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

LiDAR Surveys and Flood Mapping of Paliwan River





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

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LIST OF ACRONYMS AND ABBREVIATIONS

AAC	Asian Aerospace Corporation IMU Inertial Mea		Inertial Measurement Unit	
Ab	Abutment	Kts	Knots	
ALTM	Airborne LiDAR Terrain Mapper	LAS	LiDAR Data Exchange File format	
ARG	automatic rain gauge	LC	Low Chord	
ATQ	Antique	LGU	local government unit	
AWLS	Automated Water Level Sensor	Lidar	Light Detection and Ranging	
BA	Bridge Approach	LMS	LiDAR Mapping Suite	
BM	Benchmark	m AGL	meters Above Ground Level	
CAD	Computer-Aided Design	MMS	Mobile Mapping Suite	
CN	Curve Number	MSL	mean sea level	
CSRS	Chief Science Research Specialist	NAMRIA	National Mapping and Resource Infor- mation Authority	
DAC	Data Acquisition Component	NSTC	Northern Subtropical Convergence	
DEM	Digital Elevation Model	PAF	Philippine Air Force	
DENR	Department of Environment and Natural Resources	PAGASA	Philippine Atmospheric Geophysical and Astronomical Services Adminis- tration	
DOST	Department of Science and Tech- nology	PDOP	Positional Dilution of Precision	
DPPC	Data Pre-Processing Component	РРК	Post-Processed Kinematic [technique]	
DREAM	REAM Disaster Risk and Exposure Assess- ment for Mitigation [Program]		Pulse Repetition Frequency	
DRRM	1 Disaster Risk Reduction and Man- agement		Philippine Transverse Mercator	
DSM	Digital Surface Model	QC	Quality Check	
DTM	Digital Terrain Model	QT	Quick Terrain [Modeler]	
DVBC	Data Validation and Bathymetry Component	RA	Research Associate	
FMC	Flood Modeling Component	RIDF	Rainfall-Intensity-Duration-Frequency	
FOV	Field of View	RMSE	Root Mean Square Error	
GiA	Grants-in-Aid	SAR	Synthetic Aperture Radar	
GCP	Ground Control Point	SCS	Soil Conservation Service	
GNSS	Global Navigation Satellite System	SRTM	Shuttle Radar Topography Mission	
GPS	Global Positioning System	SRS	Science Research Specialist	
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System	SSG	Special Service Group	
HEC-RAS	Hydrologic Engineering Center - River Analysis System	ТВС	Thermal Barrier Coatings	
НС	High Chord	UPC	University of the Philippines Cebu	
IDW	Inverse Distance Weighted [interpo- lation method]	WGS	World Geodetic System	

CHAPTER 1: OVERVIEW OF THE PROGRAM AND THE PALIWAN RIVER BASIN

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

1.1 Background of the Phil-LiDAR 1 Program

The University of the Philippines Training Center for Applied Geodesy and Photogrammetry (UP-TCAGP) launched a research program entitled "Nationwide Hazard Mapping using LiDAR" or Phil-LiDAR 1 in 2014, 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 described 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 Philippine Cebu. UPC is in charge of processing LiDAR data and conducting data validation reconnaissance, cross section, bathymetric survey, validation, river flow measurements, flood height and extent data gathering, flood modeling, and flood map generation for the 22 river basins in the Central Visayas Region. The university is located in Cebu City, Cebu.

1.2 Overview of the Paliwan River Basin

Paliwan River Basin is located in the province of Antique at the west of Panay Island. The DENR river Basin Control Office (RCBO) identified it to be one of the 421 river basins in the Philippines, having an estimated 262 million cubic meter annual run-off. It is also one of the seven (7) major river basins in Antique (River Basin Control Office, 2017). The floodplain and drainage area of 38.48 km² and 28.4 km², respectively, covers the municipalities of Bugasong, Tapaz, Jamindan, Barbaza and Valderrama. The gathered LiDAR data covered 98.05% of the floodplain comprised by four (4) blocks. The LiDAR data was calibrated then mosaicked with an RMSE of -0.06 and then bathy burned. The bathy survey done reached a total length of 9.85 km starting from Maray, Bugasong up to the river mouth with 576 points surveyed. The LiDAR data also showed that there are 4013 buildings, 38.56 km roads, 11 waterbodies and 12 bridges. When Feature Extraction Attribution was conducted, among the building featured, 3852 of them are residential, 64 are schools and five (5) are medical Institutions.

Its main stem, Paliwan River, passes along the Municipality Bugasong and is part of the 23 river systems in Western Visayas. There is a total of 6,791 people residing within the immediate vicinity of the river which is distributed among seven (7) barangays located in Municipality of Bugasong, namely: Maray, Anilawan, Tagudtud North, Talisay, Cubay North, Paliwan, and Lugta (Philippine Statistics Authority, 2016). The river is rich in good quality gravel and sand wherein local private quarry companies extract from the riverbed and export abroad (Guntan, 2015).

The flood hazard map produced covers the 60.99 km², 74.98 km², 83.16 km² for the 5-year, 25-year, and 100-year rainfall return period in Barbaza which affects one (1) barangay as well as in Laua-an which affects 18 barangays, Bugasong with 28 barangays, Lambunao with one (1) barangay, Patnongon with 20 barangays, San Remigio with two (2) barangays, Tapaz with (1) barangay, and Valderrama with 23 barangays. In addition, a flood depth validation was conducted using 276 randomly generated points which was spread throughout the 6 ranges namely 0m-0.2m, 0.21m-0.5m, 0.51m-1m, 1.01m-2m, 2.10m-5m, 5m+ depth using the 25-year rainfall flood depth map. It yielded a 0.716m RMSE.



Figure 1. Map of the Paliwan River Basin (in brown)

The rating curve developed at Brgy. Anilawan Flow Site, Bugasong, Antique shows the relationship between the observed water levels at Brgy. Anilawan Flow Site and outflow of the watershed in this location. This rating curve equation, expressed as Q = 66.291e0.5476x, was used to compute the river outflow at Brgy. Anilawan Flow Site for the calibration of the HEC-HMS model. The resulting outflow was used to simulate the flooded areas using HEC-RAS. The simulated model will be an integral part in determining the real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website.

CHAPTER 2: LIDAR DATA ACQUISITION OF THE PALI-WAN FLOODPLAIN

Engr. Louie P. Balicanta, Engr. Christopher Cruz, Lovely Gracia Acuña, Engr. Gerome Hipolito, Ms. Sandra C. Poblete, and Engr. Grace Sinadjan

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

2.1. Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Paliwan Floodplain in Antique. Each flight mission has an average of 12 lines and ran for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameters for the LiDAR system is found in Tables 1 to 4. Figures 2 to 4 show the flight plans for Paliwan floodplain.

Block Name	Flying Height (m AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequen- cy (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK43B	1200	30	50	100	50	120	5
BLK43C	1200	30	50	100	50	120	5

Table 1. Flight planning parameters for Gemini LiDAR System.

Table 2. Flight planning parameters for Pegasus LiDAR System.

Block Name	Flying Height (m AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequen- cy (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK43B	1500	30	50	200	30	130	5

Table 3. Flight planning parameters for Aquarius LiDAR System.

Block Name	Flying Height (m AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequen- cy (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK43K	600	30	36	50	45	130	5

	Block Name	Flying Height (m AGL)	Integration Time	Along Track Resolution	Across Track Reso- lution	Number of Bands	Aperture	Average speed of Plane (kts)
ŀ	BLK37K	600	10 m/sec	0.6m	0.3m	72	Largest	120

Table 4. Flight planning parameters for CASI.



Figure 2. Flight plan and base stations using the Gemini system to cover Paliwan Floodplain.



Figure 3. Flight plan and base stations using the Pegasus system to cover Paliwan Floodplain.



Figure 4. Flight plan and base stations using the Aquarius system to cover Paliwan Floodplain.

2.2 Ground Base Station

The project team was able to recover three (3) NAMRIA reference points: ATQ-18, ATQ-20 and ATQ-22 which is of second (2nd) order accuracy. There are two (2) established reference points: AQ-10 and AQ-78. The certification for the base station is found in Annex 4. These were used as base stations during flight operations for the entire duration of the survey (February 2015 and October 2016). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 852 and TRIMBLE SPS 985. Flight plans and location of base stations used during the aerial LiDAR Acquisition in Paliwan floodplain are shown in Figures 2 to 4.

Figure 5 to Figure 9 shows the recovered NAMRIA control station within the area, in addition Table 5 to Table 9 show the details about the following NAMRIA control stations and established points, Table 10 shows the list of all ground control points occupied during the acquisition together with the dates they are utilized during the survey.



(a)



Figure 5. GPS set-up over ATQ-18 as recovered in Barangay Cubay, Barbaza, Province of Antique (a) NAMRIA reference point ATQ-18 (b) as recovered by the field team.

Table 5. Details of the recovered NAMRIA horizontal control point ATQ-18 used as base station for the LiDAR Acquisition.

Station Name	ATQ-18				
Order of Accuracy	2 nd				
Relative Error (horizontal positioning)	-	1 in 50,000			
	Latitude	11° 11′ 58.67081″			
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Longitude	122° 2′ 22.83300″			
	Ellipsoidal Height	10.902 meters			
Grid Coordinates, Philippine Transverse Merca-	Easting	395155.157 meters			
tor Zone 5 (PTM Zone 5 PRS 92)	Northing	1238579.674 meters			
	Latitude	11° 11′ 54.16068″ North			
Geographic Coordinates, World Geodetic Sys- tem 1984 Datum (WGS 84)	Longitude	122° 2' 28.01549" East			
	Ellipsoidal Height	65.961 meters			
Grid Coordinates, Universal Transverse Merca-	Easting	395155.87 meters			
tor Zone 51 North (UTM 51N PRS 1992)	Northing	1238146.15 meters			





Figure 6. GPS set-up over ATQ-20 as recovered in Brgy. Zaragoza of Bugasong (a) NAMRIA reference point ATQ-20 (b) as recovered by the field team.

Station Name	ATQ-20				
Order of Accuracy	2 nd				
Relative Error (horizontal positioning)	1	. in 50,000			
	Latitude	11° 0′ 42.90484″			
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Longitude	122° 2′ 54.07144″			
	Ellipsoidal Height	10.56200 meters			
Grid Coordinates, Philippine Transverse Mer-	Easting	396000.488 meters			
cator Zone 5 (PTM Zone 5 PRS 92)	Northing	1217812.272 meters			
	Latitude	11° 0' 38.44240" North			
Geographic Coordinates, World Geodetic Sys- tem 1984 Datum (WGS 84)	Longitude	122° 2' 59.27039" East			
	Ellipsoidal Height	66.09400 meters			
Grid Coordinates, Universal Transverse Merca-	Easting	396036.89 meters			
tor Zone 51 North (UTM 51N PRS 1992)	Northing	1217386.02 meters			

Table 6. Details of the recovered NAMRIA horizontal control point ATQ-20 used as base station for the LiDAR Acquisition.





Figure 7. (a) ATQ-22 as recovered in Barangay Concepcion, Belison, Province of Antique. (b) NAMRIA reference point ILO-3134 as recovered by the field team.

Table 7. Details of the recovered NAMRIA horizontal control point ATQ-22 used as base stationfor the LiDA	AR
Acquisition.	

Station Name	ATQ-22			
Order of Accuracy		2 nd		
Relative Error (horizontal positioning)	1 iı	n 50,000		
	Latitude	10° 49' 46.66618"		
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Longitude	121° 58′ 11.90221″		
	Ellipsoidal Height	12.250 meters		
Grid Coordinates, Philippine Transverse Mer-	Easting	387365.279 meters		
cator Zone 5 (PTM Zone 5 PRS 92)	Northing	1197676.056 meters		
	Latitude	10° 49' 42.24271" North		
Geographic Coordinates, World Geodetic Sys- tem 1984 Datum (WGS 84)	Longitude	121° 58' 17.11770" East		
	Ellipsoidal Height	68.022 meters		
Grid Coordinates, Universal Transverse Merca-	Easting	387404.70 meters		
tor Zone 51 North (UTM 51N PRS 1992)	Northing	1197256.85 meters		



Figure 8. GPS set-up over AQ-10 as recoverd in Brgy. Zaragoza (a) NAMRIA reference point AQ-10 (b) as recovered by the field team.

	,				
Station Name		ATQ-10			
Order of Accuracy		2 nd			
Relative Error (horizontal positioning)	1	in 50,000			
	Latitude	11° 01' 03.59755″			
Geographic Coordinates, Philippine Refer- ence of 1992 Datum (PRS 92)	Longitude	122° 03' 00.53639"			
	Ellipsoidal Height	11.054 meters			
Grid Coordinates, Philippine Transverse Mer-	Easting	396235.105 meters			
cator Zone 5 (PTM Zone 5 PRS 92)	Northing	1218020.995 meters			
	Latitude	11° 00' 59.12282" North			
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Longitude	122° 03' 05.73482" East			
	Ellipsoidal Height	66.576 meters			

Table 8. Details of the recovered NAMRIA horizontal control point AQ-10 used as base station for the LiDAR Acquisition.





Figure 9. GPS set-up over AQ-78 as recovered in Barangay Ipayo, Patnongon, Province of Antique (a) NAMRIA reference point AQ-78 (b) as recovered by the field team.

Table 9. Details of the recovered NAMRIA vertical control point AQ-78 used as base station for
the LiDAR Acquisition.

Station Name	AQ-78		
Order of Accuracy		2 nd	
Relative Error (horizontal positioning)		1 in 50,000	
	Latitude	10° 55′ 03.77330″	
Geographic Coordinates, Philippine Reference of	Longitude	121° 59′ 46.81987″	
1992 Datum (PRS 92)	Ellipsoidal Height	48.448 meters	
Grid Coordinates, Philippine Transverse Merca-	Easting	390150.425 meters	
tor Zone 5 (PTM Zone 5 PRS 92)	Northing	1207471.411 meters	
	Latitude	10° 54' 59.33002" North	
Geographic Coordinates, World Geodetic System	Longitude	121° 59' 52.02741" East	
1984 Datum (WGS 84)	Ellipsoidal Height	66.5525 meters	
Grid Coordinates, Universal Transverse Mercator	Easting	390319.320 meters	
Zone 51 North (UTM 51N WGS 1984)	Northing	1206987.603 meters	

Table 10. Ground Control Points used during LiDAR data acquisiton.

