REGION 4A

Infanta River Flood Plain:

DREAM LiDAR Data Acquistion and Processing Report

TRAINING CENTER FOR APPLIED GEODESY AND PHOTOGRAMMETRY

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Abbreviations

ALTM	Airborne Laser Terrain Mapper
DAC	Data Acquisition Component
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
DVC	Data Validation Component
FOV	Field of View
FTP	File Transfer Protocol
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
POS	Position Orientation System
PRF	Pulse Repetition Frequency
NAMRIA	National Mapping and Resource Information Authority

Introduction

Introduction

1.1 About the DREAM Program

The UP Training Center for Applied Geodesy and Photogrammetry (UP TCAGP) conducts a research program entitled "Nationwide Disaster Risk and Exposure Assessment for Mitigation (DREAM) Program" funded by the Department of Science and Technology (DOST) Grants-in-Aid Program. The DREAM Program aims to produce detailed, up-to-date, national elevation dataset for 3D flood and hazard mapping to address disaster risk reduction and mitigation in the country.

The DREAM Program consists of four components that operationalize the various stages of implementation. The Data Acquisition Component (DAC) conducts aerial surveys to collect Light Detecting and Ranging (LiDAR) data and aerial images in major river basins and priority areas. The Data Validation Component (DVC) implements ground surveys to validate acquired LiDAR data, along with bathymetric measurements to gather river discharge data. The Data Processing Component (DPC) processes and compiles all data generated by the DAC and DVC. Finally, the Flood Modeling Component (FMC) utilizes compiled data for flood modeling and simulation.

Overall, the target output is a national elevation dataset suitable for 1:5000 scale mapping, with 50 centimeter horizontal and vertical accuracies. These accuracies are achieved through the use of state-of-the-art airborne Light Detection and Ranging (LiDAR) technology and appended with Synthetic-aperture radar (SAR) in some areas. It collects point cloud data at a rate of 100,000 to 500,000 points per second, and is capable of collecting elevation data at a rate of 300 to 400 square kilometers per day, per sensor.

1.2 Objectives and Target Outputs

The program aims to achieve the following objectives:

a) To acquire a national elevation and resource dataset at sufficient resolution to produce information necessary to support the different phases of disaster management;
b) 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;
c) To develop the capacity to process, produce and analyze various proven and potential thematic map layers from the 3D data useful for government agencies;
d) To transfer product development technologies to government agencies with geospatial information requirements, and;
e) To generate the following outputs:
    1) flood hazard map
    2) digital surface model
    3) digital terrain model and
    4) orthophotograph

1.3 General Methodological Framework

The methodology employed to accomplish the project's expected outputs are subdivided into four (4) major components, as shown in Figure 1. Each component is described in detail in the following sections.

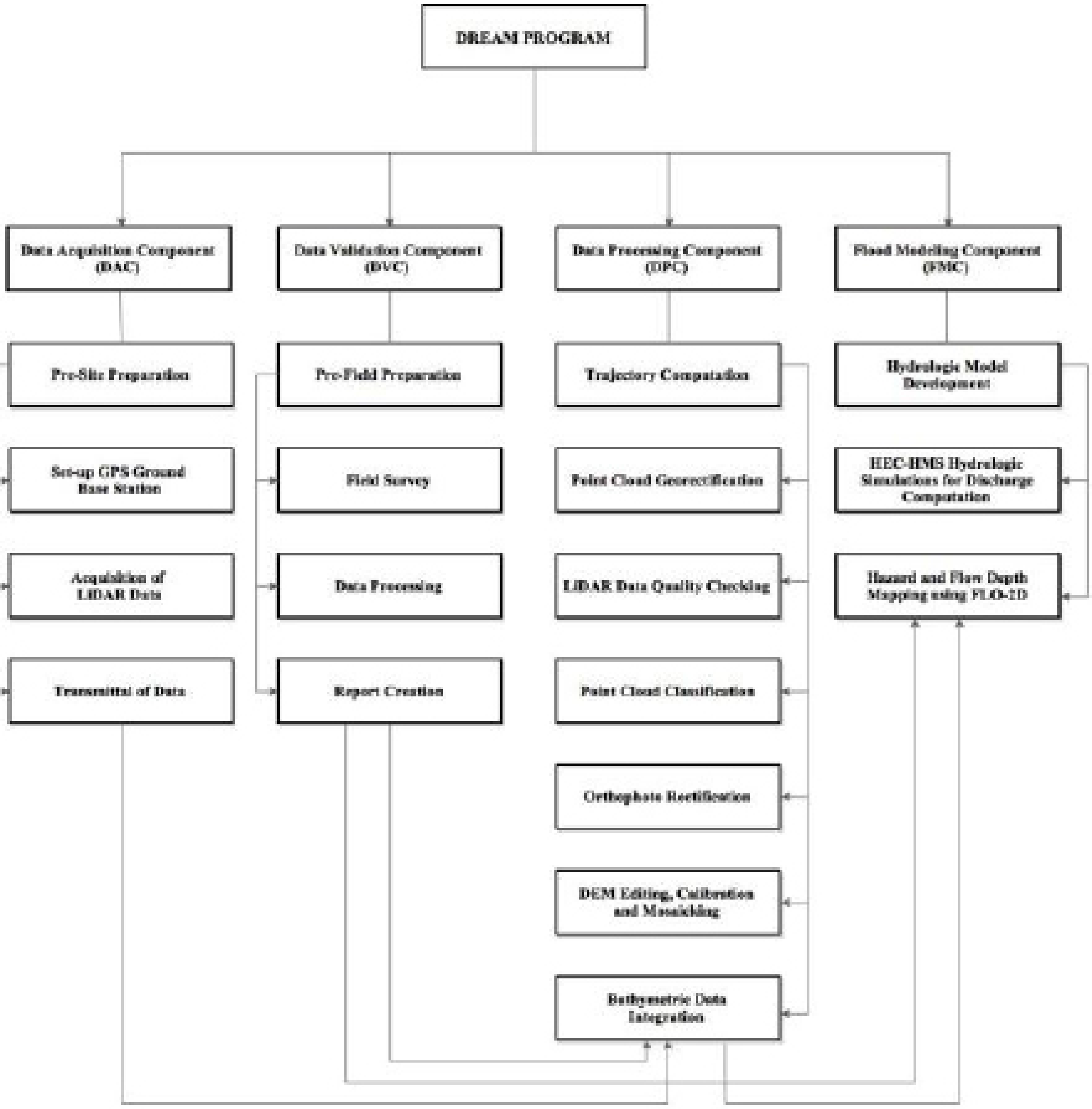

Figure 1. The General Methodological Framework of the Program

Study Area

Study Area

Considered as a first class municipality in the province of Quezon, Infanta has a total land area of 130.1 square kilometers. It contains 36 barangays, and lies along the coast of the Pacific Ocean. It is considered as a critical river system in terms of flooding. In a report by the Infanta, Quezon Municipal Engineering Office, it experienced a 342-mm rainfall event on November 29, 2004 that resulted in considerable damage to lives, infrastructure and agriculture.

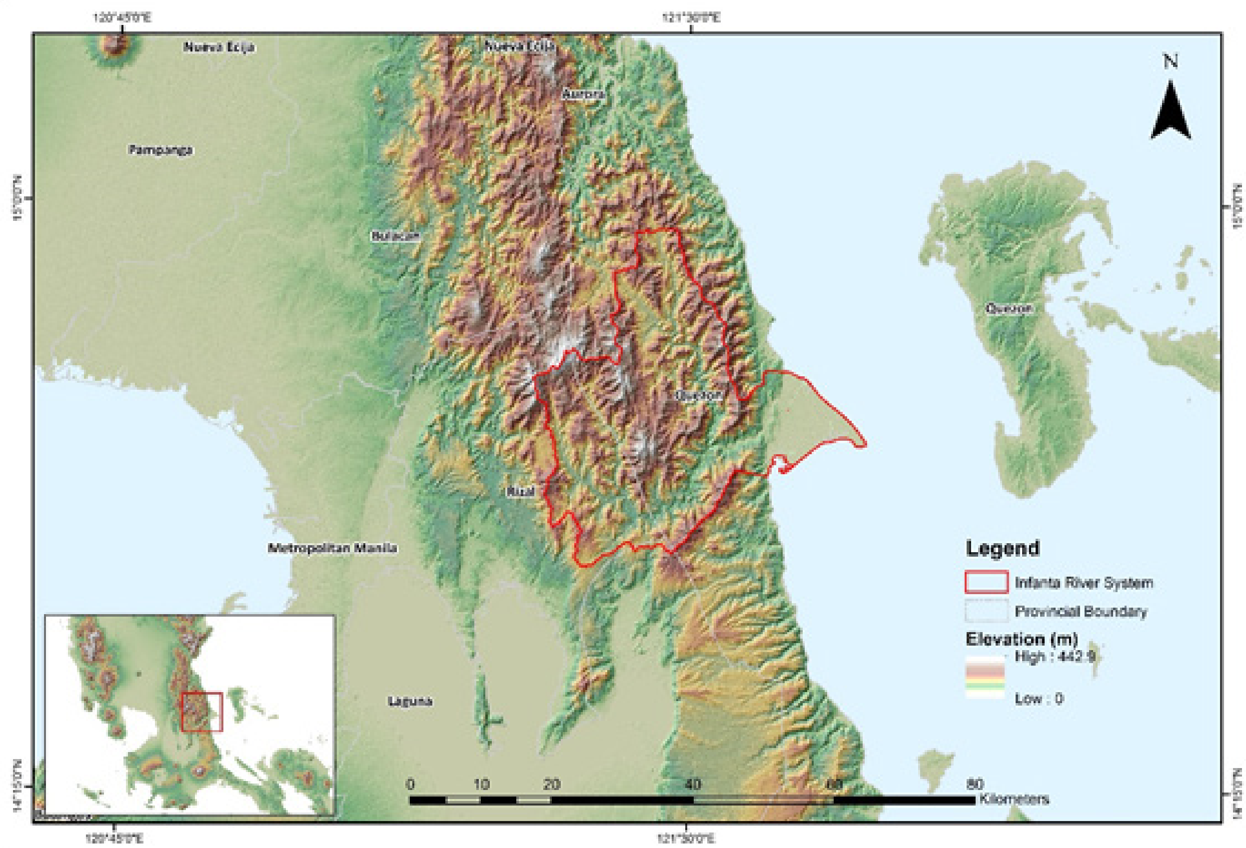

Figure 2. Infanta River System.

Some of the important parameters to be used in the characterization of the river basin (e.g., Manning's coefficient – a representation of the variable flow of water in different land covers) are the land cover and soil use. The shape files of the soil and land cover were taken from the Bureau of Soils, which is under the Department of Environment and Natural Resources Management, and National Mapping and Resource Information Authority (NAMRIA). The land and soil cover of Infanta River System are as shown in Figure 3 and Figure 4.

Study Area

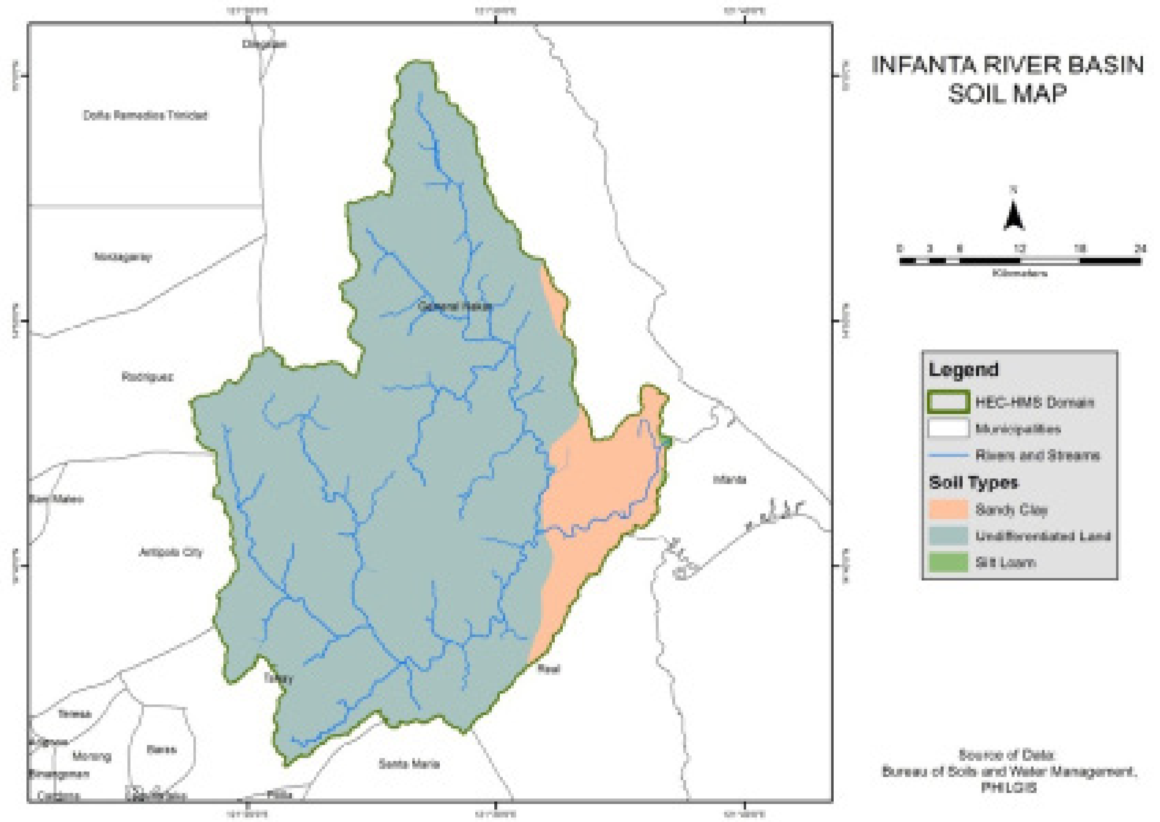

Figure 3. Infanta River Basin Soil Map

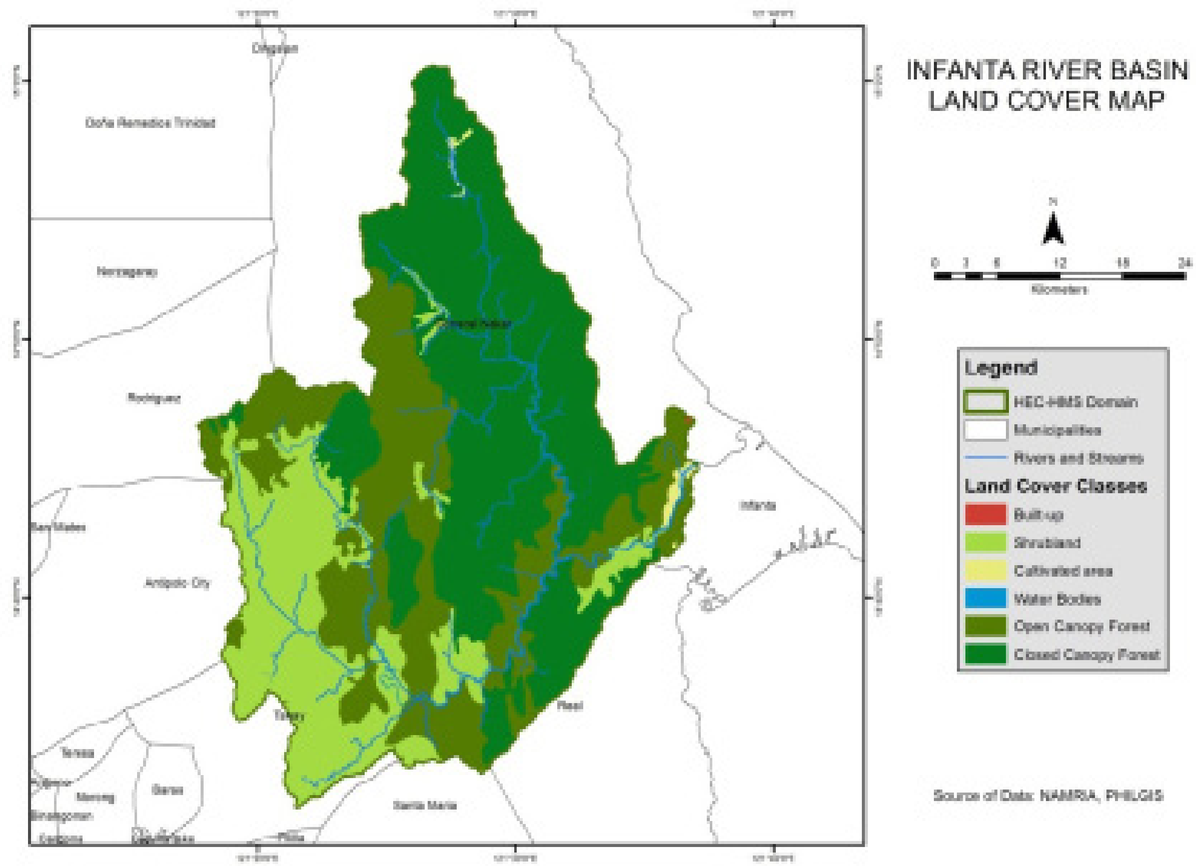

Figure 4. Infanta River Basin Land Cover Map

Methodology

Methodology

3.1 Acquisition Methodology

The methodology employed to accomplish the project's expected outputs are subdivided into four (4) major components, as shown in Figure 5. Each component is described in detail in the following sections.

