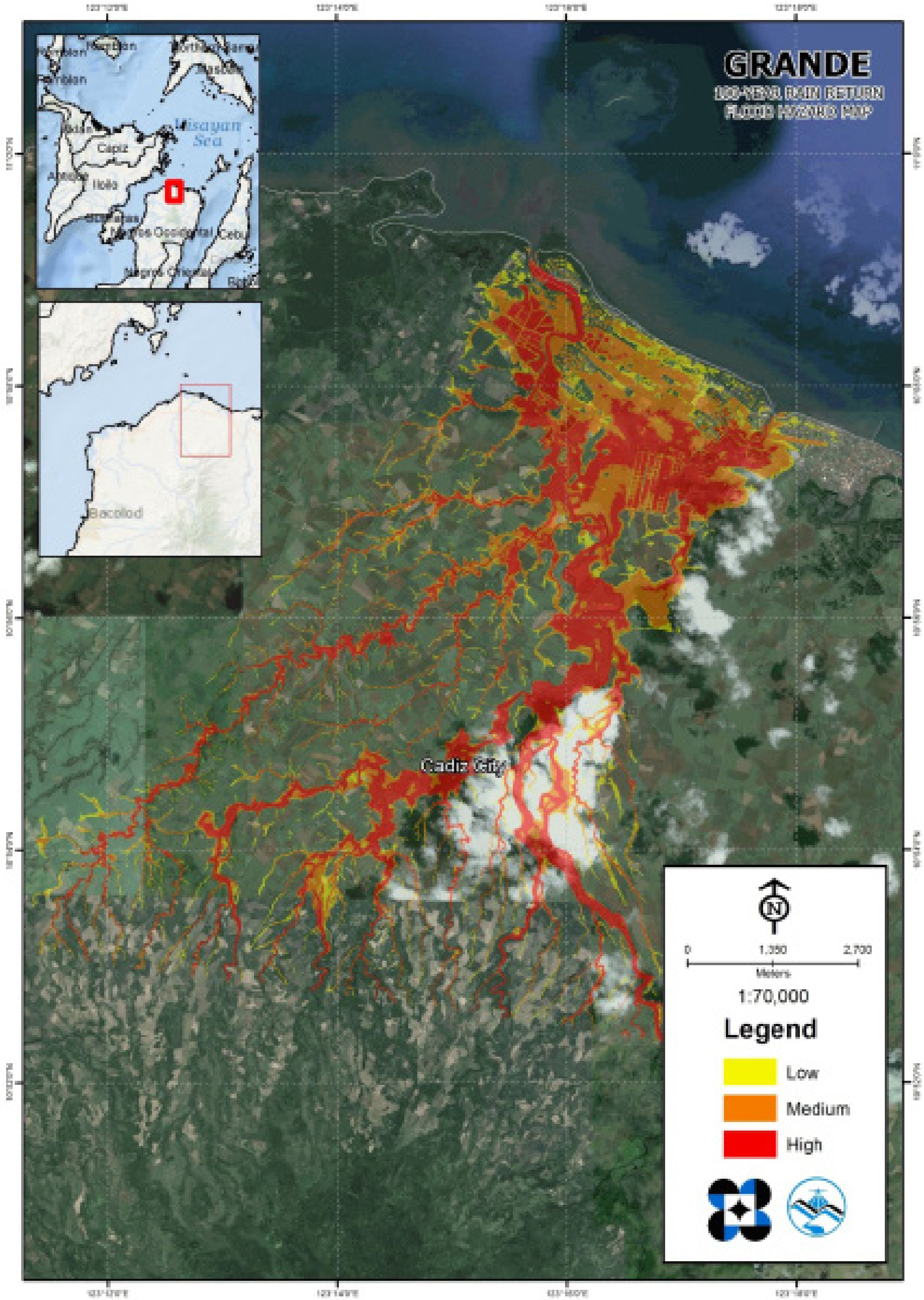


Figure 62. 100-year Flood Hazard Map for Grande Floodplain overlaid on Google Earth imagery

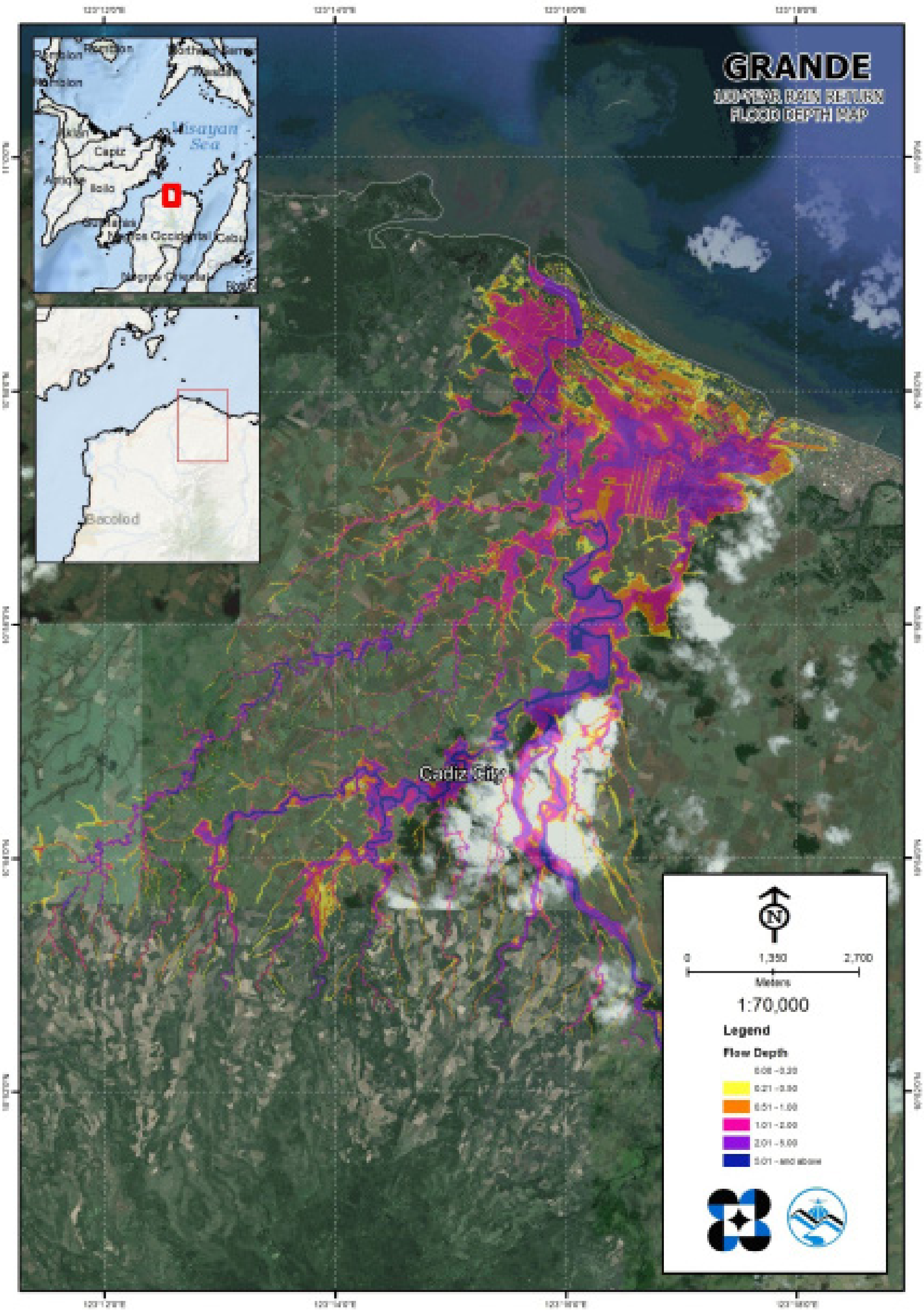


Figure 63. 100-year Flow Depth Map for Grande Floodplain overlaid on Google Earth imagery

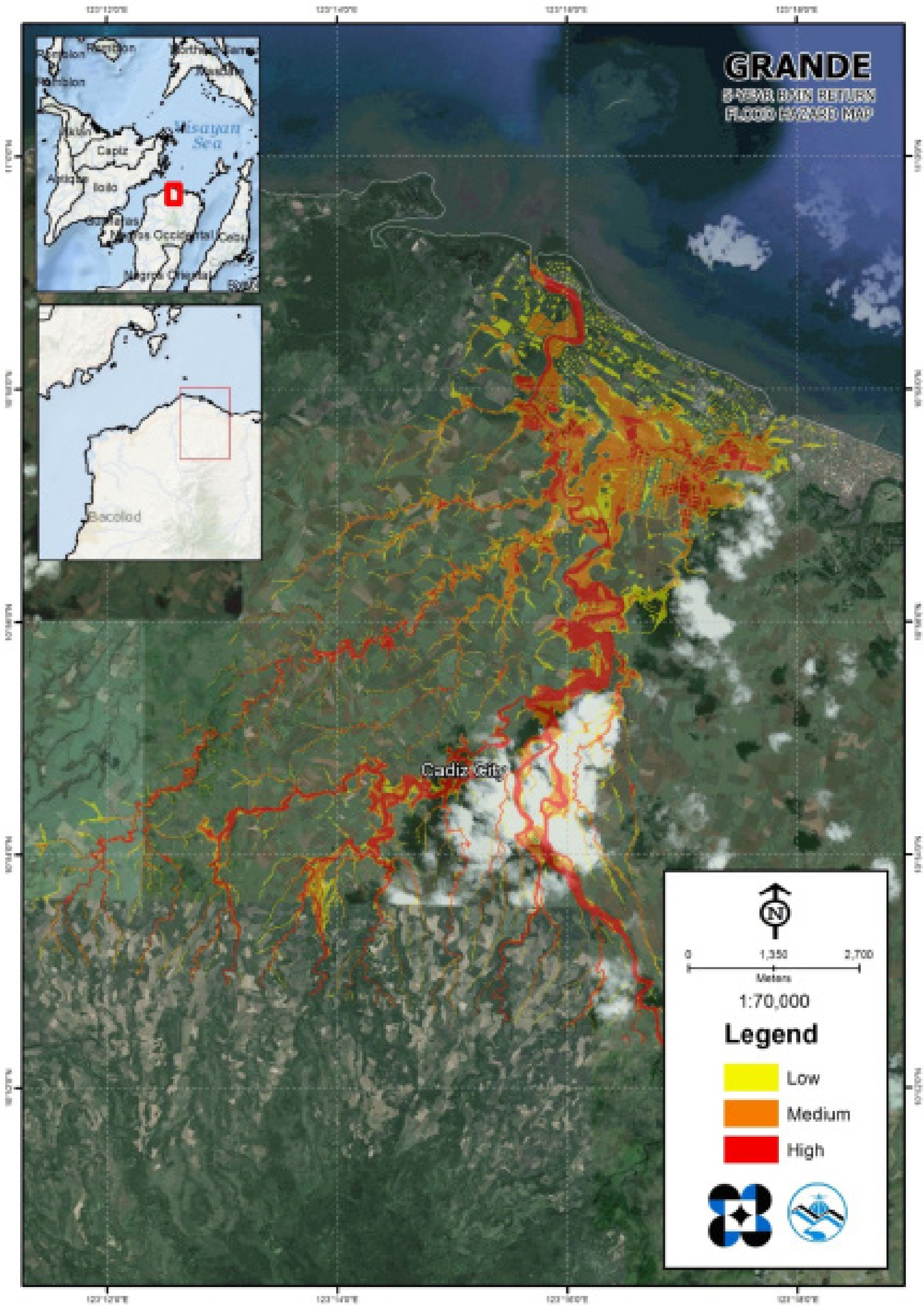


Figure 64. 25-year Flood Hazard Map for Grande Floodplain overlaid on Google Earth imagery

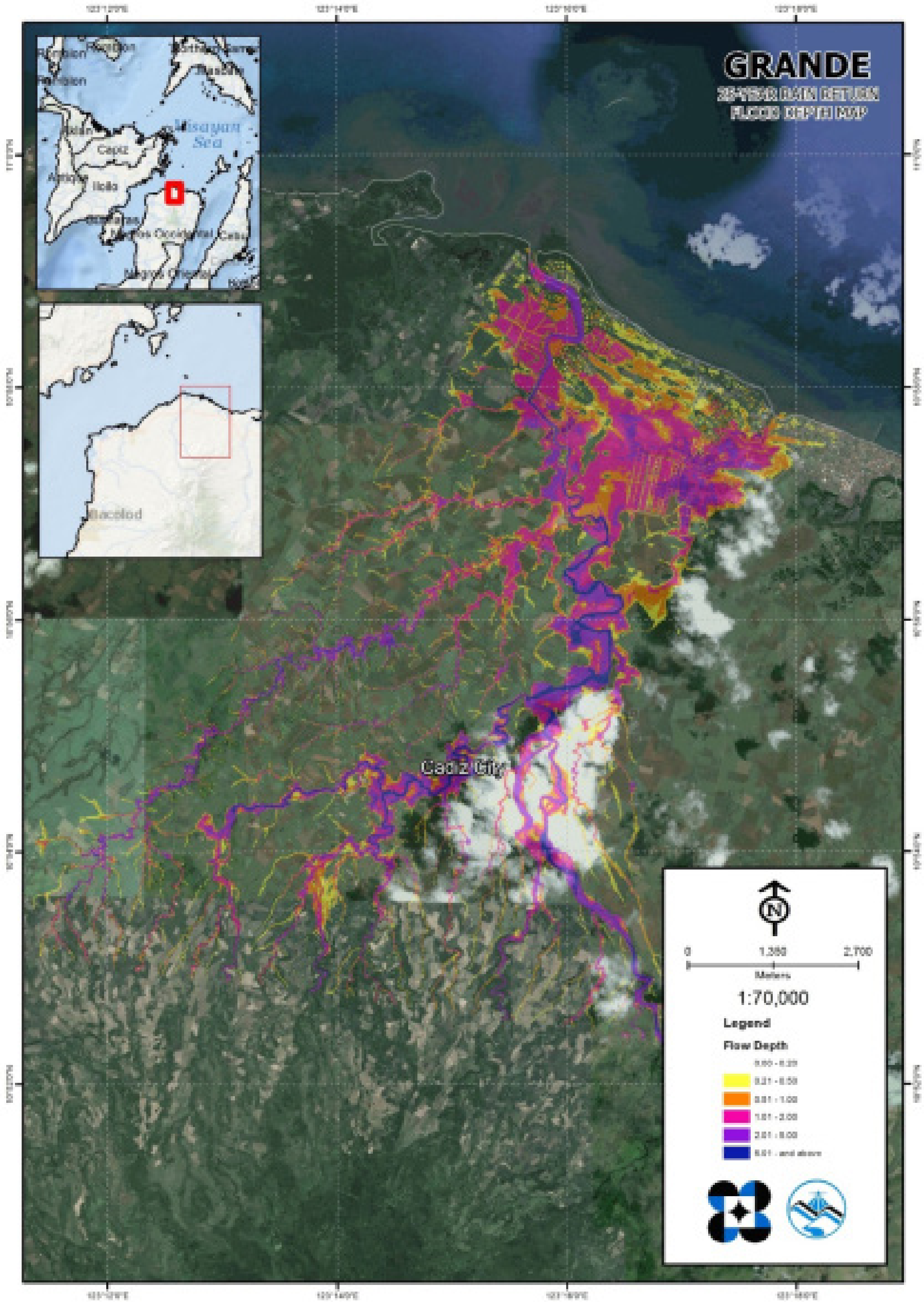


Figure 65. Granderiver (5) generated discharge

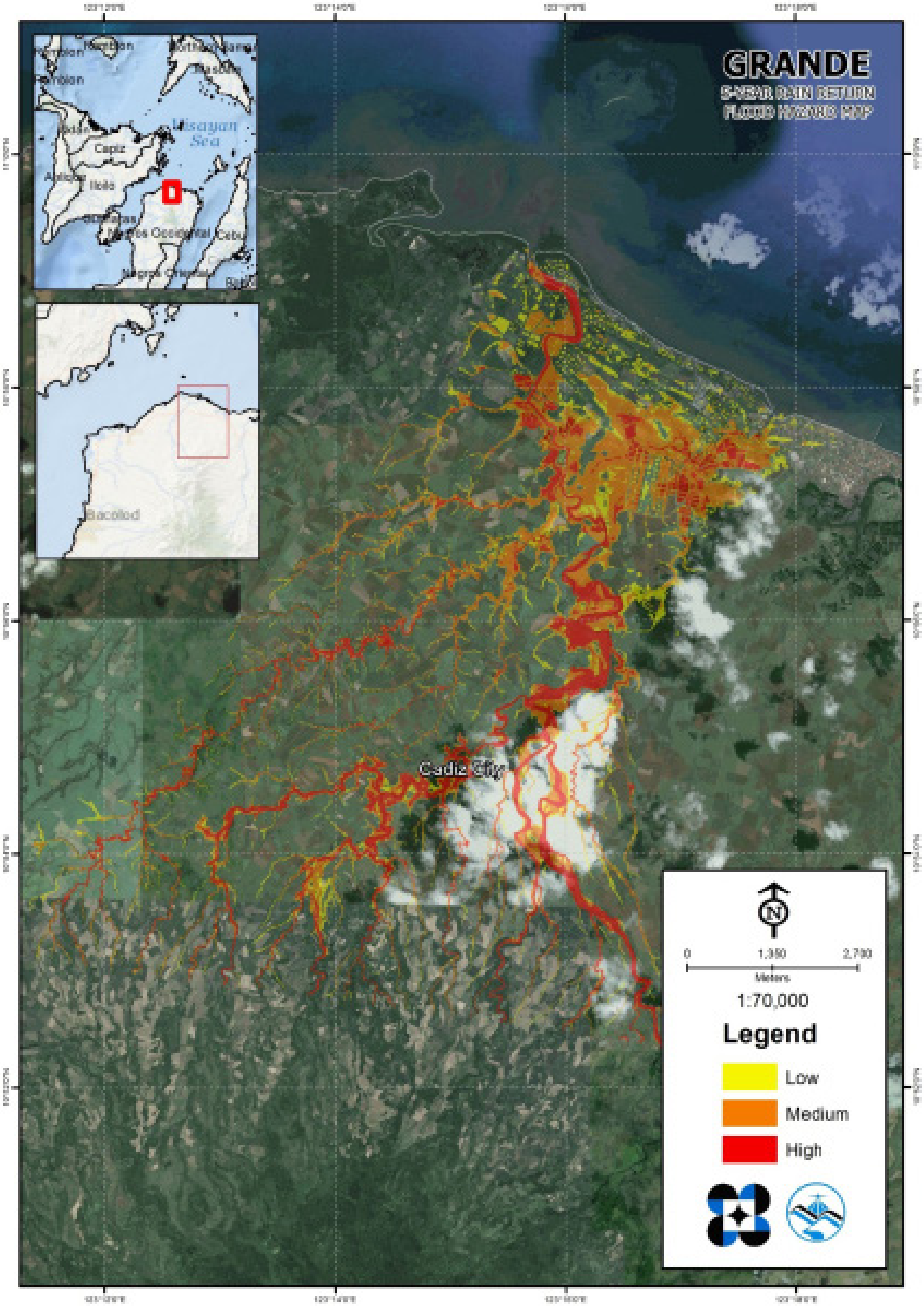


Figure 66. 5-year Flood Hazard Map for Grande Floodplain overlaid on Google Earth imagery

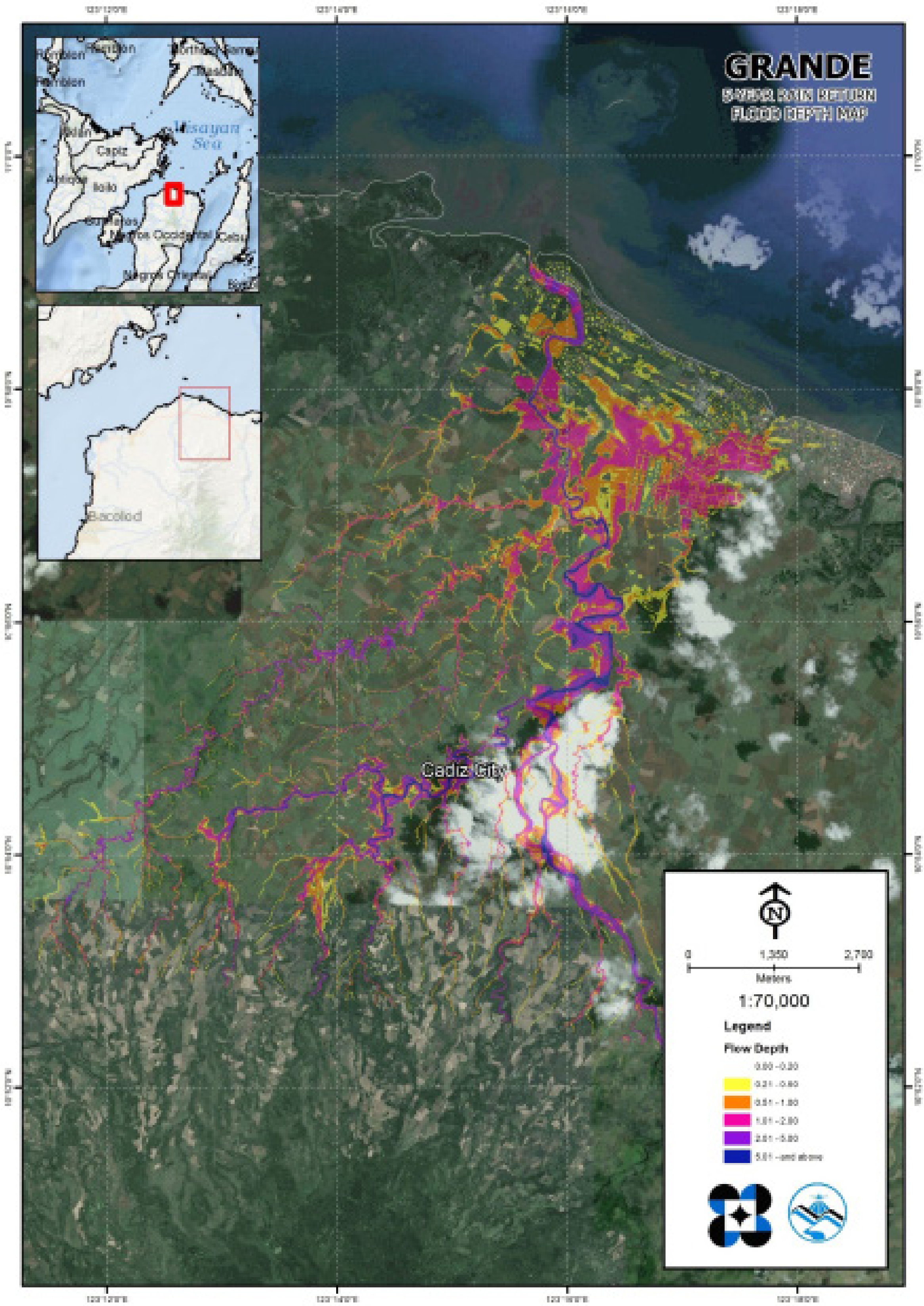


Figure 67. 5-year Flood Depth Map for Grande Floodplain overlaid on Google Earth imagery

5.10 Affected Areas

Affected barangays in the Grande river basin, grouped by municipality, are listed below. For the said basin, one city consisting of 9 barangays is expected to experience flooding when subjected to 5-yr rainfall return period.