Date Surveyed	Flight Number	Mission Name	Ground Control Points
Feb. 20, 2015	2593P	1BLK43BDG051A	ATQ-18 and ATQ-22
Feb. 25, 2015	o. 25, 2015 2602G 2BLK43B056A		ATQ-22 and AQ-78
Feb. 26, 2015	2606G	2BLK43BV057A	ATQ-22 and AQ-78
Feb. 27, 2015	2610G	2BLK43BV058A	ATQ-22 and AQ-78
Oct. 25, 2016	8511AC	3BLK43KJ299A	ATQ-20 and AQ-10
Oct. 27, 2016	8515AC	3BLK43K301A	ATQ-20 and AQ-10

2.3. Flight Missions

Six (6) missions were conducted to complete the LiDAR Data Acquisition in Paliwan Floodplain, for a total of twenty-one hours (21) of flying time for RP-C9122, RP-C9022 and RP-C9322 All missions were acquired using the Gemini, Pegasus and Aquarius LiDAR system. Table 11 shows the total area of actual coverage per mission and the flying length for each mission and Table 12 presents the actual parameters used during the LiDAR data acquisition.

Date Sur- veyed	Flight Num- ber	Flight Plan Area (km²)	Surveyed Area (km ²) Area (km ²) Area (km ²) Area Sur- veyed with- in the River Systems (km ²) Area Sur- Surveye Outside the River Systems (km ²)		Area Surveyed Outside the River Systems (km²)	No. of Images (Frames)	Flying ू	Hours Min
Feb. 20, 2015	2593P	248.27	180.57	12.88	167.69	427	3	29
Feb. 21, 2015	2602G		89.82	7.99	81.83	0	3	17
Feb. 22, 2015	2606G	224.96	221.78	17.75	204.03	0	4	5
Feb. 20, 2015	2610G		34.35	1.15	33.2	0	3	5
Feb. 25, 2015	8511AC	29.89	25.58	4.8	20.78	0	3	35
Feb. 26, 2015	8515AC		17.2	9.02	8.18	0	3	29
то	TAL	503.12	569.3	53.59	515.71	427	21	00

Table 11. Flight Missions for LiDAR Data Acquisition in Paliwan Floodplain.

Table 12	Actual Parameters	used during	LiDAR Data	Acquisiton
Table 12.	Actual I afameters	uscu uuring	LIDAK Data	Acquisiton

Flight Number	Flying Height (AGL) (m)	Overlap (%)	Field of View	PRF (Hz)	Scan Frequency (Hz)	Speed of Plane (Kts)	Average Turn times (Minutes)
2593P	1800	30	40	200	50	120	5
2602G	1200	30	40	100	50	125	5
2606G	1800	30	40	70	56	110	5
2610G	2000	30	34	70	56	110	5
8511AC	600	30	18	45	50	120	5
8515AC	600	30	18	45	50	120	5

2.4. Survey Coverage

Paliwan floodplain is located in the provinces of Antique and Iloilowith majority of the floodplain situated within the municipality of Laua-An. The list of municipalities and cities surveyed with at least one (1) square kilometer coverage, is shown in Table 13. The actual coverage of the LiDAR acquisition for Paliwan floodplain is presented in Figure 10.

Province	Municipality/City	Area of Municipality/ City (km ²)	Total Area Sur- veyed (km ²)	Percentage of Area Surveyed
	Patnongon	135.68	79.96	59 %
	Laua-An	165.65	78.94	48 %
	Bugasong	178.8	69.82	39 %
Antique	San Remigio	370.9	59.9	16 %
	Valderrama	309.67	39.53	13 %
	Barbaza	171.23	14.32	8 %
	Belison	36.8	2.62	7 %
	Sibalom	240.55	10.96	5 %
lloilo	Igbaras	132.37	7.92	6 %
	San Joaquin	200.06	9.1	5 %
	Miagao	170.53	3.11	2 %

Table 12 List of m	nunicipalities and	citios survovod	during Paliwan	floodplain LiDAR survey
Iddle T2. FISCOL II	indificipatities and	cities surveyed	uuring Paliwali	HOOUDIAIH LIDAR SUIVEY.



Figure 10. Actual LiDAR data acquisition of the Paliwan floodplain

CHAPTER 3: LIDAR DATA PROCESSING OF THE PALI-WAN 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 are checked for completeness based on the list of raw files required to proceed with the pre-processing of the LiDAR data. Upon acceptance of the LiDAR field data, georeferencing of the flight trajectory is done in order to obtain the exact location of the LiDAR sensor when the laser was shot. Point cloud georectification is performed to incorporate correct position and orientation for each point acquired. The georectified LiDAR point clouds are subject for quality checking to ensure that the required accuracies of the program, which are the minimum point density, vertical and horizontal accuracies, are met. The point clouds are then classified into various classes before generating Digital Elevation Models such as Digital Terrain Model and Digital Surface Model.

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

These processes are summarized in the flowchart shown in Figure 11.



Figure 11. Schematic Diagram for Data Pre-Processing Component

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Paliwan floodplain can be found in Annex 8 (Data Transfer Sheets). Missions flown during the first survey conducted last March 2015 used the Airborne LiDAR Terrain Mapper (ALTM[™] Optech Inc.) Pegasus system while missions acquired during the second survey last July 2015 were flown using the Gemini system over Laua-an, Antique. The Data Acquisition Component (DAC) transferred a total of 37.8 Gigabytes of Range data, 761 Megabytes of POS data, 38.69 Megabytes of GPS base station data, and 61.32 Gigabytes of raw image data to the data server last March 23, 2015 for the first survey and July 3, 2015 for the second survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Paliwan was fully transferred on July 3, 2015, as indicated on the Data Transfer Sheets for Paliwan floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 2593P, one of the Paliwan flights, which is the North, East, and Down position RMSE values are shown in Figure 12. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on February 20, 2015 00:00AM. The y-axis is the RMSE value for that particular position.



Figure 12. Smoothed Performance Metrics of a Paliwan Flight 2593P.

The time of flight wafrom 455,250 seconds to 463,500 seconds, which corresponds to morning of February 20, 2015. The initial spike that is seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the POS system starts computing for the position and orientation of the aircraft. Redundant measurements from the POS system quickly minimized the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values correspond to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 12 shows that the North position RMSE peaks at 1.00 centimeters, the East position RMSE peaks at 1.60 centimeters, and the Down position RMSE peaks at 3.30 centimeters, which are within the prescribed accuracies described in the methodology.



Figure 13. Solution Status Parameters of Paliwan Flight 2593P.

The Solution Status parameters of flight 2593P, one of the Paliwan flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 13. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Majority of the time, the number of satellites tracked was between 6 and 8. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode stayed at the value of 0 for majority of the survey with some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Paliwan flights is shown in Figure 14.



Figure 14. Best Estimated Trajectory for Paliwan floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 19 flight lines, with 6 flight lines containing two channels and the rest containing on channel only, since the Pegasus and Aquarius systems contain two and one channel respectively. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Paliwan floodplain are given in Table 14.

Parameter	Accepted Value	Computed Value
Boresight Correction stdev	(<0.001degrees)	0.000371
IMU Attitude Correction Roll and Pitch Corrections stdev	(<0.001degrees)	0.000661
GPS Position Z-correction stdev	(<0.01meters)	0.0091

Table 14. Self-Calibr	ation Results va	dues for Paliwa	n flights
-----------------------	------------------	-----------------	-----------

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

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Paliwan Floodplain is shown in Figure 15. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.



Figure 15. Boundary of the processed LiDAR data over Paliwan Floodplain

The total area covered by the Paliwan missions is 395.11 sq.km that is comprised of four (4) flight acquisitions grouped and merged into two (2) blocks as shown in Table 15.

	1	
LiDAR Blocks	Flight Numbers	Area (sq. km)
Iloilo_Blk43B	2593P	141.22
	2602G	
Iloilo_Blk43B_additional	2606G	229.08
	2610G	
Iloilo_reflights_Blk43B	8511AC	15.69
Iloilo_reflights_Blk43B_supplement	8515AC	17.23
	TOTAL	395.11 sq.km

Table 15	List of	Lidar	blocks f	for P	aliwan	floodr	lain
Table 19.	LISCOL	LIDAK	DIOCKSI	UL L	anvan	ուօսե	Jiami.

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 16. Since the Pegasus and Aquarius systems employ two and one channel respectively, we would expect an average value of 1 (blue) for areas where there is limited overlap, and a value of 2 (yellow) or more (red) for areas with three or more overlapping flight lines.



Figure 16. Image of data overlap for Paliwan floodplain.

The overlap statistics per block for the Paliwan floodplain can be found in Annex 5. One pixel corresponds to 25.0 square meters on the ground. For this area, the percent overlap is 25.93%, which passed the 25% requirement.

The 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 17. It was determined that all LiDAR data for Paliwan floodplain satisfy the point density requirement, and the average density for the entire survey area is 2.40 points per square meter.



Figure 17. Density map of merged LiDAR data for Paliwan floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 18. 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 18. Elevation difference map between flight lines for Paliwan floodplain.

A screen capture of the processed LAS data from a Paliwan flight 2593P loaded in QT Modeler is shown in Figure 19. 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 researcher was satisfied with the quality of the LiDAR data. No reprocessing was done for this LiDAR dataset.



Figure 19. Quality checking for Paliwan flight 2593P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Pertinent Class	Total Number of Points		
Ground	293,176,098		
Low Vegetation	102,063,776		
Medium Vegetation	227,297,359		
High Vegetation	439,049,485		
Building	5,263,821		

Table 16. Paliwan classification results in TerraScan.

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Paliwan floodplain is shown in Figure 20. A total of 485 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 16. The point cloud has a maximum and minimum height of 925.04 meters and 54.48 meters respectively.

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



Figure 20. Tiles for Paliwan 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 21. 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 21. 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 22. It shows that DTMs are the representation of the bare earth while on the DSMs, all features are present such as buildings and vegetation.



Figure 22. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Paliwan floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 482 1km by 1km tiles area covered by Paliwan floodplain is shown in Figure 23. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Paliwan floodplain has a total of 326.67 sq.km orthophotogaph coverage comprised of 772 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 24.



Figure 23. Paliwan floodplain with available orthophotographs.



Figure 24. Sample orthophotograph tiles for Paliwan floodplain.
3.8 DEM Editing and Hydro-Correction

Four (4) blocks were processed for Paliwan floodplain. These blocks are composed Iloilo blocks and Iloilo reflights with a total area of 395.11 square kilometers. Table 17 shows the name and corresponding area of each block in square kilometers.

Table 17. LiDAR blocks with its corresponding area.

LiDAR Blocks	Area (sq.km)
Iloilo_Blk43B	136.14
Iloilo_Blk43B_additional	226.06
Iloilo_reflights_Blk43B	15.69
Iloilo_reflights_Blk43B_supplement	17.23
TOTAL	395.11 sq.km

Portions of DTM before and after manual editing are shown in Figure 25. It shows that the paddy field (Figure 25a) has been misclassified and removed during classification process and has to be retrieved to complete the surface (Figure 25b). The bridges (Figure 25c) would be an impedance to the flow of water along the river and have to be removed (Figure 25d) in order to hydrologically correct the river.



Figure 25. Portions in the DTM of Paliwan floodplain – a paddy field before (a) and after (b) data retrieval; bridge before (c) and after (d) manual editing

3.9 Mosaicking of Blocks

Iloilo_Blk43B was used as the reference block at the start of mosaicking because it was referred to a base station with an acceptable order of accuracy. Table 18 shows the area of each LiDAR block and the shift values applied during mosaicking.

Mosaicked LiDAR DTM for Paliwan floodplain is shown in Figure 26. It can be seen that the Paliwan floodplain is 98.05% covered by LiDAR data.

Mission Blocks	Shift Values (meters)			
	х	У	Z	
Iloilo_Blk43B	0.00	0.00	-1.42	
Iloilo_Blk43B_additional(left portion)	0.00	0.00	-1.20	
Iloilo_Blk43B_additional(right portion)	0.00	1.00	-1.27	
lloilo_reflights_Blk43B	0.00	0.00	-0.49	
Iloilo_reflights_Blk43B_supplement	0.00	0.00	-0.59	

Table 18. Shift Values of each LiDAR Block of Paliwan floodplain.



Figure 26. Map of Processed LiDAR Data for Paliwan Flood Plain.

3.10 Calibration and Validation of Mosaicked LiDAR DEM

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Paliwan to collect points with which the LiDAR dataset is validated is shown in Figure 27. A total of 7,511 points were gathered for all the floodplains within the Province of Antique wherein the Paliwan is located. However, the point dataset was not used for the calibration of the LiDAR data for Paliwan because during the mosaicking process, each LiDAR block was referred to the calibrated Jalaur DEM. Therefore, the mosaicked DEM of Paliwan can already be considered as a calibrated DEM.

A good correlation between the uncalibrated Jalaur LiDAR DTM and ground survey elevation values is shown in Figure 28. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration points is 1.71 meters with a standard deviation of 0.17 meters. Calibration of Jalaur LiDAR data was done by subtracting the height difference value, 1.71 meters, to Jalaur mosaicked LiDAR data. Table 19 shows the statistical values of the compared elevation values between Jalaur LiDAR data and calibration data. These values were also applicable to the Paliwan DEM.



Figure 27. Map of Paliwan Flood Plain with validation survey points in green.



Figure 28. Correlation plot between calibration survey points and LiDAR data.

Calibration Statistical Measures	Value (meters)
Height Difference	1.71
Standard Deviation	0.17
Average	-1.70
Minimum	-2.13
Maximum	-1.16

Table 19. Calibration Statistical Measures.

A total of 165 survey points that are within Paliwan flood plain were used for the validation of the calibrated Paliwan 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 29. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.03 meters with a standard deviation of 0.03 meters, as shown in Table 20.



Figure 29. Correlation plot between validation survey points and LiDAR data.

Validation Statistical Measures	Value (meters)
RMSE	0.03
Standard Deviation	0.03
Average	0.002
Minimum	-0.04
Maximum	0.002

Table 20. Validation Statistical Measures.

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and zigzag data were available for Paliwan with 518 bathymetric survey points. The resulting raster surface produced was done by Inverse Distance Weighted (IDW) interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.0025 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Paliwan integrated with the processed LiDAR DEM is shown in Figure 30.



Figure 30. Map of Paliwan Flood Plain with bathymetric survey points shown in blue.

3.12 Feature Extraction

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

3.12.1 Quality Checking of Digitized Features' Boundary

Paliwan floodplain, including its 200 m buffer, has a total area of 34.84 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 1597 building features, are considered for QC. Figure 31 shows the QC blocks for Paliwan floodplain.



Figure 31. QC blocks for Paliwan building features.

Quality checking of Paliwan building features resulted in the ratings shown in Table 21.

FLOODPLAIN COMPLETENESS CORRECTNESS QUALITY REMARKS								
Paliwan	99.44	99.87	99.25	PASSED				

Table 21. Quality Checking Ratings for Paliwan Building Features.

3.12.2 Height Extraction

Height extraction was done for 4090 building features in Paliwan floodplain. Of these building features, 77 was filtered out after height extraction, resulting to 4013 buildings with height attributes. The lowest building height is at 2.0 m, while the highest building is at 6.88 m.

3.12.3 Feature Attribution

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

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

Table 22 summarizes the number of building features per type while Table 23 shows the total length of each road type, and Table 24 shows the number of water features extracted per type.

