Comprehensive scientific study to suggest improvements to the drainage systems inside and outside the Airport premises

Final Report

by

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Acknowledgements

We would like to acknowledge the help and unflinching support extended by Mr.A. A. Michael Raj, Joint General Manager(ENGG-CIVIL)-I, and Mr. I.Palanichamy, Asst.General Manager (E-C) -II, Civil Maintenance Division. Their commitment, involvement, and continuous follow-up with regulatory bodies to get the necessary clearances ensured smooth collection of field data and survey with UAS. Surveying with UAS in the airport operational area and in the vicinity carried out as part of this study, to develop a high resolution digital elevation model for flood modelling, is a first of its kind in the country. It involves meticulous planning and a choreographed operation of several departments in the airport. The investigators would like to place on record their sincere appreciation to Mr. Sylvester Israel, GM (ATM-CH) who led a large team of dedicated staff, each entrusted with a specific responsibility to ensure smooth, glitch free operation of the survey. In particular, the contribution of Mr. N. Nagarajan, Rtd. JGM (ATM), Consultant in coordinating the ground operation of UAS and Mr. R. Sridhar Jt. GM (ATM) at the air traffic control are significant. We would like to thank the then Airport Director, Mr. Deepak Shastri, who posed immense faith in us in carrying out this study and has been a constant source of inspiration during trying times to get various security clearances for carrying out the UAS survey. We would also like to thank the present Airport Director, Mr.G.Chandramouli for extending unwavering support in completing the project. Our sincere thanks are due to Mr. L. N. Tatwani, the then GM (Engg - Civil) and Mr. Mohammed Tajuddin, the present GM (Engg-Civil) for their entrusting this important work with us at IIT Madras.

Executive Summary

In response to the unprecedented floods of December 2015, a comprehensive scientific analysis of the drainage system in and around the Chennai airport and the flood carrying capacity of Adyar River have been carried out. These studies were carried out with an objective to 1) understand the reasons of the airport flooding during December 2015 2) propose improvements that would minimize the magnitude of flooding and if feasible eliminate it, if similar rainfall event were to recur in the future and 3) Suggest improvements to the airport storm drainage system for disposing of nuisance floods and floods caused by storms of 1 in 10 year return period.

In order to carry out this scientific study, a detailed survey of the topography including the storm drainage system was carried out. The details of the topography was mapped using high resolution photography acquired with an Unmanned Aerial System (UAS), which was subsequently used for developing a high resolution Digital Surface Model (DSM) and Digital Terrain Model (DTM). A detailed field cross section survey of the Adyar River and storm water drains within the airport and the surrounding region was also carried out with total station and DGPS systems. All these datasets were integrated together and used for modelling.

Three different types of numerical models were used: 1) Hydrologic model using HEC-HMS to simulate the amount of runoff generated in the Adyar watershed for a given design storm 2) Hydraulic model using HEC-RAS to simulate the quantity of flow in the river, specifically near runway bridge section and map the level of flood inundation and 3) Storm Water Management Model SWMM to quantify the capacity of the existing drains without surcharging and to redesign and resize them if found necessary.

The hydrologic model indicated that during the December 2015 floods, the peak flood magnitude is estimated to be approximately 5000 m^3/s (1,75,000 ft^3/s). This is as much as 3.5 to 4.5 times the maximum flood carrying capacity of the Adyar River. At its peak, the release from Chembarambakkam reservoir was only about 1000 m^3/s, whereas the flood generation from rest of the uncontrolled portion of the watershed such as Manimangalam, Thirumudivakkam, Tandalam and Tambaram contributed as much as 4000 m^3/s, pushing the peak to as much as 5000 m^3/s. This heavy discharge in response to an unprecedented amount of rainfall on Nov.30 and December 1, 2015 was due to high amount of antecedent moisture conditions caused by the saturation of the soil from previous rainfall events in November. Due to limitations of the terrain and the discharge capacity of Adyar River, it is impossible to completely prevent such floods from recurring. However, we can be better prepared in anticipation of such floods in future to reduce and minimize damages caused to the airport property and downtime of the airport.

Based on the detailed numerical modelling study carried out, This study recommends: 1) Dredging, widening and clearing of the river section for 3km D/S of the runway bridge site till the check dam before Miot hospital 2) Checking the design of the airport compound wall for withstanding the static and dynamic pressure of the water encountered during the floods of 2015 to prevent from collapsing in future from similar floods 3) Resizing and rerouting of internal storm water drains to prevent or minimize surcharging from 1 in 10 year design storms 4) Resizing and rerouting of external storm water drains from the Pallavaram and Pammal area through Cowl Bazaar into Adyar River to minimize flooding inside the airport premises and at the same time improve storm drainage infrastructure outside the airport region 5) Equip storm drains with sluice gates to prevent flooding from backflow of water from the Adyar river; along with the sluice gates, install pump houses and sumps at two critical places to quickly drain the airport region during times of extreme floods 6) Critical infrastructure such as ILS and Radar stations needed to be lifted up to a minimum height of 15m above Mean Sea Level or be equipped with deployable temporary flood barriers to prevent any damages from the water. Based on these recommendations, DPRs may be prepared for relevant components where more detailed design is necessary for successful execution of the project.

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1 Problem Statement:

Chennai airport was severely affected due to the floods of December 1 &2, 2015. Flood waters from Adyar River in the north overbanked and breached the compound wall at several places due to high intense rainfall in the watershed (highest recorded single day rainfall for this region in a century). The problem is further compounded by the fact that the neighboring region, specifically Cantonment, Mallika Nagar and Andal Nagar on the west, GST road (NH 45) and metroline on the south east all drain through the Airport toward the Adyar River due to the natural terrain of this region. Airport suffered severe damages; critical infrastructure such as radars and communication systems got submerged in the flood waters; several aircrafts were literally toyed around by the furry of flood waters and damaged; the coast guard station in the eastern side of the airport got inundated up to the lintel level. The airport remained closed and started operation only on December 7, 2017.

AAI of Chennai approached IIT Madras to do a comprehensive scientific analysis of the drainage system in an around the Chennai airport and the flood carrying capacity of Adyar River to propose improvements that would minimize the magnitude of flooding and if feasible eliminate it, if similar rainfall event were to recur in the future.

2 Scope of the study:

- Topographic survey of Airport premises inside operation area/city side and outside the Airport premises wherever the stormwater drains are entering to Airport operational areas such as Meenambakkam village, Trisulam area, Cantonment of Pallavaram, near GST road etc.
- Developing a layout of existing drainage system and cross section of the drain with invert level for inside operational area and the city side of Chennai Airport (AutoCAD drawing)
- Hydraulic analysis and checking of existing drains sizing; if the existing drain could not cater to the increased discharge, due to proposed airport expansion plans, proposal for re-sizing of existing drains or provision of new drains; for a rainfall intensity corresponding to standard recurrence interval specified for airport drainage system designs
- Study the feasibility to divert external storm drains entering Airport operations areas to discharge directly to Adyar river without entering into operation area wherever possible
- Identify and explain the reasons for historic flooding in December 2015 of the Chennai Airport and possible causes for inundation of operational area through a thorough hydrologic and hydraulic modelling study

- Study the drainage and the level of inundation close to locations of critical infrastructure and suggest appropriate measures to protect the same from flooding of different recurrence intervals
- Assessing the effect of having solid compound wall versus other type of porous barriers that would convey the flood water on the level of flood inundation within the Airport operational area and the surroundings based on hydraulic modelling studies
- Study the existing operational area security compound wall and to suggest suitable section to prevent damage during heavy rainfall/flooding
- Hydraulic analysis of river training scenarios of Adyar river (near the airport) that will minimize or eliminate flooding / inundation
- Study the feasibility of an additional flood carrier channel that would bypass the secondary runway along the periphery and would discharge back into the Adyar River at a safe distance downstream
- Recommendations
- Annexures - Drawings

3 Topographic Survey

3.1 Introduction

The topographic survey of the study area includes the following tasks:

a. UAS survey to develop high resolution Digital Surface Model (DSM) and Digital Terrain Model (DTM)
b. River cross section survey of Adyar river in the stretch from Chennai Bypass road in the west (U/S of the Adyar runway bridge) to Mount Poonamalle High road bridge to the North (D/S of Adyar runway bridge)
c. DGPS survey to establish high accuracy Ground Control Points (GCP) to serve as bench marks for ground surveys and to correct the data from UAS survey
d. Ground survey on the city side (Meenambakkam village, Trisulam area, Cantonment of Pallavaram, near GST road etc.,) to collect alignment, levels and hydraulic particulars of storm water drains entering the airport premises
e. Ground survey within the airport premises to collect alignment, levels and hydraulic particulars of storm water drains. Further, during this survey HFL markings and compound wall breaches due to flood would also be collected

A detailed report of the methodology and techniques adopted for topographic survey activities carried out is attached as annexures to this final report. Only the salient points from the topographic report are listed here for clarity

3.2 UAS survey

- UAS survey was conducted for 9 days between 19/10/2016 and 29/10/2016 successfully with a total flight duration not exceeding 60 minutes on each day (1st flight: 40min and 2nd flight: 20min)
- The entire project area was divided into four zones. A total of 64 flight lines covering 350 km were needed to cover the project area. The flight lines were designed with 70/60 % overlap to have dense cloud points and dense DSM. However, the region 4 (OTA area) was not covered as the permission is still pending from the concerned authority.
- The survey grade UAS (eBee) deployed in this project is small (630 grams, fixed wing) and completely autonomous with flight plans that were pre planned, programmed, fully automated and controlled using eMotion software. The optimized flight plan takes into account proposed flight height, output resolution, obstacles, topography, wind conditions and site layout.
- Using the high resolution photographs acquired from UAS, 3D DSM's and orthomosaics have been generated. The DSM is still not corrected using GCPs from DGPS survey. Even without this correction, the DSM has an XY (Easting – Northing) accuracy of 3cm and Z (vertical) accuracy of 6cm. Correction using GCP from DGPS survey is expected to improve this accuracy even further.
- From the UAS survey we have high resolution digital orthomosaic of the project area with a ground resolution of 10cm. DSM and DTM at the same resolution to identify and map drainage pathways and obstruction to flow in the flood plains have also been derived (Figures 3.1 to 3.4).
- From the UAS survey, high resolution landuse map was also generated which can be used for mapping the facility of the airport accurately (Figure 3.5)

3.3 River Cross Section and longitudinal survey of Adyar river

- Total-station along with auto level was used to carry out the river cross section and longitudinal survey of the Adyar river in the stretch from Chennai Bypass road in the west (U/S of the Adyar runway bridge) to Mount Poonamalle High road bridge to the North (D/S of Adyar runway bridge) (Figure 3.6).
- From the survey, the bed elevation along the length of the river at few locations is shown in Figure 3.7. Between the secondary runway bridge and Cowl bazaar, it can be observed that there is a region of local depression in the river where there is always a pool of stagnant water

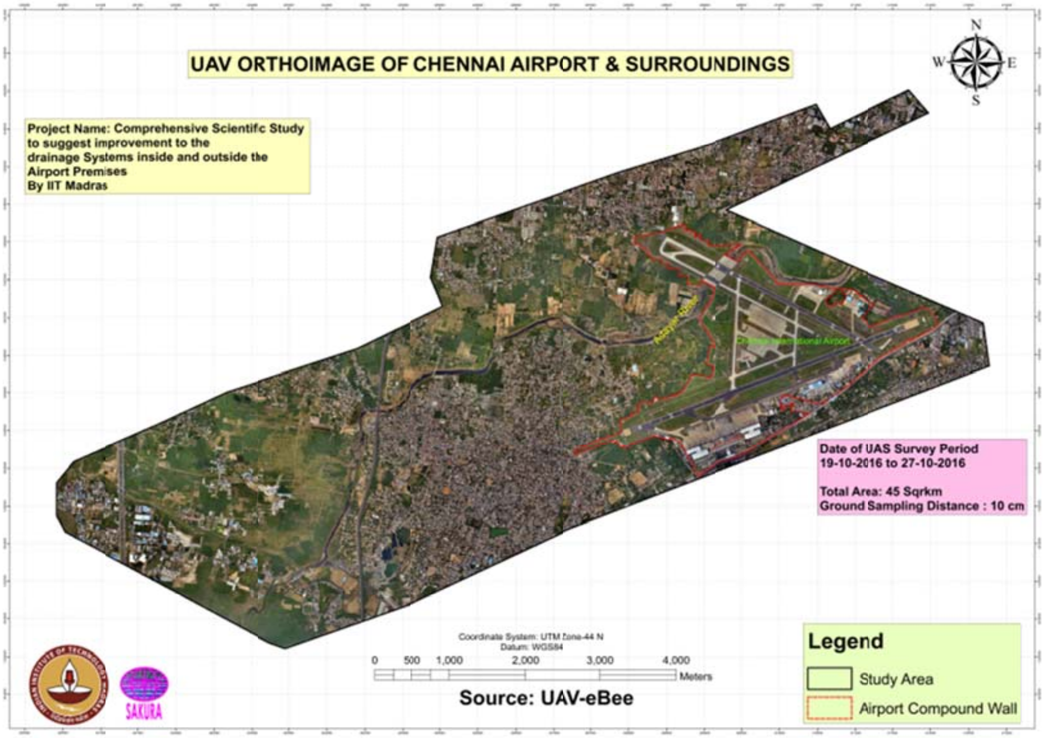


Figure 3.1 Orthophotograph of the airport and the vicinity derived from the UAS

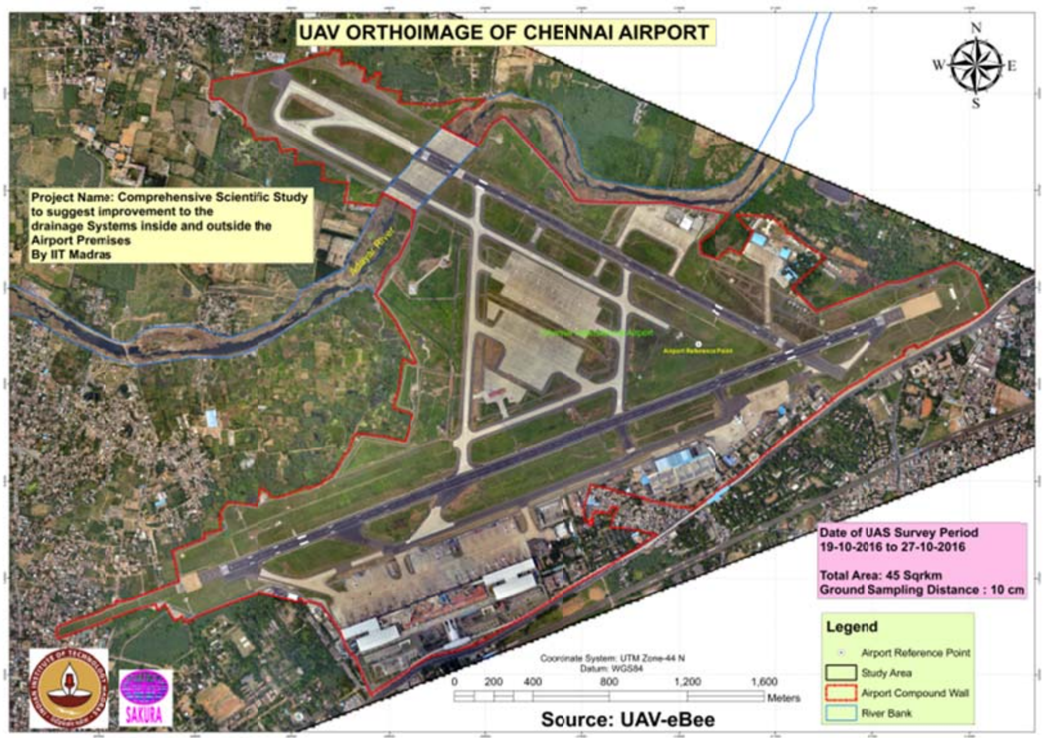


Figure 3.2 Orthophotograph of the airport region

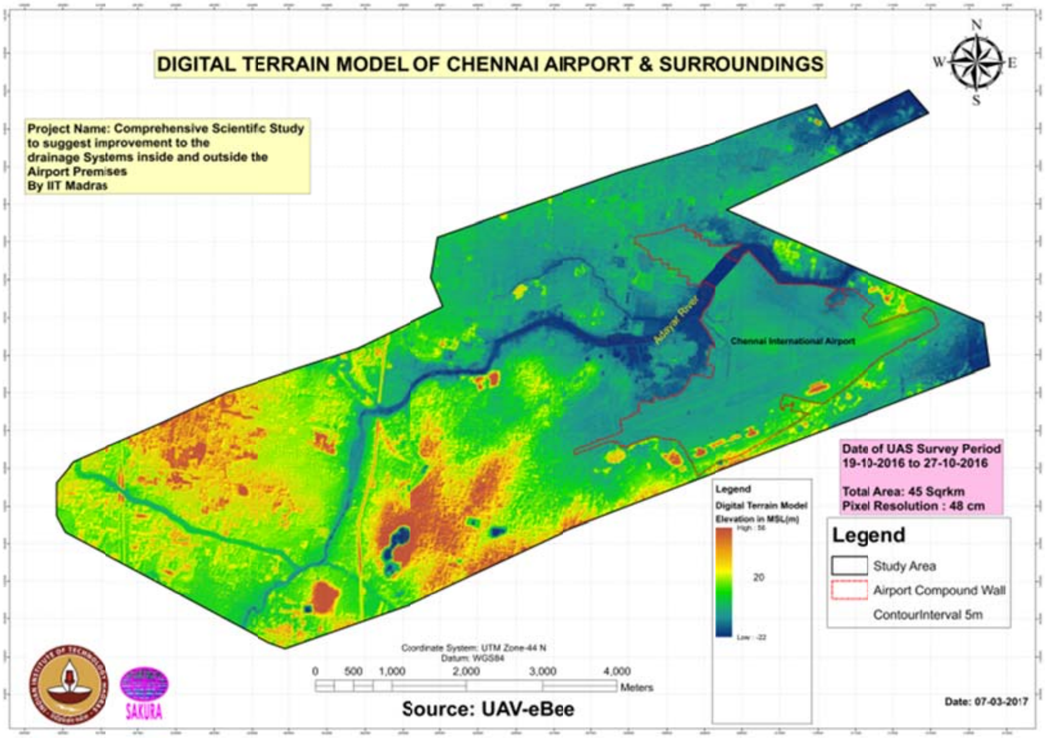


Figure 3.3 Digital Terrain Model (DTM) derived from the UAS survey

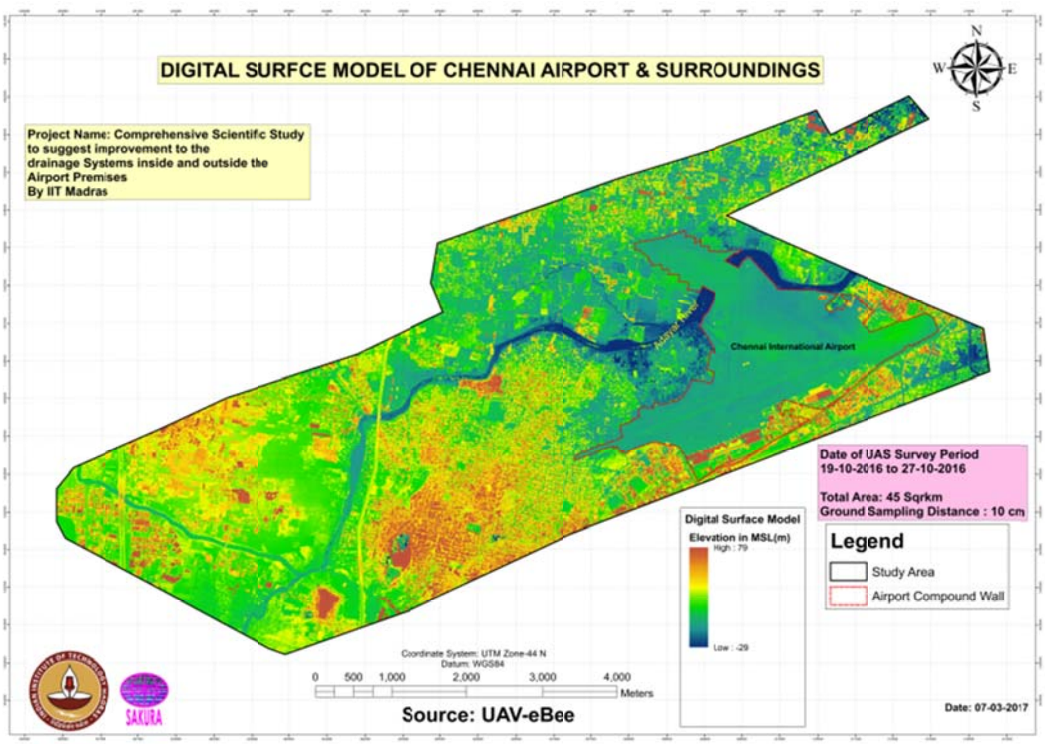


Figure 3.4 Digital Surface Model (DSM) derived from the UAS survey

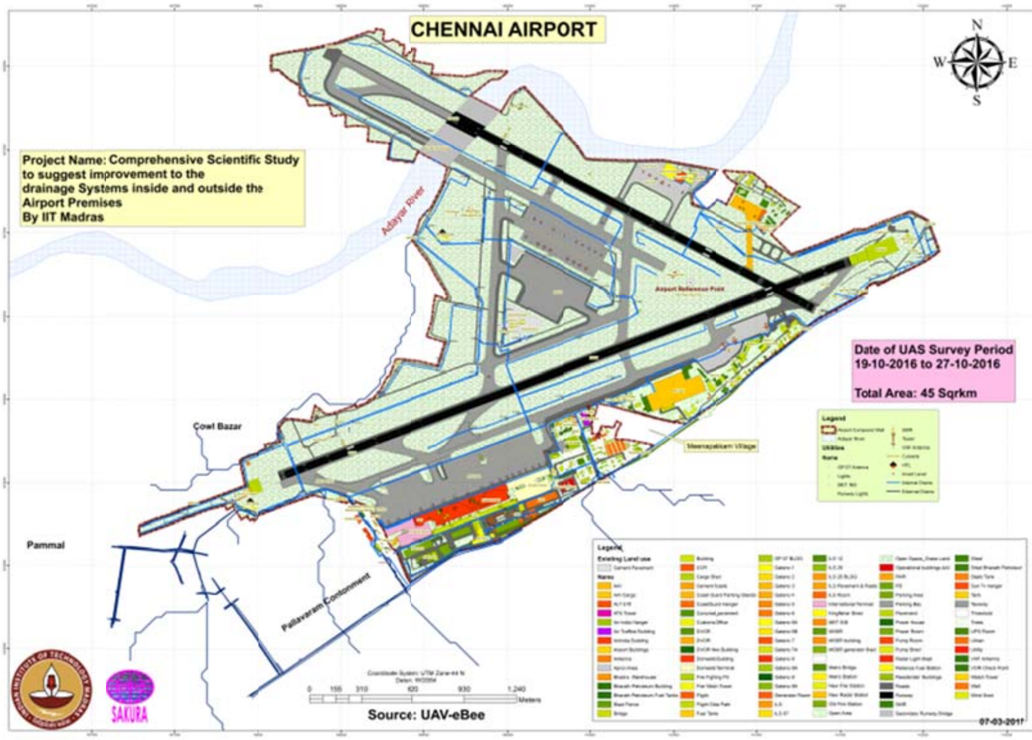


Figure 3.5 Landuse map of the airport derived from the orthophotograph

Table 3.1 Summary of River cross section survey

River Cross Section Survey Statistics	**Secondary Runway bridge close interval survey**
Total Length of River: **12.995km** Total Cross sections: **129** Cross Section interval: **100m** Spot level taken for 12.995 km approximately: **8000** **Secondary Runway Bridge Details** Total Spot Level taken inside the runway bridge is **692** Total pillars identified :**432**	Total length surveyed 600 m on both sides of Secondary runway bridge Cross Section interval **: 30m** Total Cross Section taken: **40** Total spot level identified **: 2000 locations**

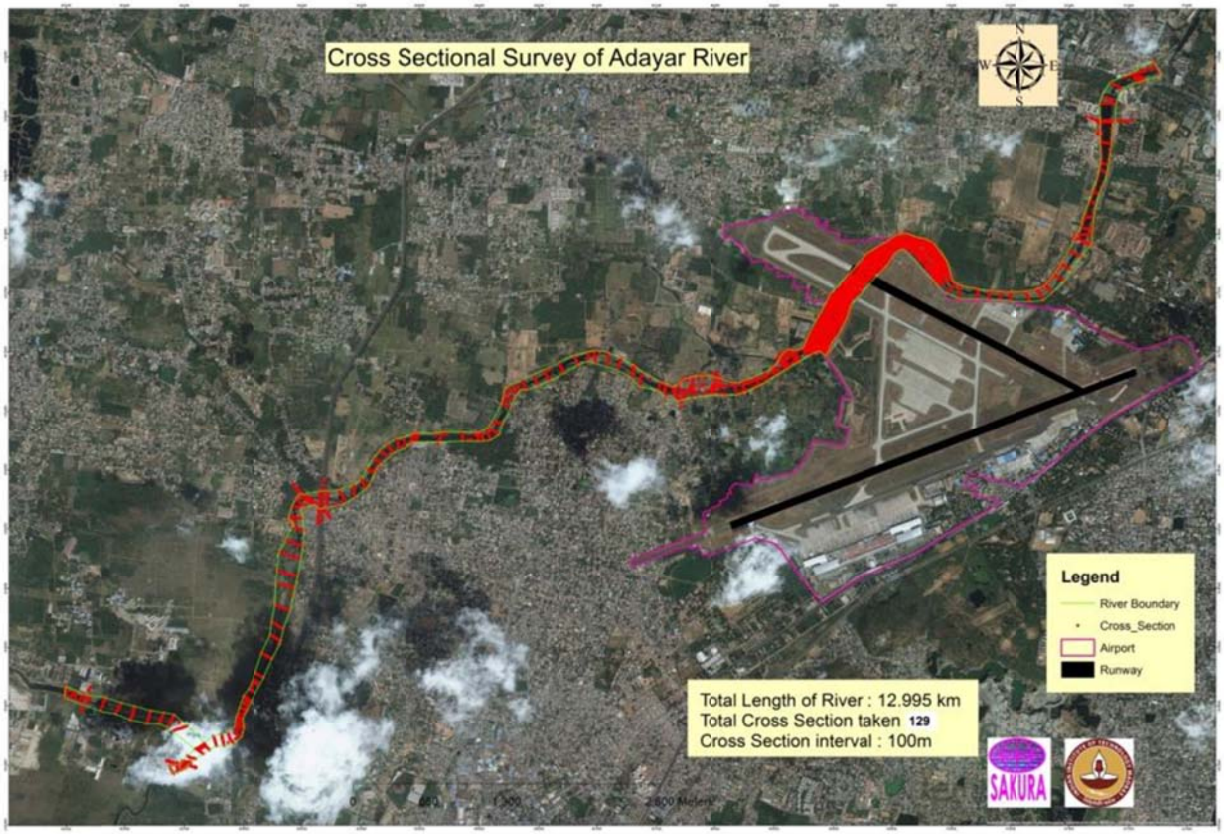


Figure 3.6 Cross-section and spot levels taken across Adyar river for a 12.9km stretch between Chennai Bypass road bridge and Mount Poonamalle High road bridge

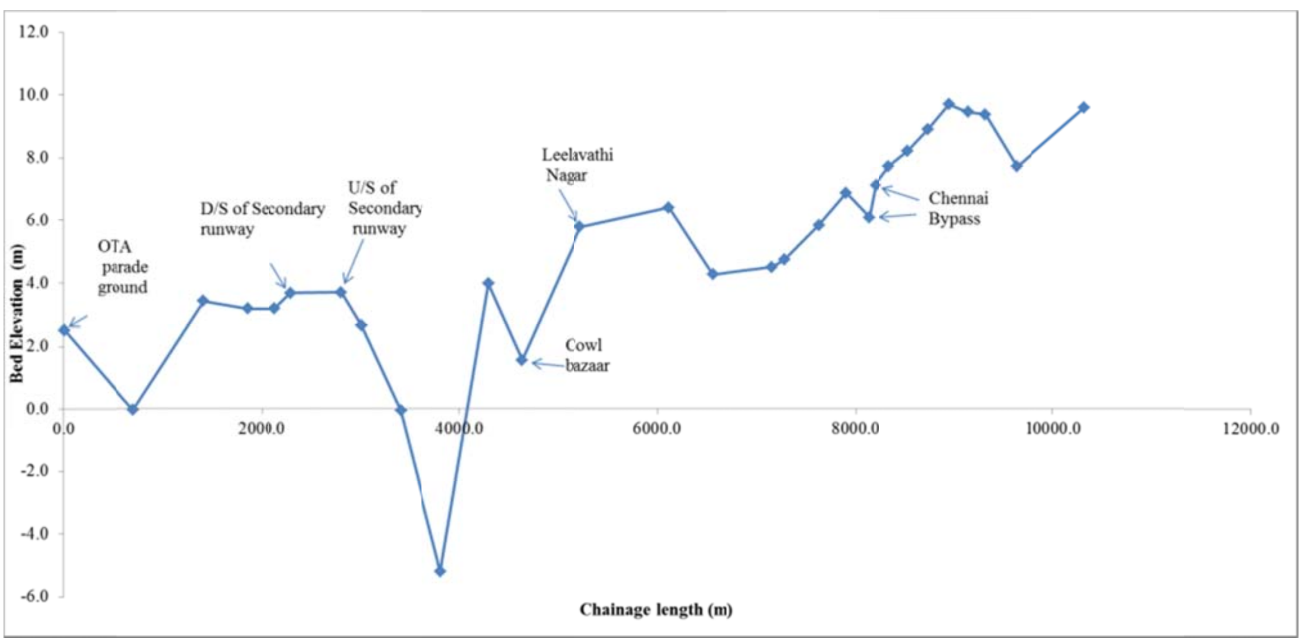


Figure 3.7 Bed elevation of the Adyar river at few locations along the length of the river

Figure 3.8. High accuracy Ground Control Points (GCPs) within the airport premises

3.4 DGPS survey to establish high accuracy Ground Control Points (GCP)

DGPS Survey has been conducted in WGS 84 spheroid, Indian Datum, and co-ordinates are in terms of Universal Transverse Mercator (UTM) Projection. Trimble DGPS SPS 855 was used for measurements. Forty two high resolution GCPs have been collected inside and in the vicinity of the airport (Figure 3.8), of which only seven GCPs were be used for correcting the DSM and DTM from UAS. The mean absolute error in elevation of the DSM surface generated from the UAS survey for the region is about 87cm and for DTM surface is about 75cm, which is the in the reasonable range for elevation derived from photogrammetric techniques. This digital elevation model is subsequently used for hydraulic modelling and flood inundation mapping.

3.5 Ground survey on the city side to collect storm water drain particulars

Storm water from outside the airport premises from four locations, Meenambakkam village, Trisulam area, Cantonment of Pallavaram, and GST road, drains through the airport often bringing large amount of runoff and dry weather (sullage) flow, causes flood like situation during monsoon season and bird menace due to sullage all through the year. These external storm water drains draining into the airport have been surveyed using total station to collect cross section and invert levels along their length (Figure 3.9). This data is currently being used to check the size of the existing storm water drains to dispose off the flood water from a design storm (10yr recurrence interval). Further, this data is being used to assess the scope for realignment and rerouting of external drains, thus study possible options for reducing the storm water load entering the airport premises from outside catchment.

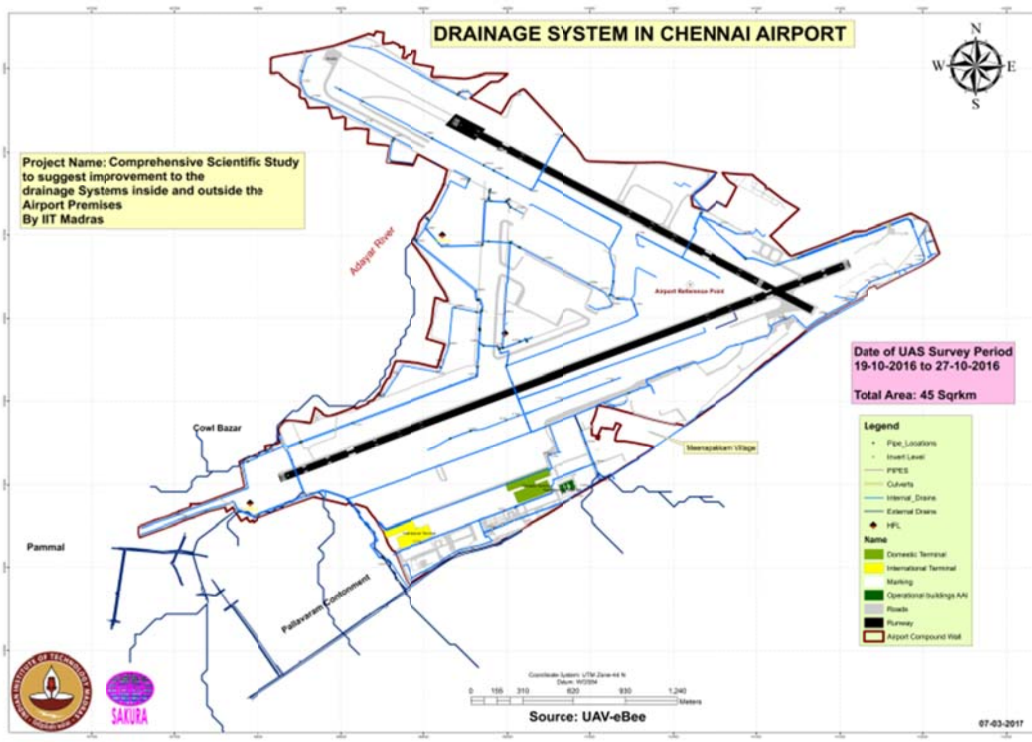


Figure 3.9 Drainage system of the Chennai Airport

3.6 Ground survey within the airport premises to collect storm water drain particulars

The objective of the survey inside the airport is to collect 1) cross section, 2) invert levels 3) Culvert hydraulic particulars 4) Drain alignment until its confluence with Adyar River 5) Constrictions due to utility lines along the storm drains 6) High Flood Marks at several places within the airport 7) Mapping the sections of compound wall that collapsed during the floods and 8) Plinth level of several critical infrastructure such as radar stations, power station etc., within the airport operational area. This data is currently being used to check the size of the existing storm water drains to dispose off the flood water from a design storm (10yr recurrence interval). Further, this data will be used along with the new master plan to check the capacity of the existing drains and assess the need to resize the storm water drains if the capacity is found to be inadequate.

From the ground survey, the HFL during the December 2015 flood is found to be 13.315m AMSL at the new radar station (in the vicinity of the secondary runway bridge). The HFL as per PWD during the earlier flood in 2005 is 9.75m AMSL.

During the ground survey, the breached section of the compound wall was also mapped (Figure 10). The compound wall breaches were observed at five locations with a cumulative length of approximately 375m (Figure 3.10). This was used within the hydraulic model to assess the static and dynamic forces acting on the compound wall so that the compound wall section can be appropriately designed to withstand the load caused due to flood of similar magnitude, thus preventing it from breaching.

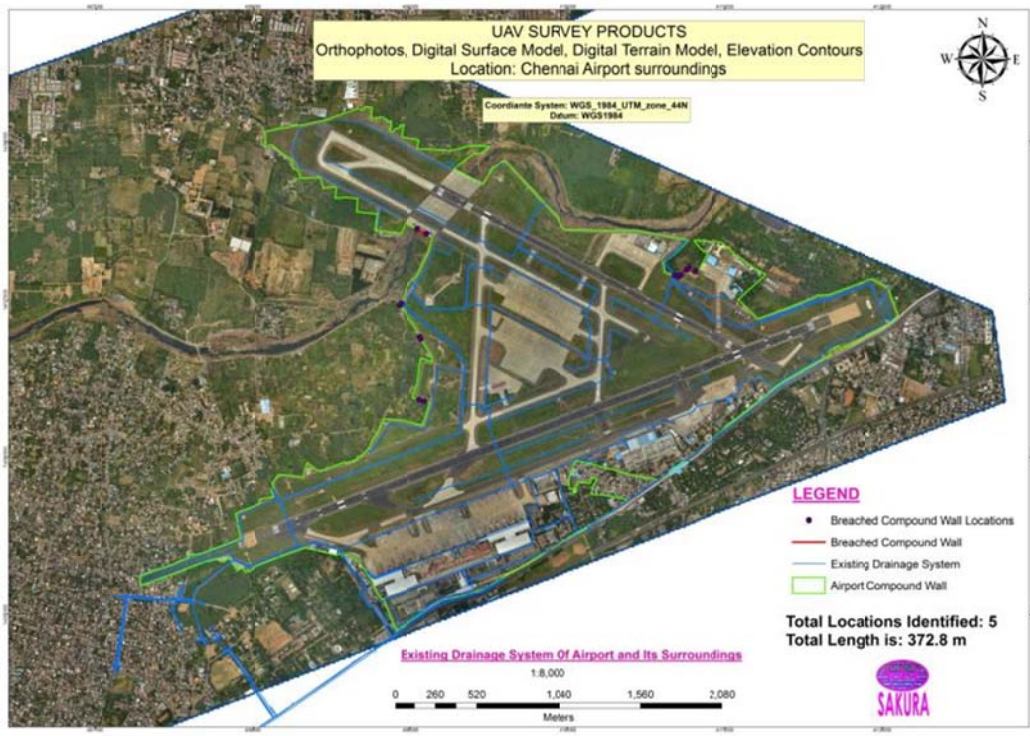


Figure 3.10 Layout of storm water drains within the airport and sections of breached compound walls

4 Modelling of river and storm water discharges

4.1 Introduction

Three different numerical models were used to understand and quantify the amount of flood discharge in the Adyar River, flood depth at different places and capacity of the storm water drains. The models used are:

1) **Hydrologic model (HEC-HMS):** For simulating the river flow entering Adyar River at the Chennai bypass road bridge in the west, including the reservoir releases from

Chembarambakkam reservoir. This will give the peak flood hydrograph for rainfall of different recurrence intervals (2, 5, 10, 25, 50 and 100 yrs).

2) **Hydraulic model (HEC-RAS 2D):** HEC-RAS 2D model will be used to route the flood through the river section adjacent to the airport, including the airport operational area and secondary runway bridge. This 2D model will help us to design possible river training works and flood by pass canals. Further, this will also help to map the flood risk faced by other sensitive infrastructure such as Radar and power stations and to redesign the plinth height.
3) **Storm Water Management Model (SWMM):** SWMM model is a standard tool to check the size of the existing storm water drain and to re-design and re-align the external and internal storm water drains taking into account the tentative master plan of airport development.

4.2 Hydrologic Modelling of Adyar river using HEC-HMS

This phase of the work intends to quantify the effect of rainfall on runoff and streamflow generated in Adyar Basin had the impact on Airport and the surrounding region, during the extreme rainfall event that occurred in Chennai during the period 26/11/2015 to 03/12/2015. As Adyar basin experienced major flooding during the extreme precipitation event, however measured levels of flood discharges at the runway bridge section is not available. Hence, the objective of the work is to simulate the rainfall-runoff process across the basin, including the runway bridge section location.   Further, simulations were also made to estimate flood discharges for 2yr, 5yr, 10yr, 25yr, 50yr and 100yr return period storms. In this context, the current study modelled the extreme rainfall events via a semi- distributed hydrological model, HEC- HMS 4.2.1 developed by USA Hydraulic Engineering center. The Hydrologic Engineering Centre's (HEC) Hydrologic Modelling System (HMS) is one of the standard models which incorporate Geographic information system (GIS) data with the watershed modelling. This numerical model simulates the behavior of entire watershed to predict time of flow, runoff characteristic, peak flow etc. It can be applied to any watershed of varying size, shape and climatic conditions. Inputs needed for the model include:

- Topographic map
- Soil map
- Watershed
- Rainfall data
- Intensity-duration frequency
- Adyar river cross-section
- Capacity of Chembarambakkam and its discharge
- Runoff curve number

Using the topography data from SRTM 30m digital elevation model (DEM), the entire Adyar river basin was divided into 17 smaller subbasins using GIS (Fig.4.1). This simulation study is needed because, only the release details from Chembarambakkam were measured. However, there is a large portion of watershed including discharge from Manimangalam tank and other smaller tanks upstream of Tiruneermalai are not controlled and measured, but would be contributing considerable quantum of discharge to the Adyar river (critical point 2 in fig.4.1). Hence, the discharge from this portion of the watershed has to be quantified based on numerical simulation. SCS curve number method was used to simulate the generation of rainfall excess and the SCS unit hydrograph approach was used to simulate the watershed response and the kinematic wave routing method for doing the hydrologic routing of the flood flow through the river.

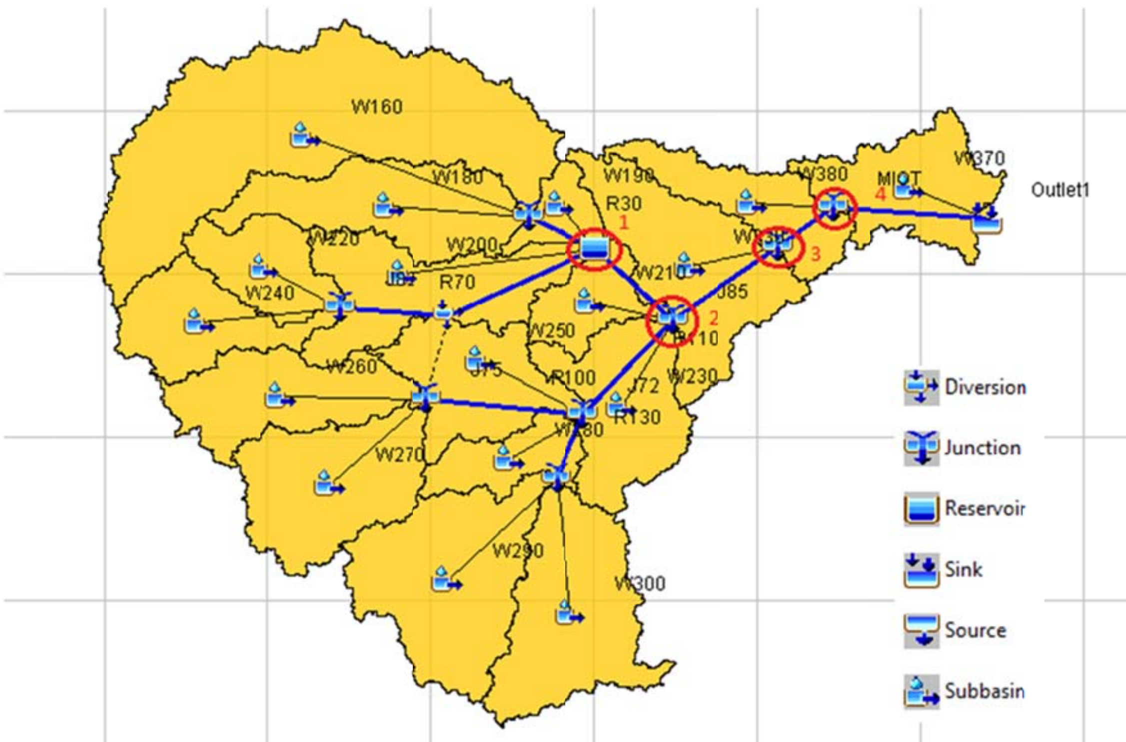


Figure 4.1 Subwatersheds of Adyar river basin and critical points. 1) Chembarambakkam Reservoir 2) Adyar river junction just upstream of the outer ring road 3) Airport secondary runway bridge and 4) Miot hospital

The watershed structure which can be imported directly to HEC-HMS was derived using HEC-GeoHMS which works within a GIS platform. The inputs to the model in order to derive the particulars included digital elevation model (Fig. 4.2) land use (Fig.4.3) and soil map along with the hydrologic soil groups (Fig.4.4) and soil characteristic information. The landuse maps were reclassified into four types namely, waterbody, urban (impervious), forest and agriculture. Based on the landuse data and hydrologic soil groups, the lumped Curve Number (CN) value (Fig.4.5) for each sub basin was generated by HEC- GeoHMS.