For the 5-year return period, 12.23% of the city of Cadiz with an area of 526.16 sq. km. will experience flood levels of less 0.20 meters. 0.97% of the area will experience flood levels of 0.21 to 0.50 meters while 0.98%, 1.08%, 0.5%, and 0.12% 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 32 are the affected areas in square kilometres by flood depth per barangay.

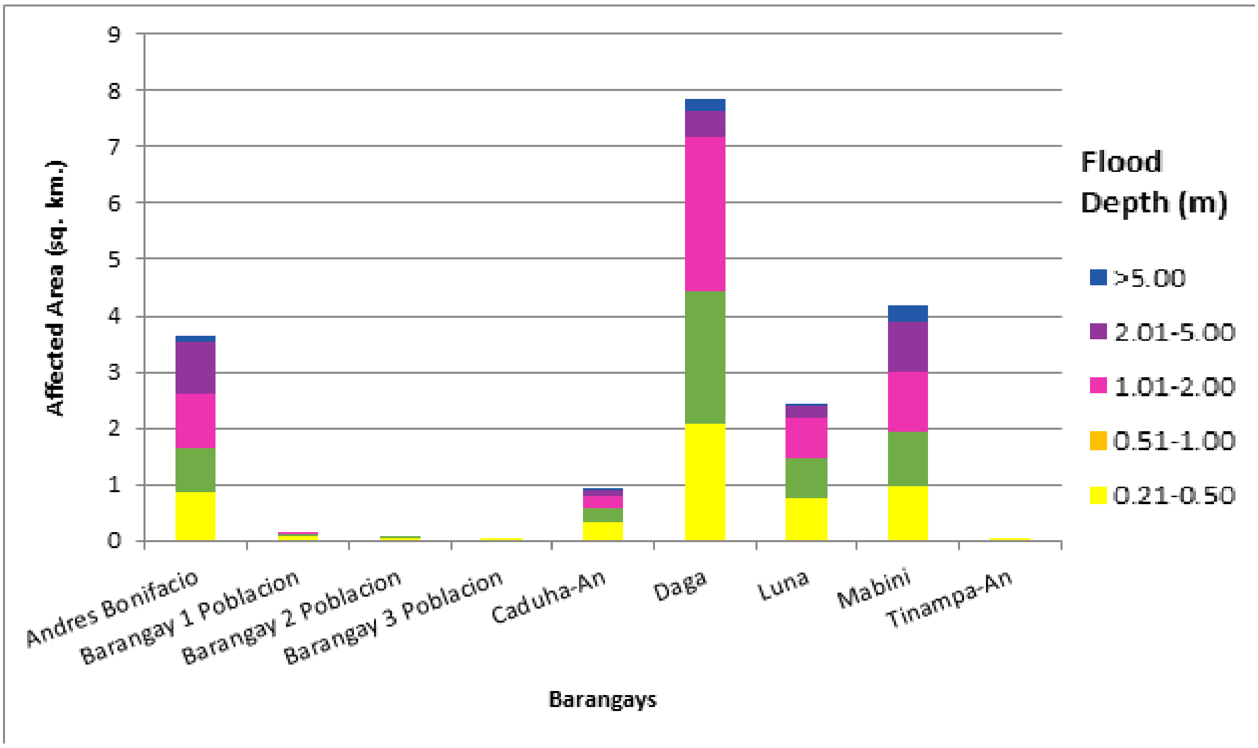


Figure 68. Affected Areas in Cadiz City, Negros Occidental during 5-Year Rainfall Return Period

Table 32. Affected Areas in Cadiz City, Negros Occidental during 5-Year Rainfall Return Period

Affected Area (sq.km.) by flood depth (m)	Affected Barangays in Cadiz City (sq. km.)				
	Andres Bonifacio	Barangay 1 Poblacion	Barangay 2 Poblacion	Barangay 3 Poblacion	Caduha-An
0.03-0.20	18.42	0.21	0.33	0.036	7.068
0.21-0.50	0.84	0.092	0.032	0.0015	0.33
0.51-1.00	0.82	0.039	0.0021	0	0.24
1.01-2.00	0.95	0.024	0	0	0.21
2.01-5.00	0.92	0	0	0	0.12
> 5.00	0.11	0	0	0	0.004

Affected Area (sq.km.) by flood depth (m)	Affected Barangays in Cadiz City (sq. km.)			
	Daga	Luna	Mabini	Tinampa-An
0.03-0.20	9.86	12.31	16.12	0.007
0.21-0.50	2.084	0.74	0.95	0.00084
0.51-1.00	2.34	0.74	0.99	0
1.01-2.00	2.73	0.69	1.051	0
2.01-5.00	0.48	0.21	0.89	0
> 5.00	0.19	0.020253	0.28	0

For the 25-year return period, 11.25% of the city of Cadiz with an area of 526.16 sq. km. will experience flood levels of less 0.20 meters. 0.93% of the area will experience flood levels of 0.21 to 0.50 meters while 1.05%, 1.56%, 0.89%, and 0.18% 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 are the affected areas in square kilometres by flood depth per barangay.

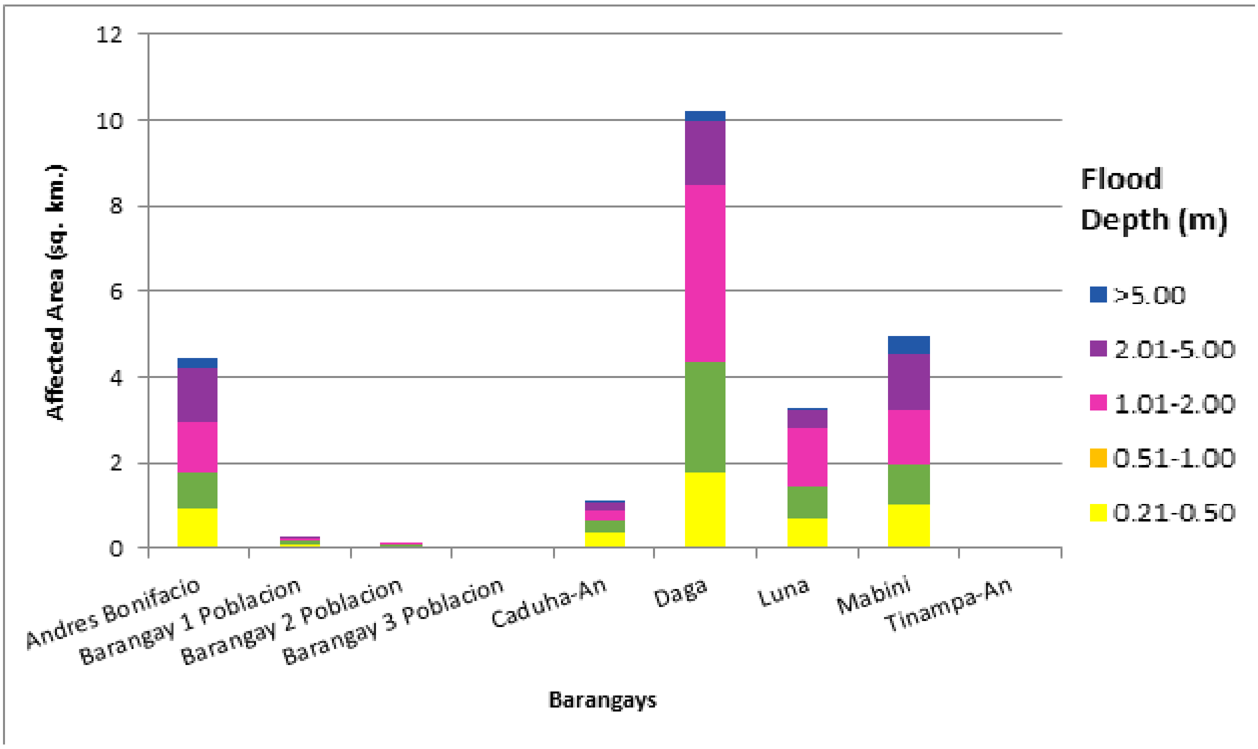


Figure 69. Affected Areas in Cadiz City, Negros Occidental during 25-Year Rainfall Return Period

Table 33. Affected Areas in Cadiz City, Negros Occidental during 25-Year Rainfall Return Period

Affected Area (sq.km.) by flood depth (m)	Affected Barangays in Cadiz City (sq. km.)				
	Andres Bonifacio	Barangay 1 Poblacion	Barangay 2 Poblacion	Barangay 3 Poblacion	Caduha-An
0.03-0.20	17.62	0.13	0.29	0.03	6.87
0.21-0.50	0.91	0.07	0.05	0	0.36
0.51-1.00	0.87	0.11	0.02	0	0.27
1.01-2.00	1.15	0.05	0	0	0.26
2.01-5.00	1.28	0	0	0	0.19
> 5.00	0.23	0	0	0	0.01

Affected Area (sq.km.) by flood depth (m)	Affected Barangays in Cadiz City (sq. km.)			
	Daga	Luna	Mabini	Tinampa-An
0.03-0.20	7.48	11.43	15.36	0.01
0.21-0.50	1.78	0.68	1.03	0
0.51-1.00	2.56	0.77	0.93	0
1.01-2.00	4.12	1.37	1.25	0
2.01-5.00	1.5	0.43	1.32	0
> 5.00	0.26	0.04	0.42	0

For the 100-year return period, 10.74% of the city of Cadiz with an area of 526.16 sq. km. will experience flood levels of less 0.20 meters. 0.9% of the area will experience flood levels of 0.21 to 0.50 meters while 1.03%, 1.7%, 1.26%, and 0.24% 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 are the affected areas in square kilometres by flood depth per barangay.

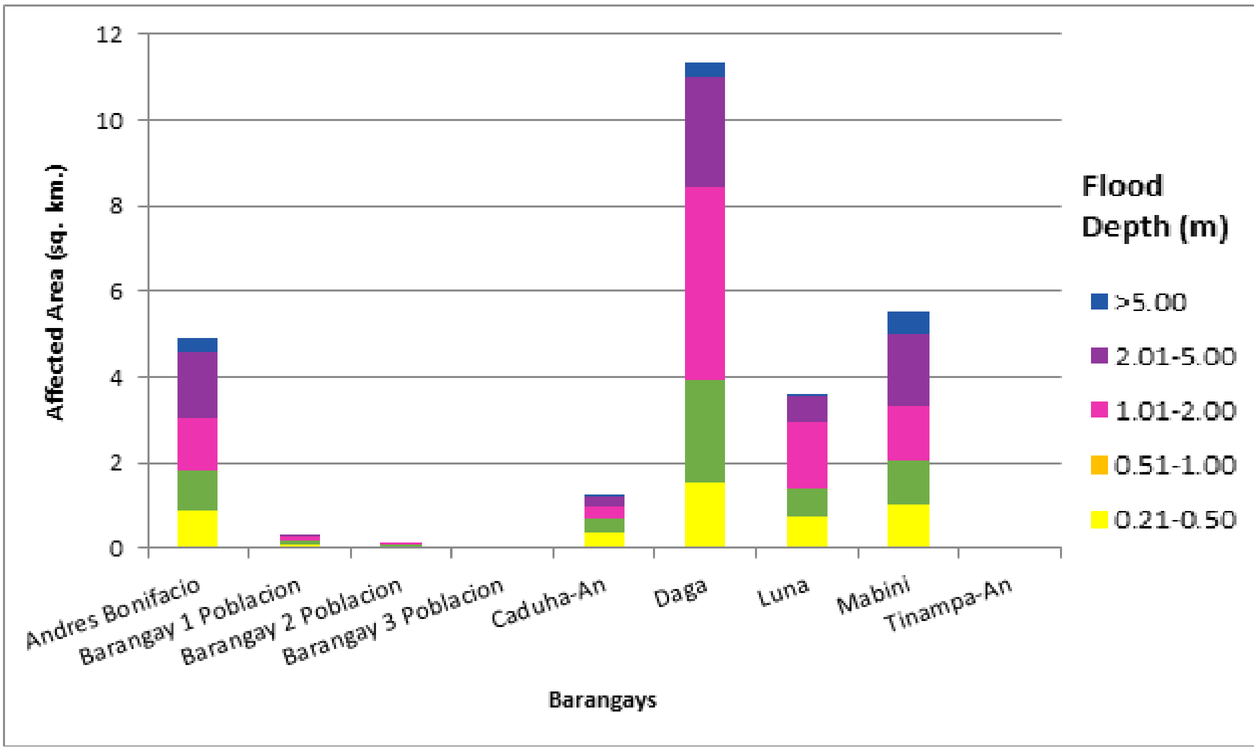


Figure 70. Affected Areas in Cadiz City, Negros Occidental during 100-Year Rainfall Return Period

Table 34. Affected Areas in Cadiz City, Negros Occidental during 25-Year Rainfall Return Period

Affected Area (sq.km.) by flood depth (m)	Affected Barangays in Cadiz City (sq. km.)				
	Andres Bonifacio	Barangay 1 Poblacion	Barangay 2 Poblacion	Barangay 3 Poblacion	Caduha-An
0.03-0.20	17.15	0.08	0.26	0.03	6.74
0.21-0.50	0.9	0.07	0.05	0	0.39
0.51-1.00	0.9	0.1	0.05	0	0.29
1.01-2.00	1.24	0.11	0	0	0.3
2.01-5.00	1.52	0.01	0	0	0.24
> 5.00	0.35	0	0	0	0.02

Affected Area (sq.km.) by flood depth (m)	Affected Barangays in Cadiz City (sq. km.)			
	Daga	Luna	Mabini	Tinampa-An
0.03-0.20	6.36	11.09	14.81	0
0.21-0.50	1.55	0.73	1.04	0
0.51-1.00	2.39	0.69	1	0
1.01-2.00	4.49	1.53	1.3	0
2.01-5.00	2.59	0.63	1.65	0
> 5.00	0.31	0.05	0.52	0

Among the barangays in the city of Cadiz, Andres Bonifacio is projected to have the highest percentage of area that will experience flood levels at 4.19%. Meanwhile, Mabini posted the second highest percentage of area that may be affected by flood depths at 0.3.86%.

Moreover, the generated flood hazard maps for the Grande 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-year, 25-year, and 100-year).

Table 35. Affected Areas in Cadiz City, Negros Occidental during 25-Year Rainfall Return Period

Warning Level	Area Covered in sq. km.		
	5-year	25-year	100-year
Low	5.004	4.81	4.71
Medium	8.36	9.79	9.69
High	6.15	10.04	12.96
Total	**19.51**	**24.64**	**27.36**

Of the 9 identified Education Institute in Grande Flood plain, 4 schools were assessed to be exposed to the Low level flooding during a 5 year scenario while 1 school were assessed to be exposed to medium level flooding in the same scenario. In the 25-year scenario, 6 schools were assessed to be exposed to the Low level flooding while 1 school were assessed to be exposed to medium level flooding. For the 100-year scenario, 5 school was assessed for Low level flooding and 3 schools for Medium level flooding.

One (1) Medical Institution was identified in Grande Floodplain, and it was assessed to be exposed to Medium level flooding in the 25 and 100-Year scenarios in Barangay Daga, Cadiz City.

5.11 Flood Validation

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

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

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

After which, the actual data from the field were compared to the simulated data to assess the accuracy of the Flood Depth Maps produced and to improve on what is needed. The points in the flood map versus its corresponding validation depths are shown in Figure 71.

The flood validation consists of 181 points randomly selected all over Grande flood plain. Comparing it with the flood depth map of the nearest storm event, the map has an RMSE value of 0.72m. Table 36 shows a contingency matrix of the comparison.

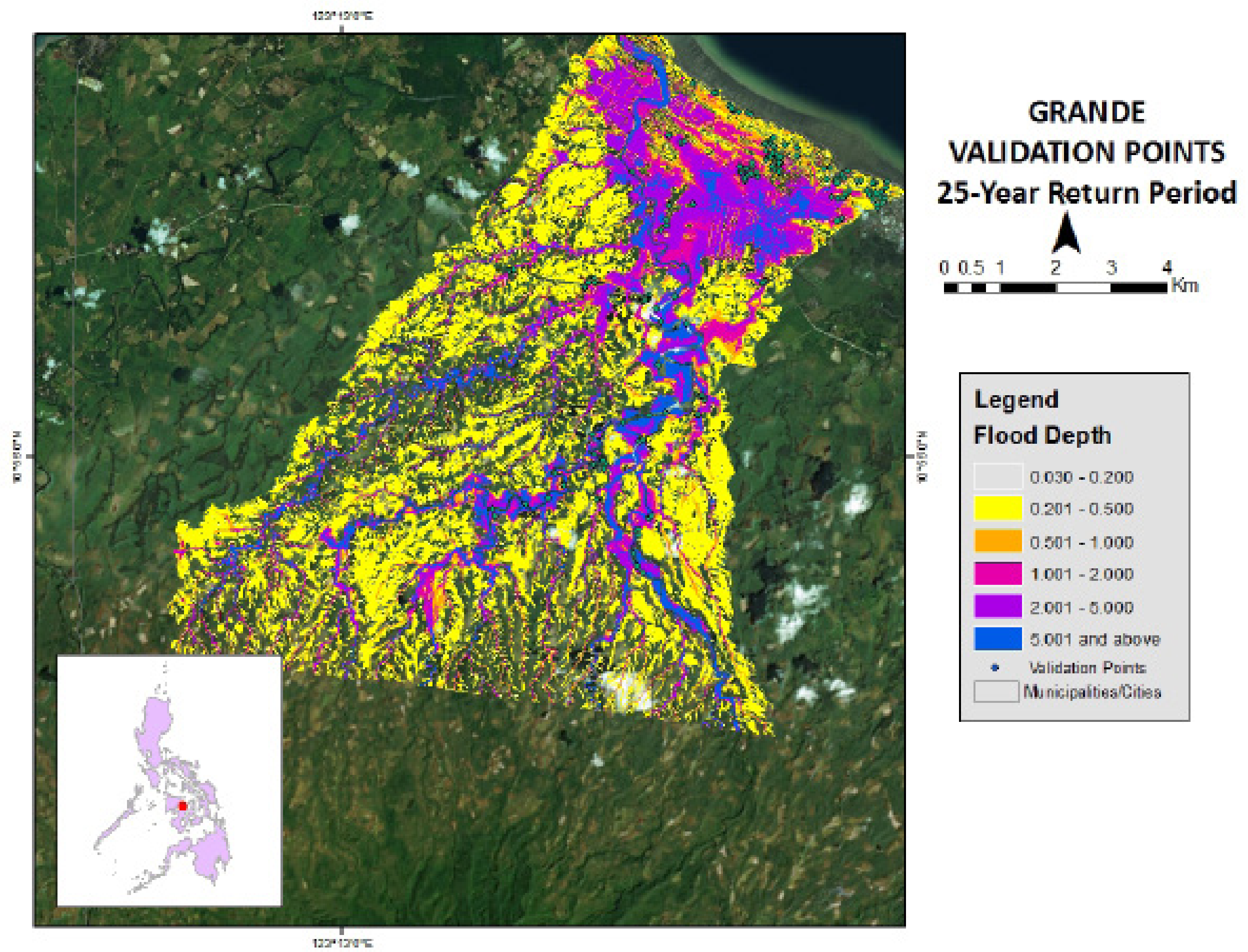


Figure 71. Validation points for 25-year Flood Depth Map of Grande Floodplain

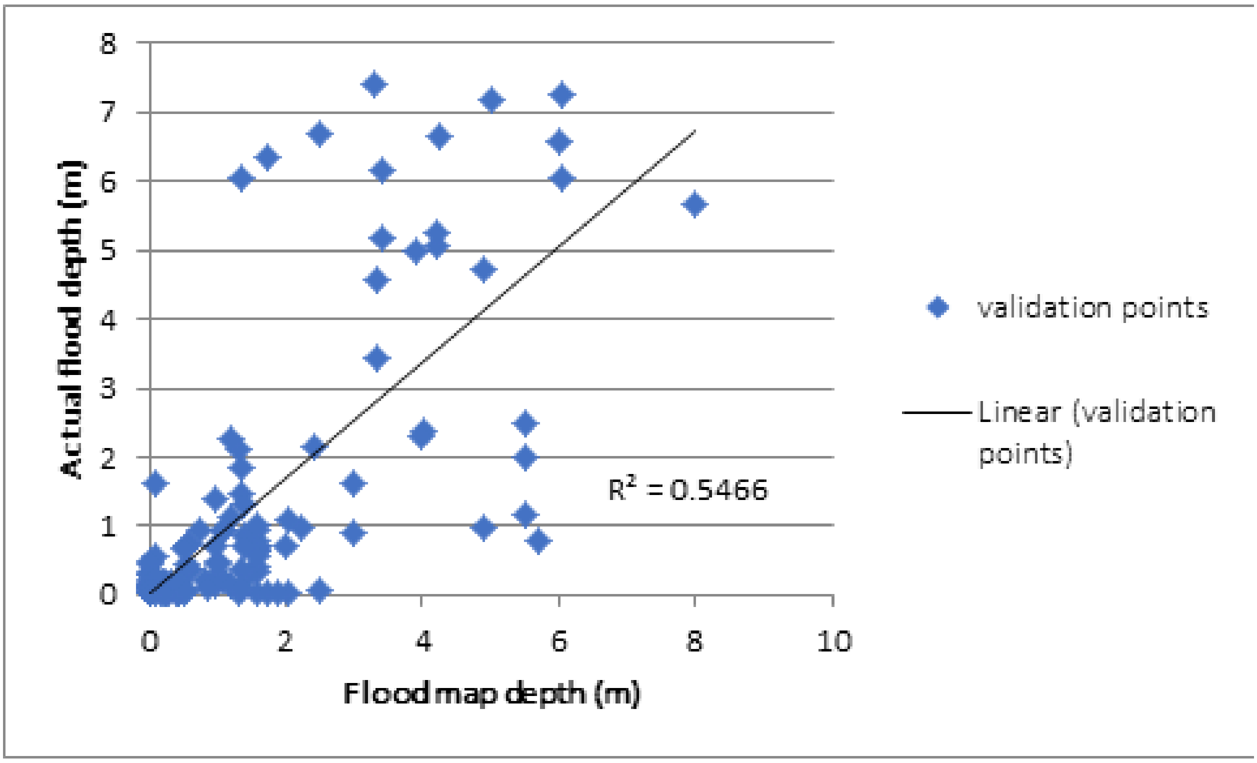


Figure 72. Flood map depth vs actual flood depth

Table 36. Actual Flood Depth vs Simulated Flood Depth at different levels in the Grande 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	46	7	1	1	0	0	55
0.21-0.50	23	0	1	0	0	0	24
0.51-1.00	8	7	5	1	0	0	21
1.01-2.00	21	5	13	5	2	2	48
2.01-5.00	5	0	3	2	7	8	25
> 5.00	0	0	1	2	1	4	8
Total	103	19	24	11	10	14	181

The overall accuracy generated by the flood model is estimated at 37.02%, with 67 points correctly matching the actual flood depths. In addition, there were 65 points estimated one level above and below the correct flood depths while there were 21 points and 23 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 23 points were overestimated while a total of 91 points were underestimated in the modelled flood depths of Grande. Table 36 depicts the summary of the Accuracy Assessment in the Grande River Basin Survey.