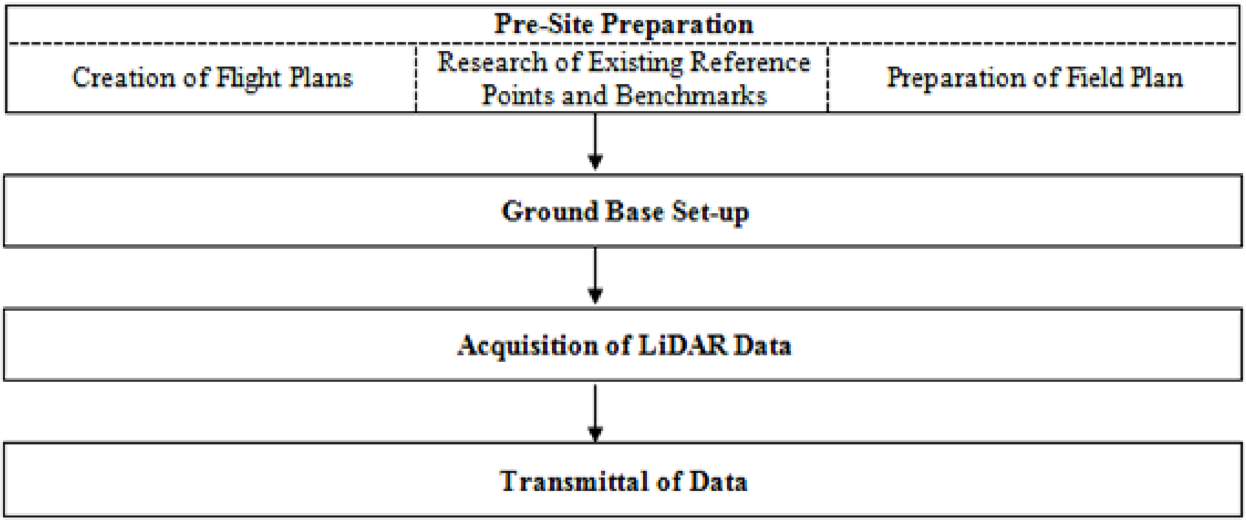

Figure 5. Flowchart of Project Methodology

3.1.1 Pre-site Preparations

3.1.1.1 Creation of Flight Plans

Flight planning is the process of configuring the parameters of the aircraft and LiDAR system (i.e. altitude, angular field of view (FOV), speed of the aircraft, scans frequency and pulse repetition frequency) to achieve a target of two points per square meter point density for the floodplain. This ensures that areas of the floodplain that are most susceptible to floods will be covered. LiDAR parameters and their computations are shown in Table 1.

The parameters set in the LiDAR sensor to optimize the area coverage following the objectives of the project and to ensure the aircraft's safe return to the airport (base of operations) are shown in Table 1. Each flight acquisition is designed for four operational hours. The maximum flying hours for Cessna 206H is five hours.

Table 1. Relevant LiDAR parameters

Parameter		Formula	Description
SW (Swath Width)		$SW = 2 * H * \tan(\theta/2)$	H – altitude Θ – angular FOV
Pointing Space	ΔXacross	$\Delta Xacross = (\Theta * H) / (N\cos2(\Theta/2))$	ΔXacross – point spacing across the flight line H – altitude Θ – angular FOV N – number of points in one scanning line
	ΔXalong	$\Delta Xalong = v / fsc$	ΔXalong- point spacing along the flight line v – forward speed (m/s) fsc – scanning rate or scan frequency
Point density, dmin		$dmin = 1 / (\Delta Xacross * \Delta Xalong)$	ΔXacross, ΔXalong point spacings
Flight line separation, e		$e = SW * (1 – \text{overlapping factor})$	SW – swath width
# of flight lines, n		$n = w / [(1 – \text{overlap}) * SW]$	w-width of the map that will be produce in meters. The direction of flights will be perpendicular to the width.

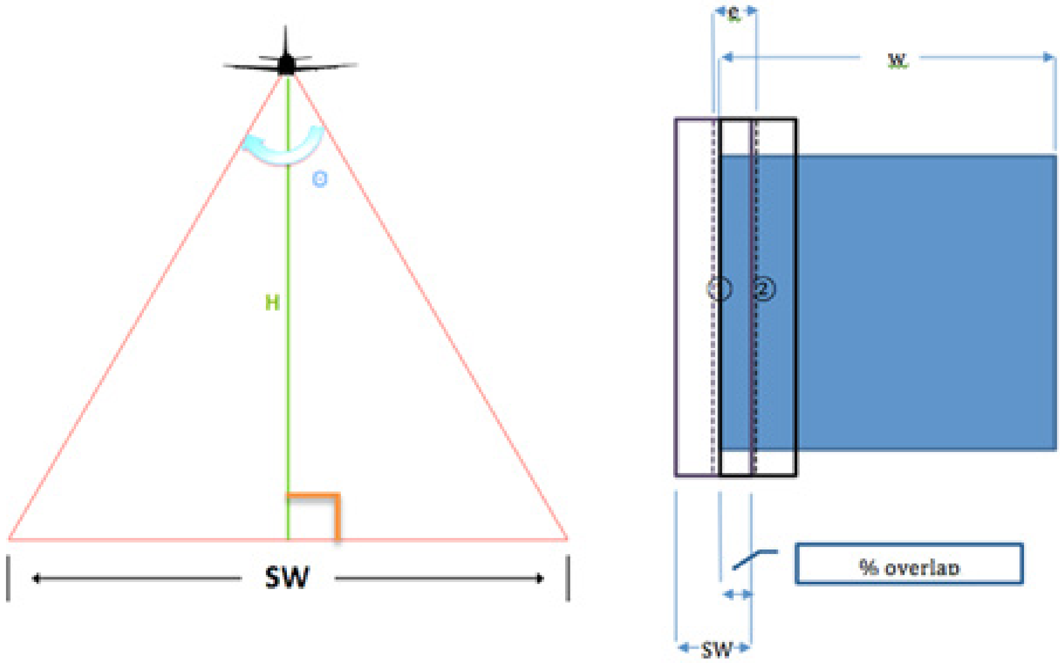

Figure 6. Concept of LiDAR data acquisition parameters

The relationship among altitude, swath, and FOV is show in Figure 6. Given the altitude of the survey (H) and the angular FOV, the survey coverage for each pass (swath) can be calculated by doubling the product of altitude and tangent of half the field of view.

3.1.1.2 Collection of Existing Reference Points and Benchmarks

Collection of pertinent technical data, available information, and coordination with the National Mapping and Resource Information Authority (NAMRIA) is conducted prior to the surveys. Reference data collected includes locations and descriptions of horizontal and vertical control (elevation benchmarks) points within or near the project area. These control points are used as base stations for the aerial survey operations. Base stations are observed simultaneously with the acquisition flights.

3.1.1.3 Preparation of Field Plan

In preparation for the field reconnaissance and actual LiDAR data acquisition, a field plan is prepared by the implementation team. The field plan serves as a guide for the actual fieldwork and included personnel, logistical, financial, and technical details. Three major factors are included in field plan preparation: priority areas for the major river basin system; budget; and accommodation and vehicle rental.

LiDAR data are acquired for the floodplain area of the river system as per order of priority based on history of flooding, loss of lives, and damages of property. The order of priority in which LiDAR data surveys are conducted by the team for the floodplain areas of the 18 major river systems and 3 additional systems is shown in Table 2.

Table 2. List of Target River Systems in the Philippines

	Target River System	Location	Area of the River System (km^2)	Area of the Flood Plain (km^2)	Area of the Watershed (km^2)
1	Cagayan de Oro	Mindanao	1,364	25	1,338.51
1.1	Iponan	Mindanao	438	33	404.65
2	Mandulog	Mindanao	714	7	707.41
2.1	Iligan	Mindanao	153	7	146.38
2.2	Agus	Mindanao	1,918	16	1,901.60
3	Pampanga	Luzon	11,160	4458	6702
4	Agno	Luzon	6,220	1725	4495
5	Bicol	Luzon	3,173	585	2,587.79
6	Panay	Visayas	2,442	619	1823
7	Jalaur	Visayas	2,105	713	1,392
8	Ilog Hilbangan	Visayas	2,146	179	1967
9	Magasawang Tubig	Luzon	1,960	483	1,477.08
10	Agusan	Mindanao	11,814	262	11,551.62
11	Tagoloan	Mindanao	1,753	30	1,722.90
12	Davao	Mindanao	1,609	54	1555
13	Tagum	Mindanao	2,504	595	1,909.23
14	Buayan	Mindanao	1,589	201	1,388.21
15	Mindanao	Mindanao	20,963	405	20,557.53
16	Lucena	Luzon	238	49	189.31
17	Infanta	Luzon	1,029	90	938.61
18	Boracay	Visayas	43.34	43.34	N/A
19	Cagayan	Luzon	28,221	10386	17,835.14

3.1.2 Ground Base Set-up

A reconnaissance is conducted one day before the actual LiDAR survey for purposes of recovering control point monuments on the ground and site visits of the survey area set in the flight plan for the floodplain. Coordination meetings with the Airport Manager, regional DOST office, local government units and other concerned line government agencies are also held.

Ground base stations are established within 30-kilometer radius of the corresponding survey area in the flight plan. This enables the system to establish its position in three-dimensional (3D) space so that the acquired topographic data will have an accurate 3D position since the survey required simultaneous observation with a base station on the ground using terrestrial Global Navigation Satellite System (GNSS) receivers.

3.1.3 Acquisition of Digital Elevation Data (LiDAR Survey)

Acquisition of LiDAR data is done by following the flight plans. The survey uses a LiDAR instrument mounted on the aircraft with its sensor positioned through a specially modified peep hole on the belly of the aircraft. The pilots are guided by the flight guidance software which uses the data out of the flight planning program with a mini-display at the pilot's cockpit showing the aircraft's real-time position relative to the current survey flight line. The reference points established by NAMRIA are also monitored and used to calibrate the data.

As the system collected LiDAR data, ranges and intensities are recorded on hard drives dedicated to the system while the images are stored on the camera hard drive. Position Orientation System (POS) data is recorded on the POS computer inside the control rack. It can only be accessed and downloaded via file transfer protocol (ftp) to the laptop computer. GPS observations were downloaded each day for efficient data management.

3.1.4 Transmittal of Acquired LiDAR Data

All data surrendered are monitored, inspected and re-checked by securing a data transfer checklist signed by the downloader (Data Acquisition Component) and the receiver (Data Processing Component). The data transfer checklist shall include the following: date of survey, mission name, flight number, disk size of the necessary data (LAS, LOGS, POS, Images, Mission Log File, Range, Digitizer and the Base Station), and the data directory within the server. Figure 7 shows the arrangement of folders inside the data server.

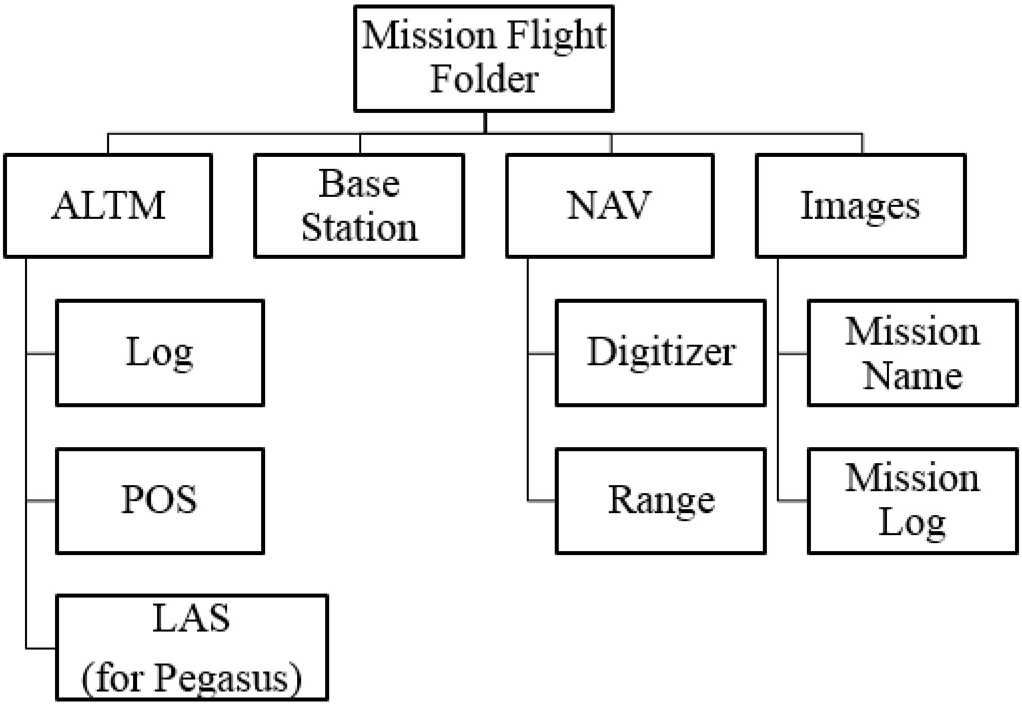

Figure 7. LiDAR Data Management for transmittal

3.1.5 Equipment (ALTM Pegasus)

The ALTM Pegasus (Optech, Inc) is a laser based system suitable for topographic survey (Figure 8). It has a dual output laser system for maximum density capability. The LiDAR system is equipped with an Inertial Measurement Unit (IMU) and GPS for geo-referencing of the acquired data (Annex A contains the technical specification of the system).

The camera of the Pegasus sensor is tightly integrated with the system. It has a footprint of 8,900 pixels across by 6,700 pixels along the flight line (Annex B contains the technical specification of the D-8900 aerial digital camera).

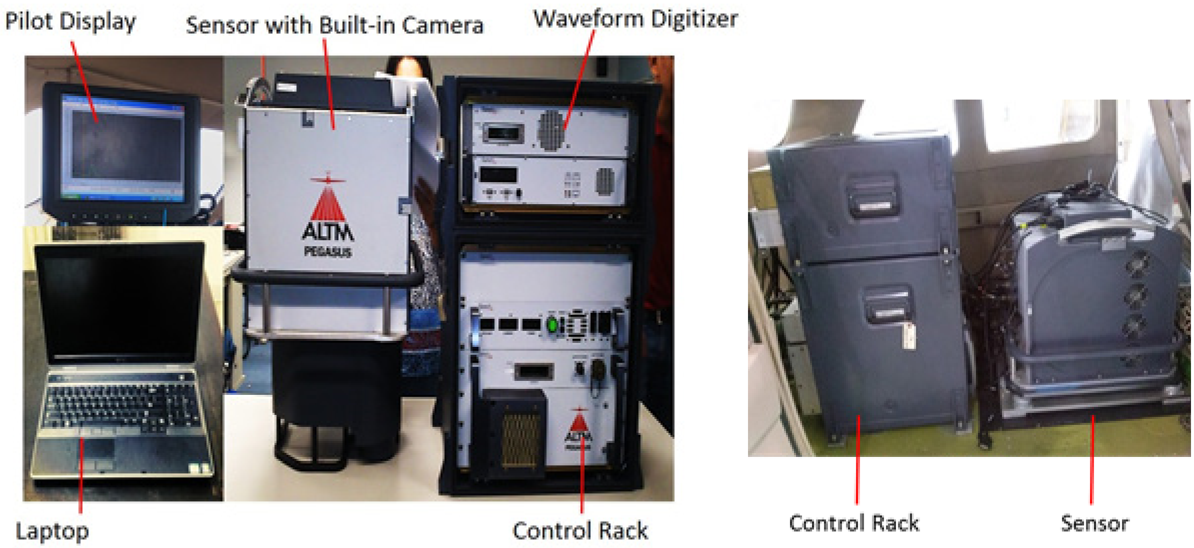

Figure 8. The ALTM Pegasus System: a) parts of the Pegasus system, b) the system as installed in Cessna T206H

3.2 Processing Methodology

The schematic diagram of the workflow implemented by the Data Processing Component (DPC) is shown in Figure 9. The raw data collected by the Data Acquisition Component (DAC) is transferred to DPC. Pre-processing of this data starts with the computation of trajectory and georectification of point cloud, in which the coordinates of the LiDAR point cloud data are adjusted and checked for gaps and shifts, using POSPac, LMS, LAStools and Quick Terrain (QT) Modeler software.

The unclassified LiDAR data then undergoes point cloud classification, which allows cleaning of noise data that are not necessary for further processing, using TerraScan software. The classified point cloud data in ASCII format is used to generate a data elevation model (DEM), which is edited and calibrated with the use of validation and bathymetric survey data collected from the field by the Data Validation and Bathymetry Component (DVBC). The final DEM is then used by the Flood Modeling Component (FMC) to generate the flood models for different flooding scenarios.

