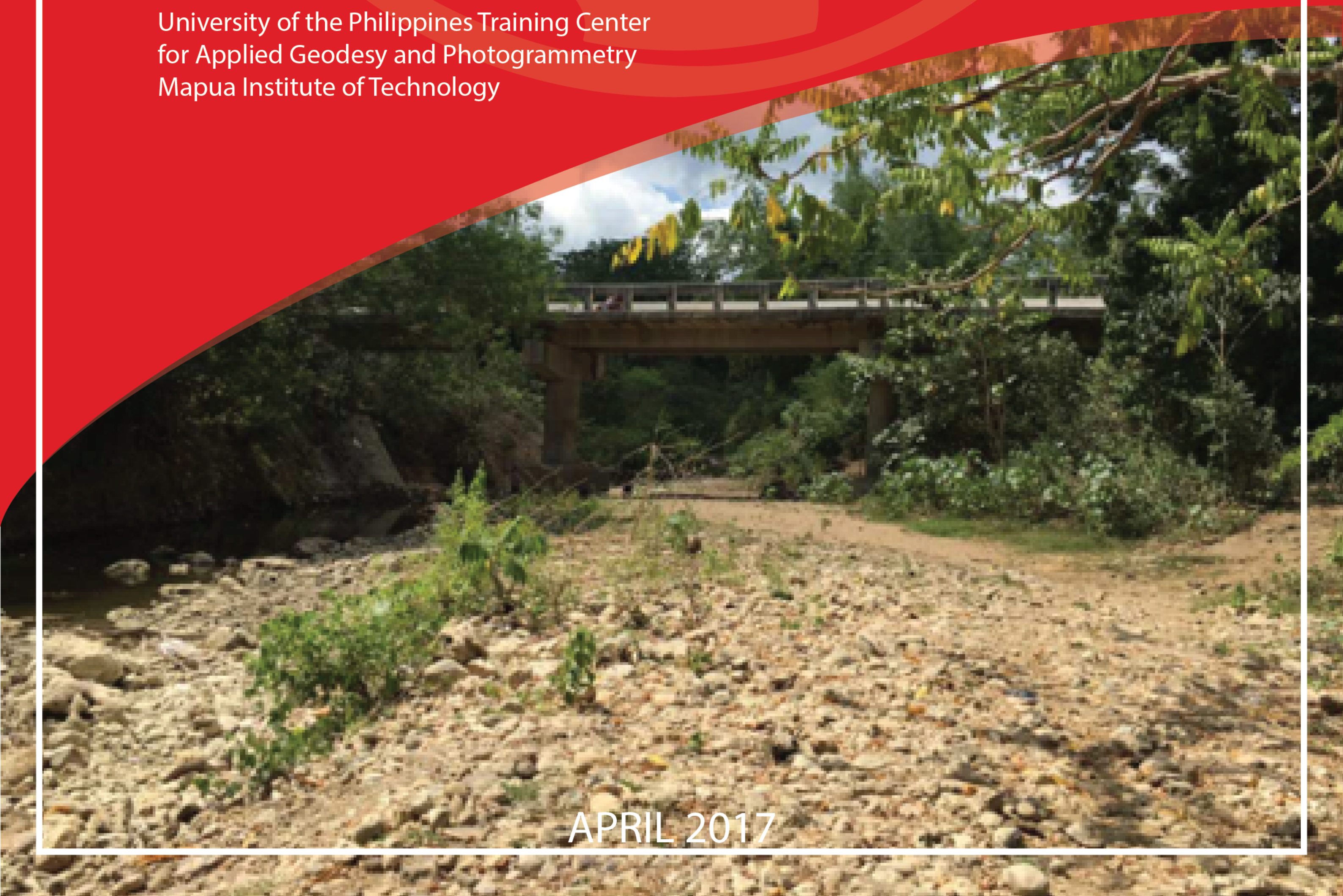
Hazard Mapping of the Philippines Using LIDAR (Phil-LIDAR 1)

LiDAR Surveys and Flood Mapping of Silongin River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
Mapua Institute of Technology



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LIST OF ACRONYMS AND ABBREVIATIONS

AAC	Asian Aerospace Corporation
Ab	abutment
ALTM	Airborne LiDAR Terrain Mapper
ARG	automatic rain gauge
ATQ	antique
AWLS	Automated Water Level Sensor
BA	Bridge Approach
BM	benchmark
CAD	Computer-Aided Design
CN	Curve Number
CSRS	Chief Science Research Specialist
DAC	Data Acquisition Component
DEM	Digital Elevation Model
DENR	Department of Environment and Natural Resources
DOST	Department of Science and Technology
DPPC	Data Pre-Processing Component
DREAM	Disaster Risk and Exposure Assessment for Mitigation [Program]
DRRM	Disaster Risk Reduction and Management
DSM	Digital Surface Model
DTM	Digital Terrain Model
DVBC	Data Validation and Bathymetry Component
FMC	Flood Modeling Component
FOV	Field of View
GiA	Grants-in-Aid
GCP	Ground Control Point
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center - River Analysis System
HC	High Chord
IDW	Inverse Distance Weighted [interpolation method]
IMU	Inertial Measurement Unit

kts	knots
LAS	LiDAR Data Exchange File format
LC	Low Chord
LGU	local government unit
LiDAR	Light Detection and Ranging
LMS	LiDAR Mapping Suite
m AGL	meters Above Ground Level
MIT	Mapua Institute of Technology
MMS	Mobile Mapping Suite
MSL	mean sea level
NAMRIA	National Mapping and Resource Information Authority
NSTC	Northern Subtropical Convergence
PAF	Philippine Air Force
PAGASA	Philippine Atmospheric Geophysical and Astronomical Services Administration
PDOP	Positional Dilution of Precision
PPK	Post-Processed Kinematic [technique]
PRF	Pulse Repetition Frequency
PTM	Philippine Transverse Mercator
QC	Quality Check
QT	Quick Terrain [Modeler]
RA	Research Associate
RIDF	Rainfall-Intensity-Duration-Frequency
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
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 SILONGIN RIVER

Enrico C. Paringit, Dr. Eng., Dr. Francis Aldrine A. Uy, and Engr. Fibor Tan

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.

The program was also 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 methods applied in this report are thoroughly described in a separate publication titled *Flood Mapping of Rivers in the Philippines Using Airborne LiDAR: Methods* (Paringit et al., 2017).

The implementing partner university for the Phil-LiDAR 1 Program is the Mapua Institute of Technology (MIT). MIT 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 26 river basins in the Southern Tagalog Region. The university is located in Intramuros in the City of Manila.

1.2 Overview of the Silongin River Basin

The Silongin River Basin covers nine (9) barangays in the Municipality of San Francisco and two (2) barangays in the Municipality of San Andres, in the province of Quezon. The DENR River Basin Control Office identified the basin to have a drainage area of 59 km2 and an estimated annual run-off of 94 million cubic meters (MCM) (RBCO, 2015).

Its main stem, Silongin River, is part of the 26 river systems in the Southern Tagalor Region. There is a total of 10,143 persons residing in the immediate vicinity of the river according to the 2010 National Census. The population is distributed among the three (3) barangays in the Municipality of San Francisco, namely Silongin, Casay, and Don Juan Vercelo. Agriculture and fishing are the two primary source of living in the area. Majority of the agricultural land is planted by coconuts, rice, citrus, and vegetables (Quezon Province website, 2016). Typhoon "Glenda" is the most recent and significant calamity in the area which caused power interruption and affected more than 4,000 families on July 2014 (NDRRMC, 2014).

is still a primary source of income alongside farming. Dense mangrove areas are also found in the coastline and swamp areas of the said barangays.353 million cubic meters (MCM) annual run-off. The municipalities of Polanco and Piñan; and cities of Silongin and Dapitan are found within the floodplain, wherein a total of 15,500 features were extracted.

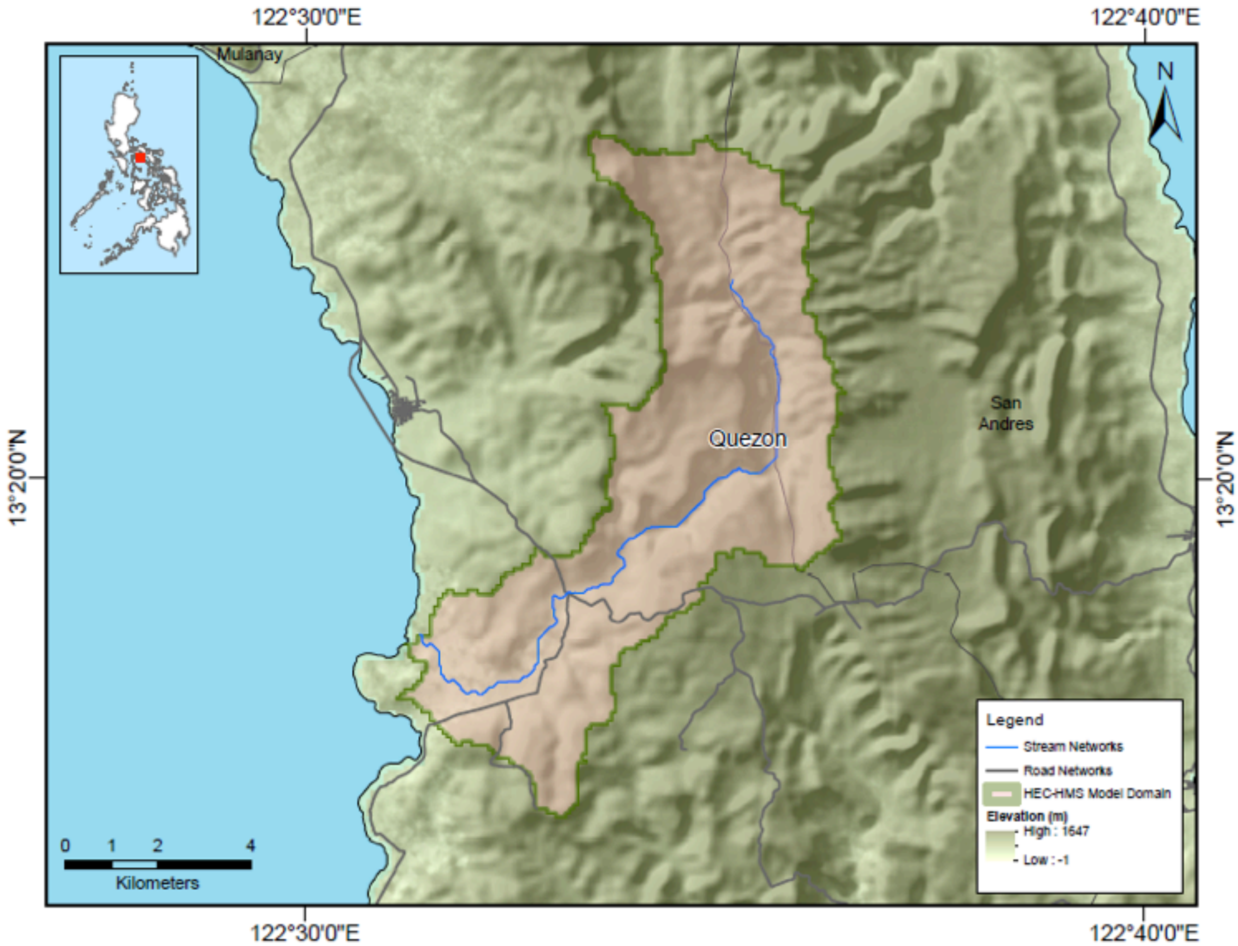

Figure 1. Map of Silongin River Basin

CHAPTER 2: LIDAR DATA ACQUISITION IN SILONGIN 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 Silongin Floodplain in Quezon. These missions were planned for 12 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 is found in Table 1. Figure 2 shows the flight plan for Silongin Floodplain.

Table 1. Flight planning parameters for Pegasus LiDAR system

Block Name	Flying Height (m AGL)	Overlap (%)	Field of view (ø)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK21G	1000	30	50	200	30	130	5
BLK21H	1000	30	50	200	30	130	5

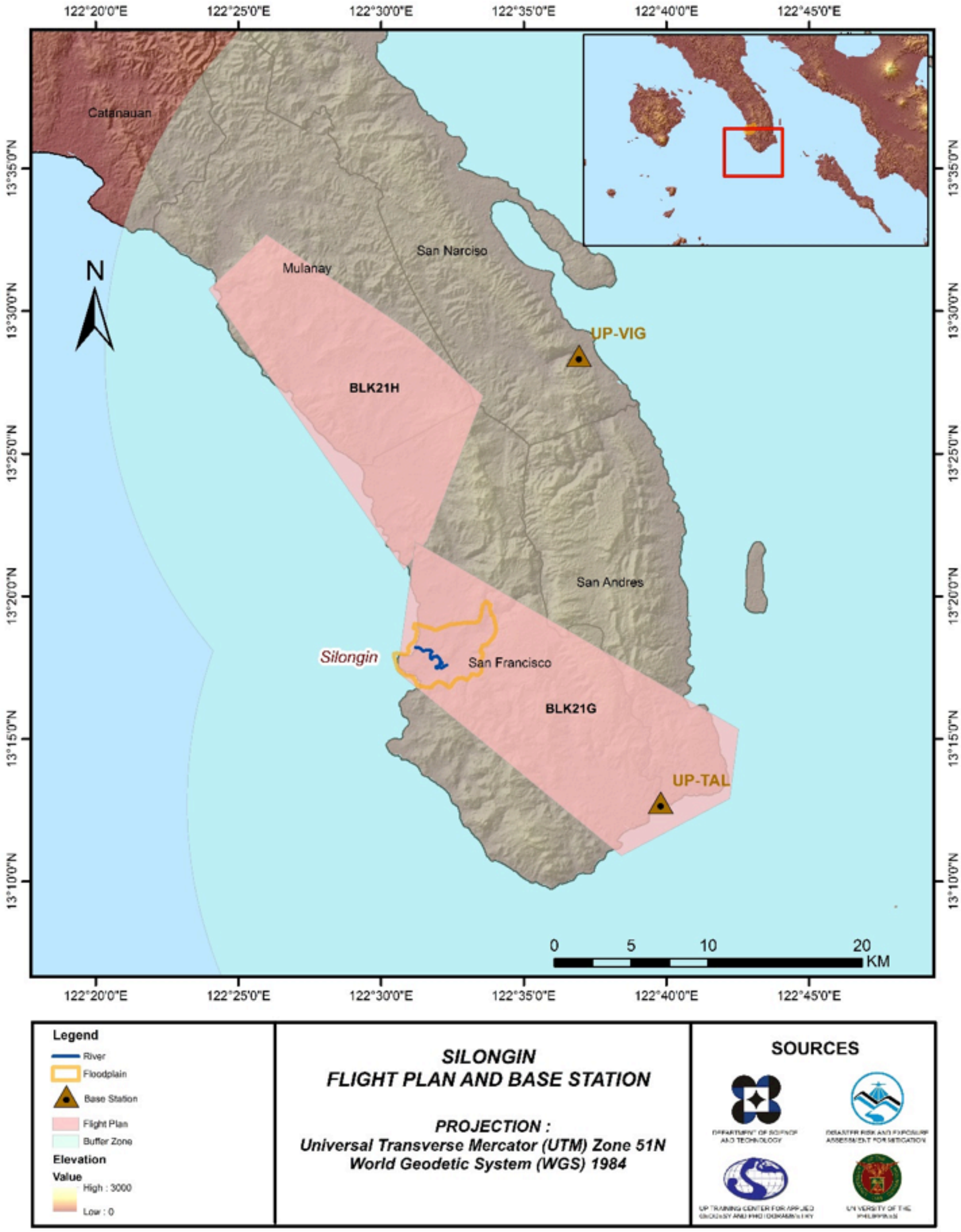
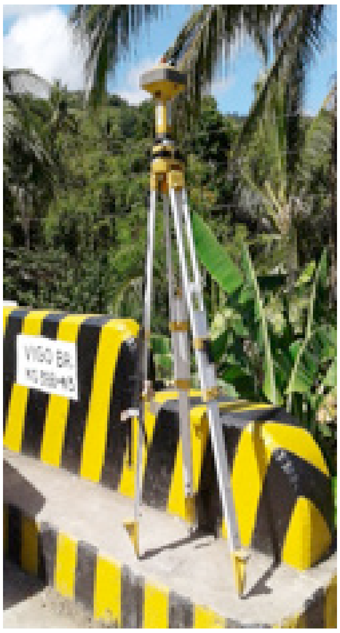


Figure 2. Flight Plans used for the Silongin Floodplain survey.

2.2 Ground Base Stations

The project team was able to establish two (2) ground control points: UP-VIG and UP-TAL. The baseline processing reports for the establishment points are found in ANNEX 2. These points were used as base stations during flight operations for the entire duration of the survey (May 12–13, 2016). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 852 and Topcon GR5. Flight plans and location of base stations used during the aerial LiDAR acquisition in Silongin Floodplain are shown in Figure 2.

Figure 3 shows the established points within the area. In addition, Table 2 and Table 3 present the details about the following NAMRIA control stations, while Table 4 lists all ground control points occupied during the acquisition together with the corresponding dates of utilization.



(a)

(b)

Figure 3. GPS set-up over UP-VIG at the left approach of Vigo Bridge along San Narciso-San Andres road in Brgy. Binay, San Narciso, Quezon (a) and ground control point UP-VIG (b) as established by the field team

Table 2. Details of the established ground control point UP-VIG used as base station for the LiDAR Acquisition

Station Name	**UP-VIG**	
Order of Accuracy	**2nd**	
Relative Error (Horizontal positioning)	**1:50,000**	
Geographic Coordinates, Philippine Reference 0f 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 28′ 30.89562″ North 122° 36′ 51.38098″ East 5.677 meters
Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 5 PRS 92)	Easting Northing	674799.015 meters 1490695.992 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	458401.422 meters 1489570.975 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 28′ 25.87599″ North 122° 36′ 56.36154″ East 56.297 meters

Table 3. Details of the established ground control point UP-TAL used as base station for the LiDAR Acquisition

Station Name	UP-TAL	
Order of Accuracy	2nd	
Relative Error (Horizontal positioning)	1:50,000	
Geographic Coordinates, Philippine Reference 0f 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 12' 55.82506" North 122° 39' 44.45670" East 5.677 meters
Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 5 PRS 92)	Easting Northing	680162.756 meters 1461822.857 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	463529.419 meters 1460676.800 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 12' 45.54766" North 122° 39' 48.22813" East 55.749 meters

Table 4. Ground control points used during LiDAR data acquisition

Data Surveyed	Flight Number	Mission Name	Ground Control Points
May 12, 2016	23342P	1BLK221G133A	UP-TAL, UP-VIG
May 13, 2016	23346P	1BLK21GS134A	UP-TAL, UP-VIG

2.3 Flight Missions

Two (2) missions were conducted to complete the LiDAR data acquisition in Silongin Floodplain, for a total of eight hours and forty one minutes (8+41) of flying time for RP-C9122. All missions were acquired using the Pegasus LiDAR system. Table 5 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 6 presents the actual parameters used during the LiDAR data acquisition.

Table 5. Flight missions for LiDAR data acquisition in Silongin Floodplain

Date Surveyed	Flight Number	Flight Plan Area (km2)	Surveyed Area (km2)	Area Surveyed within the Floodplain (km2)	Area Surveyed Outside the Floodplain (km2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
May 12, 2016	23342P	209.28	194.60	1.74	192.86	NA	4	35
May 13, 2016	23346P	209.28	179.06	18.58	160.48	NA	4	6
TOTAL		418.56	349.93	20.32	353.34	NA	8	41

Table 6. Actual parameters used during LiDAR data acquisition

Flight Number	Flying Height (AGL) (m)	Overlap (%)	FOV (θ)	PRF (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
23342P	1000	30	50	200	30	130	5
23346P	1000	30	50	200	30	130	5

2.4 Survey Coverage

Silongin Floodplain is located in the province of Quezon. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 7. The actual coverage of the LiDAR acquisition for Silongin Floodplain is presented in Figure 4.

Table 7. List of municipalities and cities surveyed during Silongin Floodplain LiDAR survey

Province	Municipality/City	Area of Municipality/ City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Quezon	San Francisco	320.48	218.16	68%
	San Andres	173.70	52.97	30%
	Mulanay	262.91	9.57	4%
Total		757.09	280.70	37.08%

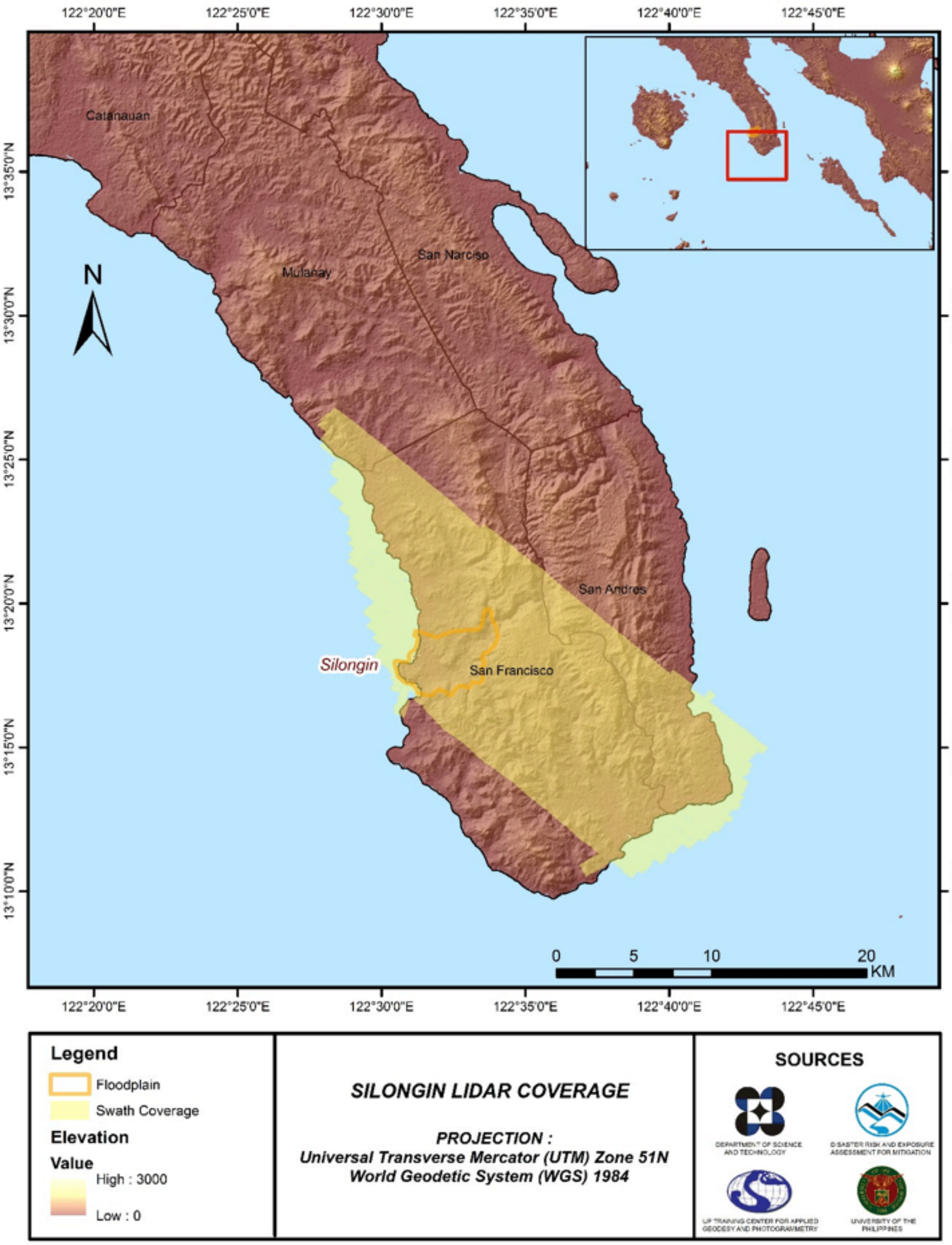


Figure 4. Actual LiDAR survey coverage for Silongin Floodplain Component

CHAPTER 3: LIDAR DATA PROCESSING FOR SILONGIN FLOODPLAIN

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3.1 Overview of LiDAR Data Pre-Processing

The data transmitted by the Data Acquisition Component were 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 was done in order to obtain the exact location of the LiDAR sensor when the laser was shot. Point cloud georectification was performed to incorporate correct position and orientation for each point acquired. The georectified LiDAR point clouds were subject for quality checking to ensure that the required accuracies of the program, which were the minimum point density, vertical and horizontal accuracies, were met. The point clouds were 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 were calibrated. Portions of the river that were barely penetrated by the LiDAR system were 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 was 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 5.

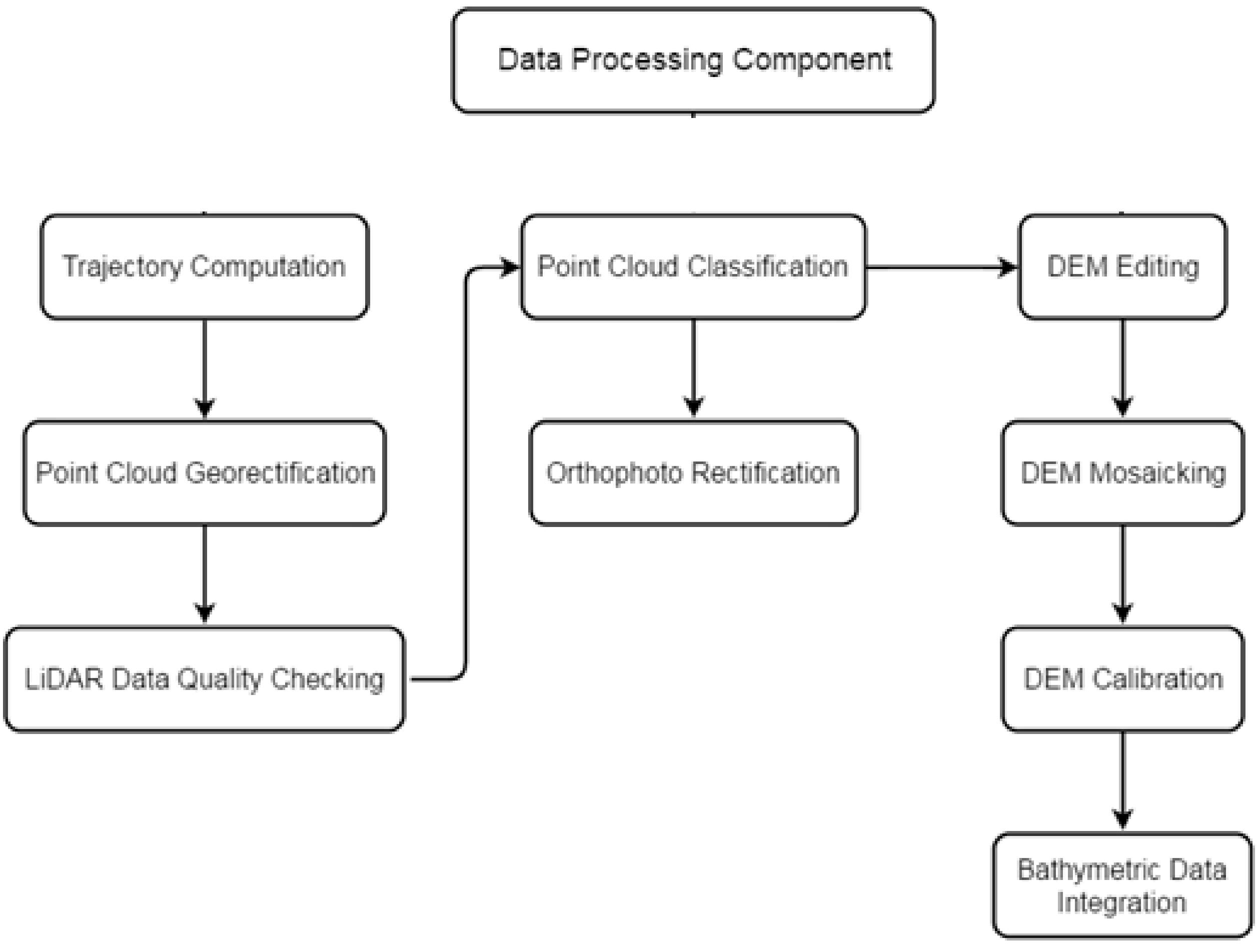

Figure 5. Schematic Diagram for Data Pre-Processing Component

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Silongin Floodplain can be found in ANNEX 5. Missions flown during the first survey conducted on May 2016 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus system over the Municipality of San Francisco, Quezon. The Data Acquisition Component (DAC) transferred a total of 61.70 Gigabytes of Range data, 560 Megabytes of POS data and 314 Megabytes of GPS base station data to the data server on June 09, 2016. There are no transferred raw image data for this floodplain. The Data Pre-Processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Silongin was fully transferred on June 14, 2016 as indicated on the data transfer sheets for Silongin Floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 23346P, one of the Silongin flights, which is the North, East, and Down positions RMSE values are shown in Figure 6. 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 May 08, 2016 00:00AM. The y-axis is the RMSE value for that particular position.

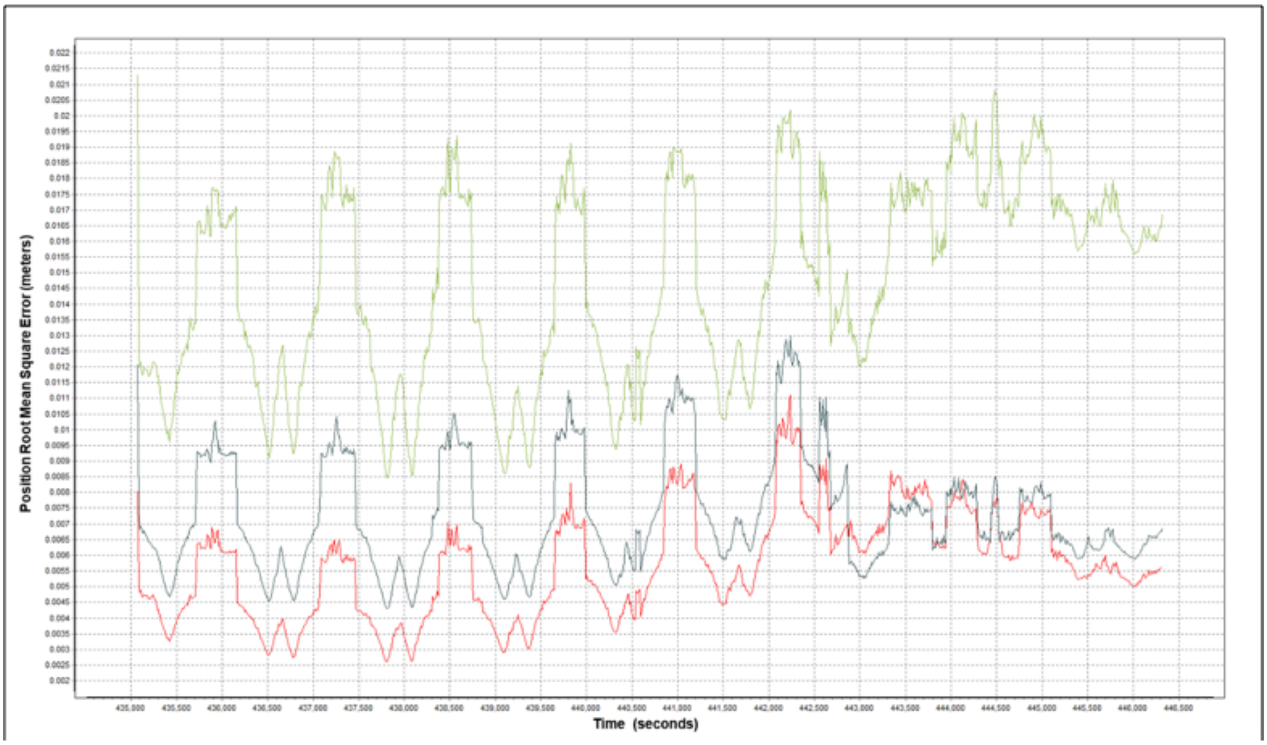

Figure 6. Smoothed Performance Metrics of a Silongin Flight 23346P.

The time of flight was from 435,000 seconds to 446,500 seconds, which corresponds to morning of May 13, 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 time the POS system started 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 6 shows that the North position RMSE peaks at 1.10 centimeters, the East position RMSE peaks at 1.30 centimeters, and the Down position RMSE peaks at 2.08 centimeters, which are within the prescribed accuracies described in the methodology.

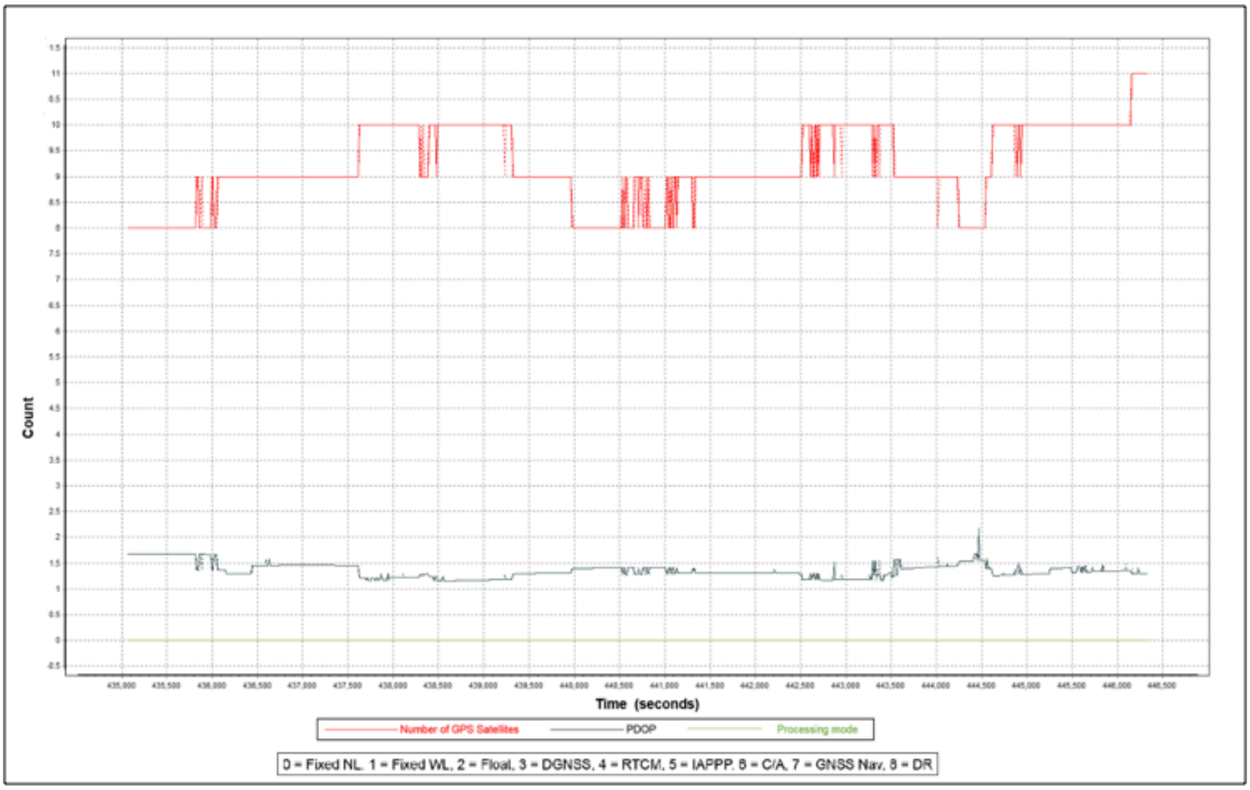

Figure 7. Solution Status Parameters of Silongin Flight 23346P.

The Solution Status parameters of flight 23346P, one of the Silongin flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 7. The graphs indicate that the number of satellites during the acquisition did not go down to 8. Majority of the time, the number of satellites tracked was between 8 and 10. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode stayed at the value of 0 for the entire survey time. 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 Silongin flights is shown in Figure 8.

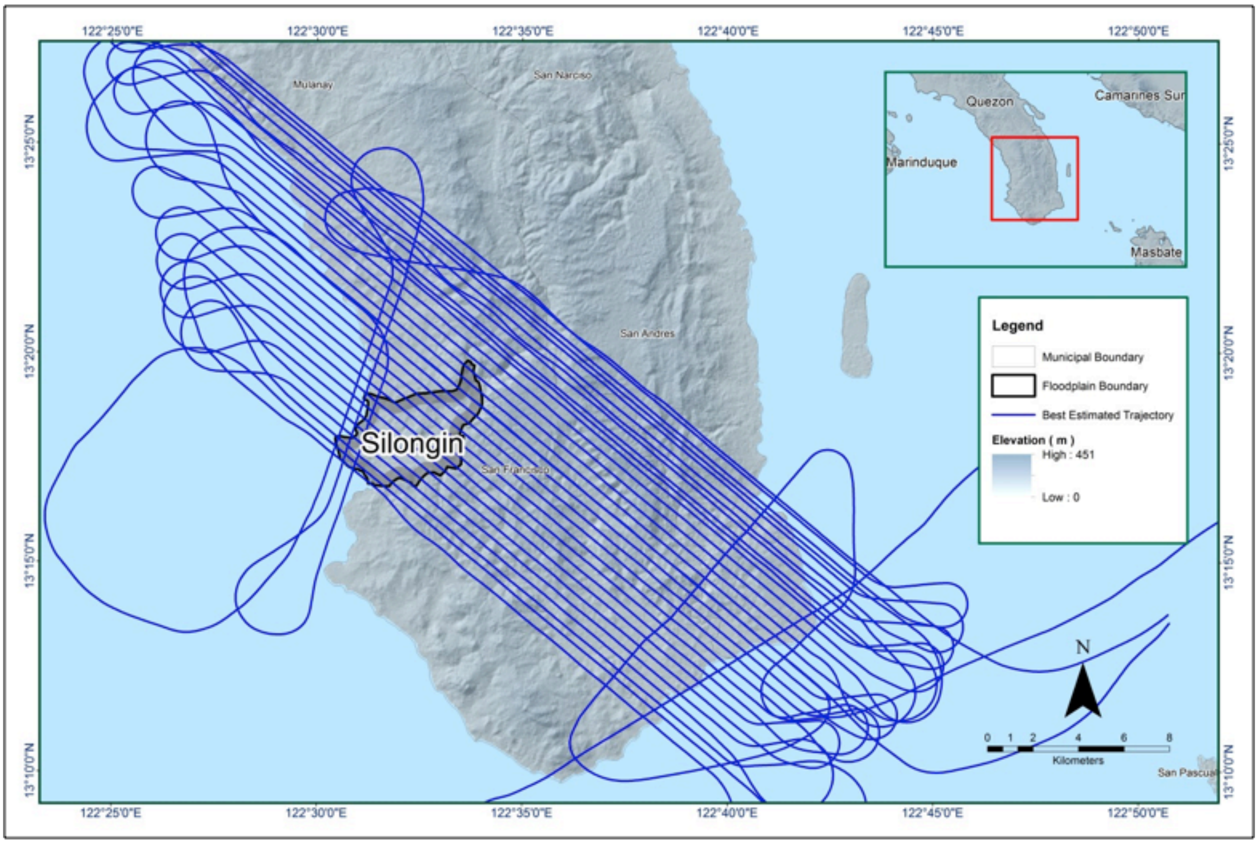

Figure 8. Best estimated trajectory of the LiDAR missions conducted over Silongin Floodplain

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 30 flight lines, with each flight line containing two channels, since the Pegasus system contains two channels. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Silongin Floodplain are given in Table 8.

Table 8. Self-calibration results values for Silongin flights

Parameter	Acceptable Value	Value
Boresight Correction stdev	(<0.001degrees)	0.000103
IMU Attitude Correction Roll and Pitch Corrections stdev	(<0.001degrees)	0.000279
GPS Position Z-correction stdev	(<0.01meters)	0.0061

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

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Silongin Floodplain is shown in Figure 9. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

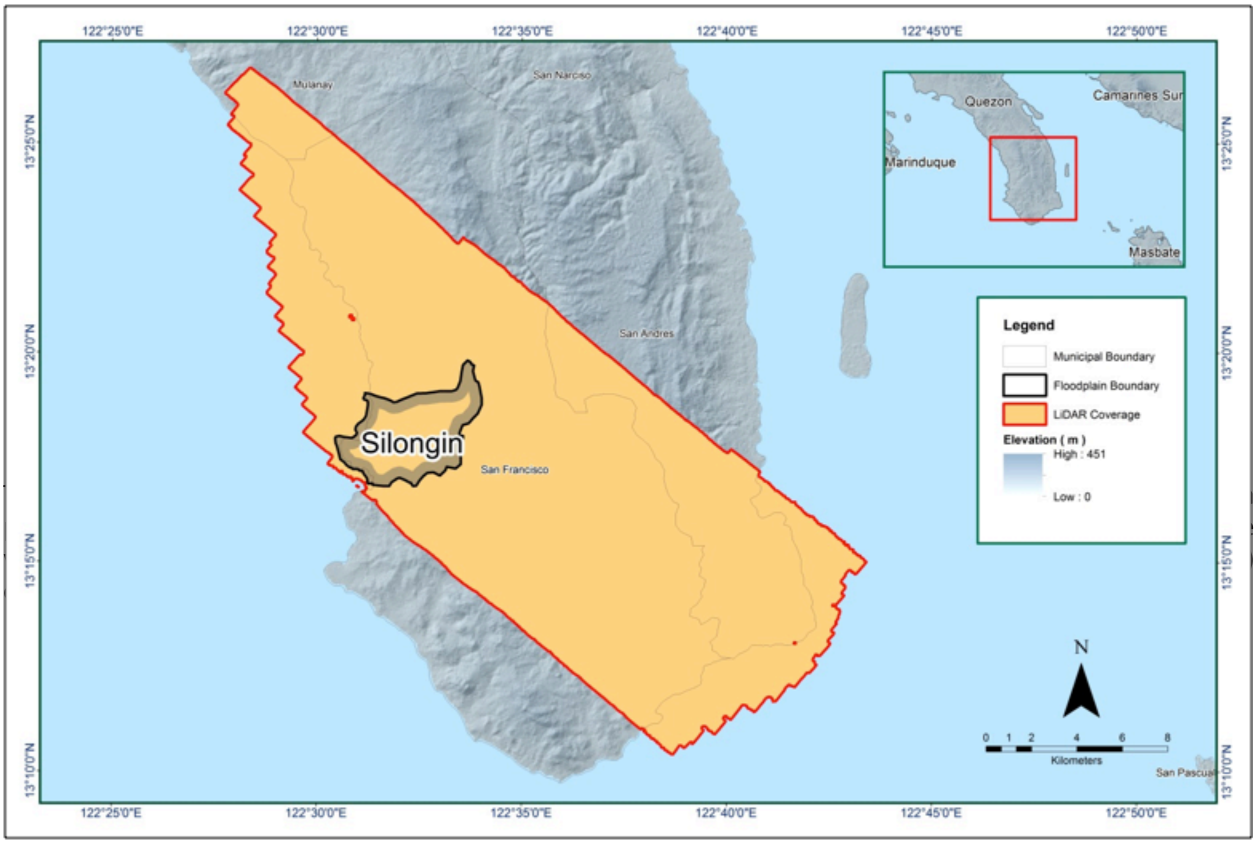

Figure 9. Boundary of the processed LiDAR data over Silongin Floodplain

The total area covered by the Silongin missions is 349.93 sq km that is comprised of two (2) flight acquisitions grouped and merged into two (2) blocks as shown in Table 9.

Table 9. List of LiDAR blocks for Silongin Floodplain

LiDAR Blocks	Flight Numbers	Area (sq km)
Bagasbas_Blk 21G	23346P	159.60
Bagasbas_Blk 21H	23342P	190.33
TOTAL		349.93

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 10. Since the Pegasus system employs two channels, an average value of 2 (blue) would be expected 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.