Table 37. Summary of Accuracy Assessment in Grande River Basin Survey

	No. of Points	%
Correct	67	37.02
Overestimated	23	12.71
Underestimated	91	50.28
Total	181	100

REFERENCES

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

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

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

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

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

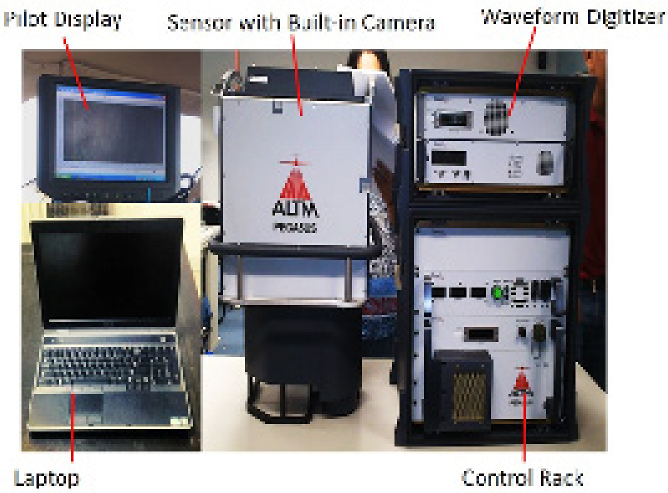
Sarmiento C., Paringit E.C., et al., 2014. DREAM Data Acquisition Component Manual. Quezon City, Philippines: UP Training Center for Applied Geodesy and Photogrammetry.

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

ANNEXES

Annex 1. Technical Specifications of the LiDAR Sensors Used

1. PEGASUS SENSOR (OPTECH)

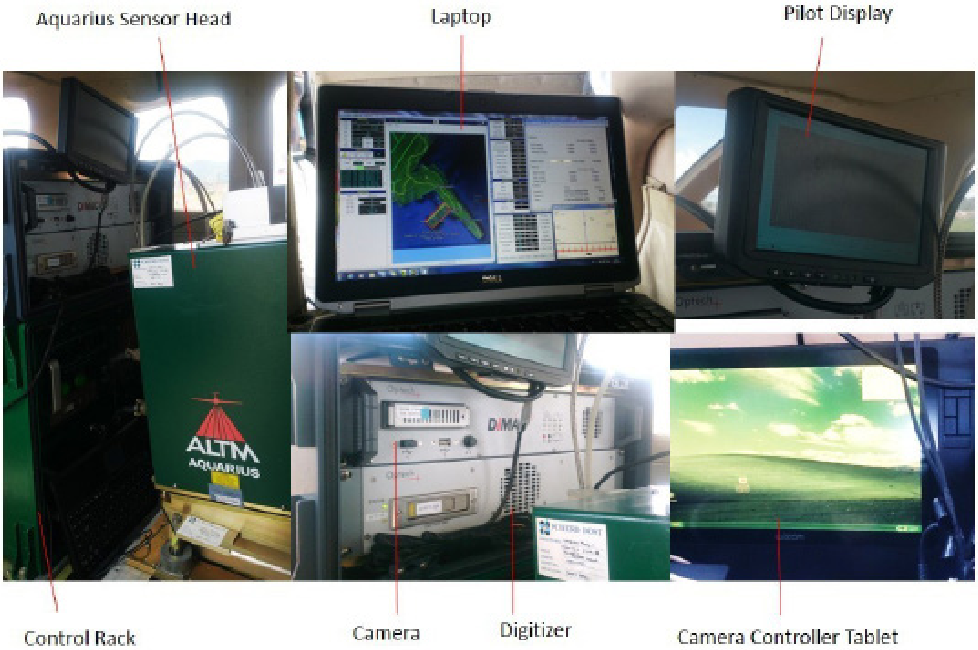


Parameter	Specification
Operational envelope (1,2,3,4)	150-5000 m AGL, nominal
Laser wavelength	1064 nm
Horizontal accuracy (2)	1/5,500 x altitude, 1σ
Elevation accuracy (2)	< 5-20 cm, 1σ
Effective laser repetition rate	Programmable, 100-500 kHz
Position and orientation system	POS AV ™AP50 (OEM)
Scan width (FOV)	Programmable, 0-75 ˚
Scan frequency (5)	Programmable, 0-140 Hz (effective)
Sensor scan product	800 maximum
Beam divergence	0.25 mrad (1/e)
Roll compensation	Programmable, ±37˚ (FOV dependent)
Vertical target separation distance	<0.7 m
Range capture	Up to 4 range measurements, including 1st, 2nd, 3rd, and last returns
Intensity capture	Up to 4 intensity returns for each pulse, including last (12 bit)
Image capture	5 MP interline camera (standard); 60 MP full frame (optional)
Full waveform capture	12-bit Optech IWD-2 Intelligent Waveform Digitizer
Data storage	Removable solid state disk SSD (SATA II)
Power requirements	28 V, 800 W, 30 A
Dimensions and weight	Sensor: 630 x 540 x 450 mm; 65 kg;
	Control rack: 650 x 590 x 490 mm; 46 kg
Operating Temperature	-10°C to +35°C
Relative humidity	0-95% non-condensing

2. D-8900 AERIAL DIGITAL CAMERA

Parameter	Specification
Camera Head	
Sensor type	60 Mpix full frame CCD, RGB
Sensor format (H x V)	8, 984 x 6, 732 pixels
Pixel size	6μm x 6 μm
Frame rate	1 frame/2 sec.
FMC	Electro-mechanical, driven by piezo technology (patented)
Shutter	Electro-mechanical iris mechanism 1/125 to 1/500++ sec. f-stops: 5.6, 8, 11, 16
Lenses	50 mm/70 mm/120 mm/210 mm
Filter	Color and near-infrared removable filters
Dimensions (H x W x D)	200 x 150 x 120 mm (70 mm lens)
Weight	~4.5 kg (70 mm lens)
Controller Unit	
Computer	Mini-ITX RoHS-compliant small-form-factor embedded
	computers with AMD TurionTM 64 X2 CPU
	4 GB RAM, 4 GB flash disk local storage
	IEEE 1394 Firewire interface
Removable storage unit	~500 GB solid state drives, 8,000 images
Power consumption	~8 A, 168 W
Dimensions	2U full rack; 88 x 448 x 493 mm
Weight	~15 kg
Image Pre-Processing Software	
Capture One	Radiometric control and format conversion, TIFF or JPEG
Image output	8,984 x 6,732 pixels
	8 or 16 bits per channel (180 MB or 360 MB per image)

3. AQUARIUS SENSOR (OPTECH)



Parameter	Specification
Operational altitude	300-600 m AGL
Laser pulse repetition rate	33, 50. 70 kHz
Scan rate	0-70 Hz
Scan half-angle	0 to ± 25 ˚
Laser footprint on water surface	30-60 cm
Depth range	0 to > 10 m (for k < 0.1/m)
Topographic mode	
Operational altitude	300-2500
Range Capture	Up to 4 range measurements, including 1st, 2nd, 3rd, and last returns
Intensity capture	12-bit dynamic measurement range
Position and orientation system	POS AVTM 510 (OEM) includes embedded 72-channel GNSS receiver (GPS and GLONASS)
Data Storage	Ruggedized removable SSD hard disk (SATA III)
Power	28 V, 900 W, 35 A
Image capture	5 MP interline camera (standard); 60 MP full frame (optional)
Full waveform capture	12-bit Optech IWD-2 Intelligent Waveform Digitizer (optional)
Dimensions and weight	Sensor:250 x 430 x 320 mm; 30 kg;
Control rack: 591 x 485 x 578 mm; 53 kg	Removable solid state disk SSD (SATA II)
Operating temperature	0-35˚C
Relative humidity	0-95% no-condensing
	Control rack: 650 x 590 x 490 mm; 46 kg
Operating Temperature	-10°C to +35°C
Relative humidity	0-95% non-condensing

4. ITRES TECHNICAL SPECIFICATION OF CASI

Parameter	Specification
Sensor type	
VNIR Push-broom Sensor	
(Compact Airborne Spectrographic Imager)	
Performance	
Spectral Range (Continuous Coverage)	380-1050 nm
# Spectral Channels	Up to 288
#Across-Track Pixels	1500
Total Field of View	40 deg
IFOV	0.49 mRad
t/#	t/3.5
Spectral Width Sampling Row	2.4 nm
Spectral Resolution (FWHM)	<3.5 nm
Pixel Size	20x20 microns
Dynamic Range	14-bits (16384:1)
Sustained Date Rate (Mpix/Second)	9.6 Mpix/Sec
Spectral Smile/Keystone Distortion	±0.35 pixels
Peak Signal Noise Ration	SNR models for various radiance conditions are available
Relative humidity	0-95% no-condensing

Annex 2. NAMRIA Certificates of Reference Points Used

1. NGW-50

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

May 05, 2014

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: **NEGROS OCCIDENTAL**
Station Name: **NGW-50**
Order: **2nd**

Island: **VISAYAS**		Barangay: **FABRICA**
Municipality: **SAGAY**		
	PRS92 Coordinates	
Latitude: **10° 53' 26.84456"**	Longitude: **123° 21' 6.66799"**	Ellipsoidal Hgt: **15.38600 m.**
	WGS84 Coordinates	
Latitude: **10° 53' 22.62478"**	Longitude: **123° 21' 11.86663"**	Ellipsoidal Hgt: **74.42200 m.**
	PTM Coordinates	
Northing: **1204272.594 m.**	Easting: **538486.927 m.**	Zone: **4**
	UTM Coordinates	
Northing: **1,203,651.08**	Easting: **538,452.46**	Zone: **51**

Location Description

NGW-50
The station is on the NW sidewalk of Himoga-an bridge at km. 73+545 along the Sagay-Bacolod national highway. Mark is the head of a 4" copper nail drilled and grouted at the center of a 30 x 30 cm. cement putty embedded on top of the concrete sidewalk with inscriptions "NGW-50, 2007; NAMRIA".

Requesting Party: **UP DREAM**
Pupose: **Reference**
OR Number: **8796117 A**
T.N.: **2014-1064**

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

www.namria.gov.ph

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

2. NGW-58

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

May 06, 2014

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: **NEGROS OCCIDENTAL**
Station Name: **NGW-58**
Order: **2nd**

Island: **VISAYAS**		Barangay: **ONOBONOB, SITIO LABARCA**
Municipality: **ESCALANTE**		
	PRS92 Coordinates	
Latitude: **10° 49' 16.43235"**	Longitude: **123° 29' 11.51295"**	Ellipsoidal Hgt: **8.72200 m.**
	WGS84 Coordinates	
Latitude: **10° 49' 12.14178"**	Longitude: **123° 29' 16.71871"**	Ellipsoidal Hgt: **68.25600 m.**
	PTM Coordinates	
Northing: **1196599.363 m.**	Easting: **553202.195 m.**	Zone: **4**
	UTM Coordinates	
Northing: **1,196,180.53**	Easting: **553,183.57**	Zone: **51**

Location Description

NGW-58
The station is on the NE sidewalk of Danao bridge. It is about 2.4 km. from Escalante City proper. Mark is the head of a 4" copper nail flushed at the center of an existing benchmark embedded on the concrete sidewalk with inscriptions "NW-100; 2007; NAMRIA".

Requesting Party: **UP DREAM**
Purpose: **Reference**
OR Number: **8796117 A**
T.N.: **2014-1066**

For **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 Reports

Project information		Coordinate System	
Name:	C:\Users\Windows User\Documents \Business Center - HCE\NW-123.vce	Name:	UTM
Size:	752 KB	Datum:	PRS 92
Modified:	4/22/2016 8:06:07 PM (UTC:8)	Zone:	51 North (123E)
Time zone:	China 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)
NGW-50 --- NW-123 (B1)	NGW-50	NW-123	Fixed	0.021	0.057	315°55'13"	3789.388	13.992
NGW-50 --- NW-123 (B2)	NGW-50	NW-123	Fixed	0.019	0.064	315°55'14"	3789.385	14.045

Acceptance Summary

Processed	Passed	Flag	Fail
2	2	0	0

NGW-50 - NW-123 (8:46:55 AM-2:12:55 PM) (S1)

Baseline observation:	NGW-50 --- NW-123 (B1)
Processed:	4/22/2016 8:33:29 PM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.021 m
Vertical precision:	0.057 m
RMS:	0.008 m
Maximum PDOP:	4.126
Ephemeris used:	Broadcast
Antenna model:	NGS Absolute
Processing start time:	4/22/2016 8:46:55 AM (Local: UTC+8hr)
Processing stop time:	4/22/2016 2:12:55 PM (Local: UTC+8hr)
Processing duration:	05:26:00
Processing interval:	1 second

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
		ENGR. LOUIE P. BALICANTA	
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUñA	UP-TCAGP
		LOVELYN ASUNCION	UP-TCAGP

FIELD TEAM

LiDAR Operation	Senior Science Research Specialist (SSRS)	JASMINE ALVIAR	UP-TCAGP
		CHRISTOPHER JOAQUIN	
	Research Associate (RA)	ENGR. RENAN PUNTO	UP-TCAGP
		DC ALDOVINO	
	RA	MA. VERLINA TONGA,	UP-TCAGP
		JONALYN GONZALES	
	Airborne Security	SSG. RAYMUND DOMINE	PILIPPINE AIR FORCE (PAF)
		SSG. LEE JAY PUNZALAN	
	Pilot	CAPT. JEFFREY JEREMY ALAJAR;	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. RANDY LAGCO	
		CAPT. BRYAN DONGUINES	AAC
		CAPT. JERICHO JECIEL	
Ground Survey, Data Download and Transfer	RA	LANCE CINCO	UP-TCAGP
		KENNETH QUISADO	UP-TCAGP

Annex 5. Data Transfer Sheet For Grande Floodplain

DATA TRANSFER SHEET
[illegible]

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS: Output LAS	RAW LAS: KML (swath)	LOGS (MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S): BASE STATION(S)	BASE STATION(S): Base Info (.txt)	OPERATOR LOGS (OPLOG)	FLIGHT PLAN: Actual	FLIGHT PLAN: KML	SERVER LOCATION
4/29/2014	1403P	1BLK44DE119A	PEGASUS	2.69GB	207/643	13.5	440	54.6	431	57.1	NA	7.14MB	1KB	1KB	22/73/32/55	NA	Z:\Airborne_Raw\1403P
5/1/2014	1411P	1BLK44D121A	PEGASUS	NA	484	15.9	221	31.6	284	28.6	NA	6.71MB	1KB	1KB	[illegible]	NA	Z:\Airborne_Raw\1411P
5/2/2014	1415P	1BLK44H122A	PEGASUS	3.27GB	212/93	14.1	288	40.3	249	22.9	NA	7.52MB	1KB	1KB	[illegible]	NA	Z:\Airborne_Raw\1415P
5/3/2014	1419P	1BLK45E123A	PEGASUS	2.73GB	[illegible]	13.4	279	NA	NA	25.7	NA	8.13	1KB	1KB	11.9	NA	Z:\Airborne_Raw\1419P
5/5/2014	1421P	1BLK44CH5125A	PEGASUS	3.11	[illegible]	15	254	51.5	5.21	29.2	NA	14.4	1KB	1KB	14/12/11/10	NA	Z:\Airborne_Raw\1421P
5/5/2014	1423P	1BLK45FGS126A	PEGASUS	3.04	[illegible]	12.5	271	58	485	27.0	NA	14.4	1KB	1KB	14/41/27/110	NA	Z:\Airborne_Raw\1423P
5/7/2014	1433P	1BLK45DS127A	PEGASUS	2.94	712	14	285	NA	NA	19.6	NA	7.16	1KB	1KB	114	NA	Z:\Airborne_Raw\1433P
5/10/2014	1447P	1BLK45FGS130A	PEGASUS	2.45	1062	14.4	284	NA	NA	32.3	NA	8.21	1KB	1KB	42	NA	Z:\Airborne_Raw\1447P
5/11/2014	1451P	1BLK45GS133A	PEGASUS	2.47	805	11.5	243	NA	NA	27.2	NA	11.4	1KB	1KB	60	NA	Z:\Airborne_Raw\1451P
5/11/2014	1453P	1BLK45DFGS133A	PEGASUS	1.8	591	7.24	173	31.5	171	16.6	NA	11.4	1KB	1KB	49.2	NA	Z:\Airborne_Raw\1453P
5/12/2014	1455P	1BLKS134A	PEGASUS	3.05	530	10.2	208	NA	NA	28.3	NA	3.9	1KB	1KB	[illegible]	NA	Z:\Airborne_Raw\1455P
5/13/2014	1459P	1BLKS136A	PEGASUS	3.23	577	14.8	247	NA	NA	31.4	NA	7.18	1KB	1KB	53	NA	Z:\Airborne_Raw\1459P
5/14/2014	1463P	1BLKS137A	PEGASUS	783MB	249	5.59	148	NA	NA	8.28	NA	5.42	1KB	1KB	119	NA	Z:\Airborne_Raw\1463P

Received from

Name C. [illegible]
Position [illegible]
Signature [signature]

Received by

Name JOIDA F. PRIETO
Position SSRS
Signature [signature] 5/26/2014

DATA TRANSFER SHEET

BACOLOD 5/18/2016

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS	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	
April 22,2016	8453AC	3BLK44AS113A	AQUA/CASI	NA	343	769	246	NA	NA	13.9	101	99.1	1KB	1KB	6	14	Z:\DAC\RAW DATA
April 23,2016	8455AC	3BLK44AS114A	AQUA/CASI	NA	247	663	233	38.5	43	10.2	85.3	91	1KB	1KB	20	30	Z:\DAC\RAW DATA
April 24,2016	8457AC	3BLK44EDS115A	AQUA/CASI	NA	197	544	222	39.6	221	8.64	66.9	94	1KB	1KB	40	22	Z:\DAC\RAW DATA
April 25,2016	8459AC	3BLK44IJS116A	AQUA/CASI	NA	240	603	262	43.4	248	10.3	66.5	100	1KB	1KB	18	38	Z:\DAC\RAW DATA
April 26,2016	8462AC	3BLK46AS117B	AQUA/CASI	NA	194	502	229	37.4	187	8.59	67.4	107	1KB	1KB	8	20	Z:\DAC\RAW DATA
April 27,2016	8464AC	3BLK46AS118B	AQUA/CASI	NA	81	209	143	9.78	3.23	4	23.9	158	1KB	1KB	8	20	Z:\DAC\RAW DATA
May 1,2016	8471AC	3BLK44FGHS122A	AQUA/CASI	NA	191	541	241	45.3	263	8.33	139	90.5	1KB	1KB	10	22	Z:\DAC\RAW DATA
May 2,2016	8473AC	3BLK46AS123A	AQUA/CASI	NA	88	320	206	5.45	3.7	4.59	55.3	64.6	1KB	NA	16	22	Z:\DAC\RAW DATA

Received from

Name R. PUNTO

Position RA

Signature [signature]

