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

LiDAR Surveys and Flood Mapping of KingKing River

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

APRIL 2017

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

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

E.C. Paringit and J.E. Acosta (Eds.), (2017), LiDAR Surveys and Flood Mapping of Digos River. Quezon City: UP Training Center for Applied Geodesy and Photogrammetry - 83pp.

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National Library of the Philippines
ISBN: 987-621-430-166-9

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

LC	Low Chord
LGU	local government unit
LiDAR	Light Detection and Ranging
LMS	LiDAR Mapping Suite
m AGL	meters Above Ground Level
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
UPM	University of the Philippines Mindanao
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 KINGKING RIVER

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1.1 Background of the Phil-LiDAR 1 Program

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

Also, the program was aimed at producing an up-to-date and detailed national elevation dataset suitable for 1:5,000 scale mapping, with 50 cm and 20 cm horizontal and vertical accuracies, respectively. These accuracies were achieved through the use of the state-of-the-art Light Detection and Ranging (LiDAR) airborne technology procured by the project through DOST. The methods applied in this report are thoroughly described in a separate publication entitled "Flood Mapping of Rivers in the Philippines Using Airborne LiDAR: Methods" (Paringit, et. al., 2017), available separately.

The implementing partner university for the Phil-LiDAR 1 Program is the University of the Philippines Mindanao (UPM). UPM is in charge of processing LIDAR data and conducting data validation reconaissance, cross section, bathymetric survey, validation, rover flow measurements, flood height and extent data gathering, flood modelling, and flood map generation for the fourteen (14) river systems in the Southern Mindanao Region The university is located in Davao City in the province of Davao del Sur.

1.2 Overview of the Kingking River Basin

The Kingking River is located in the North-East part of Pantukan in the Compostela Valley Province. It is the main drainage of Barangay Kingking. The province's inhabitants originated from the ethnic tribes of the Mansaka, Mandaya, Manobo, Mangguangan, Dibabawon, Aeta, Kamayo, Davaoweño and Kalagan. Similar to the history of other Mindanao provinces, most of the present populations of the province are descendants of migrants who came from the Luzon and Visayas islands during the pre-war and post-war eras. A Datu serves as the tribe leader, while a Babaylan serves the tribe as a priest (Graciadas, 2012; Maentz, 2014).

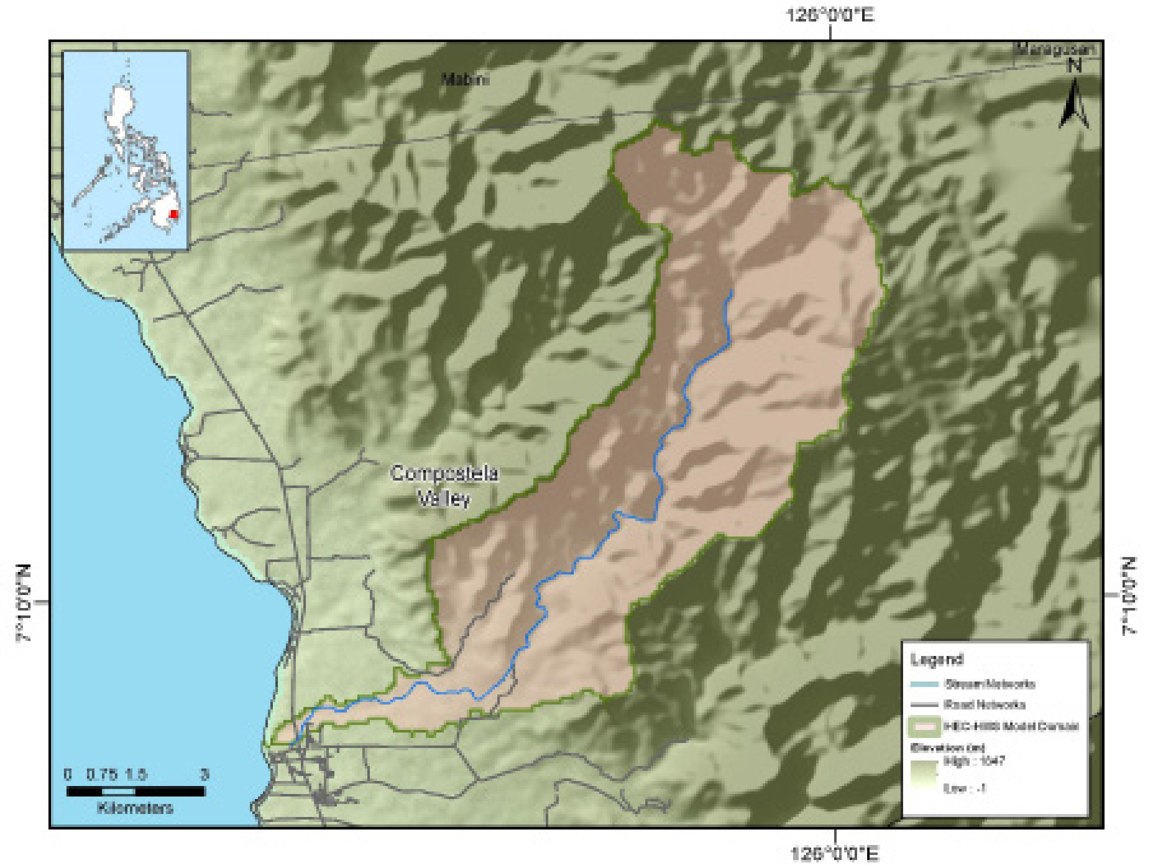

Figure 1. Location map of the Kingking River Basin (in brown)

The Kingking Watershed has a drainage area of 93 square kilometers (sq. km). The watershed area is 79 sq. km; and its river length is 24 kilometers with fifty-seven (57) sub basins, twenty-eight (28) junctions, and twenty-eight (28) reaches. It has an estimated 344 cubic meter (MCM) annual run-off (DENR RBCO, 2015). It empties into the Davao Gulf. It is the smallest among the watersheds assigned to UP Mindanao.

The watershed covers two (2) covered barangays, namely Kingking and Magnaga, which were identified and confirmed by the local government units (LGUs) as flood prone barangays during the validation survey.

The area is mildly densely populated, with 113 people per sq. km. According to the 2015 national census, a total of 26,988 persons are residing in Barangay Kingking, which is within the immediate vicinity of the river.

Agricultural production is the major economic activity of the province, with rice, corn, industrial and commercial crops, vegetables, and root crops and tubers as the major products. Additionally, the coastal municipalities of Maco, Mabini, and Pantukan are the areas for aquaculture and fisheries industries (Province of Compostela Valley, 2011).

There is a low occurrence of periods with extreme drought. However, flooding risk is extremely high. There is a high probability of cyclones hitting the Kingking River. The land area is not cultivated; most of the natural vegetation is still intact. The location is coastal, or near a large body of water. The area is classified as a subtropical moist forest biozone (Chinci World Atlas, 2011).

The river is streaked with many shades of brown cuts through farmland and jungle brush, which release its muck into the sea. There are slurry swells around the coastline, muddying the emerald waters. The source of the blight is an eroded mountainside peppered with blue tarps and tiny shacks, due to a gold mine nestled among the green hills (Traywick, 2012).

Many years ago, the river was used for domestic utilization, such as bathing and washing clothes, since the water was clear and deep. But when it started to become a channel for waste water of some mining activities in the upstream area of the river, it no longer served as a good source of water for washing and bathing. The riverbed is almost at level with the ground of residences in Barangay Kingking, because of siltation caused by the mining operations in the mountains of Pantukan. This is the main reason for frequent flooding occurrences, even during regular rains (Uswag ComVal News and Updates, 2015). Runoff from a nearby gold mine has degraded the Kingking River, where tension between small-scale miners and a foreign mining company underscores a national debate over the future of extractive industries. About 600 families reside on its steep slope, eking out a living by half-grams of gold (Traywick, 2012).

On April 22, 2011, a landslide incident occurred in a small scale mining area in Panganason-B in Barangay Kingking due to heavy rains. The NDRRMC reported thirty-six (36) casualties: fourteen (14) dead, fourteen (14) injured, and eight (8) missing (National Disaster Risk Reduction and Management Council, 2011).

According to locals, from the year 1964 to 2016, intense local rainfall and tornadoes have been the usual causes of flooding near the river. However, the PAGASA only noted typhoon events recently, such as Sendong in 2001, Pablo in 2012, and Yolanda and Crising in 2013.

Figure 2. Kingking River flood history

CHAPTER 2: LIDAR DATA ACQUISITION OF THE KINGKING 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

To initiate the LiDAR acquisition survey of the Kingking Floodplain, the Data Acquisition Component (DAC) created flight plans within the delineated priority area for the Kingking floodplain in Compostela Valley. The mission was planned for fifteen (15) lines and ran for at most four and a half (4.5) hours including take-off, landing and turning time, using the Gemini LiDAR system (See ANNEX 1 for the Gemini sensor specifications). The flight planning parameters for the LiDAR system is found in Table 1. Figure 3 shows the flight plans and base stations for the Kingking floodplain.

Table 1. Flight planning parameters for Gemini LiDAR system.

Block Name	Flying Height (m AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (KHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK85B	1000	40	40	100	50	130	5

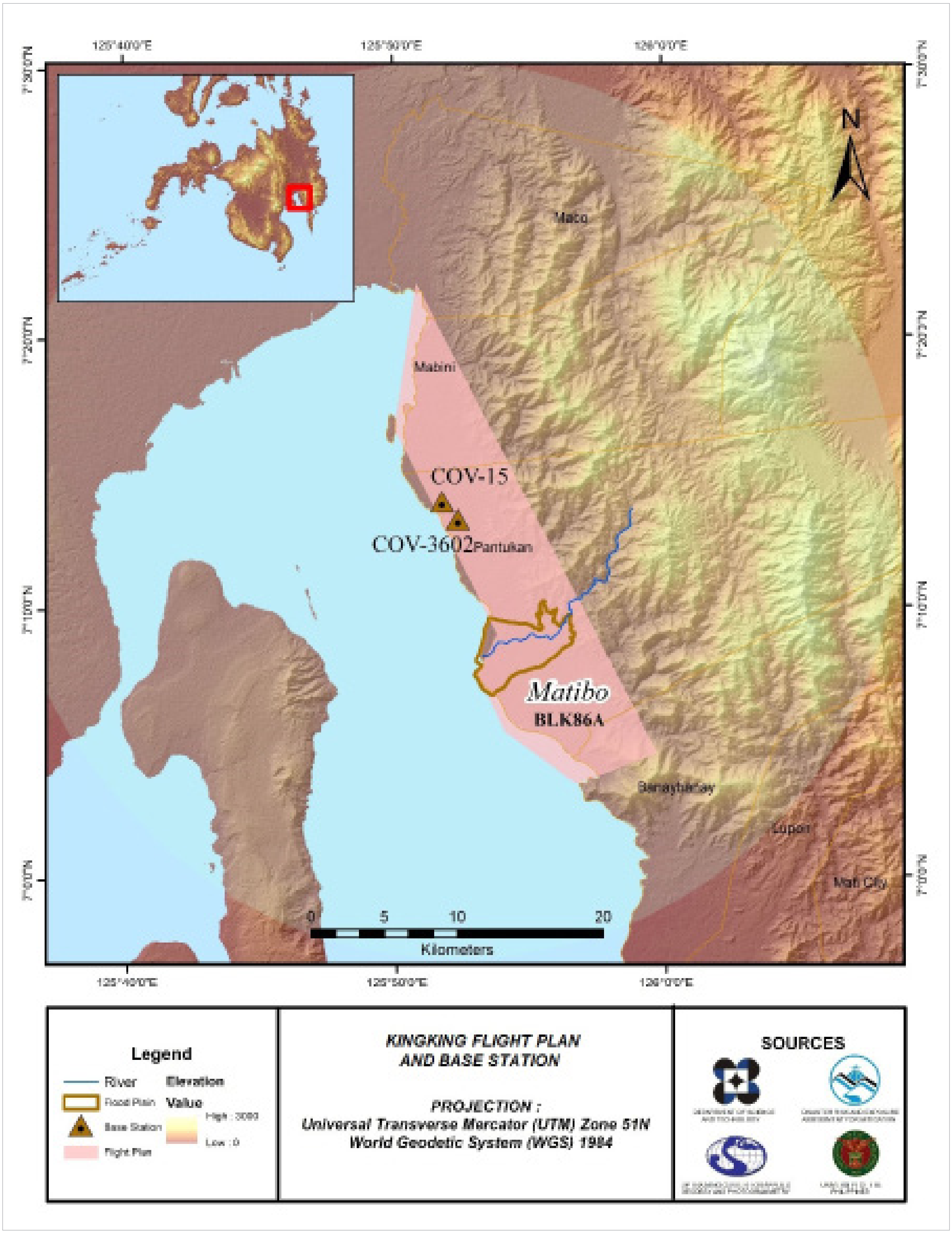


Figure 3. Flight plan and base station used to cover Kingking Floodplain survey.

2.2 Ground Base Stations

The field team for this undertaking was able to recover two (2) NAMRIA ground control points: COV-15 (2nd order accuracy) and COV-3602 (3rd order accuracy). The certifications for the NAMRIA reference points are found in ANNEX 2, while the baseline processing reports for the established control points are found in ANNEX 3. These were used as base stations during flight operations on July 4, 2014. The base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 882 and SPS 985. The flight plans and location of base stations used during the aerial LiDAR acquisition in Kingking floodplain are shown in Figure 3. The composition of the project team is shown in ANNEX 4.

Figure 4 to Figure 5 illustrate the recovered NAMRIA reference points within the area. Table 2 to Table 3 present the details about the following NAMRIA control stations, while Table 4 shows the list of all ground control points occupied during the acquisition together with the corresponding dates of utilization.

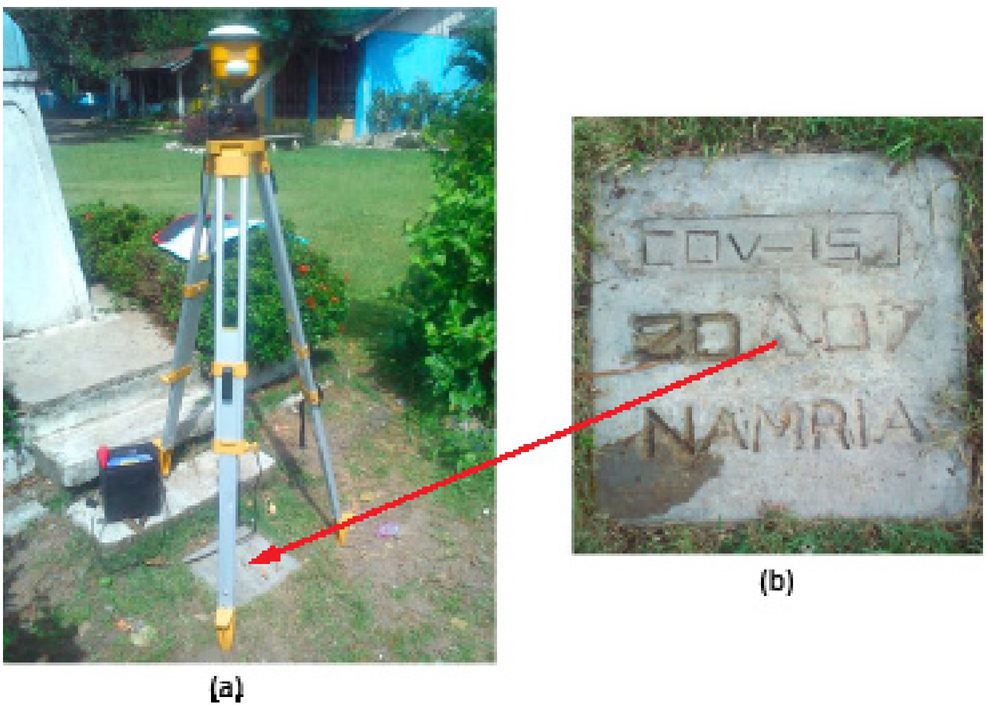
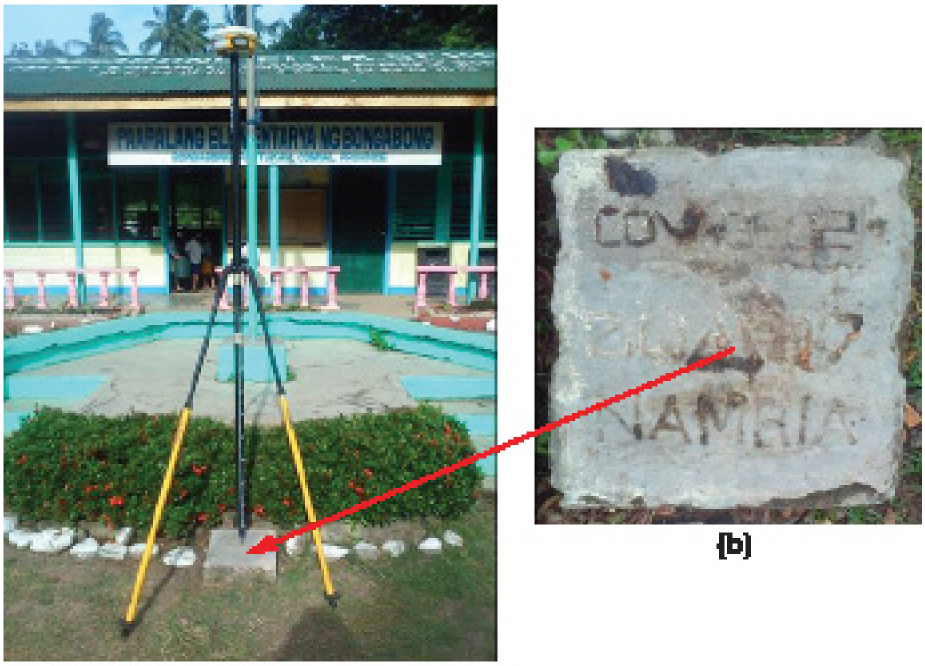


Figure 4. GPS set-up over COV-15 inside the premises of Tibagon Elementary School (a) and NAMRIA reference point COV-15 (b) as recovered by the field team.

Table 2. Details of the recovered NAMRIA horizontal control point COV-15 used as base station for the LiDAR acquisition.

Station Name	COV-15	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7°13’59.42928” North 125°51’41.37238” East 0.612 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	595142.582 meters 799845.036 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	7°13’56.28729” North 125°51’46.87850” Easrt 73.688 meters



(b)

(a)

Figure 5. GPS set-up over COV-3062 located in front of the flagpole of Bongabong Elementary School (a) and NAMRIA reference point COV-3062 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point COV-3602 used as base station for the LiDAR acquisition.

Station Name	COV-3602	
Order of Accuracy	3rd	
Relative Error (horizontal positioning)	1 in 20,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7°13'19.57444" North 125°52'15.82999" East -1.077 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	596202.079 meters 798622.708 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	7°13'16.43629" North 125°52'21.33702" East 72.043 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	817092.67 meters 799250.67 meters

Table 4. Ground control points used during LiDAR data acquisition.

Date Surveyed	Flight Number	Mission Name	Ground Control Points
July 04, 2014	7350GC	2BLK85B185A	COV-15 & COV-3062

2.3 Flight Missions

One (1) flight mission was conducted to complete the LiDAR data acquisition in the Kingking Floodplain, for a total of four hours and twenty three minutes (4+23) of flying time for RP-C9322 (See ANNEX 6: Flight logs for the flight mission). The mission was acquired using the Gemini LiDAR system. Table 5 shows the total area of actual coverage and the corresponding flying hours of the said mission, while Table 6 presents the actual parameters used during the LiDAR data acquisition.

Table 5. Flight missions for LiDAR data acquisition in Kingking floodplain.

Date Surveyed	Flight Number	Flight Plan Area (km^2)	Surveyed Area (km^2)	Area Surveyed within the Floodplain (km^2)	Area Surveyed outside the Floodplain (km^2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
July 04, 2014	7350GC	103.499	301.028	26.504	274.524	NA	4	23

Table 6. Actual parameters used during LiDAR data acquisition.

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (KHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
7350GC	1000	40	40	100	50	130	5

2.4 Survey Coverage

This certain LiDAR acquisition survey covered the Kingking floodplain (See ANNEX 7: Flight status reports). The Kingking floodplain is located in the province of Compostela Valley, specifically within the municipality of Pantukan. The list of municipalities/ cities surveyed in this province during the LiDAR acquisition is shown in Table 7. The actual coverage of the LiDAR acquisition for the Kingking floodplain is presented in Figure 6.

Table 7. List of municipalities and cities surveyed during Kingking floodplain LiDAR survey.

Province	Municipality/City	Area of Municipality/ City (km^2)	Total Area Surveyed (km^2)	Percentage of Area Surveyed
Compostela Valley	Pantukan	581.330	125.636	21.61%
	Mabini	271.354	38.729	14.27 %
Davao Oriental	Banaybanay	385.281	16.837	4.37%
	Lupon	356.281	3.161	0.89%

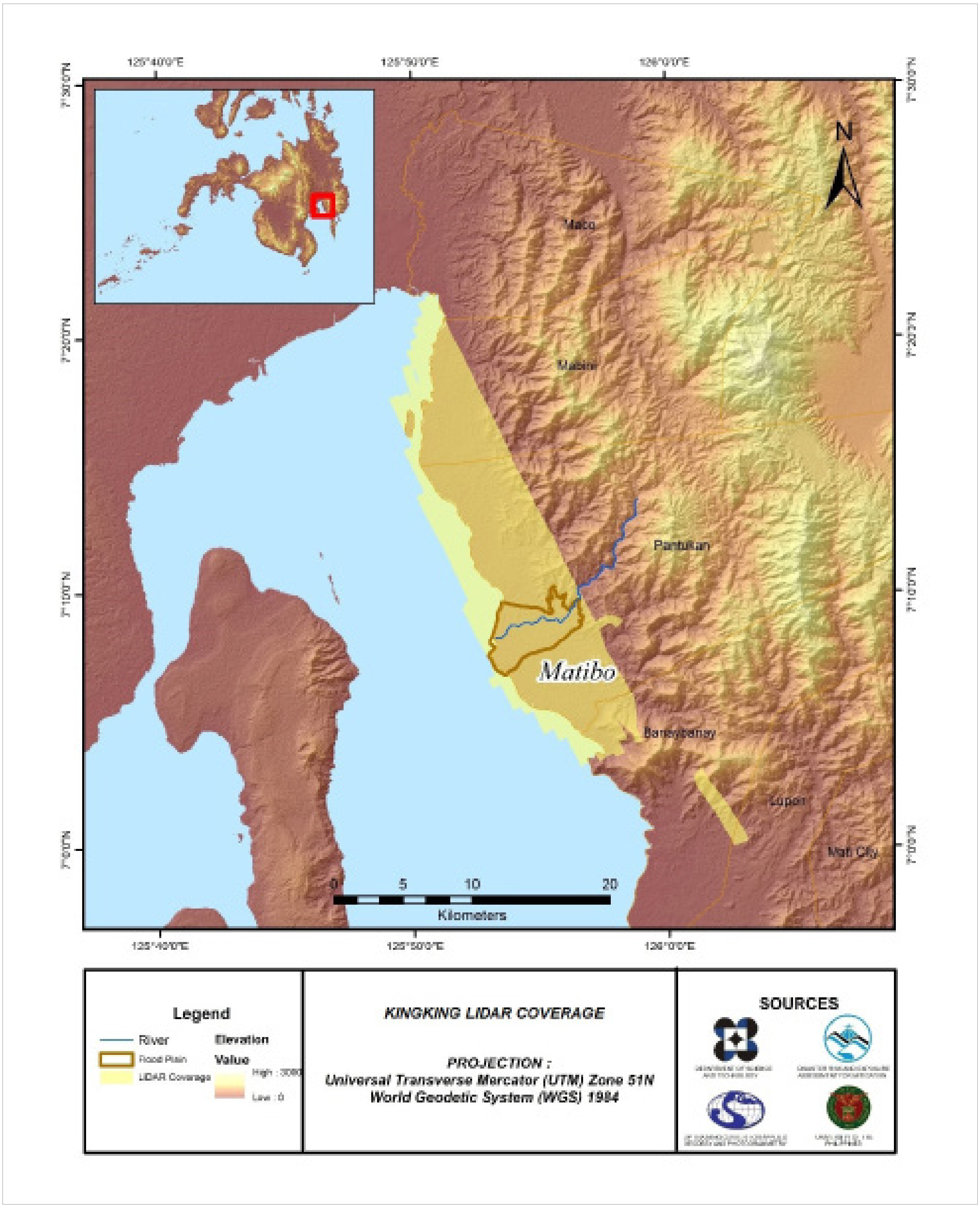


Figure 6. Actual LiDAR survey coverage of the Kingking floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE KINGKING FLOODPLAIN

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

3.1 Overview of the LIDAR Data Pre-Processing

The data transmitted by the Data Acquisition Component (DAC) 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 subjected to quality checking to ensure that the required accuracies of the program, which are the minimum point density, vertical and horizontal accuracies, are met. The point clouds were then classified into various classes before generating Digital Elevation Models, such as the Digital Terrain Model and the 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 (DVBC). LiDAR acquired temporally were 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 diagram shown in Figure 7.

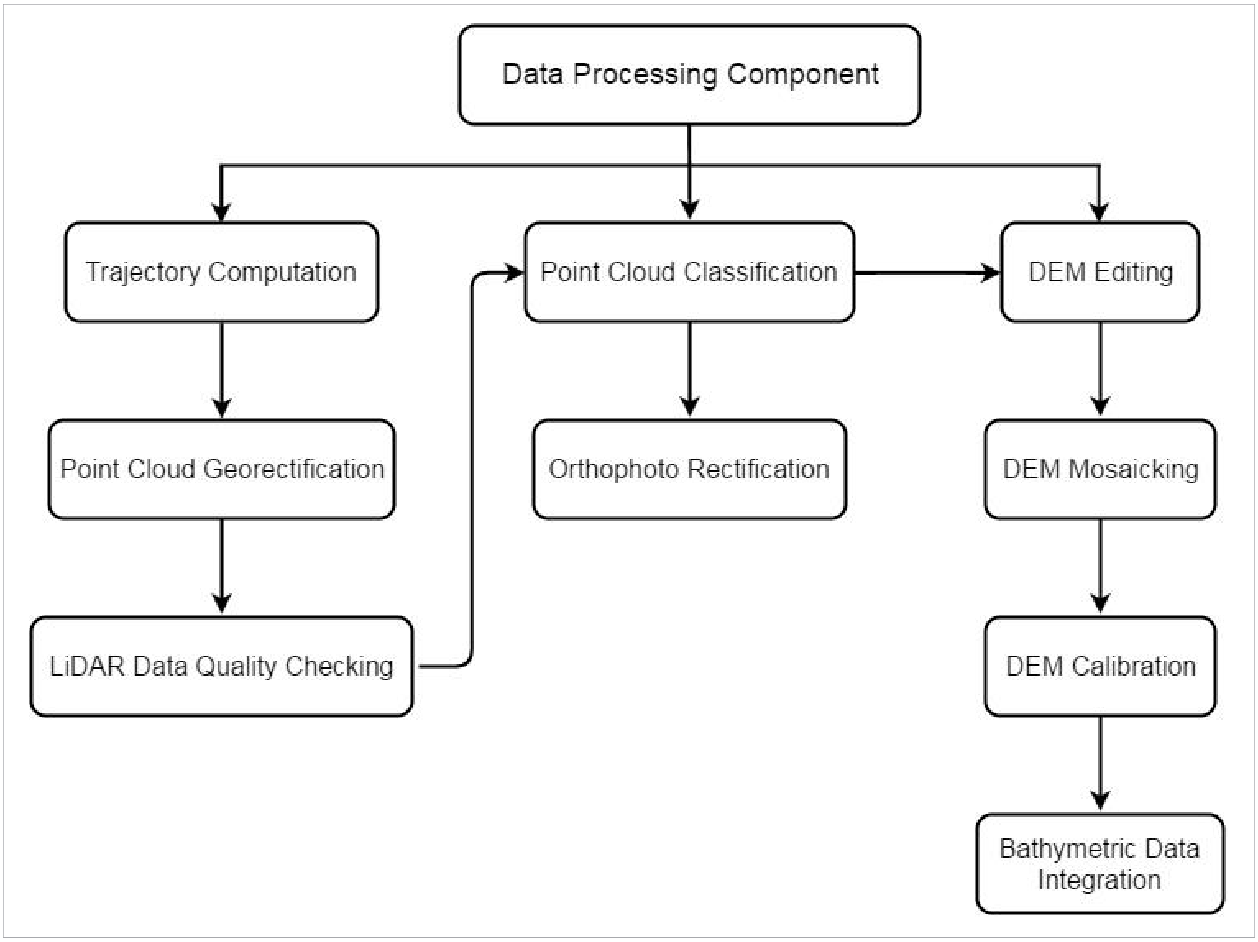

Figure 7. Schematic Diagram for Data Pre-Processing Component.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for the Kingking floodplain can be found in ANNEX 5. The mission flown during the survey conducted in July 2014 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Gemini system over Davao Oriental. The Data Acquisition Component (DAC) transferred a total of 23.8 Gigabytes of Range data, 0.26 Gigabytes of POS data, and 7.05 Megabytes of GPS base station data to the data server on July 4, 2014. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Kingking was fully transferred on July 14, 2014, as indicated on the Data Transfer Sheets for the Kingking floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metric parameters of the computed trajectory for flight 7350GC, one of the Kingking flights, which are the North, East, and Down position RMSE values are shown in Figure 8. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which fell on July 4, 2014 00:00 AM on that week. The y-axis is the RMSE value for that particular position.

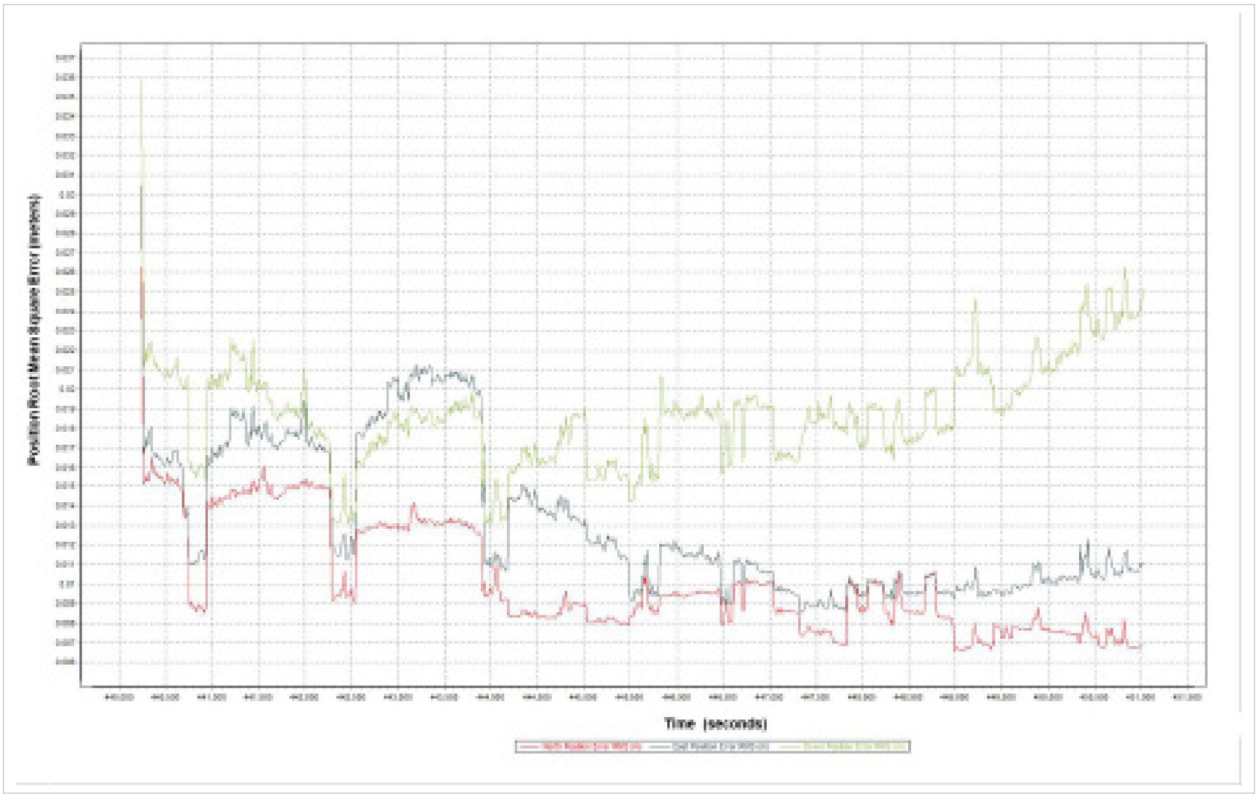

Figure 8. Smoothed Performance Metric Parameters of a Kingking Flight 7350GC.

The time of flight was from 440000 seconds to 451500 seconds, which corresponds to morning of July 04, 2014. The initial spike that is seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the POS system was starting to compute 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 corresponds to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 8 shows that the North position RMSE peaks at 1.70 centimeters, the East position RMSE peaks at 2.20 centimeters, and the Down position RMSE peaks at 2.70 centimeters, which are within the prescribed accuracies described in the methodology.

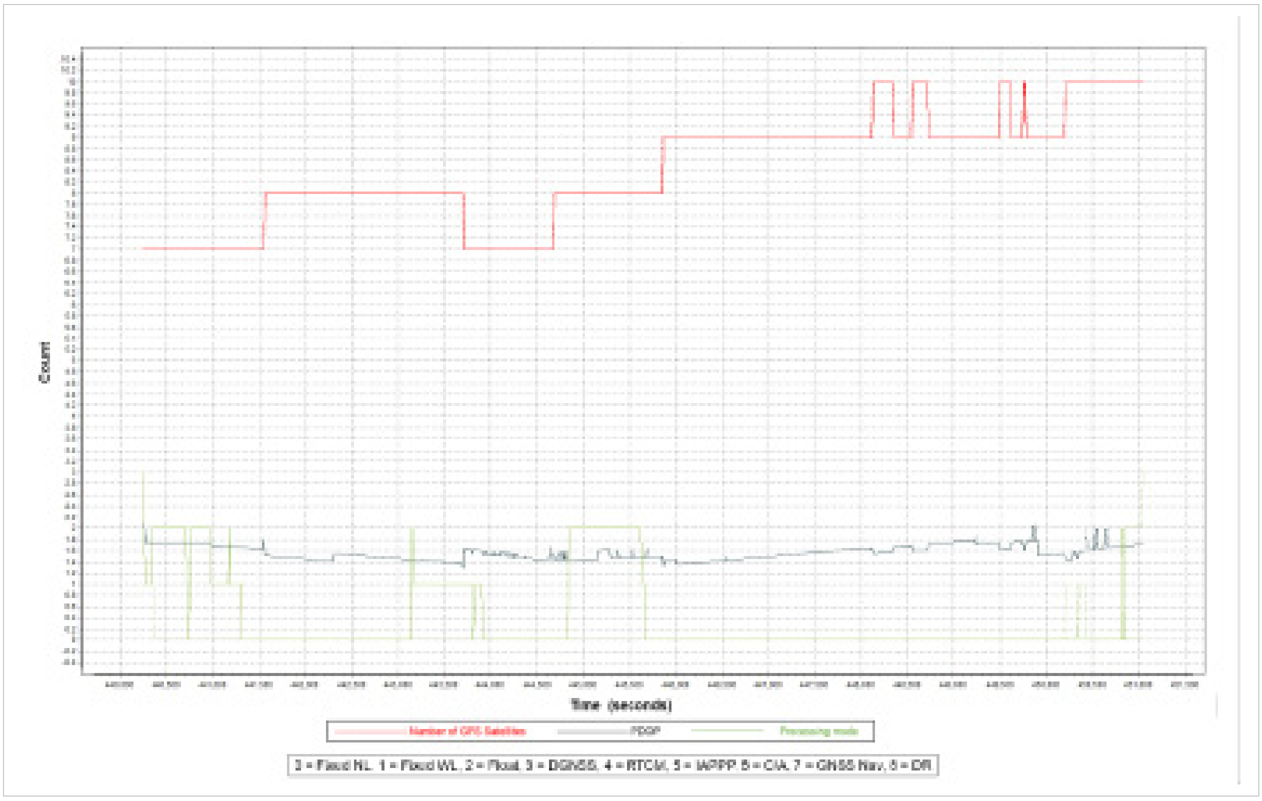

Figure 9. Solution Status Parameters of Kingking Flight 7350GC.

The Solution Status parameters of flight 7350GC, one of the Kingking flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 9. The graphs indicate that the number of satellites during the acquisition did not go down to six (6). Majority of the time, the number of satellites tracked was between seven (7) and ten (10). The PDOP value also did not go above the value of three (3), which indicates optimal GPS geometry. The processing mode stayed at the value of zero (0) for majority of the survey with some peaks up to one (1) or two (2), attributed to the turns performed by the aircraft. The value of zero (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 Kingking flights is shown in Figure 10.

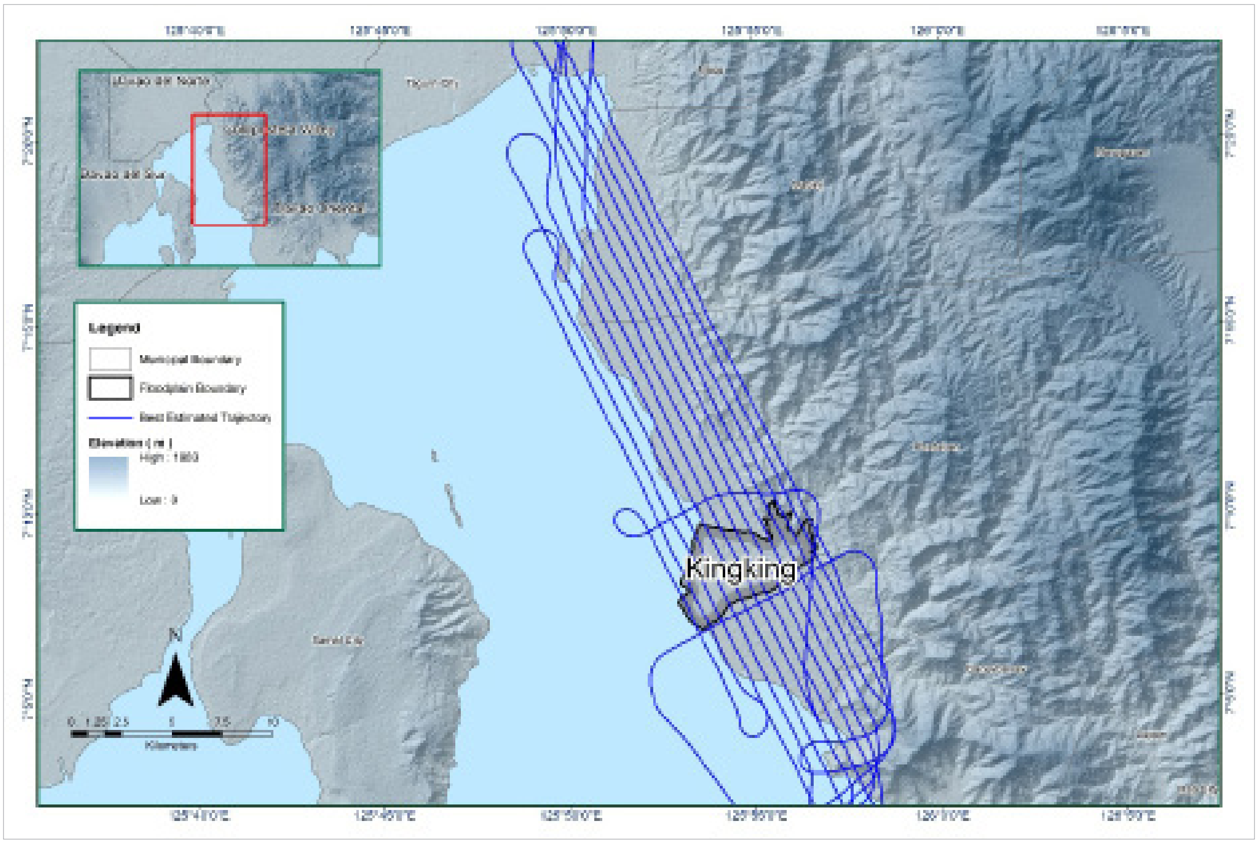

Figure 10. The best estimated trajectory conducted over the Kingking floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains thirteen (13) flight lines, with each flight line containing one (1) channel, since the Gemini system contains one channel only. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Kingking floodplain are given in Table 8.