Facility Type	No. of Features
Residential	3,852
School	64
Market	10
Agricultural/Agro-Industrial Facilities	0
Medical Institutions	5
Barangay Hall	6
Military Institution	0
Sports Center/Gymnasium/Covered Court	14
Telecommunication Facilities	0
Transport Terminal	1
Warehouse	4
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	0
Water Supply/Sewerage	0
Religious Institutions	30
Bank	0
Factory	0
Gas Station	0
Fire Station	0
Other Government Offices	1
Other Commercial Establishments	19
Others	7
Total	4,013

Table 22. Building Features Extracted for Paliwan Floodplain.

Table 23. Total Length of Extracted Roads for Failwait Proouplain.						
Road Network Length (km)						
Floodplain	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	Total
Paliwan	32.9	0	0	5.66	0.00	38.56

Table 23. Total Length of Extracted Roads for Paliwan Floodplain	1.
--	----

Table 24. Number of Extracted Water Bodies for Paliwan Floodplain.

Floodplain	Rivers/ Lakes/					Total
	Streams	Ponds	Sea	Dam	Fish Pen	
Paliwan	7	0	0	0	4	11

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

3.12.4 Final Quality Checking of Extracted Features

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

Figure 32 shows the Digital Surface Model (DSM) of Paliwan floodplain overlaid with its ground features.



Figure 52. Extracted leatures for Pairwan hoodplain.

CHAPTER 4: LIDAR VALIDATION SURVEY AND MEASUREMENTS OF THE PALIWAN RIVER BASIN

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

4.1 Summary of Activities

The Data Validation and Bathymetry Component (DVBC) conducted field survey in Paliwan River last September 25 – October 9, 2014 with the following scope of work: reconnaissance; control survey for the establishment of a control point; cross-section, bridge as-built of Paliwan Bridge piers; ground validation data acquisition of about 82.264 km for the whole province of Antique; and bathymetric survey from Brgy. Maray, Municipality of Bugasong, Antique down to Brgy. Lugta, Municipality of Bugasong, Antique with an estimated length of 9.356 km using GNSS PPK survey technique (Figure 33).



Figure 33. Extent of the bathymetric survey (in blue line) in Paliwan River.

4.2 Control Survey

The GNSS network used in Paliwan River Survey is composed of a single loop established on September 26, 2014 occupying the following reference points: ATQ-20, a second-order GCP, located in Brgy. Zaragoza, Municipality of Bugasong, Antique; and AQ-72, a first-order BM, located in Brgy. Delima, Municipality of Belison, Antique.

A control point was established on the approach of Tipuluan Bridge, namely: TPN-1, in Brgy. Pasong, Brgy. Sibalom, Antique, to use as marker during the survey.

The summary of references and control points used in Paliwan Survey is shown in Table 25, while the GNSS network established is illustrated in Figure 34.



Figure 34. The GNSS Network established in the Paliwan River

Table 25. List of references and control points occupied during the control survey in Paliwan River survey (Source: NAMRIA, UP-TCAGP)

	Order of Accuracy	Geographic Coordinates (WGS 84)							
Control Point		Latitude	Longitude	Ellipsoidal Height (Meter)	BM Ortho (Me- ter)	Date Estab- lished			
ATQ-20	2nd	11°00′38.44240″ N	122°02'59.27039" E	66.094	-	2009			
AQ-72	1 st	-	-	61.541	5.5842	2007			
TPN-1	-	-	-		-	September 26, 2014			

The GNSS set-ups on recovered reference points and established control points in Paliwan River are shown in Figure 35 to Figure 37.



Figure 35. GNSS base receiver setup, Trimble[®] SPS 852 at ATQ-20 in Brgy. Zaragoza, Municipality of Bugasong, Antique



Figure 36. Benchmark, AQ-72, with Trimble® SPS 852 in Brgy. Delima, Municipality of Belison, Antique



Figure 37. UP-TCAGP established control point, TPN-1, with Trimble^{*} SPS 882 on Tipuluan Bridge in Brgy. Pasong, Municipality of Sibalom, Antique

4.3 Baseline Processing

GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/- 20 cm and +/- 10 cm requirement, respectively. In case where one or more baselines did not meet all of these criteria, masking is performed. Masking is done by removing/masking portions of these baseline data using the same processing software. It is repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, resurvey is initiated. Baseline processing result of control points in Paliwan River Basin is summarized in Table 26 generated by TBC software.

Observation	Date of Obser- vation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	∆Height (Meter)
ATQ-20 AQ- 72 (B4775)	09-26-2014	Fixed	0.007	0.022	208°43′33″	19743.041	-4.554
ATQ-20 TPN- 1 (B4775)	09-26-2014	Fixed	0.006	0.021	184°45'37"	24723.786	22.496
AQ-72 TPN- 1 (B4776)	09-26-2014	Fixed	0.005	0.014	134°32′57″	10438.795	27.074

Table 26. Baseline processing summary report for Paliwan River control survey

As shown in Table 26, a total of three (3) baselines were processed with reference points ATQ-20 and AQ-72 held fixed for coordinate and elevation values, respectively. All of them passed the required accuracy.

4.4 Network Adjustment

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

<20cm and

Where:

 x_{e} is the Easting Error, y_{e} is the Northing Error, and z_{a} is the Elevation Error

For complete details, see Network Adjustment Report shown in Tables 27 to 30 for reference.

The control point in which the coordinates were fixed during the network adjustment is shown in Table 27. Through this reference point, the coordinates of the unknown control points were computed. A difference in elevation of 0.9288 m between geoid (EGM2008) and MSL values of the reference point AQ-72 was applied for referring the elevation of the control points to MSL.

Point ID	Туре	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
ATQ-20	Global	Fixed	Fixed	Fixed	
Fixed = 0.000001(Meter)					

Table 27. Constraints applied to the adjustment of the control points.

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 28. The fixed control point, ATQ-20, has no values for standard errors.

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
AQ-72	386654.679	0.063	1200045.589	0.033	6.513	0.256	
ATQ-20	396195.506	?	1217324.5 63	?	10.798	?	LLh
TPN-1	394067.041	0.058	1192699.1 27	0.031	33.065	0.259	

Table 28. Adjusted grid coordinates for the control points used in the Paliwan River flood plain

The network is fixed at the reference point, ATQ-20, with known coordinates. With the mentioned equation, for horizontal and for the vertical; the computation for the horizontal and vertical accuracy are as follows:

a. AQ-72

horizontal accuracy = $\sqrt{(6.3)^2 + (3.3)^2}$ = $\sqrt{(39.69 + 10.89)}$ = 7.11 cm < 20 cm

b. TPN-1

horizontal accuracy = $V((5.8)^2 + (3.1)^2)$ = V(33.64 + 9.61)= 6.58 cm < 20 cm The list of adjusted geodetic coordinates: Latitude, Longitude, Height and computed standard errors of the control points in the network are shown in Table 29.

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
AQ-72	N10°51'14.92748"	E121°57′46.85471″	61.541	0.256	
ATQ-20	N11°00'38.44240"	E122°02'59.27039"	66.094	?	LLh
TPN-1	N10°47′16.56550″	E122°01′51.73167"	88.644	0.259	

Table 29. Adjusted geodetic coordinates for control points used in the Paliwan River Floodplain validation

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 29. Based on the result of the computation, the equation is satisfied; hence, the required accuracy for the program was met.

The summary of reference and control points used is indicated in Table 30.

Table 30. The reference and control points utilized in the Paliwan River Static Survey, with their corresponding locations (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geograph	ic Coordinates (We	GS 84)	UTM ZONE 51 N		
		Latitude	itude Longitude		Easting	MSL Eleva- tion (m)	
ATQ-20	2 nd Order GCP	11°00'38.44240"	122°02'59.27039"	66.094	396195.506	9.8692	
AQ-72	1 st Order BM	10°51′14.92748″	121°57′46.85471″	61.541	386654.679	5.5842	
TPN-1	UP Estab- lished	10°47′16.56550″	122°01′51.73167″	88.644	394067.041	32.1362	

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

Cross-section and as-built survey were conducted on October 1 and 7, 2014 at the upstream side of Paliwan Bridge in Brgy. Cubay North, Municipality of Bugasong using GNSS receiver Trimble[®] SPS 882 in PPK survey technique as shown in Figure 38.



Figure 38. Cross section survey in Paliwan Bridge, Municipality of Bugasong

The cross-sectional line for Paliwan Bridge is about 250 m with twenty (20) points gathered using TAQ-20 as GNSS base station. The location map and cross-section diagram are illustrated in Figure 39 and Figure 40, while the as-built form is shown in Figure 41.



Figure 39. Location map of the Paliwan bridge cross-section survey

Paliwan Bridge

Latitude: 11° 04' 37.80268" N Longitude: 122° 03' 22.39028" E



Figure 40. Paliwan Bridge cross-section survey drawn to scale

Bridge	Data Form
Bridge Name: Paliwan Bridge	Date:October 7, 2014
River Name: Paliwan River	Time:1:18 pm
Location (Brgy, City, Region):Bugasong, Antiqu	e Garcia
Flow condition: low normal high	Weather Condition: fair rainy
Latitude:11d04'37.80268" N	Longitude:122d03'22.39028" E
	BA3 BA4 BA = Bridge Approach P = Pier LC = Low Chord Ab = Abutment D = Deck HC = High Chord
Ab1 P	
Deck (Please start your measurement fro Elevation 10.4002 m Width:	n the left side of the bank facing downstream) Span (BA3-BA2):327.3069 m
Station	High Chord Elevation Low Chord Elevation
1 -	
3 -	
5 -	
Bridge Approach (Please start your measure	ment from the left side of the bank facing downstream)

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	0	10.4272 m	BA3	-	-
BA2	-	-	BA4	327.3299 m	10.4892 m

Abutment: Is the abutment sloping?

Yes No; If yes, fill in the following information:

	Station (Distance from BA1)	Elevation
Ab1	-	-
Ab2	-	-

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

Shape: ____ Round ____ Number of Piers: _____12 ____ Height of column footing: _____

	Station (Distance from BA1)	Elevation	Pier Width
Pier 1	27.5714 m	10.4642	-
Pier 2	52.3496 m	10.4492	-
Pier 3	52.3471 m	10.4402	-
Pier 4	77.1797 m	10.4352	-
Pier 5	77.2052 m	10.4362	-
Pier 6	101.9185 m	10.4252	-
Pier 7	101.9639 m	10.4222	-

Pier 8	126.7064 m	10.4172	-
Pier 9	126.6994 m	10.4142	-
Pier 10	151.4616 m	10.4032	-
Pier 11	151.4697 m	10.4002	-
Pier 12	176.1941 m	10.4232	-

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

Figure 41. Bridge As-built of Paliwan Bridge

4.6 Validation Points Acquisition Survey

Validation Points Acquisition Survey was conducted last October 3, 5, and 6, 2014 using a survey-grade GNSS rover receiver, Trimble[®] SPS 882, mounted on a pole which was attached in front of the vehicle as shown in Figure 42. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The antenna height of 1.53 m was measured from the ground up to the bottom of notch of the GNSS Rover receiver. The survey was conducted using PPK technique on a continuous topo mode.

The first day of ground validation started from Municipality of Tibiao and traversed major roads going to Municipality of Patnongon. Meanwhile, the second day of survey started from Municipality of San Jose up to Municipality of Patnongon, and the third ground validation survey comprised of the remaining areas. ATQ-20 was used as the GNSS base station all throughout the conduct of the survey.



Figure 42. Setup of Trimble* SPS 882 attached to a vehicle (A) and Setting up of GNSS base station at ATQ-20 (B)

The survey acquired 9,787 ground validation points with an approximate length of 82.264 km using the base station ATQ-20, as shown in the map in Figure 43.



Figure 43. Extent of the LiDAR ground validation survey of Plaiwan River Basin

4.7 Bathymetric Survey

Bathymetric survey was executed in one day, last October 1, 2014 using Trimble[®] SPS 882 in GNSS PPK survey technique as shown in Figure 44. With the help from the MDRRMO of Bugasong, the survey started upstream from in Brgy. Maray, Municipality of Bugasong with coordinates 11°03′57.90330″ 122°06′17.75217″, traversed down the river by foot and ended the survey in Brgy. Paliwan, Municipality of Bugasong with coordinates 11°04′31.59860″ 122°02′48.56782″.



Figure 44. Bathymetric survey using a Trimble® SPS 882 in GNSS PPK in Paliwan River

The bathymetric line survey has an estimated length of 9.356 km with a total of 485 points acquired using ATQ-20 as GNSS base station. The processed data was generated into map using GIS and processed further using CAD for plotting the centerline of the river. The generated map, shown in Figure 45, exhibits the bathymetry survey coverage, while Figure 46 illustrates the Paliwan riverbed profile. The highest elevation was 33.40 m in mSL in Brgy. Maray, while the lowest elevation was 0.026 m in MSL in Brgy. Paliwan.



Figure 45. Extent of the Paliwan River Bathymetry Survey





CHAPTER 5: FLOOD MODELING AND MAPPING

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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

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

5.1.2 Precipitation

Precipitation data was taken from an automatic rain gauge (ARG) deployed by the UP Cebu Flood Modeling Component (FMC) team. The ARG was installed at Brgy. Maray, Bugasong, Antique (Figure 47). The precipitation data collection started from December 8, 2016 at 4:20 PM to December 9, 2016 at 1:05 AM with a recording interval of 10 minutes.

The total precipitation for this event in Brgy Maray ARG was 48.4 mm, with a peak rainfall of 6.6 mm. on December 8, 2016 at 6:00 in the evening. The lag time between the peak rainfall and discharge is 1 hour and 50 minutes.



Figure 47. The location map of Paliwan HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

A rating curve was computed using the prevailing cross-section shown in Figure 48 at Brgy Anilawan Flow Site, Bugasong, Antique (11° 4′0.49″N, 122° 5′22.27″E) to establish the relationship between the observed water levels at Brgy Anilawan Flow Site and outflow of the watershed at this location.

For Brgy. Anilawan Flow Site, the rating curve is expressed as Q = 66.291e0.5476x [see y formula] as shown in Figure 49.



Figure 48. Cross-Section Plot of Guinabanga-an Bridge in Brgy. Anilawan



Figure 49. Rating Curve at Guinabanga-an Bridge, Brgy. Anilawan

This rating curve equation was used to compute the river outflow at Brgy. Anilawan Flow Site for the calibration of the HEC-HMS model shown in Figure 50. The total rainfall for this event is 6.6 mm and the peak discharge is 29.9 m³ second at 7:50 PM, December 8, 2016.



Figure 50. Rainfall and outflow data of the Paliwan River Basin, which was used for modeling

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed the Rainfall Intensity Duration Frequency (RIDF) values for the Iloilo Rain Gauge (Figure 51). The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the value in such a way certain peak value will be attained at a certain time (Figure 52). This station chosen based on its proximity to the Paliwan watershed. The extreme values for this watershed were computed based on a 59-year record shown in Table 31.