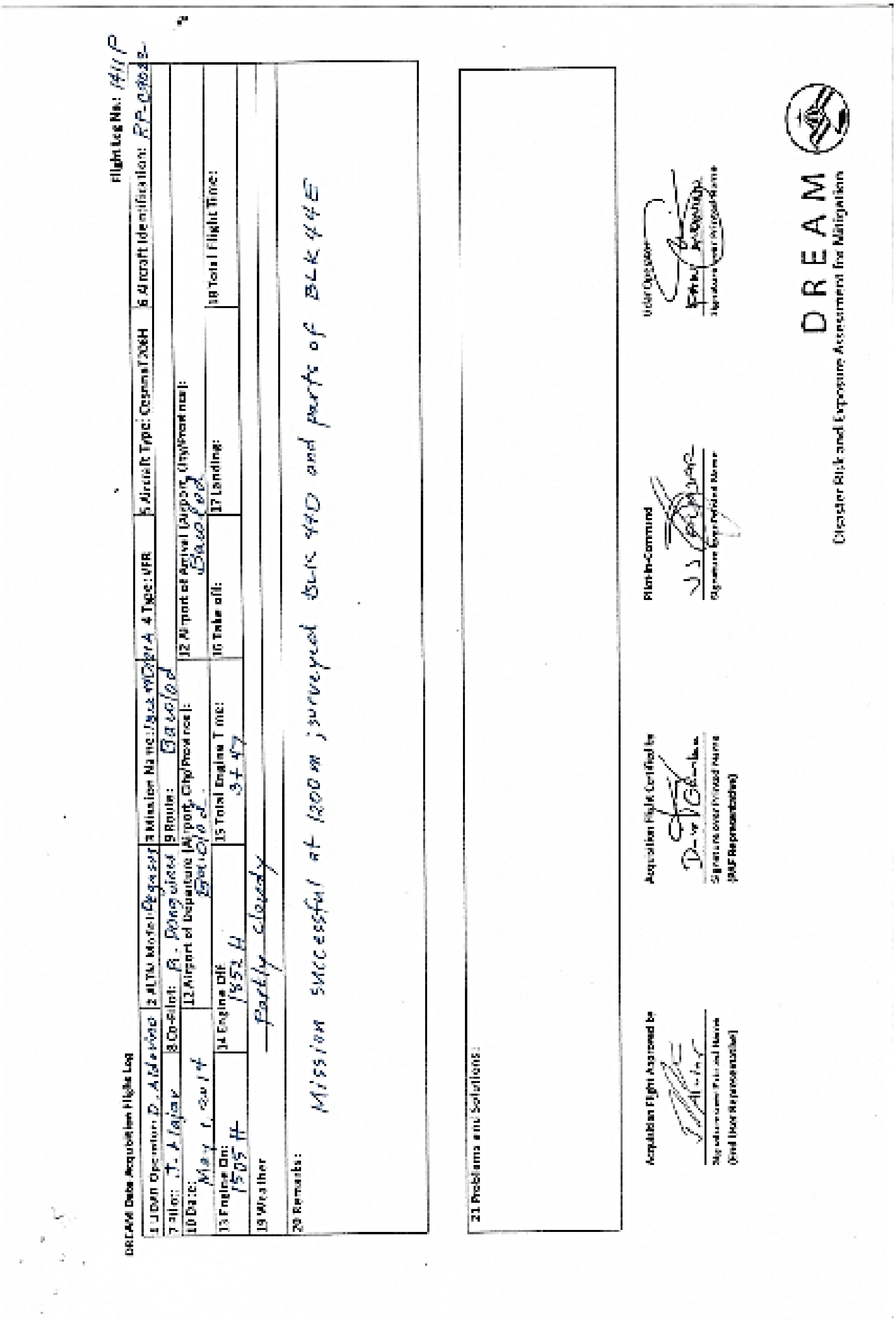
Received by

Name AC Bongat

Position SSRS

Signature [signature] 5/20/16

Annex 6. Flight Logs
Flight Log for 1441P Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 1441P

1 LiDAR Operator: D. Alderino	2 ALTM Model: Pegasus	3 Mission Name: Iysa 44D	4 Type: VFR	5 Aircraft Type: Cessna T206H	6 Aircraft Identification: RP-C9022
7 Pilot: J. Alajar	8 Co-Pilot: R. Dongwines	9 Route: Bacolod			
10 Date: May 1, 2014	12 Airport of Departure (Airport, City/Province): Bacolod		12 Airport of Arrival (Airport, City/Province): Bacolod		
13 Engine On: 1505 H	14 Engine Off: 1852 H	15 Total Engine Time: 3+47	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: Partly cloudy					

20 Remarks:

Mission successful at 1200m ; surveyed BLK 44D and parts of BLK 44E

21 Problems and Solutions:

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

DREAM — Disaster Risk and Exposure Assessment for Mitigation

Flight Log for 1415P Mission

DREAM Data Acquisition Flight Log

Flight Log No.: 1415P

1 LiDAR Operator: R. Punto	2 ALTM Model: Pegasus	3 Mission Name: 1BLK44H124A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RP-C9022
7 Pilot: J. Alajar	8 Co-Pilot: B. Donguines	9 Route: Bacolod			
10 Date: May 2, 2014	12 Airport of Departure (Airport, City/Province): Bacolod		12 Airport of Arrival (Airport, City/Province): Bacolod		
13 Engine On: 1446H	14 Engine Off: 1909H	15 Total Engine Time: 4+23	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather	Partly cloudy				

20 Remarks:

Mission successful at 1200m; surveyed BLK44H; gap in the middle

21 Problems and Solutions:

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

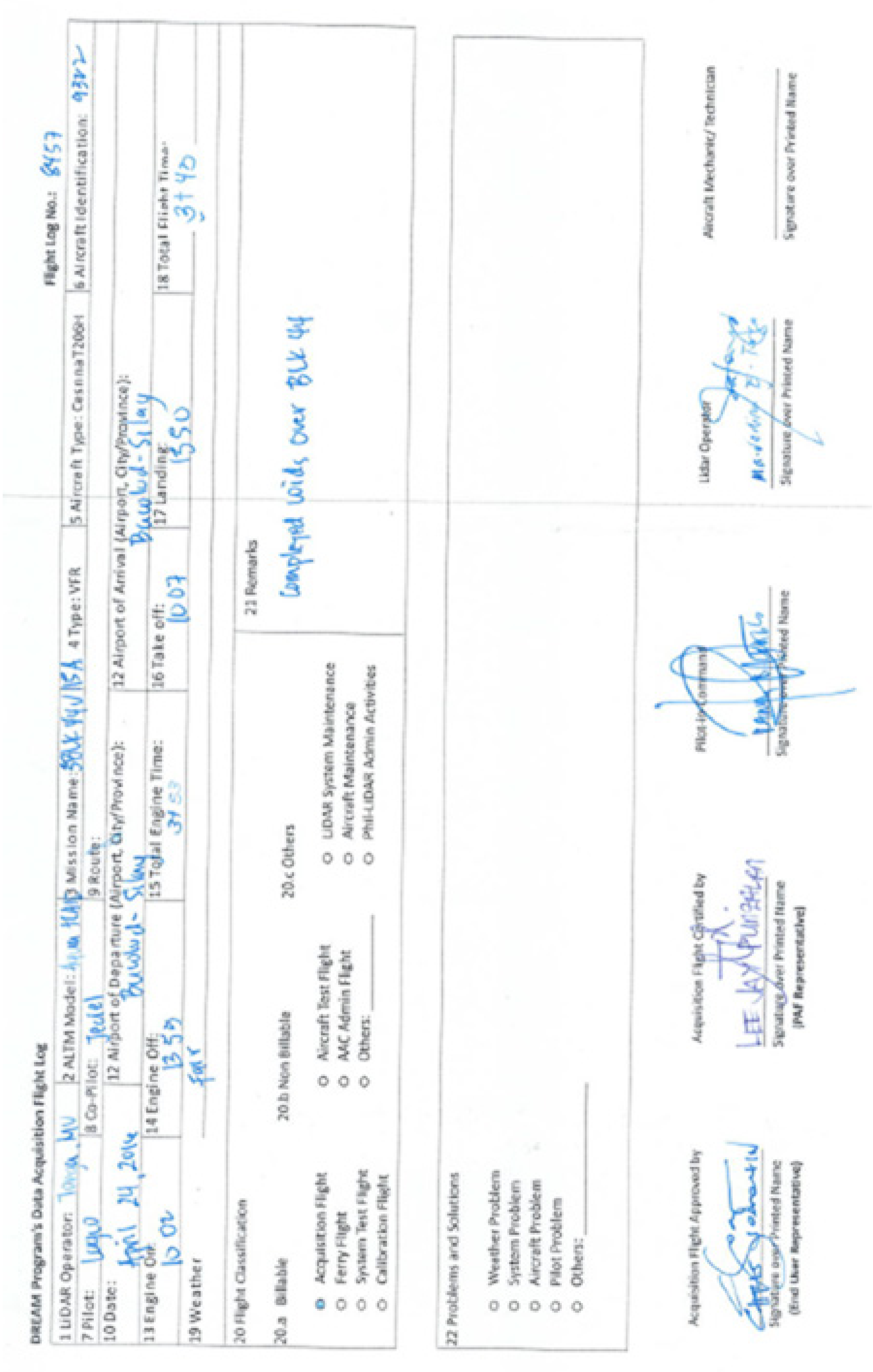
Acquisition Flight Certified by — Dave Gamban — Signature over Printed Name (PAF Representative)

Pilot-in-Command — Signature over Printed Name

Lidar Operator — Signature over Printed Name

DREAM
Disaster Risk and Exposure Assessment for Mitigation

Flight Log for 8457AC Mission


DREAM Program's Data Acquisition Flight Log

Flight Log No.: 8457

1 LiDAR Operator: Tonga, MV	2 ALTM Model: Aquarius	3 Mission Name: 3BLK44V153A	4 Type: VFR	5 Aircraft Type: Cessna T206H	6 Aircraft Identification: 9322
7 Pilot: Lugo	8 Co-Pilot: Jadel	9 Route:			
10 Date: April 24, 2014	12 Airport of Departure (Airport, City/Province): Bacolod-Silay		12 Airport of Arrival (Airport, City/Province): Bacolod-Silay		
13 Engine On: 10 02	14 Engine Off: 13 55	15 Total Engine Time: 3+53	16 Take off: 10 07	17 Landing: 13 50	18 Total Flight Time: 3+43
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 voids over BLK 44

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 — Lee Jay Punzalan — Signature over Printed Name (PAF Representative)

Pilot-in-Command — Signature over Printed Name

Lidar Operator — Signature over Printed Name

Aircraft Mechanic/ Technician — Signature over Printed Name

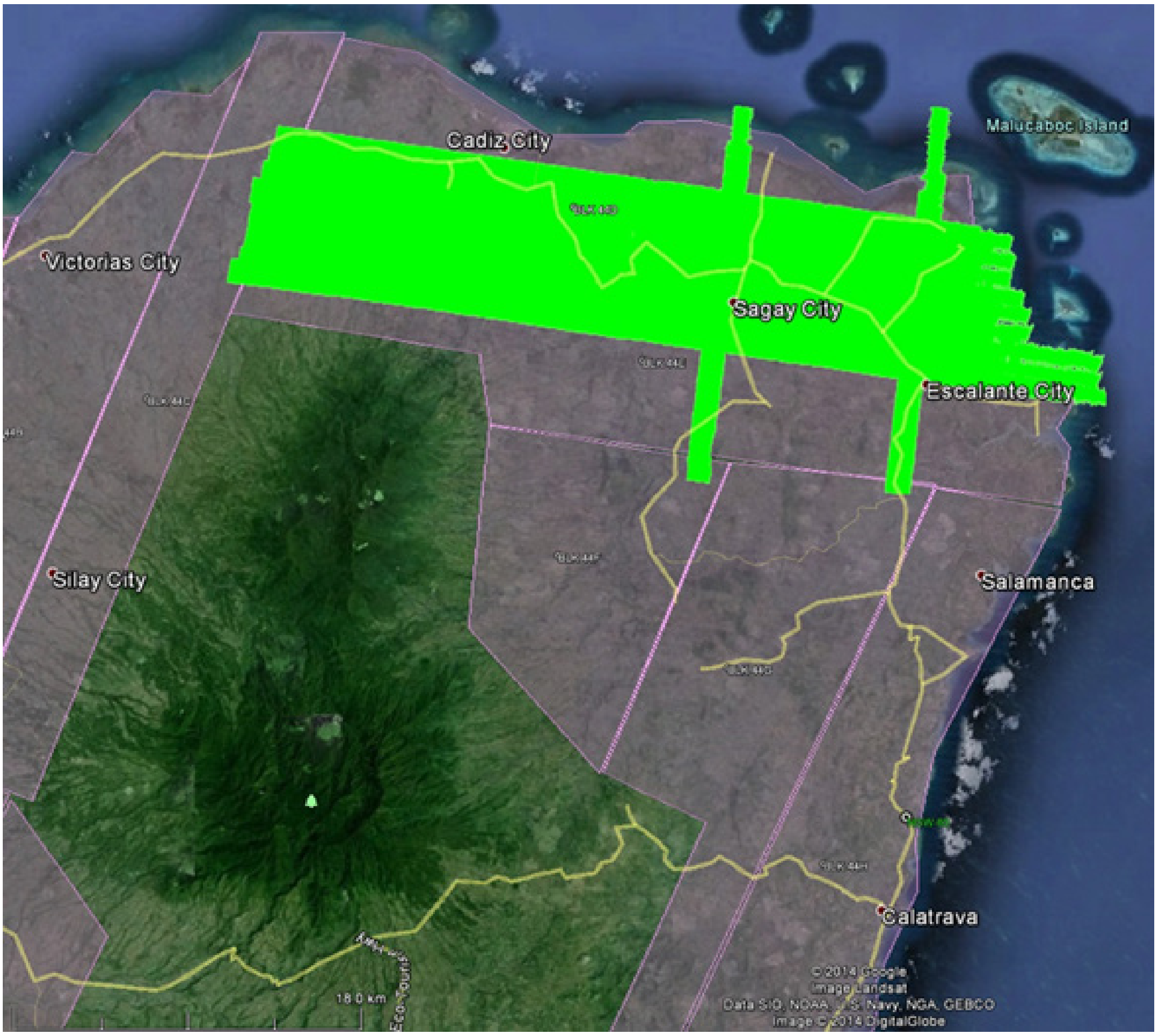
Annex 7. Flight Status

FLIGHT STATUS REPORT
GRANDE
April to May 2014 and 2016

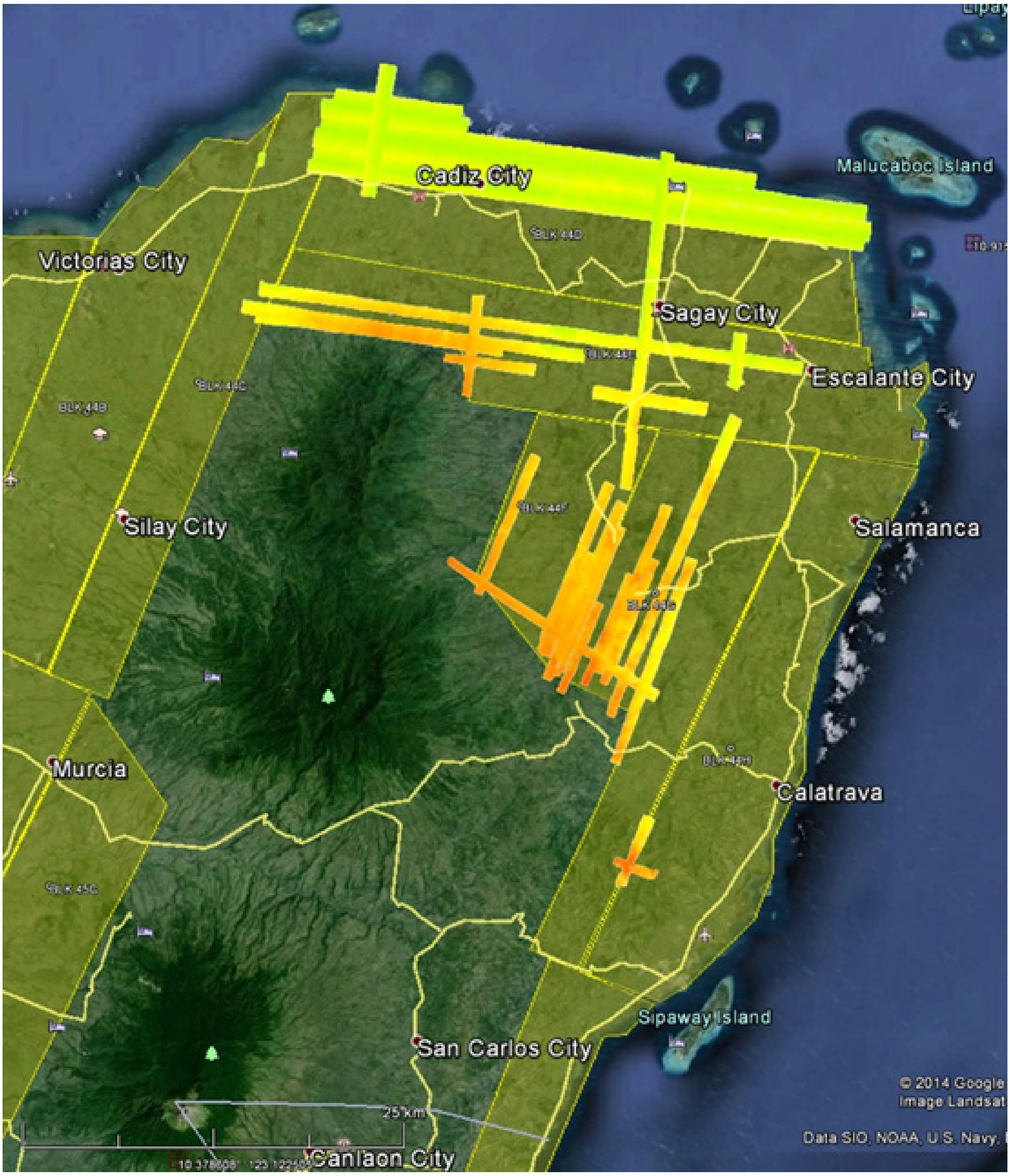
FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
1411P	BLK 44DE	1BLK44D121A	D. Aldovino	May 1, 2014	Mission successful at 1200m; surveyed BLK 44D and parts of BLK 44E
1415P	BLK 44H	1BLK44H122A	R. Punto	May 2, 2014	Mission successful at 1200m; 2-3 lines gap in the middle
8457AC	BLK44ES, BLK44DS	3BLK44EDs115A	V. TONGA	Apr 24, 2016	Surveyed BLKES AND BLK44DS

LAS/SWATH BOUNDARIES PER MISSION FLIGHT

FLIGHT NO.: 1411P
AREA: BLK 44DE
MISSION NAME: 1BLK44D121A
AREA SURVEYED: 356.01 SQ.KM.



FLIGHT NO.: 1435P
AREA: BLK 44D, 44E, 44F, 44G
MISSION NAME: 1BLK44DS127A
AREA SURVEYED: 139.55 SQ.KM NEW AREA; 131.307 GAP FILLING



FLIGHT NO.: 8457AC
AREA: BLK44ES, BLK44DS
MISSION NAME: 3BLK44EDS115A
AREA SURVEYED: 52 SQ KM

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Blk44D

Flight Area	Negros
Mission Name	Blk44D
Inclusive Flights	1411P, 1435P
Range data size	75.2 GB
POS	728 MB
Base data size	13.88
Image	31.5 GB
Transfer date	May 26, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.04
RMSE for East Position (<4.0 cm)	1.26
RMSE for Down Position (<8.0 cm)	2.51
Boresight correction stdev (<0.001deg)	0.000446
IMU attitude correction stdev (<0.001deg)	0.005774
GPS position stdev (<0.01m)	0.0134
Minimum % overlap (>25)	27.44%
Ave point cloud density per sq.m. (>2.0)	3.51
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	552
Maximum Height	395.70 m
Minimum Height	50.84 m
Classification (# of points)	
Ground	387,844,370
Low vegetation	324,638,606
Medium vegetation	458,253,579
High vegetation	120,361,293
Building	9,453,151
Orthophoto	Yes
Processed by	Engr. Jommer Medina, Engr. Carlyn Ann Ibañez, Engr. Melanie Hingpit, Engr. Gladys Mae Apat