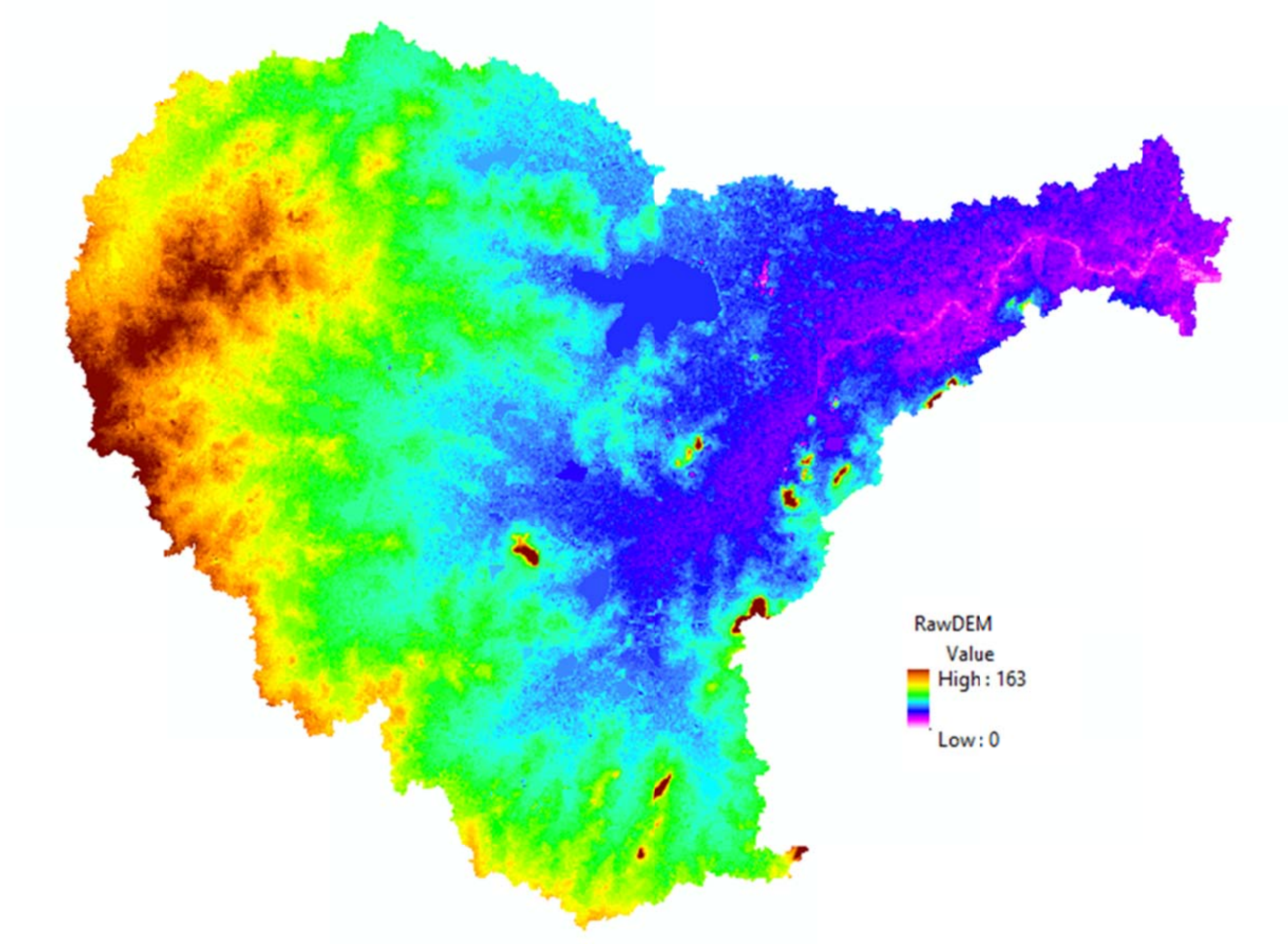


Figure 4.2 SRTM 30m digital elevation model of Adyar river basin

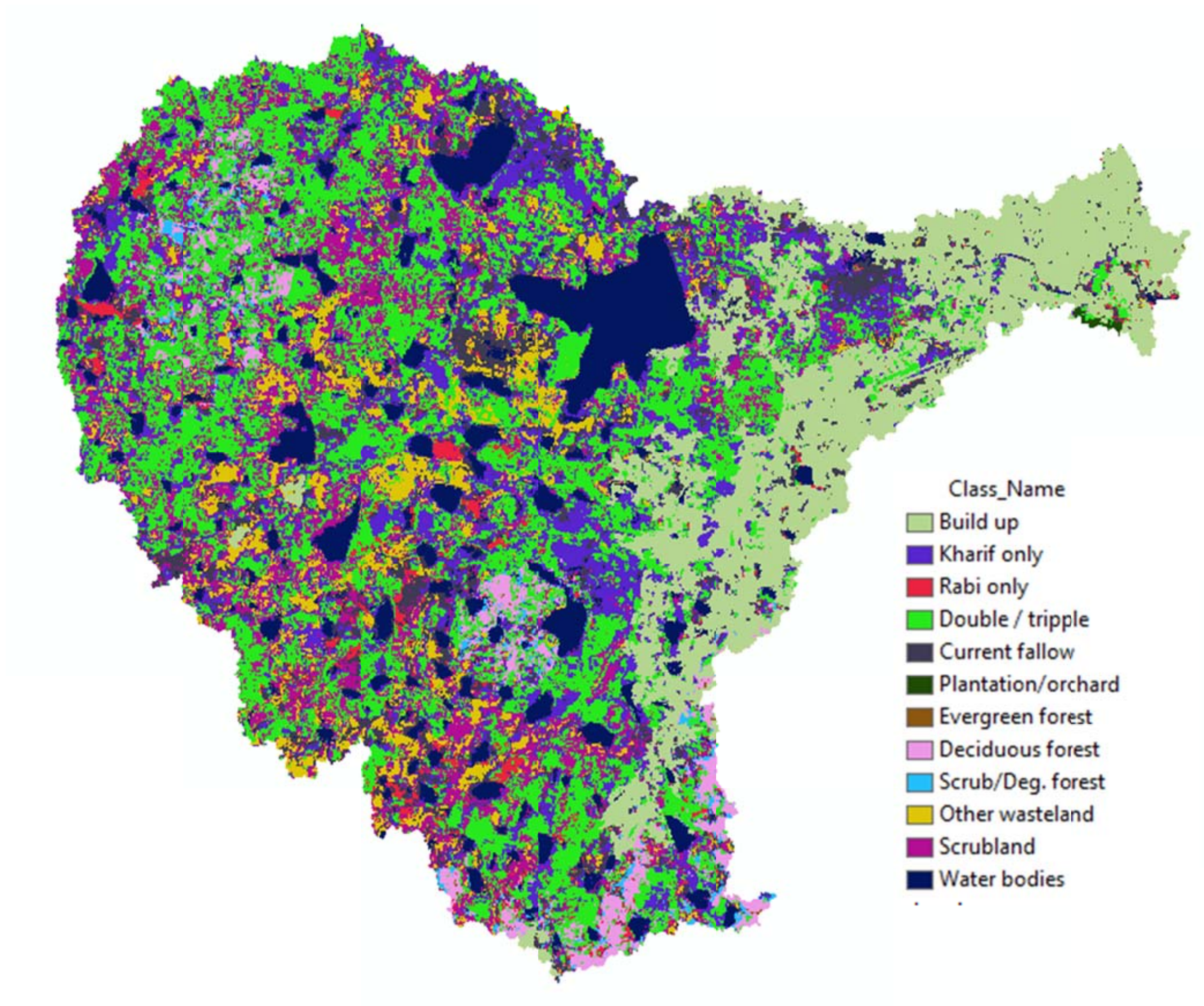


Figure 4.3 Landuse map of the Adyar river basin

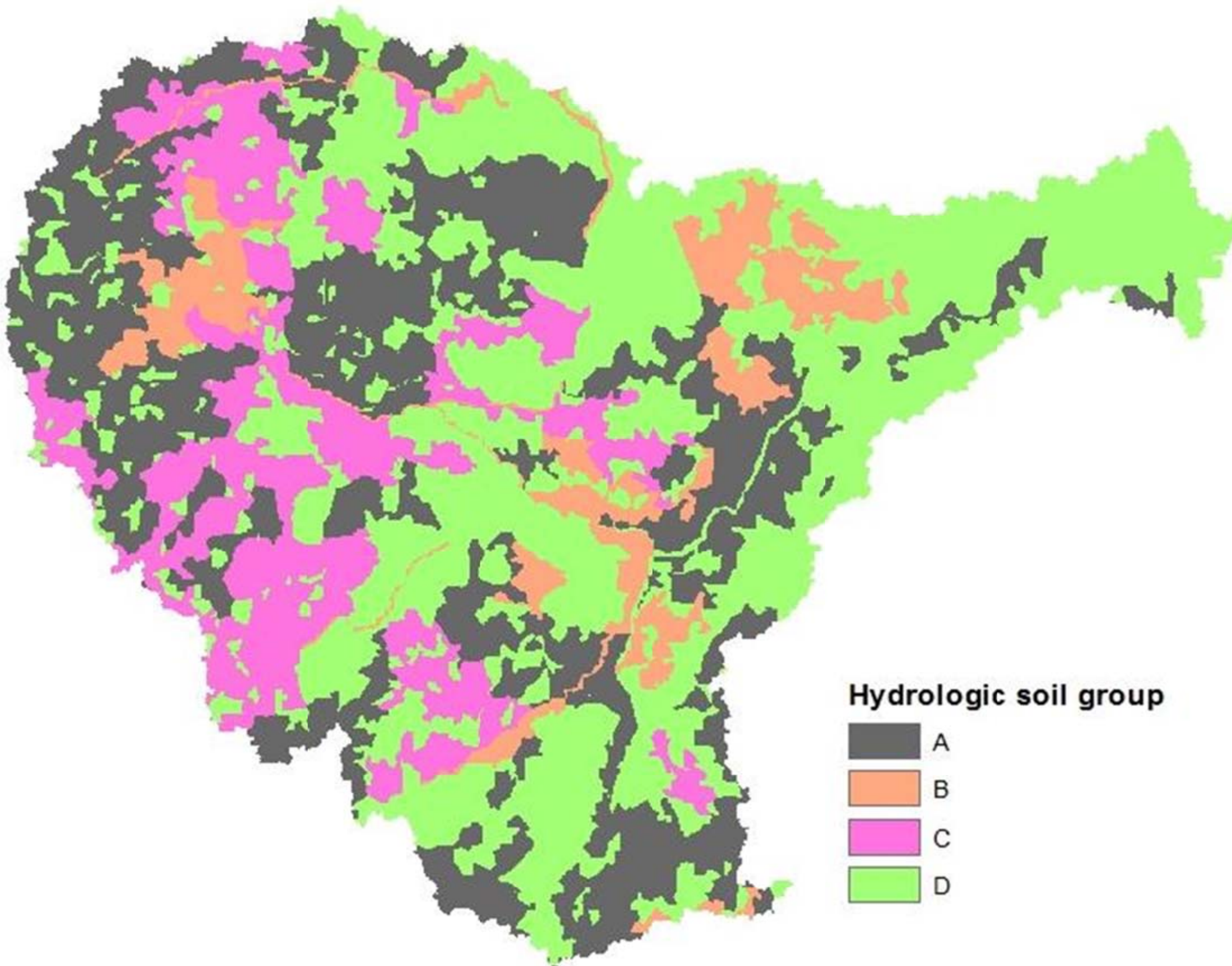


Figure 4.4 Soil hydrologic group map of the Adyar river basin

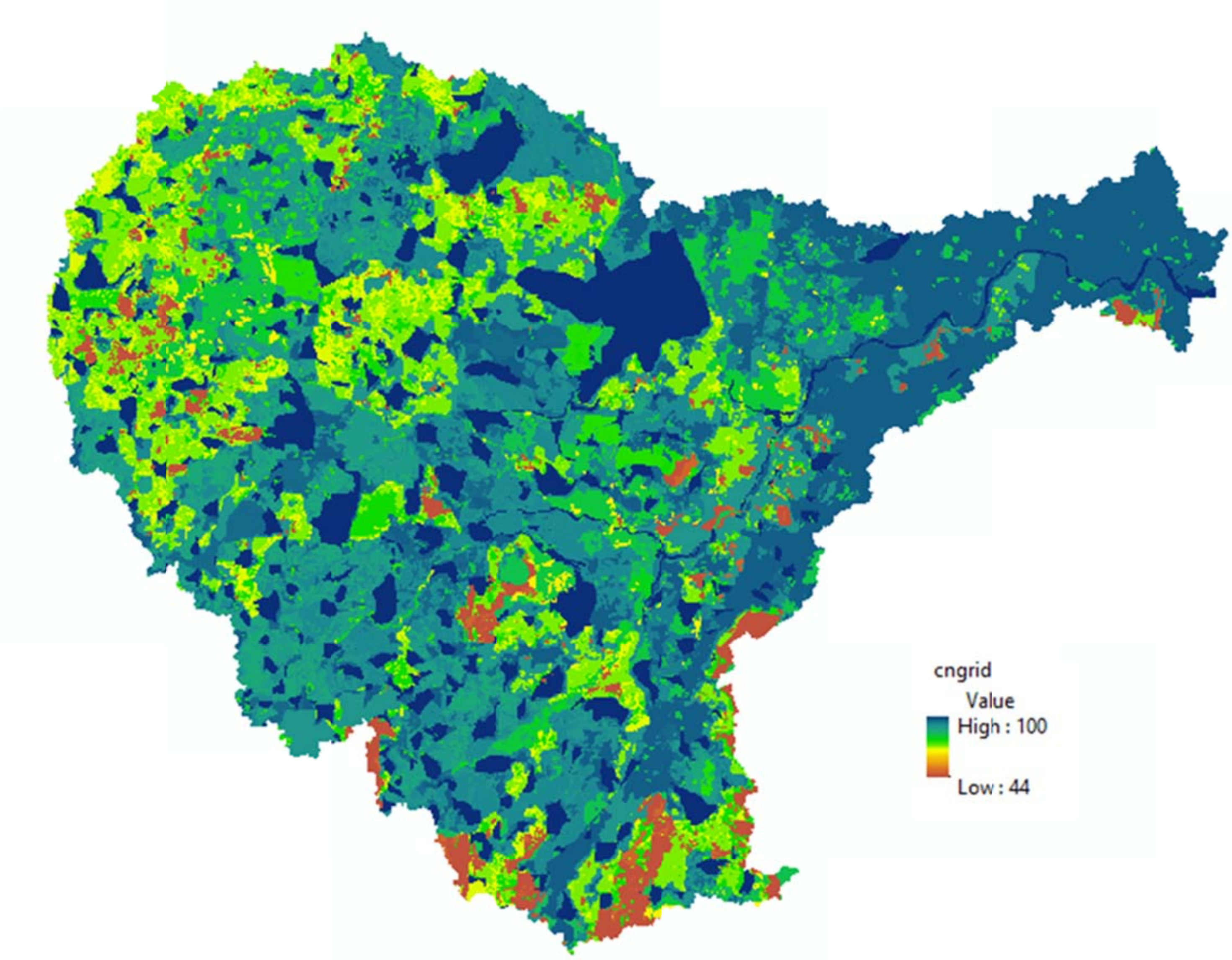


Figure 4.5 Curve Number map of the Adyar river basin

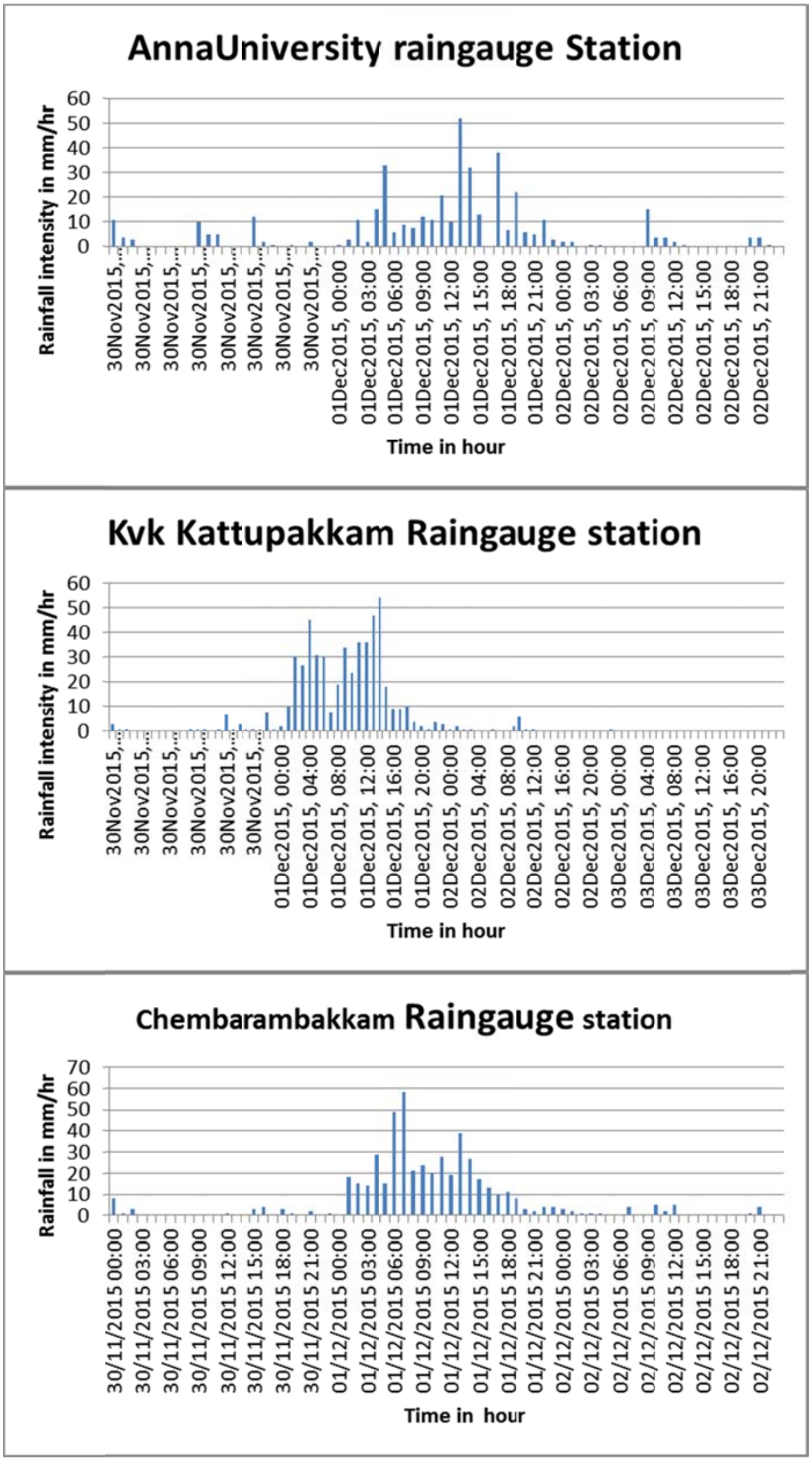


Figure 4.6 Storm hyetograph of the 2015 flood for different raingages

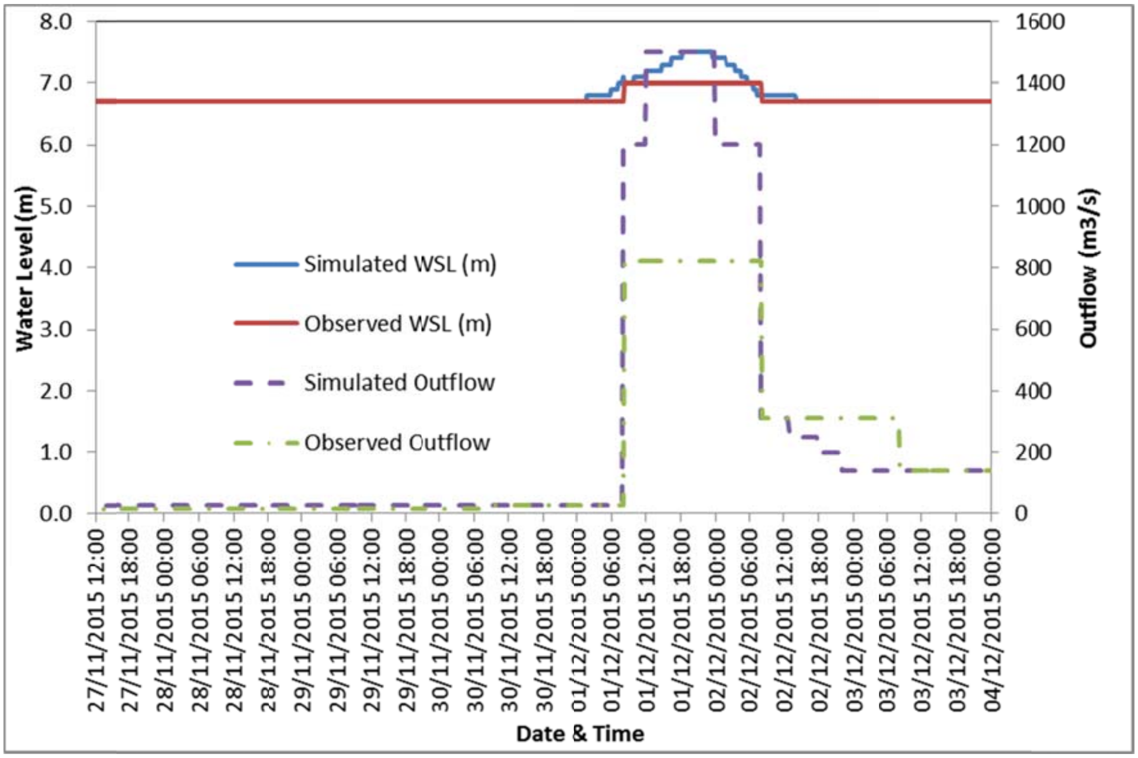


Figure 4.7 Calibrated outflow at the Chembarambakkam reservoir based on the measured water levels at the reservoir

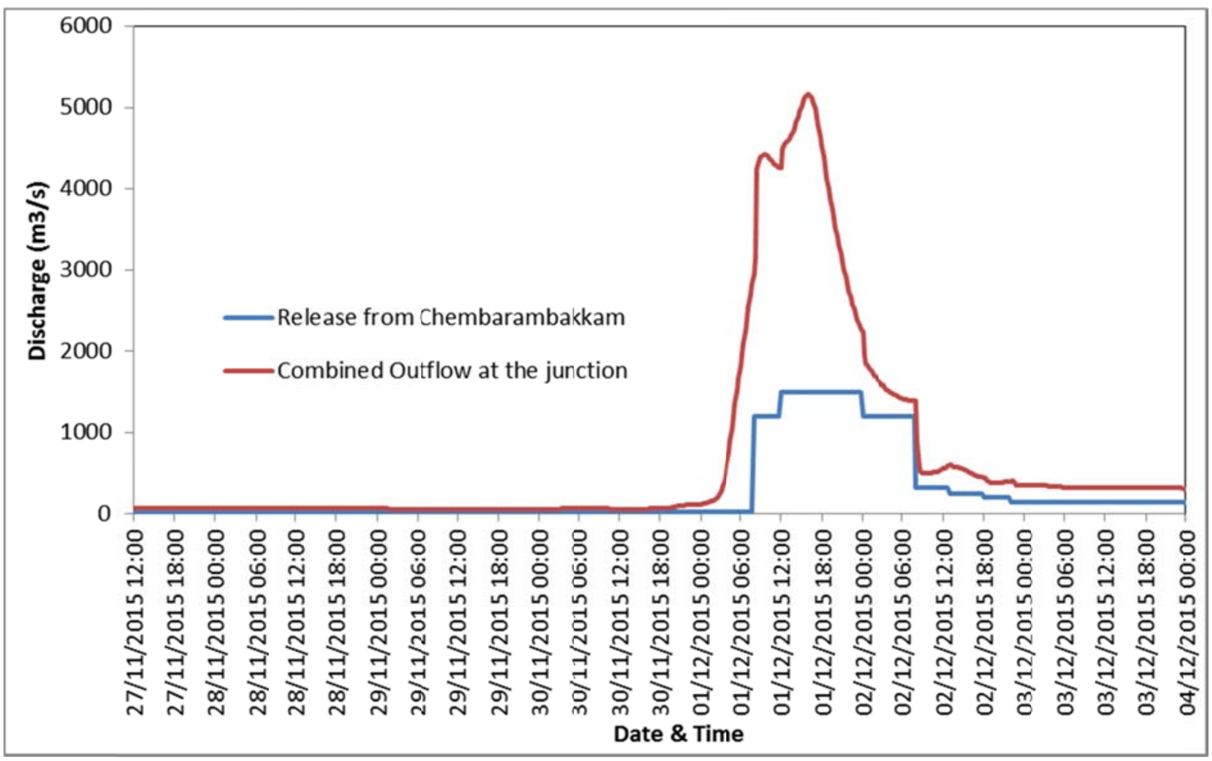


Figure 4.8 Simulated reservoir release at the Chembarambakkam reservoir and the flood hydrograph simulated at the junction of two limbs of Adyar river just upstream of outer ring road (Critical Point 2)

The hourly rainfall data for November and December 2015 were collected from IMD for several raingages (Fig.4.6) inside and surrounding the basin. Several ponds and lakes within the basin were assumed to be full during the beginning of the simulation period prior to 27/11/2015. Using the raingage data, the event simulation that caused the historical floods in 2015 was made using HEC-HMS to quantify the peak discharge in the Adyar river.

Before analyzing the model results, an attempt was made to calibrate the model with the measured water level data by adjusting the reservoir outflow (Fig.4.7). The reasonably calibrated model at the Chembarambakkam reservoir (Critical point 1) was used to analyze the flows at other critical points. The hydrograph simulated at the junction of two limbs of Adyar river just 2km upstream of the Outer ring road (critical point 2) is shown in figure4.8. The peak discharge is estimated to be approximately 5000 m^3/s (1,75,000 ft^3/s). Although the average release from Chembarambakkam for 01/12/2015 was reported at 821 m^3/s (29,000 ft^3/s), the peak release for a short duration within the day could have been much higher. Nevertheless, we can observe that in addition to reservoir release, a considerable amount of discharge was contributed to the flooding of Adyar river from the uncontrolled Manimangalam limb of Adyar river (Fig.4.8). This combined flood discharge is the main source of inundation of the Airport and the other downstream areas of Chennai city adjacent to the river. At its peak, the release from Chembarambakkam reservoir was only about 1000 m^3/s, whereas the flood generation from rest of the uncontrolled portion of the watershed such as Manimangalam, Thirumudivakkam, Tandalam and Tambaram contributed as much as 4000 m^3/s, pushing the peak to as much as 5000 m^3/s. This high discharge in response to the high amount of rainfall on Nov.30 and December 1, 2015 was due to high amount of antecedent moisture conditions caused by the saturation of the soil from previous rainfall events in November.

This flood hydrograph (Fig.4.8), at the junction of two limbs of Adyar river (at critical point 2), was used as the upstream boundary condition for simulating the flood inundation with HEC-RAS 2D model. Further, the Intensity-Duration-Frequency (IDF) relationship derived from long-term (30 years) hourly rainfall from Nungambakkam (Fig. 4.9) was used develop synthetic storm hyetographs for different return periods storms for up to 24 hour duration. These synthetic hyetographs (Fig.4.10) were then used to derive estimates of peak flood discharges of Adyar river at the junction upstream of outer ring road and at the secondary runway bridge site across Adyar river for different return periods storms for up to 24 hour duration.

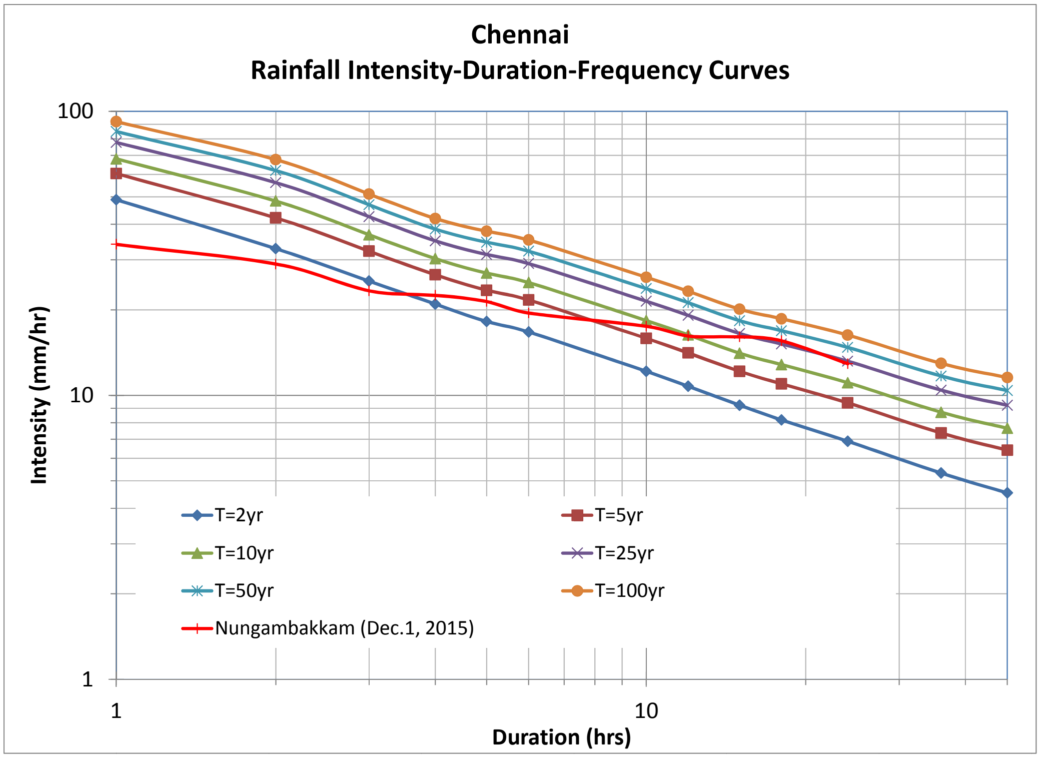


Figure 4.9. Rainfall Intensity-Duration-Frequency curves for various return periods along with the Dec. 1, 2015 event at Nungambakkam

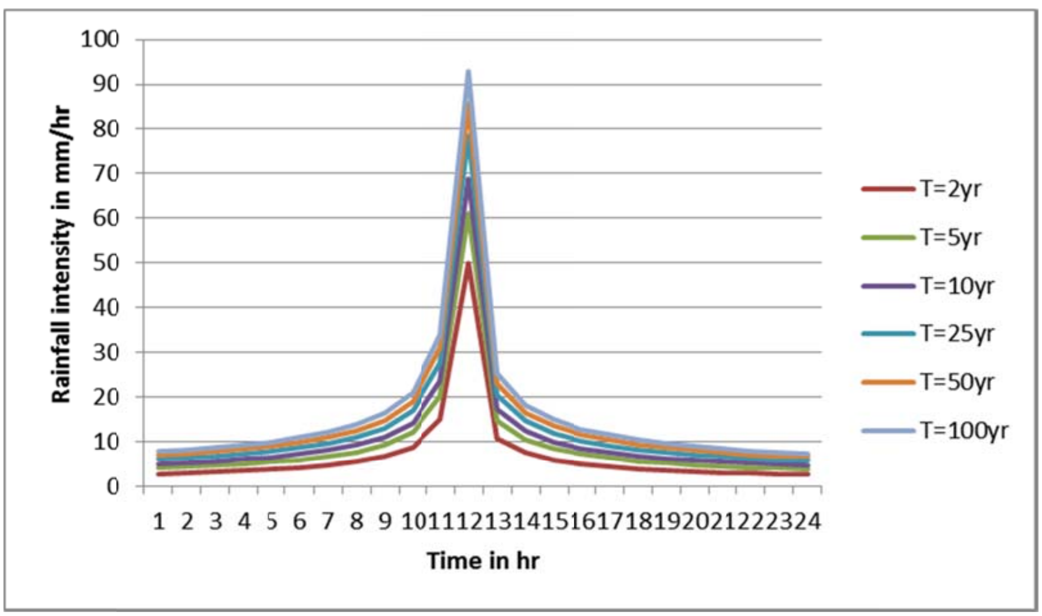


Figure 4.10 Synthetic storm hyetographs of 24hr rainfall for different return period storms (2yr, 5yr, 10yr, 25yr, 50yr, and 100yr)

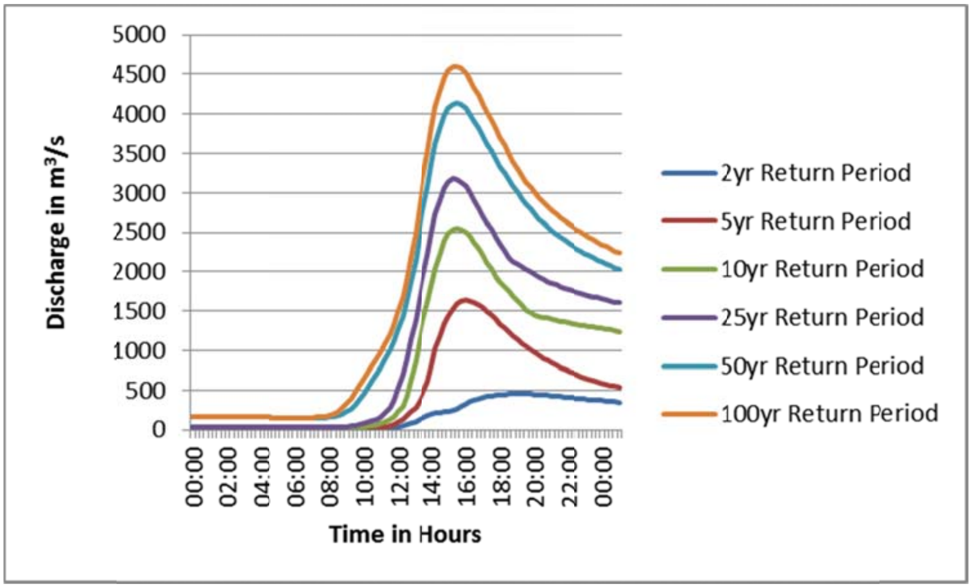


Figure 4.11 Simulated flood discharge at the junction just upstream of outer ring road based on the synthetic storm hyetographs for different return period

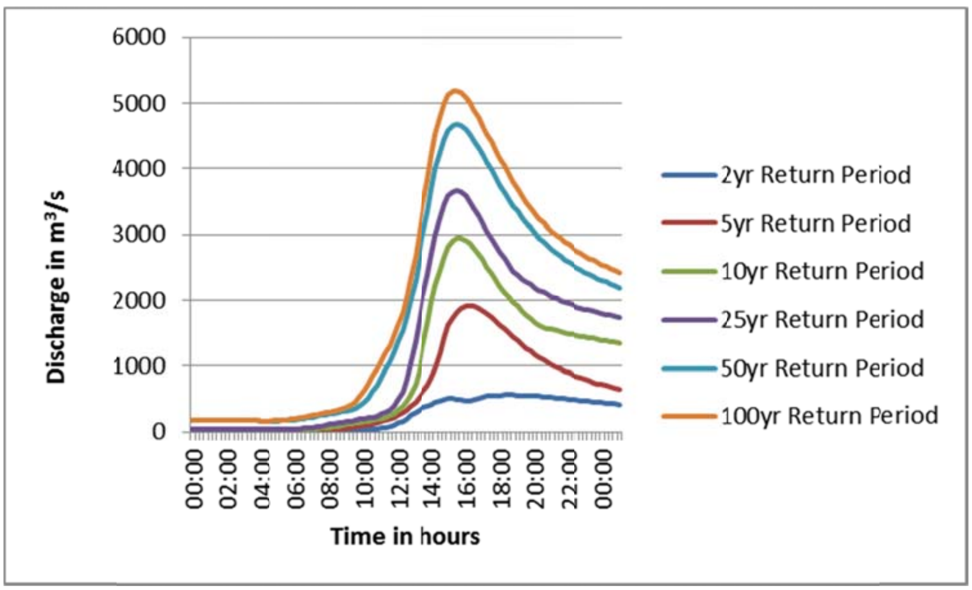


Figure 4.12 Simulated flood discharge at the airport runway bridge section (Critical point 3) based on the synthetic storm hyetographs for different return period

For simulating the flood hydrographs using the synthetic storm, it was assumed that for the 2 year flood, the initial surface storage was 25% of the maximum storage, for 5 year flood 50% of maximum storage, for 10 and 25 year floods 75% of maximum storage. For 50 and 100 yr floods the initial storage was assumed to be at 95% of maximum storage. Based on these assumptions of initial storage and synthetic storm hyetographs, the flood hydrographs are simulated at the junction upstream of outer ring road (Fig.4.11) and at the airport runway bridge section (Fig.4.12; Table 4.1).

As can be observed from the figure, the peak discharge of the 2015 flood and the peak discharge of the 100 year synthetic storm are almost the same (~5000 m^3/s). As the 2015 flood hydrographs encompass the peak flows of different return period floods, the inundation map at different levels of discharge would give the flood inundation extent and flood depth for different return periods. The hydrographs were used as boundary conditions for the the HEC-RAS 2D model to estimate the discharge capacity of the river at the soffit level of the secondary runway bridge and flood inundation map for different levels of discharges corresponding to different return period floods.

Table 4.1 Peak Discharge values at the secondary runway bridge site location

Return period of Storms	Peak Discharge (m^3/s)
2-yr	560.8
5-yr	1921.1
10-yr	2942.7
25-yr	3663.5
50-yr	4673.6
100-yr	5190.8

4.3 Flood inundation modelling and mapping using HEC-RAS 2D

4.3.1 Introduction to HEC-RAS

HEC-RAS is a robust, open source and fully dynamic hydraulic model developed by US army corps of engineers, hydraulic engineering center. It has been widely used for the analysis of flow through natural rivers and other channels to aid hydraulic engineers in floodplain management and flood insurance studies. This model consists of four components namely, graphical user interface (GUI), hydraulic analysis, data storage management and output (graphics and reports) management. It makes use of a common geometric data for performing river analysis components such as steady, un-steady, sediment transport and water quality simulations.

It uses the Saint-Venant equations in order to model hydraulic aspects and solve them numerically by finite difference method. It can also simulate flows in a single river, dendritic system or network of channel and is capable of simulating the flows in subcritical, supercritical and mixed flow regimes. The model can effectively simulate the influence of various obstructions such as bridges and culverts on the water profile variations. The simulations can be in 1-D, 2-D and combined 1-D and 2-D.

4.3.2 Development of terrain models for use in HEC-2D

For generating fairly accurate results, a more accurate representation of the terrain is required. However, the freely available open-source data are of coarser resolution. Therefore, a drone survey was conducted to obtain high-resolution data to effectively capture the topographical undulations. Using this high-resolution data, a digital terrain model was constructed. The digital terrain model (DTM) spans from Chembarambakkam, at the upstream, to OTA Bridge, which is located at approximately 1600 m downstream of the secondary runway bridge. The spatial resolution of DTM is 10 cm. However, drone survey fails to represent the actual terrain value underneath the water surface in the river. Hence, in addition to the drone survey, a manual survey was also done for obtaining the elevation data for river cross sections at various locations with the intervals ranging from 50-200m.

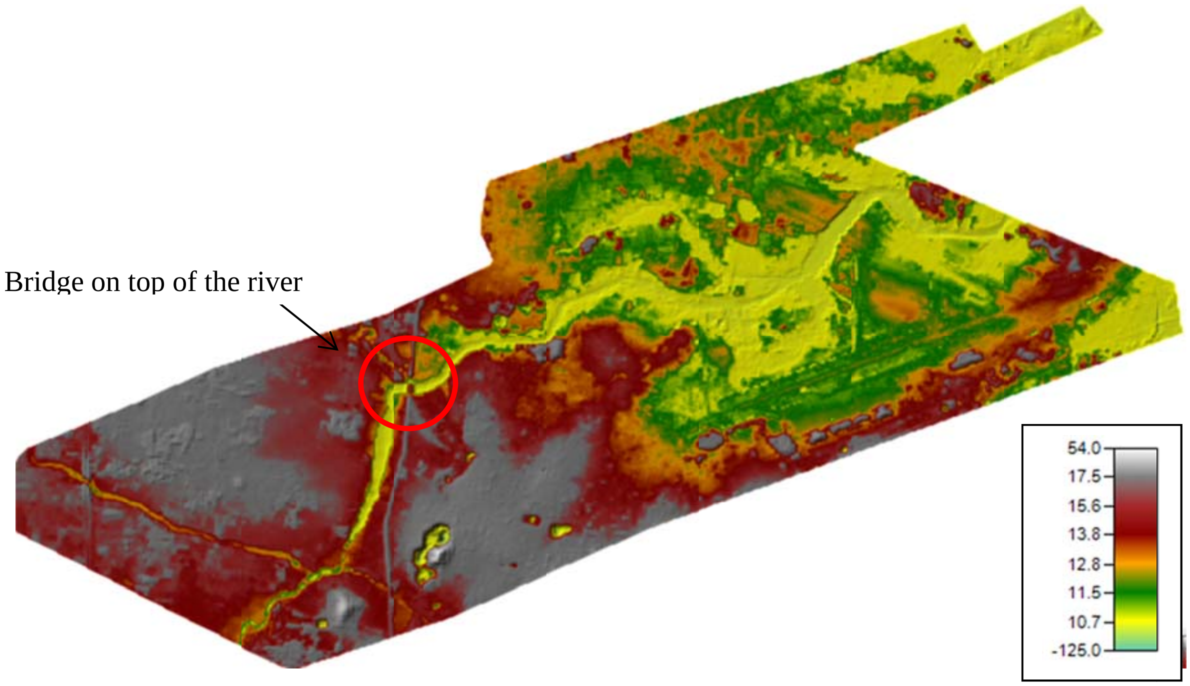


Figure 4.13 RAS Mapper with the terrain layer developed using drone data alone

HEC-2D model uses a tool called RAS mapper, for preparing the terrain model. RAS mapper is an ARC-GIS tool, which aids in developing the terrain model from tiff or img files. The window of the RAS mapper is shown in Figure 4.13. Firstly, to create a new terrain, the spatial reference should be set in the RAS mapper window. In the present study, the spatial reference was set to UTM zone 44N. After the projection was set, the terrain data was imported into RAS mapper in the floating-point grid file in *.tif format. The developed terrain model is shown in Figure 4.13 and extends from Chembarambakkam to OTA Bridge. In order to solve the governing flow equation, upstream and downstream boundary conditions are to be provided for a hydraulic model. Upstream condition is obtained from HEC-HMS generated flow conditions at the critical point 2 in the form of hydrograph (Fig.4.12). However, owing to lack of data for specifying downstream conditions, normal flow condition can be assumed. This in turn requires sufficiently long stretch of river from the bridge, so that the flow simulated at the bridge will be more accurate and error due to the normal flow assumption will be minimal. Therefore, a new terrain model including the region up to MIOT hospital is required. The elevation data from NEXTmap World 10, with a 10m resolution, was therefore incorporated into the DEM. To maintain consistency between data from different sources, the drone survey data was resampled into 10 m resolution and a relationship between the drone and NEXTmap data as a function of the x and y coordinates was established. Using this relationship, a consistent DEM data was generated (Fig. 4.14) up to MIOT hospital area.

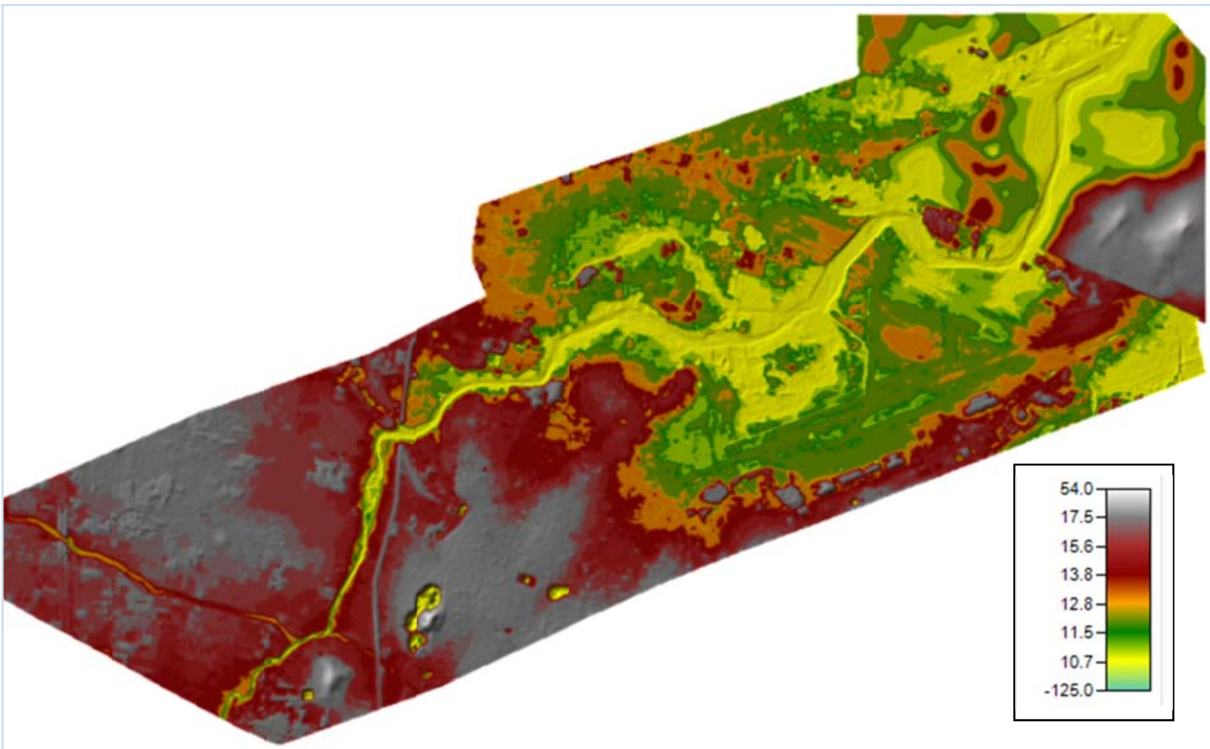


Figure 4.14 Integrated terrain map of DEM from UAS and NEXTmap data for the missing portion of the OTA

Further, it could be seen from Figure 4.13, that the drone survey provides the top elevation at the locations of the bridge, not the river bed elevations. As already mentioned, the drone data does not capture the actual terrain underneath the water surface in the river. Hence, to improve the terrain model along the river, the surveyed cross-sections were incorporated into the drone generated DTM. At first, the water surfaces and the bridge top in the river were manually digitized using the drone survey. Then, RAS Mapper was used to create the river terrain from the manual survey data. The created river terrain was then merged with drone generated DTM using ERDAS Imagine 2014 software package as shown in Figure 4.15. Finally, the enhanced terrain model was prepared using the river terrain from the manual survey for the areas that had water and the high-resolution drone data for the rest of the area (Figure 4.14). The final enhanced terrain and boundary of the air port premises indicated by red solid lines is shown in the Figure 4.16. In order to understand the effect of piers in flooding, the elevation vales were increased to 11m at the loaction of the piers in the final dtm (Figure 4.17 and Figure 4.18).