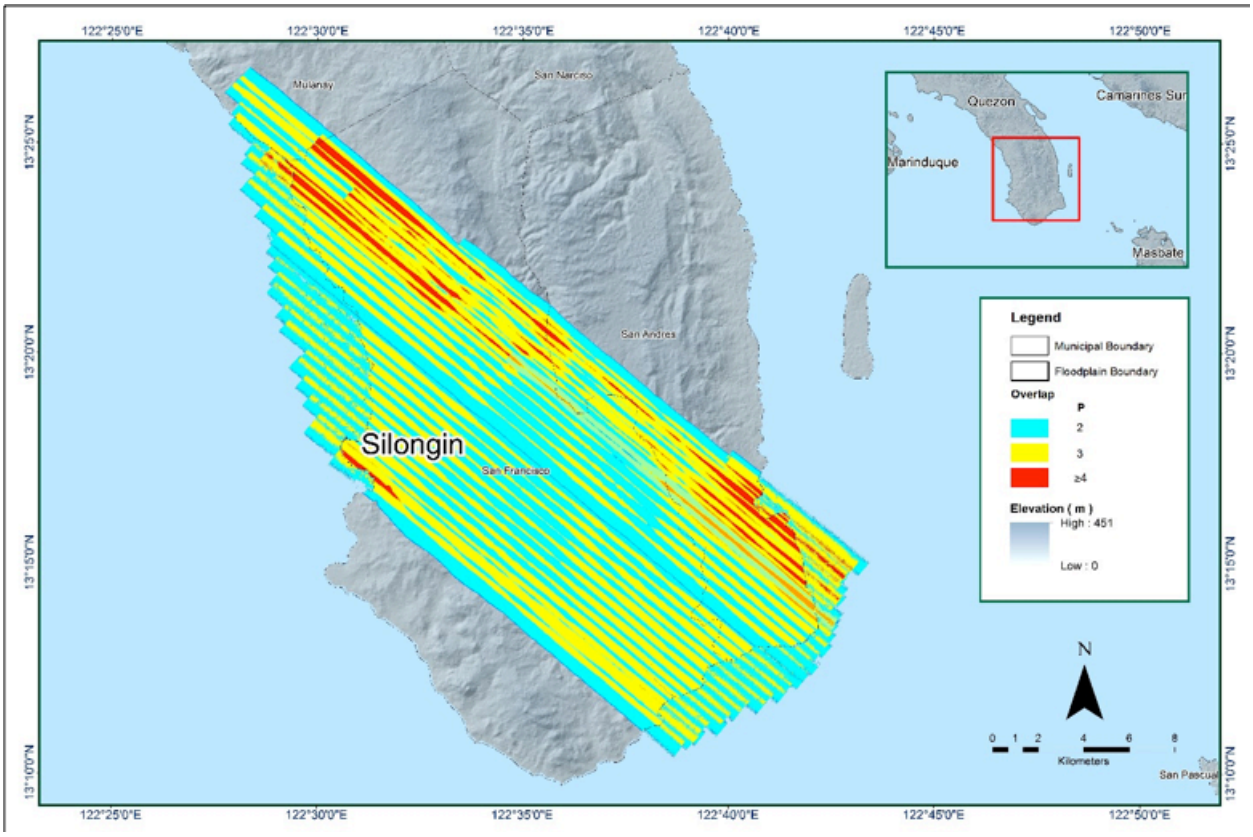

Figure 10. Image of data overlap for Silongin Floodplain

The overlap statistics per block for the Silongin Floodplain can be found in ANNEX 8. It should be noted that one pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 49.23% and 62.54%, 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 11. It was determined that all LiDAR data for Silongin Floodplain satisfy the point density requirement, and the average density for the entire survey area is 5.185 points per square meter.

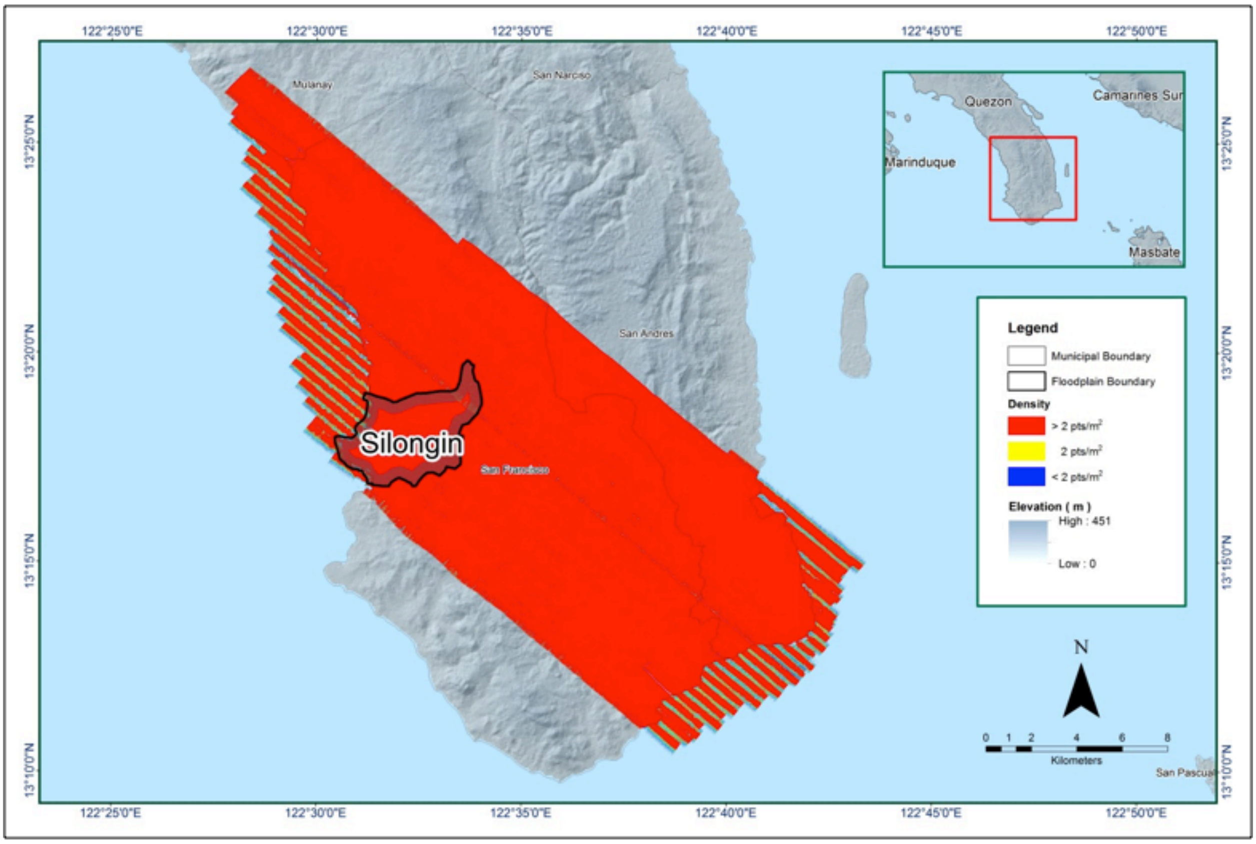

Figure 11. Pulse density map of merged LiDAR data for Silongin Floodplain

The elevation difference between overlaps of adjacent flight lines is shown in Figure 12. 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 0.20 m 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 0.20 m 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.

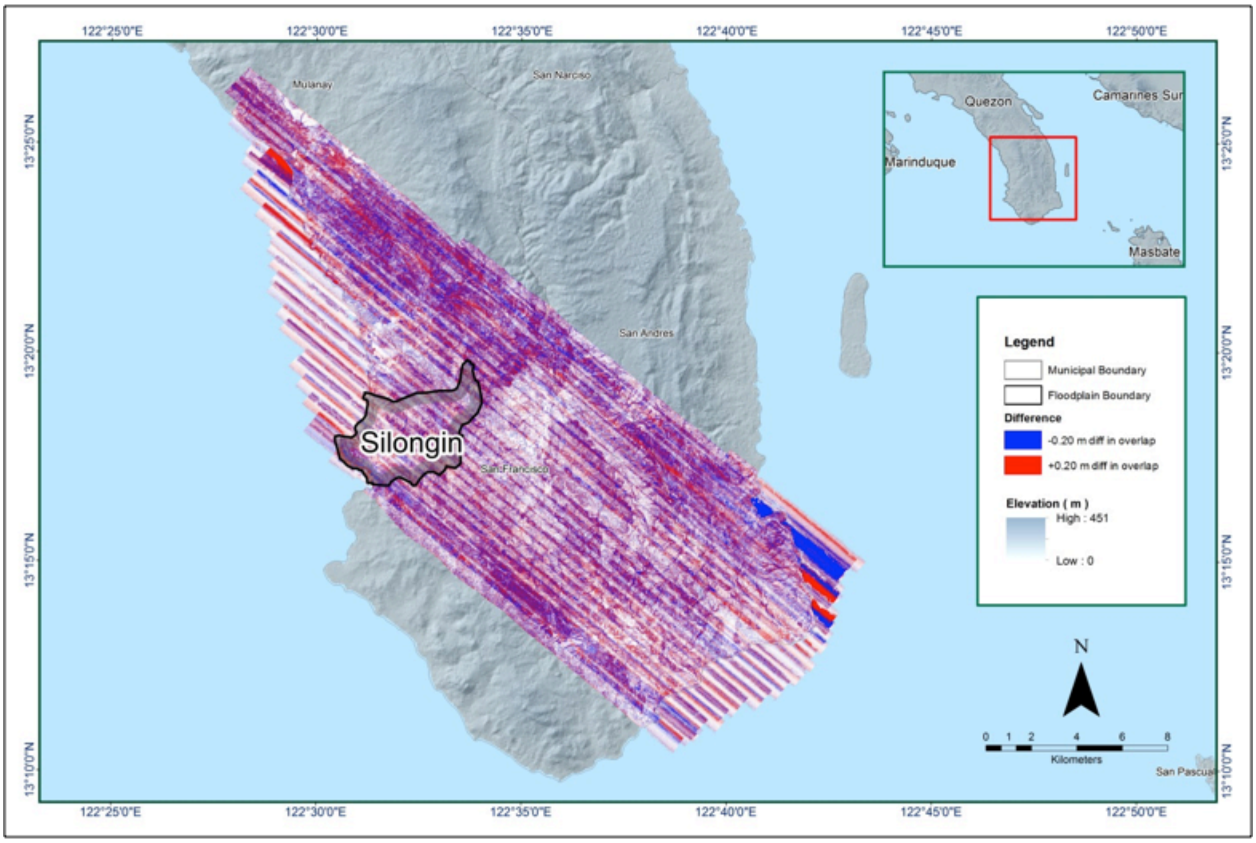

Figure 12. Elevation difference map between flight lines for Silongin Floodplain

A screen capture of the processed LAS data from a Silongin flight 23346P loaded in QT Modeler is shown in Figure 13. 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.

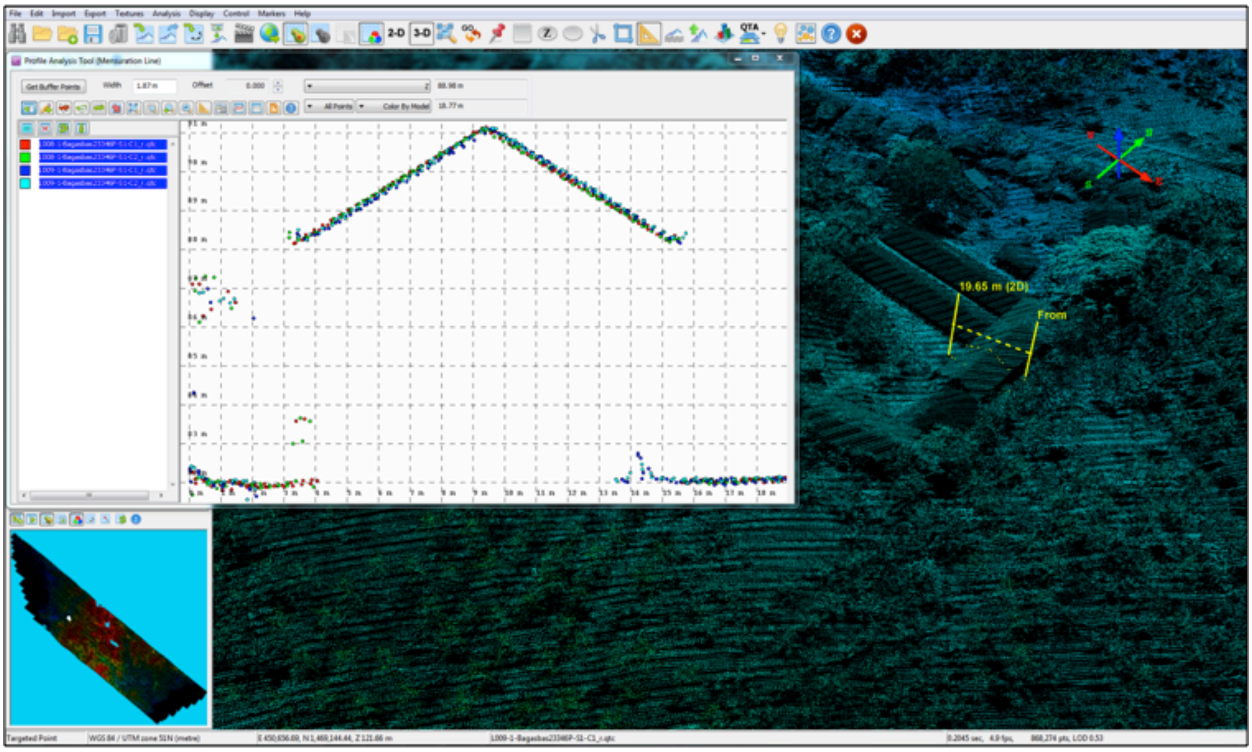

Figure 13. Quality checking for a Silongin flight 23346P using the Profile Tool of QT Modeler

3.6 LiDAR Point Cloud Classification and Rasterization

Table 10. Silongin classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	595,694,730
Low Vegetation	481,122,155
Medium Vegetation	728,736,459
High Vegetation	1,646,459,899
Building	14,731,556

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Silongin Floodplain is shown in Figure 14. A total of 460 1 km by 1 km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 10. The point cloud has a maximum and minimum height of 473.30 meters and 49.18 meters, respectively.

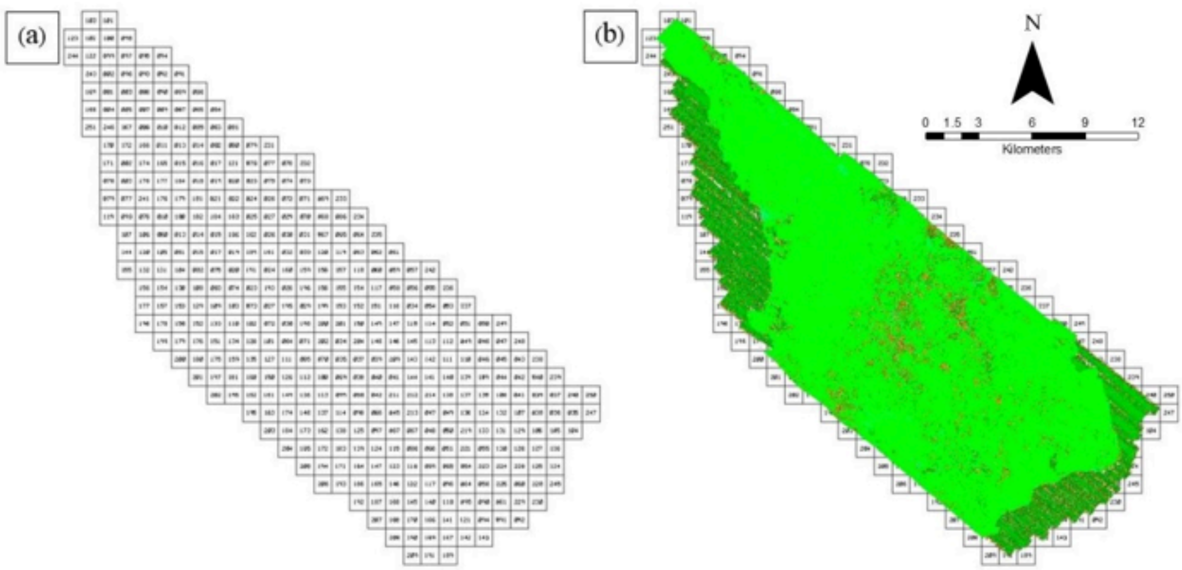

Figure 14. Tiles for Silongin Floodplain (a) and classification results (b) in TerraScan

An isometric view of an area before and after running the classification routines is shown in Figure 15. 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.

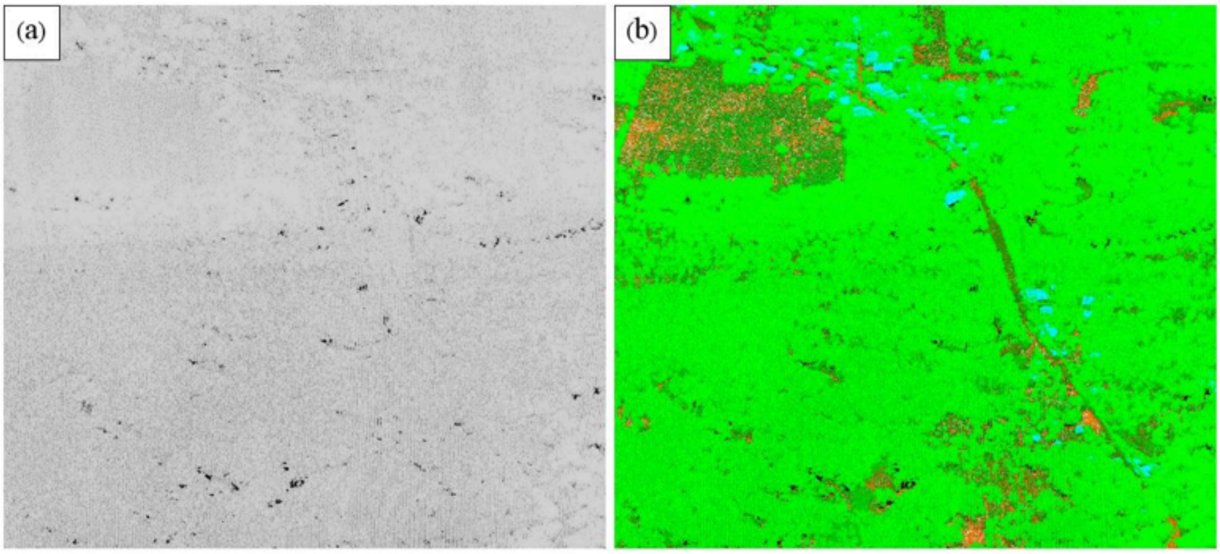

Figure 15. Point cloud before (a) and after (b) classification.

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

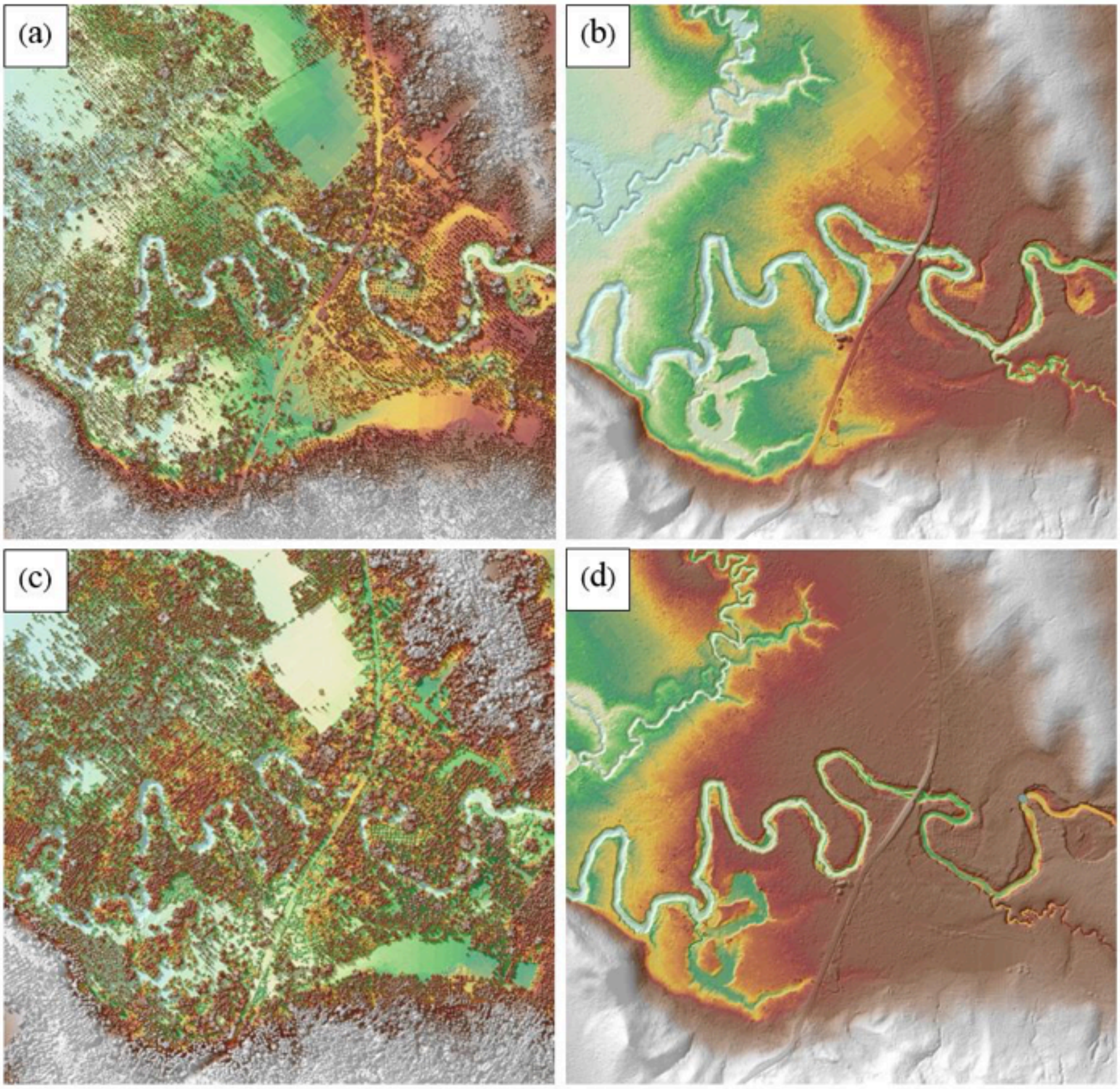

Figure 16. The production of last return DSM (a) and DTM (b); first return DSM (c) and secondary DTM (d) in some portion of Silongin Floodplain.

3. 7 LiDAR Image Processing and Orthophotograph Rectification

There are no available orthophotographs for the Silongin Floodplain.

3.8 DEM Editing and Hydro-Correction

Two (2) mission blocks were processed for Silongin Floodplain. These blocks are composed of Bagasbas block with a total area of 349.93 square kilometers. Table 11 shows the name and corresponding area of each block in square kilometers.

Table 11. LiDAR blocks with their corresponding area

LiDAR Blocks	Area (sq km)
Bagasbas_Blk21G	159.60
Bagasbas_Blk21H	190.33
TOTAL	349.93

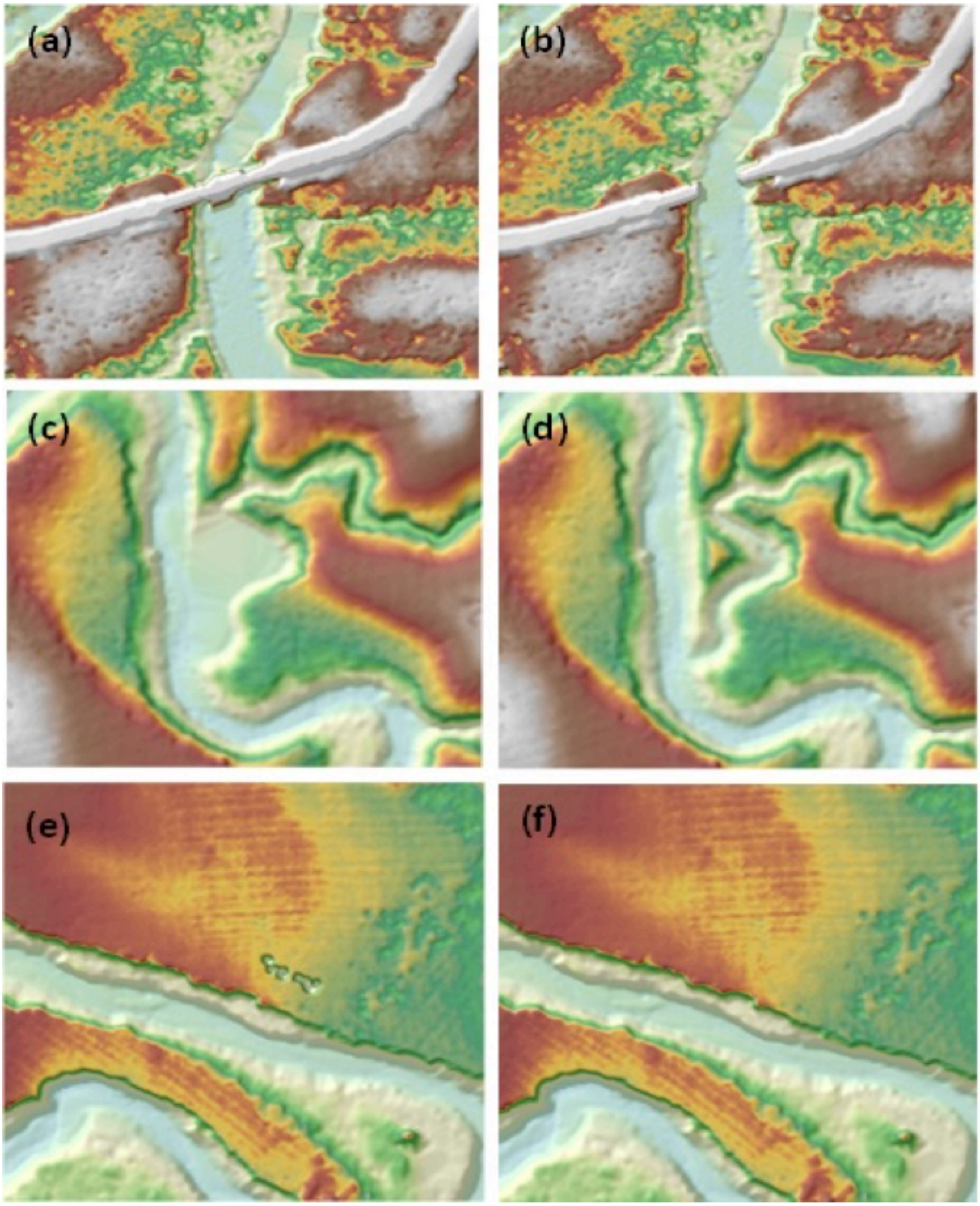

Figure 17. Portions in the DTM of Silongin Floodplain—a bridge before (a) and after (b) manual editing; a point bar before (c) and after (d) data retrieval; and a pit before (e) and after (f) manual editing

3.9 Mosaicking of Blocks

Bagasbas_Blk20F was used as the reference block at the start of mosaicking because this block is the one used as the base for other floodplains covered by Bagasbas blocks. Bagasbas_Blk21H is the block nearest from the base block that overlaps Silongin Floodplain.

Table 12. Shift values of each LiDAR block of Silongin Floodplain

Mission Blocks	Shift Values (meters)		
	x	y	z
Pagadian_Blk69A	0.00	0.00	0.96
Pagadian_Blk69D	0.00	0.00	0.66

Figure 18. Map of processed LiDAR data for Silongin Floodplain

3.10 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Silongin to collect points with which the LiDAR dataset is validated is shown in Figure 19. A total of 1,769 survey points were used for calibration and validation of Silongin LiDAR data. Eighty percent of the survey points, which were randomly selected and resulting in 1,415 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 20. 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 3.22 meters with a standard deviation of 0.09 meters. Calibration of Silongin LiDAR data was done by subtracting the height difference value, 3.22 meters, to Silongin mosaicked LiDAR data. Table 13 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

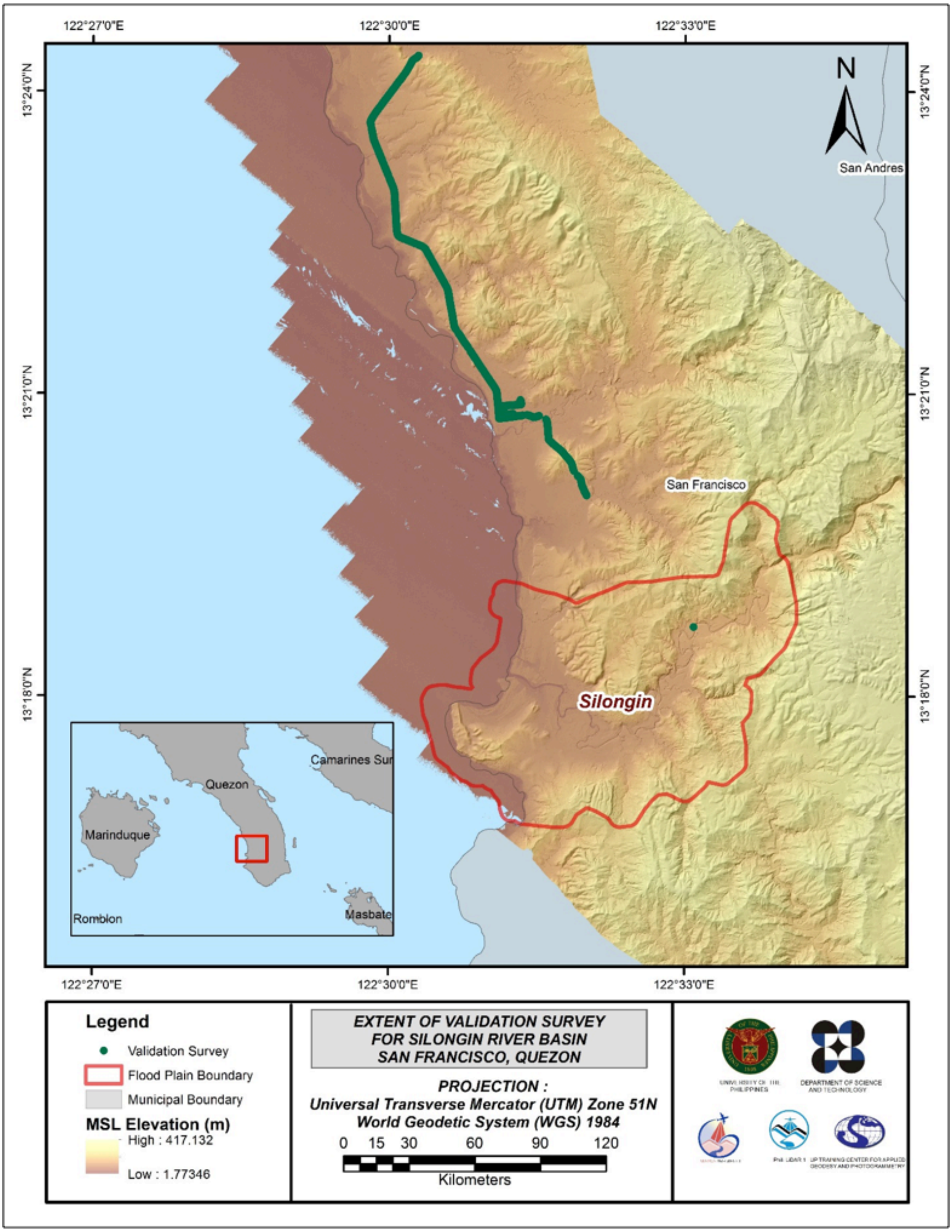

Figure 19. Map of Silongin Floodplain with validation survey points in green

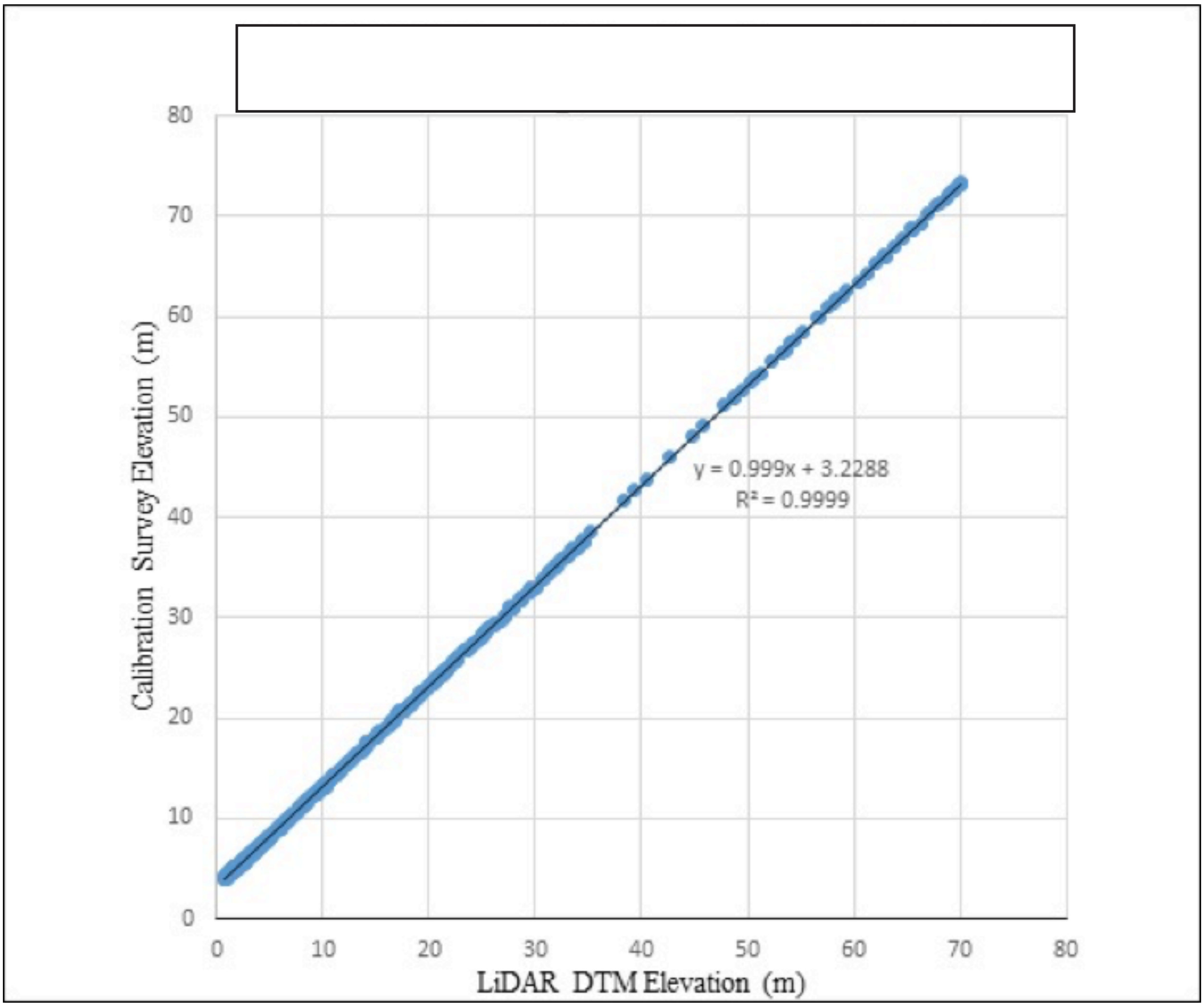

Figure 20. Correlation plot between calibration survey points and LiDAR data

Table 13. Calibration statistical measures

Calibration Statistical Measures	Value (meters)
Height Difference	3.22
Standard Deviation	0.09
Average	-3.22
Minimum	-3.48
Maximum	-2.85

The remaining 20% of the total survey points, resulting in 354 points, were used for the validation of calibrated Silongin 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 21. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.08 meters with a standard deviation of 0.08 meters, as shown in Table 14.

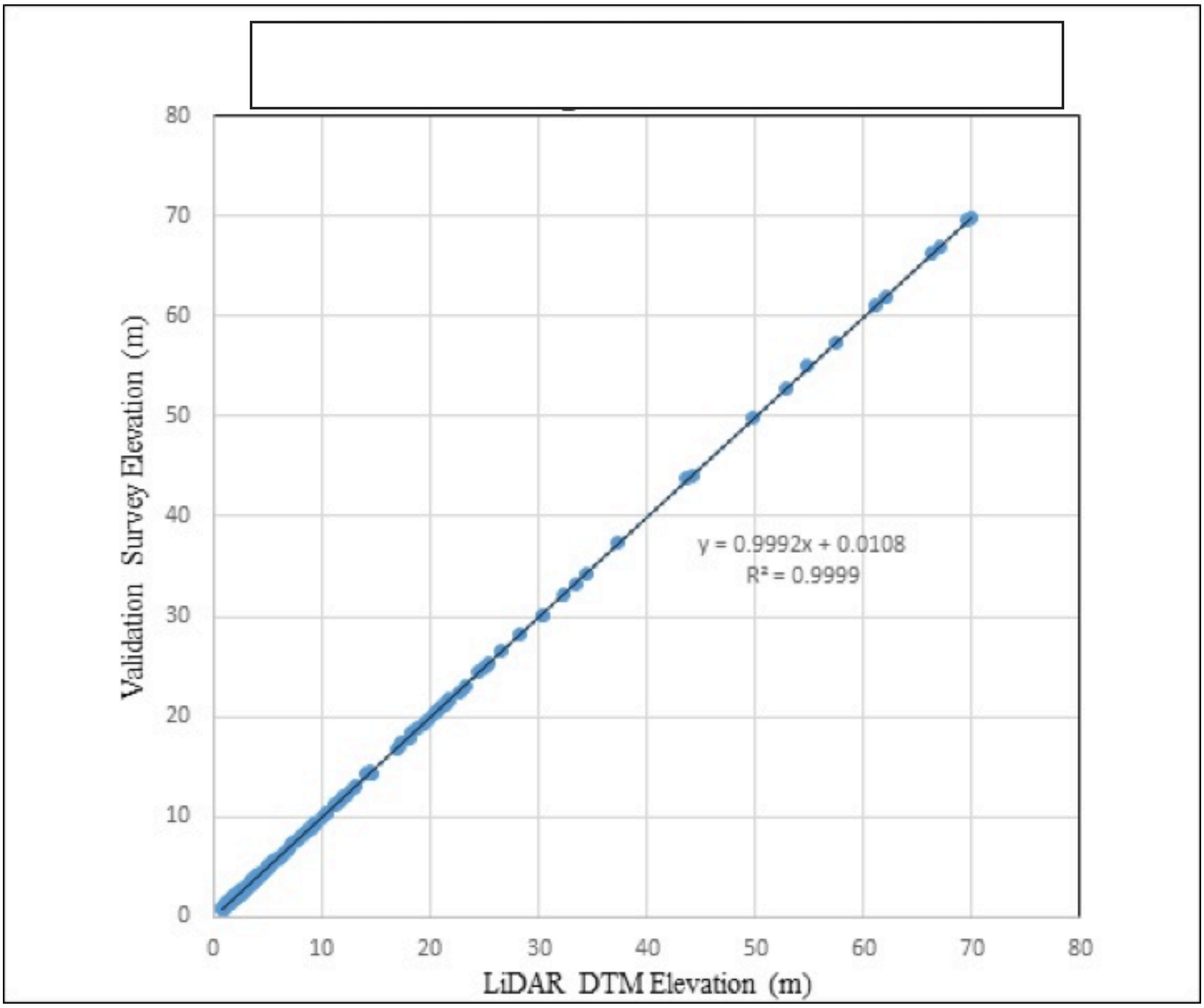

Figure 21. Correlation plot between validation survey points and LiDAR data

Table 14. Validation statistical measures

Validation Statistical Measures	Value (meters)
Height Difference	0.08
Standard Deviation	0.08
Average	-0.01
Minimum	-0.17
Maximum	0.17

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, both centerline and zigzag data were available for Silongin with 12,495 bathymetric survey points. The resulting raster surface produced was done by Kernel Interpolation with Barrier method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface was represented by the computed RMSE value of 0.22 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Silongin integrated with the processed LiDAR DEM is shown in Figure 22.

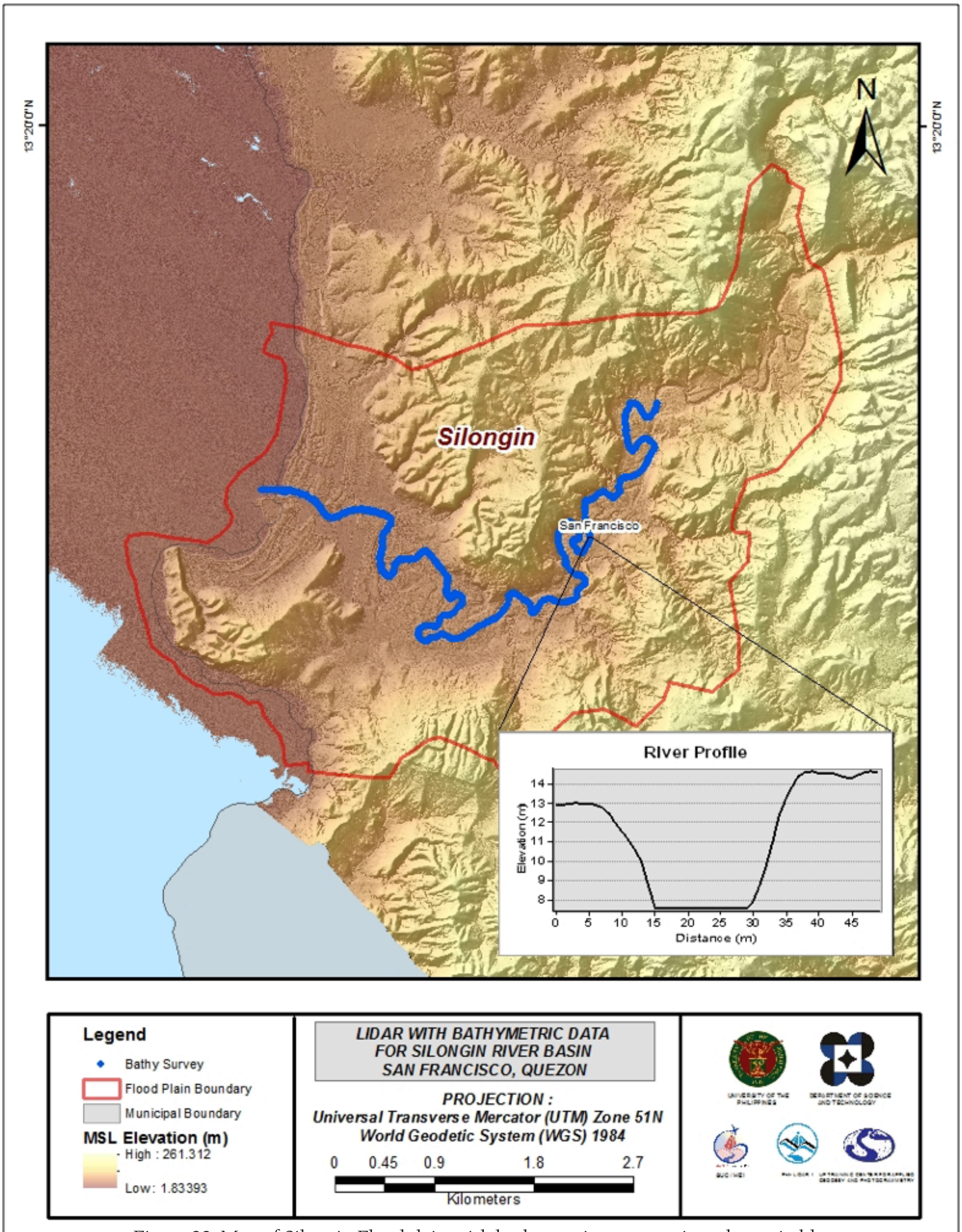

Figure 22. Map of Silongin Floodplain with bathymetric survey points shown in blue

3.12 Feature Extraction

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

3.12.1 Quality Checking of Digitized Features' Boundary

Silongin Floodplain, including its 200 m buffer, has a total area of 23.69 sq km. For this area, a total of 5.00 sq km, corresponding to a total of 598 building features, are considered for QC. Figure 23 shows the QC blocks for Silongin Floodplain.