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	10 mins	20 mins	30 mins	1 hr	2 hrs	3 hrs	6 hrs	12 hrs	24 hrs
5	28.7	39.4	48	59.4	74.9	90	114.7	131.7	165.2
10	33.9	45.6	55.6	68.1	85	103.6	133.6	155.4	198.9
25	40.5	53.5	65.3	79.2	97.6	120.8	157.6	185.3	241.5
50	45.4	59.4	72.4	87.3	107	133.5	175.3	207.4	273.1
100	50.3	65.2	79.5	95.4	116.4	146.2	193	229.4	304.5

Table 31. RIDF values for Iloilo Rain Gauge computed by PAGASA



STREAM DEL

PALIWAN

Figure 51. Location of Iloilo RIDF station relative to the Paliwan River Basin



5.3 HMS Model

The soil shapefile was taken on 2004 from the Bureau of Soils; this is under the Department of Environment and Natural Resources Management. The land cover shape file is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Paliwan River Basin are shown in Figures 53 and 54, respectively.



Figure 53. The soil map of the Paliwan River Basin



Figure 54. The land cover map of the Paliwan River Basin

For Bago, three soil classes were identified. These are sandy loam, clay, and undifferentiated soil. Moreover, four land cover classes were identified. These are open and closed forest, shubland, and cultivated area.



Figure 55. Slope map of the Paliwan River Basin



Figure 56. Stream delineation map of the Paliwan river basin

Using the SAR-based DEM, the Paliwan basin was delineated and further subdivided into subbasins. The model consists of 31 sub basins, 15 reaches, and 15 as shown in Figure 57. The main outlet is at Brgy. Anilawan Flow Site.



5.4 Cross-section Data

Riverbed cross-sections of the watershed are crucial in the HEC-RAS model setup. The cross-section data for the HEC-RAS model was derived using the LiDAR DEM data. It was defined using the Arc GeoRAS tool and was post-processed in ArcGIS (Figure 58).



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

5.5 Flo 2D Model

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

Based on the elevation and flow direction, it is seen that the water will generally flow from the south of the model to the northeast, following the main channel. As such, boundary elements in those particular regions of the model are assigned as inflow and outflow elements respectively (See Figure 59).



Figure 59. A screenshot of the river sub-catchment with the computational area to be modeled in FLO-2D Grid Development System Pro (FLO-@D GDS Pro)



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


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

5.6 Results of HMS Calibration

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



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

Enumerated in Table 32 are the adjusted ranges of values of the parameters used in calibrating the model.

Hydrologic Element	Calculation Type	Method	Parameter	Range of Cali- brated Values
	Loss	SCS Curve number	Initial Abstraction (mm)	0.12-2.36
	LOSS	SCS Curve number	Curve Number	51.5-99
Pacin	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.25-0.295
DdSIII	ITALISIOTIII		Storage Coefficient (hr)	1.25-12.1
	Desetleur Desession	Recession Constant	1	
	Dasenow	Recession	Ratio to Peak	0.0001
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.0001

Table 32. Range of Calibrated Values for the Paliwan River Basin

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 0.12 mm - 2.36 mm means that there is minimal to average amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 51.5-99 for curve number is advisable for Philippine watersheds depending on the soil and land cover of the area (M. Horritt, personal communication, 2012). For Paliwan, the basin mostly consists of shrubland, closed and open forests, and cultivated areas, and the soil consists of clay, sandy loam, and undifferentiated areas.

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 0.25 hours to 12.1 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant of 1 indicates that the basin is unlikely to quickly go back to its original discharge and instead, will be higher. Ratio to peak of 0.0001 indicates a much steeper receding limb of the outflow hydrograph.

Manning's roughness coefficient of 0.0001 for the Paliwan river basin is lower than the usual Manning's n value in the Philippines (Brunner, 2010).

Accuracy measure	Value
RMS Error	1.4
r2	0.9816
NSE	0.94
RSR	0.25
PBIAS	-4.41

Table 33. Summary of the Efficiency	Test of Paliwan HMS Model
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The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 1.4 (m3/s).

The Pearson correlation coefficient (r2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.9816.

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 0.94.

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 0.25.

The Observation Standard Deviation Ratio, RSR, is an error index. A perfect model attains a value of 0 when the error in the units of the valuable a guantified. The model has an RSR value of -4.41.

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



Paliwan Outflow using Iloilo Rainfall Intensity Duration Frequency

Figure 63. Outflow hydrograph at Paliwan Station generated using Iloilo RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of the Paliwan discharge using the Iloilo Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 34.

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	165.2	28.7	891.1	40 minutes
10-Year	198.9	33.9	1079.9	30 minutes
25-Year	241.5	40.5	1323.7	30 minutes
50-Year	273.1	45.4	1504.7	30 minutes
100-Year	304.5	50.3	1686.4	30 minutes

Table 34. Peak values of the Paliwan HEC-HMS Model outflow using the Iloilo RIDF

5.7.2 Discharge data using Dr. Horritts's recommended hydrologic method

The river discharges entering the floodplain are shown in Figure 64 to Figure 65 and the peak values are summarized in Table 35 to Table 36.



Figure 64. Paliwan river (1) generated discharge using 5-, 25-, and 100-year Iloilo rainfall intensity-duration-frequency (RIDF) in HEC-HMS



Figure 65. Paliwan river (2) generated discharge using 5-, 25-, and 100-year Iloilo rainfall intensity-duration-frequency (RIDF) in HEC-HMS

Table 35. Summary of Paliwan river	r (1) discharge generated in HEC-HMS
------------------------------------	--------------------------------------

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	1457.8	7 hours, 3 minutes
25-Year	1146.6	7 hours, 3 minutes

		0 0
RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	290.6	0 hours, 57 minutes
25-Year	231.6	0 hours, 57 minutes
5-Year	162.2	0 hours, 57 minutes

Table 36. Summary of Paliwan river (2) discharge generated in HEC-HMS

The comparison of the discharge results using Dr. Horritt's recommended hydrological method against the bankful and specific discharge estimates is shown in Table 37.

	Lable	e 37. Validation of a	river discharge est	imates	
Discharge		ODANKELI		VALIDATION	
Point	cms	Cms	cms	Bankful Dis-	Specific Dis-
				cnarge	cnarge
Sumlog (1)	1282.864	2506.382	573.673	Pass	Fail
Sumlog (2)	255.728	426.104	573.673	Pass	Fail

Table 37. Validation of river discharge estimates

Both river (1) and river (2) have satisfied the conditions for validation using the Bankful method while both rivers did not pass the conditions for validation using the specific discharge method. These values will need further investigation for the purpose of validation. It is therefore recommended to obtain actual values of the river discharges for higher-accuracy modeling.

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. The sample generated map of Paliwan River using the calibrated HMS event flow is shown in Figure 66.



Figure 66. Sample output map of the Paliwan RAS Model

5.9 Flood Depth and Flow Hazard

The resulting hazard and flow depth maps have a 10 m resolution. Figures 67 to 72 show the 5-, 25-, and 100-year rain return scenarios of the Paliwan floodplain. The floodplain, with an area of 55.28 sq.km., covers two municipalities namely, Bugasong, and Laua-An. Table 38 shows the percentage of area affected by flooding in the municipality.

Municipality	Total Area	Area Flooded	% Flooded
Bugasong	174.08	23.177	13.314
Laua-An	159.77	27.83	17.419

Table 38. Municipalities affected in the Paliwan Floodplain













5.10 Inventory of Areas Exposed to Flooding

Affected barangays in the Paliwan river basin, grouped by municipality, are listed below. For the said basin, two municipalities consisting of 34 barangays are expected to experience flooding when subjected to 5-year rainfall return period.

For the 5-year return period, 10.97% of the municipality of Ibajay with an area of 174.08 sq. km. will experience flood levels of less 0.20 meters. 1.55% of the area will experience flood levels of 0.21 to 0.50 meters while 1.04%, 0.7%, 0.36%, and 0.37% 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. Shown in Figure 73 and in Table 39 are the affected areas in square kilometres by flood depth per barangay.



Figure 73. Affected Areas in Bugasong, Antique during 5-Year Rainfall Return Period

Affected Area			Af	fected Baranga	ys in Bugasong	(in sq.km.)			
(sq. km.) by flood depth (m.)	Anilawan	Centro Ilawod	Centro Ilaya	Centro Pojo	Cubay North	Cubay South	Guija	Jinalinan	Lacayon
0.03-0.20	1.71	0.015	0.023	1.06	0.54	3.41	0.73	0.85	1.46
0.21-0.50	0.15	0	0	0.3	0.15	0.53	0.26	0.18	0.072
0.51-1.00	0.16	0	0	0.15	0.2	0.11	0.36	0.13	0.016
1.01-2.00	0.19	0	0	0.032	0.2	0.019	0.083	0.035	0.0083
2.01-5.00	0.14	0	0	0.0005	0.12	0	0.0015	0.0002	0.0037
> 5.00	0.0002	0	0	0	0	0	0	0	0
Affected Area			Af	fected Baranga	ys in Bugasong	(in sq.km.)			
(sq. km.) by flood depth (m.)	Maray	Paliwan	Sabang East	Sabang West	Tagudtud North	Tagudtud South	Talisay	Tica	Yapu
0.03-0.20	2.95	0.78	0.76	0.049	0.84	2.1	0.66	0.44	0.73
0.21-0.50	0.091	0.22	0.013	0.026	0.16	0.17	0.28	0.089	0.019
0.51-1.00	0.077	0.24	0.0025	0.000014	0.085	0.042	0.18	0.054	0.0097
1.01-2.00	0.094	0.17	0.00093	0	0.11	0.017	0.2	0.053	0.011
2.01-5.00	0.1	0.035	0.0003	0	0.018	0.014	0.065	0.026	0.092
> 5.00	0.0024	0	0	0	0	0.0002	0	0.0004	0.061

Table 39. Affected Areas in Bugasong, Antique during 5-Year Rainfall Return Period

For the municipality of Laua-An, with an area of 159.77 sq. km., 16.6% will experience flood levels of less 0.20 meters. 0.7% of the area will experience flood levels of 0.21 to 0.50 meters while 0.47%, 0.44%, 0.35%, 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 40 and shown in Figure 74 are the affected areas in square kilometres by flood depth per barangay.



Figure 74. Affected Areas in Laua-An, Antique during 5-Year Rainfall Return Period

Table 40. Affected Areas in Laua-An, Antique during 5-Year Rainfall Return Period

Con A Lot						11		
Area			ATTECTED	Barangays In L	aua-An (in sq	.Km.)		
y flood (m.)	Ragonghavan	Cadaing	Cannavan	Guinban- ga-An	Guisiian	laønikiran	Liherato	uoo
	Dagongoa yan	Cauajag	Capitayan	8a 71	Ouisijari	Jagainicail	LINCIALO	FOOI
	1.74	0.38	3.45	0.9	2.73	3.93	0.72	1.32
0	0.062	0.0057	0.07	0.029	0.16	0.084	0.0099	0.088
0	0.022	0.0011	0.03	0.022	0.1	0.032	0.0058	0.058
0	0.019	0.0003	0.02	0.039	0.12	0.014	0.0064	0.067
0	0.022	0.00039	0.0084	0.057	0.05	0.0088	0.0092	0.057
	0.0025	0	0.0002	0.0002	0.0023	0.004	0.0016	0.0007
ed Area			Affected	Barangays in L	aua-An (in sq	.km.)		
) by flood								
ch (m.)	Lugta	Maria	Pandanan	Paningayan	Pascuala	Santiago	Tibacan	Virginia
0	1.38	0.96	0.85	2.48	0.4	5.11	0.12	0.052
0	0.29	0.032	0.02	0.12	0.0066	0.13	0.001	0.00075
0	0.21	0.035	0.014	0.12	0.003	0.099	0.0012	0.0001
0	0.14	0.064	0.013	0.097	0.0024	0.11	0.0014	0
0	0.069	0.069	0.027	0.073	0.0028	0.1	0.0022	0.000077
> 5.00	0.0058	0.0036	0.0044	0.0081	0.00046	0.014	0.0004	0.000038

For the 25-year return period, 10.16% of the municipality of Ibajay with an area of 174.08 sq. km. will experience flood levels of less 0.20 meters. 1.8% of the area will experience flood levels of 0.21 to 0.50 meters while 1.2%, 0.9%, 0.46%, and 0.11% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 41 and shown in Figure 75 are the affected areas in square kilometres by flood depth per barangay.



Figure 75. Affected Areas in Bugasong, Antique during 25-Year Rainfall Return Period

Period
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Table 41.

Affected Area			Af	fected Baranga	ys in Bugasong	(in sq.km.)			
(sq. km.) by flood depth (m.)	Anilawan	Centro Ilawod	Centro Ilaya	Centro Pojo	Cubay North	Cubay South	Guija	Jinalinan	Lacayon
0.03-0.20	1.63	0.015	0.023	0.94	0.43	3.11	0.63	0.78	1.44
0.21-0.50	0.13	0	0	0.36	0.16	0.77	0.24	0.19	0.094
0.51-1.00	0.17	0	0	0.19	0.18	0.15	0.37	0.16	0.02
1.01-2.00	0.2	0	0	0.047	0.28	0.032	0.19	0.072	0.01
2.01-5.00	0.21	0	0	0.0006	0.16	0	0.0026	0.0019	0.0044
> 5.00	0.019	0	0	0	0	0	0	0	0.000067
Affected Area			Af	fected Baranga	ys in Bugasong	(in sq.km.)			
(sq. km.) by flood depth (m.)	Maray	Paliwan	Sabang East	Sabang West	Tagudtud North	Tagudtud South	Talisay	Tica	Yapu
0.03-0.20	2.89	0.68	0.75	0.042	0.72	2.04	0.5	0.38	0.68
0.21-0.50	0.086	0.22	0.015	0.032	0.22	0.2	0.29	0.095	0.021
0.51-1.00	0.09	0.26	0.0036	0.00085	0.11	0.055	0.24	0.076	0.0083
1.01-2.00	0.094	0.22	0.00083	0	0.13	0.017	0.25	0.068	0.015
2.01-5.00	0.13	0.06	0.0004	0	0.036	0.02	0.1	0.04	0.04
> 5.00	0.027	0	0	0	0	0.0002	0	0.0005	0.15

For the municipality of Laua-An, with an area of 159.77 sq. km., 16.26% will experience flood levels of less 0.20 meters. 0.8% of the area will experience flood levels of 0.21 to 0.50 meters while 0.54%, 0.5%, 0.46%, and 0.06% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 41 and shown in Figure 76 are the affected areas in square kilometres by flood depth per barangay.