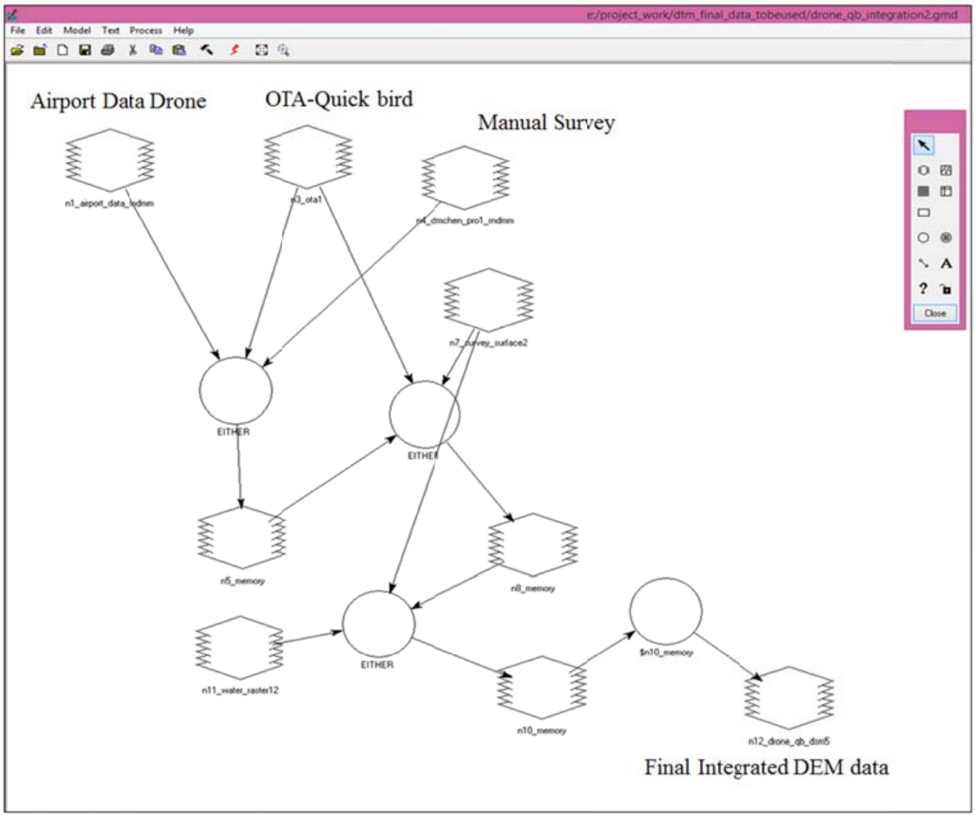


Figure 4.15 Process flow for integrating DEM from UAS with DEM from NEXTmap

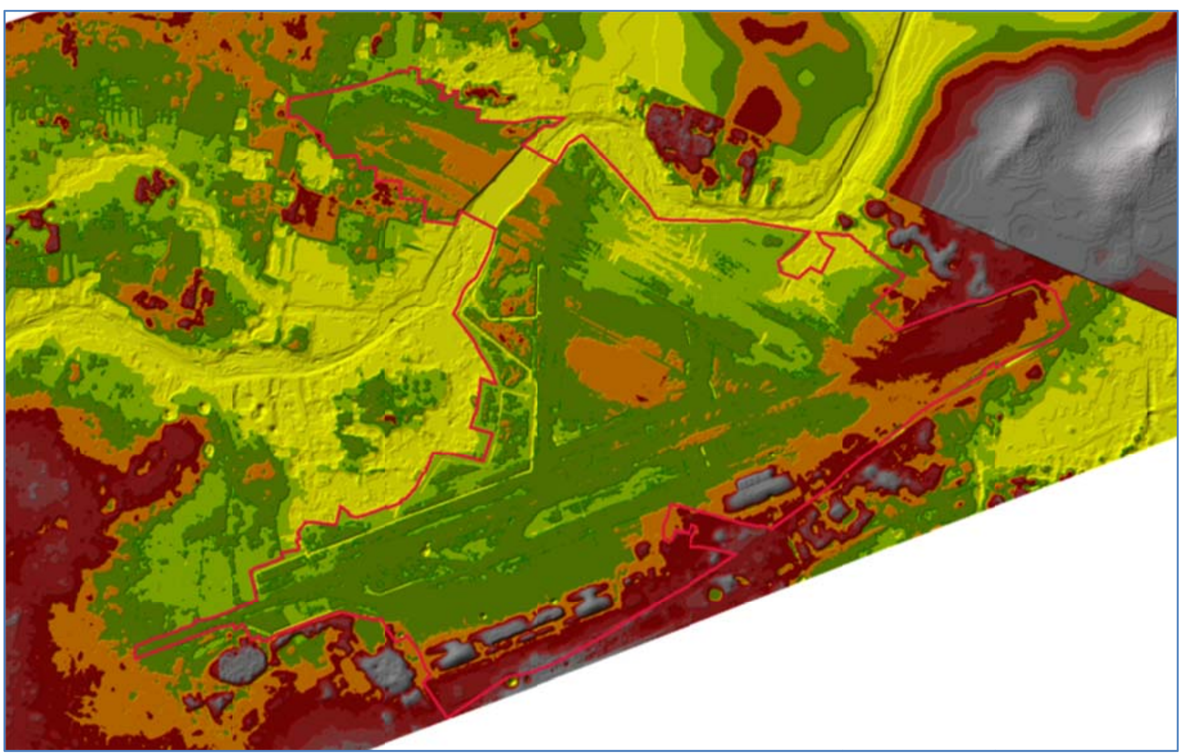


Figure 4.16 Terrain data near the premises of Chennai Airport

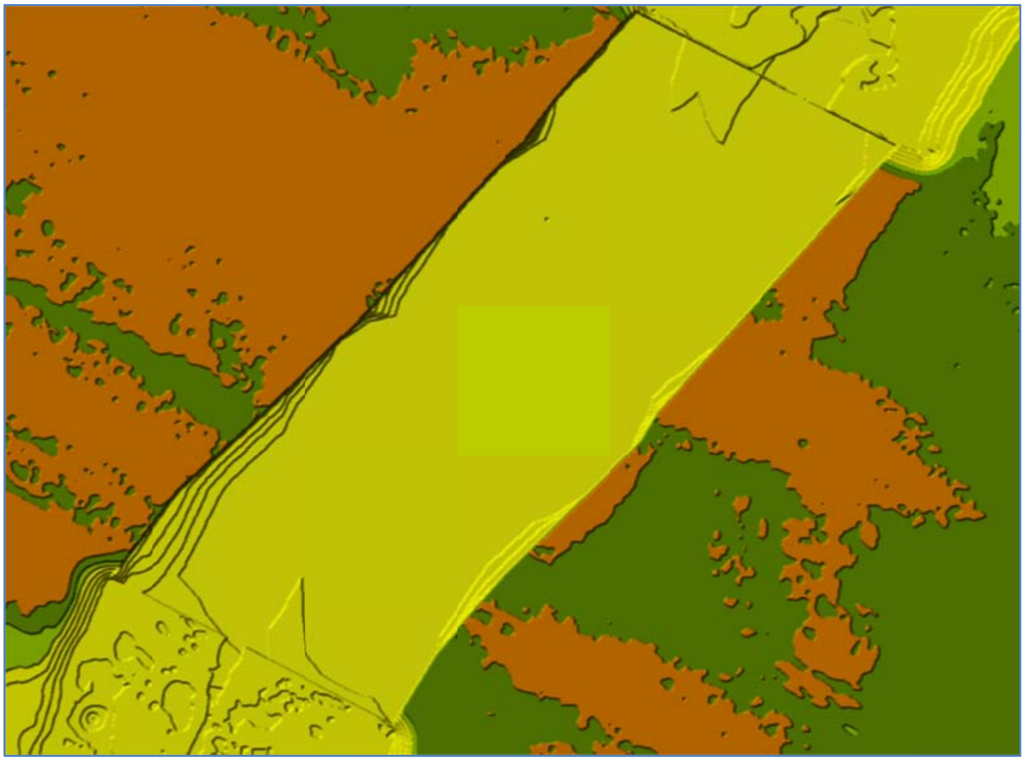


Figure 4.17 The river portion near the secondary runway bridge

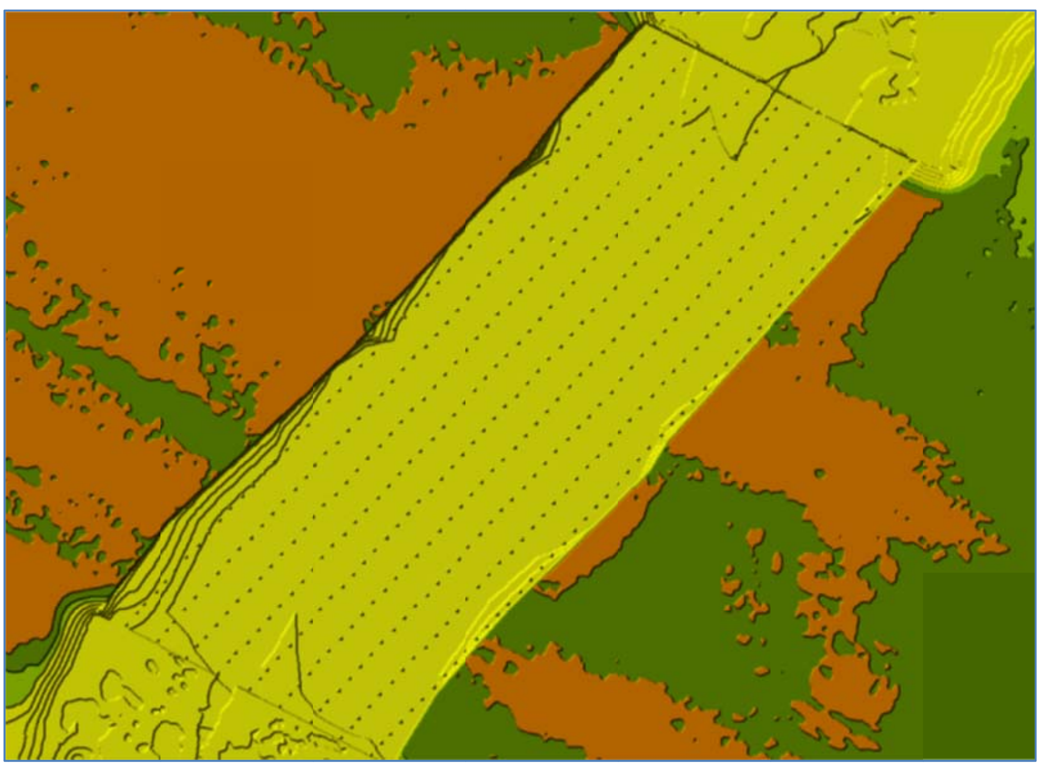


Figure 4.18 The river portion near the secondary runway bridge with piers

4.3.3 Geometry data

HEC-RAS 2D model uses the finite volume scheme (FVM) to solve the governing equations. In the FVM scheme, the computation domain is divided into a finite number of cells called as comutational mesh. The mesh generation for the computational domain is carried out in the Geometric editor of the HEC-RAS 2D.

In order to locate the boundary of the domain, either the generated terrain model or the google imagery has to be loaded as a backdrop in the Geometric editor. Such an option for the backdrop is available under the editor tool menu. Additionally, shapefies of the compound wall, locations of the drains and the physical gates were also brought in to the editor for accurate representation of the physical features. Then, the boundary of the computaional domain was created using 2D flow area drawing tool and following it a computaional mesh was created (figure NO).

As the computational domain is large, initially, a coarser mesh was generated with a spatial resolution of 30 x 30m. However, this coarser mesh failed to capture the nitty-gritty topographic details of the river and the compound wall properly. On the otherhand, if the mesh size was made finer through out the entire domain, it would cost a lot of computaional time. Therefore, optimally one could make the mesh finer on the river banks and compound walls. This could be achieved by using break lines to differentiate the regions that require coarser and finer grids (Figures 4.19 & 4.20). It also has to be noted that the discretized cells' edges will be aligned along the breaklines so that the location of the breaklines remain undisturbed. For our case, the breaklines are compound walls and river banks that are digitized using Arc-GIS. Additionally, breaklines were created along the pier locations to make the mesh even finer, so as to capture the pier elevation (Figures 4.21 to 4.24). Finally, storm drains where incorporated into the compund wall lines (Figure 4.25).

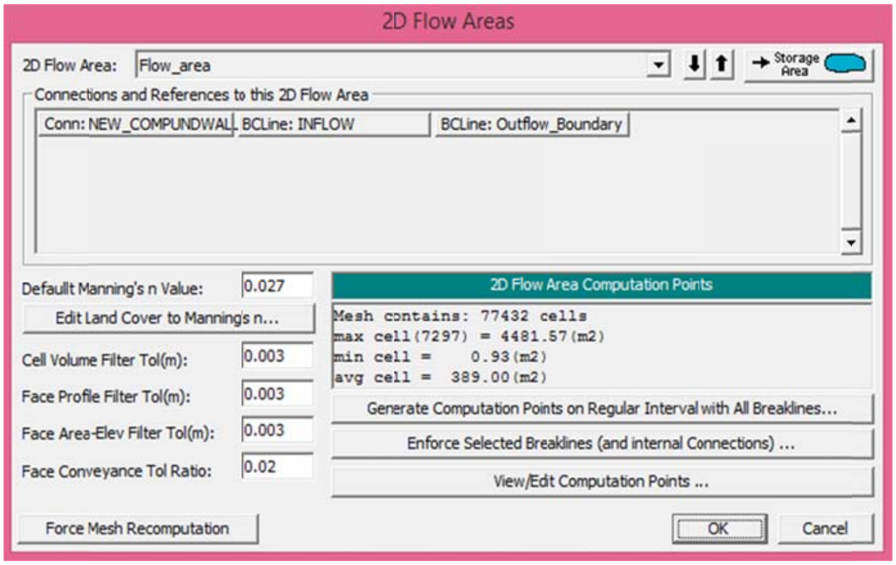


Figure 4.19 Mesh generation dialog box

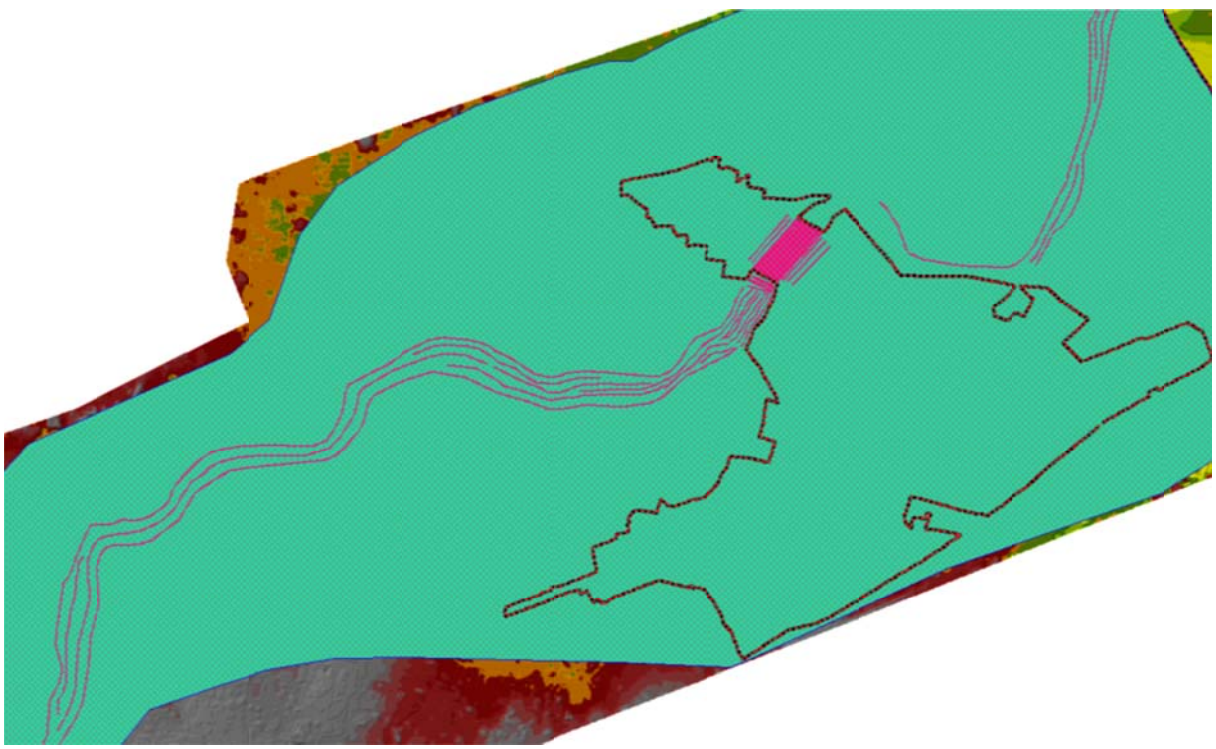


Figure 4.20 The pink lines represent river bank and bridge pier locations. The red lines indicate compound wall. The computational mesh is represented in green

In the Figure 4.20, it may seem that the mesh size is uniform but if one zooms in to the areas in river and bridge finer mesh will be seen (Figures 4.21 to 4.24).

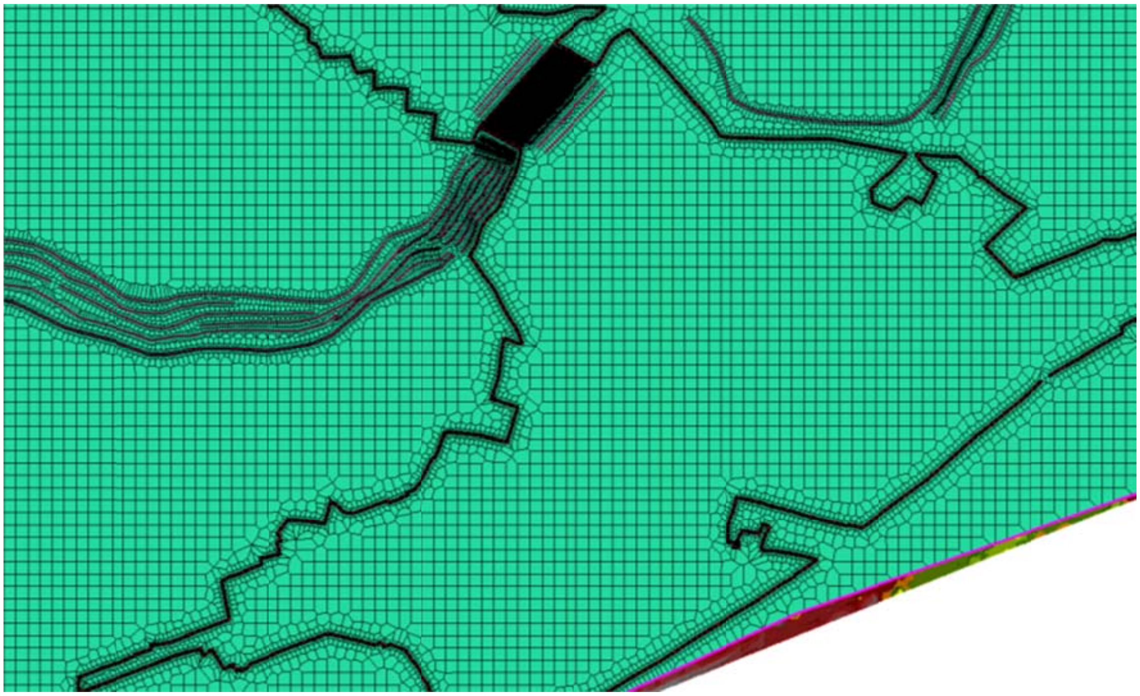


Figure 4.21 Closer view of the Airport premises

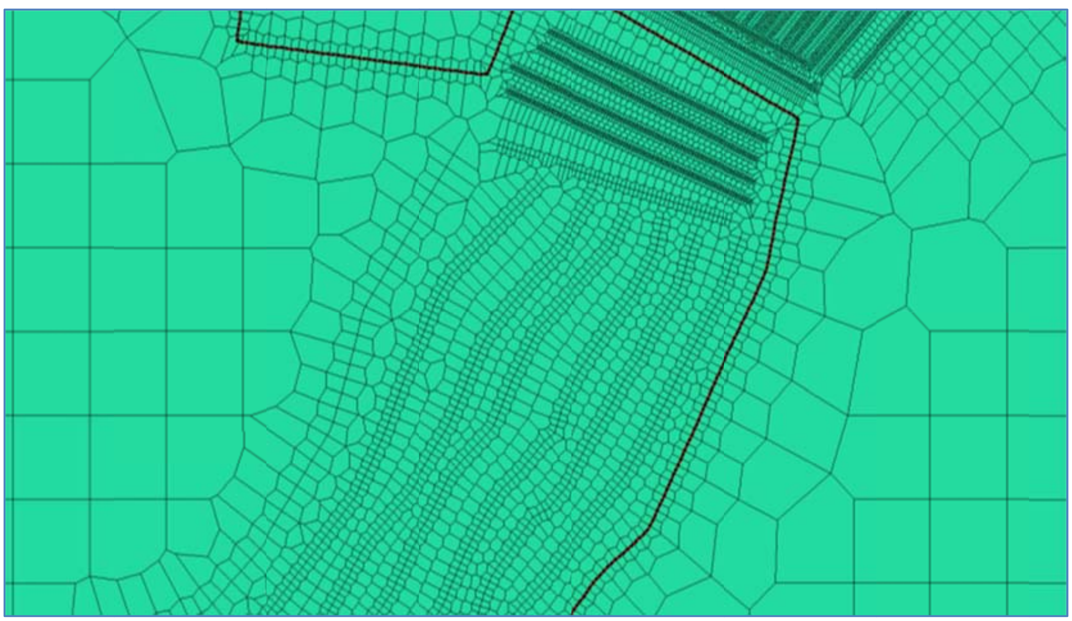


Figure 4.22 Zoomed in view of the domain at the upstream of the secondary runway bridge

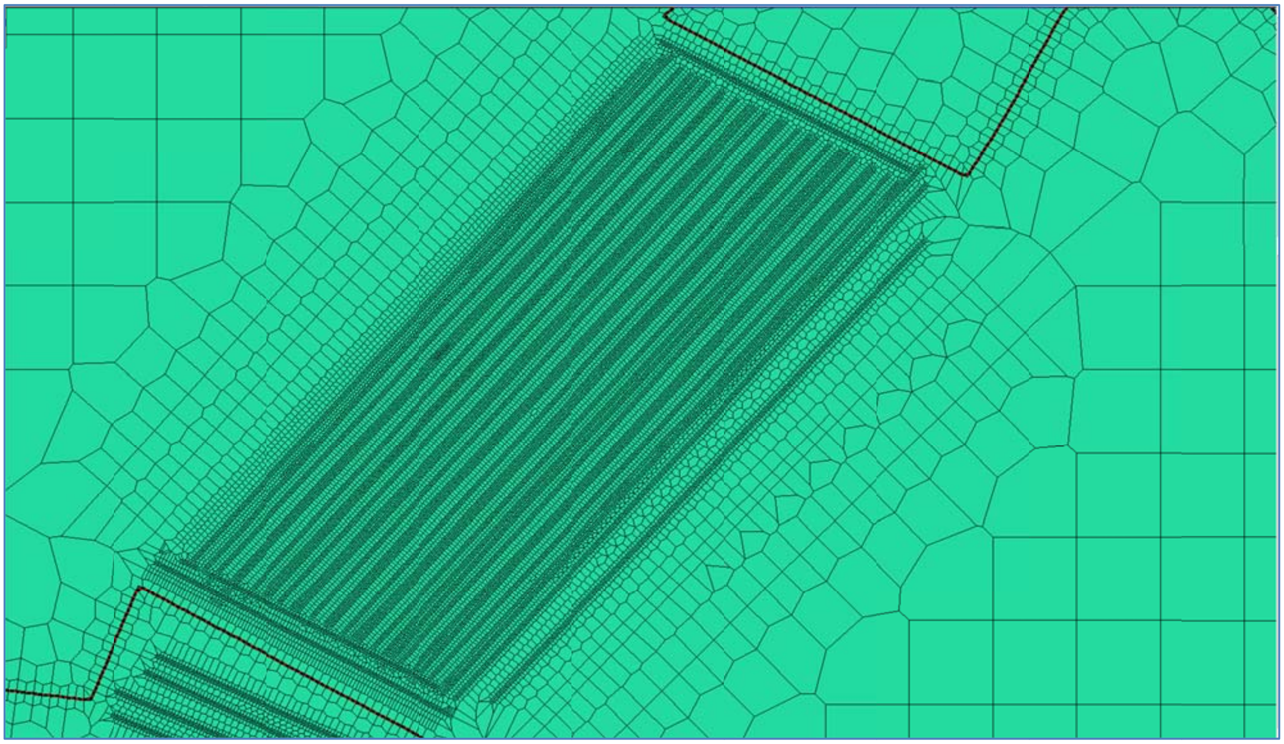


Figure 4.23 Zoomed in view of the domain at the river portion of the secondary runway bridge

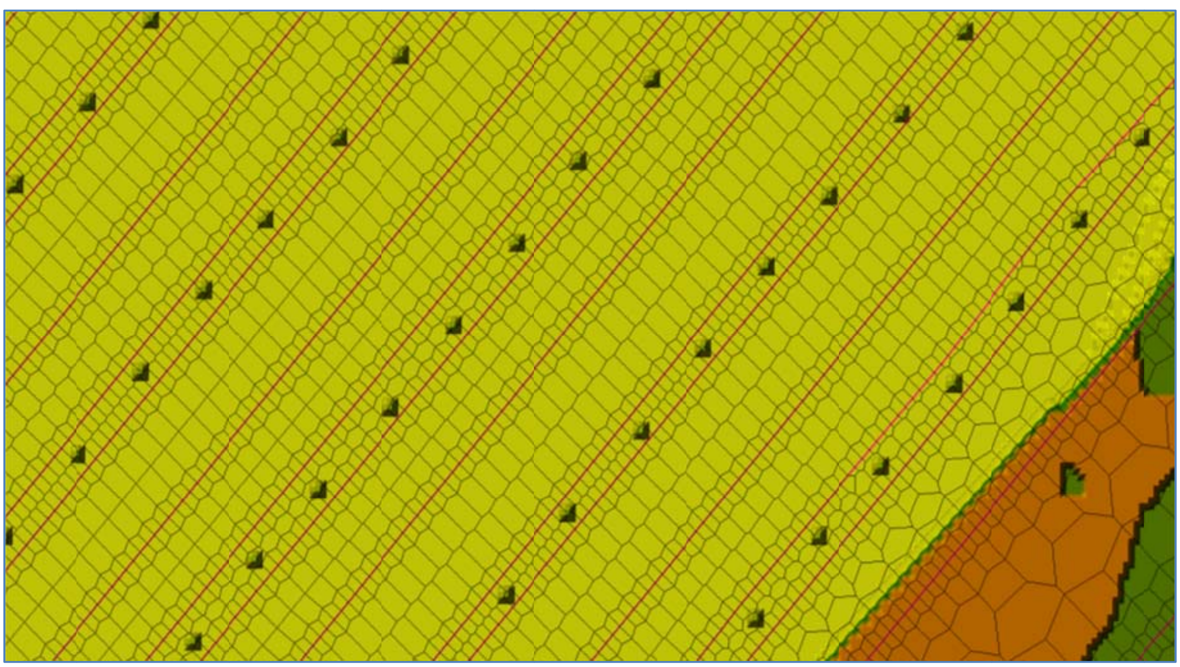


Figure 4.24 Zoomed in view showing even finer mesh refinement to capture the pier elevations

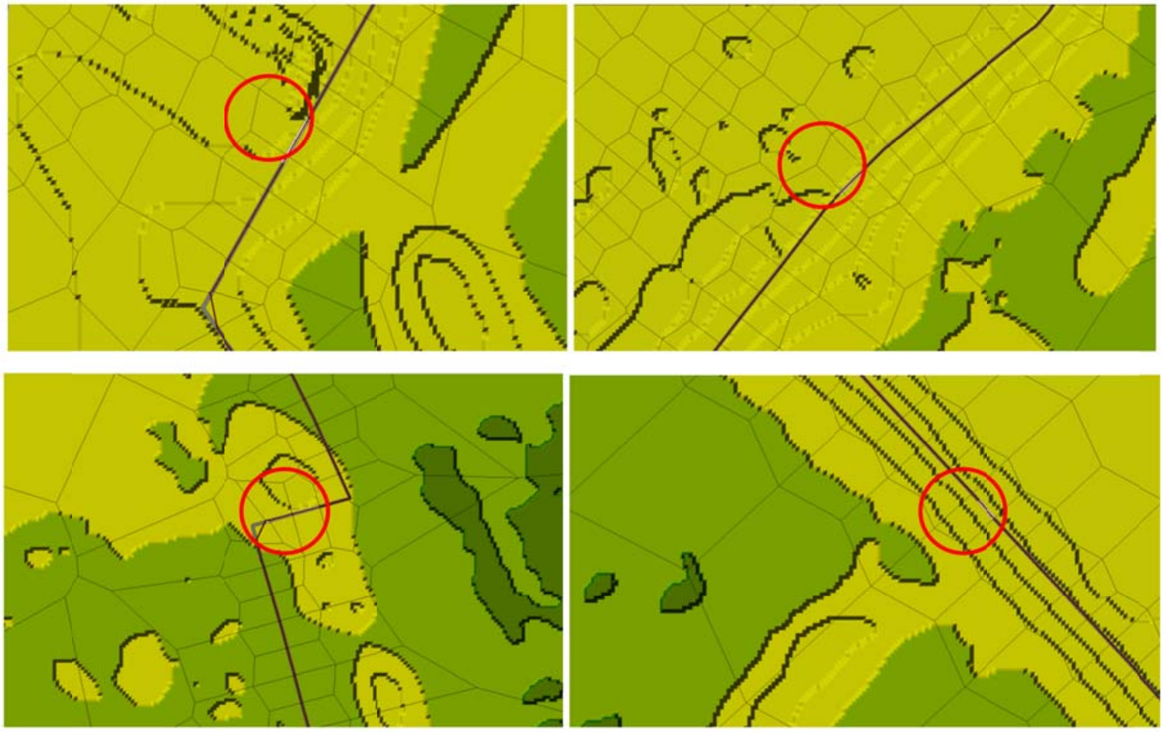


Figure 4.25 Zoomed in view showing the location of storm drains (red circles) in the compound wall break lines.

4.3.4 Inflow and Outflow boundary conditions

The inflow boundary condition is given as the stream flow hydrograph (Figure 4.26) at the upstream site indicated in Figure 4.27. The hydrograph is obtained using HEC-HMS model.

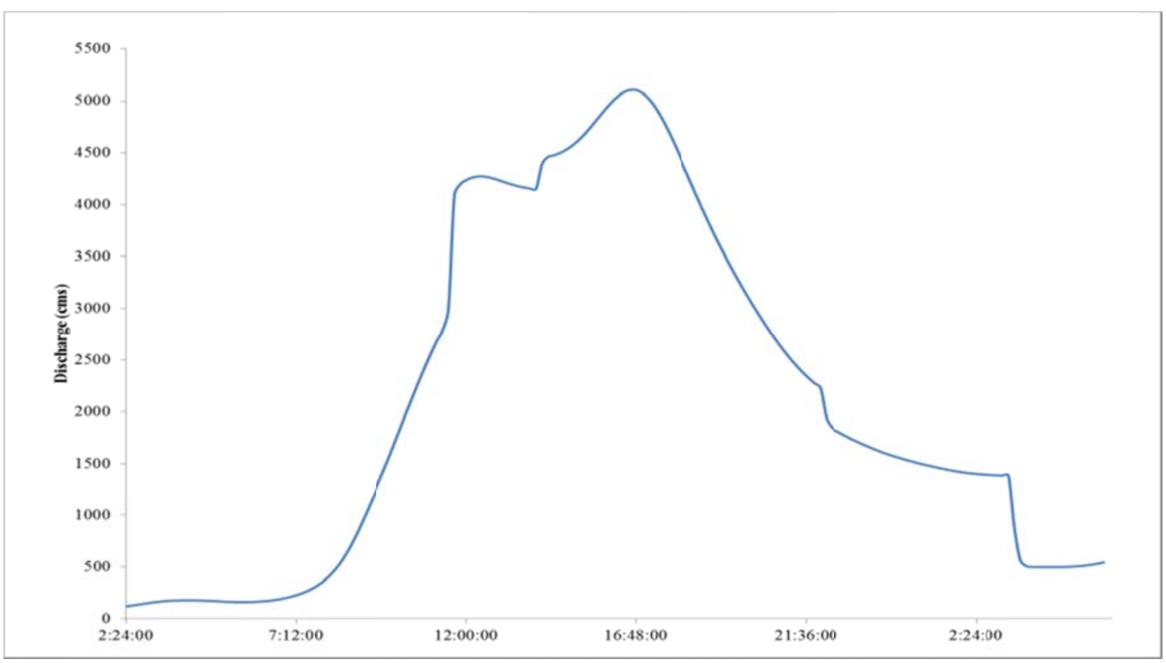


Figure 4.26 Stream flow hydrograph that given as the upstream boundary condition

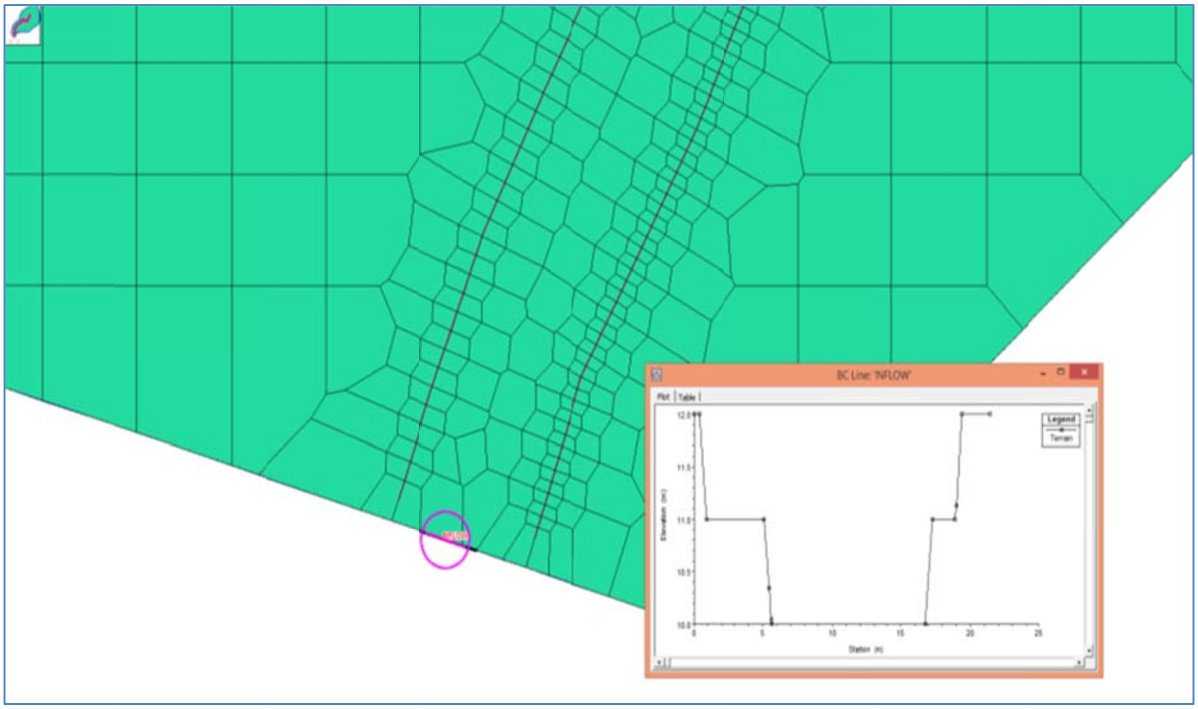


Figure 4.27 The circled portion represents the upstream boundary condition (630 m from Chennai outer bypass) site and the inner box shows the cross-section at that site.

The downstream boundary condition is the uniform flow boundary (Figure 4.28).

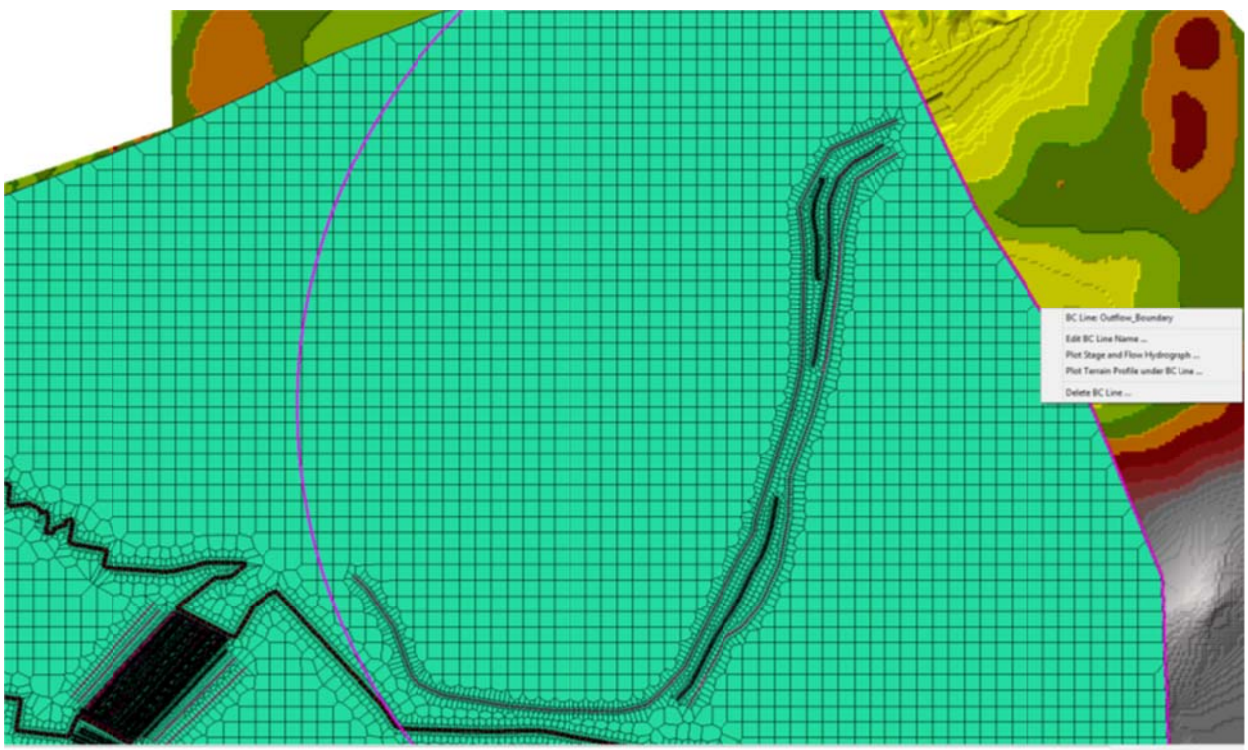


Figure 4.28 The circled portion represents the downstream boundary condition site, which is an open boundary.

4.3.5 Flow capacity of the river section at the secondary runway bridge site

After generating the refined mesh and providing the upstream and downstream boundary conditions, the 2D flow simulation was carried out for two different Manning's roughness values of 0.020 and 0.027 using two different DTMs: with piers and without piers (four model runs). The model was run for two different range of Manning's channel roughness values because the river conditions in this modelled stretch of Adyar river seem to have this range based on guidance value suggested by the USGS. The simulation was run with the time step of 3 sec. The simulation time step was determined by the grid size and the velocity of the water wave and is called as Courant–Friedrichs–Lewy (CFL) condition is a necessary condition for convergence while solving certain partial differential equations. The model simulation was carried out from 1 December 2015 to 2 December 2015. These above four cases would help us in understanding the effect of piers in deciding the flow capacity of the river section underneath the secondary runway bridge.

Simulations were carried out for different flow values for the four cases and the flow that results in water level elevation of 10.5 m corresponding to the soffit level of the bridge is the required carrying capacity of the river section underneath the bridge. When the results were analyzed for the four cases, it was found that the presence of bridge piers didn't influence the flow capacity of the river section. The reason behind this is due to the fact that the piers' influence is localized and felt in a small region of less than 2m radius around the piers. The effect of piers on the streamlines (flow vectors) is very clear from the analysis of streamlines around the piers as shown on Figure 4.29. In addition to this, the two different Manning's n cases for with piers were solved analytically for any afflux due to the presence of piers. However, the afflux calculated was <0.01m in both the cases as shown in Tables 4.2 and 4.3 and it conformed to the findings from the hydraulic model. Hence, it is understood that the impact of piers is localized and the carrying capacity of the river section underneath the secondary runway remains unaffected due to the presence of piers.

Table 4.2 Afflux calculation for n = 0.020 with pier

Flow Rate (Q)	Unobstructed width (W)	Diameter of pier (m)	Sum of Bridge Span (L)	Downstream depth (y_d)	Approach Velocity (V_a)
2041	185	0.5	180.5	7	1.68
L/W	**C_o**	**e**	**Afflux (h)**		
0.976	0.975	0.06	**<0.01m**		

Table 4.3 Afflux calculation for n = 0.027 with pier

Flow Rate (Q)	Unobstructed width (W)	Diameter of pier(m)	Sum of Bridge Span (L)	Downstream depth (y_d)	Approach Velocity (V_a)
1583	185	0.5	180.5	7	1.30
L/W	**Co**	**e**	**Afflux (h)**		
0.976	0.975	0.06	**<0.01m**		

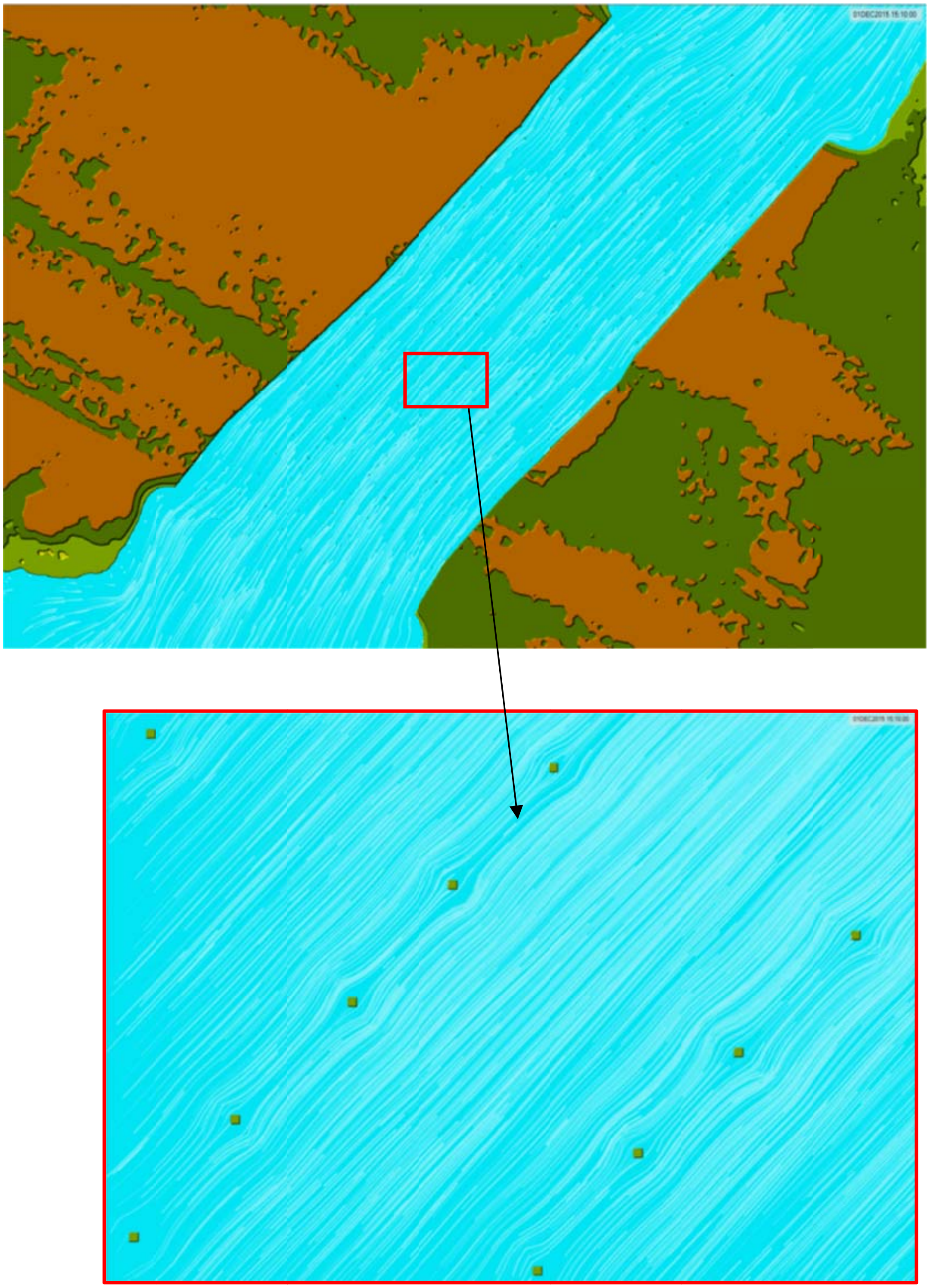


Figure 4.29 Figure showing the localized effect of piers on the streamlines. The zoomed in view is also presented for better understanding.

The rating curve for the Adyar River at the bridge section is shown in figure 4.30. The carrying capacity of the river at the runway bridge at the soffit level of 10.5m was found to be 1,104 m^3/s (***38,985 ft^3/s)*** and 1,409 m^3/s (***49,774 ft^3/s)*** for manning's n of 0.027 and 0.020 respectively (Figures 4.31 to 4.33). The overall summaries of considered four cases are provided in the Table 4.4 and 4.5. As can be seen from Tables 4.4 and 4.5, the river will flow to its full capacity (at the soffit level of 10.5m) at the secondary runway bridge section during a storm for magnitude between 2-yr and 5-yr return period. So, for any storm greater than the full capacity, the river will overbank and start flowing into the flood plain. The inundation maps of floods due to various return period storms are given in Annexure C. The flood flow corresponding to the December 2015 flood is only slightly lesser than the flood magnitude due to 100-yr design storm which is as much as 3.5 to 4.5 times (350% to 450%) more than the bank full carrying capacity of the river at the bridge site. Any river training that can be done at the bridge site, upstream or downstream can increase the flood carrying capacity only marginally (up to 20% - 25%) and it would be impossible to accommodate such a huge flood magnitude within the confines of the river banks. The effect of river training on flood carrying capacity is discussed in section 4.3.8 in detail.

