Drainage Master Plan for NCT of Delhi

Final Report

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ABBREVIATIONS

Abbreviation	Expanded Form
%	Percent
°	Degree
°C	Degree Centigrade
Y_T	T-year EV1 reduced variate
T	Return period (in years)
t	Duration (in hours)
I	Rainfall intensity (in mm/hr)
μ	Statistical PWM parameters corresponding to measures of location
α	Statistical PWM parameters corresponding to measures of scale
ACCESS	Australian Community Climate and Earth-System Simulator
ARS	Agriculture Research Service
C&D	Construction and Demolition
CPCB	Central Pollution Control Board
DDA	Delhi Development Authority
DEM	Digital Elevation Model
Delhi Cantt	Delhi Cantonment Board
DIAL	Delhi International Airport Limited
DJB	Delhi Jal Board
DMRC	Delhi Metro Rail Corporation
DSIIDC	Delhi State Industrial and Infrastructure Development Corporation
East MCD	East Delhi Municipal Corporation
GIS	Geographical Information System
GSDL	Geospatial Delhi Limited
GW	Ground Water
I&FC	Irrigation and Flood Control Department

Abbreviation	**Expanded Form**
IDF	Intensity Duration Frequency
IIT	Indian Institute of Technology
IMD	India Meteorological Department
LID	Low Impact Development
km	Kilometre
m^3	Metre cube
MBGL	Metres Below Ground Level
MCD	Municipal Corporation of Delhi
mm	Millimetre
Msl	Mean Sea Level
NCT	National Capital Territory
NDMC	New Delhi Municipal Council
North MCD	North Delhi Municipal Corporation
NTPC	National Thermal Power Corporation Limited
PWD	Public Works Department
RWA	Resident Welfare Association
South MCD	South Delhi Municipal Corporation
Sq. km	Square Kilometre
STP	Sewage Treatment Plant
SWAT	Soil Water Assessment Tool
SWM	Solid Waste Management
SWMM	Storm Water Management Model
USDA	United States Department of Agriculture
U. P.	Uttar Pradesh

EXECUTIVE SUMMARY

The storm water drainage infrastructure in our cities is in a dilapidated state on various accounts. Time has come when we need to look into this aspect to avoid undue misery to the masses and the associated loss to the national revenue. The Government of Delhi realised this need and entrusted the task of formulation of Drainage Master Plan for NCT of Delhi to IIT Delhi. The IIT Delhi went about this task in a very systematic manner, starting with the analyses of the existing conditions.

Pre-requisite for a reliable analysis of the existing storm drainage infrastructure towards its adequacy for draining the respective areas effectively, is the availability of an equally reliable data on the infrastructure in terms of cross-sections and invert levels of the drains. It would have been much easier for the consultants to design afresh the required infrastructure to drain the respective areas by totally ignoring the existing infrastructure in view of the fact that the data on the existing infrastructure was not captured despite indulging in a gigantic exercise to digitize the whole Delhi. The Consultant was conscious of the fact that the Delhi Drainage Master Plan can only be successfully and economically implemented if the existing system is accurately captured and analysed. Therefore, they were left with no choice but to engage in processing of the drainage data that was decided to be captured through fresh exercise by various agencies by deploying their contractors, although it was the responsibility of the Government of Delhi to provide duly authenticated and validated data on drainage system to the consultant. The consultant was also left to assess for connectivity, flow directions and missing/erroneous attributes like outfalls, invert levels, dimensions, etc. In addition, data on the locations of pumps and sumps, their capacity, operation policies, etc. were added to the networks with lot of iterations with the respective departments. Also, extensive efforts were made by sending IIT Delhi representatives in field to verify the connectivity of some of the crucial drains and thus make the drainage data suitable for the purpose of analysis through modelling. Thus, a massive exercise of co-ordination of data collection and correction was taken up by IIT Delhi. Bulk of the time went into data collection and processing activity, and that in a way over exhausted the budget earmarked for the study. It is important to convey that under some situations, recourse to interpolation, engineering judgment, etc., was taken to make the data worthy of simulation.

The NCT of Delhi has three major drainage basins, namely, Najafgarh, Barapullah and Trans-Yamuna basins. Using the processed datasets, the SWMM model has been setup in the present study for each of the drainage basins of Delhi to simulate the inundation depths as well as their spatial locations. The model results have been validated to certain extent through the flooding location data provided by the Delhi Traffic Police.. However, it has been found that despite all our efforts there were large number of discrepancies in the drainage network. Some of these discrepancies have been removed before final simulations to analyse the drainage systems and recommend appropriate solutions.

To alleviate the flooding conditions in various parts of the city, the stormwater infrastructure has to be made efficient. So, it is pertinent to apply corrective measures to the faulty drainage infrastructure, and introduce low cost flood preventing measures such as water bodies rejuvenation, rainwater harvesting using parks and Low Impact Development options. Further, the solid waste and the sewage has be managed in such a way that they do not interfere with the stormwater drainage. Therefore, following are our major recommendations:

No encroachments on storm drains

- Storm drains should be treated as key public assets and no encroachment should be allowed. Any encroachment of the drain should be immediately removed and reported back. Department managing the storm drain should be made responsible for keeping drain encroachment-free. Special drives to remove encroachments from the storm drains should be taken up.

No sewage in storm drains

- No natural or artificial storm drain should be allowed to carry any sewage. Only treated sewage of acceptable quality as per CPCB norms should be allowed in storm drains.
- All drains that are entering into NCT of Delhi (from Haryana, UP, etc.) should be only carrying storm water and treated sewage of acceptable quality as per CPCB norms.
- Current practice of DJB of puncturing sewer lines and draining sewage into storm drain in the event of blockage should be stopped. DJB should resort to using latest mechanisms such as supper suckers for de-clogging the sewer lines.
- No sewage should be allowed to enter the storm drains even from unauthorized colonies; interceptor sewers should be set-up wherever required by DJB to trap the sewage coming out of such colonies and take it to the nearest sewer line or STP.

No Solid Waste or C&D waste be allowed into storm drains

- No silt from the road (before or after road sweeping – manual or otherwise) be allowed to be dumped into bell-mouths/drains. Road sweeping process should be completely overhauled. Weight/volume of silt received after street sweeping should be recorded. Segments of road from where more silt is being received should be reviewed and reason of the same ascertained. If need be, possible afforestation exercise should be taken up to reduce silt on the road segment.
- No solid waste should be allowed to be dumped into storm drains.
- Construction & Demolition (C&D) waste should not be allowed to be dumped in storm drains or depressions. Amount of waste likely to be generated from a construction or demolition site should be assessed by the contractor in advance (along with the permission to construct/modify house). C&D waste should be lifted by government appointed contractors and dumped at C&D processing site.

Effectiveness of desilting of storm drains

- It has been seen that many drains are covered fully/partially. It has been noticed that most of the covered drains do not have access for desilting. If desilting is not carried out under the covered potion, effectiveness of desilting of rest of the drain is reduced significantly. Therefore, access points, if they are not there, should be provided at appropriate distance so that desilting can be carried out.
- Schedule of desilting should be publically displayed and in a manner that is understood clearly by general public. GSDL should use the GIS layout of the drainage network made by IIT Delhi with cross-section and L-section to capture and display the schedule of desilting by the contractors segment-wise and jurisdiction-wise. Crucial details such as time schedule of desilting and the amount of silt/debris removed should also be captured and displayed.

- Certification that desilting is completely and satisfactorily done, be made by the concerned agency. On this certification, local public shall be notified that work is completed and public suggestions/feedback shall be sought (through an App that allows the user to send geo-tagged photos of the concerned issue). Received public complaints should be looked into by the department within a stipulated time.
- Some of the drains are managed by multiple departments/sub-divisions within departments. Extra care is required in such cases because if desilting is not carried out in proper co-ordination (there is gap in schedule of departments/sub-division or one portion is not desilted), effectiveness of the work carried out reduces significantly.
- Weight & quality of silt removed should be mandatory to be certified from the way-bridge of receiving agency (Municipality SWM site). This information shall be recorded diligently segment-wise and displayed on GIS by GSDL and should be analyzed with year-on-year goal to reduce the amount of silt that is coming to the respective storm drains.
- Effort should be made to put all the storm water drains under single agency that shall take care of many issues identified above.

No storm water should be drained into sewer systems

- No storm drain should ever outfall into sewer system at any cost since they are never designed for such situation and shall therefore result in surcharge of sewerage network and may flood some of the areas with sewage. All such cases should be identified and immediately addressed. No such cases (temporary or permanent) should ever be allowed.
- Practice of opening sewer man-holes to discharge local storm water should be banned. Adequate system to discharge storm water should be put in place and public awareness should be increased towards ill-effects of diverting storm water into sewer lines.
- Similarly, house-holds draining storm water into the sewer lines should be penalized. Locality level storm drains should be revived or as an alternative GW recharging mechanism should be put in place by individual household – at own cost. Awareness campaign should be carried out to sensitize public in this regard.

No construction should be allowed inside any storm drains. There are two specific violations that are usually happening:

- Utilities are laid inside the storm drains
- Pillars of elevated roads/metro are built inside the storm drains.

No such activity should be allowed. Also, in the locations such compromise of the section has happened, adequate measures should be taken immediately to restore the original carrying capacity of the storm drain.

Design of new storm drains should not be done in isolation

- Overall impact of any new drain on the existing storm drainage system should be studied.
- Data collected and modelling system deployed as part of this study should be used for checking design feasibility of any new drains.
- Different scenarios have been envisaged and presented in this report to simulate the prevailing conditions as well as the interventions required to alleviate the flooding conditions in various parts of the city. After implementing the recommended practices, more scenarios can be later introduced, further enhancing the efficiency of the drainage network of the city.

- Retention cum harvesting corridors can be laid along the road to capture the runoff generated from the surface. This will enhance the ground water recharging.

Rejuvenation of water bodies

Many of the water bodies have become redundant over the years and are not even properly connected to their catchments. Once rejuvenated, these water bodies can play a pivotal role in reducing the flooding as they act as detention and recharge basins. They should be continuously monitored and maintained in order to reduce runoff into storm drains.

- Dumping of waste into water bodies should be prohibited to maintain ambient water quality.
- Regular desilting should be undertaken to avoid reduction in storage capacity of the water bodies.
- No encroachment or unauthorised construction in wetlands should be permitted.

Low Impact Development (LID) Options

In order to explore additional options for disposal of the remaining excess water, it is advisable to explore the local conditions in a comprehensive manner and wherever feasible, identify various Low Impact Development (LID) options such as infiltration trenches, rain gardens, bio-retention ponds, bio-swales, etc. in respective contributing areas of each of the drains.

Effective Administrative Management

There should be a single institution that bears an overall responsibility of the management of the total storm water drainage system within NCT of Delhi.

Additional Recommendations

It is proposed that the government should enact a law that prohibits:

1. **Sidewalk and pavement hawking**. There is a natural temptation to dispose of wastes into available storm water collection system with impunity. Use of garbage disposal bags should be made mandatory for businesses along road carriageways.
2. **Roadside delis and other eating places that do not have a hygienic and an organized pantry system within the premises for cleaning and washing of utensils.** Enforcement should be rigorous and non-compliance should carry compensatory as well as punitive penalty. Further, the license to operate should also be incumbent on a demonstrable infrastructure for an orderly disposal of solid and liquid wastes.
3. **Roadside auto service and repair shops as these require sophisticated waste handling, storage, stowing and disposal infrastructure.** It is commonly observed that chemical wastes are routinely disposed off into the nearest available storm water systems.
4. **Roadside auto dealerships that cater to both new as well as pre-owned vehicles.** These businesses invariably utilise public space for parking and display of goods on sale and the damage to roadside infrastructure is indeed inevitable.
5. **Collection and stacking of construction related building and other wastes on public spaces.** No completion certificate should be granted unless a public inspection of the sites is able to verify compliance and adherence to building waste management norms.
6. **Roadside piling of dirt and other solid wastes (road sweep) resulting from road, sidewalks and service roads.** It is a common observation that dirt is routinely swept off and stacked in front of roadside bell mouths.

7. **Weekly markets without an installable (temporary) infrastructure to collect, store and safely stow business wastes prior to its disposal at formally designated locations and in accordance with formalized protocol.** Failure to comply should result in levying punitive penalty on the organizers, individually and/or collectively.
8. **Direct access to businesses from the roadside.** As part of masterplan for the future, all access to proposed community centres, markets and business centres that are planned along road carriageways should be planned with no direct access from the roadside and should be planned with basement parking. Access to shops for customers as well as delivery of stock and other inventory from/to these businesses should only be from the rear and off the main road as shown in the Figure ES1.
9. Firm rules and policies (no tolerance zone, no parking, etc.) should be designed and executed to evade the effect of rapid urbanization on storm water infrastructure of the city.

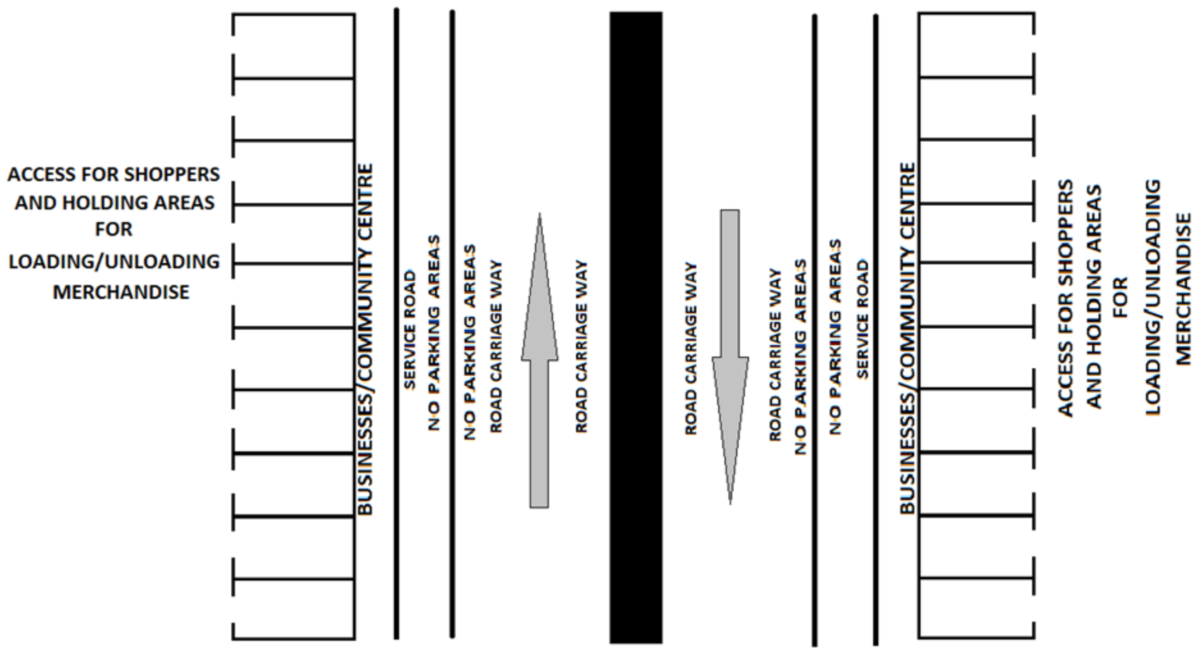


Figure ES1: Schematic of proposed road plan

Recommendations may not be effective if not implemented properly. Therefore, it is important to understand that implementation of the recommendations has to be sequential for better efficacy since it is possible that many of the data elements that have not been independently validated by the respective departments may be different on ground than the digital reality captured and used in the model. Recommendations may not be effective if not implemented properly. Firm rules and policies (no tolerance zone, no parking, etc.) should be designed and executed to evade the effect of rapid urbanization on storm water infrastructure of the city.

So, till the time the full system is not deployed and handed over, all new storm drains designs should be sent to IIT Delhi for checking their feasibility.

1. INTRODUCTION

1.1 SCOPE OF THE STUDY

The project titled "Preparation of Drainage Master Plan for NCT of Delhi" was awarded to IIT Delhi by Government of NCT of Delhi. The study entailed the following:

- Study of the existing natural drainage system comprising of (i) streams and smaller creeks, (ii) seasonal and perennial water bodies and other natural depressions, and (iii) trans-boundary water courses passing through NCT of Delhi
- Study of the engineered urban storm water system
- Study of the dynamics of possible interaction with sewerage and waste water systems wherever interconnections, both natural and man-made, exist
- Preparation of an inventory of model simulated drainage hot spots and their validation based on reported (or observed) water logging events from across the NCT of Delhi
- Preparation of a detailed diagnostic report on these drainage hot spots
- Development of design storm parameters relating rainfall intensity, storm duration and return period.
- Development of drainage projections corresponding to future requirements.

1.2 DRAINAGE SYSTEM IN THE NCT REGION

The drainage morphology of Delhi is defined in a large measure by the Aravalli foothills and connected outcrops. Under these influences, a principally easterly storm water movement is indicated from the higher elevations in the West towards Yamuna in the East. In contrast, the region to the east of Yamuna is low-lying and was originally a part of the Yamuna flood plain, and understandably remained largely uninhabited until after the India-Pakistan partition of 1947. Following large scale migration of people from erstwhile West Pakistan and their resettlement, this region, also known as the Trans-Yamuna area, is now home to about 30% of the total population of Delhi. Some of the relevant highlights pertaining to the study area are presented in Table 1.2-1.

Table 1.2-1: Relevant details for NCT of Delhi

S. No.	Details	Value
1.	Total geographical area of NCT of Delhi	1483 sq. km
2.	Last Drainage Master Plan prepared in the year	1976
3.	Population of Delhi in the year 1976	60 lakhs
4.	Population of Delhi as per Census 2011	167 lakhs
5.	Projected population as per projection in MPD-2021[1]	250 lakhs
6.	Present area urbanized in Delhi	750 sq. km
7.	Likely area to be urbanized as per MPD-2021	920 sq. km

[1] http://dda.org.in/planning/mpd-2021.htm

S. No.	Details	Value
Figure 1.2-1: Drainage map of Delhi (as per 1976 Drainage Master Plan)		

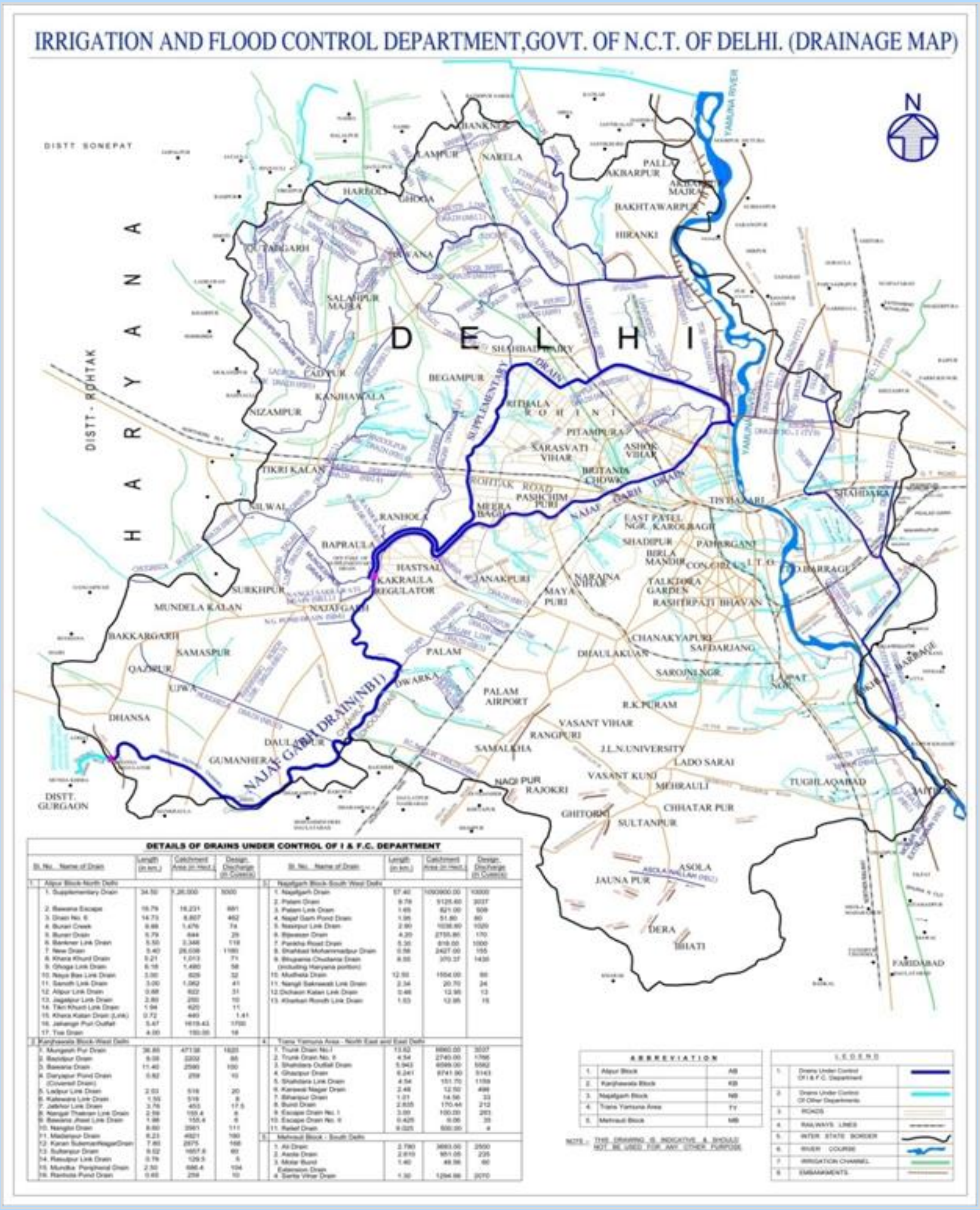


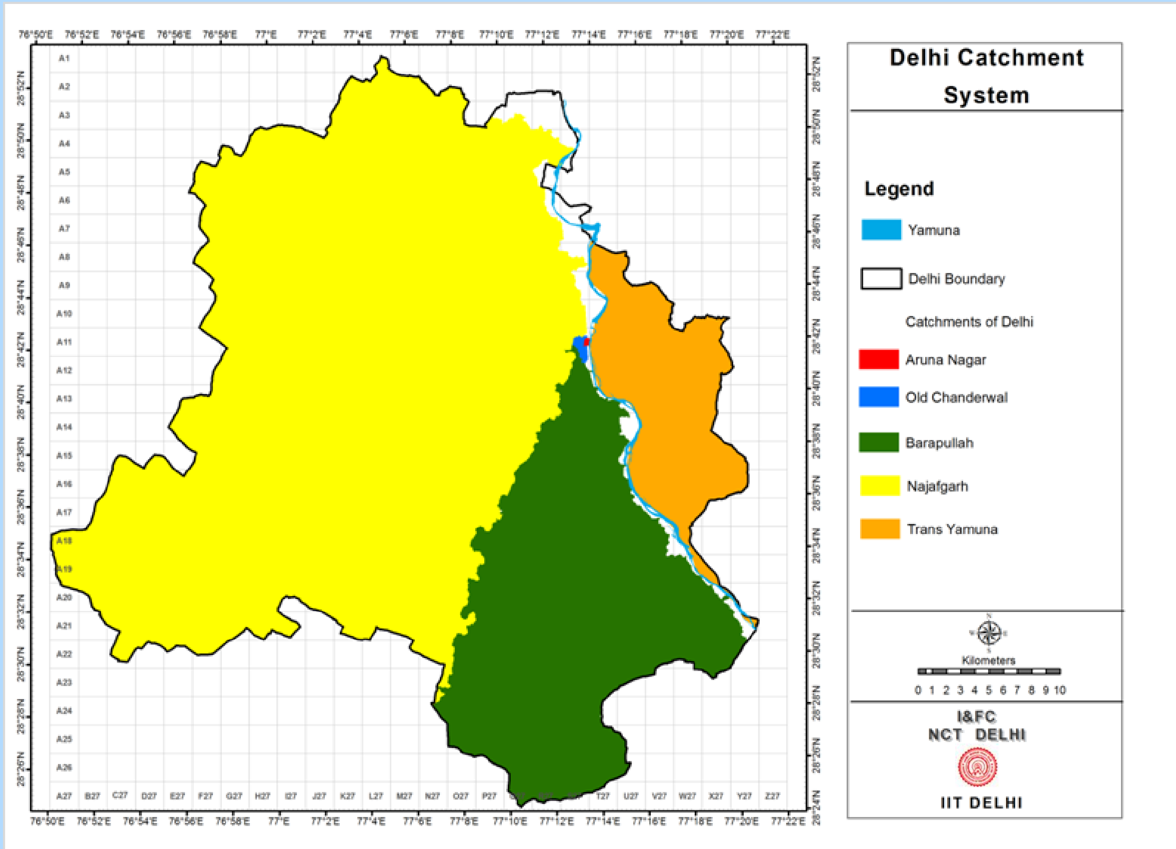
Figure 1.2-1 shows drainage zones of Delhi as defined by I&FC. Delhi has been demarcated into six drainage zones namely (i) North Zone, (ii) West Zone, (iii) Central North West and South East Zone, (iv) Central South and South East Zone, (v) East Zone, and (vi) South Zone. Table 1.2-2 lists all the agencies that manage the storm runoff emanating from the entire urban expanse of Delhi carried by a total of 426.55 km of natural drainage lines and a cumulative length of 3,311.54 km of engineered storm water drains (as digitized).

Table 1.2-2: Storm runoff system of NCT of Delhi and departmental Jurisdiction

S. No.	Agency Name	Length (km)
1.	Irrigation and Flood Control	426.55
2.	Public Works Department	2064.08
3.	South Delhi Municipal Corporation	258.78
4.	North Delhi Municipal Corporation	122.46
5.	East Delhi Municipal Corporation	140.63
6.	New Delhi Municipal Council	335.29
7.	Delhi Development Authority	251.30
8.	Delhi State Industrial and Infrastructure Development Corporation	98.12
9.	Delhi Cantonment	39.68
10.	National Thermal Power Corporation Limited	3.11
11.	UP Irrigation (Old Agra Canal)	0.311

For the purpose of the present study, NCT of Delhi has been divided in three major natural drainage basins (delineated using SWAT hydrological model) as depicted in Figure 1.2-2. There are also a couple of very small drainage basins (Aruna Nagar and Old Chanderwal) that have outfall directly into Yamuna. Basin areas for the three major basins are listed in APPENDIX II.

Figure 1.2-2: Major Basins of NCT of Delhi used for Modelling



The Najafgarh basin is the largest of all the basins and accounts for close to two third of the area of NCT of Delhi. There are a total of 201 natural drains in the three major basins of Delhi as presented in Table 1.2-3. The final disposal of majority of the storm water generated from Delhi is into river Yamuna through outfall points distributed across the stretch along its course through Delhi.

Table 1.2-3 Basin wise natural drains in Delhi as per 1976 Drainage Masterplan

S. No.	Basin	Number of drains
1	Trans-Yamuna	34
2	Barapullah	44
3	Najafgarh	123
Total number of drains		201

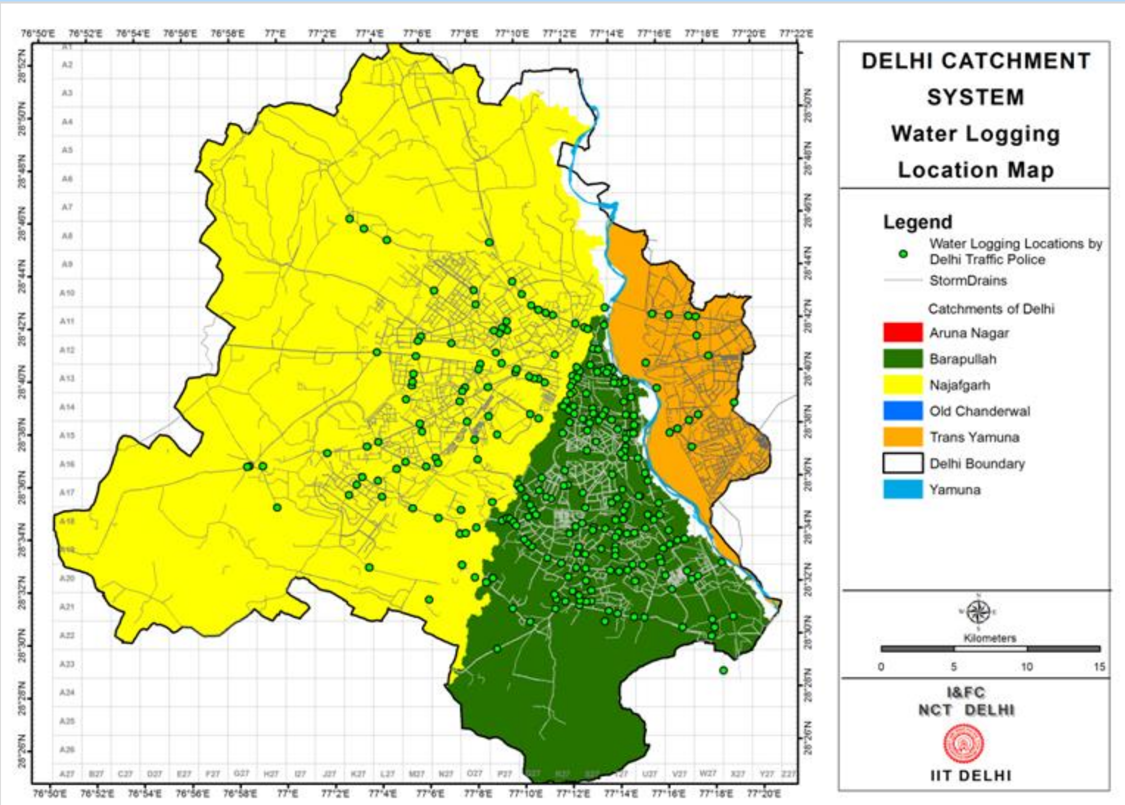
1.3 INSTITUTIONAL JURISDICTIONS

With regard to the management of the storm water drainage system within the NCT of Delhi, there is conspicuously no single institution that bears an overall responsibility of the total system. To the contrary, the administrative authority of the capital's drainage system is quixotically distributed amongst numerous civic bodies and various constituent departments of Government of NCT of Delhi as well as Government of India. These include (i) Irrigation & Flood Control, Delhi, (ii) Delhi Jal Board, (iii) various Municipal Corporations of Delhi, (iv) Urban Development, Delhi, (v) Ministry of Urban Development, Government of India, (vi) New Delhi Municipal Council, (vii) Delhi Development Authority, (viii) Delhi Cantonment Board, (ix) Delhi State Industrial Development Corporation, and (x) Public Works Department, Delhi. Other departments of the Government and civic bodies whose jurisdiction does not entail any direct responsibility pertaining to the state of the capital's drainage system but nevertheless are important, include (i) Irrigation & Flood Control, Government of Haryana, (ii) Traffic Police, Delhi, (iii) Geo Spatial Delhi Limited, (iv) Central Water Commission, Government of India, (v) India Meteorological Department, (vi) various Resident Welfare Associations (RWAs), (vii) Central Pollution Control Board of Ministry of Environment and Forests, Government of India, (viii) National Green Tribunal, (ix) National Highway Authority of India, (x) DIAL and (xi) civil society activist groups.

1.4 THE SCALE OF INSTITUTIONAL MONITORING OF FLOOD EVENTS

The existing storm runoff system of Delhi is prone to frequent episodes of drainage congestion and therefore is widely perceived to be sluggish. It is indeed noteworthy that while water logging is a frequent occurrence in the NCT of Delhi, the various agencies responsible for management of the storm water drainage neither follow the practice, nor are they mandated by legislation, to prepare formal records of the extent of inundation reported from various parts of the capital territory. As an exception, only Delhi Traffic Police is recording occurrence of such events but only from traffic movement perspective and examination of their records reveal a total of 330 segments that could be designated as drainage hot spots within the capital territory as listed in APPENDIX III. The locations of these hotspots are shown in Figure 1.4-1

Figure 1.4-1: Frequent water logging locations in NCT of Delhi as reported by Delhi traffic police



1.5 INITIATIVES BY IIT DELHI AND SOME OBSERVATIONS FROM FIELD VISITS

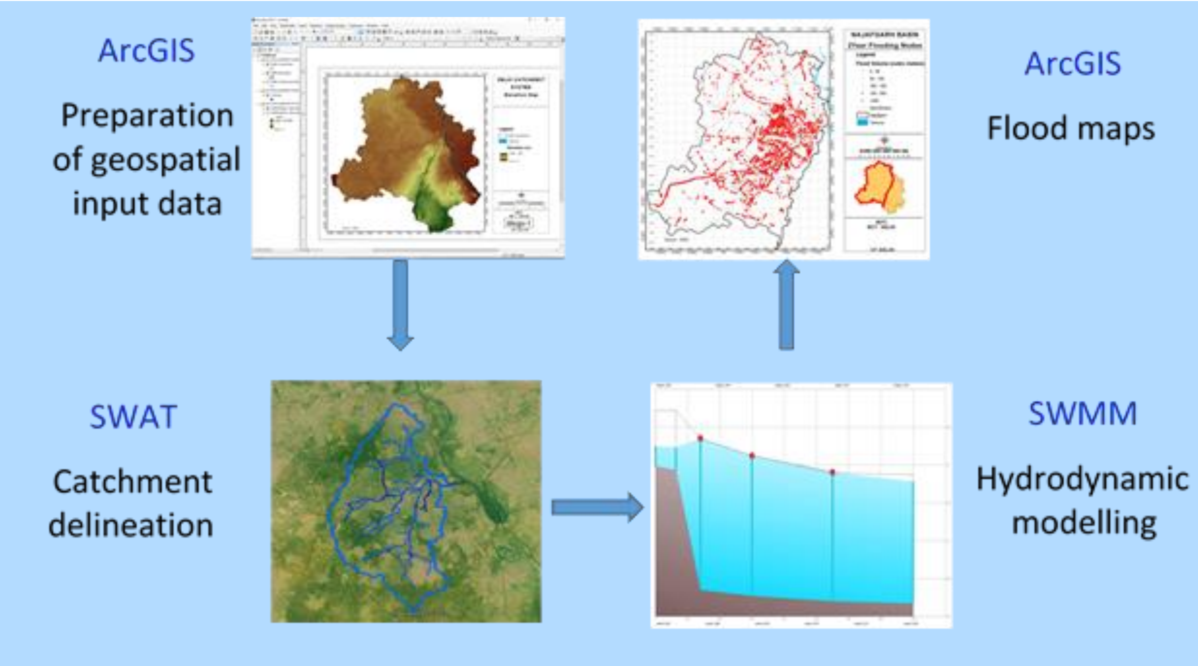
IIT Delhi, through a large number of students (more than 900), has carried out extensive visual inspection of city drainage system by making multiple visits across NCT of Delhi and captured some of the relevant details of the storm drains by making use of the geo-tagged cell phone pictures. Based on these field visits, the drainage connectivity and drainage existence were established. This excecise also helped to capture some of the details required for the modeling. The observations are summarized in APPENDIX XX. All the captured geo-tagged images showing the health of drainages in NCT of Delhi are uploaded on following webpage http://gisserver.civil.iitd.ac.in/delhidrainagemasterplan/

2. DRAINAGE MASTER PLAN METHODOLOGY

2.1 METHODOLOGY OVERVIEW

The study uses a digital model of the physical system constructed through the existing digital data with features such as natural and built topography. In addition, satellite imageries, topographic maps, relevant reports/studies have been used to understand the principal drainage features of the project area prior to development. The landuse map of 2010 provided by GSDL has been used in the study. A schematic of the methodology incorporating hydrologic and hydraulic simulations used in the study is presented in Figure 2.1-1

Figure 2.1-1: Map-Based hydrologic and hydraulic simulation schematic



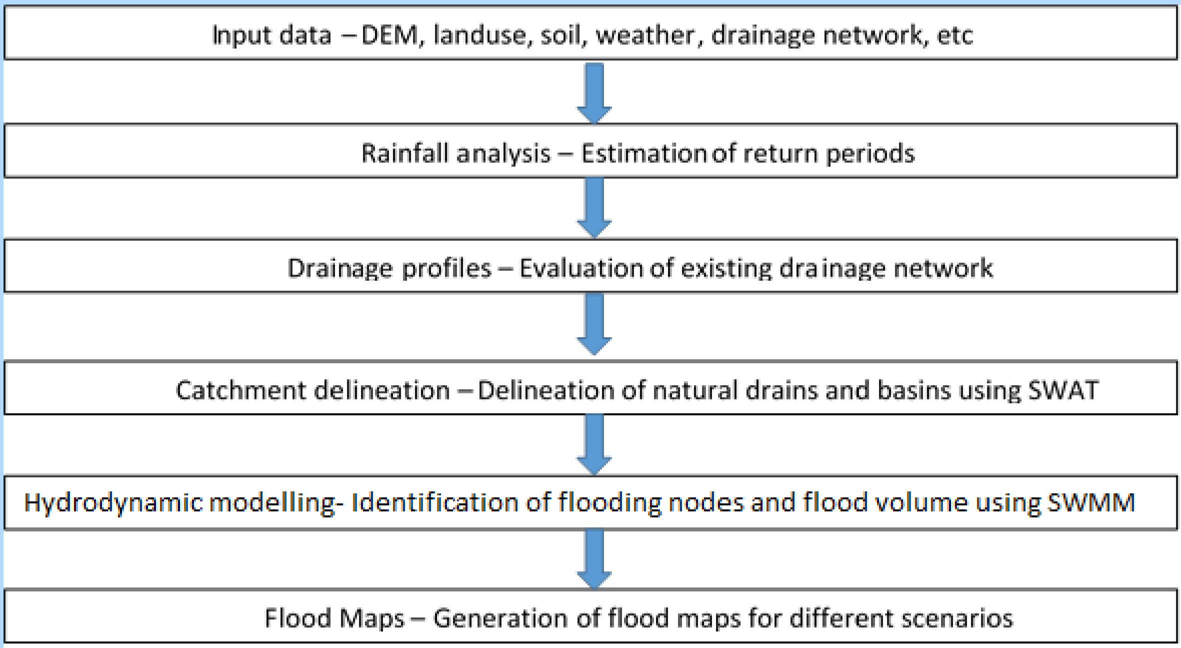
Following is the summary of the methodology adopted in the study:

- Rainfall analysis for spatial and temporal characterization, and derivation of design storm scenarios corresponding to specified design return period
- Derivation of DEM/Digital Terrain Map for area outside the NCT which needs to be modelled since some of these areas contribute to the flood runoff transport and its eventual disposal across the NCT of Delhi
- Preparation of soil type and land use data to be adopted in the study
- Terrain analysis to determine dominant areas contributing the storm runoff for each drain
- The existing storm drainage system has been evaluated for its conveyance availability and adequacy

- Hydrologic and hydrodynamic modelling to derive runoff hydrographs, surface water profiles and extent of backwater effects within the storm drainage network under various envisaged scenarios
- Using GIS in this planning process will allow the city to create a dynamic database and modelling approach which has the capability of a priory evaluating the implications of changing conditions such as, new urban planning strategies, climate change, etc., on the urban flooding

The overall flow chart of methodology is presented in Figure 2.1-2.