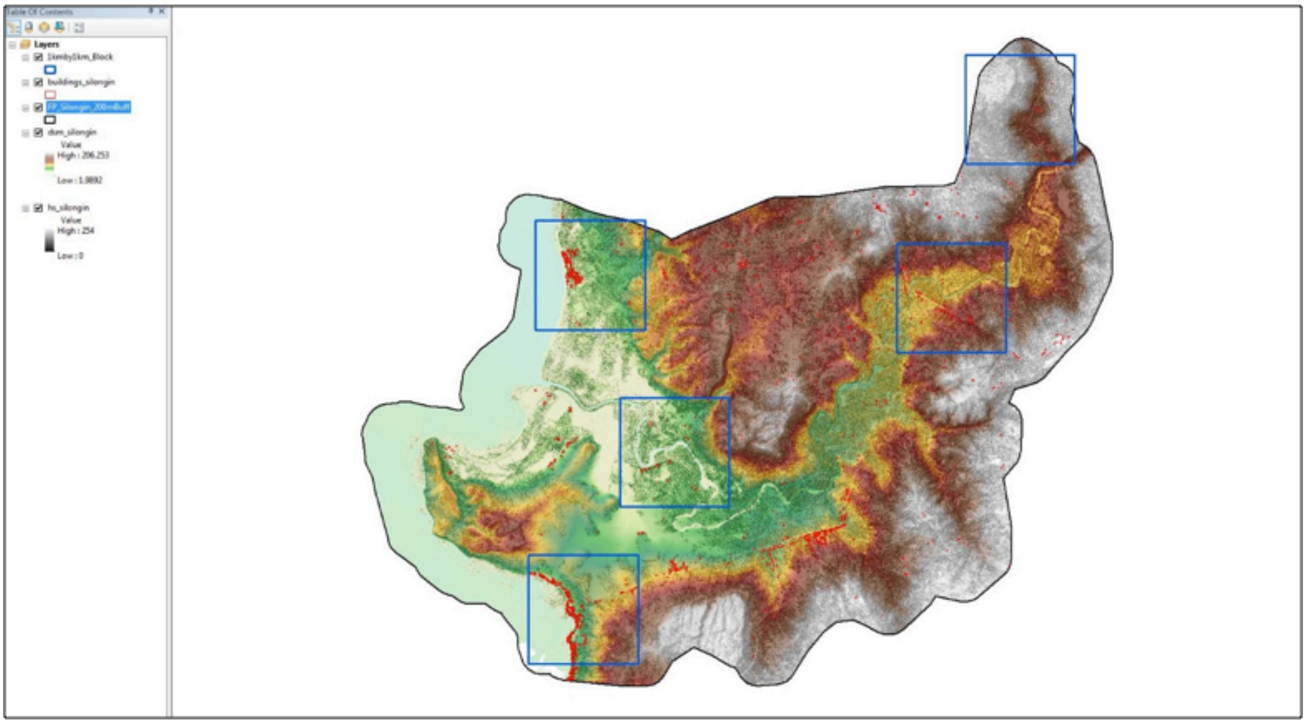

Figure 23. Blocks (in blue) of Silongin building features subjected to QC

Quality checking of Silongin building features resulted in the ratings shown in Table 15.

Table 15. Quality Checking Ratings for Silongin Building Features.

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Silongin	99.82	100.00	92.57	PASSED

3.12.2 Height Extraction

Height extraction was done for 1,309 building features in Silongin Floodplain. Of these building features, 8 were filtered out after height extraction, resulting in 1,301 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 6.25 m.

3.12.3 Feature Attribution

The attributes were obtained by field data gathering. GPS devices were used to determine the coordinates of important features. These points were uploaded and overlaid in ArcMap and then integrated with the shapefiles.

Table 16 summarizes the number of building features per type. On the other hand, Table 17 presents the total length of each road type, while Table 18 shows the number of water features extracted per type.

Table 16. Building Features Extracted for Silongin Floodplain.

Facility Type	No. of Features
Residential	1,265
School	29
Market	0
Agricultural/Agro-Industrial Facilities	0
Medical Institutions	1
Barangay Hall	2
Military Institution	0
Sports Center/Gymnasium/Covered Court	0
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	0
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	1
Water Supply/Sewerage	1
Religious Institutions	1
Bank	0
Factory	0
Gas Station	0
Fire Station	0
Other Government Offices	0
Other Commercial Establishments	1
Total	1,301

Table 17. Total Length of Extracted Roads for Silongin Floodplain.

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Silongin	8.61	5.61	3.14	0.00	0.90	18.26

Table 18. Number of Extracted Water Bodies for Silongin Floodplain.

Floodplain	Water Body Type					Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Silongin	4	0	0	0	0	4

A total of 19 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 24 shows the Digital Surface Model (DSM) of Silongin Floodplain overlaid with its ground features.

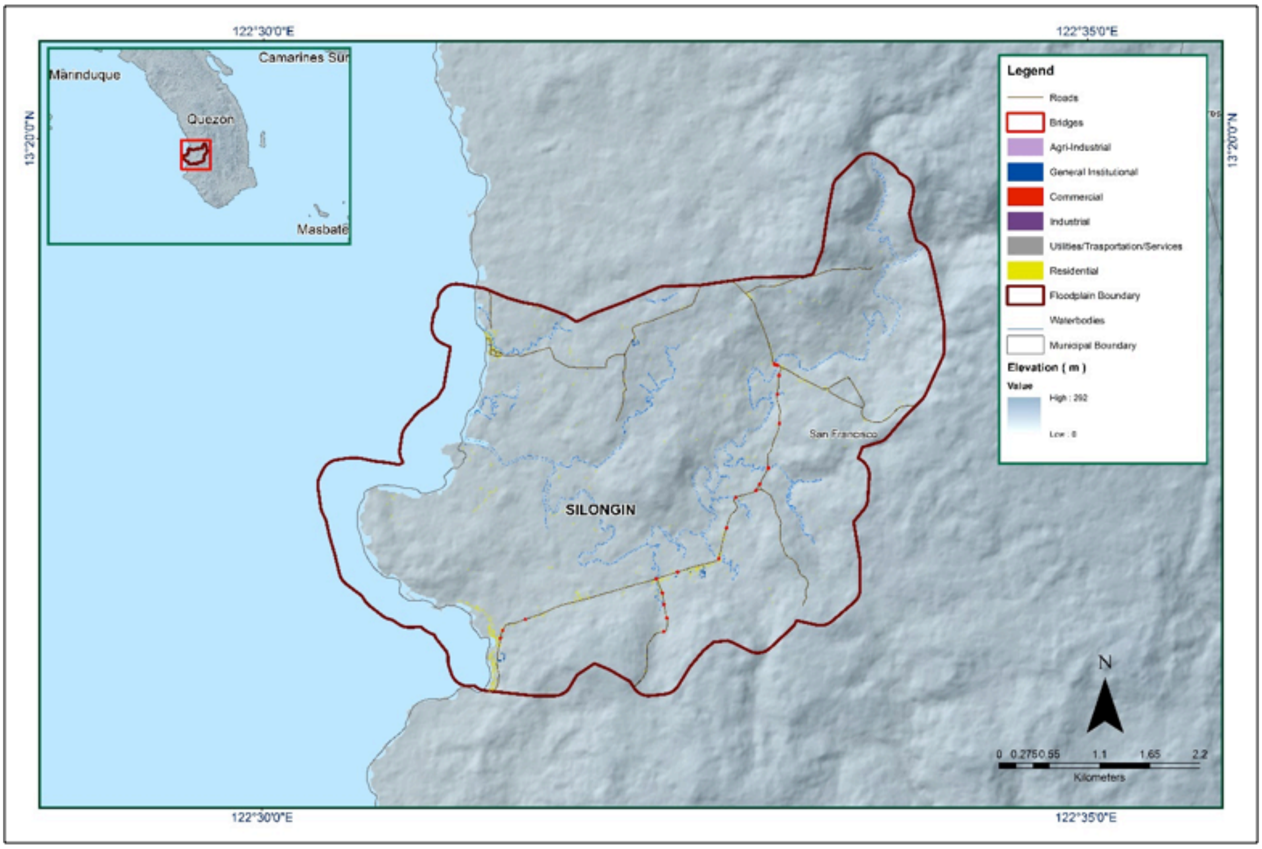

Figure 24. Extracted features for Silongin Floodplain

CHAPTER 4: LIDAR VALIDATION SURVEY AND MEASUREMENTS IN THE SILONGIN RIVER BASIN

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

4.1 Summary of Activities

The Data Validation and Bathymetry Component (DVBC) conducted a field survey in Silongin River on May 2–16, 2016 with the following scope of work: reconnaissance; control survey; cross-section and as-built survey at Kanguinsa Bridge in Brgy. Silongin, Municipality of San Fracisco; validation points acquisition of about 11.174 km covering the Silongin River Basin area; and bathymetric survey from its upstream to the mouth of the river both in Brgy. Silongin in the Municipality of San Francisco, with an approximate length of 9.235 km using Ohmex™ single-beam echo sounder and Trimble® SPS 882 GNSS PPK survey technique (Figure 25).

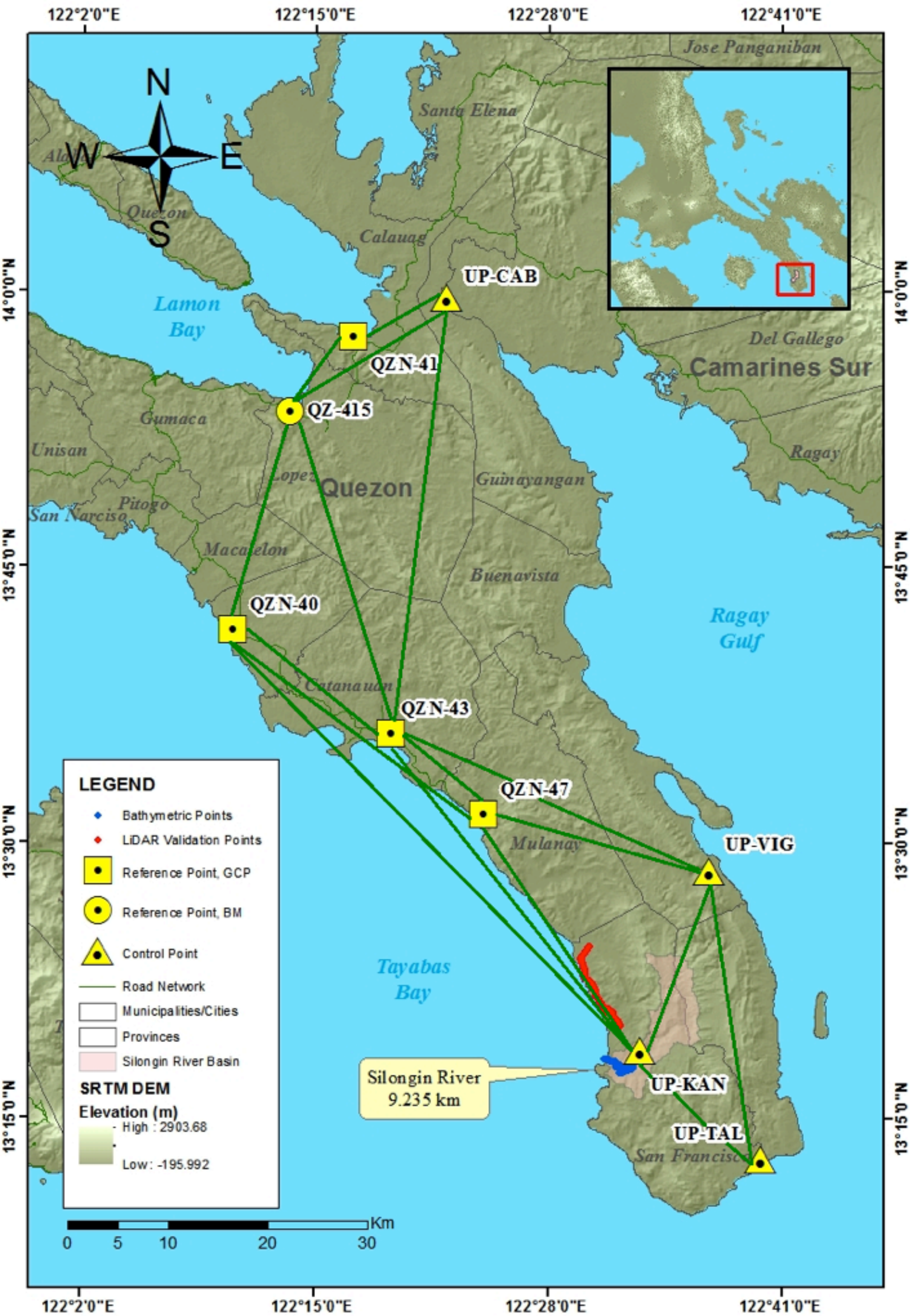


Figure 25. Extent of the bathymetric survey (in blue) in Silongin River and the LiDAR validation survey (in red)

4.2 Control Survey

The GNSS network used for Silongin River Basin is composed of nine (9) loops established on May 4 and 11, 2016 occupying the following reference points: QZN-40, a second-order GCP in Brgy. San Jose, Municipality of General Luna; QZN-43, a second-order GCP in Brgy. Matandang Sabang Silangan, Municipality of Catanauan; QZN-47, a second-order GCP in Barangay II, Municipality of Mulanay; and QZ-415, a BM with Accuracy Class at 95% CL 8 cm in Brgy. Pansol, Municipality of Lopez.

There are four (4) UP-established control points located at the approach of bridges, namely: UP-KAN at Kanguinsa Bridge in Brgy. Silongin, Municipality of San Francisco; UP-TAL at Talisay Bridge in Brgy. Pagsangahan, also in the Municipality of San Francisco; and UP-VIG at Vigo Bridge in Brgy. Vigo Central, Municipality of San Narciso. The UP-established control point UP-CAB is located in a residential court in Brgy. Aloneros, Municipality of Guinayangan. A NAMRIA established control point QZN-41 in Barangay I, Municipality of Calauag was also occupied and used as marker for the network.

The summary of reference and control points and its location is summarized in Table 19 while GNSS network established is illustrated in Figure 26.

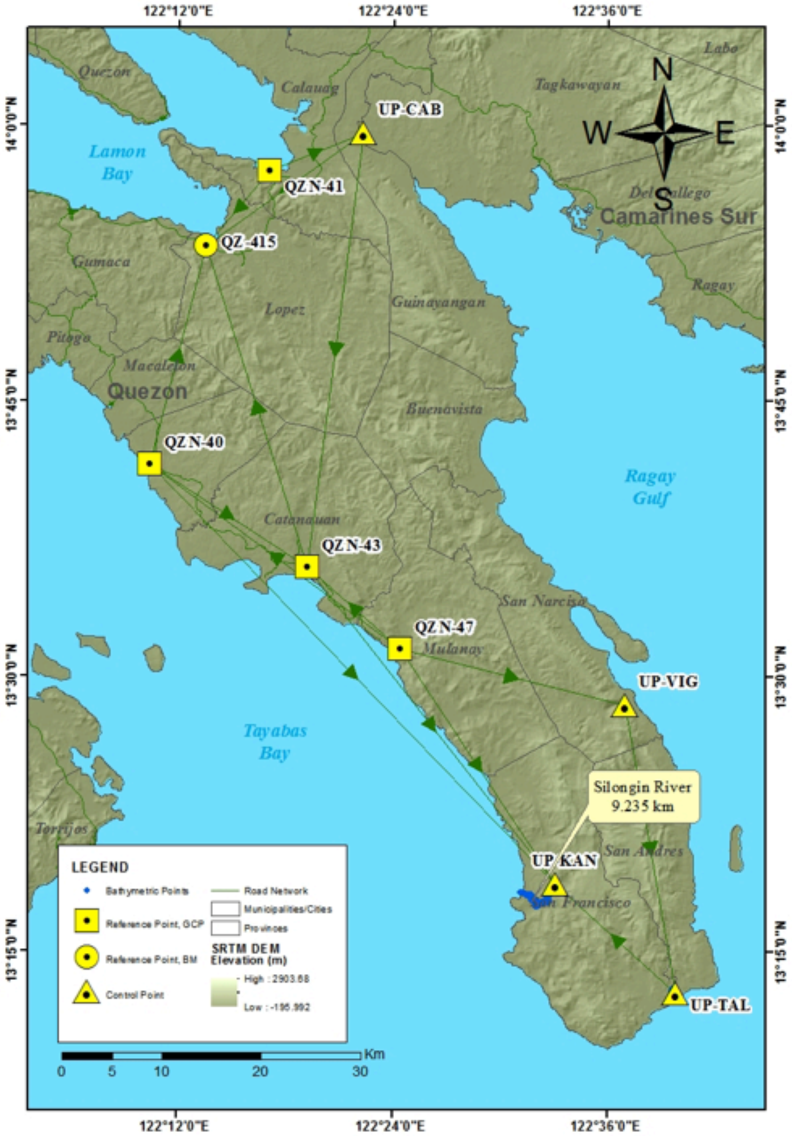


Figure 26. GNSS Network of Silongin River Field Survey

Table 19. List of References and Control Points occupied for Silongin River Survey (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (Meter)	Elevation in MSL (Meter)	Date Established
QZN-40	2nd Order, GCP	13°41'32.47595" N	122°10'25.77273" E	51.703	-	2006
QZN-43	2nd Order, GCP	13°35'55.81611" N	122°19'13.53031" E	51.015	-	2006
QZN-47	2nd Order, GCP	13°31'29.52488" N	122°24'23.44821" E	53.862	-	2006
QZ-415	1st order Order, BM	-	-	57.290	8.613	2007
QZN-41	Used as Marker	-	-	-	-	2006
UP-CAB	UP Established	-	-	-	-	05-04-2016
UP-KAN	UP Established	-	-	-	-	05-11-2016
UP-TAL	UP Established	-	-	-	-	05-11-2016
UP-VIG	UP Established	-	-	-	-	05-11-2016

The GNSS set up for control points used in the Silongin survey are shown in Figure 27 to Figure 35.

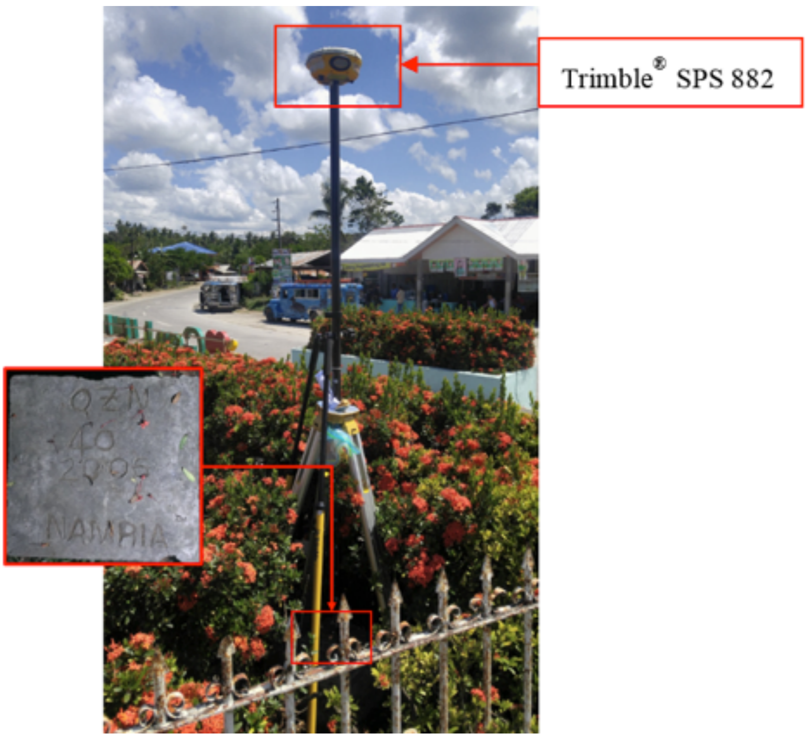


Figure 27. GNSS base set-up, Trimble® SPS 882, at QZN-40, located inside a triangular plant area found at the center of a triangular island in Brgy. San Jose, Municipality of Gen. Luna, Quezon

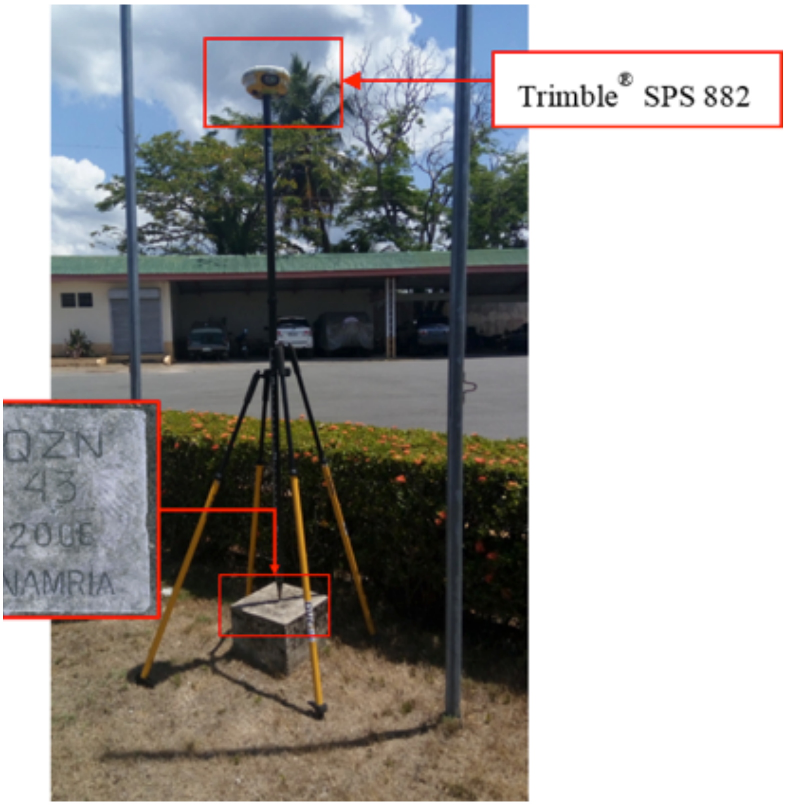


Figure 28. GNSS base set-up, Trimble® SPS 882, at QZN-43, located inside the DPWH compound in Brgy. Matandang Sabang Silangan, Municipality of Catanauan, Quezon

Figure 29. GNSS base set-up, Trimble® SPS 852, at QZN-47, located at the back of the Principal's Office of Mulanay Elementary School in Barangay II, Municipality of Mulanay, Quezon

Figure 30. GNSS base set-up, Trimble® SPS 985, at QZ-415, located at the approach of Pansol Bridge in Brgy. Pansol, Municipality of Lopez, Quezon

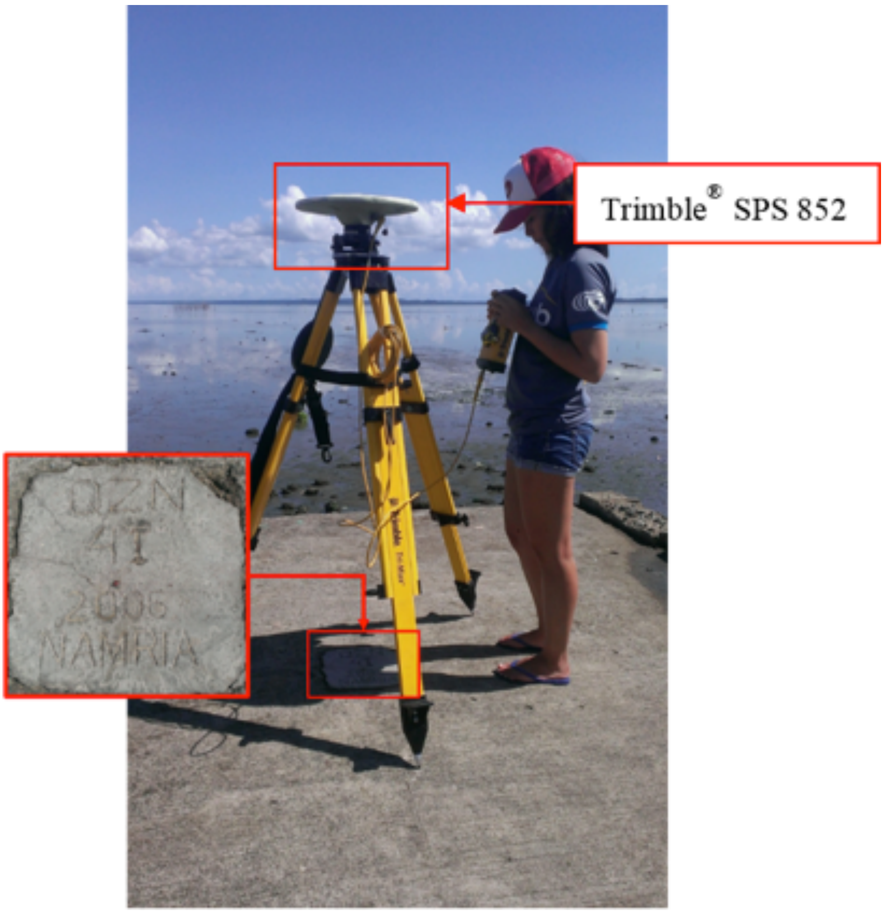


Figure 31. GNSS base set-up, Trimble® SPS 852, at QZN-41, located in front of Brgy. Sabang basketball court found in Calauag Port, Barangay I, Municipality of Calauag, Quezon

Figure 32. vGNSS base set-up, Trimble® SPS 882, at UP-CAB, located inside a basketball court in Brgy. Aloneros, Municipality of Guinayangan, Quezon

Figure 33. GNSS base set-up, Trimble® SPS 852, at UP-KAN, located at the approach of Kanguinsa Bridge in Brgy. Silongin, Municipality of San Francisco, Quezon

Figure 34. GNSS base set-up, Trimble® SPS 852, at UP-TAL, located at the approach of Talisay Bridge in Brgy. Pagsangahan, Municipality of San Francisco, Quezon

Figure 35. GNSS base set-up, Trimble® SPS 882, at UP-VIG, located at the approach of Vigo Bridge in Brgy. Vigo Central, Municipality of San Francisco, Quezon

4.3 Baseline Processing

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

Table 20. Baseline Processing Report for Silongin River Basin Static Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)
QZN-47 --- QZN-40	05-11-2016	Fixed	0.003	0.011	306°22'36"	31263.486
QZN-47 --- QZN-43	05-11-2016	Fixed	0.003	0.013	131°16'56"	12401.416
QZN-47 --- UP-VIG	05-11-2016	Fixed	0.003	0.012	103°58'19"	23335.323
QZN-47 --- UP-KAN	05-11-2016	Fixed	0.005	0.019	146°21'08"	28388.037
QZN-40 --- QZ-415	05-11-2016	Fixed	0.003	0.023	14°21'16"	22613.475
UP-CAB --- QZ-415	05-04-2016	Fixed	0.004	0.025	234°09'16"	19401.067
QZN-40 --- UP-KAN	05-11-2016	Fixed	0.011	0.027	135°49'24"	58749.581
QZN-43 --- QZ-415	05-11-2016	Fixed	0.006	0.033	342°23'19"	33841.349
QZN-43 --- UP-KAN	05-11-2016	Fixed	0.005	0.018	141°46'15"	40492.330
UP-TAL --- UP-KAN	05-11-2016	Fixed	0.005	0.018	312°01'33"	16293.271
UP-VIG --- UP-TAL	05-11-2016	Fixed	0.003	0.014	169°50'51"	29356.882
UP-VIG --- QZN-43	05-11-2016	Fixed	0.003	0.014	293°25'54"	34821.073
UP-VIG --- UP-KAN	05-11-2016	Fixed	0.005	0.021	201°04'03"	19280.526
QZN-41 --- UP-CAB	05-04-2016	Fixed	0.004	0.024	247°44'12"	10141.643
QZN-41 --- QZ-415	05-04-2016	Fixed	0.003	0.022	220°07'13"	9835.756
QZN-40 --- QZN-43	05-11-2016	Fixed	0.003	0.014	303°07'59"	18937.828
UP-CAB --- QZN-43	05-11-2016	Fixed	0.004	0.019	7°10'02"	43963.480

As shown in Table 20, a total of seventeen (17) baselines were processed with reference points QZN-40, QZN-43, and QZN-47 fixed for grid values; and QZ-415 held fixed for elevation. All of them passed the required accuracy.

4.4 Network Adjustment

After the baseline processing procedure, network adjustment is performed using TBC. Looking at the Adjusted Grid Coordinates (Table 22) 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. In equation form:

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

Where:

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

for each control point. See the Network Adjustment Report shown in ANNEX 3 to ANNEX 5 for the complete details.

The nine (9) control points, QZN-40, QZN-43, QZN-47, QZ-415, QZN-41, UP-CAB, UP-KAN, UP-TAL, and UP-VIG were occupied and observed simultaneously to form a GNSS loop. Elevation value of QZ-415 and coordinates of points QZN-40, QZN-43, and QZN-47 were held fixed during the processing of the control points as presented in Table 21. Through these reference points, the coordinates and elevation of the unknown control points will be computed.

Table 21. Control Point Constraints

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
QZN-40	Global	Fixed	Fixed		
QZN-43	Global	Fixed	Fixed		
QZN-47	Global	Fixed	Fixed		
QZ-415	Grid				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 22. The fixed control points QZN-40, QZN-43, QZN-47, and QZ-415 have no values for grid and elevation errors, respectively.

Table 22. Adjusted Grid Coordinates

Point ID	Easting	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
QZN-40	410660.624	?	1513855.137	?	2.622	0.075	LL
QZN-43	426485.118	?	1503462.996	?	1.574	0.073	LL
QZN-47	435778.405	?	1495257.875	?	4.163	0.079	LL
QZ-415	416340.495	0.010	1535736.431	0.010	8.613	?	e
QZN-41	422699.129	0.014	1543236.263	0.014	1.392	0.082	
UP-CAB	432091.726	0.012	1547052.366	0.013	3.211	0.073	
UP-KAN	451445.231	0.012	1471596.832	0.011	25.095	0.086	
UP-TAL	463529.271	0.016	1460676.916	0.014	4.949	0.095	
UP-VIG	458401.312	0.010	1489570.998	0.008	6.030	0.083	

The network is fixed at reference points QZN-40, QZN-43, and QZN-47 QZN-40, QZN-43, and QZN-47 with known coordinates, and QZ-415 with known elevation. As shown in Table 22, the standard errors (xe and ye) of QZ-415 are 1.0 cm and 1.0 cm. With the mentioned equation, $\sqrt{((x_e)^2 + (y_e)^2)}$ <20cm and $z_e < 10\ cm$ or horizontal and z_e<10 cm for the vertical,; the computation for the accuracy of the reference and control points are as follows:

QZN-40
horizontal accuracy = Fixed
vertical accuracy = 7.5 cm < 10 cm

QZN-43
horizontal accuracy = Fixed
vertical accuracy = 7.3 cm < 10 cm

QZN-47
horizontal accuracy = Fixed
vertical accuracy = 7.9 cm < 10 cm

QZ-415
horizontal accuracy = √((1. 0)² + (1.0)²
= √ (1.0 + 1.0)
= 1.41cm < 20 cm
vertical accuracy = Fixed

QZN-41
horizontal accuracy = √((1.40)² + (1.40)²
= √ (1.96+ 1.96)
= 1.98cm < 20 cm
vertical accuracy = 8.2 cm < 10 cm

UP-CAB
horizontal accuracy = √((1.20)² + (1.30)²
= √ (1.44 + 1.69)
= 1.77 cm < 20 cm
vertical accuracy = 7.3 cm < 10 cm

UP-KAN
horizontal accuracy = $\sqrt{((1.20)^2 + (1.10)^2}$
= $\sqrt{(1.44 + 1.21)}$
= **1.63 cm < 20 cm**
vertical accuracy = **8.6 cm < 10 cm**

UP-TAL
horizontal accuracy = $\sqrt{((1.60)^2 + (1.40)^2}$
= $\sqrt{(2.56 + 1.96)}$
= **2.13 cm < 20 cm**
vertical accuracy = **9.5 cm < 10 cm**

UP-VIG
horizontal accuracy = $\sqrt{((1.10)^2 + (0.80)^2}$
= $\sqrt{(1.21 + 0.64)}$
= **1.36 cm < 20 cm**
vertical accuracy = **8.3 cm < 10 cm**

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

Table 23. Adjusted geodetic coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
QZN-40	N13°41'32.47595	E122°10'25.77273"	51.703	0.075	LL
QZN-43	N13°35'55.81611	E122°19'13.53031"	51.015	0.073	LL
QZN-47	N13°31'29.52488	E122°24'23.44821"	53.862	0.079	LL
QZ-415	N13°53'25.29589	E122°13'32.50380"	57.290	?	e
QZN-41	N13°57'30.05268	E122°17'03.60722"	50.089	0.082	
UP-CAB	N13°59'35.12930	E122°22'16.30558"	52.023	0.073	
UP-KAN	N13°18'40.40211	E122°33'06.07511"	75.768	0.086	
UP-TAL	N13°12'45.55145	E122°39'48.22322"	55.864	0.095	
UP-VIG	N13°28'25.87675	E122°36'56.35787"	56.412	0.083	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 23. Based on the result of the computation, the accuracy condition is satisfied; hence, the required accuracy for the program was met.

The summary of reference and control points used is indicated in Table 24.

Table 24. Reference and control points used and their 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	BM Ortho (m)
QZN-40	2nd Order GCP	13°41'32.47595" N	122°10'25.77273" E	51.703	1513855.137	410660.624	2.622
QZN-43	2nd Order GCP	13°35'55.81611" N	122°19'13.53031" E	51.015	1503462.996	426485.118	1.574
QZN-47	2nd Order GCP	13°31'29.52488" N	122°24'23.44821" E	53.862	1495257.875	435778.405	4.163
QZ-415	1st Order BM	13°53'25.29589" N	122°13'32.50380" E	57.290	1535736.431	416340.495	8.613
QZN-41	Used as Marker	13°57'30.05268" N	122°17'03.60722" E	50.089	1543236.263	422699.129	1.392
UP-CAB	UP Established	13°59'35.12930" N	122°22'16.30558" E	52.023	1547052.366	432091.726	3.211
UP-KAN	UP Established	13°18'40.40211" N	122°33'06.07511" E	75.768	1471596.832	451445.231	25.095
UP-TAL	UP Established	13°12'45.55145" N	122°39'48.22322" E	55.864	1460676.916	463529.271	4.949

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

Cross-section survey was conducted at the downstream part of Kanguinsa Bridge on May 13, 2016 using Ohmex™ single-beam echo sounder and a GNSS receiver, Trimble® SPS 882, in PPK survey technique as shown in Figure 36.

Figure 36. Kanguinsa Bridge and the actual cross-section survey using Trimble® SPS 882 in PPK survey technique

Figure 37. Water level marking at Kanguinsa Bridge

Water surface elevation in MSL of Silongin River was determined using GNSS receiver, Trimble® SPS 882, in PPK survey technique on May 13, 2016 at 1:31 PM with a value of 17.620 m in MSL. This was translated onto marking on one of the pier of Kanguinsa Bridge using the same technique as shown in Figure 37. The markings would serve as their reference for flow data gathering and depth gauge deployment for Silongin River.

The cross-sectional line length for Silongin River is about 126.863 m with 21 total cross-sectional points acquired using UP-KAN as the GNSS base station. The location map, cross section diagram, and bridge as-built form are illustrated in Figure 38 to Figure 40.

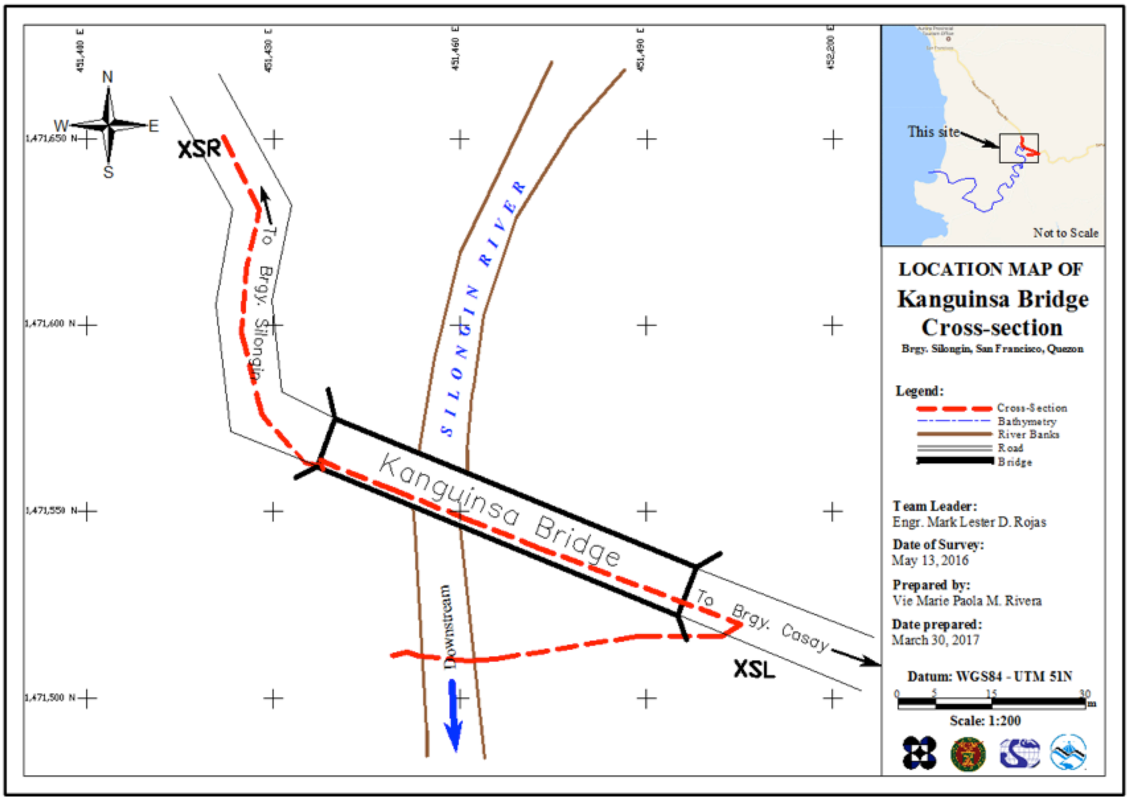


Figure 38. Kanguinsa bridge cross-section location map

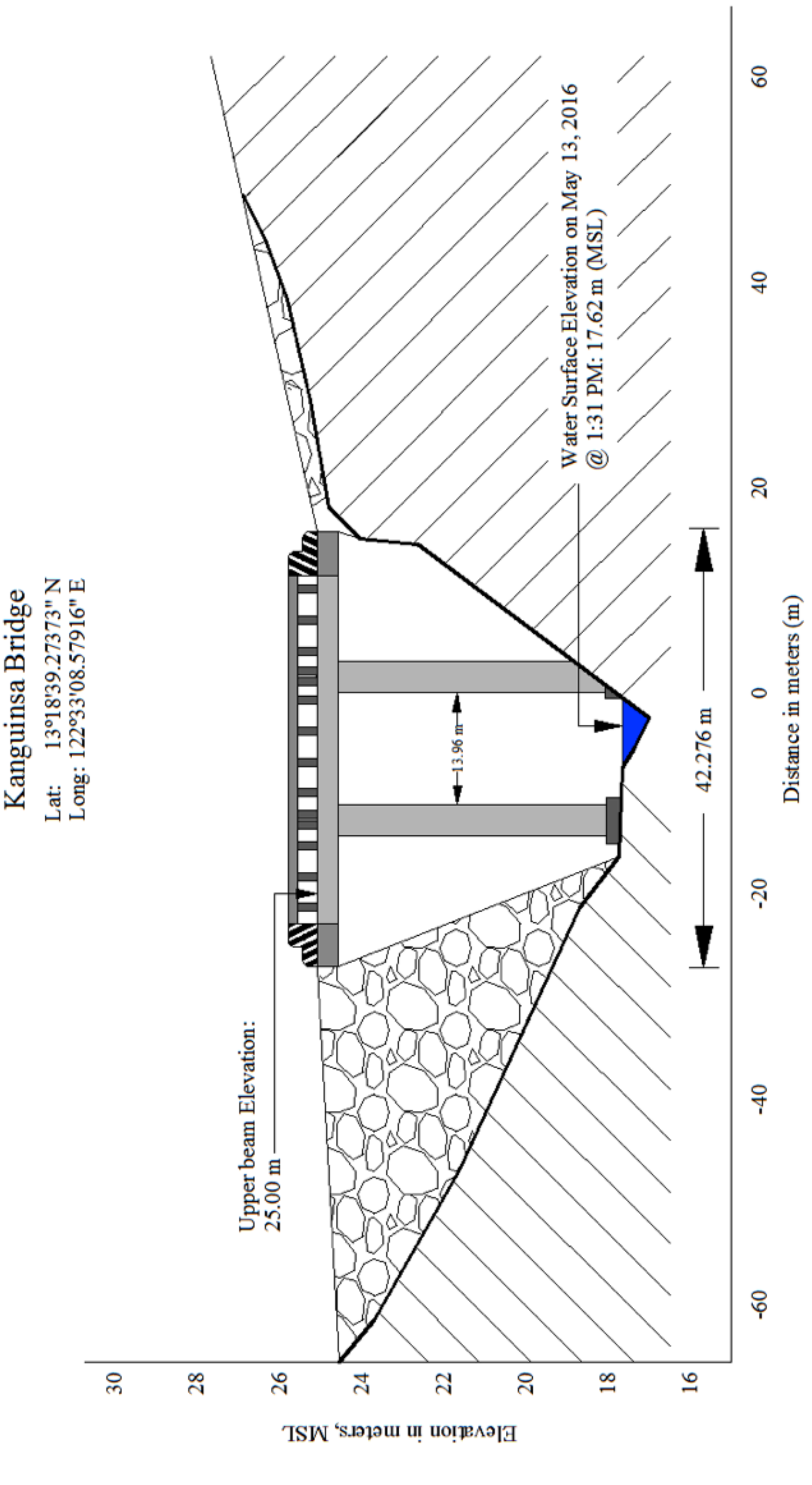


Figure 39. Kanguinsa Bridge Cross-section, Diagram

Bridge Data Form

Bridge Name: Kanguinsa Bridge **Date: May 13, 2016**

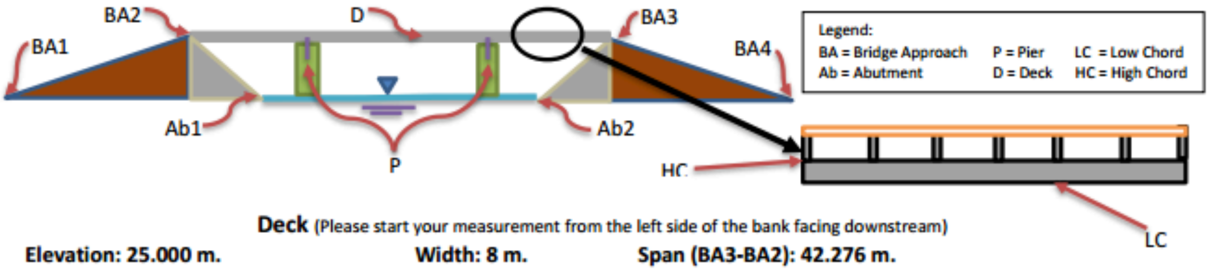
River Name: Silongin River **Time: 1:31 PM**

Location: Brgy. Silongin, Municipality of San Francisco, Quezon

Survey Team: Mark Rojas, Marla Morris, Pauline Racoma, Michael Labrador, Erlan Mendoza, Romalyn Boado

Flow condition: low ✓ normal high **Weather Condition:** ✓ fair rainy

Latitude: 13°18'39.71384"N **Longitude: 122°33'07.38494"E**



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

Elevation: 25.000 m. **Width: 8 m.** **Span (BA3-BA2): 42.276 m.**

	Station	High Chord Elevation	Low Chord Elevation
1	NA		

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	24.510	BA3	80.664	25.052
BA2	38.388	25.000	BA4	126.863	27.631

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

	Station (Distance from BA1)	Elevation
Ab1		
Ab2		

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

Shape: Cylindrical Number of Piers: 2 Height of column footing: N/A

	Station (Distance from BA1)	Elevation	Pier Width
Pier 1	52.618	25.093	8
Pier 2	66.578	25.063	8
Pier 3			
Pier 4			

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

Figure 40. Kanguinsa Bridge Data Form

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on May 13, 2016 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted on the roof of the vehicle as shown in Figure 41. It was secured with a cable tie to ensure that it was horizontally and vertically balanced. The antenna height was 1.87 m and measured from the ground up to the bottom of notch of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with UP-KAN occupied as the GNSS base station.

Figure 41. Validation points acquisition survey set up

Going north, the survey started from Brgy. Inabuan, passed through barangays Poblacion, Cawayan I, and ended in Brgy. Ibabang Tayuman, all in the Municipality of San Francisco. This route aims to cut flight strips made by the Data Acquisition Team perpendicularly. The survey gathered 2,211 points with an approximate length of 11.174 km using UP-KAN as GNSS base station for the entire extent validation points acquisition survey as illustrated in the map in Figure 42.