Table 8. Self-Calibration Results values for Kingking flights.

Parameter	**Acceptable Value**
Boresight Correction stdev (<0.001degrees)	0.002079
IMU Attitude Correction Roll and Pitch Corrections stdev (<0.001degrees)	0.000963
GPS Position Z-correction stdev (<0.01meters)	0.0105

The optimum accuracy was obtained for all Kingking flights based on the computed standard deviations of the corrections of the orientation parameters. The standard deviation values for individual blocks are available in ANNEX 8 (Mission Summary Reports).

3.5 LiDAR Data Quality Checking

The boundaries of the processed LiDAR data on top of a SAR Elevation Data over Kingking Floodplain is shown in Figure 11. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

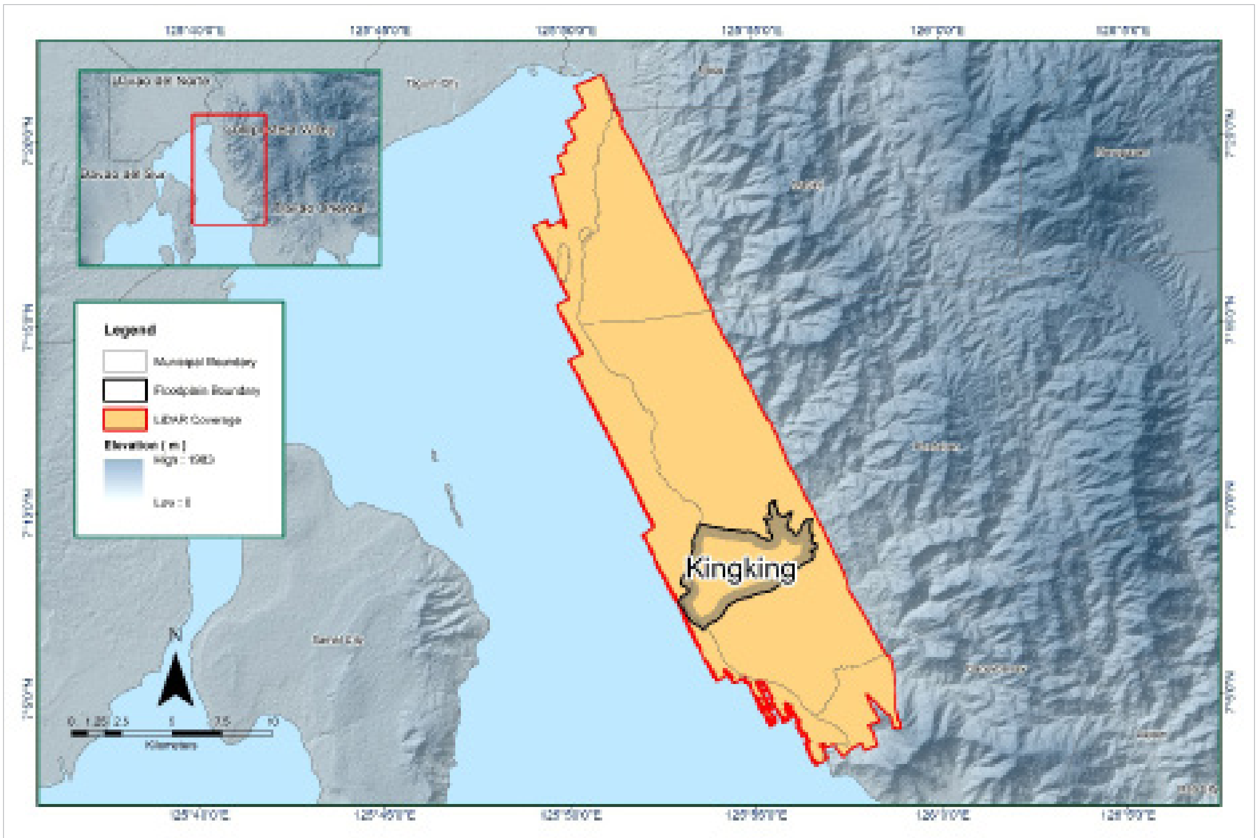

Figure 11. Boundaries of the processed LiDAR data over the Kingking Floodplain.

The total area covered by the Kingking missions is 220.28 sq.km, comprised of one (1) flight acquisition resulting into only one (1), block as shown in Table 9.

Table 9. List of LiDAR blocks for Kingking floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Davao_Oriental Blk85B	7350GC	220.28
	TOTAL	**220.28 sq.km**

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

The image overlap statistics per block for the Kingking floodplain can be found in ANNEX 8 (Mission Summary Reports). It should be noted that one pixel corresponds to 25.0 square meters on the ground. For this area, the percent overlap is 17.85%.

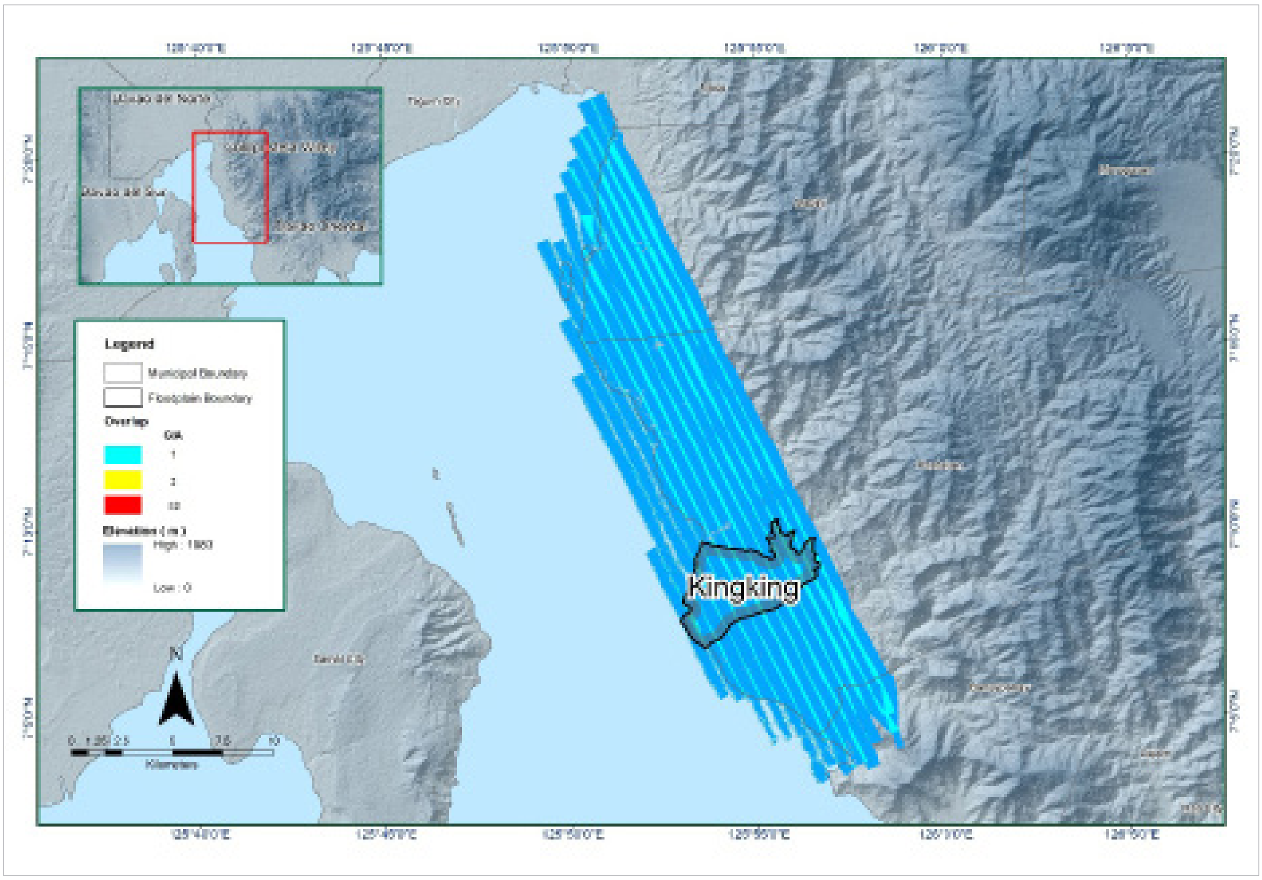

Figure 12. Image of data overlap for Kingking floodplain.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the two (2) points per square meter criterion is shown in Figure 13. It was determined that all LiDAR data for the Kingking floodplain satisfy the point density requirement, and that the average density for the entire survey area is 2.56 points per square meter.

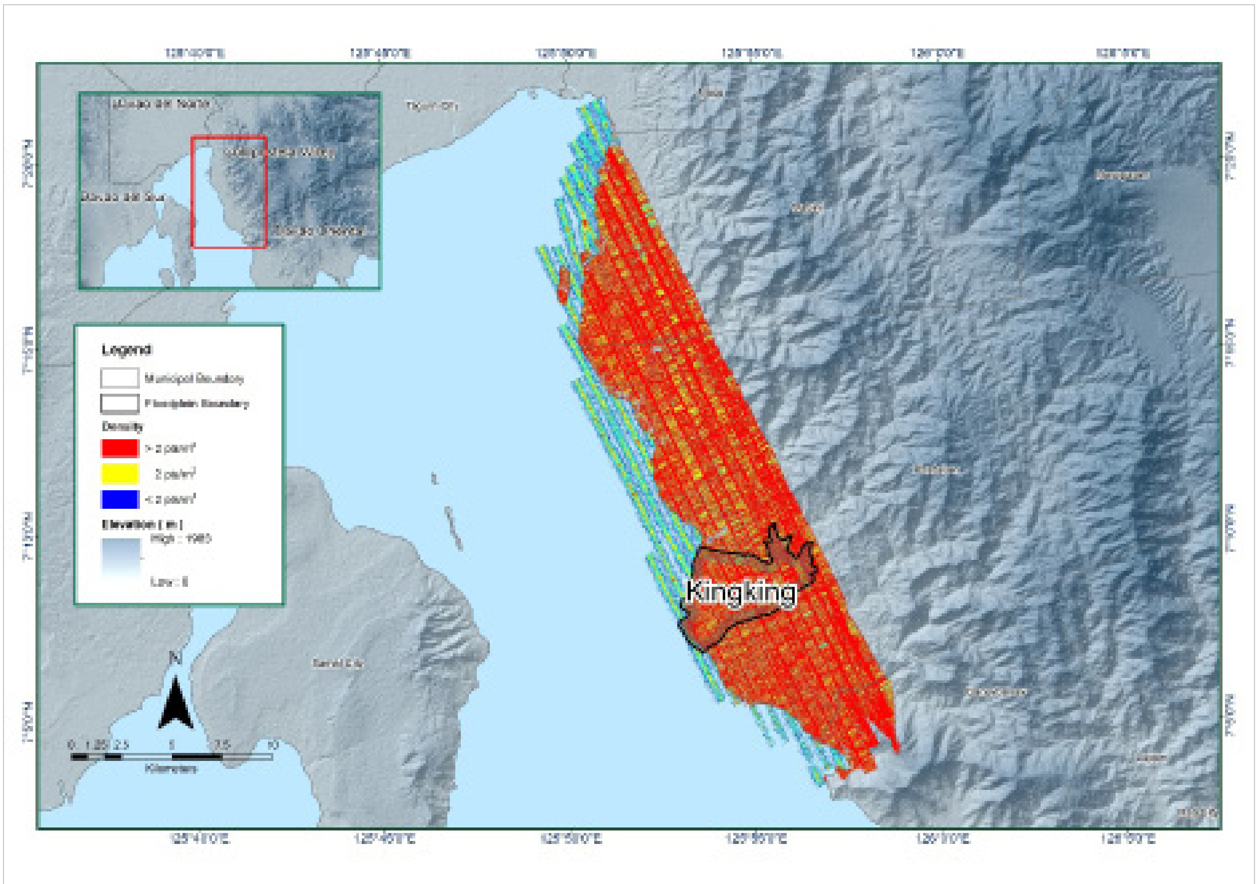

Figure 13. Pulse density map of merged LiDAR data for Kingking floodplain.

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

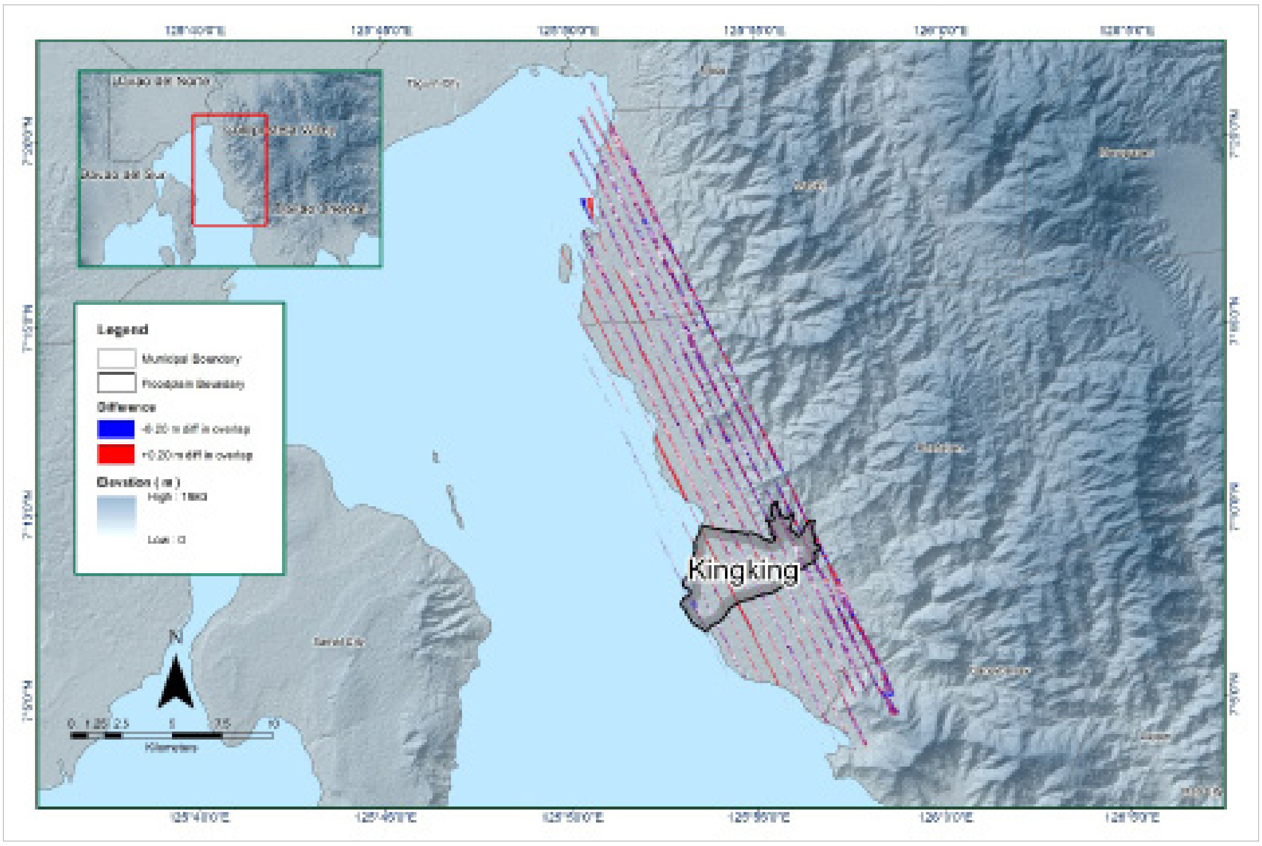

Figure 14. Elevation difference map between flight lines for Kingking floodplain.

A screen capture of the processed LAS data from a Kingking flight 7350GC loaded in QT Modeler is shown in Figure 15. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed yellow line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data became satisfactory. No reprocessing was done for this LiDAR dataset.

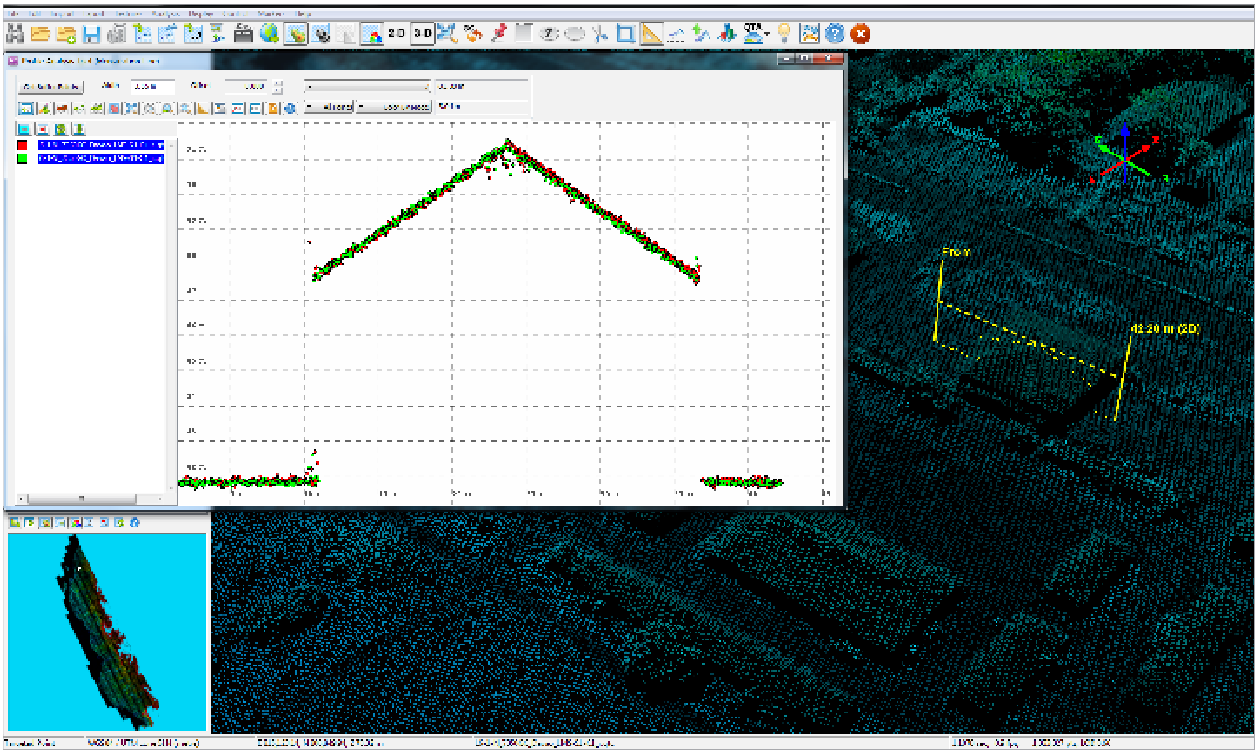

Figure 15. Quality checking for a Kingking flight 7350GC using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 10. Kingking classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	65,620,647
Low Vegetation	45,592,090
Medium Vegetation	110,105,166
High Vegetation	267,419,041
Building	2,814,515

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Kingking floodplain is shown in Figure 16. A total of 288 1km by 1km 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 728.94 meters and 67.52 meters, respectively.

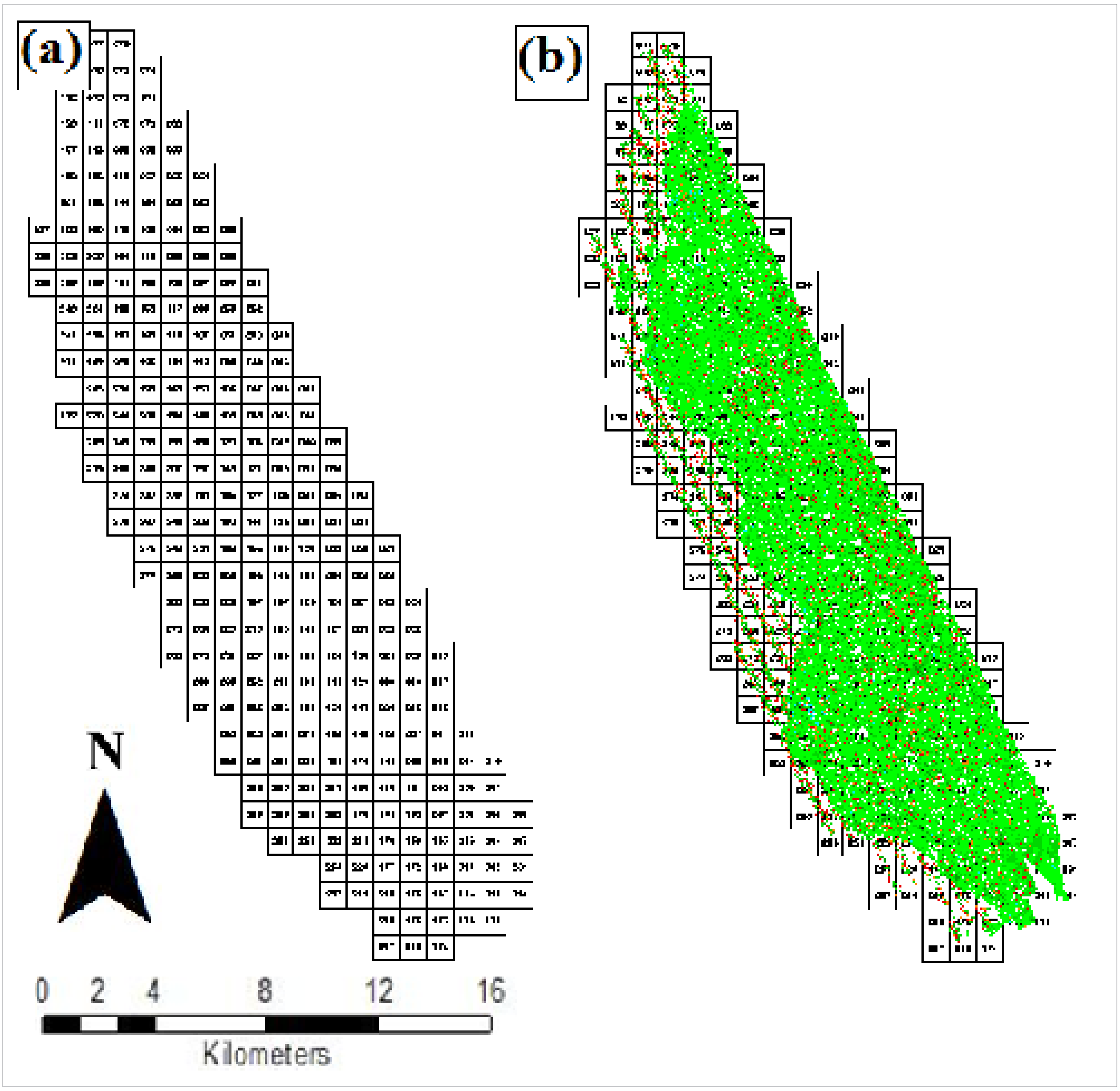

Figure 16. Tiles for Kingking floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 17. The ground points are in orange, the vegetation is in different shades of green, and the buildings are in cyan. It can be seen that residential structures adjacent or even below canopy are classified correctly, due to the density of the LiDAR data.

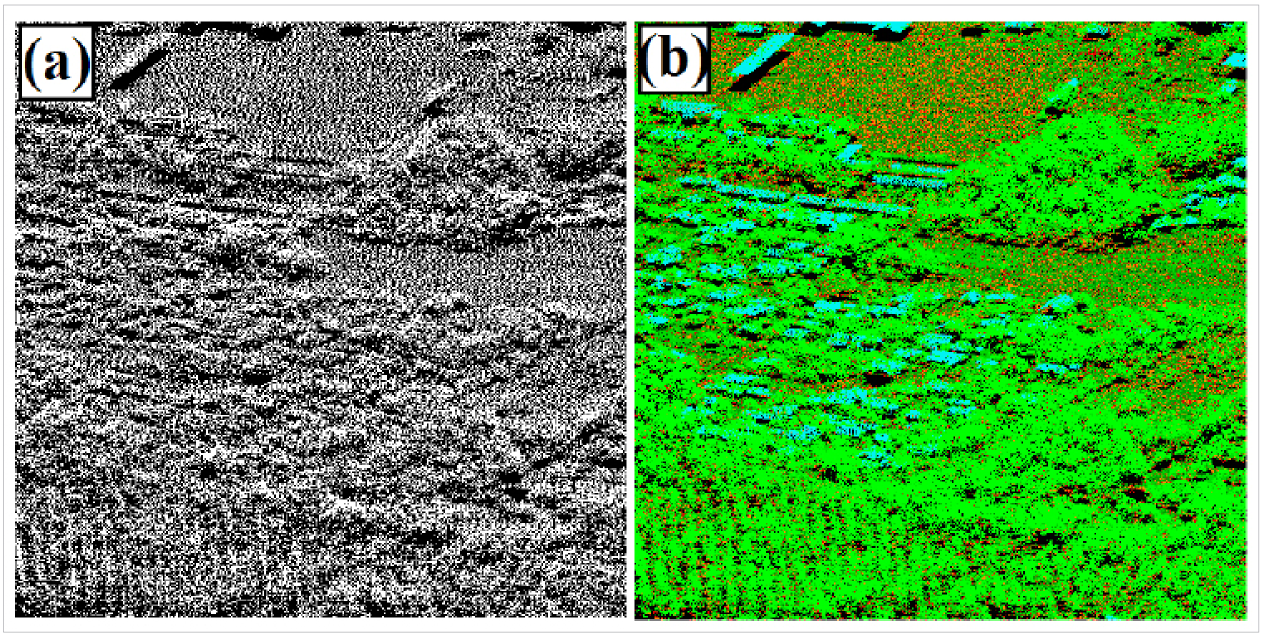

Figure 17. Point cloud before (a) and after (b) classification.

The production of last return (V_ASCII) and the secondary (T_ ASCII) DTM, first (S_ ASCII) and last (D_ ASCII) return DSM of the area in top view display are shown in Figure 18. It shows that DTMs are the representation of the bare earth, while the DSMs reflect all features, such as buildings and vegetation.

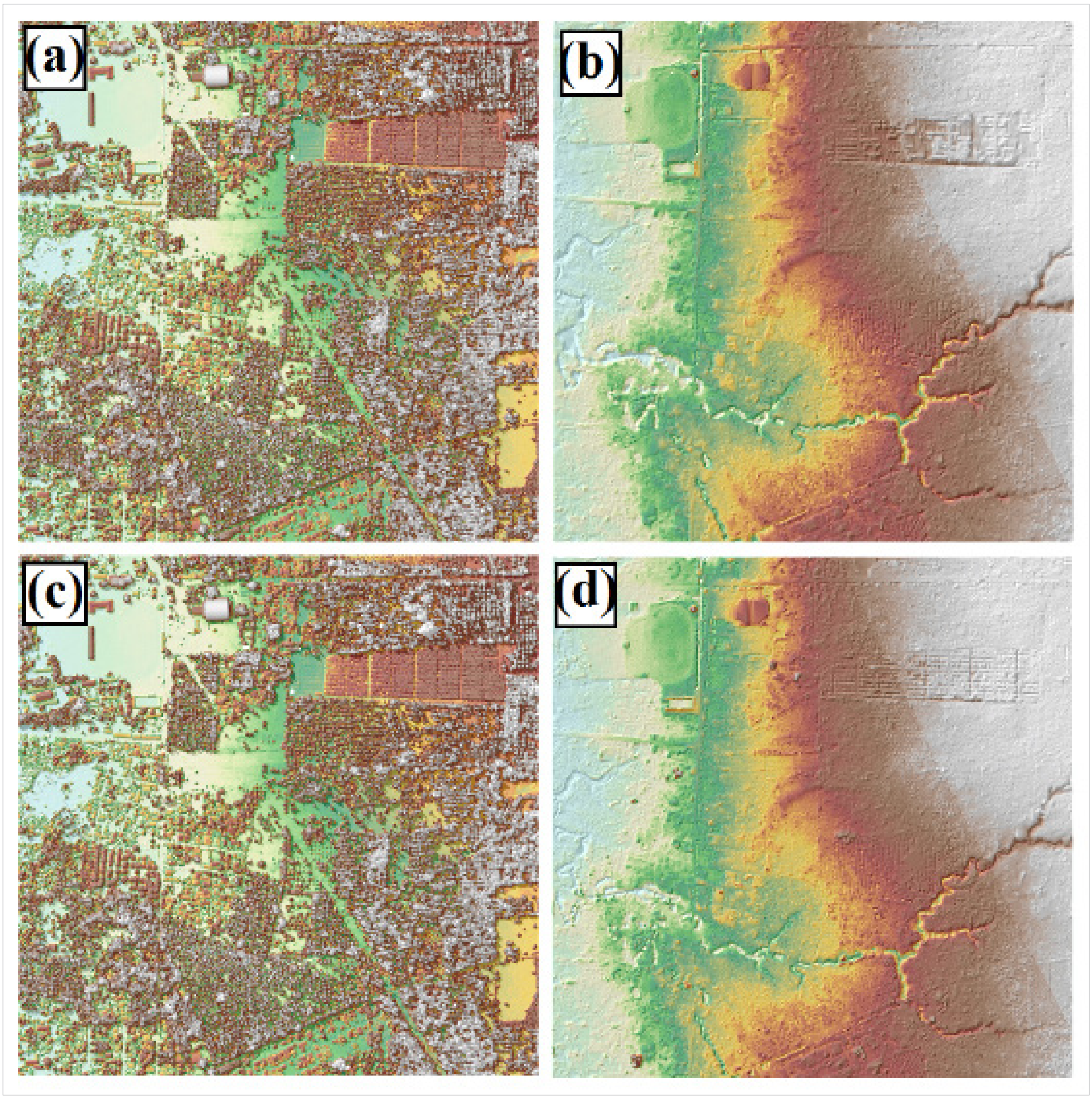

Figure 18. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Kingking floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

There are no available orthophotographs for the Kingking floodplain.

3.8 DEM Editing and Hydro-Correction

One (1) mission block was processed for the Kingking floodplain. This block is composed of the Davao_Oriental block, with a total area of 220.28 square kilometers. Table 11 shows the name and corresponding area of the said block, in square kilometers.

Table 11. LiDAR blocks with its corresponding area.

LiDAR Blocks	Area (sq.km)
Davao_Oriental_85B	220.28
TOTAL	**220.28 sq.km**

Portions of DTM before and after manual editing are shown in Figure 19. The river embankment (Figure 19a) has been misclassified and was removed during the classification process, and had to be retrieved to complete the surface (Figure B-19b) and to allow for the correct flow of water. The bridge (Figure 19c) was also considered to be an impedance to the flow of water along the river and had to be removed (Figure 19d), in order to hydrologically correct the river.

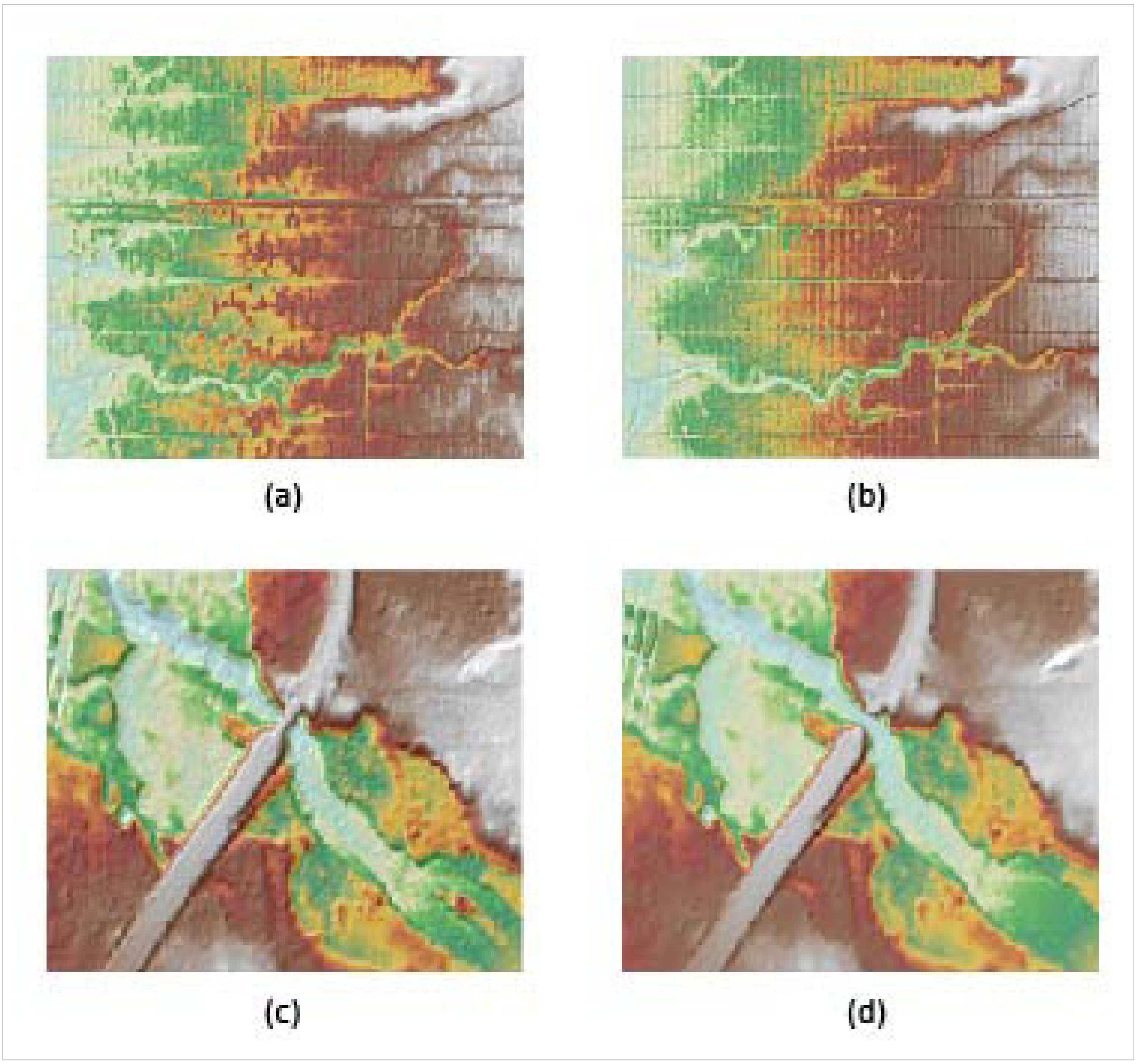

Figure 19. Portions in the DTM of Kingking floodplain – a paddy field before (a) and after (b) data retrieval; and a bridge before (c) and after (d) manual editing.

3.9 Mosaicking of Blocks

No assumed reference block was used in mosaicking, because the identified reference for shifting was an existing calibrated Sumlog DEM overlapping with the blocks to be mosaicked. Table 12 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for the Kingking floodplain is shown in Figure 20. It can be seen that the entire Kingking floodplain is 99.80% covered by LiDAR data.

Table 12. Shift Values of each LiDAR Block of Kingking floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
Davao_Oriental_85B	0.00	0.00	-1.49

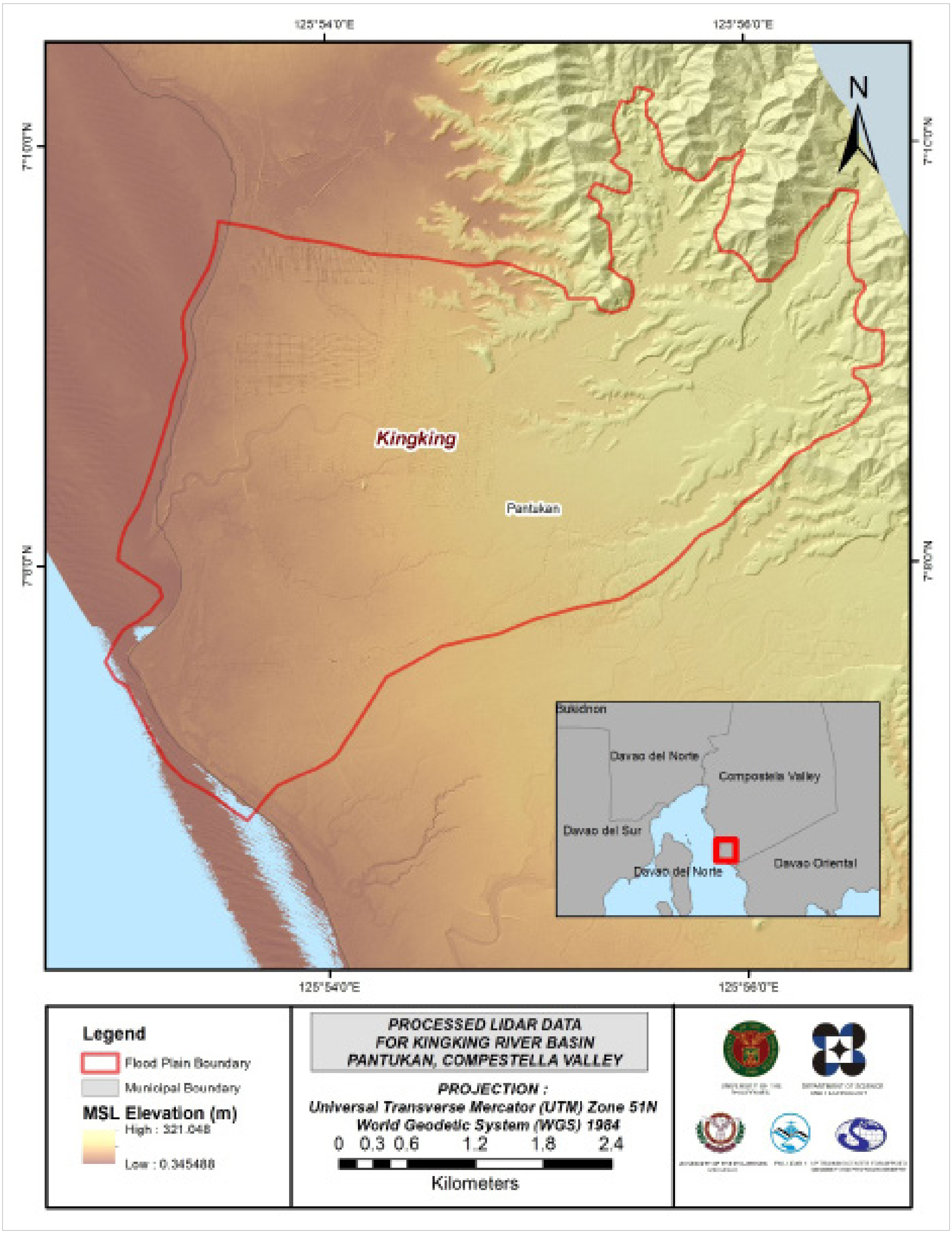

Figure 20. Map of Processed LiDAR Data for Kingking Flood Plain.