Figure 76. Affected Areas in Laua-An, Antique during 25-Year Rainfall Return Period

Table 42. Affected Areas in Laua-An, Antique during 25-Year Rainfall Return Period

Affected Area			Affected	Barangays in L	aua-An (in sq	.km.)		
(sq. km.) by flood				Guinban-				
depth (m.)	Bagongbayan	Cadajug	Capnayan	ga-An	Guisijan	Jaguikican	Liberato	Loon
0.03-0.20	1.7	0.37	3.43	0.88	2.64	3.91	0.72	1.29
0.21-0.50	0.0	0.0084	0.082	0.04	0.19	0.095	0.012	0.077
0.51-1.00	0.023	0.0013	0.035	0.017	0.13	0.04	0.0061	0.066
1.01-2.00	0.021	0.0004	0.022	0.03	0.13	0.017	0.0066	0.079
2.01-5.00	0.028	0.00039	0.013	0.074	0.063	0.012	0.0095	0.079
> 5.00	0.0032	0	0.0004	0.01	0.005	0.0049	0.0025	0.0015
Affected Area			Affected	Barangays in L	aua-An (in sq	l.km.)		
(sq. km.) by flood								
depth (m.)	Lugta	Maria	Pandanan	Paningayan	Pascuala	Santiago	Tibacan	Virginia
0.03-0.20	1.25	0.93	0.84	2.41	0.4	5.04	0.12	0.051
0.21-0.50	0.3	0.035	0.022	0.12	0.0067	0.16	0.0011	0.00085
0.51-1.00	0.27	0.03	0.016	0.13	0.0039	0.1	0.0011	0.00021
1.01-2.00	0.17	0.059	0.015	0.12	0.0022	0.11	0.001	0
2.01-5.00	0.086	0.1	0.027	0.096	0.0034	0.14	0.0027	0.000077
> 5.00	0.013	0.0058	0.011	0.013	0.00046	0.023	0.0007	0.000038

For the 100-year return period, 9.5% of the municipality of Ibajay with an area of 174.08 sq. km. will experience flood levels of less 0.20 meters. 2% of the area will experience flood levels of 0.21 to 0.50 meters while 1.2%, 1.17%, 0.6%, and 0.15% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 42 and shown in Figure 77 are the affected areas in square kilometres by flood depth per barangay.



Figure 77. Affected Areas in Bugasong, Antique during 100-Year Rainfall Return Period

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		uija Jinalinan Lacayon	0.54 0.71 1.41	0.23 0.21 0.11	0.34 0.17 0.021	0.31 0.1 0.012	0.0049 0.0044 0.0053	0 0.000067		isay Tica Yapu	0.41 0.34 0.66	0.26 0.1 0.021	0.29 0.082 0.0098	0.28 0.082 0.015	0.14 0.056 0.042		
in sq.km.)	Cubay	South	2.83	1.01	0.17	0.05	0	0	n sq.km.)	Tagudtud Tal South	1.99	0.24	0.068	0.016	0.027		
/s in Bugasong (i		Cubay North	0.34	0.15	0.16	0.34	0.22	0	/s in Bugasong (i	Tagudtud North	0.64	0.25	0.13	0.14	0.053	C	
ected Barangays i	ffected Barangays		Centro Pojo	0.86	0.41	0.21	0.063	0.0006	0	fected Barangay	Sabang West	0.037	0.031	0.0074	0	0	(
Afi	0.00 100 100 100	Centro Ilaya	0.023	0	0	0	0	0	Afi	Sabang East	0.75	0.019	0.0034	0.0011	0.0005	(
	Centro	llawod	0.015	0.000001	0	0	0	0		Paliwan	0.57	0.22	0.28	0.28	0.085	(
		Anılawan	1.58	0.12	0.13	0.21	0.26	0.04		Maray	2.86	0.084	0.072	0.12	0.13		
Affected Area	(sq. km.) by flood depth	()	0.03-0.20	0.21-0.50	0.51-1.00	1.01-2.00	2.01-5.00	> 5.00	Affected Area	(sq. km.) by flood depth (m.)	0.03-0.20	0.21-0.50	0.51-1.00	1.01-2.00	2.01-5.00		

For the municipality of Laua-An, with an area of 159.77 sq. km., 16.1% will experience flood levels of less 0.20 meters. 0.8% of the area will experience flood levels of 0.21 to 0.50 meters while 0.56%, 0.5%, 0.53%, and 0.1% 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 43 and shown in Figure 78 are the affected areas in square kilometres by flood depth per barangay.



Figure 78. Affected Areas in Laua-An, Antique during 100-Year Rainfall Return Period

Table 44. Affected Areas in Laua-An, Antique during 100-Year Rainfall Return Period

Affected Area			Affected	Barangays in L	aua-An (in sq	.km.)		
(sq. km.) by flood	-	-	(Guinban-	: (:		
	Bagongbayan	Cadajug	Capnayan	ga-An	Guisijan	Jaguikican	Liberato	Loon
0.03-0.20	1.67	0.37	3.4	0.87	2.57	3.89	0.71	1.27
0.21-0.50	0.11	0.0092	0.092	0.045	0.21	0.1	0.014	0.073
0.51-1.00	0.026	0.0013	0.039	0.018	0.14	0.042	0.0062	0.057
1.01-2.00	0.02	0.00058	0.024	0.031	0.15	0.022	0.0066	0.093
2.01-5.00	0.032	0.00039	0.018	0.069	0.079	0.013	0.0098	0.097
> 5.00	0.0043	0	0.0006	0.024	0.00	0.0067	0.0034	0.0034
Affected Area			Affected	Barangays in L	aua-An (in sq	l.km.)		
(sq. km.) by flood								
depth (m.)	Lugta	Maria	Pandanan	Paningayan	Pascuala	Santiago	Tibacan	Virginia
0.03-0.20	1.18	0.9	0.83	2.37	0.4	4.98	0.12	0.051
0.21-0.50	0.3	0.035	0.023	0.12	0.0066	0.17	0.0012	0.00079
0.51-1.00	0.28	0.029	0.017	0.13	0.0045	0.11	0.0012	0.00049
1.01-2.00	0.22	0.053	0.015	0.14	0.0025	0.12	0.0009	0
2.01-5.00	0.097	0.12	0.026	0.12	0.0034	0.16	0.0023	0.000078
> 5.00	0.017	0.024	0.018	0.018	0.00056	0.03	0.0015	0.000051

Among the barangays in the municipality of Bugasong, Cubay South is projected to have the highest percentage of area that will experience flood levels at 2.33%. Meanwhile, Aniliawan posted the second highest percentage of area that may be affected by flood depths at 1.35%.

Among the barangays in the municipality of Laua-An, Santiago is projected to have the highest percentage of area that will experience flood levels at 3.48%. Meanwhile, Jaguikican posted the second highest percentage of area that may be affected by flood depths at 2.55%.

Moreover, the generated flood hazard maps for the Paliwan Floodplain were used to assess the vulnerability of the educational and medical institutions in the floodplain. Using the flood depth units of PAG-ASA for hazard maps - "Low", "Medium", and "High" - the affected institutions were given their individual assessment for each Flood Hazard Scenario (5-year, 25-year, and 100-year) as shown in Table 44.

Manning	Are	a Covered in s	q. km.
warning Level	5-year	25-year	100-year
Low	3.49	2.97	4.29
Medium	3.21	3.88	4.22
High	3.205	4.203	5.12
Total	9.905	11.053	13.63

Table 45. Area covered by each warning level with respect to the rainfall scenario

Of the 16 identified Education Institutions in the Paliwan Flood plain, 4 schools were assessed to be exposed to the Low level flooding during a 5 year scenario.

Of the 4 identified Medical Institutions in the Paliwan Flood Plain, no schools were assessed to be exposed to any of the flooding scenarios.

5.11 Flood Validation

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

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

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

After which, the actual data from the field was compared to the simulated data to assess the accuracy of the Flood Depth Maps produced and to improve on what is needed. The points in the flood map versus its corresponding validation depths are shown in Figure 79.

The flood validation consists of 156 points randomly selected all over the Cangaranan-Paliwan flood plain. Comparing it with the flood depth map of the nearest storm event, the map has an RMSE value of 0.768 m. Table 45 shows a contingency matrix of the comparison.



Figure 79. Validation points for 25-year Flood Depth Map of Cangaranan-Paliwan Floodplain



Figure 80. Flood depth map vs Actual flood depth

Actual Flood Depth (m)	Modele	d Flood Dep	th (m)				
	0-0.21	0.21-0.50	0.51-1.00	1.01-2.00	2.01-5.00	> 5.00	Total
0-0.20	65	1	1	4	0	0	71
0.21-0.50	11	3	1	2	1	0	18
0.51-1.00	12	3	6	4	2	0	27
1.01-2.00	11	5	6	1	2	0	25
2.01-5.00	0	0	0	4	9	0	13
> 5.00	0	0	0	0	2	0	2
Total	99	12	14	15	16	0	156

Table 46. Actual Flood Depth vs. Simulated Flood Depth in the Cangaranan-Paliwan River Basin

The overall accuracy generated by the flood model is estimated at 53.85%, with 84 points correctly matching the actual flood depths. In addition, there were 34 points estimated one level above and below the correct flood depths while there were 20 points and 16 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 18 points were overestimated while a total of 54 points were underestimated in the modelled flood depths of Cangaranan-Paliwan. Table 46 depicts the summary of the Accuracy Assessment in the Cangaranan-Paliwan River Basin Survey.

Table 47. Summary of Accuracy Assessment in the Cangaranan-Paliwan River Basin Survey

PALIWAN	No. of Points	%
Correct	84	53.85
Overestimated	18	11.54
Underestimated	54	34.62
Total	156	100.00

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ANNEXES

ANNEX 1. Technical Specifications of the LiDAR Sensors used in the Paliwan Floodplain Survey

OPTECH TECHNICAL SPECIFICATION OF THE GEMINI SENSOR



Parameter	Specification
Operational envelope (1,2,3,4)	150-4000 m AGL, nominal
Laser wavelength	1064 nm
Horizontal accuracy (2)	1/5,500 x altitude, (m AGL)
Elevation accuracy (2)	<5-35 cm, 1 σ
Effective laser repetition rate	Programmable, 33-167 kHz
	POS AV™ AP50 (OEM);
Position and orientation system	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

OPTECH TECHNICAL SPECIFICATION OF THE PEGASUS SENSOR



Laptop

Control Rack

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

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OPTECH TECHNICAL SPECIFICATION OF THE AQUARIUS SENSOR



Control Rack

Digitizer

Camera Controller Tablet

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

ANNEX 2. NAMRIA CERTIFICATION OF REFERENCE POINTS USED IN THE LIDAR SURVEY

1. ATQ-18



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

March 02, 2015

CERTIFICATION

To whom it may concern:

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

	Province: ANTIQUE							
	Station Name: ATQ-18							
	Order: 2nd							
Island: VISAYAS Municipality: BARBAZA	Barangay: CUBAY MSL Elevation: PRS92 Coordinates							
Latitude: 11º 11' 58.67081"	Longitude: 122° 2' 22.83300"	Ellipsoidal Hgt:	10.90200 m.					
WGS84 Coordinates								
Latitude: 11º 11' 54.16068"	Longitude: 122° 2' 28.01549"	Ellipsoidal Hgt:	65.96100 m.					
	PTM / PRS92 Coordinates							
Northing: 1238579.674 m.	Easting: 395119.157 m.	Zone: 4						
	UTM / PRS92 Coordinates							
Northing: 1,238,146.15	Easting: 395,155.87	Zone: 51						

Location Description

ATQ-18 From San Jose, travel N to the Mun. of Barbaza. Then from the town proper, proceed to Brgy. Cubay. Station is located on the NE approach of Binangbang Bridge, about 600 m. NE of Barbaza Town Hall, 4 m. from the road centerline, 50 m. SE of Barbaza Multi-Purpose Coop./Natco Network and 25 m. SE of a funeral service outlet. Mark is the head of a 4 in. copper nail centered on a 30 cm. x 30 cm. cement putty, with inscriptions "ATQ-18 2007 NAMRIA".

Requesting Party: PHIL-LIDAR 1 Purpose: Reference OR Number: 80777541 T.N.: 2015-0504

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

2. ATQ-20

	CERTIFICATION	14, 2
To whom it may concern:		
This is to certify that according	to the records on file in this office, the requested survey information is an	i folla
	Province: ANTIQUE	
	Station Name: ATQ-20	
Island: VISAYAS	Order: 2nd Baranoav: ZARACOZA	
Municipality: BUGASONG	MSL Elevation: PRS92 Coordinates	
Latitude: 11º 0' 42.90484"	Longitude: 122° 2' 54.07144" Ellipsoidal Hgt 10.562/	00 m.
	WGS84 Coordinates	•
Latitude: 11º 0' 38,44240"	Longitude: 122° 2' 59.27039" Ellipsoidal Hgt 66.0940	0 m.
	PTM / PRS92 Coordinates	
Northing: 1217812.272 m.	Easting: 396000.488 m. Zone: 4	
Northing: 1,217,386.02	UTM / PRS92 Coordinates Easting: 396,036.89 Zone: 51	
	Location Description	
TQ-20 rom San Jose, travel N for about 45 the first approach of Cangaranan I	km, to Brgy, Zaragoza, Mun. of Bugasong. Station is located on the left	side
ment putty, with inscriptions "ATQ-	20 2007 NAMRIA".	cm.
rose: Reference		
R Number: FREE ISSUE N.: 2016-2057	1 ALL	
	RUEL DM. BELEN, MNSA	
	Difector, Mapping And Geodesy Branch	
	/ / /	
	/ / 6	

3. ATQ-22



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

March 02, 2015

CERTIFICATION

To whom it may concern:

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

_								
		Province: ANTIQUE						
	Station Name: ATQ-22							
	Order: 2nd							
	Island: VISAYAS Municipality: BELISON	Barangay: CONCEPCION MSL Elevation: PRS92 Coordinates						
	Latitude: 10º 49' 46.66618"	Longitude: 121° 58' 11.90221"	Ellipsoidal Hgt:	12.25000 m.				
		WGS84 Coordinates						
	Latitude: 10° 49' 42.24271"	Longitude: 121º 58' 17.11770"	Ellipsoidal Hgt:	68.02200 m.				
PTM / PRS92 Coordinates								
	Northing: 1197676.056 m.	Easting: 387365.279 m.	Zone: 4					
	UTM / PRS92 Coordinates							
	Northing: 1,197,256.85	Easting: 387,404.70	Zone: 51					

Location Description

ATQ-22

From San Jose, travel N to Belison for about 20 km. Station is located on top of the N edge of the NW draft on an irrigation canal, 60 m. NE to the nat'l. highway centerline, 120 m. N of the road going to the brgy. proper and about 300 m. E of Km. Post No. 110. Mark is the head of a 4 in. copper nail centered on a 30 cm. x 30 cm. cement putty, with inscriptions "ATQ-22 2007 NAMRIA".