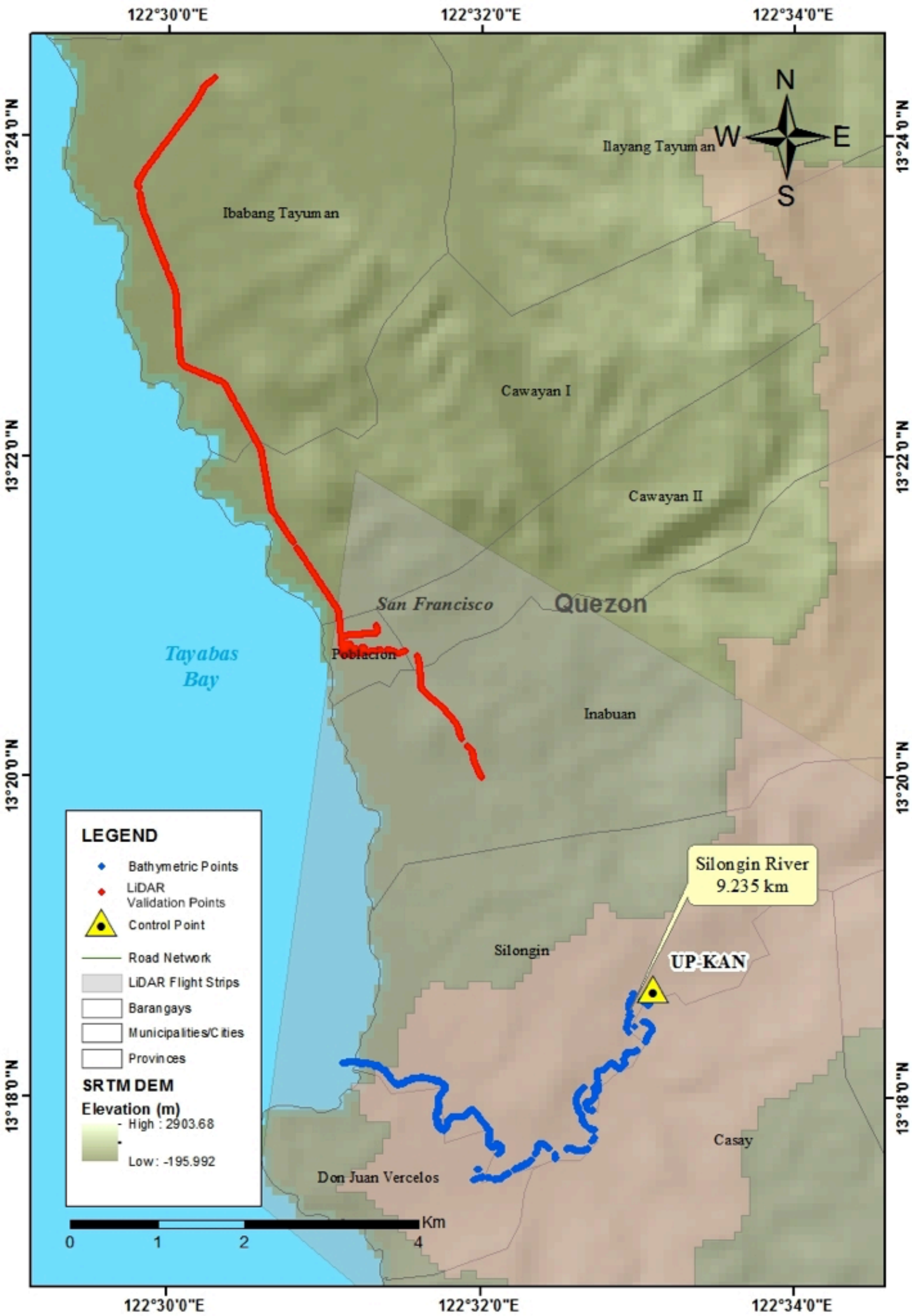


Figure 42. Validation point acquisition survey for the Silongin River Basin

4.7 Bathymetric Survey

Bathymetric survey was executed on May 13 and 14, 2016 using a Trimble® SPS 882 in GNSS PPK survey technique and an Ohmex™ single-beam echo sounder as shown in Figure 43. The extent of the survey is from the middle portion of the river in Brgy. Silongin, Municipality of San Francisco with coordinates 13°17'43.74913"N, 122°32'03.41608"E, and ended at the mouth of the river also in the same barangay with corrdinates 13°18'12.78249"N, 122°31'07.44204"E.

Figure 43. Bathymetry by boat set up for Silongin River survey

Manual Bathymetric survey, on the other hand, was executed also on May 13 and 14, 2016 using a combination of Trimble® SPS 882 in GNSS PPK survey technique and a Total Station through open traverse method as shown in Figure 44. The extent of the survey is from the upstream portion of the river in Brgy. Silongin, Municipality of San Francisco with coordinates 13°18'38.26922"N, 122°33'06.49631"E, and ended at the starting point of bathymetric survey using a boat in the same barangay and municipality.

Figure 44. Manual Bathymetry set up for Silongin River survey

A CAD drawing was also produced to illustrate the riverbed profile of Silongin River. As shown in Figure 46, the highest and lowest elevation has a 16-meter difference. The highest elevation observed is 20.552 m above MSL located at the upstream portion of the river while the lowest elevation observed is -4.200 m below MSL located around 800 m from the mouth of the river, both in Brgy. Silongin, Municipality of San Fracisco. The bathymetric survey gathered a total of 8,676 points covering 9.235 km of the river traversing mostly Brgy. Silongin and a small portion of Barangays Don Juan Vercelos and Casay. Around 5 km was added from the target bathymetric line to reach the deployment site of the partner HEI, Mapua Institute of Technology.

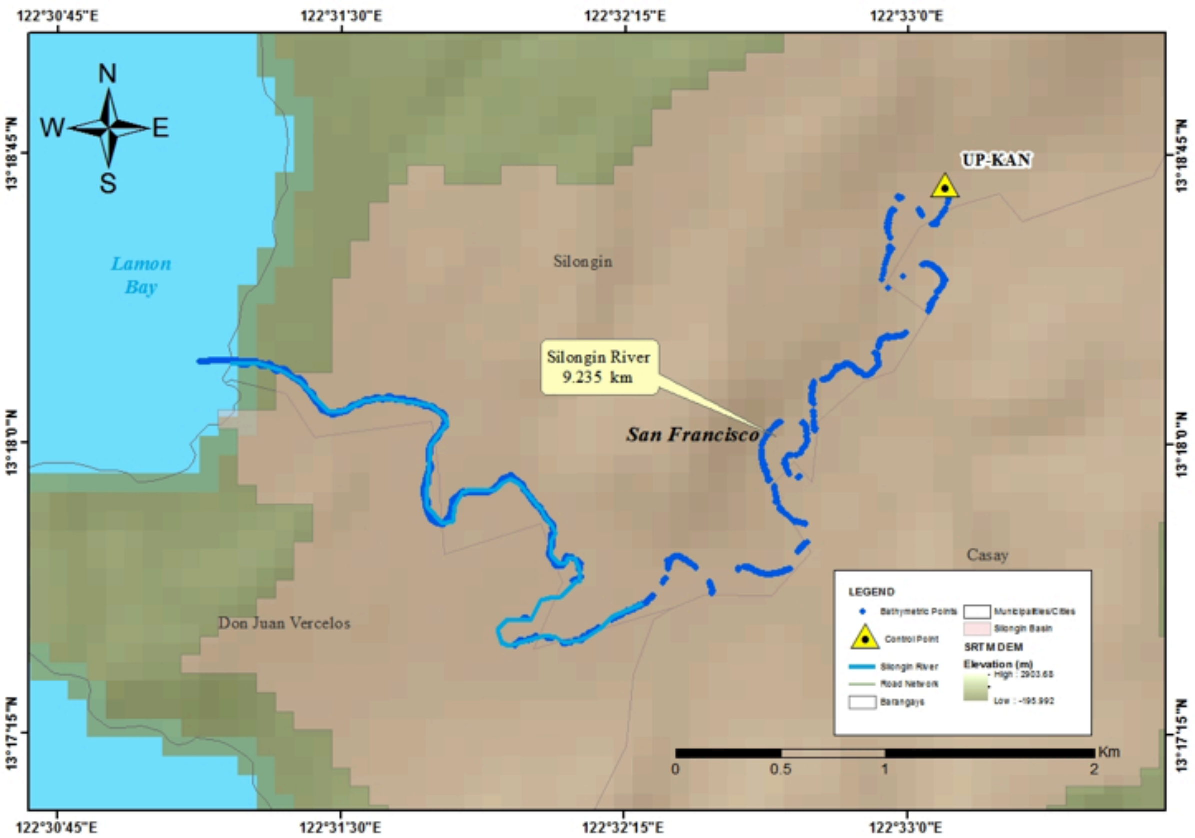


Figure 45. Bathymetric survey of Silongin River

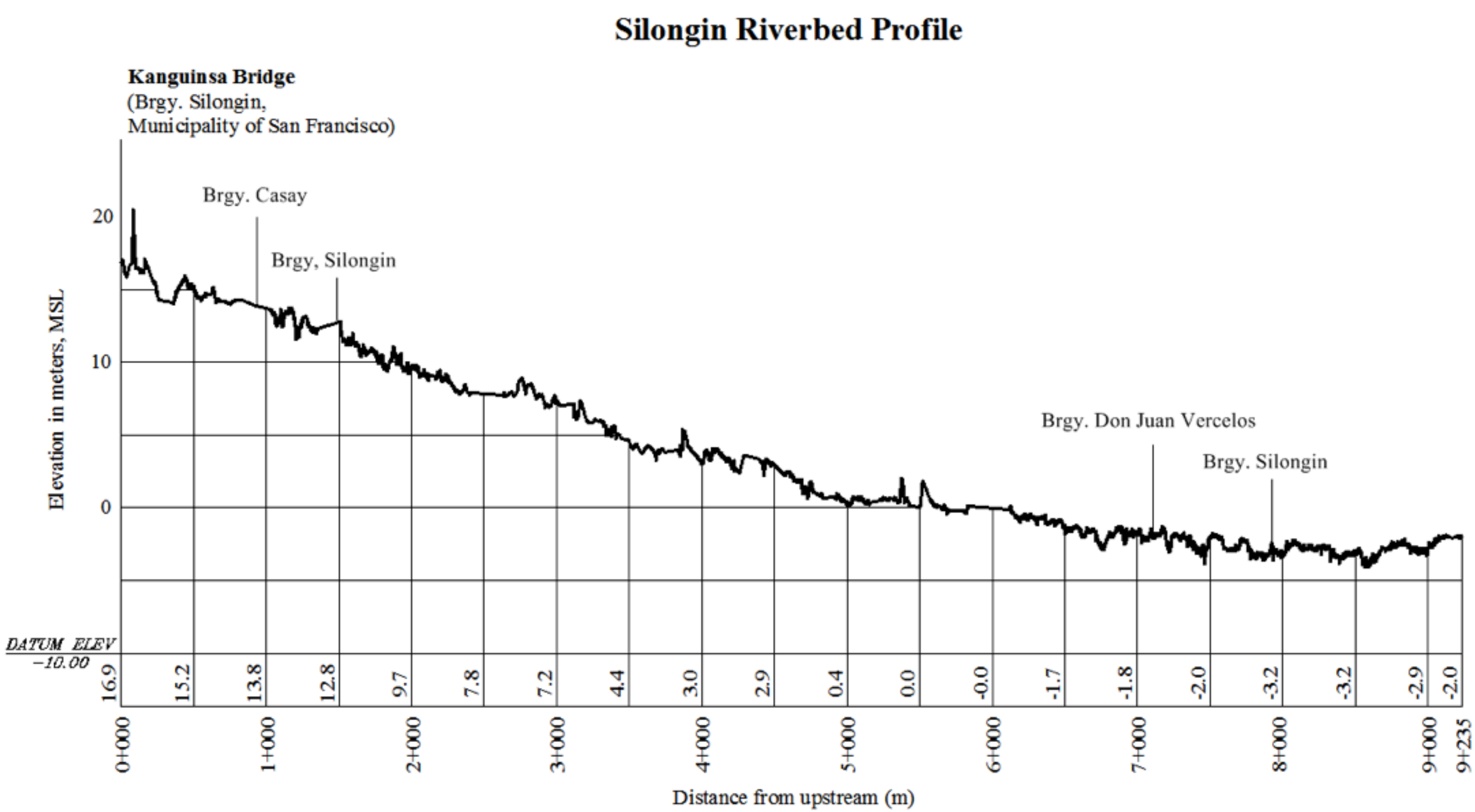


Figure 46. Riverbed profile of Silongin River

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, Pauline Racoma

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

5.1 Data used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

Rainfall, water level, and flow in a certain period of time, which may affect the hydrologic cycle of the river basin, were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from an automatic rain gauge installed by the Mapua Phil-LiDAR 1 in Casay Highschool San Francisco, Quezon (122°32’41.283”E, 13°17’28.539”N). The location of the rain gauges is seen in Figure 47. The precipitation data collection started from October 12, 2016 12:00 AM to October 12, 2016 11:45 PM with a 15-minute recording interval.

The total rain from the automatic rain gauge is 31 mm. It peaked to 9.6 mm on October 12, 2016 at 18:30. The lag time between the peak rainfall and discharge is 6 hours and 50 minutes.

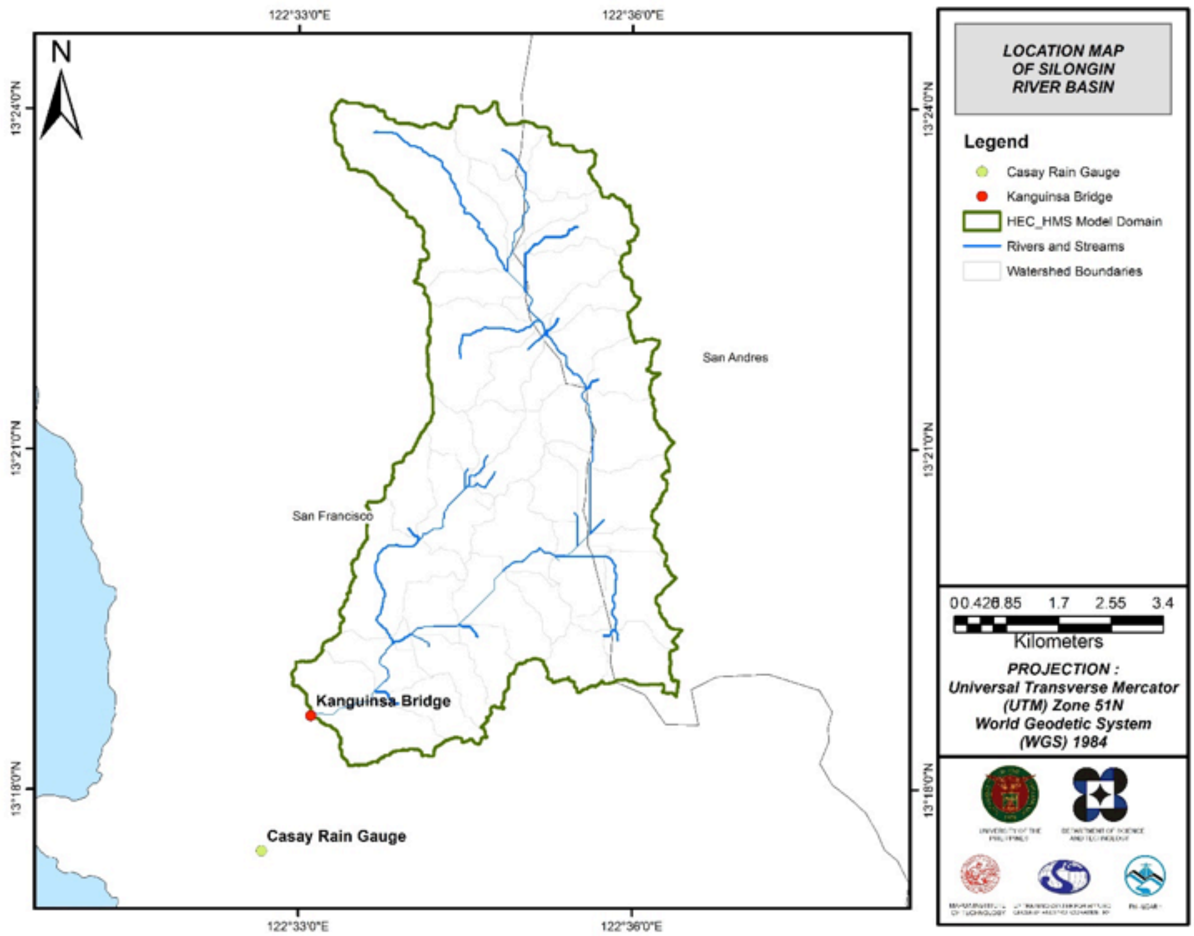


Figure 47. Location map of rain gauges used for the calibration of the Silongin HEC-HMS Model

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Kanguinsa Bridge, San Francisco, Quezon (13°18'40.03"N, 122°33'6.43"E). It gives the relationship between the observed water levels from the Kanguinsa Bridge using depth gage and outflow of the watershed got using the flow meter at this location.

For Kanguinsa Bridge, the rating curve is expressed as Q = 2E-45e5.8587x as shown in Figure 49.

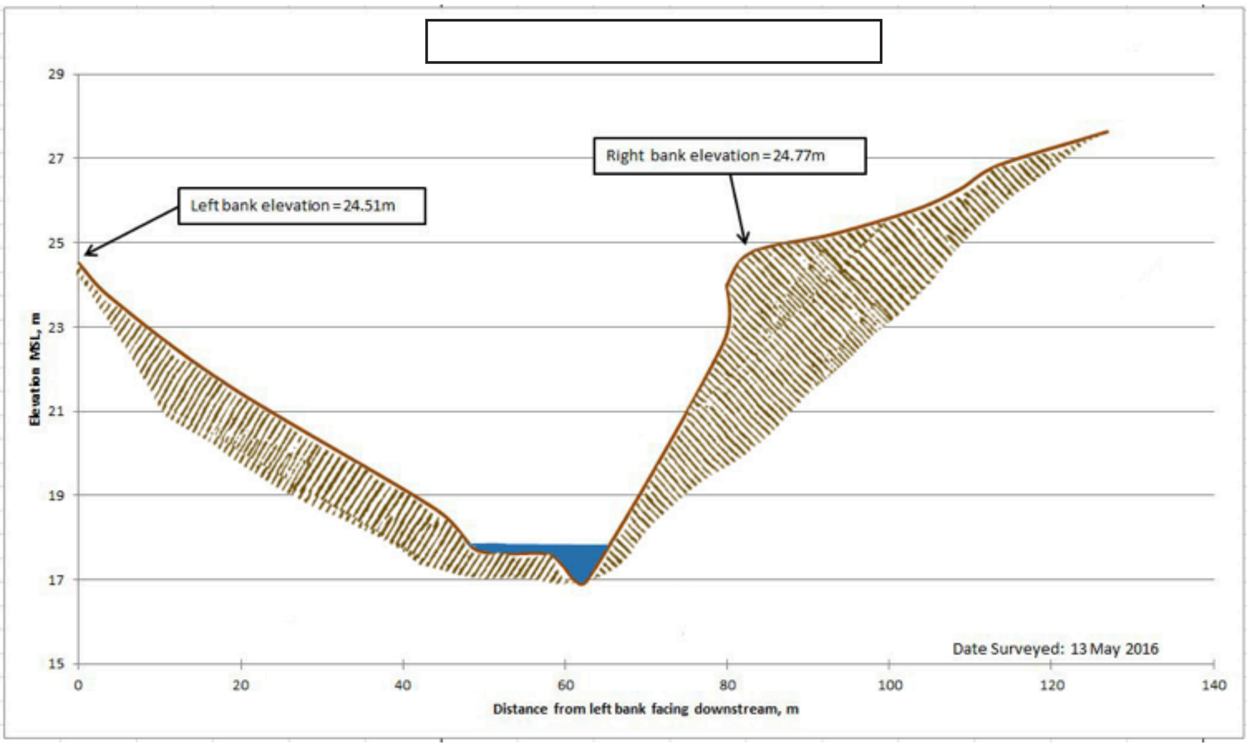


Figure 48. Cross-section plot of the Silongin Bridge

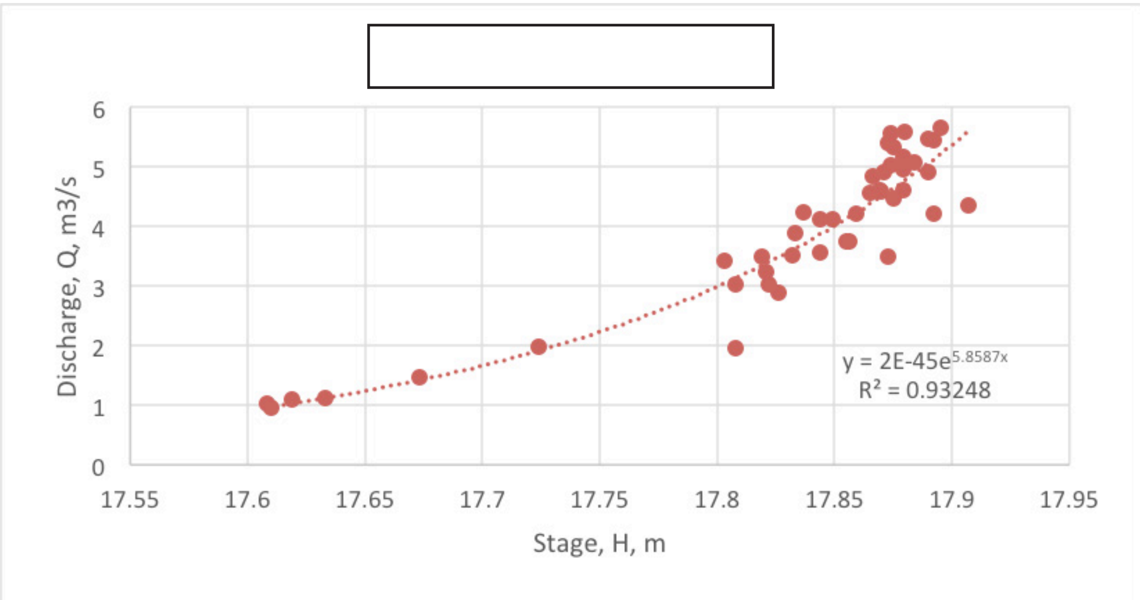


Figure 49. Rating Curve at Kanguinsa Bridge, San Francisco, Quezon.

This rating curve equation was used to compute the river outflow at Kanguinsa for the calibration of the HEC-HMS model shown in Figure 50. Peak discharge is 5.66 m3/s at 1:20 AM, Oct 13, 2016.

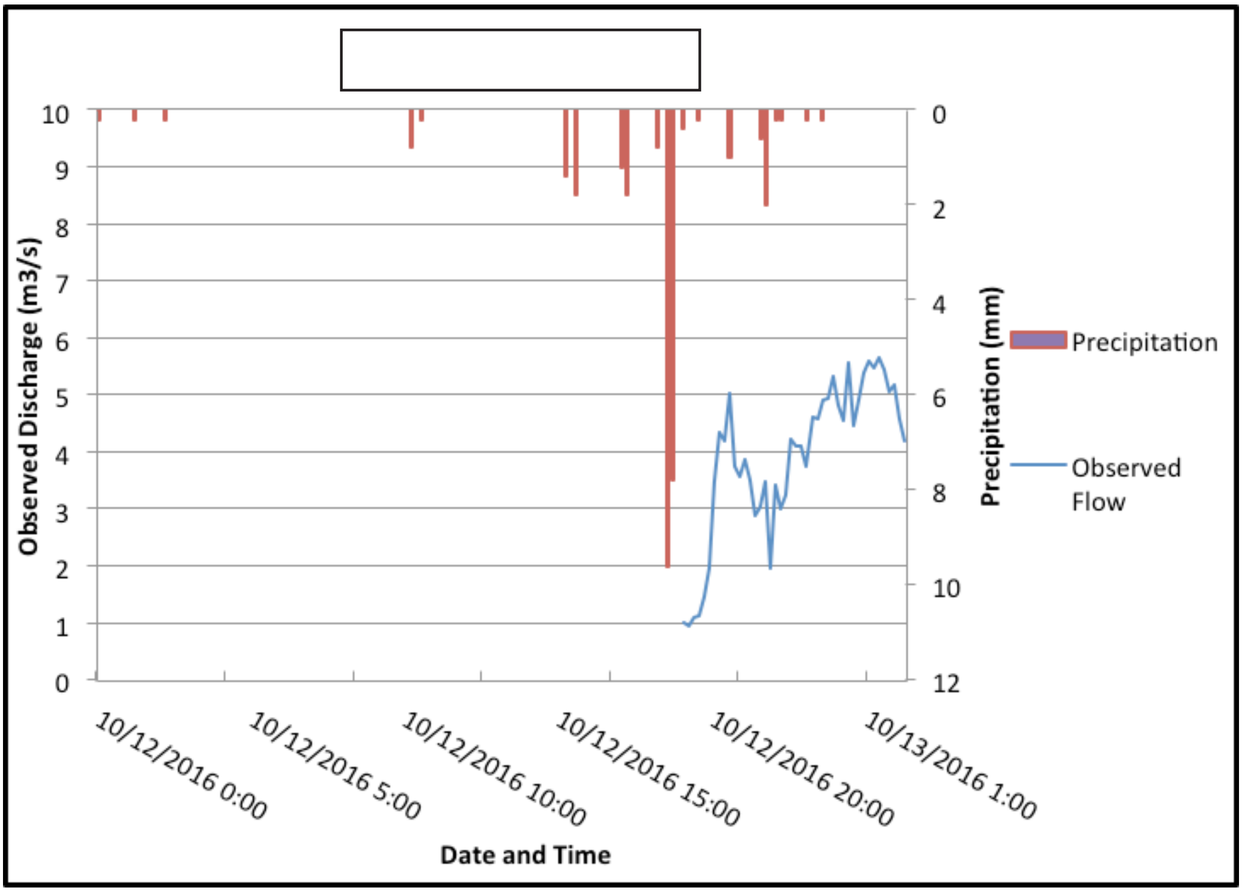


Figure 50. Rainfall and outflow data at Kanguinsa Bridge used for modeling

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Tacloban Rain Gauge. 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 was chosen based on its proximity to the Silongin watershed. The extreme values for this watershed were computed based on a 48-year record.

Table 25. RIDF values for Silongin Rain Gauge computed by PAGASA

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	10 mins	20 mins	30 mins	1 hr	2 hrs	3 hrs	6 hrs	12 hrs	24 hrs
2	18.2	27	33.5	44.3	59.5	70.4	89.5	107	119.8
5	26	37.7	46.5	60.7	82.2	97.6	125.5	152.9	171.6
10	31.1	44.8	55	71.5	97.3	115.7	149.3	183.4	205.9
15	34	48.8	59.9	77.7	105.8	125.8	162.8	200.5	225.2
20	36	51.6	63.3	82	111.8	133	172.2	212.6	238.8
25	37.6	53.8	65.9	85.3	116.4	138.4	179.4	221.8	249.2
50	42.4	60.4	74	95.4	130.5	155.3	201.8	250.3	281.4
100	47.2	67	81.9	105.5	144.5	172.1	223.9	278.6	313.3

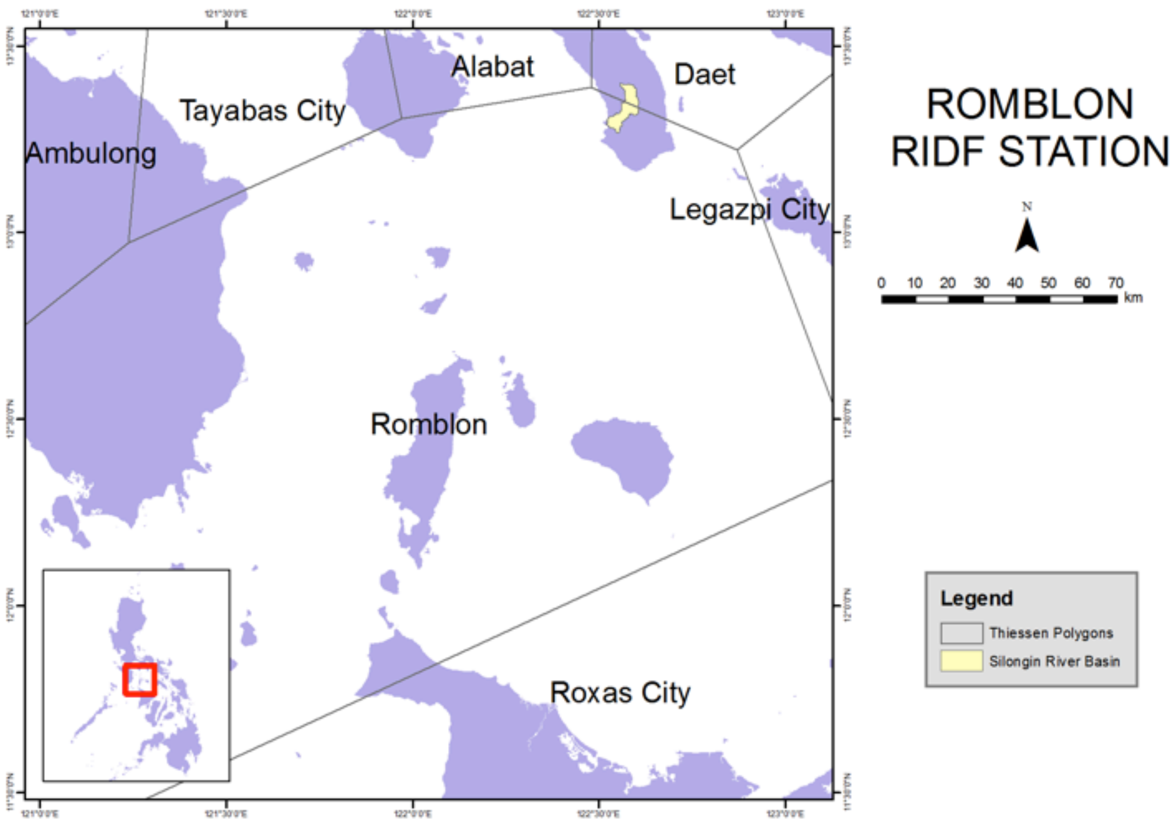


Figure 51. Romblon RIDF location relative to Silongin River Basin

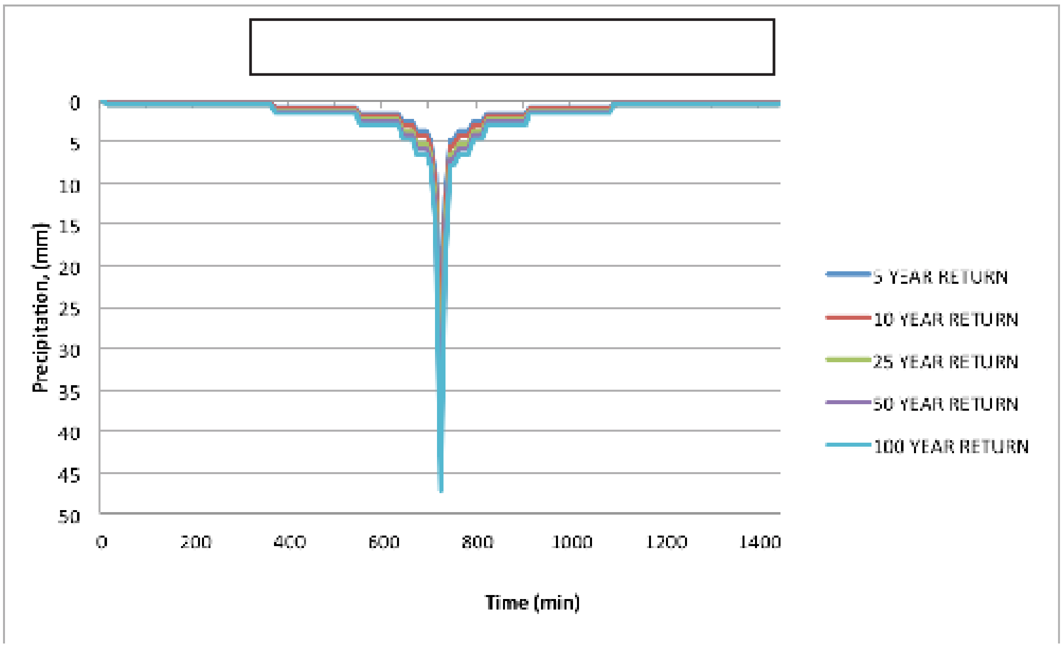


Figure 52. Synthetic storm generated for a 24-hour period rainfall for various return periods

5.3 HMS Model

The soil dataset was taken from and generated by the Bureau of Soils and Water Management (BSWM) from the Department of Agriculture (DA). The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Silongin River Basin are shown in Figure 53 and Figure 54, respectively.

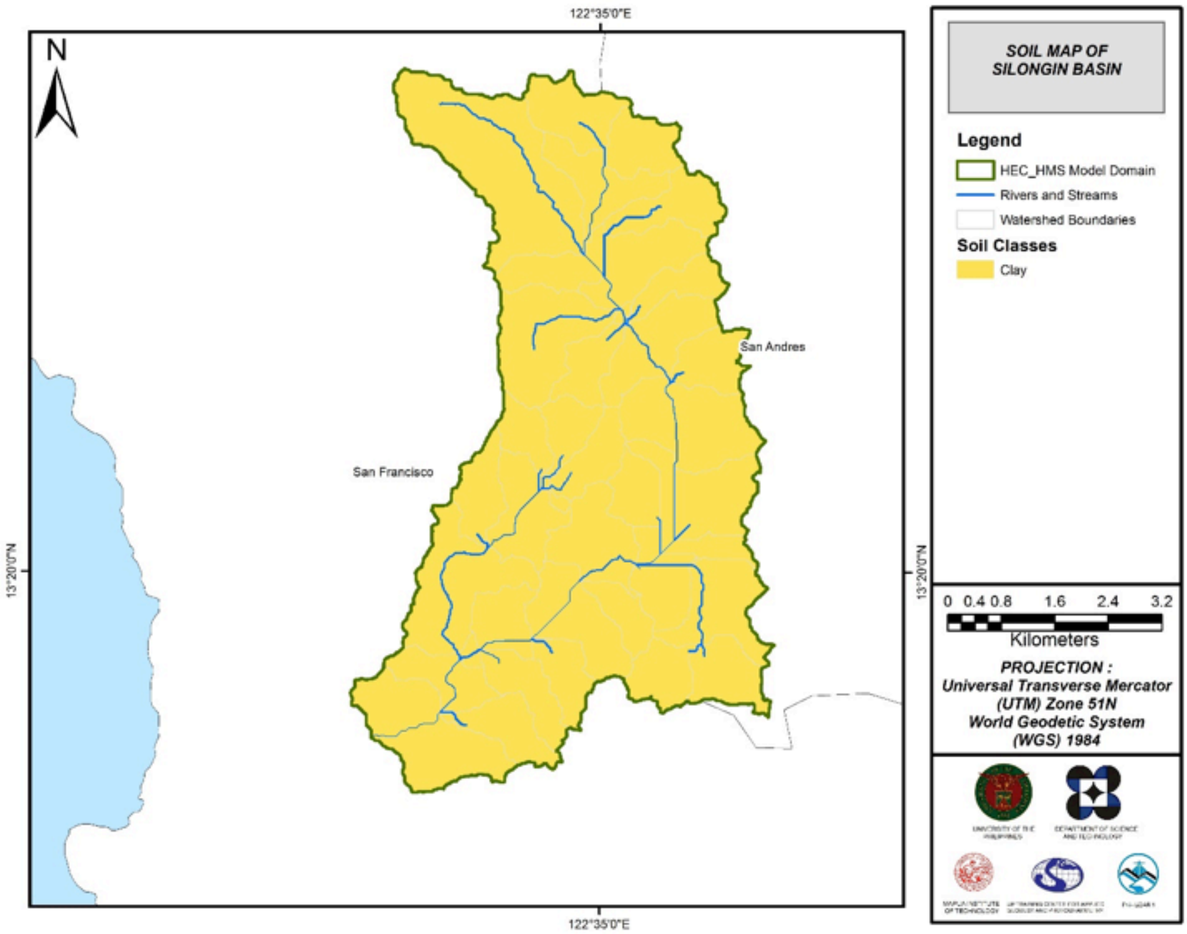


Figure 53. Soil map of Silongin River Basin

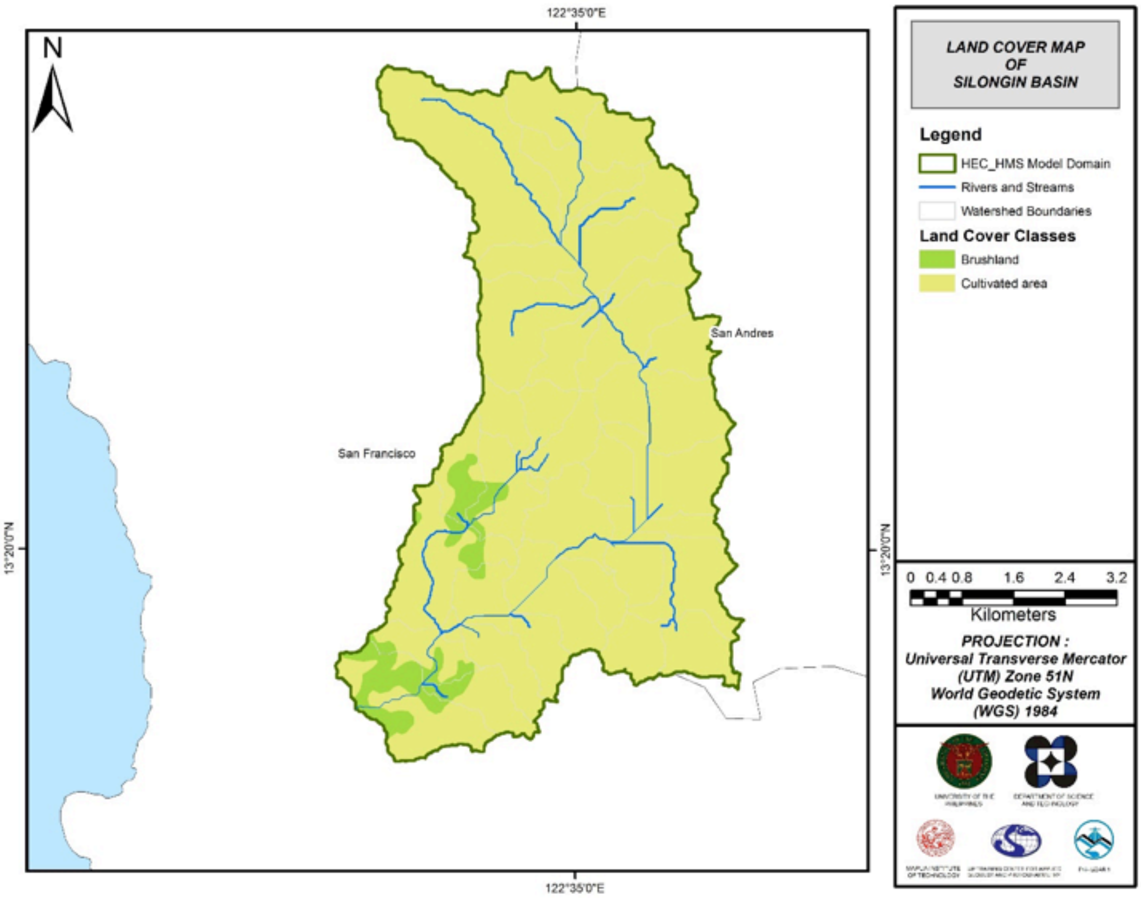


Figure 54. Land cover map of Silongin River Basin

For Silongin, the soil class identified was clay. The land cover types identified were brushland and cultivated areas.