Figure 2.1-2: Flow Chart of Methodology Employed



2.2 MODELS DEPLOYED

Two models have been deployed in the present study; a hydrological model and an urban storm water management model. The role of the hydrological model in the present study is specifically to generate the flow from the areas outside the NCT of Delhi boundary that contribute to the flow to the basins of Delhi. A brief description of the two specific models deployed in the present study is given below.

2.2.1 SWAT – Hydrological Model

SWAT [2] developed by the USDA Agriculture Research Service (ARS) is a river basin scale model to simulate the stream flow in the natural streams using the precipitation and the other geophysical characteristics of the watershed. The model is also used to quantify the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods of time. SWAT can be used to simulate a single watershed or a system of connected watersheds.

The SWAT first determines the loadings of water, sediment to the main channel and then these loadings are routed through the drainage network of the watershed. In the present case, SWAT model has been used to assess the quantity of runoff that is being generated outside the NCT of Delhi but is contributing to the NCT of Delhi and is a potential source of flooding in Delhi.

The SWAT model has also been used for delineation of the basins of NCT of Delhi to identify the areas that are contributing to the drains of different drainage systems.

2.2.2 SWMM/PCSWMM – Urban Storm Water Management Model

EPA's Storm Water Management Model (SWMM) [3] is a widely used modelling framework for planning, analysis and design related to:

(i) Storm water runoff,
(ii) Combined sewers,
(iii) Sanitary sewers,
(iv) Drainage systems in urban areas and with many applications in non-urban areas as well.

This general purpose urban hydrology cum conveyance system hydraulics software is a dynamic rainfall-runoff simulation model and may be used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM operates on a collection of sub-catchments that contributes runoff and pollutant loads and can model its transport through:

- System of pipes, Channels,
- Storage/treatment devices, and
- Pumps and other regulators.

[2] Arnold, J. G., R. Srinivasan, R. S. Muttiah, and J. R. Williams. 1998. Large-area hydrologic modelling and assessment: Part I. Model development. J. American Water Res. Assoc. 34(1): 73-89

[3] Huber, W. C., Heaney, J. P., Nix, S. J., Dickonson, R. E., and Polman, D. J. 1982. Storm water management model; User's manual, Version III , U. S. Envir. Protection Agency, Cincinnati, Ohio..

SWMM has the capability to track quantity as well as quality of runoff contributions from each sub-catchment along with corresponding flow rates and flow depth in each channel over multiple simulation time steps. SWMM can also explicitly model the hydrologic performance of specific types of Low Impact Development (LID) controls such as (i) porous pavements, (ii) rain gardens, (iii) green roofs, (iv) street planters, (v) rain barrels, (vi) infiltration trenches, and (vii) vegetative swales. The updated model allows engineers and planners to accurately represent any combination of LID controls within a study area to determine their effectiveness in managing storm water.

SWMM accommodates spatial variability by dividing a study area into a collection of smaller, homogeneous sub catchment areas and each having its own fraction of pervious and impervious sub-areas to model overland flow which may then 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 the drainage system network of pipes, channels, storage/treatment units and diversion structures. These include the ability to:

- handle drainage 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
- apply user-defined dynamic control rules to simulate the operation of pumps, orifice openings, and weir crest levels

For the present study, PCSWMM[4], a variant of SWMM has been used. However, the databases prepared and made available can be directly used with SWMM. SWMM/PCSWMM can also estimate the production of pollutant loads associated with this runoff.

2.3 DATA USED

The following data provided by GSDL and survey contractors have been used for the study:

1. DEM (Digital Elevation Model)
2. Land use
3. 4 feet and above storm drains (location and type of inlets and manholes, drain size, and invert levels)
4. Sewer network
5. Water supply network
6. Water bodies
7. Road network
8. Rail network

[4] CHIWater, 2011. PCSWMM2011: Spatial Decision Support for Urban Drainage and Watershed Modeling. http://www.chiwater.com/Files/PCSWMMBrochure.pdf.

9. DMRC network
10. Well location
11. Past flooding data
12. Location of pumps and details of operations

Reference to some issues of data availability requires a special mention.

a. IIT Delhi agreed to undertake this study on the assumption that the supply of all necessary data pertaining to the drainage system of NCT of Delhi, duly authenticated and validated by concerned departments under Govt. of Delhi, would be the responsibility of Govt. of Delhi.
b. The study proposal was prepared taking into account the assurances received by IIT Delhi that all the necessary data was available with Govt. of Delhi in a digital form as GIS layers.
c. The study proposal submitted by IIT Delhi was designed around the common understanding that all the data required in the study would be handed over to IIT Delhi in digital form as individual GIS layers after rigorous validation for accuracy and completeness.
d. The responsibility of data collection and its collation would rest solely with the designated constituent offices of Govt. of Delhi and would be made available in a final, digitally usable form, and would not require any pre-processing or data clean-up and correction at IIT Delhi prior to its adoption in the study.
e. The data on short duration rainfall intensity for various return periods forms a critical input for any storm drainage study. The proposal submitted to the Govt. of Delhi unequivocally appropriated the responsibility to procure all essential and relevant rainfall data from IMD to I&FC, Govt. of Delhi.
f. Govt. of Delhi would facilitate setting up a dedicated lease line at IIT Delhi for seamless digital data transfer protocol. The study proposal was based on the presumption that the digital databases believed to have been prepared by GSDL would be delivered online to a dedicated data server at IIT Delhi as and when these databases either are created or upgraded with newer information.

However, none of the above understanding was followed. So, a massive exercise of co-ordination of data collection and correction efforts has been taken up by IIT Delhi. Out of the overall time spent by the IIT team, more than 1,14,120 hours have gone into data collection activity and in a way over exhausted the budget earmarked for the study. It may be appropriate to mention here that IIT Delhi has taken the stipulated 18 months after the data was made available to them for the completion of the study and therefore are not responsible for the delay in completion of the study.

2.4 HANDLING OF STORM DRAIN DATA

It has been a mammoth task to get the required data from a large number of departments in Delhi. Despite best of our efforts and iterations it has not been possible to get some of the required data from the respective departments. It is important to understand that because of the interdependency of these data to formulate the drainage network, each element of drainage is equally important to construct the overall network. The Table 2.4-1 provides the final status of the data availability from various departments.

Table 2.4-1: Storm drain data status (Final)

	Trans-Yamuna Basin			Barapullah Basin			Najafagarh Basin		
Agency	**Drain data**	**Pump data**	**Sump data**	**Drain data**	**Pump data**	**Sump data**	**Drain data**	**Pump data**	**Sump data**
I&FC	Received	Received	Received	Received	Received	Received	Received	Received	Received
PWD	Received	Partial**	Partial**	Received	Partial**	Partial**	Received	Partial**	Partial**
North MCD	NA			Received	Received	Received	Received	Received	Received
East MCD	Received	Received	Received	NA			NA		
South MCD	NA			Received*	Partial**	Partial**	Received*	Partial**	Partial**
NDMC	NA			Received	Received	Received	NA		
DDA	Received	Not Received	Not Received	Not Received	Not Received	Not Received	Received	Not Received	Not Received
DSIIDC	Received*	NA	NA	Received*	NA	NA	Received*	NA	NA
Delhi Cantt	NA			NA			Received*	NA	NA
DIAL (Airport)	NA			NA			Received	Not Received	Not Received

* However, needs to be wetted for completeness and accuracy w.r.t. ground reality

** Pump locations (latitude and longitude) along with pump capacities are provided but outfall from the pumps (into which drain) is missing and pump operation policy is not available. Also, dimension of sumps is not provided

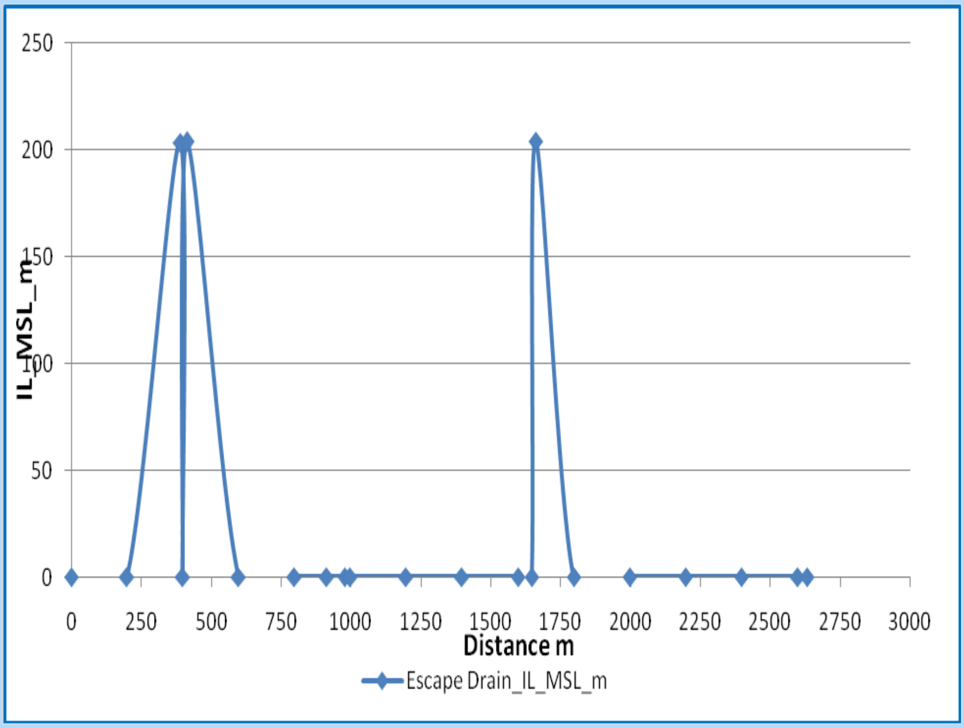
2.5. DATA LIMITATIONS AND ASSUMPTIONS

Significant efforts have been made to bring the data to a meaningful level. Huge efforts have gone into this exercise of data collection and co-ordination. However, even with such an extensive exercise, some gaps still remained and consequently appropriate engineering assumptions have been made.

As explained earlier that an extensive storm water drainage modelling of the region is required to check the adequacy of the existing drainage infrastructure, which has considerably changed due to rapid urbanization and population density. Therefore, it is essential to have a coherent and comprehensive data of the system of existing drains. However, due to unavailability of coherent data, after exhausting the other options, an extensive work has been done to fill the gaps in the data, for successful running of the SWMM model. Some of the data assumptions made are:

- In cases where some Invert levels (IL) values are available along the length, then remaining IL values are computed by interpolation as IL of many drains in the network are either completely or partially missing along the length of drains as can be seen in case of Escape drain in Figure 2.5-1.

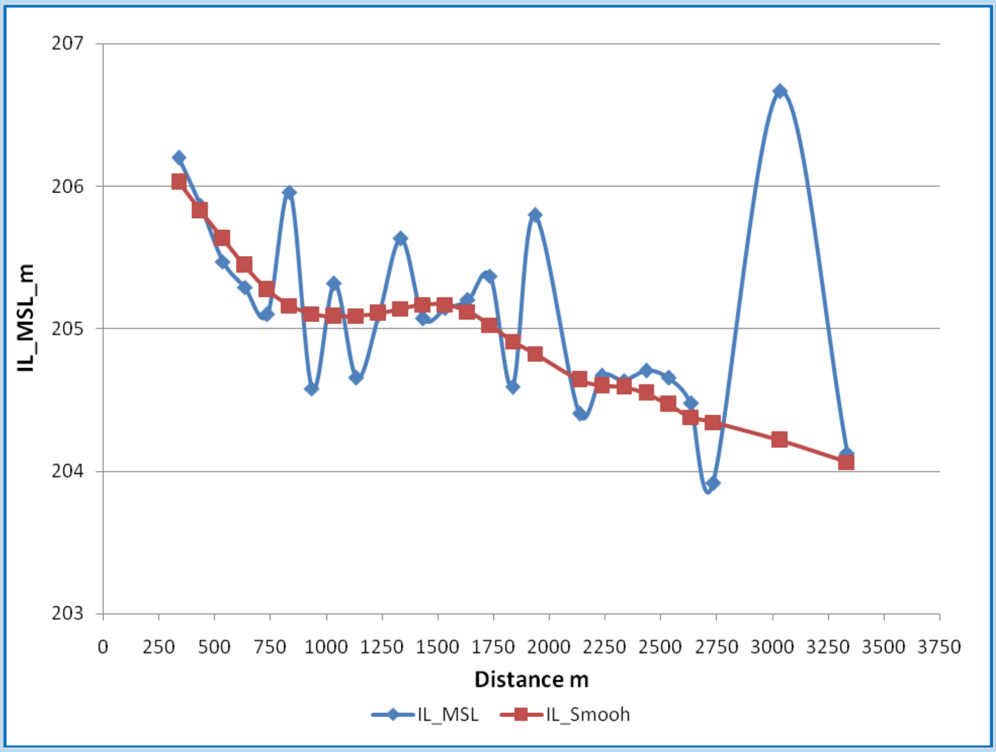
Figure 2.5-1: Example of junction point with Zero Invert Level values



(here, 0 IL_MSL_m refers to missing value of Invert Level)

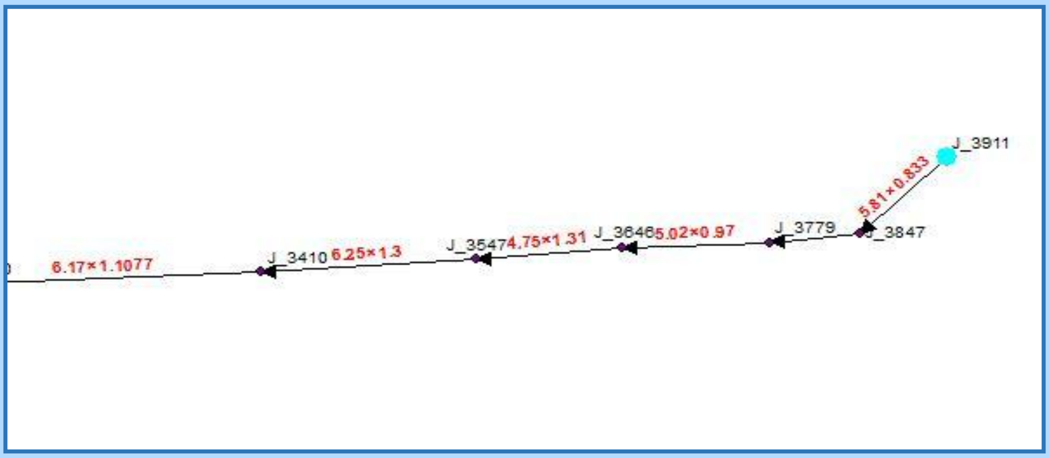
- In cases where ILs of a drain are abruptly fluctuating, then the IL values have been modified by smoothening using nearest neighbour approach. A sample of smoothening is illustrated in Figure 2.5-2.

Figure 2.5-2: Illustration of smoothening of Invert Levels



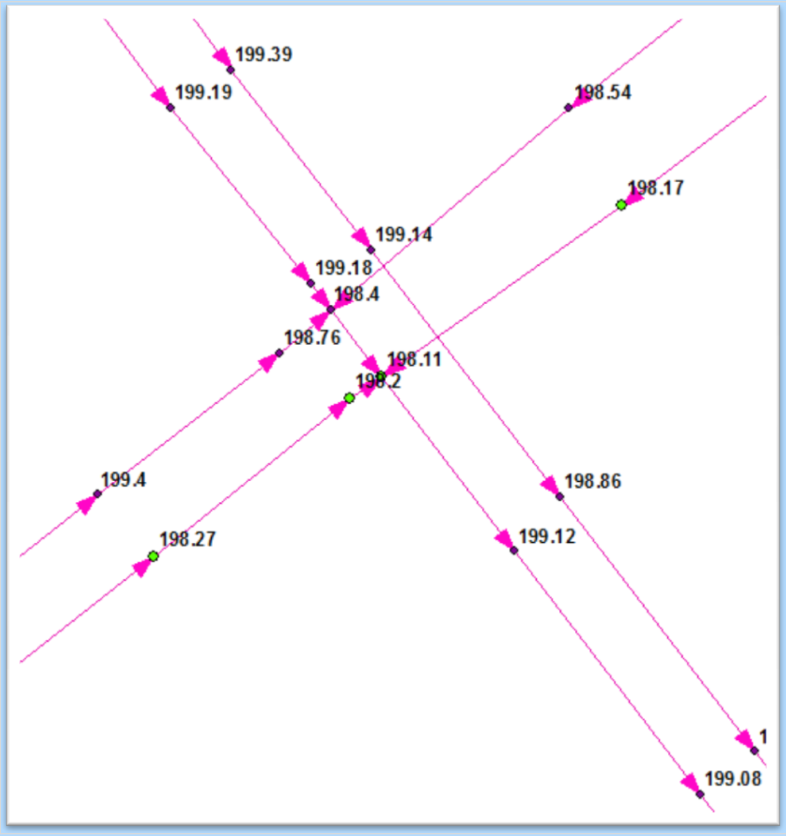
- In some cases it can be seen that drains of higher capacity are meeting drains of lower capacity. All such cases have been identified, so as to analyse the implication of such implementation. For example, in Arya Nagar drain from Arya Nagar Village to drain No.1_ shown in Figure 2.5-3, conduit with dimension 5.81 m × 0.83m (width × depth) meets the conduit with dimension 5.02 m × 0.97 m which might create flooding conditions in the drain.

Figure 2.5-3: Drains with higher dimension meeting with lower dimension (Arya Nagar)



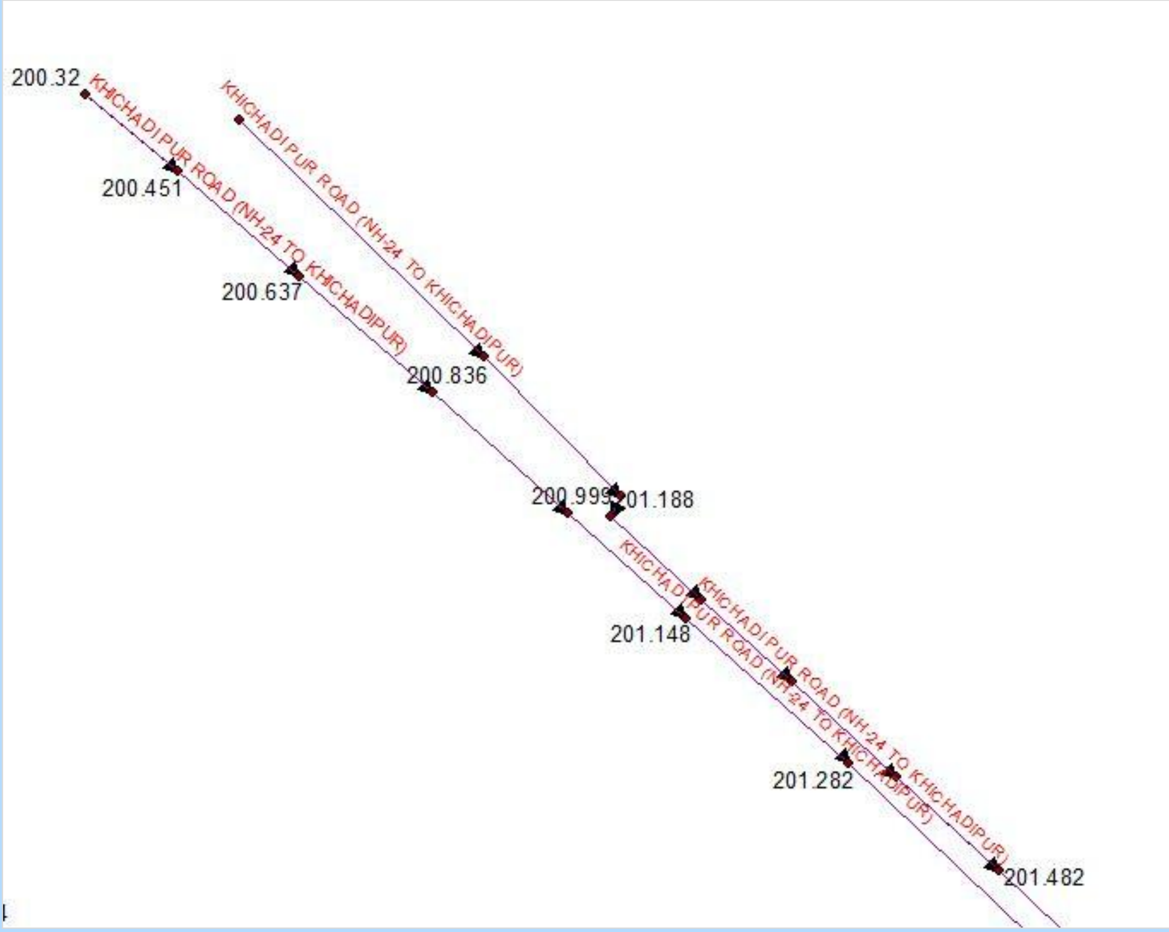
- Wherever dimensions of drains are missing, an average dimension has been computed based on the preceding and succeeding drains.
- In the absence of any pump curve data, standard pump curve of Shakti pumps has been taken.
- In the absence of any details of operations, dimensions and locations of diversions/regulators/gates/weirs/culverts/embankments, these structures have been excluded in modelling.
- Provision of portable pumps while generating various scenarios has not been included in the modelling since their locations and operation details are not known.
- In the absence of information on sewers (location and flow magnitude) draining into storm water drains and vice versa, sewers have not been included in the modelling.
- Invert levels have been found to be different at many junctions where two or more conduits meet. An example of different invert levels at same joint is shown in Figure 2.5-4. Such situations should be verified further.

Figure 2.5-4: Junction with different Invert Level at same point



- At many places, the flow direction provided is found to be against the natural gradient. For instance, the flow of storm water is towards the increasing invert level (Figure 2.5-5), which is not possible.

Figure 2.5-5: Direction of flow indicated against the Invert Level slope (Khichadipur Drain)



- Outfalls of many of the drains are not specified. In such cases, the drain has been made to outfall into the nearest drain of larger capacity.

2.6. SIMULATION SCENARIOS GENERATED

Having processed and validated the data on the drainage infrastructure to the extent possible, a systematic and stepwise strategy has been evolved that includes the following steps: (i) to simulate the present system with the prevailing infrastructure, which shall also involve the validation of the modelling of the present system, (ii) introduce the interventions required to alleviate the flooding conditions in various parts of the city, which include applying corrective measures to faulty implementation of the drainage infrastructure as well as low cost measures that can reduce the flooding such as rejuvenation of water bodies, rainwater harvesting using parks, etc., and lastly (iii) implementation of Low Impact Development options. It is important to understand that implementation of the recommendations has to be sequential for better efficacy since it is possible that many of the data elements that have not been independently validated by the respective departments may be different on ground than the digital reality captured and used in the model. However, since the total system has been captured and is in the workable form, it is now feasible to keep on updating the data perform fresh simulations to know the impact of the changed conditions. In other words, a dynamic system is being left behind that should help keep improving the drainage problems of the city with a sound scientific base. Therefore it is not advisable to conclusively make recommendations on paper about taking care of the complete flooding problems of NCT of Delhi without having a complete ground information as to the viability of the possible LIDs or similar structures.

Consequently, the following modelling scenarios have been generated for each of the drainage basins of NCT of Delhi, namely Trans-Yamuna, Barapullah and Najafgarh basins, and their efficacy evaluated through simulation.

2.6.1. Simulation with the data provided by the departments:

This scenario geared to generate the present flooding conditions considering the data provided by various organizations to supposedly represent the present condition of the drainage system. The model has been setup for each of the basins to check the performance and adequacy of the existing infrastructure of storm water drains of the respective basin using the data which IIT Delhi received from various departments/ agencies. Through this scenario:

- Assessment has been done for the water carrying capacities of the natural and engineered drainage systems including culverts and other cross drainage structures corresponding to the existing land use status.
- The existing storm drainage system has been evaluated for its conveyance adequacy.
- An inventory has been prepared for model deduced flooding hot spots along with details on reported (as observed) extreme water logging events for the drainage basins. Therefore, this scenario, in a way provides a mechanism for model validation.

2.6.2. Simulation with changed/corrected cross sections of the drains:

This scenario incorporates the changes made in the cross-sections, wherever adverse slopes have been encountered, by changing the invert levels and width of the cross sections in case a constriction is encountered. While making these corrections, following aspects have been kept in mind:

- The corrections to the invert levels, wherever required, have been done to ensure smooth gradual slope for the flow of water in drains.
- Abruptly varying and fluctuating values of invert levels of junctions in conduits have been modified by smoothening it using a nearest neighbour approach.
- Changes in width of the drains have only been made wherever constriction in the width has been encountered.
- Invert levels of conduits have been corrected to ensure that drains of different capacity meet appropriately at a junction.

2.6.3. Simulation after incorporating the existing water bodies:

This scenario has been formulated by incorporating the existing water bodies to detain some of the excess runoff generated from the sub catchments. Many of the water bodies have become redundant over the years and are not even properly connected to their catchments. Once rejuvenated, these water bodies can play a pivotal role in reducing the flooding. The following considerations have been made:

- Water bodies identified in each sub basin have been incorporated in the modelling to absorb the surplus water wherever feasible. These water bodies shall act as detention as well as recharge bodies.
- Model computations have been made available to quantify the effectiveness of the rejuvenated wetlands/water bodies in reducing the flooding.

2.6.4. Simulation after diverting storm water to additional storages/ recharge areas:

Outlets into the nearby parks (preferably DDA parks) from the storm drains have been created for absorbing some volume of storm water. In this scenario:

- The storm water is diverted from drains to nearby parks where depression storages have been created to reduce flooding.
- The design is such that storm water will be diverted as a practice to the nearby parks by creating 0.3m depression in the park area excluding the foot path area, if any.
- The storages so created shall also be useful for recharging the groundwater. Provision has been made for carrying overflow of any surplus water from this storage into a nearby drain.

2.6.5. Towards no flooding for 2 year return period storm

After scenario 3 and 4 in which some of the excess flood volume was diverted to existing and potential water bodies and parks whereby a substantial reduction in flood volume was observed, the next step was taken to explore the mechanism for further reducing any flooding if persists corresponding to 2 year return period storm.

In order to explore additional options for disposal of the remaining excess water, it shall be advisable to explore the local conditions in a comprehensive manner and identify various Low Impact Development (LID) options such as infiltration trenches, rain gardens, bio-retention ponds, bio-swales wherever feasible in respective contributing areas of each of the drains. Therefore, in scenario 5:

- Additional volumes that are required to be handled have been quantified and presented for each junction.
- In some of the pilot sub basins simulation has been done by incorporating some of the LID options by studying the landuse pattern of the respective areas and making a preliminary selection of the appropriate LIDs.
- Thus, for each sub basin, suitable LIDs can be identified and the effectiveness of the same can be established through simulation and the consequent reduction as well as unaccounted surplus runoff volume can be quantified.
- While formulating scenario 5 another decision has been taken to ignore all the junctions that are getting flooded for a duration of 15 mins or less.

Simulations have been performed for each of the basins of NCT of Delhi using all the simulation scenarios explained above. Detailed simulation results have been provided for each of the basins in the following sections. Volumetric analysis has also been done to evaluate the volume of water that is accumulating at each junction. The impact of using various scenarios on the reduction of flooding has also been depicted for each junction of the drainage network. Table 2.6-1 summarizes the simulation scenarios used.

Table 2.6-1: Summary of simulation scenarios generated

S. No.	Scenarios	Highlights
1.	Simulation with the data provided by the departments	The model has been setup for each of the basins using the data which IIT Delhi received from various departments/ agencies
2.	Simulation with changed/corrected cross sections of the drains	Invert Levels and width of the cross sections have been changed wherever adverse slopes or constriction is encountered
3.	Simulation after incorporating the water bodies	Water bodies have been incorporated in the modelling to absorb the surplus water wherever feasible
4.	Simulation after diverting storm water to additional storages/ recharge areas	Storm water is diverted from drains to nearby parks and depression storages to reduce flooding at the location through detention and recharge
5.	Simulation with no flooding junction for 2 year return period	Flooded junctions were transformed into the storages. However, these storages may be replaced by other LID structures if feasible.

3. BASIN-WISE REPORT

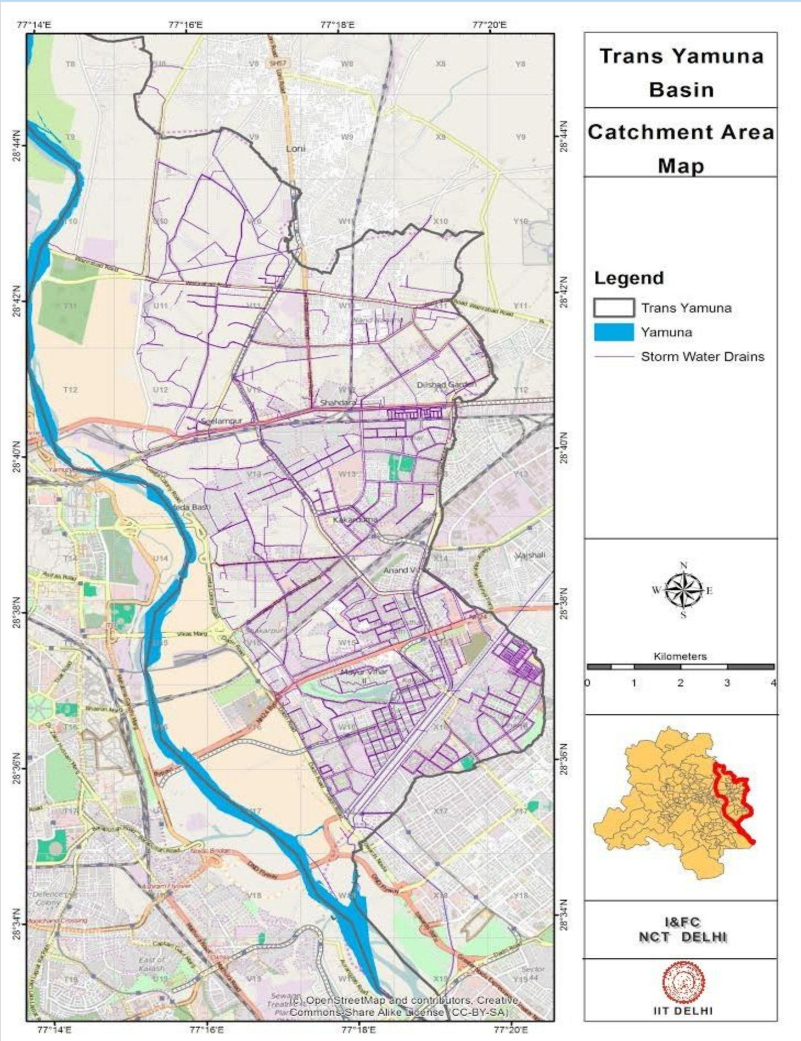
3.1. TRANS YAMUNA BASIN

3.1.1. Introduction

3.1.1.1. Basin characteristics

Trans Yamuna region spreading over North-East Delhi, Shahdara and Eastern Delhi covers around 196.929 sq. km. area. A basin map with major roads and storm drains is given in Figure 3.1-1.

Figure 3.1-1: General Layout of Trans Yamuna Basin



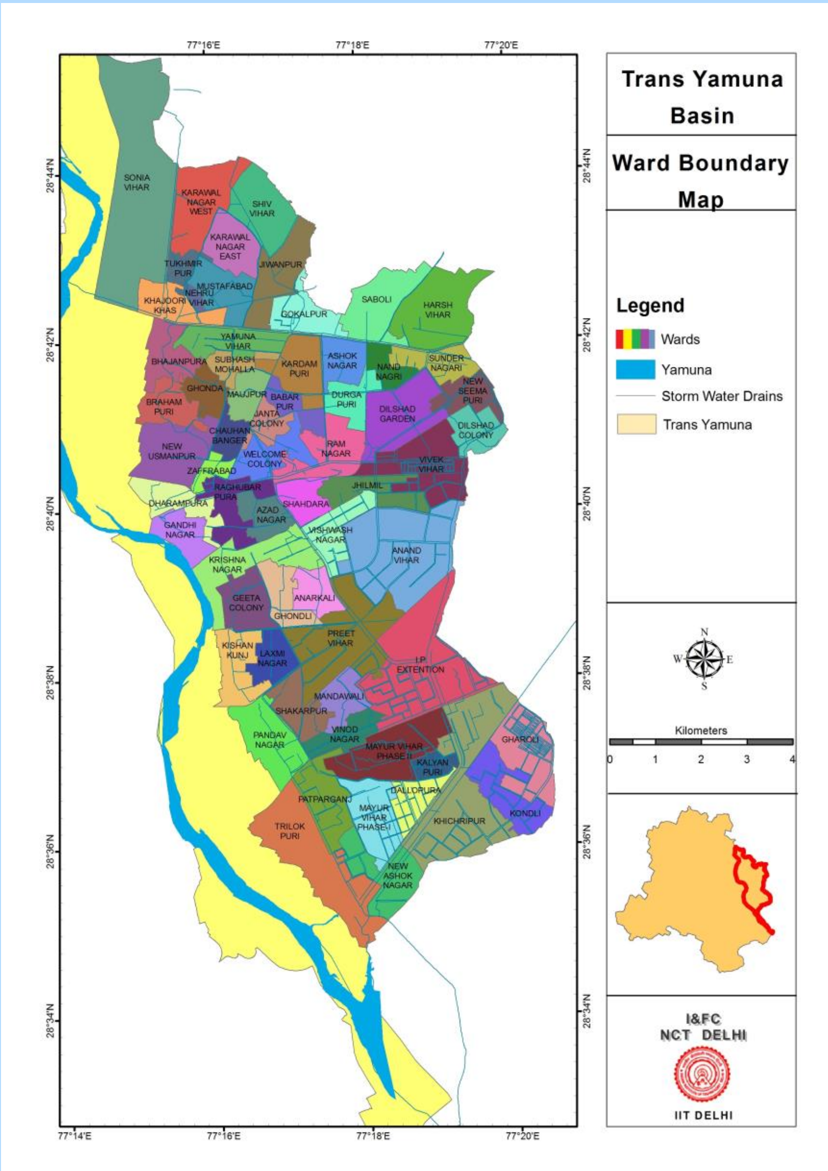
Entire region of Trans Yamuna basin falls on the eastern bank of river Yamuna and is bounded by river Hindon on the East, river Yamuna on the West, district Ghaziabad (U. P.) on the North and district

Noida (U. P.) on the South. Grand Trunk Road (G. T. Road) running from West to East divides the region into two districts: East and North East Delhi. Trans Yamuna region above the G. T. Road is known as North East Delhi and that below the G. T. Road is known as East Delhi.