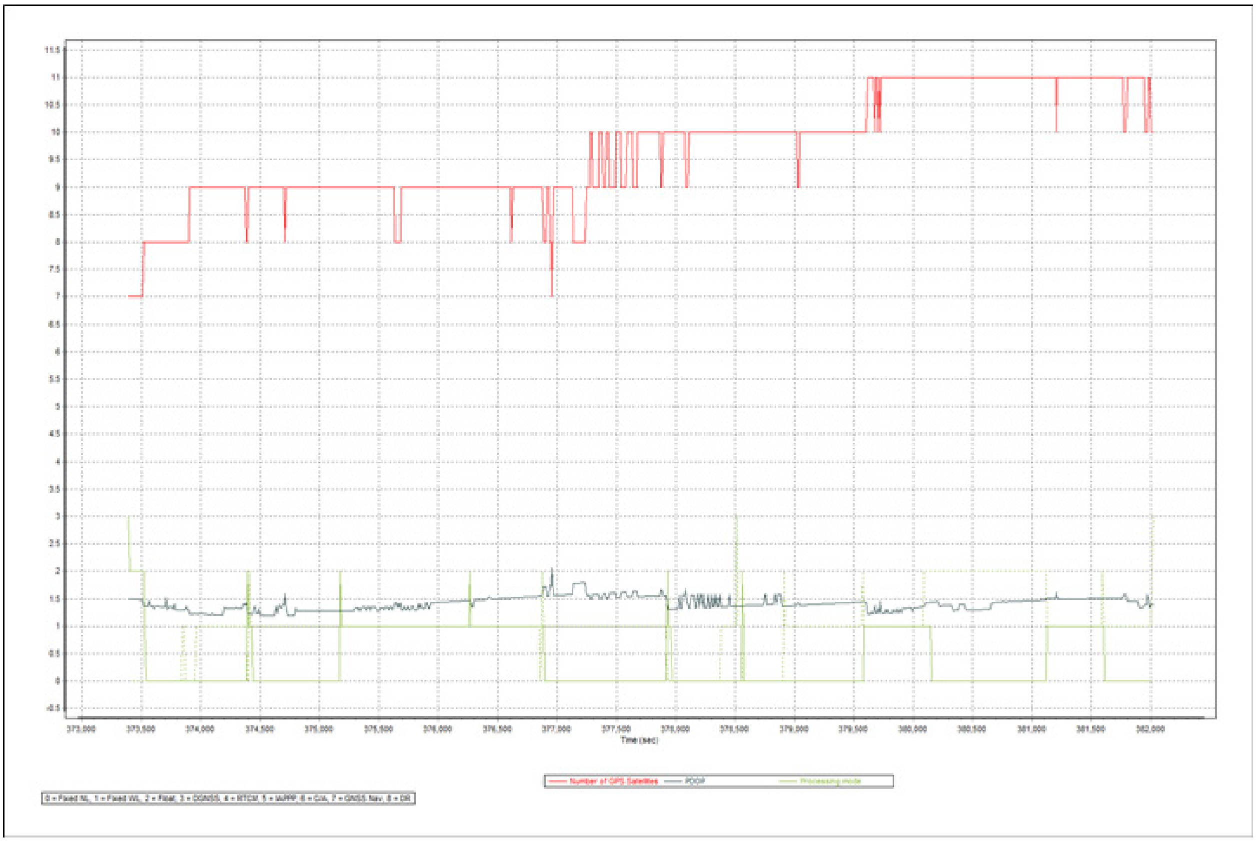


Figure A-8.1. Solution Status

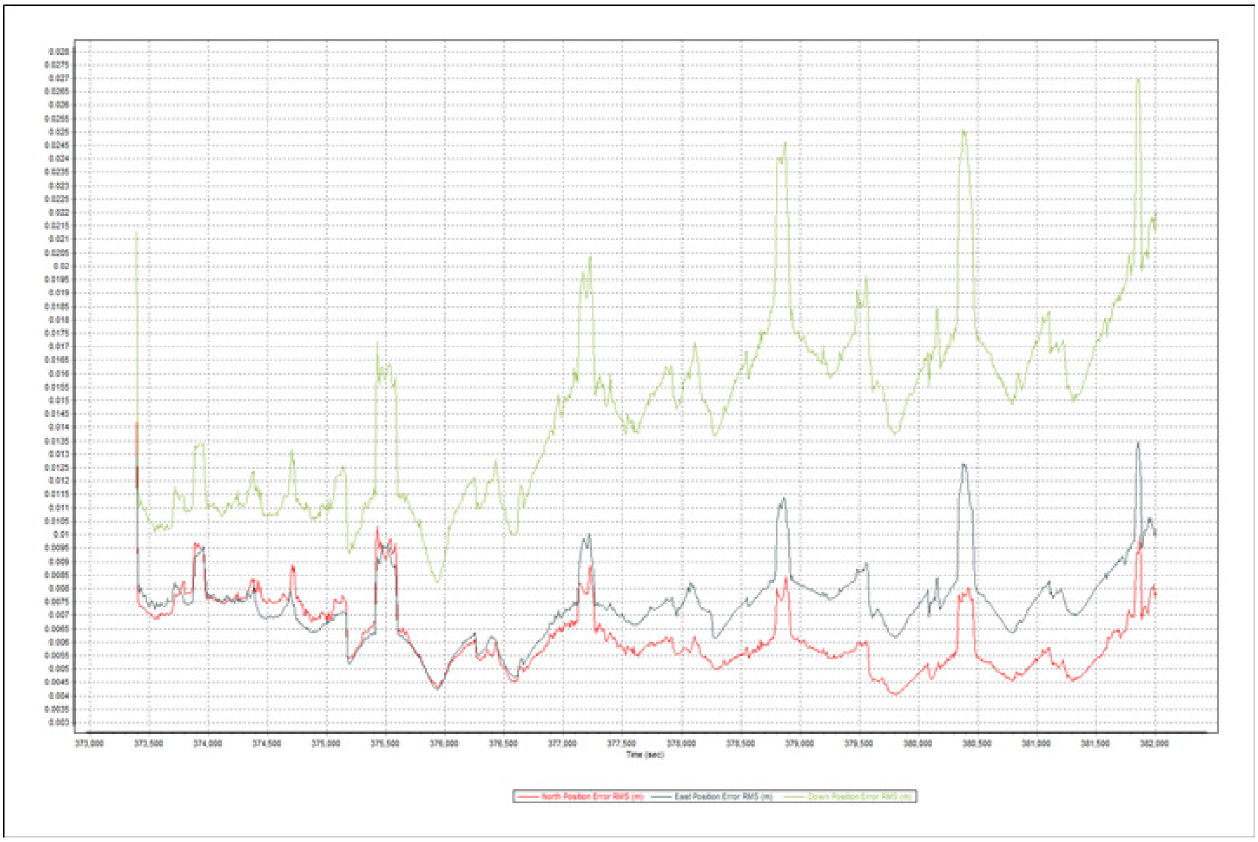


Figure A-8.2. Smoothed Performance Metric Parameters

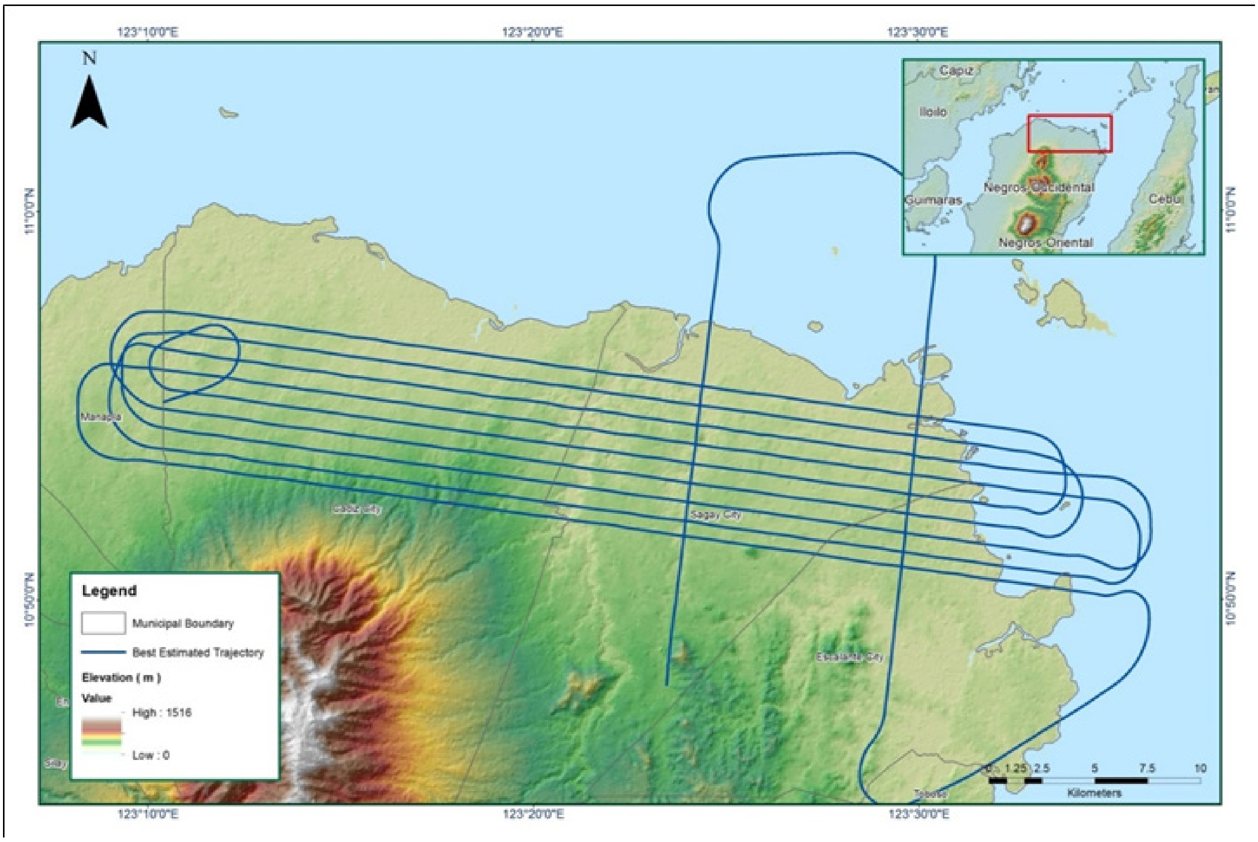


Figure A-8.3. Best Estimated Trajectory

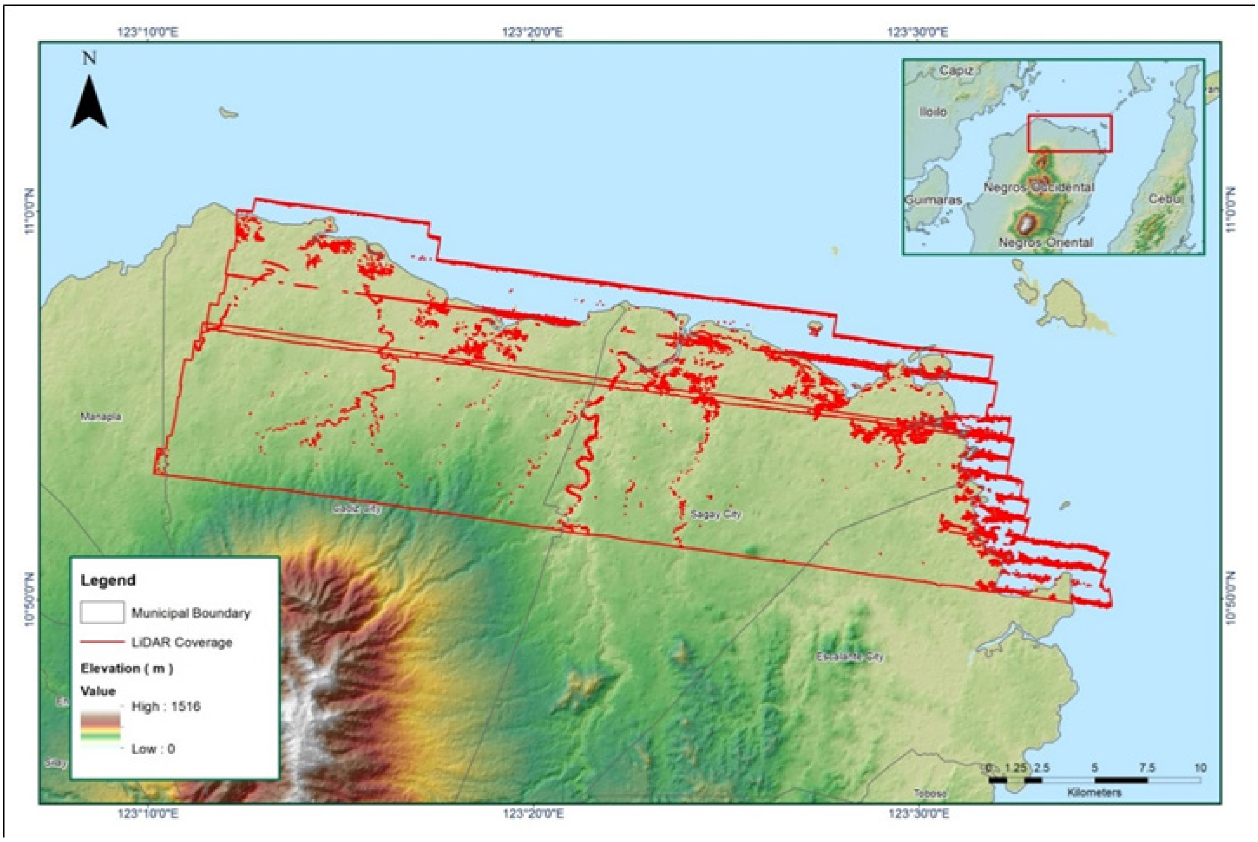


Figure A-8.4. Coverage of LiDAR data

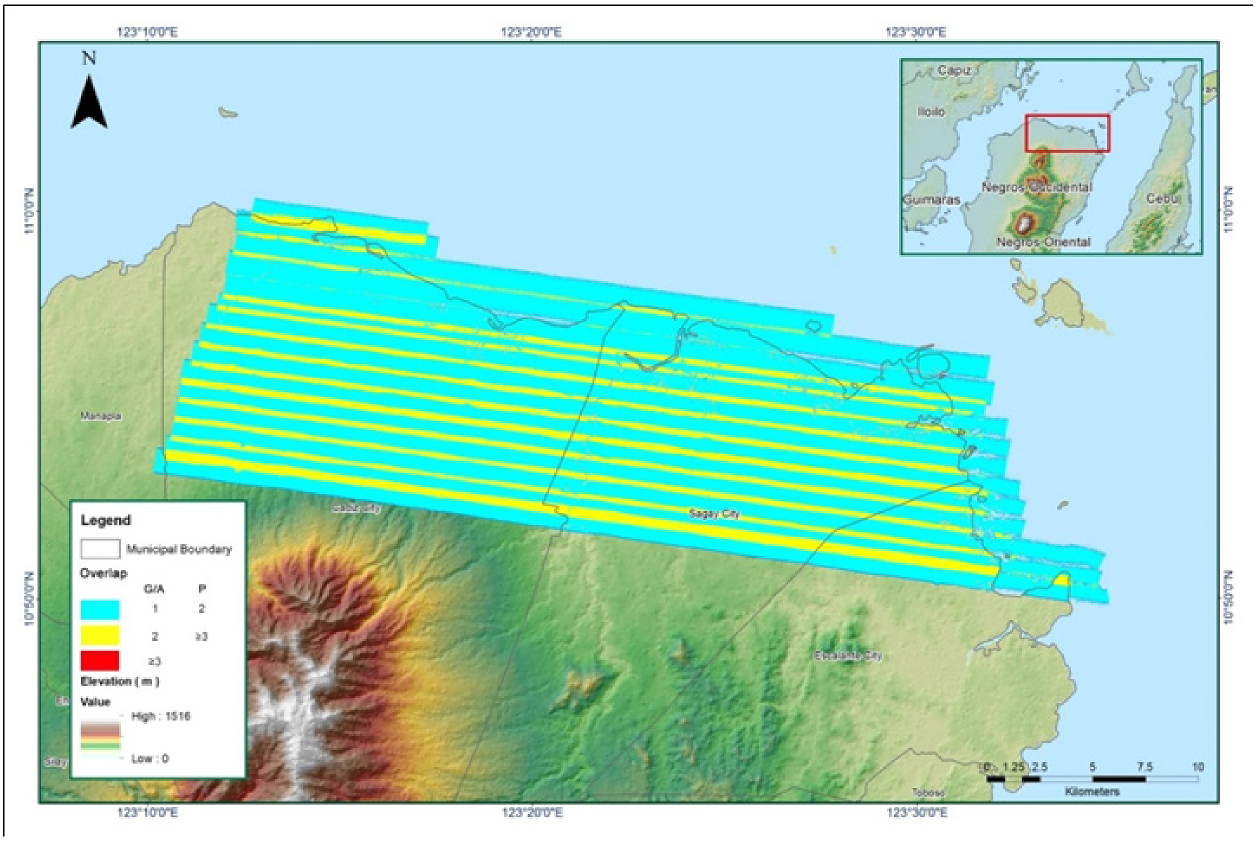


Figure A-8.5. Image of data overlap

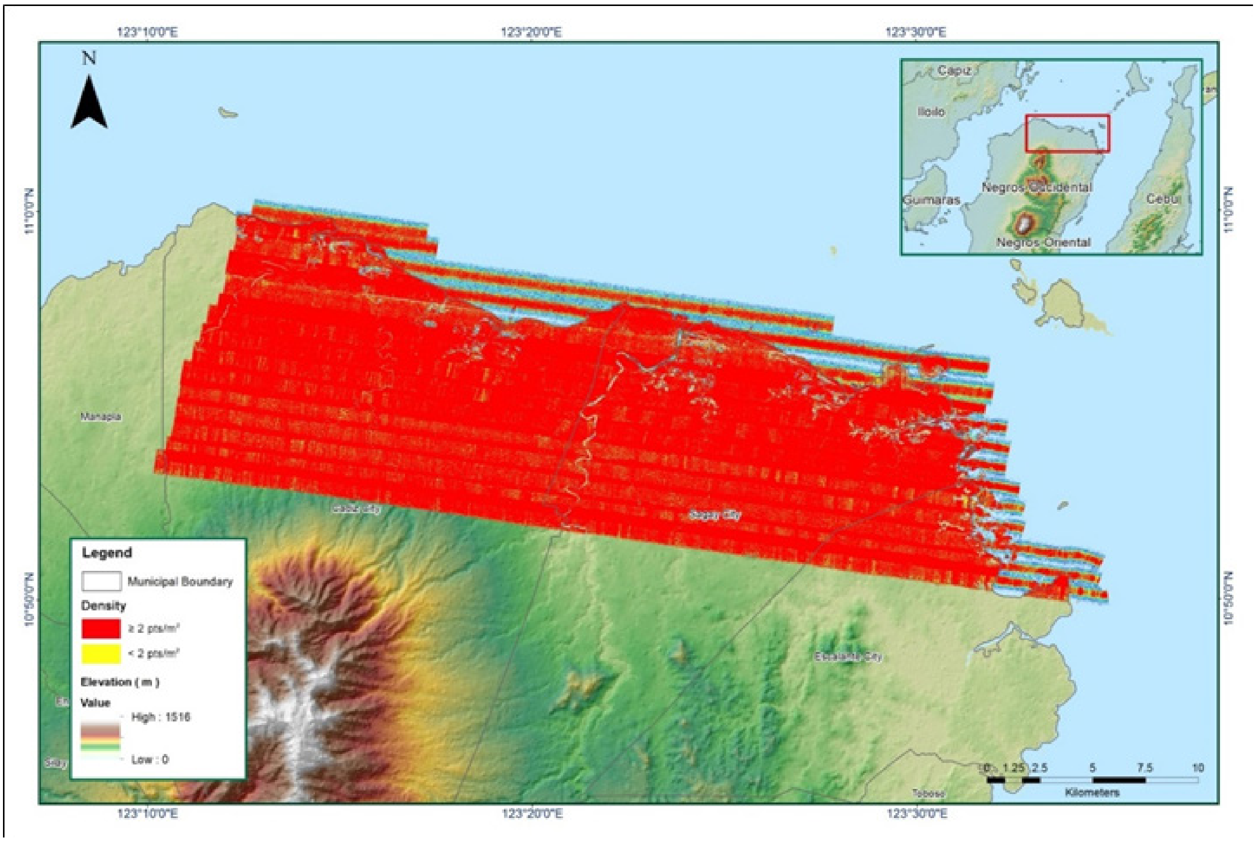


Figure A-8.6. Density map of merged LiDAR data

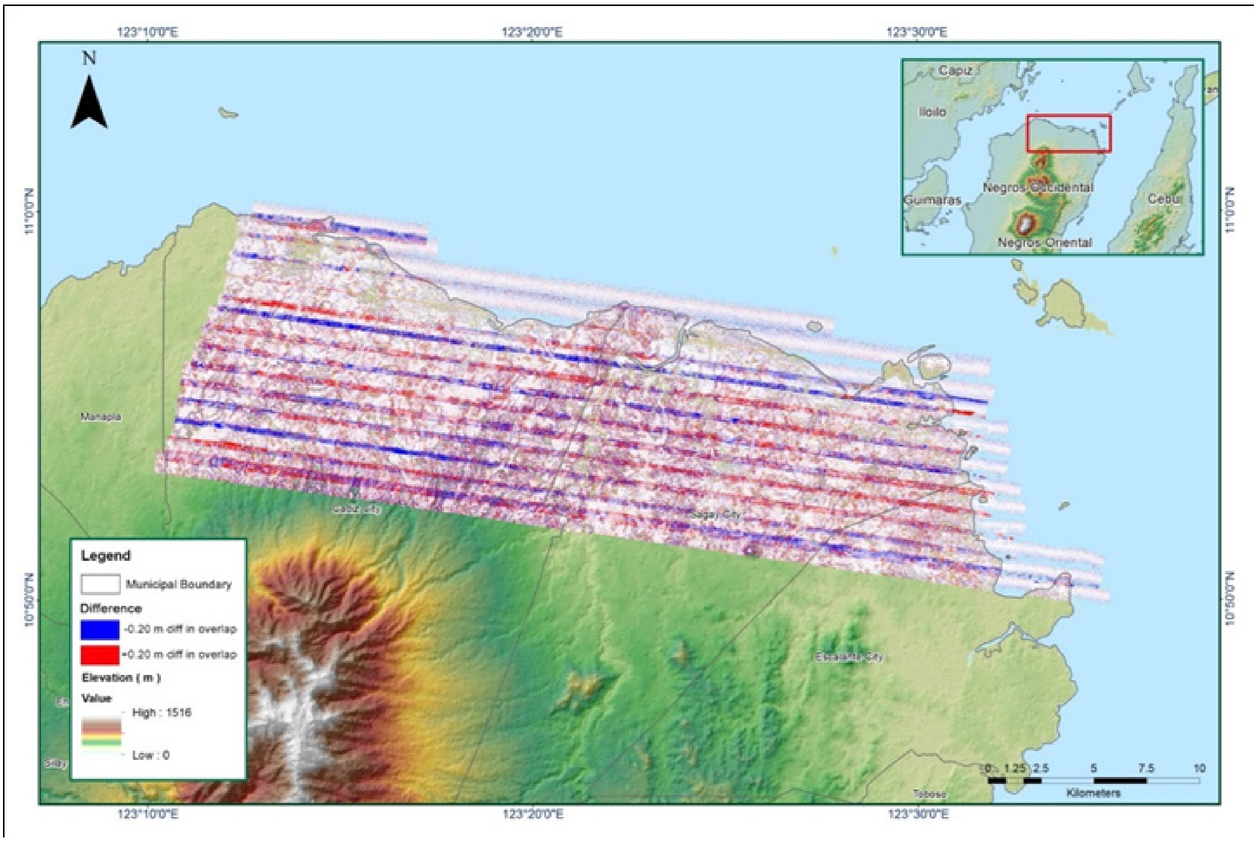


Figure A-8.7. Elevation difference between flight lines

Table A-8.2. Mission Summary Report for Mission Block 44C

Flight Area	Bacolod
Mission Name	Block 44C
Inclusive Flights	8457AC
Range data size	8.64 GB
POS data size	222 MB
Base data size	94
Image	39.6
Transfer date	May 20, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	No
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.2
RMSE for East Position (<4.0 cm)	1.204
RMSE for Down Position (<8.0 cm)	5.78
Boresight correction stdev (<0.001deg)	0.000378
IMU attitude correction stdev (<0.001deg)	0.000822
GPS position stdev (<0.01m)	0.0021
Minimum % overlap (>25)	20.54
Ave point cloud density per sq.m. (>2.0)	3.88
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	18
Maximum Height	259.65
Minimum Height	109.24
Classification (# of points)	
Ground	9,549,947
Low vegetation	9,452,615
Medium vegetation	10,376,030
High vegetation	4,489,278
Building	168,409
Orthophoto	None
Processed by	Engr. Irish Cortez, Aljon Rie Araneta, Engr. Elainne Lopez