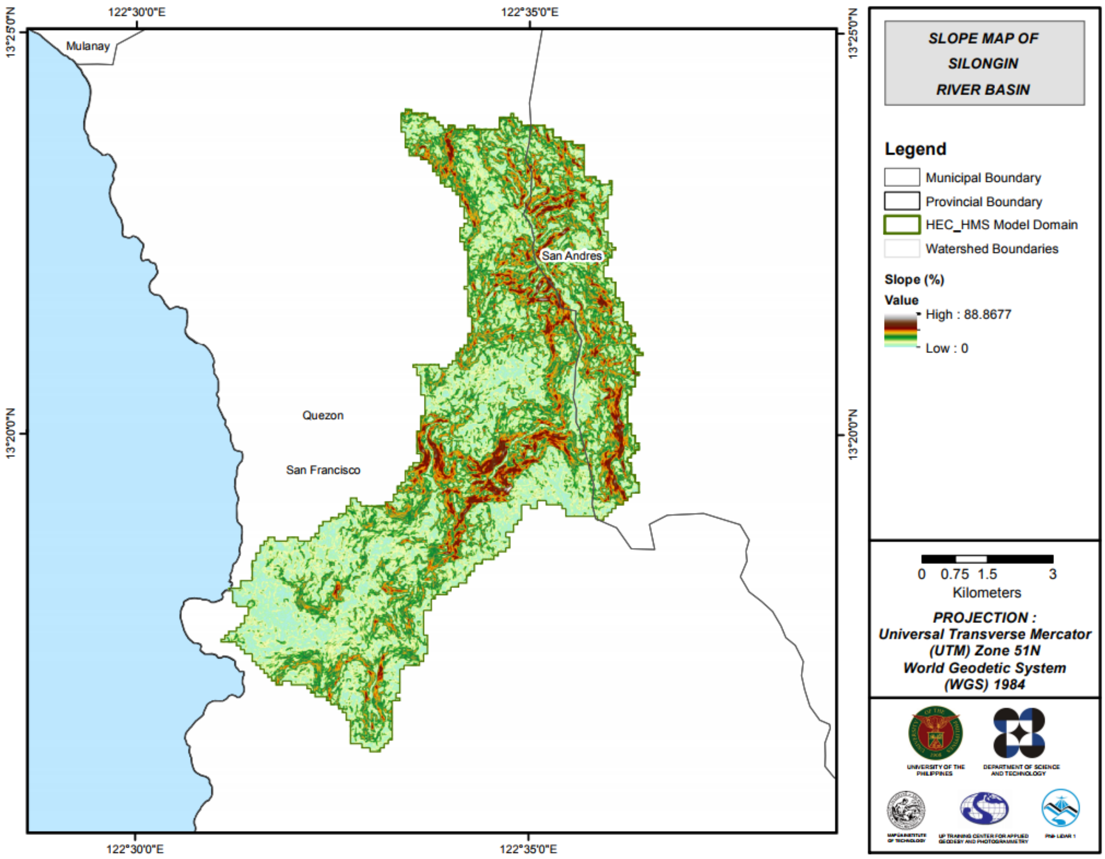


Figure 55. Slope map of Silongin River Basin

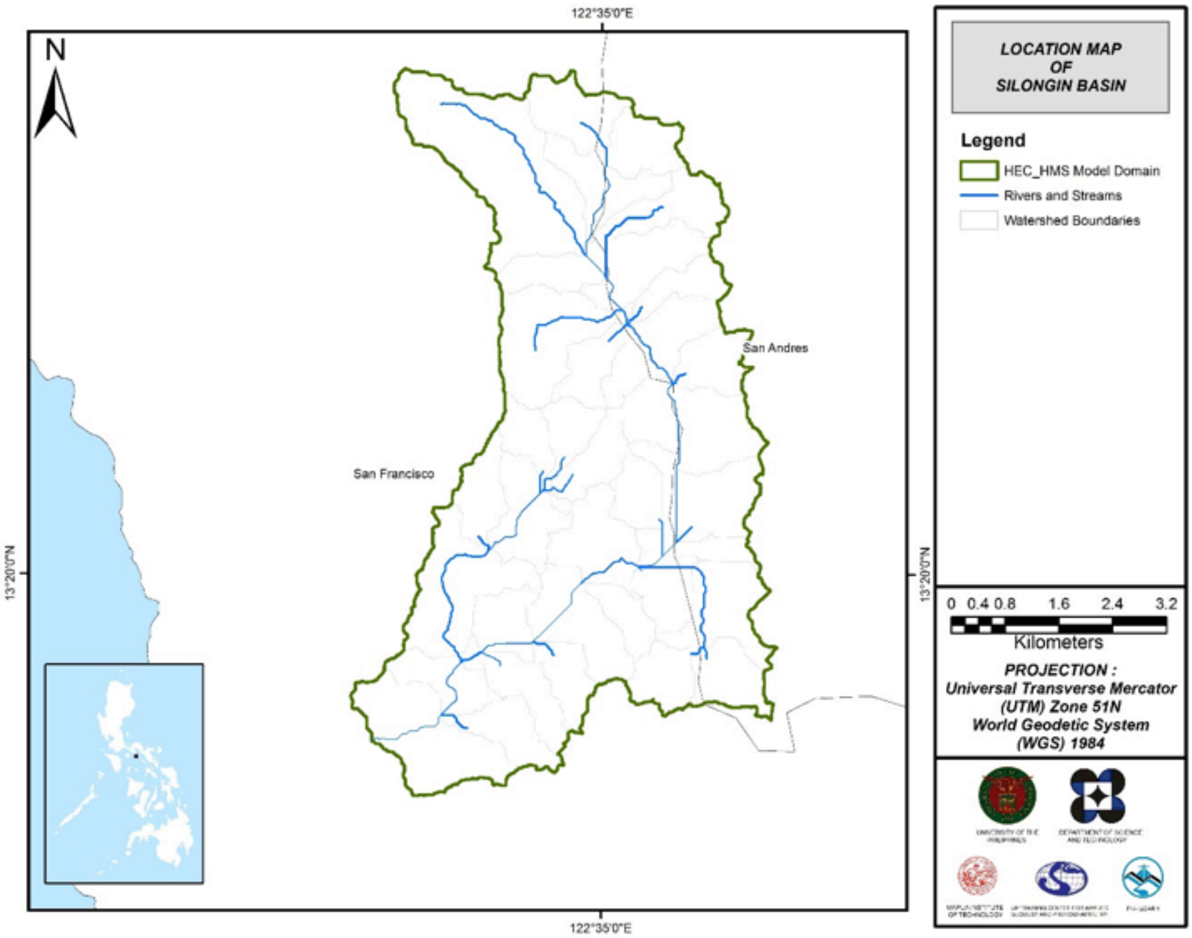


Figure 56. Stream delineation map of Silongin River Basin

The Silongin basin model consists of 41 subbasins, 20 reaches, and 20 junctions. The main outlet is located at the southwest part of the watershed. This basin model is illustrated in Figure 57. The basins were identified based on soil and land cover characteristics of the area. Precipitation was taken from manual rain gauge. Finally, it was calibrated using data from the Kanguinsa Bridge

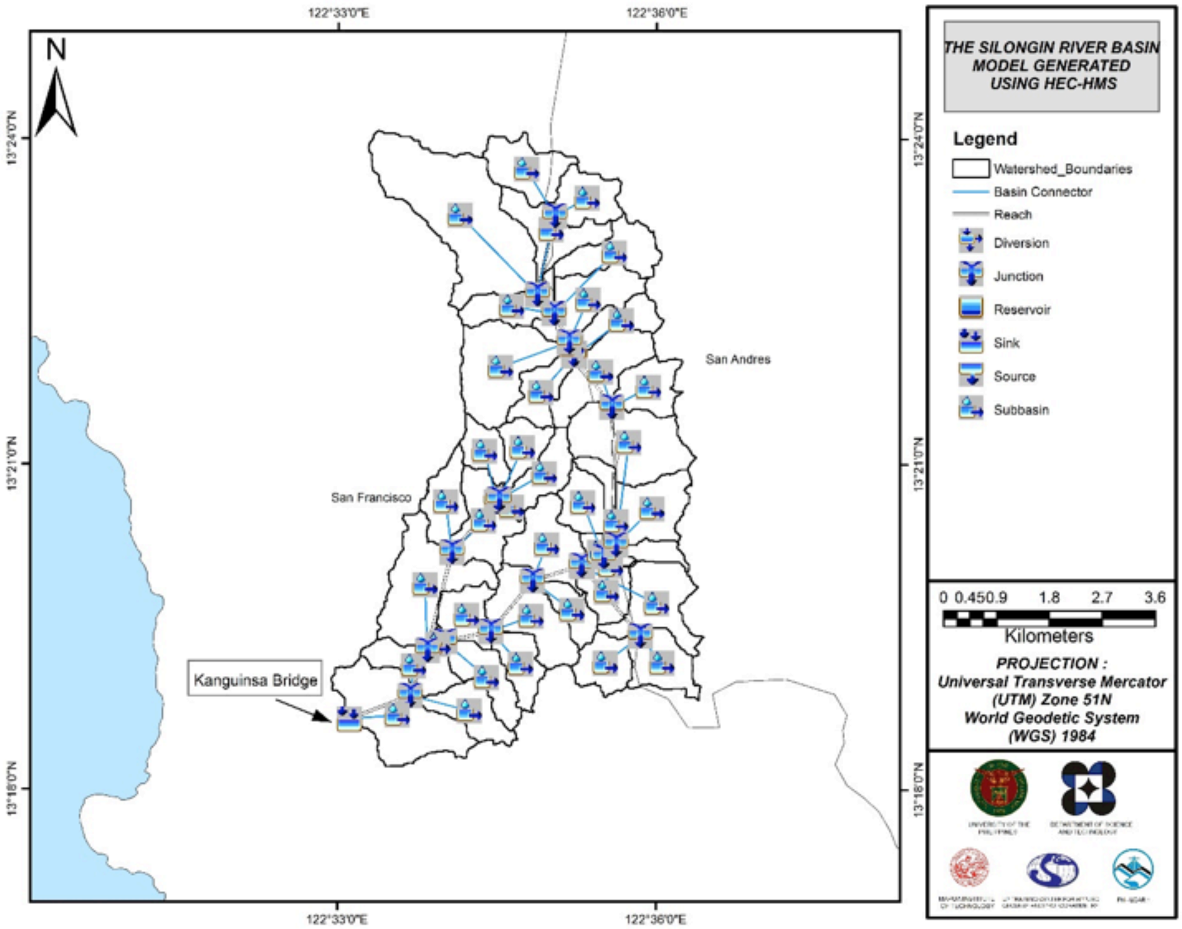


Figure 57. The Silongin River Basin model domain generated by HEC-HMS

5.4 Cross-section Data

Riverbed cross-sections of the watershed were necessary in the HEC-RAS model set-up. The cross-section data for the HEC-RAS model was derived from the LiDAR DEM data. It was defined using the Arc GeoRAS tool and was post-processed in ArcGIS.

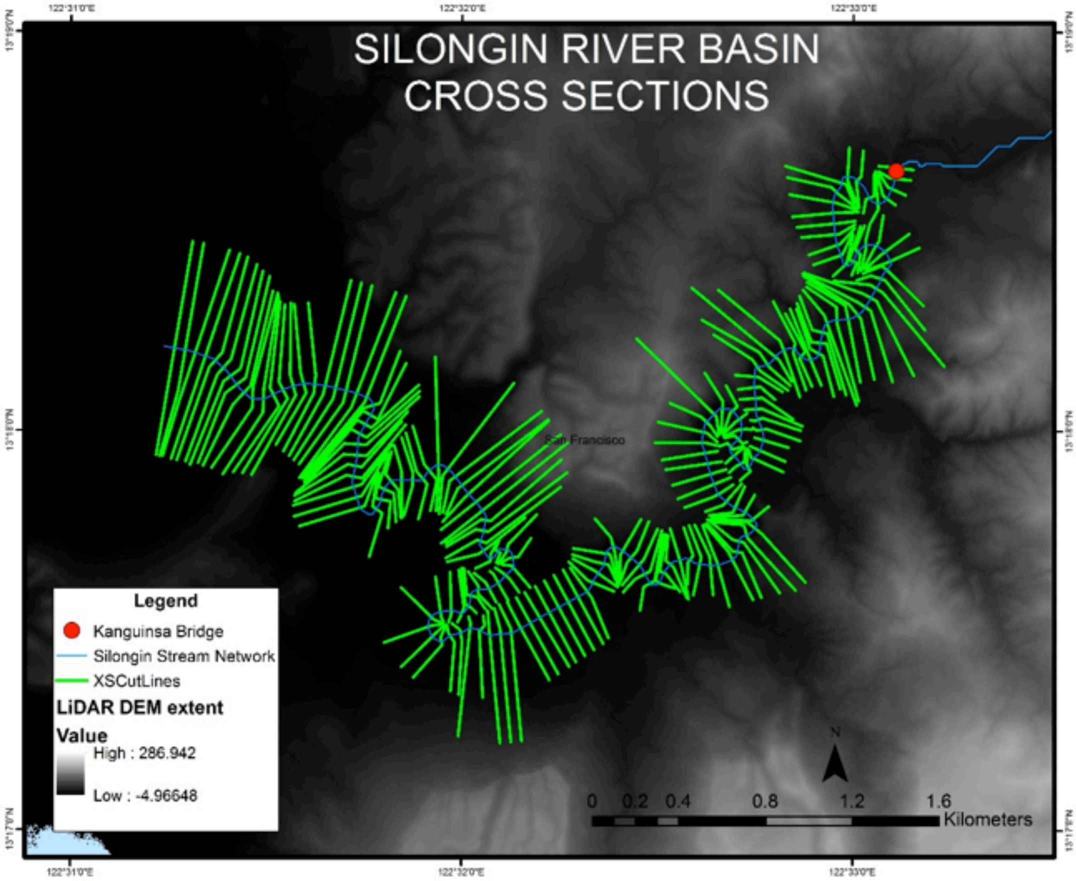


Figure 58. River cross-section of Silongin River generated through Arcmap HEC GeoRAS tool

5.4.1 Manning's n

The Manning's n is a constant value that depends on the nature of the channel and its surface. Determining the roughness coefficient of the channel is important in determining the water flow. Appropriate selection of Manning's n values is based on the land cover type of the watershed area.

A look-up table was derived to have a standardized Manning's n value for the HEC-RAS model.

Table 26. Look-up table for Manning's n values (Source: Brunner, 2010)

Land-cover Class	Corresponding Manning's *n* Class	Manning's *n*
Barren Land	Cultivated areas, no crop	0.030
Built-up Area	Concrete, float finished	0.015
Cultivated land, annual crop	Cultivated areas, mature field crops	0.040
Cultivated land, perennial crop	Cultivated areas, mature row crops	0.035
Fishpond	Excavated, earth, straight and uniform	0.018
Inland Water	Main channel, clean, straight, no rifts or deep pools	0.030
Grassland	Pasture, no brush, short grass	0.030
Mangrove Forest	Trees, heavy stand, flow into branches	0.120
Shrub land	Medium to dense brush	0.100

5.5 Flo 2D Model

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

Based on the elevation and flow direction, it is seen that the water will generally flow from the 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 59. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

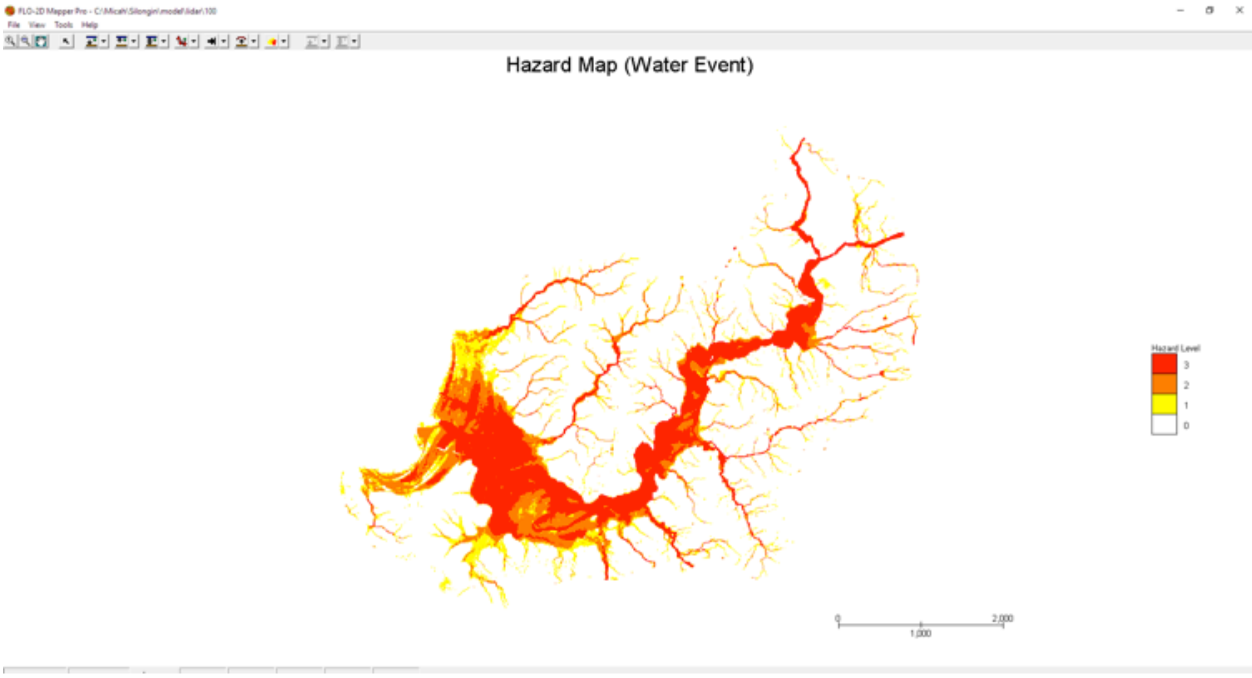


Figure 60. Generated 100-year rain return hazard map from Flo 2D Mapper

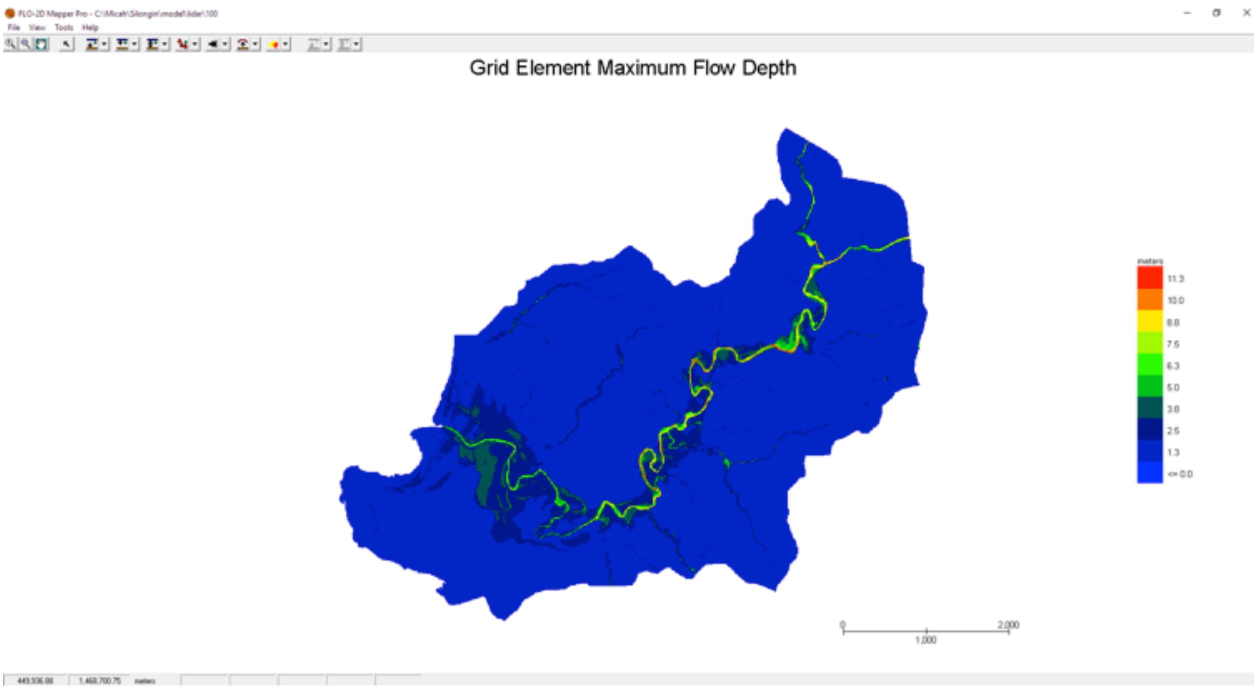


Figure 61. Generated 100-year rain return flow depth map from Flo 2D Mapper

5.6 Results of HMS Calibration

After calibrating the Silongin HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 62 shows the comparison between the two discharge data.

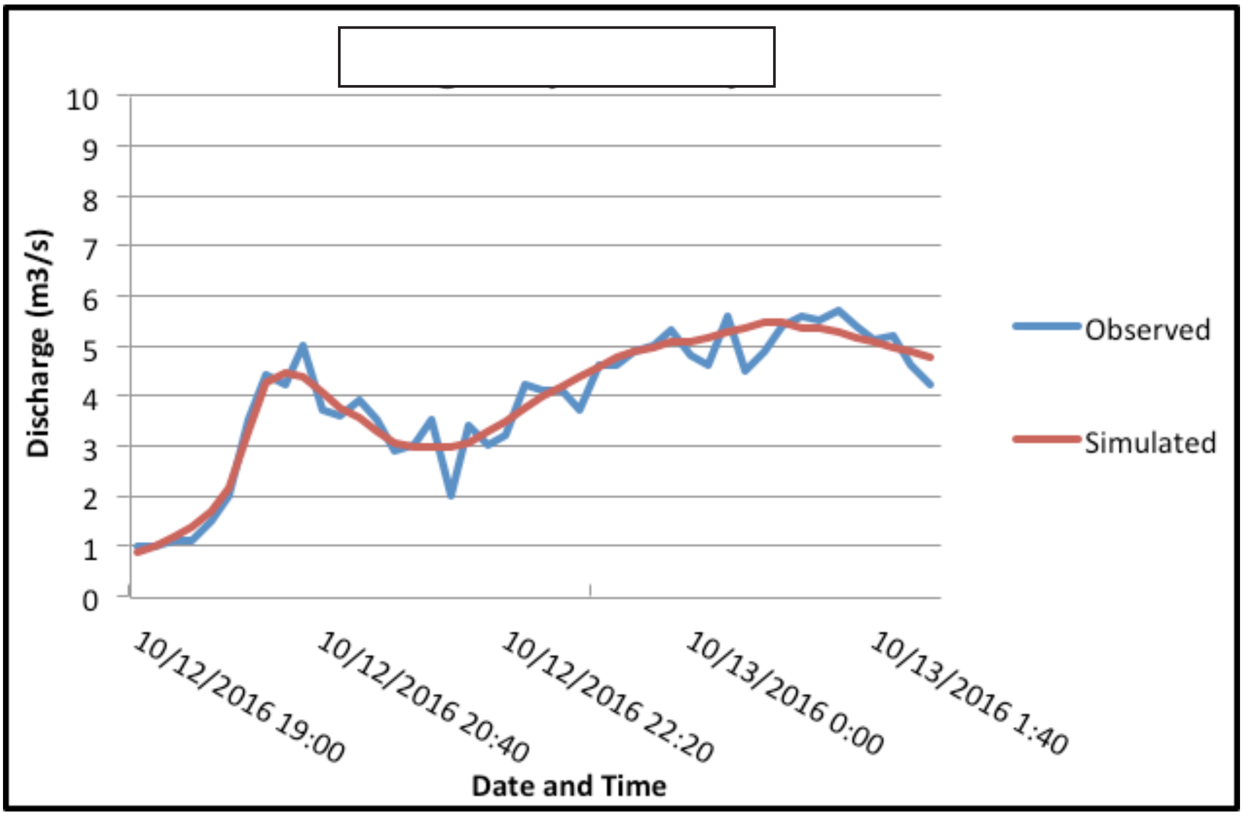


Figure 62. Outflow hydrograph of Silongin produced by the HEC-HMS model compared with observed outflow

Enumerated in Table 27 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 27. Range of Calibrated Values for Silongin River Basin

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	0.60 – 5.17
			Curve Number	35.12 – 99.00
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.055 – 8.18
			Storage Coefficient (hr)	0.05 – 8.86
	Baseflow	Recession	Recession Constant	0.00001 - 1
			Ratio to Peak	0.043 - 1
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.0001 – 0.21

Initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as initial abstraction decreases. A range of values from 0.60 mm to 5.17 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. For Silongin, the basin mostly consists of brushlands and cultivated areas and the soil consists of clay.

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 0.055 hours to 8.18 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. There is a large variance in the recession constants and ratio to peak numbers of each subbasin. Generally, the receding limb of the outflow hydrograph is relatively shallow with it not returning to its original discharge quickly.

Table 28. Summary of the Efficiency Test of Silongin HMS Model

Accuracy Measure	Value
RMSE	0.37
r^2	.9325
NSE	0. 92
PBIAS	-1.49
RSR	.28

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 0.37 (m3/s).

The Pearson correlation coefficient (r2) assesses the strength of the linear relationship between the observations and the model. A value 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 .9325.

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 0.922.

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 -1.49.

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 0.28.

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

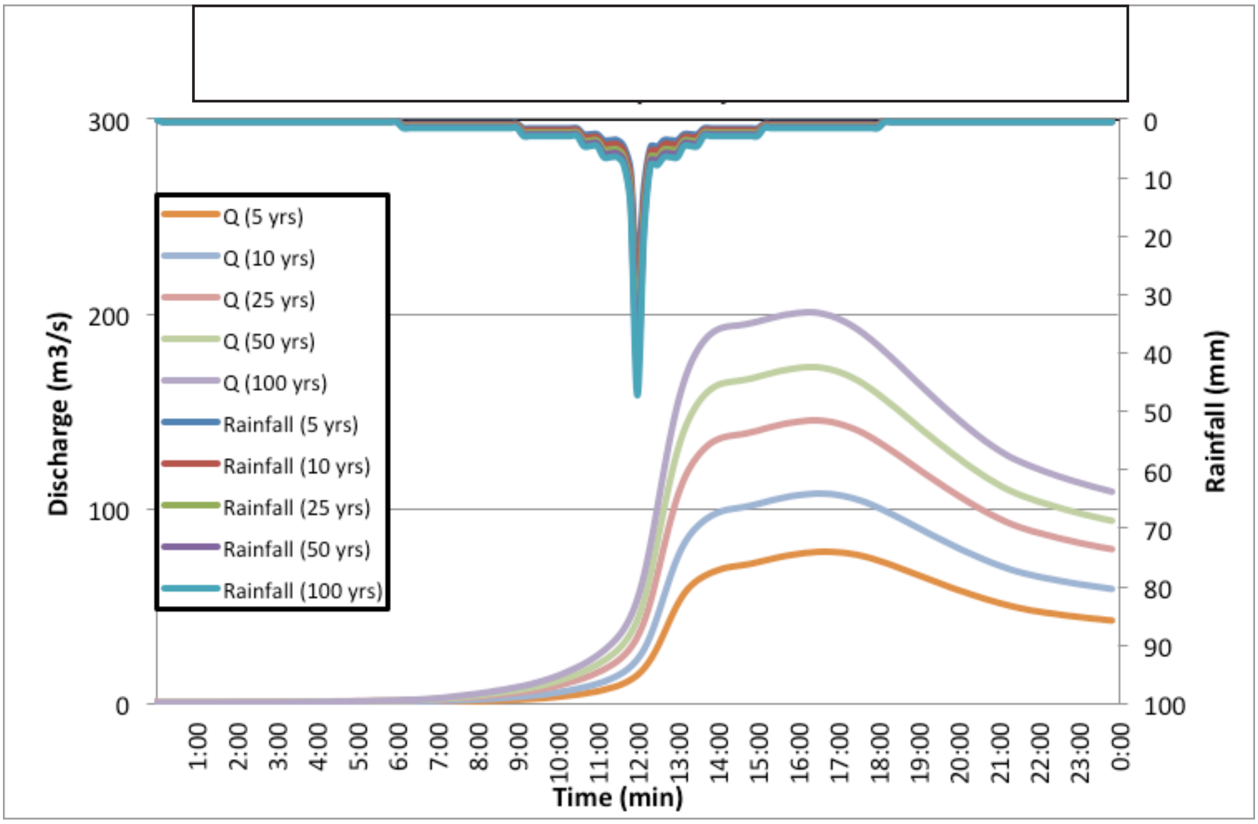


Figure 63. Outflow hydrograph at Silongin Station generated using Romblon RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow, and time to peak of the Silongin River discharge using the Romblon RIDF curves in five different return periods is shown in Table 29.

Table 29. Peak values of the Silongin HECHMS Model outflow using Silongin RIDF

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	152.9	26	78	16 hours and 40 min
10-Year	183.4	31.1	107.7	16 hours and 30 min
25-Year	221.8	37.6	144.8	16 hours and 30 min
50-Year	250.3	42.4	172.4	16 hours and 20 min
100-Year	278.6	47.2	200.7	16 hours and 20 min

5.8 River Analysis Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. For this publication, only a sample output map river was to be shown, since only the Flood Acquisition and Validation Component (MIT-FAVC) base flow was calibrated. The sample generated map of Silongin River using the calibrated HMS base flow is shown in Figure 64.

Figure 64. Sample output of Silongin RAS Model

5.9 Flood Hazard and Flow Depth Map

The resulting hazard and flow depth maps have a 10 m resolution. Figure 65 to Figure 70 show the 100-, 25-, and 5-year rain return scenarios of the Silongin Floodplain.

Table 30. Municipalities affected in Silongin Floodplain

Municipality	Total Area	Area Flooded	% Flooded
San Francisco	315.95	22.28	7.05%

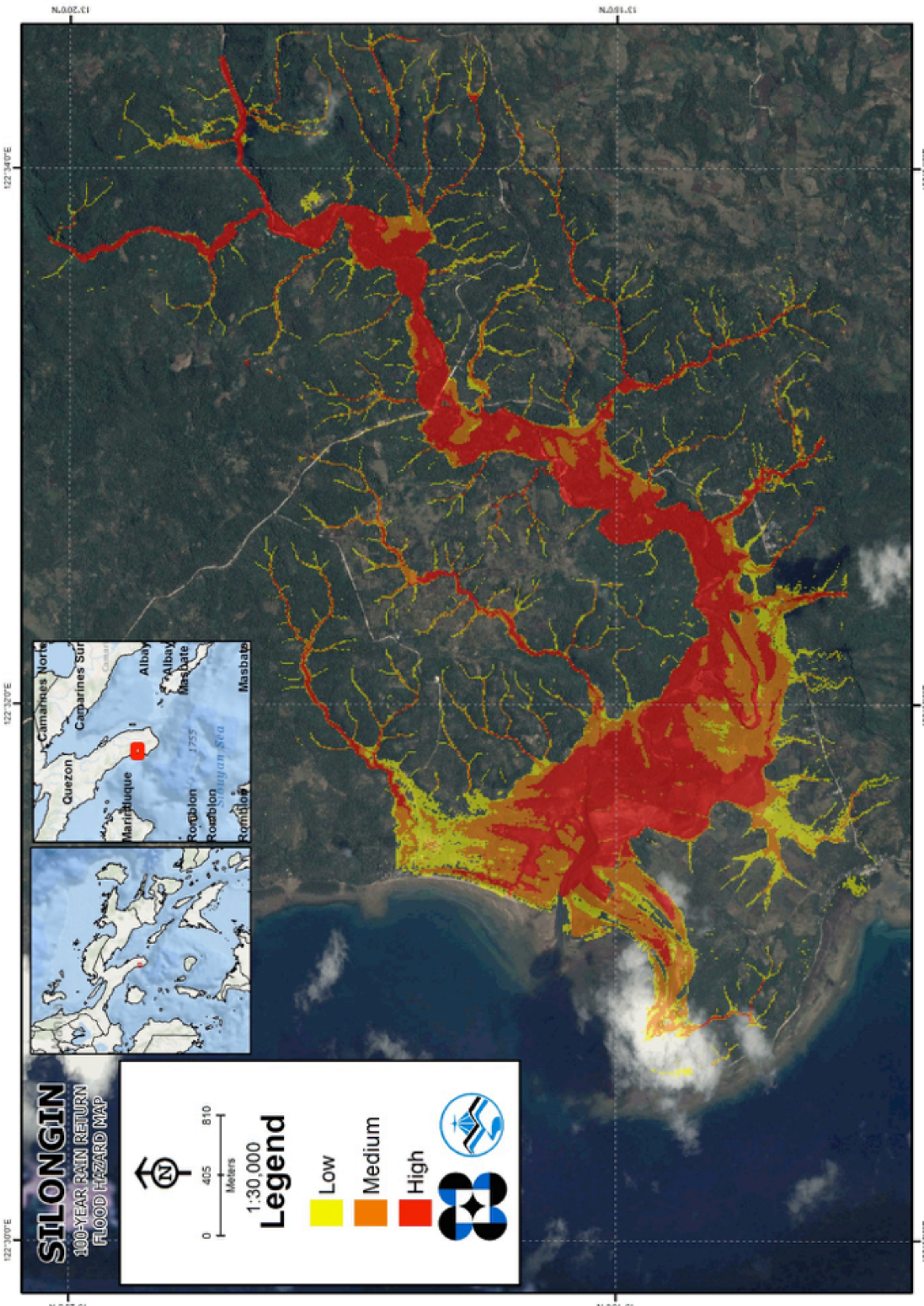


Figure 65. 100-year flood hazard map for Silongin Floodplain

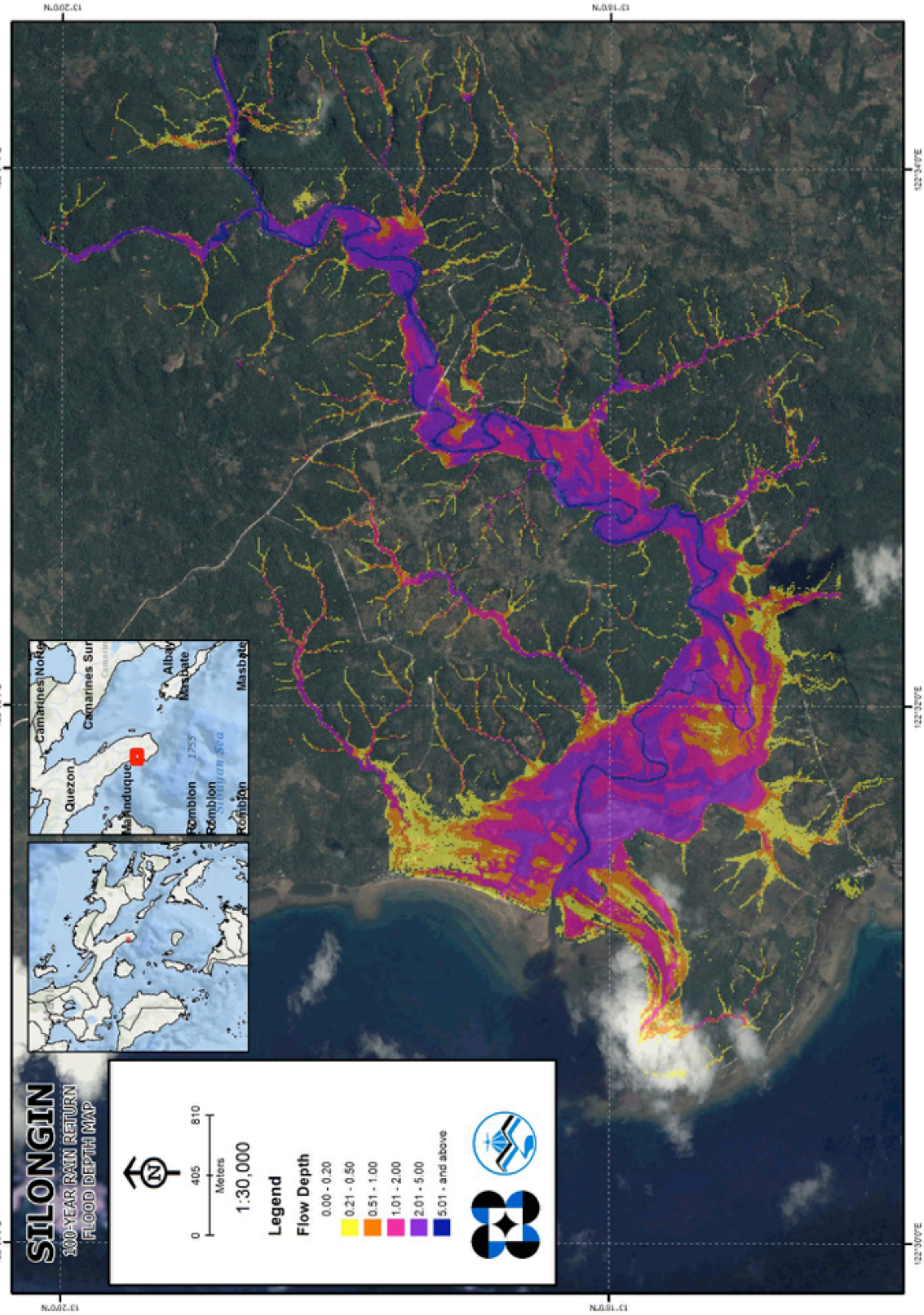


Figure 66. 100-year flow depth map for Silongin Floodplain

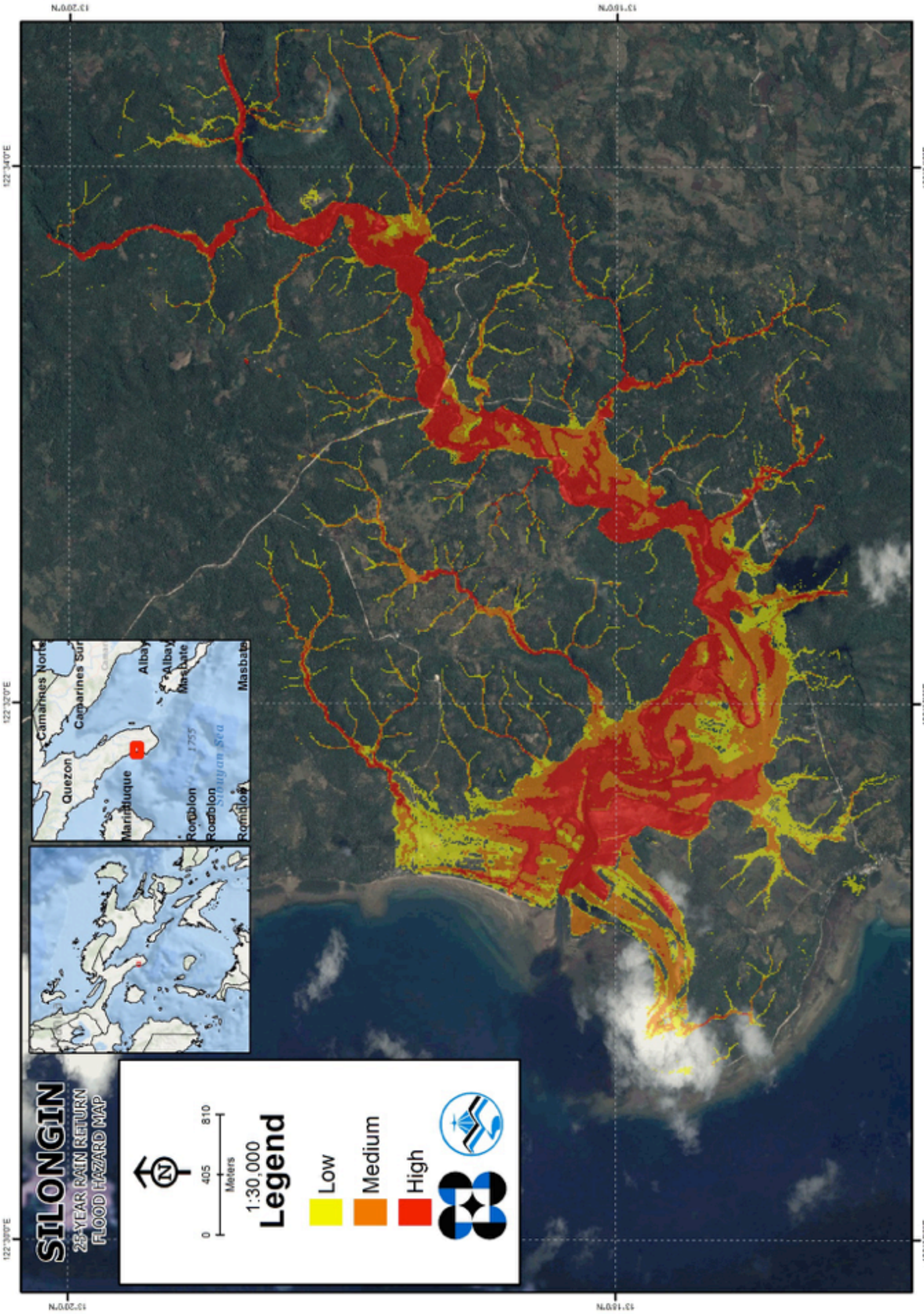


Figure 67. 25-year flood hazard map for Silongin Floodplain

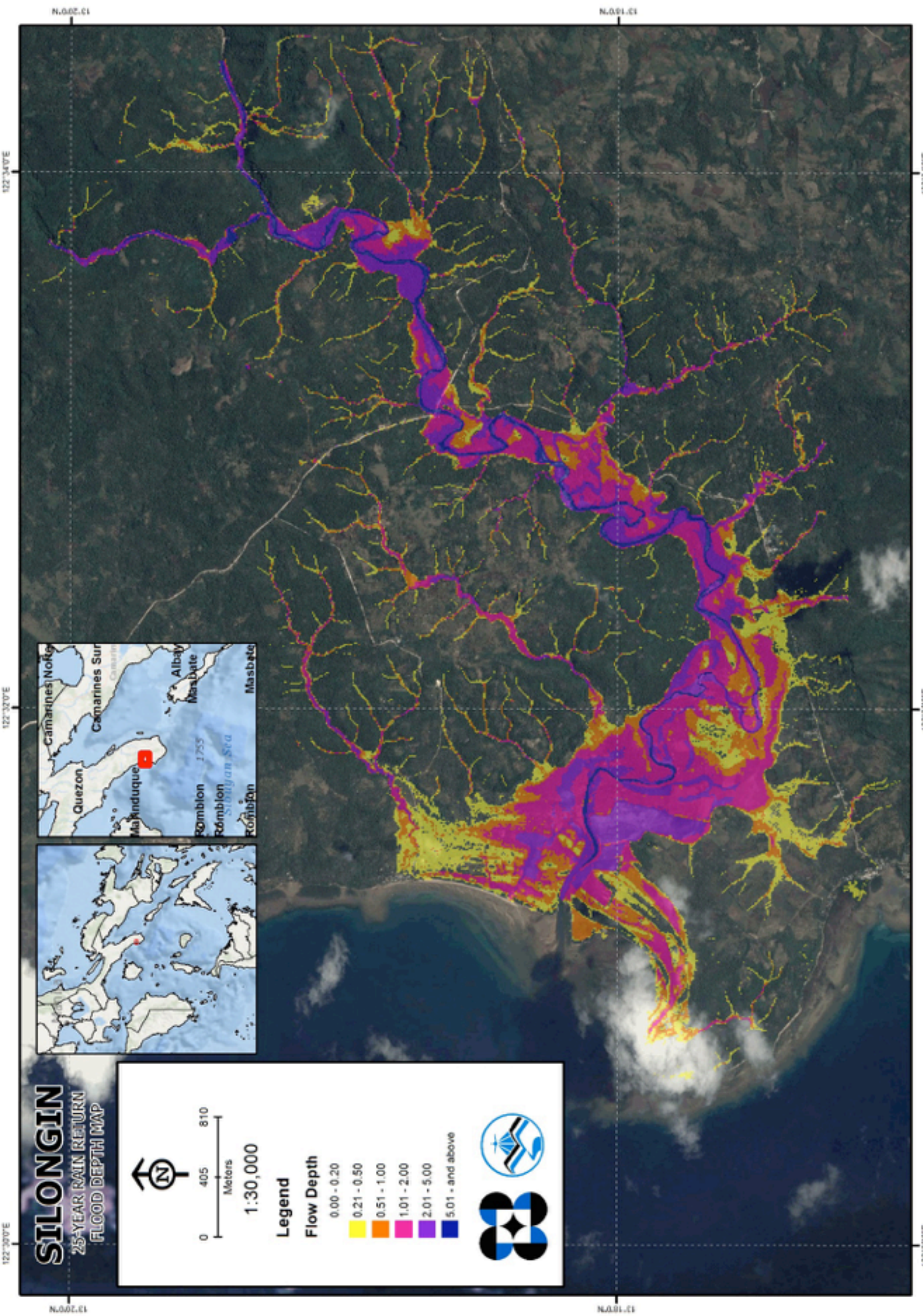


Figure 68. 25-year flow depth map for Silongin Floodplain

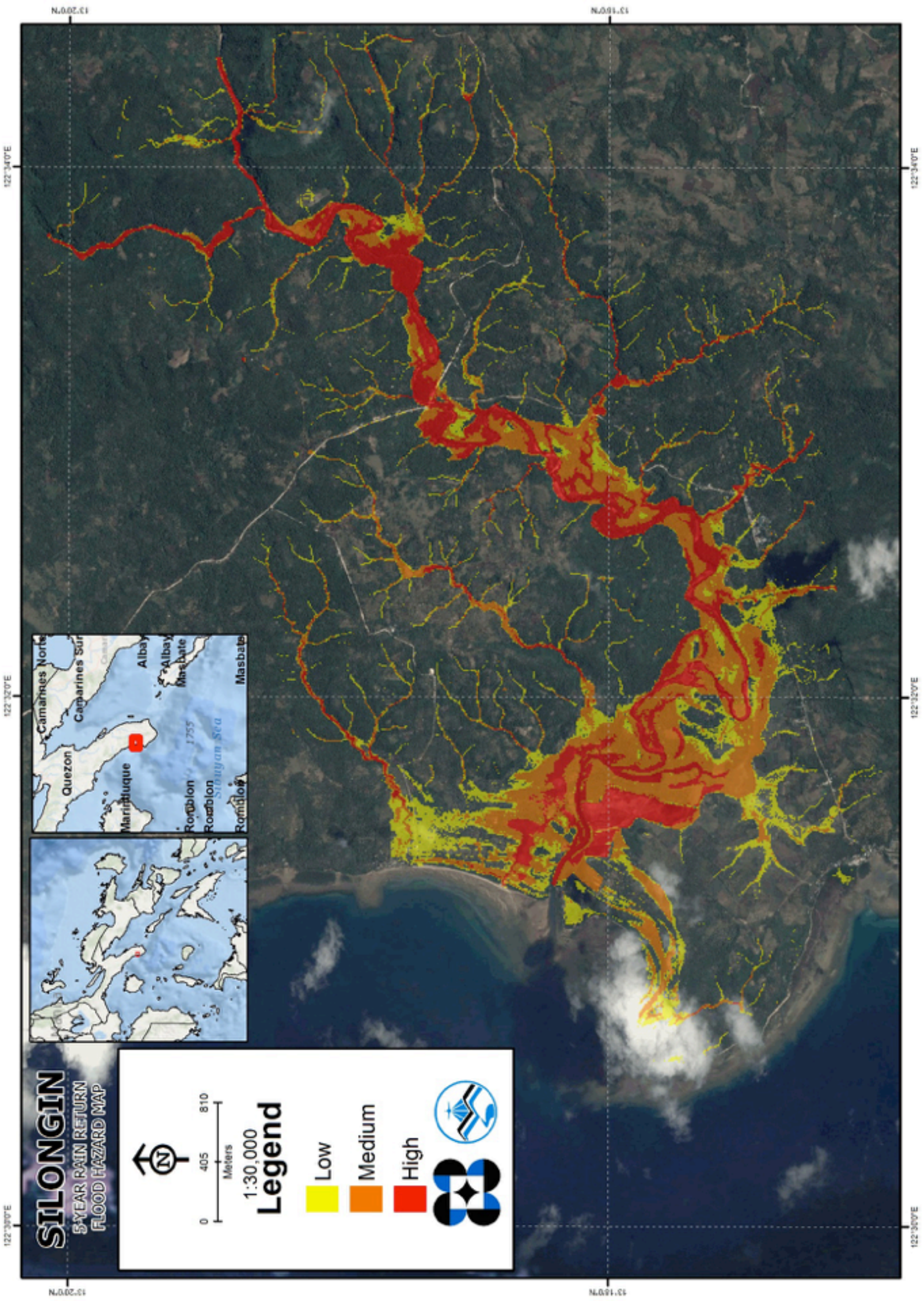


Figure 69. 5-year flood hazard map for Silongin Floodplain

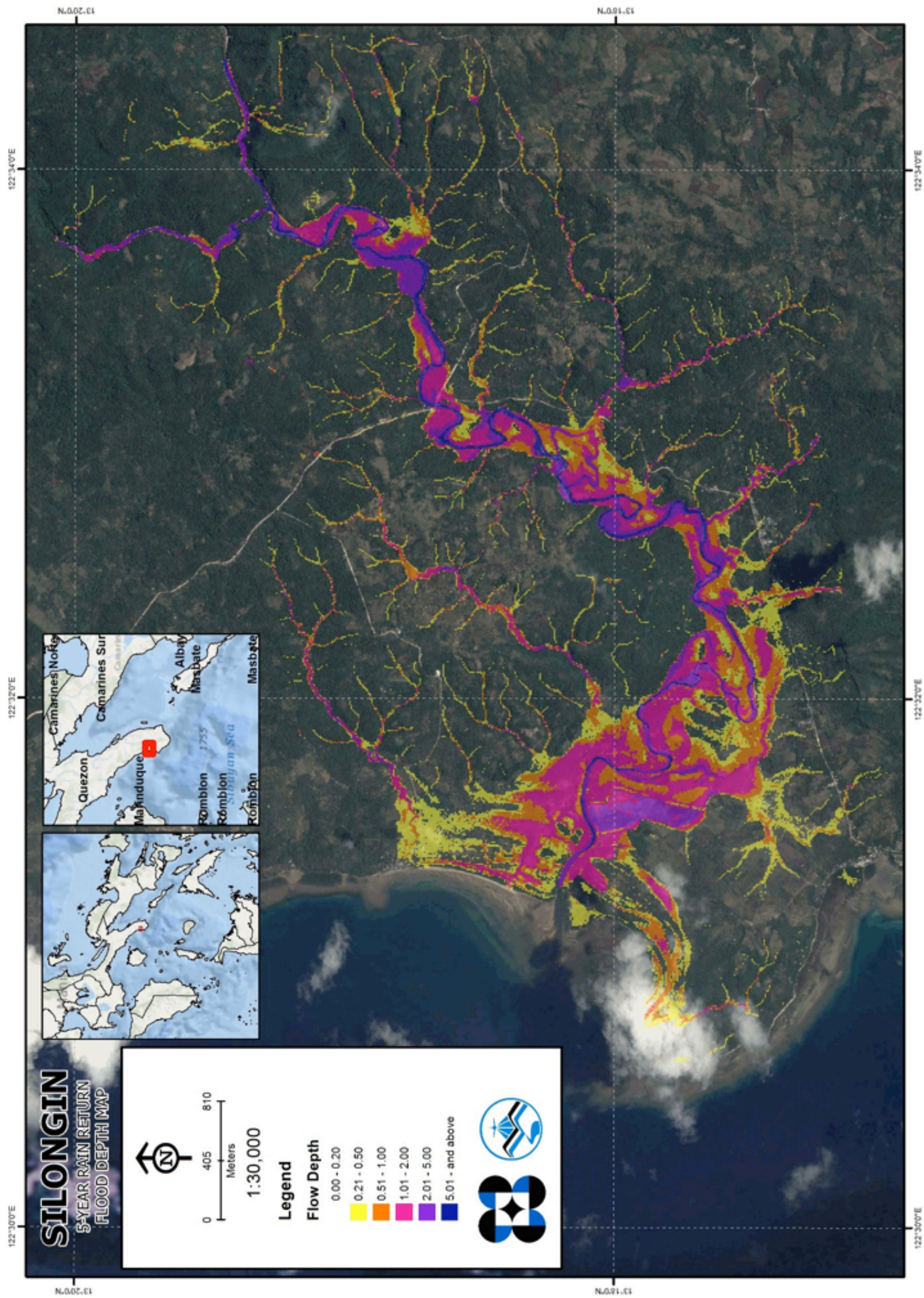


Figure 70. 5-year flow depth map for Silongin Floodplain

5.10 Inventory of Areas Exposed to Flooding

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

For the 5-year return period, 5.50% of the municipality of San Francisco with an area of 315.95 sq km will experience flood levels of less than 0.20 meters; 0.45% of the area will experience flood levels of 0.21 to 0.50 meters; while 0.38%, 0.46%, 0.20%, and 0.06% 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 31 are the affected areas in square kilometers by flood depth per barangay.