 Requesting Party:
 PHIL-LIDAR 1

 Purpose:
 Reference

 OR Number:
 8077754 I

 T.N.:
 2015-0503

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

4. AQ-78



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

March 02, 2015

CERTIFICATION

To whom it may concern:

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

	Province: ANTIQUE Station Name: AQ-78	
Island: Visayas	Municipality: PATNONGON	Barangay: IPAYO
Elevation: 10.6092 m.	Order: 1st Order	Datum: Mean Sea Level
Latitude: 10° 54' 59.40000"	Longitude: 121° 59' 52.10000"	

Location Description

BM AQ-78

Station is located at the northwestern side of the side walk of Ipayo Bridge km. 122+244.79. Mark is the head of a 4in. copper nail set flush on a cement putty with inscriptions "AQ-78,2007,NAMRIA".

PHIL-LIDAR 1
Reference
8077754 I
2015-0506

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. BASE PROCESSING REPORTS OF CONTROL POINTS USED IN THE LIDAR SURVEY

From:	ATQ-20							
	Grid		Local		Global		ilobal	
Easting	396036.890 m	Latta	ude N11°00	42.90484"	Latitude		N11°00'38.44240'	
Northing	1217386.017 m	Long	tude E122°02	'54.07144"	Longitude		E122°02'59.27039"	
Elevation	10.798 m	Helg	ht	10.563 m	Height		66.094 m	
To:	AQ-							
	Grid	Local Gir			bai			
Easting	396235.105 m	Latita	ude N11°01	'03.59755"	Latitude		N11°00'59.13382"	
Northing	1218020.995 m	Long	stude E122°03	'00.53639"	Longitude		E122°03'05.73482"	
Elevation	11.276 m	Helg	ht	11.054 m	.054 m Height		66.576 m	
Vector								
∆Easting	198.21	15 m	NS Fwd Azimuth		17°09'16"	ΔX	-102.123 m	
ΔNorthing	634.97	78 m	Ellipsoid Dist.		665.374 m	ΔY	-206.684 m	
AFlaudian	0.43	70	Allolaht		0.404 -	47	624 160 m	

Standard Errors

Vector errors:						
σ ΔEasting	0.001 m	σ NS fwd Azimuth	0°00'00"	σΔΧ	0.001 m	
σΔNorthing	0.000 m	σ Ellipsoid Dist.	0.000 m	σΔΥ	0.001 m	
σ ΔElevation	0.001 m	σΔHeight	0.001 m	σΔΖ	0.000 m	

Aposteriori Covariance Matrix (Meter^a)

	x	Y	Z
x	0.000003727		
Y	-0.000004068	0.0000012949	
Z	-0.0000001072	0.000002886	0.000002405
ANNEX 4. THE LIDAR SURVEY TEAM COMPOSITION

Data Acquisition Component	Designation	Name	Agency/Affiliation
Sub-team			
Data Acquisi- tion Component Leader	Data Component Program Leader	ENRICO C. PARINGIT	UP-TCAGP
Data Acquisi- tion Component Leader	Data Component Proj- ect Leader -I	ENGR. CZAR JAKIRI S. SARMIEN- TO	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP TCAGP
		ENGR. LOVELYN ASUNCION	
LiDAR Operation	Senior Science Re- search Specialist	ENGR. GEROME HIPOLITO	UP TCAGP
		ENGR. IRO NIEL ROXAS	
		PAULINE JOANNE ARCEO	
		VERLINA TONGA	
	Research Associate	REGINA FELISMINO	UP TCAGP
LiDAR Operation		MARY CATHERINE ELIZABETH BALIGUAS	
		RENAN PUNTO	
	Research Associate	MA. REMEDIOS VILLANUEVA	UP TCAGP
		KRISTINE ANDAYA	
		JERIEL PAUL ALAMBAN	
Ground Survey	Research Associate	KENNETH QUISADO	UP TCAGP
,		IRO NIEL ROXAS	
		SANDRA POBLETE	
		RENAN PUNTO	
Data Download and Transfer	Senior Science Re- search Specialist	VERLINA TONGA	UP TCAGP
		MA. REMEDIOS VILLANUEVA	
		SSG. LEE JAY PUNZALAN	PILIPPINE AIR
LiDAR Operation	Airborne Security	SSG. DAVE GUMBAN	FORCE (PAF)
		CAPT. JACKSON JAVIER	
LiDAR Operation	Pilot	CAPT. JEFFREY ALAJAR	CORPORATION (AAC)
		CAPT. BRYAN	(
		CAPT. NEIL ACHILLES AGAWIN	
LiDAR Operation	Co-Pilot	CAPT. ALBERT LIM	AAC
		САРТ. НОҮА	

	SHT PLAN SERVED	KML LOCATION	19 Z:UDACIRAW DATA	15/12 Z:UDACIRAW DATA	3 Z:IDACIRAW DATA	na Z:IDACIRAW DATA	8 Z-IDACIRAW DATA	13 Z-IDACIRAW DATA	10 Z:IDACIRAW DATA	10 Z:DACIRAW DATA	14 ZIDACIRAW DATA			
	ATOR FLIC	GS Actual	19	7/4	3	7	4	9	5	ŝ	9			
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	00	SI RANGE	13	21.9	21.7	19.4	16.2	4.65	8.3	8 12.1	3 16.3		A F. PRI	
-gem)	MISSION	CASI FILEICA	206	383	342	67.8	203	57.4	6:09	94.4/62	17.2/16	d by	alon .	
03/23/2015(Iloild		OS IMAGESI	09 28	22 46.6	22 48.5	84 8.07	63 25.6	06 6.84	15.4	198 21.2	28.2	Receive	Name Position Signature	
	-	OGS(MB)	1.13	1.34	1.43	891	066	254	670	0.97	1.05			
	LAS	KML (swath)	1517	962	1078	586	740	169	613	694	856			
	RAW	Output LAS	na	g	e	S	na	ua Na	na	na	na			
		SENSOR	gemini	gemini	gemini	gemini	gemini	gemini	gemini	gemini	gemini		Intrantin the	
		MISSION NAME	2BLK37V047A	2BLK37GSIV047B	2BLK43H048A	2BLK43GV050A	2BLK43F050B	2BLK43A051A	2BLK43A052A	2BLK43A053A	2BLK43C054A	Received from	Name Position Signature	
		FLIGHT NO.	2566G	2568G	2570G	2578G	25806	2582G	2586G	2590G	2594G			
		DATE	16-Feb-15	16-Feb-15	17-Feb-15	19-Feb-15	19-Feb-15	20-feb-15	21-Feb-15	22-Feb-15	23-Feb-15			

ANNEX 5. DATA TRANSFER SHEET FOR CABULIG FLOODPLAIN

ł		ľ											
	17.7	44	10.7	256	22.2	225	20.0	1.27	2.13	sneefad	18U/371FV053A	26012	22-feb-15
	¢.11	2	21	274	27.9	257	6.65	1.39	2.00	arcelas	18LK43N052A	25978	21-Feb-15
	II.		16.3	218	n	213	7.62	1.01	3.14	prested	18LK438DG051A	4665Z	20-feb-15
r.	9.7	11	53	242	46.9	105	9.47	1,63	5.53	onsetted.	18LK371050B	47652	19-Feb-15
~	15	M	12.3	523	17.3	417	1.78	9CT	¢1	sected	TRUKKSEFU050A	2589P	19-Feb-15
- At		'n	17.4	1071	643	190	50.5	1.02	17	sneeted	1B1K43E00496	25879	18-Feb-15
E.IN		æ	27.8	314	43	165	6.97	1.71	2.91	sreated	15UKA3EFO49A	25859	18-feb-15
2012		21	1IA	127	14	57	6.05	210	11.4	crimtes	18LK43b0486	2583P	17-Feb-15
20.2		2	21.4	215	S.K	161	46.6	1.35	2.06	tentos	18UK49MANOH3A	25818	17-feb-15
12.2		в	19.5	122	24.4	223	10.4	1.21	1.13	ermefned	154Kq3MO47B	25792	16-Feb-15
10.5		2	14.4	12435	33.56	195	56.9	949	\$.20	snated	18LKA3DO4SA	25050	14-feb-15
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BCV0	Γ			NUMBER	D.LW			SYLE	AVE				

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

Name Position Signoture

C.L

Prox - - L

Nerve Position Signature

1010A F. PRIETO 3/23/2015

SERVER	Z'IDACIRAW	Z'IDACIRAW NATA	Z'IDACIRAW DATA	Z:IDACIRAW DATA	ZIDACIRAW	ZIDACIRAW	ZIDACIRAW	ZIDACIRAW	Z:IDACIRAW DATA	Z:IDACIRAW DATA	ZIDACIRAW	Z'IDACIRAW DATA	DATA	ZIDACIRAW	
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RANGE	5,95	12.6	2.95	5.2	5.05	12.5	10	34.5	27.3	18.3	8.09	18.3	17.8	7.9	Sr. P
MISSION LOG FILE/CASI LOGS	61	92	25	122.9	100	200	134	457	414	237	88	264	4	105	and the second s
RAW	8.44	22.5	2.88	14.6	23.2	27.5	17.6	66.2	48.1	32.8	9.94	35.8	71.5	15.1	Received by Name Signature
SOd	167	208	173	170	205	234	151	260	245	245	114	263	235	202	
LOGS(MB)	402	932	190	532	770	894	6.14	12.3	12.8	9.81	4.92	10.1	9.62	5.92	
4S AL (swath)	278	739	100	298	468	581	652	2.14	1.93	1.15	510	66.	1.16	505	
Itput LAS KI	NA	NA	NA	NA	NA	NA	1.94	7.28	3.11	1.82	858	2.74	NA	582	
SENSOR	EMINI	EMINI	EMINI	EMINI	INIME	EMINI	EGASUS	EGASUS	EGASUS	EGASUS	EGASUS	EGASUS	EGASUS	EGASUS	T
MISSION NAME	2BLK43B056A G	2BLK43BV057A G	2BLK43BV058A G	2BLK37FV064A G	2BLK43OS064B G	2BLK43OS065A G	1BLK37IFV056A P	1BLK37OP057A P	1BLK37P058A P	1BLK43NO062A P	1BLK37M062B P	1BLK37Q064A	1BLK37MQ064B	1BLK37Q065A F	Received from Name C · J And II Postion Barature
FLIGHT NO.	2602G	2606G	2610G	2634G	2636G	2638G	2613P	2617P	2621P	2637P	2639P	2645P	2647P	2649P	
DATE	25-Feh-15	26-Feb-15	27-Feb-15	S-Mar-15	5-Mar-15	6-Mar-15	25-Feb-15	26-Feb-15	27-Feb-15	3-Mar-15	3-Mar-15	5-Mar-15	S-Mar-15	6-Mar-15	

		October 27, 2016	October 26, 2016	October 26, 2016	October 25, 2016	October 24, 2016	October 24, 2016	October 23, 2016	DATE	
		8515AC	8514AC	8513AC	8511AC	8510AC	8509AC	8507AC	FLIGHT NO.	
		3BLK43K3 01A	3BLK43G3 00B	3BLK43D3 00A	3BLK43KJ2 99A	3BLK37B2 98B	3BLK37A2 98A	3BLK37C2 97A	NAME	
		AQUA CAS	AQUA CAS	AQUA CAS	SENSOR					
Name Position Signature	Rece	NA	I NA	NA	I NA	NA	NA	NA	Output LAS	RA
I THE TE	ived from	156	41	316	92	116	105	198	KML (swath	WLAS
- To		273	127	664	337	642	311	686	1) LOGS	
		189	142	244	217	160	204	206	POS	
		NA	NA	NA	NA	NA	NA	NA	RAW IMAGES/CAS	
		NA	NA	NA	NA	NA	NA	NA	FILE/CASI	MISSION I DO
Name Posilion Signature	Rec	3.35	2.7	13.2	4.91	5.11	5.27	8.18	RANGE	
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		NA	NA	NA	NA	NA	20	NA	KML	T PLAN
		Z:\DAC\RAV DATA	Z:\DAC\RAV DATA	Z:IDACIRAV DATA	Z:\DAC\RAV DATA	Z:IDACIRAVI DATA	Z:IDACIRAM DATA	Z:\DAC\RAW DATA	LOCATION	CEDVED

ANNEX 6. FLIGHT LOGS FOR THE FLIGHT MISSIONS

1. Flight Log for 2593P Mission

Oberator: UNANA 2 ALTM Model: Vol	Mission Name: 18/ K45/51	0, 4, 4, ype: VFR 5 AIRCRATT 1 ype: Les	UNUS I SUBH 0	AIrcraft Identification: JCF - ~
Al Purso 8 co-Pilot: J. Joyn	9 Route: Prive (Aimort Citv/Province): 1	2 Airport of Arrival (Airport, City/Province	e):	
1-20-2015 Iloilo		etaba off. 17 Landing.	1	8 Total Flight Time:
14 Define Off: 14 Engine Off: フォリン マントレンション ストレンション ストレンション ストレンション ストレンション マントレンション マンション ロッシュ ロッシュ アイ・レンション ロッシュ ロッシュ ロッシュ ロッシュ ロッシュ ロッシュ ロッシュ ロッシュ	15 Total Engine Time: $3 + 29$		1	
ther fair				
arks: Surveyed BLK	43B and Voids	over BLK 43D and L	136.	
oblems and Solutions:				
Acquisition Flight Approved by <i>Acquisition Flight Approved by</i> <i>Signature over Printed Name</i> (End User Representative)	Acquisition Flight Certified by L.I.P.W.P.L.M.M. Signature over Printed Name (PAF Representative)	Pilot-in-Command II C. ALFONSO II Signature over Printed Name		lidar Operator

2. Flight log for 2602G Mission

e v v e La constance de la constance de			-
Acquisition Flight Approved by	21 Problems and Solutions:	PHILLIDAR 1 Data Acquisition Flight Log 1 LIDAR Operator: MNE Torgo 7 Filot: J. Alajor 10Date: 2.5 F.exo 13 Engine On: 18 : 14 13 Engine On: 18 : 14 14 Engine Off: 19 Weather 20Remarks: 3	
Acquisition Filgint Certified by <u>Signature over Printed itame</u> (PAF Representative)		del: Grainin 3 Mission Name: 28xx438 05 (A) Lin 9 Route: 110110 or Departure (Airport, Gty/Province): 12 110/10 15 Total Engine Time: 17 16 11-31 15 Total Engine Time: 17 12 Innes: of BLX 43 B; abort presoribed plying height	
Pilot-In-Command PD Wandth Impo Signature over Printed Plane		4 Type: VFR 5 Aircraft Type: CesnnaT206 Airport of Arrival (Airport rim/Province): Take off. [17 Landing: Take off. [17 Landing: ed due to cloud [vuild up	
Lidar Operator Jafo Kal Signatufe over Printed Name		Flight Log No.: 2 60 H 6 Aircraft Identification: 9/22 18 Total Flight Time:	