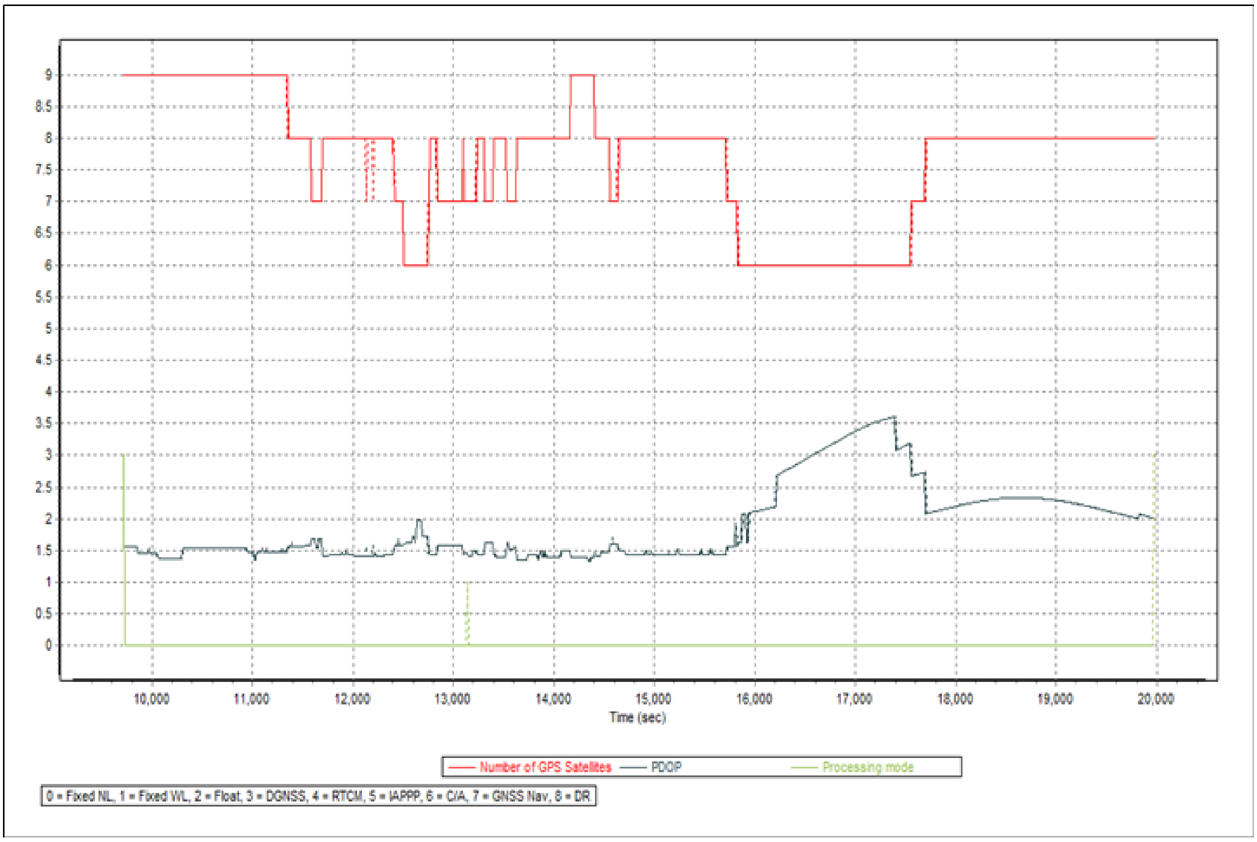


Figure A-8.8. Solution Status

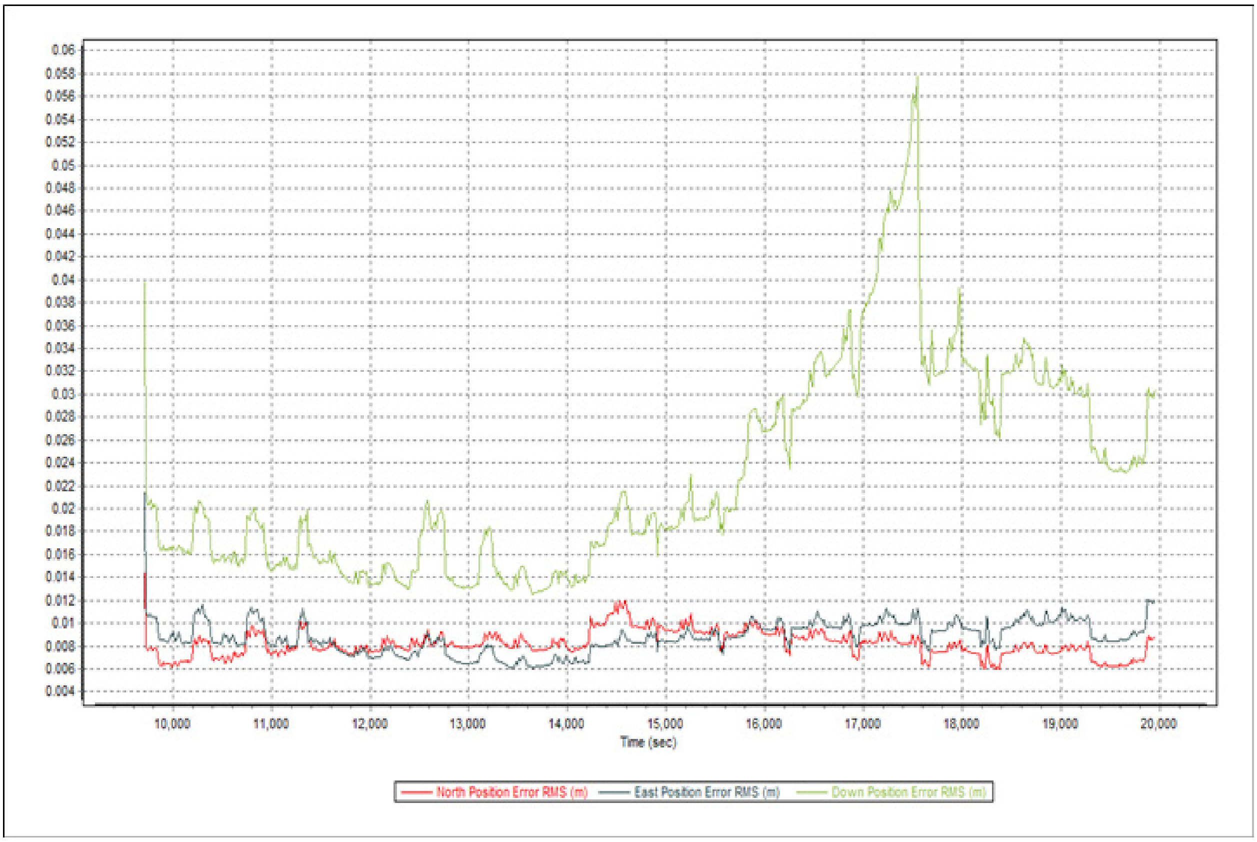


Figure A-8.9. Smoothed Performance Metric Parameters

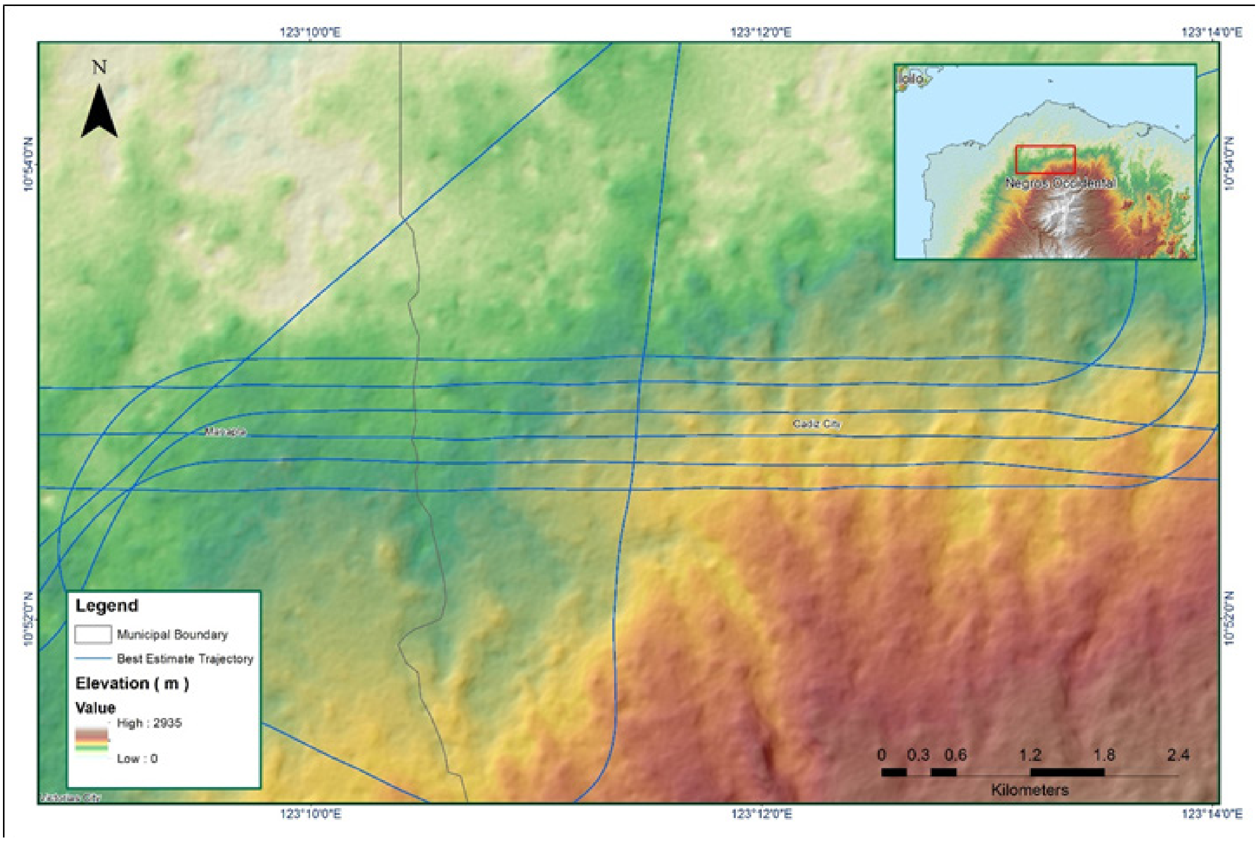


Figure A-8.10. Best Estimated Trajectory

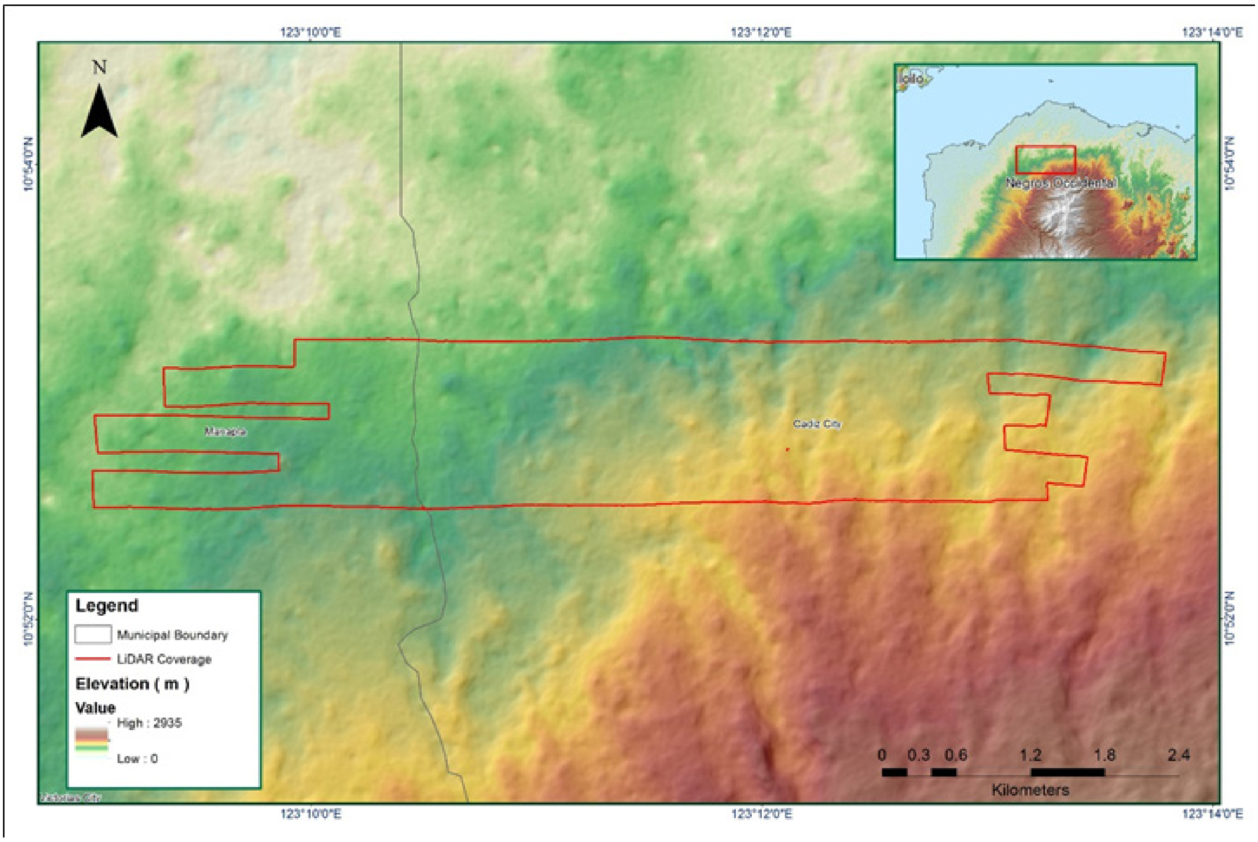


Figure A-8.11. Coverage of LiDAR data

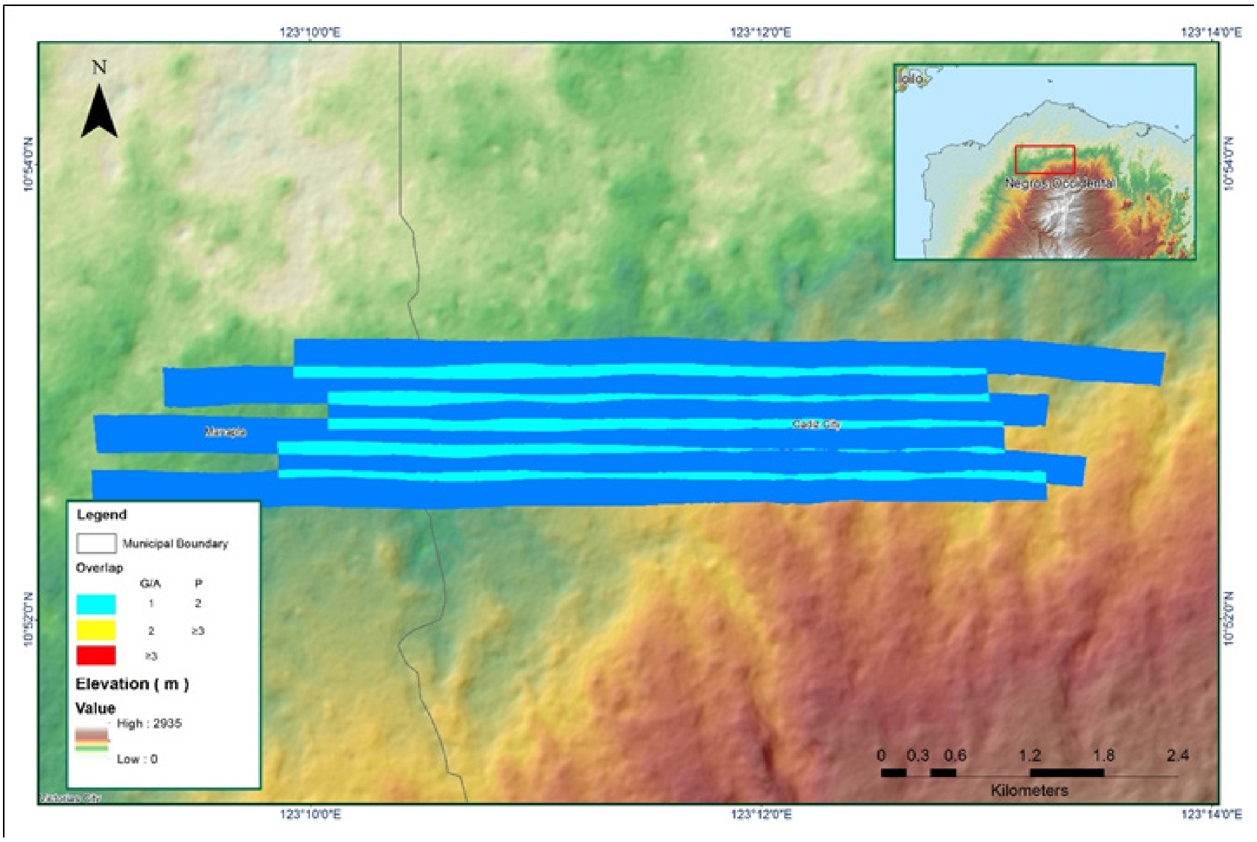


Figure A-8.12. Image of data overlap

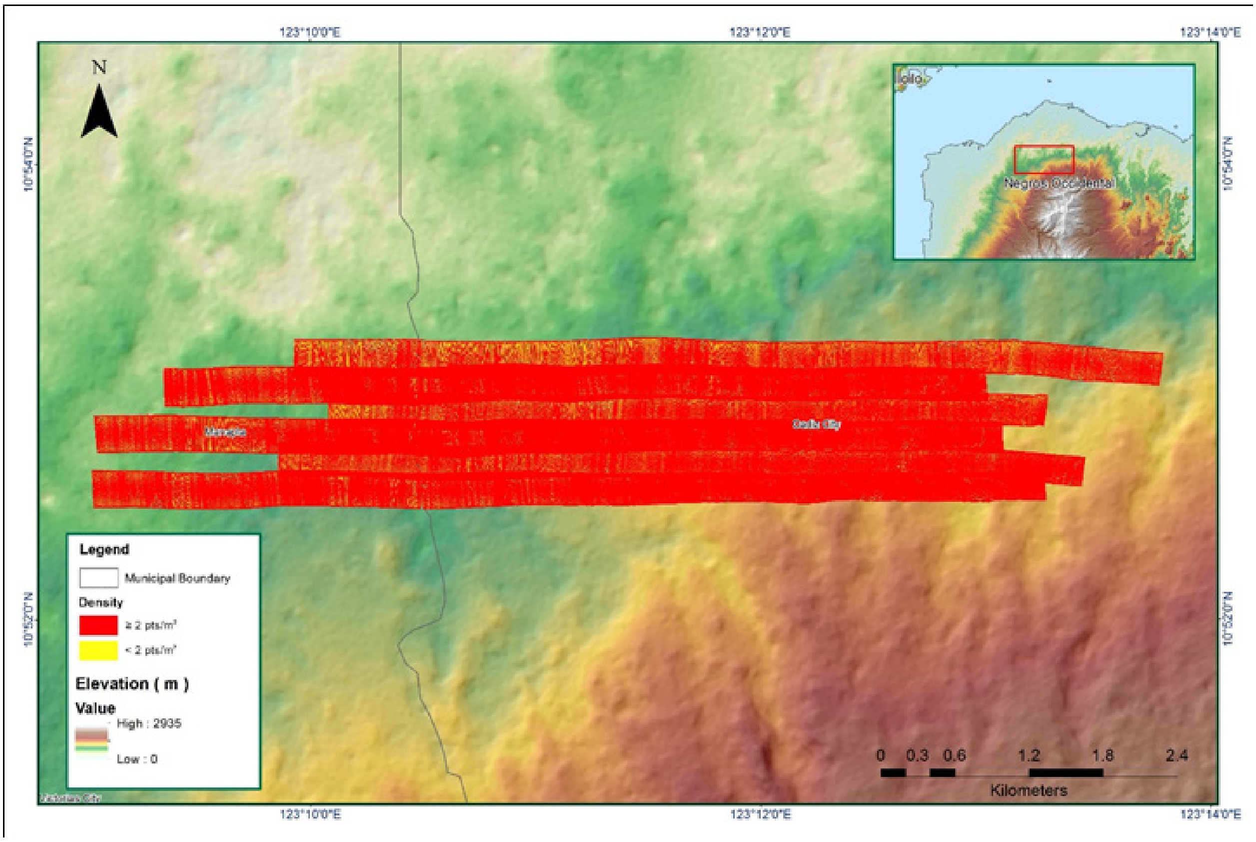


Figure A-8.13. Density map of merged LiDAR data

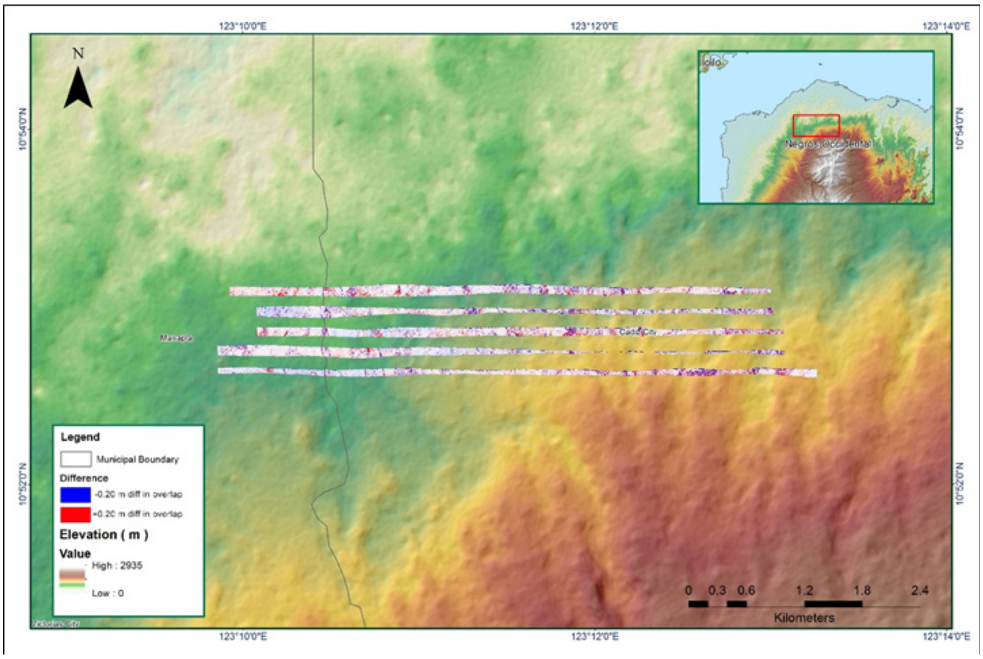


Figure A-8.14. Elevation difference between flight lines

Table A-8.3. Mission Summary Report for Mission Blk44D

Flight Area	Bacolod
Mission Name	Block 44D
Inclusive Flights	8457AC
Range data size	8.64 GB
POS data size	222 MB
Base data size	94
Image	39.6
Transfer date	May 20, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	No
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.2
RMSE for East Position (<4.0 cm)	1.204
RMSE for Down Position (<8.0 cm)	5.78
Boresight correction stdev (<0.001deg)	0.000478
IMU attitude correction stdev (<0.001deg)	0.000940
GPS position stdev (<0.01m)	0.0025
Minimum % overlap (>25)	30.10
Ave point cloud density per sq.m. (>2.0)	3.33
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	48
Maximum Height	106.51
Minimum Height	57.85
Classification (# of points)	
Ground	11,374,042
Low vegetation	10,746,942
Medium vegetation	12,511,682
High vegetation	8,971,525
Building	2,031,597
Orthophoto	None
Processed by	Engr. Irish Cortez, Engr. Melanie Hingpit, Engr. Monalyne Rabino