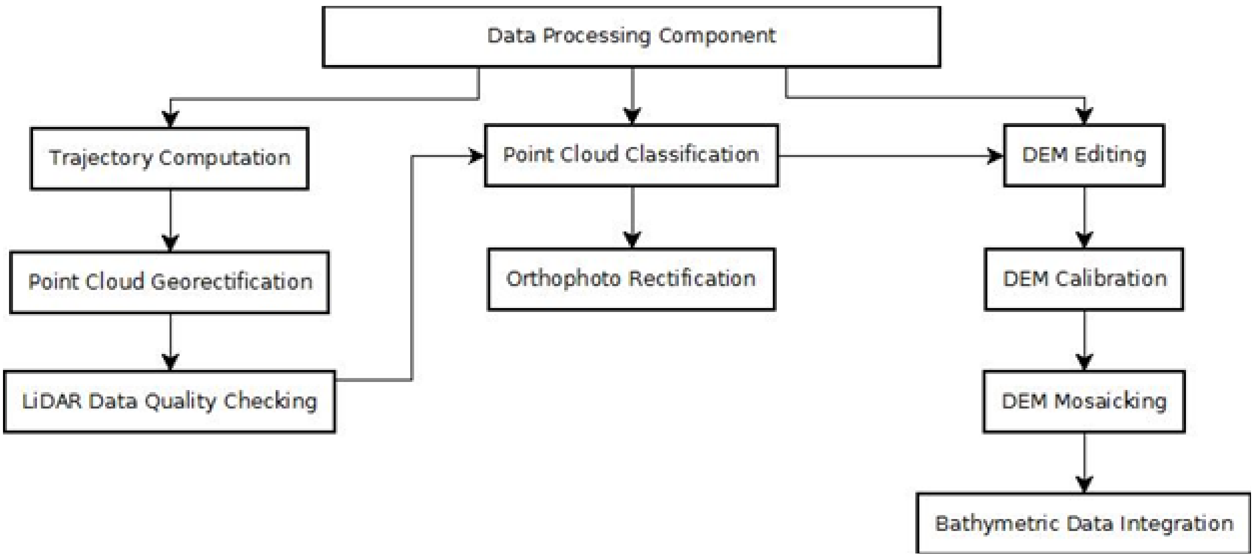

Figure 9. Schematic diagram of the data processing

3.2.1 Data Transfer

The Infanta mission, named 1INFB186A, was flown with the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) by Pegasus system on July 6, 2013. The Data Acquisition Component (DAC) transferred 10.3 Gigabytes of range data, 222 Megabytes of POS data, 6.27 / 8.99 Megabytes of GPS base station data, and no raw image data to the data server on July 10, 2013. DPC verified the completeness of the transferred data. The whole Infanta dataset was fully transferred on September 18, 2013.

3.2.2 Trajectory Computation

The trajectory of the aircraft is computed using the software POSPAC MMS v6.2. It combines the POS data from the integrated GPS/INS system installed on the aircraft, and the Rinex data from the GPS base station located within 25 kilometers of the area. It then computes the Smoothed Best Estimated Trajectory (SBET) file, which contains the best estimated trajectory of the aircraft, and the Smoothed Root Mean Square Estimation error file (SMRMSG), which contains the corresponding standard deviations of the position parameters of the aircraft at every point on the computed trajectory.

The key parameters checked to evaluate the performance of the trajectory are the Solution Status parameters and the Smoothed Performance Metrics parameters. The Solution Status parameters characterize the GPS satellite geometry and baseline length at the time of acquisition, and the processing mode used by POSPAC. The acceptable values for each Solution Status parameter are shown in Table 3.

The Smoothed Performance Metrics parameters describe the root mean square error (RMSE) for the north, east and down (vertical) position of the aircraft for each point in the computed trajectory. A RMSE value of less than 4 cm for the north and east position is acceptable, while a value of less than 8 cm is acceptable for the down position.

Table 3. Smoothed Solution Status parameters in POSPAC MMS v6.2.

Parameter	Optimal Value
Number of satellites	More than 6 satellites
Position Dilution of Precision	Less than 3
Baseline Length	Less than 30 km
Processing mode	Less than or equal to 1, however short burtsts of values greater than 1 are acceptable

3.2.3 LiDAR Point Cloud Rectification

The trajectory file (SBET) and its corresponding accuracy file (SMRMSG) generated in POSPAC are merged with the Range file to compute the coordinates of each individual point. The coordinates of points within the overlap region of contiguous strips vary due to small deviations in the trajectory computation for each strip. These strip misalignments are corrected by matching points from overlapping laser strips. This is done by the Lidar Mapping Suite (LMS) software developed by Optech.

LMS is a LiDAR software package used for automated LiDAR rectification. It has the capability to extract planar features per flight line and to form correspondence among the identical planes available in the overlapping areas (illustrated in Figure 10). In order to produce geometrically correct point cloud, the redundancy in the overlapping areas of flight lines is used to determine the necessary corrections for the observations.

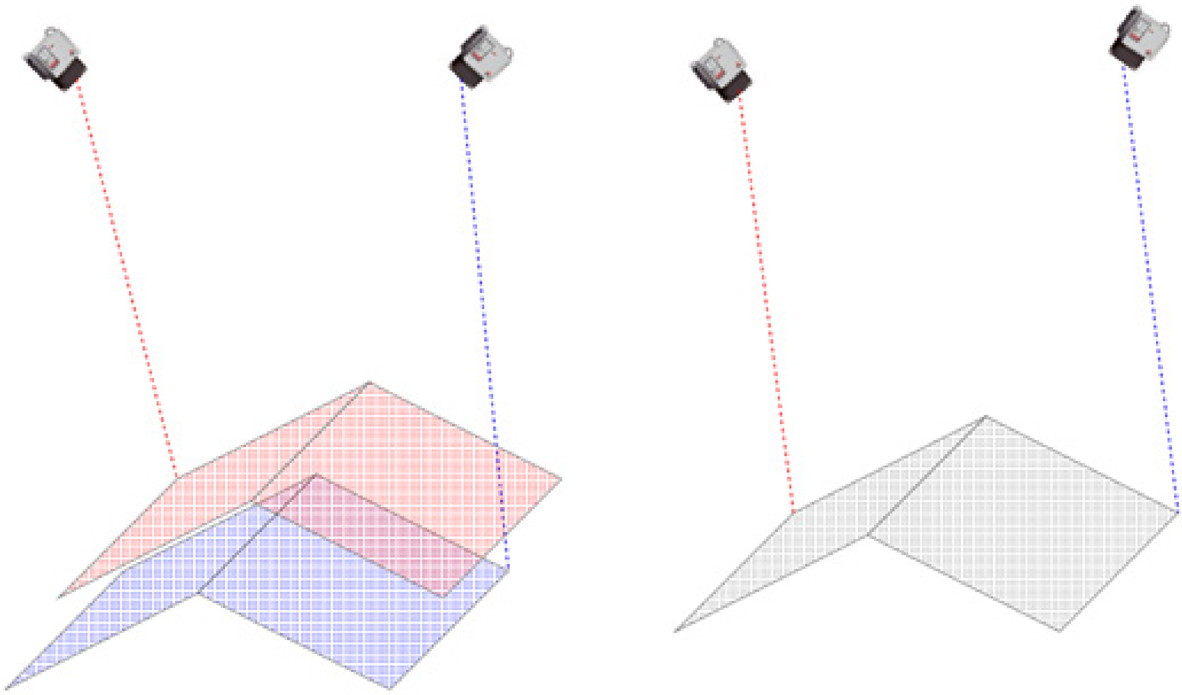

Figure 10. Misalignment of a single roof plane from two adjacent flight lines, before rectification (left). Least squares adjusted roof plane, after rectification (right).

The orientation parameters are corrected in LMS by using least squares adjustment to obtain the best-fit parameters and improve the accuracy of the LiDAR data. The primary indicators of the LiDAR rectification accuracy are the standard deviations of the corrections of the orientation parameters. These values are seen on the Boresight corrections, GPS position corrections, and IMU attitude corrections, all of which are located on the LMS processing summary report. Optimum accuracy is obtained if the Boresight and IMU attitude correction standard deviations are less than 0.001°, and if the GPS position standard deviations are below 0.01 m.

3.2.4 LiDAR Data Quality Checking

After the orientation parameters are corrected and the point cloud coordinates are computed, the entire point cloud data undergoes quality checking, to see if: (a) there are remaining horizontal and vertical misalignments between contiguous strips, and; (b) to check if the density of the point cloud data reach the target density for the site. The LAStools software is used to compute for the elevation difference in the overlaps between strips and the point cloud density. It is a software package developed by Rapidlasso GmbH for filtering, tiling, classifying, rasterizing, triangulating and quality checking Terabytes of LiDAR data, using robust algorithms, efficient I/O tools and memory management. LAStools can quickly create raster representing the computed quantities, which provide guiding images in determining areas where further quality checks are necessary. The target requirements for floodplain acquisition, computed by LAStools, are shown in Table 4.

Table 4. Parameters investigated during quality checks.

Criteria	Requirement
Minimum per cent overlap	25%
Average point cloud density per square meter	2.0
Elevation difference between strips (on flat areas)	0.20 meters

LAStools can provide guides where elevation differences probably exceed the 20 cm limit. An example of LAStools output raster visualizing points in the flight line overlaps with a vertical difference of +/- 20 cm (displayed as dense red/blue areas) is shown in Figure 11.

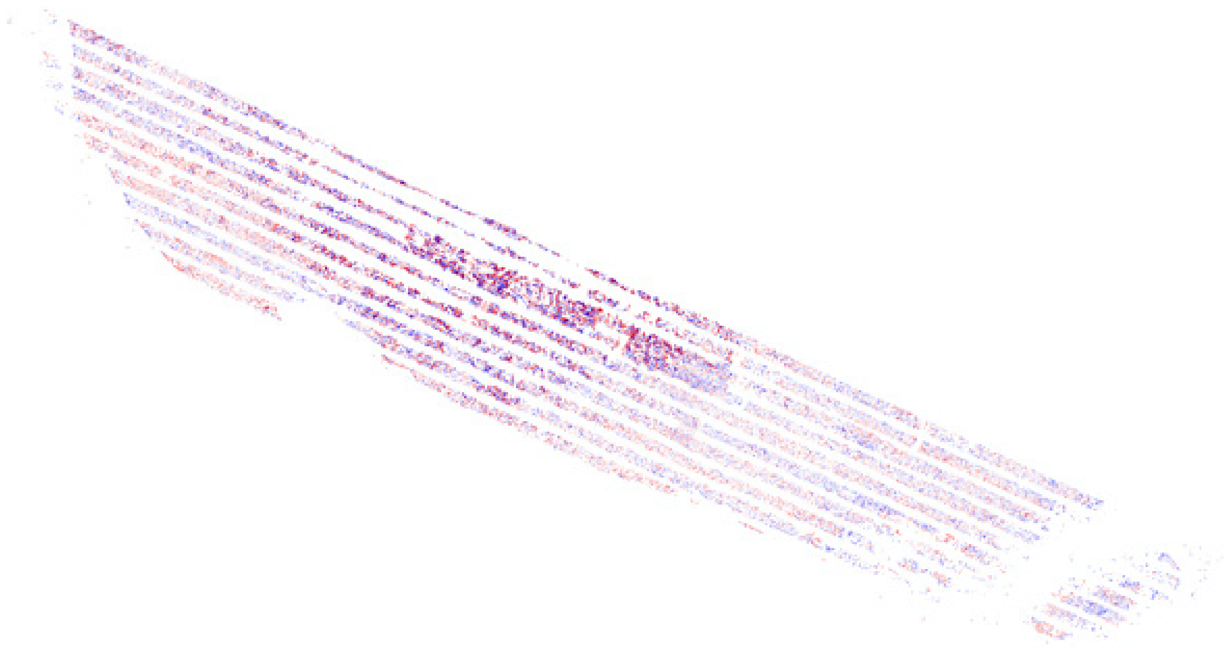

Figure 11. Elevation difference between flight lines generated from LAStools

To investigate the occurrences of elevation differences in finer detail, the profiling tool of Quick Terrain Modeler software is used. Quick Terrain Modeler (QT Modeler) is a 3D point cloud and terrain visualization software package developed by Applied Imagery, Inc. The profiling capability of QT Modeler is illustrated in Figure 12.

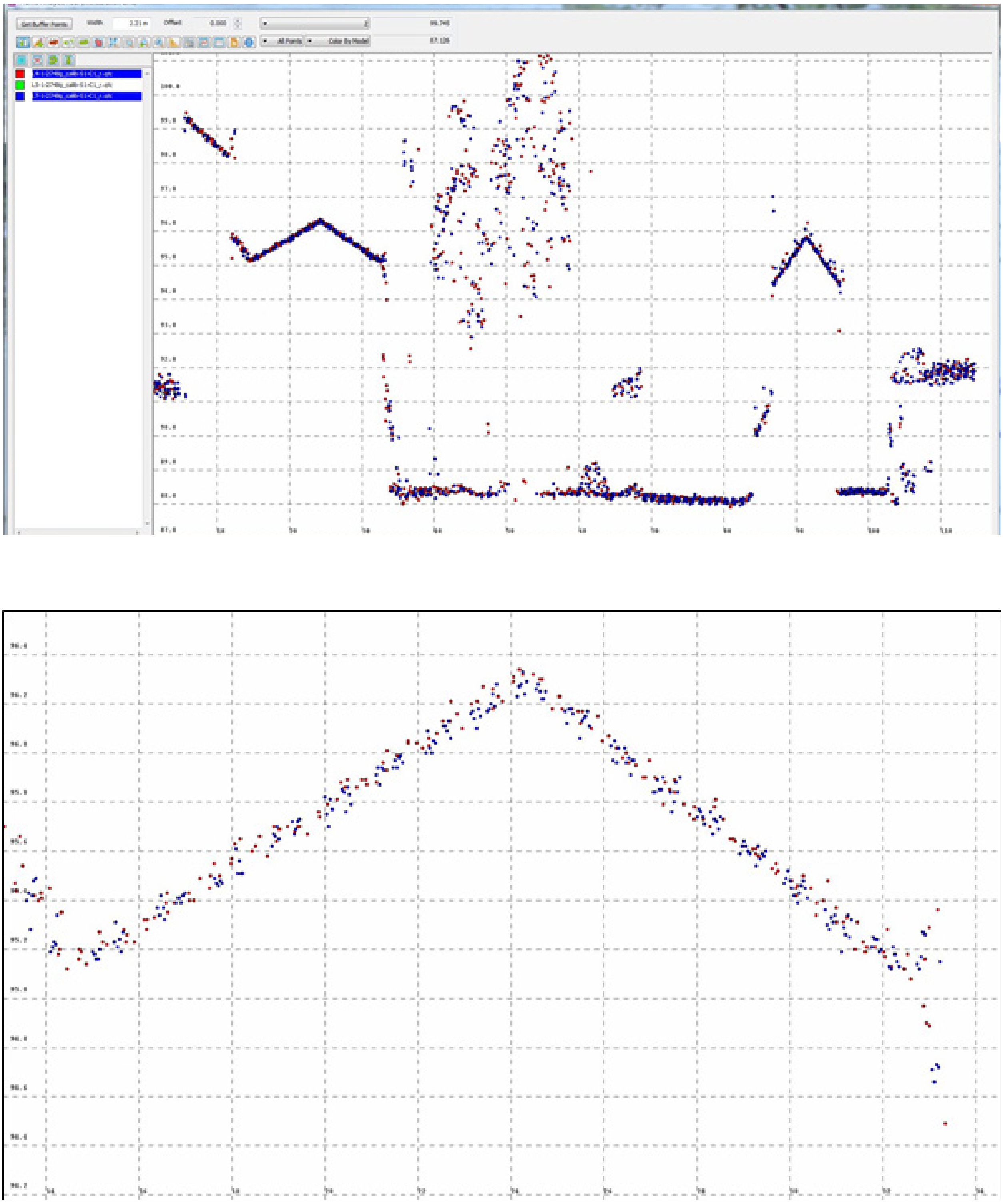

Figure 12. Profile over roof planes (a) and a zoomed-in profile on the area encircled in yellow (b)

The profile (e.g., over a roof plane) shows the overlapping points from different flight lines which serve as a good indicator that the correction applied by LMS for individual flight lines is good enough to attain the desired horizontal and vertical accuracy requirements. Flight lines that do not pass quality checking are subject for reprocessing in LMS until desired accuracies are obtained.

3.2.5 LiDAR Point Cloud Classification and Rasterization

Point cloud classification commences after the point cloud data has been rectified. TerraScan is a TerraSolid LiDAR software suite used for the classification of point clouds. It can read airborne and vehicle-based laser data in raw laser format, LAS, TerraScan binary or other ASCII-survey formats. Its classification and filtering routines are optimized by dividing the whole data into smaller geographical datasets called blocks, to automate the workflow and increase efficiency. In this study, the blocks were set to 1 km by 1 km with a 50 m buffer zone to prevent edge effects.

The process includes the classification of all points into Ground, Low Vegetation, Medium Vegetation, High Vegetation and Buildings. The classifier tool in TerraScan first filters air points and low points by finding points that are 5 standard deviations away from the median elevation of a search radius, which is 5 meters by default. It then divides the region into 60m by 60m search areas (the maximum area where at least one laser point hits the ground) and assigns the lowest points in these areas as the initial ground points from which a triangulated ground model is derived. The classifier then iterates through all the points and adds the points to the ground model by testing if it is (a) within the maximum iteration angle of 4° by default from a triangle plane, and (b) if it is within the maximum iteration distance (1.2 m by default) from a triangle plane. The ground plane is continuously updated from these iterations. The ground classification technique is illustrated in Figure 13. It is apparent that the smaller the iteration angle, the less eager the classifier is to follow changes in the point cloud (small undulations in terrain or hits on low vegetation). An angle close to 4° is used in flat terrain areas while an angle of 10° is used in mountainous or hilly terrains.

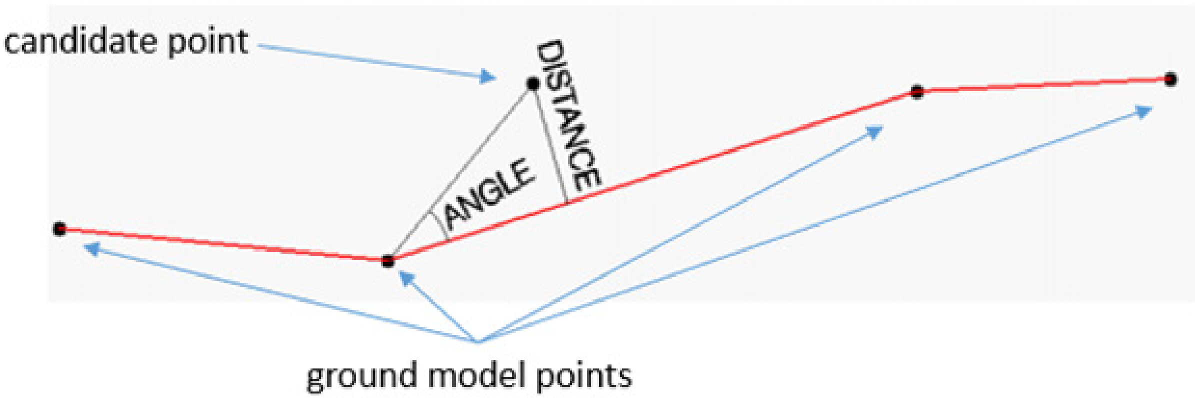

Figure 13. Ground classification technique employed in Terrascan

The parameters for ground classification routines used in floodplain and watershed areas are listed in Table 5.