3.10 Calibration and Validation of Mosaicked LiDAR DEM

To undertake the data validation of the Mosaicked LiDAR DEM, the Data Validation and Bathymetry Component (DVBC) conducted a validation survey along the Kingking floodplain. The extent of the validation survey done in Kingking to collect points with which the LiDAR dataset is validated is shown in Figure 21, with the validation survey points highlighted in green. A total of 1,350 survey points were used for calibration and validation of Kingking LiDAR data. Random selection of 80% of the survey points, resulting to 1,080 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 22. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and to obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration elevation values is 1.36 meters, with a standard deviation of 0.19 meters. Calibration of Kingking LiDAR data was done by subtracting the height difference value, 1.36 meters, from the Kingking mosaicked LiDAR data. Table 13 shows the statistical values of the compared elevation values between the LiDAR data and the calibration data.

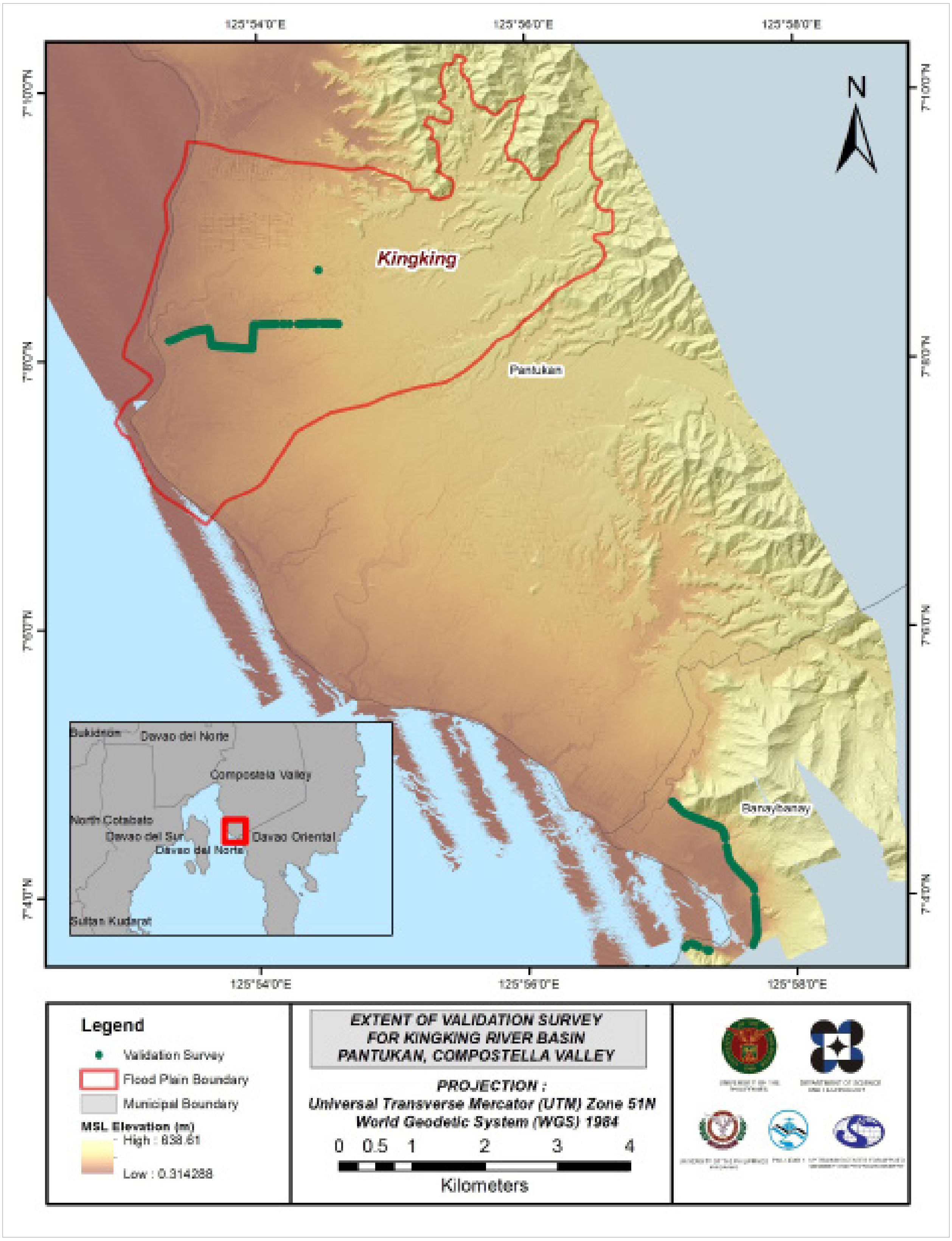

Figure 21. Map of Kingking Floodplain with validation survey points in green.

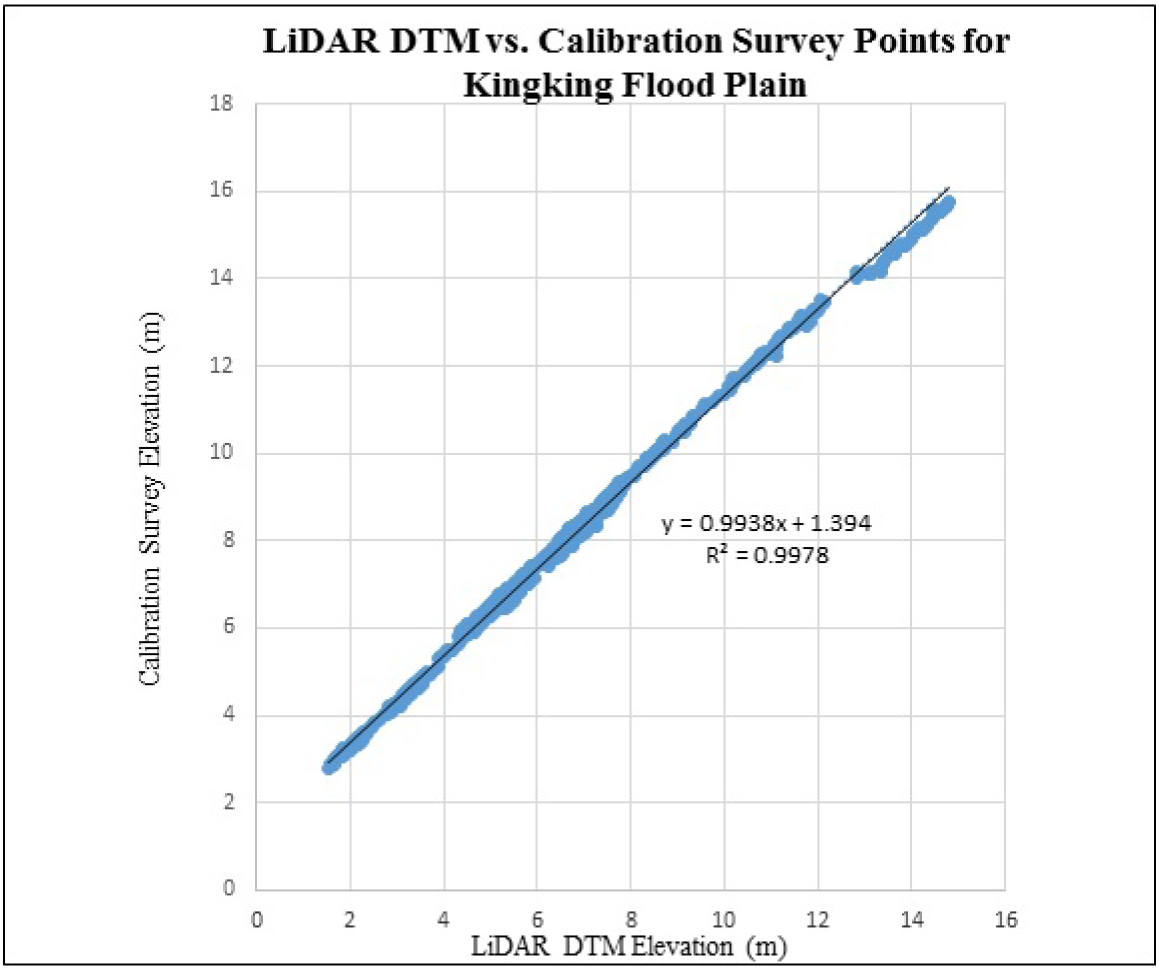

Figure 22. Correlation plot between calibration survey points and LiDAR data.

Table 13. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	1.36
Standard Deviation	0.19
Average	-1.35
Minimum	-1.72
Maximum	-0.97

The remaining 20% of the total survey points, resulting to 270 points, were used for the validation of the calibrated Kingking 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 23. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.19 meters, with a standard deviation of 0.19 meters, as shown in Table 14.

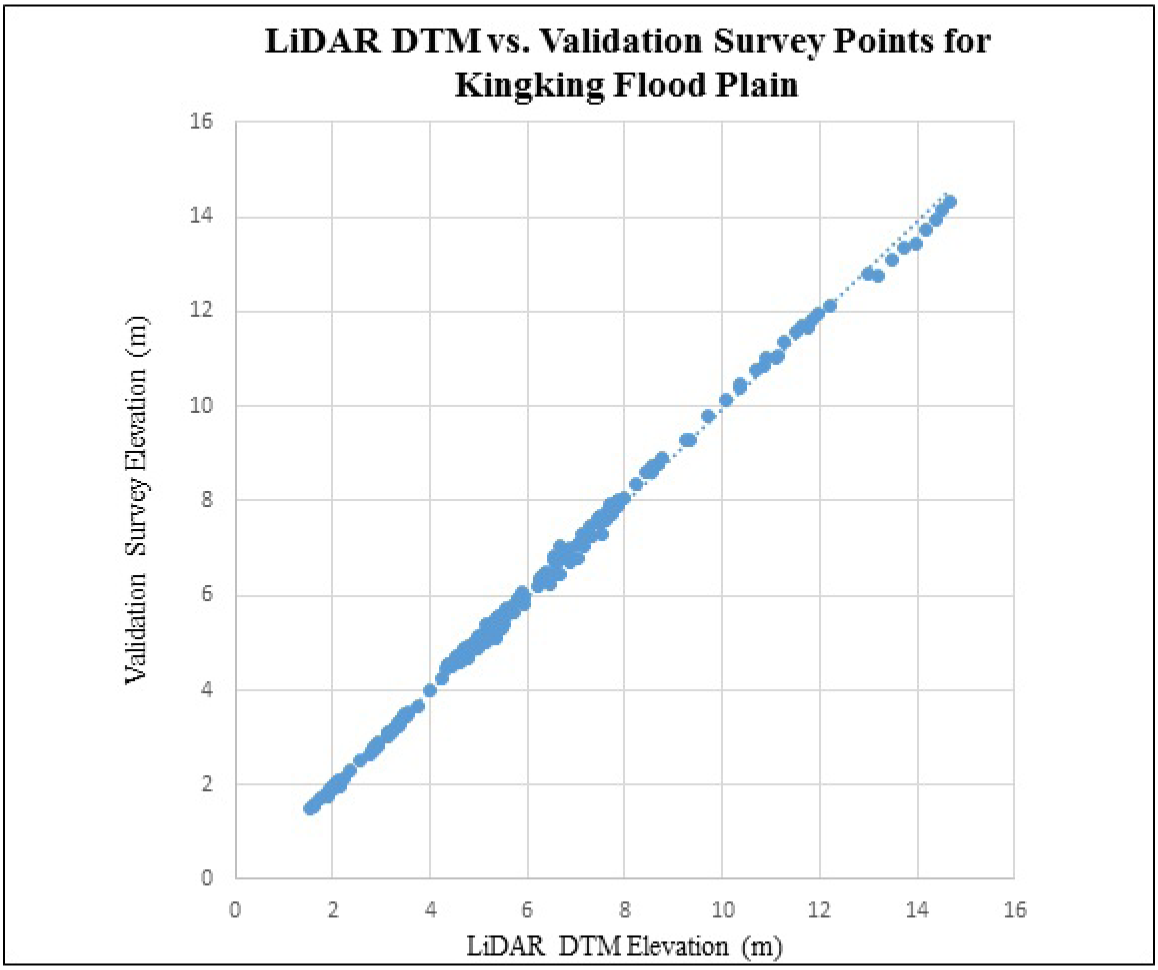

Figure 23. Correlation plot between validation survey points and LiDAR data.

Table 14. Validation Statistical Measures.

Validation Statistical Measures	Value (meters)
RMSE	0.19
Standard Deviation	0.19
Average	0.01
Minimum	-0.37
Maximum	0.01

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, only cross-section data was available for Kingking, with 3,402 bathymetric survey points. The resulting raster surface produced was accomplished by Kernel Interpolation with Barriers Interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface was represented by the computed RMSE value of 0.49 meters. The extent of the bathymetric survey done by the DVBC in Kingking integrated with the processed LiDAR DEM is shown in Figure 24.

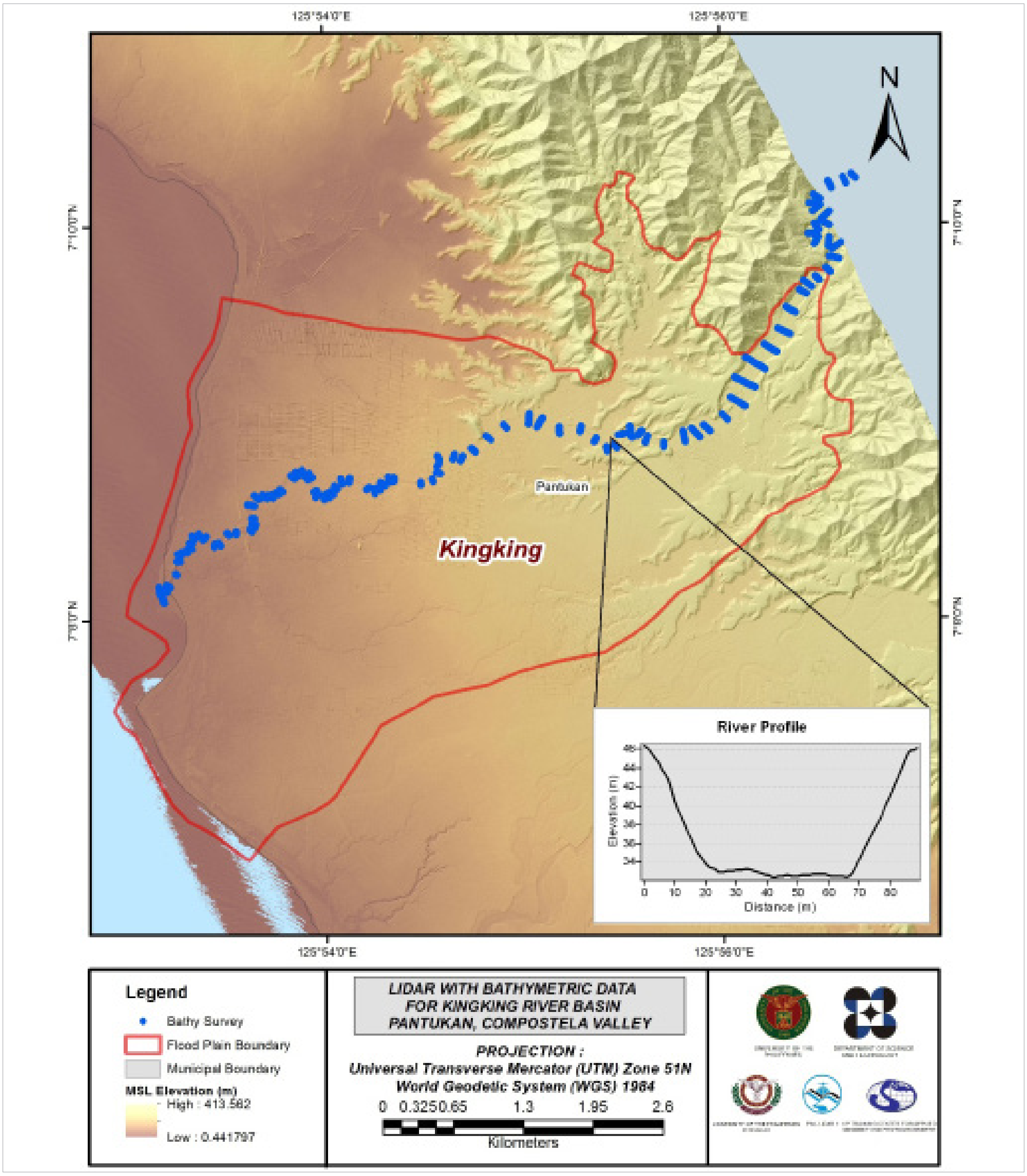

Figure 24. Map of Kingking Floodplain with bathymetric survey points shown in blue.

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 a 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, comprised of main thoroughfares such as highways and municipal and barangay roads, are essential for routing of disaster response efforts. These features are represented by a network of road centerlines.

3.12.1 Quality Checking (QC) of Digitized Features' Boundary

The Kingking floodplain, including its 200-m buffer, has a total area of 27.09 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 1,186 building features, were considered for QC. Figure 25 shows the QC blocks for Kingking floodplain in blue.

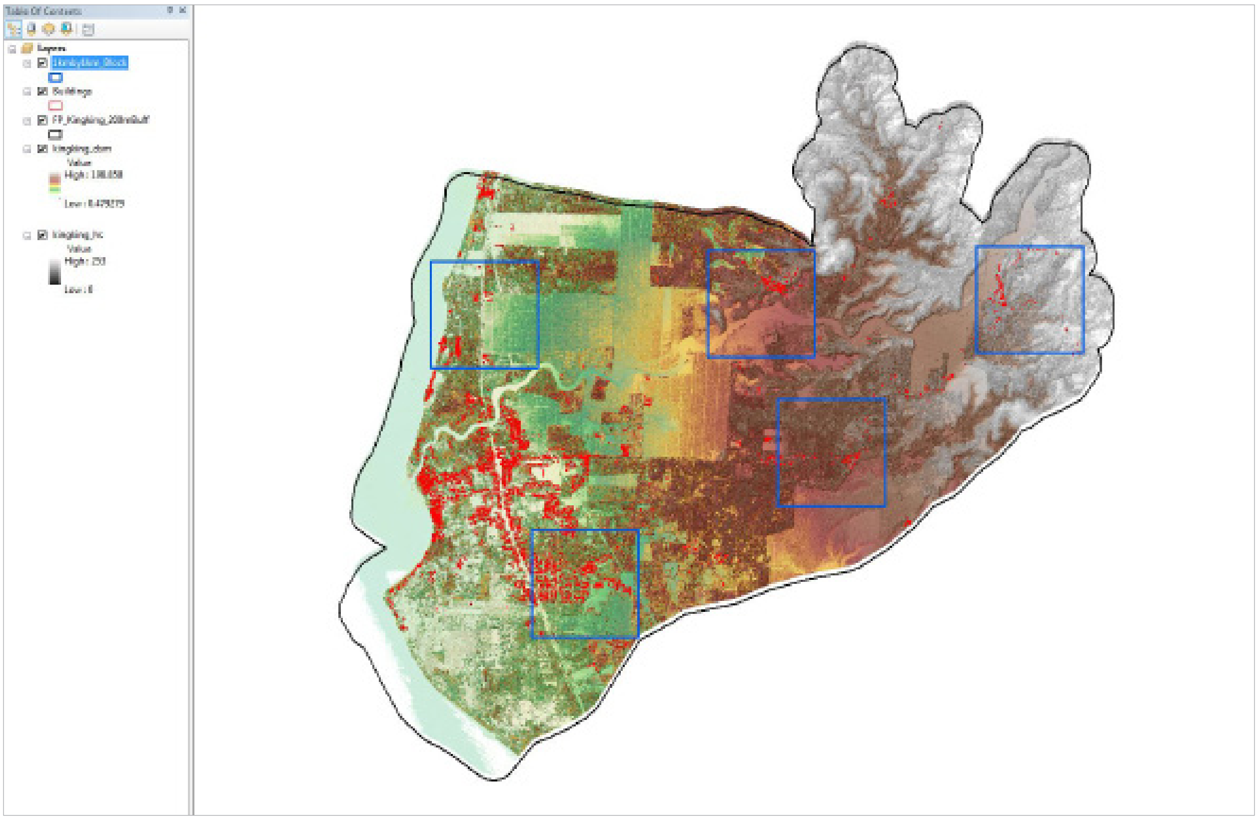

Figure 25. Blocks (in blue) of Kingking building features that were subjected to QC.

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

Table 15. Quality Checking Ratings for Kingking Building Features.

Floodplain	Completeness	Correctness	Quality	Remarks
Kingking	97.24	98.15	91.99	PASSED

3.12.2 Height Extraction

Height extraction was done for 5,047 building features in the Kingking floodplain. Of these building features, 179 were filtered out after height extraction, resulting to 4,868 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 14.48 m.

3.12.3 Feature Attribution

Before the actual field validation, courtesy calls were conducted to seek permission and assistance from the local government units (LGUs) of each barangay. This was done to ensure the safety and security in the area, for the smooth conduct of the field validation process. Verification of barangay boundaries was also done to finalize the distribution of features for each barangay.

The courtesy calls and project presentations were done on March 31, 2016. Barangay Health Workers (BHWs) were requested and hired to guide the University of the Philippines Mindanao Phil-LiDAR1 field enumerators during validation. The field work activity was conducted on April 11-15, 2016. The local BHWs deployed by the barangay captains were given a brief orientation by the field enumerators before the actual field work. Some of the personnel volunteered to use their own motorcycle vehicles during the validation proper. The team surveyed the two (2) barangays covered by the floodplain, namely Magnaga and Kingking, located in the Pantukan Municipality.

The lack of cellular phones and GPS signals in the area were experienced by the team, which hindered them from communicating and locating their assigned areas in a timely manner. The municipality representatives expressed to the team that they desire for the national government to address their problems on mining outflow, which greatly affect their community. They also conveyed their concerns on nearby rivers, such as Lahi and Matiao. The Lahi River affects the northern reaches of Pantukan, specifically Barangay Magnaga. When it overflows, the water goes south towards Barangay Kingking. The Matiao River, on the other hand, affects barangays south of the Kingking floodplain. Matiao River's flood intensity is described to be similar in strength with that of Kingking River. Barangay Bongbong, a barangay adjacent to the Matiao River, gets completely flooded when the latter overflows.

Table 16 summarizes the number of building features per type. Table 17 shows 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 Kingking Floodplain.

Facility Type	**No. of Features**
Residential	4,286
School	128
Market	1
Agricultural/Agro-Industrial Facilities	87
Medical Institutions	17
Barangay Hall	1
Military Institution	1
Sports Center/Gymnasium/Covered Court	8
Telecommunication Facilities	2
Transport Terminal	6
Warehouse	5
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	3
Water Supply/Sewerage	0
Religious Institutions	72
Bank	2
Factory	9
Gas Station	9
Fire Station	0
Other Government Offices	30
Other Commercial Establishments	201
Total	**4,868**

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

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/ Municipal Road	Provincial Road	National Road	Others	
Kingking	34.11	10.09	0.00	5.22	0.00	**49.42**

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

Floodplain	Water Body Type					Total
	Rivers/ Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Kingking	1	1	0	0	0	**2**

A total of three (3) 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 26 shows the Digital Surface Model (DSM) of the Kingking floodplain overlaid with its ground features.

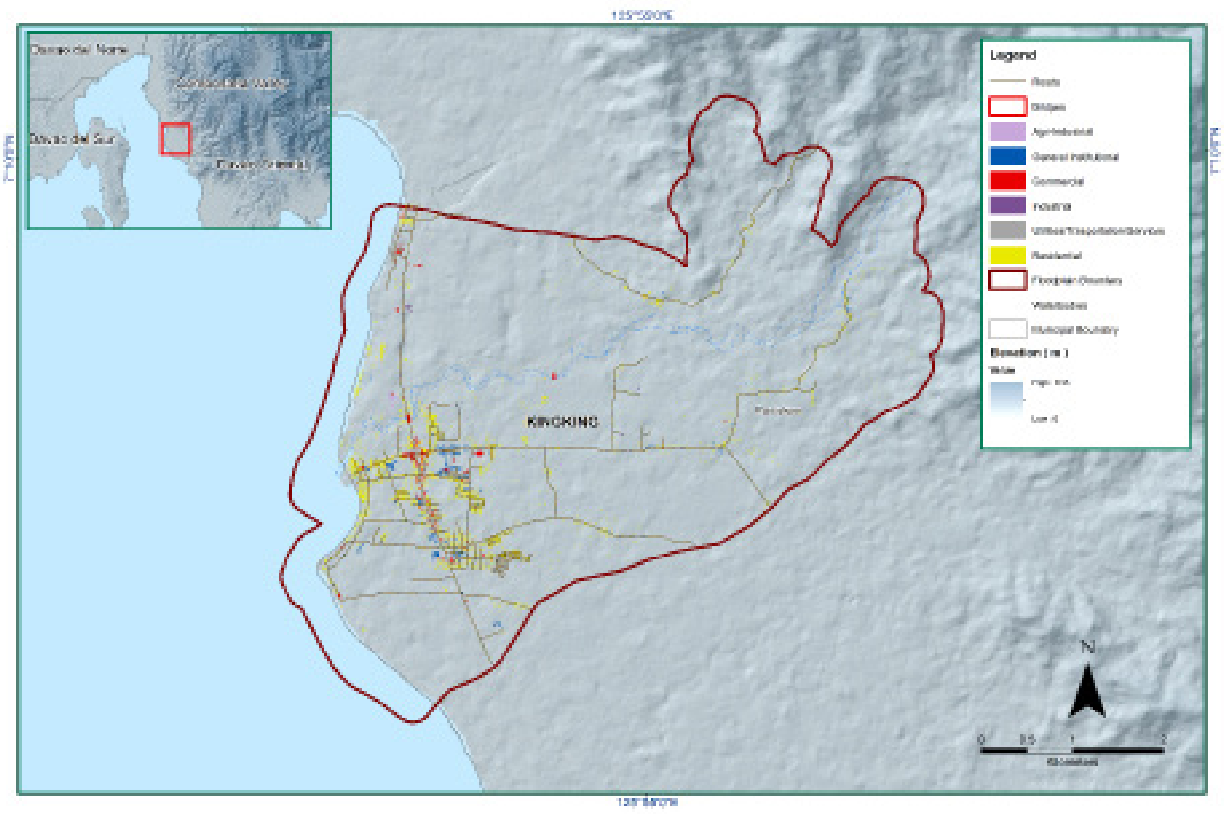

Figure 26. Extracted features for Kingking floodplain.

CHAPTER 4: LIDAR VALIDATION SURVEY AND MEASUREMENTS OF THE KINGKING 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

Field surveys were conducted in the Kingking River on March 16-17, 2016; March 21-24, 2016; March 29, 2016; and April 5, 2016, with the following scope: (i.) initial reconnaissance; (ii.) control point survey; (iii.) cross-section and bridge as-built survey at the Musahamat Bridge in Barangay Kingking, Pantukan, Compostela Valley; and (iv.) bathymetric survey from the river's upstream to its mouth, located in Brgy. Kingking, Pantukan, Compostela Valley, with an approximate length of 11.04 km using a Nikon® Total Station. Random checking points for the contractor's cross-section and bathymetry data were gathered by the DVBC on May 10-24, 2016, using a survey grade GNSS receiver Trimble® SPS 985 GNSS PPK survey technique. In addition to this, a validation points acquisition survey was conducted, covering the Kingking River Basin area. The entire survey extent is illustrated in Figure 27.

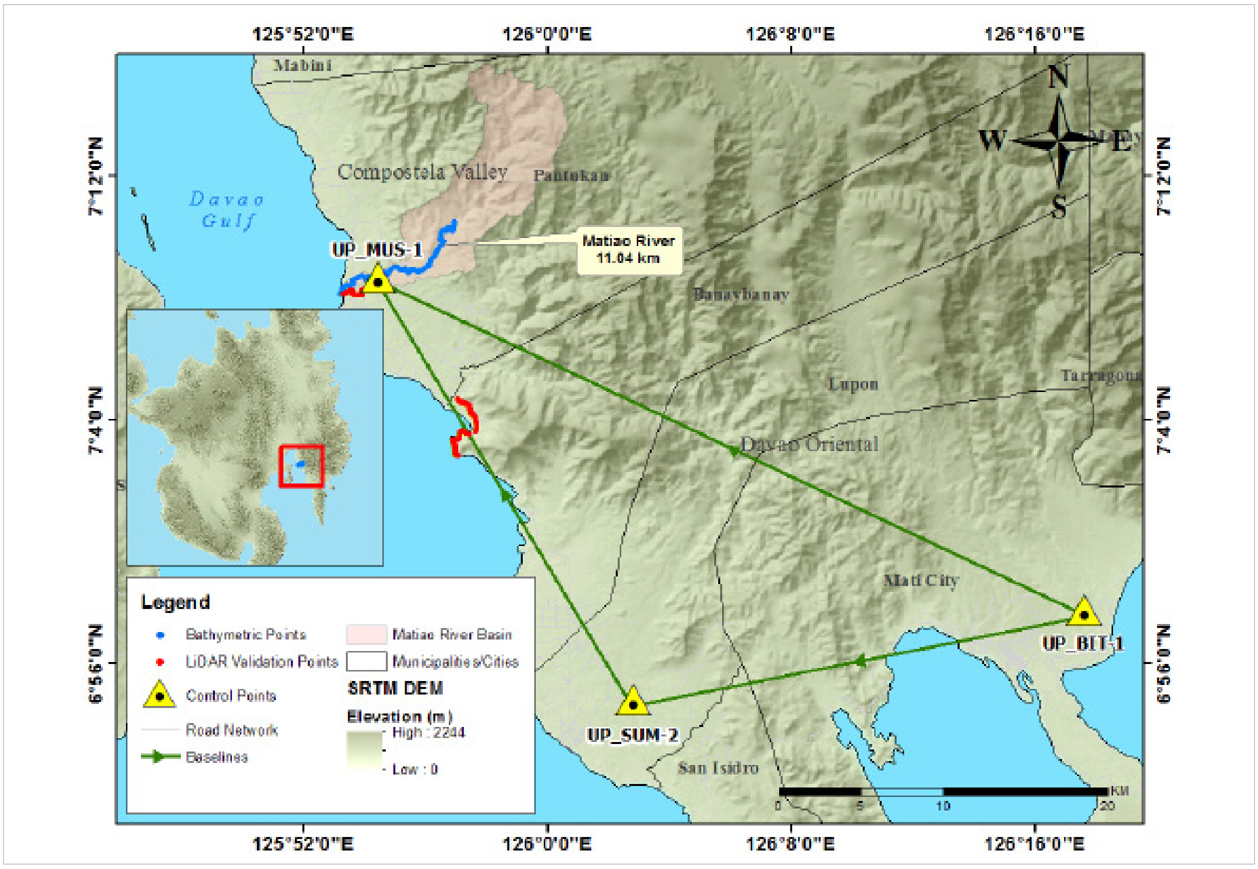


Figure 27. Extent of the bathymetric survey (in blue line) in Kingking River and the

4.2 Control Survey

The GNSS network used for the Kingking River is composed of one (1) loop established on May 20, 2016, occupying the following reference point: UP_BIT-1, an established control point from the static survey of the Bitanayan River on May 10-24, 2016, located in in Barangay Don Enrique Lopez, Mati City, Davao Oriental.

Two (2) control points established in the area by were also occupied for the survey: (i.) UP_MUS-1 at the approach of the Musahamat Bridge located in Barangay Kingking, Pantukan, Province of Compostela Valley; and (ii.) UP_SUM-2 located beside the approach of the Sumlog Bridge in located in Barangay Ilangay, Lupon, Davao Oriental.

The summary of reference and control points and their corresponding locations is enumerated in 19, while the GNSS network established is illustrated in Figure 28.

Table 19. List of reference and control points used during the survey in Kingking River (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS UTM Zone 52N)				
		Latitude	Longitude	Ellipsoid Height (m)	Elevation (MSL) (m)	Date of Establish-ment
UP_BIT-1	Established	6°57'46.30507"N	126°17'35.96635"E	80.537	15.21	2-26-16
UP_MUS-1	Established	7°08'40.27743"N	125°54'27.05429"E	82.138	14.547	3-23-16
UP_SUM-2	Established	6°54'48.60496"N	126°02'48.52278"E	84.364	18.125	3-17-16

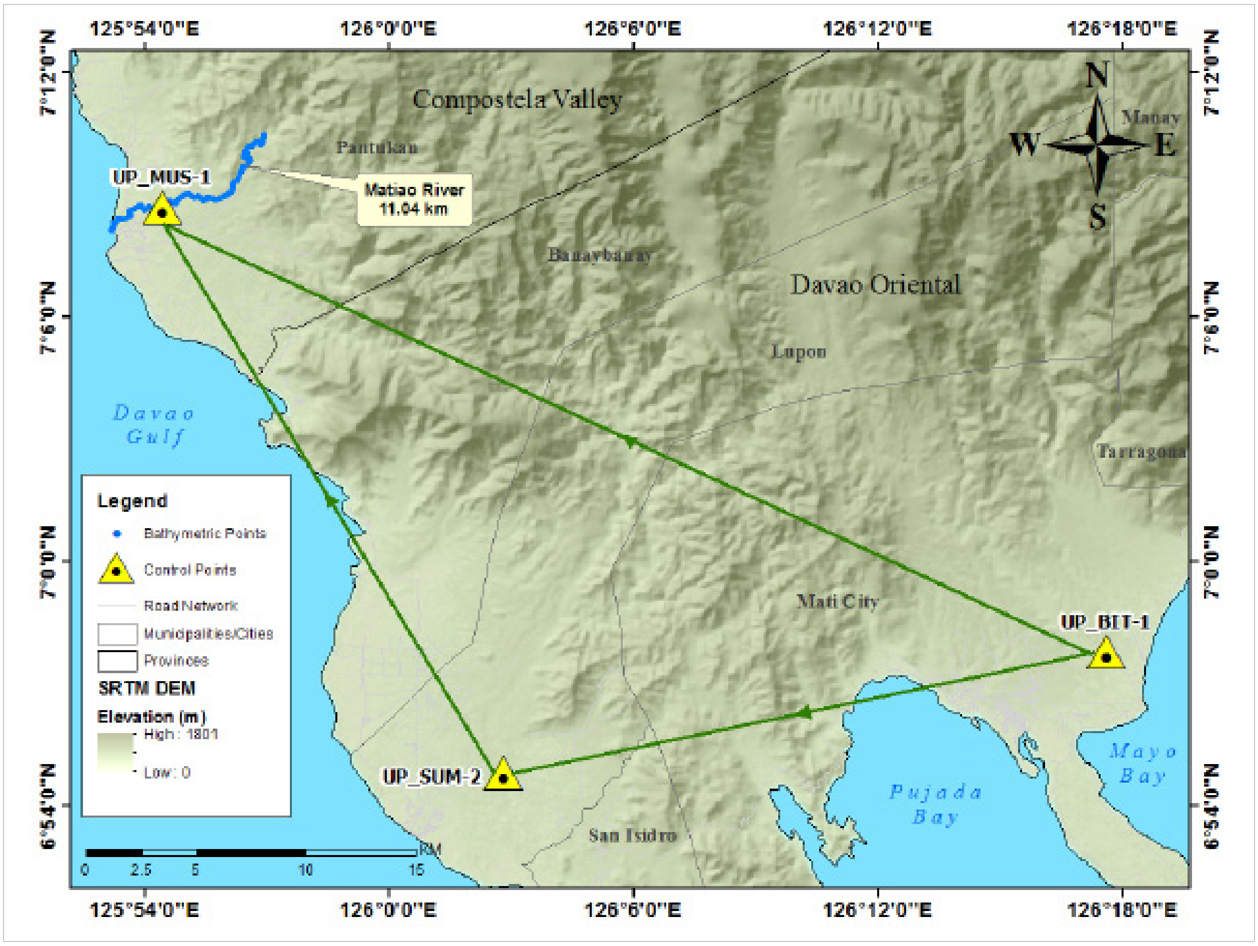


Figure 28. The GNSS Network established in the Kingking River Survey.

The GNSS set-ups on recovered reference points and established control points in the Kingking River are shown in Figures 29 to 31.

Figure 29. GNSS receiver set up, Trimble® SPS 852, at UP_BIT-1, located at the side of the railing near the approach of Bitanagan Bridge in Brgy. Don Enrique Lopez, City of Mati, Davao Oriental.

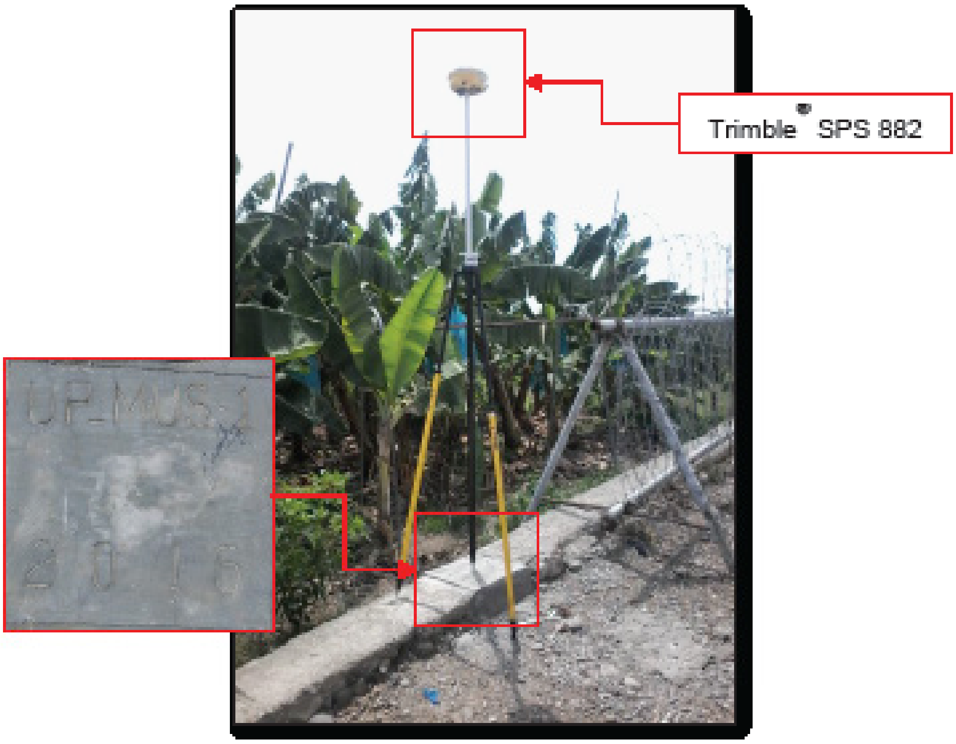


Figure 30. GNSS receiver set up, Trimble® SPS 882, at UP_MUS-1, located at the approach

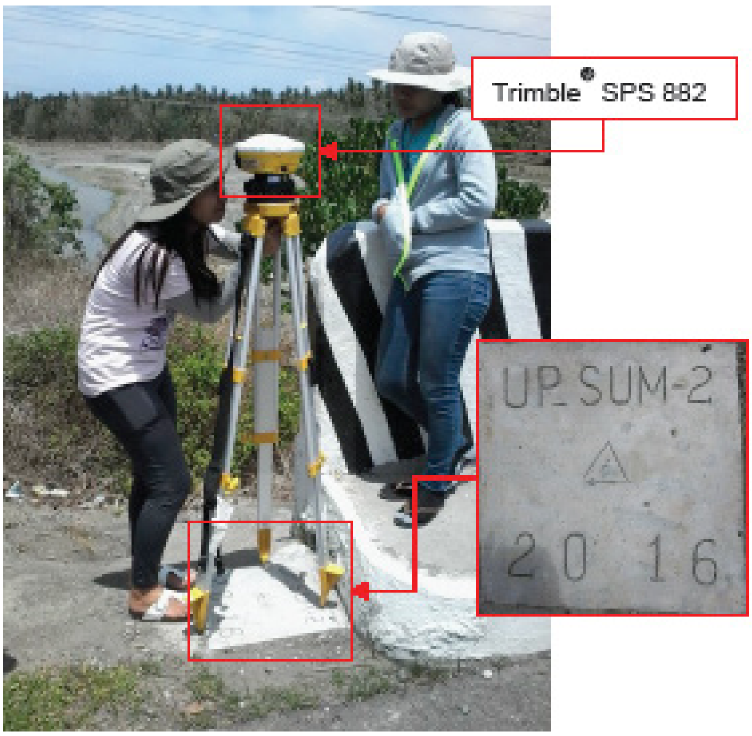


Figure 31. GNSS receiver set up, Trimble® SPS 882, at UP_SUM-2, located beside the approach of Sumlog Bridge in Brgy. Ilangay, Municipality of Lupon, Province of Davao Oriental.