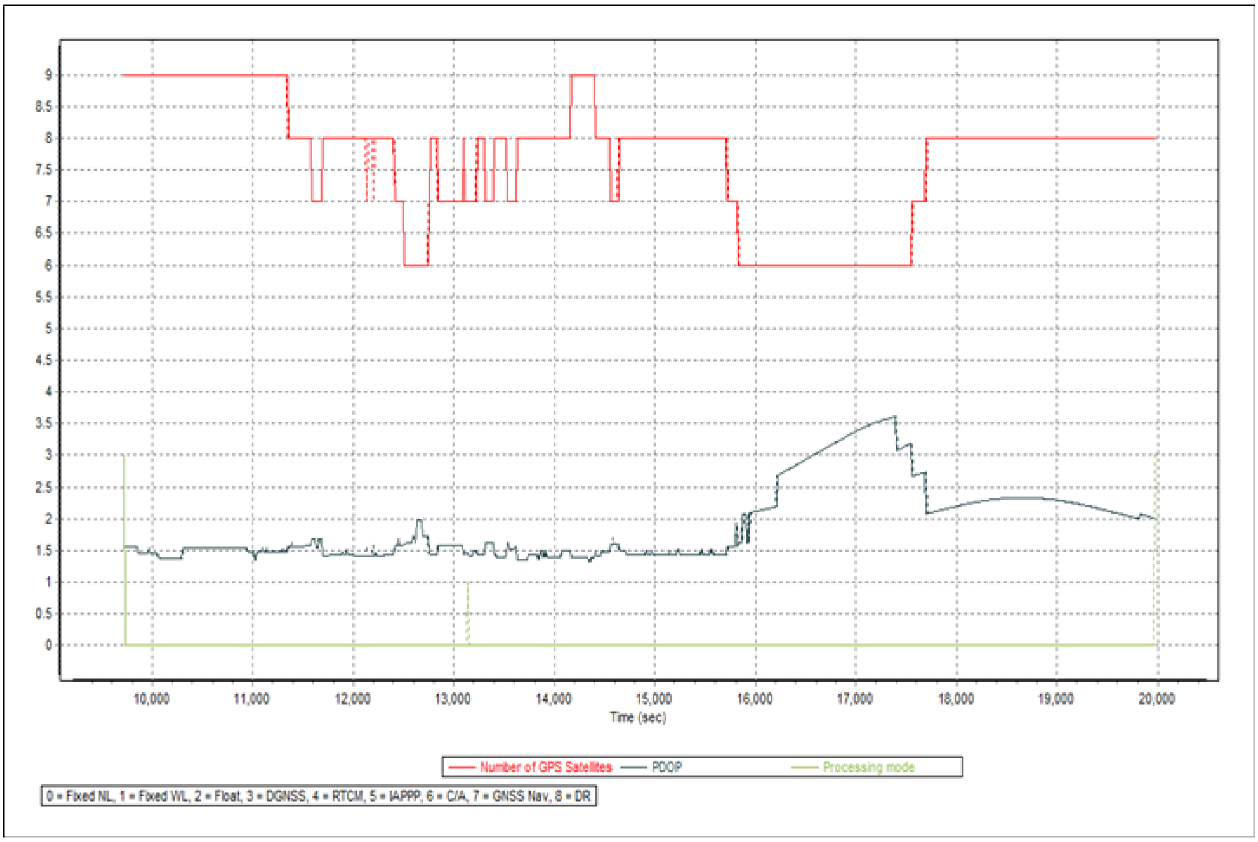


Figure A-8.15. Solution Status

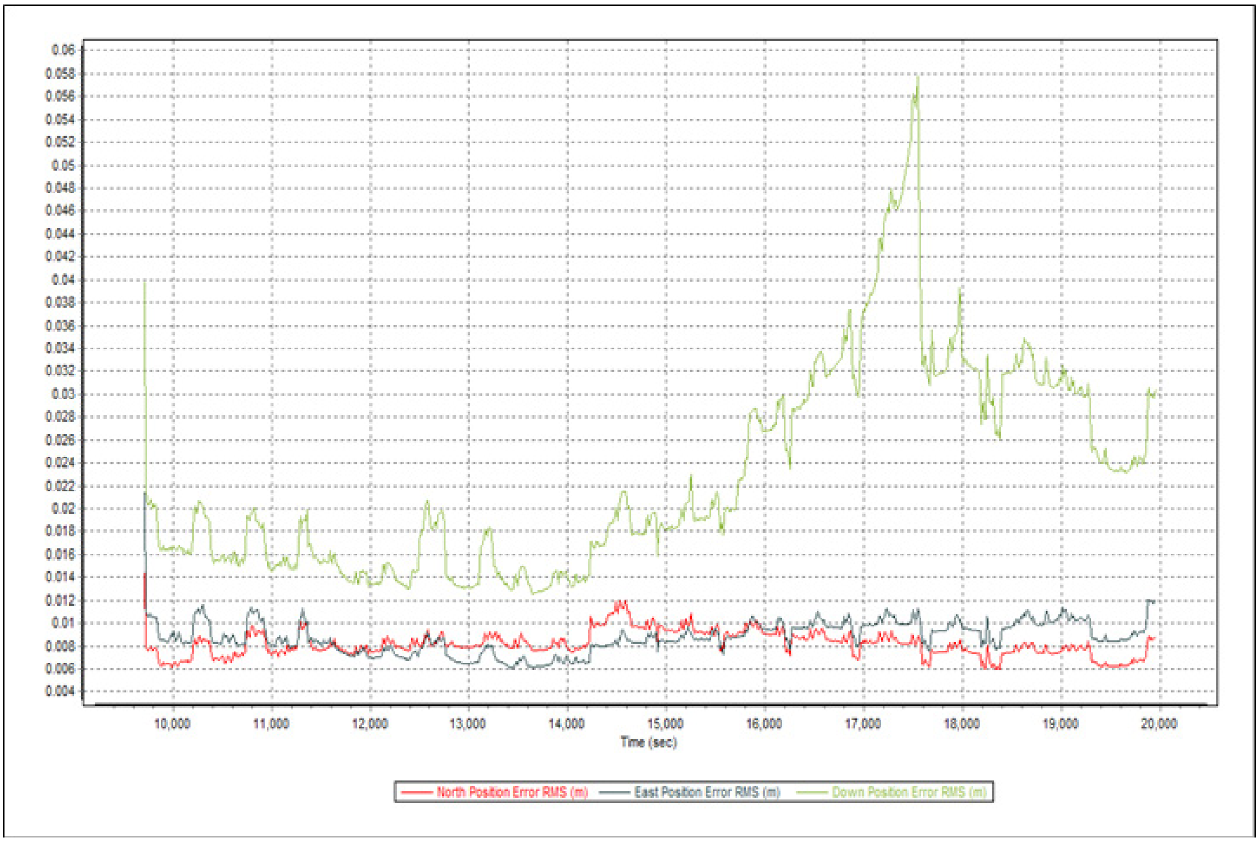


Figure A-8.16. Smoothed Performance Metric Parameters

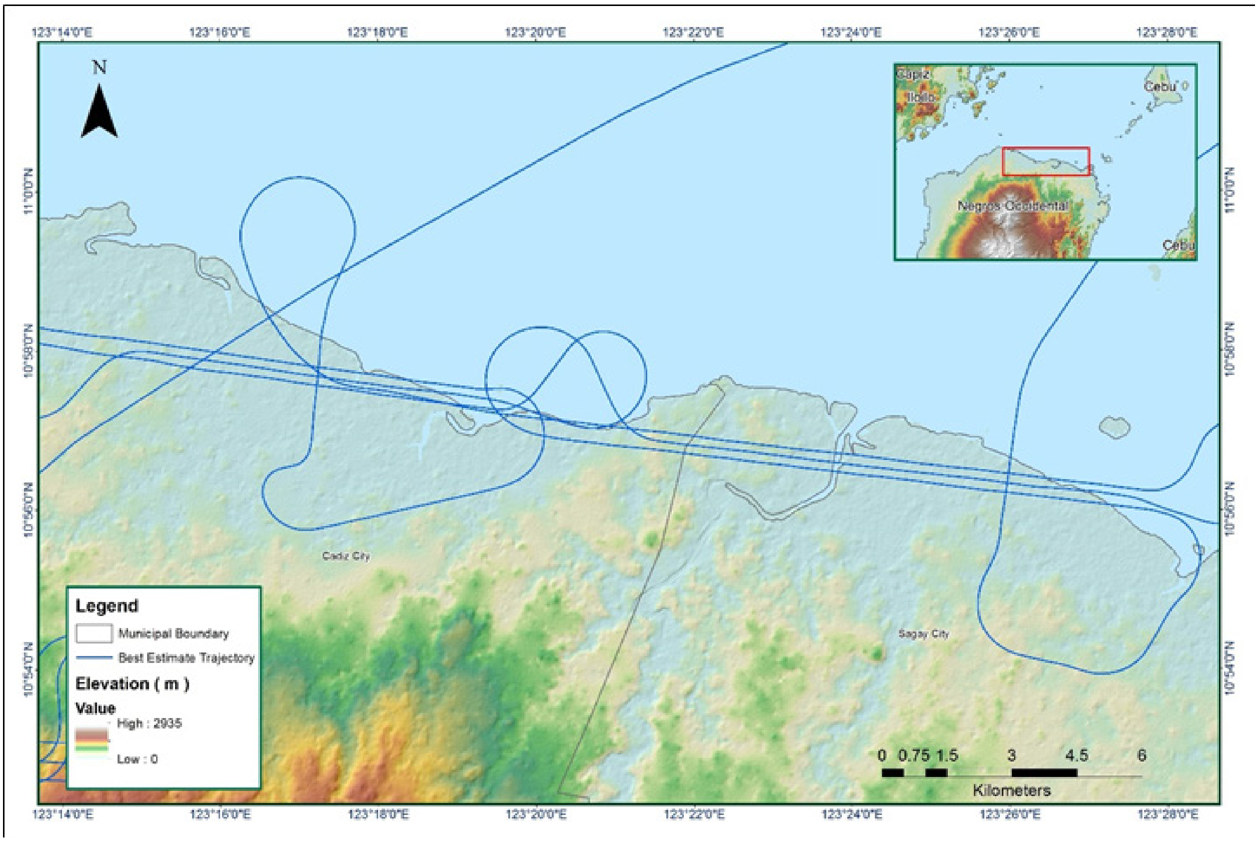


Figure A-8.17. Best Estimated Trajectory

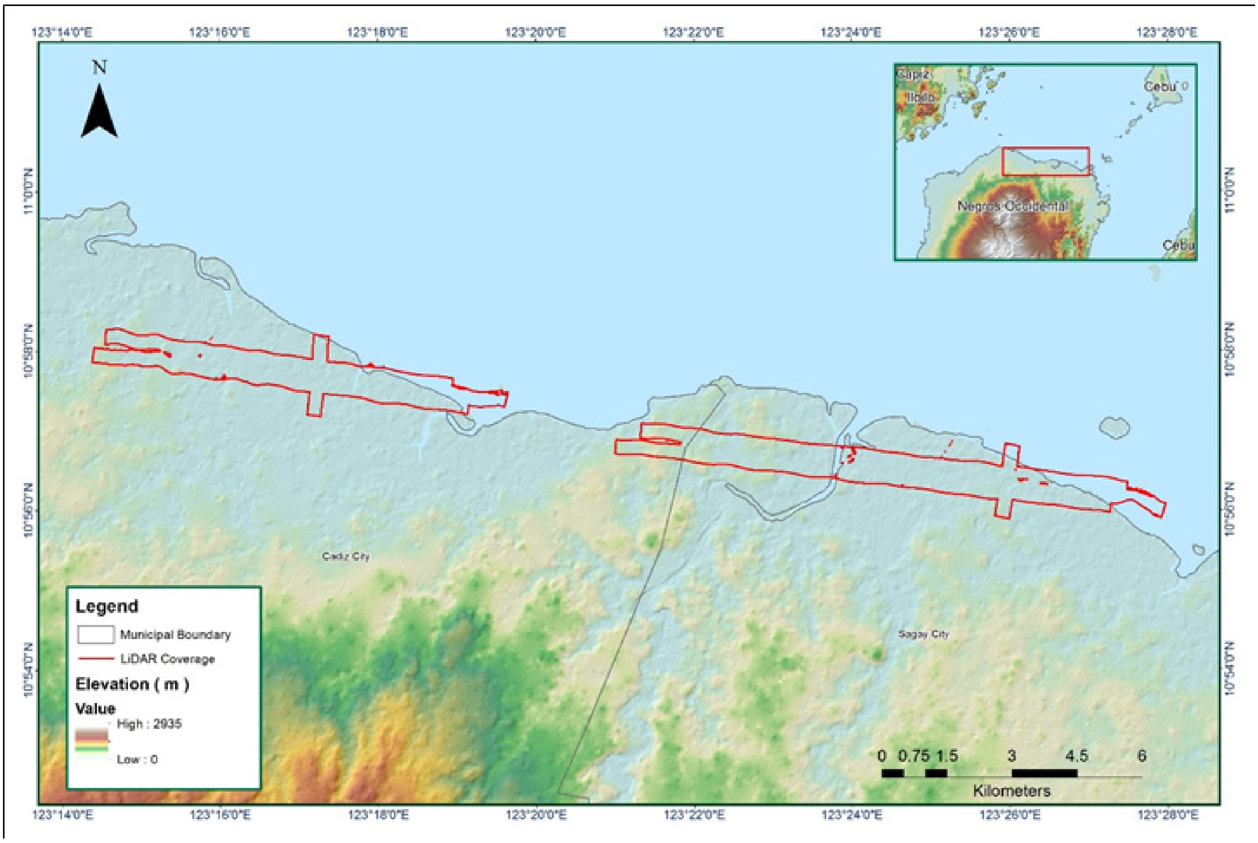


Figure A-8.18. Coverage of LiDAR data

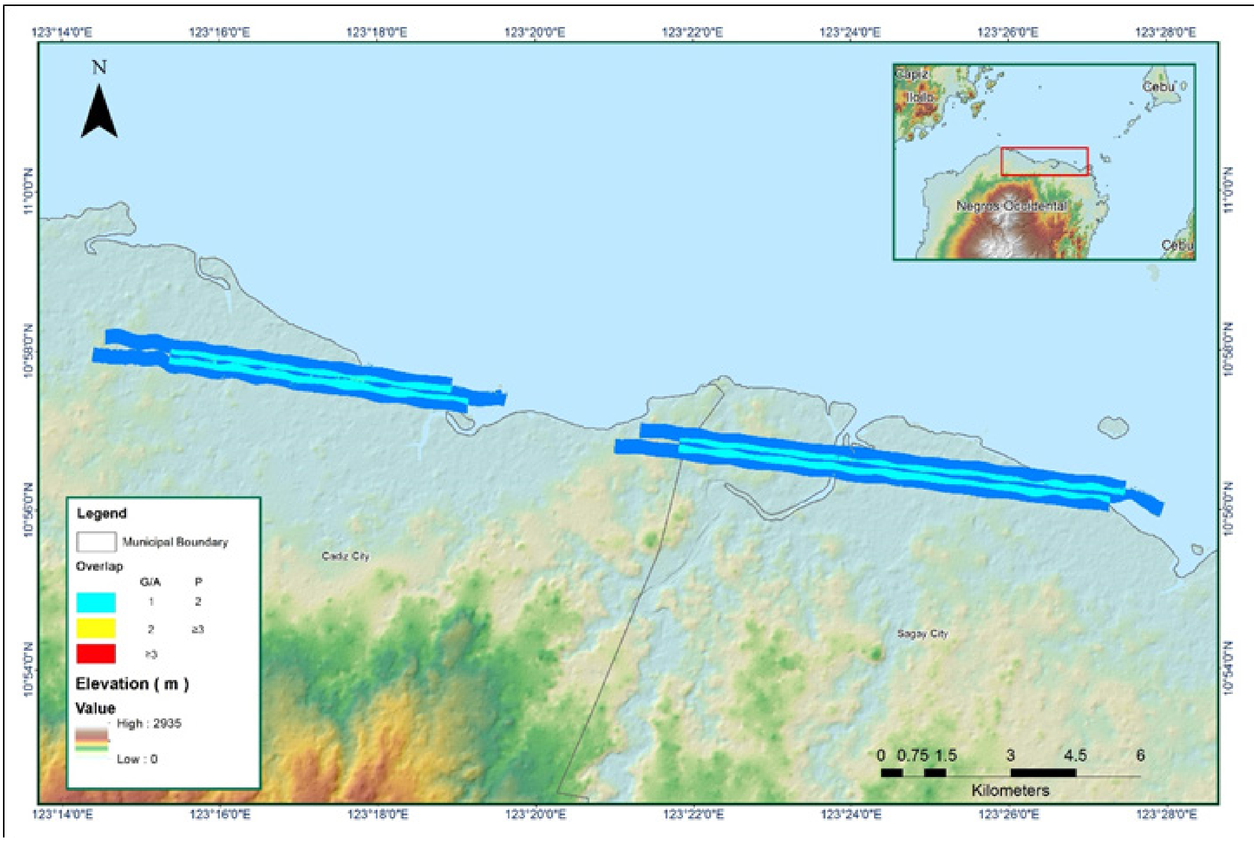


Figure A-8.19. Image of data overlap

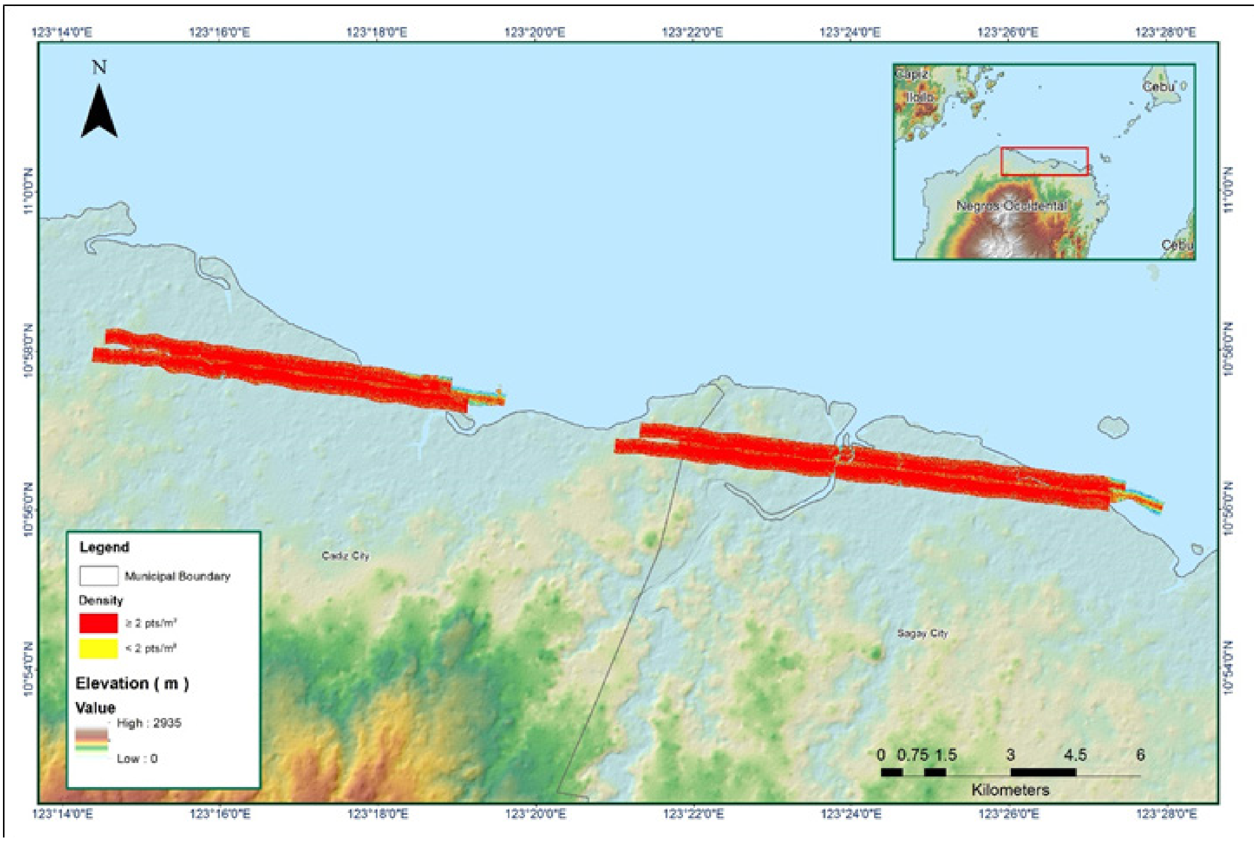


Figure A-8.20. Density map of merged LiDAR data

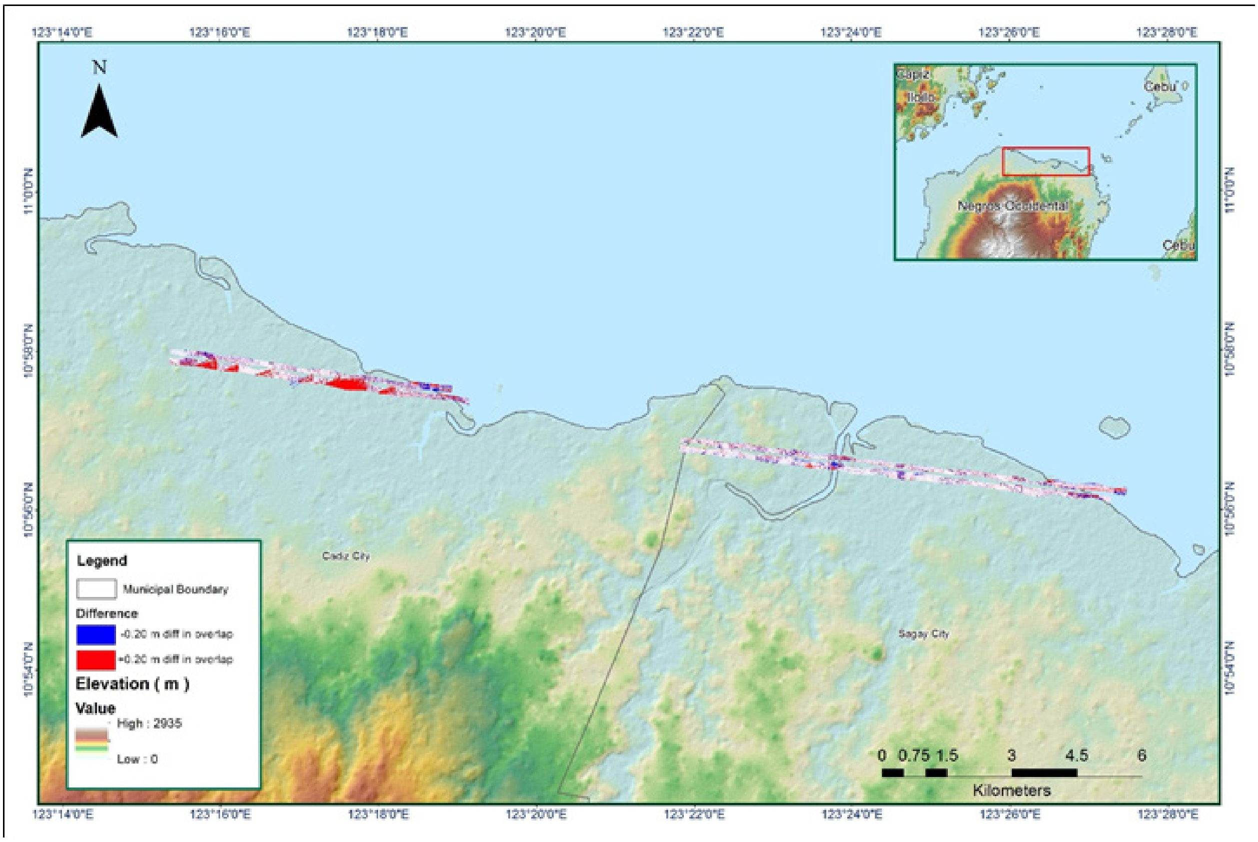


Figure A-8.21. Elevation difference between flight lines

Annex 9. Grande Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
W220	9.6889	99	0	0.13413	0.711425	Discharge	0.42983	0.85	Ratio to Peak	0.4
W230	6.6161	99	0	0.12777	0.6777	Discharge	0.45287	0.85	Ratio to Peak	0.4
W240	9.0353	56.47	0	0.095	0.503875	Discharge	0.58648	0.85	Ratio to Peak	0.4
W250	35.216	55.844	0	0.135225	0.71725	Discharge	0.46482	0.85	Ratio to Peak	0.4
W260	9.7257	99	0	0.059515	0.315675	Discharge	0.29844	0.85	Ratio to Peak	0.4
W270	39.353	86.325	0	0.0381233	0.2022059	Discharge	0.09233	0.85	Ratio to Peak	0.4
W280	23.6	83.766	0	0.0307293	0.1629875	Discharge	0.0486	0.85	Ratio to Peak	0.4
W290	35.114	55.844	0	0.050985	0.27041	Discharge	0.07346	0.85	Ratio to Peak	0.4
W300	36.746	52.713	0	0.076465	0.405575	Discharge	0.38138	0.85	Ratio to Peak	0.4
W310	23.599	86.348	0	0.0419545	0.22253	Discharge	0.0388949	0.85	Ratio to Peak	0.4
W320	27.214	79.352	0	0.0647734	0.34355	Discharge	0.79757	0.85	Ratio to Peak	0.4
W330	51.182	72.99	0	0.0380873	0.202015	Discharge	0.1062	0.85	Ratio to Peak	0.4
W340	51.797	65.822	0	0.1047168	0.55542	Discharge	1.1762	0.85	Ratio to Peak	0.4
W350	44.729	84.537	0	0.0623238	0.330575	Discharge	0.42539	0.85	Ratio to Peak	0.4
W360	78.18	71.161	0	0.088145	0.467525	Discharge	1.1219	0.85	Ratio to Peak	0.4
W370	41.663	71.688	0	0.072115	0.38249	Discharge	0.56536	0.85	Ratio to Peak	0.4
W380	53.852	71.945	0	0.0380939	0.2020499	Discharge	0.11484	0.85	Ratio to Peak	0.4
W390	58.913	63.376	0	0.1055788	0.56	Discharge	0.6785	0.85	Ratio to Peak	0.4
W400	36.176	71.945	0	0.0619162	0.3284	Discharge	0.43673	0.85	Ratio to Peak	0.4
W410	95.042	57.196	0	0.08791	0.466275	Discharge	0.53235	0.85	Ratio to Peak	0.4
W420	94.904	57.232	0	0.1232804	0.653875	Discharge	1.8899	0.85	Ratio to Peak	0.4

Annex 10. Grande 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	4650.76	0.001649	0.0614912	Trapezoid	25.78	1
R20	Automatic Fixed Interval	2068.65	0.011004	0.0627461	Trapezoid	25.78	1
R40	Automatic Fixed Interval	3955.76	0.006485	0.21609	Trapezoid	25.78	1
R50	Automatic Fixed Interval	212.132	0.019747	0.19803	Trapezoid	25.78	1
R70	Automatic Fixed Interval	1513.97	0.004965	0.098	Trapezoid	25.78	1
R90	Automatic Fixed Interval	1681.25	0.015014	0.3316	Trapezoid	25.78	1
R100	Automatic Fixed Interval	1127.82	0.010857	0.15209	Trapezoid	25.78	1
R110	Automatic Fixed Interval	1675.1	0.021617	0.0993158	Trapezoid	25.78	1
R140	Automatic Fixed Interval	1208.41	0.018324	0.14465	Trapezoid	25.78	1
R190	Automatic Fixed Interval	3784.63	0.029072	0.22722	Trapezoid	25.78	1

Annex 11. Field Validation

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
0	10.95946314	123.3015192	0.04	0	0.002		
1	10.95942189	123.3010237	0.05	0	0.003		
2	10.9670589	123.2855814	0.03	0	0.001		
3	10.95910454	123.3020779	0.14	0	0.020		
4	10.91573735	123.2590578	0.03	0	0.001		
5	10.96319403	123.2950854	0.21	0.8	0.348	Yolanda	5-Year
6	10.90428559	123.2642862	0.04	0	0.002		
7	10.90478041	123.2639406	0.03	0	0.001		
8	10.96313292	123.2941583	0.03	0	0.001		
9	10.96646356	123.2898029	0.05	0	0.003		
10	10.91496107	123.258779	0.03	0	0.001		
11	10.96358786	123.2859725	0.06	0	0.004		
12	10.96694517	123.2849325	0.04	0	0.002		
13	10.9648902	123.2863266	0.11	0	0.012		
14	10.95722061	123.2692857	0.03	0	0.001		
15	10.96589103	123.2848334	0.12	0	0.014		
16	10.96771033	123.2855518	0.14	0	0.020		
17	10.95886737	123.2976232	0.03	0	0.001		
18	10.96148646	123.2974724	0.57	0.1	0.221	Zoraida	5-Year
19	10.96685807	123.2878839	0.03	0	0.001		
20	10.96718263	123.2851988	0.05	0	0.003		
21	10.96476828	123.2858519	0.06	0	0.004		
22	10.90990486	123.2575462	0.29	0	0.084		
23	10.96142375	123.2946195	0.03	0	0.001		
24	10.96518865	123.2898475	0.03	0	0.001		
25	10.95903514	123.2976044		0	0.000		
26	10.93525714	123.2649347	0.13	0.98	0.723	Ondoy	5-Year
27	10.95495906	123.2689079	0.03	0	0.001		
28	10.96217098	123.2826037	0.65	1.57	0.846	Pepang	5-Year
29	10.96265143	123.298014	0.38	0.6	0.048	Zoraida	5-Year
30	10.95833864	123.2965512	0.04	0	0.002		
31	10.95945135	123.2981605	0.34	0	0.116		
32	10.95502449	123.2969617	0.44	0	0.194		
33	10.96411902	123.2871836	0.29	0	0.084		
34	10.96173929	123.2835309	0.35	1.57	1.488	Pepang	5-Year
35	10.96091975	123.2960869	0.47	1	0.281	Zoraida	5-Year
36	10.9448486	123.2562695	0.99	2.23	1.538	Toyang	5-Year
37	10.96348152	123.2825975	0.4	1.57	1.369	Pepang	5-Year
38	10.96144693	123.2965683	0.3	1	0.490	Zoraida	5-Year
39	10.94529179	123.2571584	0.04	0	0.002		

40	10.96221464	123.2971149	0.37	0.6	0.053	Zoraida	5-Year
41	10.94484543	123.2571771	0.23	1.07	0.706	Seniang	5-Year
42	10.95853352	123.2953219	0.75	0.6	0.023	Zoraida	5-Year
43	10.96136889	123.2962668	0.43	1	0.325	Zoraida	5-Year
44	10.96247299	123.2833822	0.03	1.57	2.372	Pepang	5-Year
45	10.94415172	123.2555369	0.94	0.73	0.044	Yolanda	5-Year
46	10.90521794	123.2641971	0.04	1.3	1.588	Yolanda	5-Year
47	10.95828479	123.2972995	0.05	0.5	0.203	Zoraida	5-Year
48	10.942702	123.2659003	0.44	0.55	0.012	Yolanda	5-Year
49	10.95465755	123.2962093	0.5	0	0.250		
50	10.96085913	123.2962733		1	1.000	Zoraida	5-Year
51	10.96733139	123.2711622	0.73	0.55	0.032	Pepang	5-Year
52	10.9438245	123.2557334	0.03	0.4	0.137	Yolanda	5-Year
53	10.94679855	123.2435846	1.48	1.35	0.017	Labuyo	5-Year
54	10.96249177	123.2807258	0.94	1.57	0.397	Pepang	5-Year
55	10.96201318	123.2818167	0.8	1.57	0.593	Pepang	5-Year
56	10.96307736	123.281693	0.67	1.57	0.810	Pepang	5-Year
57	10.96227421	123.2823874	0.7	1.57	0.757	Pepang	5-Year
58	10.95315313	123.2679664	0.94	1.09	0.023	Labuyo	5-Year
59	10.95385465	123.2688831	0.92	1.09	0.029	Labuyo	5-Year
60	10.96248755	123.2808907		1.57	2.465	Pepang	5-Year
61	10.94395495	123.2556477	1.38	0.96	0.176	Ruping	5-Year
62	10.96110951	123.2814216	0.62	1.57	0.903	Pepang	5-Year
63	10.91651879	123.2584336	0.03	0	0.001		
64	10.9631998	123.2809202	0.7	1.57	0.757	Pepang	5-Year
65	10.9468791	123.2439986	2.1	1.3	0.640	Labuyo	5-Year
66	10.94220531	123.2648903	1.61	0.1	2.280	Undang	5-Year
67	10.9639713	123.2826429	0.57	1.57	1.000	Pepang	5-Year
68	10.96342789	123.2807213	0.31	1.47	1.346	Pepang	5-Year
69	10.96150918	123.2813372	1.01	1.57	0.314	Pepang	5-Year
70	10.96845815	123.2692625	0.71	0.97	0.068	Yolanda	5-Year
71	10.95739914	123.2730431	0.89	3	4.452	Pablo	5-Year