3. Flight log for 2606G Mission

4. Flight log for 2610G Mission

Acquisition Fight Acquisition Fight Sugnaturedover Pr Sugnaturedover Pr	21 Problems and Solution	20 Remarks: Sur Veyet dr J	19 Weather Cloudy	13 Engine On: 7:0 3	10 Date: 27 FEB 24	1 LiDAR Operator: MVE To 7 Pilot: B. Dorquines	PHIL-LIDAR 1 Data Acquisition
approved by ideal Name centative)	250	kids of RLK storg und	and the second sec	14 Engine Off: 10:05	οις 12 Airport of Departs	B CO-PILOT: A. Lim	Flight Log
Acquisition Flight Certified by LN PURPEALINI Signature over Printed Hame (PAF Representative)		A3B; mission		15 Total Engine Time:	ure (Airport, City/Province):	ini 3 Mission Name: 28442 9 Route:	
Filot-in-Command Signature over Printed Name		about 2 duc to cloud		16 Take off: 17 Landing: 70. 03	12 Airport of Arrival (Airport, City/Province):	384834 4 Type: VFR 5 Aircraft Type: CesnnaT	
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6. Flight log for 8515AC Mission

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ANNEX 7. FLIGHT STATUS

FLIGHT STATUS REPORT

PALIWAN

(February 2015)

FLIGHT NO.	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
2593P	BLK 43B, 43D, 43G	1BLK43BDG051A	IRO ROXAS	20 FEB 15	Surveyed BLK43B and voids on BLK 43D and 43G
2602G	BLK 43B	2BLK43B056A	MVE TONGA	25 FEB 15	Surveyed 2 lines of BLK43B; aborted due to cloud buildup below the prescribed flying height
2606G	BLK 43B	2BLK43BV057A	RA FELISMINO	26 FEB 15	Surveyed 10 lines of BLK43B
2610G	BLK 43B, 43C	2BLK43BV058A	MVE TONGA	27 FEB 15	Surveyed voids of BLK43B; mission abort- ed due to cloud buildup and strong wind
8511AC	BLK43K, Sibalom2 FP	3BLK43KJ299A	MS REYES	25 OCT 16	Covered voids over Cairawan, Paliwan, and Sibalom2 Floodplains
8515AC	BLK43K	3BLK43K301A	MS REYES	27 OCT 16	Coverd voids over Cairawan, Paliwan, and Cangaranan Floodplains

LAS BOUNDARIES PER MISSION FLIGHT

Flight No. 2593P Area: BLK 43B, 43D, 43G Mission Name: 1BLK43BC051A Total Area Surveyed: 181.2 sq km



Flight No. : 2602G Area: BLK 43B Mission Name: 2BLK43B056A Total Area Surveyed: 89.4442 sq km



START	STOP	LINE#	ALT	PRF	FREQ	ANGLE	MP	DIV	RC	MPM	HDG	Plan File
01:16:44.084	01:16:53.609	6	2007	70	56.00	17.00	OFF	NAR	OFF	OFF	359.00	BLK43B+voids.pln
01:19:10.718	01:29:02.284	6	2010	70	56.00	17.00	OFF	NAR	OFF	OFF	359.00	BLK43B+voids.pln
01:34:53.261	01:37:49.33	7	1998	70	56.00	17.00	OFF	NAR	ON	OFF	179.00	BLK43B+voids.pln
01:49:20.984	01:55:26.476	13	2009	70	56.00	17.00	OFF	NAR	ON	OFF	179.00	BLK43B+voids.pln
01:55:43.231	01:56:35.811	13	2000	70	56.00	17.00	OFF	NAR	ON	OFF	179.00	BLK43B+voids.pln
01:55:43.231	01:56:35.811	13	2000	70	56.00	17.00	OFF	NAR	ON	OFF	179.00	BLK43B+voids.pln
02:01:38.303	02:03:14.407	13	1998	70	56.00	17.00	OFF	NAR	ON	OFF	179.00	BLK43B+voids.pln
02:01:38.303	02:03:14.407	13	1997	70	56.00	17.00	OFF	NAR	OFF	OFF	175.00	BLK43B+voids.pln
02:06:19.196	02:08:56.229	15	2007	70	56.00	17.00	OFF	NAR	OFF	OFF	355.00	BLK43B+voids.pln
02:06:19.196	02:08:56.229	15	2007	70	56.00	17.00	OFF	NAR	OFF	OFF	355.00	BLK43B+voids.pln
02:15:37.301	02:18:46.919	18	1317	100	50.00	20.00	OFF	NAR	ON	OFF	175.00	BLK43B+voids.pln
02:15:37.301	02:18:46.919	18	1315	100	50.00	20.00	OFF	NAR	ON	OFF	175.00	BLK43B+voids.pln
02:23:29.657	02:26:09.025	19	1322	100	50.00	20.00	OFF	NAR	ON	OFF	355.00	BLK43B+voids.pln

Flight No.: 2606G Area: BLK 43B Mission Name: 2BLK43BV057A Total Area Surveyed: 221.78 sq km



Flight No.: 2610G Area: BLK 43B, 43C Mission Name: 2BLK43BV058A Total Area Surveyed: 34.3481 sq km

00:13:25.97

00:14:48.759

24

1986



56.00

17.00

OFF

NAR

OFF

OFF

266.00

BLK43V.pln

Flight no.: 8511AC Mission Name: 3BLK43J299A Area: BLK43K, Sibalom2 FP Total area surveyed: 18.2km²



Flight no.: 8515AC Mission Name: 3BLK43K301A Area: BLK43K Total area surveyed: 15.52km²



ANNEX 8. MISSION SUMMARY REPORT

Flight Area	lloilo					
Mission Name	Blk43B					
Inclusive Flights	2593P					
Range data size	16.3 GB					
POS	213 MB					
Base Data Size	11 MB					
Image	27 GB					
Transfer date	March 23, 2015					
Solution Status						
Number of Satellites (>6)	Yes					
PDOP (<3)	Yes					
Baseline Length (<30km)	No					
Processing Mode (<=1)	No					
Smoothed Performance Metrics (in cm)						
RMSE for North Position (<4.0 cm)	1.01					
RMSE for East Position (<4.0 cm)	1.56					
RMSE for Down Position (<8.0 cm)	3.33					
Boresight correction stdev (<0.001deg)	0.000371					
IMU attitude correction stdev (<0.001deg)	0.000661					
GPS position stdev (<0.01m)	0.0091					
Minimum % overlap (>25)	25.93%					
Ave point cloud density per sq.m. (>2.0)	2.57					
Elevation difference between strips (<0.20 m)	Yes					
Number of 1km x 1km blocks	200					
Maximum Height	594.49 m					
Minimum Height	54.70 m					
Classification (# of points)						
Ground	152,186,273					
Low vegetation	75,056,947					
Medium vegetation	152,053,797					
High vegetation	281,227,721					
Building	4,634,683					
Orthophoto	Yes					
Processed by	Engr. Analyn Naldo, Engr. Harmond Santos, Engr. Melissa Fernandez					



Figure 1.1.1 Solution Status



Figure 1.2.2 Smoothed Performance Metric Parameters



Figure 1.1.3 Best Estimated Trajectory



Figure 1.1.4 Coverage of LiDAR data



Figure 1.1.5 Image of data overlap



Figure 1.1.6 Density map of merged LiDAR data



Figure 1.1.7 Elevation difference between flight lines

Flight Area	lloilo					
Mission Name	Blk43B_additional					
Inclusive Flights	2602G, 2606G, 2610G					
Range data size	21.5 GB					
POS	548 MB					
Base data size	27.69 MB					
Image	33.82 GB					
Transfer date	July 07, 2015					
Solution Status						
Number of Satellites (>6)	Yes					
PDOP (<3)	Yes					
Baseline Length (<30km)	No					
Processing Mode (<=1)	Yes					
Smoothed Performance Metrics (in cm)						
RMSE for North Position (<4.0 cm)	1.34					
RMSE for East Position (<4.0 cm)	1.45					
RMSE for Down Position (<8.0 cm)	3.95					
Boresight correction stdev (<0.001deg)	0.000279					
IMU attitude correction stdev (<0.001deg)	0.017983					
GPS position stdev (<0.01m)	0.0032					
Minimum % overlap (>25)	24.04%					
Ave point cloud density per sq.m. (>2.0)	1.91					
Elevation difference between strips (<0.20 m)	Yes					
Number of 1km x 1km blocks	285					
Maximum Height	925.04 m					
Minimum Height	54.48 m					
Classification (# of points)						
Ground	140,989,825					
Low vegetation	27,006,829					
Medium vegetation	75,243,562					
High vegetation	157,821,764					
Building	629,138					
Orthophoto	Yes					
Processed by	Engr. Irish Cortez, Engr. Antonio Chua, Jr., Maria Tamsyn Malabanan					



Figure 1.2.1 Solution Status



Figure 1.2.2 Smoothed Performance Metric Parameters



Figure 1.2.3 Best Estimated Trajectory



Figure 1.2.4 Coverage of LiDAR data



Figure 1.2.5 Image of data overlap



Figure 1.2.6 Density map of merged LiDAR data



Figure 1.2.7 Elevation difference between flight lines

Flight Area	lloilo				
Mission Name	Blk43B				
Inclusive Flights	8511AC				
Range data size	4.91 GB				
POS	217 MB				
Base data size	71.7 MB				
Image	NA				
Transfer date	October 25, 2016				
Solution Status					
Number of Satellites (>6)	Yes				
PDOP (<3)	Yes				
Baseline Length (<30km)	No				
Processing Mode (<=1)	No				
Smoothed Performance Metrics (in cm)					
RMSE for North Position (<4.0 cm)	1.02				
RMSE for East Position (<4.0 cm)	1.29				
RMSE for Down Position (<8.0 cm)	2.57				
Boresight correction stdev (<0.001deg)	0.000449				
IMU attitude correction stdev (<0.001deg)	0.000900				
GPS position stdev (<0.01m)	0.0013				
Minimum % overlap (>25)	47.78				
Ave point cloud density per sq.m. (>2.0)	4.16				
Elevation difference between strips (<0.20 m)	Yes				
Number of 1km x 1km blocks	50				
Maximum Height	270.21				
Minimum Height	51.5				
Classification (# of points)					
Ground	14,416,707				
Low vegetation	13,416,268				
Medium vegetation	12,278,605				
High vegetation	17,861,711				
Building	2,114,843				
Orthophoto	None				
Processed by					



Figure 1.3.1 Solution Status



Figure 1.3.2 Smoothed Performance Metric Parameters



Figure 1.33 Best Estimated Trajectory



Figure 1.3.4 Coverage of LiDAR data



Figure 1.3.5 Image of data overlap



Figure 1.3.6 Density map of merged LiDAR data



Figure 1.3.7 Elevation difference between flight lines

Flight Area	Iloilo Reflights					
Mission Name	Blk43B_supplement					
Inclusive Flights	8515AC					
Range data size	3.35 GB					
Base data size	104 MB					
POS	189 MB					
Image	NA					
Transfer date	October 27, 2016					
Solution Status						
Number of Satellites (>6)	Yes					
PDOP (<3)	Yes					
Baseline Length (<30km)	Yes					
Processing Mode (<=1)	Yes					
Smoothed Performance Metrics (in cm)						
RMSE for North Position (<4.0 cm)	0.82					
RMSE for East Position (<4.0 cm)	1.27					
RMSE for Down Position (<8.0 cm)	2.21					
Boresight correction stdev (<0.001deg)	0.000392					
IMU attitude correction stdev (<0.001deg)	0.000914					
GPS position stdev (<0.01m)	0.0093					
Minimum % overlap (>25)	42.86					
Ave point cloud density per sq.m. (>2.0)	3.91					
Elevation difference between strips (<0.20 m)	Yes					
Number of 1km x 1km blocks	38					
Maximum Height	481.19					
Minimum Height	58.9					
Classification (# of points)						
Ground	23,696,880					
Low vegetation	10,611,556					
Medium vegetation	9,775,696					
High vegetation	13,078,875					
Building	590,106					
Ortophoto	None					
Processed by	Engr. Jennifer Saguran, Engr. Melanie Hingpit, Engr. Harmond Santos					







Figure 1.4.2. Smoothed Performance Metric Parameters



Figure 1.4.3 Best Estimated Trajectory



Figure 1.4.4 Coverage of LiDAR data



Figure 1.4.5 Image of data overlap



Figure 1.4.6 Density Map of merged LiDAR data



Figure 1.4.7 Elevation Difference Between flight lines
ANNEX 9. PALIWAN MODEL BASIN PARAMETERS

SCS Curve Number Lo	urve Number Lo	er Lo	SS	Clark Unit Hydre	ograph Transform		Rece	ssion Basefl	MO	
Initial Ab- straction Number (%)	Curve Imperviou: Number (%)	Imperviou: (%)	()	Time of Con- centration (HR)	Storage Coeffi- cient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
1.0629 96.314 0	96.314 0	0		0.27431	4.4247	Discharge	0.43437		Ratio to Peak	0.0001
0.68659 99 0	0 66	0		0.0596092	2.1676	Discharge	0.13207	-	Ratio to Peak	0.0001
0.95465 99 0	0 66	0		0.0626814	3.3373	Discharge	0.0923162		Ratio to Peak	0.0001
1.1697 94.868 0	94.868 0	0		0.0666273	1.8537	Discharge	0.1106	-	Ratio to Peak	0.0001
0.63195 99 0	0 66	0		0.11565	1.722	Discharge	0.32935	-	Ratio to Peak	0.0001
0.98641 98.5 0 0	98.5 0	0	0	.0591217	2.539	Discharge	0.0646545		Ratio to Peak	0.0001
0.81573 91.463 0 0	91.463 0 0	0	0	.071831	8.8378	Discharge	0.0656467	-	Ratio to Peak	0.0001
0.58691 85.162 0 C	85.162 0 C	0	0	.079049	1.9789	Discharge	0.11044		Ratio to Peak	0.0001
0.1912 62.812 0 0	62.812 0 0	0	0	.0944182	11.817	Discharge	0.29476	-	Ratio to Peak	0.0001
0.27053 58.813 0	58.813 0	0		0.29361	2.1391	Discharge	0.36017	.	Ratio to Peak	0.0001
1.007 87.569 0	87.569 0	0		0.081234	2.6602	Discharge	0.14386	-	Ratio to Peak	0.0001
0.31125 67.65 0	67.65 0	0		0.12263	6.168	Discharge	0.343	.	Ratio to Peak	0.0001