3.1.1.2. Population statistics

According to the 2011 census [5], total population in the region that includes 48 villages is around 39.5 lakhs. Almost whole of the Trans Yamuna region is densely populated. A map showing the location of wards in Trans Yamuna region is given in Figure 3.1-2 (Ward Numbers of these wards are given in APPENDIX I

Figure 3.1-2: Details of wards in Trans Yamuna Catchment



[5] Government of NCT Delhi 2014 Directorate of Economics and Statistics STATISTICAL ABSTRACT OF DELHI 2014 and Government of NCT Delhi 2014 Revenue Department.

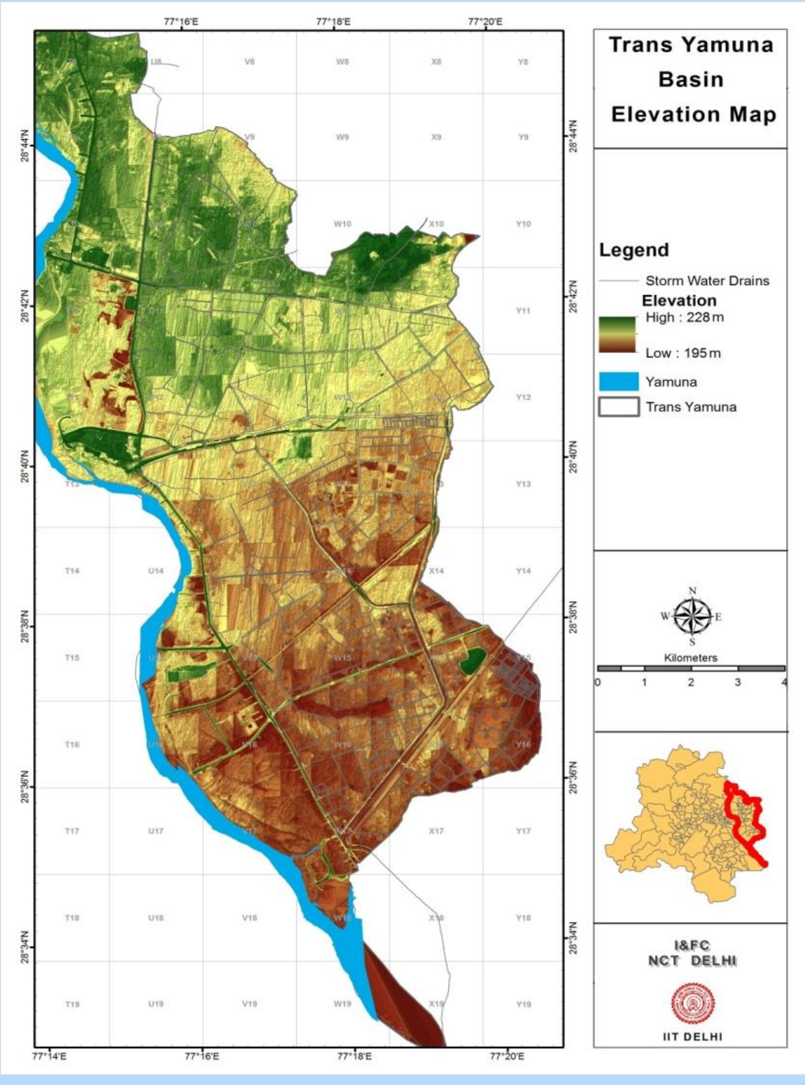
North East Delhi: North East Delhi district comprises 27 villages including Seelampur and Shahdara villages. The district is very densely populated with a density of about 36,155 people per sq. km. Census 2011 reports that the population density in this region has increased by 26.73% in the last decade as population of approximately 17 lakhs in 2001 has increased to approximately 22 lakhs in 2011.

East Delhi: East Delhi district is densely populated comprising 21 villages including Khichripur, Hasanpur, Karkardooman villages, which are the major population growth centres facing rapid urbanization. The population density of East Delhi as per 2011 census is 27132 people per sq. km. The population density in this region has increased by 16.68% in last decade, with approximately 14.5 lakhs in 2001 rising to approximately 17 lakhs in 2011.

3.1.1.3. Topography and land use

Majority of the Trans-Yamuna region has elevation below the high flood level of river Yamuna. The digital elevation model (DEM) map of the region is shown in Figure 3.1-3.

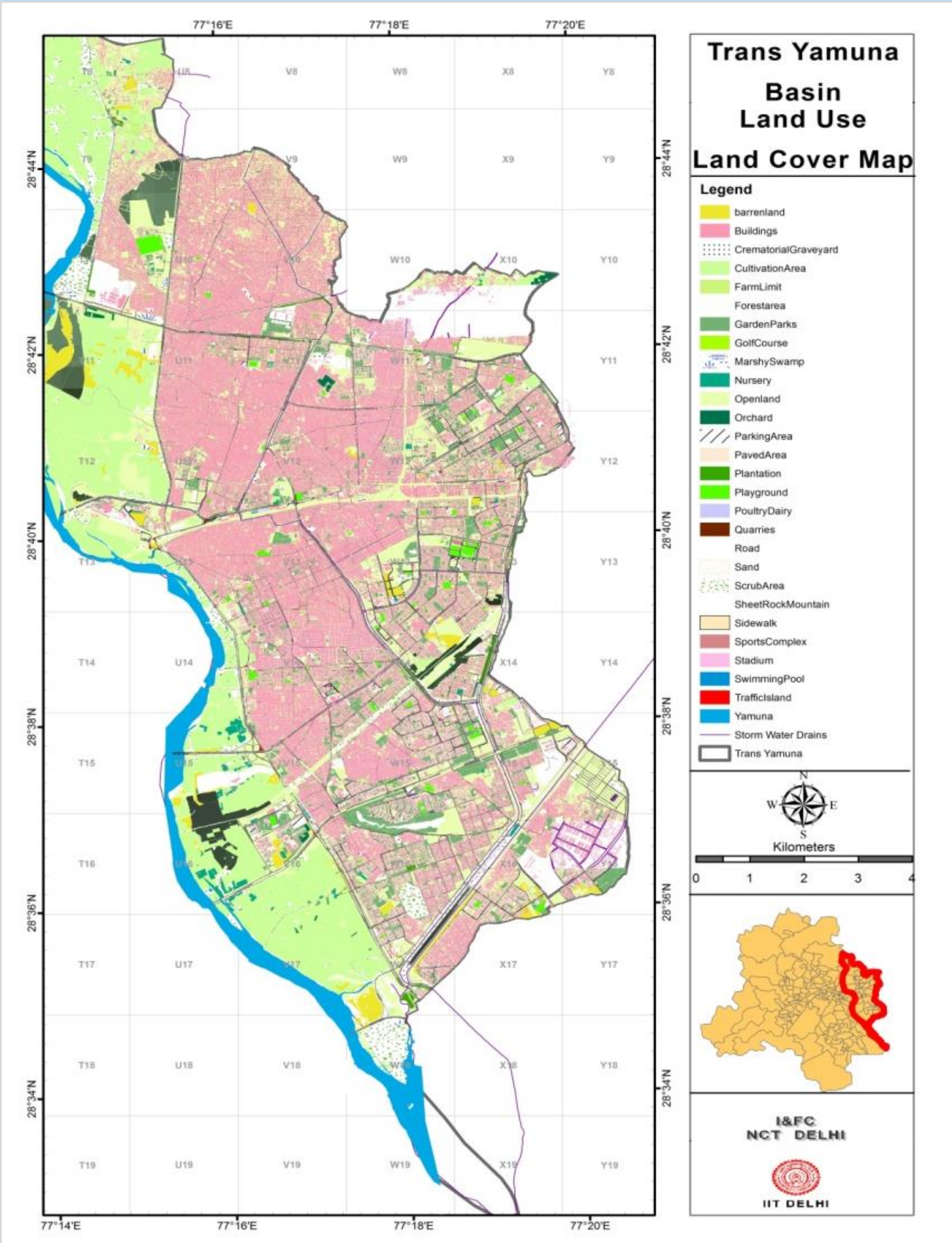
Figure 3.1-3: Digital Elevation Model (DEM) map of Trans Yamuna Region



The surface elevation of Trans Yamuna basin lies between 195.047 m to 228.035 m above m.s.l., with an average elevation of 211.541 m over the region. Northern parts of the region are at a higher elevation when compared to the southern parts. The flood plains of Yamuna exhibit lower elevation levels. On account of majority of the area once being part of the flood plain of Yamuna, natural flow direction of this region is majorly towards river Yamuna and partially towards river Hindon. Hence, storm drains of this region are designed mostly against the natural slope of the terrain, which is the most unique characteristic of this region.

The whole region carries alluvium soil. The land use of the region can be broadly divided into crop land, urban, river and water bodies, grass and fallow lands. The region is majorly urbanized with approximately 68 % of total the area contributing to built-up land use as shown in Figure 3.1-4.

Figure 3.1-4: Built-Up area of Trans Yamuna region



The percentage area of each land use in the region is given in Table 3.1-1. The central region of Trans Yamuna is densely populated. The informal sector units locate themselves strategically near work centres, commercial areas, outside the boundaries of schools colleges, hospitals and transport nodes and near large housing clusters. A very high percentage of this activity has been observed in Trans Yamuna area and old commercial areas. The runoff characteristics of the regions has significantly changed due to low infiltration and percolation resulting from the rapid increase in built-up area.

Table 3.1-1: Area (in sq. km. and in percentage) of each land use

S.No	Land Use	Sub Divisions	Area (sq. km.)	Percentage of Total Area (%)
1	Rural/Crop Land	Cultivation Area, Farm limit, Plantation Area	17.24	21.19
2	Urban	Building Full, Parking, Paved Area, Poultry Dairy Farm, Road, Sports Complex, Traffic Islands etc.	55.35	68.04
3	River/ Water Bodies	River, Lake	3.51	4.32
4	Grass	Golf Course, Garden Parks, Marshy Swamps, Nursery, Playground	2.39	2.95
5	Fallow	Barren Land, Open Land, Orchard, Quarries, Sand Area	1.56	1.92
6	Deciduous	Forest Area, Scrub Area, Sheet Rock	1.29	1.59

Apart from river Yamuna, numerous water bodies are also present in the basin. The flood plain of the river Yamuna is more or less undisturbed. It is primarily used for agricultural activities or as an open area for the drainage outfalls. However, an encroachment of paved settlement was established in 2010 when the Commonwealth Games Village was constructed on the flood plains of Yamuna.

3.1.1.4. Rainfall and groundwater scenario

The average annual rainfall of the basin is 668.5 mm [6] of which about 81% of the annual rainfall is received during monsoon months July, August and September.

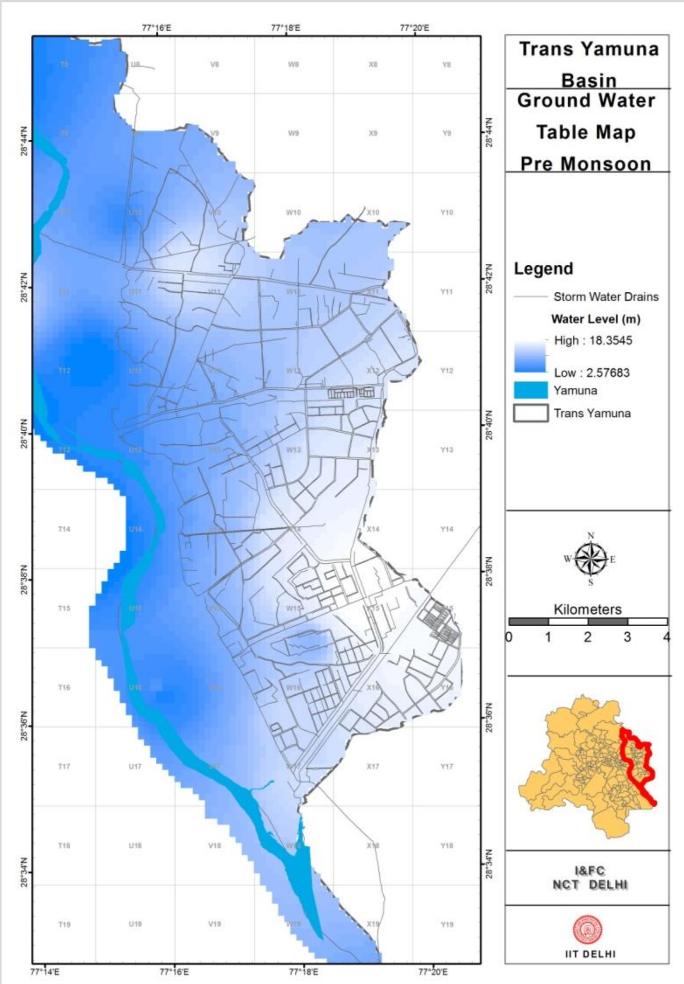
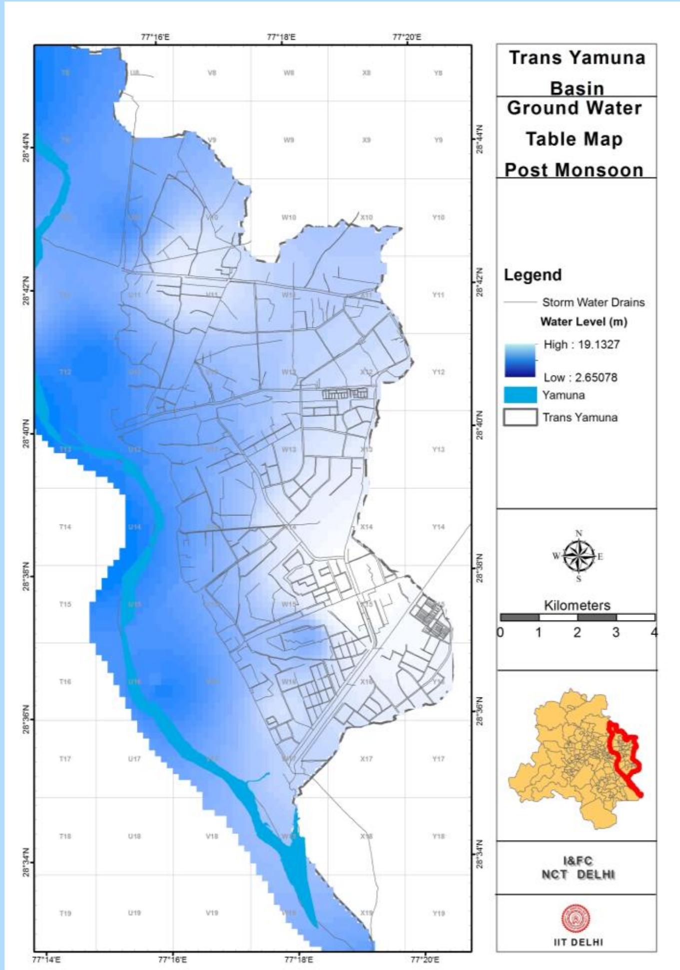
In 2014, the pre-monsoon ground water level in the North Eastern region varied from 2.89 to 8.73 mbgl [7] and post-monsoon water level varied from 4.01 to 10.22 mbgl (Figure 3.1-5).

The pre-monsoon ground water level in the Eastern parts varies from 3.69 to 18.40 mbgl and post-monsoon water level varies from 4.29 to 19.18 mbgl. Ground water levels are shallower along the western border of the basin and relatively deeper towards the eastern parts. It has been observed that the groundwater table decreases in the post monsoon period, indicating greater groundwater extraction than groundwater recharge.

[6] Central Ground Water report of North and North East District of Delhi
[7] Water Resources Information System, INDIA (www.india-wris.nrsc.gov.in)

Figure 3.1-5: Ground Water Table Map for Trans Yamuna region

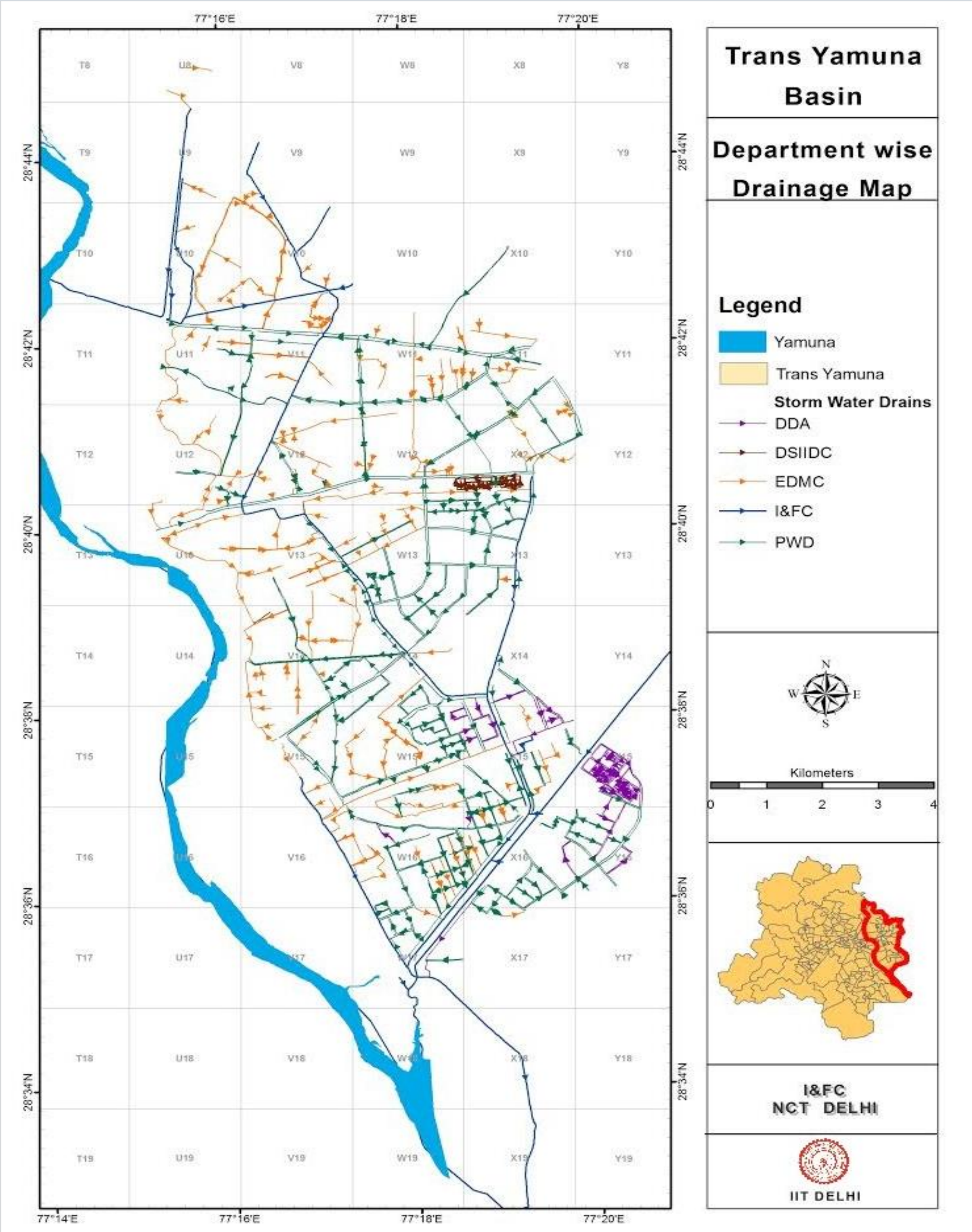
Water Resources Information System, INDIA (www.india-wris.nrsc.gov.in)

Pre Monsoon Ground Water Level (2014)	Post Monsoon Ground Water Level (2014)
	

3.1.2. Details of existing drainage network as captured

Storm drains of the region are under the jurisdiction of multiple agencies. A dense drainage network of length 560 Km (as digitised) is present in the Trans Yamuna to carry the storm water to the outfalls. A map depicting the storm drainage network (of 4 feet and above) under the jurisdiction of various agencies is shown in Figure 3.1-6.

Figure 3.1-6: Storm drainage network under various jurisdictions



As mentioned before, the natural flow direction is towards river Yamuna. Marginal embankments have been constructed to avoid frequent flooding. Shahdara Marginal (S.M.) Bund (11.95Km) in the northern region and Left Marginal (L.M.) Bund (6.7Km) in the southern region were constructed in 1955-56. A network of natural drains includes Relief drain, Trunk Drain1, Trunk Drain2, Escape Drain, Bund drain, Biharipur Drain, Karawal Nagar Drain, Ghazipur Drain, Shahdara Link Drain and Shahdara Outfall Drain, which come under the jurisdiction of Irrigation and Flood Control department (I&FC). The engineered drains present in this region are box type and circular type, whereas the natural drains are irregular in shape.

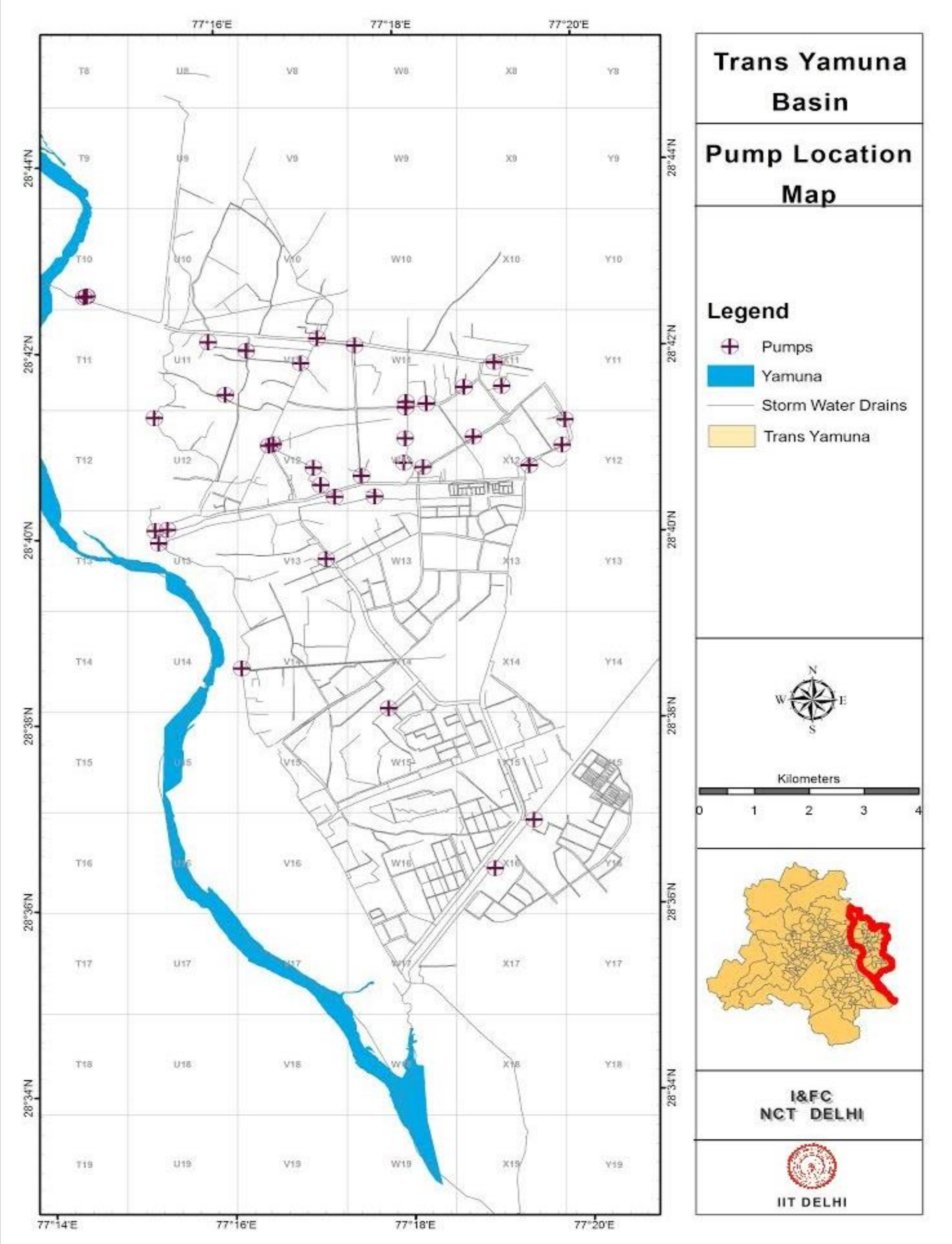
3.1.3. Major drainage problems in the region

As discussed before, rapid unplanned urbanization, shallow groundwater level and low elevation have resulted in frequent flooding problems in this region. The major problems are as follows:

- Shallow Ground Water table: Majority of areas lying in the western side face frequent water logging problems, primarily due to shallow groundwater levels during pre and post-monsoon periods.
- Reversal of Flow Direction: The region is protected from frequent flooding in river Yamuna by providing two marginal bunds. This also prevents any direct outfall into the river. Relief Drain is the only drain which is having the outfall in the river. Majority of drains flow from west to east (from the Yamuna River to the eastern side of the basin) against the natural flow direction. The water from the North Eastern basin gets collected into the G.T. Road drain which carries it across the region and drains it into TD2.

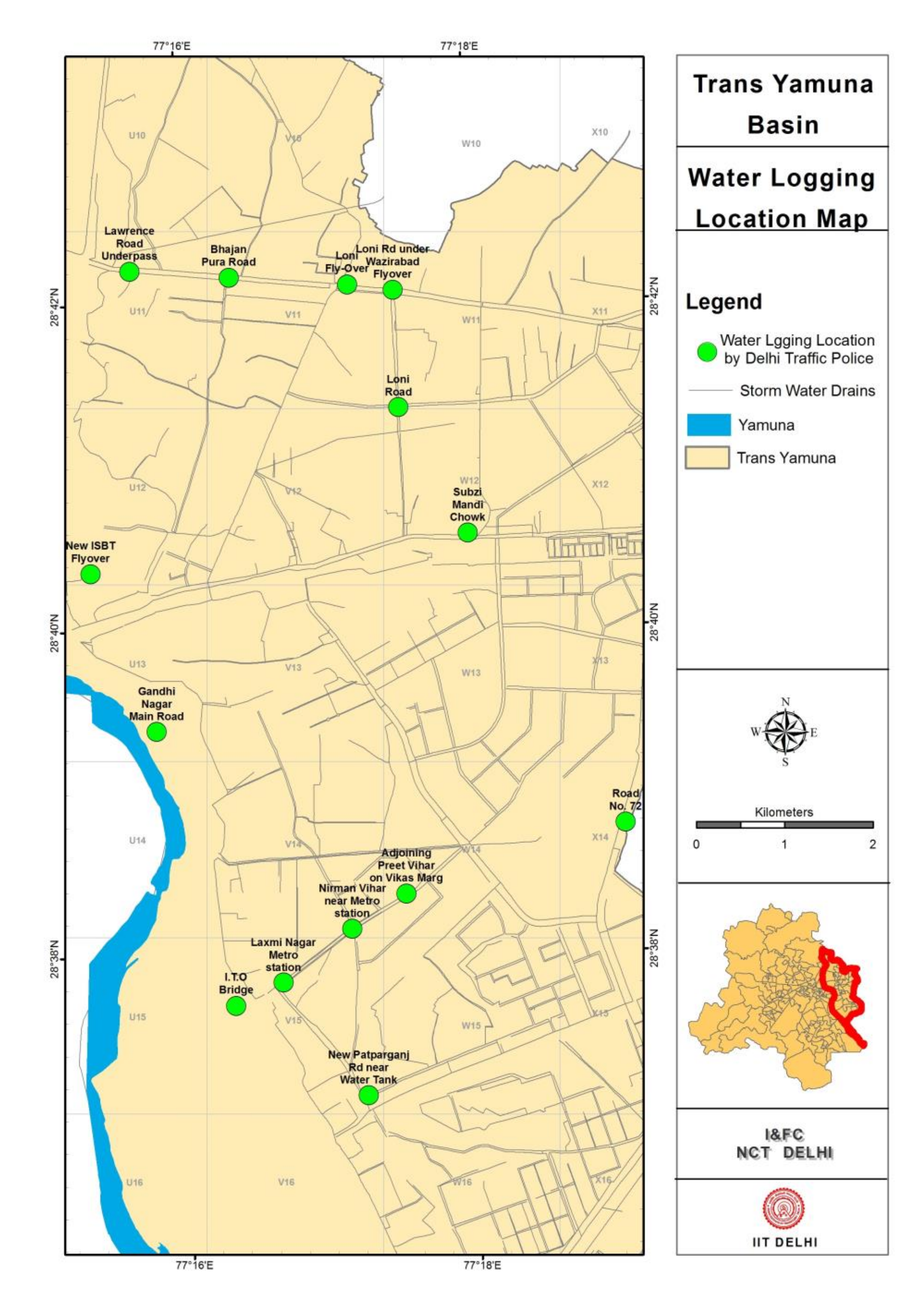
The natural flow direction is reversed and collected runoff is pumped to river Yamuna or other nearby drains, especially during average or heavy flood periods. Pumps have been installed at various locations by the government to pump out the collected water into the Yamuna River. Location details of installed pumps are shown in Figure 3.1-7. Majority of the pumps are installed in the North-East region. The failure of these pumps leads to drainage congestion in these areas. In addition, constant usage of mobile pumps is also done to pump out the surplus amount of water into nearby drains, whenever required. However, this often causes flooding in the downstream areas.

Figure 3.1-7: Location details of pumps installed in Trans Yamuna Region



About 14 hotspots have been identified by the Delhi Traffic Police where water logging conditions occur predominantly, viz., Bhajan Pura Road, Loni Fly-Over, Loni Road under Wazirabad flyover, Loni Road, Subzi Mandi Chowk, Gandhi Nagar Main Road, New ISBT Flyover, Road No. 72, adjoining Preet Vihar on Vikas Marg, Nirmaan Vihar near metro station, Laxmi Nagar Metro Station, I.T.O Bridge, New Patparganj Road near Water Tank (Figure 3.1-8). Apart from these, interior built-up areas have been also reported to be affected by water logging conditions, especially during monsoon period.

Figure 3.1-8: Areas facing a frequent water logging as reported by Delhi Traffic Police



3.1.4. Simulation scenarios

The following modelling scenarios have been generated for Trans Yamuna basins with rainfall event of 2 days (9/12/1997 to 9/13/1997) of 15 minutes interval and 2 year return period using rainfall data of Safdarjung station. The detailed comparative analysis of simulation for the total network of Trans Yamuna basin for all the scenarios as described below is provided in APPENDIX XI.

3.1.4.1. Scenario 1 – Simulation with data provided by the departments

This scenario has been used to generate the flooding conditions with respect to the data provided by various organizations to supposedly represent the present condition of the drainage system. The model has been setup to check the performance of the existing infrastructure of storm water drains which IIT Delhi received from various departments/ agencies. It was unfortunate that various departments passed on the survey data without vetting the data properly, therefore the authenticity of the data provided has been to certain extent indirectly vetted through this scenario.

After analyzing results of simulation of scenario 1 (scenario with invert levels and cross sections provided by agencies), it has been found that there are around 560 nodes flooded (APPENDIX XI). Table 3.1-2 shows the results of the simulation run on a segment of Drain AA taken as a sample. This table records the flood volume in the junctions and duration of flooding in Drain AA. Similar details on flooding time and flood volume for all segments of the drainage network are available as part of the detailed outputs provided in the working model of the basin not only for this scenario but all the subsequent scenarios as well.

Table 3.1-2: Flood volume at junctions in a sample segment of Drain AA after simulation of scenario 1

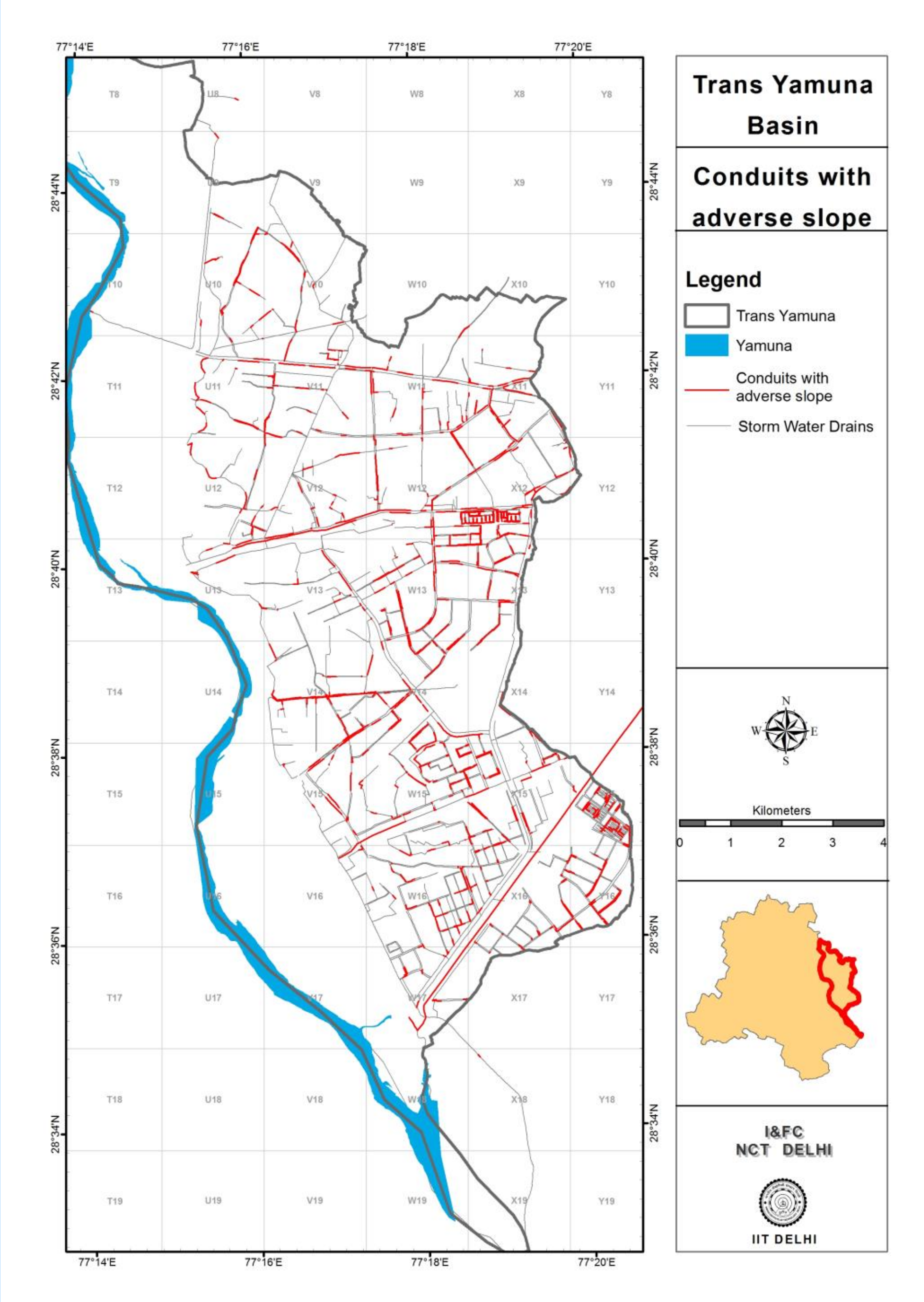
Node	Flooding Hours (in hours)	Flood volume (m^3)
J_817	0.5	320
J_840	0.33	29
J_851	0.32	151
J_865	0	0
J_877	0	0
J_896	0	0
J_920	0	0

3.1.4.2. Scenario 2 – Simulation with changes made to cross-sections

Scenario 2 represents the incorporation of changes made in the cross-sections wherever adverse slopes were encountered by changing the invert levels and width of the cross section in cases where constriction is encountered. There are 1651 segments with adverse slope out of 6381 conduits in Trans Yamuna as shown in Figure 3.1-9.

The invert levels have been corrected keeping in mind the slope of the preceding drain and also the elevation taken from the digital elevation model of NCT of Delhi provided by Geo Spatial Delhi Limited. Along with the corrections made to the Invert Levels in the segments with adverse slope, the width of the cross sections have also been changed, wherever a constriction in width is encountered and the node witnesses flooding (APPENDIX V). The simulation has been made after incorporating these changes.