Table 31. Affected areas in San Francisco, Quezon during a 5-year rainfall return period

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in San Francisco (in sq. km.)				
	Casay	Don Juan Vercelo	Inabuan	Santo Nino	Silongin
0.03-0.20	5.65	2.69	0.23	0.6	8.21
0.21-0.50	0.35	0.4	0.0041	0.025	0.63
0.51-1.00	0.28	0.36	0.0022	0.014	0.56
1.01-2.00	0.23	0.34	0.0087	0.0049	0.86
2.01-5.00	0.11	0.13	0.0079	0.0014	0.38
> 5.00	0.033	0.0047	0.001	0.0003	0.16

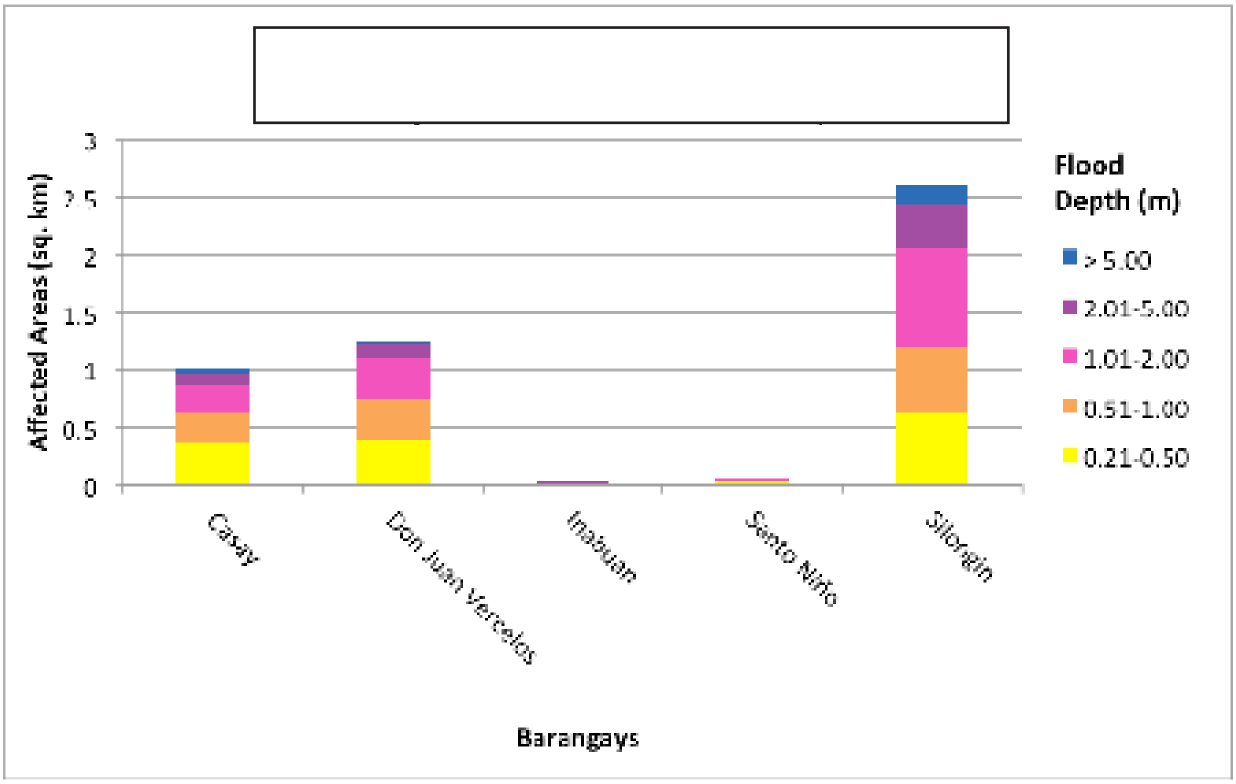


Figure 71. Affected areas in San Francisco, Quezon during a 5-year rainfall return period

For the 25-year return period, 5.27% of the municipality of San Francisco with an area of 315.95 sq km will experience flood levels of less than 0.20 meters; 0.46% of the area will experience flood levels of 0.21 to 0.50 meters;while 0.37%, 0.54%, 0.34%, and 0.08% 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 kilometers by flood depth per barangay.

Table 32. Affected areas in San Francisco, Quezon during a 25-year rainfall return period

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in San Francisco (in sq. km.)				
	Casay	Don Juan Vercelo	Inabuan	Santo Nino	Silongin
0.03-0.20	5.5	2.41	0.23	0.6	7.92
0.21-0.50	0.35	0.44	0.0053	0.028	0.62
0.51-1.00	0.29	0.35	0.002	0.016	0.5
1.01-2.00	0.3	0.49	0.0059	0.0082	0.9
2.01-5.00	0.18	0.21	0.012	0.0015	0.67
> 5.00	0.038	0.0085	0.0015	0.0003	0.19

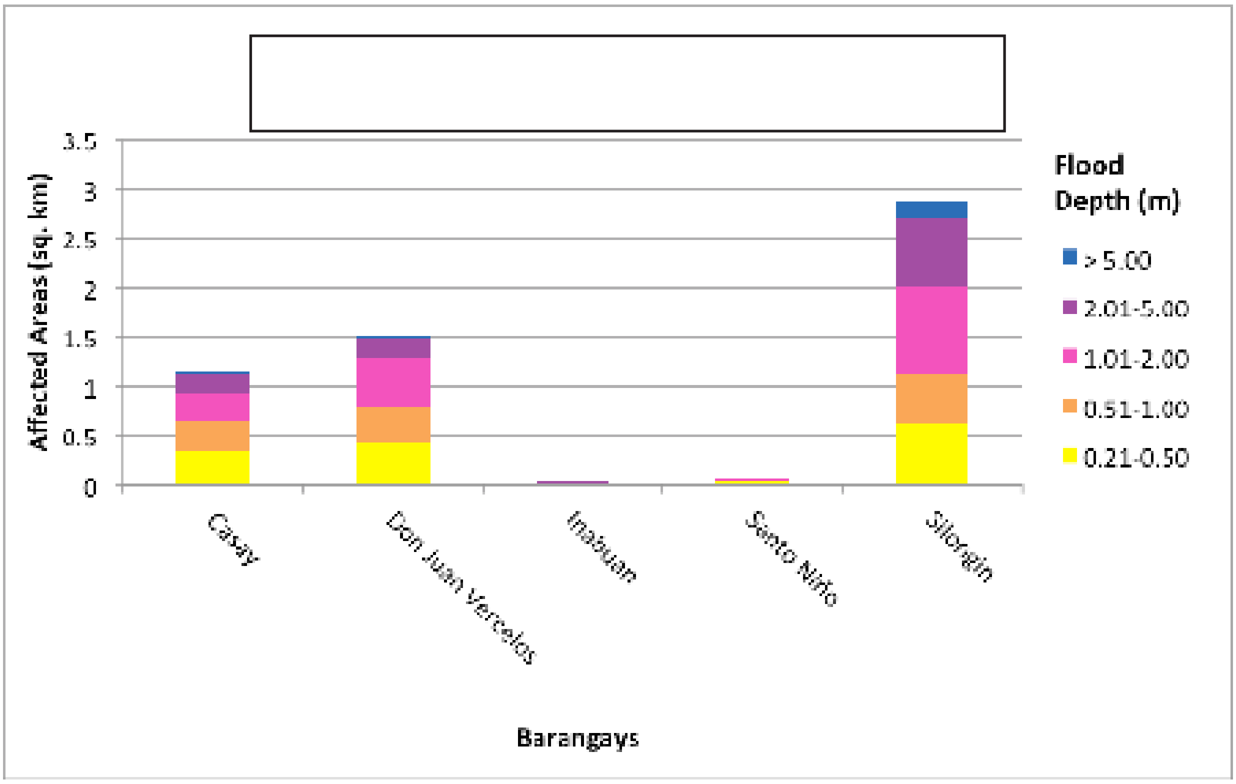


Figure 72. Affected areas in San Francisco, Quezon during a 25-year rainfall return period

For the 100-year return period, 5.13% of the municipality of San Francisco with an area of 315.95 sq km will experience flood levels of less than 0.20 meters; 0.43% of the area will experience flood levels of 0.21 to 0.50 meters; while 0.36%, 0.51%, 0.52%, and 0.09% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 33 are the affected areas in square kilometers by flood depth per barangay.

Table 33. Affected areas in San Francisco, Quezon during a 100-year rainfall return period

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in San Francisco (in sq. km.)				
	Casay	Don Juan Vercelo	Inabuan	Santo Nino	Silongin
0.03-0.20	5.39	2.28	0.23	0.59	7.72
0.21-0.50	0.34	0.39	0.0064	0.028	0.6
0.51-1.00	0.25	0.39	0.0024	0.018	0.49
1.01-2.00	0.35	0.48	0.003	0.0098	0.77
2.01-5.00	0.28	0.36	0.015	0.0025	0.99
> 5.00	0.045	0.013	0.0019	0.0003	0.23

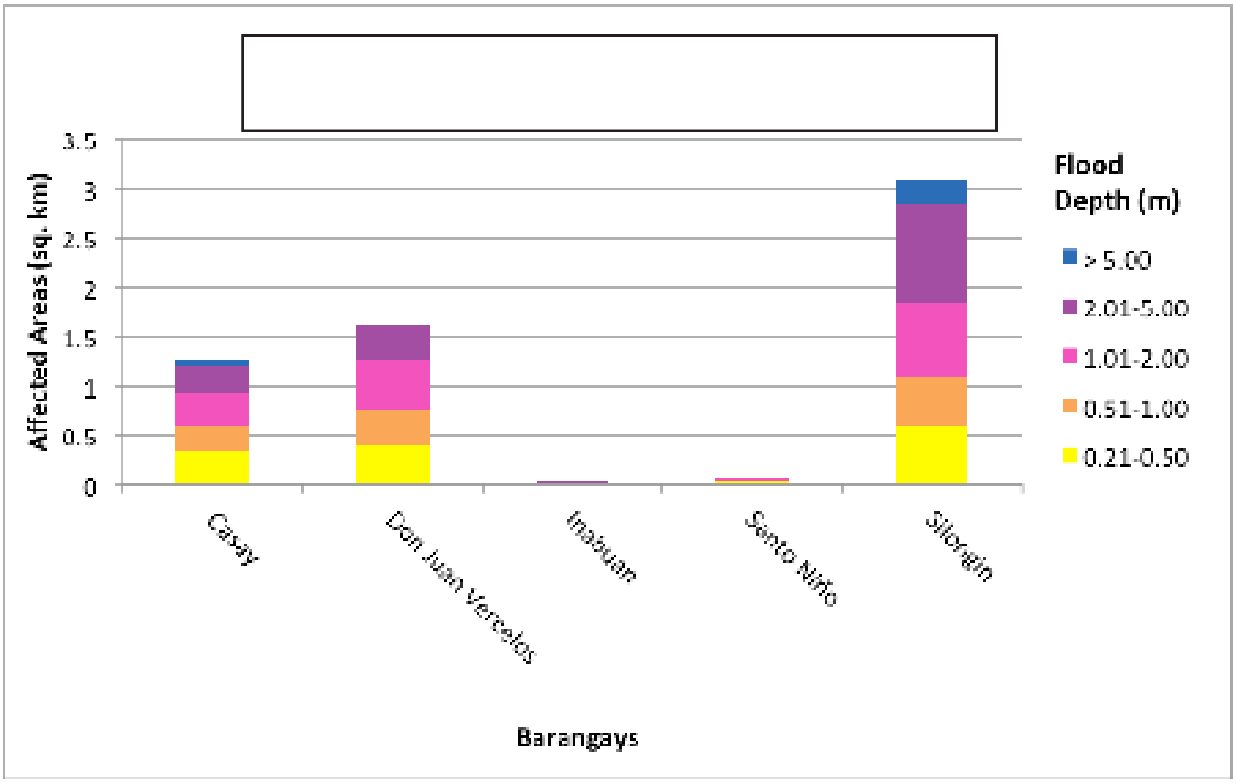


Figure 73. Affected areas in San Francisco, Quezon during a 100-year rainfall return period

Moreover, the generated flood hazard maps for the Silongin Floodplain were used to assess the vulnerability of the educational and medical institutions in the floodplain. Using the flood depth units of PAGASA 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 10-year).

Table 34. Areas covered by each warning level with respect to the rainfall scenarios

Warning Level	Area Covered in sq. km.		
	5 year	25 year	100 year
Low	1.39	1.42	1.34
Medium	2.047	2.033	1.92
High	1.47	2.20	2.85
Total	4.91	5.65	6.11

Of the six (6) identified educational institutions in Silongin Floodplain, one (1) school, Casay National High School in Brgy. Casay, San Francisco, Quezon, was exposed to low-level flooding for the 25- and 100-year scenarios.

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 by contacting a local DRRM office to obtain maps or situation reports about the past flooding events or by interviewing 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 77.

The flood validation consists of 336 points randomly selected all over the Silongin floodplain (Figure 74). Comparing it with the flood depth map of the nearest storm event, the map has an RMSE value of 1.88 m. Table 42 shows a contingency matrix of the comparison.

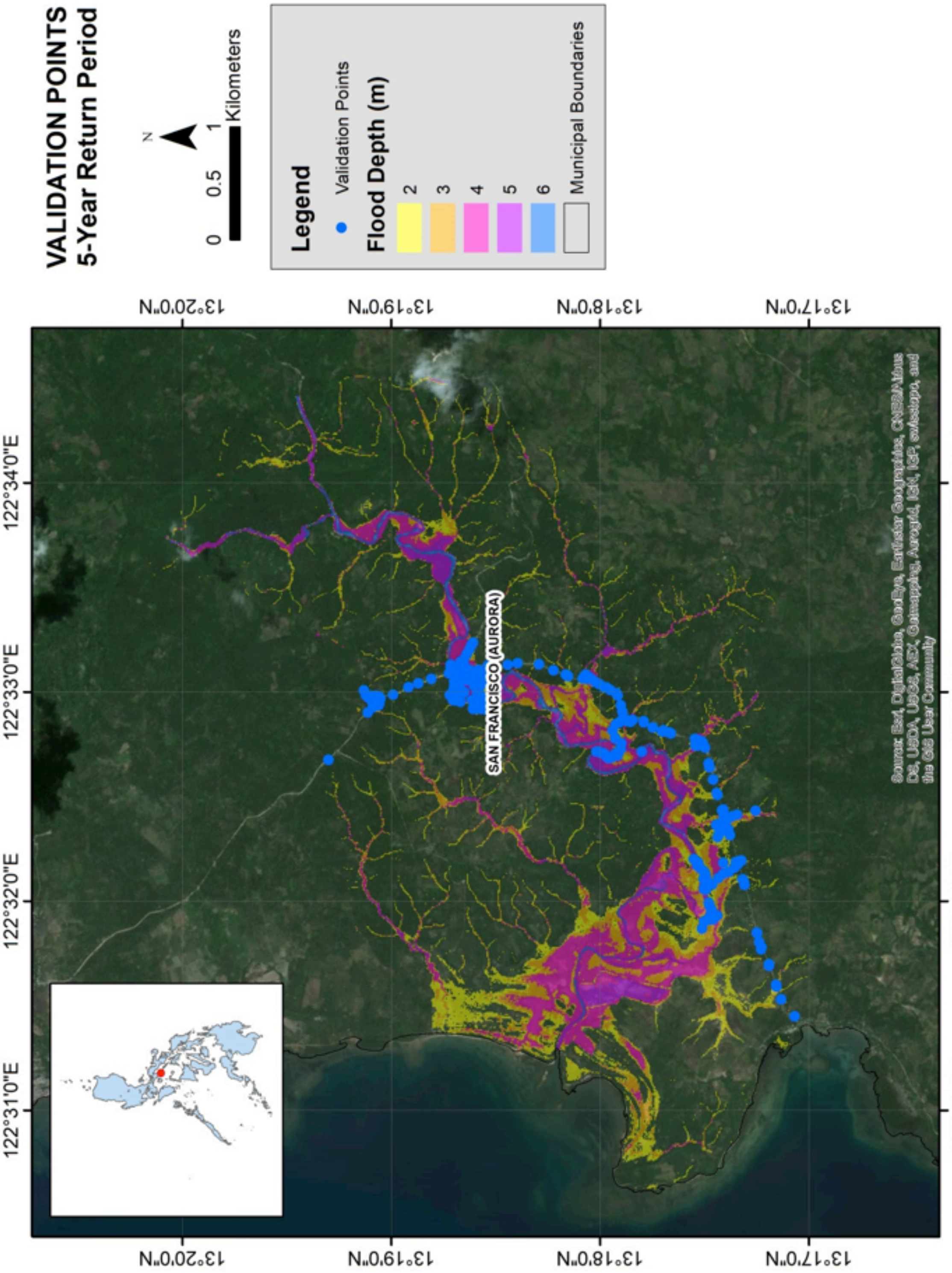


Figure 74. Validation points for 5-year flood depth map of Silongin Floodplain

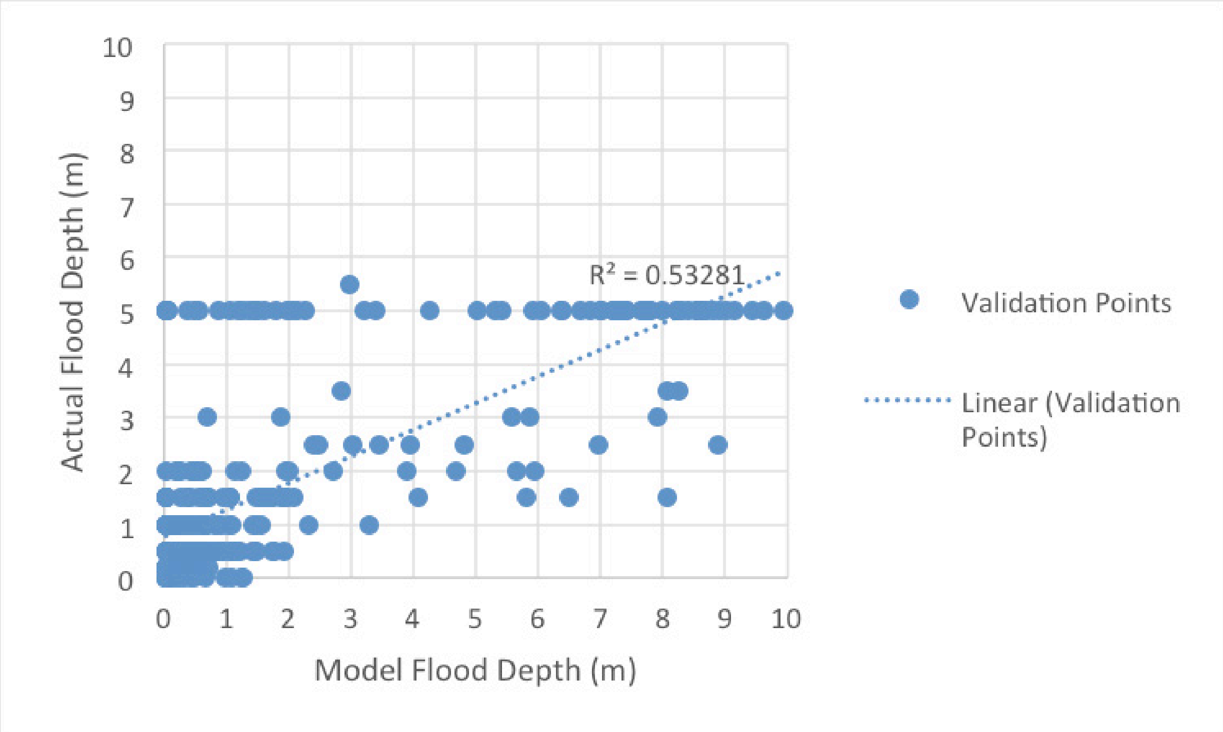


Figure 75. Flood map depth vs actual flood depth

Table 35. Actual Flood Depth vs Simulated Flood Depth in Silongin 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	73	10	5	3	0	0	91
0.21-0.50	22	19	18	11	0	0	70
0.51-1.00	15	7	10	5	2	0	39
1.01-2.00	8	8	10	14	6	5	51
2.01-5.00	7	2	3	10	13	49	84
> 5.00	0	0	0	0	1	0	1
Total	125	46	46	43	22	54	336

The overall accuracy generated by the flood model is estimated at 38.39% with 129 points correctly matching the actual flood depths. In addition, there were 131 points estimated one level above and below the correct flood depths while there were 49 points and 20 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 4 points were overestimated while a total of 93 points were underestimated in the modeled flood depths of Silongin.

Table 36. Summary of accuracy assessment in Silongin River Basin Survey

	No. of Points	%
Correct	129	38.39
Overestimated	114	33.93
Underestimated	93	27.68
Total	336	100.00

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.

NDRRMC. 2014. Final Report re Effects of Typhoon "Glenda" or Rammasun.

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.

Quezon Province website. 2016. Economy. Retrieved from http://www.quezon.gov.ph/homepage/?info=economy

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. OPTECH Technical Specification of the Pegasus Sensor

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

1. Target reflectivity ≥20%
2. Dependent on selected operational parameters using nominal FOV of up to 40° in standard atmospheric conditions with 24-km visibility
3. Angle of incidence ≤20˚
4. Target size ≥ laser footprint5 Dependent on system configuration

Annex 2. NAMRIA Certificates of Reference Points Used in the LiDAR Survey

There are no NAMRIA Certificates for the Silongin River Basin.

Annex 3. Baseline Processing Report of Control Points Used in the LiDAR Survey

UP-TAL and UP-VIG

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
QZN-47 --- QZN-40 (B31)	QZN-47	QZN-40	Fixed	0.003	0.011	306°22'36"	31263.486	-2.177
QZN-47 --- QZN-43 (B27)	QZN-43	QZN-47	Fixed	0.003	0.013	131°16'56"	12401.416	2.822
QZN-47 --- UP-VIG (B23)	QZN-47	UP-VIG	Fixed	0.003	0.012	103°58'19"	23335.323	2.557
QZN-47 --- UP-KAN (B36)	QZN-47	UP-KAN	Fixed	0.005	0.019	146°21'08"	28388.037	21.906
QZN-40 --- QZ-415 (B14)	QZN-40	QZ-415	Fixed	0.003	0.023	14°21'16"	22613.475	5.492
UP-CAB --- QZ-415 (B15)	UP-CAB	QZ-415	Fixed	0.004	0.025	234°09'16"	19401.067	5.290
QZN-40 --- UP-KAN (B33)	QZN-40	UP-KAN	Fixed	0.011	0.027	135°49'24"	58749.581	24.083
QZN-43 --- QZ-415 (B20)	QZN-43	QZ-415	Fixed	0.006	0.033	342°23'19"	33841.349	6.326
QZN-43 --- UP-KAN (B34)	QZN-43	UP-KAN	Fixed	0.005	0.018	141°46'15"	40492.330	24.748
UP-TAL --- UP-KAN (B35)	UP-TAL	UP-KAN	Fixed	0.005	0.018	312°01'33"	16293.271	19.903
UP-VIG --- UP-TAL (B25)	UP-VIG	UP-TAL	Fixed	0.003	0.014	169°50'51"	29356.882	-0.547
UP-VIG --- QZN-43 (B28)	UP-VIG	QZN-43	Fixed	0.003	0.014	293°25'54"	34821.073	-5.389
UP-VIG --- UP-KAN (B37)	UP-VIG	UP-KAN	Fixed	0.005	0.021	201°04'03"	19280.526	19.353
QZN-41 --- UP-CAB (B18)	UP-CAB	QZN-41	Fixed	0.004	0.024	247°44'12"	10141.643	-1.873
QZN-41 --- QZ-415 (B16)	QZN-41	QZ-415	Fixed	0.003	0.022	220°07'13"	9835.756	7.245
QZN-40 --- QZN-43 (B29)	QZN-43	QZN-40	Fixed	0.003	0.014	303°07'59"	18937.828	0.672
UP-CAB --- QZN-43 (B22)	QZN-43	UP-CAB	Fixed	0.004	0.019	7°10'02"	43963.480	1.070

1

Vector Components (Mark to Mark)

From:	UP-VIG				
Grid		Local		Global	
Easting	458401.422 m	Latitude	N13°28'25.87599"	Latitude	N13°28'25.87599"
Northing	1489570.975 m	Longitude	E122°36'56.36154"	Longitude	E122°36'56.36154"
Elevation	5.915 m	Height	56.297 m	Height	56.297 m

To:	UP-TAL				
Grid		Local		Global	
Easting	463529.419 m	Latitude	N13°12'45.54766"	Latitude	N13°12'45.54766"
Northing	1460676.800 m	Longitude	E122°39'48.22813"	Longitude	E122°39'48.22813"
Elevation	4.834 m	Height	55.749 m	Height	55.749 m

Vector					
ΔEasting	5127.997 m	NS Fwd Azimuth	169°50'51"	ΔX	-7951.962 m
ΔNorthing	-28894.175 m	Ellipsoid Dist.	29356.882 m	ΔY	2826.041 m
ΔElevation	-1.081 m	ΔHeight	-0.547 m	ΔZ	-28117.966 m

Standard Errors

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

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000147120		
Y	-0.0000202520	0.0000324907	
Z	-0.0000059864	0.0000096550	0.0000038376

Annex 4. The LiDAR Survey Team Composition

Data Acquisition Component Sub -Team	Designation	Name	Agency / Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	ENGR. CZAR JAKIRI SARMIENTO	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUñA	UP-TCAGP
		LOVELYN ASUNCION	UP-TCAGP

FIELD TEAM

LiDAR Operation	Senior Science Research Specialist (SSRS)	JASMINE ALVIAR	UP-TCAGP
	Research Associate (RA)	JERIEL PAUL ALAMBAN	UP-TCAGP
	RA	KRISTINE JOY ANDAYA	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	JASMIN DOMINGO	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. ERWIN DELOS SANTOS	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. KHALIL CHI	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. CESAR ALFONSO III	AAC

Annex 5. Data Transfer Sheet For Silongin Floodplain

DATA TRANSFER SHEET
09/06/2016 ~~NAGA B~~ Bagasbas

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
5/6/2016	23324P	1BLK21F127A	PEGASUS	2.55	62.1	10.5	240	NA	NA	26.5	NA	55.5	1KB	1KB	53/70/63/5	NA	Z:\DAC\RAWDATA
5/7/2016	23326P	1BLK21E128A	PEGASUS	3.13	43.7	13.8	283	NA	NA	31	NA	81.2	1KB	1KB	74/41/185/	NA	Z:\DAC\RAWDATA
5/10/2016	23334P	1BLK21D131A	PEGASUS	3.57	48.9	13.1	301	NA	NA	36.2	NA	33	1KB	1KB	53/48/41/3 6/33/51/64 /39/51	NA	Z:\DAC\RAWDATA
5/12/2016	23342P	1BLK21G133A	PEGASUS	3.42	38.4	15.5	290	NA	NA	35	NA	180	1KB	1KB	258	NA	Z:\DAC\RAWDATA
5/13/2016	23346P	1BLK21GS134A	PEGASUS	2.43	54.4	13	270	NA	NA	26.7	NA	134	1KB	1KB	43/176	NA	Z:\DAC\RAWDATA
5/15/2016	23354P	1BLK21EF136A	PEGASUS	1.99	93	13.1	277	NA	NA	24.2	NA	121	1KB	1KB	176	NA	Z:\DAC\RAWDATA
5/16/2016	23358P	1BLK21H137A	PEGASUS	3.21	40.1	11.7	214	7.27	NA	31.6	NA	121	1KB	(1KB) N/A	301	NA	Z:\DAC\RAWDATA
5/17/2016	23362P	1BLK21S138A	PEGASUS	628	55.3	7.29	178	22.4	NA	9.43	NA	98.9	1KB	1KB	228	NA	Z:\DAC\RAWDATA

Name DARRYL AUSTRIA
Position R.A.
Signature

Name AC Bongat
Position SSRS
Signature

Annex 6. Flight Logs

Flight Log for 23342P Mission

UP DREAM Data Acquisition Flight Log

Flight Log No.:

1 LIDAR Operator: [illegible]	2 ALTM Model: Peg	3 Mission Name: 2BLK2[illegible]	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9122
7 Pilot: [illegible]	8 Co-Pilot: [illegible]	9 Route: Naga – Naga			
10 Date: [illegible] 2016	12 Airport of Departure (Airport, City/Province): Naga		12 Airport of Arrival (Airport, City/Province): Naga		
13 Engine On: 0750	14 Engine Off: 1225	15 Total Engine Time: 4+35	16 Take off: 0755	17 Landing: 1220	18 Total Flight Time: 4+25
19 Weather: [illegible]					

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

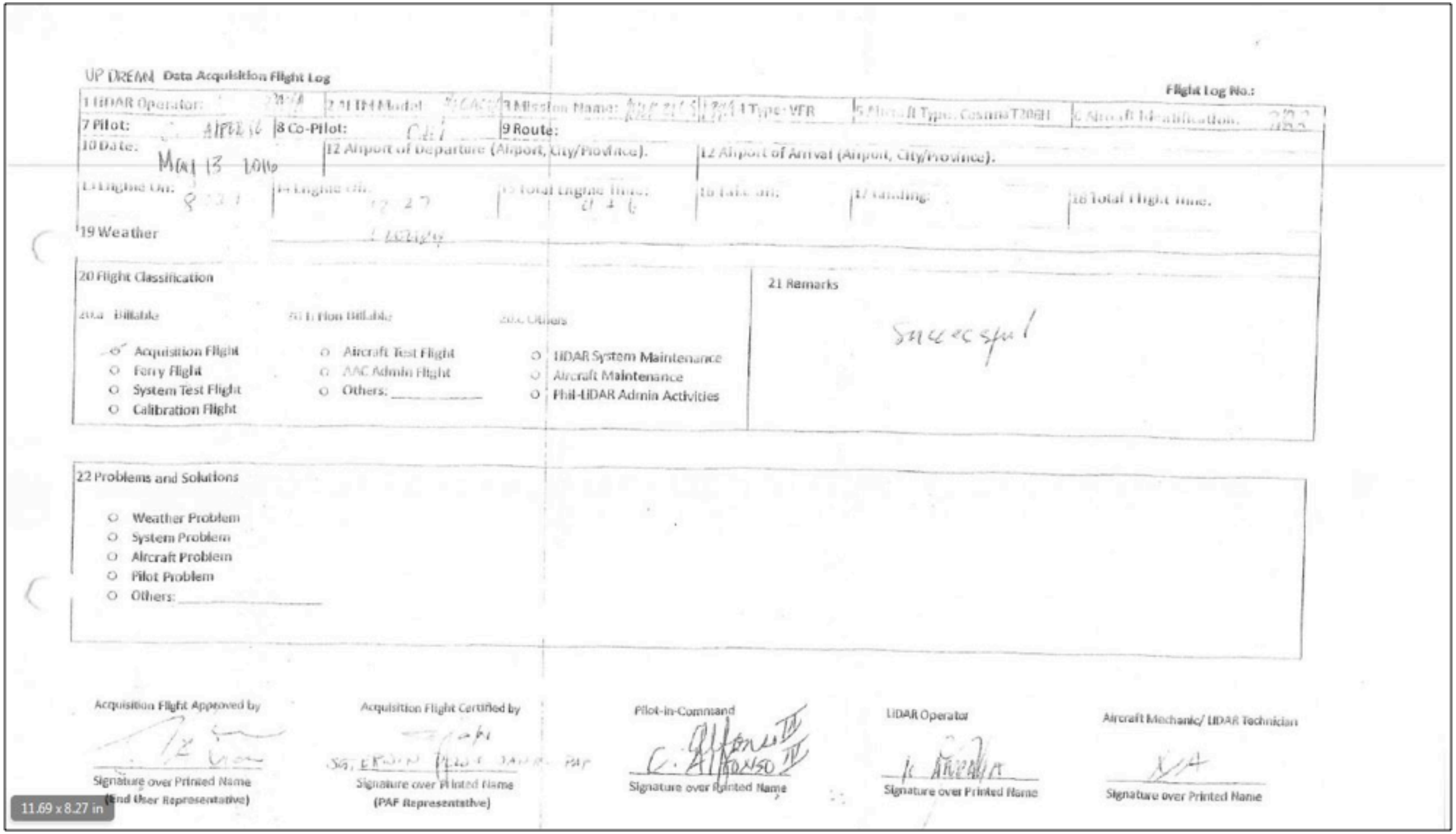
21 Remarks

Successful

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	LIDAR Operator	Aircraft Mechanic/ LIDAR Technician
[illegible]	SGT ERWIN [illegible] PAF	C. Alfonso III	K. Anoppa[illegible]	[illegible]
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

Flight Log for 23342P Mission



UP DREAM Data Acquisition Flight Log

Flight Log No.:

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

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

10 Date: May 13 2016 | 12 Airport of Departure (Airport, City/Province): | 12 Airport of Arrival (Airport, City/Province):

13 Engine On: | 14 Engine Off: | 15 Total Engine Time: | 16 Take off: | 17 Landing: | 18 Total Flight Time:

19 Weather

20 Flight Classification

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

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

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

21 Remarks

Successful

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

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

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

Pilot-in-Command — C. Alfonso IV — Signature over Printed Name

LiDAR Operator — Signature over Printed Name

Aircraft Mechanic/ LiDAR Technician — Signature over Printed Name

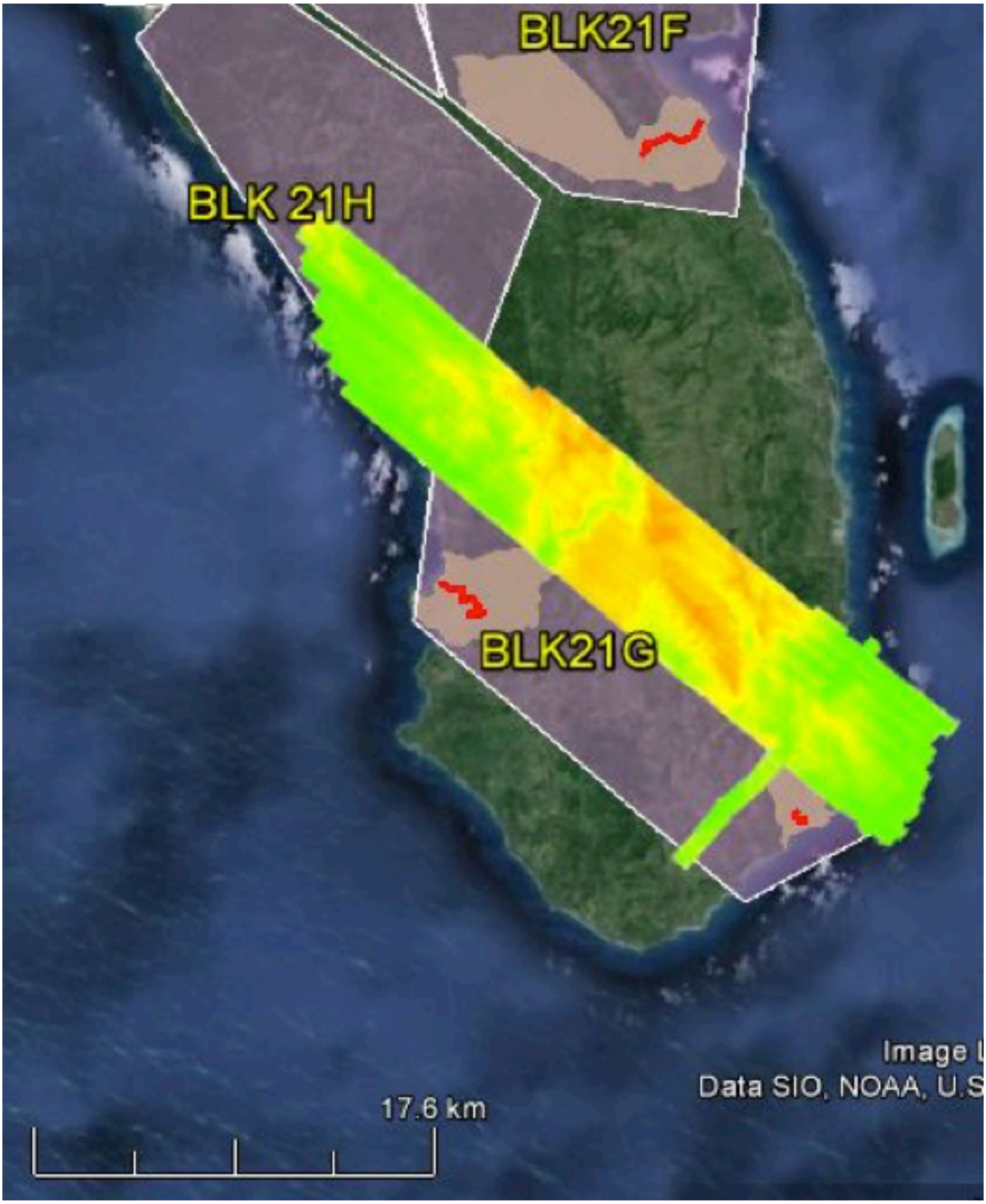
Annex 7. Flight Status

FLIGHT STATUS REPORT
QUEZON
May 12-13, 2016

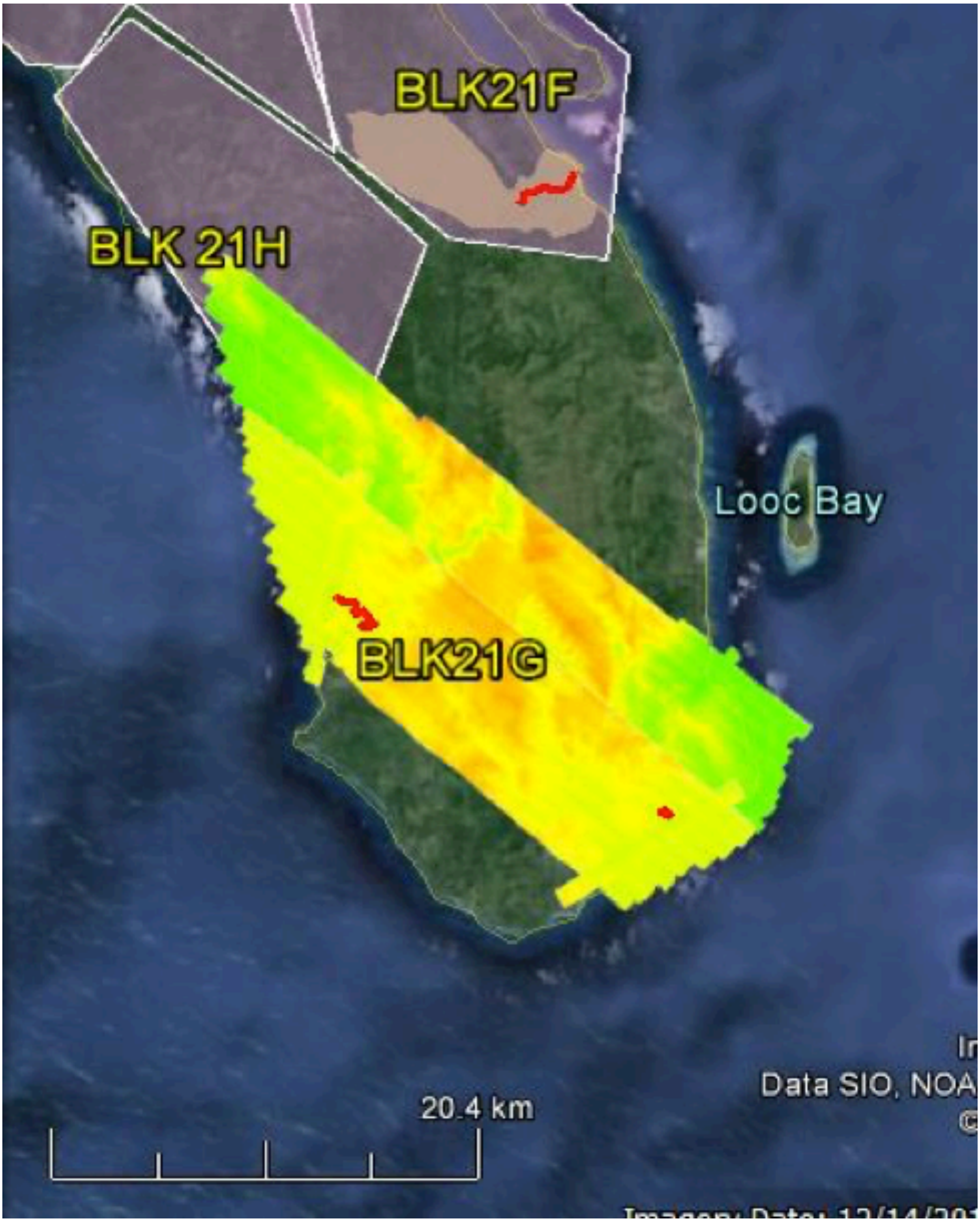
FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
23342P	BLK 21G SILONGIN AND YABAHAAN FPs	1BLK221G133A	K ANDAYA	MAY 12, 2016	SURVEYED BLK 21G
23346P	BLK 21G SILONGIN AND YABAHAAN FPs 1BLK221G133A	1BLK21GS134A	K ANDAYA	MAY 13, 2016	SURVEYED BLK 21G