4.3 Baseline Processing

GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions, with horizontal and vertical precisions within +/- 20 cm and +/- 10 cm requirement, respectively. In cases where one or more baselines did not meet all of these criteria, masking was performed. Masking is the removal of 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, a resurvey is initiated. Baseline processing results of control points in the Kingking River Basin is summarized in Table 20, generated by TBC software.

Table 20. Baseline Processing Report for Kingking River Static Survey.

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	Height (m)
UP_BIT-1 — UP_MUS-1	5-20-2016	Fixed	0.210	0.112	295°15'31"	47122.295	1.549
UP_MUS-1 — UP_SUM-2	5-20-2016	Fixed	0.007	0.011	328°56'37"	29826.325	-2.222
UP_MUS-1 — UP_SUM-2	5-20-2016	Fixed	0.005	0.040	328°56'37"	29826.333	-2.228
UP_BIT-1 — UP_SUM-2	5-20-2016	Fixed	0.009	0.028	258°41'02"	27783.534	3.833

As shown in Table 20, a total of four (4) baselines were processed, with the coordinate and elevation values of UP_BIT-1 held fixed. All of the baselinesm passed satisfied the required accuracy.

4.4 Network Adjustment

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

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

Where:

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

for each control point. See the Network Adjustment Report shown from 21 to 23 for the complete details.

The three (3) control points, UP-BIT-1, UP_MUS-1, and UP-SUM-2, were occupied and observed simultaneously to form a GNSS loop. The coordinate values of DVE-42 and elevation of DE-160 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 were computed.

Table 21. Control Point Constraints

Point ID	Type	North (Meter)	East (Meter)	Height (Meter)	Elevation (Meter)
UP_BIT-1	Global	Fixed	Fixed	Fixed	
Fixed = 0.000001(Meter)					

The list of adjusted grid coordinates; i.e., Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 22. All fixed control points have no values for grid errors and elevation error.

Table 22. Adjusted Grid Coordinates

Point ID	Northing (Meter)	Northing Error (Meter)	Easting (Meter)	Easting Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
UP_BIT-1	770500.332	?	200912.560	?	15.210	?	LLh
UP_MUS-1	790872.748	0.005	158376.175	0.010	14.547	0.041	
UP_SUM-2	765199.921	0.006	173616.342	0.009	18.125	0.040	

With the aforementioned equation, $\surd((x_e)^2 + (y_e)^2\ ) < 20\ cm$ for horizontal and $z_e < 10\ cm$ for the vertical; the computations for the accuracy are as follows:

a. UP_BIT-1

Horizontal Accuracy = Fixed

Vertical Accuracy = Fixed

b. UP_MUS-1

Horizontal Accuracy = $\surd((0.3)^2 + (1.0)^2$

= $\surd\ (0.09 + 1.00)$

= 1.09 < 20 cm

Vertical Accuracy = 4.1 < 10 cm

c. UP_SUM-2

Horizontal Accuracy	=	$\sqrt{((0.6)^2 + (0.9)^2}$
	=	$\sqrt{(0.36 + 0.81)}$
	=	1.17 < 20 cm
Vertical Accuracy	=	4.0 < 10 cm

Following the given formula, the horizontal and vertical accuracy results of the two (2) occupied control points are within the required precision.

Table 23. Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
UP_BIT-1	N6°57'46.30507"	E126°17'35.96635"	80.537	?	LLh
UP_MUS-1	N7°08'40.27743"	E125°54'27.05429"	82.138	0.041	
UP_SUM-2	N6°54'48.60496"	E126°02'48.52278"	84.364	0.040	

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

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

Table 24. Reference and control points used and its location (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS UTM Zone 52N)					
		Latitude	Longitude	Ellipsoidal Height (Meter)	Northing (m)	Easting (m)	BM Ortho (m)
UP_BIT-1	Established	6°57'46.30507"N	126°17'35.96635"E	80.537	770500.332	200912.56	15.21
UP_MUS-1	Established	7°08'40.27743"N	125°54'27.05429"E	82.138	790872.748	158376.175	14.547
UP_SUM-2	Established	6°54'48.60496"N	126°02'48.52278"E	84.364	765199.921	173616.342	18.125

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

Cross-section and bridge as-built surveys were conducted on March 29, 2016 at the downstream side of the Musahamat Bridge in Barangay Kingking, Municipality of Pantukan, as shown in Figure 32. A Nikon® Total Station was utilized for this survey, as shown in Figure 33.

Figure 32 . Musahamat Bridge facing downstream

Figure 33. As-built survey of Musahamat Bridge.

The length of the cross-sectional line surveyed in the Musahamat Bridge is about 112 m, with sixty-seven (67) cross-sectional points, using the control points UP_MUS-1 and UP_MUS-2 as the GNSS base stations. The location map, cross-section diagram, and the bridge data form are shown in Figure 34, Figure 35 and Figure 36, respectively. Gathering of random points for the checking of the bridge cross-section and bridge points data was performed by the DVBC on May 19, 2016, using a survey grade GNSS Rover receiver attached to a 2-m pole.

Linear square correlation (R^2) and RMSE analysis were performed on the two (2) datasets. The linear square coefficient range is determined to ensure that the submitted data of the contractor is within the accuracy standard of the project, which is ±20 cm and ±10 cm for horizontal and vertical, respectively. The R^2 value must be within 0.85 to 1. An R^2 approaching 1 signifies a strong correlation between the vertical (elevation values) of the two datasets. A computed R^2 value of 0.99 was obtained by comparing the data of the contractor and DVBC; signifying a strong correlation between the two (2) datasets.

In addition to the Linear Square Correlation, Root Mean Square (RMSE) analysis was also performed in order to assess the difference in elevation between the DVBC checking points and the contractor's. The RMSE value should only have a maximum radial distance of 5 m, and the difference in elevation within the radius of 5 meters should not be beyond 0.50 m. For the bridge cross-section data, a computed value of 0.294 was acquired. The computed R^2 and RMSE values are within the accuracy requirement of the program.

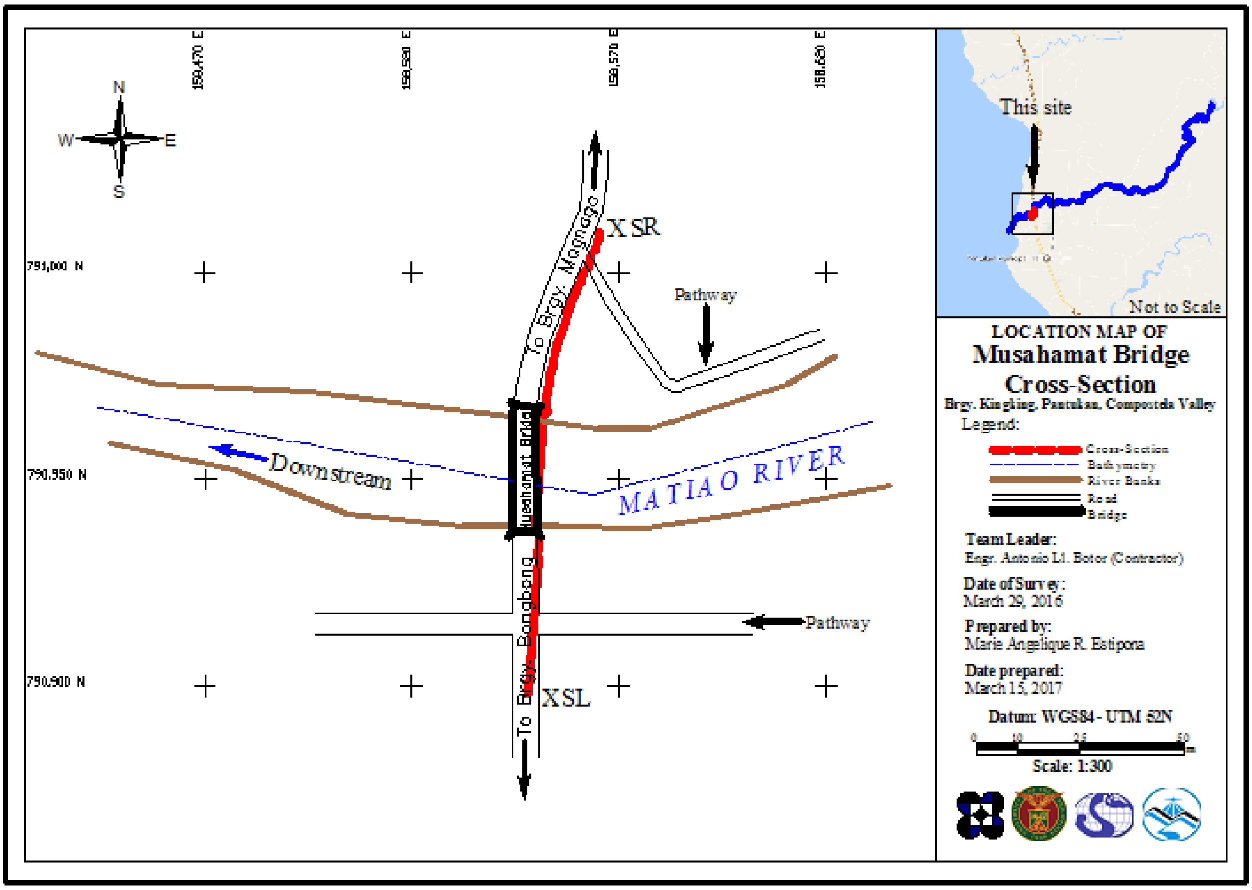


Figure 34. Location map of Muahamat Bridge Cross Section Survey.

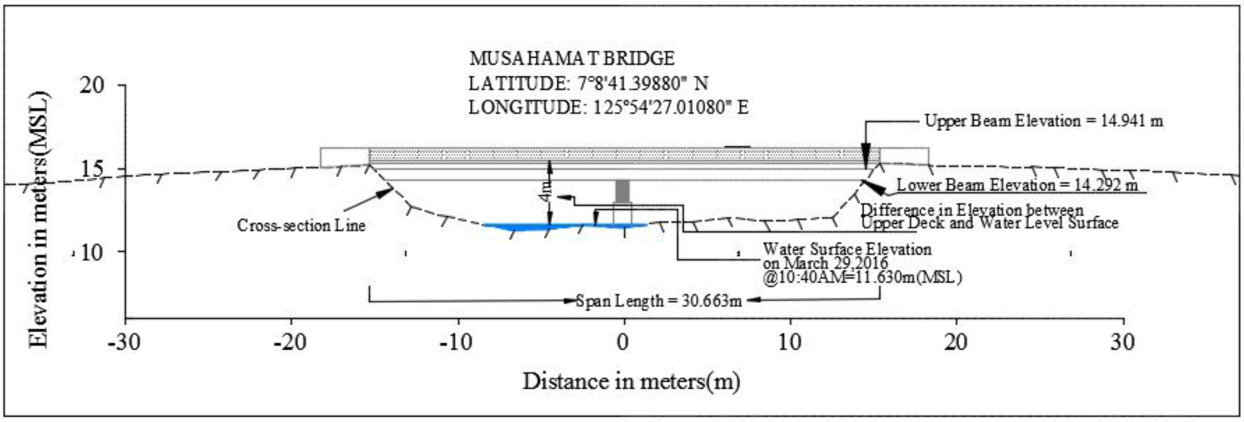


Figure 35. Musahamat Bridge Cross-section Diagram.

Bridge Data Form

Bridge Name: Musahamat Bridge

River Name: Kingking River

Location (Brgy, City, Region): Brgy. Kingking, Pantukan, Compostela Valley

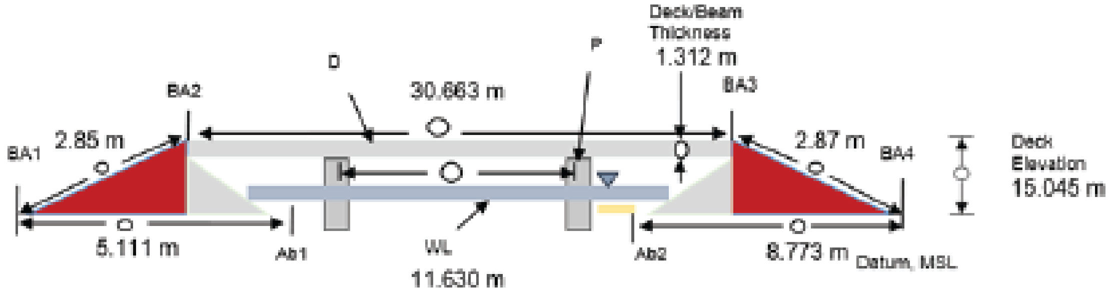
Survey Team: Jayson Ilustre, Ryan Antonio, Daniel Diaz

Date and Time: March 29, 2016, 10:40 A.M.

Flow Condition: low ✔normal high

Weather Condition: ✔fair rainy

Cross-sectional View (not to scale):



Legend:

BA = Bridge Approach
P = Pier
Ab = Abutment
D = Deck
WL = Water Level/Surface
MSL = Mean Sea Level
◯ = Measurement Value

Line Segment	Measurement (m)	Remarks
1. BA1-BA2	2.85 m	
2. BA2-BA3	30.663 m	
3. BA3-BA4	2.87 m	
4. BA1-Ab1	5.111 m	
5. Ab2-BA4	8.773 m	
6. Deck/beam thickness	1.312 m	
7. Deck elevation	15.045 m	

Figure 36. Musahamat Bridge Data Sheet.

Note: Observer should be facing downstream

The water surface elevation of the Kingking River was determined by a Nikon® Total Station on March 29, 2016 at 10:40 AM at the Musahamat Bridge area, with a value of 11.630 m in MSL, as shown in Figure 35. This was translated into marking on the bridge's pier, as shown in Figure 37. The marking will serve as reference for flow data gathering and depth gauge deployment of the partner HEI responsible for the Kingking River, UP Mindanao.

Figure 37. Water-level markings on Musahamat Bridge.

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted by the DVBC on May 10-24, 2016, using a survey grade GNSS Rover receiver, Trimble® SPS 985, mounted on a range pole attached on the front of a vehicle, as shown in Figure 38. It was secured with cable ties and ropes to ensure that it was horizontally and vertically balanced. The antenna height was 2.476 m, measured from the ground up to the bottom of the quick release of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode, with UP_MUS-1 occupied as the GNSS base station during the conduct of the survey.

Figure 38. Validation points acquisition survey set-up for Kingking River.

The survey started in Barangay Kingking, Pantukan, Compostela Valley and headed south east along the national highway, and traversed two (2) flight strips in Barangay Pintatagan, Banaybanay, Davao Oriental. The survey gathered a total of 1,349 points with an approximate length of 8.5 km, using UP_MUS-1 as GNSS base station for the entire extent of validation points acquisition survey, as illustrated in the map in Figure 39.

Figure 39. Extent of the LiDAR ground validation survey of Kingking River basin.

4.7 Bathymetric Survey

A manual bathymetric survey was executed on March 21-23, 2016 and April 5, 2016 using a Nikon® Total Station, as depicted in Figure 40. The survey started in Barangay Kingking, Pantukan, Compostela Valley with coordinates 7° 10' 32.64306"N, 125° 56' 54.35782"E, and ended at the mouth of the river in Barangay Kingking, Pantukan, Compostela Valley, with coordinates 7° 8' 5.38299"N, 125° 53' 11.08865"E. The control points UP_MUS-1 and UP_MUS-2, served as the GNSS base stations all throughout the survey.

Figure 40. Manual bathymetric survey of ABSD at Kingking River using Nikon® Total Station.

Gathering of random points for the checking of the bathymetric data was performed by the DVBC on May 19, 2016, using a GNSS Rover receiver, Trimble® SPS 985 attached to a 2-m pole. A map showing the DVBC bathymetric checking points is shown in Figure 42.

Linear square correlation (R^2) and RMSE analysis were also performed on the two (2) datasets, and a computed R^2 value of 0.98 is within the required range for R^2, which is 0.85 to 1. Additionally, an RMSE value of 0.194 was obtained. Both the computed R^2 and RMSE values are within the accuracy required by the program.

The bathymetric survey for Kingking River gathered a total of 4,390 points, covering 11.04 km of the river traversing Barangay Kingking in the Municipality of Pantukan, Compostela Valley. To further illustrate this, A CAD drawing was also produced to depict the riverbed profile of Kingking River. As shown in Figure 43, the highest and lowest elevation has a 98-m difference. The highest elevation observed was 97.262 m above MSL located in Barangay Kingking, Pantukan while the lowest was -0.956 m below MSL located in Barangay Kingking, Pantukan as well.

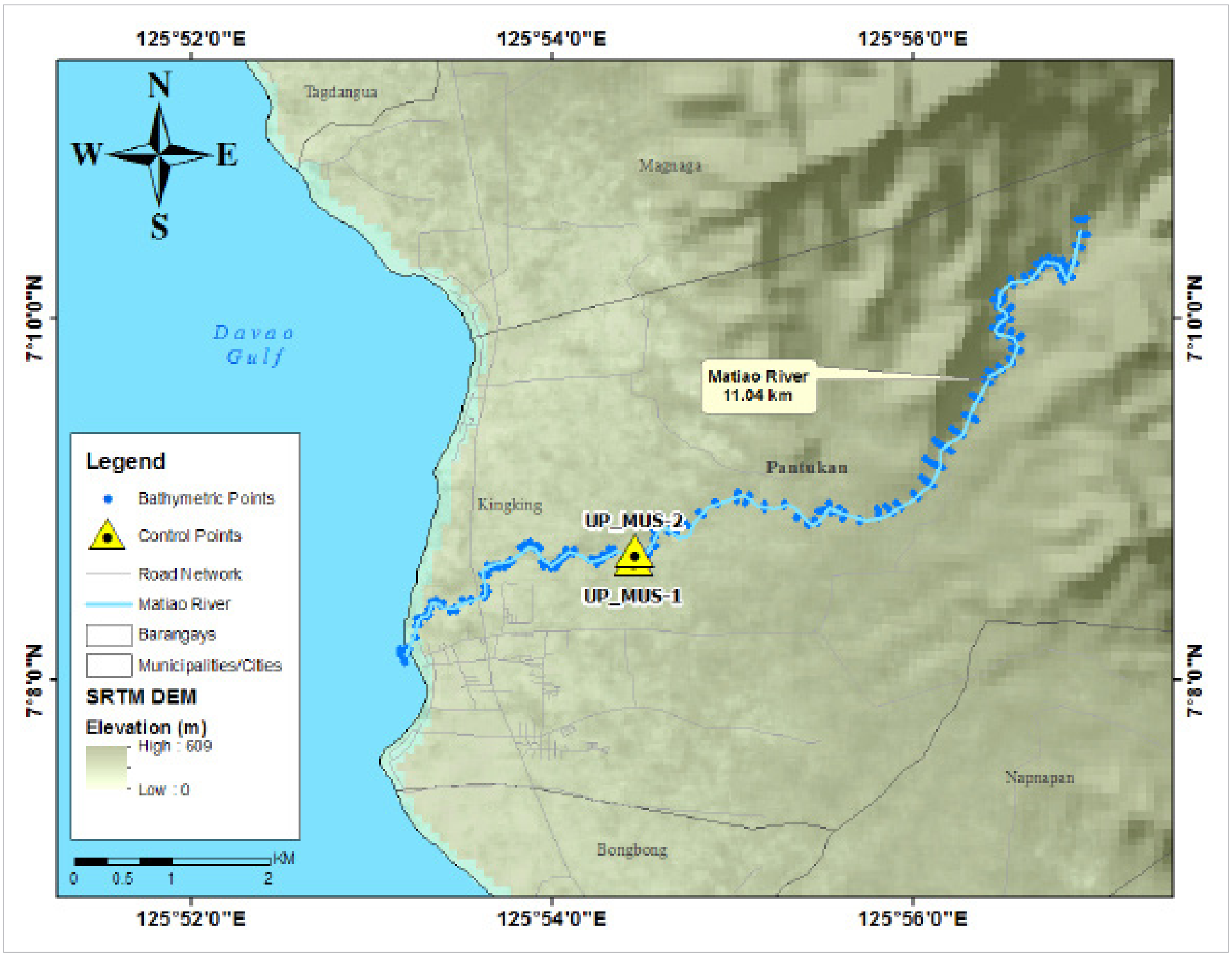


Figure 41. Extent of the bathymetric survey of Kingking River.

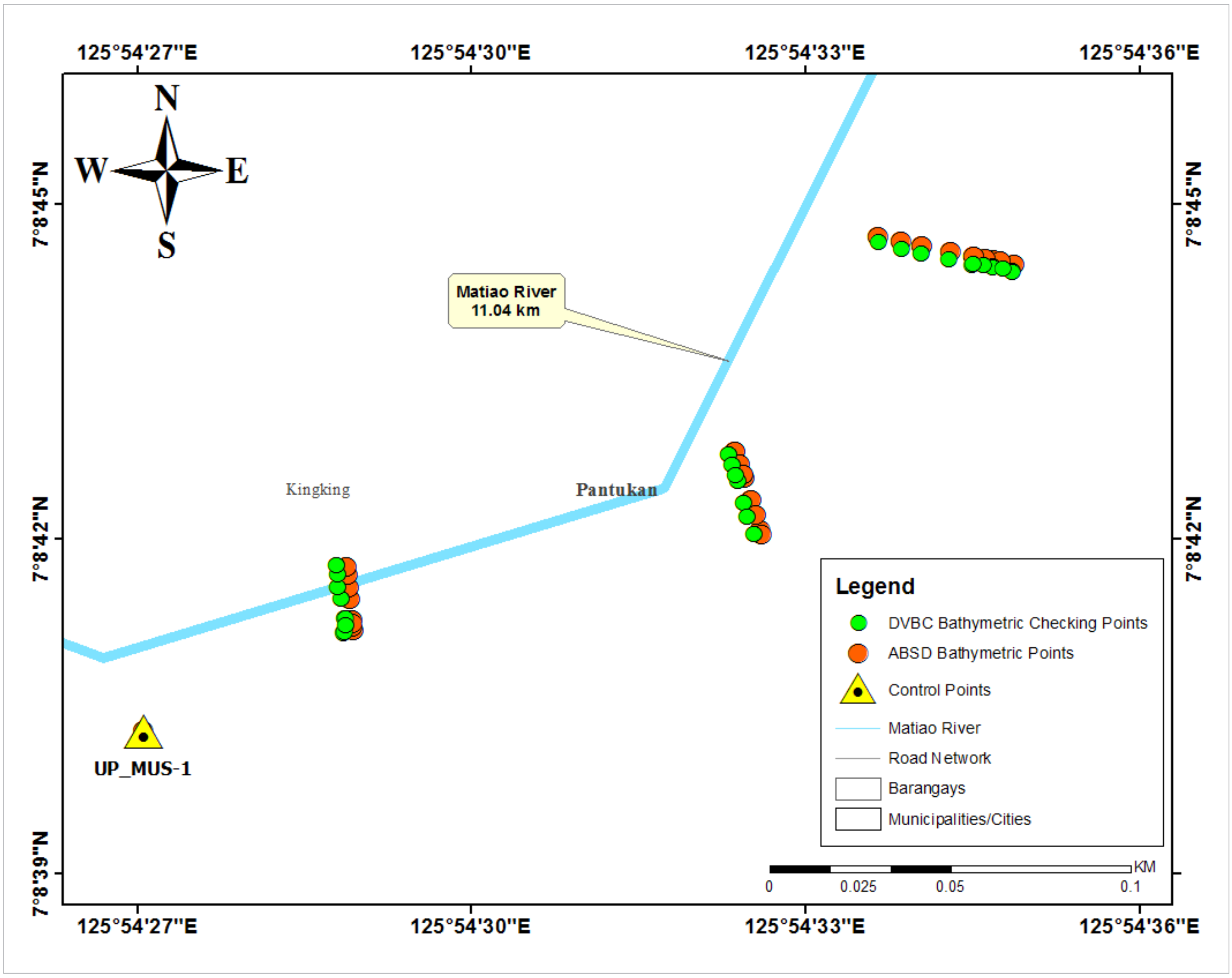


Figure 42. Quality checking points gathered along Kingking River by DVBC.

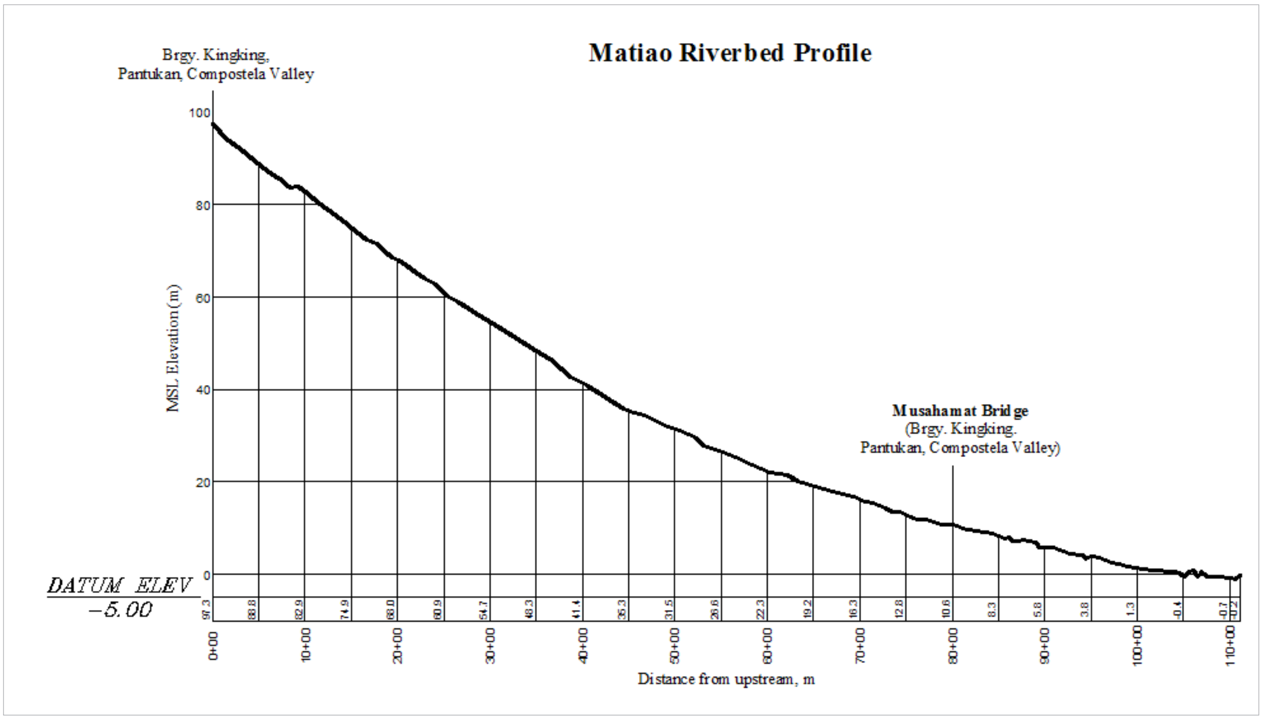


Figure 43. Kingking Riverbed Profile

CHAPTER 5: FLOOD MODELING AND MAPFPING

Dr. Alfredo Mahar Lagmay, Christopher Uichanco, Sylvia Sueno, Marc Moises, Hale Ines, Miguel del Rosario, Kenneth Punay, Neil Tingin, Narvin Clyd Tan and Hannah Aventurado

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

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

5.1.2 Precipitation

Precipitation data was taken from the rain gauge installed by the University of the Philippines Mindanao Phil-LiDAR 1 Team. This rain gauge is located in Barangay Kingking, Pantukan, Compostela Valley with the following coordinates: 7°9’0.22” N, 125°56’18.38” E (Figure 44). The precipitation data collection started from June 19, 2016 at 9:00 PM until June 20, 2016 at 11:40 PM, with a 10-minute recording interval.

The total precipitation for this event in the installed rain gauge was 55.2 mm. It had a peak rainfall of 11.6 mm. on June 20, 2016 at 1:00 PM. The lag time between the peak rainfall and discharge is 4 hours and 20 minutes.

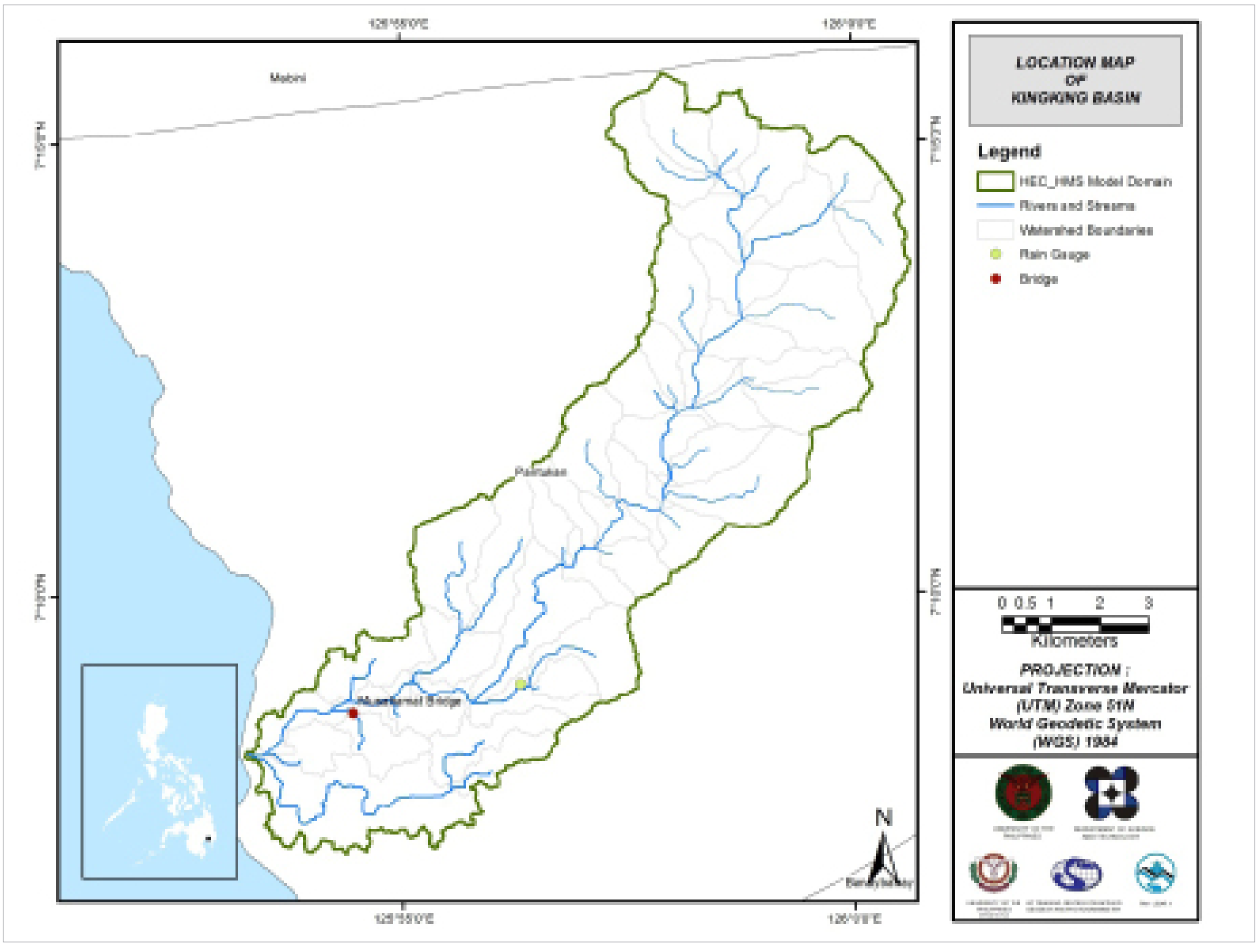


Figure 44. The location map of Kingking HEC-HMS model used for calibration.

5.1.3 Rating Curves and River Outflow

A rating curve was developed at the Musahamat Bridge, Brgy. Kingking, Pantukan, Compostela Valley (7°8’41.39” N, 125°54’27.07” E) to establish the relationship between the observed water level at the Musahamat Bridge and the outflow of the watershed at this location.

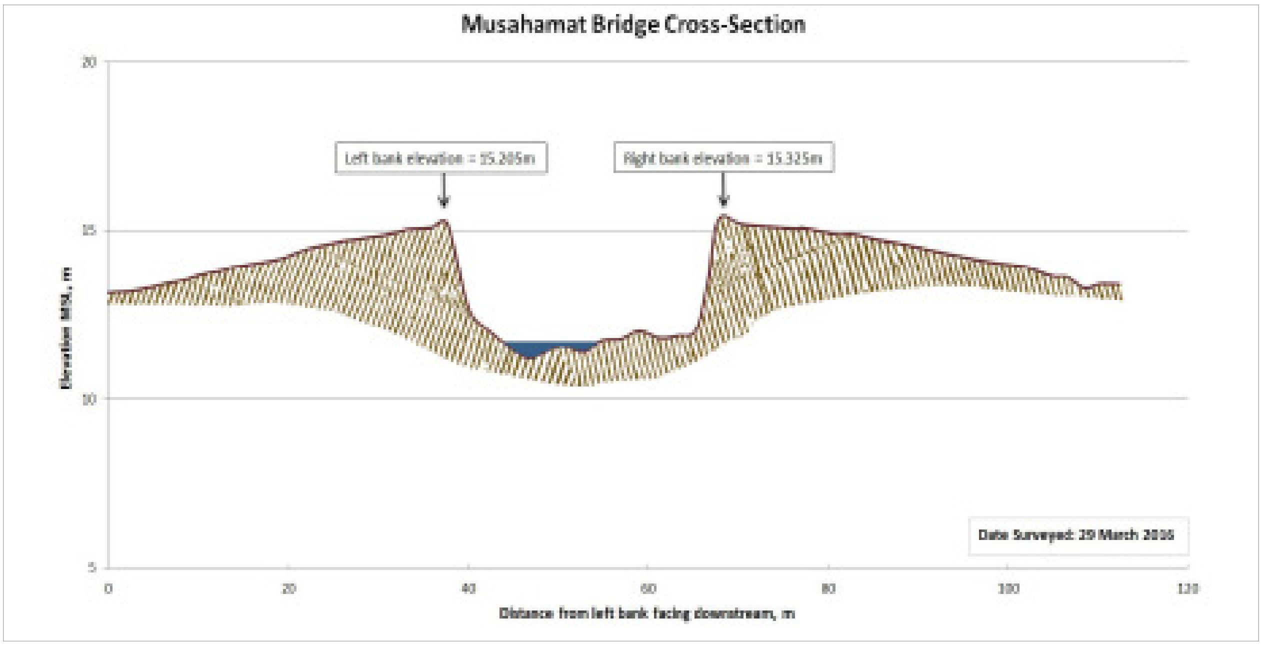


Figure 45. Cross-Section Plot of Musahamat Bridge.

For Musahamat Bridge, the rating curve is expressed as: Q = 6E-12e2.2951x, as shown in Figure 46.

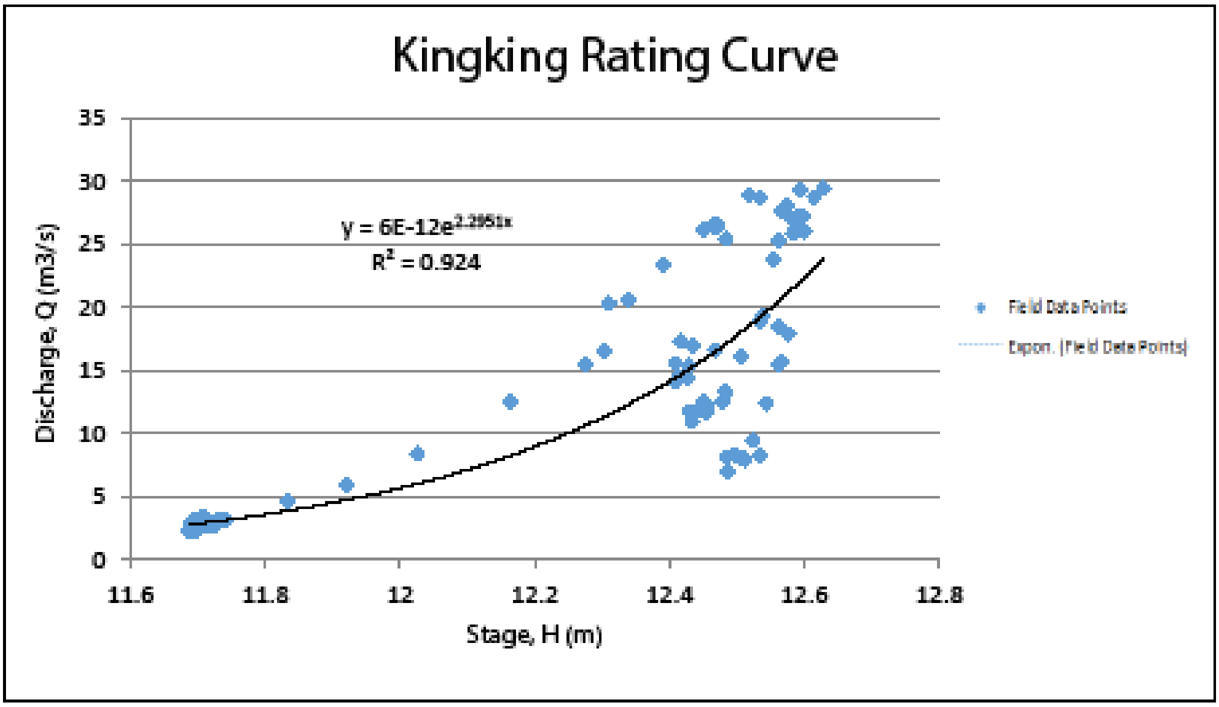


Figure 46. Rating Curve at Musahamat Bridge, Pantukan, Compostela Valley.

The rating curve equation was used to compute for the river outflow at the Musahamat Bridge for the calibration of the HEC-HMS model for Kingking, as shown in Figure 47. The total rainfall for this event is 55.2 mm, and the peak discharge is 29.4 m^3/s at 5:20 PM of June 20, 2016.