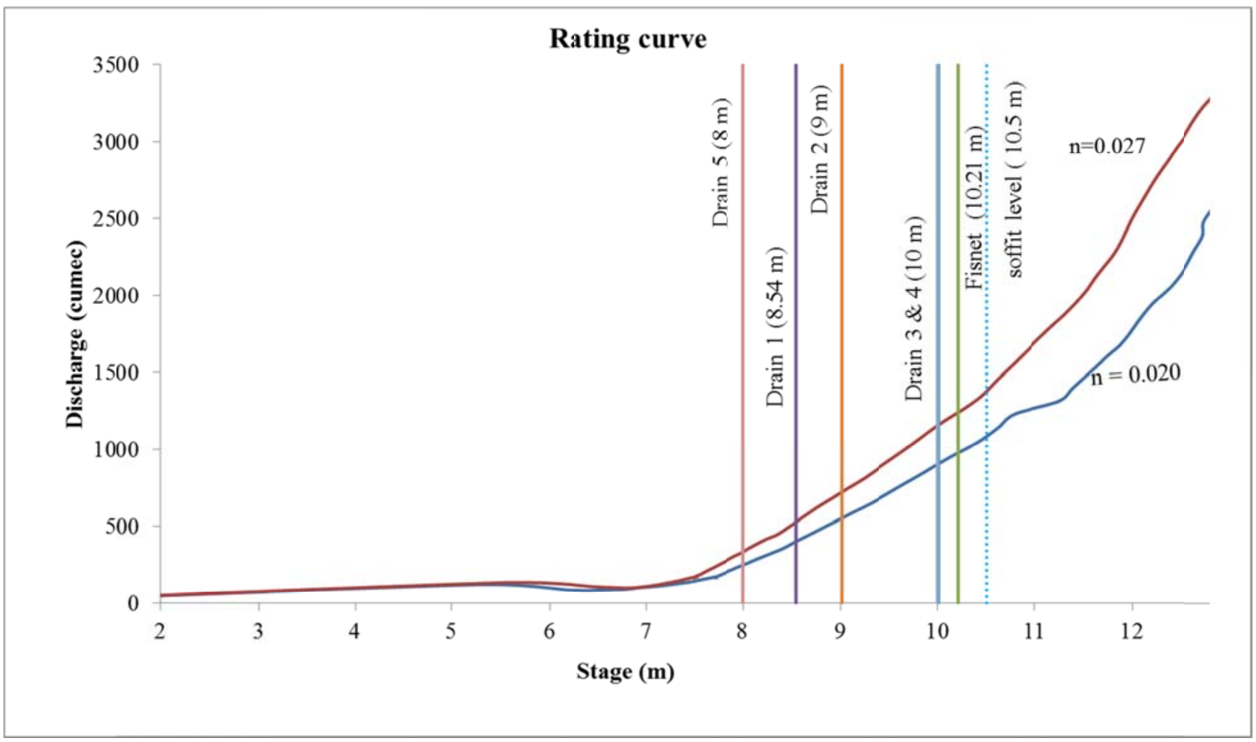


Figure 4.30 Rating curve for the Adyar river at the bridge section

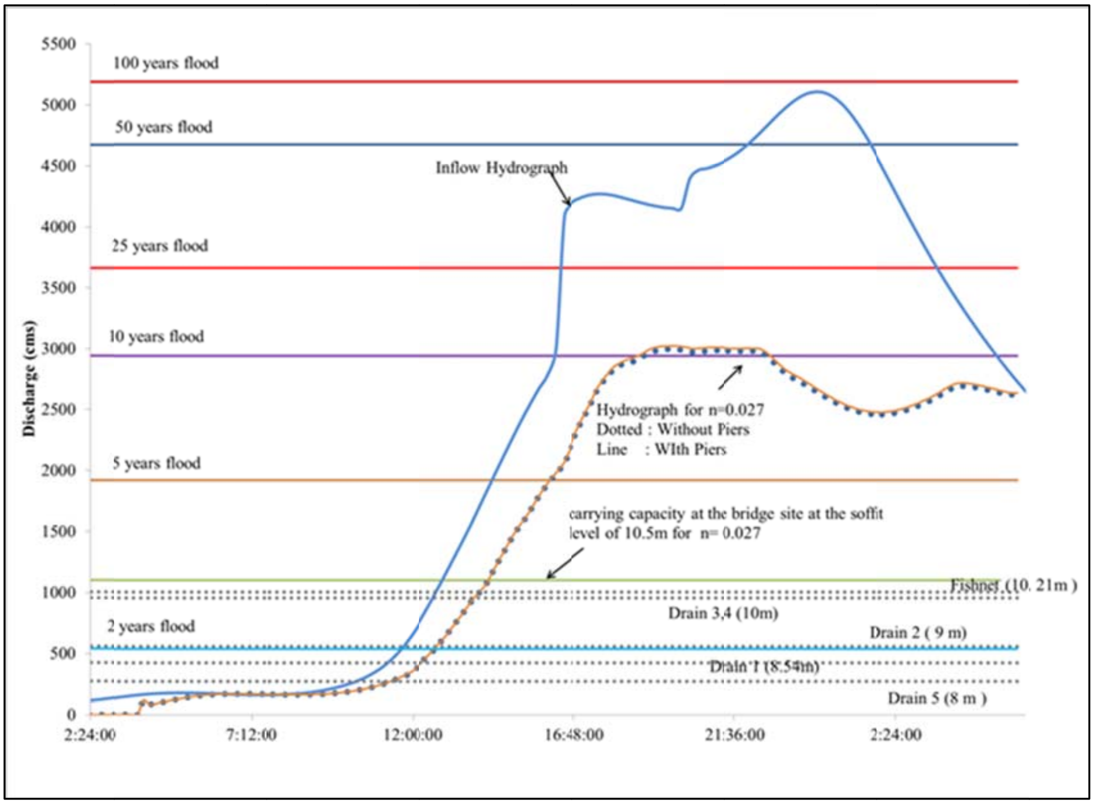


Figure 4.31 Figure showing the hydrograph at the inlet boundary and at the upstream of the secondary runway bridge for n=0.027 with and without piers

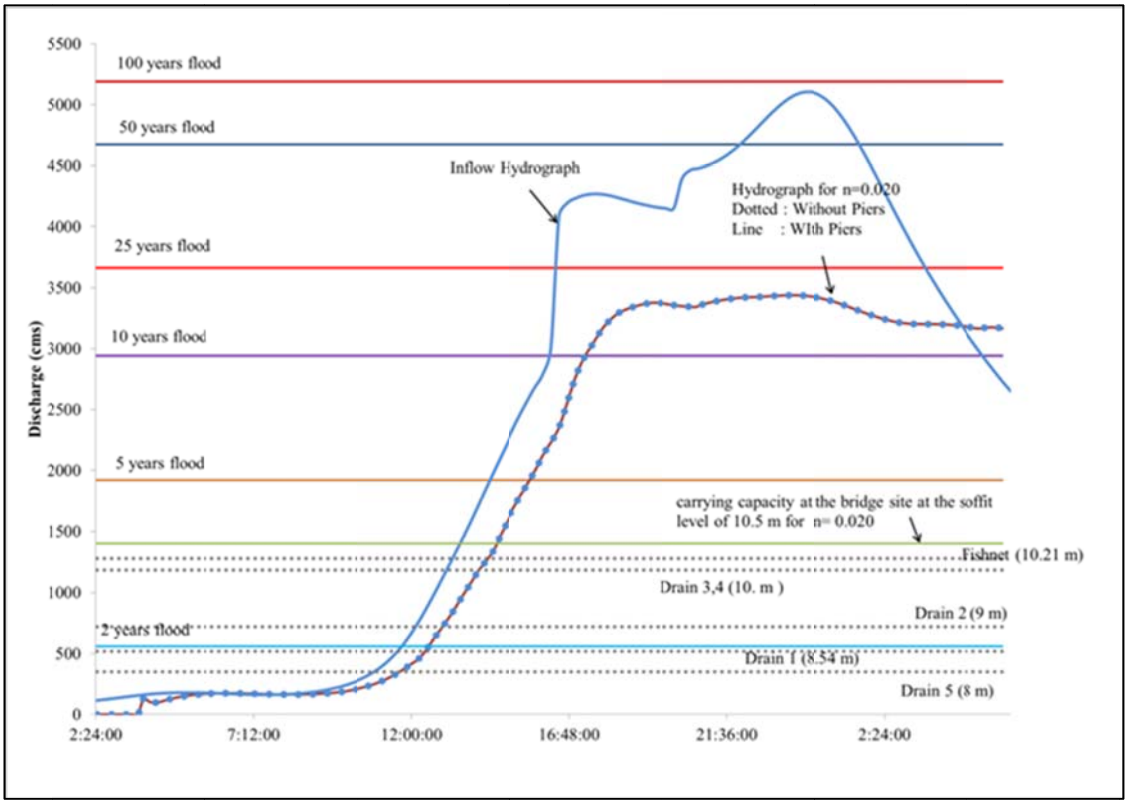


Figure 4.32 Figure showing the hydrograph at the inlet boundary and at the upstream of the secondary runway bridge for n=0.020 with and without piers

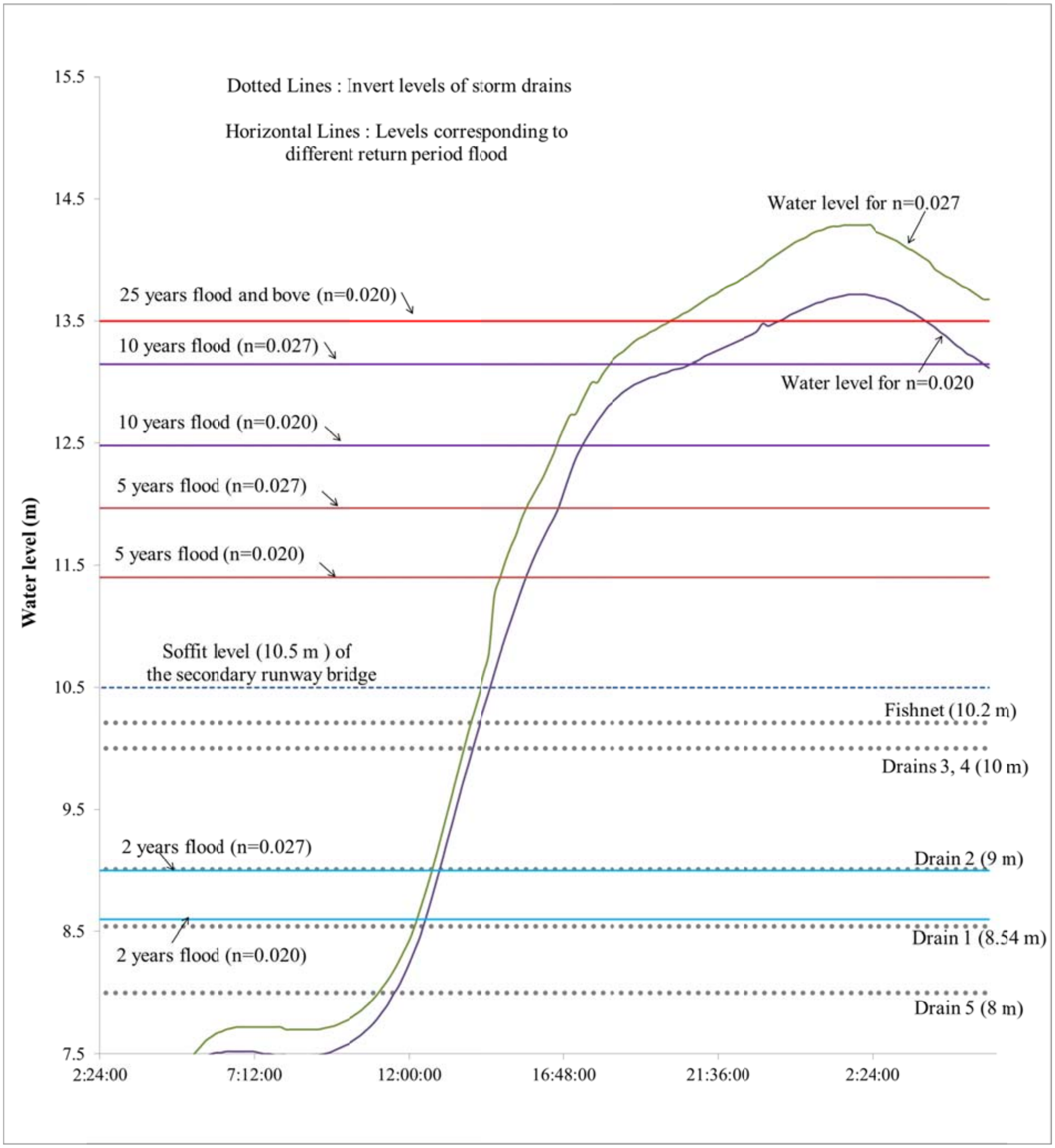


Figure 4.33 Figure showing the water level Vs time obtained from DSM with piers and DSM without piers at the river near the upstream portion of the secondary runway bridge (n = 0.020 and n=0.027)

Table 4.4 Summary of the simulation for n=0.020

Model Description		Outputs		
Inputs			Flow rate m3/s	Water level
		Carrying capacity	1409.45	10.50
No of cells	77432	2 yr storm	560.80	8.60
Model type	Diffusive approach	5 yr storm	1921.10	11.40
Time step	0.5 sec	10 yr storm	2942.70	12.48
Manning's n	0.02	25 yr storm	3663.50	13.50
Inflow Boundary	Hydrograph	50 yr storm	4673.60	-
Outflow Boundary	Normal depth	100 yr storm	5190.80	-

Table 4.5 Summary of the simulation for n=0.027

Model description		Output		
Inputs			Flow rate m3/s	Water level
		Carrying capacity	1103.73	10.50
No of cells	77432	2 yr storm	560.80	9.00
Model type	Diffusive approach	5 yr storm	1921.10	11.97
Time step	0.5 sec	10 yr storm	2942.70	13.15
Manning's n	0.027	25 yr storm	3663.50	-
Inflow Boundary	Hydrograph	50 yr storm	4673.60	-
Outflow Boundary	Normal depth	100 yr storm	5190.80	-

It was observed that for both manning's n = 0.020 and 0.027 that the back flow of the water from the Adyar River in to storm water drains were taking place during the simulation (shown in Figure 4.34, 4.35 and 4.36). The back flow from the river into the drain takes place even for a 2-yr return period storm (Drains 1, 2 and 5) (Figs.4.31 to 4.33). However, all the storm water drains begin to back flow for floods resulting from any storm greater than 5-yr return period. When the Adyar River flows full at the soffit level (10.5m) all the six major drains, including the fishnet drain, on the river side take in backflow leading to poor drainage and standing water inside the airport premises. Hence, this may warrant installation of sluice gates and pumping mechanisms. Sluice gates and pumping requirements are discussed separately in section 4.3.8.

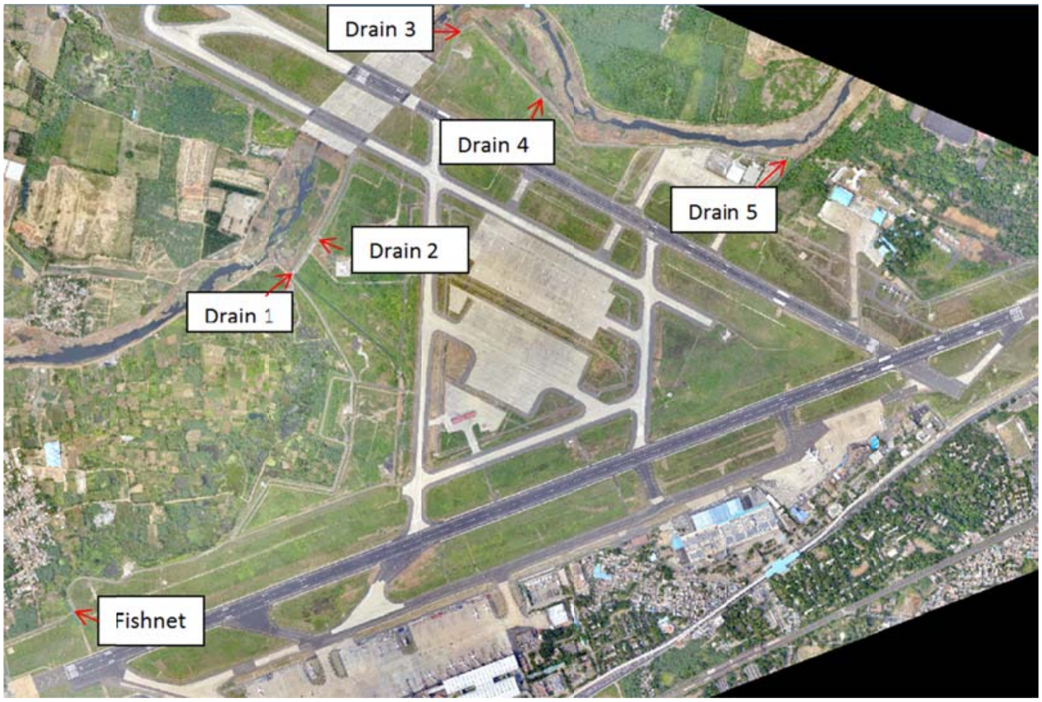


Figure 4.34 Locations of the major drains flowing towards the river

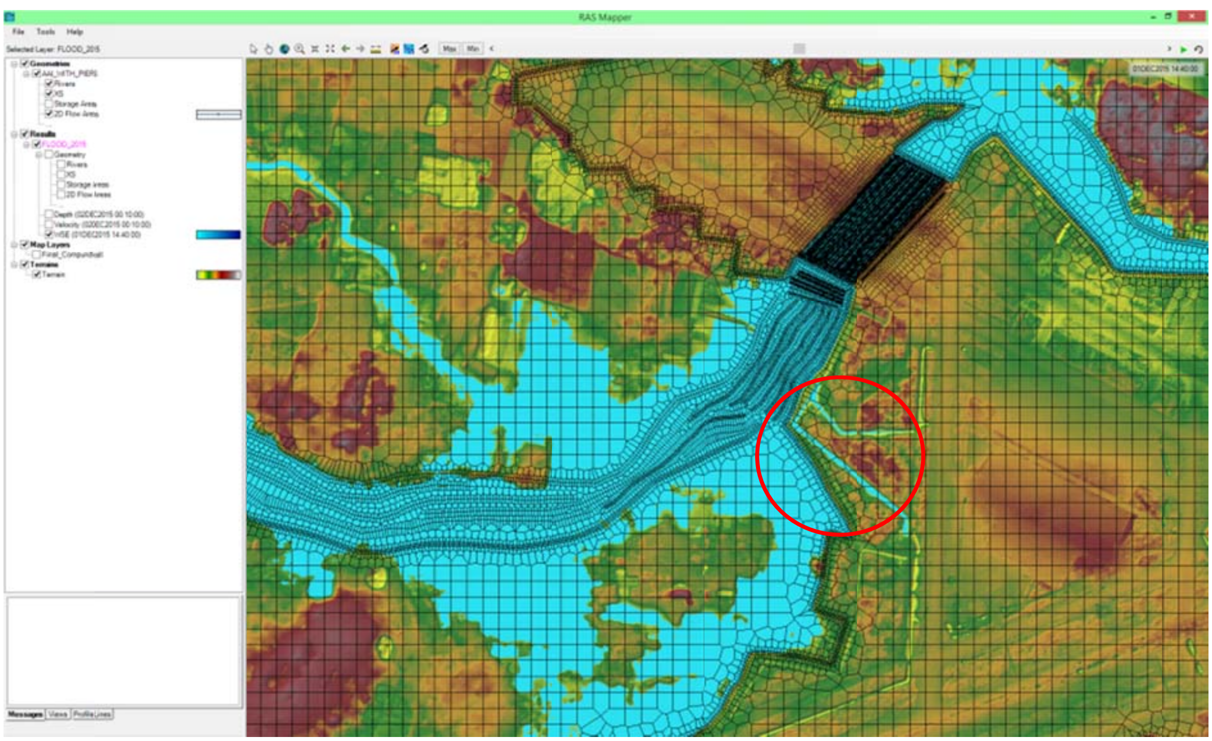


Figure 4.35 Figure showing the back flow in the drain at the upstream of the secondary bridge.

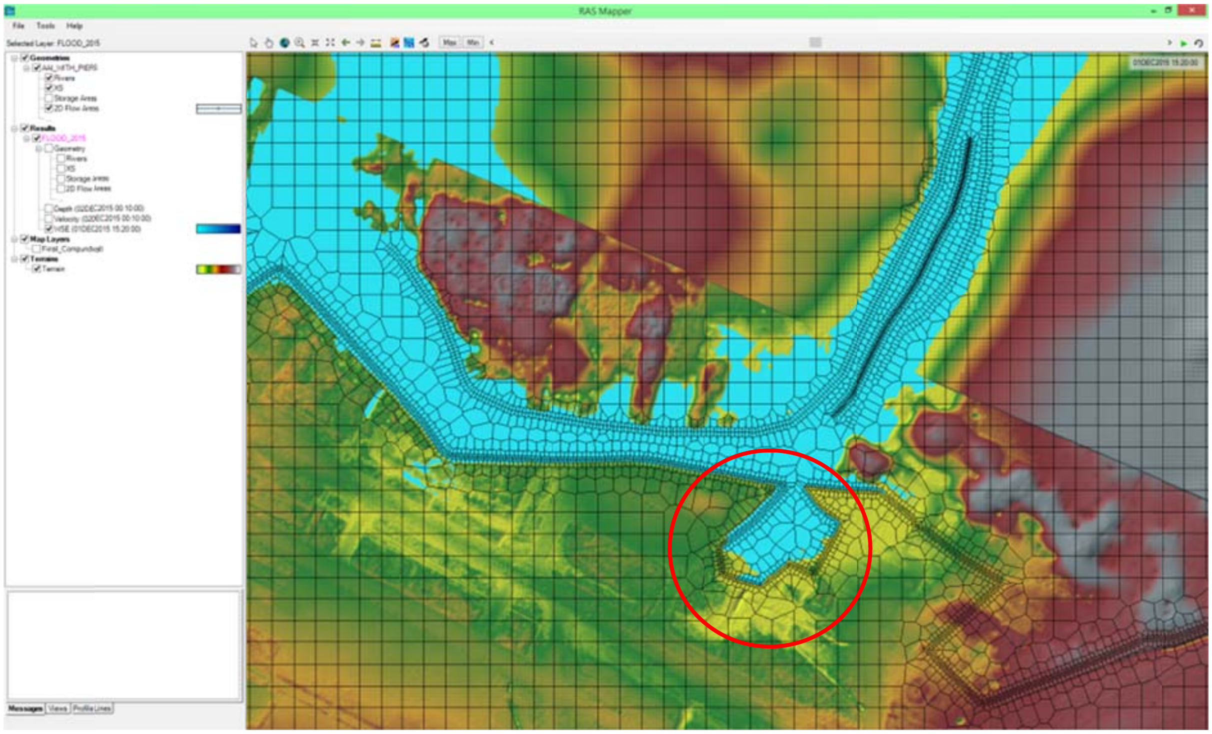


Figure 4.36 Figure showing the back flow in the drain at the downstream of the secondary bridge.

4.3.6 Simulated maximum water level at some of the critical installations

The maximum water levels from the simulation for the two scenarios of roughness in the river and the flood plain, n = 0.020 and 0.027, are provided in the Table 5 and the corresponding locations are shown in the Figure.4.37. The observed high flood level (HFL) at ILS Radar Station was 13.756 m. It can be clearly seen from the table that the observed HFL falls within the simulated HFL range (13.749 -14.343 m). The observed HFL at the New Radar Station and New fire station was 13.315 m and 13.056 m and are closer to the simulated values (13.787-14.417 m) and (13.872 – 14.350 m). These discrepancies in HFL may be attributed to the manning roughness coefficients, the resolution of the computational mesh and minor errors due to simplifications in the 2D model in simulating the actual 3D flow. Further, the carrying capacity of the model between *38,985* ft^3/s and *49,774* ft^3/s for manning's n of 0.027 and 0.020 which is closer the design capacity of 50,000 ft^3/s of the river section near the bridge confirms that the overall prediction was good.

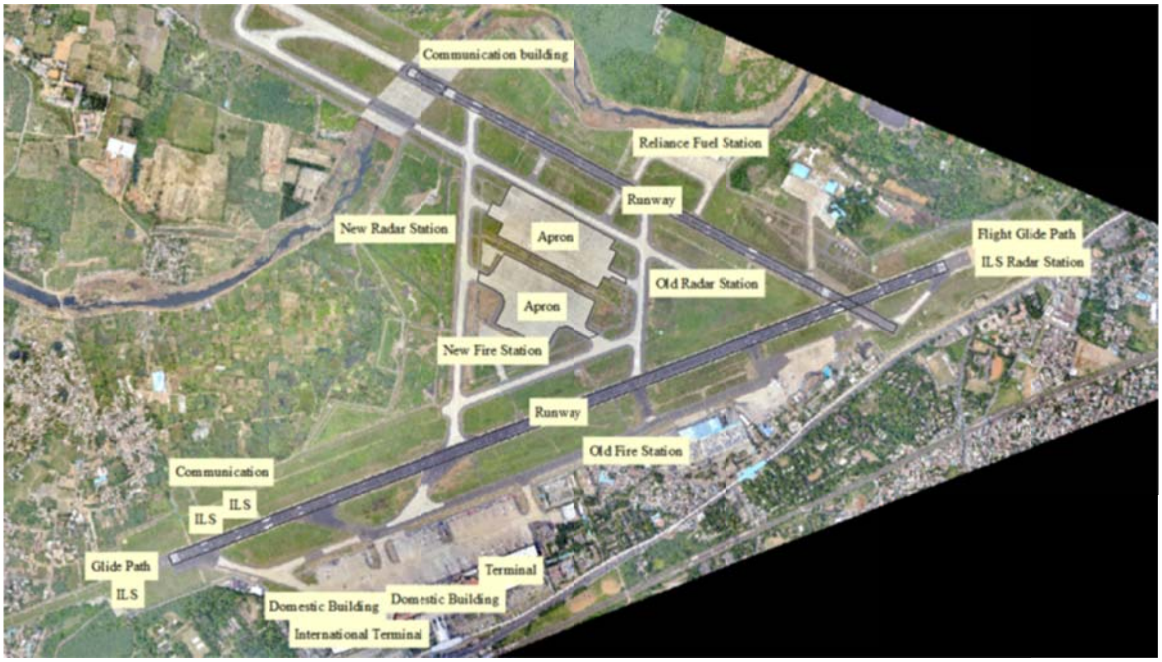


Figure 4.37 The locations of the critical infrastructure inside the airport

Table 4.6 Maximum water levels at critical locations

Location	Maximum Water surface elevation (m)	
	n=0.027	n=0.020
International Terminal	14.285	13.799
Domestic Building	14.367	13.785
Domestic Building	14.375	13.786
Terminal	14.363	13.787
New Fire Station	14.350	13.782
New Radar Station	14.417	13.787
Old Fire Station	14.360	13.784
Runway	14.385	13.786
Runway secondary	14.400	13.786
Old Radar Station	14.395	13.786
Reliance Fuel Station	14.334	13.782
Flight Glide Path	14.343	13.749
ILS Radar Station	14.343	13.749
ILS	14.350	13.781
Glide Path	14.369	13.785
ILS	14.413	13.787
Communication building	14.418	13.787
ILS	14.429	13.787
Apron	14.415	13.786

4.3.7 Hydrostatic and Dynamic pressure distribution along the compound wall

The pressure distribution along the compound wall is due to both hydrostatic pressure caused by the height of the water and dynamic pressure caused due to the velocity of the water. The hydrostatic pressure distribution was calculated by extracting the height of the water column above the bottom of the compound wall, whereas the dynamic pressure was calculated by extracting the maximum velocity of the water near the compound wall. The hydrostatic pressure on the compound wall was calculated as:

$$P_s = \frac{1}{2}\gamma_w h^2$$

Where, P_s – Hydrostatic Pressure in KN per unit length of the compound wall, γ_w – Specific weight of water (9.8 KN/m^3); h – height of the water column above the footing of the compound wall. The pressure due to dynamic load caused by the velocity of the water is calculated as:

$$P_v = \frac{1}{2}\rho_w v^2 h$$

Where, P_v – Dynamic Pressure in KN per unit length of the compound wall, ρ_w – Density of water (1000 Kg/m^3); h – height of the water column above the footing of the compound wall and v – is the velocity of the water flowing on to the compound wall.

The total pressure distribution due to static and dynamic load along the compound walls are calculated and are shown in Figures 4.38 and 4.39. These total pressure distribution values will aid in redesign/improvement of the present compound wall sections and identification of sections that are most vulnerable.

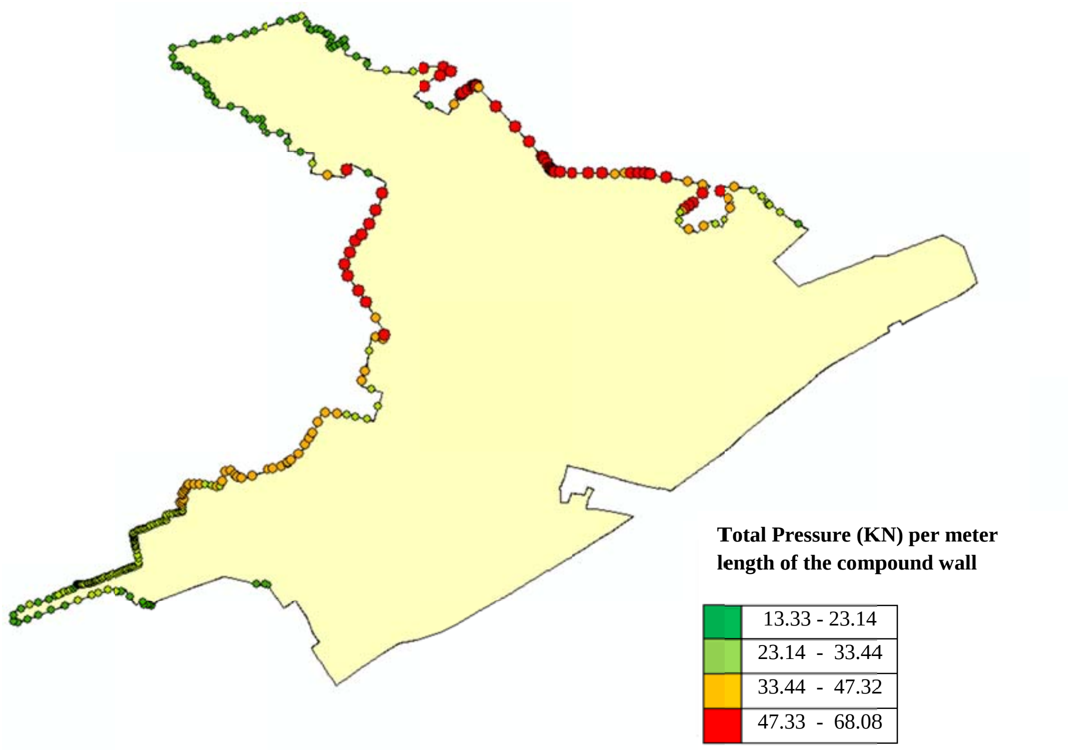


Figure 4.38 Total pressure distribution (in Newton) along the compound wall for n=0.027

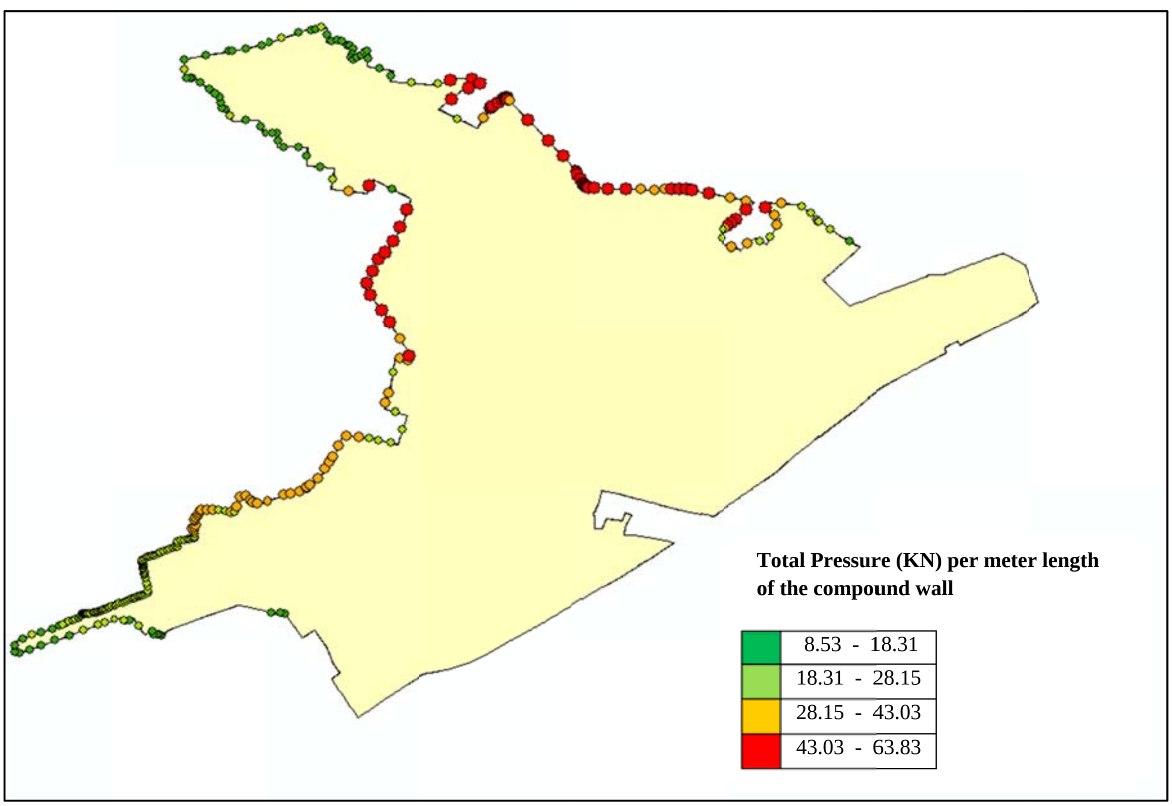


Figure 4.39 Total pressure distribution (in Newton) along the compound wall for n=0.020

4.3.8 Measures to improve the flood carrying capacity of the river (Interventions outside the airport premises)

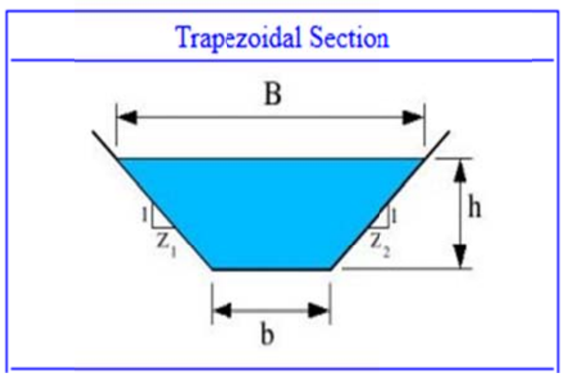
4.3.8.1 Bypass channel near secondary runway bridge site

For improving the carrying capacity of the river at the secondary runway bridge, different types of river training were carried out and are discussed as flows. As a first case, a small bypass channel was considered between the upstream (U/S) and downstream (D/S) of the secondary runway bridge (Figure 4.40) running along the periphery of the secondary runway beyond the bridge to the north towards Gerugambakkam. As an optimal combination, a trapezoidal channel of 2m bottom width and 4 m depth (depth allowed by the existing terrain) was assumed with the slope of 0.0003 for diverting part of water from the upstream of the secondary runway. From the HEC-RAS 2D simulation conducted for the maximum flow capacity of Adyar river, the average velocity at the upstream of secondary bridge Adyar river was 2.138 m/s. Based on the above inputs, the capacity of the bypass channel was estimated to be only 50 m^3/s (Figure 4.41). However, this quantity is very less in comparison with the total quantity of flow at the soffit level of 10.5 m (1,104 –1,409 m^3/s). Further, the earthwork involved in this diversion channel will be expensive and some private properties need to be disturbed (Figure 4.40). Therefore, it **may not be a good option** to divert water from upstream to downstream of the secondary runway bridge with a bypass channel.

4.3.8.2 River widening and dredging upstream of the bridge

As an alternative, the river widening and dredging was considered to improve the flow rate at the Adyar river section near the secondary runway bridge. First, the river bottom underneath the secondary runway bridge i.e. the deposited soil was dredged. Numerically the dredging was carried out by extracting the river cross-section using the HEC-GEORAS arc tool and then the improved (smoothened) cross sections were punched into the actual terrain. The simulation was run using the improved terrain; however, the flow capacity at 10.5m soffit level did not show any increase. As the next step, the river stretch at the upstream (Figures 4.42 to 4.44) upto to 1km U/S from the bridge site was dredged as well as widened (in the range of 1-2m) was considered. Even in this case the carrying capacity was not improved (1105.2 and 1103.7 m^3/s for with and without river training for n=0.027 and 1413.3 and 1409.5 m^3/s for with and without river training for n=0.020). The reason for no significant change in the flow rate is because, the width of river at the upstream of the secondary runways bridge is ~200m, whereas at the downstream, the river width is in the range of 80-100m (from OTA to Miot Hospital). Hence, the upstream acts like a pool when the water level goes beyond 9m (Figure 4.45) and the downstream sections further reduce the velocity of the flow. This phenomenon is well captured in the simulation and confirmed during the field visit as well. Hence, river widening and dredging at the upstream side of the bridge alone will not yield a desired result of increase in flow capacity.

Figure 4.40 Intended path of a diversion channel



Input	
Flow depth h (m)	4
Bottom width b (m)	2
Left side slope z_1	1
Right side slope z_2	1
Longitudinal slope S (%)	0.03
Manning's n	0.012

Results	
Flow rate Q (cms)	51.3096
Top width B (m)	10
Flow area A (m^2)	24
Average velocity V (m/s)	2.138
Critical depth h_c (m)	2.682
Froude number Fr	0.441
Bottom shear stress T_d (Pa)	11.77

Figure 4.41 Design of a diversion channel

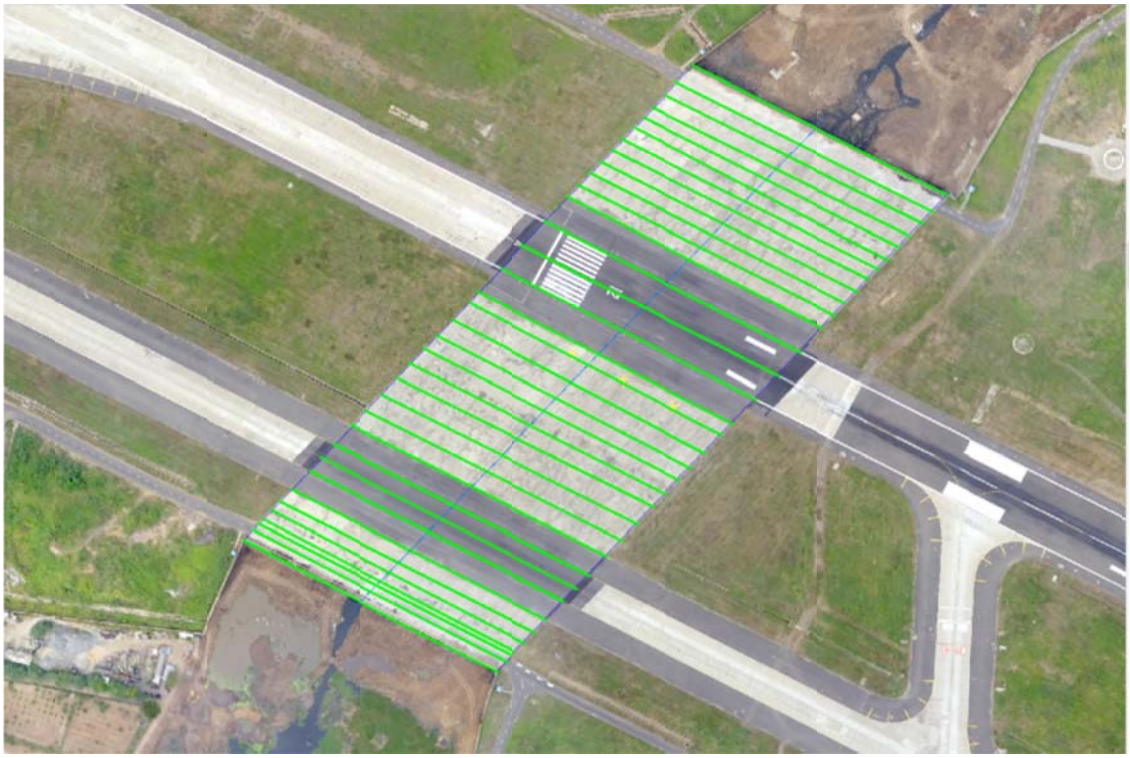


Figure 4.42 Dredging the river bottom underneath the secondary runway bridge

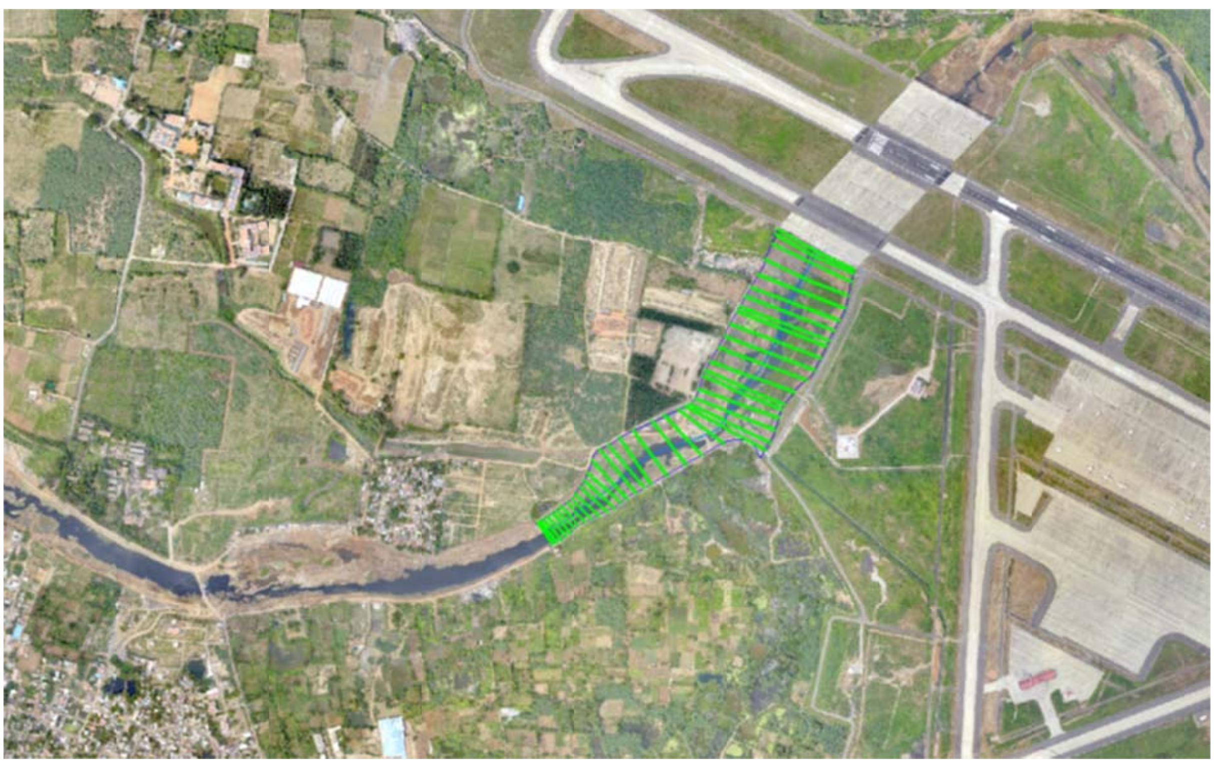


Figure 4.43 River training at the upstream of the secondary runway bridge up to 1km from the bridge site (ortho photo)

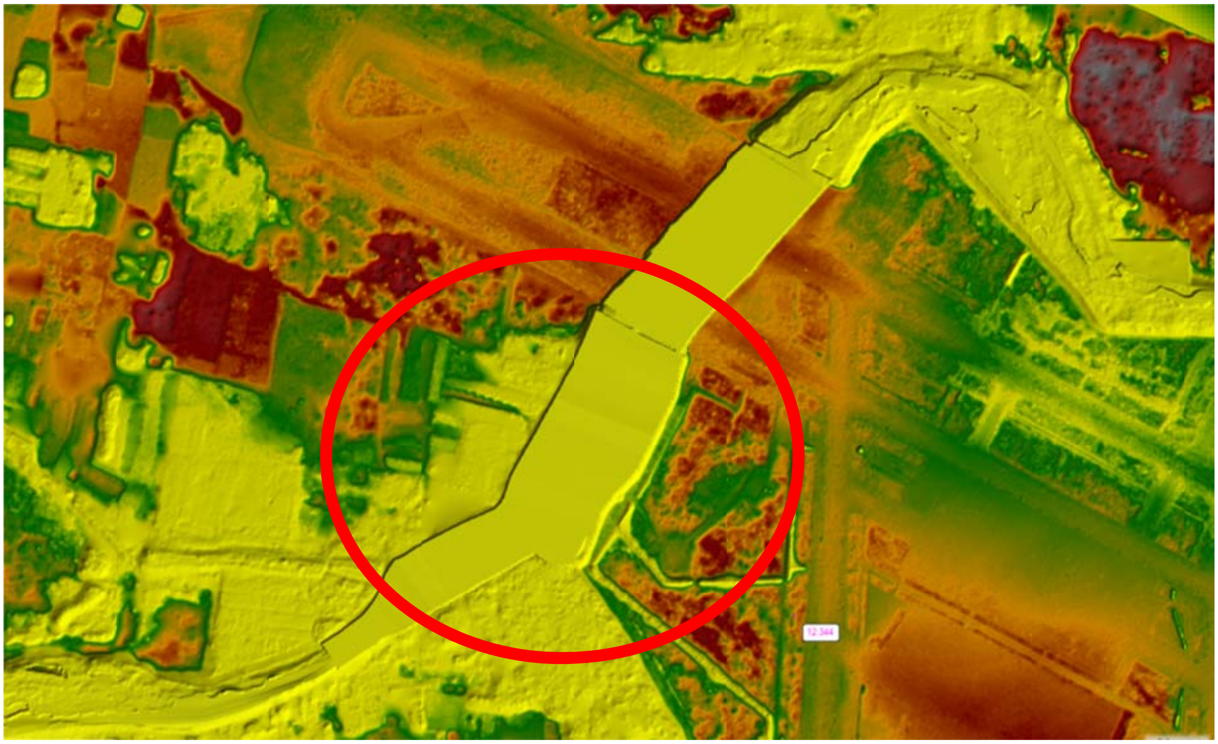


Figure 4.44 River training at the upstream of the secondary runway bridge up to 1km from the bridge site (DSM)

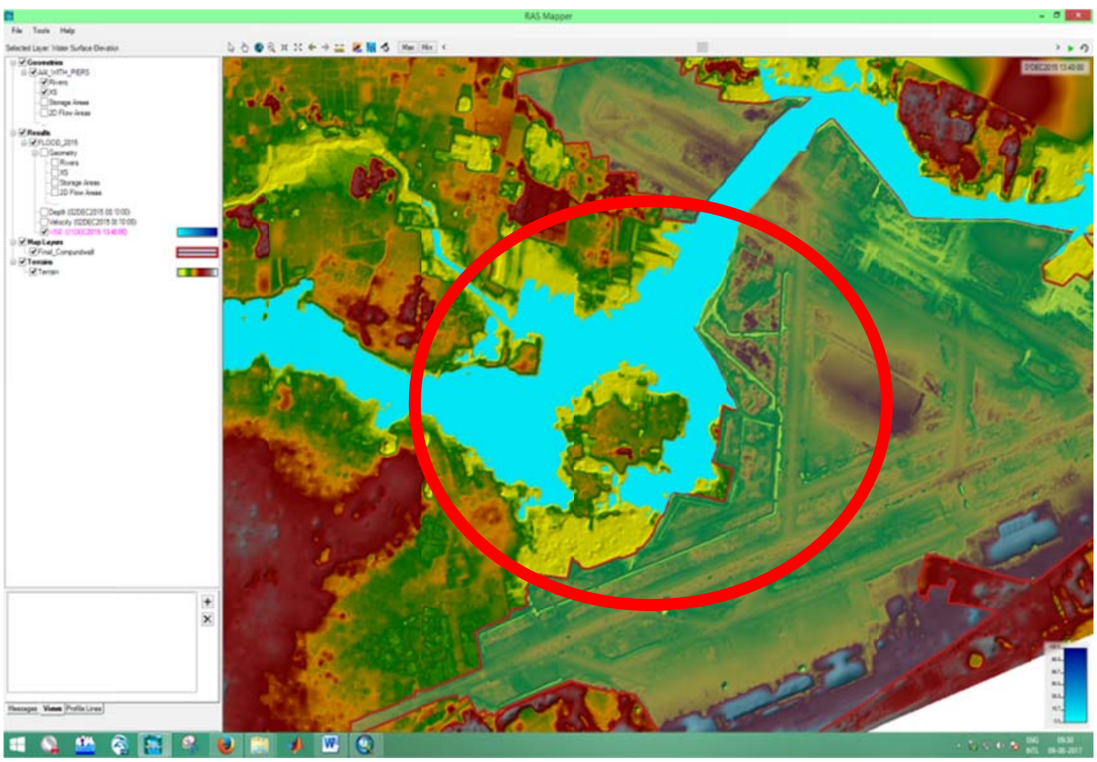


Figure 4.45 Water pool effect at the upstream of the secondary runway bridge

4.3.8.3 River widening and dredging from downstream of the bridge till just before OTA

As simulations with the dredging and widening of the river section just U/S of bridge section did not result in increase of flow capacity, the downstream river sections from the bridge were dredged up to just before OTA ground in addition to 1-2m river widening (Figures 4.46 and 4.47) up to a distance of 2km D/S of secondary runway bridge site along the river length, but just before the OTA bridge. The simulated results for this case show an increase of 207 to 325 m^3/s (depending of channel roughness) in the carrying capacity of the river at the secondary bridge. From this analysis, it is clear that it is highly recommended to dredge, widen and clean the downstream stretch before each monsoon to enhance and maintain the flow capacity of the river.