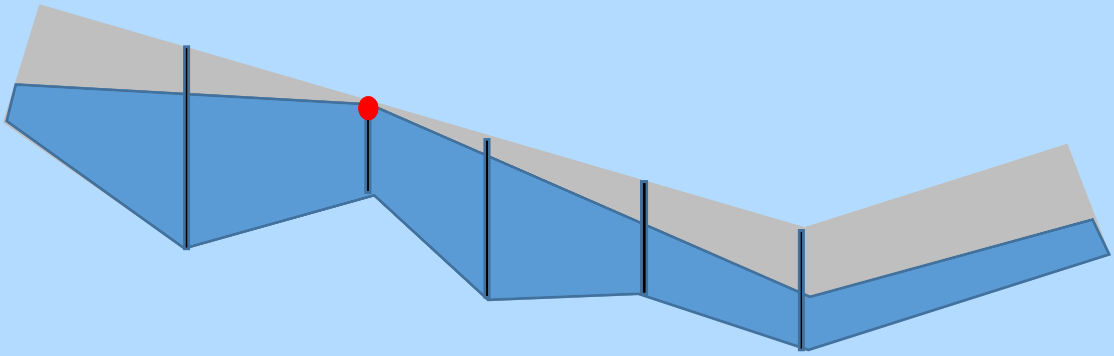
Figure 3.1-9: Trans Yamuna basin showing conduits with negative slope



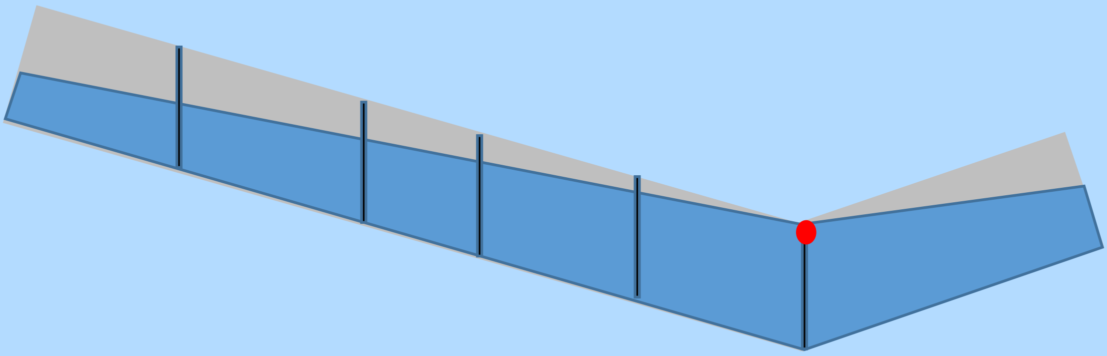
Following are some of the observations from simulation of scenario 2 as compared with the simulation of scenario 1:

- In some cases, the flooding at junctions that are flooded in scenario 1 has considerably reduced and at some other junctions the flooding has totally removed.
- However, in some other cases, flooding has moved to upstream or downstream of flooded junctions. This is possible on account of the hydraulic response of the stretch after modification of the gradients (Figure 3.1-10).

Figure 3.1-10:Flooding location moved downstream after modification of drain bed



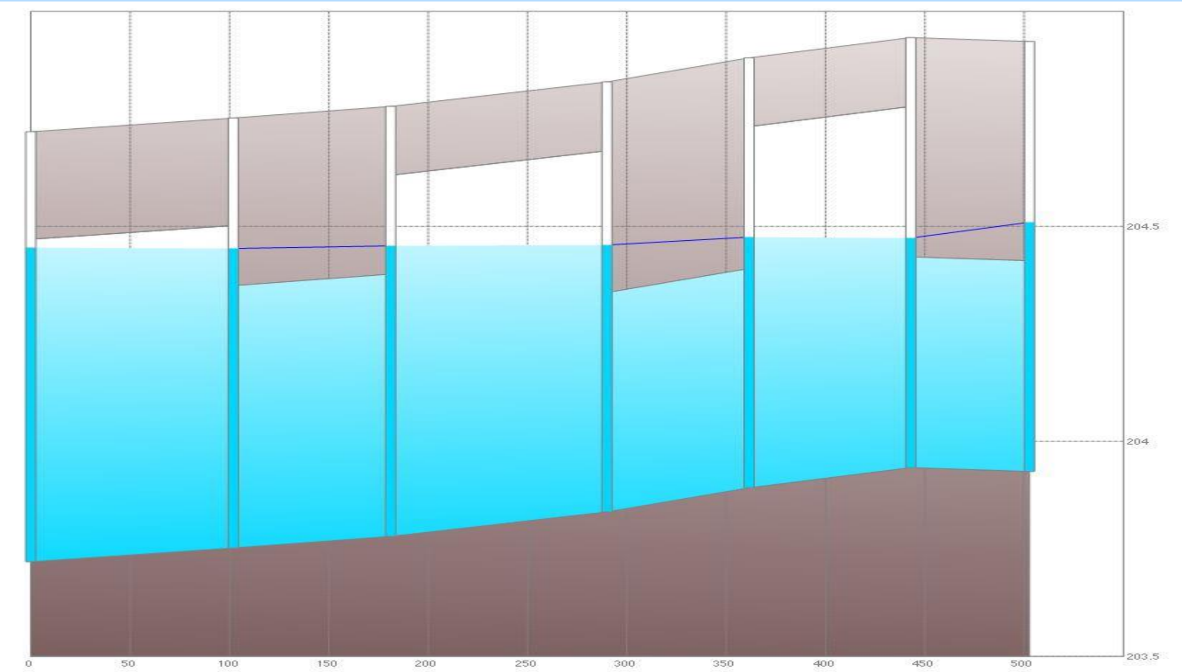
Scenario 1: With data provided by the departments



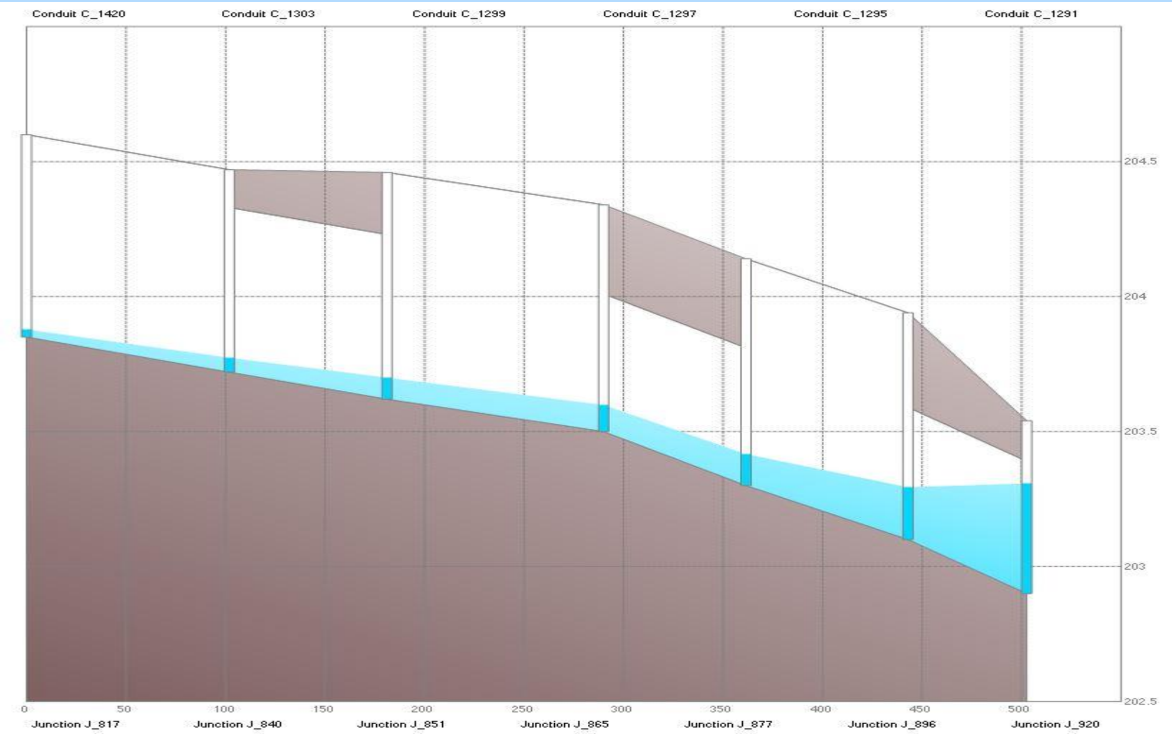
Scenario 2: With changes made to cross-sections

Comparison of water profiles in a segment of drain AA after simulation of scenario 1 and scenario 2 has been shown in Figure 3.1-11.

Figure 3.1-11: Comparison of water profiles in the segment of drain after simulation of scenario 1 and scenario 2



Scenario 1: With data provided by the departments



Scenario 2: With changes made to cross-sections

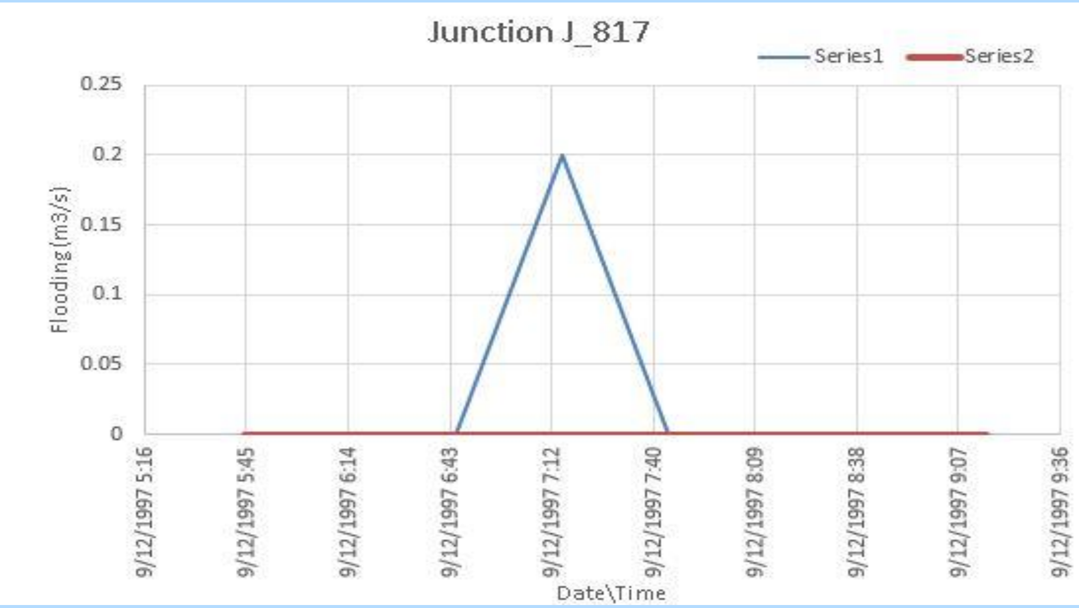
There can be a reasonable decrease in volume of surplus water in some drains after making the corrections in the gradient. Following is an example of the reduction of flood volume at different junctions in the sample drain (Table 3.1-3).

Table 3.1-3 Comparison between the flood volume at junctions of a segment of drain after simulation of scenario 1 and scenario 2

Node	Flood volume (m^3)	
	Scenario 1	Scenario 2
J_817	320	0
J_840	29	0
J_851	151	0
J_865	0	0
J_877	0	0
J_896	0	0
J_920	0	0

Change in flood volume of water at one of the junctions (J_817) of Table 3.1-3 can be seen in Figure 3.1-12 depicting the extent of flooding as well as the duration of flooding. The graph shows that J_817 was originally flooded with 320 m^3 volume of excess water, while in the scenario 2 after changing the Invert Levels, the flooding at the junction is totally removed.

Figure 3.1-12: Comparison between the flood volumeat a sample junction after simulation of scenario 1 and scenario 2



3.1.4.3. Scenario 3 – Simulation towards rejuvenation of water bodies

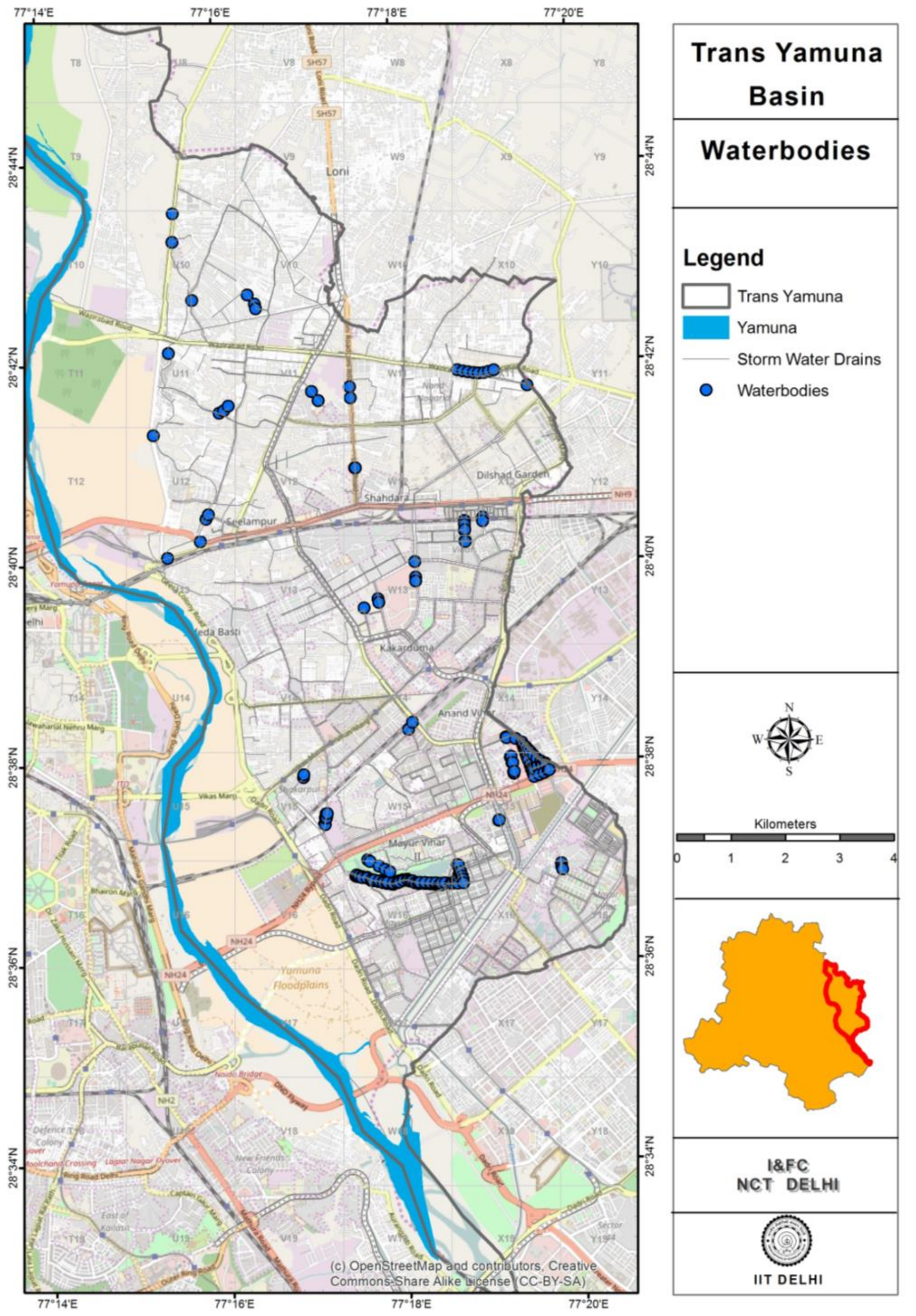
This scenario has been formulated by incorporating the water bodies into the scenario 2, so as to absorb some of the excess runoff generated from the sub catchments and at the same time rejuvenating the water bodies. In Trans Yamuna basin, there are total of 171 water bodies, which have been incorporated and treated as storages in the model (Figure 3.1-13). The runoff from the sub catchments are first routed towards the water bodies. Provision has also been made to take any overflow from these water bodies to the nearest downstream drain. This reduces the total flood volumeat the junction. Trans Yamuna being the smallest of all three basins in Delhi, contains a few major water bodies including Sanjay Lake, Shahdara Jheel and many other small water bodies. As per the departmental input, the depth of the water bodies has been considered as 2 m.

APPENDIX VIII presents all the junctions that can be connected to water bodies and parks in Trans Yamuna basin.

Following are some of the generic observations from simulation of scenario 3 as compared to the simulation of scenario 2:

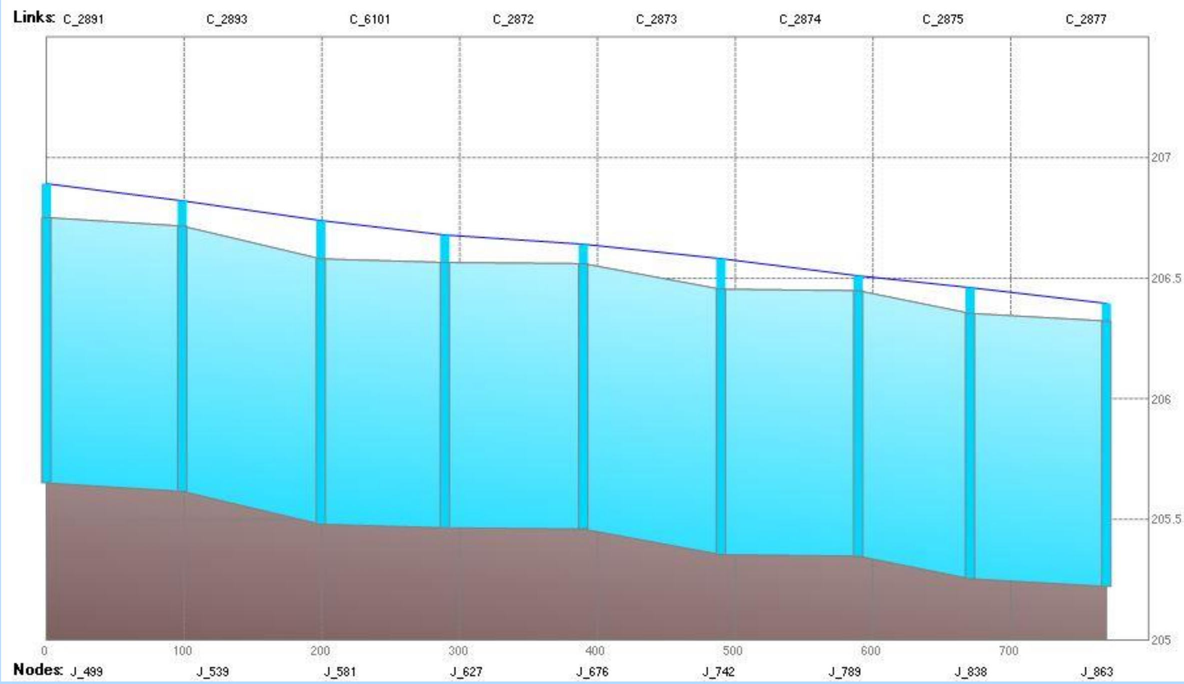
- In some cases, water bodies captivate the flooded volume of water, thus removing the flood at some of the junctions or reducing the volume at others.
- Additional conduits have been provided to connect water bodies and nearby junctions for transfer of excess water in water bodies after they have been filled up with water coming from the subcatchment.

Figure 3.1-13: Water bodies connected to junction to divert the excess water

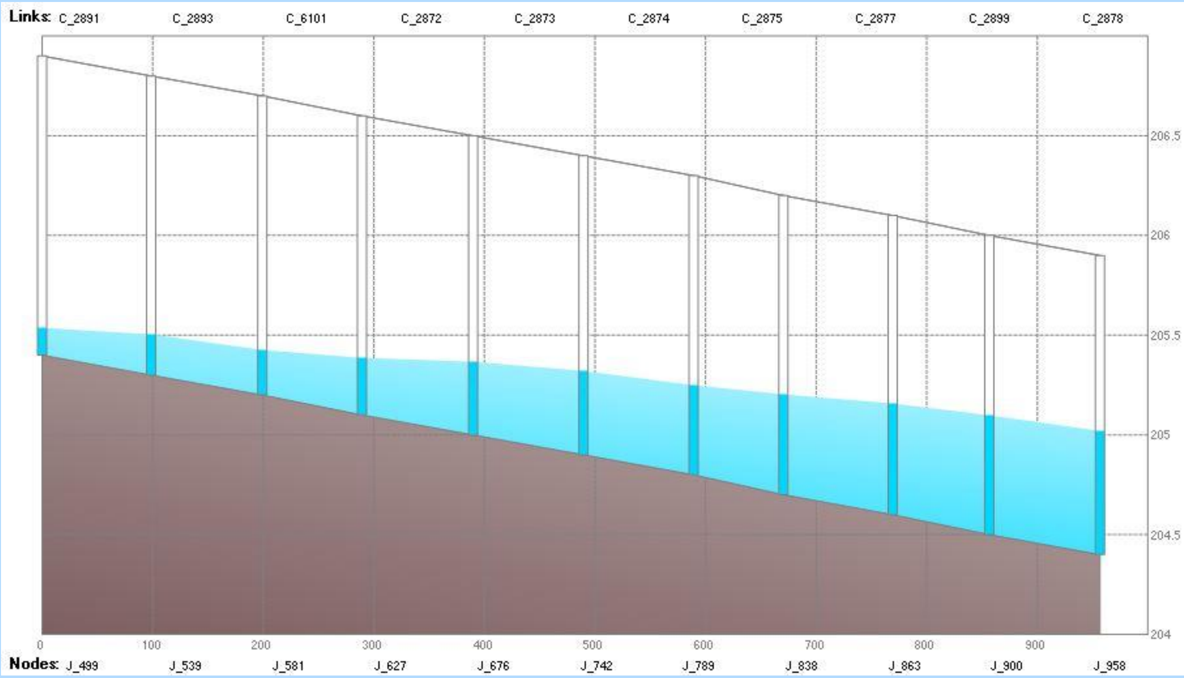


Comparison of water profiles in the segment of a sample drain after simulation of scenario 2 and scenario 3 Has been shown in Figure 3.1-14.

Figure 3.1-14: Comparison of water profiles in the segment of drain after simulation of scenario 2 and 3



Scenario2: Before inclusion of water body in basin



Scenario 3: After inclusion of water body

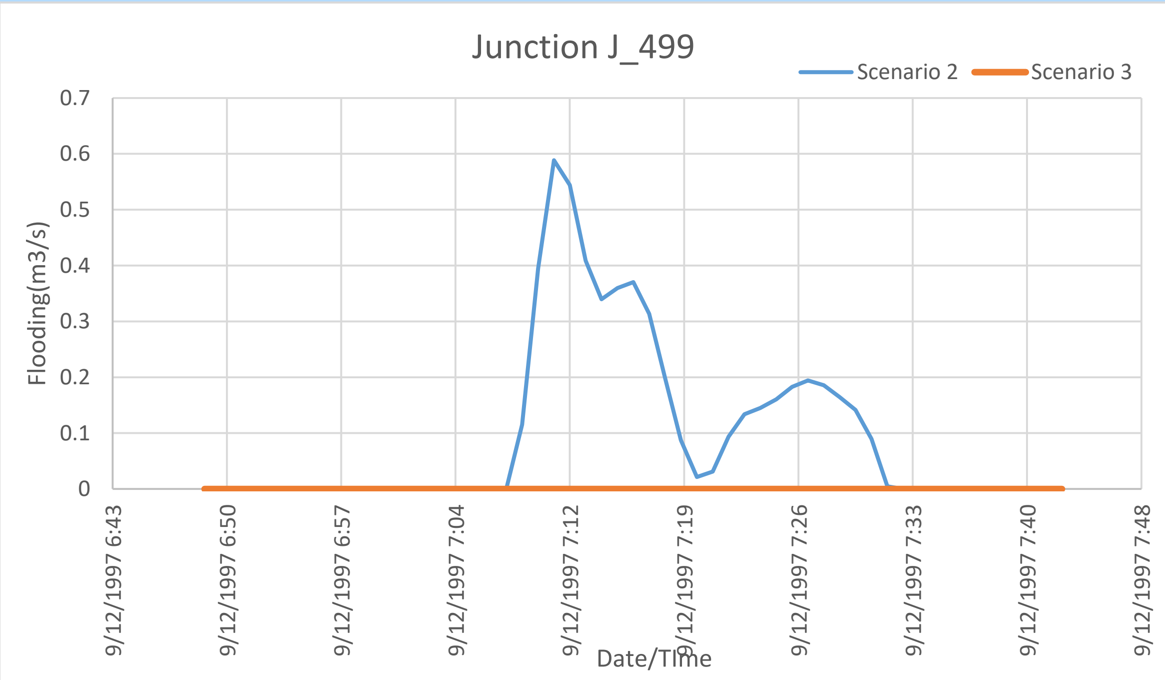
An example of the reduction in flood volume at different junctions in the sample drain is shown below in Table 3.1-4. In the present example, the junction J_499 is capturing runoff from a big sub catchment and is not able to cater to the requirement and thus is flooded after simulation of scenario 2. In scenario 3, the runoff from the sub-catchment is first made to flow into a nearby water body which could store a good amount of volume and thus prevents the junction from flooding.

Table 3.1-4 Comparison between the flood volume at junctions of a segment of drain after simulation of scenario 2 and scenario 3

Node	Flood volume (m^3)	
	Scenario 2	Scenario 3
J_499	317	0
J_539	274	0
J_581	341	0
J_627	281	0
J_676	205	0
J_742	223	0
J_789	138	0

Change in flooded volume of water at a single junction can be seen in Figure 3.1-15. The graph shows the reduction in the flooding at junction J_499 after incorporating water body at this junction.

Figure 3.1-15: Comparison between the flood volumeat a sample junction after simulation of scenario 2 and scenario 3



3.1.4.4. Scenario 4 – Simulation with public parks as recharge zones

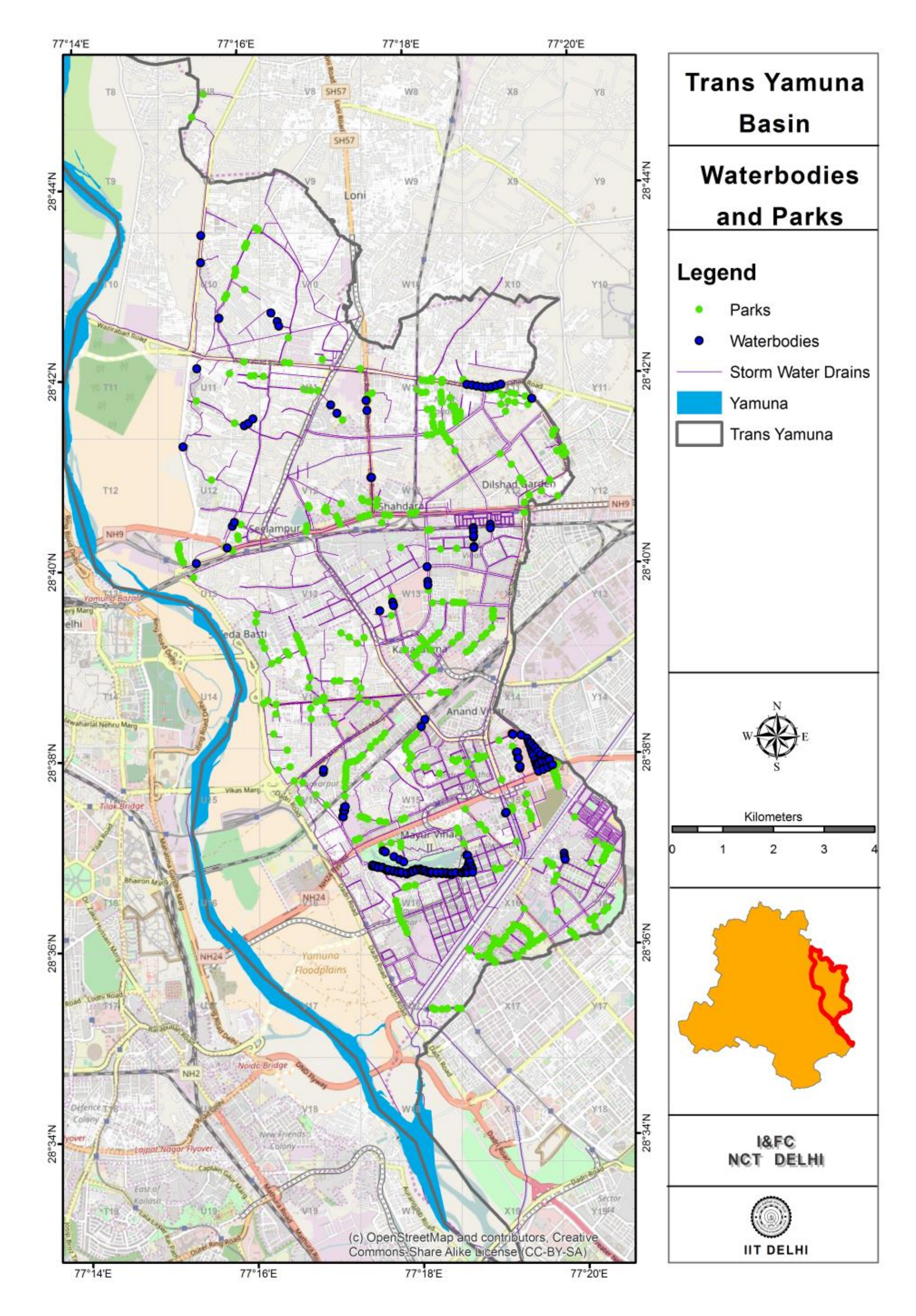
After including water bodies to the basin (scenario 3), scenario 4 has been designed to divert the excess volume of water from junctions to the nearby parks and other open areas wherever possible. DDA parks and other parks within the basin have been incorporated with a standard depth of 1 feet (0.30 meters). In Trans Yamuna basin, there are total of 428 water bodies and parks, which have been incorporated and treated as depression storages in the model (Figure 3.1-16).

APPENDIX VIII presents all the junctions that can be connected to water bodies and parks in Trans Yamuna basin.

Following are some of the generic observations from simulation of scenario 4 as compared with the simulation of scenario 3:

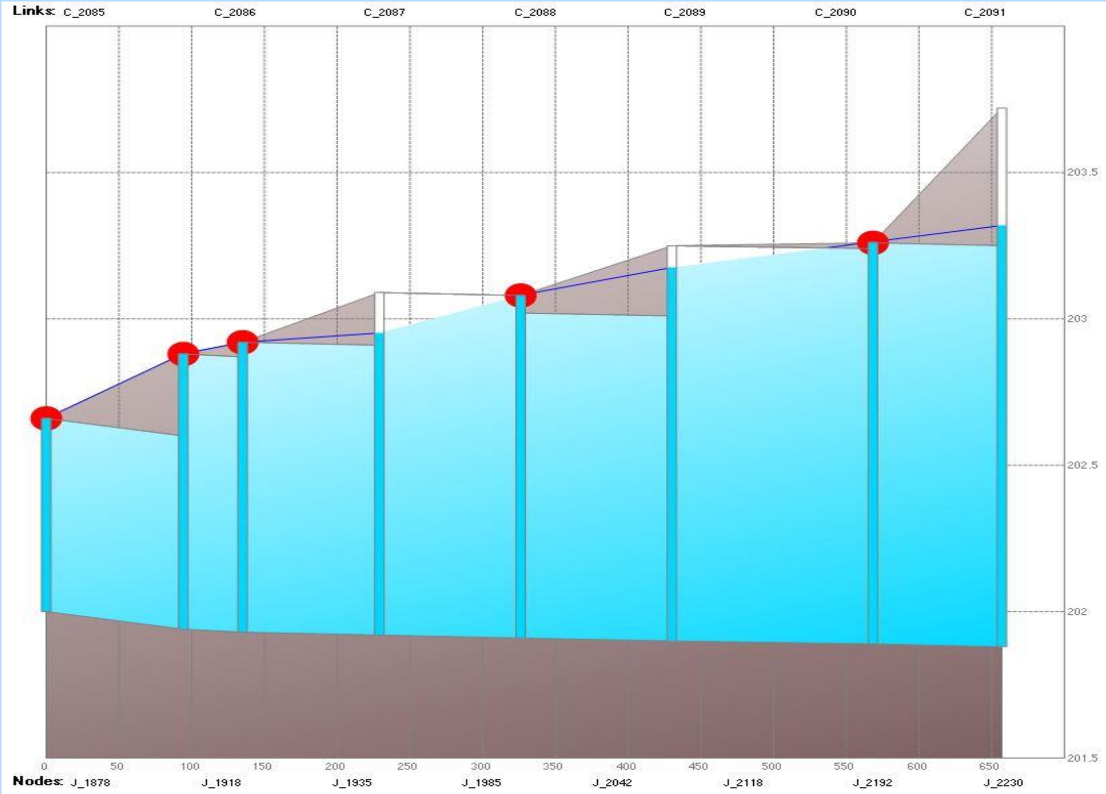
- In some cases, the flooded volume of water from the junction is diverted to nearest parks and open spaces to remove or reduce the flood at some of the junctions.
- Additional length of conduits has been provided wherever required to connect the flooded junctions to nearby parks for transfer of excess water from junctions.

Figure 3.1-16: Water body and parks connected to drains to divert the excess water

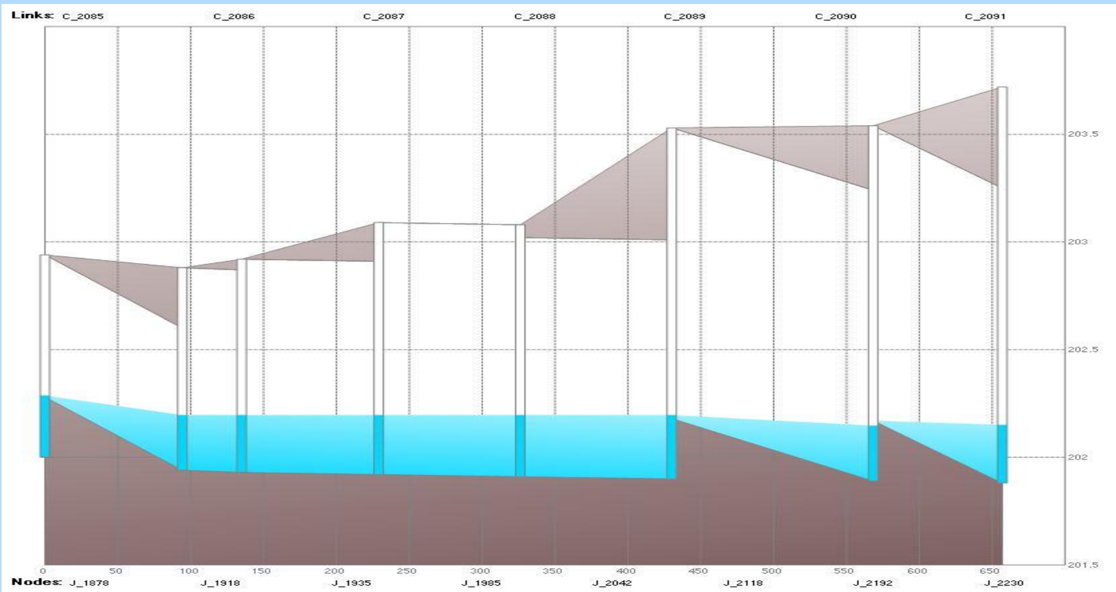


Comparison of water profiles in the sample segment of drain after simulation of scenario 3 and scenario 4 is shown in Figure 3.1-17.