LAS BOUNDARIES PER MISSION FLIGHT

Flight No. :	23342P			
Area:	BLK21GH			
Parameters:	PRF:	200 kHz;	Scan Frequency:	30Hz
	Scan Angle:	25 deg;	Overlap:	30%



Flight No. :	23346P			
Area:	BLK21GH			
Parameters:	PRF:	200 kHz;	Scan Frequency:	30Hz
	Scan Angle:	25 deg;	Overlap:	30%



Annex 8. Mission Summary Reports

FLIGHT AREA	BAGASBAS
MISSION NAME	BAGASBAS_BLK21G
INCLUSIVE FLIGHTS	23346P
RANGE DATA SIZE	26.7 GB
BASE DATA SIZE	134 MB
POS DATA SIZE	270 MB
BASE DATA SIZE	134 MB
IMAGE	N/A
TRANSFER DATE	SEPTEMBER 6, 2016
SOLUTION STATUS	
NUMBER OF SATELLITES (>6)	YES
PDOP (<3)	YES
BASELINE LENGTH (<30KM)	NO
PROCESSING MODE (<=1)	YES
SMOOTHED PERFORMANCE METRICS (IN CM)	
RMSE FOR NORTH POSITION (<4.0 CM)	1.1
RMSE FOR EAST POSITION (<4.0 CM)	1.3
RMSE FOR DOWN POSITION (<8.0 CM)	2.1
BORESIGHT CORRECTION STDEV (<0.001DEG)	0.000103
IMU ATTITUDE CORRECTION STDEV (<0.001DEG)	0.000268
GPS POSITION STDEV (<0.01M)	0.0061
MINIMUM % OVERLAP (>25)	49.23%
AVE POINT CLOUD DENSITY PER SQ.M. (>2.0)	4.32
ELEVATION DIFFERENCE BETWEEN STRIPS (<0.20 M)	YES
NUMBER OF 1KM X 1KM BLOCKS	209
MAXIMUM HEIGHT	348.62
MINIMUM HEIGHT	49.18
CLASSIFICATION (# OF POINTS)	
GROUND	265274506
LOW VEGETATION	205322997
MEDIUM VEGETATION	245788005
HIGH VEGETATION	582076822
BUILDING	4268406
ORTHOPHOTO	NO
PROCESSED BY	ENGR. JOMMER MEDINA, ENGR. JOVELLE CANLAS, ENGR. ELAINNE LOPEZ

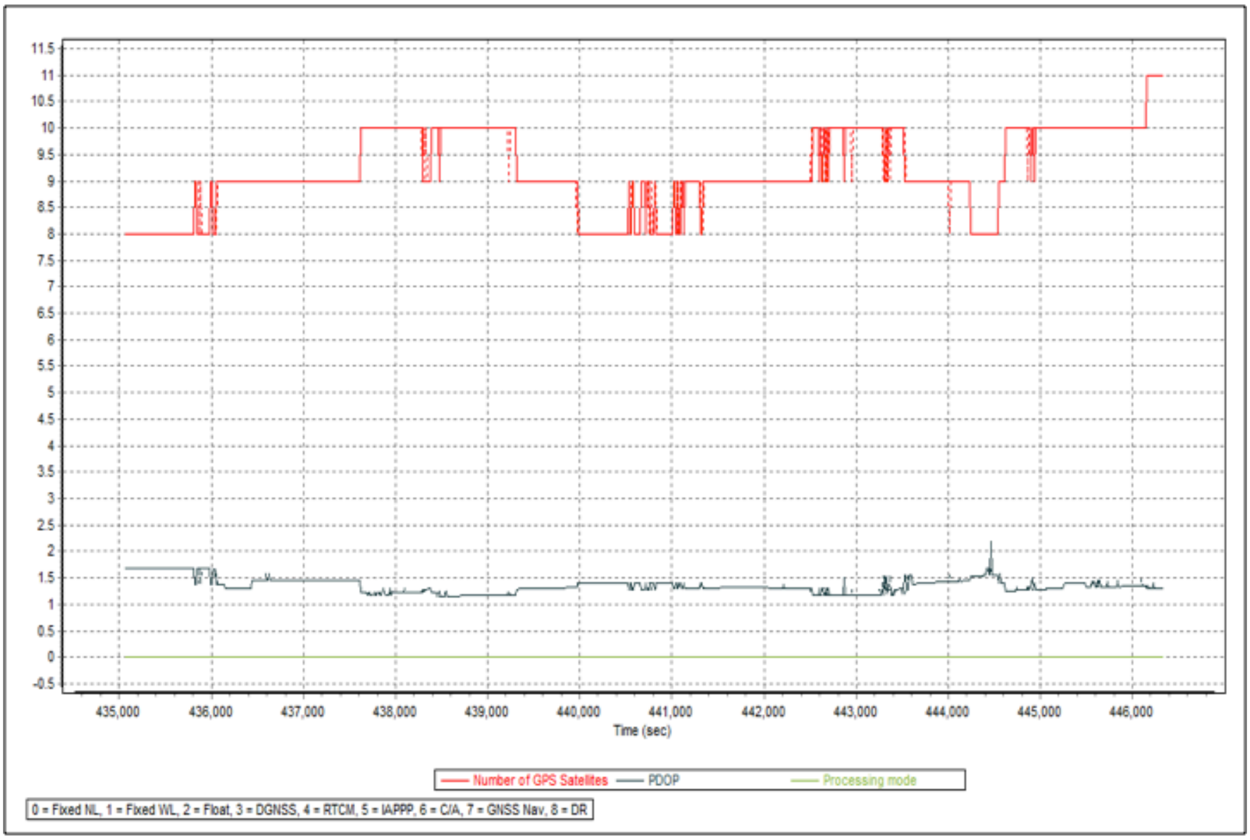


Figure 1.1.1. Solution Status

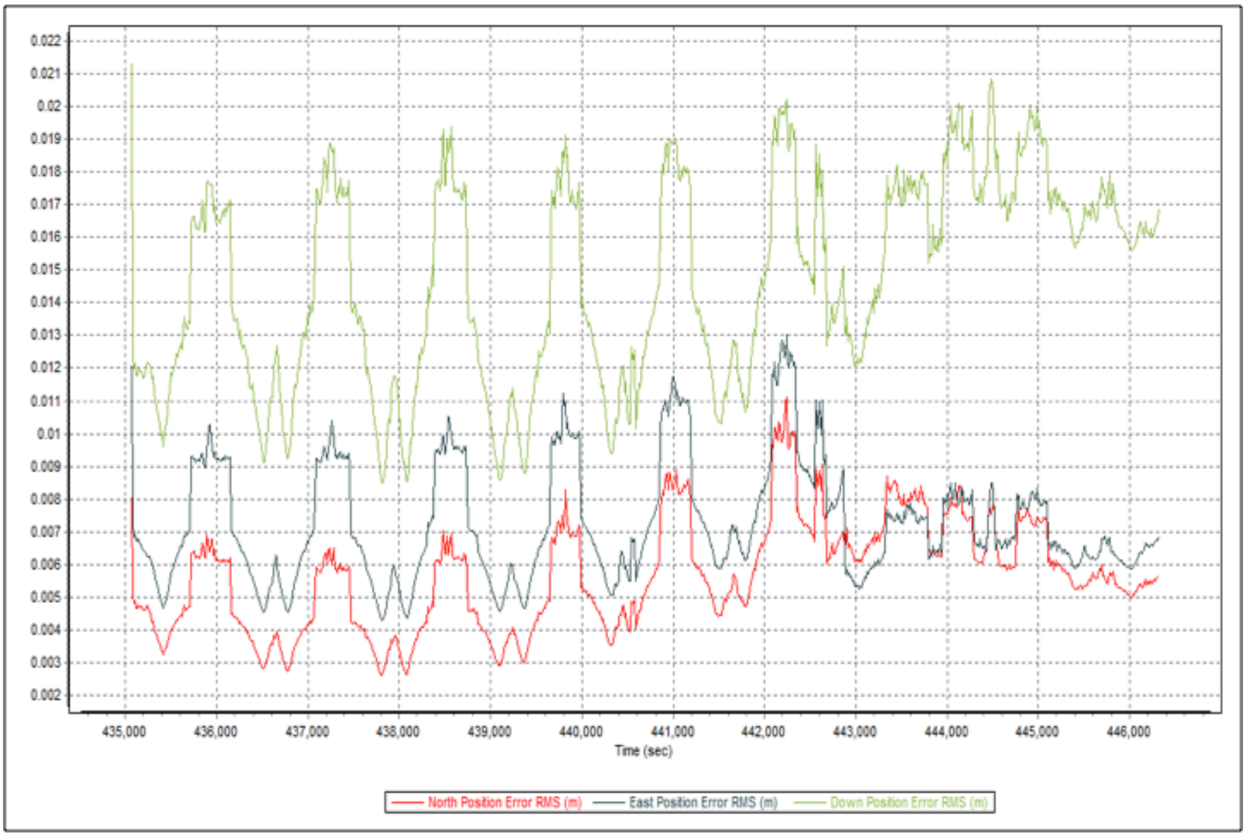


Figure 1.1.2. Smoothed Performance Metric Parameters

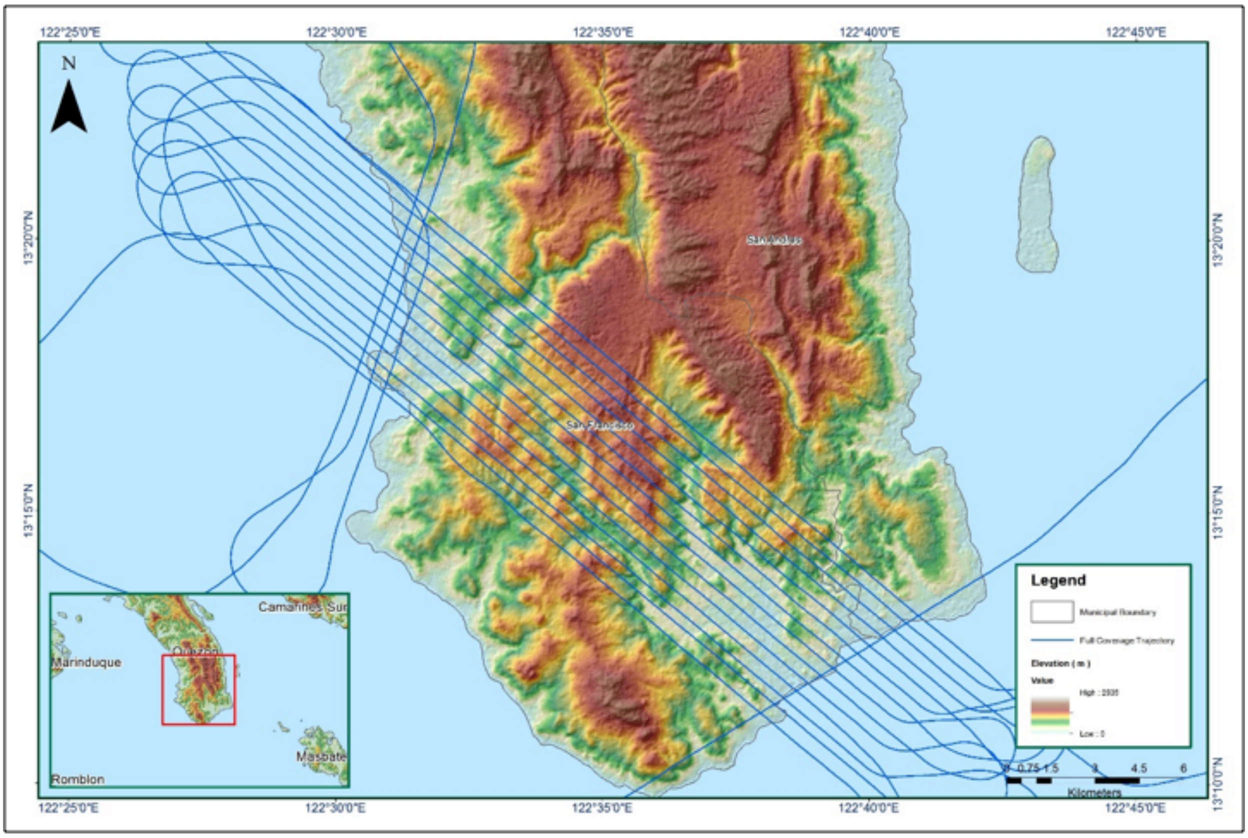


Figure 1.1.3. Best Estimated Trajectory

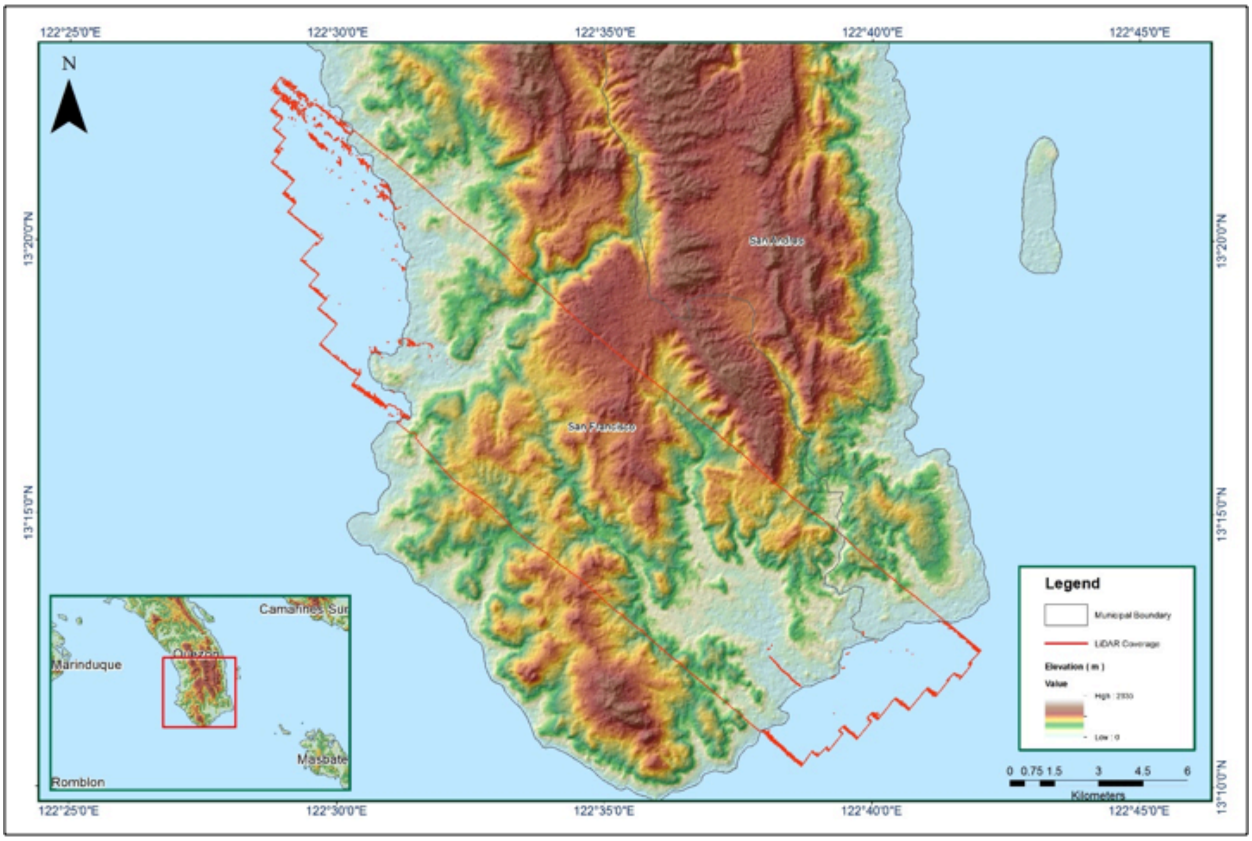


Figure 1.1.4. Coverage of LiDAR Data

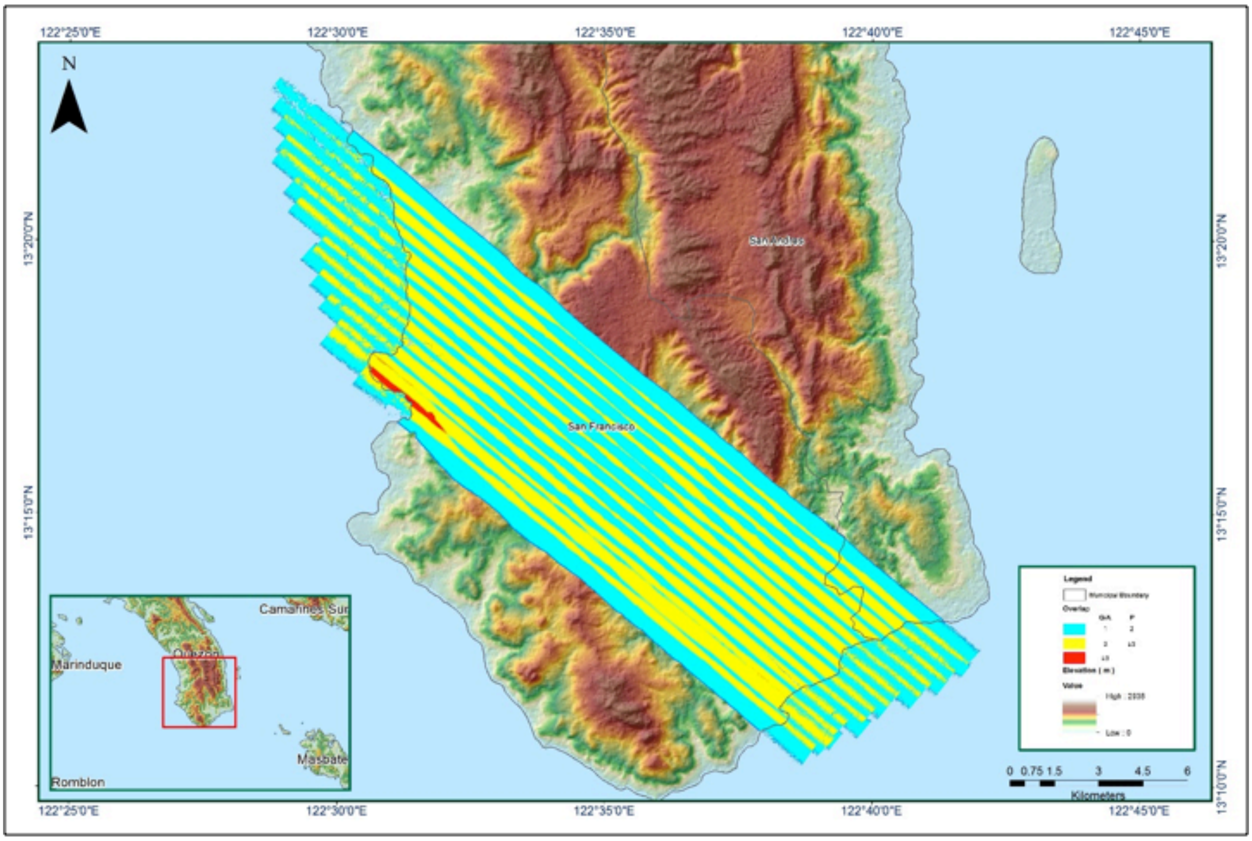


Figure 1.1.5. Image of data overlap

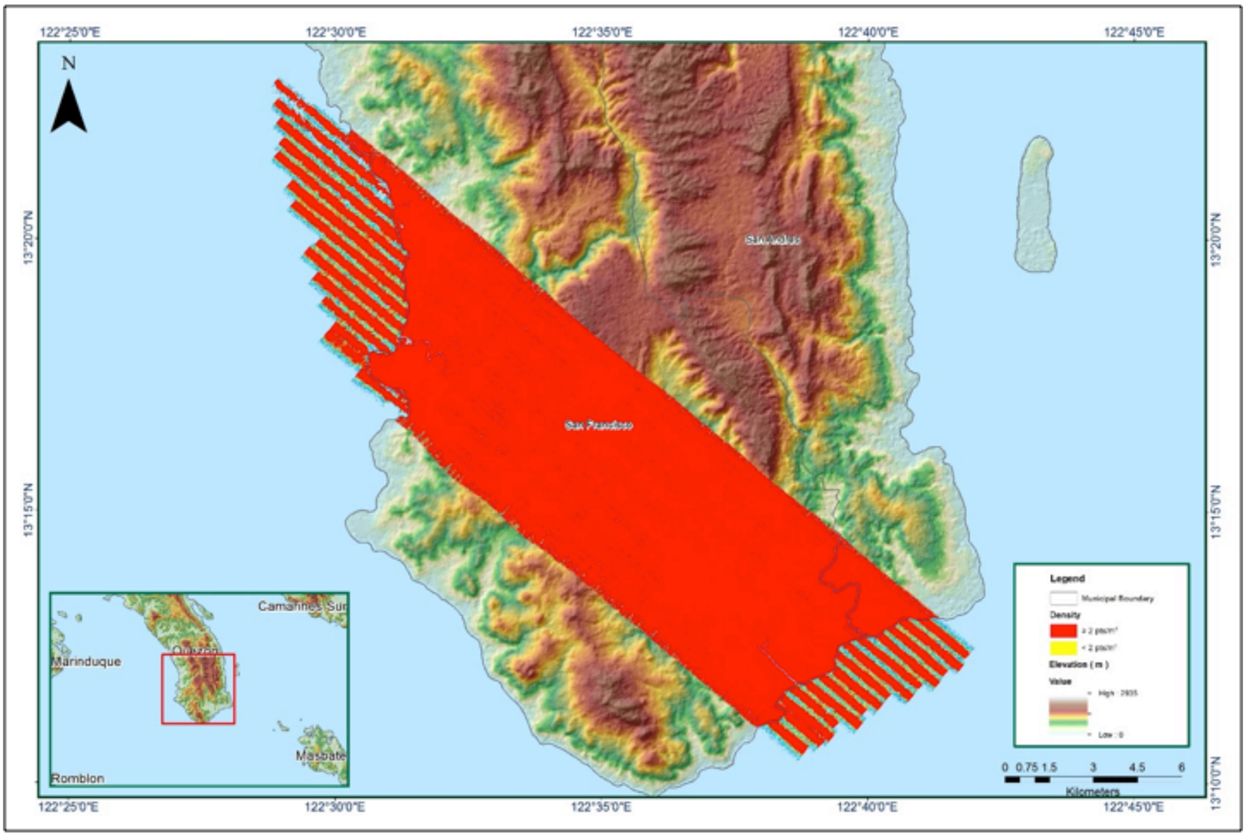


Figure 1.1.6. Density map of merged LiDAR data

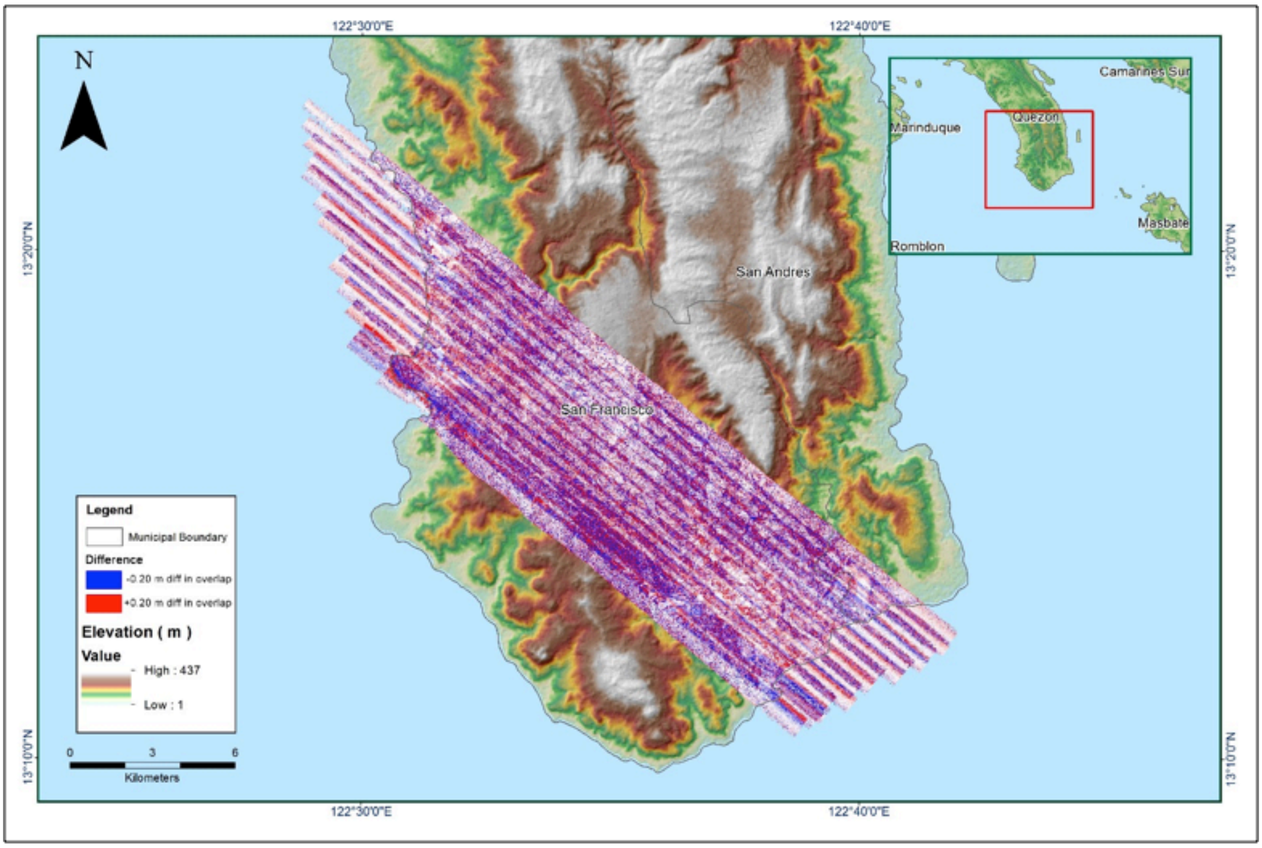


Figure 1.1.7. Elevation difference between flight lines

FLIGHT AREA	BAGASBAS
MISSION NAME	BAGASBASA_BLK21H
INCLUSIVE FLIGHTS	23342P
RANGE DATA SIZE	35 GB
BASE DATA SIZE	180 MB
POS DATA SIZE	290 MB
BASE DATA SIZE	180 MB
IMAGE	N/A
TRANSFER DATE	SEPTEMBER 6, 2016
SOLUTION STATUS	
NUMBER OF SATELLITES (>6)	YES
PDOP (<3)	YES
BASELINE LENGTH (<30KM)	NO
PROCESSING MODE (<=1)	NO
SMOOTHED PERFORMANCE METRICS (IN CM)	
RMSE FOR NORTH POSITION (<4.0 CM)	1.4
RMSE FOR EAST POSITION (<4.0 CM)	1.6
RMSE FOR DOWN POSITION (<8.0 CM)	2.9
BORESIGHT CORRECTION STDEV (<0.001DEG)	0.000121
IMU ATTITUDE CORRECTION STDEV (<0.001DEG)	0.000762
GPS POSITION STDEV (<0.01M)	0.0074
MINIMUM % OVERLAP (>25)	62.54%
AVE POINT CLOUD DENSITY PER SQ.M. (>2.0)	6.06
ELEVATION DIFFERENCE BETWEEN STRIPS (<0.20 M)	YES
NUMBER OF 1KM X 1KM BLOCKS	251
MAXIMUM HEIGHT	473.30 M
MINIMUM HEIGHT	48.95 M
CLASSIFICATION (# OF POINTS)	
GROUND	330,456,714
LOW VEGETATION	275,861,681
MEDIUM VEGETATION	482,884,623
HIGH VEGETATION	1,064,480,938
BUILDING	10,367,950
ORTHOPHOTO	NO
PROCESSED BY	ENGR. JENNIFER SAGURAN, ENGR. MELANIE HINGPIT, ALEX ESCOBIDO