4.3.8.4 River widening and dredging from downstream of the bridge beyond OTA till MIOT

It was observed that near the OTA bridge the river width is almost half (<50m) of what it is just 500m upstream. In order to study the impact of widening the OTA bridge, the following reach of the river up to Nandampakkam bridge, just upstream of the check dam before the MIOT hospital, was widened up to 100m. This value was taken as the maximum width available for river widening and dredging based on the site conditions and the width of the river just immediately upstream. The simulated results for this case show an increase of 300 to 400 m^3/s (Table 4.7) (depending on channel roughness) in the carrying capacity of the river at the secondary bridge. When compared to the previous scenario, widening of the river from the OTA bridge till the check dam seem to increase the flow capacity of the river by additional 100 m^3/s. From this analysis, it is clear that it is highly recommended to dredge, widen and clean the downstream stretch before each monsoon to enhance and maintain the flow capacity of the river.

These scenarios clearly indicate that the current flow capacity which is between 1,104 m^3/s (***38,985*** ***ft^3/s)*** and 1,409 m^3/s (***49,774*** ***ft^3/s)*** could be potentially increased to between 1,400 m^3/s **(49,440** ***ft^3/s*****)** and 1,806 m^3/s **(63,778** ***ft^3/s*****)** due to river dredging and widening up to 3km D/S of the runway bridge site including widening of the OTA bridge.

Figure 4.46 River dredging and widening at the downstream of the secondary runway bridge up to 2km D/S of the runway bridge (Ortho photo)

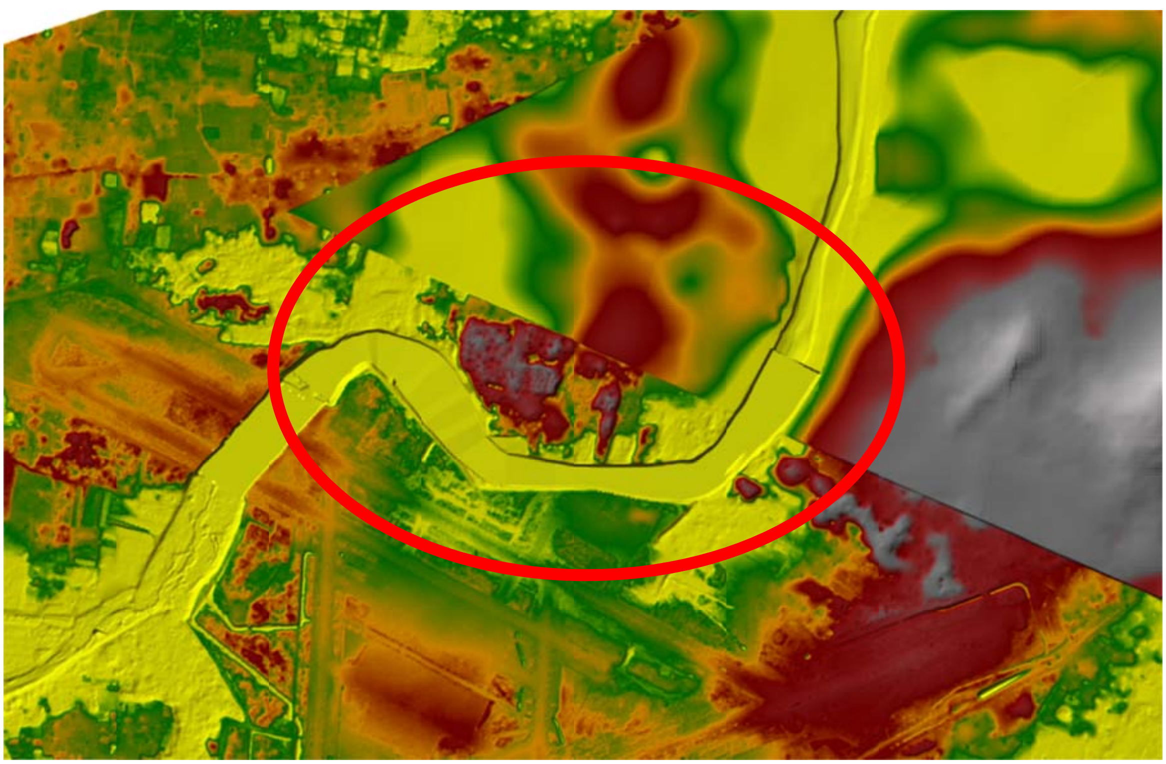


Figure 4.47 River dredging and widening at the downstream of the secondary runway bridge up to 2km D/S of the runway bridge (DSM)

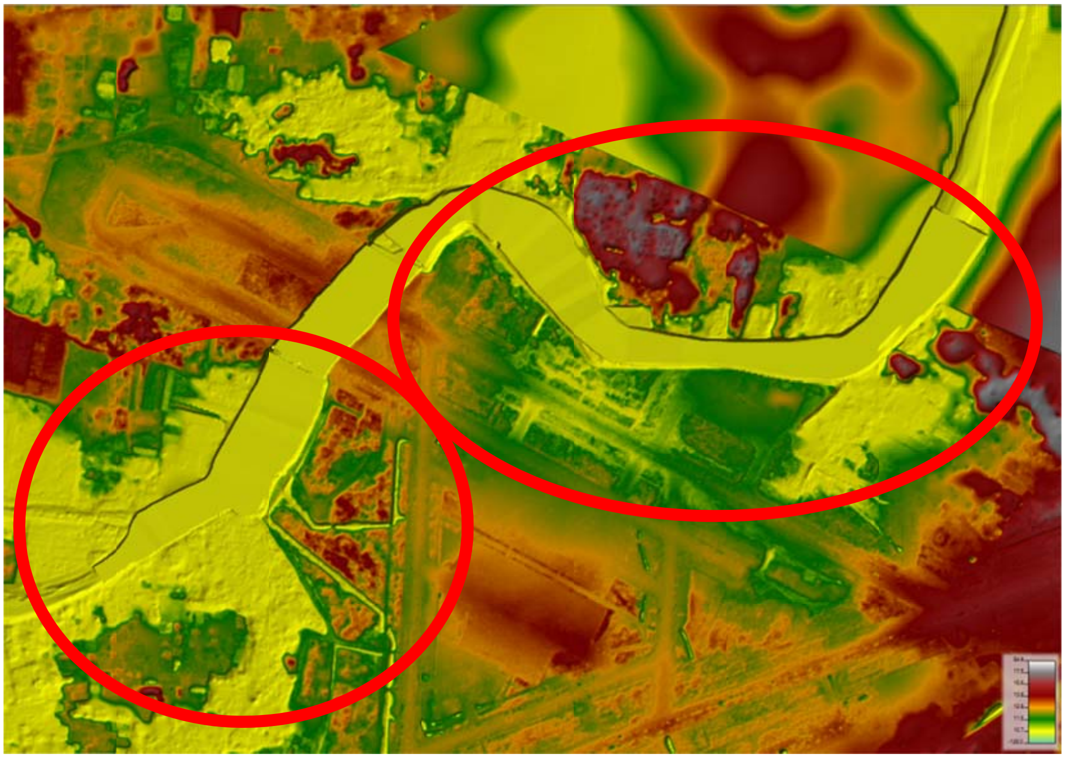


Figure 4.48 Comprehensive river training considering the upstream 1km and downstream river training up to 2km from the runway bridge

Figure 4.49 River dredging and widening at the downstream of the secondary runway bridge up to 3km D/S of the runway extending bridge beyond OTA till the check dam before Miot hospital (Ortho Photo)

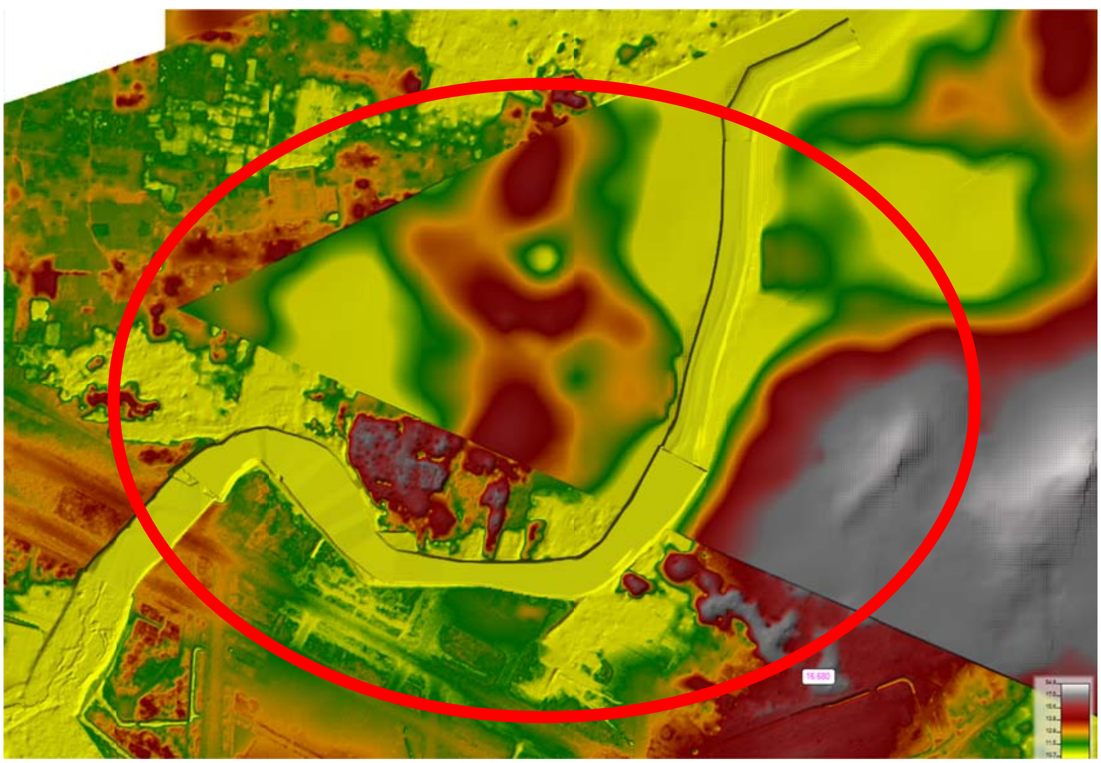


Figure 4.50 River dredging and widening at the downstream of the secondary runway bridge up to 3km D/S of the runway extending bridge beyond OTA till the check dam before Miot hospital (DSM)

Table 4.7 Carrying capacity of the river at the upstream of the secondary runway bridge for different river training

River Training Scenarios	Flow rate (m^3/s)	
	n=0.027	n=0.020
Without river training (flow capacity of the river at the soffit level of 10.5m)	1,104	1,409
Upstream dredging and widening	1,105	1,413
Downstream dredging and widening (till OTA)	1,312	1,736
U/S and D/S dredging and widening (till OTA)	1,313	1,738
U/S and D/S dredging and widening (beyond OTA till Miot)	1,400	1,806

4.3.8.5 Bridge scour and preventive measures

The bridge piers for the proposed site are tied up by beams with each other at the river bed level. The space within the beams are covered by boulders. This has taken care of bed scour as it is clear from the ground survey. However, the upstream side of the bridge is not protected and hence there may be scour at this location. The scour around a bridge pier is calculated from the Lacey's formula adopted by the Indian Road Congress (IRC 1998 & 2000) as given below

$$D_{Lq} = 1.34\left(q^2 / f\right)^{1/3}$$

where, D_{Lq} is the mean scour depth (m) below the design flood level, q is the design flood discharge intensity in $m^3/s/m$ allowing for concentration of flow and f is the Lacey's silt factor ($1.76\sqrt{d}$) related to the median size of bed material d (mm). For simplifying the calculation, the dimensions of the bridge at the upstream are used in the above equation. After substituting the values from the simulated results and from the published literature (Q = 1800 m^3/s, width = 200 m, d = 0.13 mm), the scour depth is 6.74 m from the design flood level ~5 m. Therefore, the potential scour below the bed level is estimated to be around D_s = **1.74 m** in an extreme condition.

The ground survey just after the 2015 flood did not show scour around bridge piers. In fact, there was scattered sediment deposition on the upstream side. However, the upstream side was also muddy and hence there could be scour below the ground level which could not be surveyed. Considering the potential scour, it is recommended that the upstream side and two banks close to the bridge for a certain distance need to be protected by stone pitching. The banks need to be given proper slope from stability point of view. The following information may be used for protection.

Bank side slopes

The side slopes of the banks have to be fixed from stability considerations which depend on the material of which the bund is made and also its height. Generally the side slopes of the guide bund vary from 2:1 to 3:1 (H:V). In this case, gentle side slope of 3:1 should be preferred.

Size and thickness of pitching

As per IRC code the size and weight of stone pitching are calculated as following

$$D = 0.04176V^2$$

$$W = 0.101V^6$$

For the velocity up to 1.8 m/sec as observed in the simulations, the pitching stone size should be 0.13 cm and weight of individual stone should be 3.4 Kg. The thickness of pitching should be calculated using the Pilarczyk formula given below

$$t = 0.025V^2$$

And the thickness for the proposed site is calculated as 0.08 m which is lower than the suggested minimum thickness 25 cm. Hence, the thickness should be at least 25 cm.

Length of stone pitching

As per the design criteria for launching apron given in CBIP (1989), the length of stone pitching should not be less than 1.5D_s, i.e 2.6 m, but this seem to be very lower value. On the contrary, in easily erodible rivers, too long stone pitching is liable to damage and failure. Hence, it would be better to construct shorter ones in the beginning and extend them gradually as silting between them proceeds.

Design caution: The stone pitching in the vicinity of bridge needs to follow several IRC codes and it's an exhaustive procedure. Therefore, while going for stone pitching IRC code should be followed. A detailed DPR can list give all the specifications.

4.3.9 Flood diversion canal from Adyar to Palar

As discussed in section 4.3.5, the magnitude of the December 2015 flood is only slightly lesser in magnitude than the flood caused from 1 in 100 year design storm. The peak flood was as much as 3.5 to 4.5 times (350% to 450%) more than the bank full carrying capacity of the river at the bridge site. As discussed in section 4.3.8, river training could increase the bank full flow capacity of the river by only about 25%. Hence, there is a need to consider a flood carriage way to divert the flood waters of Adyar River originating from the Chembarambakkam surplus weir and route it to Palar near Vallipuram, just downstream of Vallipuram bridge. There is only a mild gradient of 5m available over a distance of 75 km (a fall of only 6.5cm for every one km). A compound channel as shown in figure 4.51, was considered to divert the flood waters. Due to the existing terrain conditions and difficulty in finding the right of way, the maximum channel depth was restricted to only 4m. The top width of the channel was restricted to 100m (as wide as Adyar River). The rest of the channel parameters are summarized in table 4.8. Due to the mild gradient, the massive channel could only convey a peak flow of about 391 m^3/s. However, as we saw earlier in section 4.3.8, dredging and widening of Adyar River section D/S of the secondary runway bridge site to a distance of about 3km, itself could increase the discharge capacity of the river by almost 300 to 400 m^3/s. At the first look, this flood diversion look very massive and for the floods of magnitude such as December 2015 flood, this flood channel will serve only limited purpose due to the small gradient available for diversion. Further, such a large flood carriage way would have to cut through several villages, agricultural fields and has serious environmental implications and cost implications. There may also be few sections where some tunnels are needed below dense habitation along the flood diversion canal. **Hence, without a thorough feasibility study, the option of considering flood carriage way to carry the excess flow from Adyar to Palar does not seem to be viable.** However, a flood carriageway such as this is required as more urbanization to the west of Tambaram would bring more flood waters into the airport and into the Chennai city. Hence, this option needs to be comprehensively investigated in greater detail.

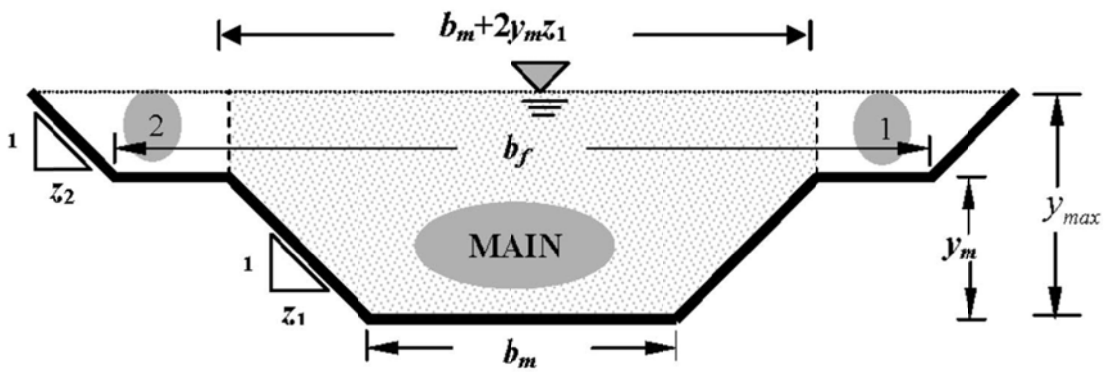


Figure 4.51 Compound channel section to divert flood waters from Adyar to Palan

Table 4.8 Compound channel parameters for flood carriage way from Adyar to Palar

Bottom of main channel b_m *(m)*	54.0
Bottom of flood plain channel bf *(m)*	86.0
Depth of main channel (y_m) *(m)*	2.0
Total depth (Y_{max}) *(m)*	4.0
Top width *(m)*	100.0
Side slope of main channel z1	2
side slope of flood pain z2	2
Manning n (Rubble Masonry)	0.017
Bottom slope (m/m)	0.000065
Discharge capacity (m^3/s)	391.5

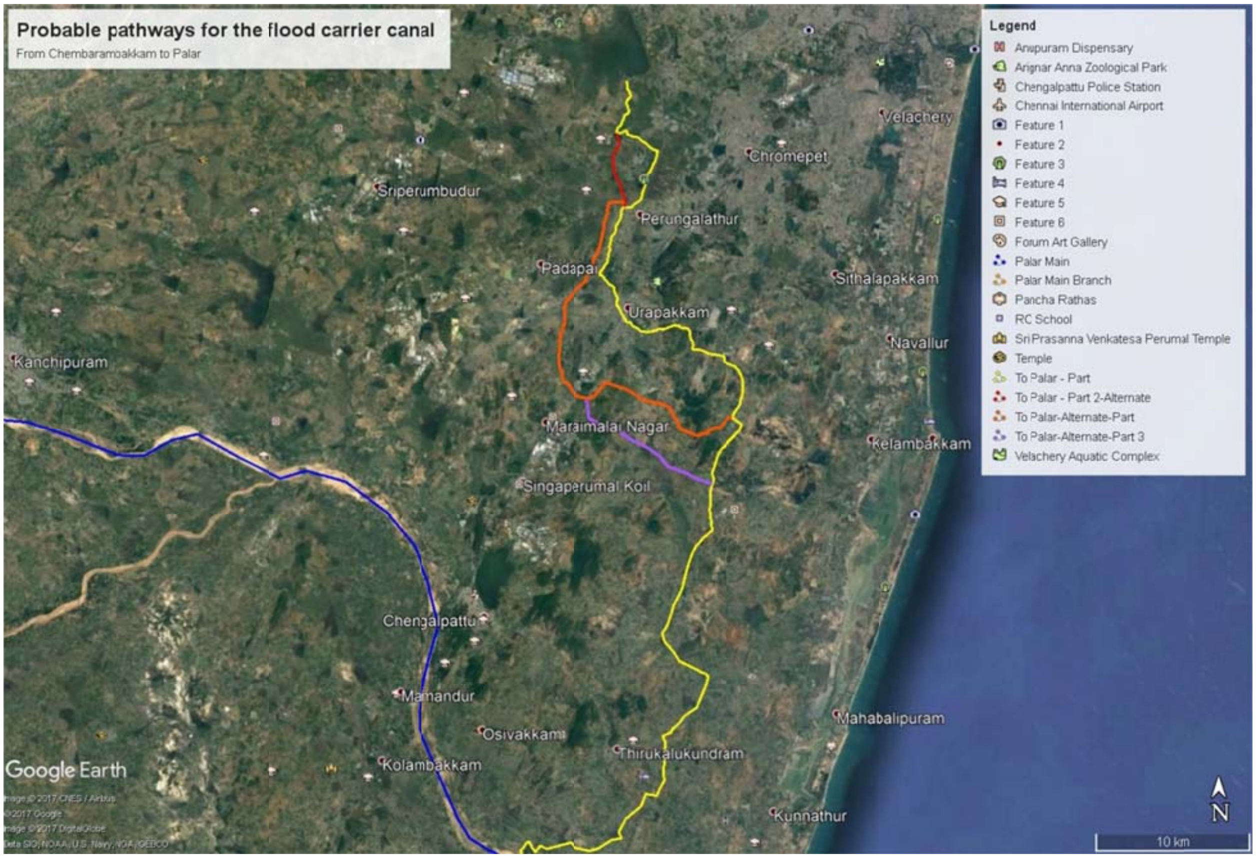


Figure 4.52 Probable pathways for the flood carrier canal from Chembarambakkam and Adyar to Palar

5 Storm Water Management Model (SWMM) of Chennai Airport

5.1 Introduction

SWMM is an open source dynamic hydrology-hydraulic simulation model primarily from urban areas developed by the US Environment Protection Agency (USEPA). SWMM is a dynamic rainfall-runoff simulation model used for single event or continuous simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM operates on a collection of sub-catchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity of runoff generated within each sub-catchment, and the flow rate and flow depth in each pipe and channel during a simulation period.

SWMM accounts for various hydrologic processes that produce runoff from urban areas. These include:

- time-varying rainfall

- evaporation of standing surface water
- rainfall interception from depression storage
- infiltration of rainfall into unsaturated soil layers
- percolation of infiltrated water into groundwater layers
- nonlinear reservoir routing of overland flow
- capture and retention of rainfall/runoff with various types of low impact development (LID) practices

Spatial variability in all of these processes is achieved by dividing a study area into a collection of smaller, homogeneous sub-catchment areas, each containing its own fraction of pervious and impervious sub-areas. Overland flow can be routed between sub-areas, between sub-catchments, or between entry points of a drainage system. SWMM also contains a flexible set of hydraulic modelling capabilities used to route runoff and external inflows through a drainage system network of pipes, channels, storage/treatment units and diversion structures. These include the ability to:

- handle networks of unlimited size
- use a wide variety of standard closed and open conduit shapes as well as natural channels
- model special elements such as storage/treatment units, flow dividers, pumps, weirs, and orifices
- apply external flows and water quality inputs from surface runoff, groundwater interflow, rainfall-dependent infiltration/inflow, dry weather sanitary flow, and user-defined inflows
- utilize either kinematic wave or full dynamic wave flow routing methods
- model various flow regimes, such as backwater, surcharging, reverse flow, and surface ponding

In this study, runoff generation and flow routing are the two processes modelled. The infiltration model used for runoff computation is based on the Curve number method. The flow routing model is based on the dynamic wave equation. Hazen Williams's equation is used by the model for dynamic wave routing computation. The storm drainage channel data, including open / closed channel inside the Airport and storm drainage inlets that enter inside the airport along with culverts are given as input to model the flow hydraulics (Fig.5.1 and 5.2). In this study, SWMM was used to analyse the capacity of the existing drainage networks inside and outside the Airport, to accommodate Storm water generated. The natural sub catchments in the Airport region has been delineated using HEC-GEOHMS and given as the input for SWMM.

Airport has a storm drainage length of close to 36km. The total length of external storm drains entering the airport premise is about 4.2km; total existing storm drains modelled being 41km. These storm drains were digitized and discretized into 297 conduits, involving about 284 junction points (Table 5.1 and 5.2) . The type of storm water drain, size, and invert levels were obtained from the ground survey (Annexure D). Major storm water drains from the external catchment enters the airport at three different points. The storm drains mostly within the airport area is modelled in a detailed way with SWMM. However, the external storm water drains (Fig. 5.3 and 5.4) that enter the airport premises were modelled with HEC-HMS and the hydrograph was used as input into SWMM to route the flow through the storm drains within the airport premises.

SWMM model was run for three different design storms with return periods 2 years, 5 years, 10 year and 2015 Chennai flood, to identify the carrying capacity of existing drains inside the Airport. The design return periods of 2, 5 and 10 yrs were chosen because any return period more than that would result in unreasonable sizing of the storm water drains. This would help to identify the sites for resizing the storm water drains and the necessity to divert external storm water drains. The flood hydrographs of external watersheds given as input to SWMM are show in figures 5.5 and 5.6.

Table 5.1 Total length of storm water drains

Scenarios	Total length of conduits(in Kms)	
	Inside the Airport	Outside the Airport
Existing Storm water drains	41.64	4.23
Resizing & Internal Rerouting of drains	43.53	4.29
Diversion of External Drains	43.53	6.25

Table 5.2 Length of storm water drains to be resized

Scenarios	Total length of conduits to be modified (in Kms)	
	Inside the Airport	Outside the Airport
Resizing & Internal Rerouting of drains	15.66	0.6
Diversion of External Drains		2.02

Table 5.3 Conduits and Nodes modelled for different scenarios

	Existing	Resizing & Internal Rerouting	Diversion of External Drains
Number of conduits modelled	329	346	359
Number of nodes modelled	316	327	341

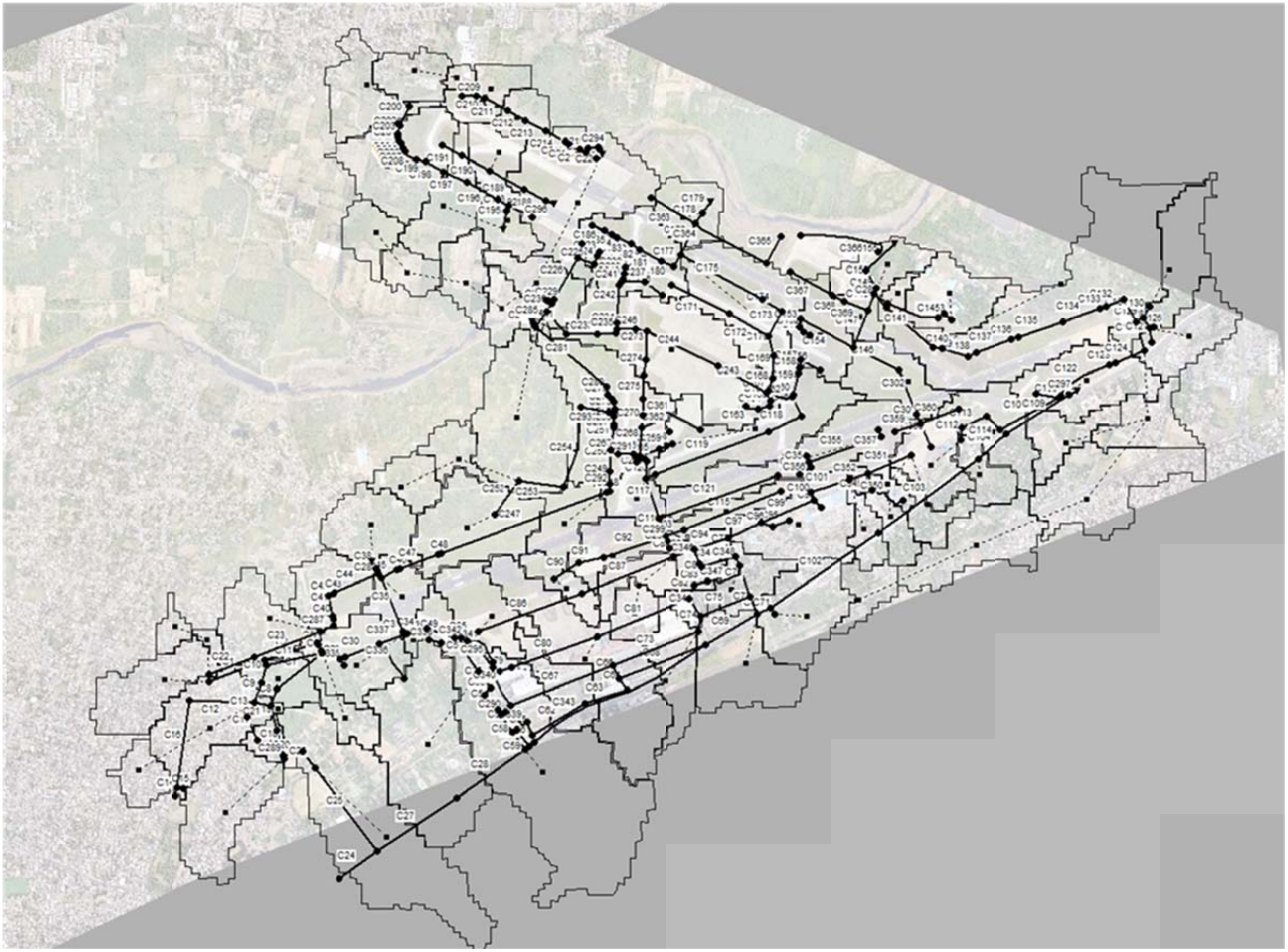


Figure 5.1 SWMM setup of the storm water drains and watersheds within and adjacent to the airport

Figure 5.2 SWMM conduits and junctions

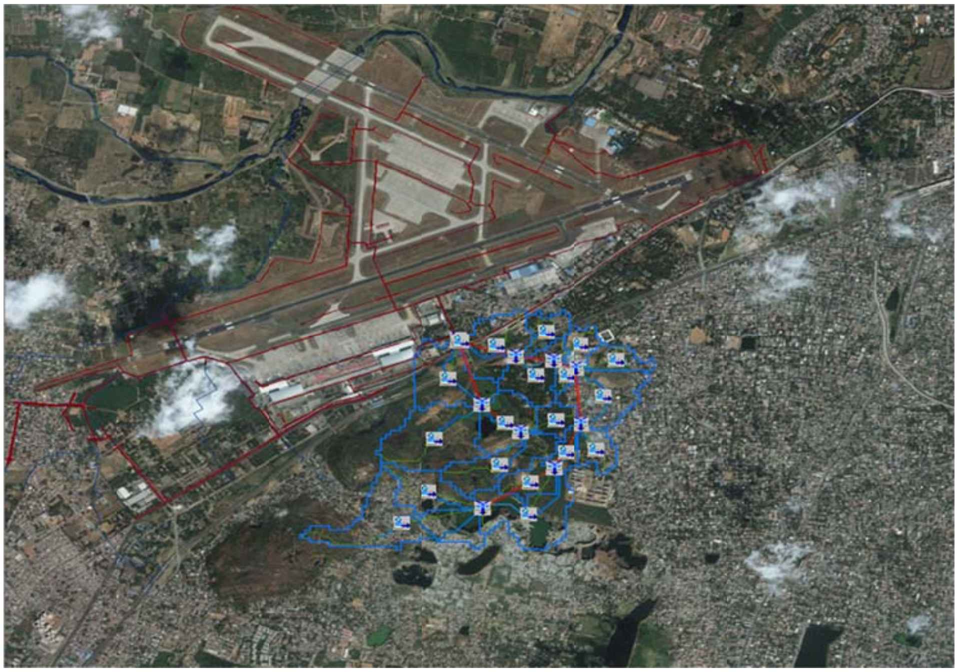


Figure 5.3 External storm water drain at the GST road side near the road leading to ATC simulated using HEC-HMS

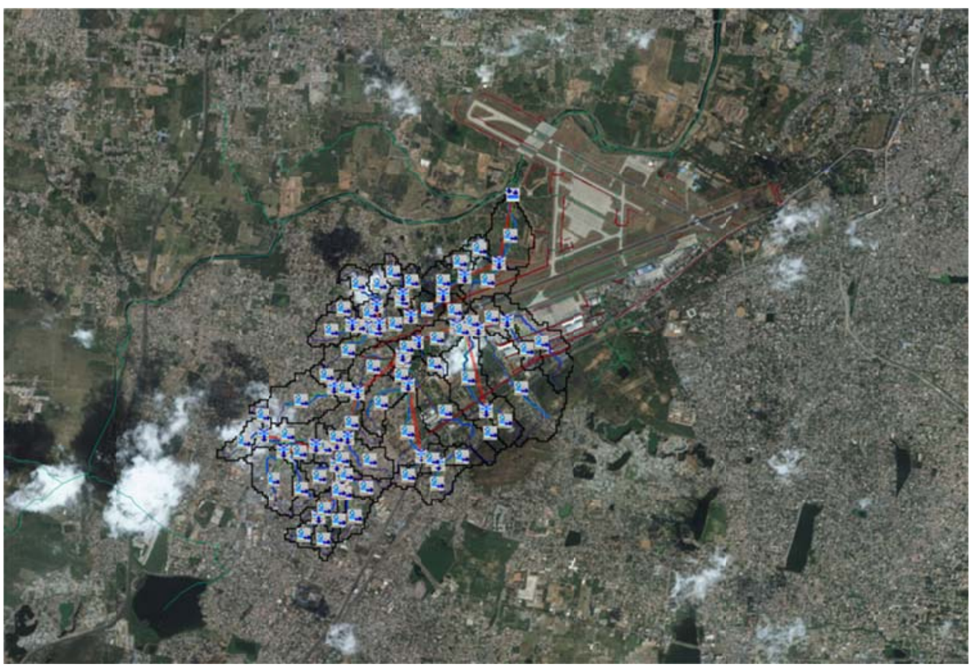


Figure 5.4 External storm water drain near Pallavaram and Pammal side simulated using HEC-HMS

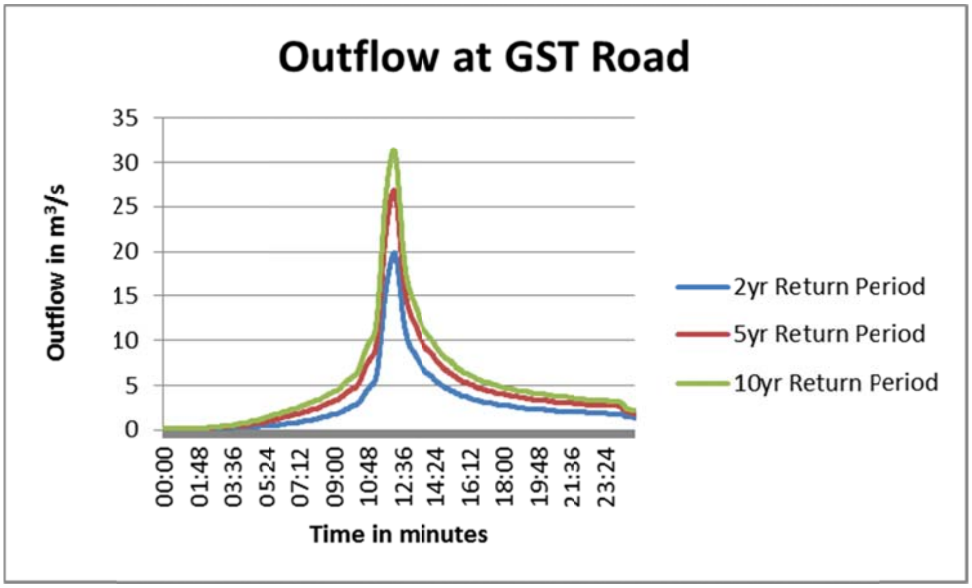


Figure 5.5 Flood hydrograph for different return periods from the external drains at the GST road side drain from the Thirusulam area

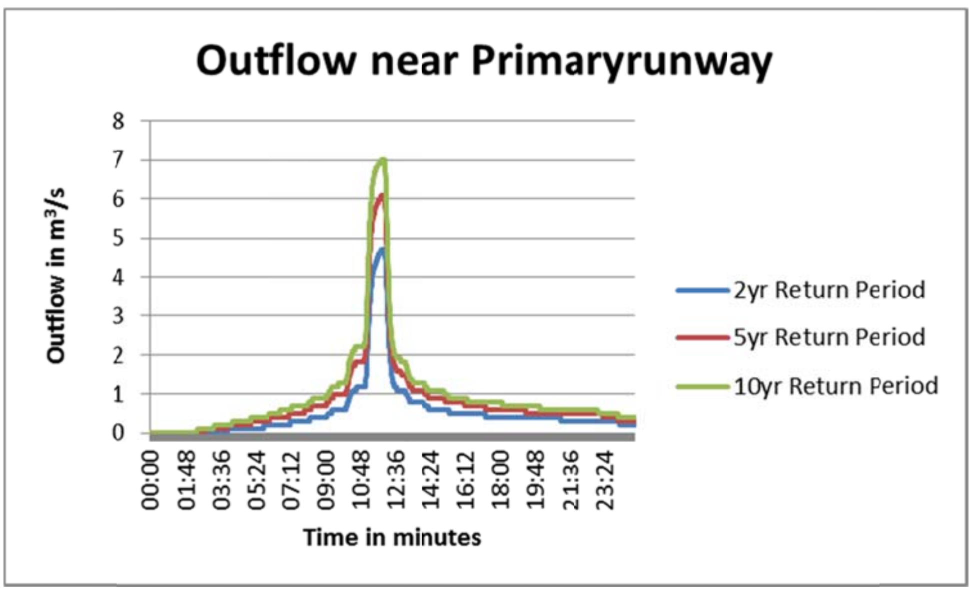


Figure 5.6 Flood hydrographs for different return periods from the external drain near Taj Kitchen from Pallavaram

5.2 Storm drainage capacity of the existing storm water drains

The SWMM model was first used to check the size of the current drains to estimate their flood carrying capacity without surcharging. It was found that the existing storm water drains surcharge at several locations even for the runoff resulting from 2-yr design storm due to flows from external drains of Pammal, Pallavaram and Thirusulam. Most of the drains / conduits are not able to safely dispose off the runoff resulting from 10-yr design flood without surcharging.

Hence, sections of the storm water drains have to be resized and regraded to accommodate the runoff resulting from 10-yr design storm.

Based on the model simulations (Table 5.3), totally 73 conduits of 329 conduits surcharged for a 2 year storm, 86 conduits surcharged for 5-yr storm and 86 conduits surcharged for 10-yr design storm. About 9.6, 12.75 and 12.75km length of drains out of 41km of storm water drains within the airport surcharged respectively for 2-yr, 5-yr and 10-yr design storm (Figures 5.7 to 5.11).

Table 5.4 Conduits surcharging for design storm of different return periods

Conduits number	Surcharged for 2 year return period rainfall	Surcharged for 5 year return period rainfall	Surcharged for 10 year return period rainfall
1	☑	☑	☑
20	☑	☑	☑
25	☑	☑	☑
26	☑	☑	☑
50	☑	☑	☑
56		☑	☑
57		☑	☑
72		☑	☑
73		☑	☑
74		☑	☑
75		☑	☑
76	☑	☑	☑
77	☑	☑	☑
78		☑	☑
79		☑	☑
80		☑	☑
81		☑	☑

Conduits number	Surcharged for 2 year return period rainfall	Surcharged for 5 year return period rainfall	Surcharged for 10 year return period rainfall
82	☑	☑	☑
83	☑	☑	☑
84	☑	☑	☑
85	☑	☑	☑
87		☑	☑
88	☑	☑	☑
89	☑	☑	☑
90	☑	☑	☑
91	☑	☑	☑
92	☑	☑	☑
93	☑	☑	☑
94	☑	☑	☑
95	☑	☑	☑
96	☑	☑	☑
97	☑	☑	☑
98	☑	☑	☑
99	☑	☑	☑
100	☑	☑	☑
107	☑	☑	☑
108	☑	☑	☑
109	☑	☑	☑
112	☑	☑	☑
113	☑	☑	☑
114	☑	☑	☑
115	☑	☑	☑

Conduits number	Surcharged for 2 year return period rainfall	Surcharged for 5 year return period rainfall	Surcharged for 10 year return period rainfall
116	☑	☑	☑
122	☑	☑	☑
123	☑	☑	☑
124	☑	☑	☑
125	☑	☑	☑
127	☑	☑	☑
129	☑	☑	☑
131	☑	☑	☑
132	☑	☑	☑
141	☑	☑	☑
142	☑	☑	☑
200	☑	☑	☑
202	☑	☑	☑
203	☑	☑	☑
204	☑	☑	☑
205	☑	☑	☑
206	☑	☑	☑
207	☑	☑	☑
208	☑	☑	☑
209		☑	☑
211		☑	☑
249	☑	☑	☑
250	☑	☑	☑
251	☑	☑	☑
252	☑	☑	☑

Conduits number	Surcharged for 2 year return period rainfall	Surcharged for 5 year return period rainfall	Surcharged for 10 year return period rainfall
253	☑	☑	☑
254	☑	☑	☑
259	☑	☑	☑
260	☑	☑	☑
265	☑	☑	☑
268	☑	☑	☑
269	☑	☑	☑
271	☑	☑	☑
292	☑	☑	☑
295	☑	☑	☑
298	☑	☑	☑
299	☑	☑	☑
341	☑	☑	☑
342	☑	☑	☑
345	☑	☑	☑
346	☑	☑	☑
347	☑	☑	☑
348	☑	☑	☑
349	☑	☑	☑
350	☑	☑	☑

From the figures 5.7 to 5.11, it is clear, that the surcharging drains are distributed across the airport and not concentrated in any one region. However, the major drains that surcharge are the drains that also bring considerable amount of discharge from external catchments of Thirusulam and Pallavaram / Pammal region. These drains might have been designed when there was not much urbanization in Thirusulam and Pallavaram / Pammal region. Due to urbanization and the resulting increase in the impervious portion of the watershed, the runoff generated in these external watersheds has increased considerably. Further, there have been several expansions even within the airport premises itself. Hence, it becomes necessary to resize, regrade and reroute several internal and external storm water drains.

5.3 Resizing, regrading and rerouting the internal storm water drains

SWMM Model was run to redesign the existing channels inside and outside airport to accommodate flood discharges resulting from 10 year return period storm. While redesigning using SWMM it was found that resizing alone will not be effective as the culverts that cross the active runway portions may not be sufficient and hence resizing them would disturb the aircraft operation. Hence, regrading the invert levels of the drains and rerouting with additional links in the storm water drains becomes import. The channels / culverts crossing the active runway portions were not considered for resizing and rerouting. Instead, the channels were regraded and rerouted to another direction. Specifically, due to external flows from the Thirusulam area, the conduits near the old fire station and Indian oil storage regions surcharge considerably. Due to the capacity limitations in the culverts across the runway, a new storm water drain was proposed parallel to the existing drain, but to the north of the taxi ways “A” & “B” and crosses Taxi ways “D” & “C” before joining the existing storm drain to the east of the cargo apron at the beginning of “A” Taxi way. This rerouted water from the external storm water drain that enter the airport near the Indian oil storage and from the apron region H of the main terminal, will ultimately discharge through the new drain into the Adyar River near the North-West portion of the Coast-Guard station.

While developing the model for resizing and rerouting, the width of the channel was kept at a maximum of about 6.5m keeping in view the limitations of the site conditions. The drain sizes were optimized using SWMM model to bring down the node surcharge to less than 1 hour at most places. At other places wherever further redesigning may not be practically possible due to terrain and other limitations, the surcharge was brought down close to two hours. The design parameters of the modified conduits are presented in Annexure D. The stretch of storm water drain that was newly proposed to reroute the flow toward the Coast Guard station is shown in figure 5.12.

5.4 Rerouting the external storm drain from Pammal

The storm water drain from the Pammal and Pallavaram region brings considerable amount of flood discharges that eventually drain through the Fishnet drain into the Manikka Odai in the northern side of the airport which subsequently drain into the Adyar River. This external discharge also brings along with it considerable amount of solid waste and organic load that attracts birds into the runway portion. Hence, rerouting of this drain through the Cowl Bazaar directly into the Adyar River was explored. This proved to be a very good option for diversion as the terrain gradient is also in the same direction. Further, this region does not have a dedicated storm drain and hence this newly proposed storm drain could be a good infrastructure for this region as well to effectively drain the flood waters from this region. The new route for this external drain is shown in figure 5.13. The design parameters of the modified conduits are presented in Annexure D.