Table 5. Ground classification parameters used in Terrascan for floodplain and watershed areas

Classification maximums	Floodplain (default)	Watershed (adjusted)
Iteration angle (degrees)	4	8
Iteration distance (meters)	1.20	1.50

The comparison between the produced DTM using the default parameters versus the adjusted is shown in Figure 14. The default parameters may fail to capture the sudden change in the terrain, resulting to less points being classified as ground that makes the DTM interpolated (Figure 14a). The adjusted parameters work better in these spatial conditions as shown in Figure 14b. Statistically, the number of ground points and model key points correctly classified can increase by as much as fifty percent (50%) when using the adjusted parameters.

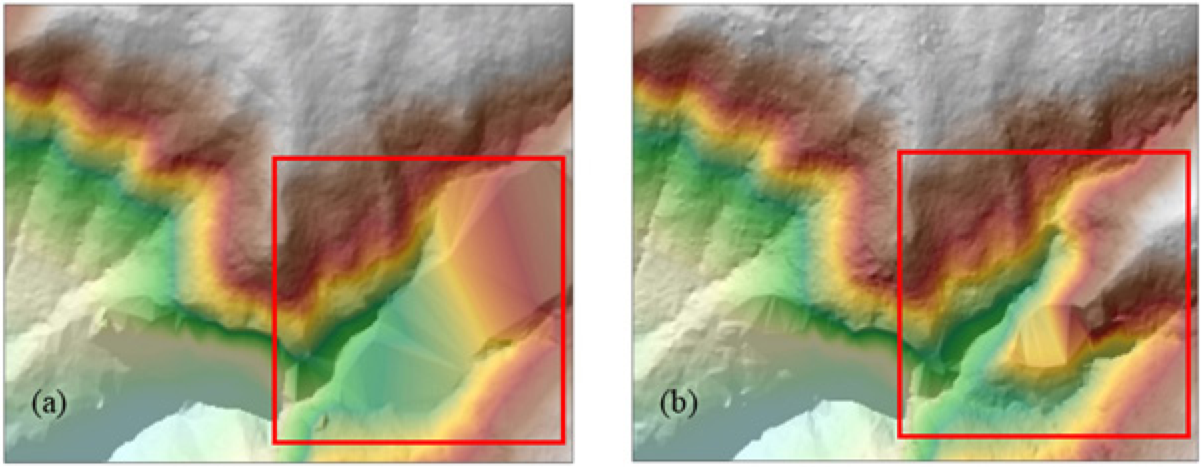

Figure 14. Resulting DTM of ground classification using the default parameters (a) and adjusted parameters (b)

The classification to Low, Medium and High vegetation is a straightforward testing of how high a point is from the ground model. The range of elevation values and its corresponding classification is shown in Table 6.

Table 6. Classification of Vegetation according to the elevation of points

Elevation of points (meters)	Classification
0.05 to 0.15	Low Vegetation
0.15 to 2.50	Medium Vegetation
2.50 to 50.0	High Vegetation

The classification to Buildings routine tests points above two meters (2.0 m) if they only have one echo, and if they form a planar surface of at least 40 square meters with points adjacent to them. Minimum size and Z tolerance are the parameters used in the classify buildings routine as shown in Figure 15.

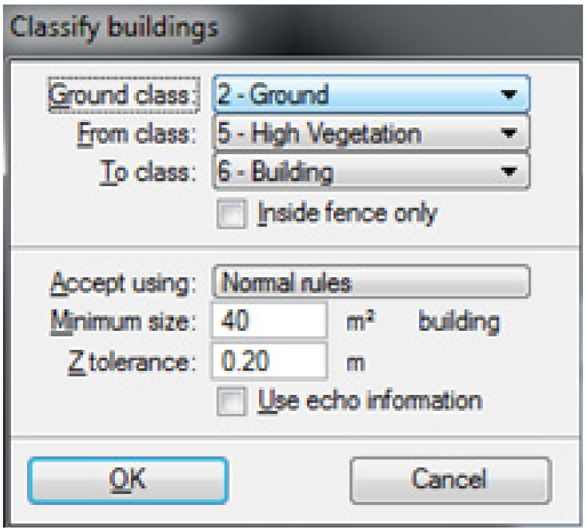

Figure 15. Default TerraScan building classification parameters

Minimum size is set to the smallest building footprint size of 40 m2 while the Z tolerance of 20cm is the approximate elevation accuracy of the laser points.

The point cloud data are examined for possible occurrences of air points which are to be deleted manually in the TerraScan window. Air points are defined as groups of points which are significantly higher or lower from the ground points. The different examples of air points are shown in Figure 16.

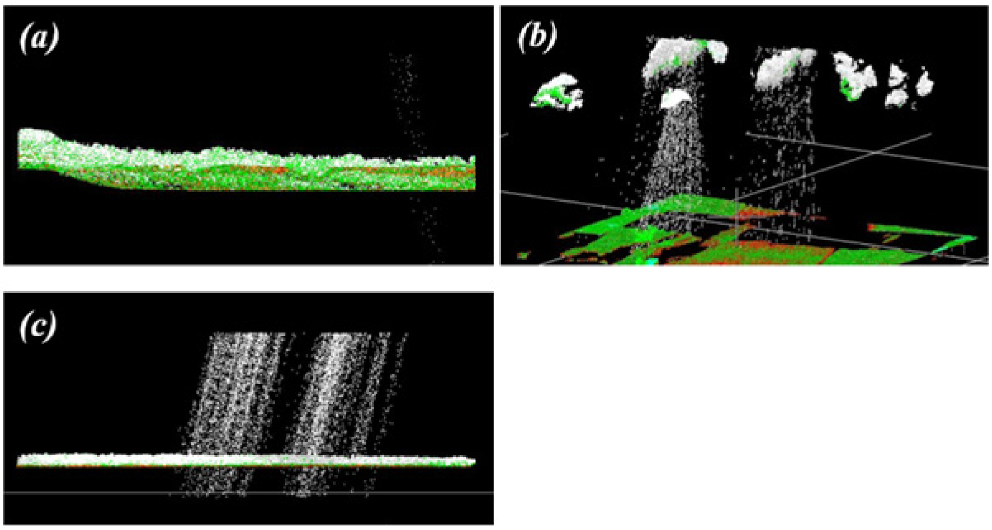

Figure 16. Different examples of air points manually deleted in the TerraScan window

The noise data can be as negligible as shown in Figure 16a or can be as severe as the one shown in Figure 16c. A combination of cloud points and shower of short ranges is displayed in Figure 16b. Shower of short ranges are caused by signal interference from the radio transmission of the tower and the aircraft. During every transmission on a specific frequency (around 120MHz), the signal is getting distorted due to the interference causing showers of short ranges in the output LAS.

Classified LiDAR point clouds that are free of air points, noise and unwanted data are processed in TerraScan to produce Digital Terrain Model (DTM) and the corresponding first and last return Digital Surface Models (DSM). These ground models are produced in the American Standard Code for Information Interchange format (ASCII) format. DTMs are produced by rasterizing all points classified to ground and model key points in a 1 m by 1 m grid. The last return DSMs are produced by rasterizing all last returns from all classifications (Ground, Model Key Points, Low, Medium, High Vegetation, Buildings and Default) in a 1 m by 1 m grid. The first return DSMs on the other hand are produced by rasterizing all first returns from all classifications. Power lines are usually included in this model. All of these ground models are used in the mosaicking, manual editing and hydro correction of the topographic dataset, in preparation for the floodplain hydraulic modelling.

3.2.6 DEM Editing and Hydro-correction

Even though the parameters of the classification routines are optimized, various digital elevation models (DTM, first and last return DSM) that are automatically produced may still display minor errors that still need manual correction to make the DEMs suitable for fine-scale flood modelling. This is true especially for features that are under heavy canopy. Natural embankments on the side of the river might be flattened or misrepresented because no point pierced the canopy on that area. The same difficulty might also occur on smaller streams that are under canopy. The DTM produced might have discontinuities on these channels that might affect the flood modelling negatively. Manual inspection and correction is still a very important part of quality checking the LiDAR DEMs produced.

To correctly portray the dynamics of the flow of water on the floodplain, the river geometry must also be taken into consideration. The LiDAR data must be made consistent to the topographic surveys done for the area, and the bathymetric data must be "burned", or integrated, into the DEM to make the dataset suitable for hydraulic analyses. However, no cross-sectional survey was performed for this area.

Results
and Discussion

4.1 LiDAR Acquisition in Infanta Floodplain

4.1.1 Flight Plans

Plans were made to acquire LiDAR data within the flood plain. Each flight mission had an average of 10 flight lines and ran for at most 2 hours including take-off, landing and turning time. The parameter used in the LiDAR system for acquisition is found in Table 7.

Table 7. Parameters used in LiDAR System during Flight Acquisition.

Fixed Variables	Values		
Flying Height (AGL - Above Ground Level) (m)	750m	1000 m	1200 m
Overlap	30 %	30%	30 %
Max. field of View	50	50	50
Speed of Plane (kts)	130	130	130
Turn around minutes	5	5	5
Swath	661.58 m	882 m	1058.53 m

The parameters that set in the LiDAR sensor to optimize the area coverage following the objectives of the project and to ensure the aircraft's safe return to the airport (base of operations) are shown in Table 7. Each flight acquisition is designed for four operational hours. The maximum flying hours for Cessna 206H is five hours.

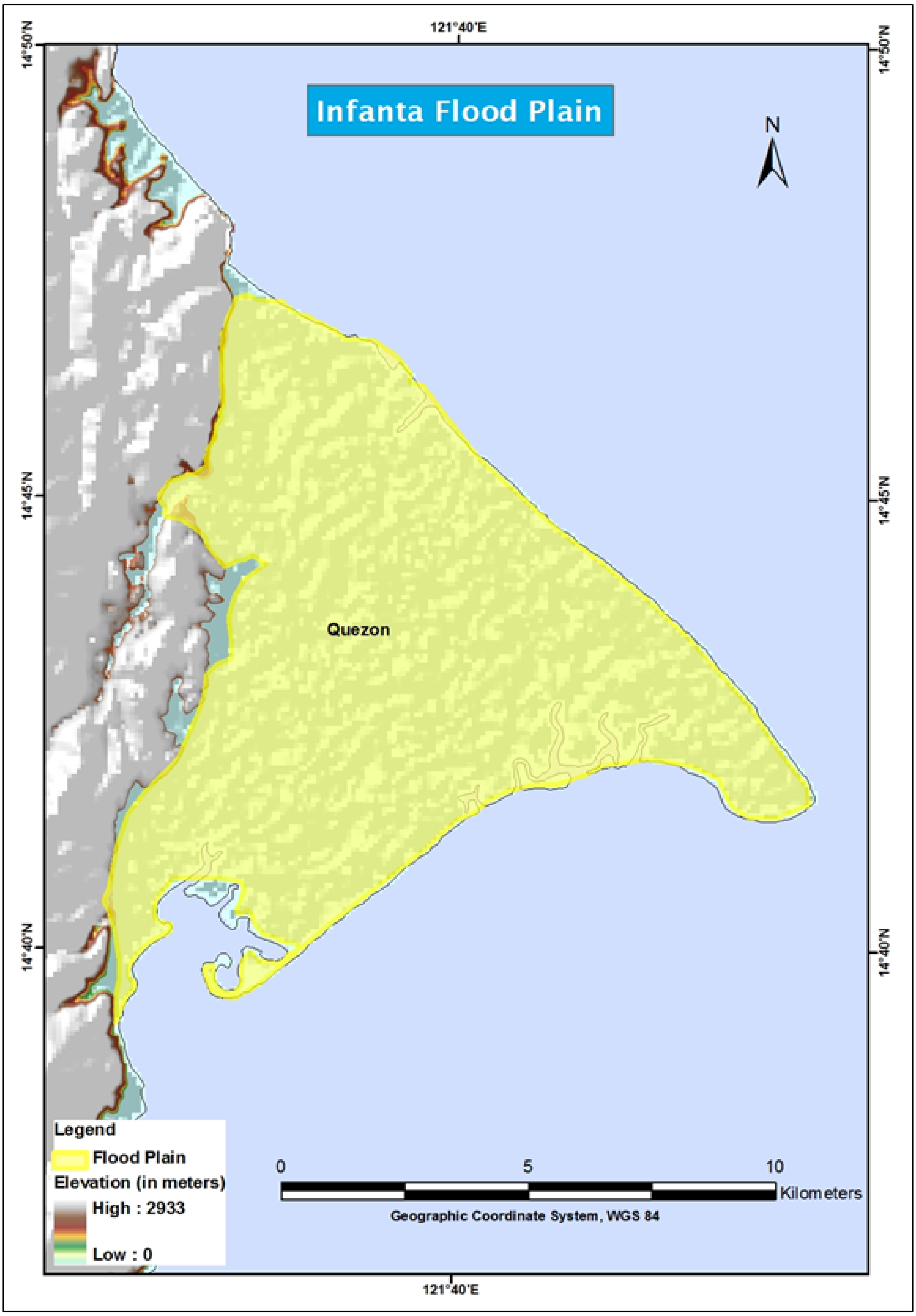

Figure 17. Infanta Floodplain Flight Plans.

4.1.2 Ground Base Station

The project team was able to recover one (1) NAMRIA control station (QZN-5) with first (1st) order accuracy. The ground control point (GCP) was used as reference point during flight operations using TRIMBLE SPS R8, a dual frequency GPS receiver.

Table 8. Details of the recovered NAMRIA horizontal control point QZN-5 used as base station for the LiDAR Acquisition.

Station Name	QZN-5	
Order of Accuracy	1st	
Relative Error (horizontal positioning)	1 in 100,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	14° 39’ 59.29674”
	Longitude	121° 36’ 14.26977”
	Ellipsoidal Height	4.85400 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting	565054.861 meters
	Northing	1621991.577 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	14° 39’ 53.91240” North
	Longitude	121° 36’ 19.15477” East
	Ellipsoidal Height	49.67610 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting	349670.53 meters
	Northing	1621800.83 meters
BM-Ortho	61.8177m	

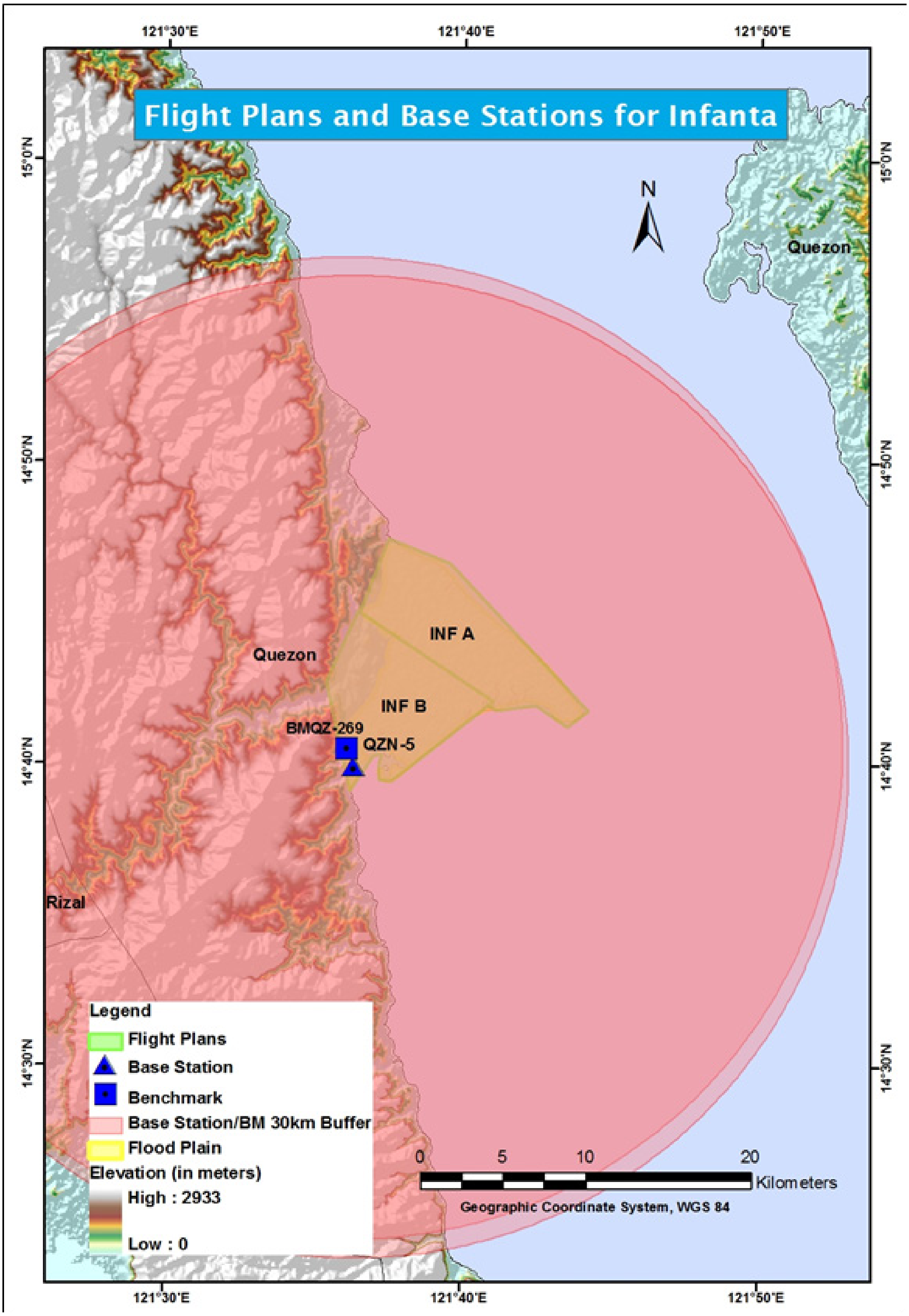

Figure 18. Infanta Flight Plans and Base Stations.