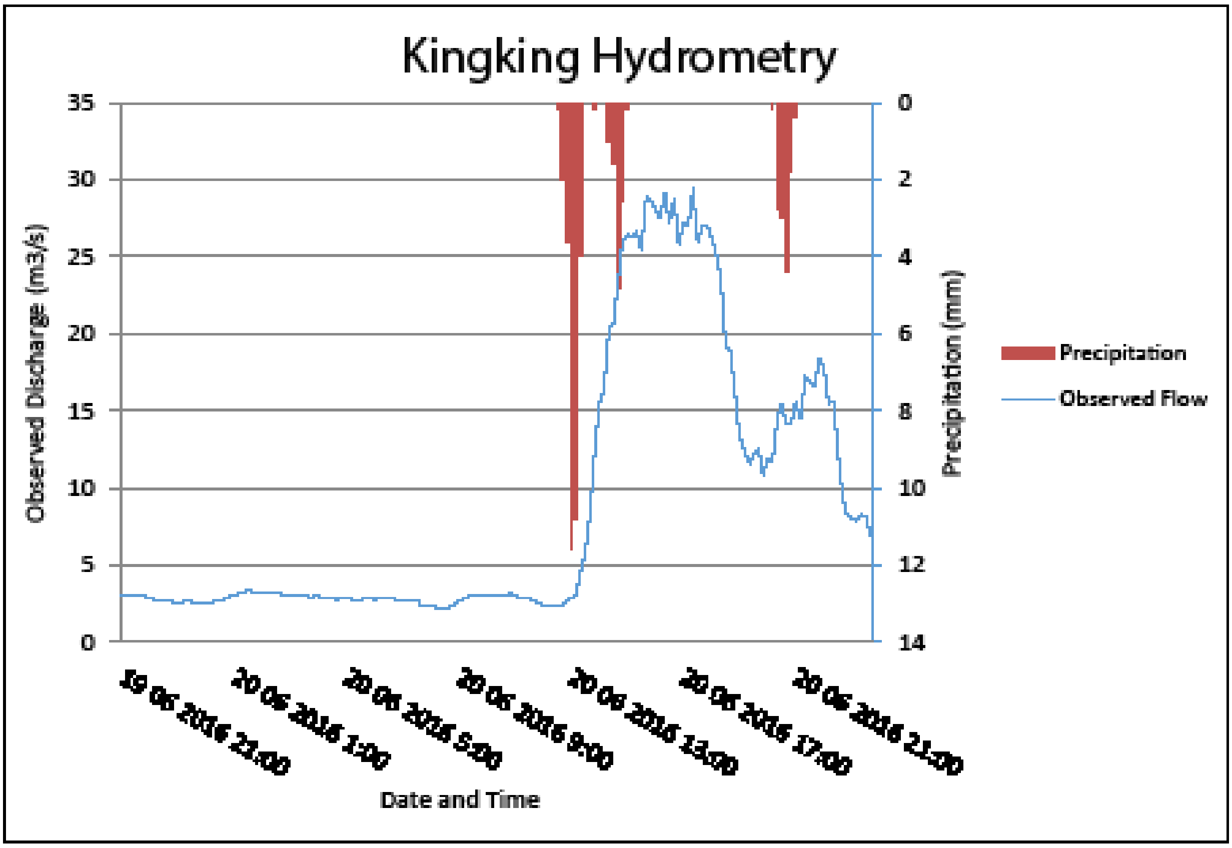


Figure 47. Rainfall and outflow data at Musahamat Bridge used for modeling.

5.2 RIDF Station

The Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed for Rainfall Intensity Duration Frequency (RIDF) values for the Davao Rain Gauge (Table 25). This station was selected based on its proximity to the Kingking watershed (Figure 48).The RIDF rainfall amount for 24 hours was converted into a synthetic storm by interpolating and re-arranging the values such that a certain peak value will be attained at a certain time. The extreme values for this watershed were computed based on a 59-year record.

Table 25. RIDF values for Davao 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	19.5	30	38.2	53.2	65.2	71.6	80.3	85.8	91.4
5	25.1	39.3	51	73.2	88.8	96.4	108.7	114.9	121.1
10	28.8	45.4	59.4	86.5	104.5	112.8	127.5	134.1	140.7
15	30.9	48.9	64.2	94	113.3	122.1	138.1	145	151.8
20	32.4	51.3	67.6	99.3	119.5	128.6	145.5	152.6	159.5
25	33.5	53.2	70.1	103.3	124.2	133.6	151.2	158.5	165.5
50	37	59	78.1	115.8	138.9	149	168.8	176.5	183.9
100	40.5	64.7	85.9	128.1	153.5	164.2	186.3	194.4	202.1

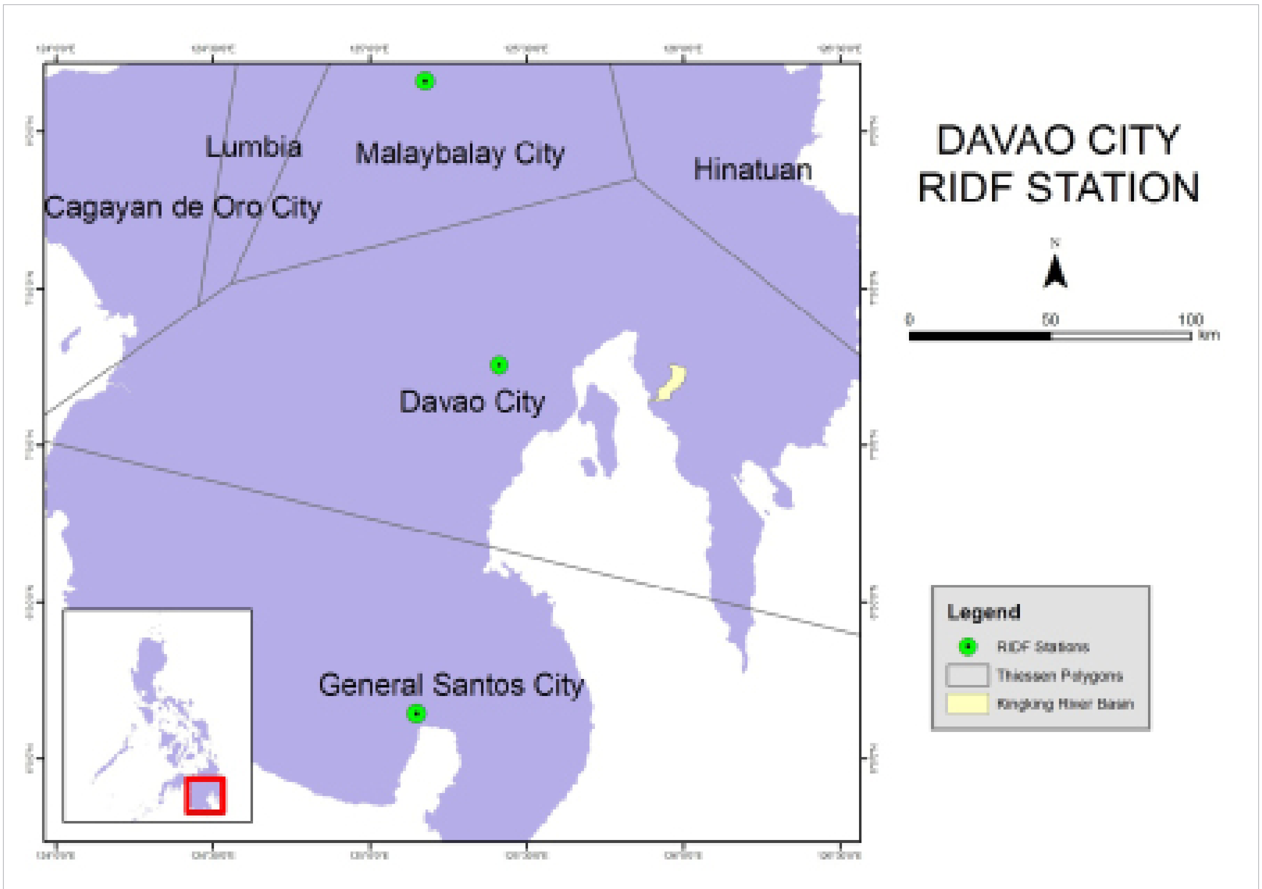


Figure 48. Location of Davao RIDF Station relative to Kingking River Basin.

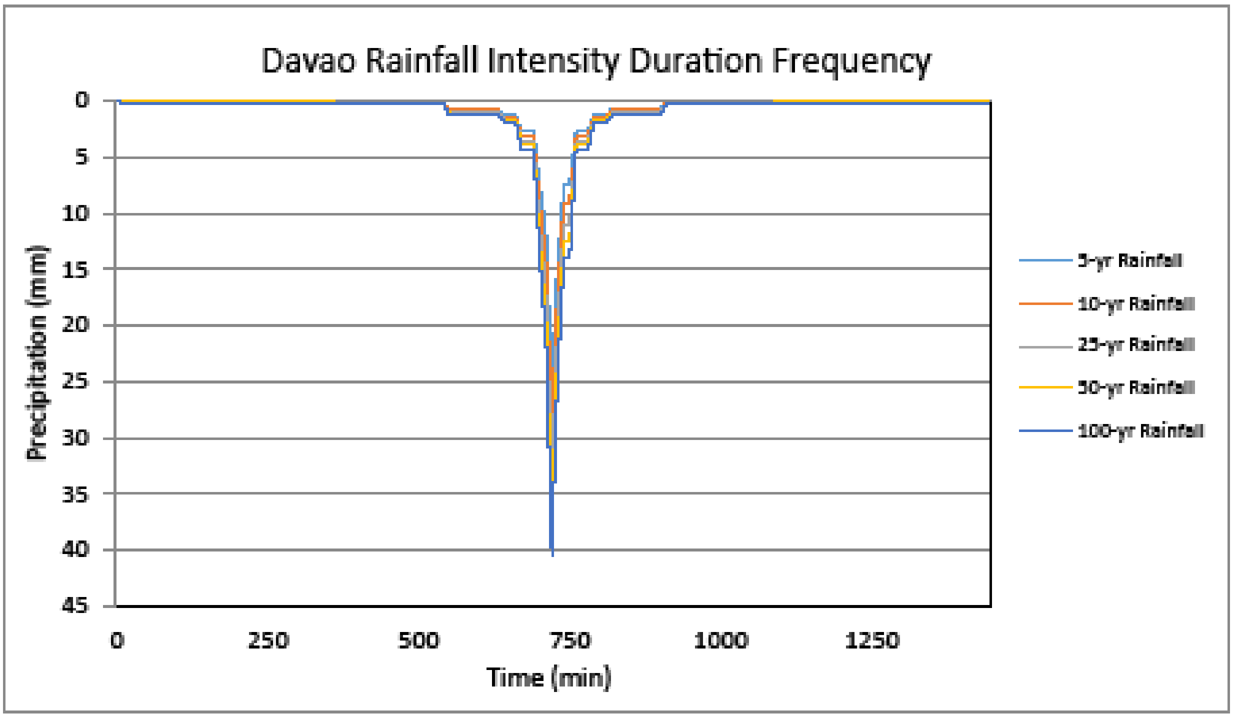


Figure 49. Synthetic storm generated for a 24-hr period rainfall for various return periods.

5.3 HMS Model

The soil shapefile was taken from the Bureau of Soils and Water Management (BSWM) under the Department of Agriculture (DA). The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). These soil datasets were taken before 2004. The soil and land cover of the Kingking River Basin are shown in Figures 50 and 51, respectively.

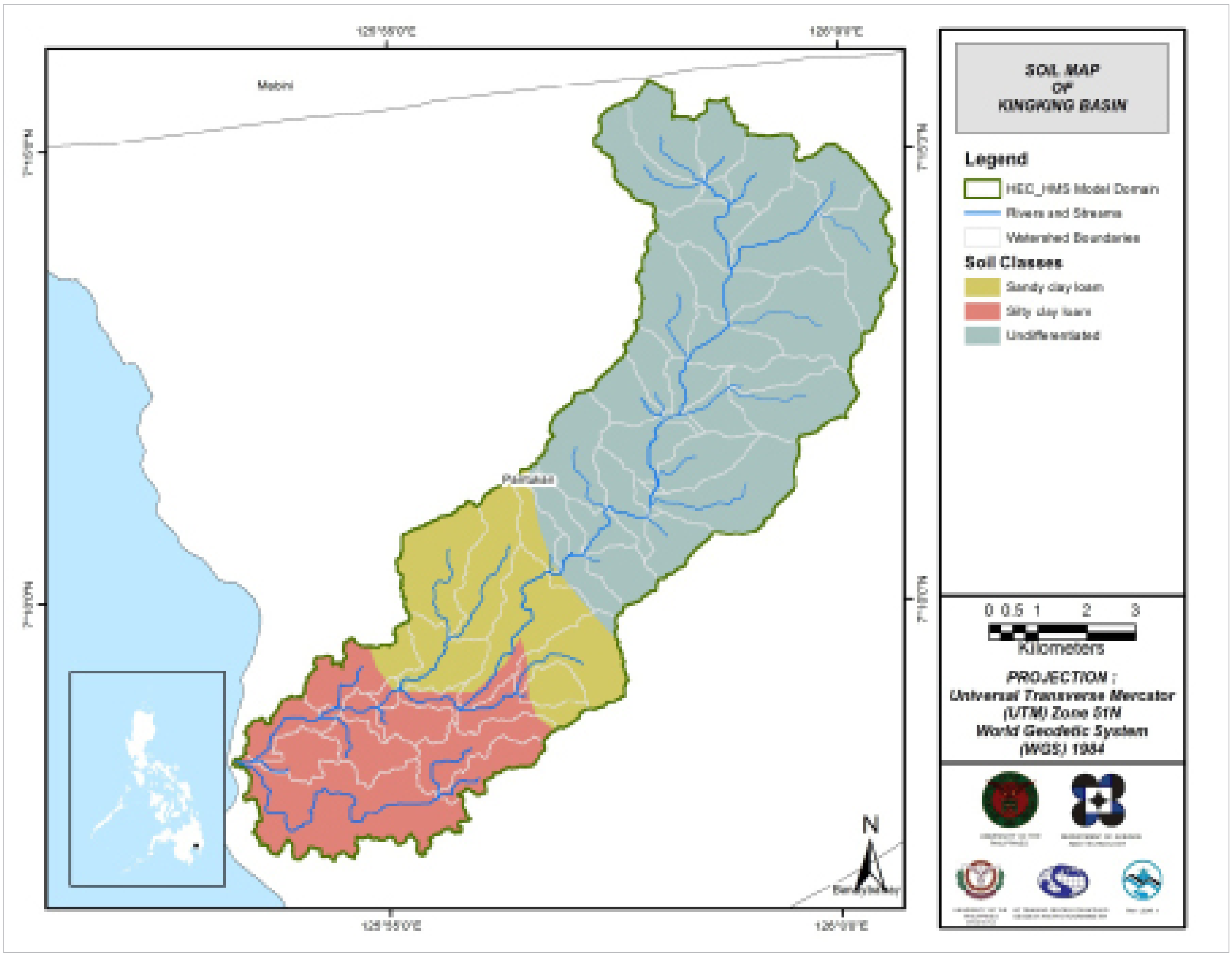


Figure 50. Soil Map of Kingking River Basin (Source: DA)

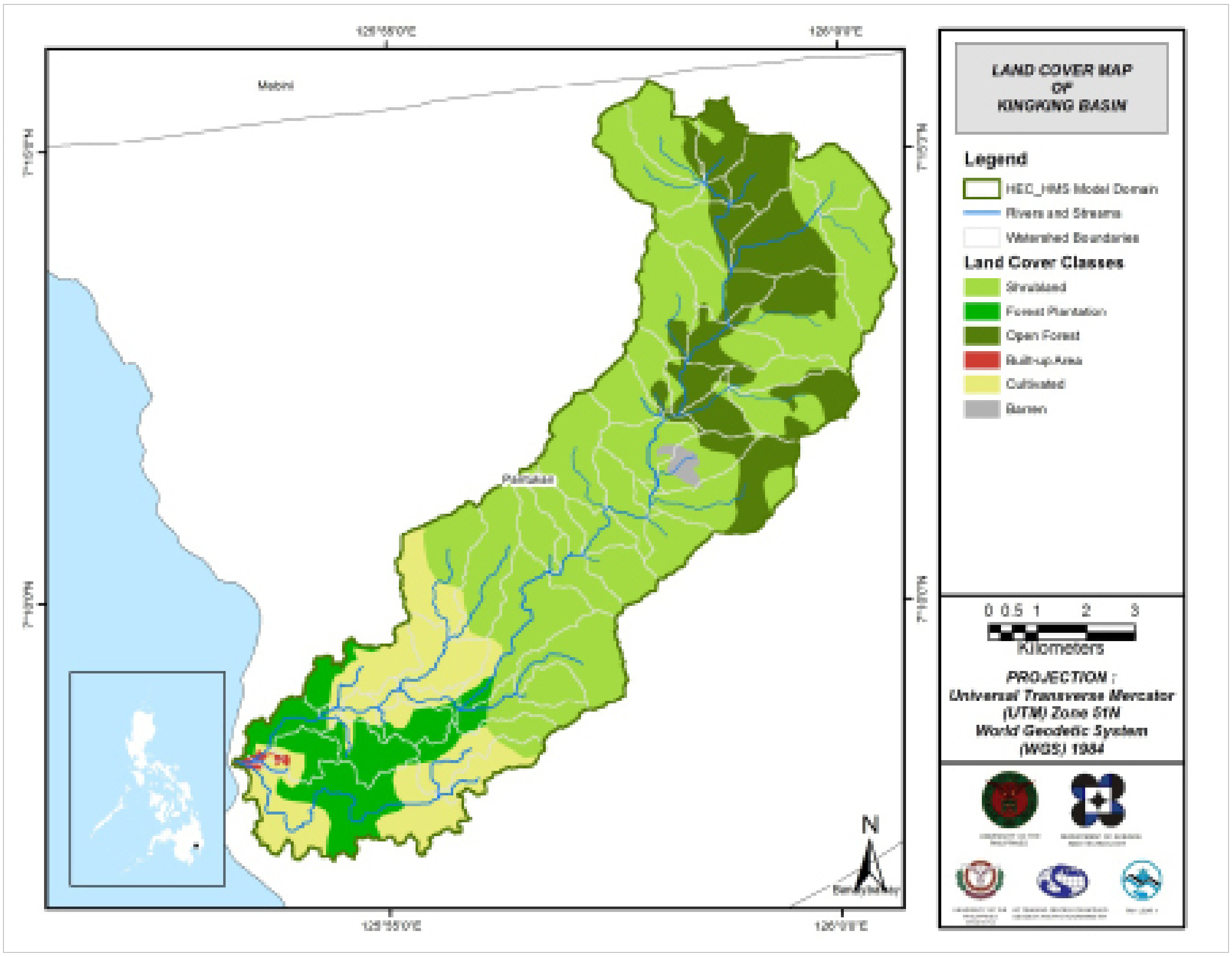


Figure 51. Land Cover Map of Kingking River Basin (Source: NAMRIA)

For Kingking, three (3) soil classes were identified. These are sandy clay loam, silty clay loam, and undifferentiated land. Moreover, six (6) land cover classes were identified. These are shrublands, forest plantations, open forest, built-up areas, cultivated areas, and barren land.

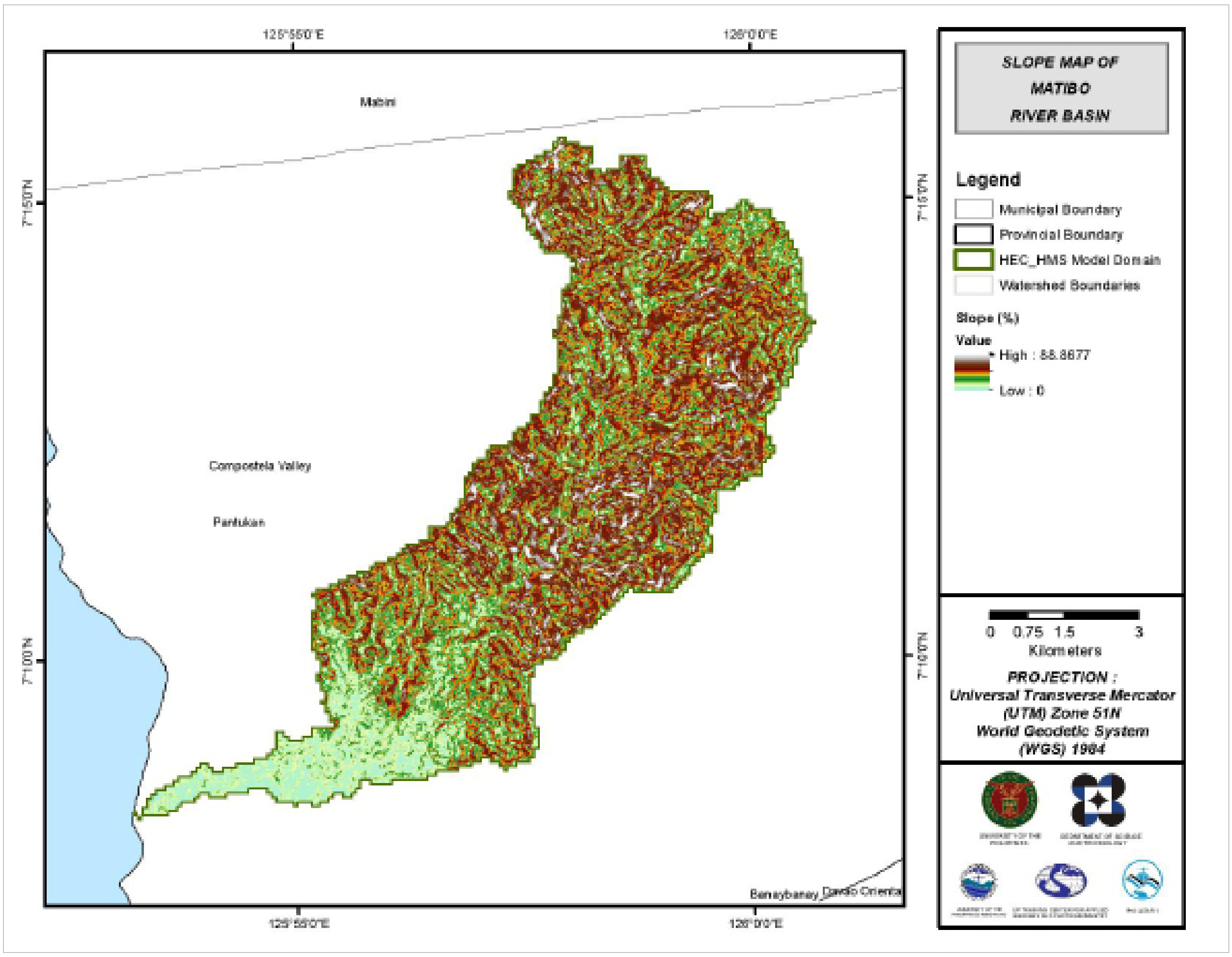


Figure 52. of Kingking River Basin

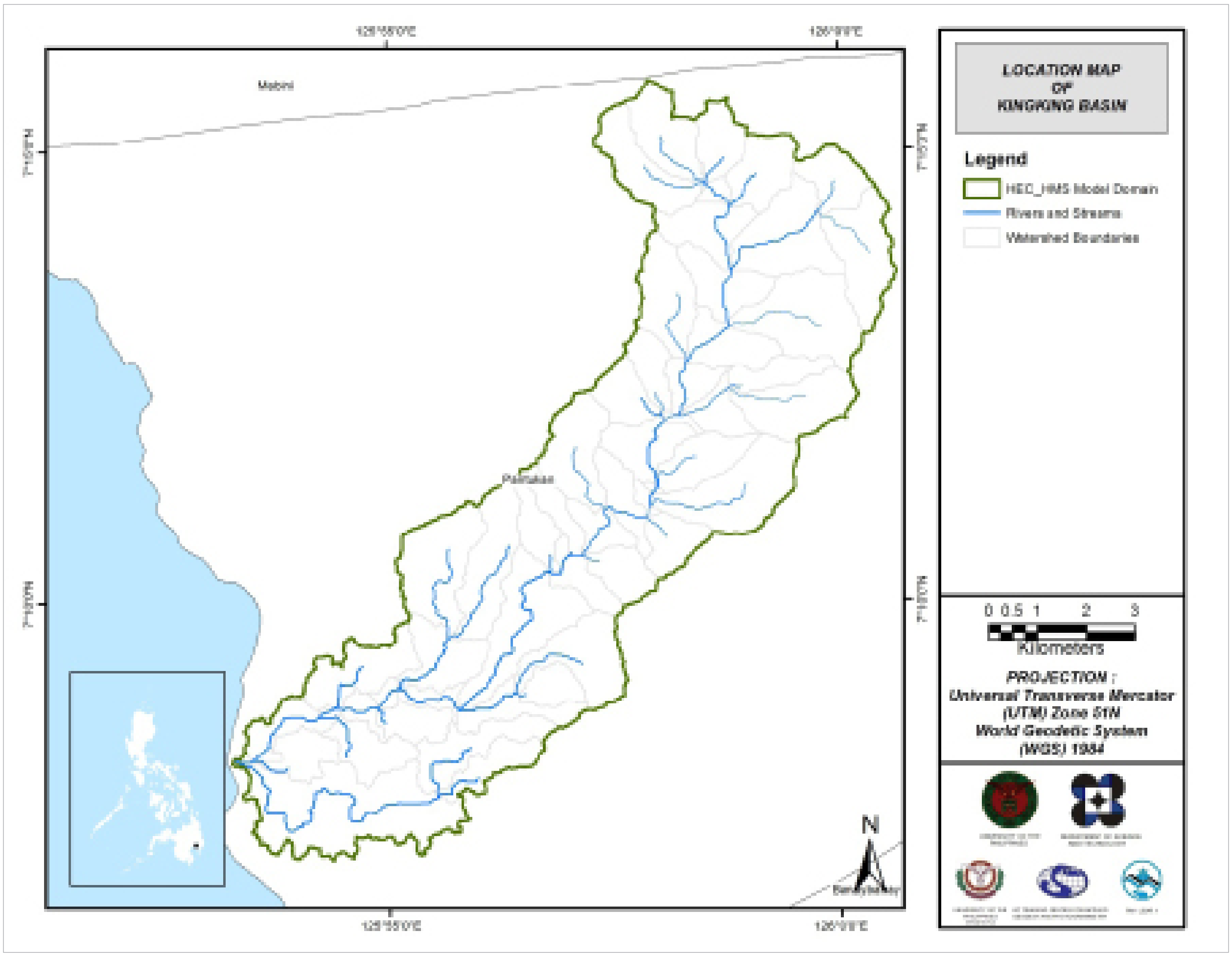


Figure 53. Stream Delineation Map of Kingking River Basin

Using the SAR-based DEM, the Kingking basin was delineated and further subdivided into sub basins. The model consists of fifty-seven (57) sub basins, twenty-eight (28) reaches, and twenty-eight (28) junctions, as shown in Figure 54. The main outlet is at the Musahamat Bridge. See ANNEX 10 for the Kingking Model Reach Parameters.

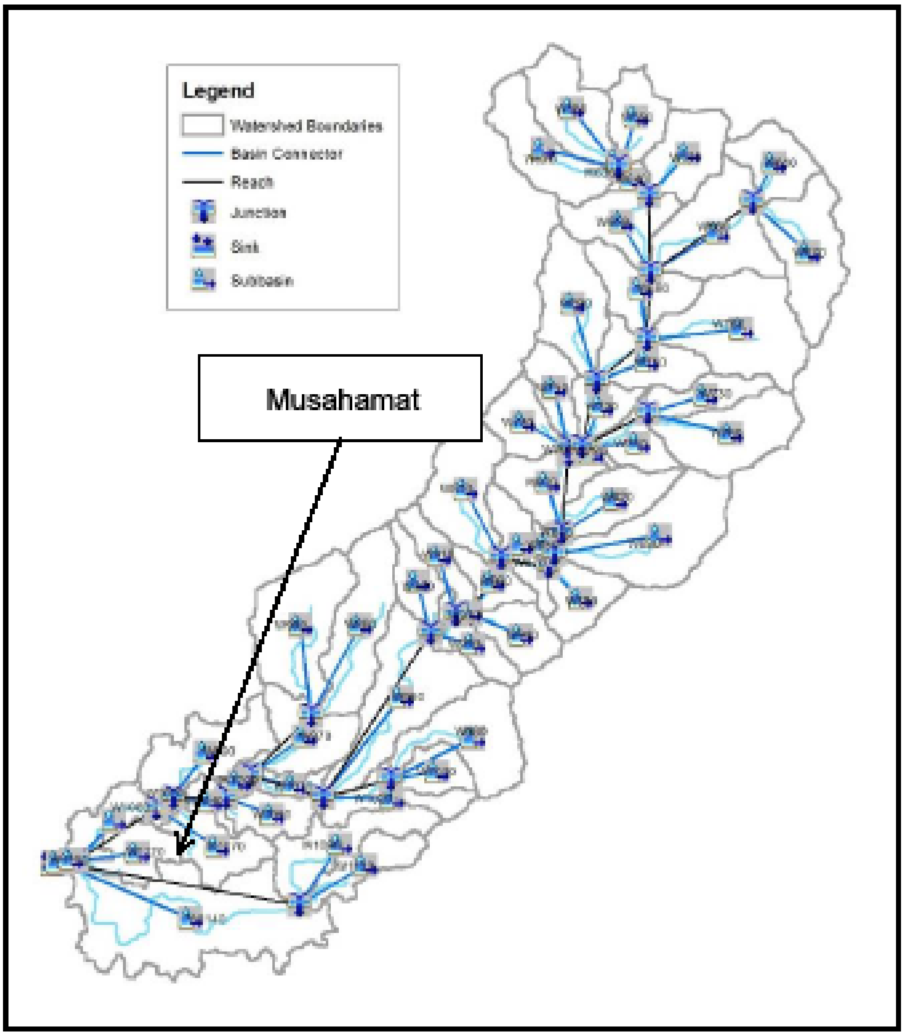


Figure 54. The Kingking river basin model generated using HEC-HMS.

5.4 Cross-section Data

Riverbed cross-sections of the watershed were necessary in the HEC-RAS model setup. 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 55).

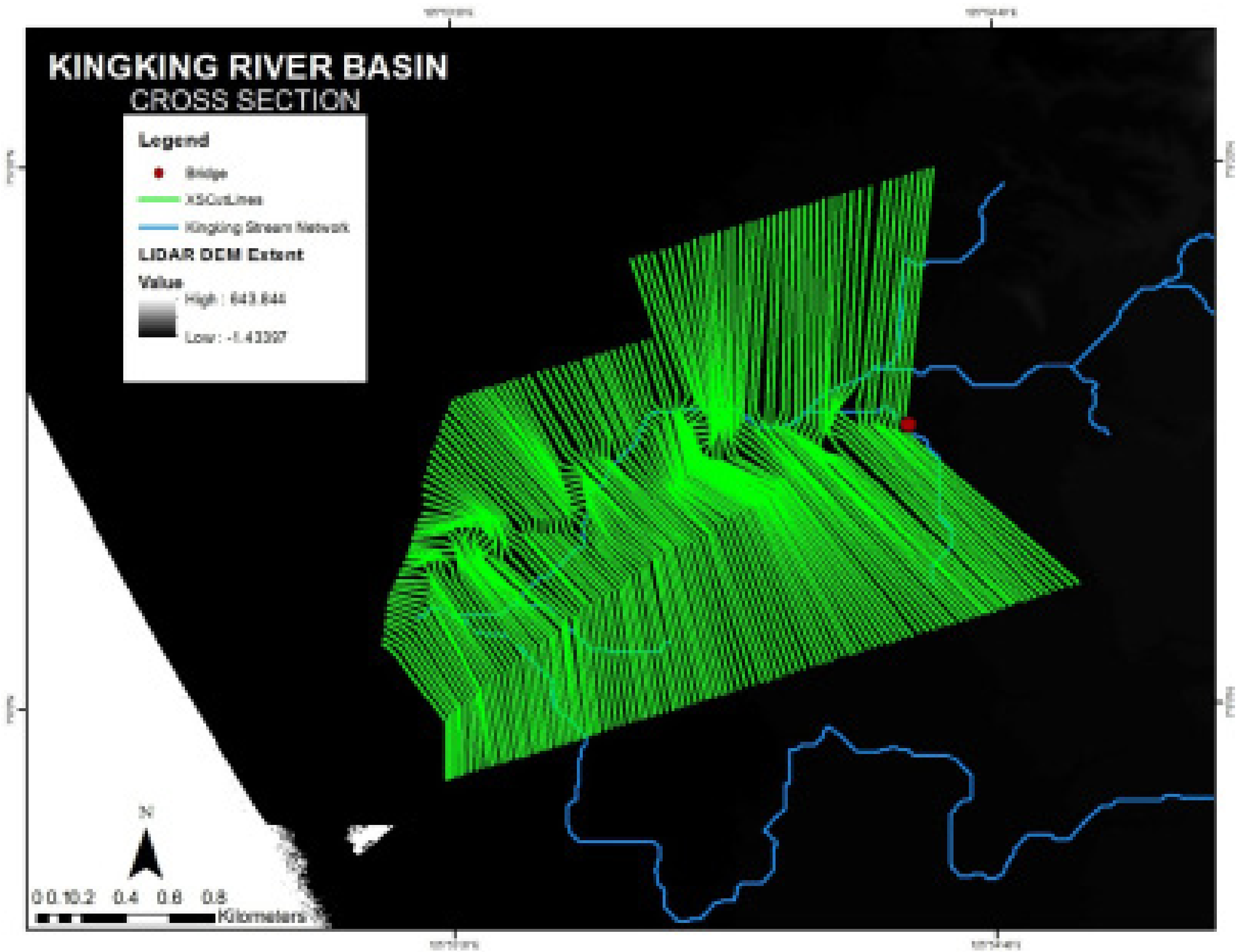


Figure 55. River cross-section of Kingking River generated through Arcmap HEC GeoRAS tool

5.5 Flo 2D Model

The automated modeling 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 was divided into square grid elements, 10 meters by 10 meters in size. Each element was assigned a unique grid element number which served as its identifier, then attributed with the parameters required for modeling, such as x- and y-coordinate of centroid, names of adjacent grid elements, Manning coefficient of roughness, infiltration, and elevation value. The elements were 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 northeast of the model to the southwest, following the main channel. As such, boundary elements in those particular regions of the model were assigned as inflow and outflow elements, respectively.

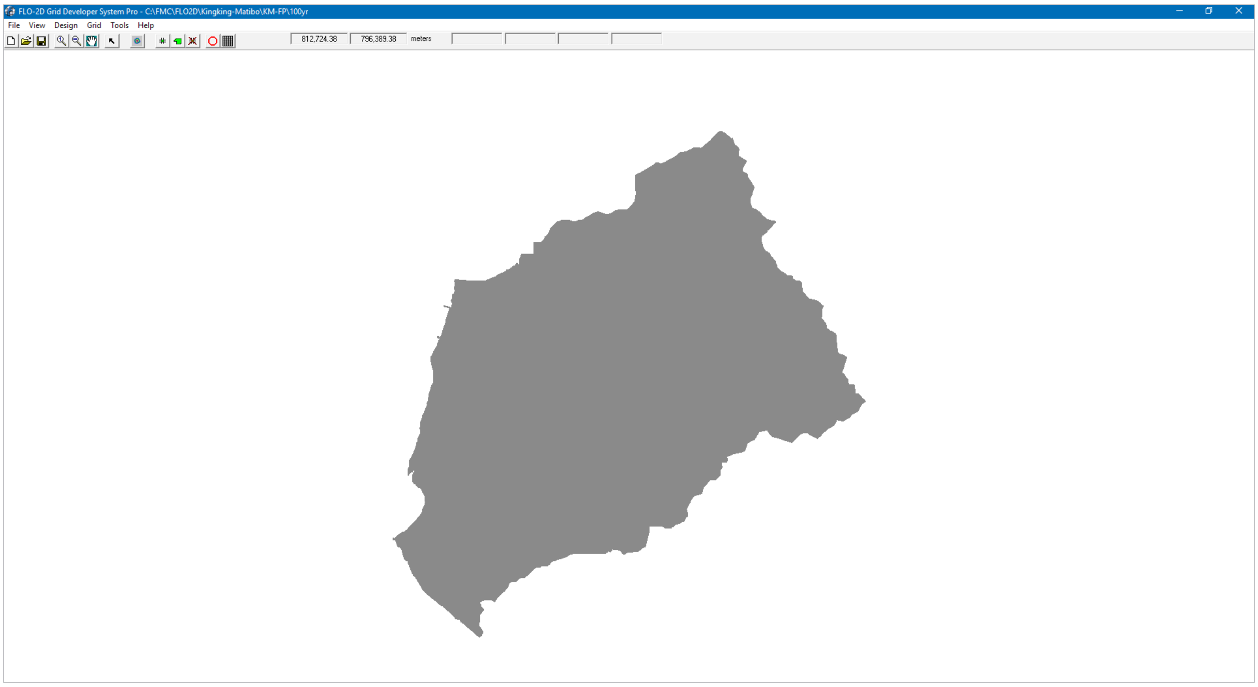


Figure 56. A screenshot of the river subcatchment with the computational area to be modeled in FLO-2D Grid Developer System Pro (FLO-2D GDS Pro)

The simulation was then run through FLO-2D GDS Pro. This particular model had a computer run time of 14.63965 hours. After the simulation, FLO-2D Mapper Pro was used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following flood hazard maps. Most of the default values given by FLO-2D Mapper Pro were used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m2/s. The generated hazard maps for Kingking are in Figures 60, 62, and 64.

The creation of a flood hazard map from the model also automatically creates a flow depth map, depicting the maximum amount of inundation for every grid element. The legend used by default in Flo-2D Mapper was not a good representation of the range of flood inundation values, so a different legend was used for the layout. In this particular model, the inundated parts cover a maximum land area of 31 937 500.00 m2. The generated flood depth maps for Kingking are in Figures 61, 63, and 65.

There is a total of 29 725 237.25 m3 of water entering the model. Of this amount, 12 597 244.33 m3 is due to rainfall, while 17 127 992.92 m3 is inflow from other areas outside the model. 3 644 297.00 m3 of this water is lost to infiltration and interception, while 2 243 397.38 m3 is stored by the flood plain. The rest, amounting to up to 23 837 542.97 m3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Kingking HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 57 shows the comparison between the two discharge data. See ANNEX 9 for the Kingking Model Basin Parameters.