Figure 3.1-17: Comparison of water profiles in the sample segment of drain after simulation of scenario 3 and scenario 4



Scenario 3: Without including any recharge zones



Scenario 4: With public parks as recharge zones

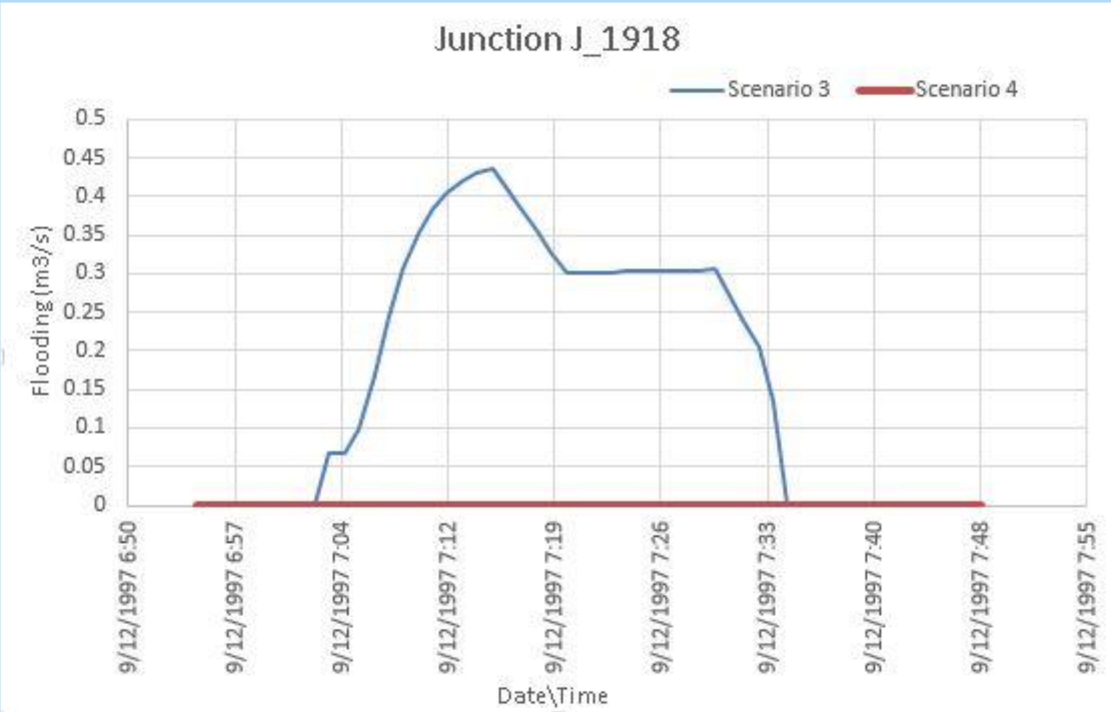
An example of the reduction of flood volume at different junctions in the sample drain is shown below in Table 3.1-5. In the present example, the junction J_1918 is flooded after simulation of scenario 3. In scenario 4, the flood volume at J_1918 is made to flow into the nearest park which could store a considerable volume and thus preventing many of the junctions from flooding.

Table 3.1-5 Comparison between the flood volume at junctions of a segment of drain after simulation of scenario 3 and scenario 4

Node	Flood volume (m3)	
	Scenario 3	Scenario 4
J_1878	2186	0
J_1918(Park)	539	0
J_1985	0	0
J_2042	750	0
J_2118	0	0
J_2192	0	0
J_2230	0	0

Change in flooded volume of water at a single junction can be seen in Figure 3.1-18. The graph shows the reduction in the flooding at another Junction J_1918 after diverting the excess water from it to the nearest park.

Figure 3.1-18: Comparison between the flood volumeat a sample junction after simulation of scenario 3 and scenario 4



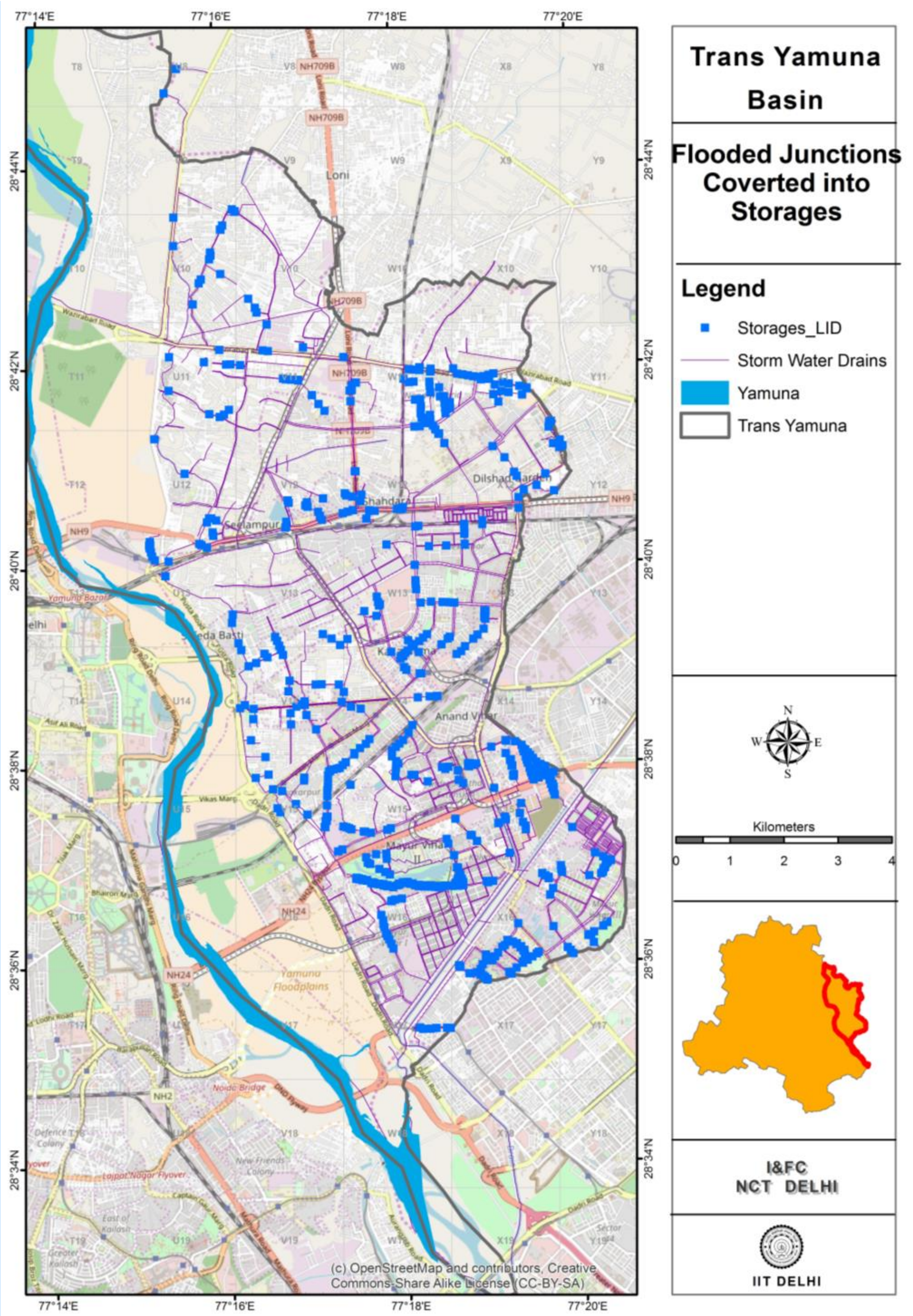
3.1.4.5. Scenario 5 - Towards no flooding junction for 2 year return period storm

For each subbasin suitable LIDs can be identified and the effectiveness of the same can be established through simulation and the consequent reduction as well as unaccounted surplus runoff volume can be quantified.

While formulating scenario 5 another decision has been taken to consider all the junctions that are getting flooded for a duration of more than 15 minutes.

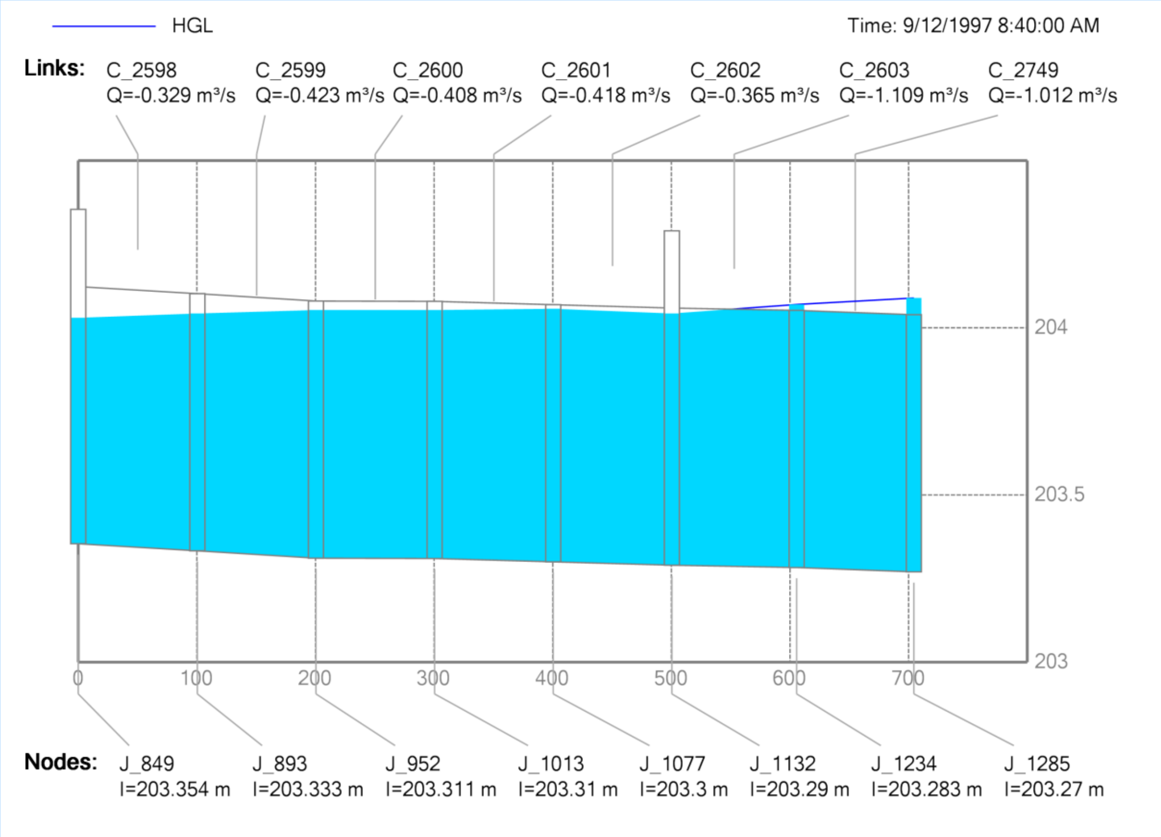
Total 455 junctions (Figure 3.1-19) which have been flooded, are transformed into the storages, taking care of the excess volume of water in the drain. However, these storages may be replaced by other LID structures if feasible. Based on ground realities suitable LIDs are implemented in a case study.

Figure 3.1-19: Flooded Junctions Converted into Storages

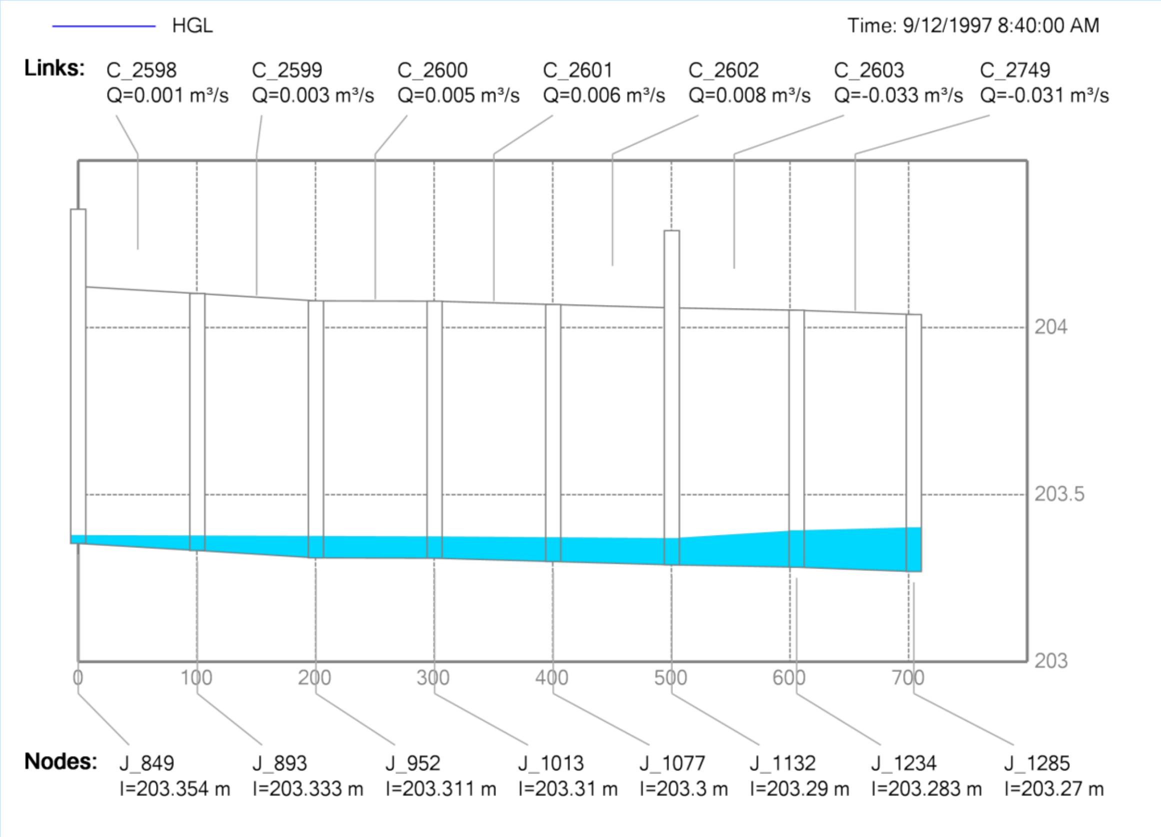


Comparison of water profiles in the segment of drain after simulation of scenario 4 and scenario 5 is shown in **Figure 3.1-20**.

Figure 3.1-20: Comparison of water profile in the segment of the drain after scenario 4 and 5



Scenario 4 Before the application of storage junctions



Scenario 5: After the application of storage junctions

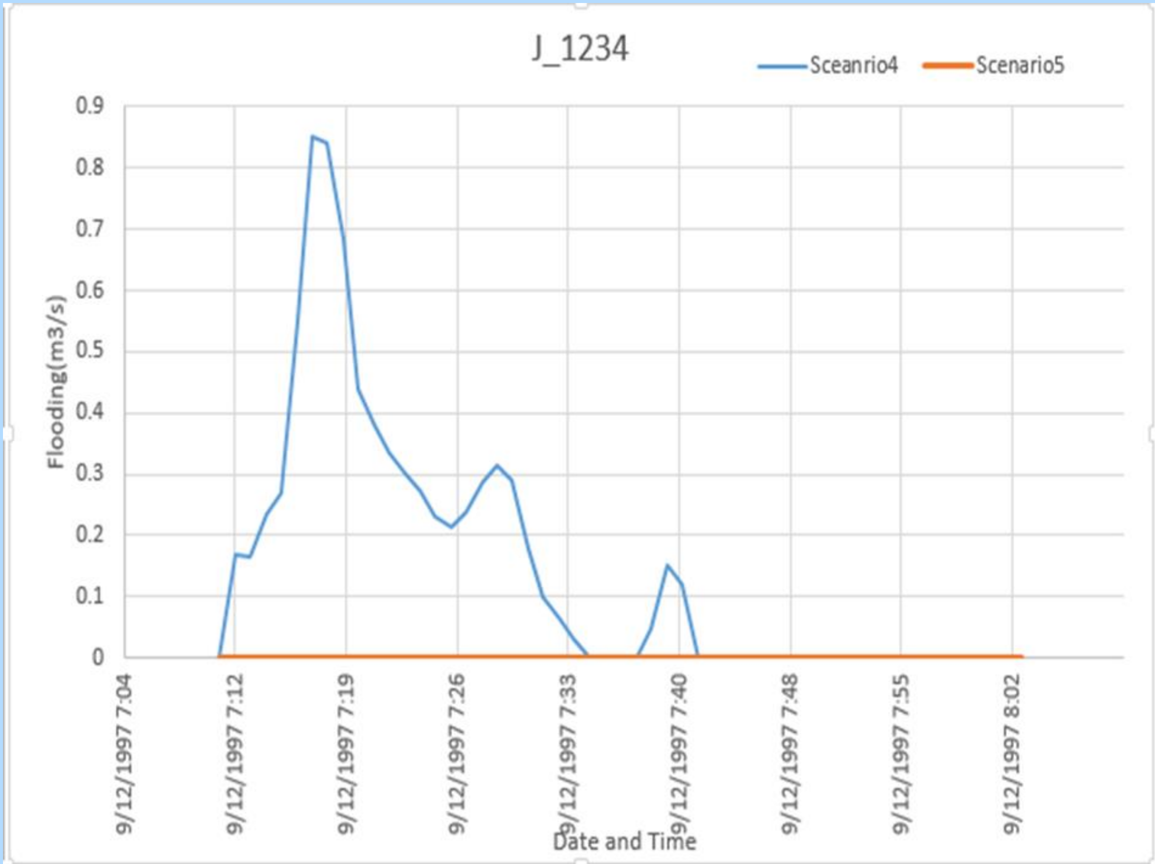
An example of the reduction of flood volume at different junctions in the sample drain is shown below in Table 3.1-6. In the present example, the Junction J_1234 is flooded after simulation of scenario 4. In scenario 5, the flood volume at J_1234 has been made to store in the retention tank/ detention tank/ LID structure which could store a desired amount of volume and thus preventing the junction from flooding.

Table 3.1-6: Comparison between the flood volume at junctions of a segment of the drain after simulation of scenario 4 and scenario 5

Node	Flood volume (m3)	
	Scenario 4	Scenario 5
J_849	154	0
J_893	460	0
J_952	474	0
J_1013	456	0
J_1077	446	0
J_1132	191	0
J_1234	461	0
J_1285	457	

Change in flooded volume of water at a single junction can be seen in **Error! Reference source not ound.**. In the present example, the Junction J_1234 is catering to the runoff from a big sub catchment and thus is flooded after simulation of scenario 4. The graph shows the reduction in the flooding at Junction J_1294 after incorporating storage at this junction.

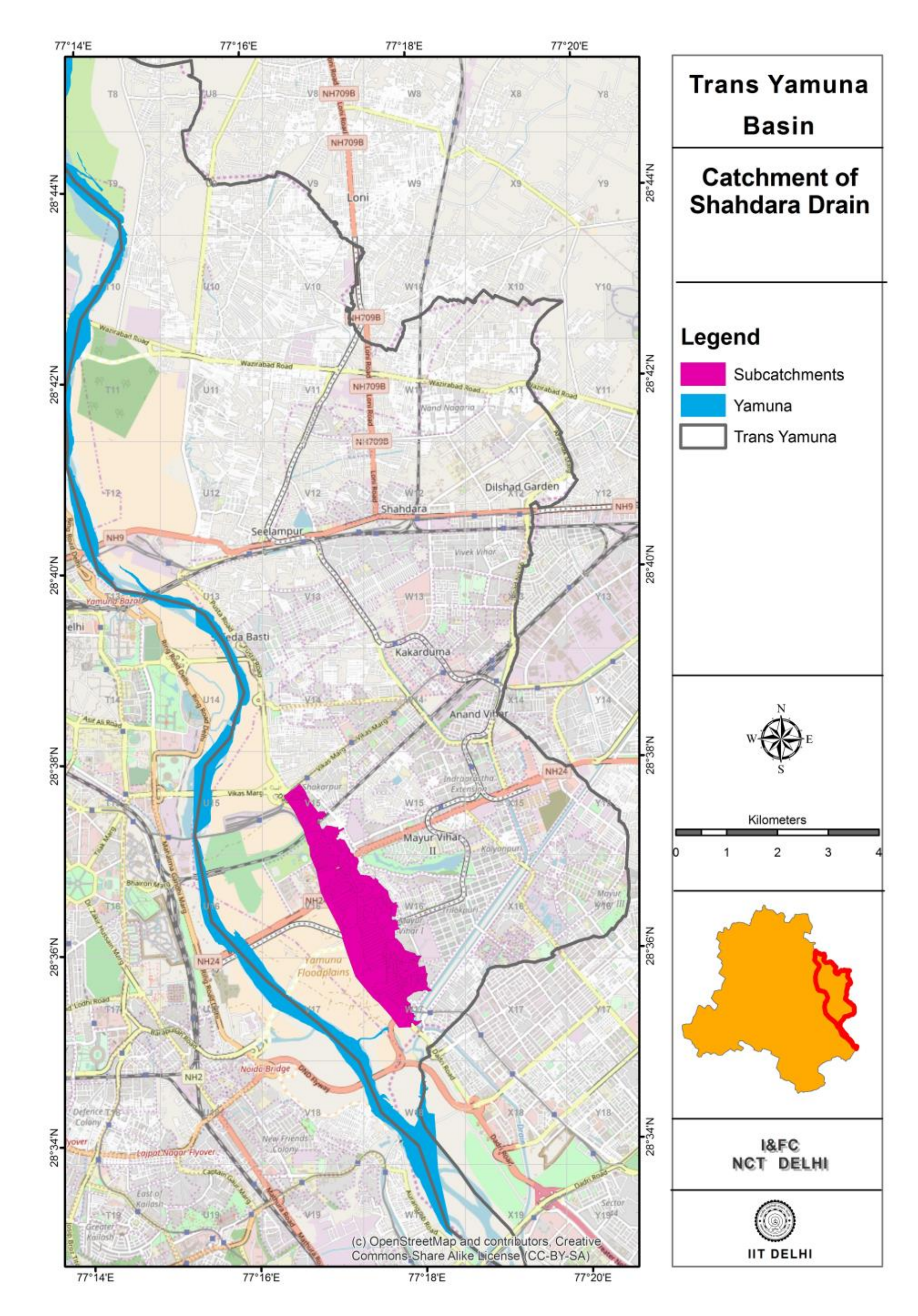
Figure 3.1 21: Comparison between the flood volumeat a sample junction after simulation of scenario 4 and scenario 5



CASE STUDY FOR LID IMPLEMENTATION

A catchment of Shahdara drain (Trans Yamuna Basin) has been considered as shown in Figure 3.1-21 for demonstrating how the LIDs can be identified and implemented for further reduction of flooding. This drain carries runoff from the catchment and outfalls into Yamuna River.

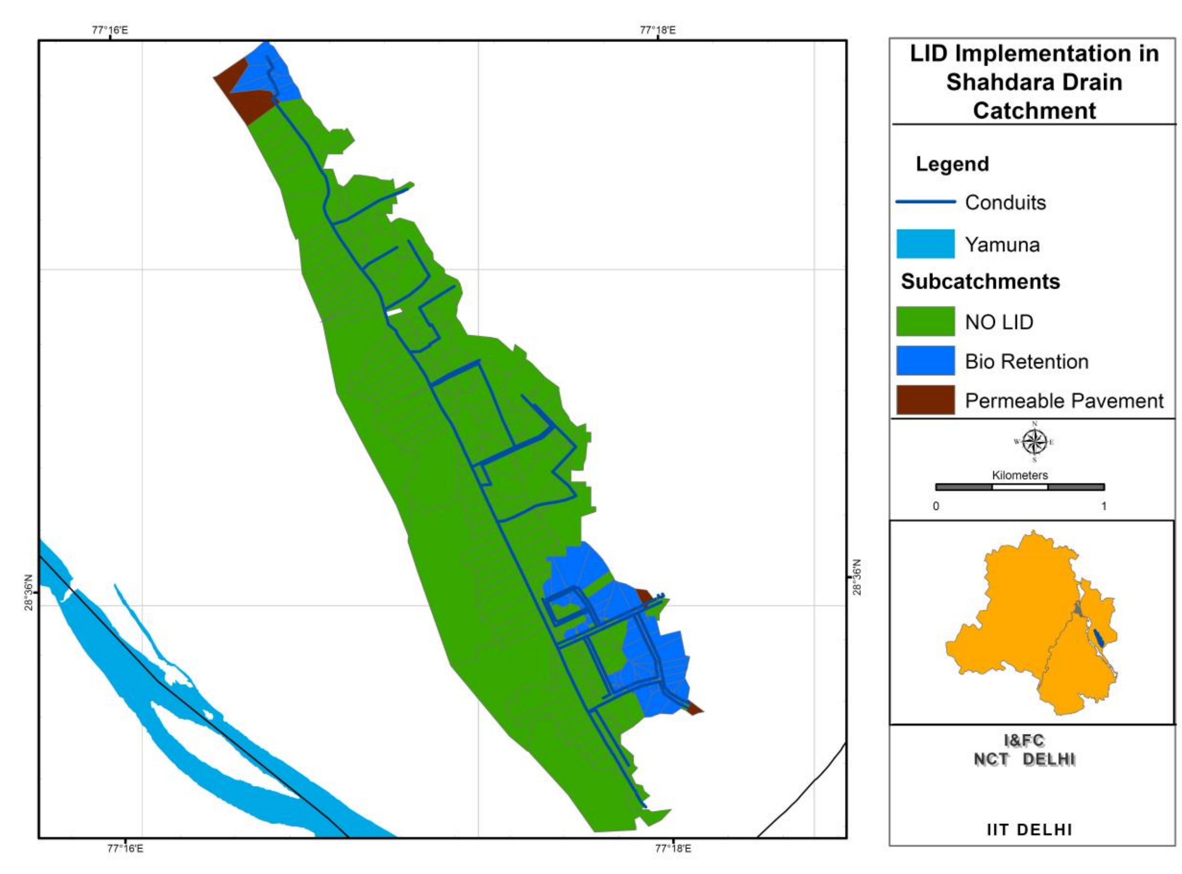
Figure 3.1-21: Shahdara Drain Catchment in Trans-Yamuna Basin



After studying the landuse, geography of the area and the soil properties of the NCT of Delhi region, only two types of LIDs were identified and implemented; (a) Bio Retention Cell and, (b) Continuous Permeable Pavement as shown in **Figure 3.1-22**.

The simulations are then performed to quantify the effectiveness of the selected LID (Bio Retention Cell and Permeable Pavement) which have been established through the model results which show significant reduction in the flood volumes at the junctions.

Figure 3.1-22: LID Implementation in Shahdara Drain Catchment



The comparison of flood volume between scenario 4 and after implementing LID is shown in Table 3.1-7.

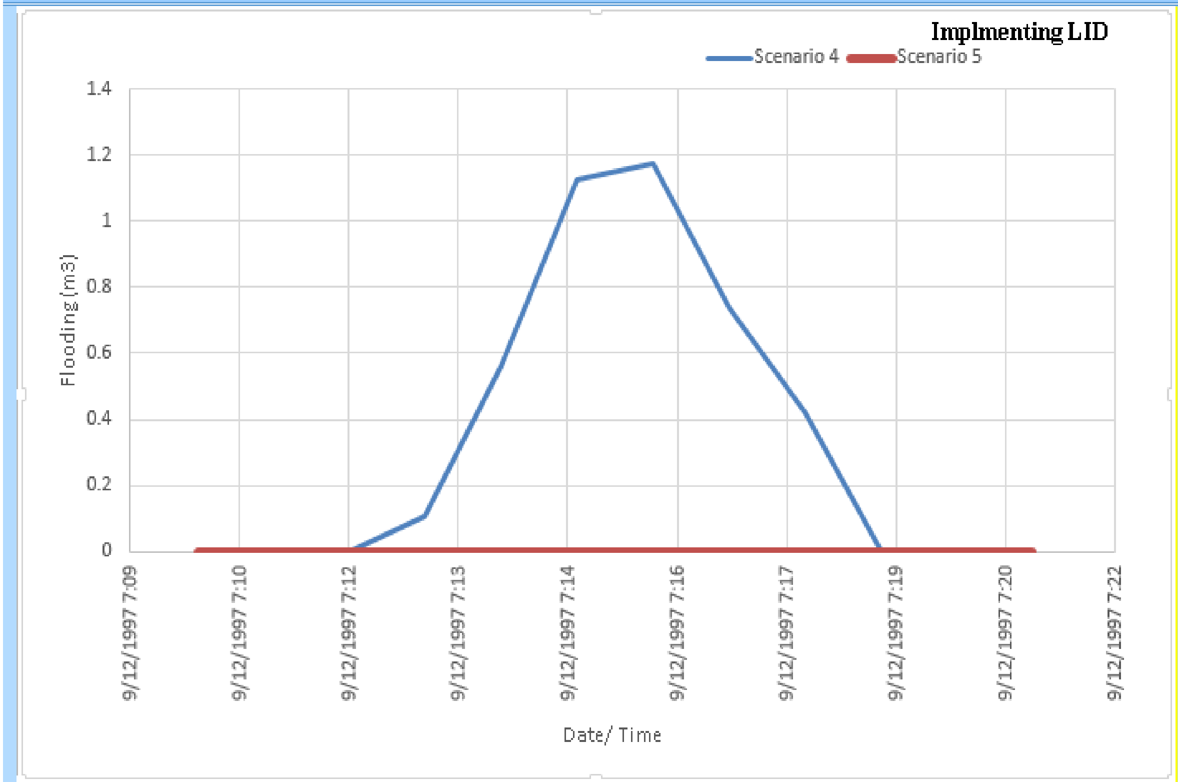
Table 3.1-7: The comparison of flood volume between scenario 4 and after implementing LID in Shahdra Drain Catchment

Node	Flood volume (10^6 ltr)	
	Scenario 4	Implementing LID
J_2246	0.001	0
J_2272	0.001	0
J_2431	0.009	0

J_2504	0.001	0
J_2610	0.065	0.031
J_2631	0.215	0.155
J_2725	0.005	0
J_2743	0.066	0.033
J_2767	0.265	0.129
J_2776	0.012	0
J_2807	0.184	0.01
J_2808	0.007	0
J_2847	0.002	0
J_2881	0	0
J_2891	0.006	0.003
J_2924	0.02	0
J_1050	4.631	2.213

For some Junctions these flooding values have reduced so much that they can be considered as a flood free junction. A tremendous drop in flood volume has been observed in Junction J_2807 after the implementation of LIDs in the sub catchment. The graph in **Figure 3.1-23** reflects the considerable drop in flood volume after the implementation of LIDs:

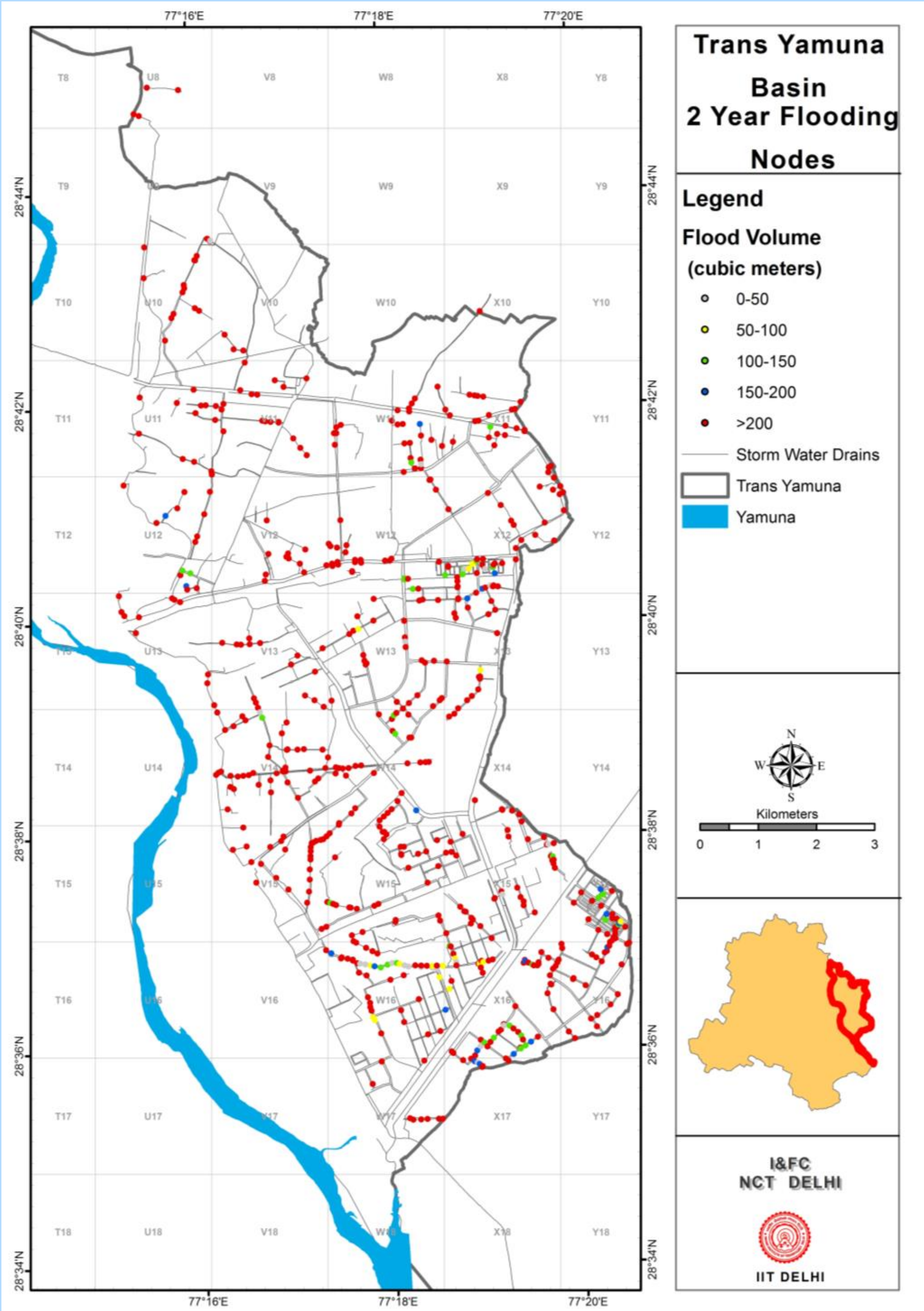
Figure 3.1-23: Graph reflecting the change in Flood volume for J_2807



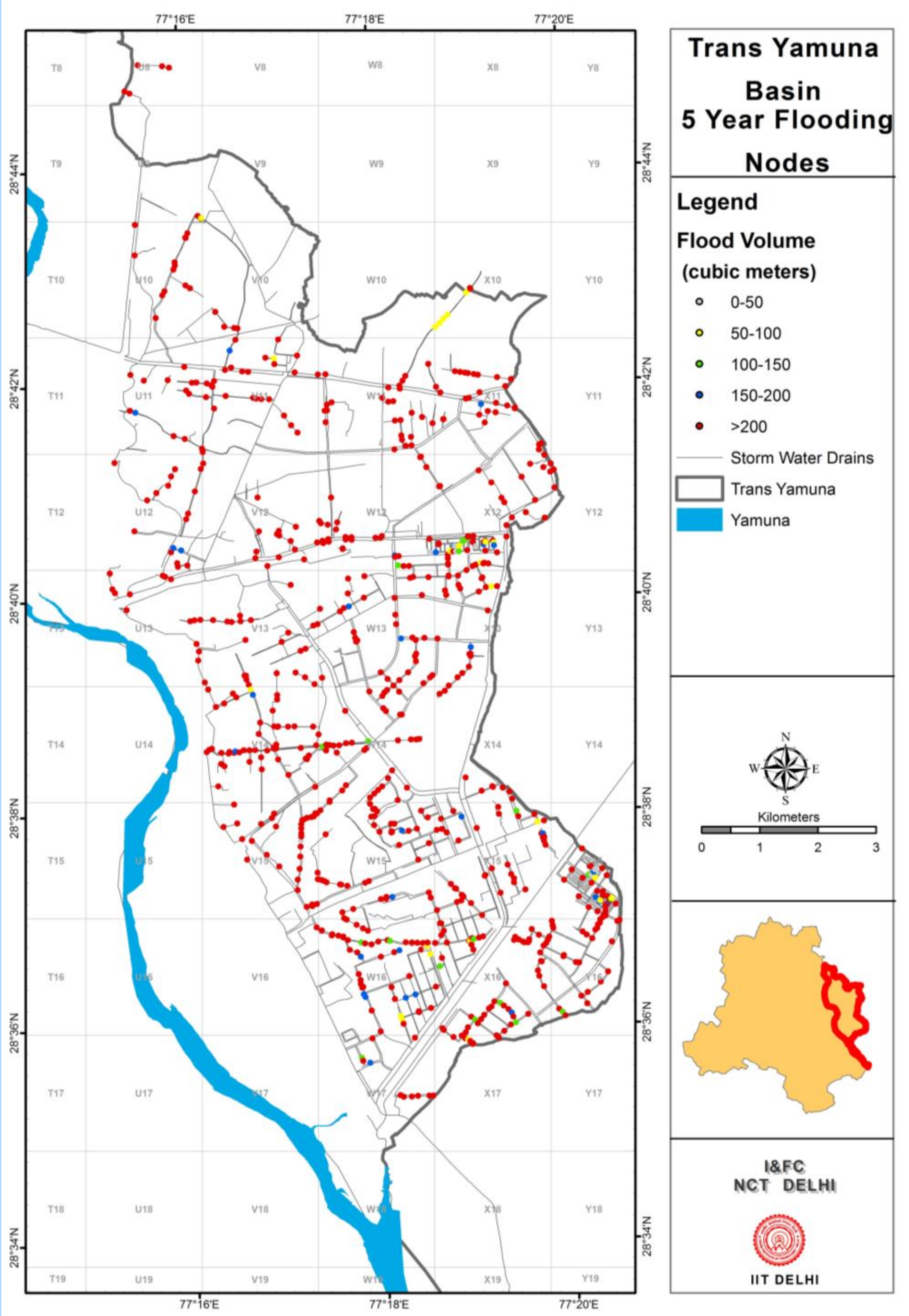
3.1.4.6. Comparison of Simulations with 2 year and 5 year return period rainfall events

Exhaustive simulations of the stormwater drainage network have been done using the rainfall events for 2 year return period and a series of scenarios. Similar simulations have also been done for the same network using 5 year return period rainfall event and using the scenario 4. Figure 3.1-24 shows the number of junctions flooded with the 2 year and 5 year return period rainfall events in scenario 4.