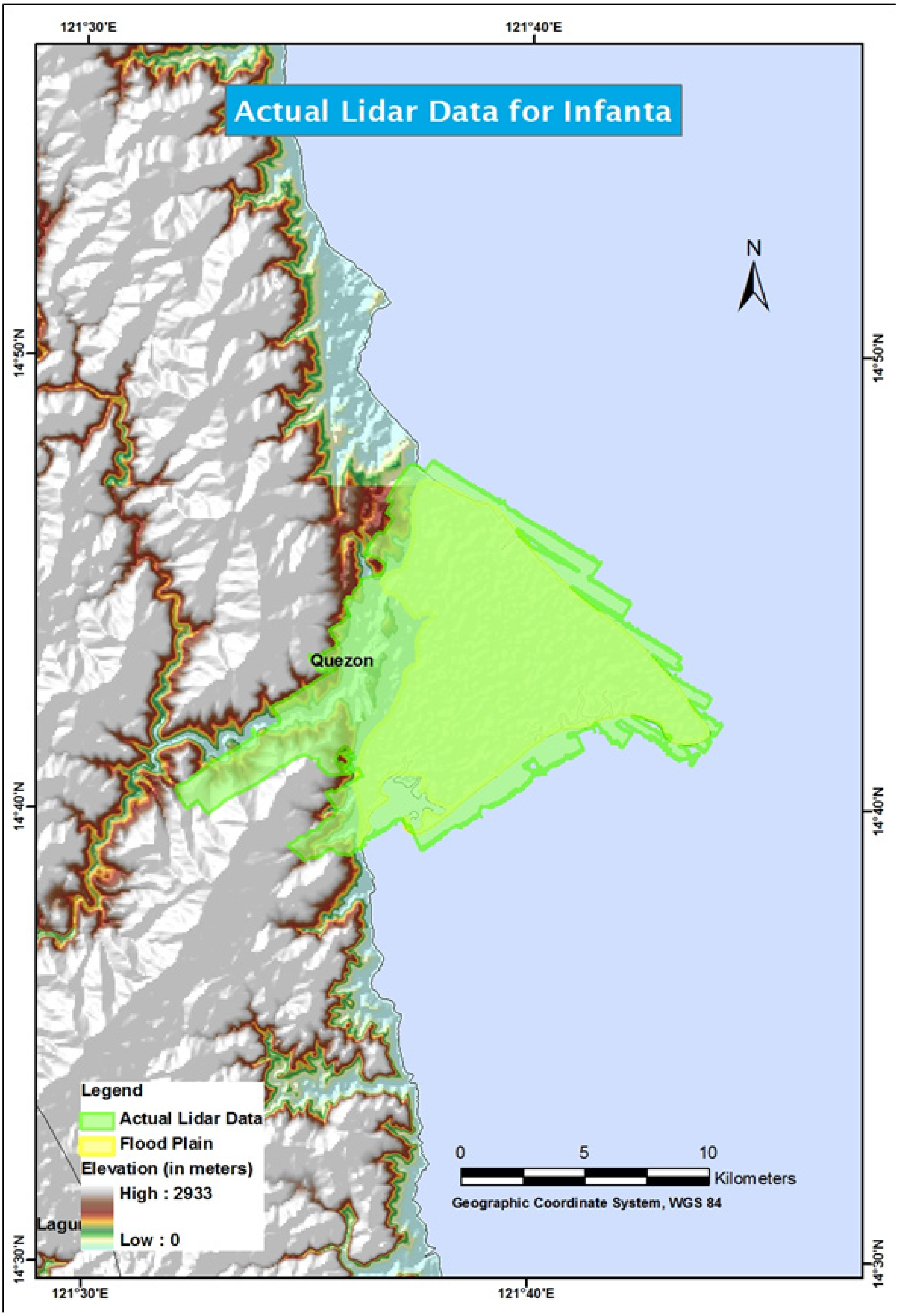

Figure 19. Infanta Floodplain Data Acquisition LAS Output.

Table 9. Flight Missions for LiDAR Data Acquisition in Infanta floodplain.

Date Surveyed	Name	Flight Plan Area (km^2)	Surveyed Area (km^2)	Area Surveyed within the River System (km^2)	Area Surveyed Outside the River Systems (km^2)	No. of Images (Frames)	Flying Hours	
							Hours	Minutes
July 6, 2013	INF 1B	69.133	106.15	87.697	18.453	No camera data	3	15
July 7, 2013	INF 1A	58.177	77.678	62.298	15.38	No camera data	3	40
July 10, 2013	INF 1A	69.133	79.316	73.504	5.812	No camera data	3	10

Three missions were conducted to complete the LiDAR Data Acquisition in Infanta floodplain, for a total of 10 hours and 5 minutes of flying time for RP-C9022. Both missions were acquired using the Pegasus LiDAR system. Table 9 shows the total area to be surveyed according to the flight plan and the total area of actual coverage per mission.

Table 10. Area of Coverage (in sq km) of the LiDAR Data Acquisition in Infanta floodplain.

Location	Date Surveyed	Operator	Mission Name	Floodplain Surveyed Area (km^2)	Total Floodplain Area (km^2)	Watershed Surveyed Area (km^2)	Total Watershed Area (km^2)
INFANTA	July 6, 2013	M. Ano	1INFB186A	66.356	90	21.341	938.61
	July 7, 2013	C. Joaquin	1INFA187A	45.993		16.305	
	July 10, 2013	M. Ano	1INF190A	43.777		29.727	

Infanta floodplain with an area of 90 square kilometer (sq. km.) was completely surveyed by Mark Ano and Christopher Joaquin from July 6-10, 2013 as shown in Table 10.

4.2 LiDAR Data Processing

4.2.1 Trajectory Computation

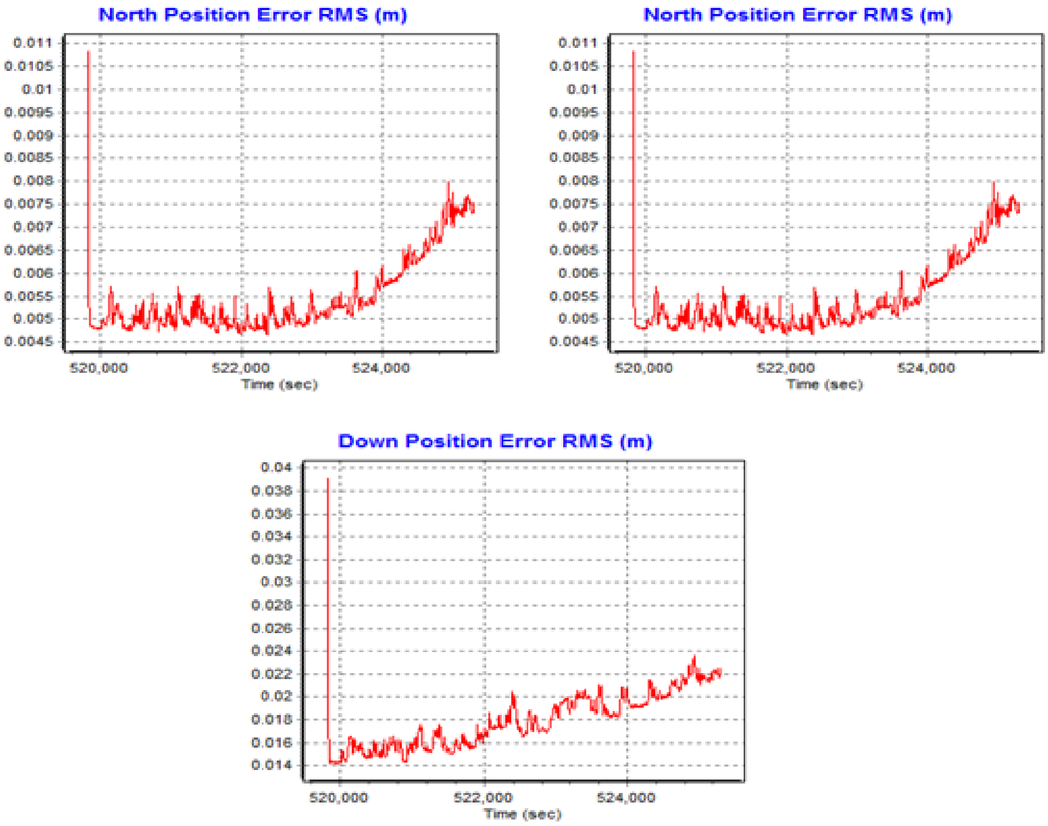

Figure 20. Smoothed Performance Metric Parameters of Infanta flight

The *Smoothed Performance Metric* parameters of the Infanta flight are shown in Figure 20. The x-axis is the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week. The y-axis is the RMSE value for a particular aircraft position with respect to GPS survey time. The North (Figure 20a) and east (Figure 20b) position RMSE values fall within the prescribed accuracy of 4 centimeter, and all Down (Figure 20c) position RMSE values fall within the prescribed accuracy of 8 centimeter.

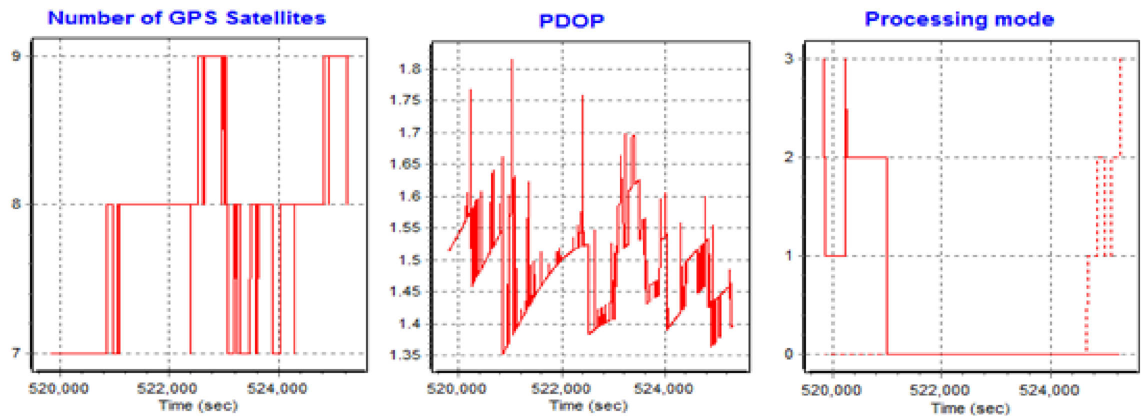

Figure 21. Solution Status Parameters of Infanta Flight.

The *Solution Status* parameters of the computed trajectory for Infanta flight, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used are shown in Figure 21. The number of GPS satellites (Figure 21a) graph indicates that the number of satellites during the acquisition was between 7 and 9. The PDOP (Figure 21b) value does not exceed the value of 3, indicating optimal GPS geometry. The processing mode (Figure 21c) varies from 0 to 3, the value 0 corresponds to a Fixed, Narrow-Lane mode, which indicates an optimum solution for trajectory computation by POSPac MMS v6.2; the value 1 corresponds a Wide-Lane mode; and the value 2 corresponds a Float mode. All of the parameters satisfied the accuracy requirements for optimal trajectory solutions as indicated in the methodology.

4.2.2 LiDAR Point Cloud Computation

The LAS data output contains 9 flight lines, with each flight line containing two channels, a feature of the Pegasus system. The result of the boresight correction standard deviation values for both channel 1 and channel 2 are better than the prescribed 0.001°. The position of the LiDAR system is also accurately computed since all GPS position standard deviations are less than 0.0018 meter. The attitude of the LiDAR system passed accuracy testing since the standard deviation of the corrected roll and pitch values of the IMU attitudes are less than 0.001°.

4.2.3 LiDAR Data Quality Checking

The LAS boundary of the LiDAR data on top of the SRTM elevation data is shown in Figure 22. The map shows gaps in the LiDAR coverage that are attributed to cloud cover present during the survey.

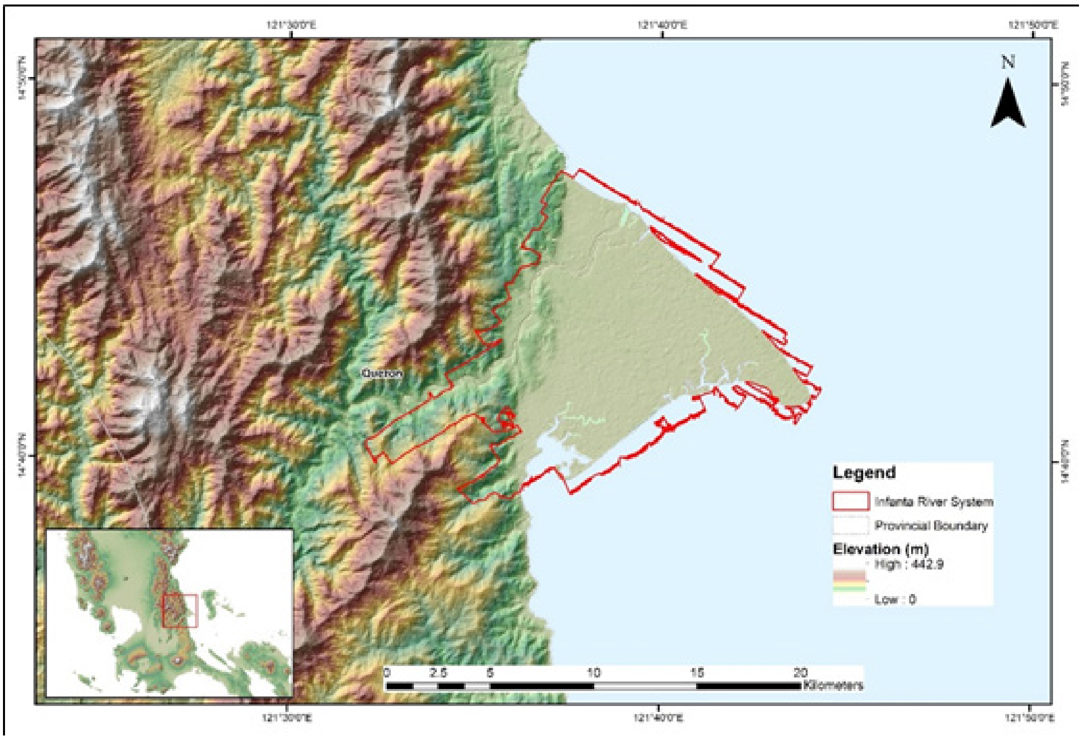

Figure 22. Coverage of LiDAR data for the Infanta mission

The overlap data for the merged LiDAR data showing the number of channels that pass through a particular location is shown in Figure 23. Since the Pegasus system employs two channels, an average value of 2 (blue) for areas where there are only two overlapping flight lines, and a value of 3 (yellow) or more (red) for areas with three or more overlapping flight lines, are expected. The average data overlap for this Infanta flight is 71.73%.

Results and Discussion

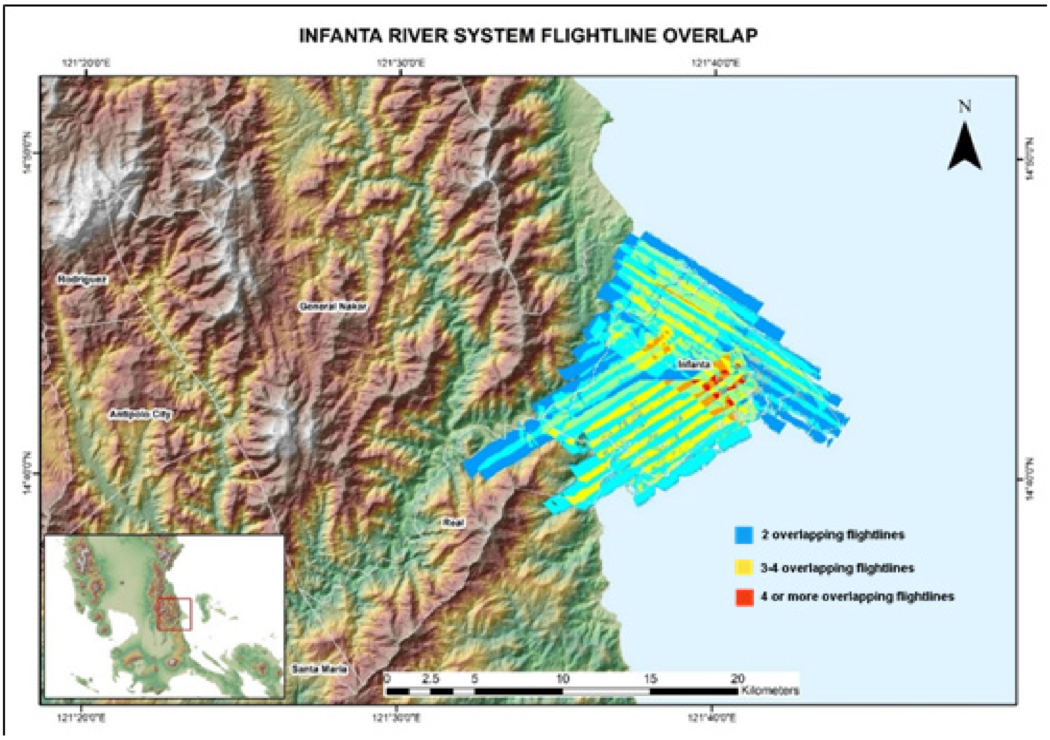

Figure 23. Image of data overlap for the Infanta mission

The density map for the merged LiDAR data, with the red areas showing the portions of the data that satisfy the 2 points per square meter requirement, is shown in Figure 24. It was determined that 93.4% of the total area satisfied the point density requirement.