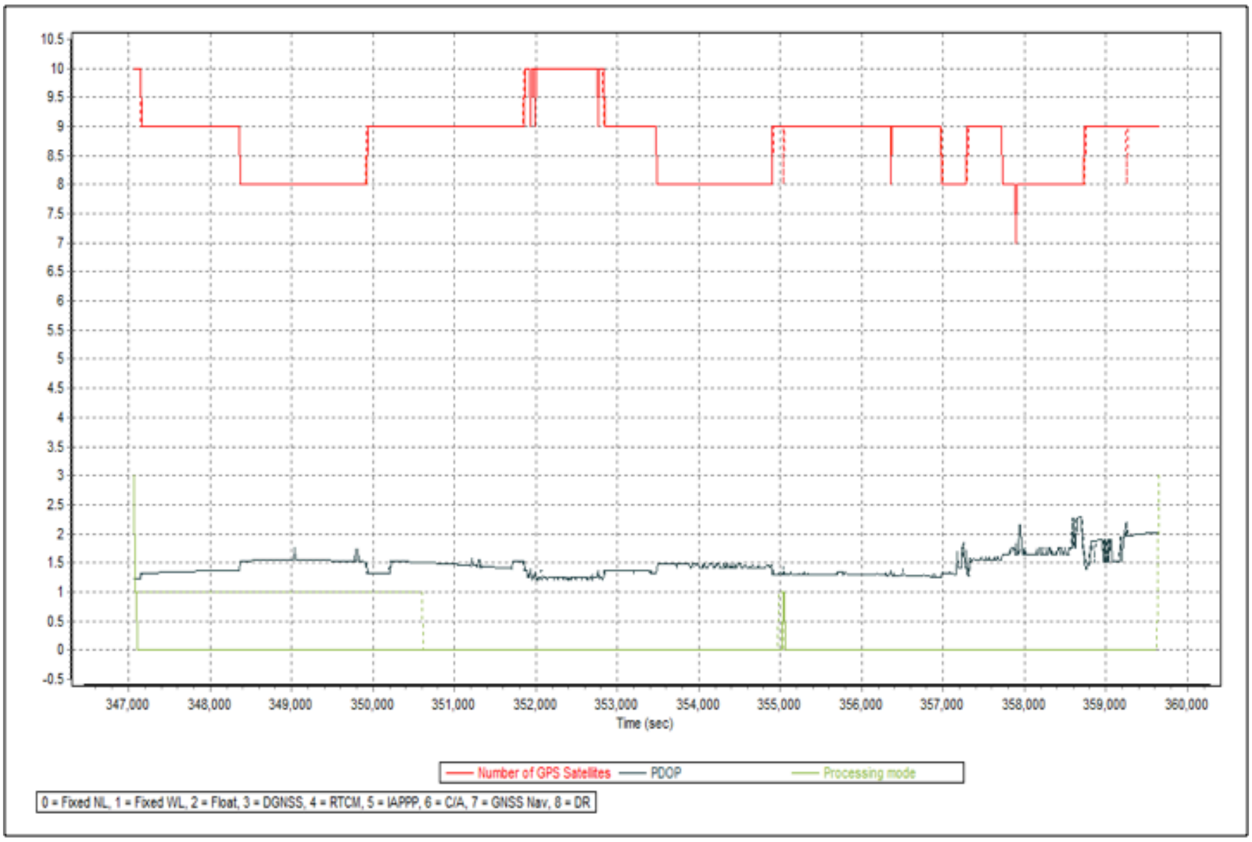


Figure 1.2.1. Solution Status

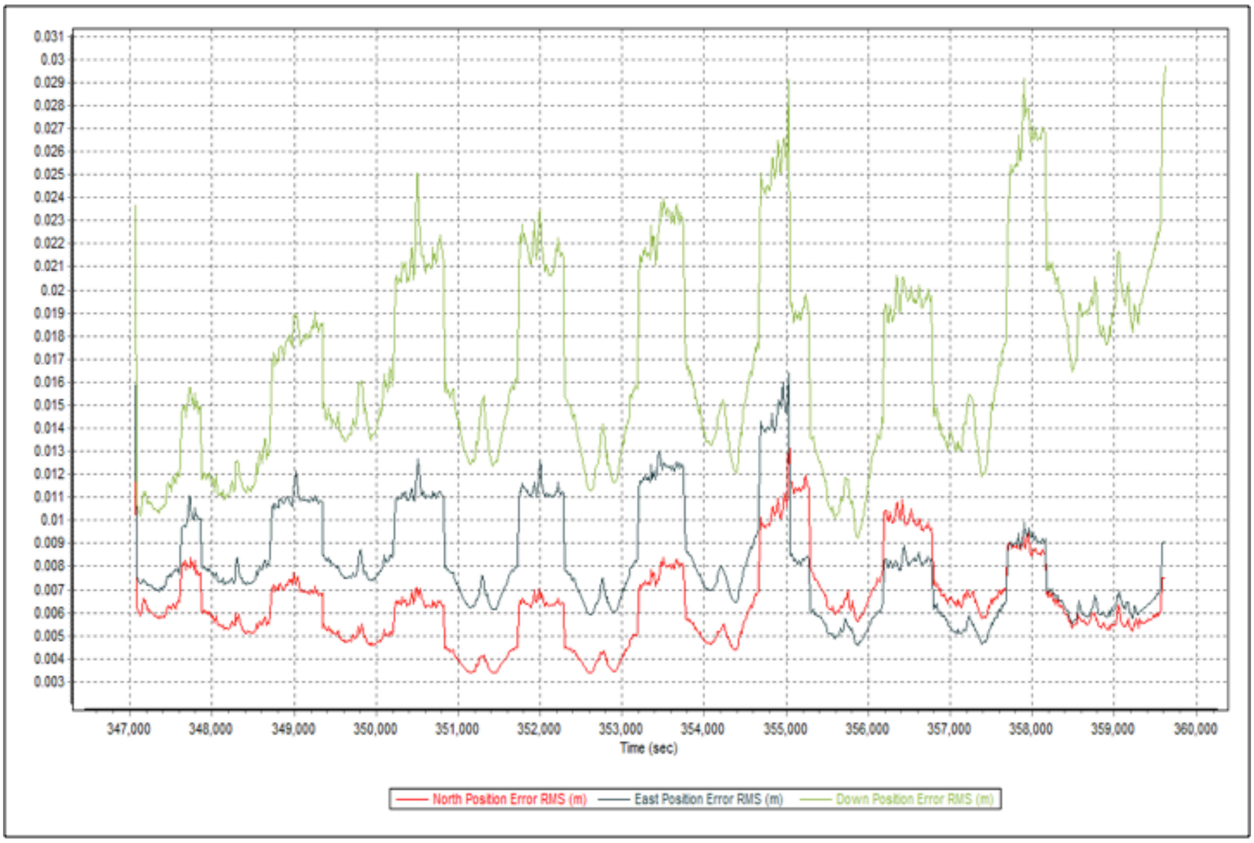


Figure 1.2.2. Smoothed Performance Metric Parameters

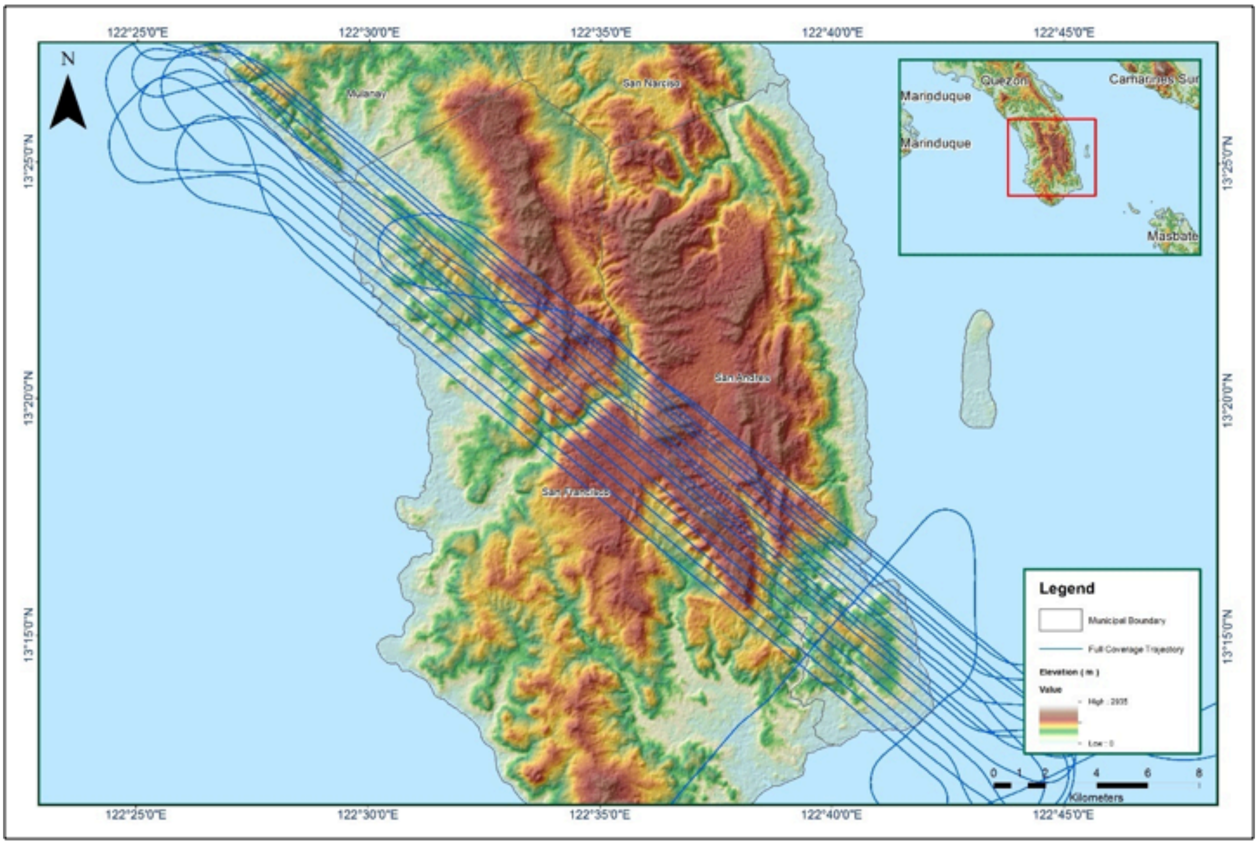


Figure 1.2.3. Best Estimated Trajectory

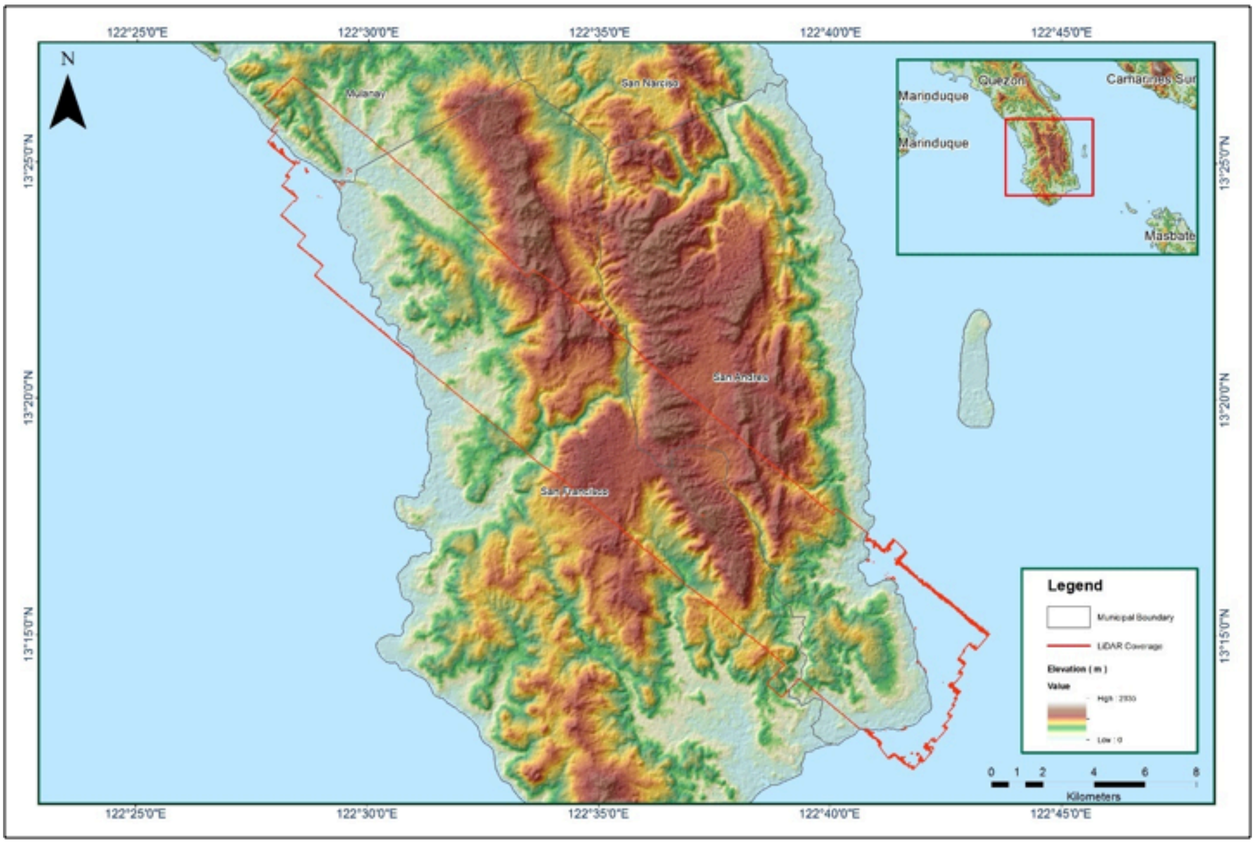


Figure 1.2.4. Coverage of LiDAR Data

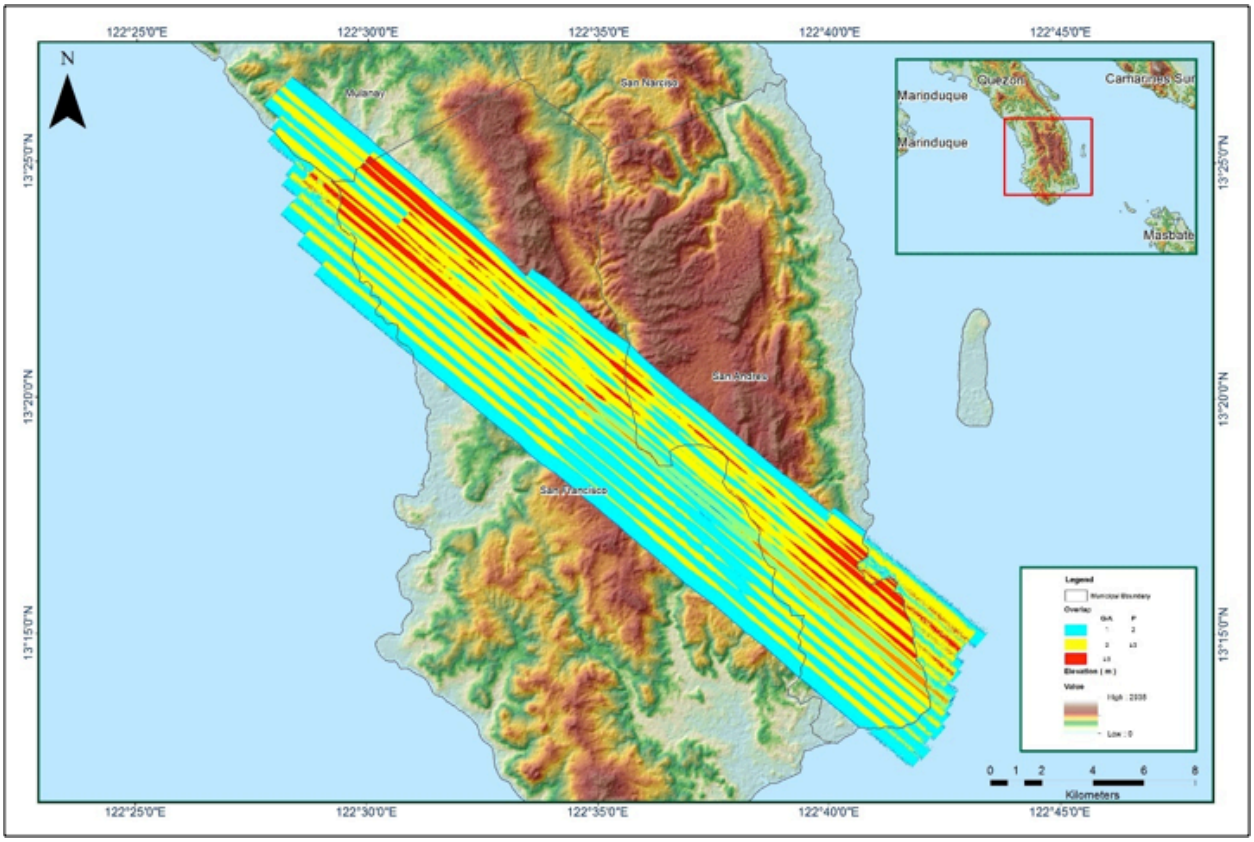


Figure 1.2.5. Image of data overlap

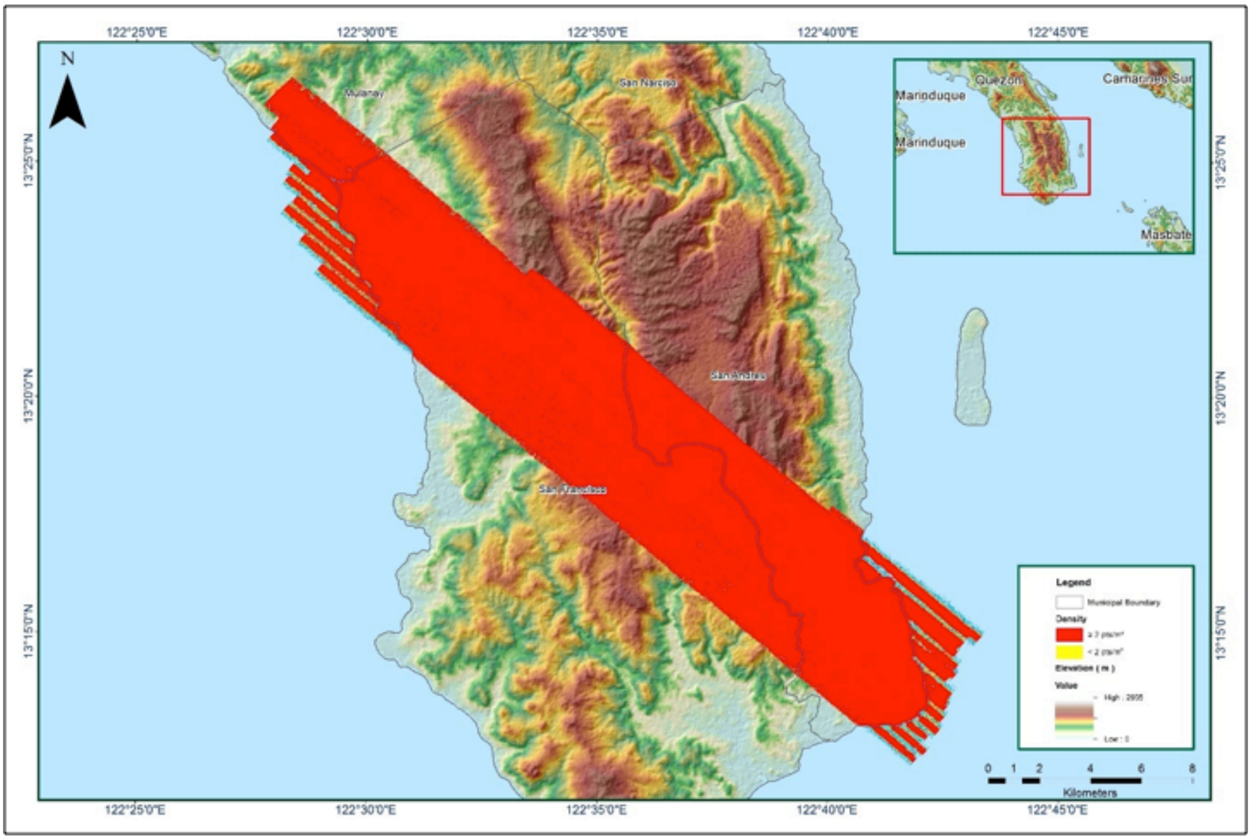


Figure 1.2.6. Density map of merged LiDAR data

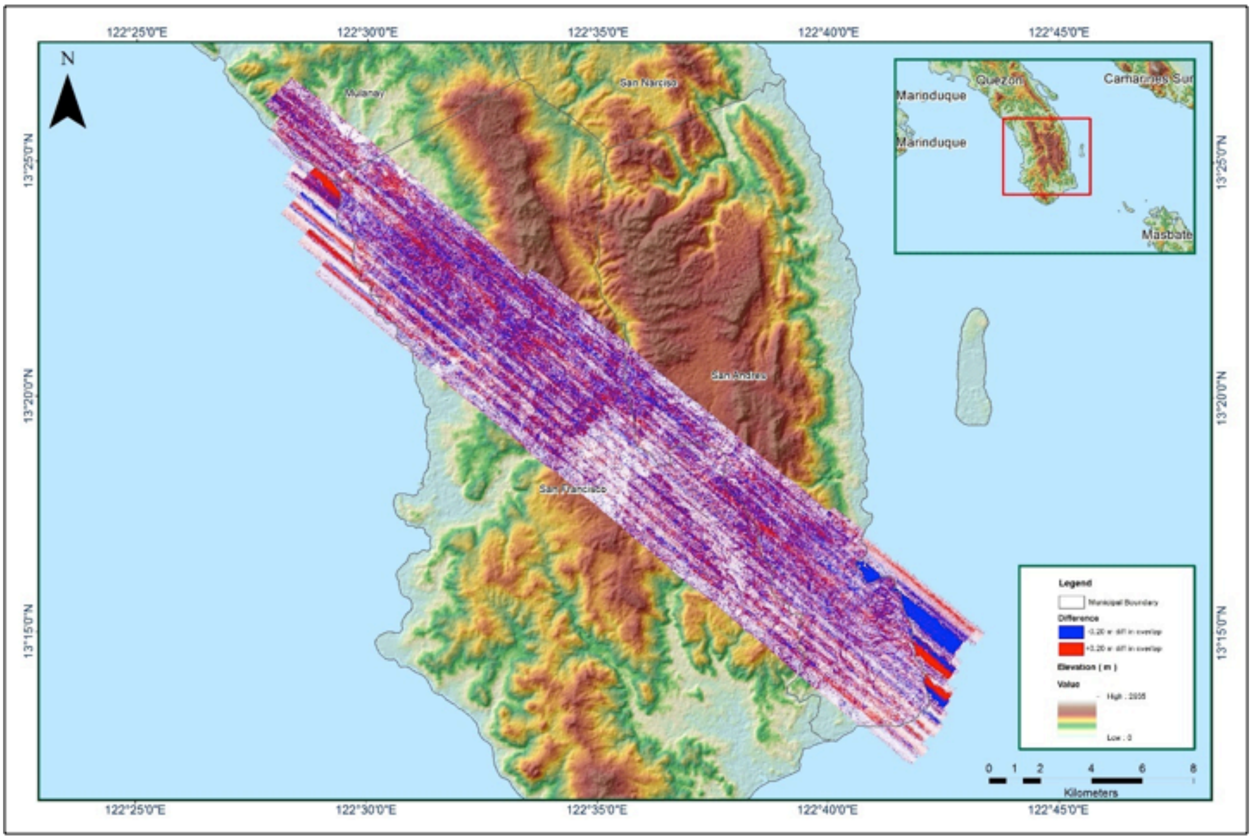


Figure 1.2.7. Elevation difference between flight lines

Annex 9. Silongin 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
W420	1.5268	76.561	0	4.454	2.9483	Discharge	3.54E-02	1	Ratio to Peak	0.4802
W430	2.2439	40.401	0	1.2359	3.9534	Discharge	0.0095384	1	Ratio to Peak	0.31373
W440	2.6613	40.925	0	2.1185	2.2573	Discharge	7.34E-03	1	Ratio to Peak	0.5
W450	1.2146	64.938	0	4.0223	1.5686	Discharge	0.009448	0.97878	Ratio to Peak	0.5
W460	1.002	35.199	0	0.83758	0.56901	Discharge	0.0088028	1	Ratio to Peak	0.32014
W470	1.7441	40.422	0	5.0676	2.5486	Discharge	7.07E-03	0.64543	Ratio to Peak	0.50225
W480	5.1699	35.123	0	0.99568	0.83088	Discharge	0.0109885	0.67536	Ratio to Peak	0.043017
W490	1.7641	45.288	0	4.5166	2.2931	Discharge	0.005482	0.96022	Ratio to Peak	0.50243
W500	1.5853	42.6	0	4.3077	4.3357	Discharge	0.0168522	0.64872	Ratio to Peak	0.75338
W510	3.4679	57.468	0	0.0548	0.0548	Discharge	0.000462814	0.29481	Ratio to Peak	0.41491
W520	2.2827	40.114	0	1.5406	5.4961	Discharge	0.0061314	0.99	Ratio to Peak	0.28937
W530	1.3458	99	0	4.511	3.3863	Discharge	8.11E-05	0.55908	Ratio to Peak	0.32667
W540	1.4576	46.376	0	5.025	1.2961	Discharge	0.0119327	1.00E-05	Ratio to Peak	0.33494
W550	2.2164	40.32	0	5.0474	1.8692	Discharge	0.007139	0.64601	Ratio to Peak	0.49083
W560	0.99343	40.724	0	6.0127	1.9559	Discharge	0.0173344	0.28456	Ratio to Peak	0.49226
W570	0.95929	35.68	0	0.36843	0.86402	Discharge	0.0055614	0.42684	Ratio to Peak	0.29528
W580	1.4296	58.827	0	0.56007	0.36931	Discharge	0.0050183	1	Ratio to Peak	0.31345
W590	1.4605	47.64	0	0.69866	2.4644	Discharge	0.0065698	0.66667	Ratio to Peak	0.45197
W600	1.6242	42.338	0	0.0797	0.0797	Discharge	0.000673108	0.088167	Ratio to Peak	0.32318
W610	1.6624	39.543	0	1.4709	0.70504	Discharge	0.0101532	0.9	Ratio to Peak	0.32139
W620	0.97893	42.666	0	0.2665	0.97785	Discharge	0.0059786	0.19541	Ratio to Peak	0.47913
W630	2.3577	45.445	0	4.6635	4.2312	Discharge	0.010301	1	Ratio to Peak	0.50226

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
W640	1.2957	42.197	0	1.8381	1.075	Discharge	0.0070959	1	Ratio to Peak	0.37724
W650	1.4368	48.256	0	0.37482	1.0442	Discharge	0.0068358	0.9	Ratio to Peak	0.37724
W660	2.0507	53.989	0	6.8079	2.9718	Discharge	0.0182921	1	Ratio to Peak	0.32617
W670	1.4661	72.405	0	0.79185	0.35586	Discharge	0.0022997	0.18023	Ratio to Peak	0.5
W680	1.4585	35.236	0	0.43234	6.195	Discharge	0.0113212	1	Ratio to Peak	0.47139
W690	0.59827	87.915	0	8.1805	8.8572	Discharge	0.000133439	0.19096	Ratio to Peak	0.21342
W700	1.5031	35.245	0	6.1531	3.8968	Discharge	0.0119698	1	Ratio to Peak	1
W710	1.4661	67.081	0	0.48999	2.1104	Discharge	0.0059532	1	Ratio to Peak	0.5
W720	1.5284	61.222	0	7.5939	8.0139	Discharge	0.0124943	0.27888	Ratio to Peak	0.4776
W730	1.4682	43.928	0	0.79633	1.2563	Discharge	0.0048773	0.18399	Ratio to Peak	0.50221
W740	1.9736	65.645	0	2.0108	0.66603	Discharge	0.0066922	0.28915	Ratio to Peak	0.21774
W750	2.2547	45.405	0	3.4192	1.1006	Discharge	0.006161	0.017255	Ratio to Peak	0.32167
W760	1.7972	42.11	0	0.40736	0.59618	Discharge	0.0067133	0.057602	Ratio to Peak	0.21445
W770	2.2329	49.136	0	0.16365	8.504	Discharge	0.0078535	1.00E-05	Ratio to Peak	0.31851
W780	1.5109	60.643	0	0.11386	0.33754	Discharge	0.000956877	1.00E-05	Ratio to Peak	0.5048
W790	0.97394	73.405	0	2.2045	0.73534	Discharge	0.0074185	0.43312	Ratio to Peak	0.21778
W800	1.606	37.706	0	0.16659	2.1503	Discharge	0.007389	0.085518	Ratio to Peak	0.48218
W810	2.6208	63.213	0	6.8707	2.5871	Discharge	0.0192448	0.2421	Ratio to Peak	0.22222
W820	2.1833	63.852	0	2.3615	4.4402	Discharge	0.0075376	0.26782	Ratio to Peak	0.096791

Annex 10. Silongin Model Reach Parameters

Reach	Muskingum Cunge Channel Routing								
	Time Step Method	Length (m)	Slope	Manning's n	Invert	Shape	Diameter	Width	Side Slope
R130	Automatic Fixed Interval	1213	0.025902	0.16218		Trapezoid		16	1
R180	Automatic Fixed Interval	56.569	0.018718	0.0001		Trapezoid		16	1
R190	Automatic Fixed Interval	2471.8	0.008638	0.07952		Trapezoid		16	1
R220	Automatic Fixed Interval	1296.1	0.017296	0.079229		Trapezoid		16	1
R240	Automatic Fixed Interval	296.98	0.021067	0.065659		Trapezoid		16	1
R250	Automatic Fixed Interval	437.99	0.032507	0.19855		Trapezoid		16	1
R260	Automatic Fixed Interval	28.284	0.058512	0.005062		Trapezoid		16	1
R280	Automatic Fixed Interval	1048.8	0.020186	0.026335		Trapezoid		16	1
R300	Automatic Fixed Interval	1159.9	0.002003	0.035367		Trapezoid		16	1
R310	Automatic Fixed Interval	2189.1	0.030374	0.003983		Trapezoid		16	1
R320	Automatic Fixed Interval	850.42	0.003755	0.052638		Trapezoid		16	1
R360	Automatic Fixed Interval	2521.4	0.045546	0.038693		Trapezoid		16	1
R370	Automatic Fixed Interval	362.13	0.11662	0.10685		Trapezoid		16	1
R390	Automatic Fixed Interval	1049.5	0.010593	0.026847		Trapezoid		16	1
R40	Automatic Fixed Interval	1532.3	0.017385	0.21116		Trapezoid		16	1
R410	Automatic Fixed Interval	1276.2	0.00001	0.051439		Trapezoid		16	1
R50	Automatic Fixed Interval	450.12	0.013967	0.045356		Trapezoid		16	1
R70	Automatic Fixed Interval	630.83	0.014827	0.041981		Trapezoid		16	1
R80	Automatic Fixed Interval	253.14	0.025572	0.056074		Trapezoid		16	1
R90	Automatic Fixed Interval	28.284	0.092411	0.000239		Trapezoid		16	1

Annex 11. Silongin Field Validation

Point No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
1	122.552439	13.311065	2.13	5	2.87	Typhoon Ondoy/ September 28, 2009	5-year
2	122.552303	13.310943	1.50	5	3.50	Typhoon Ondoy/ September 28, 2009	5-year
3	122.552211	13.310912	1.97	5	3.03	Typhoon Ondoy/ September 28, 2009	5-year
4	122.551937	13.310912	7.20	5	-2.20	Typhoon Ondoy/ September 28, 2009	5-year
5	122.551874	13.310772	7.40	5	-2.40	Typhoon Ondoy/ September 28, 2009	5-year
6	122.551861	13.310665	8.56	5	-3.56	Typhoon Ondoy/ September 28, 2009	5-year
7	122.551814	13.311131	8.22	5	-3.22	Typhoon Ondoy/ September 28, 2009	5-year
8	122.551901	13.311648	8.30	5	-3.30	Typhoon Ondoy/ September 28, 2009	5-year
9	122.552058	13.311749	5.01	5	-0.01	Typhoon Ondoy/ September 28, 2009	5-year
10	122.552216	13.311949	8.64	5	-3.64	Typhoon Ondoy/ September 28, 2009	5-year
11	122.551842	13.310592	8.56	5	-3.56	Typhoon Ondoy/ September 28, 2009	5-year
12	122.551838	13.310567	8.56	5	-3.56	Typhoon Ondoy/ September 28, 2009	5-year
13	122.551735	13.31046	8.54	5	-3.54	Typhoon Ondoy/ September 28, 2009	5-year
14	122.55177	13.31039	8.80	5	-3.80	Typhoon Ondoy/ September 28, 2009	5-year
15	122.551612	13.309962	2.05	5	2.95	Typhoon Ondoy/ September 28, 2009	5-year
16	122.551349	13.309717	8.92	5	-3.92	Typhoon Ondoy/ September 28, 2009	5-year
17	122.551286	13.309689	5.93	5	-0.93	Typhoon Ondoy/ September 28, 2009	5-year
18	122.551168	13.309558	9.01	5	-4.01	Typhoon Ondoy/ September 28, 2009	5-year
19	122.55102	13.309482	8.71	5	-3.71	Typhoon Ondoy/ September 28, 2009	5-year
20	122.550953	13.309489	6.84	5	-1.84	Typhoon Ondoy/ September 28, 2009	5-year
21	122.550902	13.309572	7.41	5	-2.41	Typhoon Ondoy/ September 28, 2009	5-year
22	122.550745	13.309651	9.14	5	-4.14	Typhoon Ondoy/ September 28, 2009	5-year

Point No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
23	122.550697	13.309722	7.28	5	-2.28	Typhoon Ondoy/ September 28, 2009	5-year
24	122.550649	13.3098	9.42	5	-4.42	Typhoon Ondoy/ September 28, 2009	5-year
25	122.550668	13.309893	9.63	5	-4.63	Typhoon Ondoy/ September 28, 2009	5-year
26	122.550597	13.309977	7.36	5	-2.36	Typhoon Ondoy/ September 28, 2009	5-year
27	122.550556	13.310055	9.94	5	-4.94	Typhoon Ondoy/ September 28, 2009	5-year
28	122.552137	13.308934	0.06	5	4.94	Typhoon Ondoy/ September 28, 2009	5-year
29	122.552204	13.307387	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
30	122.552342	13.306577	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
31	122.552234	13.304904	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
32	122.551768	13.30372	0.03	5	4.97	Typhoon Ondoy/ September 28, 2009	5-year
33	122.551393	13.302648	0.32	0.5	0.18	Typhoon Ondoy/ September 28, 2009	5-year
34	122.551334	13.301246	1.10	0.5	-0.60	Typhoon Ondoy/ September 28, 2009	5-year
35	122.55143	13.301145	0.58	1	0.42	Typhoon Ondoy/ September 28, 2009	5-year
36	122.551238	13.301019	1.10	0.5	-0.60	Typhoon Ondoy/ September 28, 2009	5-year
37	122.551102	13.301201	0.81	1	0.19	Typhoon Ondoy/ September 28, 2009	5-year
38	122.551067	13.30102	0.66	0	-0.66	Typhoon Ondoy/ September 28, 2009	5-year
39	122.55066	13.300087	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
40	122.550206	13.2992	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
41	122.547765	13.298285	0.06	0	-0.06	Typhoon Ondoy/ September 28, 2009	5-year
42	122.547576	13.298509	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
43	122.547469	13.298746	0.05	0	-0.05	Typhoon Ondoy/ September 28, 2009	5-year
44	122.546969	13.299023	0.49	0	-0.49	Typhoon Ondoy/ September 28, 2009	5-year
45	122.546367	13.298786	0.42	0	-0.42	Typhoon Ondoy/ September 28, 2009	5-year

Point No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
46	122.545953	13.298311	0.87	5	4.13	Typhoon Ondoy/ September 28, 2009	5-year
47	122.54549	13.298363	7.76	5	-2.76	Typhoon Ondoy/ September 28, 2009	5-year
48	122.545181	13.298538	7.00	5	-2.00	Typhoon Ondoy/ September 28, 2009	5-year
49	122.54497	13.298603	1.61	5	3.40	Typhoon Ondoy/ September 28, 2009	5-year
50	122.545151	13.298744	6.35	5	-1.35	Typhoon Ondoy/ September 28, 2009	5-year
51	122.545076	13.298839	1.19	5	3.81	Typhoon Ondoy/ September 28, 2009	5-year
52	122.544859	13.299024	7.27	5	-2.27	Typhoon Ondoy/ September 28, 2009	5-year
53	122.544772	13.299181	8.42	5	-3.42	Typhoon Ondoy/ September 28, 2009	5-year
54	122.544759	13.29932	8.24	5	-3.24	Typhoon Ondoy/ September 28, 2009	5-year
55	122.544816	13.299393	7.21	5	-2.21	Typhoon Ondoy/ September 28, 2009	5-year
56	122.544933	13.299532	7.81	5	-2.81	Typhoon Ondoy/ September 28, 2009	5-year
57	122.545133	13.299658	7.79	5	-2.79	Typhoon Ondoy/ September 28, 2009	5-year
58	122.545212	13.299976	7.75	5	-2.75	Typhoon Ondoy/ September 28, 2009	5-year
59	122.545282	13.300124	7.66	5	-2.66	Typhoon Ondoy/ September 28, 2009	5-year
60	122.545297	13.300298	7.68	5	-2.68	Typhoon Ondoy/ September 28, 2009	5-year
61	122.545285	13.296688	4.26	5	0.74	Typhoon Ondoy/ September 28, 2009	5-year
62	122.547644	13.297591	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
63	122.547725	13.296526	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
64	122.546806	13.294458	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
65	122.54629	13.292453	0.03	5	4.97	Typhoon Ondoy/ September 28, 2009	5-year
66	122.546136	13.292024	1.03	1	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
67	122.546161	13.292374	0.06	5	4.94	Typhoon Ondoy/ September 28, 2009	5-year
68	122.546181	13.292151	0.37	5	4.63	Typhoon Ondoy/ September 28, 2009	5-year

Point No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
69	122.545996	13.29205	0.97	0	-0.97	Typhoon Ondoy/ September 28, 2009	5-year
70	122.54585	13.292121	1.10	0	-1.10	Typhoon Ondoy/ September 28, 2009	5-year
71	122.546249	13.292374	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
72	122.545609	13.29163	0.05	0	-0.05	Typhoon Ondoy/ September 28, 2009	5-year
73	122.544357	13.291353	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
74	122.543048	13.290999	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
75	122.540652	13.290232	0.19	2	1.81	Typhoon Ondoy/ September 28, 2009	5-year
76	122.536617	13.288719	0.12	0.2	0.09	Typhoon Ondoy/ September 28, 2009	5-year
77	122.536579	13.28885	0.18	0.3	0.12	Typhoon Ondoy/ September 28, 2009	5-year
78	122.536473	13.289183	0.15	0.3	0.15	Typhoon Ondoy/ September 28, 2009	5-year
79	122.53606	13.289276	0.11	0.4	0.29	Typhoon Ondoy/ September 28, 2009	5-year
80	122.535684	13.289748	0.86	0.5	-0.36	Typhoon Ondoy/ September 28, 2009	5-year
81	122.535527	13.290177	0.70	3	2.31	Typhoon Ondoy/ September 28, 2009	5-year
82	122.535209	13.290592	1.28	5	3.72	Typhoon Ondoy/ September 28, 2009	5-year
83	122.534691	13.291042	0.47	5	4.53	Typhoon Ondoy/ September 28, 2009	5-year
84	122.534281	13.291558	5.31	5	-0.31	Typhoon Ondoy/ September 28, 2009	5-year
85	122.534318	13.291732	1.38	5	3.62	Typhoon Ondoy/ September 28, 2009	5-year
86	122.534439	13.291674	1.05	5	3.95	Typhoon Ondoy/ September 28, 2009	5-year
87	122.534807	13.291561	1.79	5	3.21	Typhoon Ondoy/ September 28, 2009	5-year
88	122.535158	13.291514	2.97	5.5	2.53	Typhoon Ondoy/ September 28, 2009	5-year
89	122.535433	13.291577	3.22	5	1.78	Typhoon Ondoy/ September 28, 2009	5-year
90	122.535646	13.291661	3.39	5	1.61	Typhoon Ondoy/ September 28, 2009	5-year
91	122.535775	13.291735	5.42	5	-0.42	Typhoon Ondoy/ September 28, 2009	5-year

Point No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
92	122.53595	13.291958	1.48	0.5	-0.98	Typhoon Ondoy/ September 28, 2009	5-year
93	122.536355	13.292142	1.42	0.5	-0.92	Typhoon Ondoy/ September 28, 2009	5-year
94	122.536478	13.292215	1.22	0.5	-0.72	Typhoon Ondoy/ September 28, 2009	5-year
95	122.536706	13.292527	0.94	0.5	-0.44	Typhoon Ondoy/ September 28, 2009	5-year
96	122.536198	13.292239	0.84	0.5	-0.34	Typhoon Ondoy/ September 28, 2009	5-year
97	122.535132	13.291751	1.26	0	-1.26	Typhoon Ondoy/ September 28, 2009	5-year
98	122.536435	13.29019	0.53	0.5	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
99	122.551531	13.311159	0.89	0.5	-0.39	Typhoon Ondoy/ September 28, 2009	5-year
100	122.551358	13.311121	1.19	0.5	-0.69	Typhoon Ondoy/ September 28, 2009	5-year
101	122.551225	13.311122	1.24	2	0.76	Typhoon Ondoy/ September 28, 2009	5-year
102	122.550358	13.311314	2.01	2	-0.01	Typhoon Ondoy/ September 28, 2009	5-year
103	122.550244	13.311171	2.27	5	2.73	Typhoon Ondoy/ September 28, 2009	5-year
104	122.550041	13.310865	2.70	2	-0.70	Typhoon Ondoy/ September 28, 2009	5-year
105	122.550371	13.311572	1.94	2	0.06	Typhoon Ondoy/ September 28, 2009	5-year
106	122.549986	13.311538	1.24	0	-1.24	Typhoon Ondoy/ September 28, 2009	5-year
107	122.549607	13.311605	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
108	122.549385	13.31159	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
109	122.549379	13.311763	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
110	122.549682	13.311682	0.11	0.4	0.29	Typhoon Ondoy/ September 28, 2009	5-year
111	122.549794	13.312013	0.10	0.4	0.30	Typhoon Ondoy/ September 28, 2009	5-year
112	122.549799	13.311707	0.22	2	1.78	Typhoon Ondoy/ September 28, 2009	5-year
113	122.550826	13.311191	1.44	5	3.56	Typhoon Ondoy/ September 28, 2009	5-year
114	122.551547	13.311372	0.03	5	4.97	Typhoon Ondoy/ September 28, 2009	5-year

Point No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
115	122.551486	13.311412	0.03	5	4.97	Typhoon Ondoy/ September 28, 2009	5-year
116	122.551315	13.31141	0.56	5	4.44	Typhoon Ondoy/ September 28, 2009	5-year
117	122.551386	13.311538	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
118	122.551512	13.312048	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
119	122.551075	13.313468	0.09	0	-0.09	Typhoon Ondoy/ September 28, 2009	5-year
120	122.55072	13.314504	0.15	0	-0.15	Typhoon Ondoy/ September 28, 2009	5-year
121	122.550425	13.315296	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
122	122.549834	13.316536	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
123	122.549408	13.317559	0.08	0.1	0.02	Typhoon Ondoy/ September 28, 2009	5-year
124	122.549059	13.318018	0.04	0.1	0.06	Typhoon Ondoy/ September 28, 2009	5-year
125	122.54922	13.318112	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
126	122.549281	13.318233	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
127	122.549595	13.318511	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
128	122.549772	13.31871	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
129	122.550171	13.31884	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
130	122.549684	13.318375	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
131	122.54974	13.318221	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
132	122.549706	13.31803	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
133	122.549728	13.317871	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
134	122.549696	13.317693	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
135	122.549539	13.31754	0.03	0.1	0.07	Typhoon Ondoy/ September 28, 2009	5-year
136	122.549093	13.317622	0.06	0	-0.06	Typhoon Ondoy/ September 28, 2009	5-year
137	122.548976	13.317707	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year

Point No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
138	122.549063	13.317902	0.15	0	-0.15	Typhoon Ondoy/ September 28, 2009	5-year
139	122.548828	13.318134	0.08	0	-0.08	Typhoon Ondoy/ September 28, 2009	5-year
140	122.548397	13.31855	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
141	122.544621	13.321694	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
142	122.529537	13.287154	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
143	122.528205	13.286536	0.03	0	-0.03	Typhoon Ondoy/ September 28, 2009	5-year
144	122.545769	13.292404	0.65	1	0.35	Typhoon Ondoy/ September 28, 2009	5-year
145	122.551066	13.300718	0.36	1	0.64	Typhoon Ondoy/ September 28, 2009	5-year
146	122.540614	13.29027	0.45	0.2	-0.25	Typhoon Ondoy/ September 28, 2009	5-year
147	122.540101	13.290119	0.56	0.2	-0.36	Typhoon Ondoy/ September 28, 2009	5-year
148	122.539597	13.290273	0.27	0.2	-0.07	Typhoon Ondoy/ September 28, 2009	5-year
149	122.539494	13.290576	0.27	0.2	-0.07	Typhoon Ondoy/ September 28, 2009	5-year
150	122.539432	13.290747	0.13	0.2	0.07	Typhoon Ondoy/ September 28, 2009	5-year
151	122.539274	13.290524	0.37	0.2	-0.17	Typhoon Ondoy/ September 28, 2009	5-year
152	122.53904	13.290457	0.40	0.2	-0.20	Typhoon Ondoy/ September 28, 2009	5-year
153	122.539065	13.289767	0.07	0.2	0.13	Typhoon Ondoy/ September 28, 2009	5-year
154	122.53173	13.291732	0.62	0.2	-0.42	Typhoon Ondoy/ September 28, 2009	5-year
155	122.53085	13.287504	0.03	0.2	0.17	Typhoon Ondoy/ September 28, 2009	5-year
156	122.550372	13.299492	0.03	0.2	0.17	Typhoon Ondoy/ September 28, 2009	5-year
157	122.529699	13.287139	0.05	0.2	0.15	Typhoon Ondoy/ September 28, 2009	5-year
158	122.52835	13.286537	0.05	0.2	0.15	Typhoon Ondoy/ September 28, 2009	5-year
159	122.526719	13.285964	0.13	0.2	0.07	Typhoon Ondoy/ September 28, 2009	5-year
160	122.525551	13.285565	0.03	0.2	0.17	Typhoon Ondoy/ September 28, 2009	5-year

Point No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
161	122.524181	13.284499	0.03	0.2	0.17	Typhoon Ondoy/ September 28, 2009	5-year
162	122.548455	13.298224	0.04	0.2	0.16	Typhoon Ondoy/ September 28, 2009	5-year
163	122.547793	13.297958	0.71	0.2	-0.51	Typhoon Ondoy/ September 28, 2009	5-year
164	122.547807	13.297408	0.03	0.2	0.17	Typhoon Ondoy/ September 28, 2009	5-year
165	122.547631	13.296514	0.03	0.2	0.17	Typhoon Ondoy/ September 28, 2009	5-year
166	122.547196	13.29581	0.03	0.2	0.17	Typhoon Ondoy/ September 28, 2009	5-year
167	122.546905	13.294932	0.22	0.2	-0.02	Typhoon Ondoy/ September 28, 2009	5-year
168	122.546731	13.294343	0.03	0.2	0.17	Typhoon Ondoy/ September 28, 2009	5-year
169	122.550839	13.300351	0.03	0.2	0.17	Typhoon Ondoy/ September 28, 2009	5-year
170	122.538639	13.289642	0.03	0.5	0.47	Typhoon Ondoy/ September 28, 2009	5-year
171	122.532772	13.291151	0.30	0.5	0.20	Typhoon Ondoy/ September 28, 2009	5-year
172	122.532962	13.291241	0.19	0.5	0.31	Typhoon Ondoy/ September 28, 2009	5-year
173	122.533091	13.291308	0.95	0.5	-0.45	Typhoon Ondoy/ September 28, 2009	5-year
174	122.533235	13.291327	0.78	0.5	-0.28	Typhoon Ondoy/ September 28, 2009	5-year
175	122.551433	13.302766	0.62	0.5	-0.12	Typhoon Ondoy/ September 28, 2009	5-year
176	122.551294	13.30255	0.12	0.5	0.38	Typhoon Ondoy/ September 28, 2009	5-year
177	122.551098	13.30141	0.48	0.5	0.02	Typhoon Ondoy/ September 28, 2009	5-year
178	122.55118	13.30127	0.57	0.5	-0.07	Typhoon Ondoy/ September 28, 2009	5-year
179	122.551191	13.300854	1.46	0.5	-0.96	Typhoon Ondoy/ September 28, 2009	5-year
180	122.544021	13.291278	0.12	0.5	0.38	Typhoon Ondoy/ September 28, 2009	5-year
181	122.550432	13.299664	0.03	0.5	0.47	Typhoon Ondoy/ September 28, 2009	5-year
182	122.549758	13.298615	0.03	0.5	0.47	Typhoon Ondoy/ September 28, 2009	5-year
183	122.548983	13.298365	0.03	0.5	0.47	Typhoon Ondoy/ September 28, 2009	5-year

Point No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
184	122.547907	13.298084	0.03	0.5	0.47	Typhoon Ondoy/ September 28, 2009	5-year
185	122.546906	13.295055	0.11	0.5	0.40	Typhoon Ondoy/ September 28, 2009	5-year
186	122.546997	13.294958	0.34	0.5	0.16	Typhoon Ondoy/ September 28, 2009	5-year
187	122.546882	13.294875	0.11	0.5	0.39	Typhoon Ondoy/ September 28, 2009	5-year
188	122.546101	13.291931	1.10	0.5	-0.60	Typhoon Ondoy/ September 28, 2009	5-year
189	122.539654	13.289993	0.35	0.5	0.15	Typhoon Ondoy/ September 28, 2009	5-year
190	122.541977	13.290704	0.39	0.5	0.11	Typhoon Ondoy/ September 28, 2009	5-year
191	122.540095	13.290086	0.51	0.5	-0.01	Typhoon Ondoy/ September 28, 2009	5-year
192	122.539909	13.289948	0.29	0.5	0.21	Typhoon Ondoy/ September 28, 2009	5-year
193	122.54005	13.289708	0.34	0.5	0.16	Typhoon Ondoy/ September 28, 2009	5-year
194	122.540064	13.289589	0.41	0.5	0.10	Typhoon Ondoy/ September 28, 2009	5-year
195	122.540273	13.289061	0.07	0.5	0.43	Typhoon Ondoy/ September 28, 2009	5-year
196	122.540136	13.289441	0.34	0.5	0.16	Typhoon Ondoy/ September 28, 2009	5-year
197	122.540588	13.287602	0.14	0.5	0.36	Typhoon Ondoy/ September 28, 2009	5-year
198	122.539097	13.28978	0.21	0.5	0.29	Typhoon Ondoy/ September 28, 2009	5-year
199	122.538863	13.290433	0.37	0.5	0.13	Typhoon Ondoy/ September 28, 2009	5-year
200	122.538683	13.290532	0.37	0.5	0.13	Typhoon Ondoy/ September 28, 2009	5-year
201	122.538459	13.290611	0.57	0.5	-0.07	Typhoon Ondoy/ September 28, 2009	5-year
202	122.531887	13.29132	0.68	0.5	-0.18	Typhoon Ondoy/ September 28, 2009	5-year
203	122.531841	13.291523	0.62	0.5	-0.12	Typhoon Ondoy/ September 28, 2009	5-year
204	122.532678	13.291132	0.34	0.5	0.17	Typhoon Ondoy/ September 28, 2009	5-year
205	122.546185	13.292195	0.20	0.5	0.30	Typhoon Ondoy/ September 28, 2009	5-year
206	122.532203	13.290646	1.06	1.5	0.44	Typhoon Ondoy/ September 28, 2009	5-year

Point No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
207	122.531934	13.290952	0.72	1.5	0.78	Typhoon Ondoy/ September 28, 2009	5-year
208	122.531885	13.29111	0.64	1.5	0.86	Typhoon Ondoy/ September 28, 2009	5-year
209	122.531173	13.291873	0.67	1.5	0.83	Typhoon Ondoy/ September 28, 2009	5-year
210	122.532281	13.291188	0.95	1.5	0.55	Typhoon Ondoy/ September 28, 2009	5-year
211	122.532558	13.291091	0.37	1.5	1.14	Typhoon Ondoy/ September 28, 2009	5-year
212	122.546077	13.291908	1.63	1.5	-0.13	Typhoon Ondoy/ September 28, 2009	5-year
213	122.540677	13.290176	0.19	1	0.81	Typhoon Ondoy/ September 28, 2009	5-year
214	122.540318	13.290155	0.68	1	0.32	Typhoon Ondoy/ September 28, 2009	5-year
215	122.536356	13.288982	0.24	1	0.76	Typhoon Ondoy/ September 28, 2009	5-year
216	122.535117	13.288626	0.40	1	0.60	Typhoon Ondoy/ September 28, 2009	5-year
217	122.534982	13.288553	0.60	1	0.40	Typhoon Ondoy/ September 28, 2009	5-year
218	122.534671	13.288466	0.34	1	0.66	Typhoon Ondoy/ September 28, 2009	5-year
219	122.530818	13.287458	0.29	1	0.71	Typhoon Ondoy/ September 28, 2009	5-year
220	122.53011	13.287306	0.06	1	0.94	Typhoon Ondoy/ September 28, 2009	5-year
221	122.526537	13.285926	0.09	1	0.91	Typhoon Ondoy/ September 28, 2009	5-year
222	122.53936	13.290173	0.49	1	0.52	Typhoon Ondoy/ September 28, 2009	5-year
223	122.547703	13.297835	0.03	1	0.97	Typhoon Ondoy/ September 28, 2009	5-year
224	122.546006	13.291799	0.63	1	0.38	Typhoon Ondoy/ September 28, 2009	5-year
225	122.545868	13.292227	0.86	1	0.14	Typhoon Ondoy/ September 28, 2009	5-year
226	122.54577	13.292216	1.07	1	-0.07	Typhoon Ondoy/ September 28, 2009	5-year
227	122.541843	13.290639	0.12	1	0.88	Typhoon Ondoy/ September 28, 2009	5-year
228	122.549939	13.298699	0.10	1	0.90	Typhoon Ondoy/ September 28, 2009	5-year
229	122.548682	13.310068	0.10	0.5	0.41	Typhoon Ondoy/ September 28, 2009	5-year

Point No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
230	122.549253	13.311143	0.03	0.5	0.47	Typhoon Ondoy/ September 28, 2009	5-year
231	122.549607	13.311433	0.03	0.5	0.47	Typhoon Ondoy/ September 28, 2009	5-year
232	122.549887	13.311655	0.50	0.5	0.00	Typhoon Ondoy/ September 28, 2009	5-year
233	122.55012	13.311724	0.03	0.5	0.47	Typhoon Ondoy/ September 28, 2009	5-year
234	122.550474	13.311644	1.74	0.5	-1.24	Typhoon Ondoy/ September 28, 2009	5-year
235	122.55087	13.311643	0.67	0.5	-0.17	Typhoon Ondoy/ September 28, 2009	5-year
236	122.551507	13.309456	0.49	0.5	0.01	Typhoon Ondoy/ September 28, 2009	5-year
237	122.550287	13.309867	0.51	0.5	-0.01	Typhoon Ondoy/ September 28, 2009	5-year
238	122.550041	13.30983	0.56	0.5	-0.06	Typhoon Ondoy/ September 28, 2009	5-year
239	122.549797	13.309554	0.63	0.5	-0.13	Typhoon Ondoy/ September 28, 2009	5-year
240	122.548766	13.308862	1.76	0.5	-1.26	Typhoon Ondoy/ September 28, 2009	5-year
241	122.548632	13.30909	1.93	0.5	-1.43	Typhoon Ondoy/ September 28, 2009	5-year
242	122.548699	13.309725	0.37	0.5	0.13	Typhoon Ondoy/ September 28, 2009	5-year
243	122.548679	13.310133	0.05	0.5	0.45	Typhoon Ondoy/ September 28, 2009	5-year
244	122.551708	13.309565	0.91	0.5	-0.41	Typhoon Ondoy/ September 28, 2009	5-year
245	122.55099	13.309628	4.08	1.5	-2.58	Typhoon Ondoy/ September 28, 2009	5-year
246	122.551786	13.309696	2.09	1.5	-0.59	Typhoon Ondoy/ September 28, 2009	5-year
247	122.551242	13.309325	0.37	1.5	1.13	Typhoon Ondoy/ September 28, 2009	5-year
248	122.550943	13.309304	0.57	1.5	0.93	Typhoon Ondoy/ September 28, 2009	5-year
249	122.55062	13.309486	0.27	1.5	1.23	Typhoon Ondoy/ September 28, 2009	5-year
250	122.550506	13.309591	0.43	1.5	1.07	Typhoon Ondoy/ September 28, 2009	5-year
251	122.549552	13.309217	1.48	1.5	0.02	Typhoon Ondoy/ September 28, 2009	5-year
252	122.549328	13.30911	1.58	1.5	-0.08	Typhoon Ondoy/ September 28, 2009	5-year

Point No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
253	122.54937	13.310231	5.80	1.5	-4.30	Typhoon Ondoy/ September 28, 2009	5-year
254	122.549171	13.308863	8.06	1.5	-6.56	Typhoon Ondoy/ September 28, 2009	5-year
255	122.553048	13.310659	1.06	1.5	0.44	Typhoon Ondoy/ September 28, 2009	5-year
256	122.548899	13.308624	1.98	1.5	-0.48	Typhoon Ondoy/ September 28, 2009	5-year
257	122.553443	13.310438	0.70	1.5	0.80	Typhoon Ondoy/ September 28, 2009	5-year
258	122.553766	13.310266	0.03	1.5	1.47	Typhoon Ondoy/ September 28, 2009	5-year
259	122.551788	13.311724	6.50	1.5	-5.00	Typhoon Ondoy/ September 28, 2009	5-year
260	122.551684	13.311714	0.03	1.5	1.47	Typhoon Ondoy/ September 28, 2009	5-year
261	122.551629	13.311499	0.03	1.5	1.47	Typhoon Ondoy/ September 28, 2009	5-year
262	122.550978	13.310691	1.56	1.5	-0.06	Typhoon Ondoy/ September 28, 2009	5-year
263	122.550935	13.310232	1.93	1.5	-0.43	Typhoon Ondoy/ September 28, 2009	5-year
264	122.55265	13.310857	1.86	1.5	-0.36	Typhoon Ondoy/ September 28, 2009	5-year
265	122.552429	13.31115	2.32	1	-1.32	Typhoon Ondoy/ September 28, 2009	5-year
266	122.552011	13.311932	0.61	1	0.39	Typhoon Ondoy/ September 28, 2009	5-year
267	122.551325	13.311258	0.93	1	0.08	Typhoon Ondoy/ September 28, 2009	5-year
268	122.550997	13.310933	1.48	1	-0.48	Typhoon Ondoy/ September 28, 2009	5-year
269	122.549765	13.309738	0.63	1	0.37	Typhoon Ondoy/ September 28, 2009	5-year
270	122.548989	13.308346	1.55	1	-0.55	Typhoon Ondoy/ September 28, 2009	5-year
271	122.5487	13.309357	1.44	1	-0.44	Typhoon Ondoy/ September 28, 2009	5-year
272	122.55398	13.31015	0.03	1	0.97	Typhoon Ondoy/ September 28, 2009	5-year
273	122.551494	13.309764	8.87	2.5	-6.37	Typhoon Ondoy/ September 28, 2009	5-year
274	122.550758	13.309758	6.98	2.5	-4.48	Typhoon Ondoy/ September 28, 2009	5-year
275	122.551605	13.311305	0.26	2	1.74	Typhoon Ondoy/ September 28, 2009	5-year

Point No.	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
276	122.549193	13.310004	2.84	3.5	0.66	Typhoon Ondoy/ September 28, 2009	5-year
277	122.549199	13.308582	8.06	3.5	-4.56	Typhoon Ondoy/ September 28, 2009	5-year
278	122.549118	13.309492	8.25	3.5	-4.75	Typhoon Ondoy/ September 28, 2009	5-year

Annex 12. Educational Institutions Affected by Flooding in Silongin Floodplain

SAMAR				
Pinabacdao				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
CASAY ELEMENTARY SCHOOL	Casay	None	None	None
CASAY NATIONAL HIGH SCHOOL	Casay	None	Low	Low
DAY CARE CENTER	Don Juan Vercelos	None	None	None
DAY CARE CENTER	Silongin	None	None	None
LOAWAN ELEMENTARY SCHOOL	Silongin	None	None	None
LOOK AWASAN ELEMENTARY SCHOOL	Don Juan Vercelos	None	None	None

Annex 13. Health Institutions Affected in Silongin Floodp

QUEZON				
San Francisco				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
HEALTH CENTER	Silongin	None	None	None