Figure 3.1-24: Junctions flooded with respect to 2 year and 5 year return period rainfall events



Junctions flooded in rainfall event of 2 year return period



Junctions flooded in rainfall event of 5 year return period

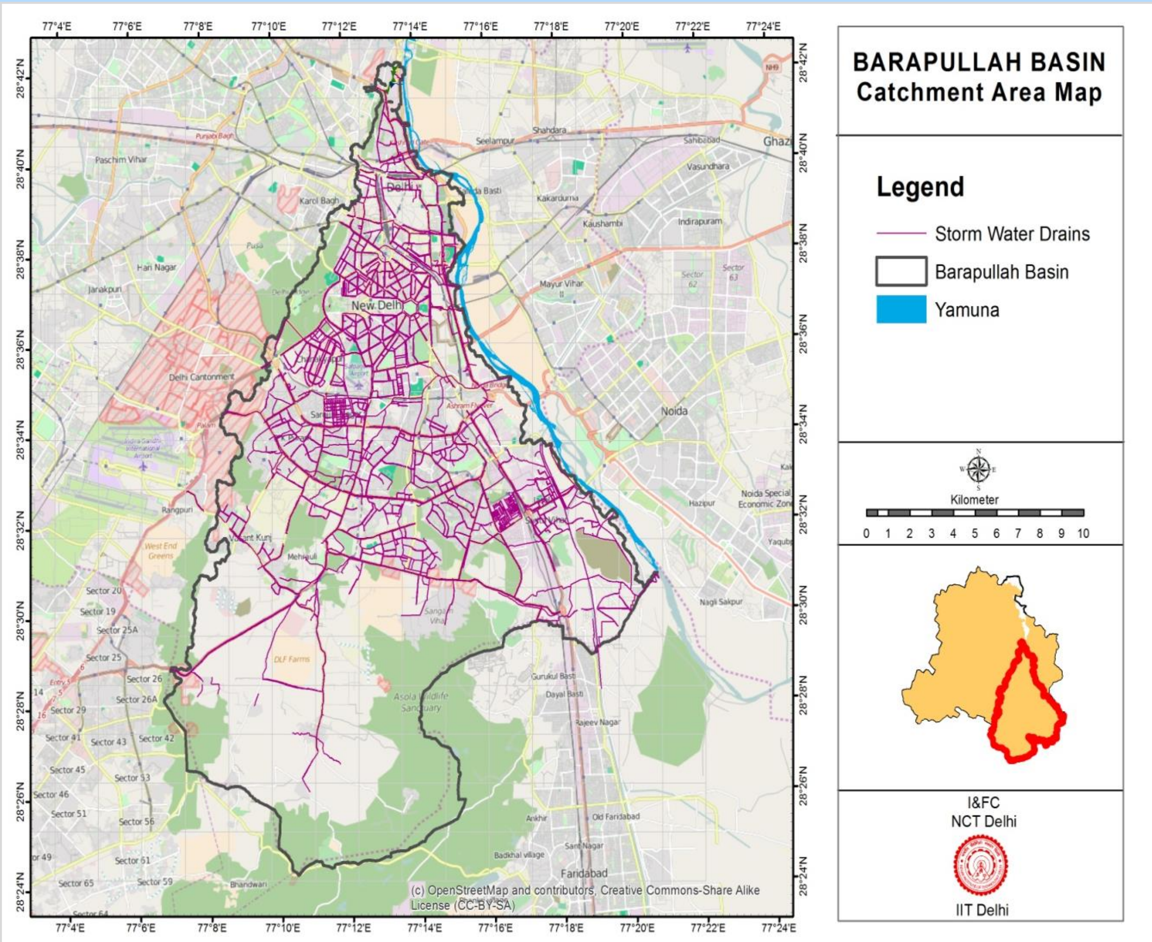
3.2. Barapullah Basin

3.2.1. Introduction

3.2.1.1. Basin characteristics

Barapullah basin is situated on the western bank of the Yamuna River and is on the southern part of National Capital Territory of Delhi. The basin is surrounded by River Yamuna on the east, Haryana state on the south and Najafgarh basin on the north and west sides. The areas in this basin are completely urbanized. In this basin, Barapullah Nallah/drain is the biggest drain which carries almost 80% of the storm water from this region and outfalls into River Yamuna. Along with Barapullah drain, there are few more drains which are directly out falling into River Yamuna. Agra canal is passing through this basin region in which, four storm water drains outfall into it. The total catchment area of this Barapullah basin is 376.27 sq.km. A map of the general characteristics of the region with the major roads and storm drains is given in Figure 3.2-1.

Figure 3.2-1: General Characteristics of Barapullah Basin



3.2.1.2. Population statistics

According to the 2011 census, total population in the region is approximately 33.89 lakhs and includes 5 districts. A map showing the location of wards in Barapullah basin is given in Figure 3.2-2.

Figure 3.2-2: Details of wards in Barapullah basin

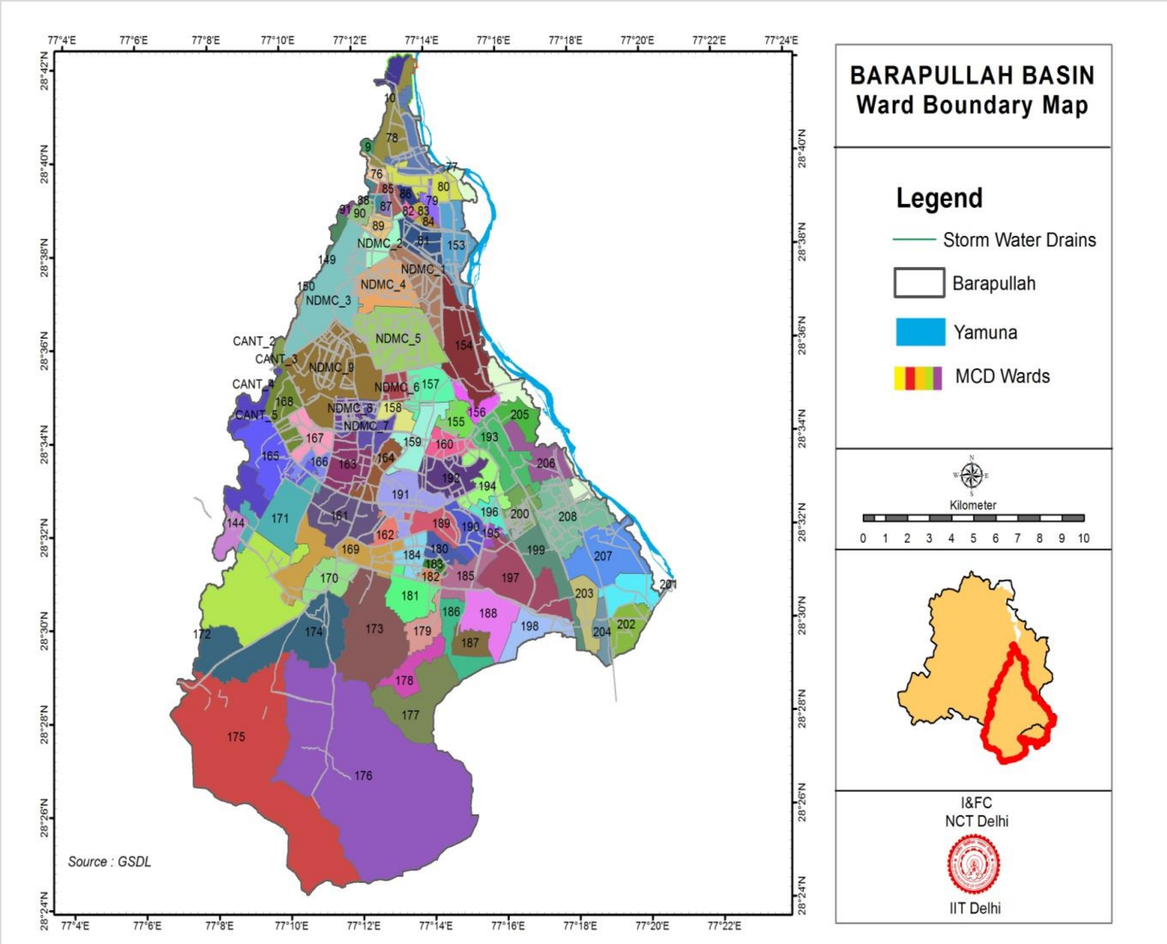


Table 3.2-1: Population Statistics - Barapullah Basin

District	% Area in the Barapullah Basin	Population within Barapullah Basin	Density (person per sq. km.)
Central Delhi	65.91761	381446.093	23149
East Delhi	0.32405	5533.882863	26683
New Delhi	95.47892	127667.7283	3820
North Delhi	18.60209	164334.2114	14973
North West Delhi	0.01307	477.2198127	8298
South Delhi	91.01374	2488089.938	10935
South West Delhi	12.10974	277599.1992	5445
Total Population		**3445148.272**	

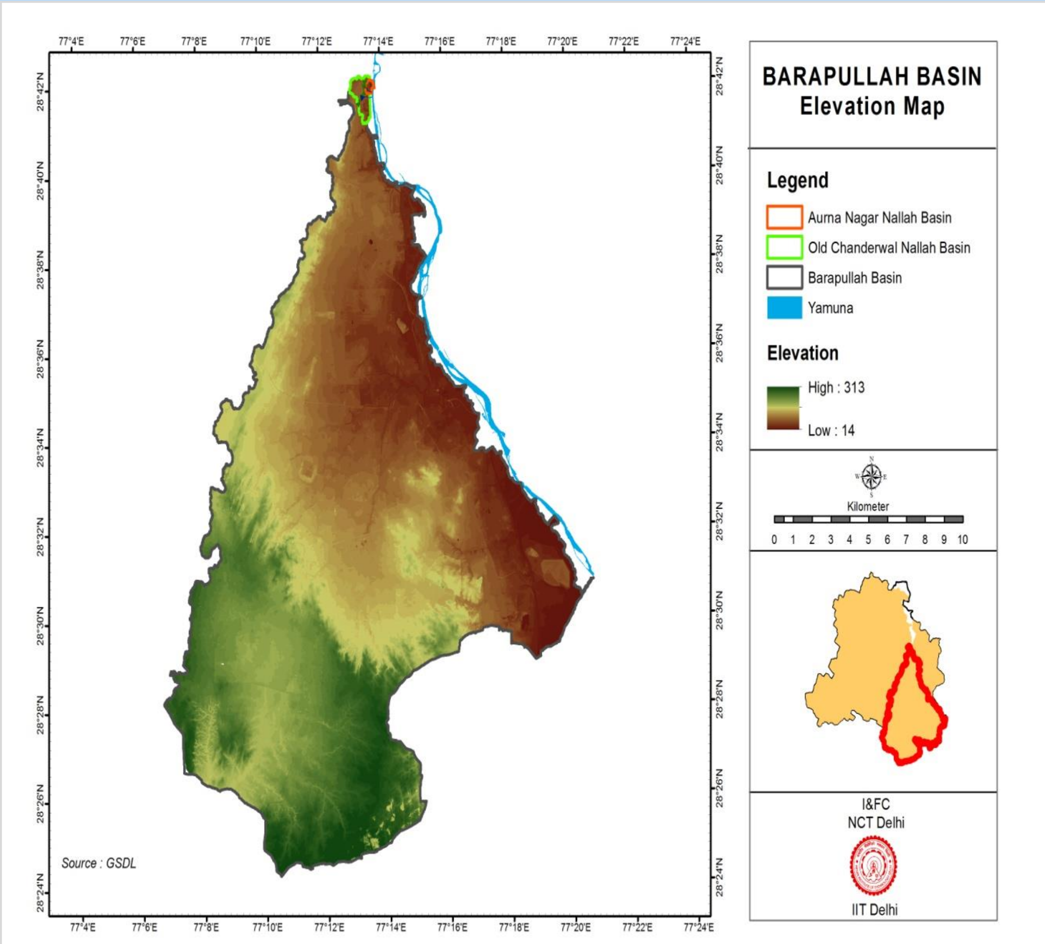
District area and population is given in Table 3.2-1. From Table 3.2-1, it can be seen that New Delhi is least populated district whereas Central Delhi is densely populated district. In this basin, the area is divided into 90 numbers of wards (refer APPENDICES

APPENDIX I).

3.2.1.3. Topography and land use

Barapullah basin is in the flood plain of River Yamuna. This basin fully/partially covers 5 districts of NCT of Delhi, which are, Central Delhi (39.43%), New Delhi (100%), North Delhi (21.79%), South Delhi (100%) and South West Delhi (13.32%). The digital elevation map for the catchment area is shown in Figure 3.2-3. The surface average elevation of 233 m (ranging from 14 to 313 m) above mean sea level.

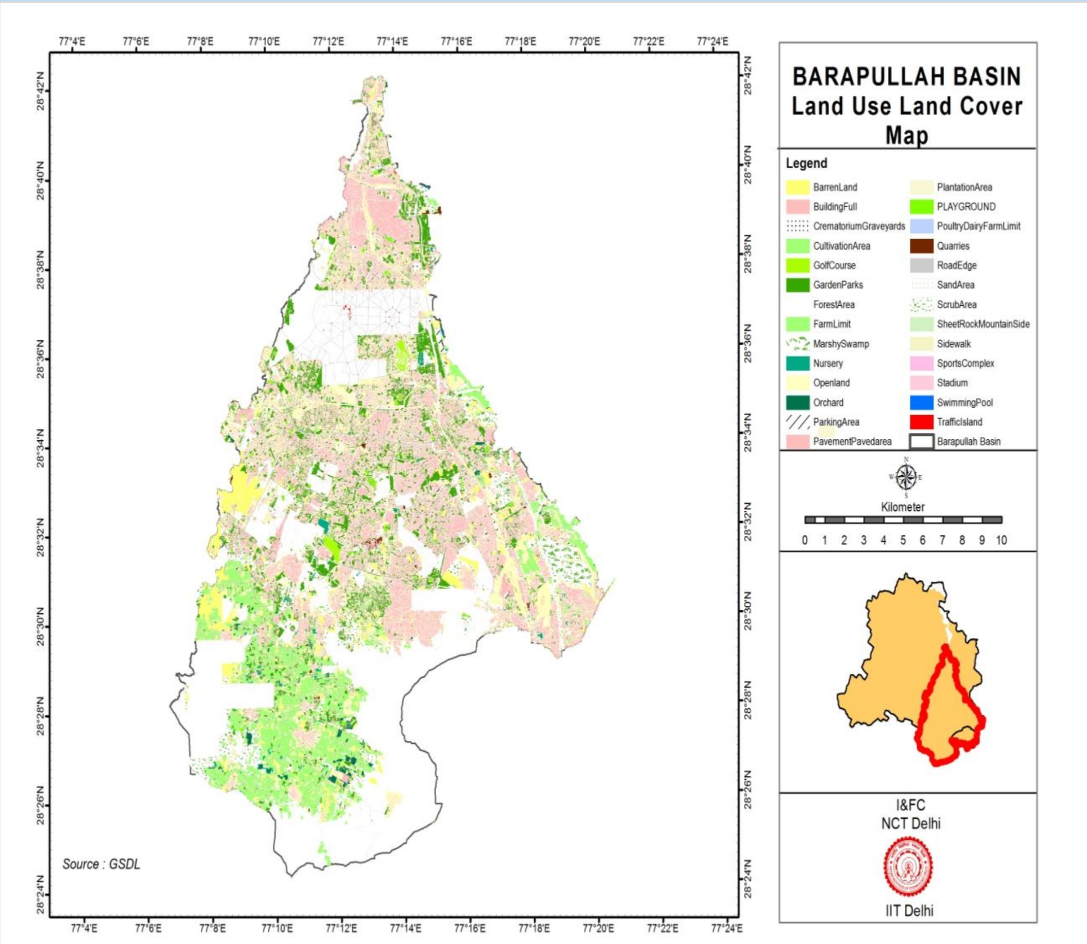
Figure 3.2-3: Digital Elevation Model (DEM) map of Barapullah Basin



Southern part of the Barapullah catchment in on higher elevation level as compared to northern part of the catchment, because of the existence of hilly area in the southern part. The natural terrain of the flow is in south-east direction, i.e., towards River Yamuna. The land surface profile is such that there exist 3 different drains, i.e., Aruna Nagar Nallah, Old Chanderwal Nallah and Barapullah Nallah which are directly falling into Yamuna River and form 3 different basins. These 3 basins are Aruna Nagar Nallah basin (0.204 sq. km.), Old Chanderwal Nallah basin (1.26 sq. km.) and Barapullah basin (374.81 sq. km.). In this region, Barapullah basin is the biggest basin. Topographically, 10% of the area is occupied by rocky ridge which starts from the Wazirabad Barrage (in north Delhi district) and running in Southerly direction, i.e., through central district, New Delhi district, south west Delhi district in the west side and finally joining the hilly region in the Mehrauli area. This hilly catchments separates the Barapullah basin from Najafgarh basin. Apart from river Yamuna, large numbers of water bodies are also present in the basin. The flood plain of the river Yamuna is more or less undisturbed. It is primarily used for agricultural activities or as an open area for the drainage outfalls.

The type of soil present in the entire basin region is sandy and clay soil. The land use of the region is broadly divided into crop land, urban, river and water bodies, grass and fallow lands. The basin region is the highly urbanized region in Delhi with approx. 30 % of total area contributing to built-up land use as shown in Figure 3.2-4.

Figure 3.2-4: Built-Up area of Barapullah Basin



The region is primarily an institutional area with government offices, cultural buildings, embassy area, Delhi University, etc. The informal sector units locate themselves strategically near work centres, commercial areas, outside the boundaries of schools colleges, hospitals and transport nodes and near large housing clusters. A very high percentage of this activity has been observed in this basin area. The runoff characteristics of the region has significantly changed due to low infiltration and seepage phenomenon resulting from the rapid increase in built-up area. The percentage area of each land use in the region is given in Table 3.2-2.

Table 3.2-2: Area (in sq. km. and in percentage) of each land use - Barapullah Basin

S.No	Land Use	Sub Divisions	Area (sq. km.)	Percentage of Total Area (%)
1	Rural/Crop Land	Cultivation Area, Farm limit, Plantation Area	31.10	10.09
2	Urban	Building Full, Parking, Paved Area, Poultry Dairy Farm, Road, Sports Complex, Traffic Islands etc.	91.83	29.79
3	Grass	Golf Course, Garden Parks, Marshy Swamps, Nursery, Playground	34.91	11.33
4	Fallow	Barren Land, Open Land, Orchard, Quarries, Sand Area	68.65	22.27
5	Deciduous	Forest Area, Scrub Area, Sheet Rock	81.62	26.48

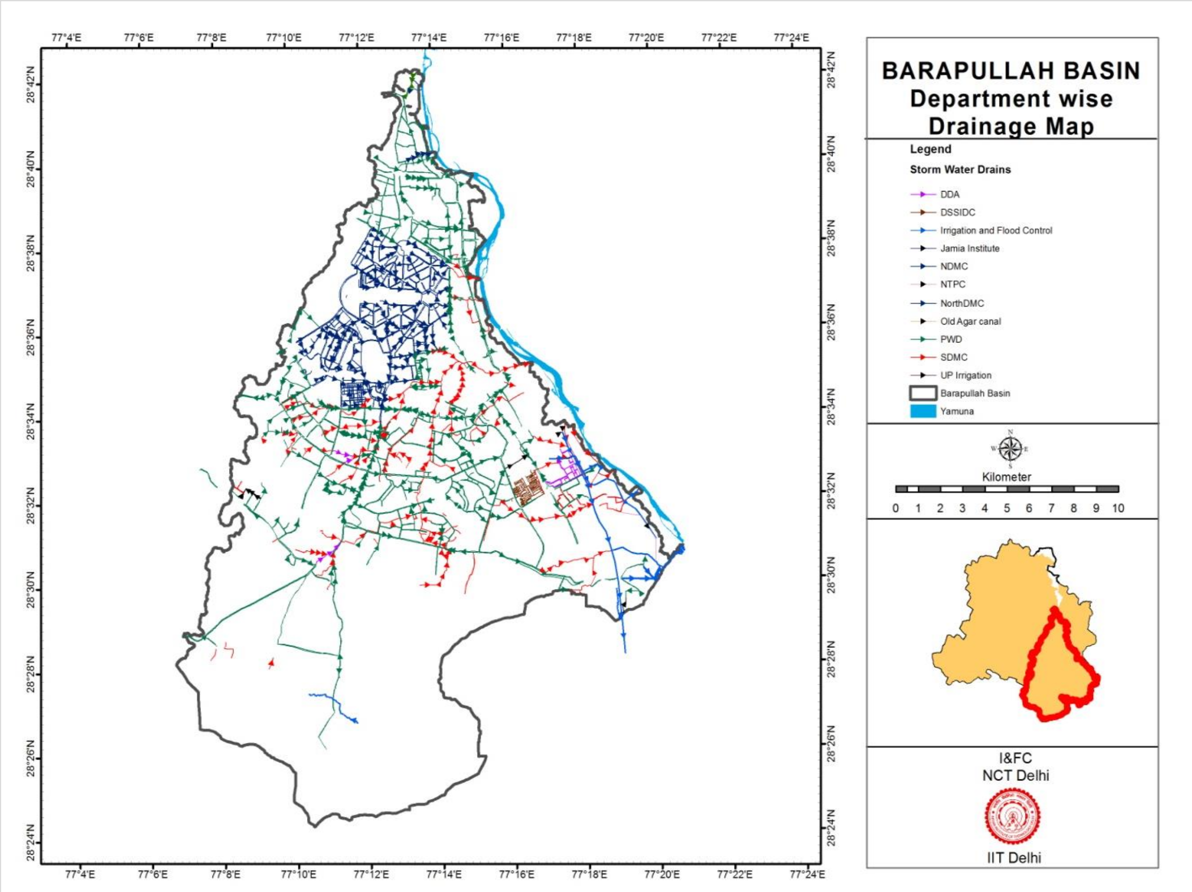
The average annual rainfall of the basin is 617 mm. About 81% of the annual rainfall is received during monsoon months July, August and September.

3.2.2. Details of existing drainage network

Storm drains of various agencies together form complete storm network in Barapullah catchment which is densely populated. A dense conduit network of length 1124.716 km carries the storm water to the outfalls. A map depicting the storm drainage network and respective agencies is shown in Figure 3.2-5.

As mentioned before, the natural flow direction is towards river Yamuna and marginal embankments have been constructed to avoid frequent flooding. Several bunds like Mahipalpur bund, Mehurali bund, Ghitorni bund, Bhati bund, Sultanpur bund, Asola bunds were constructed in the south and south west district to prevent runoff coming into the basin. In this basin, there are natural as well as engineered drains. The natural drains are managed by Irrigation and Flood Control department (I&FC), South Delhi Municipal Corporation (SDMC) and North Delhi Municipal Corporation (North DMC). The engineered drains are managed by SDMC, North DMC, New Delhi Municipal Council (NDMC), Public works department (PWD), Delhi Development Authority (DDA) and Delhi State Industrial and Infrastructure Development Corporation (DSIIDC).

Figure 3.2-5: Strom drainage network under various jurisdictions - Barapullah Basin



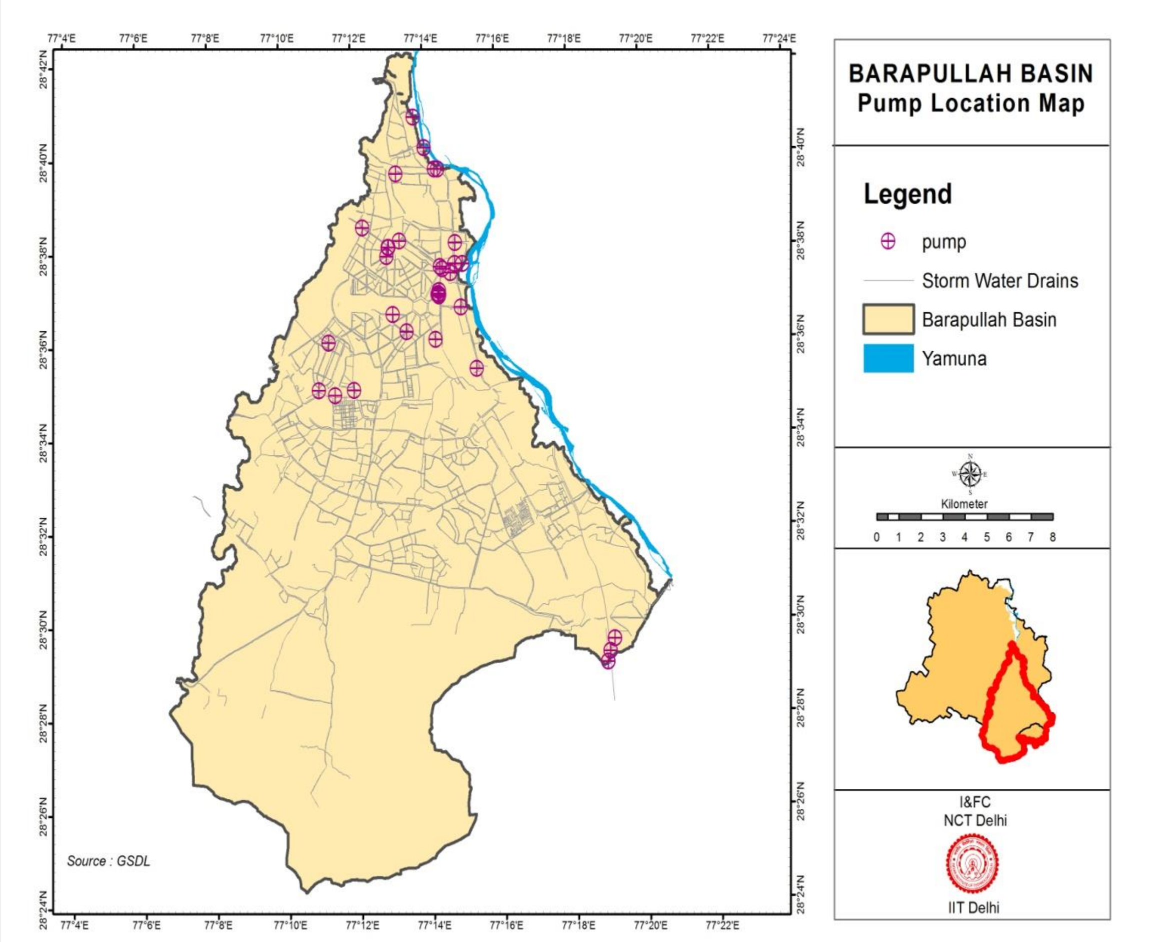
3.2.3. Major drainage problems in the region

As mentioned before, rapid unplanned urbanization, shallow groundwater level, low to medium elevation have resulted in frequent flooding problems in this region. The major problems are highlighted below.

- Increasing paved surface, reducing water percolation and increasing runoff.
- Reversal of flow direction and inadequate/failure in pumping: The region is protected by a check dam in the Mehrauli area to prevent surface runoff coming from Haryana state and also to prevent water logging in the area. Chirag Delhi drain is the longest drain in the basin which carries all the runoff as well as sewage from the south district part of the basin and outfalls into Barapullah drain.
- Often the construction debris in the new drains is not cleared, garbage is dumped on the road side drains. No segregation between sewerage and storm water infrastructure.
- Low lying areas experience acute drainage congestion.
- Encroachment by covering the drain and using the space for parking (as is the case at Khanpur chowk, where Chirag Delhi drain was covered and now the space is used for parking).

There are many pumps installed at various locations in this region by the agencies to pump out excessive water into Yamuna River during heavy flood periods. Location details of installed pumps is

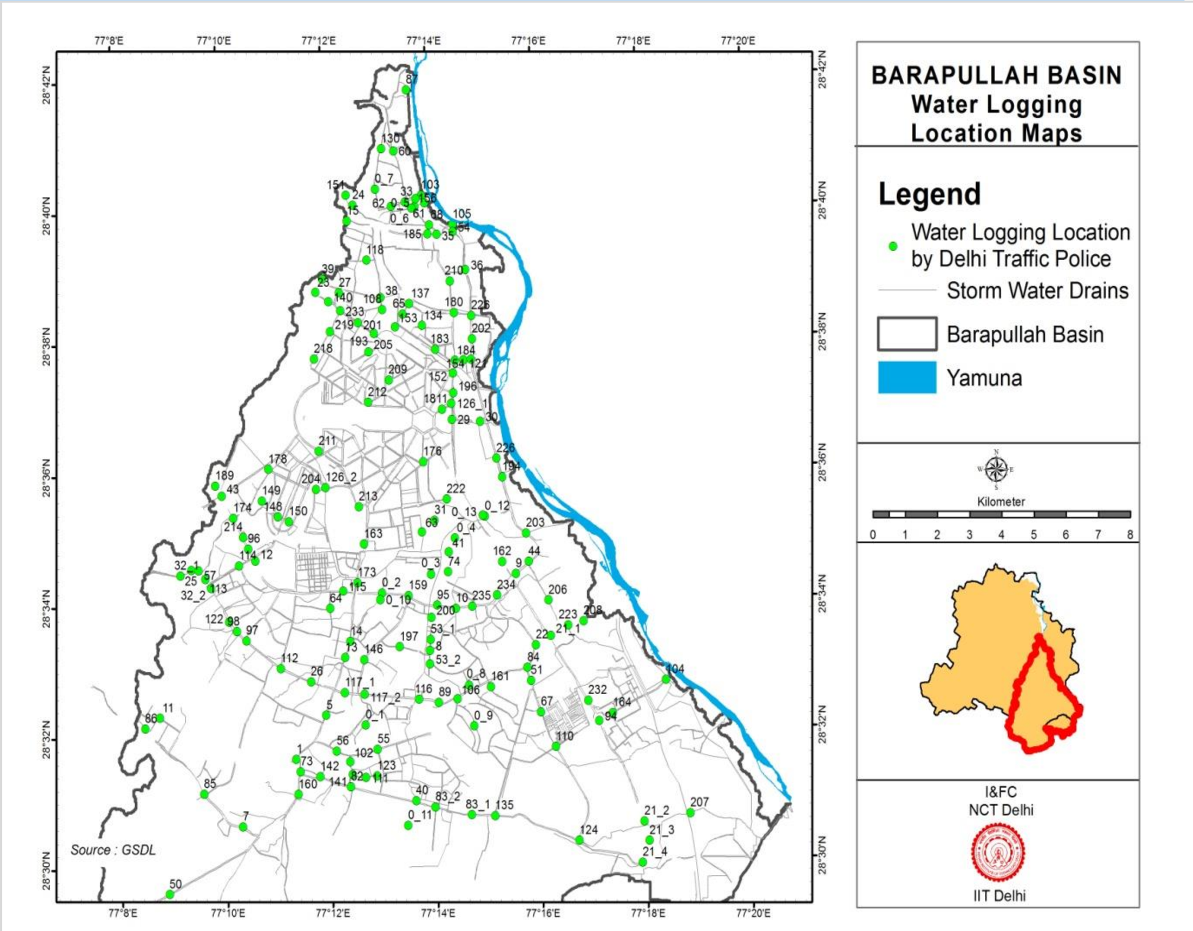
Figure 3.2-6: Location details of pumps installed - Barapullah Basin



shown in Figure 3.2-6. Majority of the pumps are installed along the River Yamuna and in the northern part of the basin. In addition, mobile pumps are also used to pump surplus amount of water into the nearby drains.

There are 162 water logging locations which have been identified by Delhi Traffic Police and are shown in Figure 3.2-7. The details of location/area are also given in the APPENDIX III. Apart from these, interior built-up areas have also been reported to be affected by water logging conditions, especially during monsoon period.

Figure 3.2-7: Areas facing frequent water logging as reported by Delhi Traffic Police - Barapullah Basin



3.2.4. Data limitations and assumptions

An extensive storm water drainage modelling of the region has been done. It is desired to check the adequacy of drainage infrastructure, under the changed scenarios of rapid urbanization and population density.

The network of existing drains of this basin is highly dense and due to unavailability of full and coherent data, an extensive work has been done to fill in the gaps in the data. In the absence of various data for successfully running the simulations in SWMM software, few data assumptions have been adopted. Some of these assumptions are:

- Invert levels (IL) of many drains in the network are either completely or partially missing along the length of drains as can be seen in case of Sri Aurobindo Marg Flyover drain in Figure 3.2-8. If the ILs are completely unavailable for any drain, then IL value has been left blank for that drain. If the IL values are partially available along the length of any drain, then final IL values have been computed by interpolation. This procedure has been adopted in around 2458 locations out of 17885 locations.

Figure 3.2-8: Example of junction points with Zero Invert Level values

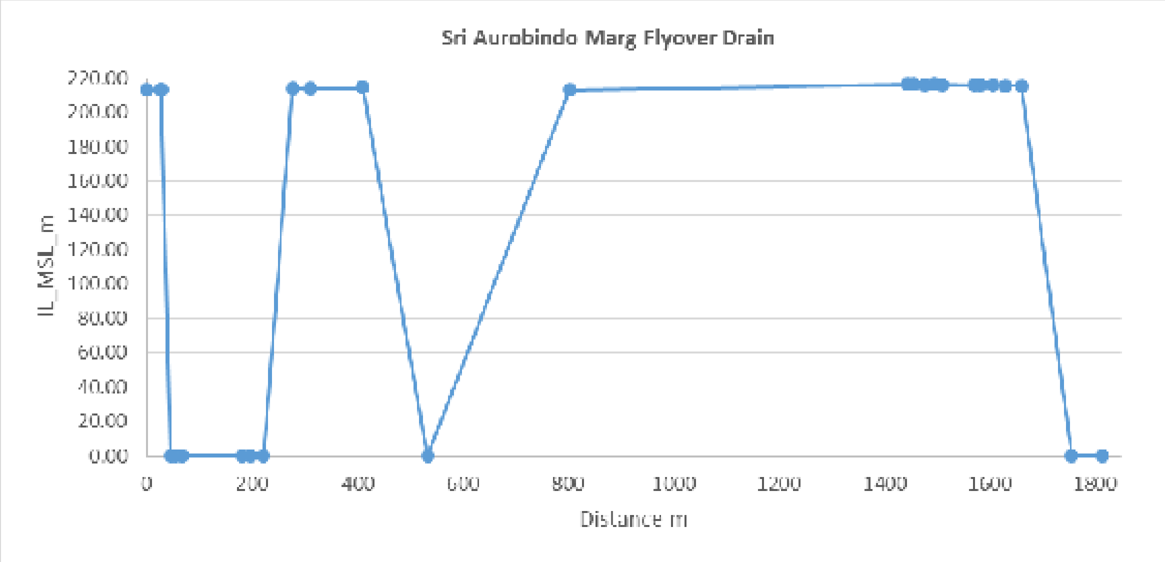
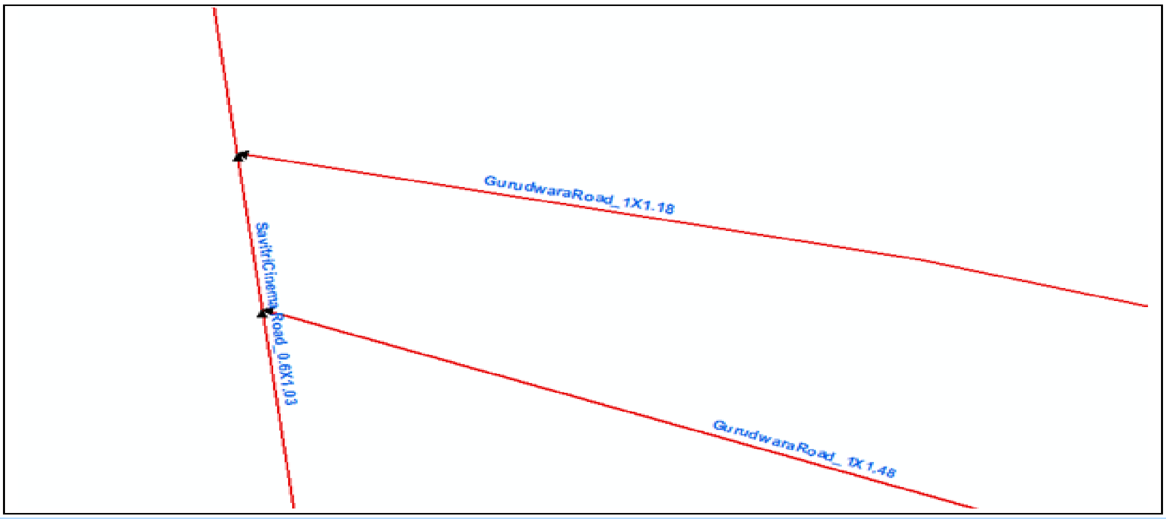


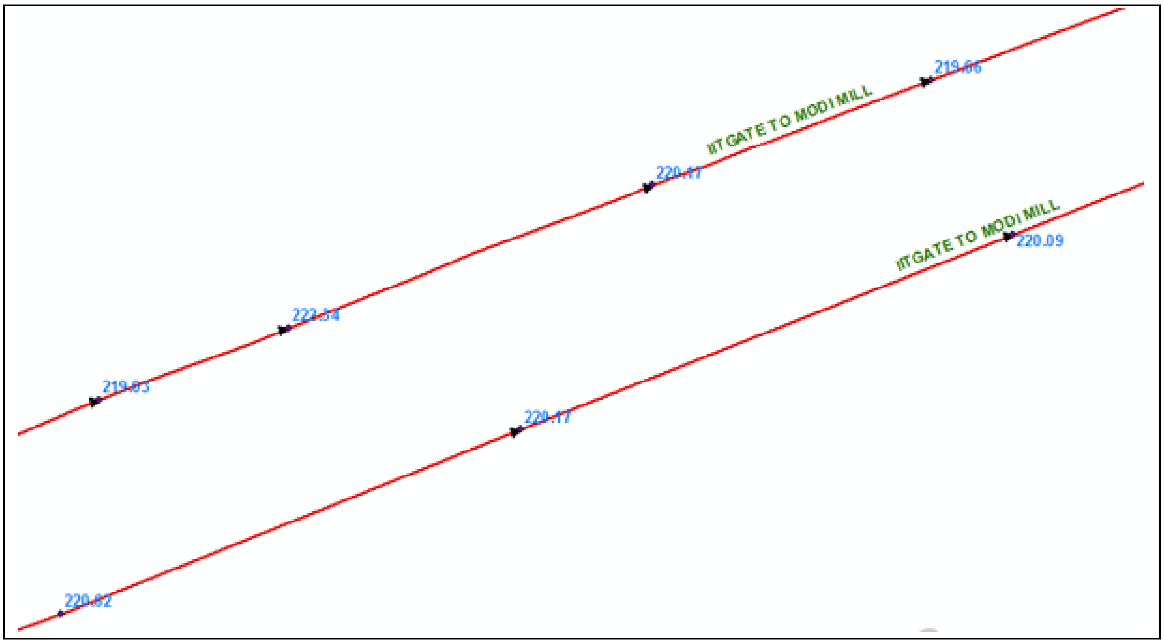
Figure 3.2-9: Drains with higher dimension meeting with lower dimension



- Dimensions of conduits are either missing or drains of higher capacity are found to meet drains of lower capacity, which is usually impractical. Drains with higher dimensions are meeting drains with lower dimensions. For example, Gurudwara Road with dimension 1m × 1.18m (width × depth) has outfall in Savitri Cinema Road of dimensions 0.6m × 1.03m as shown in Figure 3.2-9 and is bound to create flooding conditions in the area.
- Wherever dimensions of drains are missing (3021 conduits out of 18007 conduits), an average dimension based on the preceding and succeeding drains has been computed.
- Rainfall data used in the modelling is from the rain-gauge station which is located in the region itself i.e., IMD Lodhi Road, Safadarjung and Aya Nagar Station.
- In the absence of rainfall data of flood years 2010 and 2013, presently the highest event of 2012 has been used for modelling.