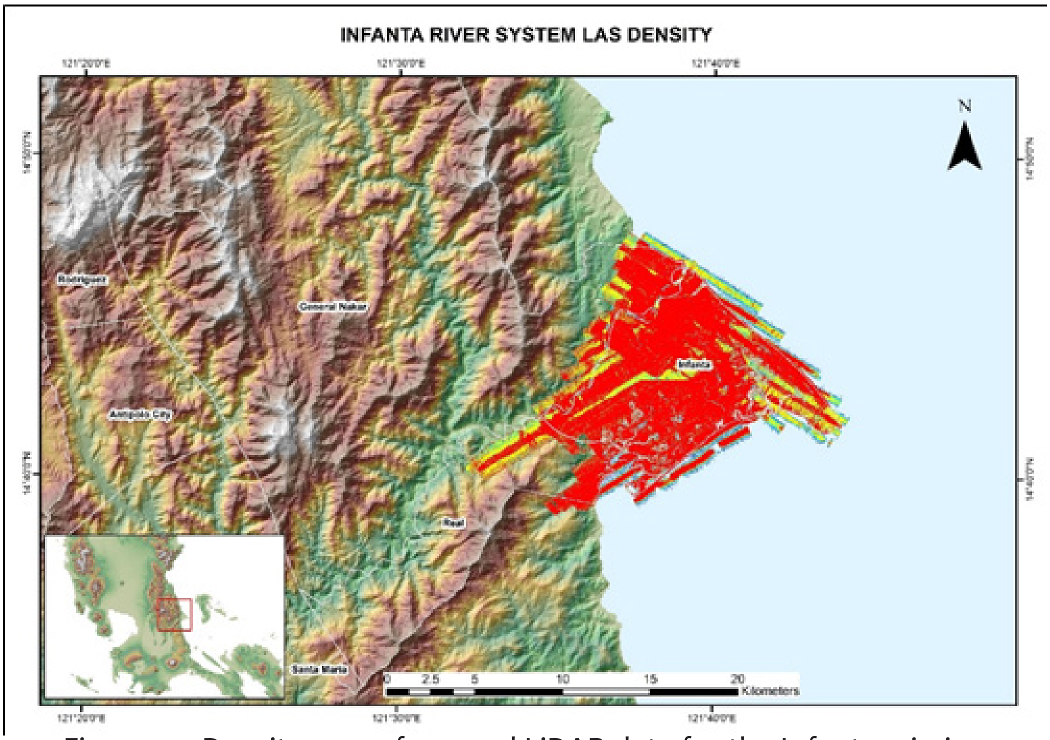

Figure 24. Density map of merged LiDAR data for the Infanta mission

Results and Discussion

The elevation difference between overlaps of adjacent flight lines is shown in Figure 25. The default color range is from blue to red, where bright blue areas correspond to a -0.20 meter difference, and bright red areas correspond to a +0.20 meter difference. Areas with bright red or bright blue need to be investigated further using QT Modeler.

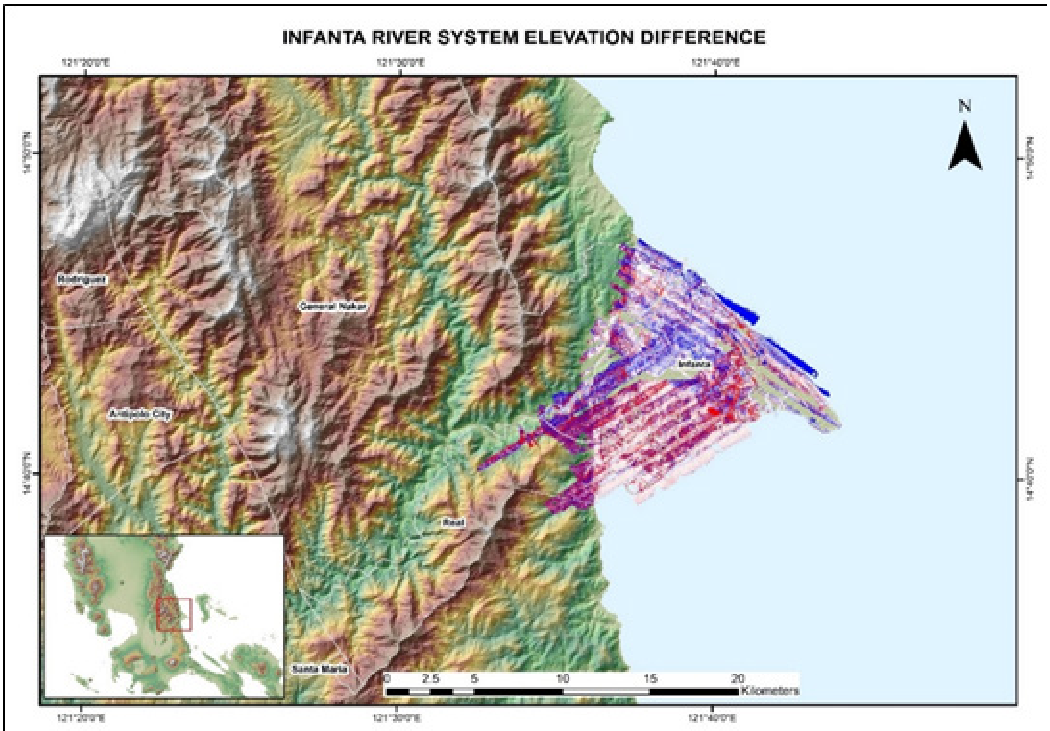

Figure 25. Elevation difference map between flight lines

A screen capture of the LAS data loaded in QT Modeler is shown in Figure 26a. A line graph showing the elevations of the points from all of the flight strips traversed by the profile in red line is shown in Figure 26b. It is evident that there are differences in elevation, but the differences do not exceed the 20 centimeter mark. No reprocessing was necessary for this LiDAR dataset.

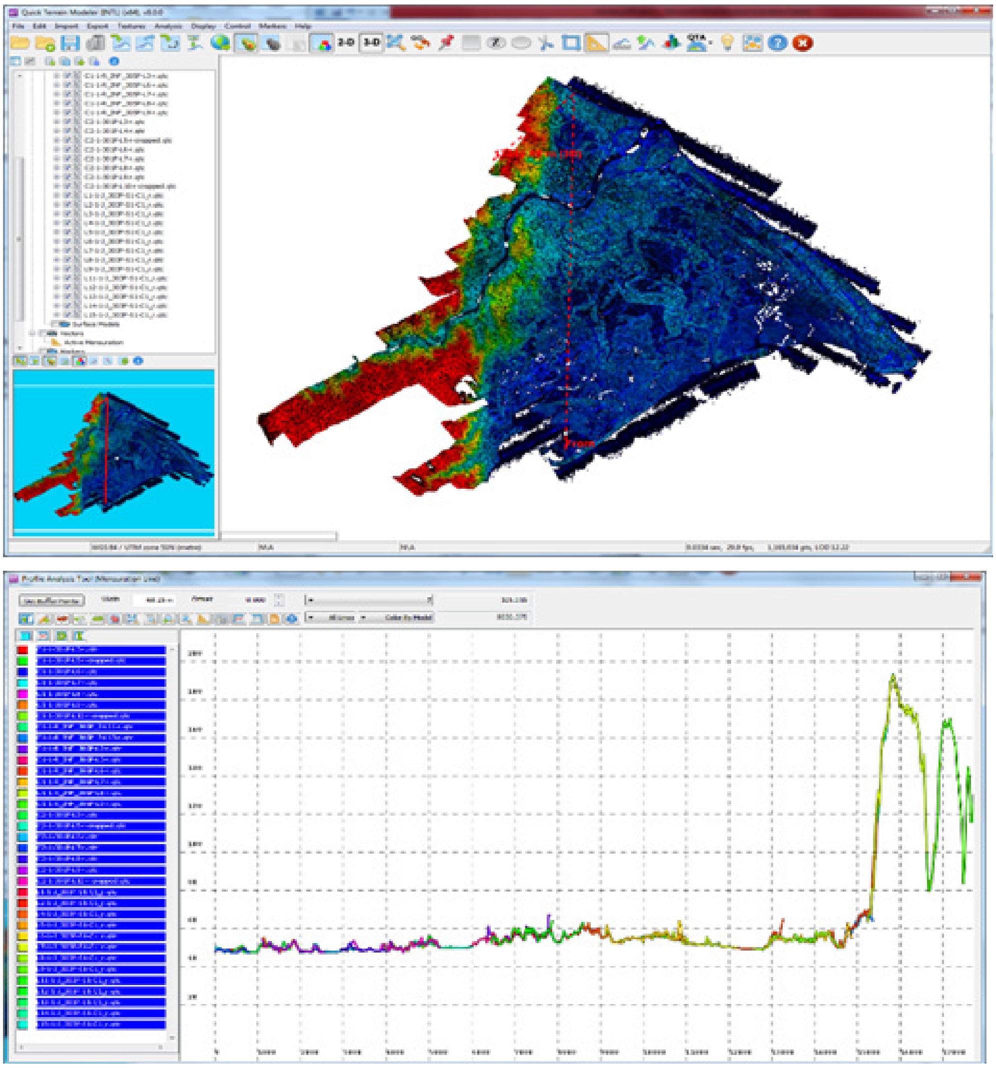

Figure 26. Quality checking with the profile tool of QT Modeler

4.2.4 LiDAR Point Cloud Classification and Rasterization

The block system that TerraScan employed for the LiDAR data is shown in Figure 27a generated a total of 216 1 kilometer by 1 kilometer blocks. The final classification of the point cloud for a mission in the Infanta floodplain is shown in Figure 27b. The number of points classified to the pertinent categories along with other information for the mission is shown in Table 11.

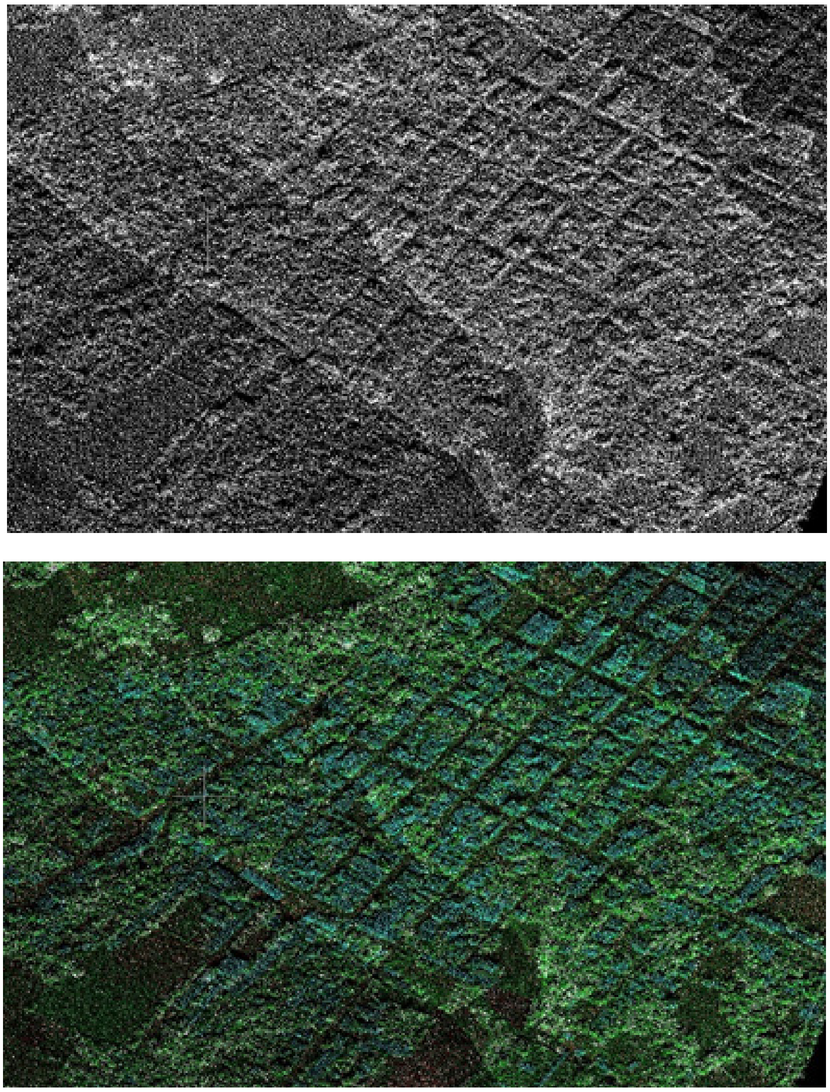

Figure 27. Point cloud (a) before and (b) after classification.

4.2.5 DEM Editing and Hydro-correction

Portions of DTMs before and after manual editing are shown in Figure 28. It shows that the embankment might have been drastically cut by the classification routine in Figure 28a and clearly needed to be retrieved to complete the surface as in Figure 28b to allow to hydrologically correct flow of water. A small stream suffers from discontinuity of flow due to an existing bridge in Figure 28c. The bridge is removed also in order to hydrologically correct the flow of water through the river in Figure 28d.

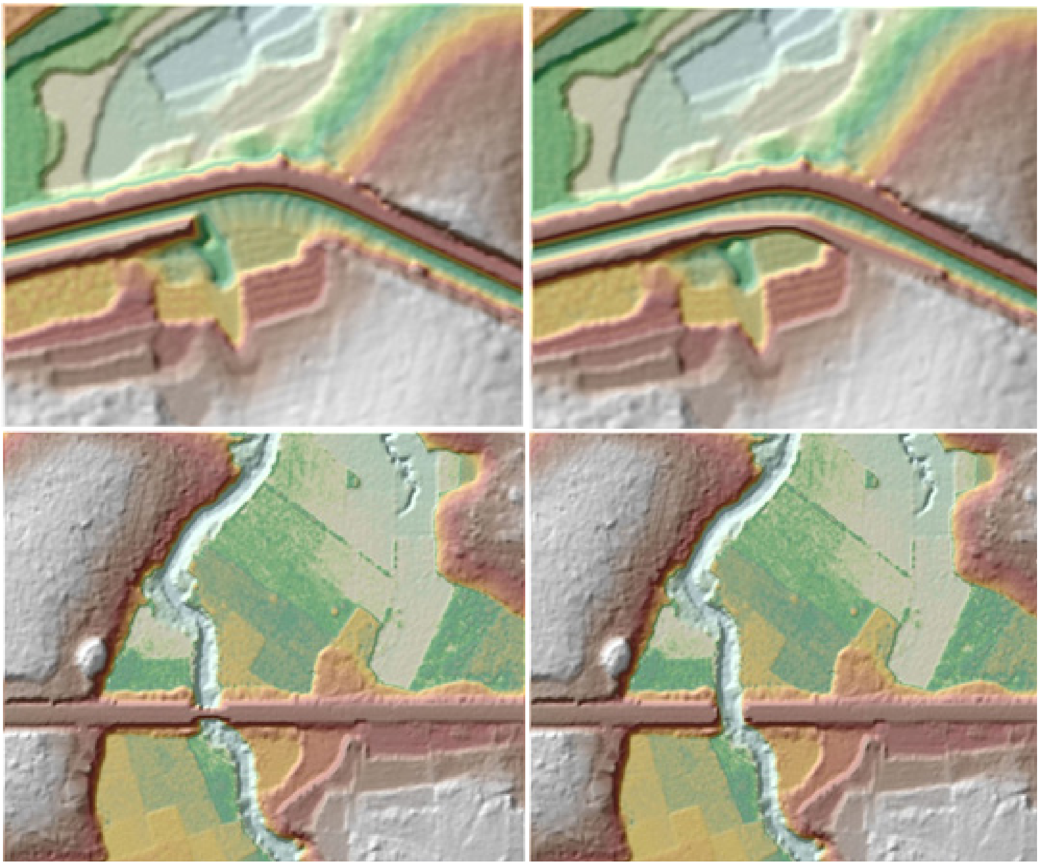

Figure 28. Images of DTMs before and after manual editing. Image (a) shows an embankment that might have been cut by the classification routine while image (b) shows the changes in the same area after manual editing. Image (c) and (d) show an example of a stream

The extent of the validation survey done by the Data Validation Component (DVC) in Infanta to collect points with which the LiDAR dataset is validated is shown in Figure 29. A total of 2,407 control points were collected. The good correlation between the airborne LiDAR elevation values and the ground survey elevation values, which reflects the quality of the LiDAR DTM is shown in Figure 30. The computed RMSE between the LiDAR DTM and the surveyed elevation values is 10.952 centimeter with a standard deviation of 8.720 centimeter. The LE 90 value represents the linear vertical distance that 90% of the sampled DEM points and their respective DVC validation point counterparts should be found from each other. Other statistical information can be found in Table 14. The final DTM and extent of the bathymetric survey done along the river is shown in Figure 31.