		Ratio to Peak	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	MO	Threshold Type	Ratio to Peak	Ratio to Peak	Ratio to Peak	Ratio to Peak	Ratio to Peak	Ratio to Peak	Ratio to Peak	Ratio to Peak	Ratio to Peak	Ratio to Peak	Ratio to Peak	Ratio to Peak	Ratio to Peak	Ratio to Peak
	ssion Basefl	Recession Constant				. 	~	~		~	~	~	~	-	-	~
1	Rece	Initial Discharge (M3/S)	0.10369	0.65588	0.13169	0.0807787	0.12574	0.46475	0.10399	0.0021609	0.10452	0.0468615	0.16884	0.0928457	0.20987	0.0788076
	-	Initial Type	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge
•	ograph Transform	Storage Coeffi- cient (HR)	1.4152	6.3296	6.3373	1.487	11.294	12.079	2.8945	3.4133	2.8382	3.0647	6.3113	2.5234	6.946	2.7889
	Clark Unit Hydro	Time of Con- centration (HR)	0.13291	0.26011	0.0767774	0.13743	0.13478	0.21943	0.076959	0.13553	0.0787234	0.12166	0.0765576	0.0451855	0.12252	0.0742638
	er Loss	Impervious (%)	0	0	0	0	0	0	0	0	0	0	0	ο	ο	ο
:	Irve Numbe	Curve Number	94.678	81.199	57.836	93.803	59.231	51.538	70.474	81.319	57.883	74.483	79.059	85.016	82.379	73.142
	SCS Cu	Initial Ab- straction (mm)	1.2941	0.29526	0.33697	0.84897	0.32524	0.36588	0.21362	0.39926	0.34326	0.1829	0.29772	0.36089	0.4107	0.14547
		Basin Number	W480	W490	W500	W510	W520	W530	W540	W550	W560	W570	W580	W590	W600	W610

	Ratio to Peak	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
wo	Threshold Type	Ratio to Peak					
ssion Basefl	Recession Constant			-	-	-	~
Rece	Initial Discharge (M3/S)	0.18583	0.10607	0.34946	0.0828219	0.077096	0.0021476
	Initial Type	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge
ograph Transform	Storage Coeffi- cient (HR)	2.1857	6.1709	2.7678	1.7536	1.9095	1.2529
Clark Unit Hydre	Time of Con- centration (HR)	0.09075	0.10997	0.1642	0.0475412	0.0516449	0.0252515
er Loss	Impervious (%)	0	0	0	0	0	0
Irve Numbe	Curve Number	81.468	74.781	76.182	72.159	80.149	80.799
SCS CH	Initial Ab- straction (mm)	0.29329	0.12044	0.56505	0.2009	0.22043	2.3541
	Basin Number	W620	W630	W640	W650	W660	W670

ANNEX 10. PALIWAN MODEL REACH PARAMETERS

	Side Slope	1	1	1	L .	1	Ţ	1	1	1	1	1	1	1	1	1	1	~
	Width	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300
	Shape	Trapezoid	Tranezoid															
Channel Routing	Manning's n	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.001
Muskingum Cunge	Slope	0.070163	0.060855	3.28E-02	0.026171	0.023764	0.017139	0.007438	0.105927	0.021348	0.003718	0.008448	0.000829	0.0187	0.004916	0.009267	0.010361	0.004143
	Length (m)	2188.36	1949.66	1673.38	2278.65	5785.83	3522.62	3888.53	42.4264	494.975	2422.38	3688.48	2356.08	4119.78	2657.7	298.995	450.416	7481.15
	Time Step Method	Automatic Fixed Interval																
hood	Number	R30	R50	R70	R90	R110	R130	R160	R170	R190	R240	R250	R260	R280	R290	R300	R310	R340

ANNEX 11. CANGARANAN-PALIWAN FIELD VALIDATION

Point	Validation Co	oordinates	Model Var	Validation		Event/	Rain
No.	Lat	Long	(m)	Points (m)	Error	Date	Return/ Scenario
1	11.04404016	122.0643791	0.059999999	0	0.004		
2	11.04719627	122.0663977	0.029999999	0	0.001		
3	11.06351053	122.0677705	0.029999999	0.43	0.160	Yolanda	5-Year
4	11.00539743	122.0456257	0.100000001	0	0.010		
5	11.02699656	122.0551218	0.029999999	0	0.001		
6		122.068/581	0.579999983	0	0.336	Euro a Li	100 \/===
/			0.0399999999	0.3	0.068	Frank	<u> </u>
8	10 0//2034/	122.0040525	0.200000003	0.51	0.090	Volanda	<u> </u>
10	11 00387028	121.9965045	0.0299999999	0.2	0.029	TUIattua	J-Teal
11	11.00507028	122.1300023	0.020000000	0.51	0.000		
12	11 00990291	122.125051	0.020000001	0	0.001		
14	11.06532562	122.0816394	0.0299999999	0	0.001		
15	10 97468923	122.0010331	0.090000004	0	0.001		
16	11.04346102	122.0638124	0.0299999999	0	0.001		
17	11.04348437	122.0613686	0.0299999999	0.5	0.221	Undang	5-Year
18	11.00606276	122.0470849	0.07	0	0.005	Undding	5 1001
19	11.06772967	122.0827564	0.029999999	0	0.001		
20	11.04149721	122.068553	0.029999999	0	0.001		
21	10.98812702	122.0928609	2.539999962	0	6.452		
22	11.01691689	122.0528669	0.029999999	0	0.001		
24	11.06558671	122.0813709	0	0	0.000		
25	11.04670697	122.0652931	0.029999999	0	0.001		
26	11.03026556	122.0566565	0.029999999	0	0.001		
27	11.0069148	122.0498218	0.129999995	0	0.017		
28	11.06059115	122.0784158	0.100000001	0	0.010		
29	11.04139844	122.0521073	1	1.2	0.040	Frank	<u> 100-Year</u>
30	11.062625	122.0801022	0.029999999	0	0.001		
31	<u>11.04856519</u>	122.0678507	1.460000038	0.49	0.941	Frank	<u> 100-Year</u>
34	10.9643594	122.0148831	0.029999999	0	0.001		
36	10.94/2019	122.033573	0.059999999	0	0.004		F \/
38	10.95911653	122.0094681	0.0299999999	0.2	0.029	Yolanda	5-year
50		122.005/988	0.0299999999	0	0.001		
51		122.078375		0	1 664		
52	11.00723319	122.046041	0.020000000	0	0.004		
53	11.02790202	122.0507448	0.029999999	1.06	0.001	Erank	100-Voor
55	11 022/9607	122.0524585	0.3833333374	1.00	0.221	Frank	100-Year
56	10 98090202	122.0450001	0.1500000006	0	0.023	Папк	100 1001
58	11.00986712	122.0640066	0	0	0.000		
59	11.04588023	122.0511686	0.029999999	0.97	0.884	Frank	100-Year
60	11.01102341	122.0621546	0.209999993	0	0.044		
61	11.01053478	122.0655382	0.059999999	0.31	0.063	Yolanda	5-Year
62	11.02196988	122.0473721	0.029999999	0.82	0.624	Ruping	5-Year
63	11.00339685	122.1306646	0	0.51	0.260		
64	10.98151275	122.0302327	0.029999999	0	0.001		
65	11.04558119	122.0598263	0.029999999	0.5	0.221	Frank	100-Year
66	10.97746062	122.0243589	0.029999999	0	0.001		
67	11.00458605	122.1295053	0	0	0.000		
68	11.05069275	122.0495481	0.029999999	0	0.001		
69	11.02284123	122.0491835	0	1.21	1.464	Frank	100-Year
70	11.00551415	122.1304933	0.1199999997	0	0.014		
/1	11.00059276		0.100000001	0	0.010	Frank	100 Veer
/ <u>/</u> 72		122.0495/01	0.330000013	0.68	0.122	Frank	TOD-leal
73	11 027/1051	122.1300369			0.000		
74	11 00202074	122.033524	0.1122222222		0.014	Erank	100-Voor
75	11 06623/60	122.1300143		0.55	0.003	Frank	100-1eai
77	11.06617004	122.0661093	Λ	<u> </u>	0.810	Frank	100-Year
78	11.04290752	122.067271	0.029999999	0	0.001		200 1001
79	11.0443049	122.06588	0.029999999	0.26	0.053	Frank	100-Year
80	11.00978012	122.0666671	0.029999999	0	0.001		
81	11.01965115	122.051459	0	1.04	1.082	Frank/	100-Year
						Nitang	
82	11.04550668	122.0652323	0.029999999	0	0.001		

Deint	Validation Co	ordinates		Validation		Friend /	Rain
Point	Lat	Long	widdel var	Validation	Error	Event/	Return/
NO.	Lat	Long	(m)	Points (m)		Date	Scenario
83	11.00056741	122.0838646	0	0	0.000	Valanda	
84	11.01065581	122.0651629	0 360000014	0.31	0.096	Frank	<u>5-Year</u>
86	11.01834642	122.0592003	0.560000014	1.06	0.250	Frank	100-Year
87	11.01912883	122.0519958	0	0.5	0.250	Yolanda	5-Year
88	10.95756417	122.0085821	0.029999999	0	0.001		
91	11.08717759	122.0483329	0.029999999	0.9	0.757	Yolanda	5-Year
94	10.96952395	122.0/02/49	0.029999999	0	0.001		
95	11.02724008	122.0299397	0.050000001		0.003	Frank	100 Voor
100	11.02724908	122.0515141	0.40000000	1 25	1 563	Frank	100-Year
100	11.01081041	122.0641007	0.07	0	0.005		100 1001
102	11.0787808	122.0864507	0.07	0	0.005		
103	11.06489892	122.080985	0.029999999	0	0.001		
104	11.01820445	122.0517452	0	1.06	1.124	Frank	100-Year
105	11.01/93002	122.052489	0.029999999	0	0.001	Euro a la	100 \/= = =
105		122.0520374		0.95	0.903	<u>Frank</u>	100-Year
107	11.00303965	122.0293031	0.023333333	0.08	0.000	TIAIIK	100-1641
109	11.04328321	122.0589588	0.039999999	0.35	0.096	Frank	100-Year
110	11.07132661	122.0611982	0.029999999	1	0.941	Frank	100-Year
111	11.07236273	122.0612561	1.25999999	1.21	0.002	Frank	<u>100-Year</u>
112	11.00475658	122.1306831	0.3499999994	0.5	0.023	Frank	<u>100-Year</u>
113	11.01092881	122.0640487	0	1 21	0.000	Erank	100 Voor
114	10 9562659	122.1313115	0	0.3	0.090	Frank	100-Year
117	11.02647552	122.0551956	0	0.9	0.000		100 1001
118	10.95728511	122.0084105	0	0	0.000		
119	11.01771548	122.0515164	0	1.63	2.657	Frank	100-Year
120	11.04570445	122.0595503	0	0.5	0.250	Frank	<u>100-Year</u>
121	11.04048376	122.0698528	0.21000000	1	$\frac{1.000}{2.169}$	Frank	100-Year
122	<u>11.0058059</u> 11.045929	122.1299462	0.2199999999	2	0.001	LdWIII	<u> </u>
124	11.03307078	122.0574816	0.0299999999	0	0.001		
125	11.00378924	122.1312014	0	1.21	1.464	Frank	100-Year
126	11.00405804	122.1304097	0.310000002	0	0.096		
127	11.02263259	122.0475884	0.829999983	0.73	0.010	Frank	<u>100-Year</u>
128		122.0481969	0	1.25	$\frac{1.563}{0.022}$	Frank	100-Year
130	10 93902928	122.0475469	0 029999999	0.96	0.922	LdWIII	5-fear
131	11.04839076	122.0504137	0.99000001	1	0.000	Frank	100-Year
132	11.0184566	122.0527233	0	0	0.000	Frank	100-Year
133	10.96238128	122.0129551	0.029999999	0	0.001		
134	11.01683328	122.0514692	0.689999998	1.45	0.578	Frank	100-Year
13/	10.93818813	122.0004052	0.029999999	07	0.001	Frank	100 Voor
138	10.95733435	122.0089883	0	0.7	0.490	Frank	100-Year
139	11.00617698	122.0423088	0.75999999	1.5	0.548	Frank	100-Year
140	10.99594444	122.03/6456	0.029999999	0	0.001		
141	11.09183229	122.0491072	0.029999999	0	0.001		100.14
142	11.00337	122.1152199	0.769999981	0.9	0.01/	Frank	100-Year
143	10.95301962	122.046/185	0.360000014	0.61	0.062		400.1/
148	11.0122/141	122.0749224	2.420000076	6.39	0.640	Frank	100-Year
150	11.0/31/951	122.0596864	1.299999952	0.5	0.640	Frank	100-Year
151	11.00341534	122.0803316	0	0	0.000	Euro in la	100 //
152	11.00/415/4	122.04953	0	0.52	0.270	Frank	TOD-lear
153	11 0/65/609	122.0000020			0.000	Erank	100 Voor
154	11 007/7157	122.0510000	1.070000052	0.97	0.010	FIDIIK	TOO-leal
155	11.00747132	122.0+30377	0 02000000		0.000	Volanda	E Voor
0,01	11.01230109	122.0222022	0.029999999	0.0	0.325	TUIATIOA	5-rear

ANNEX 12. EDUCATIONAL INSTITUTIONS AFFECTED BY FLOODING IN PALIWAN FLOODPLAIN

	Antique			
E	Bugasong			
Duilding Norra	Derenerativ	Ra	ainfall Scen	ario
Building Name	Barangay	5-year	25-year	100-year
School	Bugasong	Low		
School	Bugasong			
School	Bugasong			
School	Bugasong			
Jaguiguican Elementary School	Bugasong			
	Laua-An	<u>^</u>		
Building Name	Barangay	Ra	ainfall Scen	ario
Building Name	Darangay	5-year	25-year	100-year
Guinbanga-an Elementary School	Guinbanga-An			
CRANS National School	Guisijan	Low		
Guisijan Elementary School	Guisijan			
Barangay Maria Day Care Center	Loon			
Eastern Laua-an National High School	Loon	Low		
Maria Elementary School	Loon			
Lugta Day Care Center	Lugta	Low		
Lugta Elementary School	Lugta			
Maria Elementary School	Paningayan	Mediun		
Paningayan Day Care Center	Santiago			
Paningayan Primary School	Santiago			

ANNEX 13. MEDICAL INSTITUTIONS AFFECTED BY FLOODING IN PALIWAN FLOODPLAIN

	Laua-An			
Duilding Name	Barangay		Rainfall Scer	nario
Building Name	Darangay	5-year	25-year	100-year
Guinbanga-an Day Care Center	Guinbanga-An			
Guinbanga-an Health Center	Guinbanga-An			
Guisijan Health Center	Guisijan			
Paningayan Health Center	Santiago			

ANNEX 14. UPC PHIL-LIDAR 1 TEAM COMPOSITION

Project Leader Jonnifer R. Sinogaya, PhD.

Chief Science Research Specialist Chito Patiño

Senior Science Research Specialists Christine Coca Jared Kislev Vicentillo

Research Associates

Isabella Pauline Quijano Jarlou Valenzuela Rey Sidney Carredo Mary Blaise Obaob Rani Dawn Olavides Sabrina Maluya Naressa Belle Saripada Jao Hallen Bañados Michael Angelo Palomar Glory Ann Jotea