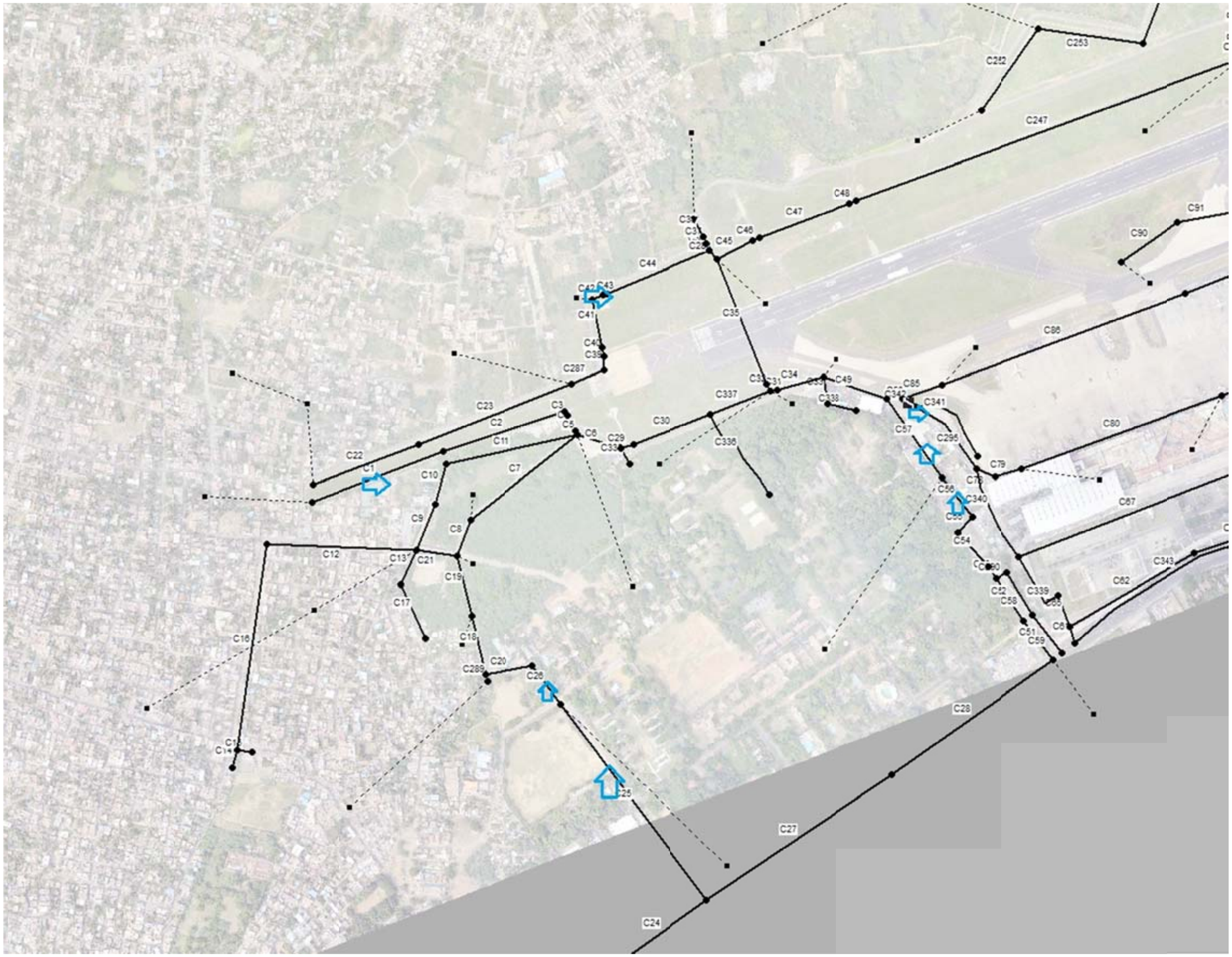


Figure 5.7 Conduits that surcharged for 2-yr, 5-yr and 10-yr storm (Part 1)

Figure 5.8 Conduits that surcharged for 2-yr, 5-yr and 10-yr storm (Part 2)

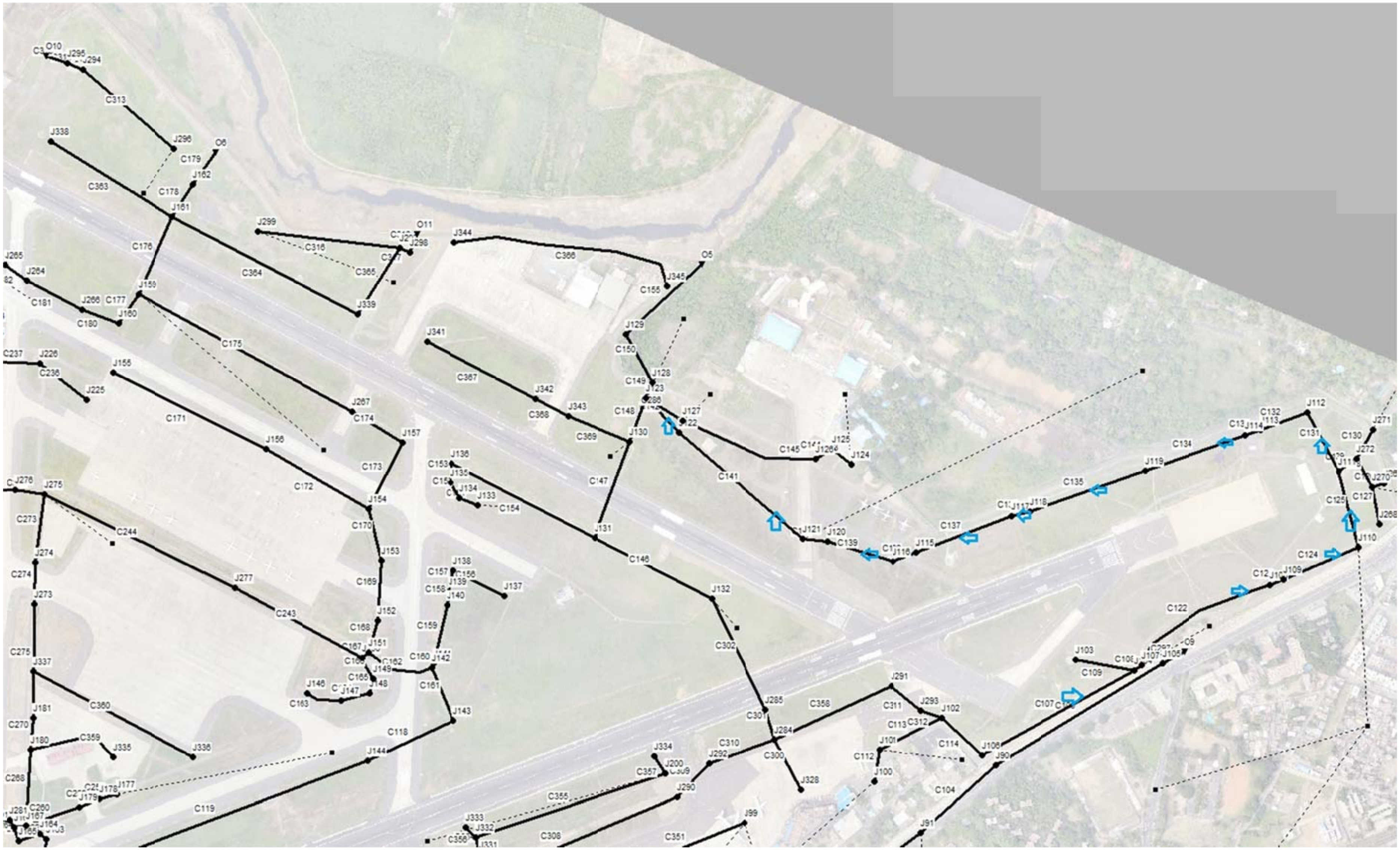


Figure 5.9 Conduits that surcharged for 2-yr, 5-yr and 10-yr storm (Part 3)

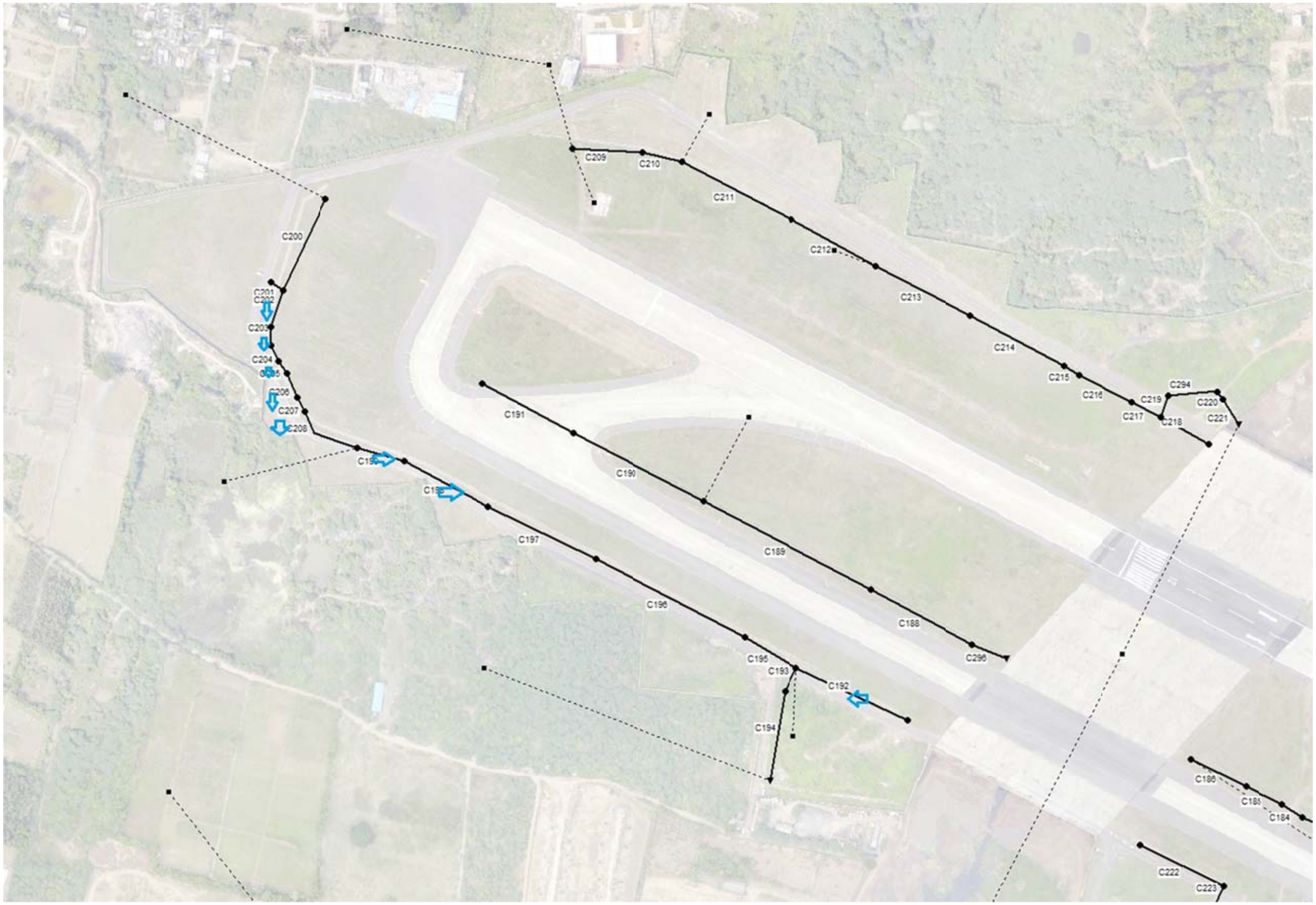


Figure 5.10 Conduits that surcharged for 2-yr, 5-yr and 10-yr storm (Part 4)

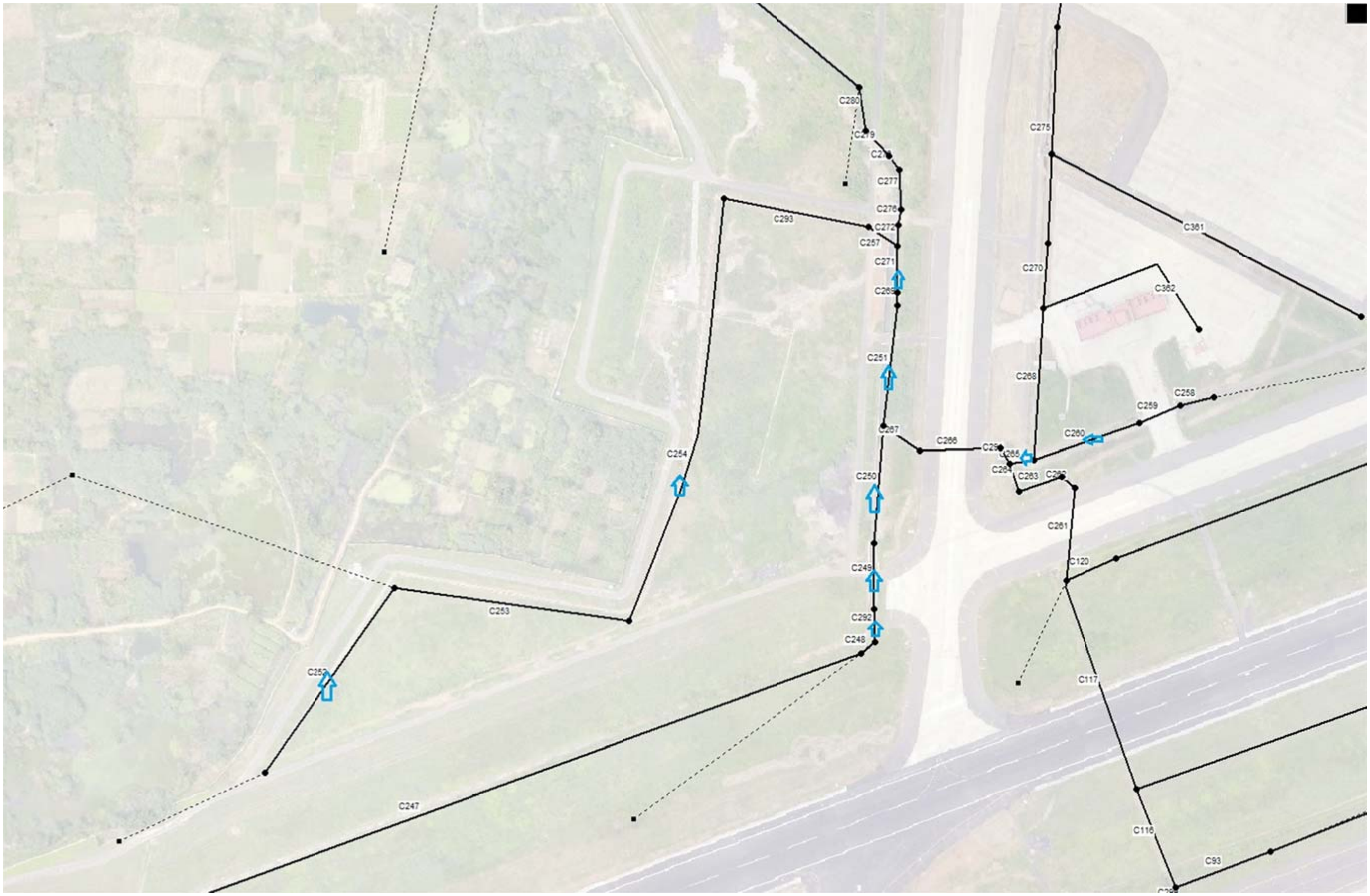


Figure 5.11 Conduits that surcharged for 2-yr, 5-yr and 10-yr storm (Part 5)

Figure 5.12 New internal storm drain proposed to reroute the flood waters from the Thirusulam area to the outlet near Coast guard station

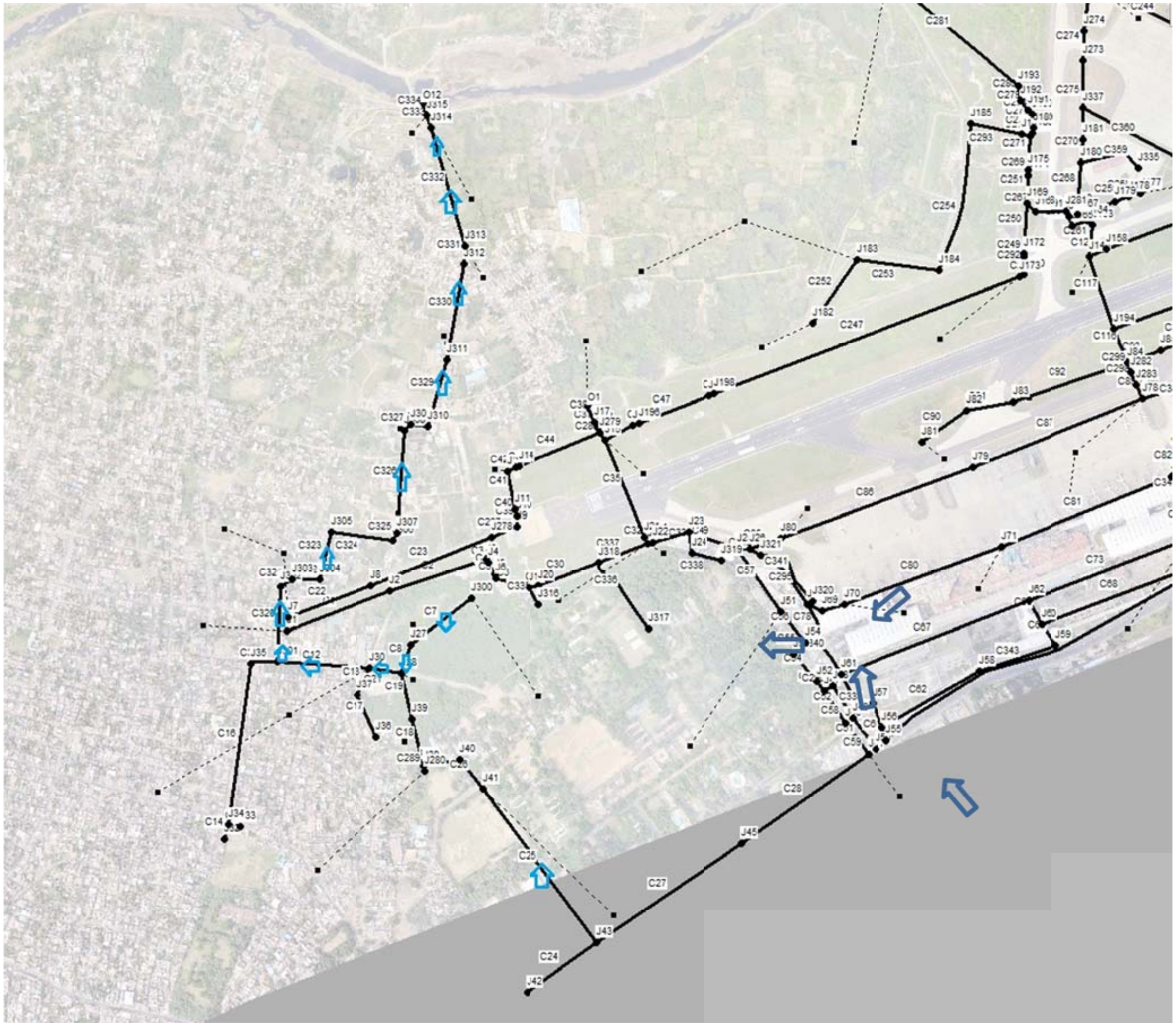


Figure 5.13 New external storm drain proposed through Cowl Bazaar to redirect the flow from Pallavaram and Pammal region directly in to Adyar river without entering the airport

5.5 Measures to prevent back flow of flood water from Adyar River into the airport drains

As was seen earlier (section 4.3.5; Figures 4.31 to 4.33), the storm water drains near the river side of the airport will begin to backflow even for a 2-yr and 5-yr recurrence interval storms. The back flow of the drains will lead to localized flooding of the airport as well as cause delay in draining of the flood waters. In order to prevent this, we recommend installation of automatic water level recorders at the secondary runway bridge site, sluice gates for all the storm water drains, sumps/recharge pits and pump stations. A critical period analysis was carried out to find the size of the pump and the volume of the sump needed to safely intercept and dispose off the storm water. The hydrograph needed for the critical period analysis came from the SWMM simulations for the 10-yr design storm for the Resized and rerouted storm drainage network.

While doing this analysis, it was assumed that the majority of the water draining through the Fishnet drain from the Pammal region will be diverted directly through Cowl Bazaar area into the Adyar river and hence will not enter the airport (See details in section 5.4). Hence, two pump houses and sumps are proposed. These were designed primarily for Drains 1 and 2 near the new radar station location and for Drain 5 near the Coast guard station (Fig.4.34).

The critical period analysis carried out as illustrated in figure 5.14 showed that for the site near the New Radar station, the sump will be of dimension 150m X 60m X 4m. The total capacity of the high volume pumps required is 25 m^3/s. This pump house need to be operated when the flood levels in the Adyar River reaches 8.5m near Drains 1 and 2 near the new radar station. A similar critical period analysis (Fig.5.15) carried for the site near Coast guard station showed, the sump will be of dimension 100m X 100m X 3.5m and the total capacity of the high volume pumps required is 40 m^3/s. This pump house needs to be operated when the flood levels in the Adyar River reach 8.0m near Drain 5 close to Coast guard station.

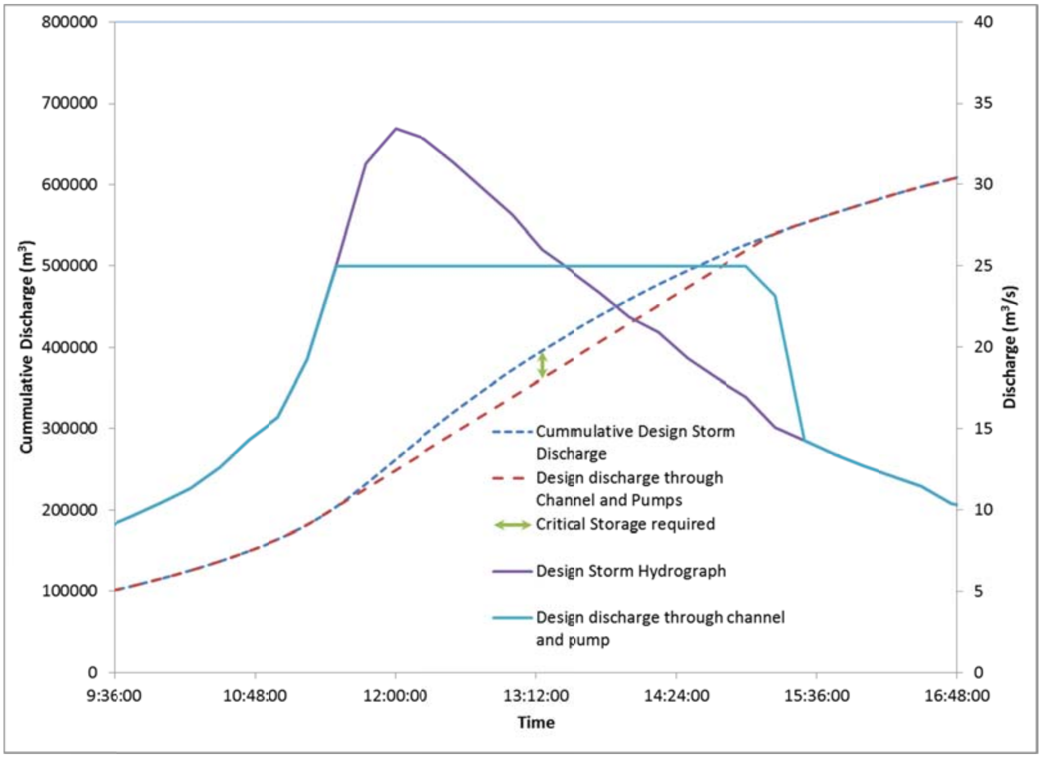


Figure 5.14 Critical period analysis for arriving at pump and sump size for drains near the New Radar station

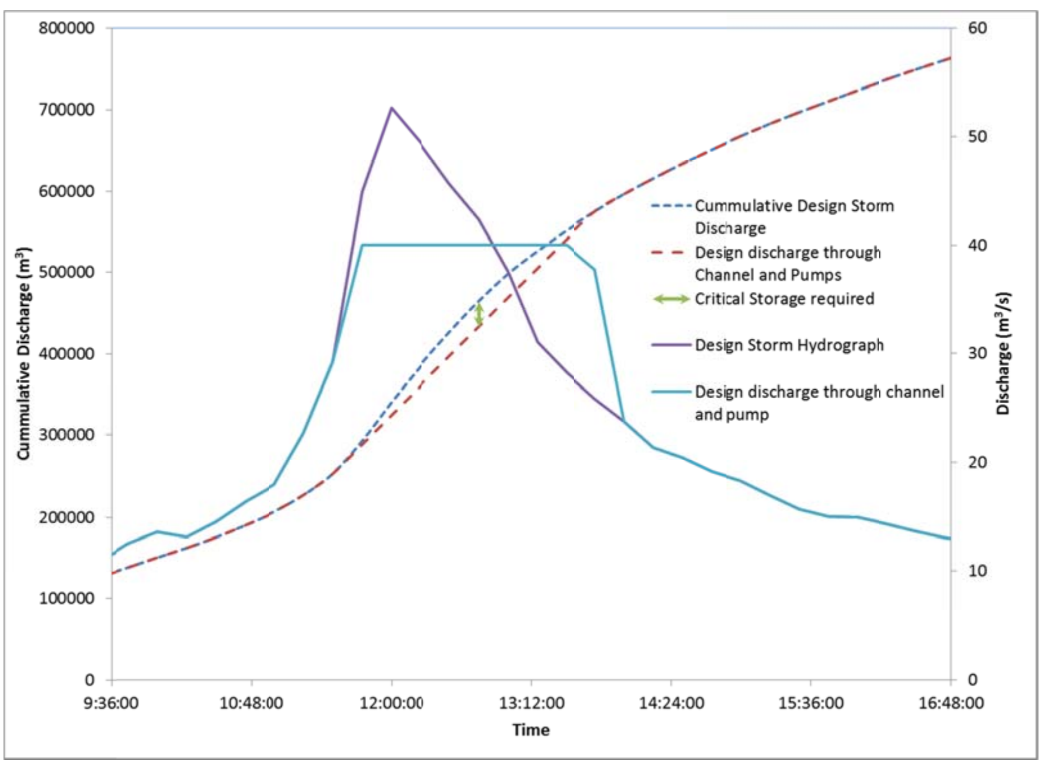


Figure 5.15 Critical period analysis for arriving at pump and sump size for drains near the Coast Guart Station

These dimensions of sumps and pumps were arrived for discharging the 10-yr design storm safely without surcharging the sump and the airport premises. For any floods higher than the 10-yr design storm, the sumps and channels will surcharge. However, continuous operation of the pumps would ensure draining of the operational area of the airport quickly. The tentative sites for these are given in figures 5.16 and 5.17. **Hence, we strongly recommend installation of sumps and pumps in these locations in conjunction with the installation of sluice gates for undisturbed operations of the airport.** Typical illustration of sluice gate is shown in figure 5.18. If the flood rises above the level of the security gates, then flood barriers such as the ones shown in figure 5.19 may be procured and installed to make the security / access gates also water tight.

Figure 5.16 Proposed site location for pump house and sump near the new radar station

Figure 5.17 Proposed site location for pump house and sump near the coast guard station

Figure 5.18 Typical sluice gates to avoid backflow through the storm drains

5.6 Protection of critical infrastructure and emergency flood control measures

Section 4.3.6 described about the maximum flooding depth simulated for the December 2015 flood in the vicinity of the critical infrastructure (Figure 4.37). Table 4.6 lists the HFL that has most likely occurred near these critical infrastructure. As can be observed from this table, the HFL of 13.315 m observed at the airport periphery is often lower by as much as 1m to the HFL that is most likely to have occurred at some of the critical infrastructure. Hence, it is important to make sure that the plinth and threshold levels of these critical infrastructure be raised at or above the value shown in table 4.6. For safety reasons, it is recommended that the installation of critical equipment be raised to a level of 15m (above MSL) to avoid the recurrence of getting inundated during a record flood such as in December 2015.

We also suggest that the critical infrastructure, hangers, aprons and security gates at the periphery be equipped with temporary flood barriers such as the ones shown in figure 4.56, which may be rapidly deployed just prior to a flood event in the event of a flood alarm. To deploy these barriers no permanent fixtures are necessary and these are generally taken down immediately after the flood threat has passed. We suggest that a radar type automatic water level recorder may be installed at the secondary runway bridge site and the levels continuously monitored at a control station. When the river swells above the 9.5m mark, then temporary flood barriers may be deployed.

Figure 5.19 Variety of temporary flood barriers that can be rapidly deployed just prior to a flood event

6 Salient Findings

1. The flooding of the airport during the December 2015 was due to much large regional extent of the storm that brought flood waters from about 680 sq.km area upstream of the airport, including reservoir release from Chembarambakkam, and not necessarily due to the local flood waters from about 50 sq.km area in the immediate vicinity of the airport. Hence, any flood prevention measures at the airport has to comprehensively look at the regional topographical features to develop appropriate flood control measures.
2. The magnitude of the floods of December 2015 is only slightly less than the flood magnitude caused due to 1 in 100 year design storm which is as much as 3.5 to 4.5 times (350% to 450%) more than the bank full carrying capacity of the river at the bridge site. The bank full capacity of the river at the runway bridge at the soffit level of 10.5m was found to be range between 1,104 m^3/s (38,985 ft^3/s) and 1,409 m^3/s (49,774 ft^3/s) depending on the channel roughness.
3. The hydraulic models indicate that the bridge piers of the runway bridge across Adyar River do not have any noticeable impact on the flood carrying capacity of the river at this section.
4. The December 2015 flood is a flood of unprecedented magnitude. Any structural interventions to deal with floods of such magnitude will be massive. Hence, in order to keep the size of structural interventions within a reasonable level, a recurrence interval of 10 year may be adopted. Federal Aviation Administration (FAA) of the United States recommends that the storm drainage structures within the airport can be designed for a design storm with return period of greater than or equal to 5 years. Hence, a 10-yr design storm for designing storm drainage structures within the airport would suffice.
5. Dredgening, widening and clearning of the river bed U/S of the runway bridge has minimal impact on the river discharge capacity. However, dredging, widening and clearing of the river section to a length of about 3km D/S of the runway bridge site, including widening of the OTA bridge, increases the river discharge capacity by 25% (increased discharge of 300 to 400 m^3/s).
6. Flood bypass channel near the runway bridge site does not increase the flood discharge capacity considerably. Hence, this is not a viable option to increase the flood discharge at the bridge site
7. Flood carriage way from Chembarambakkam in Adyar to Vallipuram in Palar could carry only a maximum discharge of about 391 m^3/s due to its mild gradient (6.5cm drop over a 1km length). This channel will have a top width of 100m, depth of 4m over a length of 75 km. As the flood carrying capacity is not much, considering the environmental, economic and social implications, the option does not seem viable. However, a flood carriageway such as this is required as more urbanization to the west of Tambaram

would bring more flood waters into the airport and into the Chennai city. Hence, this option needs to be comprehensively investigated in greater detail.

8. All the airport drains begin to backflow with water from Adyar River due to the higher water level in Adyar even for floods caused by 2-yr and 5-yr return period design storms.
9. Storm drains from external drains bring considerable amount of flood water from the neighboring into the airport premises due to urbanization over several decades since the airport construction. Further, about 9.7km of 36km of internal drains were found to surcharge for a design storm of 1 in 10 year return period. Hence, there is a need to consider resizing and rerouting both internal and external storm water drains.

7 Specific Recommendations

Immediate Action (Airport Authority, Chennai Corporation and the PWD)

1. Annually before the monsoon, it is most important to dredge and clear the Adyar river to a distance of about 3km D/S of the runway bridge, beyond OTA till the check dam just before Miot hospital. Further, we strongly recommend widening at the bridge site near OTA. These measures alone would increase the discharge capacity of the Adyar river by 200 to 300 m^3/s. Details of this are in section 4.3.8

Immediate Action (Airport Authority)

2. We also suggest that the critical infrastructure, hangers, aprons and security gates at the periphery be equipped with temporary flood barriers such as the ones shown in figure 4.56, which may be rapidly deployed just prior to a flood event in the event of a flood alarm.
3. We suggest that a radar type automatic water level recorder may be installed at the secondary runway bridge site and the levels continuously monitored at a control station. When the river swells above the 9.5m mark, then temporary flood barriers may be deployed.

Long-term plans (Airport Authority)

4. During floods of high magnitude, the compound walls, specifically the wall section on the U/S side of runway bridge perpendicular to flow current, encounter both hydrostatic pressure due to the water column as well dynamic pressure due to the high velocity of the flowing water. These redesigned sections of compound wall need to be checked for stability to withstand this total load. See section 4.3.7 for details about the total pressure encountered by the compound wall at different places. The complete design of the compound wall with reinforcement would need a separate DPR.

5. We propose a new stretch of storm water drain running parallel to the Taxiway along A&D to divert the local storm water as well as flood discharges from Thirusulam area, entering near the Indian Oil storage yard, toward the drain near Coast guard station. The proposed new stretch reduces the flood load on culverts crossing the active runway, thus avoiding resizing them. Details of this are in section 5.3. This report contains the hydraulic design. The structural design of the channels would need a separate DPR.
6. For preventing backflow of flood water from the river into the storm water drains, we recommend installation of automatic water level recorders, drains mouth equipped with sluice gates, sumps and pump houses. The water level recorder would sound an alarm at a control room when the water level reaches a certain level. In response to the alarm, the sluice gates may be closed and the pumps may be operated. One pump house and sump is recommended near the new radar station near drains 1 and 2, while another pump house and sump is recommended near Drain 5 close to the coast guard station. Further, access gates and security gates may be protected with temporary flood barriers that may be easily deployed and removed during times of high floods to make these vulnerable points water tight. Please see section 5.5 for details. Based on the hydraulic design in this report the structural design and number of pumps need to be arrived at through a separate DPR.
7. Due to the maximum water level encountered near the critical infrastructure, we recommend rising the plinth level or increasing the threshold elevations to at least 15m (M.S.L). If this is not possible, we strongly recommend securing these critical infrastructures with temporary flood gates that may be rapidly deployed and removed during times of heavy floods. Please refer sections 4.3.6 and 5.6.

<u>Long-term plans (PWD and Chennai Corporation)</u>

8. We propose diversion of external storm water drain from Pallavaram and Pammal region through the Cowl Bazaar and draining into Adyar River. This diversion would reduce significant amount of storm water load entering the airport and surcharging the storm drains near Fishnet region. Further, the Cowl Bazaar area also does not have a dedicated storm water drain and suffer from localized flooding during storm events. Hence, this external diversion of storm water drain would benefit the airport as well as the surrounding community at large. Please see section 5.4 for details. This report contains the hydraulic design. The structural design of the channels would need a separate DPR.
9. A flood diversion canal from Adyar to Palar as proposed in section 4.3.9 may be studied thoroughly. Without a thorough feasibility study, the option of considering flood carriage way to carry the excess flow from Adyar to Palar does not seem to be viable.

Annexure

Annexure A1
Methodology of UAS-based topographic survey and field survey of river cross sections

1. Introduction

In this interim report the followings have been presented:

a) Completed UAS surveying schedule
b) UAS survey products:
   i. Orthophoto
   ii. DSM
   iii. DEM
   iv. Contour
c) Topographic Survey and river profiling

2. Background

The Unmanned Aerial System (UAS) survey was conducted between 19/10/2016 and 29/10/2016 successfully. River profiling and other ground surveys started in August. River profiling completed on 17/10/2016. The further ground survey is underway.

3. Supporting Administrative tasks:

Several paper works have been processed for obtaining clearances by preparing and providing supportive documents for the projects. IIT Madras provided data for SOPs, Contingency plans, flight scheduling and others. AAI facilitated the process by working with BCAS, ATC, Collectorate, Police and with other local administrative agencies.

4. Compliance with regard to scopes

As per the scope of the work the followings have been completed:

a) The survey area has divided into four zones (figure A1);
b) The flight plan was finalised in consultation with ATC, Airport Authority of India, Chennai;
c) Contingency plans formed;
d) Flight plan approval sheets signed;
e) A checklist as per the norms of the project has been followed;
f) UAS survey for 45 Sq. km carried out within 9 days as per the schedule sheet (table A1).

Concurrent to these above UAS survey, a ground survey team has completed surveying river (cross section @ 129 places and a longitudinal section with topographic contours) covering 12.99 km stretch of Adyar river. River cross section and flood plain survey was completed in the Adyar River in the stretch from Chennai Bypass road in the west (U/S of the Adyar runway bridge) to Mount Poonamalle High road bridge to the North (D/S of Adyar Runway Bridge) along with the compound wall elevation details of the airport along the river stretch.

Table A1 Tasks and schedule

S.No	Work	Schedule for completion	Task completion
1	**Topographic Survey**	**City side** outside the Airport premises wherever the stormwater drains are entering to Airport operational areas such as Meenambakkam village, Trisulam area, Cantonment of Pallavaram, near GST road etc. and discharging into the Adyar river.	**90 % completed. 10 % will be finished by 11/12/2016**
2	**Topographic survey**	Airport premises inside the operational area. HFL Marking, canal survey	**20/12/2016**
3	**Developing layout of existing drainage system**	The layout of existing drainage system and cross section of the drain with invert level for inside operational area and the city side of Chennai Airport (AutoCAD / GIS drawing).	**25/12/2016**

5. Project Area

The study area including Airport and its immediate vicinity (within approximately 5km radius) was divided into four regions so that the flight lines can be planned. Survey area covers Chennai Airport premises (Figure A1) inside operation area/city side and outside the Airport premises wherever the storm water drains are entering to Airport operational areas such as Meenambakkam village, Trisulam area, Cantonment of Pallavaram, near GST road etc. and storm drain outlets draining into the Adyar river. The total area covered by all the clusters is 45 Sq.km. A basemap with village boundary and taluk location was prepared (refer to Annexure-A2).

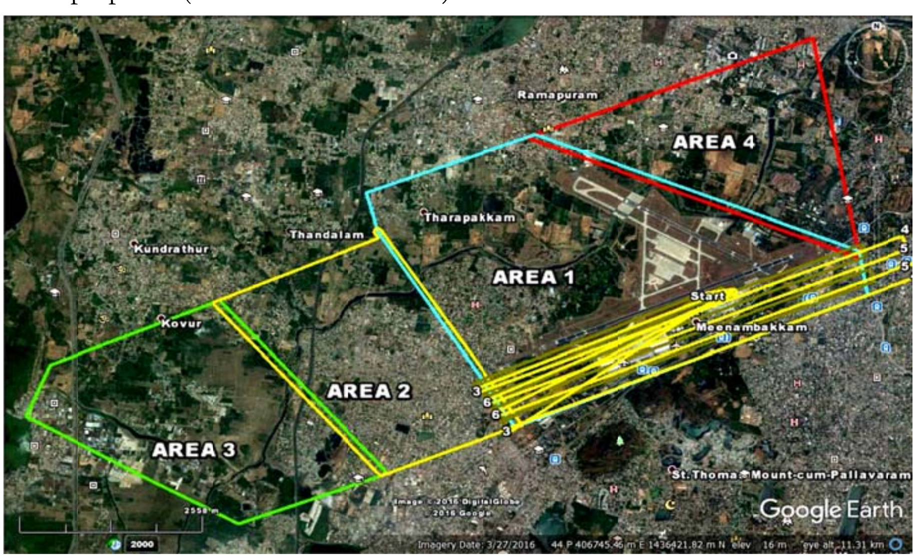


Figure A1. Project Study Area with zones and first-day flight line

6. UAS Setup and Deployment, Data Acquisition

The survey grade UAS (eBee) deployed in this project is a small (630 grams) fixed wing aircraft that can be assembled on site (figure 2). Once at the survey site, the flight plans were programmed into the eMotion software, the flight plan takes into account proposed flight height, output resolution, obstacles, topography, wind conditions and site layout.

Once programmed and launched, the flight is fully autonomous. Once the eBee is launched, it follows the pre-programmed flight path / elevation, capturing photos at set intervals. Travelling at speeds of up to 50km/h the eBee had a maximum flight time of approximately 40 minutes (first leg) and 20 minutes (2nd leg) per day. On return to the base station after completing the first leg, aircraft was relaunched to continue capture within a span of 3 minutes. The photos were then processed in Pix4D software to form a single ortho rectified image and terrain model as per the requirement.

With the on-board Sony camera, the UAS took a collection of high-definition still images that were used to generate Ortho airphotos, DSM maps and contour lines of the surveyed area.

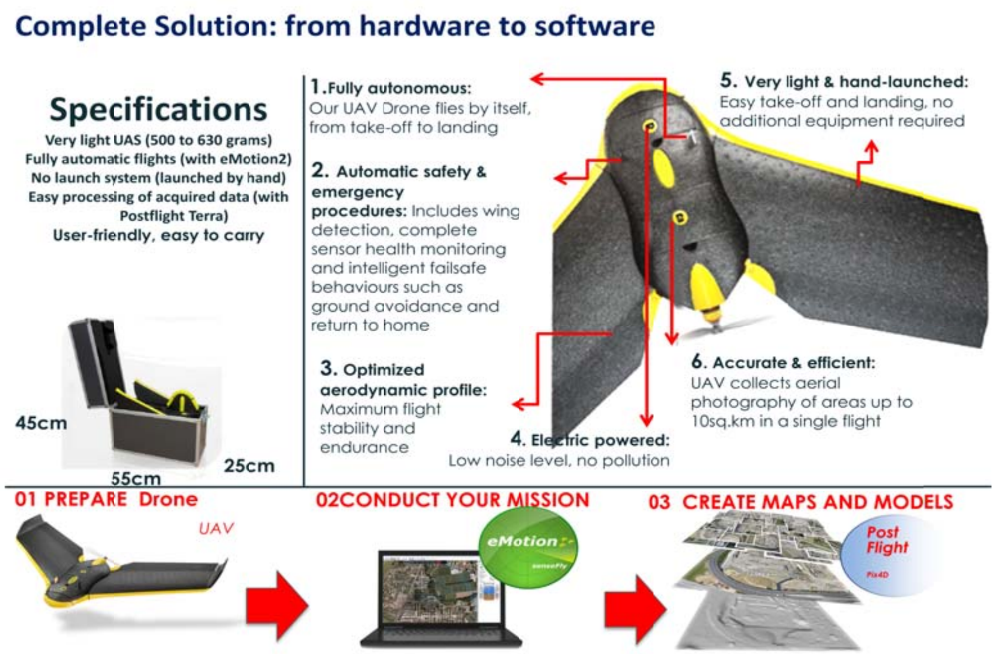


Figure A2.Specifications of Survey Grade UAS.

6.1. Flight operation and safety management

A stringent Safety Management System was maintained. As a policy, it was operated within the pre-determined take-off and landing areas. Adequate precautions were ensured with regard to UAS launching and landing position such that, it will not inadvertently cause any injury to others or damage to property. Personnel involved in piloting the USA have the highest regard to having a safe operation and have undertaken the training to ensure all risks are minimised. Further, the UAS is also very light weight (750g when fully assembled with the camera and accessories), made of thermocol material; hence, should an accident occur, will not cause serious injury or damage.

6.2. Designations and Responsibilities for UAS operation

Three different groups of well-experienced resources and crews were set up.

a) Ground Station Crew (GSC)

b) Pilot in Command –PIC and

c) System Operator-Software (SOS) for controlling the missions listed below:

Ground Station Crew (Director): Familiarity and operations of the aircraft; Familiar with the construction and configuration of UAS; Familiar with GPS/UAS electronics and configuration; Familiar with field repair procedures for each UAS; Familiar with the latest revision of ground control and image processing software; Understands the inherent risks of being in the vicinity of flight operations.

Pilot in Command (PIC): Physical handling of UAS, Mission Controller, on the field operation, Health of UAS, controlling Pilot At Controls (PAC) stationed at ATC, SOS, Ground System Crew (GSC), Familiar with the construction and configuration of UAS, Familiar with field repair procedures for each UAS, Familiar with the latest revision of ground control software –e.g eMotion

System Operator-Software (SOS): In-house planner, the software operator, controlled by PIC and PAC, No physical handling of the UAS, Monitoring the flight on a mission, who is familiar with GPS/UAS electronics and configuration.

For the current shorter mission, PIC was allowed to do the role of PAC, GSC and as an observer. The PAC role was controlled by IIT and ATC team

The project was executed with three constraints formulated on requirements of project as shown in figure A3.

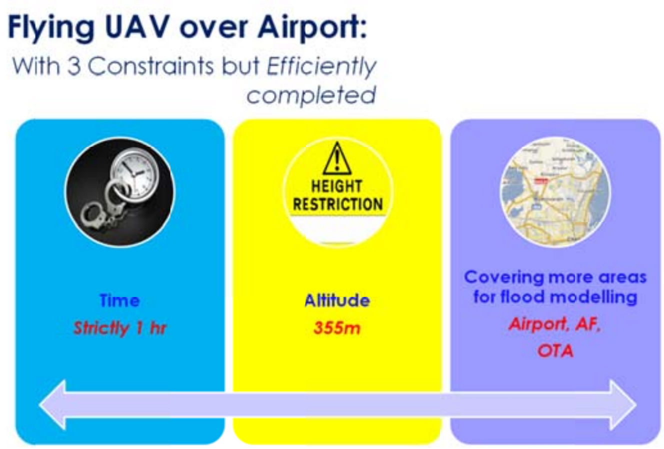


Figure A3 Current constraints for UAS flying

The mapping workflow (Figure A4) consists of the definition of the preparation phase, flight planning, autonomous flight, quality check of the data, data processing – determination of the flight trajectory. For the automated data acquisition, the flight trajectory of the UAS has been calculated in advance (Figure A5). Project parameters like object type, output data, camera sensor, type UAS and flight restrictions are standard project parameters.

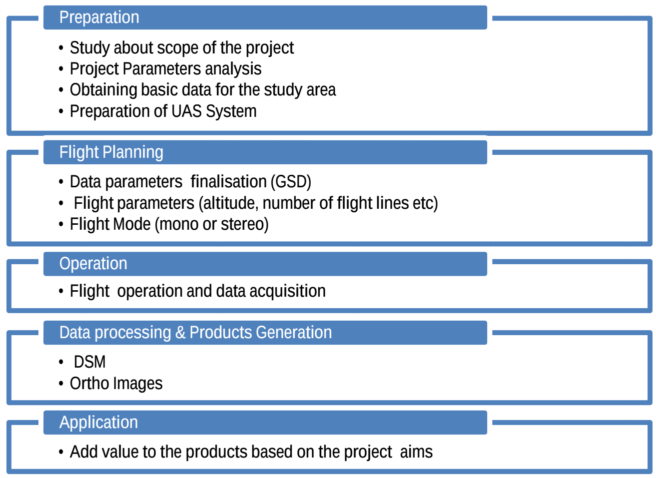


Figure A4. Workflow for UAS data acquisition and processing.

Figure A5 shows flight lines. A total of 64 flight lines covering 350 km were used to cover the project area. The flight lines were designed with 60% to 70 % overlap to have dense cloud points and dense DSM. Care was taken to ensure that the first flight in a day should be longer (40 minutes) with more flight lines, and the second leg with 20 minutes to complete the four regions. However, the region 4 (Officers Training Academy – OTA) was not covered as the permission is still awaited from the concerned authority.

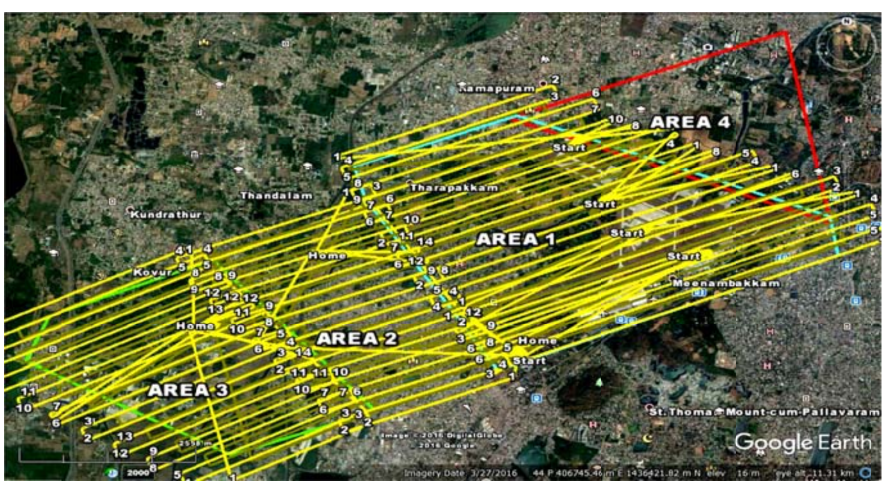


Figure A5 Flight plans used to capture data

After making all the flight lines, a standard procedure of meetings was followed as shown in figure A6.