72	10.96742521	123.2716185		0.55	0.303	Pepang	5-Year
73	10.94505785	123.2846535	1.08	2.02	0.884	Puring	5-Year
74	10.91636051	123.2585707	0.08	2.5	5.856	Trining	5-Year
75	10.92363211	123.2738533	1.84	1.35	0.240	Puring	5-Year
76	10.92643614	123.2742503	1.3	1.4	0.010	Seniang	5-Year
77	10.94215143	123.2649585		0.1	0.010	Undang	5-Year
78	10.94496562	123.284468		2.02	4.080	Puring	5-Year

79	10.94236984	123.2650547	1.11	1.2	0.008	Yolanda	5-Year
80	10.9419728	123.2650653	0.16	1.2	1.082	Yolanda	5-Year
81	10.92656596	123.2747614	0.87	1.4	0.281	Seniang	5-Year
82	10.94505261	123.2848374	0.03	2.02	3.960	Puring	5-Year
83	10.91613478	123.258505		2.5	6.250	Trining	5-Year
84	10.92352618	123.2738807		1.35	1.823	Puring	5-Year
85	10.94495102	123.2847151		2.02	4.080	Puring	5-Year
86	10.92651199	123.2745738		1.4	1.960	Seniang	5-Year
87	10.92341165	123.2740211	0.37	1.35	0.960	Puring	5-Year
88	10.926643	123.2746206		1.4	1.960	Seniang	5-Year
89	10.92600155	123.2749976	0.7	1.4	0.490	Seniang	5-Year
90	10.92650068	123.2746966		1.4	1.960	Seniang	5-Year
91	10.92364558	123.2738261		1.35	1.823	Puring	5-Year
92	10.94696235	123.2441973		1.55	2.403	Yolanda	5-Year
93	10.94465073	123.2841872	0.7	2	1.690	Puring	5-Year
94	10.92664432	123.274635		1.4	1.960	Seniang	5-Year
95	10.94486215	123.2843459		0.57	0.325	Juan	5-Year
96	10.90687007	123.2658997	4.73	4.9	0.029	Trining	5-Year
97	10.91558773	123.2574768	6.36	1.75	21.252	Trining	5-Year
98	10.92049962	123.256788	2.36	4.02	2.756	Trining	5-Year
99	10.9406254	123.2670483	5.08	4.2	0.774	Yolanda	5-Year
100	10.93151681	123.2675927	5.24	4.2	1.082	Yolanda	5-Year
101	10.96254781	123.2632547	1.17	5.5	18.749	Ruping	5-Year
102	10.90117989	123.2634408	5.19	3.4	3.204	Yolanda	5-Year
103	10.91721496	123.2572434	7.18	5	4.752	Trining	5-Year
104	10.89928273	123.2639863	6.68	2.5	17.472	Trining	5-Year
105	10.93858041	123.2679139	2.49	5.5	9.060	Uring	5-Year
106	10.91007378	123.249821	2.16	2.43	0.073	Trining	5-Year
107	10.90917048	123.2461649	5.67	8	5.429	Trining	5-Year
108	10.91232143	123.2522618	6.05	6.04	0.000	Trining	5-Year
109	10.90839776	123.2407832	3.42	3.35	0.005	Yolanda	5-Year
110	10.92223443	123.2618814	4.99	3.9	1.188	Trining	5-Year
111	10.91933042	123.2644743	6.03	1.34	21.996	Trining	5-Year
112	10.93816817	123.2720769	1.98	5.5	12.390	Uring	5-Year
113	10.92385668	123.2687143	2.31	4	2.856	Trining	5-Year
114	10.91410057	123.2509262	7.27	6.04	1.513	Trining	5-Year
115	10.91573811	123.2568825	6.66	4.25	5.808	Trining	5-Year
116	10.91223697	123.2523504	6.57	6	0.325	Trining	5-Year
117	10.90735174	123.2664406	0.98	4.9	15.366	Trining	5-Year
118	10.91949986	123.2649403	6.15	3.43	7.398	Trining	5-Year
119	10.90725369	123.2411748	4.57	3.35	1.488	Yolanda	5-Year
120	10.94241848	123.2701188	0.8	5.7	24.010	Ruby	5-Year
121	10.92346222	123.2660609	7.4	3.3	16.810	Trining	5-Year
122	10.91544797	123.2570974	0.03	1.75	2.958	Trining	5-Year
123	10.89809503	123.265121	1.62	3	1.904	Trining	5-Year

124	10.94176533	123.264997	2.27	1.18	1.188	Frank	100-Year
125	10.94205791	123.2653466		1.42	2.016	Openg	5-Year
126	10.94184778	123.2650651		1.42	2.016	Openg	5-Year
127	10.94184108	123.2648471		1.18	1.392	Frank	100-Year
128	10.94211941	123.2653271		1.42	2.016	Openg	5-Year
129	10.94187131	123.2651083		1.42	2.016	Openg	5-Year
130	10.94192621	123.2649432		1.18	1.392	Frank	100-Year
131	10.94219381	123.2655113	0.05	1.9	3.423		
132	10.95882201	123.3013943	0.14	0	0.020		
133	10.94219277	123.2657884		0.41	0.168	Yolanda	5-Year
134	10.94237743	123.2654527		0.84	0.706	Yolanda	5-Year
135	10.94200147	123.2653624		1.42	2.016	Openg	5-Year
136	10.9585937	123.3030958	0.73	0.54	0.036	Frank	100-Year
137	10.96505281	123.2855731	0.1	0	0.010		
138	10.9645588	123.2848165	0.03	0	0.001		
139	10.95835592	123.3039771	0.67	0.5	0.029	Frank	100-Year
140	10.96395233	123.2868777	0.18	0	0.032		
141	10.96443322	123.2848209		0	0.000		
142	10.95846091	123.3031184		0.57	0.325	Frank	100-Year
143	10.9655963	123.2857192	0.03	0.15	0.014	Yolanda	5-Year
144	10.96296665	123.2864505	0.19	0.26	0.005	Yolanda	5-Year
145	10.96285046	123.2870006	0.14	0.26	0.014	Yolanda	5-Year
146	10.96661026	123.2862378	0.03	0.43	0.160	Yolanda	5-Year
147	10.9731305	123.2789735	0.03	0	0.001		
148	10.96720753	123.2847975	0.19	0.21	0.000	Yolanda	5-Year
149	10.96301216	123.2869414	0.03	0.26	0.053	Yolanda	5-Year
150	10.96701297	123.2847204	0.17	0.21	0.002	Yolanda	5-Year
151	10.97243984	123.2794876	0.13	0.3	0.029	Juan	5-Year
152	10.96652264	123.2864629		0.43	0.185	Yolanda	5-Year
153	10.97225423	123.2804411	0.12	0.87	0.563	Yolanda	5-Year
154	10.9593635	123.303297	0.15	0.41	0.068		
155	10.96529611	123.2865563	0.12	0	0.014		
156	10.97255948	123.2794566		0.3	0.090	Juan	5-Year
157	10.96078426	123.3019572	0.1	0	0.010		
158	10.97681102	123.2730198	0.16	0.4	0.058	Yolanda	5-Year
159	10.96350733	123.2857745		0	0.000		
160	10.97200723	123.2817904	0.03	0.29	0.068	Yolanda	5-Year
161	10.96126922	123.2995931	0.03	0.23	0.040	Yolanda	5-Year
162	10.96125551	123.3000654	0.19	0.32	0.017	Yolanda	5-Year
163	10.96071804	123.3023272	0.23	0	0.053		
164	10.96079935	123.3019364		0	0.000		
165	10.97205401	123.2817643		0.29	0.084	Yolanda	5-Year
166	10.97288373	123.2793069	0.27	0.1	0.029	Frank	100-Year
167	10.96671825	123.2860337	0.03	0.43	0.160	Yolanda	5-Year
168	10.96808718	123.285959	0.1	0	0.010		

169	10.97527713	123.2768874	0.06	0.42	0.130	Frank	5-Year
170	10.96503169	123.2870369	0.03	0	0.001		
171	10.95748798	123.3035737	0.05	0	0.003		
172	10.97188014	123.2821317	0.03	0.1	0.005	Tropical Depression Emong	5-Year
173	10.96001935	123.3040227	0.05	0.2	0.023	Yolanda	5-Year
174	10.9582018	123.3020298	0.12	1.34	1.488	Yolanda	5-Year
175	10.97534721	123.2764563	0.17	0.42	0.063	Frank	100-Year
176	10.95679027	123.3027356		0.5	0.250	Yolanda	5-Year
177	10.95732083	123.3027496	0.06	0.55	0.240	Yolanda	5-Year
178	10.96246169	123.2869486		0.26	0.068	Yolanda	5-Year
179	10.95904174	123.3026348	0.03	0	0.001		
180	10.96103296	123.3042598		0	0.000		

Annex 12. Educational Institutions Affected in Grande Floodplain

Cadiz City				
Building Name	Barangay	Rainfall Scenario		
		5-Year	25-Year	100-Year
Andres Bonifacio Day Care	Andres Bonifacio	Low	Low	Low
Daga Elementary School	Daga	Low	Low	Medium
Hca. Lamata Day Care Center	Luna	Low	Low	Low
Philippine Normal University – Visayas	Zone 1	Medium	Medium	Medium
Daga SPED High School	Daga	Low	Low	Low
Had. Canaan Day Care Center	Mabini		Low	Medium
Dr. VFGM National High School			Low	
Had. Pag-asa Day Care Center	Luna			Low
Villa Cristina Day Care Center	Zone 1			Low

Annex 13. Medical Institutions Affected in Grande Floodplain

Cadiz City				
Building Name	Barangay	Rainfall Scenario		
		5-Year	25-Year	100-Year
Cadiz District Hospital	Daga		Low	Medium

Annex 14. UPC Phil-LiDAR 1 Team Composition

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