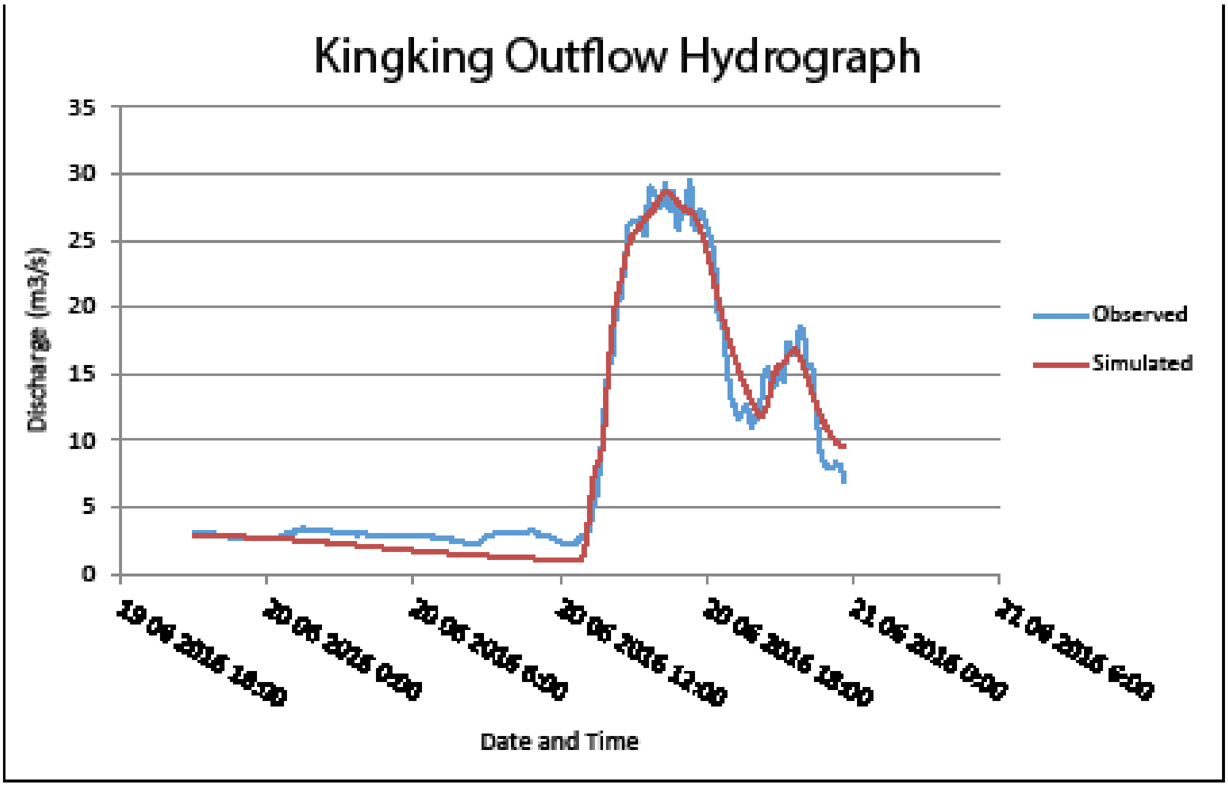


Figure 57. Outflow Hydrograph of Kingking produced by the HEC-HMS model compared with observed outflow

Enumerated in Table 26 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 26. Range of Calibrated Values for Kingking

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve Number	Initial Abstraction (mm)	0.001 – 74.94
			Curve Number	35 – 99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.0167 – 2.064
			Storage Coefficient (hr)	0.068 – 6.65
	Baseflow	Recession	Recession Constant	0.0002 – 0.254
			Ratio to Peak	0.00028 – 0.38
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.017 – 0.408

Initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as initial abstraction decreases. The range of values from 0.001 mm to 74.94 mm means that the amount of infiltration, or rainfall interception by vegetation all over the basin, varies greatly.

The 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 the curve number increases. The range of 65 to 90 for the curve number is advisable for Philippine watersheds depending on the soil and land cover of the area (M. Horritt, personal communication, 2012). For Kingking, the basin consists mainly of shrublands and cultivated lands; and the soil consists of mostly undifferentiated land, clay loam, and silt loam.

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 0.0167 hours to 6.65 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events; and ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant values within the range of 0.0002 to 0.254 indicate that the basin is likely to quickly go back to its original discharge. Values of ratio to peak within the range of 0.00028 to 0.38 indicate a much steeper receding limb of the outflow hydrograph.

Manning’s roughness coefficients correspond to the common roughness of Philippine watersheds. The Kingking River Basin reaches’ Manning’s coefficients range from 0.017 to 0.408, showing that there is variety in surface roughness all over the catchment (Brunner, 2010).

Table 27. Summary of the Efficiency Test of Kingking HMS Model

RMSE	1.4
r^2	0.98
NSE	0.98
PBIAS	4.46
RSR	0.16

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 1.4 m^3/s.

The Pearson correlation coefficient (r^2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured at 0.98.

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 0.98.

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 4.46.

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 are quantified. The model has an RSR value of 0.16.

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

5.7.1 Hydrograph using the Rainfall Runoff Model

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

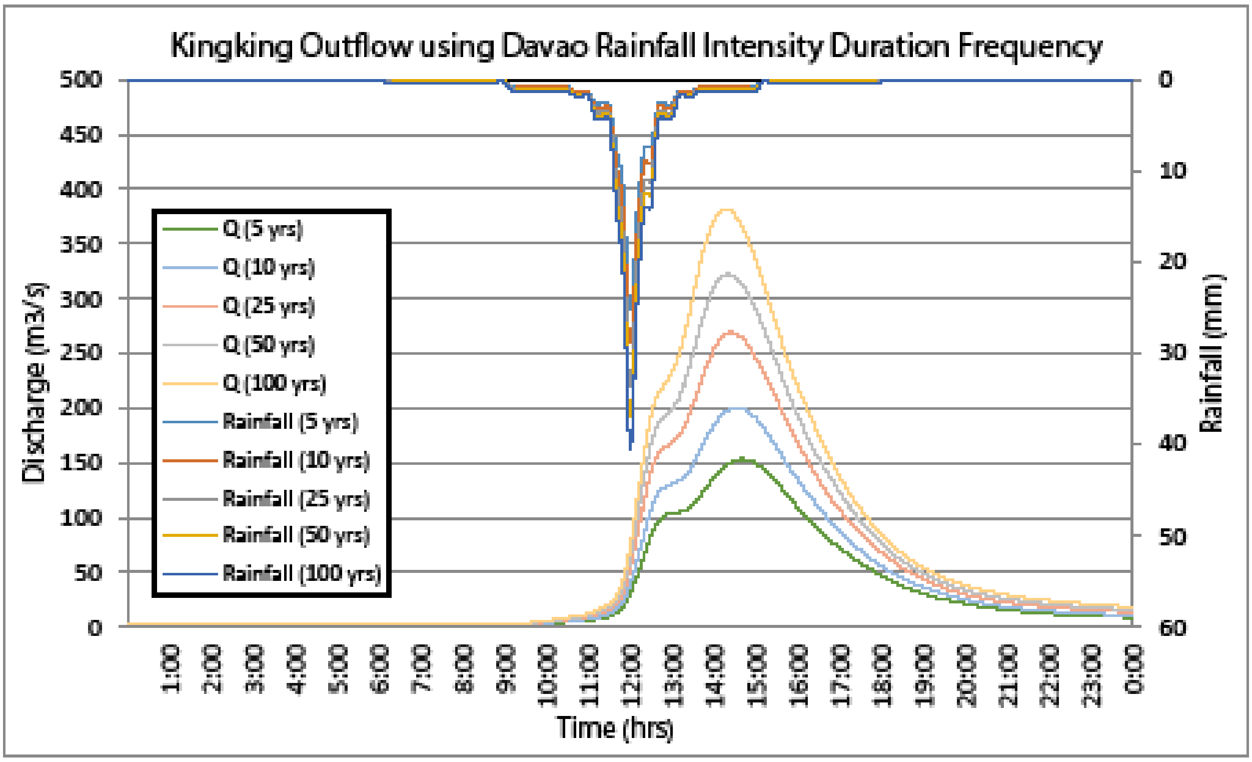


Figure 58. Outflow hydrograph at Kingking Station generated using the Davao RIDF simulated in HEC-HMS.

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of the Kingking discharge using the Davao RIDF in five (5) different return periods is shown in Table 28.

Table 28. Peak values of the Kingking HEC-HMS Model outflow using the Davao RIDF

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m3/s)	Time to Peak
5-Year	121.1	25.1	153.1	2 hours, 40 minutes
10-Year	140.7	28.8	200.7	2 hours, 30 minutes
25-Year	165.5	33.5	268.6	2 hours, 30 minutes
50-Year	183.9	37	322.7	2 hours, 20 minutes
100-Year	202.1	40.5	381.5	2 hours, 20 minutes

5.8 River Analysis (RAS) 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 is presented. The sample generated map of the Kingking River using the calibrated HMS base flow is shown in Figure 59.

Figure 59. Sample output of Kingking RAS Model

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. The 5-, 25-, and 100-year rain return scenarios of the Kingking floodplain are shown in Figures 60 to 65. The floodplain, with an area of 31.94 sq. km., covers only part of the municipality of Pantukan, Compostela Valley. Table 29 shows the percentage of area affected by flooding per municipality.

Table 29. Municipalities affected in Kingking floodplain

Province	Municipality	Total Area	Area Flooded	% Flooded
Compostela Valley	Pantukan	581.33	31.86	5.48%

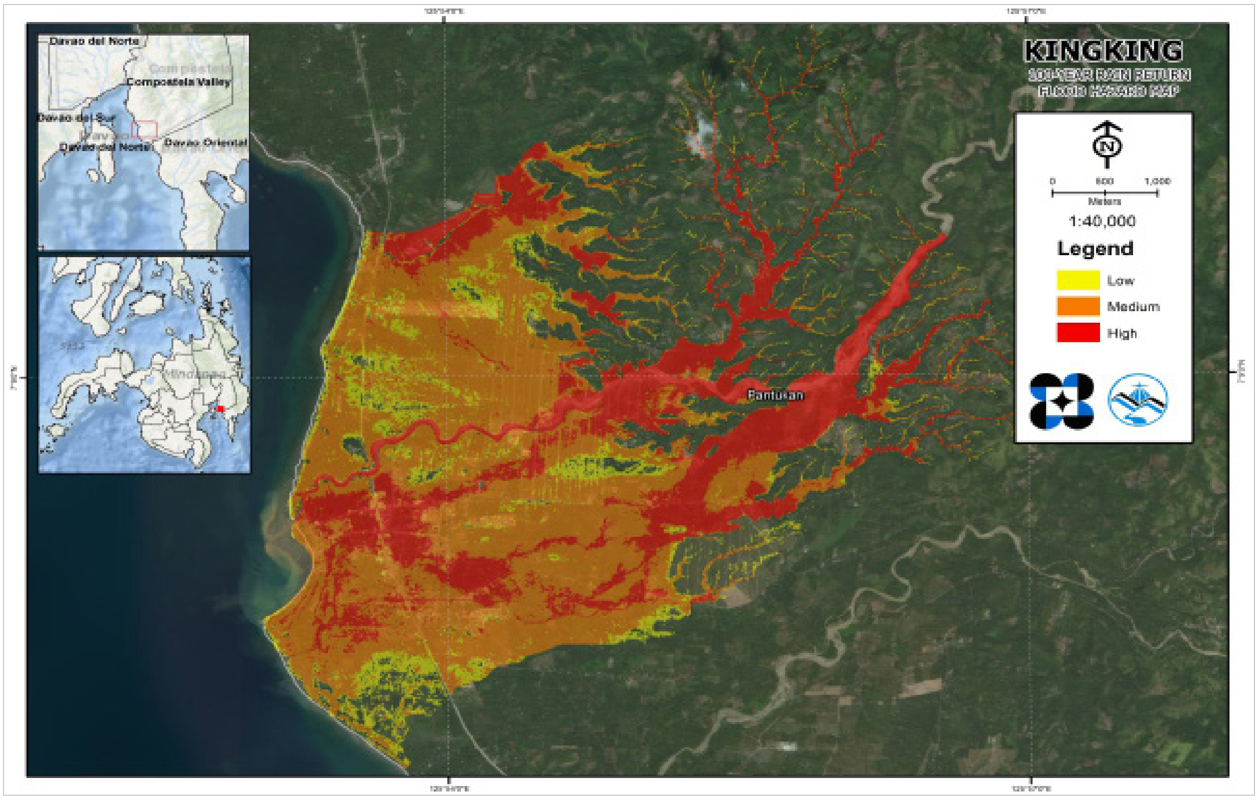


Figure 60. 100-year Flood Hazard Map for Kingking Floodplain overlaid on Google Earth imagery

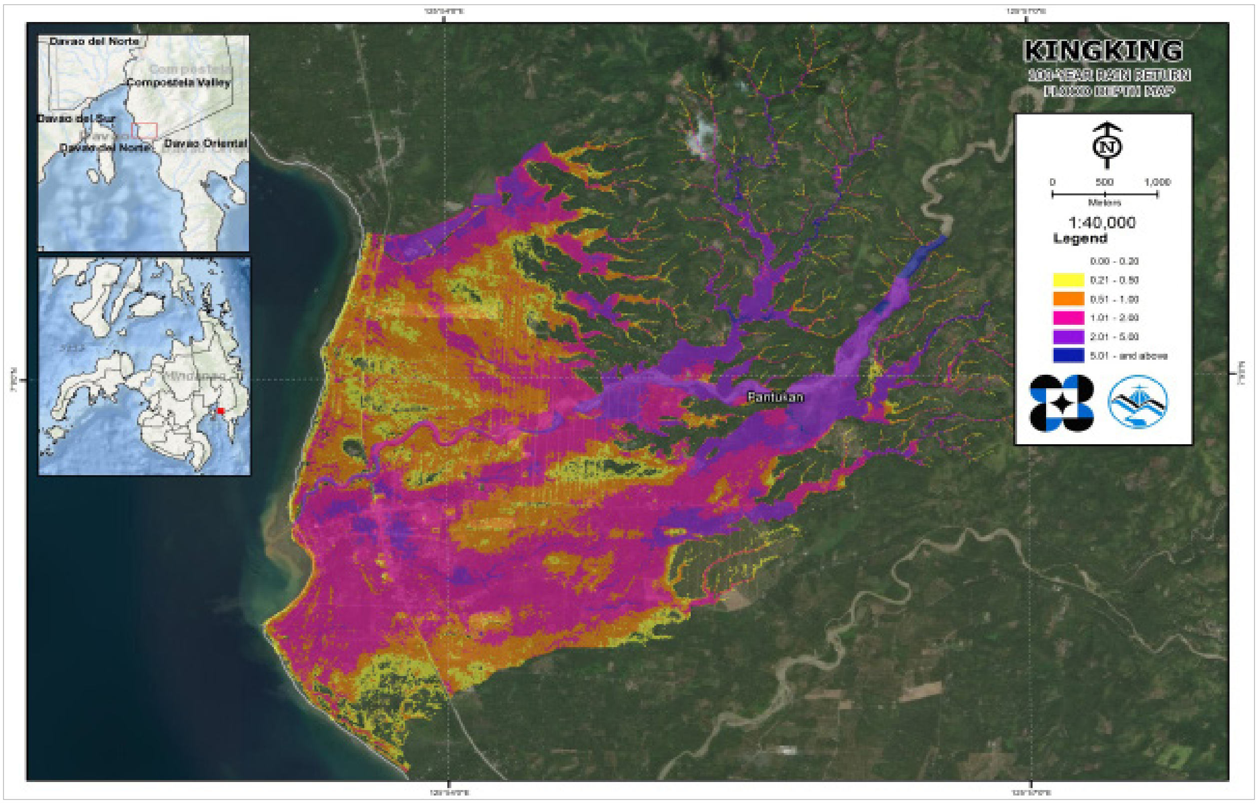


Figure 61. 100-year Flow Depth Map for Kingking Floodplain overlaid on Google Earth imagery

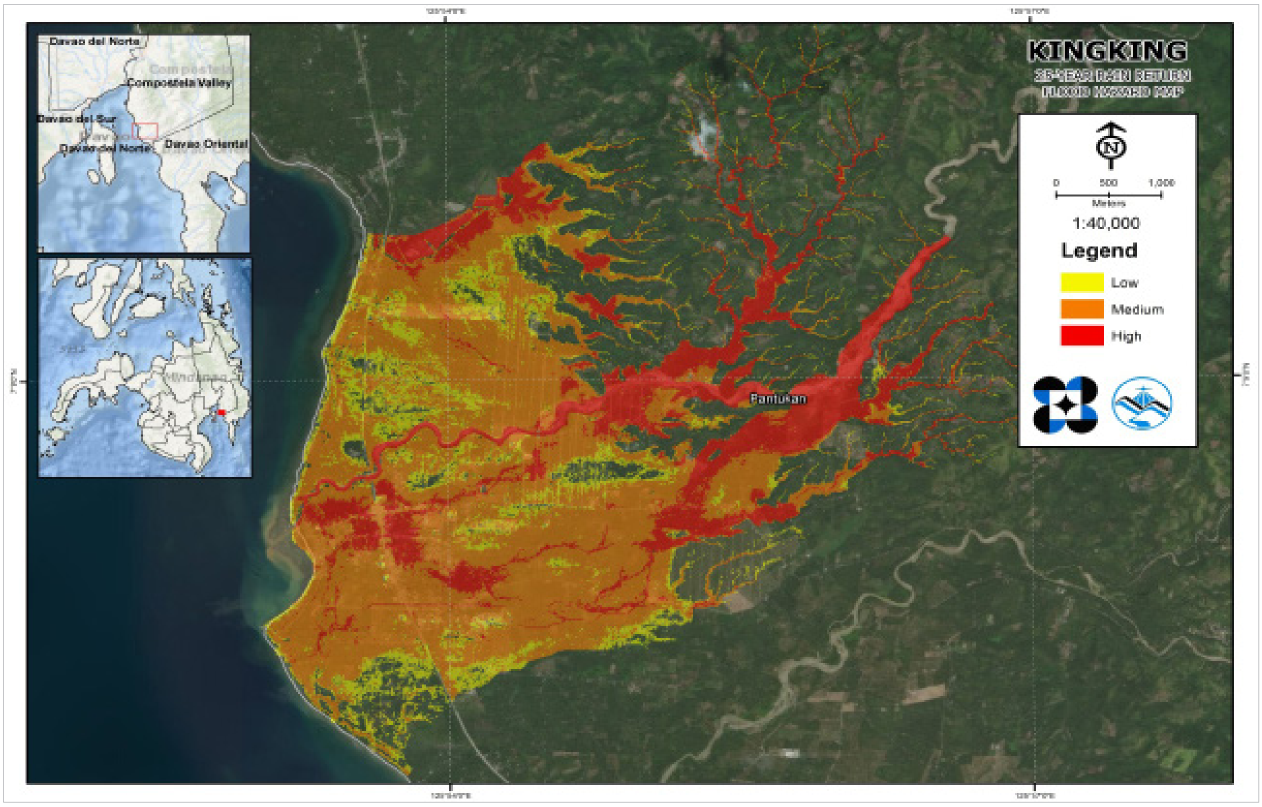


Figure 62. 25-year Flood Hazard Map for Kingking Floodplain overlaid on Google Earth

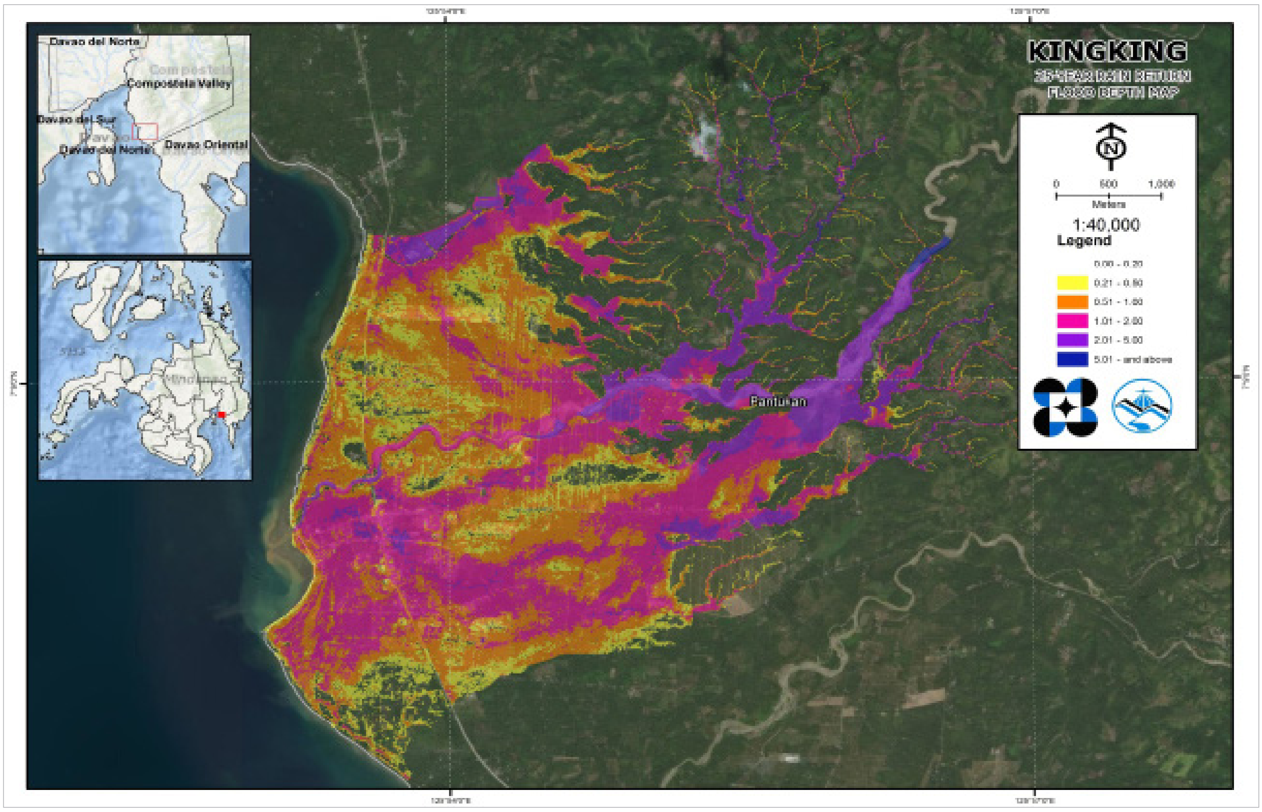


Figure 63. 25-year Flow Depth Map for Kingking Floodplain overlaid on Google Earth imagery

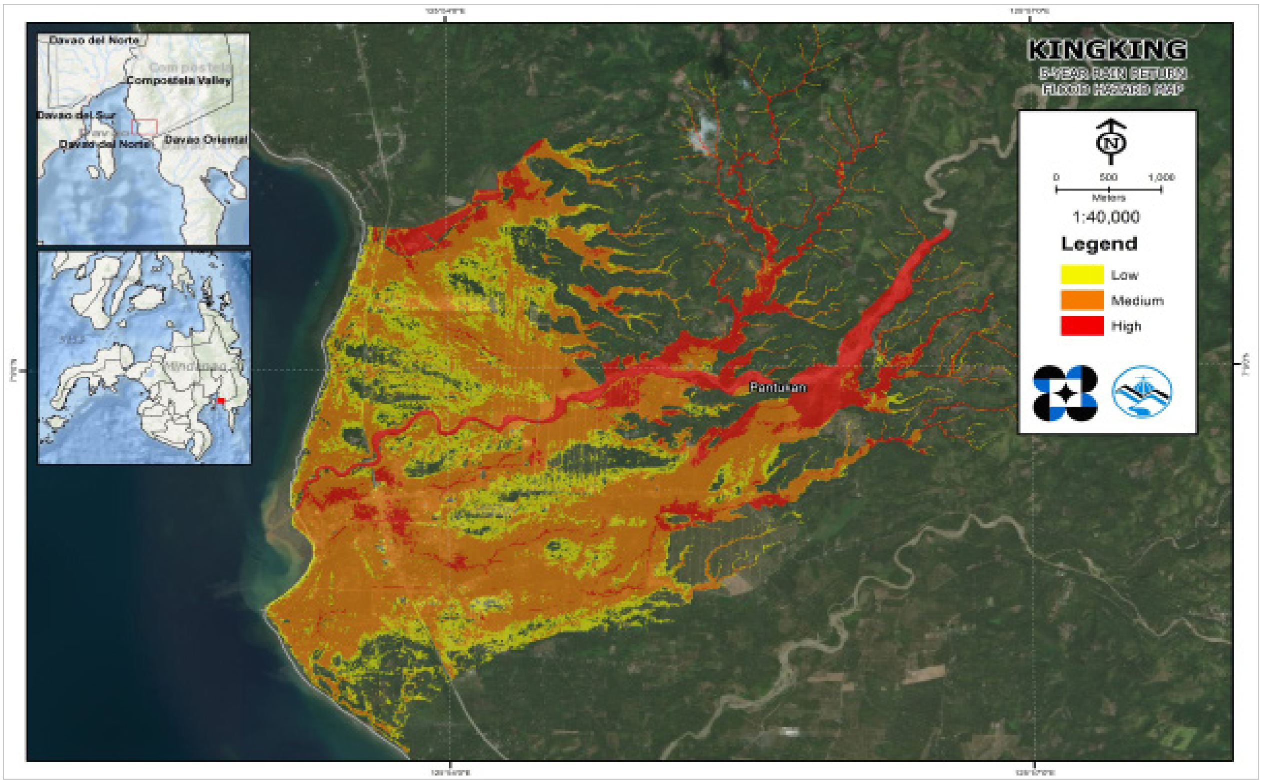


Figure 64. 5-year Flood Hazard Map for Kingking Floodplain overlaid on Google Earth imagery

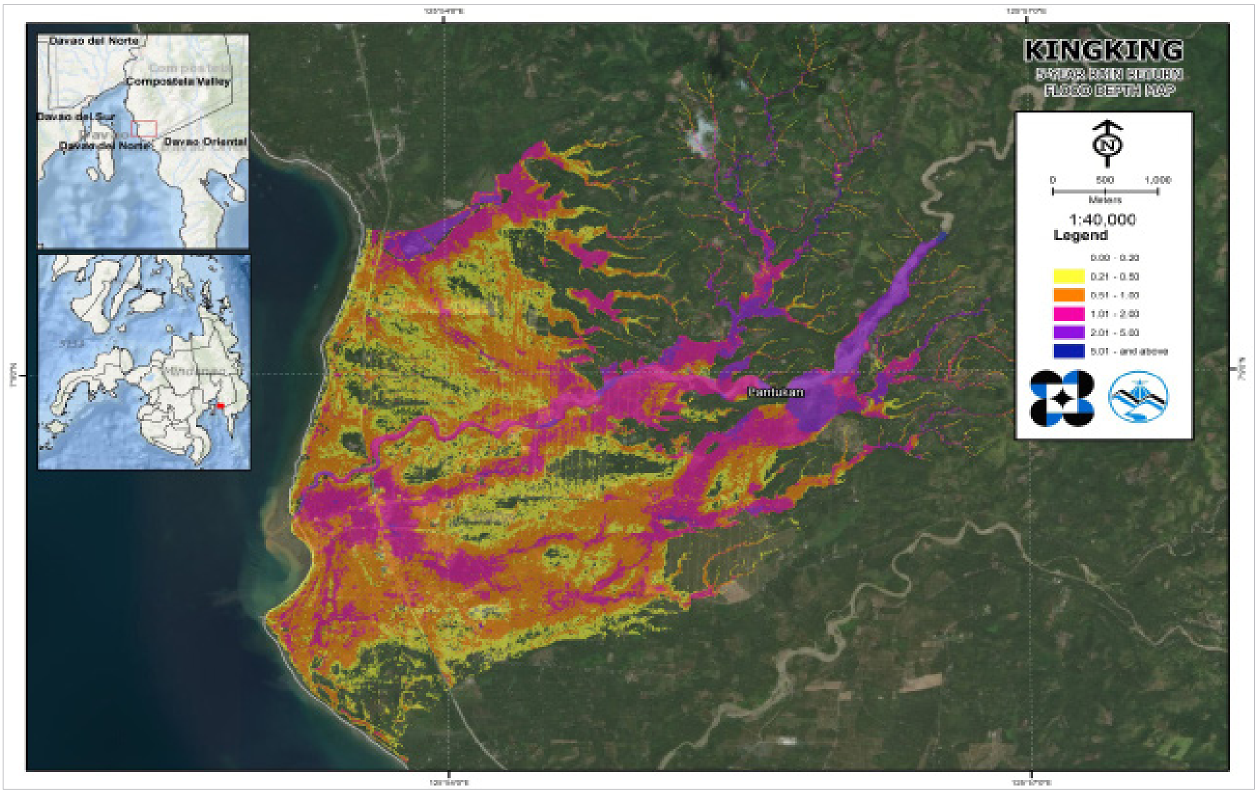


Figure 65. 5-year Flow Depth Map for Kingking Floodplain overlaid on Google Earth imagery

5.10 Inventory of Areas Exposed to Flooding

Affected barangays in the Kingking River Basin, grouped by municipality, are listed below. For the said basin, only the municipality of Pantukan in the province of Compostela Valley, consisting of three (3) barangays, is expected to experience flooding when subjected to 5-year rainfall return period.

For the 5-year return period, 2.59% of the municipality of Pantukan, with an area of 581.33 sq. km., will experience flood levels of less than 0.20 meters. 0.79% of the area will experience flood levels of 0.21 to 0.50 meters; while 1.14%, 0.75%, and 0.22% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, and 2.01 to 5 meters, respectively. Listed in Table 30 are the affected areas, in square kilometers, by flood depth per barangay.

Table 30. Affected Areas in Pantukan, Compostela Valley during 5-Year Rainfall Return Period

Affected area (sq. km.) By flood depth (in m.)	Area of affected barangays in Pantukan (in sq. km)		
	Bongbong	Kingking	Magnaga
0-0.20	0.75	12.41	1.88
0.21-0.50	0.29	4.2	0.072
0.51-1.00	0.17	6.37	0.069
1.01-2.00	0.018	4.23	0.088
2.01-5.00	0	1.27	0.013
> 5.00	0	0.027	0.0013

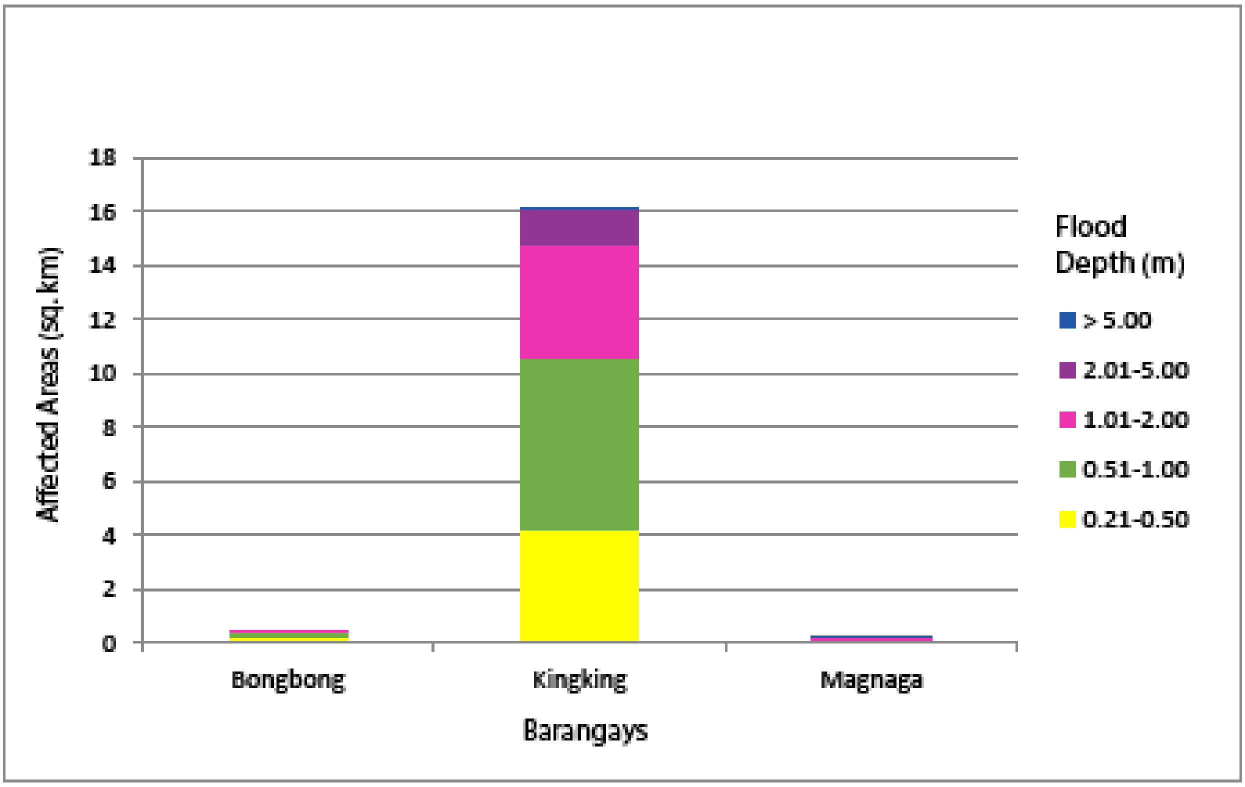


Figure 66. Affected Areas in Pantukan, Compostela Valley during 5-Year Rainfall Return Period

For the 25-year return period, 2.33% of the municipality of Pantukan, with an area of 581.33 sq. km., will experience flood levels of less than 0.20 meters. 0.55% of the area will experience flood levels of 0.21 to 0.50 meters; while 1.08%, 1.10%, 0.41%, and 0.01% 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 Pantukan, Compostela Valley during 25-Year Rainfall Return Period

Affected area (sq. km.) By flood depth (in m.)	Area of affected barangays in Pantukan (in sq. km)		
	Bongbong	Kingking	Magnaga
0-0.20	0.54	11.13	1.86
0.21-0.50	0.41	2.69	0.07
0.51-1.00	0.22	6.02	0.066
1.01-2.00	0.064	6.25	0.09
2.01-5.00	0	2.34	0.038
> 5.00	0	0.073	0.0027

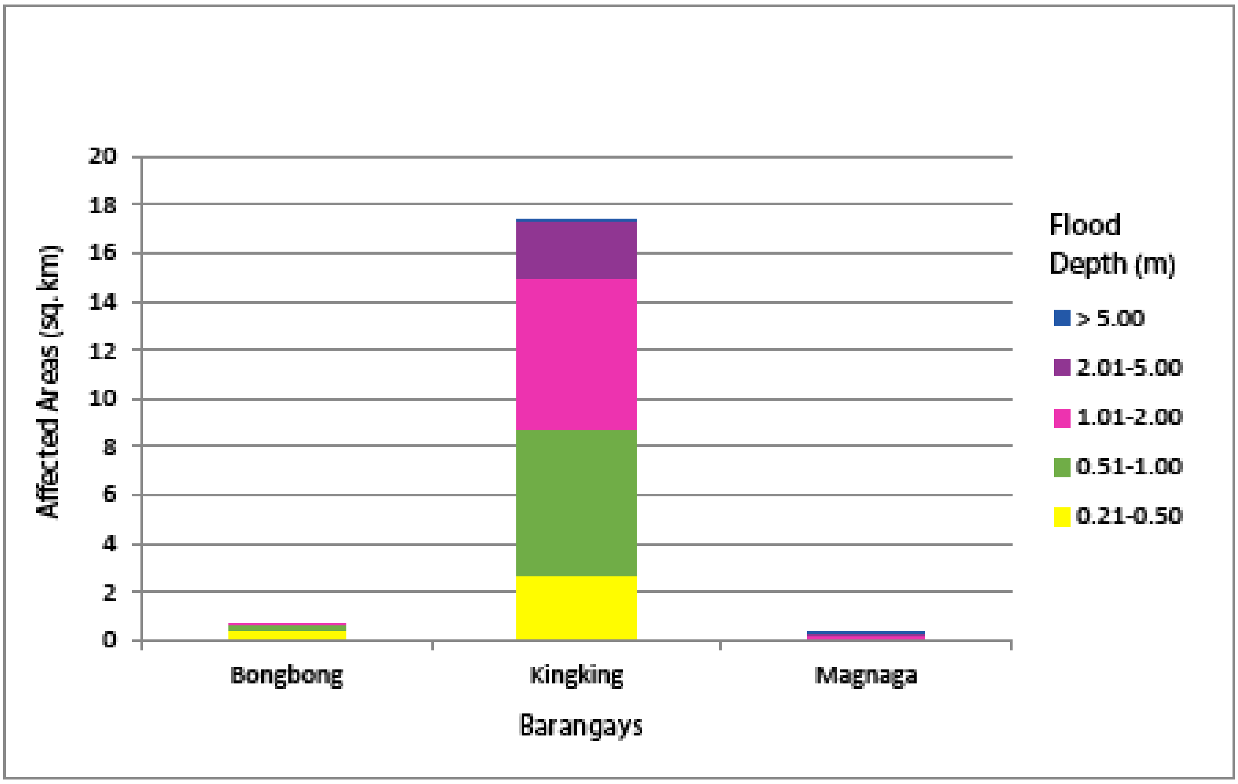


Figure 67. Affected Areas in Pantukan, Compostela Valleyduring 25-Year Rainfall Return Period

For the 100-year return period, 2.21% of the municipality of Pantukan, with an area of 581.33 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 0.99%, 1.29%, 0.53%, and 0.03% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 32 are the affected areas, in square kilometers, by flood depth per barangay.

Table 32. Affected Areas in Pantukan, Compostela Valley during 100-Year Rainfall Return Period

Affected area (sq. km.) By flood depth (in m.)	Area of affected barangays in Pantukan (in sq. km)		
	Bongbong	Kingking	Magnaga
0-0.20	0.39	10.63	1.84
0.21-0.50	0.44	1.99	0.067
0.51-1.00	0.28	5.4	0.068
1.01-2.00	0.13	7.3	0.087
2.01-5.00	0	3.04	0.056
> 5.00	0	0.15	0.0038

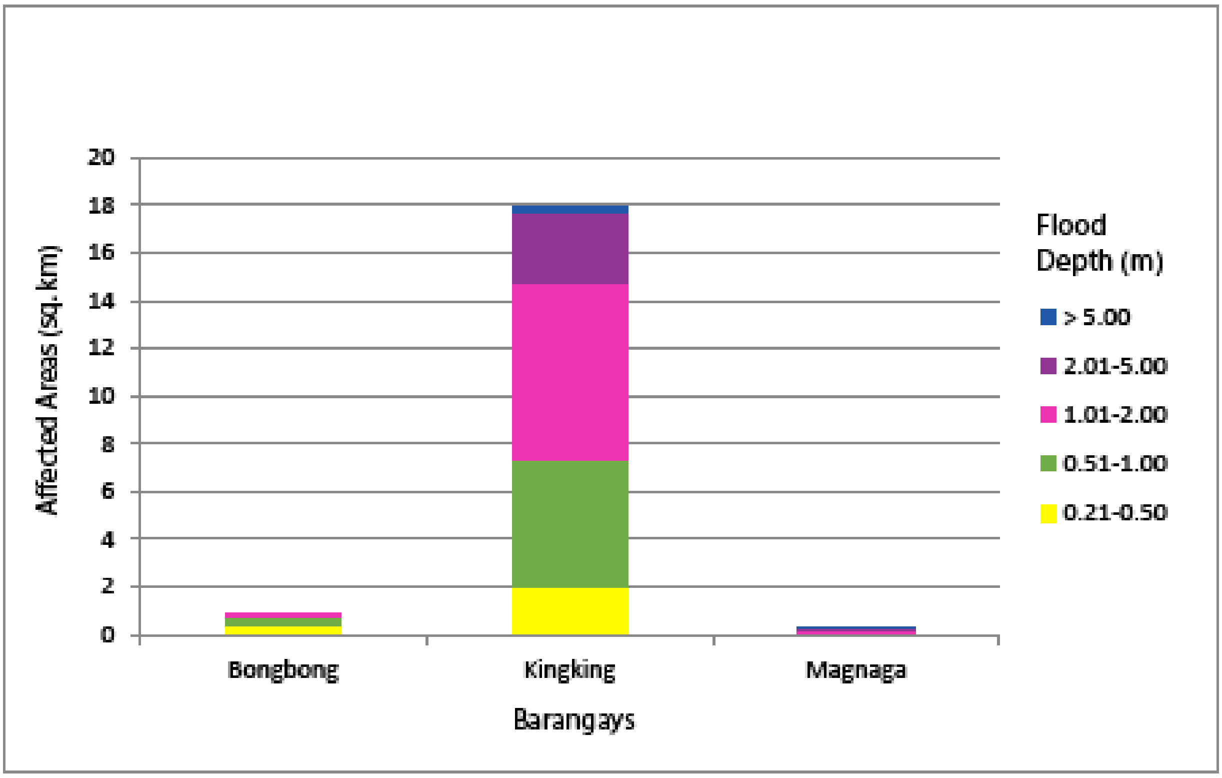


Figure 68. Affected Areas in Pantukan, Compostela Valley during 100-Year Rainfall Return Period

Among the barangays in the municipality of Pantukan in Compostela Valley, Kingking is projected to have the highest percentage of area that will experience flood levels at 4.90%. Meanwhile, Magnaga posted the second highest percentage of area that may be affected by flood depths at 0.37%.