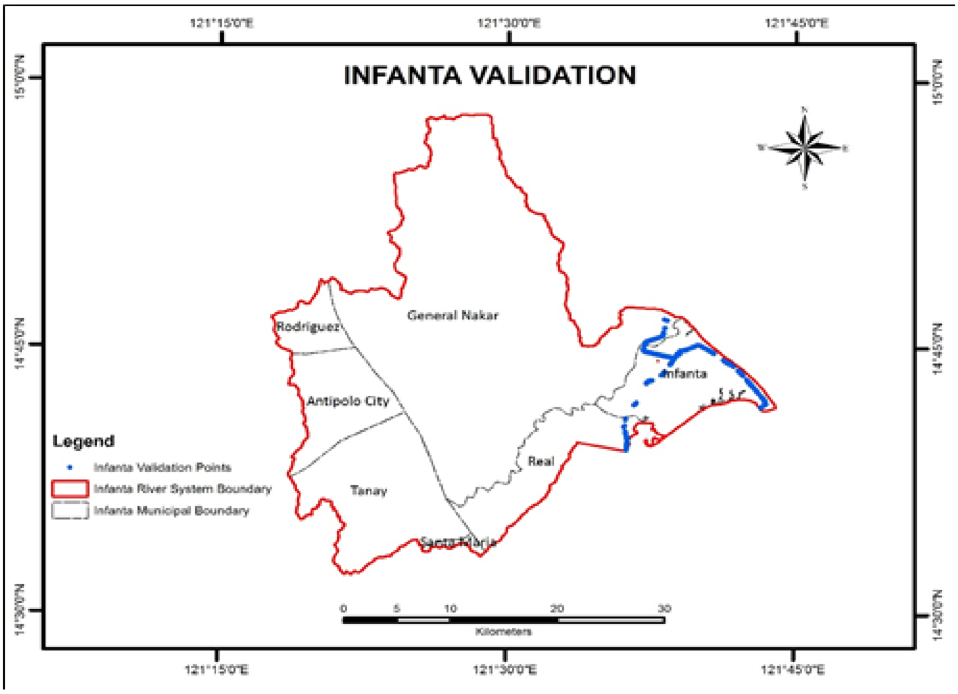

Figure 29. Map of Infanta River System with validation survey shown in blue

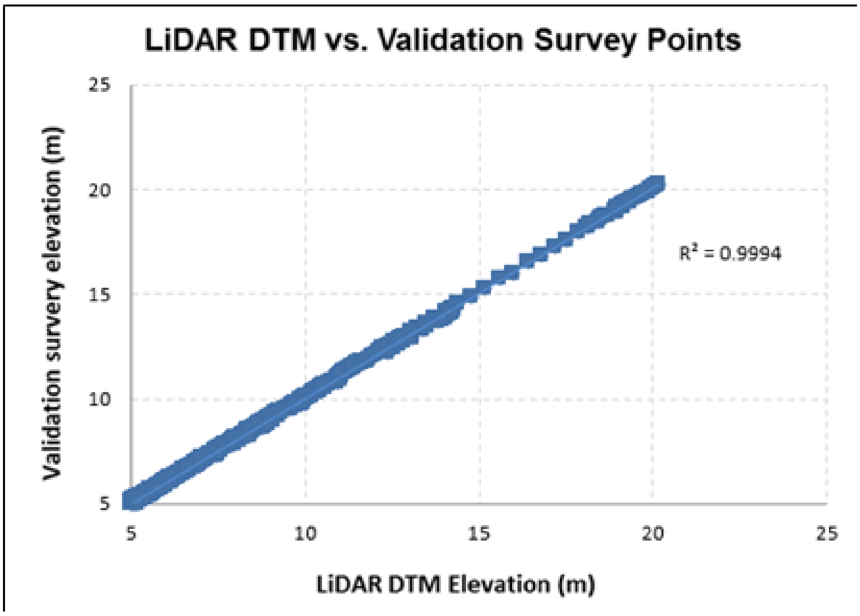

Figure 30. One-one Correlation plot between topographic and LiDAR data

Table 11. Statistical values for calibration of Infanta flights.

Statistical Information	Values (cm)
Min	-17.241
Max	17.597
RMSE	8.720
Stdev	8.720
LE90	14.076

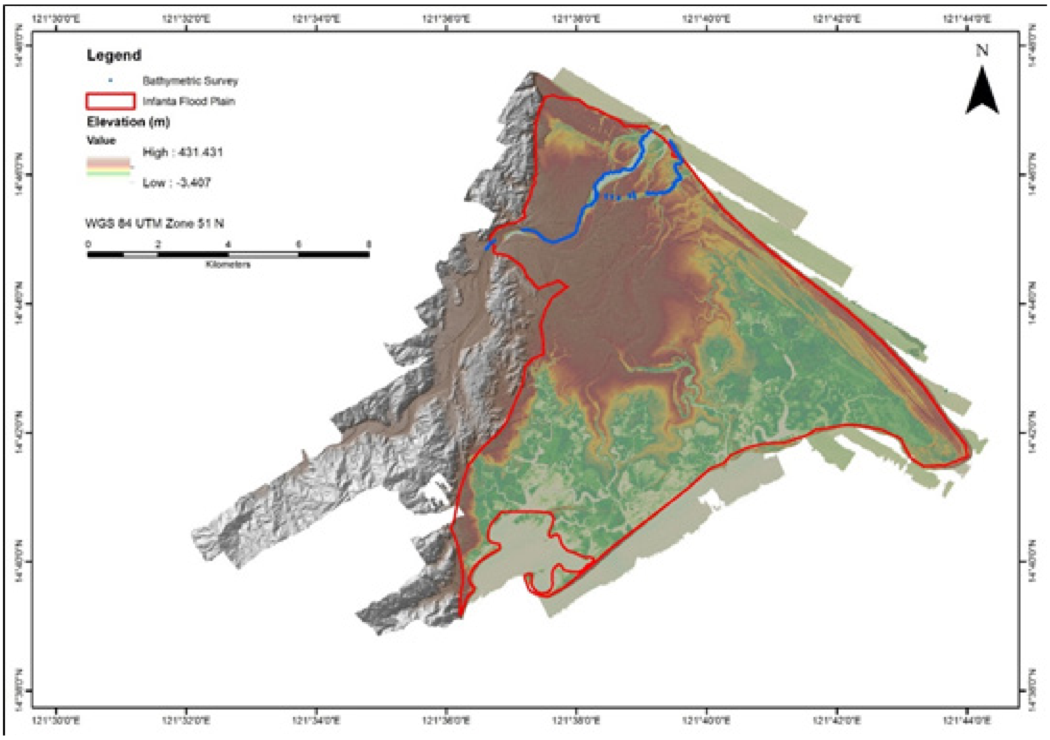

Figure 31. Final DTM of Infanta with validation survey shown in blue

The floodplain extent for Infanta is also presented, showing the completeness of the LiDAR dataset and DSM produced, is shown in Figure 32. Samples of 1 kilometer by 1 kilometer of DSM and DTM are shown in Figure 33 and Figure 34 respectively.

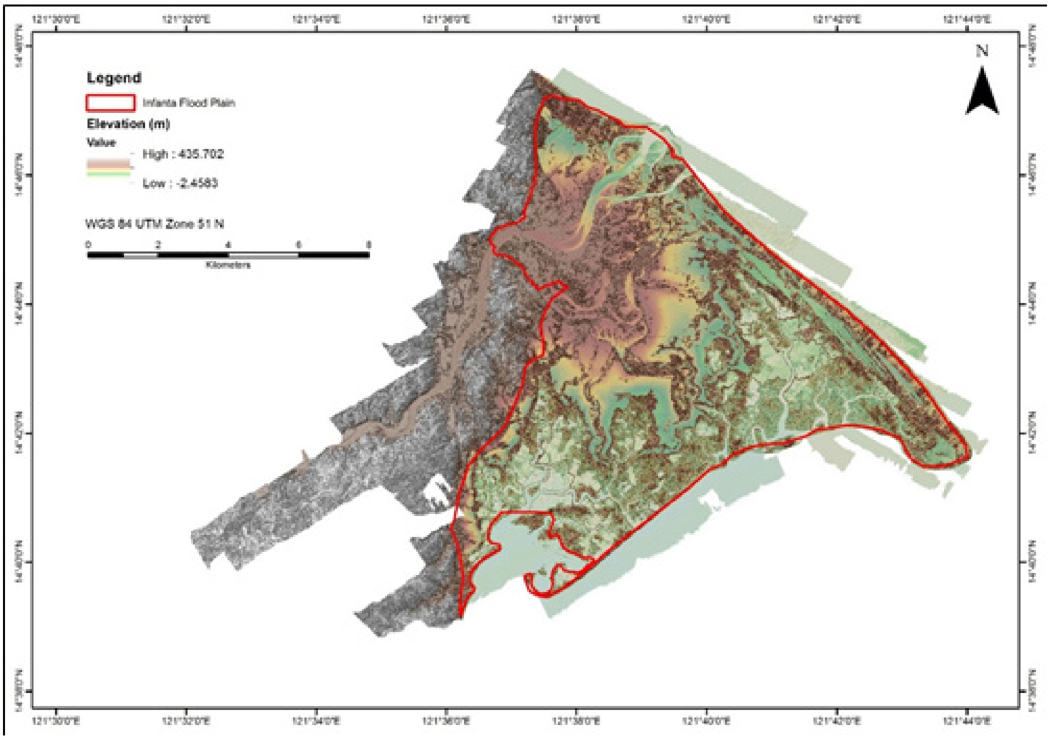

Figure 32. Final DSM in Infanta

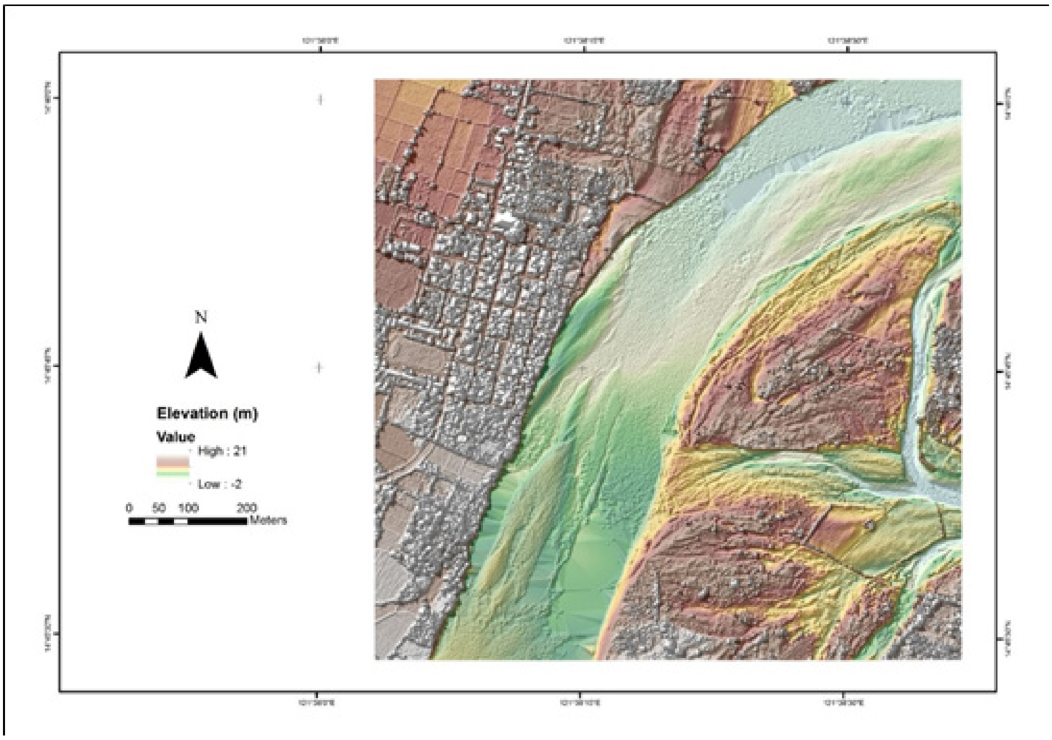

Figure 33. Sample 1x1 Square Kilometer DSM.

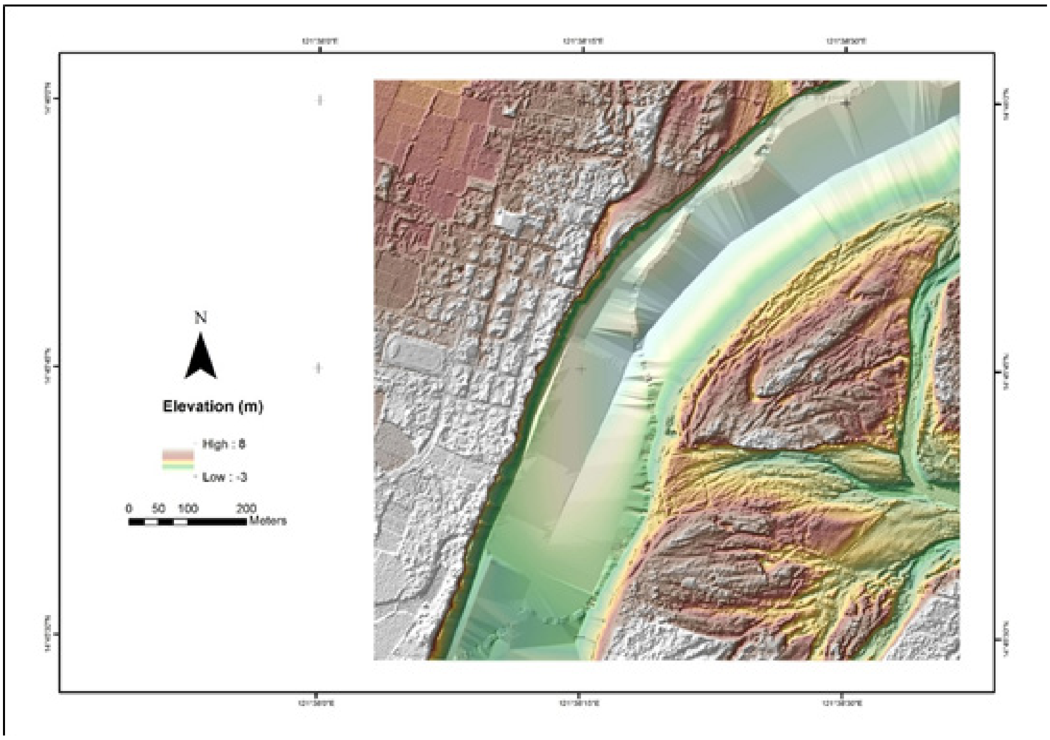

Figure 34. Sample 1x1 square kilometer DTM

Annexes

Annex A. Optech Technical Specification Of The Pegasus Sensor

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

1 Target reflectivity ≥20%

2 Dependent on selected operational parameters using nominal FOV of up to 40° in standard atmospheric conditions with 24-km visibility

3 Angle of incidence ≤20°

4 Target size ≥ laser footprint

5 Dependent on system configuration

Annex B. Optech Technical Specification Of The D-8900 Aerial Digital Camera

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

Annex C. The Survey Team

Data Acquisition Component Sub-team	Designation	Name	Agency/ Affiliation
Data Acquisition Component Leader	Data Component Project Leader –I	ENGR. CZAR JAKIRI S. SARMIENTO	UP TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP TCAGP
LiDAR Operation	Senior Science Research Specialist	MARK GREGORY ANO	UP TCAGP
LiDAR Operation	Senior Science Research Specialist	JASMINE ALVIAR	UP TCAGP
LiDAR Operation/ Data Download and Transfer	Research Associate	CHRISTOPHER JOAQUIN	UP TCAGP
Ground Survey	Senior Science Research Specialist	ENGR. GEROME HIPOLITO	UP TCAGP
Ground Survey	Research Associate	MARVY FUNTILON	UP TCAGP
LiDAR Operation	Airborne Security	SSG. PRADYUMNA DAS RAMIREZ	Philippine Air Force (PAF)
LiDAR Operation	Pilot	CAPT. JAMAAL CLEMENTE	ASIAN AEROSPACE CORP (AAC)

Annex D. NAMRIA Certification

QZN-5

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

July 17, 2013

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: **QUEZON**
Station Name: **QZN-5**
Order: **1st**

Island: **LUZON**
Municipality: **REAL**
Barangay: **TOWN PROPER**

PRS92 Coordinates

Latitude: **14° 39' 59.29674"** Longitude: **121° 36' 14.26977"** Ellipsoidal Hgt: **4.85400 m.**

WGS84 Coordinates

Latitude: **14° 39' 53.91240"** Longitude: **121° 36' 19.15477"** Ellipsoidal Hgt: **49.67610 m.**

PTM Coordinates

Northing: **1621991.577 m.** Easting: **565054.861 m.** Zone: **3**

UTM Coordinates

Northing: **1,621,800.83** Easting: **349,670.53** Zone: **51**

Location Description

QZN-5
Is located on the playground of Real Elem. School, approx. 100 m. SE of the DENR Bldg., about 50 m. SE of the school bldg.; 20 m. SE of the basketball court and approx. 200 m. N of the public market. It is accessible by 2-wheel drive vehicle. Station mark is a 0.15 m. x 0.01 m. dia. brass rod set in standard concrete monument 0.7 m. deep and 0.15 m. above the ground, flush with the ground surface and inscribed with the station name. Sub-surface mark is a bottle set in concrete block. The top of the bottle is 0.617 m. below station mark. Reference mark is a 0.15 m. x 0.01 m. brass rod set in concrete blocks 0.45 m. deep and 0.15 m. above the ground, flushed with the ground surface and inscribed with the station name and RM number.

Requesting Party: **UP-TCAGP**
Pupose: **Reference**
OR Number: **3943939 B**
T.N.: **2013-0701**

RUEL DM. BELEN, MNSA
Director, Mapping and Geodesy Department

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CERTIFICATION INTERNATIONAL ISO 9001:2008
CIP/4701/12/09/814

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

Annex E

QZ-301

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

July 17, 2013

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: **QUEZON**
Station Name: **QZ-301**

Island: **LUZON**	Municipality: **CANDELARIA**	Barangay: **MASIN NORTE**
Elevation: **61.8177 m.**	Order: **1st Order**	Datum: **Mean Sea Level**

Location Description

BM QZ-301

BM QZ 301 is in the island of Luzon, province of Quezon, town of Candelaria, barangay Masin Norte. Station is along the national highway, 4m S of the road centerline. It is on top of the concrete pavement of the SE corner of Masin bridge at sta. 106 + 600. Mark is the head of a 4" copper nail, cemented and flushed, with the inscription: "QZ 301, 2007, NAMRIA."