- Data about pump's rating curve and exact numbers of pumps installed is missing /not provided. In absence of the required data, pump rating curve of standard Shakti pumps has been assumed in the model.
- In the absence of any details of operations, dimensions and locations of diversions/regulators/gates/weirs/culverts/embankments, these structures have been excluded in modelling.
- Portable pumps that are invariably used in real scenario, could not be included in the modelling since their locations and operation details are not known.
- In the absence of information of sewers (location and flow magnitude) draining into storm water drains and vice versa, the same has not been included in the modelling.
- At many places, the flow direction provided has been found to be against the natural gradient. For example, the flow of storm water is towards the increasing Invert Level (Figure 3.2-10).

Figure 3.2-10: Direction of flow indicated against the Invert Level slope



3.2.5. Simulation scenarios

In addition to the numerous assumptions taken to rectify the defects in the network information provided, data gaps have been filled through extensive exercises. The sufficiency of existing storm drainage network has been examined by simulating for 2 years return period rainfall events of 2 days (9/12/1997 to 9/13/1997) of 15 minutes interval of Safdarjung station for the region. After incorporating all the details such as precipitation data, conduit data, etc., in Storm Water Management Model (SWMM) and also in PCSWMM Model, the occurrences of flooding, if any, have been examined. The detailed comparative analysis of the flood at junctions of the drainage network of Barapullah basin is provided in APPENDIX XIIAPPENDIX to understand the improvements made in flooding from a 1 in 2 year storm in terms of volume of flooding and duration of flooding under different scenarios.

3.2.5.1. Scenario 1 – Simulation with data provided by the departments

This is the scenario to generate the flooding conditions with respect to the data provided by various organizations to supposedly represent the present condition of the drainage system. The model has been setup to check the performance of the existing infrastructure of storm water drains which IIT Delhi received from various departments/ agencies. It was unfortunate that the various departments passed on the survey data without vetting the data properly. Therefore, the authenticity of the data provided has been to certain extent indirectly vetted through this scenario. The results of this simulation are presented in the APPENDIX .

After analyzing results of simulation of scenarios 1 (scenario with Invert Levels and Cross Sections provided by agencies), it has been found that there are around 5448 junctions flooded. Table 3.2-3 shows results of the simulation run on a segment of a drain. The table records the junctions that are flooded along with the duration of flood and total flooded volume. Similar details on flooding time and flood volume for all segments of the drainage network are available as part of the detailed outputs provided in the working model of the basin not only for this scenario but all the subsequent scenarios as well.

Table 3.2-3: Flood volume of junctions in a sample segment of a drain after simulation of scenario 1

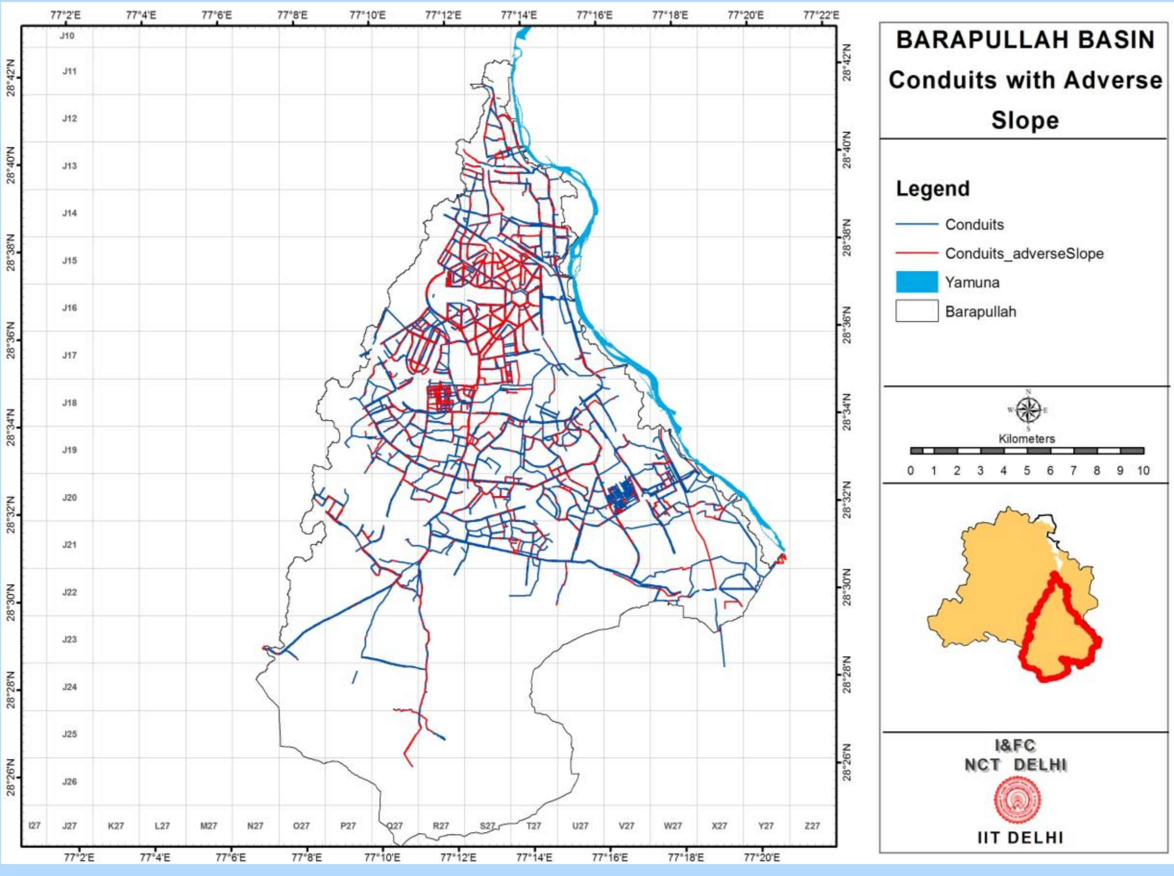
Node	Flooding hours (in hours)	Flood volume (m^3)
J_19	0.16	2335
J_17	0	0
J_23	0.35	475
J_26	0	0
J_27	0.47	9863

3.2.5.2. Scenario 2 – Simulation with changes made to cross-sections

Scenario 2 represents the incorporation of changes made in the cross-sections wherever adverse slopes has been encountered by changing the Invert Levels and width of the Cross Section in case if constriction is encountered. There are 4401 segments with adverse slope out of 16977 conduits in Barapullah basin as shown in Figure 3.2-11.

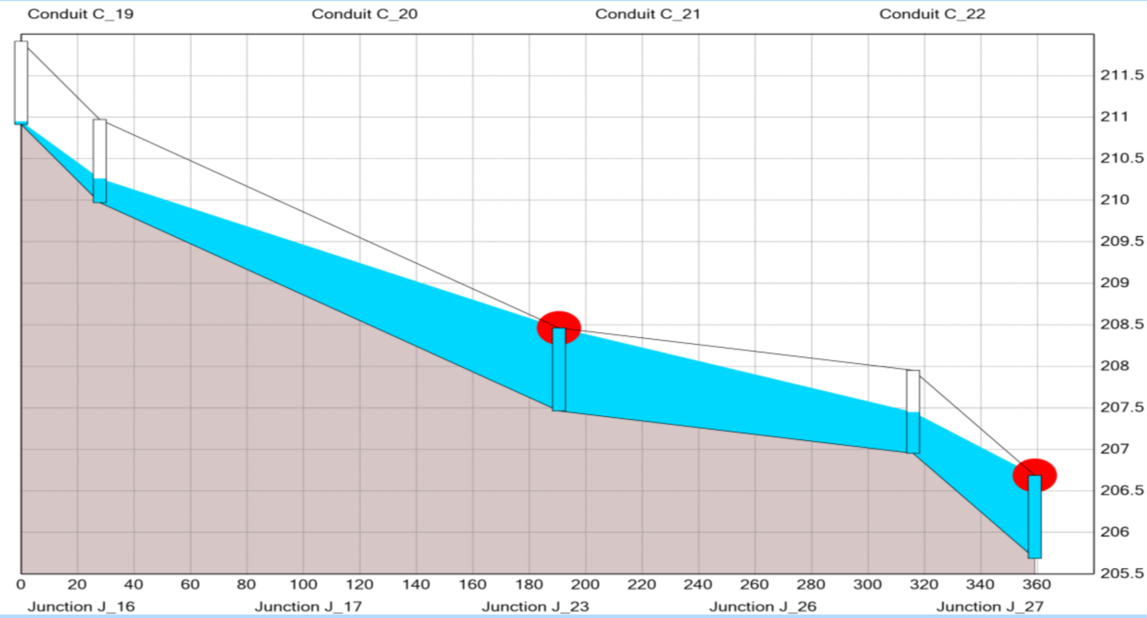
The invert levels have been corrected keeping in mind the slope of the preceding drain and also the elevation taken from Digital Elevation Model of NCT Delhi provided by Geo Spatial Delhi Limited. Along with the corrections made to the Invert Levels in the segments with adverse slope, the width of the cross section has also been changed wherever a constriction in width has been encountered and the junction is flooded (APPENDIX VI). The simulation has been made after incorporating these changes. The flooded junctions got reduced to 3584 (APPENDIX XII).

Figure 3.2-11: Barapullah basin showing conduits with negative slope

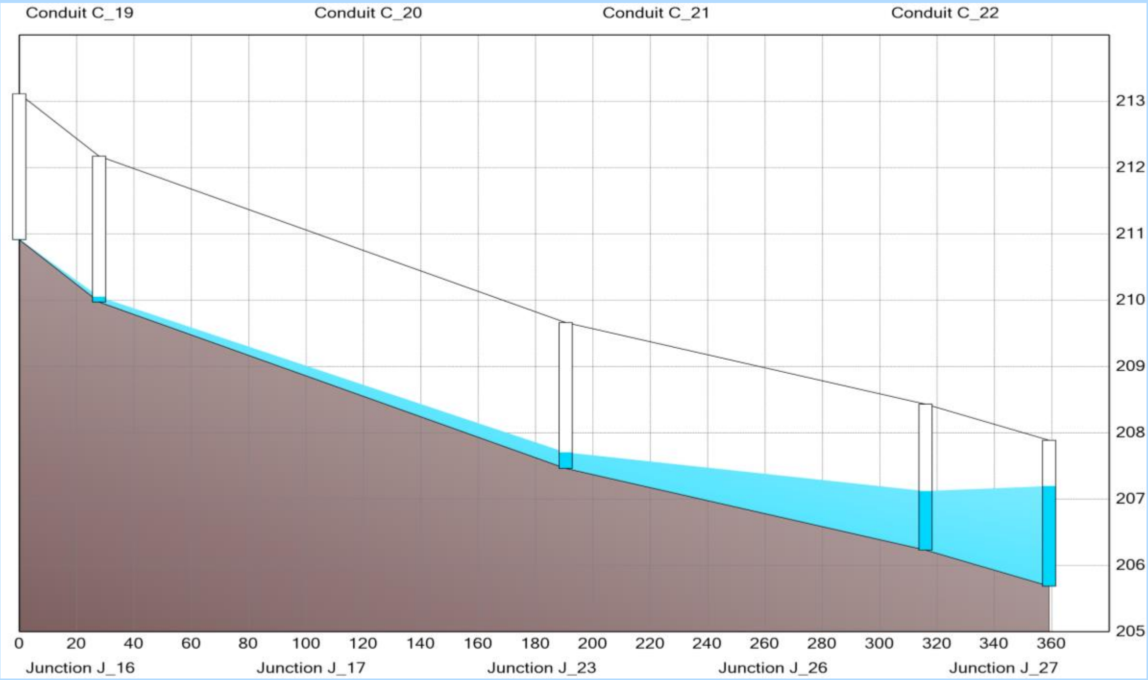


The reduction of flooding in the sample network is presented in Figure 3.1-12. Figure shows comparison of water profiles in a segment of drain after simulation of scenario 1 and scenario 2. Also, in some cases the flooding at junctions that are flooded in scenario 1, has considerably reduced and at some other junctions the flooding is totally removed. However, in some other cases, flooding has moved to upstream or downstream of flooded junctions. This is possible on account of the hydraulic response of the stretch after modification of the gradients (Figure 3.1-10).

Figure 3.2-12: Comparison of water profiles in the segment of drain after simulation of scenario 1 and scenario 2



Scenario 1: With data provided by the departments



Scenario 2: With changes made to cross-sections

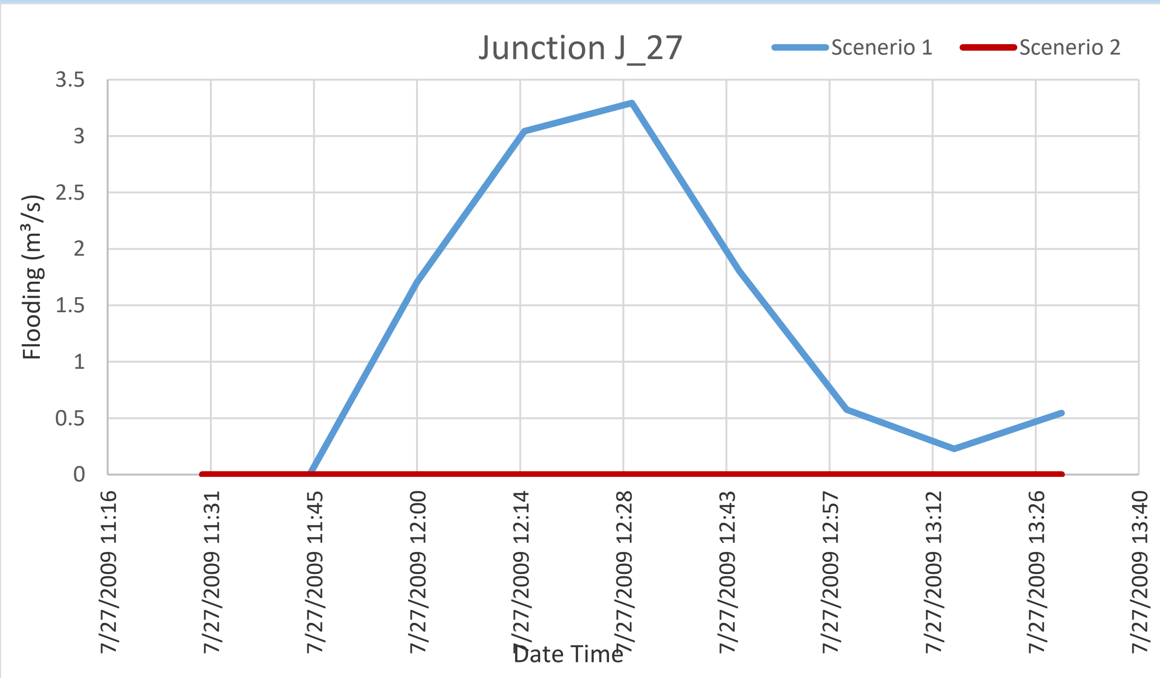
There can be a reasonable decrease in volume of surplus water in some drains after making the corrections in the gradient. Following is an example of the reduction of flood volume at different junctions in the sample drain (Table 3.2-4):

Table 3.2-4: Comparison between the flood volume at junctions of a segment of drain after simulation of scenario 1 and scenario 2

Node	Flood volume(m^3)	
	Scenario 1	Scenario 2
J_19	2335	0
J_17	0	0
J_23	475	0
J_26	0	0
J_27	9863	0

Change in flood volume of water at one of the junctions of Table 3.2-4 can be seen in Figure 3.2-13, which depicts the extent of flooding as well as the duration of flooding. The graph shows that J_27 was originally flooded with 9863 m^3 volume of excess water over a period of 1hrs 27 mins, while in the scenario 2 after changing the Invert Levels, the flooding at the junction got totally removed.

Figure 3.2-13: Comparison between the flood volumeat a sample junction after simulation of scenario 1 and scenario 2



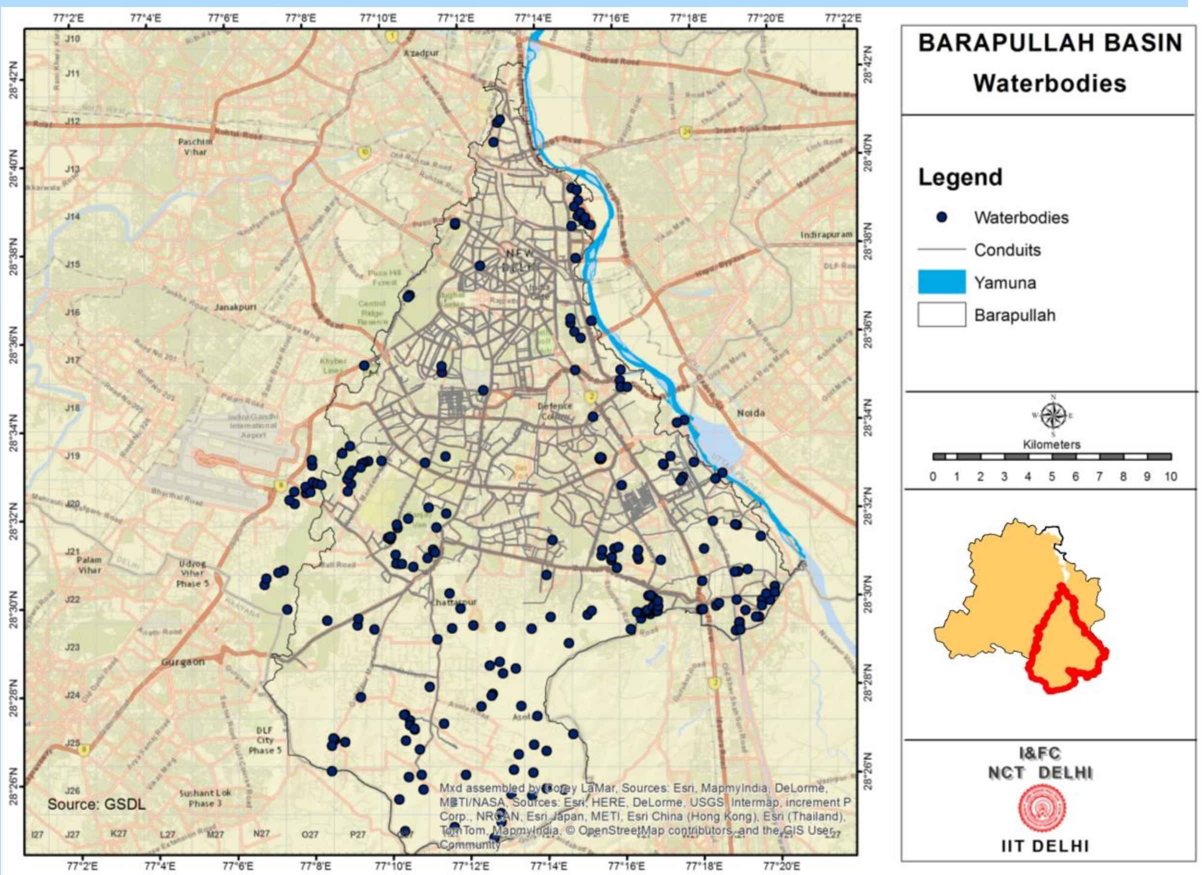
3.2.5.3. Scenario 3 – Simulation towards rejuvenation of water bodies

This scenario has been formulated by incorporating the water bodies into the scenario 2, so as to absorb some of the excess runoff generated from the sub catchments and at the same time rejuvenating the water bodies to recharge the groundwater. In Barapullah basin, there are a total of 233 water bodies which have been incorporated as storages in the model (Figure 3.2-14). The runoff from the sub catchments are first routed towards the water bodies. Provision has also been made to take any overflow from these water bodies to the nearest downstream drain. The linking of water bodies with the stormwater drainage network minimizes the flooding occurring at the junctions. Barapullah basin is the completely urbanized basin in Delhi region where 233 numbers of water bodies exists. As per the information provided by the I&FC department, the depth of the water bodies has been considered as 2 meters.

Provision has also been made to connect the overflow from the water bodies to the nearest natural drain. After providing the connectivity to the nearest water bodies wherever possible, the total flooding nodes in the basin reduces to 2455 numbers. Some of these connections to the water bodies might already exist. However, some of them may be disconnected or dysfunctional at present, and needs to be restored, therefore, these connections are also considered.

APPENDIX IX presents all the water bodies connected to junctions in Barapullah basin along with the new conduits joining flooded junction to water bodies.

Figure 3.2-14: Water bodies connected to junctions to divert the excess water

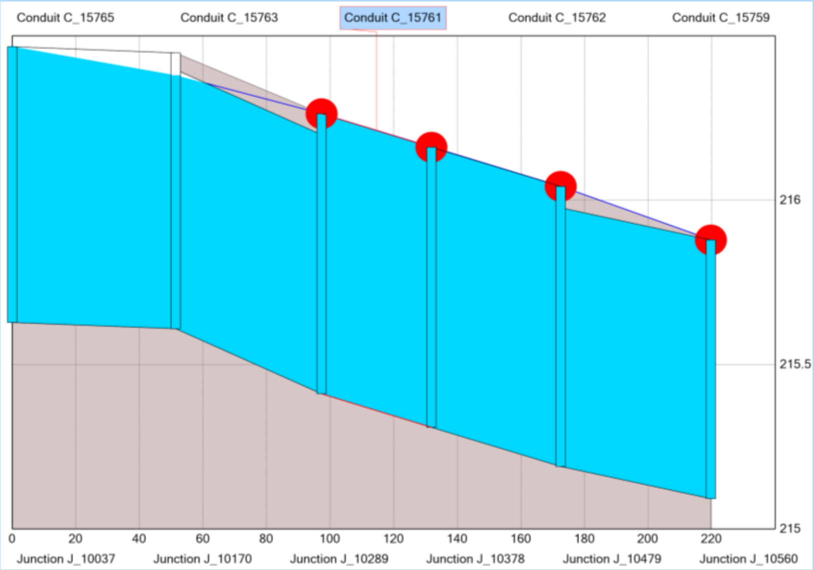


Following are some of the generic observations from simulation of scenario 3 as compared to the simulation of scenario 2:

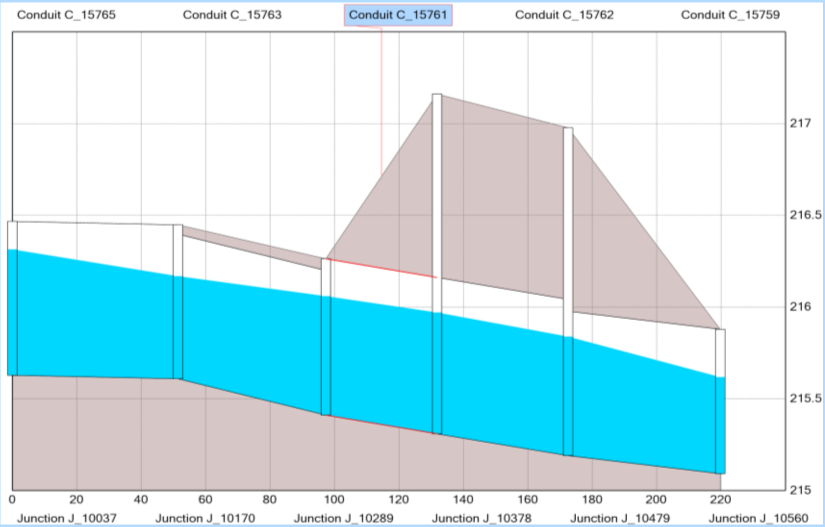
- In some cases, water bodies captivate the flooded volume of water and thus removing the flood at some of the junctions or reducing the volume at others.
- Additional length of conduits has been provided to connect water bodies and nearby junctions to transfer of excess water in water bodies after they have been filled up with water coming from the subcatchment.

Comparison of water profiles in the segment of a sample drain after simulation of scenario 2 and scenario 3 has been shown in Figure 3.2-15.

Figure 3.2-15: Comparison of water profiles in the segment of drain after simulation of scenario 2 and scenario 3



Scenario 2: Before inclusion of water body in basin



Scenario 3: After inclusion of water body

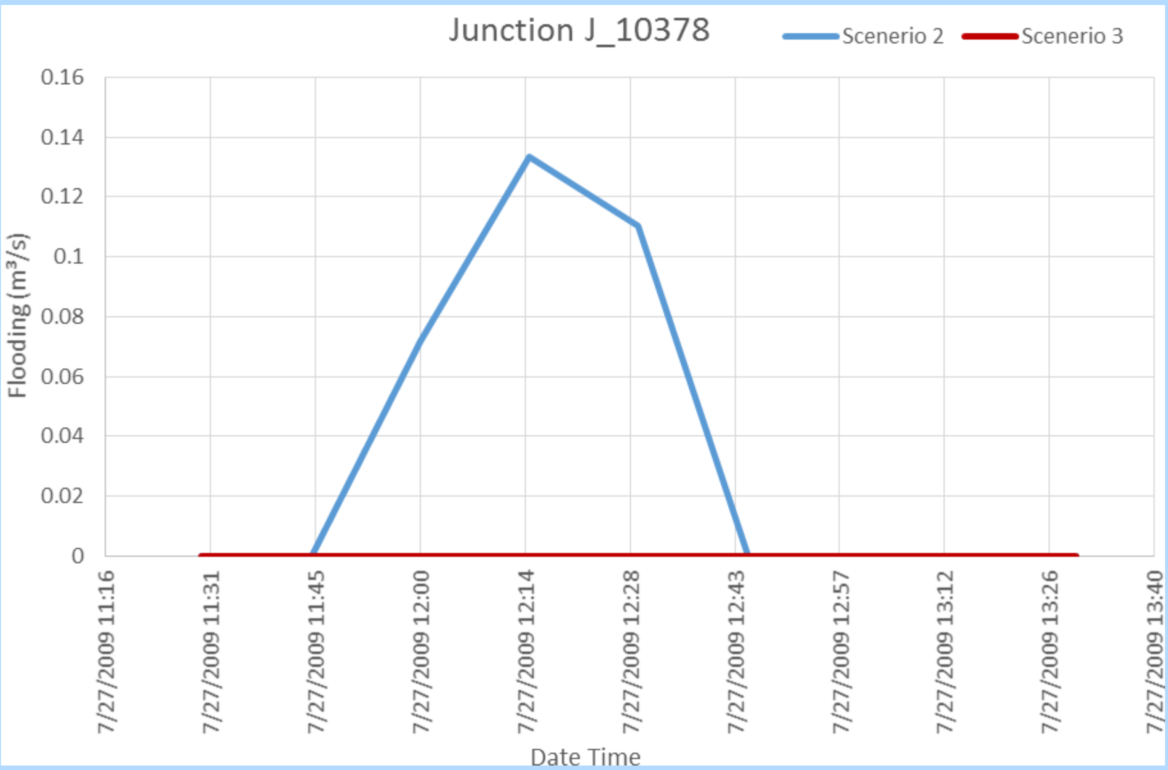
An example of the reduction of flood volume at different junctions in the sample drain is shown below in Table 3.2-5. In the present example, the junction J_3078 is capturing runoff from a big sub catchment and is not able to cater to the requirement and thus is flooded after simulation of scenario 2. In scenario 3, the runoff from the subcathment is first made to flow into a nearby water body, which could store a good amount of volume and thus preventing the junction from flooding.

Table 3.2-5: Comparison between the flood volume at junctions of a segment of drain after simulation of scenario 2 and scenario 3

Node	Flood volume (m^3)	
	Scenario 2	Scenario 3
J_10037	394	380
J_10170	226	172
J_10289	215	126
J_10378	187	0
J_10479	135	0
J_10037	394	380

Change in flooded volume of water at a single junction can be seen in Figure 3.2-16. The graph shows the reduction in the flooding at Junction J_10378 after incorporating water body at this junction.

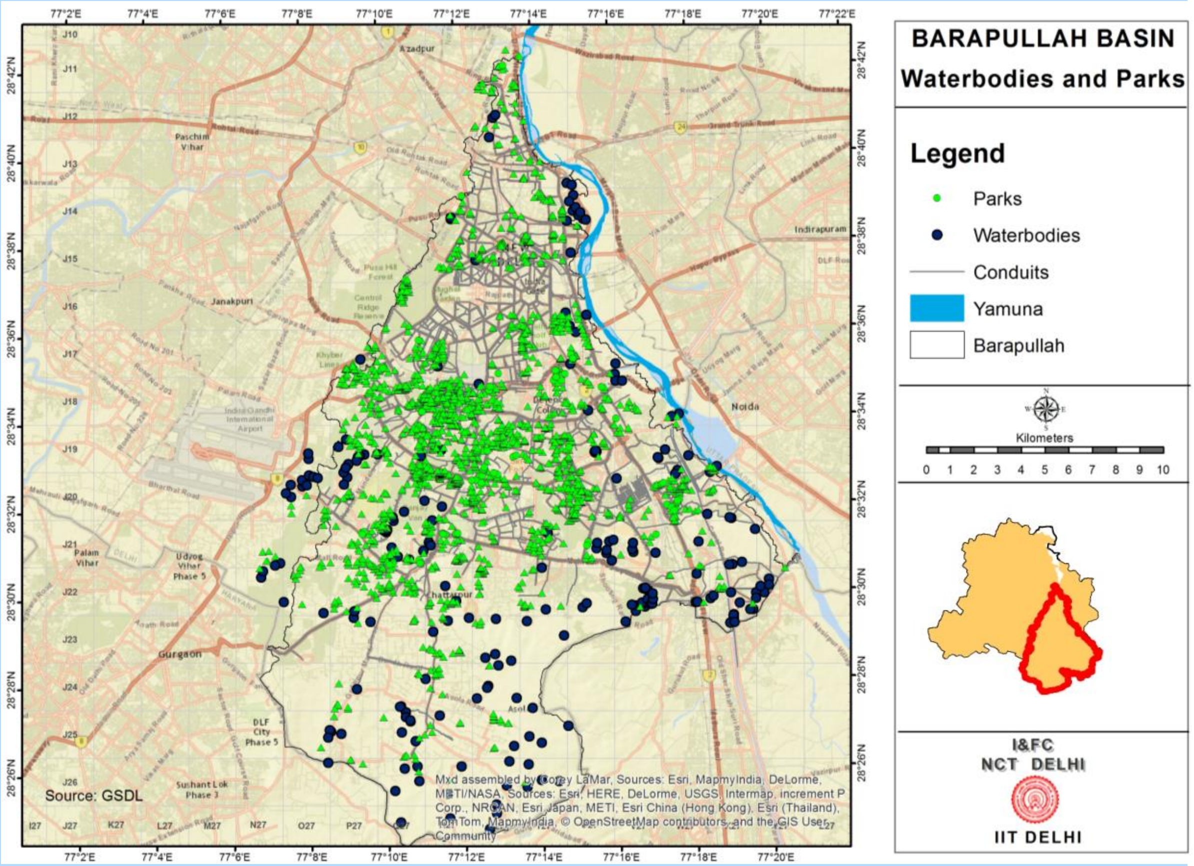
Figure 3.2-16: Comparison between the flood volumeat a sample junction after simulation of scenario 2 and scenario 3



3.2.5.4. Scenario 4 – Simulation with public parks as recharge zones

Having incorporated the water bodies as detention basins (scenario 3), another scenario (scenario 4) has been designed to divert the extra volume of water from junction, to the nearby parks and other open areas wherever possible (Figure 3.2-17). The DDA parks and other parks with in the basin have been incorporated with a standard depth of 1 feet (0.3 meters). APPENDIX IX presents all the junctions connected to parks in Barapullah basin along with the new conduits joining flooded junction to parks.