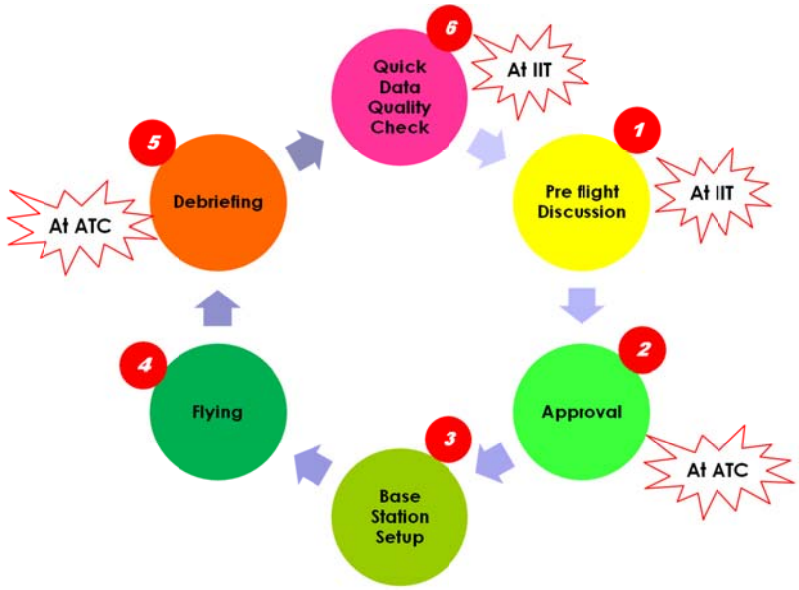


Figure A6 Daily procedure followed pre and post flight (ATC=Air Traffic Control)

Then a daily operational procedure has been formulated as shown in figure A7. Table A2 shows

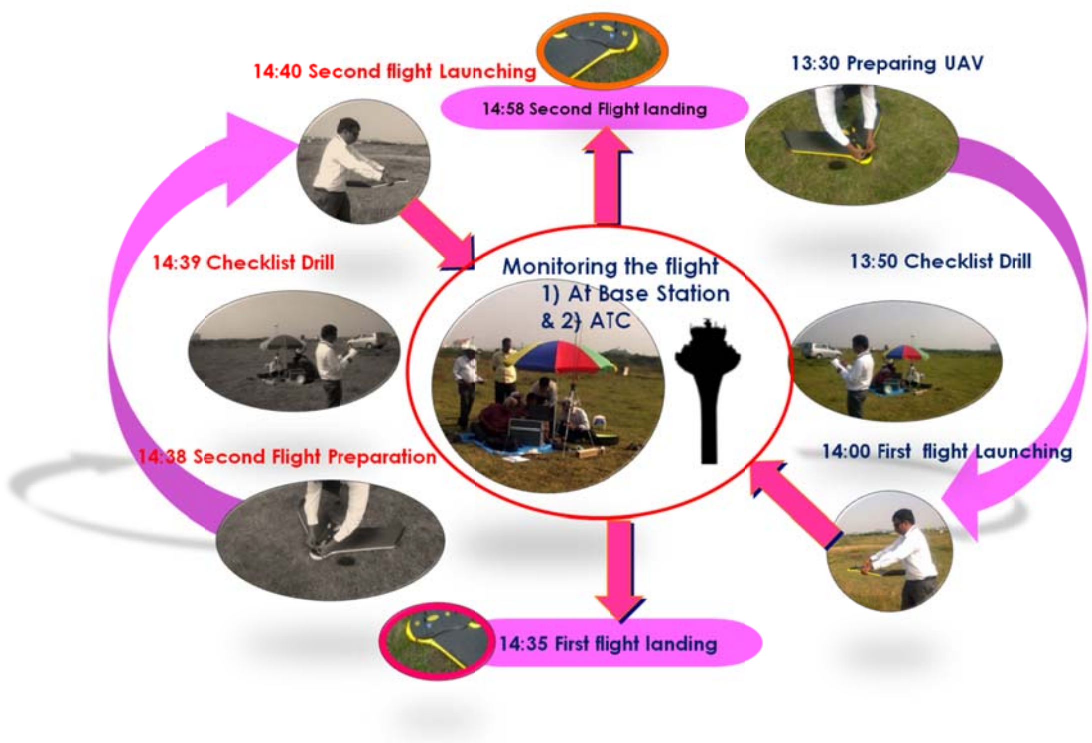


Figure A7.Flight planning and monitoring by four steps.

Table 2. Table of UAS flight programme used for pre-Drone launching approval

UAS FLIGHT PROGRAMME					
UAV TYPE – Category of UAS - UIN			eBee - Civil Micro - NA		
DATE	20-10-2016		ETD	14:00 IST	
REMOTE PILOT STATION/POINT OF DEPARTURE		FLIGHT ID	FLIGHT RULE	VS ↑ ↓	PAYLOAD
	New Fire Station		VLOS		
REMOTE PILOT STATION CONTACT DETAILS					
REMOTE PILOT STATION/POINT OF LANDING		New Fire Station			
CRUISING ALTITUDE	1000 Ft	CRUISING SPEED		10.5 m/s	
AREA / Route to be Followed	WAY Pt.1	WAY Pt.2	WAY Pt.3	WAY Pt.4	WAY Pt.5
	WAY Pt.6	WAY Pt.7	WAY Pt.8	WAY Pt.9	WAY Pt.10
1 2 3 4 5	WAY Pt.11	WAY Pt.12	WAY Pt.13	WAY Pt.14	WAY Pt.15
	WAY Pt.16	WAY Pt.17	WAY Pt.18	WAY Pt.19	WAY Pt.20
DURATION OF FLIGHT / POWER BACKUP		/45Min			

DGCA Approval: 05-13/2014-AED-Vol-III dated 31st May, 2016 ---- MAX All Up Weight: 750g

Legend – A: AREA D: DAY (1 TO 10) F: FLIGHT NA: NOT APPLICABLE Coordinates: WGS 84

1. Met Briefing obtained: 2.
2. I hereby undertaking the responsibility of operating the UAS within the Civil Airspace only and the information provided as above is true to the best of my knowledge

Signature by IIT (M)

Verified by Core Team Leader:

The flight programme as mentioned above is duly accepted considering ATM point of view & accepted by:

Approved By:

7. Data Post-Processing & Final Product Presentation

Initial image quality check was carried out at the end of each acquisition and submitted earlier. By using Pix4Dmapper Pro a quick Quality Report directly after the field works was generated and submitted. After the drone landed, data was imported into eMotion, to perform local processing in Pix4Dmapper, and a quick quality report was generated. Pix4Dmapper's workflow is fully automated (figure A8). After initial processing, orthomosaics, 3D digital surface models (DSMs) and 3D point clouds from UAS's images were generated. The software handled all the necessary calibration and processing to give survey-grade accurate outputs.

An overview of the foundations and necessary steps in post-processing aerial imagery is provided in figure A8. For the automated flight the autonomous data triggering, camera viewing angles, the position and orientations of the sensors have been stored on board. For quality control, the defined and acquired data acquisition points/trajectories, as well as the ground coverage, have to be compared and validated.

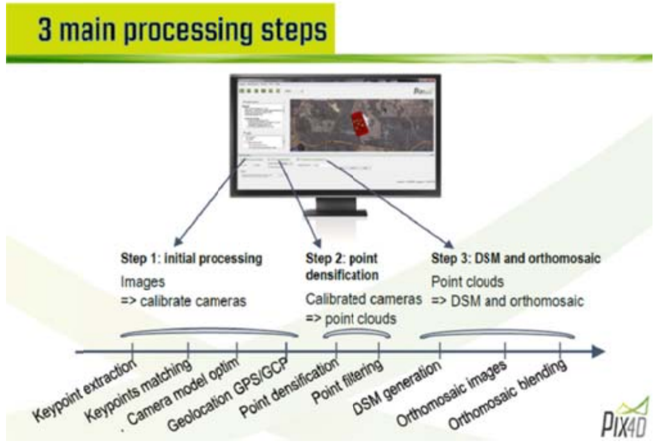
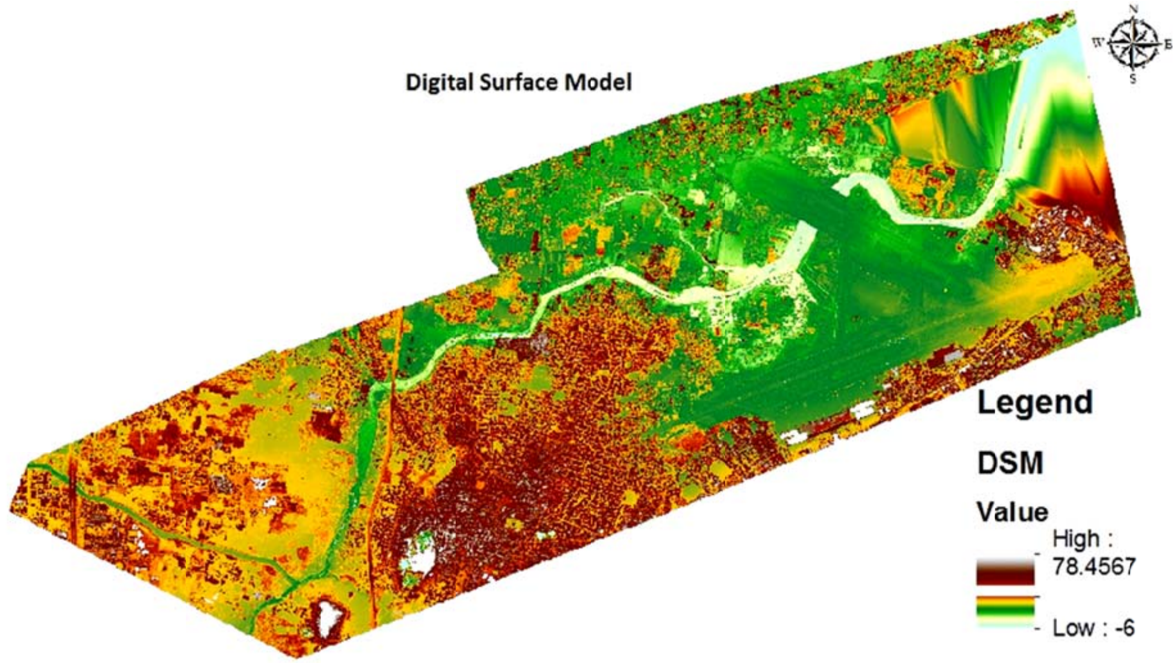


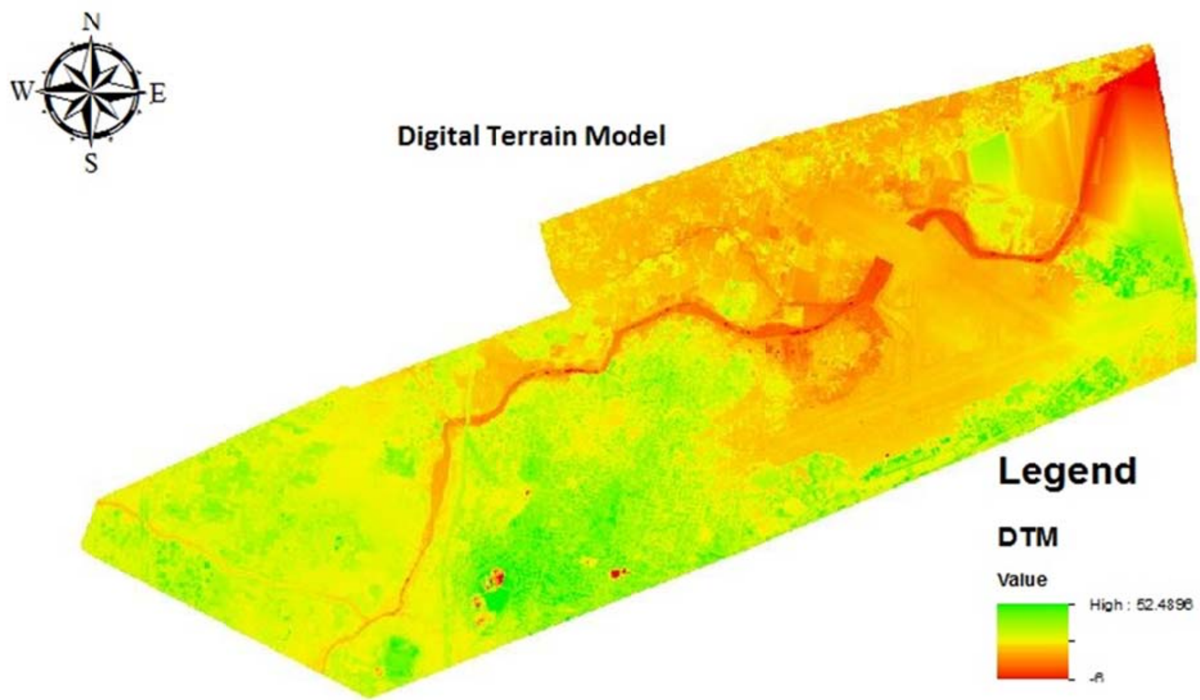
Figure A8 Main steps in data processing

The position and orientation data are generated by the navigation unit of the UAS, which was improved by bundle adjustment and direct georeferencing using control points (which will be done soon). Finally, out of the acquired raw data products, orthoimages (Figure A9a), DSM (Figure A9b), DTMs (Figure A9c), and DTM contour maps (Figure A9d) have been generated.

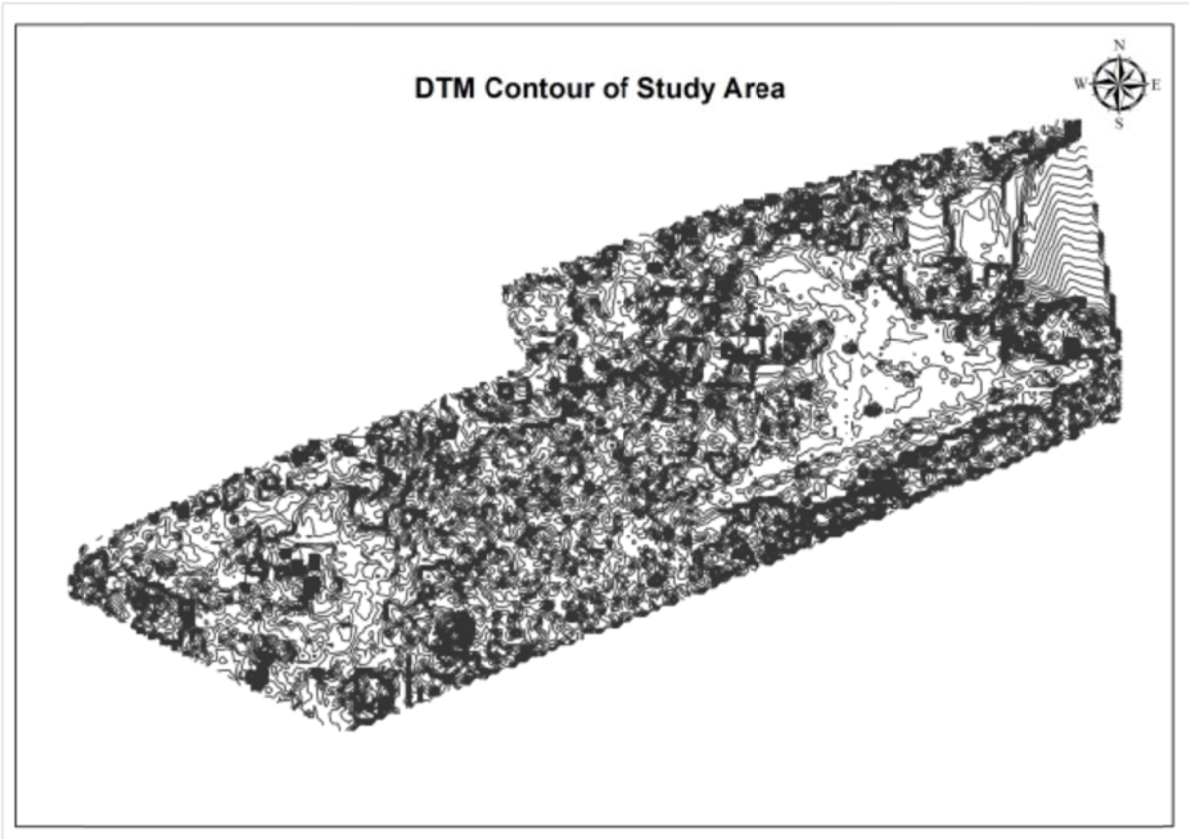
a. Ortho mosaic


Digital Surface Model
Legend
DSM
Value
High : 78.4567
Low : -6

b. DSM


Digital Terrain Model
Legend
DTM
Value
High : 52.4896
-6

c. DTM



d. contour- DSM

Figure A9 Processed data products a) mosaic Orthoimage b) DSM c) DTM d) Contour (DTM)

8. Completed Project Phases

Summary of the completed project phases is illustrated in Figure A10. UAS and the topographic project involved the following key phases, from start till the end is summarised in Table A3. Table A4 shows up a summary of the mission completed.

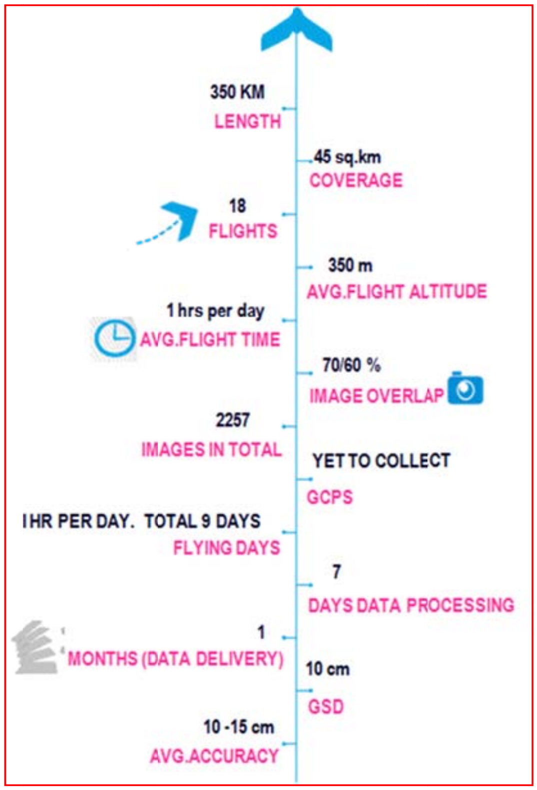


Figure A10 Summary statistics of UAS survey completed

Table A3 Completed project phases

Phase No.	Phase	Description of Phase	Status at the time of this report
I	Mobilisation phase	Finalise the project charter, contract agreement, obtaining statutory permissions, on boarding.	Completed
II	Ground Survey	GCP Placement, Topographic survey at Selective locations	*20 % pending*
III	Data acquisition	This phase involves collection of data using A) Ground topographic survey for GCP collection, Topographic survey using TS at selective places identified by the client B) Survey grade UAS.	A) 60% completed B) 90% completed (*10% pending as delay in grant of OTA permission)*
IV	Processing of Data	Processing for features, DSM, DTM and Ortho images extraction	Completed
V	Final Phase	Final report submission, Data submission in desired format.	UAS survey products submission completed Ground Survey for River and channels completed.

Table A4 Survey summary

FLIGHT PLAN LOG	PROJECT	AAI-IIT-SAKURA 10/2016				APPROVED BY: (NAME, SIGNATURE &			
	SITE	Chennai, Tamilnadu							
	DATE	16/10/2016							
	UAV	eBee							
	ALTITUDE	350 m							
	UAV CONTROLLER	Mr Nishadh S		Mobile	9791562466				
	SOFT.ENGINEER	Mr Palanikumar K		Mobile	9003166941				
S.NO	DAY	DATE OF ACTUAL OPERATION	HOME STATION LOCATION		FLIGHT ID	DURATIO N (H:M:S)	No. of Flight Lines	Lengt h(Km)	No of Phots
			Latitude	Longitude					
1	*1*	19/10/2016	12°59'26.73"N	80°10'23.48"E	A1-D1-F1	00:30:00	2	22.2	186
2	*1*	19/10/2016	"	"	A1-D1-F2	00:30:00	2	21.5	112
3	*2*	20/10/2016	12°59'38.39"N	80°09'56.60"E	A1-D2-F1	00:35:00	3	25.6	166
4	*2*	20/10/2016	"	"	A1-D2-F2	00:20:00	1	14.5	54
5	*3*	21/10/2016	13°00'03.87"N	80°09'45.46"E	A1-D3-F1	00:37:00	4	27.2	196
6	*3*	21/10/2016		"	A1-D3-F2	00:19:00	2	14.3	87
7	*4*	22/10/2016	12°58'47.32"N	80°06'35.47"E	A3-D4-F1	00:37:00	3	27	190
8	*4*	22/10/2016	"	"	A3-D4-F2	00:22:00	6	16.7	94
9	*5*	23/10/2016	12°59'11.63"N	80°09'13.52"E	A2-D5-F1	00:23:00	3	17.2	82
10	*5*	23/10/2016	"	"	A2-D5-F2	00:29:00	6	21.8	155
11	*6*	24/10/2016	13° 0'27.55"N	80° 9'29.17"E	A1-D6-F1	00:34:00	6	24.7	174
13	*7*	25/10/2016	12°58'48.81"N	80° 6'36.22"E	A3-D7-F1	00:32:00	6	24.5	174
14	*7*	25/10/2016	"	"	A3-D7-F2	00:21:00	3	16	81
15	*8*	26/10/2016	13° 0'3.87"N	80° 9'45.57"E	A1-D8-F1	00:18:00	2	13.7	82
16	*8*	26/10/2016	"	"	A4-D8-F2	00:30:00	5	21.6	153
17	*9*	27/10/2016	12°59'26.24"N	80° 7'28.83"E	A2-D9-F1	00:35:00	7	26	187
18	*9*	27/10/2016	"	"	A2-D9-F2	00:20:00	3	14.8	84
19	*10*	*****	13° 0'2.59"N	80°10'18.39"E	A4-D10-F1	00:32:00	10		
20	*10*	*****	"	"	A4-D10-F2	00:34:00	5		
SUMMARY						7:52:00	79	349.3	2257
NOTE:					Battery Change tim	00:30:00			
A) Flight plans should be attached along with this flight log					Total Time	8:22:00			
B) Should be approved by the executing agency									
C) Fill up the yellow boxes									
D) Red Color boxes showing survey not done yet(OTA)									

9. Steps followed for processing UAS photos, Quality and accuracy

Automatic generation of high-quality, dense point clouds from digital images by image matching is a recent, cutting-edge step forward in digital photogrammetric technology. The major components of the system for point cloud generation are a UAS imaging system, an image data collection process using high image overlaps, and post-processing with image orientation and point cloud generation.
The photogrammetric processing line provided dense and accurate point clouds that followed the theoretical principles of photogrammetry.

The following steps available in Pix4D were used to obtain good data to achieve the best results.

Step 1.

Configuring the Camera Settings

Getting GCPs in the Field or Through Other Sources (Pending)

Step 2.

Importing the Images

Configuring the Image Properties

a. Selecting Image Coordinate System –WGS84

b. Importing Images Geolocation and Orientation from the drone

c. Editing Camera Model –Used the RGB Sony

4. Selecting the Output / GCP Coordinate System

5. Selecting the Processing Options Template

Step 3.

1. Initial Processing
2. Analysing the Quality Report
3. Point Cloud and Mesh
4. DSM, Orthomosaic and Index

9.1. Quality Check

1. Quality Check

Verified that:

All the checks are green.

All or almost all the images are calibrated in **one block**.

The relative difference between initial and optimized internal camera parameters is below 5%. (optional)

If using GCPs, the GCP error is below 3×GSD.

(Positioning accuracy achieved is less than 30 cm without GCP)

2. Preview

For projects with nadir images and for which the orthomosaic preview has been generated, verify that the orthomosaic:

Does not contain holes.; Does not have distortions.

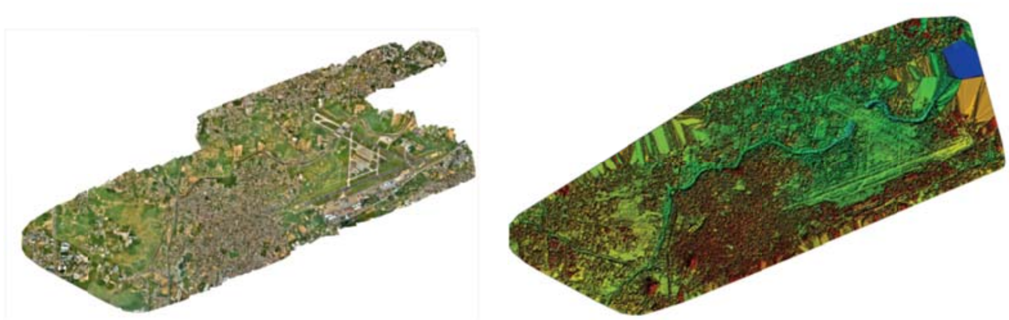


Figure A11 Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification

3. Initial Image Positions

Verified that the initial Image Positions figures corresponds to the flight plan.

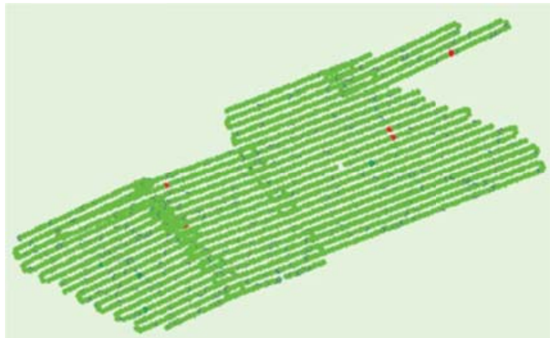


Figure A12 Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

4. Computed Images and overlaps

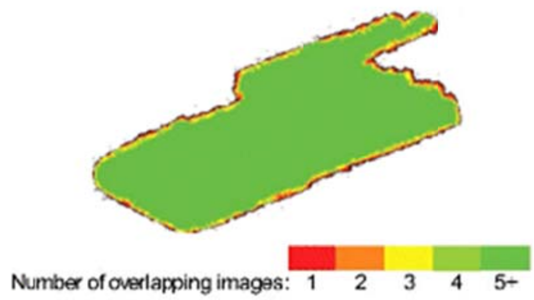


Figure A13 Number of overlapping images computed for each pixel of the orthomosaic.

Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas.

5.DSM, Orthomosaic and Index Details

DSM and Orthomosaic Resolution	1 x GSD (9.77 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: TriangulationMerge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Contour Lines Generation	Generated: yes Contour Base [m]: 0Elevation Interval [m]: 0.1Resolution [cm]: 10Minimum Line Size [vertices]: 20
Index Calculator: Radiometric Calibration	Generated: yes

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D point

9.2. Accuracy with UAS data

The accuracy that is achieved without GCP in X and Y is about 30cm and in height (Z) about 60 cm.

10. Topographic Surveys

Leica Auto level and total station were used for carrying out the drainage elevation and alignment and transfer of reference levels from a specified Survey of India Bench Mark. This instrument has a telescope length of 215 mm and a maximum focusing distance of 2000 m. It has the levelling accuracy of ± 1.0 mm for 1 km double run levelling. Using AutoCAD, the measured cross sections will be processed and presented.

DGPS Survey has been conducted in WGS 84 spheroid, and coordinates are in terms of Universal Transverse Mercator (UTM) Projection for Zone 44. Trimble DGPS SPS 855 was used for measurements. Trimble SCS900 Site Controller Software make the SPS855 easy to use, fast to setup and more productive on the job.

10.1. Channel Surveys

A survey of the stream channel is a critical component of the monitoring activities and provides a reference for other measurements and photographs. Replicate channel surveys with a common datum and coordinate system will enable detection of a geomorphic change that might occur as a result of scour, bed-material aggradation, or lateral channel migration due to recurrent floods.

Total-station survey with a survey-grade GPS survey was adopted for channel monitoring. The channel survey produced location (Northing and Easting) and elevation data that can be used to quantify longitudinal and cross-sectional characteristics of the reach (figure A14). These data also can be used to generate topographic maps of the reconfigured reach, the streambed, gravel bars, banks, and low terraces. Miscellaneous features, such as levees, diversion structures, habitat-enhancement boulders, and bank-protection structures also can be surveyed.

Figure A11 shows a plan view of a typical channel survey. The survey was referenced to WGS 84 datum and UTM44 projection and coordinate system corrected to SOI benchmark.

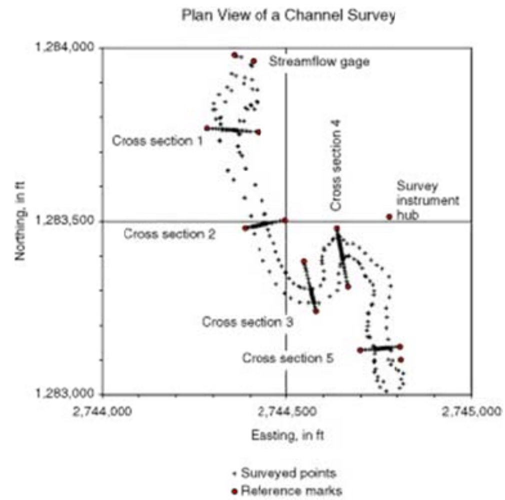


Figure A14 Plan view of a channel survey

10.2. Cross Sections

Channel cross sections were physically surveyed, oriented perpendicular to the bankfull flow and were spaced up and downstream along the channel length at an average of about 3 to 6 times the mean bankfull channel width (figure A14).

10.3. Section Survey Method

Section surveying is an important part of river survey. It included profiles survey (equal to mid-stake survey in concept) and cross-section survey. The section surveying method was undertaken by level, transit stadia and direction set plus poles.

Here opposite side surveying is used in watercourse section survey. Watercourse cross-section surveying is referred to the river-crossing levelling over two banks of the river/drainage. So, that even if two sides of the mainstream/drainage have invisibility, either the river-crossing levelling, or two levels with tower tapes could be used.

Method followed in the project is described here: As in Figure A15, an open control point was found like C3 near the section to be surveyed then the station was set. The height of the station and the prism were given as an input. The internal procedure of radiation surveying function in the total station was used. The seventh mid-stake Z7 as the first target point of the section was taken and then aimed at each section point on the left side of Z7 in sequence to perform the surveying, during which the horizontal distance and difference of elevation from each section point to that of the mid-stake were obtained. Similar procedure was repeated to the right side of Z7 to complete the section.

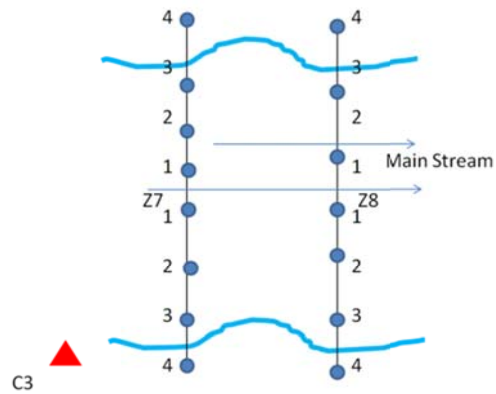


Figure A15 Diagrammatic sketch about section point measuring of the section surveying

If the next section is needed to be surveyed in the following time, the instrument over the station doesn't need to move, as the station and the section point are intervisible, so that aim at the mid-stake in the next stake to take it as the first target, then survey the other section points in sequence. In that case, multiple sections can be surveyed by setting only one station, thereby to improve the efficiency greatly.

In longer reaches, the cross sections were located in subreaches that are representative of the whole reach. Cross section spacing is determined by site-specific considerations. Cross sections was spaced wider apart where the channel is uniform (has little curvature, similar cross-section shape, same grade, same roughness) and was spaced more closely where the channel is irregular (width or slope vary abruptly, islands or bends are present, roughness varies), near bridge abutments and piers.

Survey shots along the cross section are in a straight line (under a stretched tagline or along a navigated course between two GPS-located endpoints) and is made at about 30-40 locations between the banks. Closer spacing was used when there is great streambed irregularity, and wider spacing when the streambed is more uniform and on the flood plain (figure A16).

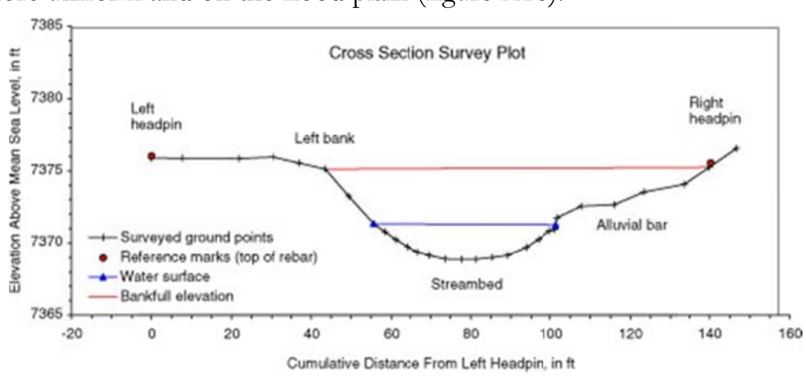


Figure A16 Typical cross section survey plot

10.4. Longitudinal Transect Surveys

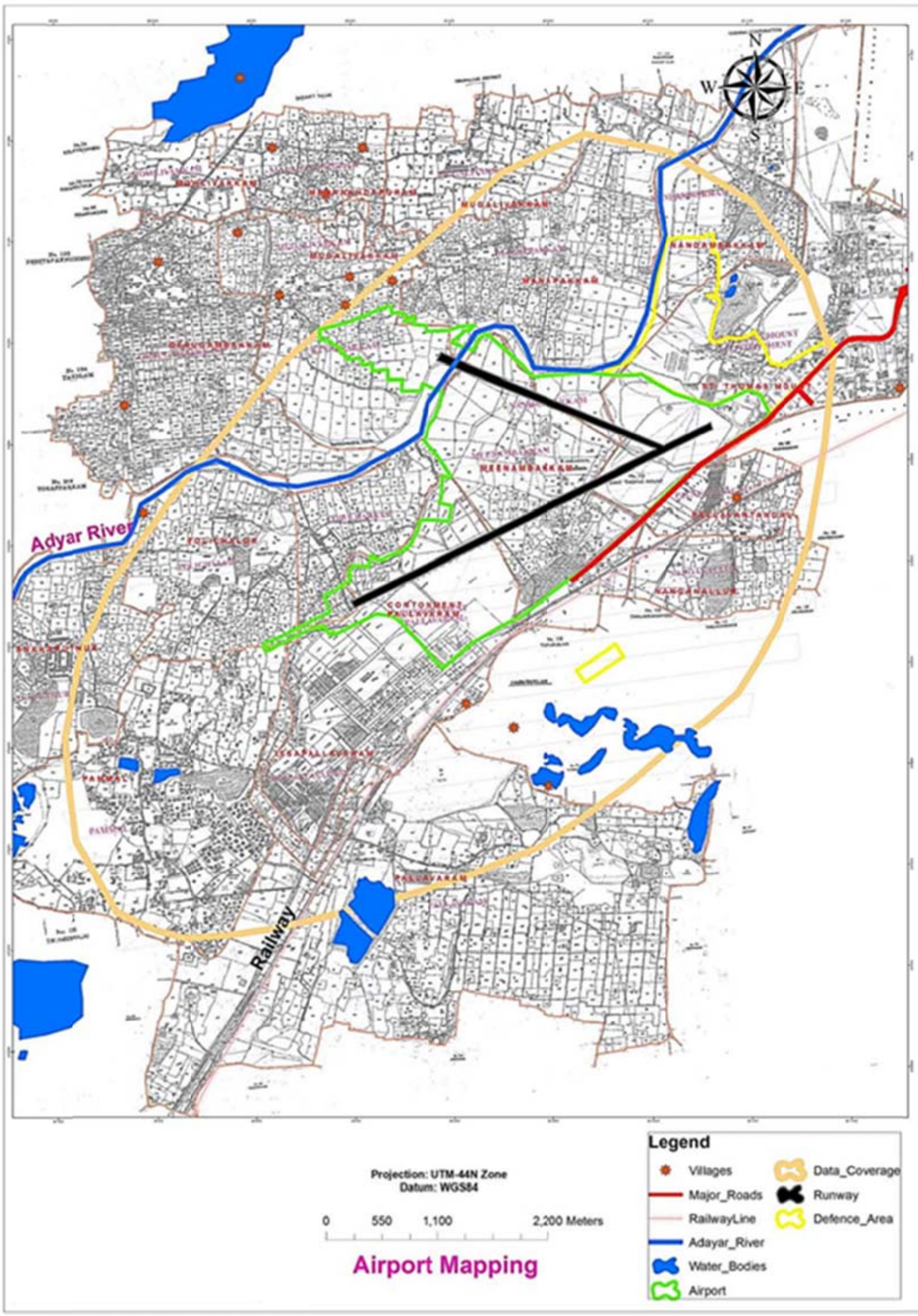
Longitudinal channel transects define the downstream slope or grade, and identify, for mapping purposes, the edge of the water, bars, banks, and other topographic features. These transects could include the left and right edge of the water, the deepest part of the channel, the left and right banks, the tops of gravel bars, levees, and terrace scarps. Features surveyed will vary from reach to reach. Longitudinal transects do not need endpoint monuments because their location will change from year to year in future resurveys and because shots of them are referenced to the channel survey northing and easting coordinates. The spacing between longitudinal transect shots can be wider than for the cross-section shots.

10.5. Accuracy of Topography survey (ground)

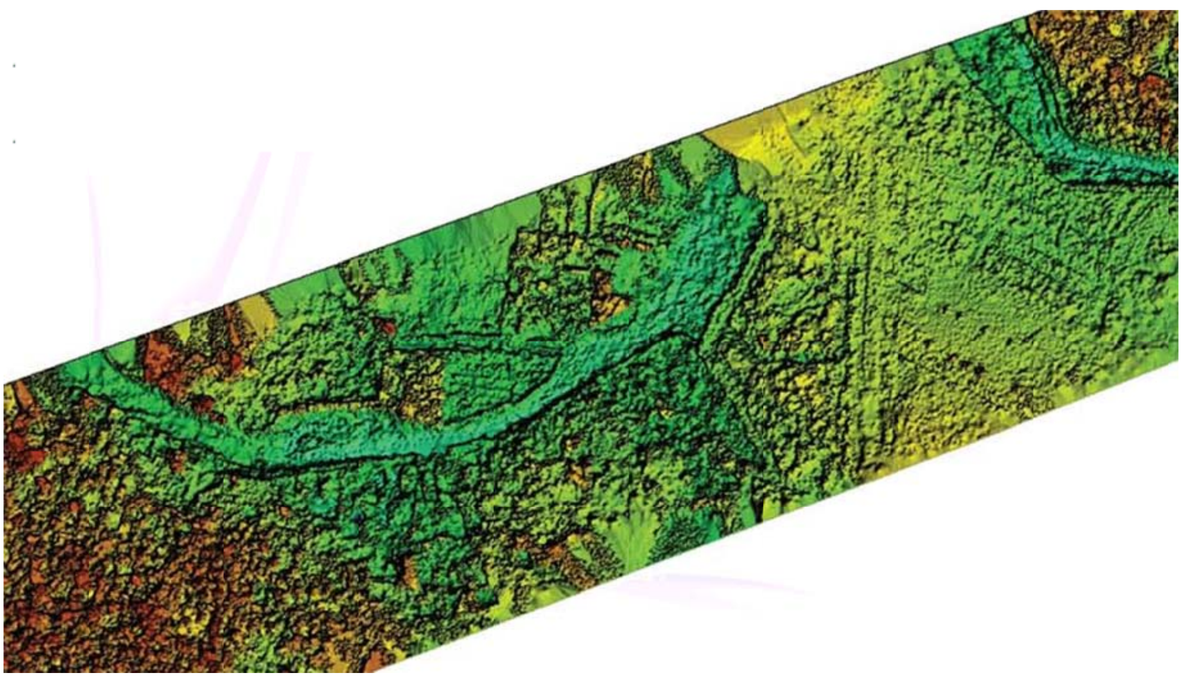
The accuracy achieved in the topography survey (ground) in X and Y is about ±10mm and in elevation (Z) about ±0.9mm.