Requesting Party:	**UP-TCAGP**
Pupose:	**Reference**
OR Number:	**3943939 B**
T.N.:	**2013-0699**

RUEL DM. BELEN, MNSA
Director, Mapping and Geodesy Department

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CERTIFICATION INTERNATIONAL ISO 9001:2008
CIP/4701/12/09/814

NAMRIA OFFICES:
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www.namria.gov.ph

Annex E. Data Transfer Sheet For Infanta Floodplain

Data Transfer Sheet for 1INFB186A, 1INFA187A and 1INFS190A

DATA TRANSFER SHEET

Jul 10, 2013

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS	LOGS	POS	RAW IMAGES	MISSION LOG FILE	RANGE	DIGITIZER	BASE STATION(S)	OPERATOR COMMENTS (DPC LOGS)	FLIGHT PLAN	SERVER LOCATION
Jul 4, 2013	297P	1LUC184A	PEGASUS	119MB	1.17MB	214MB	N/A	N/A	13.3GB	N/A	7.11MB	456B	56KB	Z:\Airborne_Raw\297P
Jul 5, 2013	299P	1LUC185A	PEGASUS	92.3MB	1.06MB	180MB	N/A	N/A	10.5GB	N/A	6.43MB	255B	23.5KB	Z:\Airborne_Raw\299P
Jul 6, 2013	301P	1INFB186A	PEGASUS	31.5MB/47.9MB	422KB/788KB	222MB	N/A	N/A	10.3GB	N/A	6.27MB/8.99MB	147B	27/28KB	Z:\Airborne_Raw\301P
Jul 7, 2013	303P	1INFA187A	PEGASUS	65.3MB/24.3MB	842KB/293KB	198MBMB	N/A	N/A	11.5GB	N/A	7.75MB	572B	27/28KB	Z:\Airborne_Raw\303P
Jul 10, 2013	305P	1INFS190A	PEGASUS	26.1/17.8MB	690KB/405KB	192MB	N/A	N/A	5.55/2.34GB	N/A	14.97 MB	1KB	28/27KB	Z:\Airborne_Raw\305P

Received from

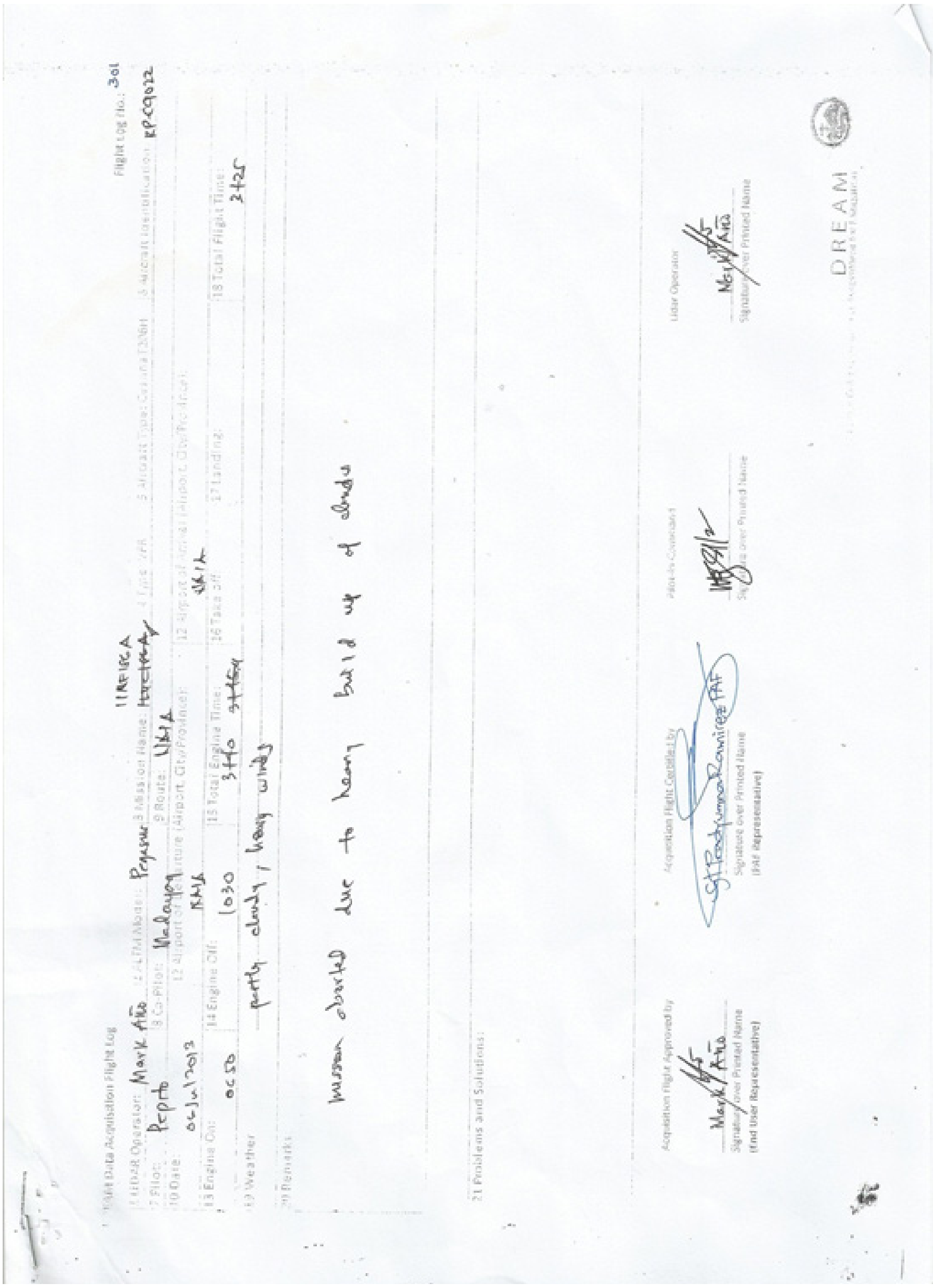
Name/Signature C. Joaquin
Position R/A
Date 07/10/13 Updated 9-18-13

Received by

Name/Signature Benjoffin Magallon
Position SSRS
Date 9/18/13

Annex F. Flight Logs

Flight Log for 1INF186A Mission


Data Acquisition Flight Log

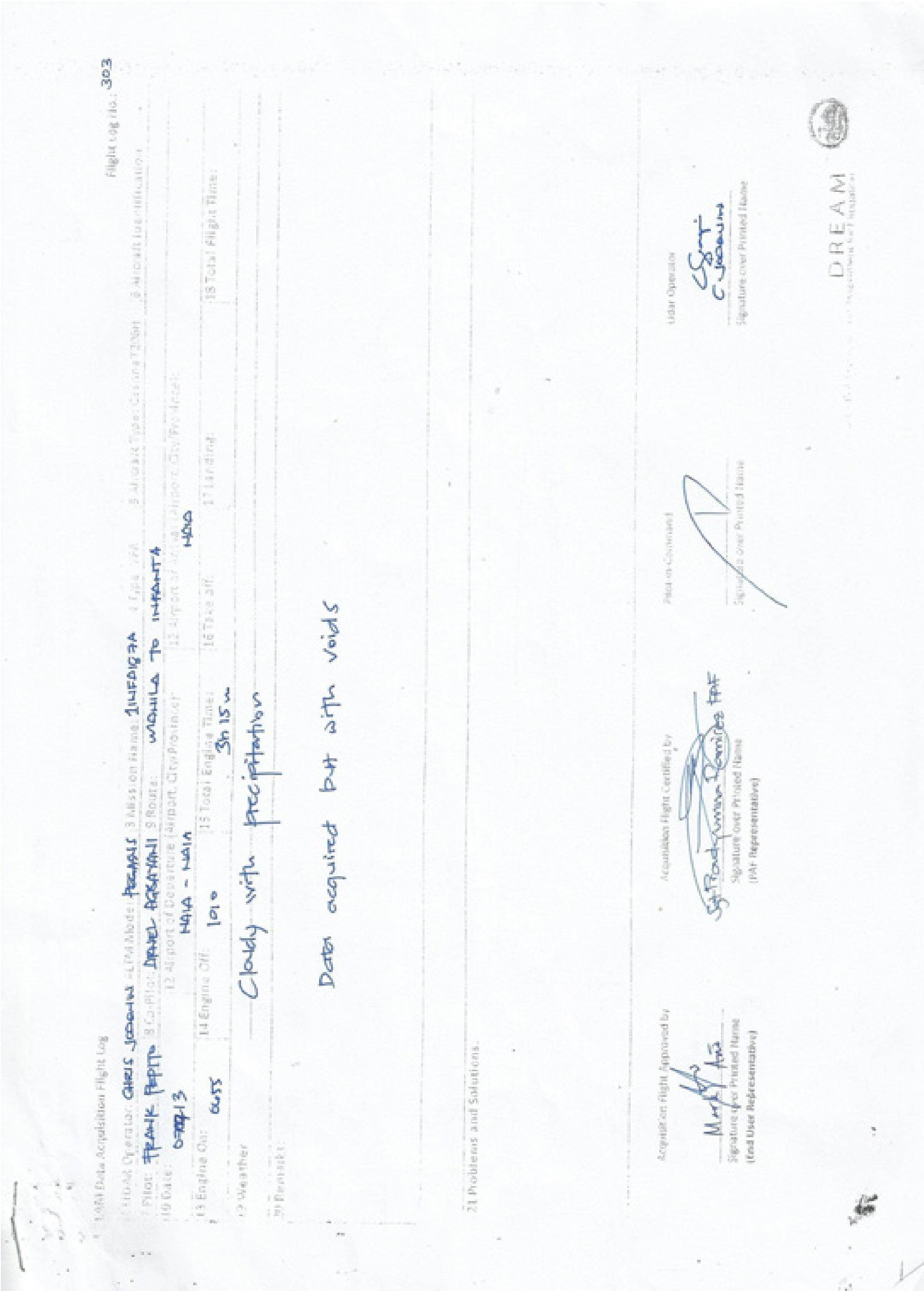
Flight Log No.: 301

1 LiDAR Operator: Mark Año
2 ALTM Model: Pegasus
3 Mission Name: 1INF186A
4 Type: VFR
5 Aircraft Type: Cessna T206H
6 Aircraft Identification: RP-C9022
7 Pilot: Pepito
8 Co-Pilot: Madayag
9 Route: NAIA
10 Date: 06 Jul 2013
12 Airport of Departure (Airport, City/Province): NAIA
12 Airport of Arrival (Airport, City/Province): NAIA
13 Engine On: 0650
14 Engine Off: 1030
15 Total Engine Time: 3+40
16 Take off:
17 Landing:
18 Total Flight Time: 3+25
19 Weather: partly cloudy, heavy winds
20 Remarks: mission aborted due to heavy build up of clouds
21 Problems and Solutions:

Acquisition Flight Approved by: Mark Año, Signature over Printed Name (End User Representative)
Acquisition Flight Certified by: S/I Pradyumna Ramirez PAF, Signature over Printed Name (PAF Representative)
Pilot-in-Command: Signature over Printed Name
Lidar Operator: Mark Año, Signature over Printed Name

DREAM

Flight Log for 1INFA187A Mission



1 LiDAR Data Acquisition Flight Log

Flight Log No.: 303

1 LiDAR Operator: CHRIS JOAQUIN | 2 ALTM Model: PEGASUS | 3 Mission Name: 1INFDI87A | 4 Type: VFR | 5 Aircraft Type: Cessna T206H | 6 Aircraft Identification:

7 Pilot: FRANK PEPITO | 8 Co-Pilot: DANIEL ACAYANI | 9 Route: MANILA TO INFANTA

10 Date: 07/12/13 | 12 Airport of Departure (Airport, City/Province): NAIA - NAIA | 12 Airport of Arrival (Airport, City/Province): NAIA

13 Engine On: 0655 | 14 Engine Off: 1010 | 15 Total Engine Time: 3h 15m | 16 Take off: | 17 Landing: | 18 Total Flight Time:

19 Weather: Cloudy with precipitation

20 Remarks: Data acquired but with voids

21 Problems and Solutions:

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

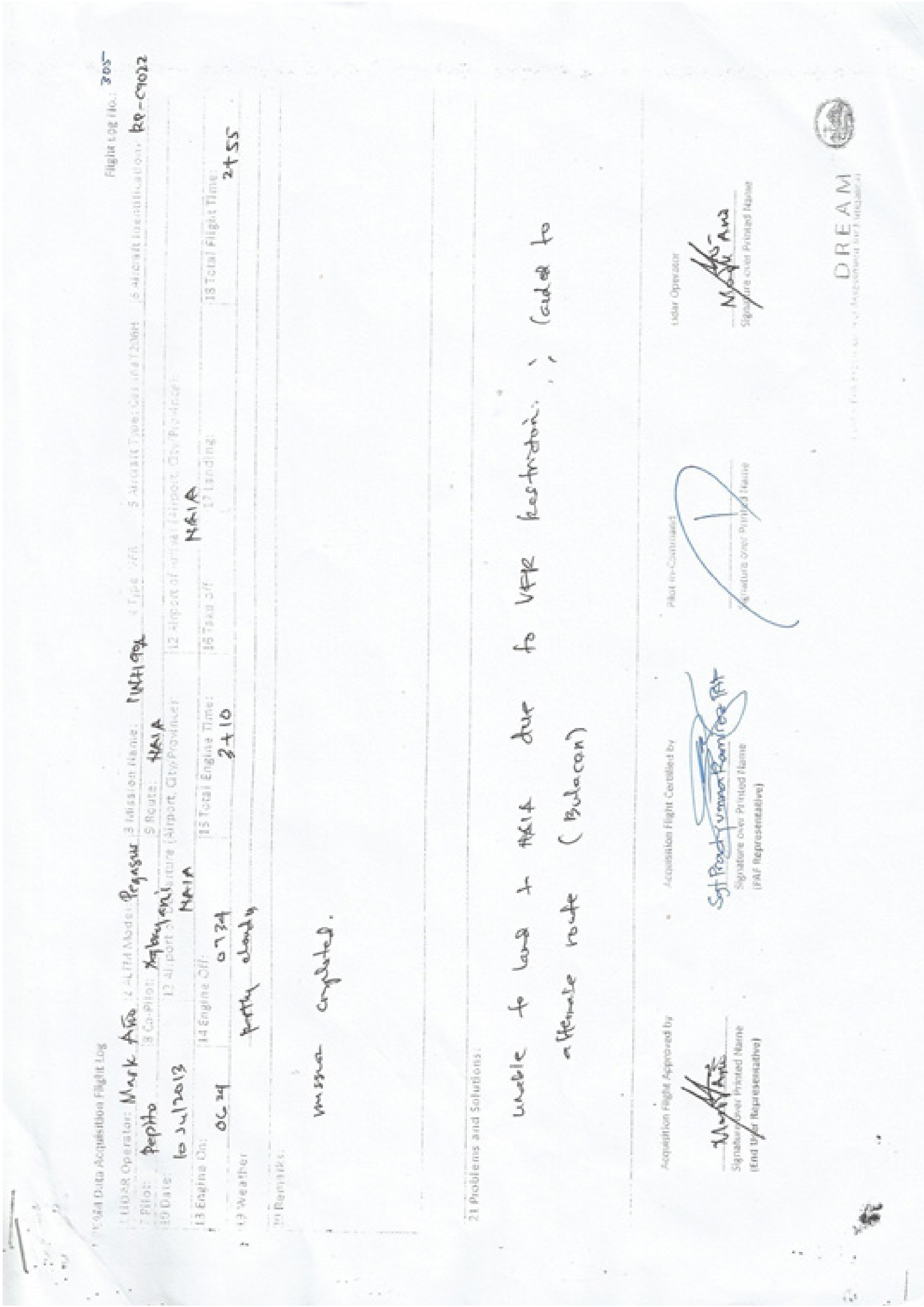
Acquisition Flight Certified by — Signature over Printed Name (PAF Representative)

Pilot-in-Command — Signature over Printed Name

Lidar Operator — C JOAQUIN — Signature over Printed Name

DREAM

Flight Log for 1INF190A Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 305

1 LIDAR Operator: Mark Año | 2 ALTM Model: Pegasus | 3 Mission Name: 1INF190A | 4 Type: VFR | 5 Aircraft Type: Cessna T206H | 6 Aircraft Identification: RP-C9022

7 Pilot: Pepito | 8 Co-Pilot: Agbayani | 9 Route: NAIA

10 Date: 10 Jul 2013 | 12 Airport of Departure (Airport, City/Province): NAIA | 12 Airport of Arrival (Airport, City/Province): NAIA

13 Engine On: 0624 | 14 Engine Off: 0734 | 15 Total Engine Time: 3+10 | 16 Take off: | 17 Landing: | 18 Total Flight Time: 2+55

19 Weather: partly cloudy

20 Remarks:

mission completed.

21 Problems and Solutions:

unable to land at NAIA due to VFR restriction; ; landed to alternate route (Bulacan)

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

Acquisition Flight Certified by: Sgt Pradyumna Ramirez PAF; Signature over Printed Name (PAF Representative)

Pilot-in-Command: Signature over Printed Name

Lidar Operator: Mark Año; Signature over Printed Name

DREAM

D R E A M

Disaster RIsk and Exposure Assessment for Mitigation