The generated flood hazard maps for the Kingking Floodplain were also used to assess the vulnerability of the educational and medical institutions in the floodplain. ANNEX 12 and ANNEX 13 present the educational and health institutions exposed to flooding, respectively. 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-yr, 25-yr, and 100-yr).

Table 33. Areas covered by each warning level with respect to the rainfall scenario

Warning Level	Area Covered in sq. km		
	5 year	25 year	100 year
Low	4.56	3.14	2.46
Medium	9.59	10.66	10.48
High	2.85	4.67	6.18

Of the eighteen (18) identified educational institutions in the Kingking Floodplain, two (2) schools were assessed to be relatively prone to flooding, as they are exposed to High-level flooding for all three rainfall scenarios. These are the Doroteo Day Care Center and Tugop Daycare Center in Barangay Kingking. Another school was found to be also susceptible to flooding, assessed to experience Medium-level flooding in the 5-year return period, and High-level flooding in the 25- and 100-year rainfall scenarios.

Five (5) medical institutions were identified in the Kingking floodplain. The Kingking Health Center in Barangay Kingking was found to be relatively prone to flooding, assessed to experience Medium-level flooding in the 5- and 25-year rainfall scenarios, and High-level flooding in the 100-year return period.

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 occurrences in the respective areas within the major river systems in the Philippines.

From the flood depth maps produced by the 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 the river basin and gathered data on the actual flood level in each location. Data gathering was conducted through assistance from a local DRRM office to obtain maps or situation reports about the past flooding events, or through interviews with some residents with knowledge or experience of flooding in the 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 the results of the flood map. The points in the flood map versus the corresponding validation depths are illustrated in Figure 70.

The flood validation survey was conducted on October 3-6, 2016. The flood validation consists of 180 points randomly selected all over the Kingking Floodplain. It has an RMSE value of 0.99. Table 34 shows a contingency matrix of the comparison. The validation points are found in ANNEX 11.

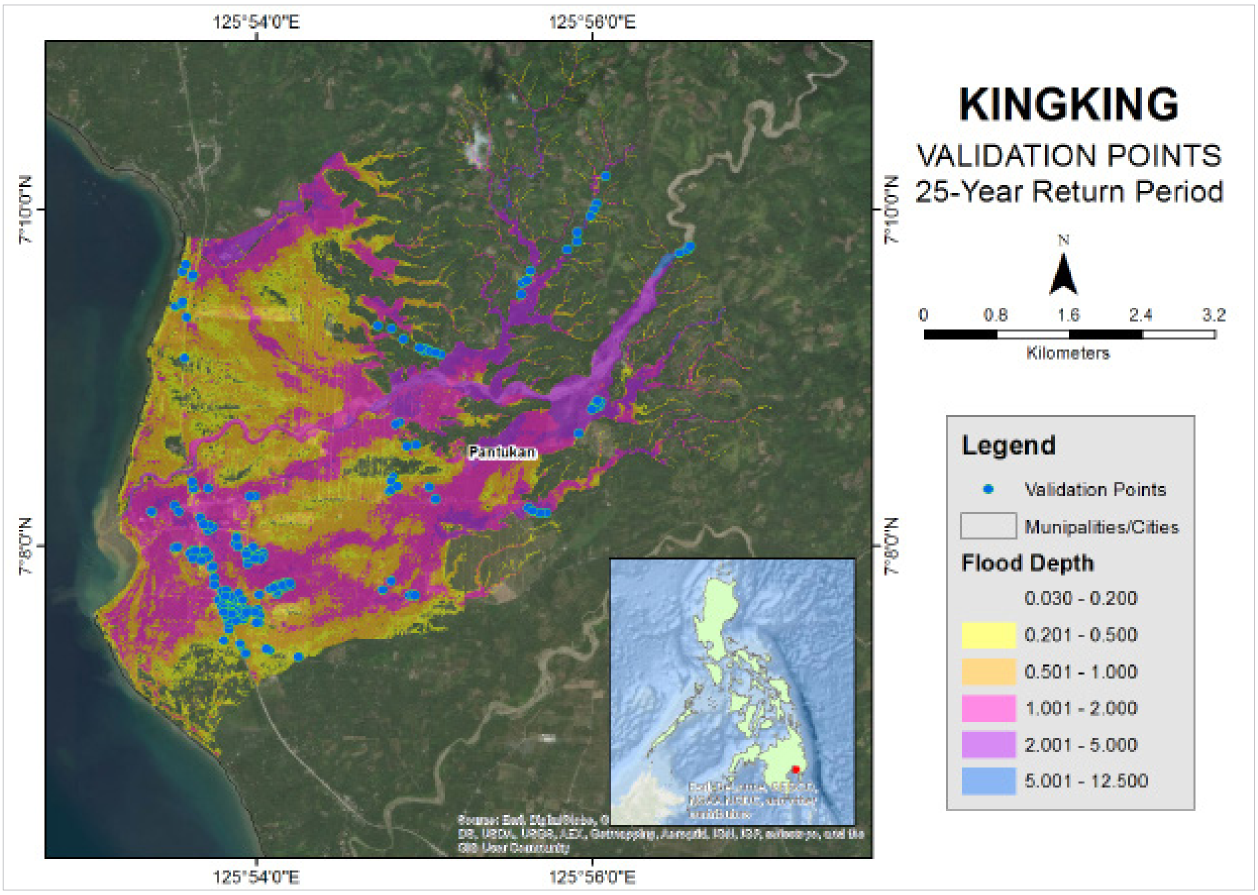


Figure 69. Flood Validation Points of Kingking River Basin

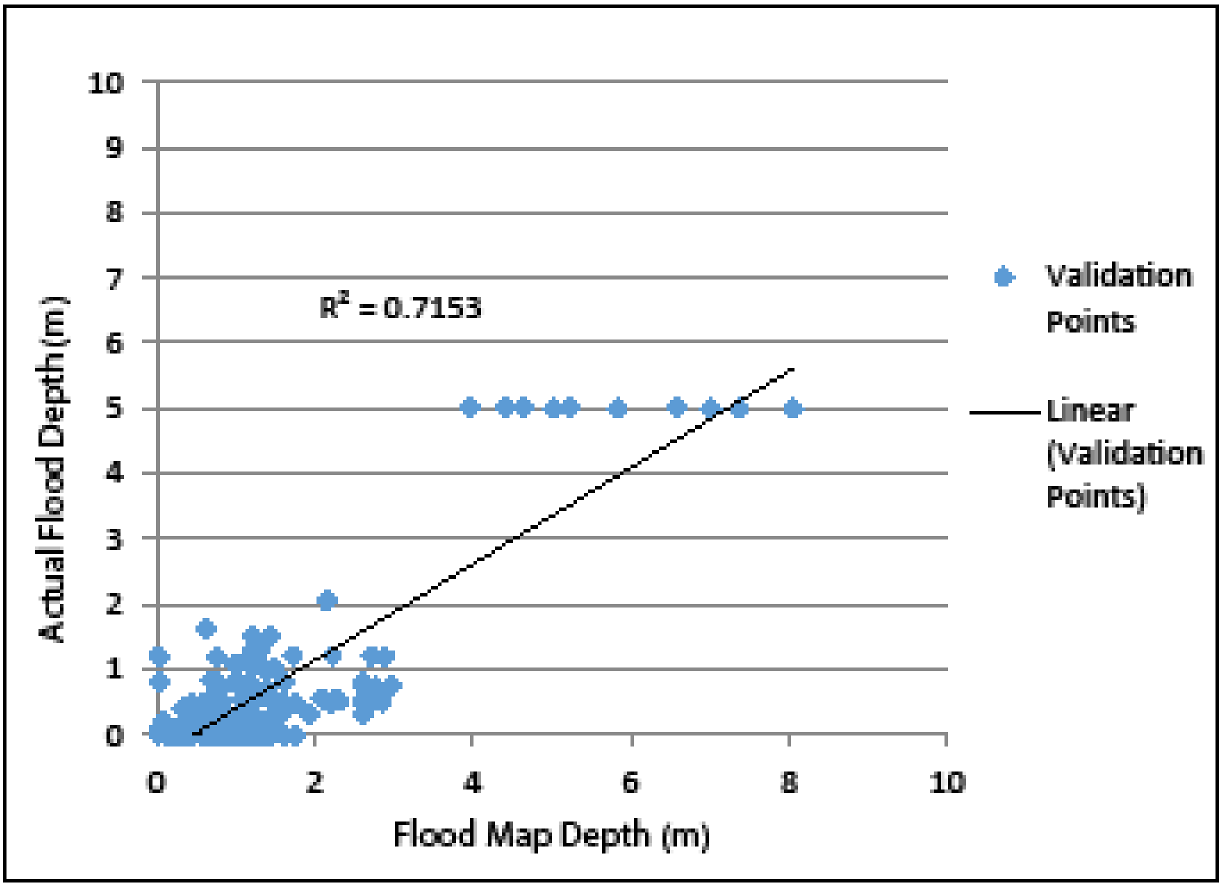


Figure 70. Flood Map Depth vs Actual Flood Depth for Kingking

Table 34. Actual Flood Depth vs Simulated Flood Depth in Kingking

KINGKING BASIN		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
Actual Flood Depth (m)	0-0.20	13	10	33	33	0	0	89
	0.21-0.50	0	4	18	10	5	0	37
	0.51-1.00	1	0	5	10	9	0	25
	1.01-2.00	1	0	3	11	3	0	18
	2.01-5.00	0	0	0	0	4	7	11
	> 5.00	0	0	0	0	0	0	0
	Total	15	14	59	64	21	7	180

The overall accuracy generated by the flood model is estimated at 20.56%, with thirty-seven (37) points correctly matching the actual flood depths. In addition, there were fifty-one (51) points estimated one level above and below the correct flood depths; while there were fifty-three (53) points and thirty-nine (39) points estimated two (2) levels above and below, and three (3) or more levels above and below the correct flood depth, respectively. A total of one hundred and thirty-eight (138) points were overestimated, while a total of five (5) points were underestimated in the modeled flood depths of Kingking.

Table 35. Summary of Accuracy Assessment in Kingking

	No. of Points	%
Correct	37	20.56
Overestimated	138	76.67
Underestimated	5	2.78
Total	**180**	**100**

REFERENCES

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

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

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

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

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

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

ANNEX

Annex 1. Technical Specifications of the Gemini LiDAR Sensor used in the Kingking Floodplain Survey

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

Annex 2. NAMRIA Certification of Reference Points used in the LiDAR Survey

1. COV-15

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

July 11, 2014

CERTIFICATION

To whom it may concern:

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

Province: **COMPOSTELA VALLEY**
Station Name: **COV-15**
Order: **2nd**

Island: **MINDANAO**		Barangay: **TIBAGON**
Municipality: **PANTUKAN**		MSL Elevation:
	PRS92 Coordinates	
Latitude: **7° 13' 59.42928"**	Longitude: **125° 51' 41.37238"**	Ellipsoidal Hgt: **0.61200 m.**
	WGS84 Coordinates	
Latitude: **7° 13' 56.28729"**	Longitude: **125° 51' 46.87850"**	Ellipsoidal Hgt: **73.68800 m.**
	PTM / PRS92 Coordinates	
Northing: **799845.036 m.**	Easting: **595142.582 m.**	Zone: **5**
	UTM / PRS92 Coordinates	
Northing:	Easting:	Zone:

Location Description

COV-15
"COV-15" is in Barangay Tibagon, Pantukan, Compostela Valley. To reach the station travel for about 500 m. from Pantukan towards Tibagon taking the National Highway until reaching the Tibagon Elem. School. Mark is the head of 4" copper nail embedded in a 0.30 x 0.30 x 1.0 m. concrete monument with inscription "COV-15 2007 NAMRIA".

Requesting Party: **UP TCAGP / Engr. Christopher Cruz**
Pupose: **Reference**
OR Number: **8796507 A**
T.N.: **2014-1589**

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

9 9 0 7 1 1 2 0 1 4 1 4 5 7 5 0

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

2. COV-3602

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

July 11, 2014

CERTIFICATION

To whom it may concern:

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

Province: **COMPOSTELA VALLEY**
Station Name: **COV-3602**
Order: **3rd**

Island: **MINDANAO**		Barangay: **BONGBONG**
Municipality: **PANTUKAN**		MSL Elevation:
	PRS92 Coordinates	
Latitude: **7° 13' 19.57444"**	Longitude: **125° 52' 15.82999"**	Ellipsoidal Hgt: **-1.07700 m.**
	WGS84 Coordinates	
Latitude: **7° 13' 16.43629"**	Longitude: **125° 52' 21.33702"**	Ellipsoidal Hgt: **72.04300 m.**
	PTM / PRS92 Coordinates	
Northing: **798622.708 m.**	Easting: **596202.079 m.**	Zone: **5**
	UTM / PRS92 Coordinates	
Northing: **799,250.67**	Easting: **817,092.67**	Zone: **51**

Location Description

COV-3602
"COV-3602" is in Barangay Bongabong, Pantukan, Compostela Valley. To reach the station travel for about 10 kms. from Tagum towards Maki taking the National Highway 50 meters away until reaching the Bongabong Elementary School. Station is located infront of the flagpole. Mark is the head of 4" copper nail embedded in a 0.30 x 0.30 x 1.0 m concrete monument with the inscription "COV-3602 2007 NAMRIA".

Requesting Party: **UP TCAGP / Engr. Christopher Cruz**
Pupose: **Reference**
OR Number: **8796507 A**
T.N.: **2014-1590**

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Annex 3. The LiDAR Survey Team Composition

Data Acquisition Component Sub-Team	Designation	Name	Agency / Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	ENGR. CZAR JAKIRI SARMIENTO	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUÑA	UP-TCAGP
		ENGR. LOVELYN ASUNCION	UP-TCAGP
FIELD TEAM			
LiDAR Operation	Senior Science Research Specialist (SSRS)	JULIE PEARL MARS	UP-TCAGP
	Research Associate (RA)	FOR. MA. VERLINA TONGA	UP-TCAGP
	RA	ENGR. LARAH KRISELLE PARAGAS	UP-TCAGP
Ground Survey	RA	ENGR. KENNETH QUISADO	UP-TCAGP
LiDAR Operation	Airborne Security	TSG. MIKE DIAPANA	Philippine Air Force (PAF)
	Pilot	CAPT. RAUL CZ SAMAR II	Asian Aerospace Corporation (AAC)
		CAPT. BRYAN JOHN DONGUINES	AAC

Annex 4. Data Transfer Sheet for the Kingking Floodplain Flights

DATA TRANSFER SHEET

[illegible]

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
6/27/2014	7337GC	2BLK80A178A	Gemini	NA	209/70	386	183	NA	NA	16.9	NA	7.55	1KB	1KB	4/4/5/5/5/4	24	Z:\Airborne_Raw\[illegible]
6/28/2014	7339GC	2BLK79C179A	Gemini	NA	179/11	387	74.8	NA	NA	14.3	NA	5.08	1KB	1KB	5	179/11	Z:\Airborne_Raw\[illegible]
6/29/2014	7340GC	2BLK79B180A	Gemini	NA	115	580	285	NA	NA	38.2	NA	4.65	1KB	1KB	5	115	Z:\Airborne_Raw\[illegible]
7/1/2014	7344GC	2BLK84B182A	Gemini	NA	158/22	188	174	NA	NA	2.50/6.69	NA	6.95	1KB	1KB	5	158/22	Z:\Airborne_Raw\[illegible]
7/2/2014	7346GC	2BLK79SSA183A	Gemini	NA	376	613	276	NA	NA	29.7	NA	5.32	1KB	1KB	5	376	Z:\Airborne_Raw\[illegible]
7/3/2014	7348GC	2BLK79V184A	Gemini	NA	597	203	212	NA	NA	6.58	NA	6.48	1KB	1KB	14	597	Z:\Airborne_Raw\[illegible]
7/4/2014	7350GC	2BLK85B185A	Gemini	NA	300	499	258	NA	NA	23.8	NA	7.05	1KB	1KB	8	300	Z:\Airborne_Raw\[illegible]

Received from

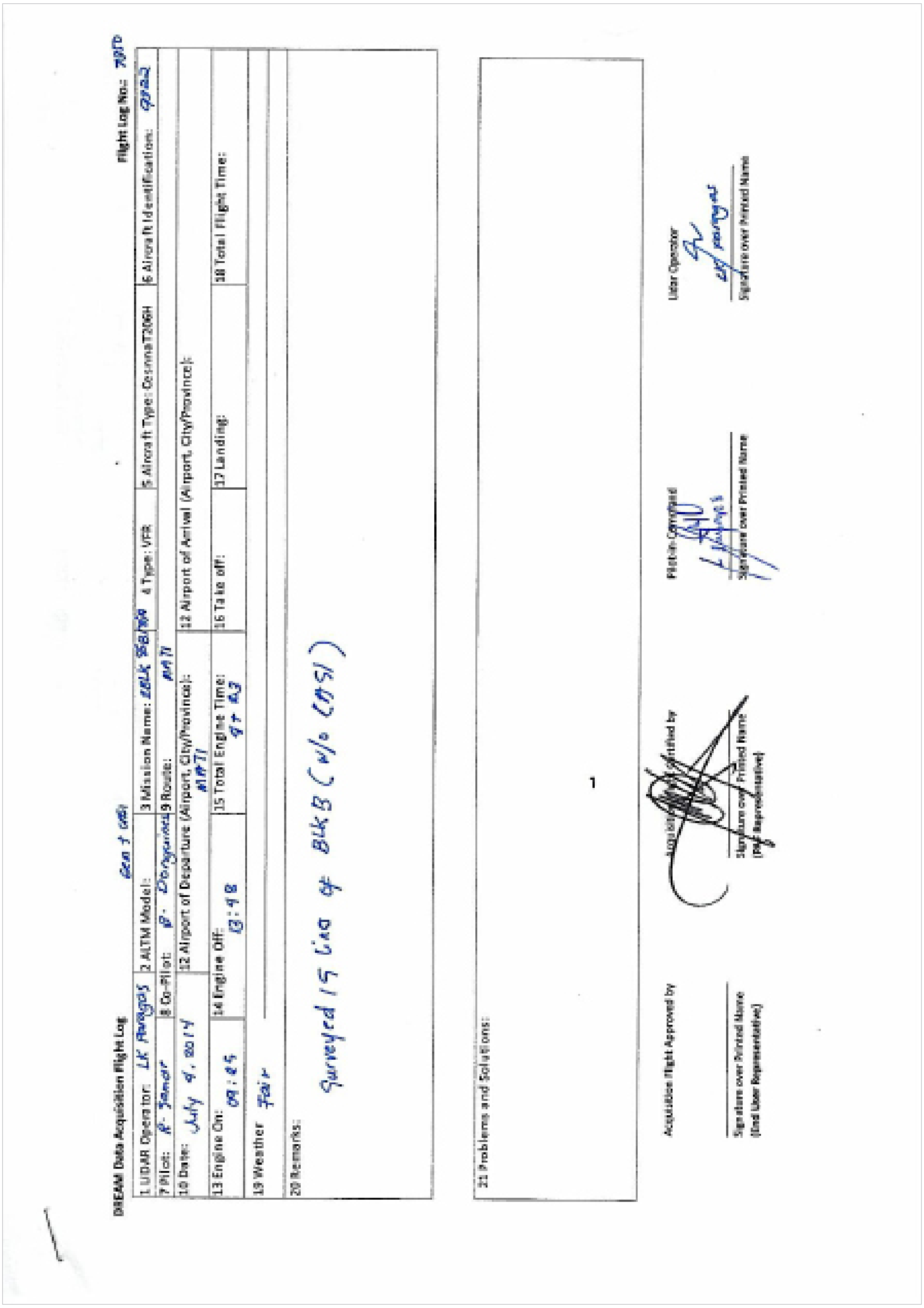
Name Kristine Andaya
Position E.A
Signature

Received by

Name JOIDA F. PRIETO
Position SSRS
Signature 7/17/14

Annex 5. Flight Logs for the Flight Mission

1. Flight Log for 7350GC Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 7350

1 LIDAR Operator: LK Paragas	2 ALTM Model:	3 Mission Name: 2BLK 58B	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9322
7 Pilot: R. Samar	8 Co-Pilot: B. Dongumas	9 Route: MATI			
10 Date: July 9, 2014	12 Airport of Departure (Airport, City/Province): MATI		12 Airport of Arrival (Airport, City/Province):		
13 Engine On: 09:25	14 Engine Off: 13:48	15 Total Engine Time: 4+23	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: Fair					

20 Remarks:

Surveyed 15 lines of BLK B (w/o CASI)

21 Problems and Solutions:

Acquisition Flight Approved by

Signature over Printed Name
(End User Representative)

Acquisition Flight Certified by

Signature over Printed Name
(PAF Representative)

Pilot-in-Command

Signature over Printed Name

Lidar Operator

LK Paragas

Signature over Printed Name

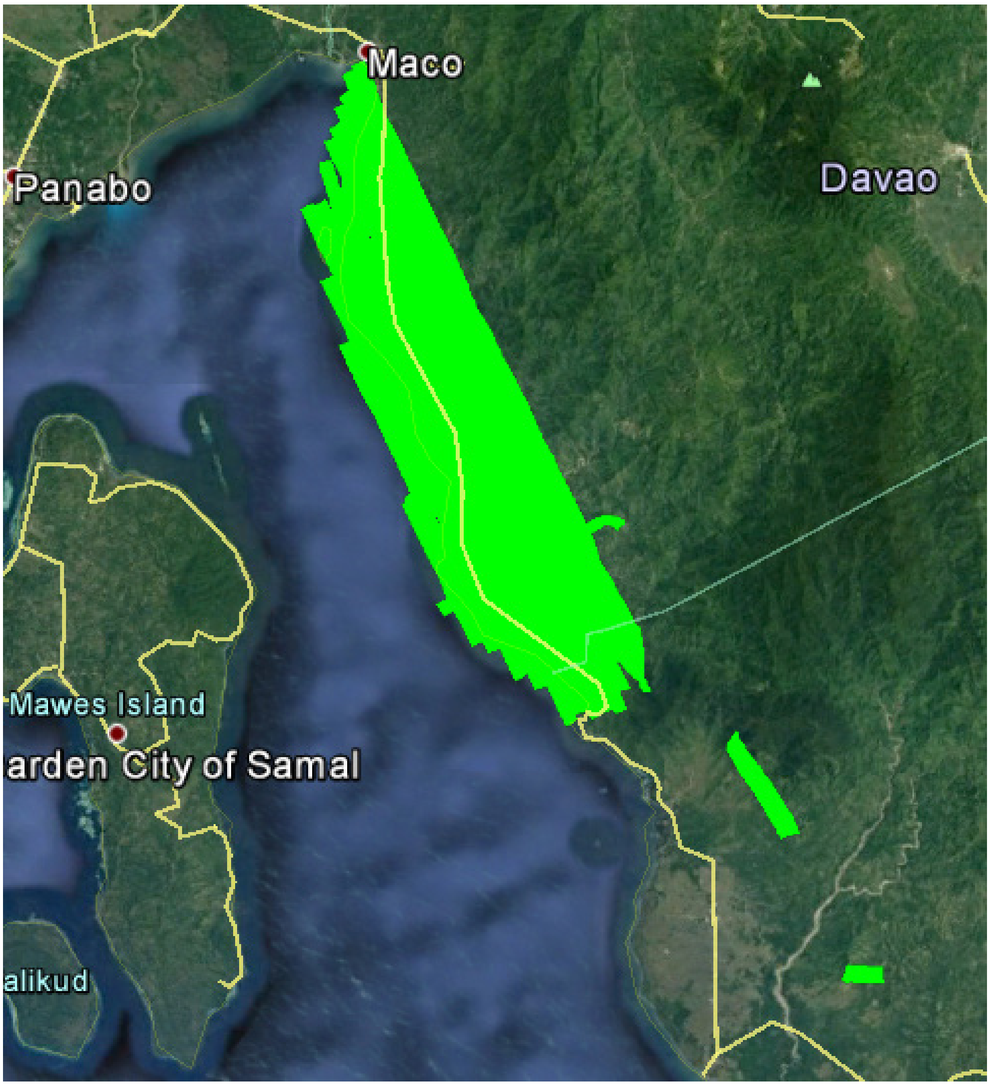
Annex 6. Flight Status Report

DAVAO ORIENTAL (June 16 - July 16, 2014)

Flight No	Area	Mission	Operator	Date Flown	Remarks
7350GC	BLK85B	2BLK85B185A	LK PARAGAS	July 04, 2014	15 lines at 1000m

LAS BOUNDARIES PER FLIGHT

Flight No. :	7350GC
Area:	BLK85B
Mission name:	2BLK85B185A
Parameters:	Altitude: 1000 m; Scan Frequency: 50 Hz;
Scan Angle:	Overlap: 40%
Area covered:	301.028 km^2



Annex 7. Mission Summary Report

Flight Area	Davao Oriental
Mission Name	Blk85B
Inclusive Flights	7350G
Range data size	23.8 GB
POS	258 MB
Image	na
Transfer date	July 14, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.6
RMSE for East Position (<4.0 cm)	2.1
RMSE for Down Position (<8.0 cm)	2.6
Boresight correction stdev (<0.001deg)	0.002079
IMU attitude correction stdev (<0.001deg)	0.005849
GPS position stdev (<0.01m)	0.0163
Minimum % overlap (>25)	17.85%
Ave point cloud density per sq.m. (>2.0)	2.56
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	288
Maximum Height	728.94 m
Minimum Height	67.52 m
Classification (# of points)	
Ground	65620647
Low vegetation	45592090
Medium vegetation	110105166
High vegetation	267419041
Building	2814515
Orthophoto	No
Processed by	Engr. Kenneth Solidum, Engr. Analyn Naldo, Engr. Melanie Hingpit, Engr. John Dill Macapagal