Annexure A2
Maps and Photographs

1. Basemap prepared for the project

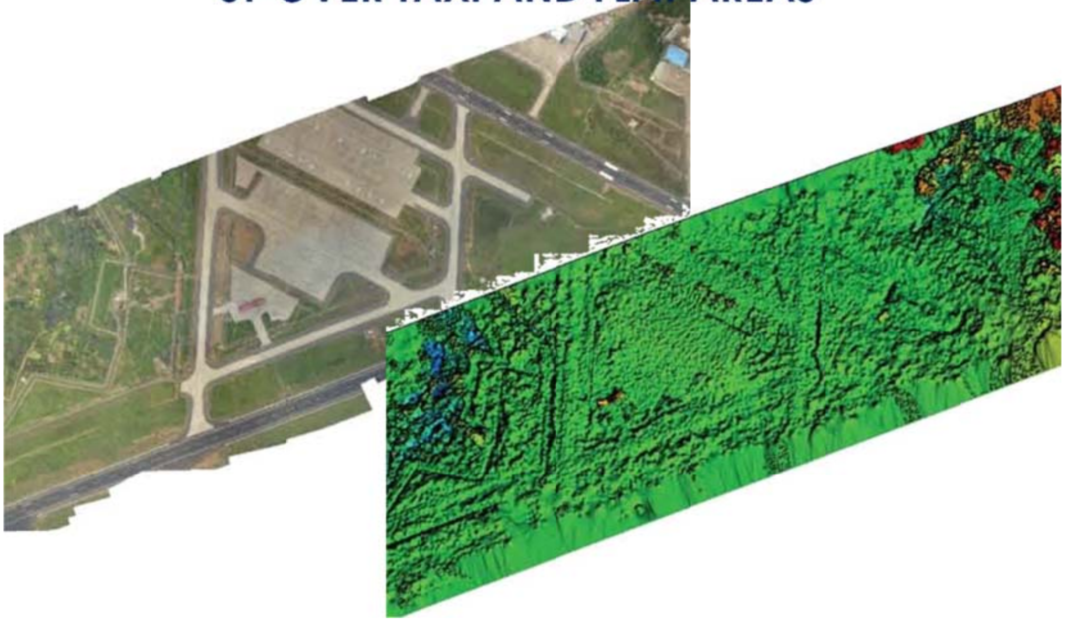


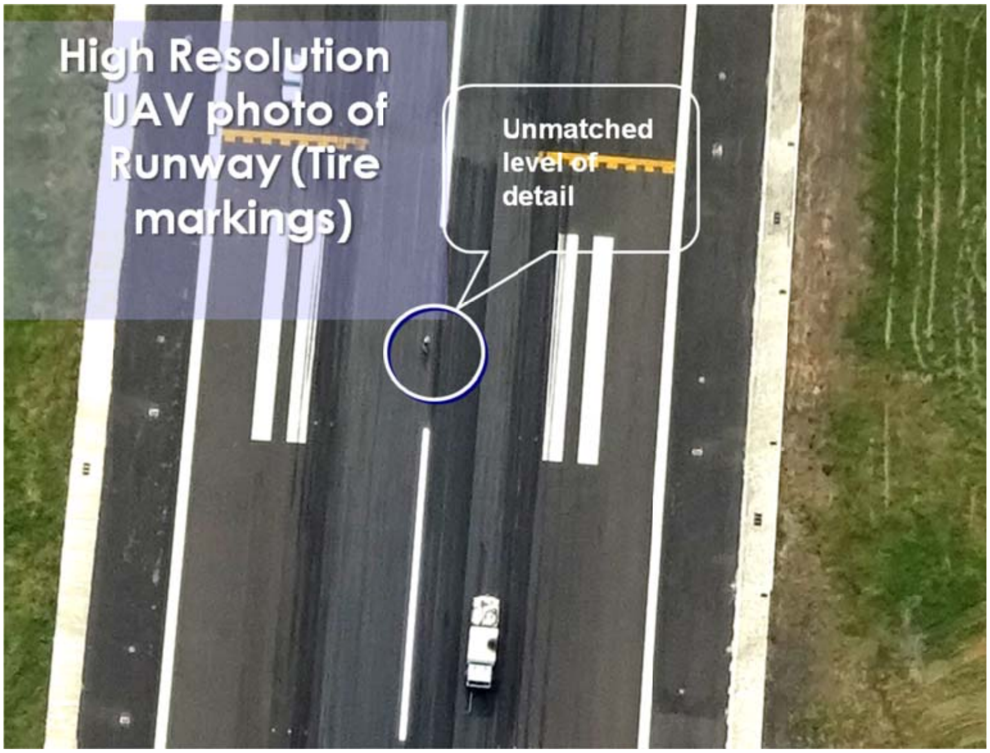
2. Sample Data



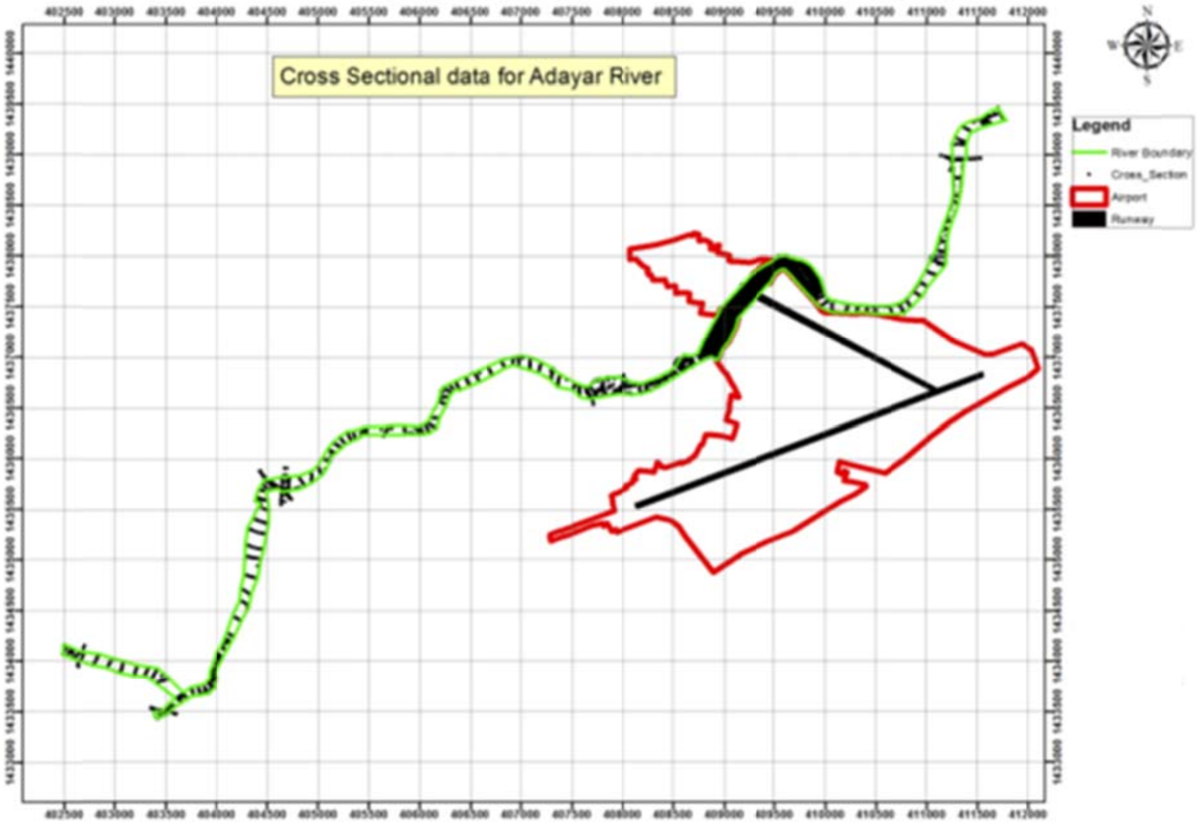
DSM

SUBTLE ELEVATION VARIATIONS PICKED UP OVER TAXI AND FLAT AREAS

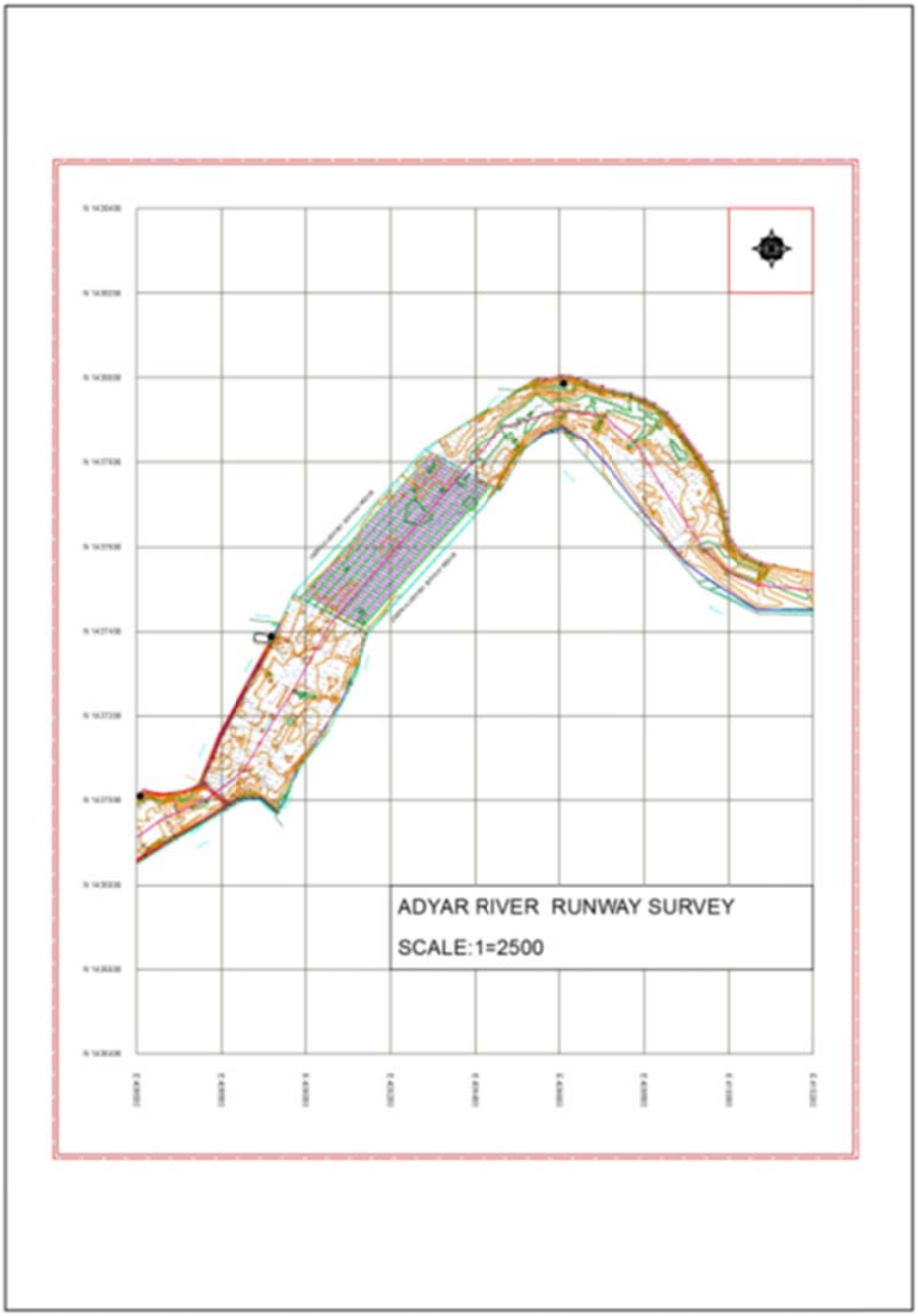



High Resolution UAV photo of Runway (Tire markings)
Unmatched level of detail

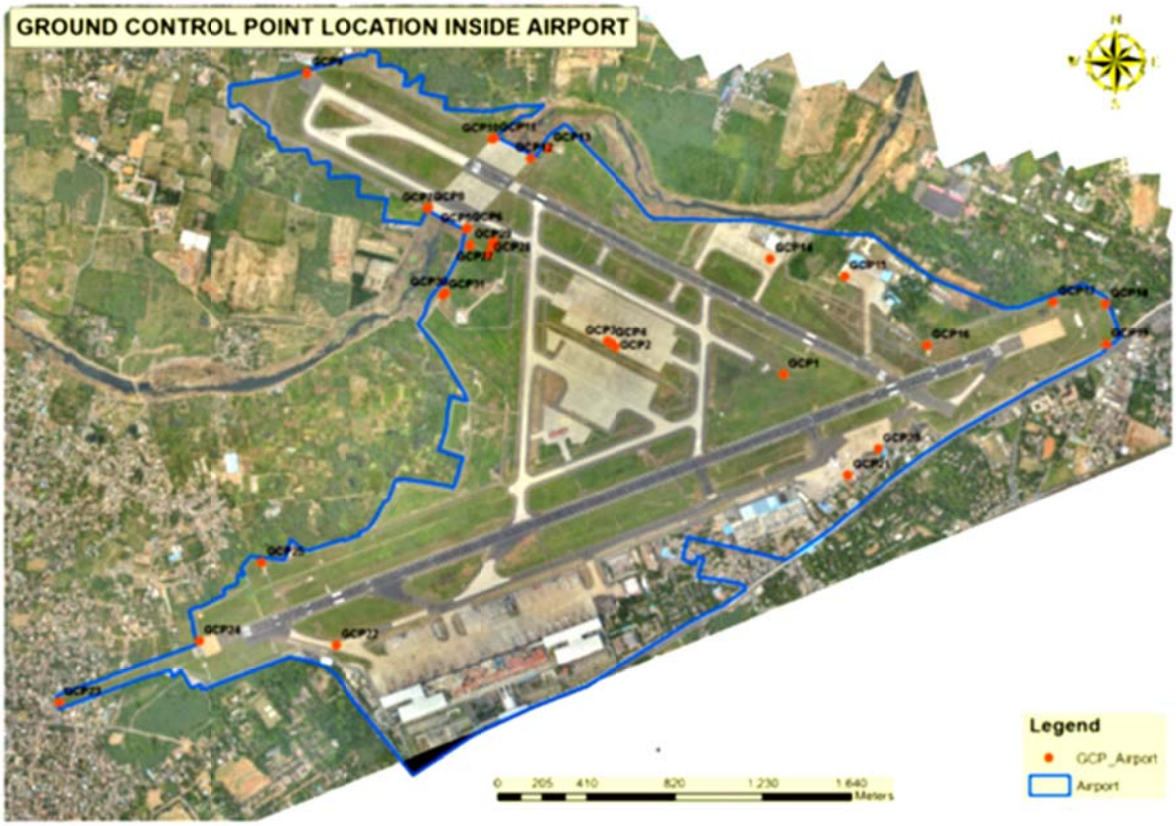
3. Location of cross sections survey at 129 places along Adyar River



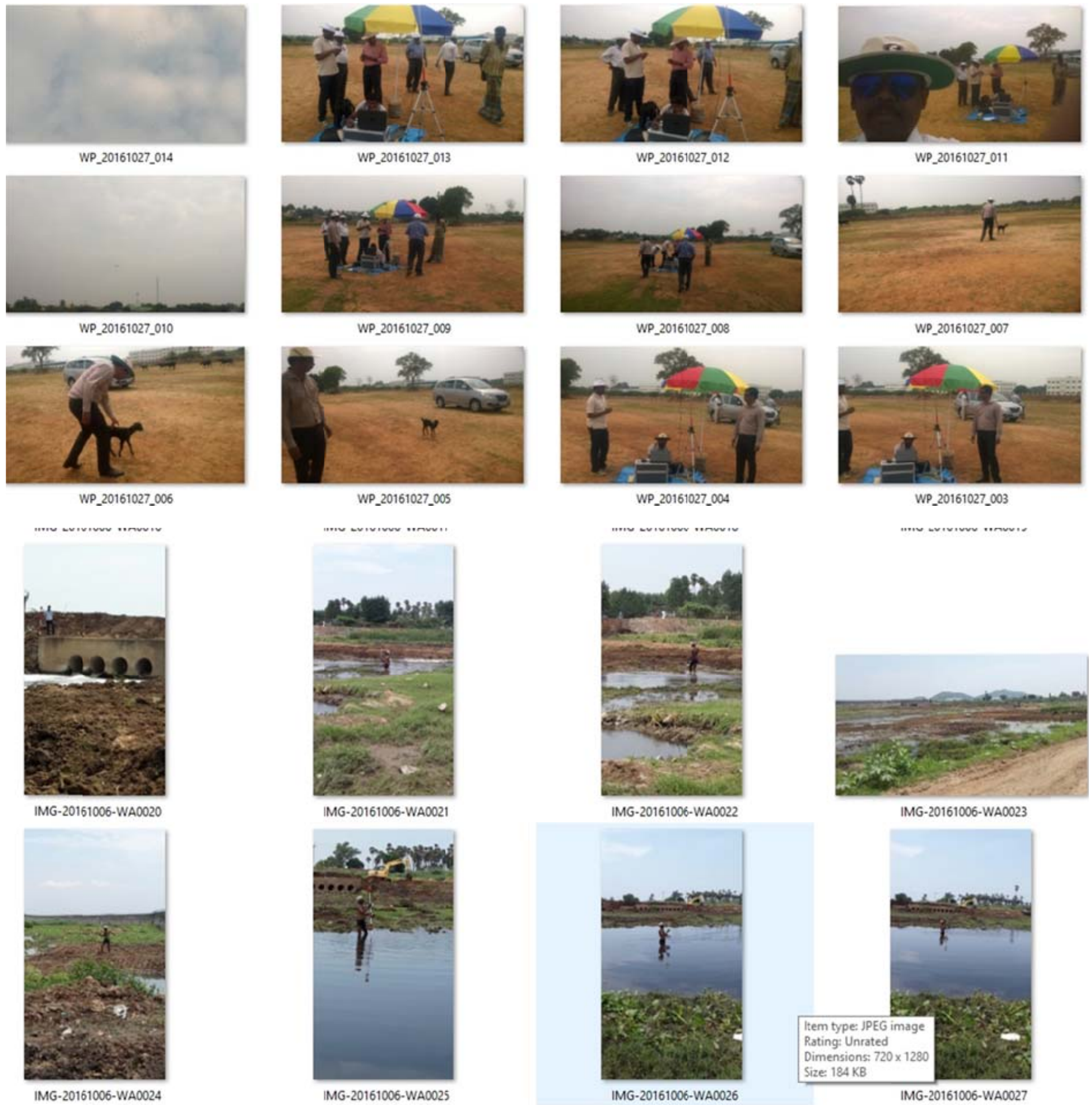
4. Ground Survey Processed Data

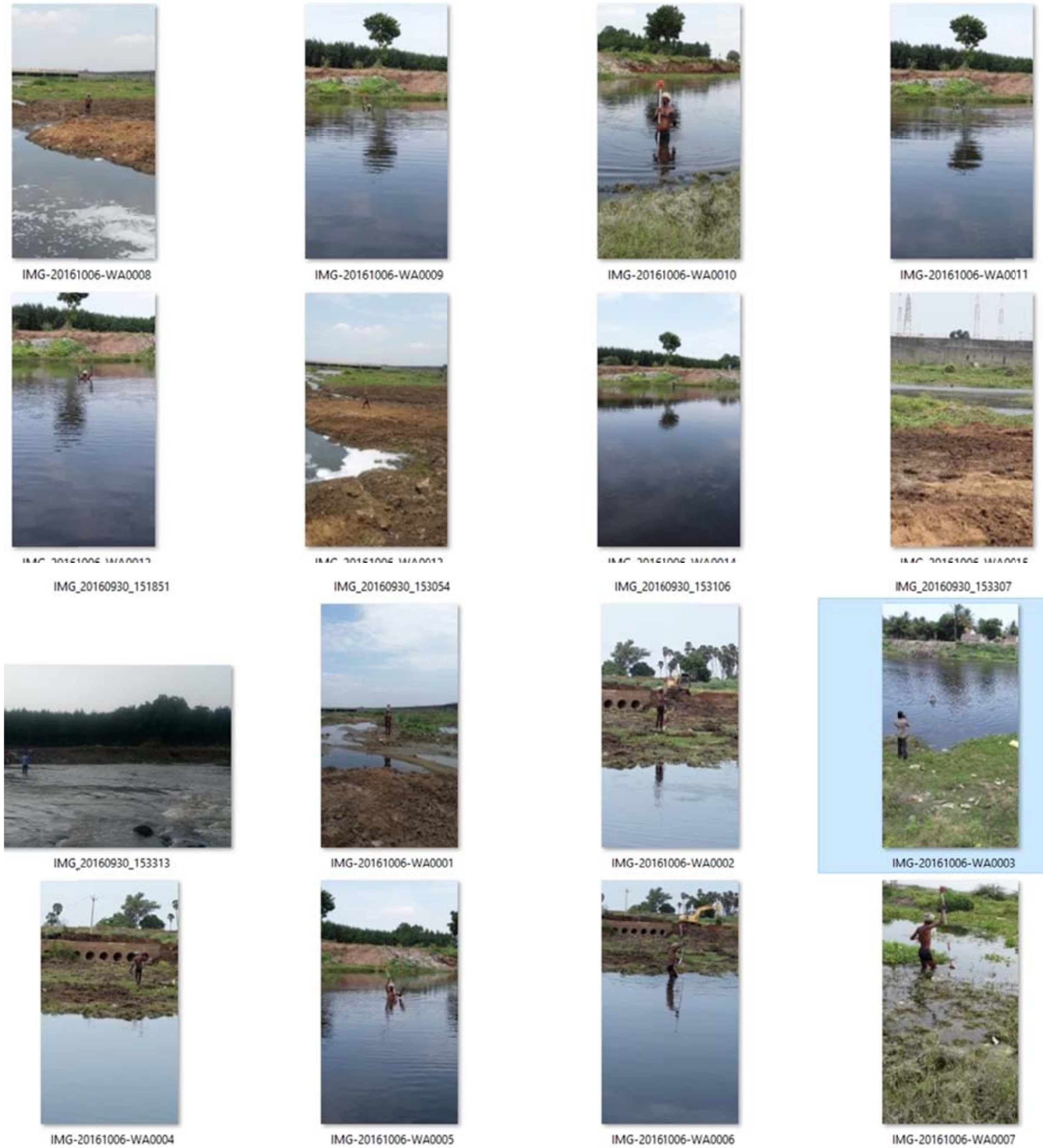


5. Ground Control Point Locations Inside Airport



6. Field Photos




IMG-20161006-WA0008
IMG-20161006-WA0009
IMG-20161006-WA0010
IMG-20161006-WA0011
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IMG_20160930_153054
IMG_20160930_153106
IMG_20160930_153307
IMG_20160930_153313
IMG-20161006-WA0001
IMG-20161006-WA0002
IMG-20161006-WA0003
IMG-20161006-WA0004
IMG-20161006-WA0005
IMG-20161006-WA0006
IMG-20161006-WA0007


IMG_20160913_140154


IMG_20160913_145953


IMG_20150913_145957


IMG_20160913_150000


IMG_20160913_150010


IMG_20160922_104742


IMG_20150922_104802


IMG_20160922_105042


IMG_20160913_110622


IMG_20160913_111904


IMG_20160913_111910


IMG_20160913_124942


IMG_20160913_124945


IMG_20160913_124950


IMG_20160913_125001


IMG_20160913_125007

IMG-20161112-WA0042

IMG-20161112-WA0043

IMG-20161112-WA0044

IMG-20161112-WA0045

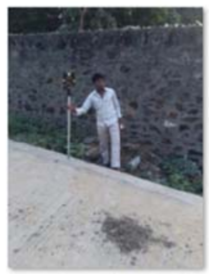
IMG-20161112-WA0046

IMG-20161112-WA0047

IMG-20161112-WA0048

IMG-20161112-WA0034

IMG-20161112-WA0035



IMG-20161112-WA0036

IMG-20161112-WA0037

IMG-20161112-WA0038

IMG-20161112-WA0039

IMG-20161112-WA0040

IMG-20161112-WA0041

IMG-20161112-WA0010 IMG-20161112-WA0011 IMG-20161112-WA0012 IMG-20161112-WA0013




IMG-20161112-WA0014 IMG-20161112-WA0015 IMG-20161112-WA0016 IMG-20161112-WA0017




IMG-20161112-WA0018 IMG-20161112-WA0019 IMG-20161112-WA0020 IMG-20161112-WA0021




IMG-20161112-WA0002 IMG-20161112-WA0003 IMG-20161112-WA0004 IMG-20161112-WA0005





IMG-20161111-WA0016


IMG-20161111-WA0017


IMG-20161111-WA0018


IMG-20161111-WA0019


IMG-20161111-WA0012


IMG-20161111-WA0013


IMG-20161111-WA0014


IMG-20161111-WA0015


IMG-20161111-WA0004
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IMG-20161111-WA0006
IMG-20161111-WA0007
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IMG_20161205_104537
IMG_20161205_104541


IMG-20161111-WA0012
IMG-20161111-WA0013
IMG-20161111-WA0014
IMG-20161111-WA0015
IMG_20160924_122227
IMG_20160924_122245
IMG_20160924_122253
IMG_20160924_122409
IMG_20160924_122426
IMG_20160924_122433
Item type: JPEG image
Date taken: 24/09/2016 12:24
Rating: Unrated
Dimensions: 3264 x 2448
Size: 3.61 MB
IMG_20160924_122445
IMG_20160924_122624

Annexure A3
Template of check lists for UAS Survey

1. Template of check list adopted by IIT Madras

Date:

No	Items to check prior to leaving IIT Madras campus:	Check (√) / Remark
1.	Are the two batteries of drone charged full	
2.	Are the wifi dongles and Cell phones charged full	
3.	Are the laptops charged full	
4.	Is the Camera SD card inserted properly and has adequate space	
5.	Is the camera lense clean	
6.	Are the airport security passes for all team members in their possession	
7.	Is the vehicle pass available in possession	
8.	Does the base station team have copy of the agreement and paperwork in their possession	
9.	Is the backup hard disk ready	
10.	Water bottles and cap	
	Name:	
	Signature:	
	Leave the campus at 10:00AM	
	Items to check at the flight planning session at AAI	
1.	Are the flight lines away from sensitive ground features by a safe distance	
2.	Is the flight duration based on simulation within 60 minutes	
3.	Are the flight plans saved	
	Name of flight plan file1: Duration:	
	Name of flight plan file2: Duration:	
	Name:	
	Signature:	
	Leave for base station at 12:30 PM	
	Items to check at the base station / ATC Station	
	The following checks should start at or before 1:00PM between base station and the ATC tower station	
1.	Are the cell phone signals available in at least one of the wifi dongles and screen can be shared with the base station	
2.	Do a flight simulation of the planned flight line for the day and share the screen at ATC for checking if it is working fine	
	Hibernate or put the system to sleep after check	
3.	Is the camera SD card inserted properly	
4.	Is the camera lense clean	
5.	Is the camera inserted properly in the drone	

6.	Are the drone batteries inserted properly	
7.	Is the drone powering up	
	Switch on the base station system and ATC system and do the same checks at 1:45PM	
	Drone Launch time 1: Landing time:	
	Drone Launch time 2: Landing time:	
	Name:	
	Signature:	
	Items to check after the flight at the planning room	
1.	Download the images to the system	
2.	Download the images to the harddrive backup of ATC	
3.	Download the images to the harddrive backup of IIT madras	
4.	Do the flight planning for the following day	
5.	Are the flight lines away from sensitive ground features by a safe distance	
6.	Is the flight duration based on simulation within 60 minutes	
7.	Are the flight plans saved	
	Name of flight plan file: Duration:	
	Name of flight plan file: Duration:	
	Name:	
	Signature:	
	Items to check after coming back to IIT Madras	
1.	Download the images to the workstation for preliminary processing	
2.	Run the quality check in the process software	
3.	Delete the images from the SD card of the drone camera	
4.	Put the drone batteries to charge	
5.	Put the laptop to charge	
6.	Put the dongles to charge	
7.	Put your mobile phones to charge	
8.	Check firmware updates for the drone	
	Name:	
	Signature:	

2. Template of check list adopted by ATC, Chennai

 24/x/18

UAS OPERATION PRE FLIGHT CHECKLIST

Annexure II

Sl. No.	Description	Time/Action	Remarks
1	Flight Programme Submitted	1155	
	WSO, SSO	1215	
	Tower Supervisor	1215	
	4AFMLU	1215	
2	Airport Fire Station	–	
3	UAS Tracker Connectivity Check	✓	
	Walkie-Talkie connectivity/Range Check (TWR & Base)	✓	
4	Verification of the Base Station coordinates with the Physical location of Base Station.	✓	
5	Availability of CISF/police personnel at Base Station	✓	
6	Verification of Sector prior to upload	✓	
7	Verification of Altitude of the flight	✓	
8	UAS Tracker Calibration Accuracy in Tower	✓	
9	UAS Tracker Calibration Accuracy at Base Station	✓	
10	Uploading of Sector into UAS	✓	
11	Time Departure of UAS	1359 ✓ 1404	
12	Availability of Binocular Airport to Base Station.	✓	

Signature of IIT(M)

डॉ. बालाजी नरसिंहन
Dr. BALAJI NARASIMHAN
सह प्राध्यापक / Associate Professor
सिविल इंजीनियरिंग विभाग
Department of Civil Engineering
भारतीय प्रौद्योगिकी संस्थान मद्रास
INDIAN INSTITUTE OF TECHNOLOGY MADRAS

Signature of Core Team

Annexure II

UAS OPERATION CHECKLIST PRIOR TO COMMENCEMENT

Date: 24/10/2016

Period of Activity 1400-1500 IST

Sl. No.	Description	Time/Action	Remarks
1	Core Team Assemble Time	1050	
2	Proposed ETDs of UAS	1400 1424	
3	Runway in Use	07/25	
4	Visibility	>5 KM	
5	Meteorological Forecast		
6	VVIP Movement	NIL	
7	Main Sector	NORTH OF RWY 07/25 WEST OF RWY 12/30	
8	Alternate Sector	—	
6	Flight Programme Planning	YES	
7	Instruction to UAS Coordinator (Tower/Base Station)	operational on a directive	
8	Availability of AEP with Base Station personnel	YES	
9	Availability & Serviceability of Walkie-Talkie	✓	
10	Availability & Connectivity of Tracker (Tower / Base)	✓	
11	Coordination with Other Agencies(OTA/CG/CMRL/Tambaram) as applicable	NA	

Submitted for approval by GM(ATM-CH)

डॉ. बालाजी नरसिंहन
Dr. BALAJI NARASIMHAN
सह प्राध्यापक / Associate Professor
सिविल इंजीनियरिंग विभाग
Department of Civil Engineering

Signature of IIT(M), Core Team

Signature of Core Team

The flight Programme is approved from Chennai ATM point of View subject to the conditions specified under SOP for UAS operations.

Signature of GM(ATM-CH)

FLT 1

UAS FLIGHT PROGRAMME					
UAV TYPE - Category of UAS - UIN		eBee - Civil Micro - NA			
DATE	24-10-2016	ETD	14:00 IST		
REMOTE PILOT STATION/POINT OF DEPARTURE		FLIGHT ID	FLIGHT RULE	VS ↑ ↓	PAYLOAD
13 00 27.55N 80 09 29.17E	Abeam beginning of Rlw 12	A1-D7-F2-1	VLOS	550 ft/s	100 Grams
REMOTE PILOT STATION CONTACT DETAILS		+91 9940348713, +91 9791562466, +91 9003166941			
REMOTE PILOT STATION/POINT OF LANDING		POINT OF DEP/LANDING SAME			
CRUISING ALTITUDE	1000 ft	CRUISING SPEED		10.5 m/s	

AREA / Route to be Followed	WAY Pt.1	WAY Pt.2	WAY Pt.3	WAY Pt.4	WAY Pt.5
	13 00 31.49 N 80 10 07.79 E	12 59 42.26 N 80 07 52.00 E	12 59 46.36 N 80 07 50.36 E	13 00 32.37 N 80 09 52.10 E	—
	WAY Pt.6	WAY Pt.7	WAY Pt.8	WAY Pt.9	WAY Pt.10
	—	—	—	—	—
1	WAY Pt.11	WAY Pt.12	WAY Pt.13	WAY Pt.14	WAY Pt.15
2 3	—	—	—	—	—
4	WAY Pt.16	WAY Pt.17	WAY Pt.18	WAY Pt.19	WAY Pt.20
5	—	—	—	—	—
DURATION OF FLIGHT / POWER BACKUP			22 Min	/45Min	

2 LEGS

DGCA Approval: 05-13/2014-AED-Vol-III dated 31st May, 2016 ---- MAX All Up Weight: 750g

Legend - A: AREA D: DAY (1 TO 10) F: FLIGHT NA: NOT APPLICABLE Coordinates: WGS 84

1. Met Briefing obtained: 2.
2. I hereby undertaking the responsibility of operating the UAS within the Civil Airspace only and the information provided as above is true to the best of my knowledge

Verified by Core Team Leader: [signature] 24/10/16

Signature by IIT(M) [signature] डॉ. बालाजी नरसिंहन Dr. BALAJI NARASIMHAN सह प्राध्यापक / Associate Professor सिविल इंजीनियरिंग विभाग Department of Civil Engineering

The flight programme as mentioned above is duly accepted considering ATM point of view & accepted by: [signature] R. SRIDHAR JGM ATM

Approved By: [signature] (SAS) 24/10/16

FLT II

UAS FLIGHT PROGRAMME						
UAV TYPE – Category of UAS - UIN			eBee - Civil Micro - NA			
DATE	24-10-2016		ETD	14:24 IST		
REMOTE PILOT STATION/POINT OF DEPARTURE			FLIGHT ID	FLIGHT RULE	VS ↑ ↓	PAYLOAD
13 00 27.55N 80 09 29.17E	1 beginning of Rwy 12		A1 – D7 – F1	VLOS	550 f/s	100 Gram
REMOTE PILOT STATION CONTACT DETAILS			+919940348713, +919791562466, +919003166941			
REMOTE PILOT STATION/POINT OF LANDING			Point of DEP/LANDING SAME			
CRUISING ALTITUDE		1000 ft	CRUISING SPEED		10.5 m/s	

AREA / Route to be Followed	WAY Pt.1	WAY Pt.2	WAY Pt.3	WAY Pt.4	WAY Pt.5
	13 00 16.00 N 80 07 38.82 E	13 00 51.85 N 80 09 13.68 E	13 00 47.75 N 80 09 15.31 E	13 00 09.66 N 80 07 40.05 E	13 00 05.56 N 80 07 41.68 E
	WAY Pt.6	WAY Pt.7	WAY Pt.8	WAY Pt.9	WAY Pt.10
	13 00 45.06 N 80 09 31.71 E	13 00 40.96 N 80 09 33.34 E	12 59 57.79 N 80 07 44.63 E	12 59 53.69 N 80 07 46.26 E	13 00 35.76 N 80 09 43.08 E
(1) 2 3 4 5	WAY Pt.11	WAY Pt.12	WAY Pt.13	WAY Pt.14	WAY Pt.15
	—	—	—	—	—
	WAY Pt.16	WAY Pt.17	WAY Pt.18	WAY Pt.19	WAY Pt.20
	—	—	—	—	—
DURATION OF FLIGHT / POWER BACKUP			36 Min	/45Min	

5 LEGS

DGCA Approval: 05-13/2014-AED-Vol-III dated 31st May, 2016 ---- MAX All Up Weight: 750g

Legend – A: AREA D: DAY (1 TO 10) F: FLIGHT NA: NOT APPLICABLE Coordinates: WGS 84

1. Met Briefing obtained: 2.
2. I hereby undertaking the responsibility of operating the UAS within the Civil Airspace only and the information provided as above is true to the best of my knowledge

Verified by Core Team Leader: [signature] 24/X/16

Signature by IIT (M) N. [signature]

The flight programme as mentioned above is duly accepted considering ATM point of view & accepted by: [signature] R. SRIDHAR Sr.M ATM

डॉ. बालाजी नरसिंहन
Dr. BALAJI NARASIMHAN
सह प्राध्यापक / Associate Professor
सिविल इंजीनियरिंग विभाग
Department of Civil Engineering
भारतीय प्रौद्योगिकी संस्थान मद्रास
INDIAN INSTITUTE OF TECHNOLOGY MADRAS
Chennai - 600 036 भारत / INDIA

Approved By: [signature] /SOS 24/X/16

Annexure - II

UAS OPERATION CHECKLIST – AFTER COMPLETION OF FLIGHT

Sl. No.	Description	Time/Action	Remarks
1	Flight Path Conformity Check		
2	Airspace Boundary Violation Check	✓ NIL	
3	Interference with Navigational Aids	NIL	
	ILS: LLZ,GP	NIL	
	VOR	NIL	
	DME	NIL	
4	Surveillance Facilities	NIL	
	ELSDIS- MSSR, PSR		
	RF LINK	✓	
5	Return Home	✓	
6	Link Failure between Base and UAS	NIL	
7	Crossing Sector Boundary	NIL	
8	Level Deviation	NIL	
9	Lateral Deviation	NIL	
10	Avoidance of pre-selected area	NA	
11	Dynamic Avoidance of a designated area after assigning a particular airspace.	NA	
12	Bird Menace	NIL	
13	Safety to other Aircraft Operations	NIL	
14	Safety Infringement	NIL	
15	Any other including contingency	NIL	
16	UAS Landed Time	~~1402~~ 1443	
17	Survey Data Collection	✓	
28	Handing over of Data Collected	YES	
29	Winding up of Base Station	1450	
30	Physical Identification of Next Day Base Station	✓	
31	Departure from Operational Area by Base Station Personnel	YES	
32	Core Team Reassemble at ATS Conference Hall	YES	
33	Planning of Next Day Activity	YES	
34	Other Observations:	NIL	
35	Log entry	[illegible]	

IIT (M) Personnel [signature] AAI Civil Personnel [signature] 24/10/2016

Core Team Lead [signature] 24/10/16

डॉ. बालाजी नरसिंहन
Dr. BALAJI NARASIMHAN
सह प्राध्यापक / Associate Professor
सिविल इंजीनियरिंग विभाग
Department of Civil Engineering
भारतीय प्रौद्योगिकी संस्थान मद्रास
INDIAN INSTITUTE OF TECHNOLOGY MADRAS
चेन्नै / Chennai - 600 036, भारत / INDIA

1. **Template of check list adopted during the the UAS survey on the field**

Operational Checklist											
S.No	**Task**	**Flight1**	**Flight2**	**Flight3**	**Flight4**	**Flight5**	**Flight6**	**Flight7**	**Flight8**	**Flight9**	**Flight10**
1	Assemble Drone										
2	Open eMotion Software(**Real Drone Connector**)										
3	Connect Radio link Modem										
4	Upload Flight Plan (SetupPhase TAB)										
5	A. Mission Area Load										
6	B. Check for Flight Altitude Parameter & Resolution										
7	Check for Working area radius										
8	Security Action uncheck Rc Signal & 30 Sec										
9	Ground Camera Check On in Camera tab										
10	Check for Full or Half Flight										
11	If Half Flight check for Start Waypoint Camera On										
12	Check For Flight Altitude Parameter										
13	Check for takeoff and landing Direction										
14	Ensure is Battery Is installed										
15	Check for Flight plan saved to drone										

Annexure A4
Copies of permission letters

1. **One time NOC from Ministry of Home Affairs, GoI**

08/09 2016 5:58PM FAX +91 11 24611104 MEMBER (PLANNING), AAI 0001

SECRET

No.II/20034/236/2016-IS-II
Government of India
Ministry of Home Affairs
IS-I Division (IS-II Section)

North Block, New Delhi
Dated: the 06 Sept. 2016

OFFICE MEMORANDUM

Sub: One time no objection for operation of UAS for Aerial Survey in and around Chennai Airport – reg.

The undersigned is directed to refer to M/o Civil Aviation's OM No. AV-24011/18/2016-AAI (115854) dated 01.07.2016 on the above subject and to convey "No Objection" for operating UAS (for one-hour maximum for 10 days) for conducting the aerial (Drone) survey by IIT-Madras in and around the Chennai Airport subject to the following conditions in addition to conditions laid down by the DGCA in permission granted vide letter dated 30.06.2016 (copy enclosed): -

(i) UAS operations should be carried out strictly by the officials duly authorized by AAI/IIT Madras;

(ii) Concerned District Authority should be informed about the proposed UAS operation well in advance so that they can also associate themselves in monitoring the same.

(R.N. Singh)
Under Secretary to Govt. of India

Ministry of Civil Aviation
(Shri K V Unnikrishanan, Under Secretary),
'B' Block, Rajiv Gandhi Bhawan,
New Delhi

Copy to:
Director General of Civil Aviation,
(Shri Lalit Gupta, Jt. Director General)
Opp. Safdarjung Airport, New Delhi-3.

AGM(C)-II
For information please
09/9/16
JGM(C)

DRONE Survey

2. One time NoC from DGCA

GOVERNMENT OF INDIA
OFFICE OF THE
DIRECTOR GENERAL OF CIVIL AVIATION
OPP. SAFDARJUNG AIRPORT, NEW DELHI - 1100 003
AIRCRAFT ENGINEERING DIRECTORATE

भारत सरकार
महानिदेशक नागर विमानन का कार्यालय
सफदरजंग एयरपोर्ट के सामने
नई दिल्ली - ११० ००३
वायुयान इंजीनियरिंग निदेशालय

Tele-Fax: +91-11-24623211
E-mail: lalit.dgca@nic.in

Reference No.: संख्या: 05-13/2014-AED-Vol-III
Dated: दिनांक: 31-05-2016

The Chairman,
Airports Authority of India,
Rajiv Gandhi Bhawan,
New Delhi-3.

(Kind Attn: Shri S. Raheja)

Subject: One time no objection for operation of UAS for aerial survey in and around Chennai Airport

Sir,

Reference may please be made to AAI's DO no. AAI/M(Plg.)/Chennai/2016/78 dated 19-05-2016, wherein AAI have requested DGCA's permission to carry out drone survey in and around Chennai Airport for study of geography and terrain of the area to avoid re-occurrence of stoppage of operation at Chennai Airport during heavy rains.

Based on your request and justification, this office hereby accords "one time no-objection" to Airports Authority of India to operate UAS for aerial survey in and around Chennai Airport. However, this 'one time no-objection' shall be valid if all conditions as stated in Annexure-I to this letter are strictly adhered to.

This issues with approval of the Director General of Civil Aviation.

Encl: As stated

(Lalit Gupta)
Joint Director General of Civil Aviation
for Director General of Civil Aviation

Copy for information to:

1. Joint Secretary (Internal Security), Ministry of Home Affairs, New Delhi-01.
2. Joint Secretary (Shri B.S. Bhullar), Ministry of Civil Aviation, New Delhi-03.

Annexure – I

Conditions to operate UAS by IIT Madras on behalf of AAI for aerial survey in and around Chennai Airpor

1. This "one time no objection" is accorded to Airports Authority of India (AAI) to operate UAS for the above mentioned purpose only.
2. AAI shall obtain necessary security clearances from (a) Ministry of Home Affairs, and (b) local administrations prior to operating the UAS.
3. AAI shall issue applicable required NOTAMs without jeopardizing operation of manned aircraft.
4. The operation of UAS shall be restricted in and around Chennai Airport and not more than 20 AGL at any case.
5. The operation of UAS shall be restricted to day operation and within visual line of sight (VLOS) only.
6. AAI shall ensure that the UA is not flown over any defence installations or private property without the permission of the concerned authority. If UA flying is required, necessary permission from Ministry of Defence to be obtained.
7. AAI shall be responsible for any eventualities due to malfunction/ disorientation of equipment.
8. AAI/ IIT Madras shall have adequate level of insurance to cover any damage to third party resulting from accident/ incident.
9. In case of any injury to any person due to physical contact with the equipment, AAI/ IIT Madras shall be responsible for medico-legal issues.
10. The UAS shall not carry any hazardous material or variable payload under any circumstances.
11. AAI shall ensure that only trained/ experienced bona fide personnel of IIT Madras operates the UAS
12. AAI/ IIT Madras shall ensure safety, security and privacy of spectators, property, operator etc.
13. This no-objection shall be valid till the issue of guidelines for operation of UAS by DGCA. AAI/ IIT Madras shall approach DGCA for required permission/ approval as and when guidelines for operation of UAS comes into effect.
14. In case of violation of any of the above mentioned conditions, this no-objection accorded to AAI shall be withdrawn.
15. **This letter and conditions mentioned above does not override restrictions/ SOP on Unmanned Aircraft Systems framed by other Government Agencies.**

3. **NoC from BCAS**

No.: CAS-12(10)/2008/Div-I(General Aviation)-85147
भारत सरकार / **Government of India**
(नागर विमानन मंत्रालय) / **(Ministry of Civil Aviation)**
नागर विमानन सुरक्षा ब्यूरो / **Bureau of Civil Aviation Security**
'ए' विंग, प्रथम तल, जनपथ भवन, जनपथ / **'A' Wing –I, II, III, Janpath Bhawan, Janpath,**
नई दिल्ली-110001 / **New Delhi-110 001**
Dated: 21/06/2016

To
Ministry of Civil Aviation
Rajiv Gandhi Bhawan
Safdarjung Airport
New Delhi.

(Kind Attn.: Shri Satish Chander, Under Secretary)

Subject: **One time no objection for operation of UAS for aerial survey in and around Chennai airport - regarding.**

Sir,

Reference is AAI CHQ letter No. AAI/MISC-11/A-Sec/2016/358 dated 06/06/2016 on the subject matter, copy addressed to Director, MCA also.

2. I am directed to inform you that BCAS has no objection for use of UAS by AAI subject to the conditions mentioned in DGCA's Permission dated 31/05/2016.

3. AAI shall arrange necessary clearance from MHA and local administration before operating UAS.

4. RDCOS, Chennai will ensure DGCA permission, MHA clearance and local administration clearance along with required Police verifications of the applicants before issuance of AEP/TAEP in this regard.

Yours faithfully,

Encl.: As above.

21/6
(Mathai P.U.)
Dy. Director(Policy)
Ph. No. 011-23731721 / Fax- 011- 23355167

Copy to:

1. GM(Security), AAI CHQ - Rajiv Gandhi Bhawan Safdarjung Airport, New Delhi. — This refers to his letter of even number dated 06/06/2016. For information please.
2. RDCOS(CA), BCAS, Chennai Region, Chennai International Airport, Chennai.

RDCOS	
ACS	
AOS	
ALP	
RGI	1694- 27/6/16

2016

भारत सरकार / Government of India
नागर विमानन सुरक्षा ब्यूरो / Bureau of Civil Aviation Security (Ministry of Civil Aviation)
क्षेत्रीय निदेशक का कार्यालय / O/o Regional Director,
चेन्नई क्षेत्र, चेन्नई – 600 027 / Chennai Region, Chennai – 600 027

No. C/DCS/SA - Chen /16 Date: 29.6.2016

To

The Airport Director
AAI
Chennai Airport
Chennai

Sub:- One-time No Objection for operation of UAS for aerial survey in and around Chennai Airport -- Reg

Sir,

Kindly refer to your letter No. AAM/GME/2016-17/141, dated 28.6.2016 on the above cited subject. In this regard, kindly find the copy of letter received from BCAS HQ. In view of paras 3 and 4 of the ibid letter, you are requested to ensure MHA clearance and local administration clearance also along with required police verifications of the applicants before issuance of AEP/TAEP in this regard in addition the DGCA permission already obtained.

Yours faithfully,

(Sanjay Sharma)
Deputy Director, BCAS, Chennai

Encl. As above.

Forwarded for kind information and further necessary action please.

29/6/16

एस. सुरेश राज कुमा
S. SURESH RAJ KUMA
सहायक महाप्रबन्धक (सुरक्षा)
Asst. General Manager (Security / CSO)
भा.वि.प्रा. चेन्नै एयरपोर्ट, चेन्नै - 600 0
AAI, Chennai Airport, Chennai - 600

GM Engg (Civil)
29/06/2016

(1) APD,
(2) JGM(CS-C)

4. **Local Clearance from the District Collector**

Proceedings of the District Collector of Kancheepuram District at Kancheepuram.
Present : Tmt. R. Gajalakshmi, I.A.S.,

Rc. No. 15431 / 2016 / M1 Dated 21.9.2016

Sub: Drone Survey – Kancheepuram District – Alandur Taluk – Meenambakkam and Thrisoolam Villages - Airports Authority of India – Request for Security Clearance / Permission to carry out Drone Survey in and around Chennai Airport – Permission granted - Regarding.

Read:
1) Director General of civil Aviation, Government of India, Opposite Safdarjung Airport, New Delhi – Public Notice File No. 05-13/2014-AED Dated 7.10.2014.
2) Air Marshal, HQ Southern Air Command, Indian Air Force, Trivandrum Letter No. SAC/S 2017/2/AD, dated 1.2.2016.
3) Copy of the Joint Director General of civil Aviation, Government of India, Opposite Safdarjung Airport, New Delhi Ref. No. 05-13/2014-AED Vol. III Dated 31.5.2016.
4) Airport Director, Airports Authority of India, Chennai Airport, Chennai 27 Letter No. AAM/GME/2016-17/139 Dated 10.6.2016 received on 14.6.2016.
5) This office Letter Rc. No. 4044 / 2016 / M1 Dated 14.6.2016
6) Revenue Divisional Officer, Tambaram Letter Rc No. 1400/2016 A Dated 31.8.2016.
7) Under Secretary to Government of India, Ministry of Home Affairs, IS-I Division (IS-II Section), North Block New Delhi Letter No. II/20034/236/2016-IS-II, Dated 6.9.2016

****

ORDER:

In the reference 4th cited, the Airport Director, Airports Authority of India, Chennai Airport has requested permission to carry out Drone Survey in and around Chennai Airport for study of Geography and terrain of the area to avoid re-occurrence of stoppage of operations at Chennai Airport during heavy rains.

In the reference 6th cited, the Revenue Divisional Officer, Tambaram has stated that he has inspected Chennai Airport and surroundings on 1.7.2016 along with the Airport Authority officials, Airport Advisory Committee Member and concerned Revenue officials and that the exact area for carrying out Drone Survey was called for from the Airport Director. The

Airport Director has sent a Map showing the area where the Drone Survey was going to be taken place and that the Chennai Airport was affected a lot during last years heavy floods, this sort of Drone Survey is essential. He has recommended for approving the enclosed map for carrying out "Drone Survey" by Chennai Airport.

In the reference 3rd cited, the Joint Director General of Civil Aviation, Government of India, New Delhi has accorded one time no objection to Airport Authority of India to operate UAS (Unmanned Aircraft System) for aerial survey in and around Chennai Airport subject to 15 conditions.

In the reference 7th cited, the Under Secretary to Government of India, Ministry of Home Affairs, New Delhi has conveyed 'No Objection' for operating UAS (for one-hour maximum for 10 days) for conducting the aerial (Drone) survey by IIT Madras in and around the Chennai Airport subject to the following conditions

i) UAS operations should be carried out strictly by the officials duly authorized by AAI / IIT, Madras.
ii) Concerned District Authority should be informed about the proposed UAS operation well in advance so that they can also associate themselves in monitoring the same.

In this connection, permission is hereby granted to the Airport Director, Airports Authority of India, Chennai Airport, Chennai-27 to carry out Drone Survey in and around Chennai Airport for study of Geography and terrain of the area to avoid re-occurrence of stoppage of operations at Chennai Airport during heavy rains, subject to adhere to the conditions mentioned in the letter of the Joint Director General of Civil Aviation, Government of India, New Delhi and subject to the conditions issued by the Ministry of Home Affairs, IS-I Division, Government of India, New Delhi vide reference 7th cited. Further the prior intimation / permission to be obtained from the concerned police Authority

Sd./- R. Gajalakshmi,
District Collector,
Kancheepuram.

/by order/

23/9/2016

Huzur Sarishtadar (M.)

To
The Airport Director, Airports Authority of India,
Chennai Airport, Chennai 27
Copy to the Revenue Divisional Officer, Tambaram

5. **Permission from the local Police**

PROCEEDINGS OF THE DEPUTY COMMISSIONER OF POLICE, SECURITY, GREATER CHENNAI POLICE

PRESENT:THIRU. G. RAMAR.

No. 32/DC-SCP/Admn. /2016 Dt: 24-10-2016

Sub: Indian Institute of Technology Madras - Permission sought to carry out topographical survey of Chennai airport and vicinity using a survey grade drone - reg.

Read: 1) Application dated: 26-9-2016 from Dr. Balaji Narasimhan, Associate Professor, Department of Civil Engineering, Indian Institute of Technology Madras, Chennai-36 enclosing a letter from the Asst. General Manager (E-C)-II, Civil Maintenance Division-I, Chennai Airport, Chennai-45.

2) One time no objection for operation of Unmanned Aircraft System for Aerial Survey in and around Chennai Airport in the office memorandum No. II/20034/236/2016-IS-II, dt: 6-9-2016 from the Under Secretary to Government of India, Ministry of Home Affairs.

3) Permission proceedings issued by the District Collector of Kancheepuram District to carry out Drone Survey in and around Chennai Airport in RC. No. 15431/2016/M 1, dt: 21-9-2016

* * *

ORDER:

Permission is granted to the applicant to carry out Drone Survey in and around Chennai Airport for the study of Geography and terrain of the area to avoid re-occurrence of stoppage of operations at Chennai Airport during heavy rains, with the following condition and subject to the conditions stipulated by the Director General of Civil Aviation, Government of India, New Delhi and Ministry of Home Affairs, IS-I Division, Government of India, New Delhi. Further the applicant is advised to get necessary permission from Ministry of Defence, if UAS flying over any defence installation is required.

(ii) **The applicant is instructed to intimate the survey schedule to the undersigned well in advance.**

Conditions:

i. This "one time no objection" is accorded to Airports Authority of India (AAI) to operate UAS for the above mentioned purpose only.

ii. The operation of UAS shall be restricted to day operation by a trained/experienced bonafide persons.

iii. AAI shall ensure that the UAS is not flown over any defence installations or private property without the permission of the concerned authority. If UAS flying is required over any defence installations necessary permission from Ministry of Defence to be obtained.

iv. AAI shall be responsible for any eventualities due to malfunction / disorientation of equipment.

v. In case of any injury to any person due to physical contact with the equipment, AAI / IIT Madras shall be responsible for medico-legal issues.

vi. AAI / IIT Madras shall ensure safety, security and privacy of spectators, property, operator, etc.

Office of the Dy. Commissioner of Police, Date 24/10/16, Security, Chennai Police, Chennai-2

24/10/16

Dy.Commissioner of Police,
Security, Greater Chennai Police

To:- The Applicant.