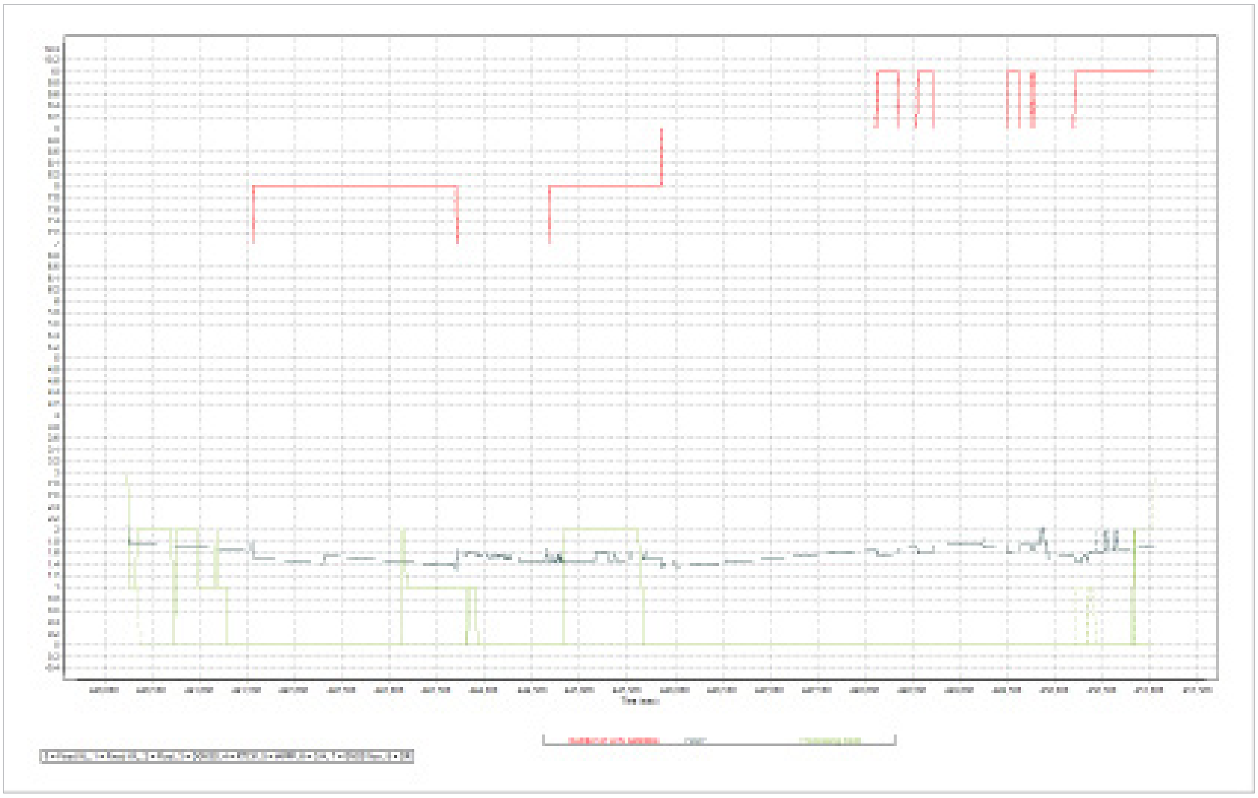


Figure 71. Solution Status

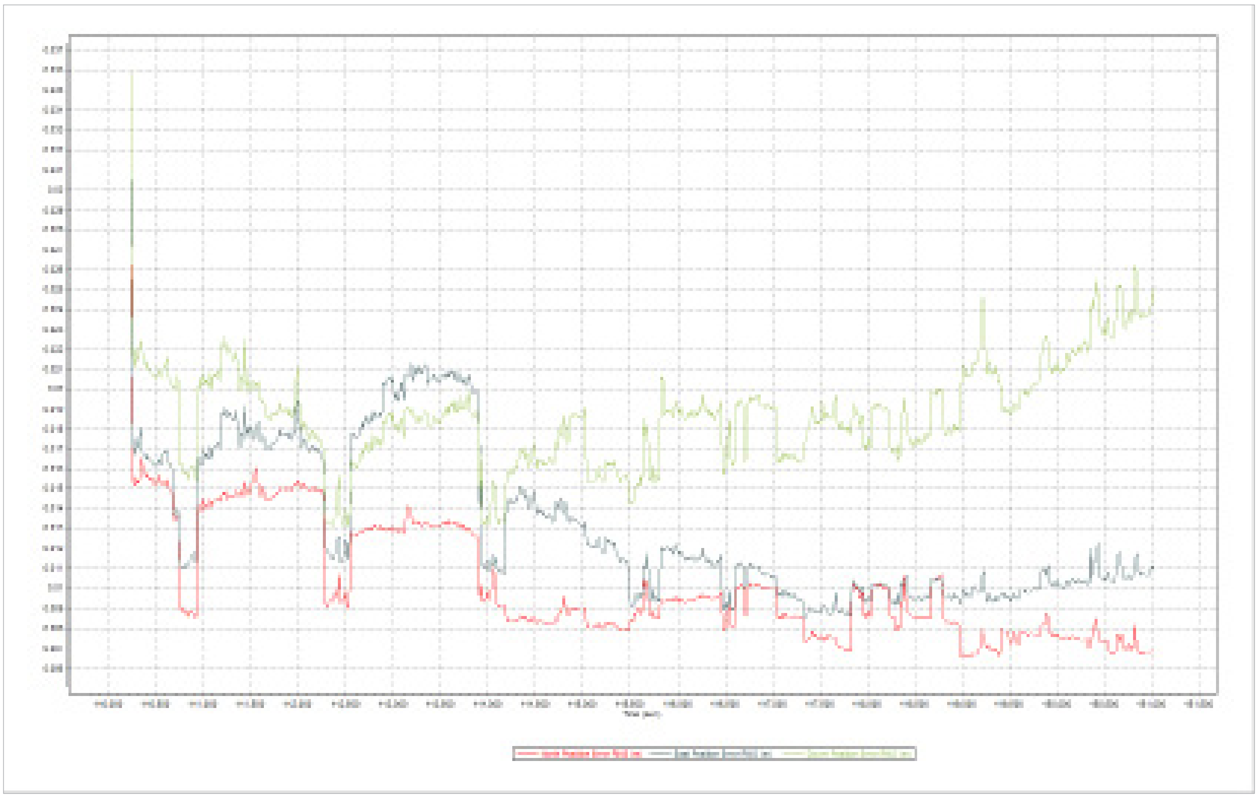


Figure 72. Smoothed Performance Metric Parameters

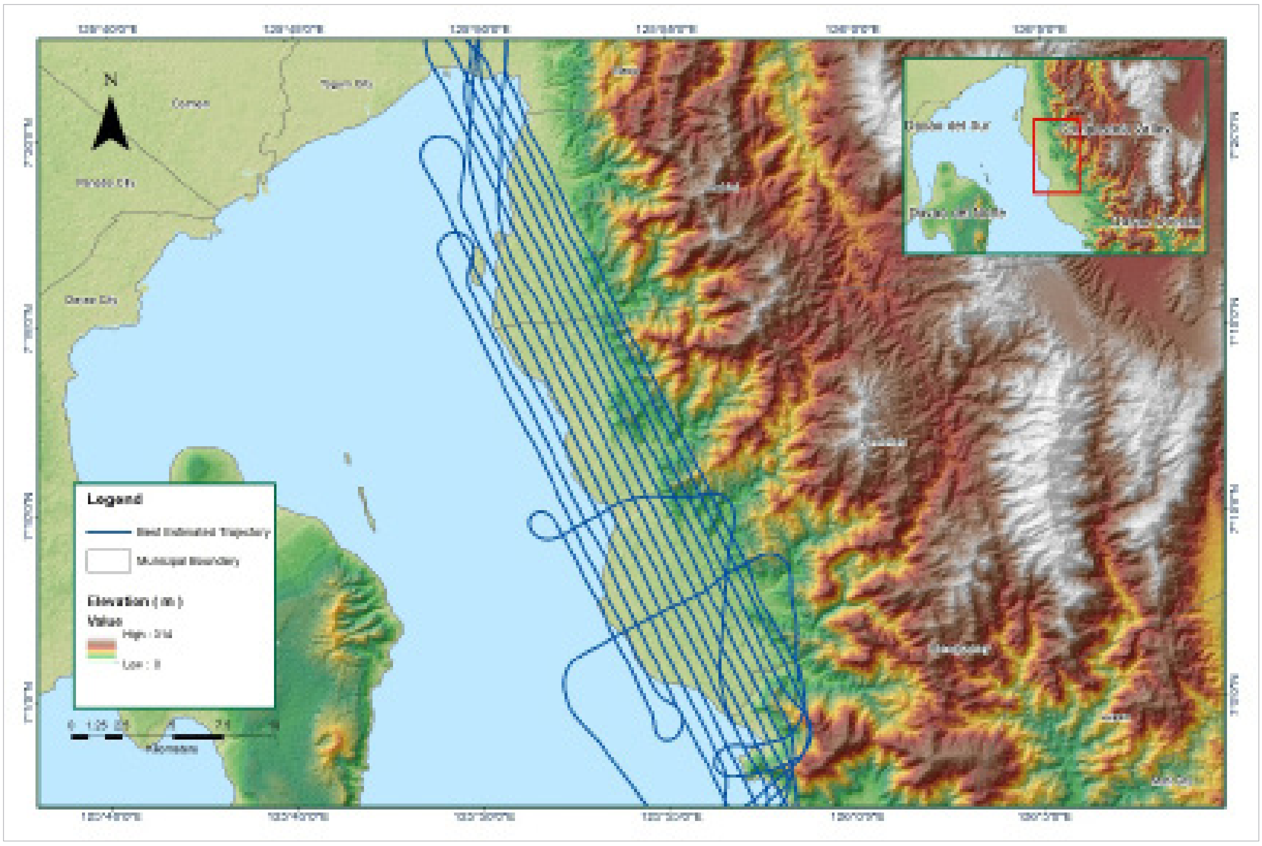


Figure 73. Best Estimated Trajectory

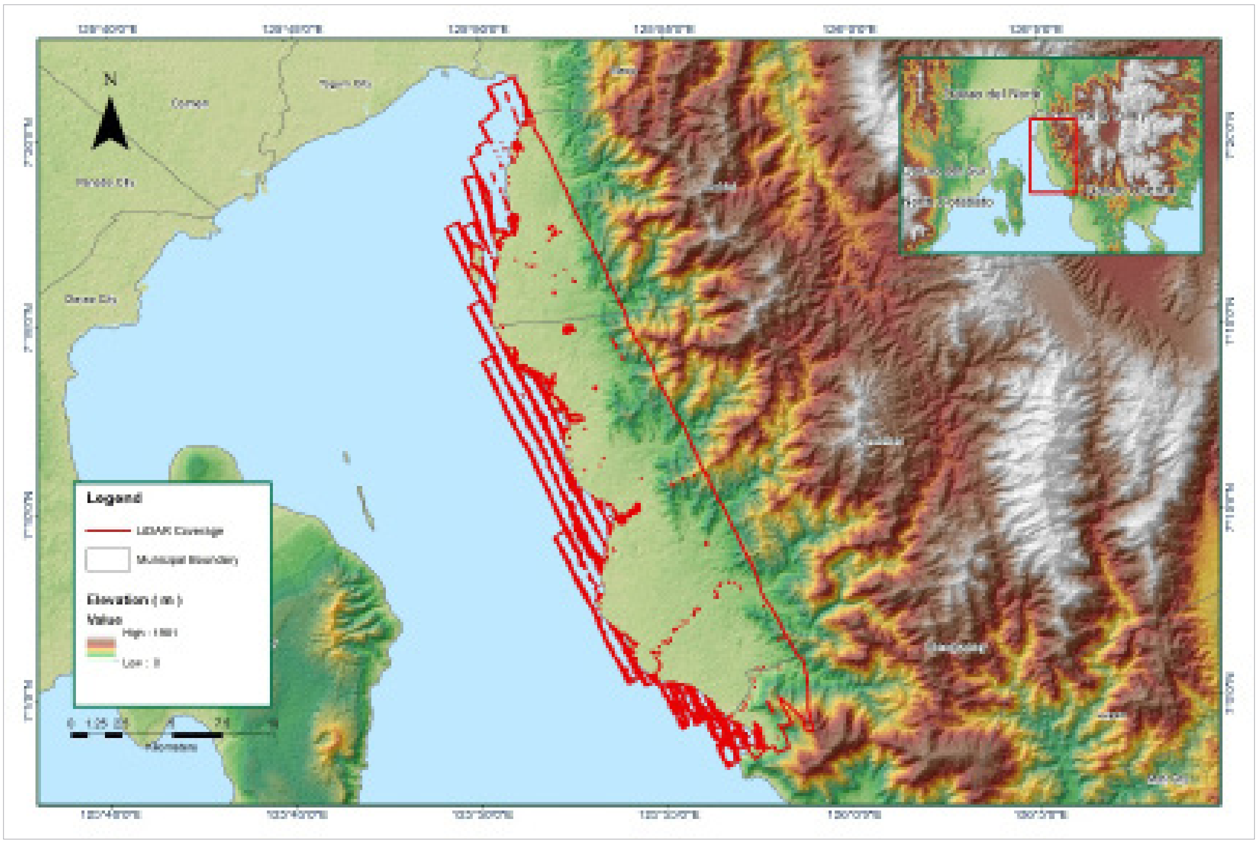


Figure 74. Coverage of LiDAR data

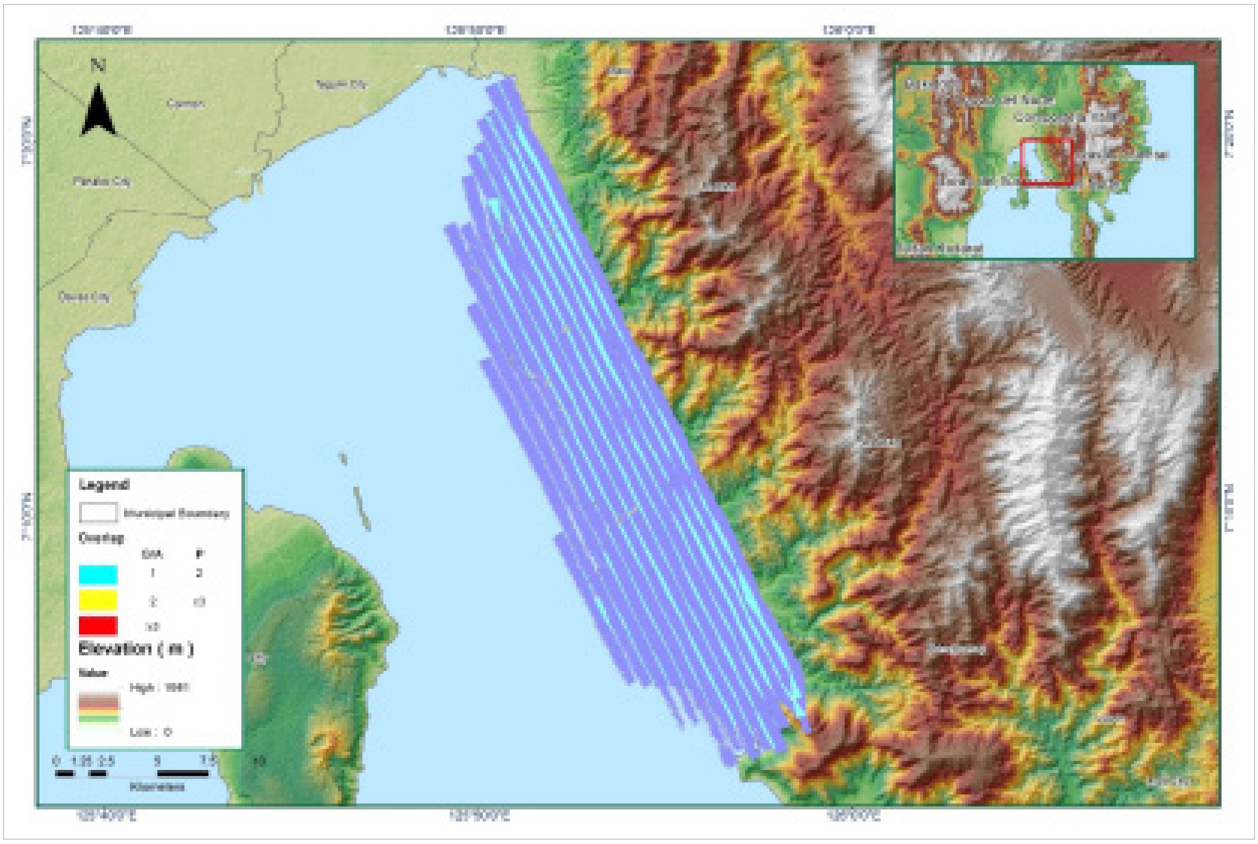


Figure 75. Image of data overlap

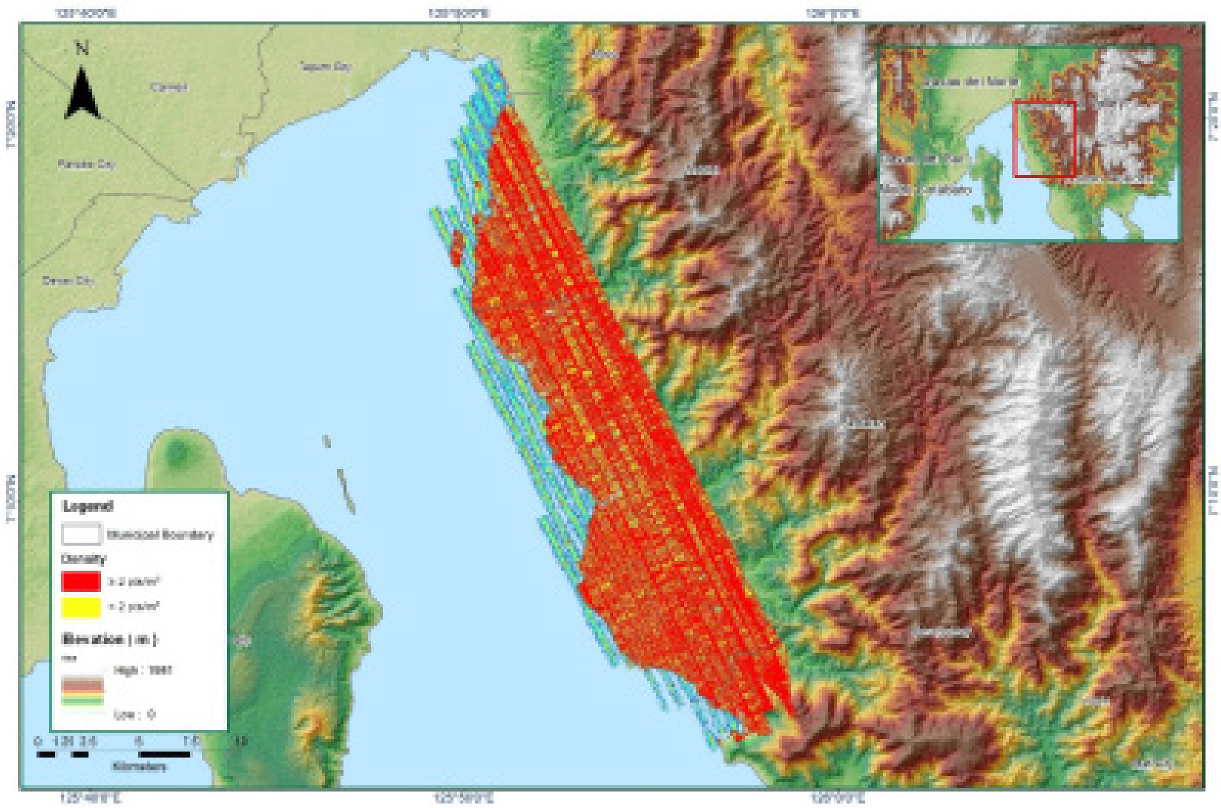


Figure 76. Density map of merged LiDAR data

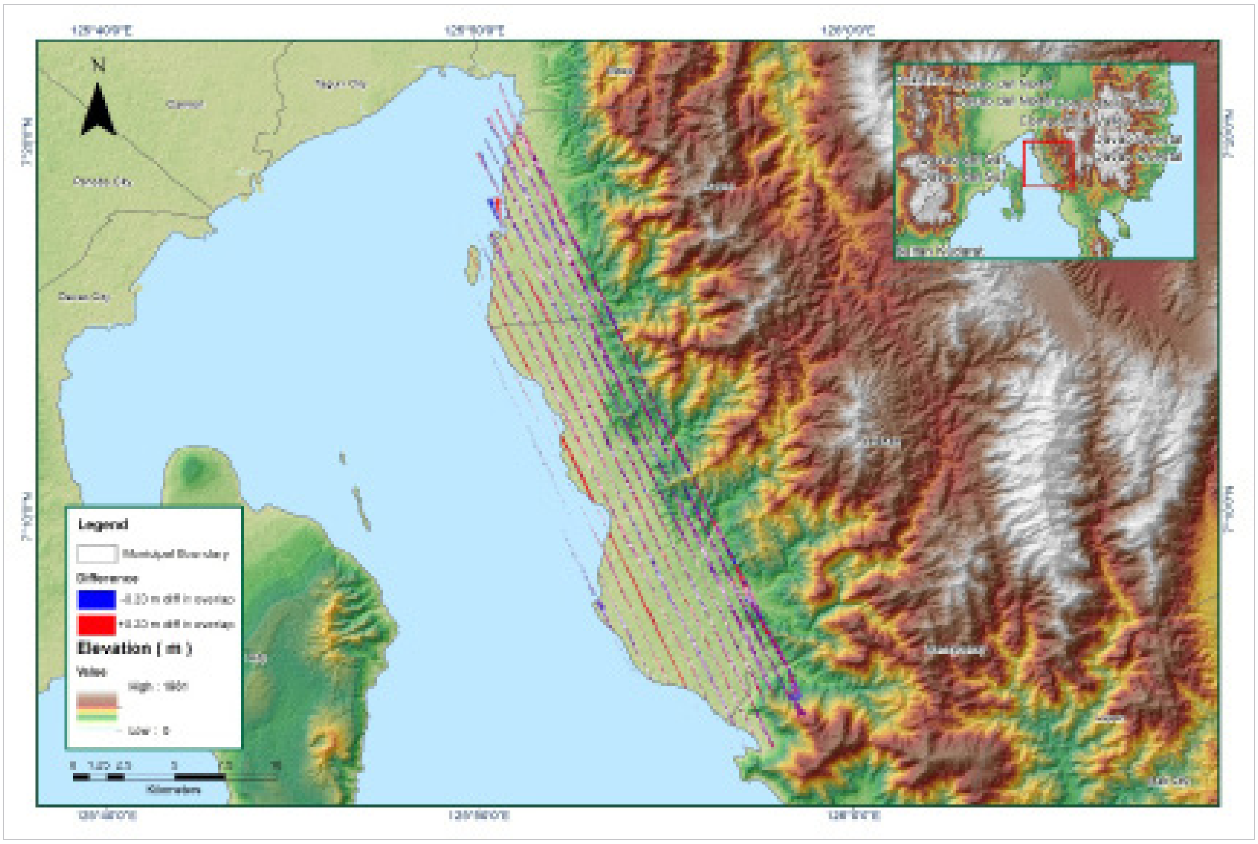


Figure 77. Elevation difference between flight lines

Annex 8. Kingking 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 (cms)	Recession Constant	Threshold Type	Ratio to Peak
W1000	2.2614	93.533	0	0.12116	0.068098	Discharge	0.008803	0.000168	Ratio to Peak	0.086727
W1010	54.861	1	0	0.14155	3.0469	Discharge	0.030206	0.0011	Ratio to Peak	0.028196
W1020	1.4824	99	0	0.44903	1.7262	Discharge	0.041597	0.004263	Ratio to Peak	0.00552
W1030	1.164	99	0	0.16571	1.3121	Discharge	0.01837	0.002891	Ratio to Peak	0.010069
W1040	1.058	98.917	0	0.13727	0.085574	Discharge	0.016158	0.000789	Ratio to Peak	0.27645
W1050	0.55604	93.017	0	0.11845	0.10035	Discharge	0.003109	0.000958	Ratio to Peak	0.046263
W1060	0.0396558	1	0	0.14259	0.17942	Discharge	0.035664	0.014332	Ratio to Peak	0.001862
W1070	1.6133	99	0	0.15004	1.1162	Discharge	0.050179	0.006865	Ratio to Peak	0.010466
W1080	0.0010038	1	0	1.2035	0.27343	Discharge	0.04045	0.011253	Ratio to Peak	0.005305
W1090	1.177	1	0	0.36291	0.072953	Discharge	0.067155	0.057464	Ratio to Peak	0.007766
W1100	4.2035	92.759	0	0.14864	1.7265	Discharge	0.001517	0.004416	Ratio to Peak	0.011391
W1110	0.0012767	1	0	0.030983	0.076637	Discharge	0.000691	0.001255	Ratio to Peak	0.070319
W1120	0.22982	35.176	0	0.16346	0.51067	Discharge	0.039802	0.008749	Ratio to Peak	0.008291
W1130	54.206	35.176	0	0.14366	0.54193	Discharge	0.041677	0.074646	Ratio to Peak	0.037607
W1140	1.4591	77.021	0	0.016667	1.4529	Discharge	0.21625	0.025658	Ratio to Peak	0.045411
W580	42.045	99	0	1.2152	0.84493	Discharge	0.069407	0.085723	Ratio to Peak	0.067924
W590	9.1386	35.175	0	0.14526	0.35413	Discharge	0.044015	0.13339	Ratio to Peak	0.011079
W600	0.0019181	1	0	0.13495	0.080347	Discharge	0.058899	0.16176	Ratio to Peak	0.016757
W610	70.557	44.376	0	0.20498	0.66352	Discharge	0.048735	0.05641	Ratio to Peak	0.086621

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 (cms)	Recession Constant	Threshold Type	Ratio to Peak
W620	72.778	44.878	0	0.31754	0.91087	Discharge	0.072259	0.066185	Ratio to Peak	0.089489
W630	55.338	35.176	0	0.056379	0.39713	Discharge	0.001176	0.021059	Ratio to Peak	0.71976
W640	31.459	99	0	0.1059	0.40438	Discharge	0.009726	0.084064	Ratio to Peak	0.050685
W650	0	63.7	0	0.22571	1.8632	Discharge	0.058428	0.085671	Ratio to Peak	0.07523
W660	34.638	35.176	0	7.4554	3.4375	Discharge	0.10348	0.12933	Ratio to Peak	0.025934
W670	66.018	42.874	0	0.43625	0.62287	Discharge	0.09056	0.046523	Ratio to Peak	0.076813
W680	0.0736311	35.181	0	0.86738	0.52276	Discharge	0.057824	0.076355	Ratio to Peak	0.033414
W690	66.24	47.955	0	0.54145	1.6154	Discharge	0.076494	0.055151	Ratio to Peak	0.078544
W700	0.31101	35.177	0	1.4384	0.97052	Discharge	0.12259	0.049363	Ratio to Peak	0.041781
W710	0.32806	35.176	0	0.64873	1.5232	Discharge	0.054885	0.13835	Ratio to Peak	0.037927
W720	1.1722	99	0	1.9405	0.56539	Discharge	0.031781	0.000857	Ratio to Peak	0.000848
W730	57.646	35.176	0	0.10843	2.9345	Discharge	0.035965	0.072702	Ratio to Peak	0.025721
W740	4.3487	99	0	0.07619	0.74553	Discharge	0.033652	0.000241	Ratio to Peak	0.000701
W750	74.943	35.176	0	0.11555	6.6515	Discharge	0.035227	0.122	Ratio to Peak	0.025995
W760	7.296	35.176	0	0.24682	0.95553	Discharge	0.084885	0.17256	Ratio to Peak	0.036832
W770	63.321	35.176	0	0.38232	1.5555	Discharge	0.042401	0.1349	Ratio to Peak	0.04421
W780	0.33249	99	0	0.083851	0.13412	Discharge	0.005303	0.00479	Ratio to Peak	0.00028
W790	51.016	35.175	0	0.025651	0.073947	Discharge	6.15E-05	0.002644	Ratio to Peak	0.018824
W800	3.5318	35.176	0	0.56528	1.392	Discharge	0.054132	0.13141	Ratio to Peak	0.03198
W810	0.33045	35.176	0	1.8735	1.0763	Discharge	0.081583	0.14914	Ratio to Peak	0.038377

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 (cms)	Recession Constant	Threshold Type	Ratio to Peak
W820	3.4002	35.176	0	0.66245	1.1526	Discharge	0.053741	0.06125	Ratio to Peak	0.020463
W830	0.0048108	35.177	0	3.1514	0.41811	Discharge	0.11627	0.13584	Ratio to Peak	0.016334
W840	63.143	52.5	0	0.090276	0.32931	Discharge	0.002371	0.05818	Ratio to Peak	0.005452
W850	58.905	52.5	0	0.10185	5.501	Discharge	0.007105	0.030019	Ratio to Peak	0.9675
W860	54.622	35.176	0	0.24858	6.0028	Discharge	0.030561	0.15611	Ratio to Peak	0.24878
W870	2.0312	35.176	0	0.14858	0.42207	Discharge	0.040841	0.066884	Ratio to Peak	0.004872
W880	1.6434	99	0	0.2533	1.3322	Discharge	0.04222	0.033097	Ratio to Peak	0.005255
W890	3.7035	35.176	0	1.1068	1.2741	Discharge	0.091751	0.04434	Ratio to Peak	0.010534
W900	1.6313	35.176	0	0.1295	1.6373	Discharge	0.1051	0.051796	Ratio to Peak	0.015602
W910	53.467	35	0	5.1995	3.9895	Discharge	0.030351	0.020857	Ratio to Peak	0.068838
W920	1.4021	35.176	0	0.78348	0.39963	Discharge	0.035056	0.076408	Ratio to Peak	0.004774
W930	54.669	35	0	0.091452	6.6456	Discharge	0.000246	0.01965	Ratio to Peak	0.38081
W940	54.637	35	0	1.5331	6.5835	Discharge	0.041434	0.075592	Ratio to Peak	0.079517
W950	1.704	35.176	0	0.12682	1.0123	Discharge	0.034792	0.1049	Ratio to Peak	0.016891
W960	2.4986	35.176	0	1.9054	0.70635	Discharge	0.12158	0.25432	Ratio to Peak	0.038072
W970	1.3684	99	0	0.37877	1.3321	Discharge	0.062674	0.000924	Ratio to Peak	0.01458
W980	8.1341	35.176	0	2.0641	0.41457	Discharge	0.085536	0.075086	Ratio to Peak	0.008151
W990	0.35464	35.176	0	0.018	0.12298	Discharge	0.074822	0.000226	Ratio to Peak	0.14571

Annex 9. Kingking Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R100	Automatic Fixed Interval	2470.4	0.045265	0.40791	Trapezoid	30	1
R110	Automatic Fixed Interval	1257.7	0.037647	0.09948	Trapezoid	30	1
R140	Automatic Fixed Interval	1232.7	0.041603	0.14997	Trapezoid	30	1
R170	Automatic Fixed Interval	1403.3	0.03203	0.1384	Trapezoid	30	1
R180	Automatic Fixed Interval	1403	0.12915	0.15615	Trapezoid	30	1
R20	Automatic Fixed Interval	42.426	0.001	0.29541	Trapezoid	30	1
R210	Automatic Fixed Interval	130	0.23891	0.092015	Trapezoid	30	1
R220	Automatic Fixed Interval	287.99	0.091344	0.17154	Trapezoid	30	1
R230	Automatic Fixed Interval	1583	0.017897	0.095929	Trapezoid	30	1
R250	Automatic Fixed Interval	429.71	0.024192	0.016938	Trapezoid	30	1
R280	Automatic Fixed Interval	263.14	0.17915	0.078708	Trapezoid	30	1
R290	Automatic Fixed Interval	964.26	0.033008	0.10275	Trapezoid	30	1
R310	Automatic Fixed Interval	1314.4	0.043452	0.061819	Trapezoid	30	1
R330	Automatic Fixed Interval	274.14	0.03564	0.063461	Trapezoid	30	1
R360	Automatic Fixed Interval	718.7	0.007753	0.072388	Trapezoid	30	1
R390	Automatic Fixed Interval	1792.4	0.010249	0.22202	Trapezoid	30	1
R420	Automatic Fixed Interval	596.69	0.004931	0.080133	Trapezoid	30	1
R440	Automatic Fixed Interval	1565.4	0.013953	0.12106	Trapezoid	30	1
R450	Automatic Fixed Interval	4280.4	0.015313	0.053082	Trapezoid	30	1

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R460	Automatic Fixed Interval	1371.5	0.003803	0.06233	Trapezoid	30	1
R470	Automatic Fixed Interval	995.27	0.005709	0.062973	Trapezoid	30	1
R480	Automatic Fixed Interval	378.7	0.00653	0.16979	Trapezoid	30	1
R50	Automatic Fixed Interval	758.41	0.0556	0.086219	Trapezoid	30	1
R510	Automatic Fixed Interval	1972.4	0.003117	0.08429	Trapezoid	30	1
R520	Automatic Fixed Interval	286.57	0.001	0.076217	Trapezoid	30	1
R530	Automatic Fixed Interval	193.99	0.001	0.12201	Trapezoid	30	1
R570	Automatic Fixed Interval	6965	0.002494	0.069925	Trapezoid	30	1
R90	Automatic Fixed Interval	1687.1	0.028434	0.10009	Trapezoid	30	1

Annex 10. Kingking Field Validation Points

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error (m)	Event/Date	Rain Return/ Scenario
	Lat	Long					
1	7.125076	125.897237	0.38	0.20	0.0324	Yolanda/ November 2013	25-Year
2	7.123905	125.896778	0.44	0.00	0.1936	1971	25-Year
3	7.127058	125.898154	0.56	0.00	0.3136		25-Year
4	7.126071	125.897153	0.54	0.10	0.1936	Pablo/ December 2012	25-Year
5	7.127054	125.898878	0.83	0.00	0.6889		25-Year
6	7.125619	125.897241	0.59	0.10	0.2401	Pablo/ December 2012	25-Year
7	7.126961	125.899239	0.97	0.10	0.7569	Pablo/ December 2012	25-Year
8	7.123442	125.898494	0.82	0.46	0.1296	Pablo/ December 2012	25-Year
9	7.126070	125.897334	0.64	1.61	0.9409	Upstream Rainfall	25-Year
10	7.125979	125.897424	0.7	0.81	0.0121	Upstream Rainfall	25-Year
11	7.122973	125.901294	0.67	0.46	0.0441	Heavy Rainfall	25-Year
12	7.123065	125.901024	0.67	0.50	0.0289	Heavy Rainfall	25-Year
13	7.127046	125.900144	0.78	0.80	0.0004	Pablo/ December 2012	25-Year
14	7.122322	125.904185	0.53	0.30	0.0529	Heavy Rainfall/ 2015	25-Year
15	7.126412	125.900412	0.6	0.00	0.3600		25-Year
16	7.122626	125.898941	0.67	0.30	0.1369	Pablo/ December 2012	25-Year
17	7.125690	125.900317	0.45	0.00	0.2025		25-Year
18	7.126607	125.898152	0.91	0.30	0.3721	Intense Rainfall/ 2003	25-Year
19	7.123624	125.898404	0.83	0.50	0.1089	Pablo/ December 2012	25-Year
20	7.125691	125.900045	0.6	0.00	0.3600		25-Year
21	7.126433	125.896975	0.89	0.10	0.6241	Pablo/ December 2012	25-Year
22	7.126155	125.898149	0.89	0.30	0.3481	Intense Rainfall/ 2003	25-Year
23	7.126693	125.898785	0.96	0.00	0.9216		25-Year
24	7.126063	125.898420	0.97	0.80	0.0289	Pablo/ December 2012	25-Year
25	7.126061	125.898781	0.98	0.00	0.9604		25-Year
26	7.126777	125.899781	1.04	0.80	0.0576	Pablo/ December 2012	25-Year
27	7.125885	125.897966	1.18	0.80	0.1444	Pablo/ December 2012	25-Year
28	7.126421	125.898874	1.07	0.00	1.1449		25-Year
29	7.126878	125.898063	1.07	0.30	0.5929	Upstream Rainfall/ March 2016	25-Year
30	7.126691	125.899057	1.16	0.10	1.1236	Pablo/ December 2012	25-Year
31	7.127061	125.897793	0.45	0.50	0.0025	Pablo/ December 2012	25-Year
32	7.132141	125.894478	0.71	0.00	0.5041		25-Year
33	7.132319	125.894931	0.89	0.00	0.7921		25-Year
34	7.131140	125.895557	0.83	0.40	0.1849	Upstream Rainfall/ June 2008	25-Year
35	7.132407	125.895294	0.65	0.10	0.3025	Pablo/ December 2012	25-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error (m)	Event/Date	Rain Return/ Scenario
	Lat	Long					
36	7.128143	125.898071	0.82	0.50	0.1024	Intense Rainfall/ July 1905	25-Year
37	7.132869	125.893668	0.97	0.10	0.7569	Heavy Rainfall/ Rainy Season	25-Year
38	7.128783	125.896899	0.73	0.50	0.0529	Intense Rainfall/ 2014	25-Year
39	7.130145	125.895822	0.7	0.40	0.0900	Upstream Rainfall/ June 2008	25-Year
40	7.132227	125.895202	0.73	0.10	0.3969	Pablo/ December 2012	25-Year
41	7.132233	125.894117	0.2	0.00	0.0400		25-Year
42	7.126609	125.897699	0.69	0.50	0.0361	Intense Rainfall/ 2011	25-Year
43	7.128594	125.898255	0.77	0.20	0.3249	Pablo/ December 2012	25-Year
44	7.132599	125.893395	0.83	0.20	0.3969	Intense Rainfall/ September 2016	25-Year
45	7.127958	125.898703	0.78	0.50	0.0784	Heavy Rainfall/ 2013	25-Year
46	7.132866	125.894030	0.72	0.00	0.5184		25-Year
47	7.126520	125.897518	0.76	0.50	0.0676	Intense Rainfall/ 2011	25-Year
48	7.129422	125.895818	0.75	0.00	0.5625		25-Year
49	7.132055	125.893754	0.87	0.20	0.4489	Intense Rainfall/ September 2016	25-Year
50	7.128784	125.896628	0.79	0.50	0.0841	Intense Rainfall/ 2014	25-Year
51	7.131320	125.895739	0.79	0.40	0.1521	Upstream Rainfall/ June 2008	25-Year
52	7.131869	125.894567	0.75	0.00	0.5625		25-Year
53	7.127430	125.896529	0.76	0.00	0.5776		25-Year
54	7.126796	125.896796	0.65	0.00	0.4225		25-Year
55	7.127515	125.897434	0.72	0.60	0.0144	Intense Rainfall	25-Year
56	7.127694	125.897616	0.76	0.00	0.5776		25-Year
57	7.127965	125.897617	1.02	0.00	1.0404		25-Year
58	7.127967	125.897346	1.03	1.10	0.0049	Typhoon/ May 2015	25-Year
59	7.128872	125.897080	1.08	0.10	0.9604	Intense Rainfall	25-Year
60	7.127790	125.896712	1.07	0.00	1.1449		25-Year
61	7.127974	125.896261	1.25	0.00	1.5625		25-Year
62	7.127609	125.896801	1.11	0.40	0.5041	Upstream Rainfall/ 2010	25-Year
63	7.128061	125.896804	1.15	0.50	0.4225	Pablo/ 2013	25-Year
64	7.128149	125.897166	1.16	1.10	0.0036	Typhoon/ May 2015	25-Year
65	7.128237	125.897438	1.29	0.25	1.0816	Intense Rainfall/ July 2014	25-Year
66	7.128963	125.896991	1.29	0.10	1.4161	Intense Rainfall	25-Year
67	7.128331	125.896896	1.28	0.60	0.4624	Intense Rainfall/ 2015	25-Year
68	7.129649	125.902784	1.39	1.00	0.1521	Pablo/ December 2012	25-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error (m)	Event/Date	Rain Return/ Scenario
	Lat	Long					
69	7.128570	125.902053	1.21	1.10	0.0121	Pablo/ December 2012	25-Year
70	7.128841	125.902055	1.27	1.10	0.0289	Pablo/ December 2012	25-Year
71	7.129198	125.902781	1.15	0.50	0.4225	Heavy Rainfall	25-Year
72	7.129738	125.903056	1.27	0.00	1.6129		25-Year
73	7.129473	125.902059	1.57	0.05	2.3104	Intense Rainfall/ May 2011	25-Year
74	7.129293	125.901967	1.46	1.00	0.2116	Intense Rainfall/ 2004	25-Year
75	7.129379	125.902601	1.24	0.50	0.5476	Heavy Rainfall	25-Year
76	7.129374	125.903415	1.07	0.00	1.1449		25-Year
77	7.129026	125.901333	1.22	1.10	0.0144	Pablo/ December 2012	25-Year
78	7.128490	125.900334	0.99	1.10	0.0121	Pablo/ December 2012	25-Year
79	7.129204	125.901695	1.5	1.00	0.2500	Heavy Rainfall/ 2005	25-Year
80	7.129646	125.903326	1.23	0.00	1.5129		25-Year
81	7.133151	125.891861	0.6	0.00	0.3600		25-Year
82	7.132861	125.894935	0.71	0.00	0.5041		25-Year
83	7.133240	125.892133	1.11	0.00	1.2321		25-Year
84	7.137307	125.891887	1.45	1.50	0.0025	Pablo/ December 2012	25-Year
85	7.134847	125.895219	2.09	0.55	2.3716	Intense Rainfall/ 2014	25-Year
86	7.135205	125.895673	2.27	0.55	2.9584	Intense Rainfall/ 2014	25-Year
87	7.136762	125.892336	1.23	1.50	0.0729	Pablo/ December 2012	25-Year
88	7.138251	125.899853	0.75	0.69	0.0036	Pablo/ December 2012	25-Year
89	7.139002	125.895245	1.03	1.04	0.0001	Pablo/ December 2012	25-Year
90	7.139011	125.893798	2.23	1.20	1.0609	Pablo/ December 2012	25-Year
91	7.136116	125.894412	1.24	0.00	1.5376		25-Year
92	7.139645	125.893621	2.15	2.06	0.0081	Pablo/ December 2012	25-Year
93	7.135388	125.895312	2.26	0.55	2.9241	Intense Rainfall/ 2014	25-Year
94	7.135482	125.894770	1.76	0.00	3.0976	Pablo/ December 2012	25-Year
95	7.136688	125.889713	1.95	0.30	2.7225	Pablo/ December 2012	25-Year
96	7.136779	125.889623	1.57	0.30	1.6129	Pablo/ December 2012	25-Year
97	7.138253	125.899401	1.63	0.80	0.6889	Pablo/ December 2012	25-Year
98	7.132923	125.899367	1.18	0.00	1.3924		25-Year
99	7.133745	125.898016	1.21	0.20	1.0201	Upstream Rainfall/ 2013	25-Year
100	7.134287	125.898019	1.44	0.00	2.0736		25-Year
101	7.131931	125.899180	1.29	1.30	0.0001	Pablo/ December 2012	25-Year
102	7.132554	125.900541	1.35	0.00	1.8225		25-Year
103	7.132644	125.900632	1.26	0.00	1.5876		25-Year
104	7.132381	125.899364	1.39	0.20	1.4161	Intense Rainfall/ March 2015	25-Year
105	7.133565	125.897924	1.42	0.20	1.4884	Upstream Rainfall/ 2013	25-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error (m)	Event/Date	Rain Return/ Scenario
	Lat	Long					
106	7.132193	125.900629	1.61	0.00	2.5921		25-Year
107	7.133292	125.898194	1.32	0.00	1.7424		25-Year
108	7.131569	125.899178	1.4	0.71	0.4761	Buhawi/ 2008	25-Year
109	7.132015	125.900085	1.36	0.00	1.8496		25-Year
110	7.134106	125.898018	1.34	0.00	1.7956		25-Year
111	7.132563	125.899184	1.42	0.20	1.4884	Intense Rainfall/ March 2015	25-Year
112	7.133012	125.899549	0.81	0.00	0.6561		25-Year
113	7.133193	125.899640	1.21	0.00	1.4641		25-Year
114	7.132376	125.900178	1.12	0.00	1.2544		25-Year
115	7.132745	125.899004	1.23	0.00	1.5129		25-Year
116	7.132013	125.900447	1.43	0.00	2.0449		25-Year
117	7.132111	125.899272	1.22	1.30	0.0064	Pablo/ December 2012	25-Year
118	7.132474	125.899003	1.46	0.00	2.1316		25-Year
119	7.132107	125.899905	0.95	0.00	0.9025		25-Year
120	7.157093	125.891921	0.35	0.00	0.1225		25-Year
121	7.157269	125.892556	0.62	0.00	0.3844		25-Year
122	7.151937	125.892884	0.23	0.00	0.0529		25-Year
123	7.160521	125.892667	0.42	0.40	0.0004	Intense Rainfall	25-Year
124	7.156001	125.893090	0.24	0.00	0.0576		25-Year
125	7.159973	125.893658	0.31	0.00	0.0961		25-Year
126	7.157540	125.892648	0.25	0.00	0.0625		25-Year
127	7.161241	125.893033	0.93	0.20	0.5329	Intense Rainfall/ 2016	25-Year
128	7.160153	125.893750	0.33	0.40	0.0049	Pablo/ December 2012	25-Year
129	7.128955	125.912548	1.45	0.51	0.8836	Intense Rainfall/ 2014	25-Year
130	7.147610	125.934193	2.9	1.20	2.8900	Pablo/ December 2012	25-Year
131	7.136622	125.928787	0.76	1.20	0.1936	Pablo/ December 2012	25-Year
132	7.137085	125.926981	2.61	0.51	4.4100	Pablo/ December 2012	25-Year
133	7.147433	125.933650	2.68	0.50	4.7524	Pablo/ December 2012	25-Year
134	7.136626	125.928154	2.72	1.20	2.3104	Pablo/ December 2012	25-Year
135	7.128396	125.915258	1.62	0.50	1.2544	Intense Rainfall	25-Year
136	7.128485	125.915439	2.21	0.50	2.9241	Intense Rainfall	25-Year
137	7.129854	125.913368	1.42	0.20	1.4884	Pablo/ December 2012	25-Year
138	7.147163	125.933467	2.62	0.74	3.5344	Pablo/ December 2012	25-Year
139	7.147249	125.934101	2.7	0.50	4.8400	Pablo/ December 2012	25-Year
140	7.147341	125.933920	2.86	0.50	5.5696	Pablo/ December 2012	25-Year
141	7.146981	125.933556	2.78	0.74	4.1616	Pablo/ December 2012	25-Year
142	7.147702	125.933832	1.73	1.20	0.2809	Pablo/ December 2012	25-Year
143	7.136812	125.927431	2.32	0.51	3.2761	Pablo/ December 2012	25-Year
144	7.144462	125.932002	2.61	0.80	3.2761	Pablo/ December 2012	25-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error (m)	Event/Date	Rain Return/ Scenario
	Lat	Long					
145	7.146893	125.933284	2.97	0.74	4.9729	Pablo/ December 2012	25-Year
146	7.128393	125.915710	1.76	0.50	1.5876	Buhawi/ 2002	25-Year
147	7.138709	125.913152	0.09	0.20	0.0121	Pablo/ December 2012	25-Year
148	7.138888	125.913425	0.88	0.20	0.4624	Pablo/ December 2012	25-Year
149	7.139135	125.917135	0.98	0.00	0.9604		25-Year
150	7.140242	125.913614	0.25	0.10	0.0225	Pablo/ 2012	25-Year
151	7.145568	125.914281	0.6	0.50	0.0100	Pablo/ 2012	25-Year
152	7.143299	125.915895	0.03	0.00	0.0009		25-Year
153	7.143214	125.914990	0.03	0.10	0.0049	Pablo/ 2012	25-Year
154	7.139701	125.913430	0.34	0.10	0.0576	Pablo/ 2012	25-Year
155	7.137957	125.917760	1.21	0.00	1.4641		25-Year
156	7.145390	125.913828	0.44	0.31	0.0169	Intense Rainfall/ 2016	25-Year
157	7.139245	125.914060	0.58	0.00	0.3364		25-Year
158	7.162376	125.941976	6.59	5.00	2.5281		25-Year
159	7.170012	125.934698	3.96	5.00	1.0816	Pablo/ December 2012	25-Year
160	7.162642	125.942792	7.01	5.00	4.0401	Pablo/ December 2012	25-Year
161	7.162718	125.930853	5.23	5.00	0.0529	Pablo/ December 2012	25-Year
162	7.167217	125.933776	5.02	5.00	0.0004	Pablo/ December 2012	25-Year
163	7.166677	125.933501	4.64	5.00	0.1296	Pablo/ December 2012	25-Year
164	7.164429	125.931859	4.43	5.00	0.3249	Pablo/ December 2012	25-Year
165	7.163092	125.943066	8.05	5.00	9.3025		25-Year
166	7.163525	125.931853	5.84	5.00	0.7056	Pablo/ December 2012	25-Year
167	7.165956	125.933135	7.37	5.00	5.6169	Pablo/ December 2012	25-Year
168	7.160573	125.927221	0.03	1.20	1.3689	Intense Rainfall/ 2013	25-Year
169	7.159404	125.926399	1.08	0.51	0.3249	Intense Rainfall/ January 2016	25-Year
170	7.158230	125.926301	0.03	0.80	0.5929	Pablo/ December 2012	25-Year
171	7.152318	125.918304	0.03	0.00	0.0009		25-Year
172	7.152690	125.916678	0.03	0.00	0.0009		25-Year
173	7.153787	125.914605	0.03	0.00	0.0009		25-Year
174	7.155158	125.912081	0.03	0.00	0.0009		25-Year
175	7.154879	125.913436	0.03	0.00	0.0009		25-Year
176	7.152870	125.916770	0.03	0.00	0.0009		25-Year
177	7.152687	125.917221	0.13	0.00	0.0169		25-Year
178	7.152502	125.917762	0.03	0.00	0.0009		25-Year
179	7.152964	125.916228	0.03	0.00	0.0009		25-Year
180	7.159672	125.926853	2.62	0.30	5.3824	Intense Rainfall/ June 2016	25-Year
				RMSE	**0.990568**		

Annex 11. Educational Institutions Affected by Flooding in Kingking Floodplain

COMPOSTELA VALLEY

Pantukan

Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
PANTUKAN COLLEGE	Bongbong		Low	Low
ARABIC SCHOOL	Kingking	Medium	Medium	Medium
AYAN DAY CARE CENTER	Kingking	Medium	Medium	Medium
AYAN ELEMENTARY SCHOOL	Kingking	Medium	Medium	High
DAY CARE CENTER	Kingking	Medium	High	High
DEL CARMEN DAY CARE	Kingking	Medium	Medium	Medium
DOROTEO DAY CARE CENTER	Kingking	High	High	High
DOROTEO DE CASTRO ELEMENTARY SCHOOL	Kingking			
KINGKING CENTRAL ELEMENTARY SCHOOL	Kingking	Medium	Medium	High
NESTOR FANSTA MEMORIAL COLLEGE	Kingking	Medium	Medium	Medium
PANTUKAN DAY CARE CENTER	Kingking	Medium	Medium	Medium
PANTUKAN ELEMENTARY SCHOOL	Kingking	Medium	Medium	High
PANTUKAN NATIONAL HIGH SCHOOL	Kingking	Medium	Medium	High
PANTUKAN NATIONAL HIGH SCHOOL (PRINCIPAL'S OFFICE)	Kingking	Medium	Medium	High
PANTUKAN NATIONAL HIGH SCHOOL LIBRARY	Kingking	Medium	Medium	High
SACRED CHILDREN LEARNING CENTER	Kingking	Medium	Medium	Medium
TUGOP DAYCARE CENTER	Kingking	High	High	High
TUGOP ELEMENTARY SCHOOL	Kingking			

Annex12. Medical Institutions Affected by Flooding in Kingking Floodplain

COMPOSTELA VALLEY

Pantukan

Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
COMPOSTELA VALLEY PROVINCIAL HOSPITAL (PANTUKAN)	Kingking		Low	Medium
HEALTH CENTER	Kingking	Medium	Medium	High
LLANTO BLDG. / SAN ROQUE MATERNITY CLINIC	Kingking	Low	Low	Medium
NUTRITION CENTER	Kingking	Medium	Medium	Medium
PANTUKAN RURAL HEALTH UNIT (HEALTH CENTER)	Kingking	Medium	Medium	Medium