Figure 3.2-17: Parks connected to junction to divert the excess water

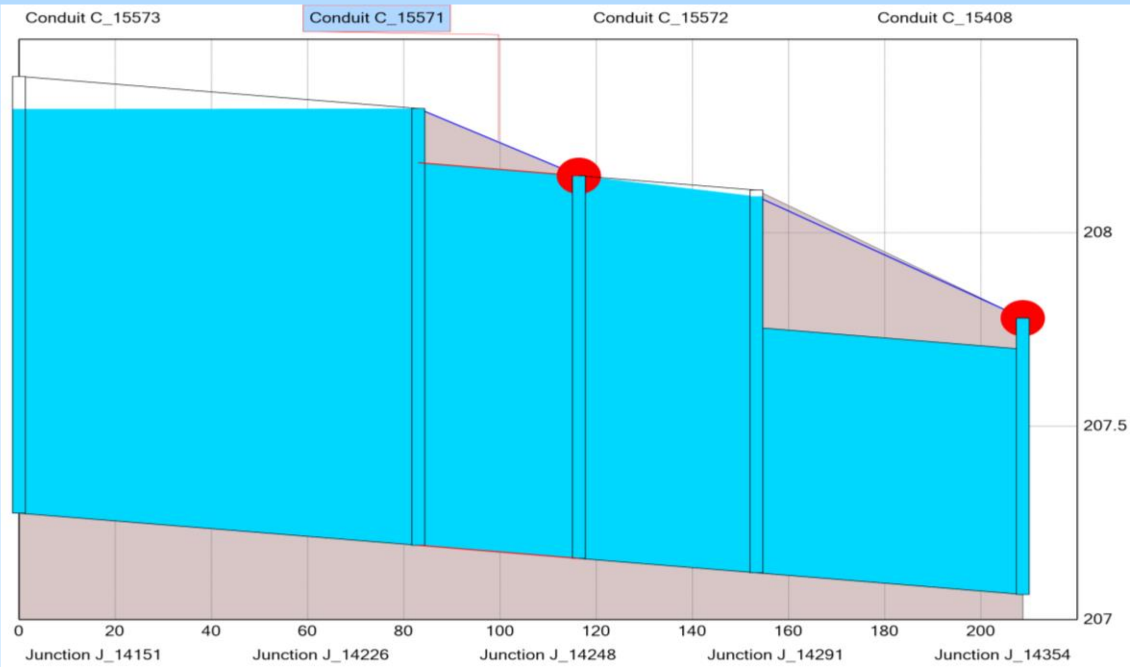


Following are some of the generic observations from simulation of scenario 4 as compared with the simulation of scenario 3:

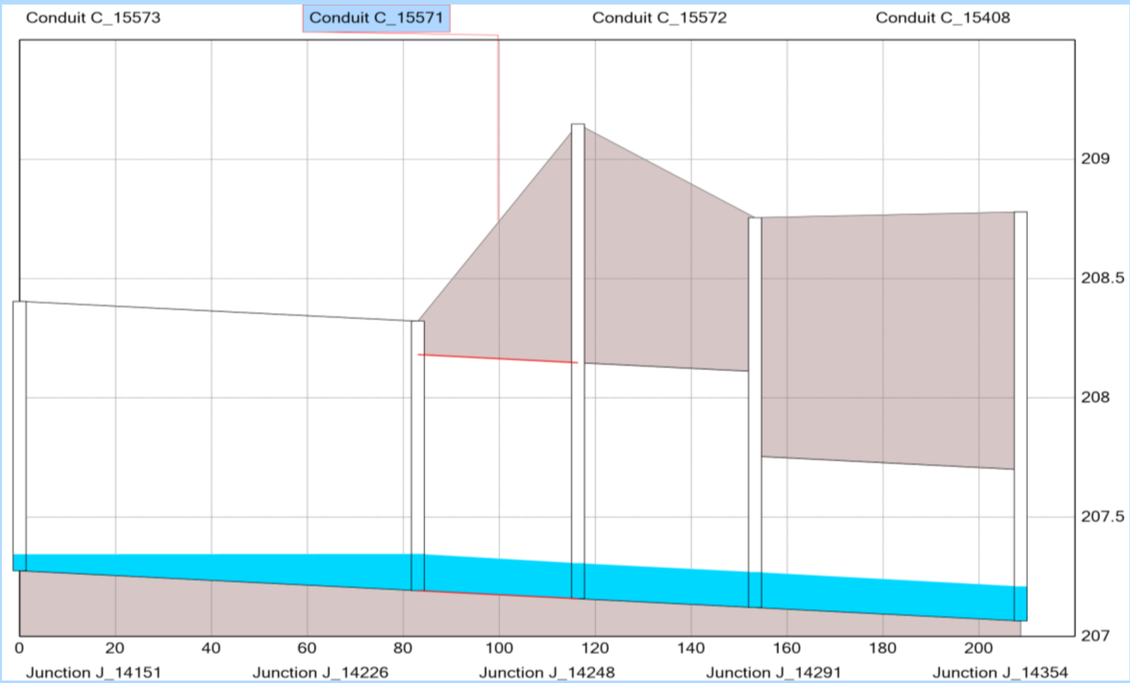
- In some cases, the flooded volume of water from the junction is diverted to nearest parks and open spaces to remove or reduce the flood at some of the junctions.
- Additional length of conduits has been provided wherever required to connect the flooded junctions to nearby parks for transfer of excess water from junctions.

Comparison of water profiles in the sample segment of drain after simulation of scenario 3 and scenario 4 is shown in Figure 3.2-18.

Figure 3.2-18: Comparison of water profiles in the segment of drain after simulation of scenario 3 and scenario 4



Scenario 3: without including any recharge zones



Scenario 4: with public parks as recharge zones

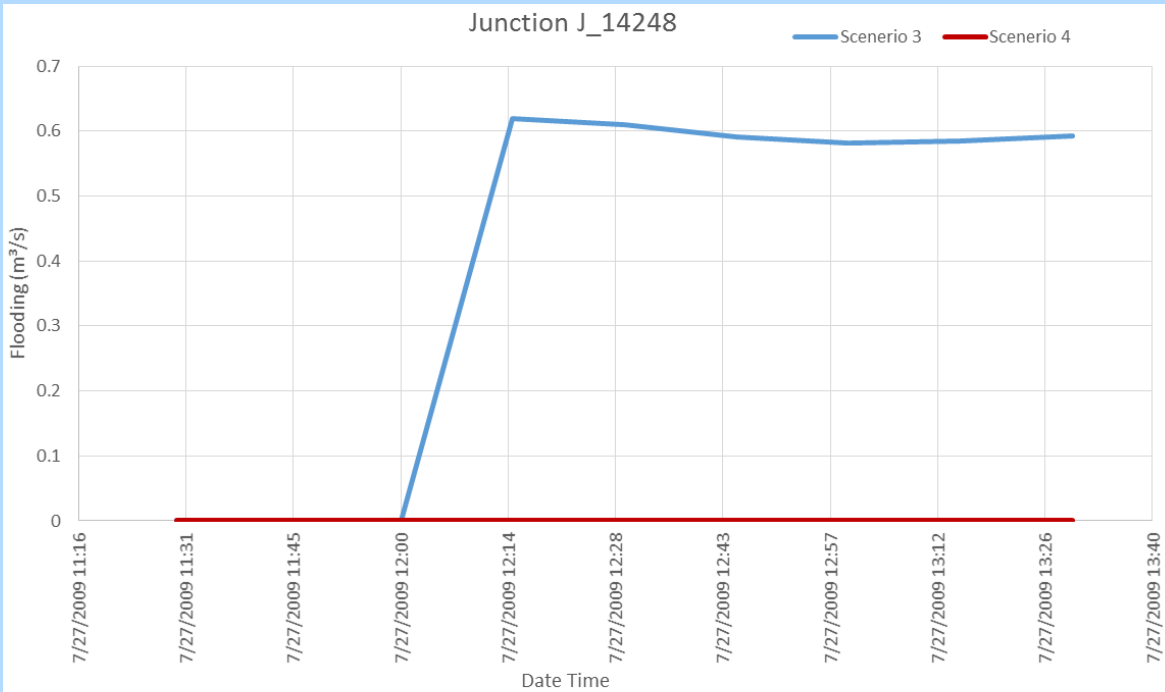
An example of the reduction of flood volume at different junctions in the sample drain is shown below in Table 3.2-6. In the present example, the Junction J_14248 was flooded after simulation of scenario 3. In scenario 4, the flood volume at J_14248 has been made to flow into the nearest park which could store a considerable volume and thus preventing many of the junctions from flooding.

Table 3.2-6: Comparison between the flood volume at junctions of a segment of drain after simulation of scenario 3 and scenario 4

Node	Flood volume (m^3)	
	Scenario 3	Scenario 4
J_14151	0	0
J_14226	6082	5798
J_14248	3453	0
J_14291	0	0
J_14354	2552	0

Change in flooded volume of water at a single junction can be seen in Figure 3.2-19. The graph shows the reduction in the flooding at Junction J_14248 after diverting the excess water from it to the nearest park.

Figure 3.2-19: Comparison between the flood volumeat a sample junction after simulation of scenario 3 and scenario 4



3.2.5.5. Scenario 5 - Towards no flooding junction for 2 year return period

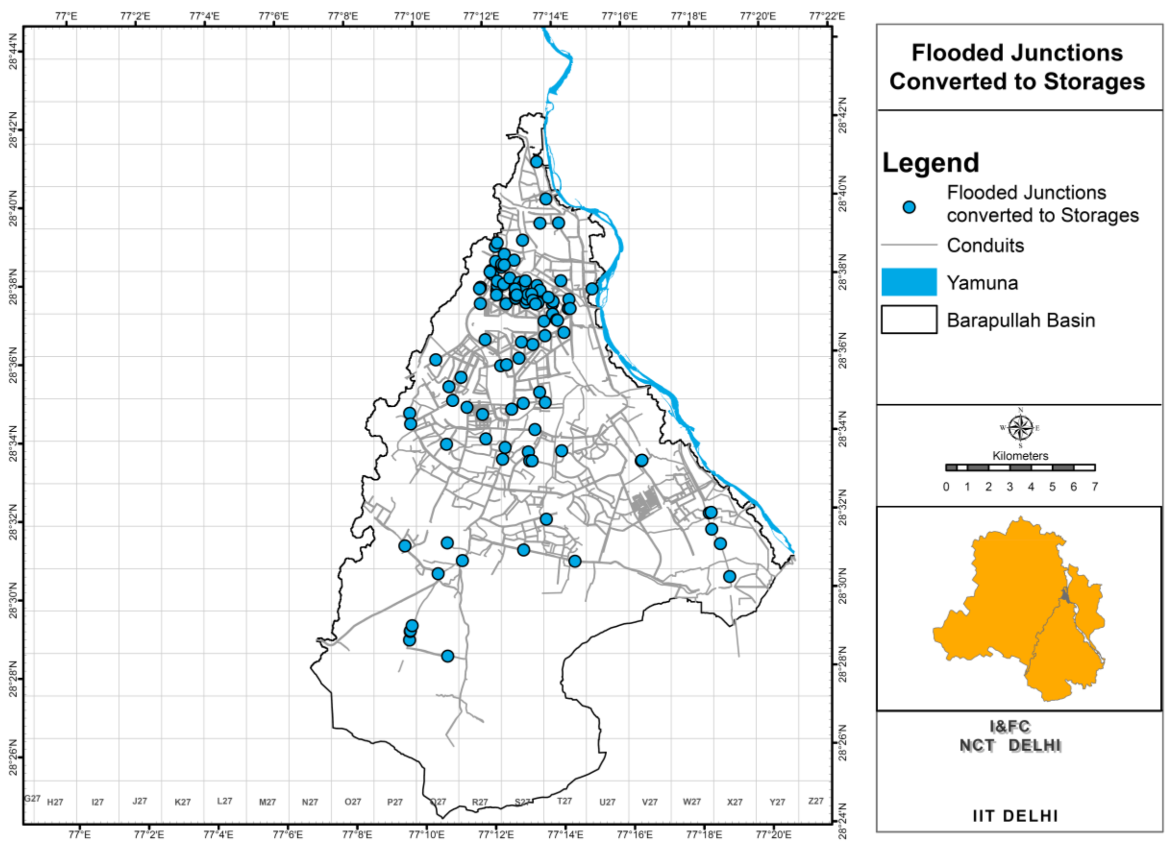
After scenario 3 and 4 in which some of the excess flood volumes was diverted to existing and potential water bodies and parks whereby a substantial reduction in flood volume was observed.

In the present scenario, additional volumes at each junctions have been quantified and such junctions were transmuted to storages. Other options like LID (as already recommended in chapter 2) can also be implemented based on the surroundings ground conditions and visual inspection. Thus, for each sub basin, suitable LIDs can be identified and the effectiveness of the same can be established through simulation and the consequent reduction as well as unaccounted surplus runoff volume can be quantified.

While formulating scenario 5 another decision has been taken to consider all the junctions that are getting flooded for a duration of more than 15 minutes.

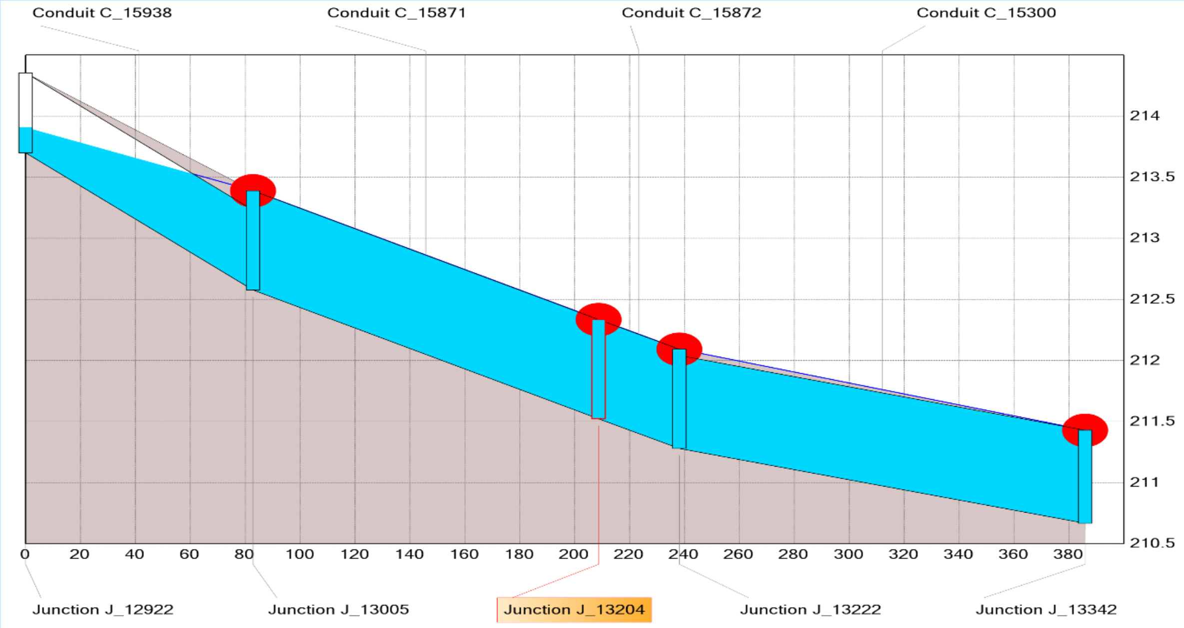
Total 281 number of junctions (**Figure 3.2-20**) which were flooded were transformed into the storages, taking care of the excess volume of water in the present scenario for model simulation. However, these storages may be replaced by other LID structures if feasible. Based on ground realities suitable LIDs are implemented in a case study.

Figure 3.2-20: Flooded junctions were transferred into Storages

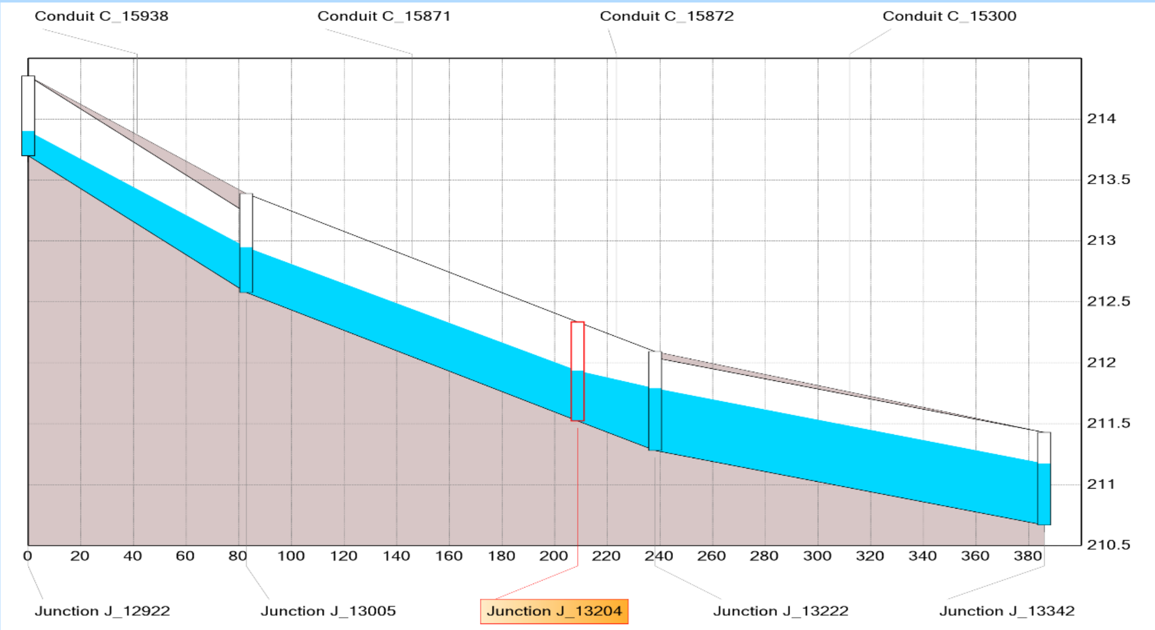


Comparison of water profiles in the segment of drain after simulation of scenario 4 and scenario 5 is shown in **Figure 3.2-21**.

Figure 3.2-21: Comparison of water profile in the segment of the drain after scenario 4 and 5



Scenario 4: Before the application of storage junctions



Scenario 5: After the application of storage junctions

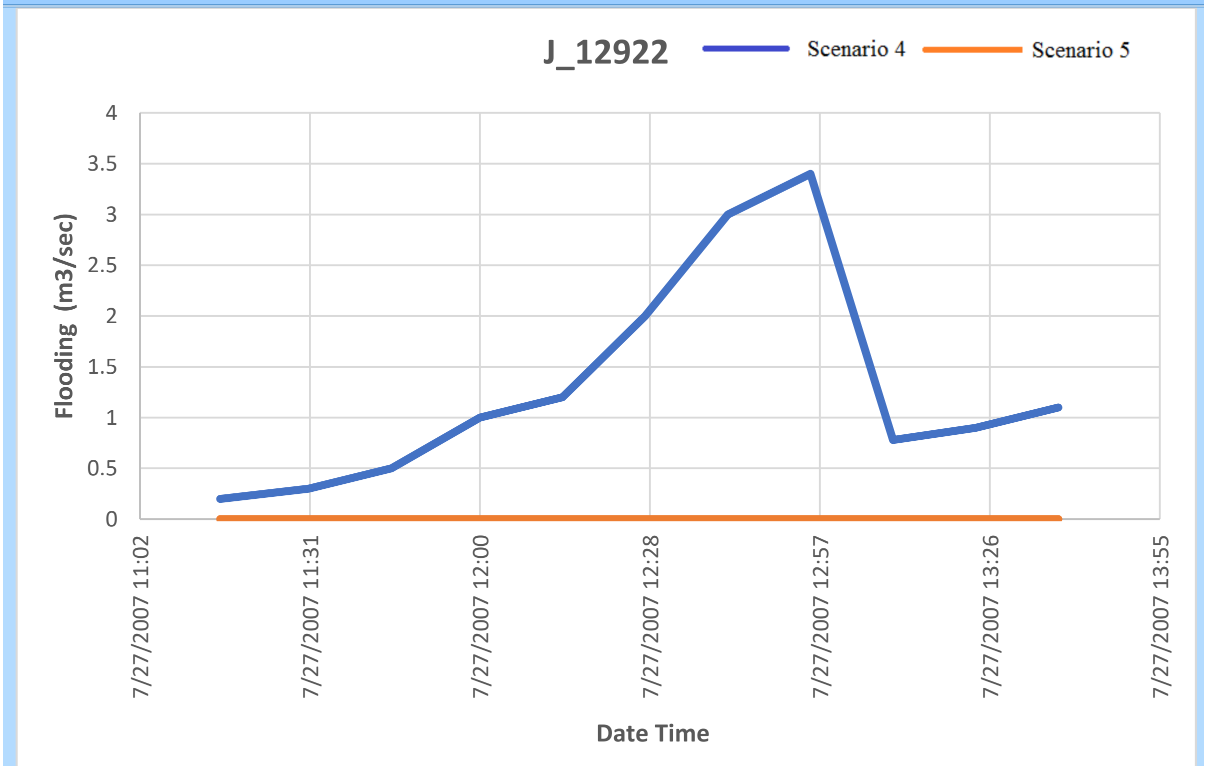
An example of the reduction of flood volume at different junctions in the sample drain is shown below in Table 3.2-7. In the present example, the Junctions J_12922, J_13005, J_13204, J_13222 and J_13342 was flooded after simulation of scenario 4. In scenario 5, the flood volume at J_12922, J_13005, J_13204, J_13222 and J_13342 has been made to store in the retention tank/ detention tank/ LID structure which could store a desired amount of volume and thus prevent the junction from flooding.

Table 3.2-7: Comparison between the flood volume at junctions of a segment of the drain after simulation of scenario 4 and scenario 5

Node	Flood volume (m3)	
	Scenario 4	Scenario 5
J_12922	76000	0
J_13005	87000	0
J_13204	119000	0
J_13222	555000	0
J_13342	59000	0

Change in flooded volume of water at a single junction can be seen in **Figure 3.2-22**. In the present example, the Junction J_12922 is catering to the runoff from a big sub catchment and thus is flooded after simulation of scenario 4. The graph shows the reduction in the flooding at Junction J_12922 after incorporating storage at this junction.

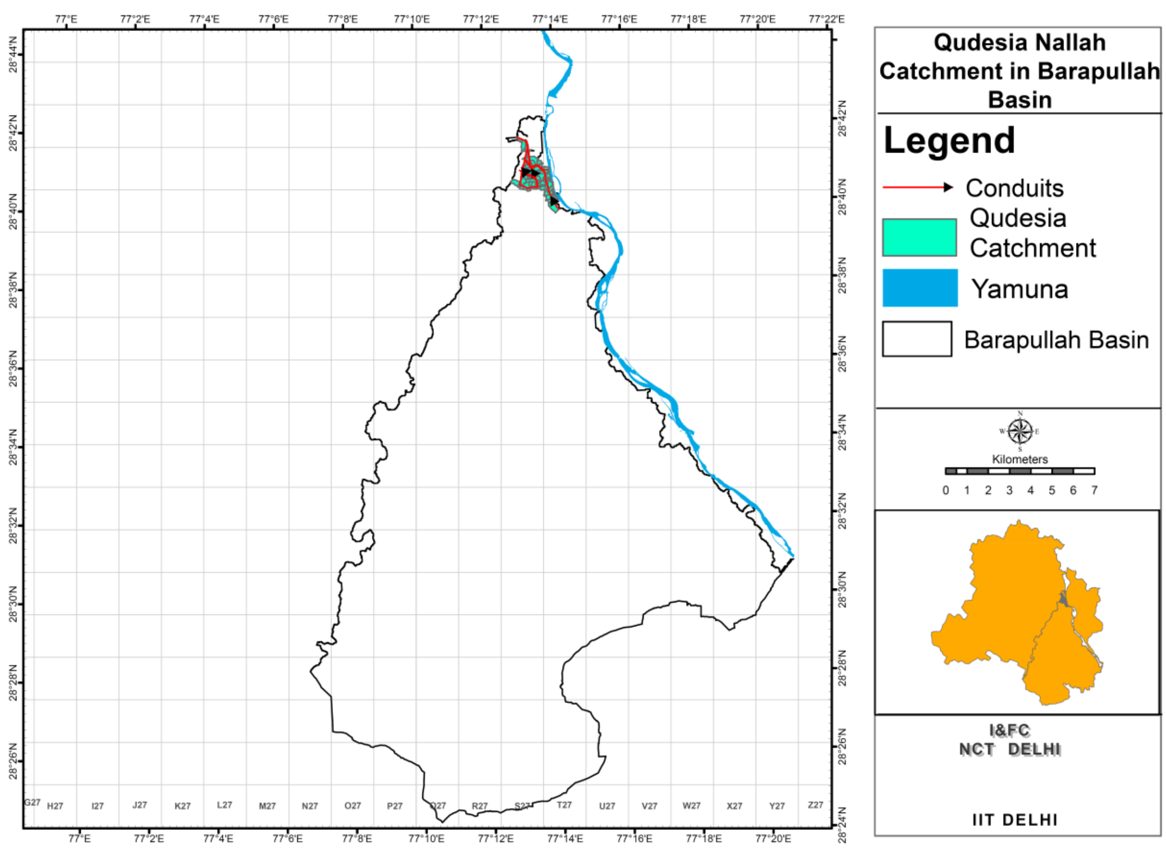
Figure 3.2-22: Graph of Volume Before Flooding and After Flooding



CASE STUDY FOR LID IMPLEMENTATION

A the catchment of Qudesia Nallah (Barapullah Basin) has been considered as shown in **Figure 3.2-23**, for demonstrating how the LIDs can be identified and implemented for further reduction of flooding.

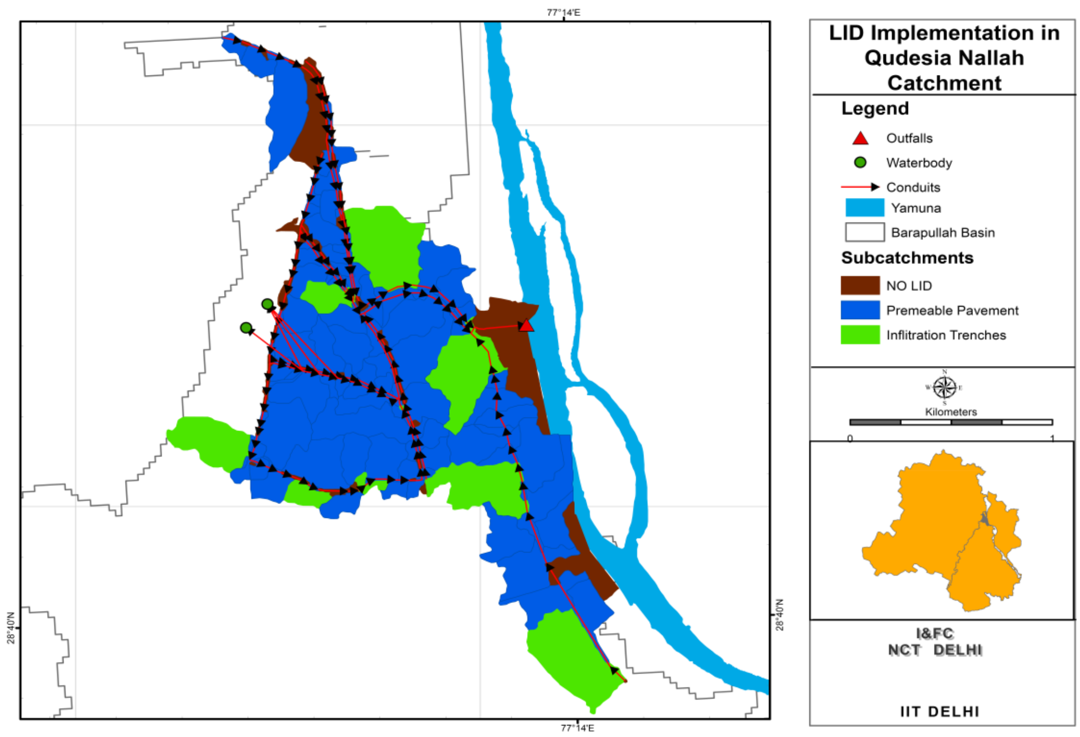
Figure 3.2-23 : Qudesia Nallah Catchment in Barapullah Basin



After studying the landuse, geography of the area and the soil properties of the Delhi region, only two types of LIDs were identified and implemented; (a) Permeable Pavement and, (b) Infiltration Trench as shown in Figure 3.2-25.

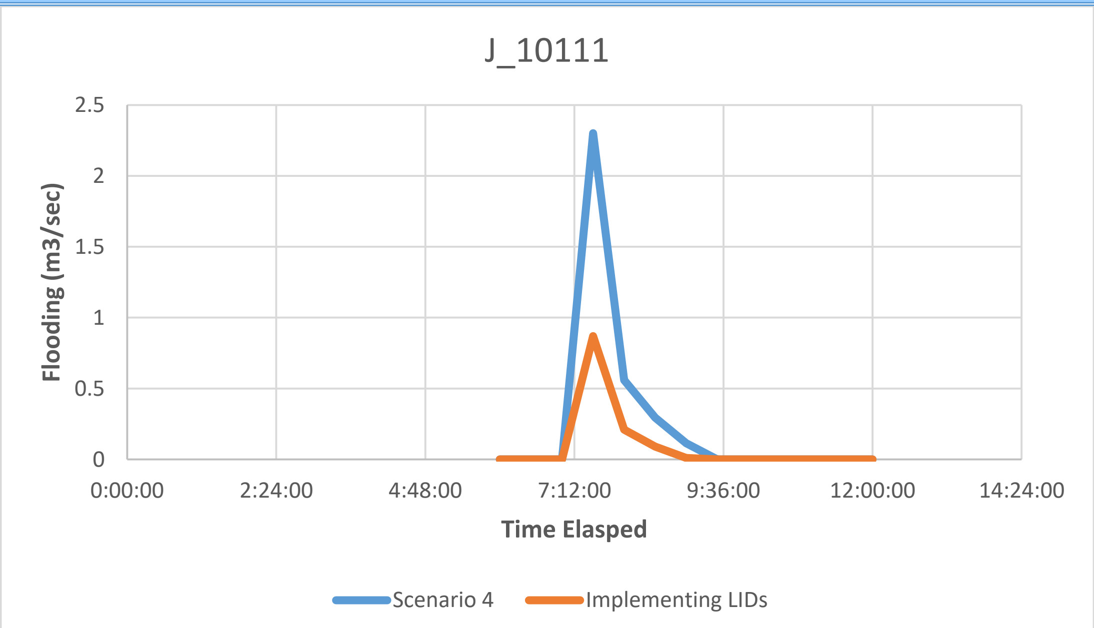
The simulations are then performed to quantify the effectiveness of the selected LID (Permeable Pavement and Infiltration Trench) which has been established through which show significant reduction in the flood volumes at the junctions.

Figure 3.2-24: LID Implementation in Qudesia Nallah Catchment



By incorporating LID in the subcatchments, a substantial reduction in flood volume was observed in Junction J_10111. The following **Figure 3.2-25** reflects the considerable drop in flood volumeafter the implementation of LIDs.

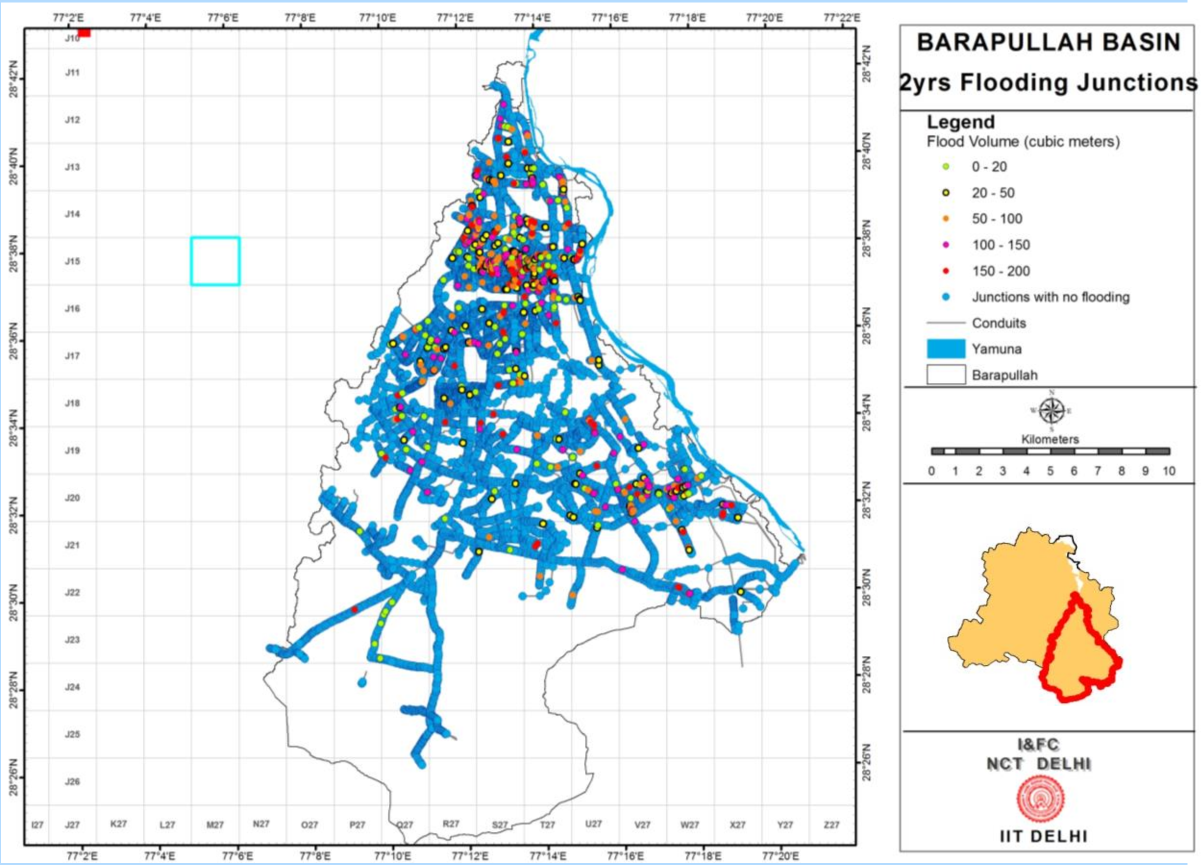
Figure 3.2-25: Graph reflecting the change in Flood volume for J_10111



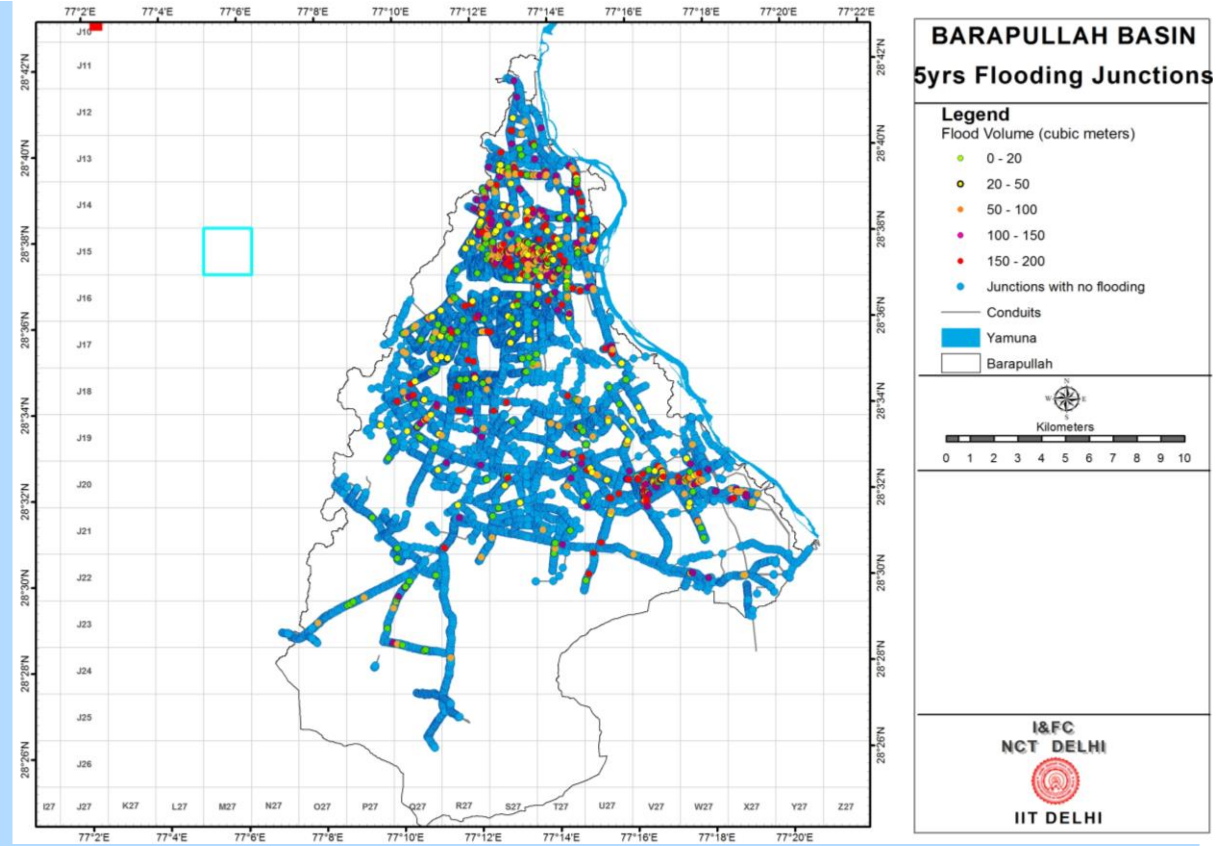
3.2.5.6. Comparison of Simulations with 2 year and 5 year return period rainfall events

Exhaustive simulation of the stormwater drainage network has been done using the rainfall events for 2 year return period. Similar simulation has also been done for the same network using 5 year return period rainfall events. Figure 3.2-26 shows the number of junctions flooded on the basis 2 year and 5 year return period rainfall events.

Figure 3.2-26: Junctions flooded with respect to 2 year and 5 year return period rainfall events



Junctions flooded in rainfall event of 2 year return period



Junctions flooded in rainfall event of 5 year return period

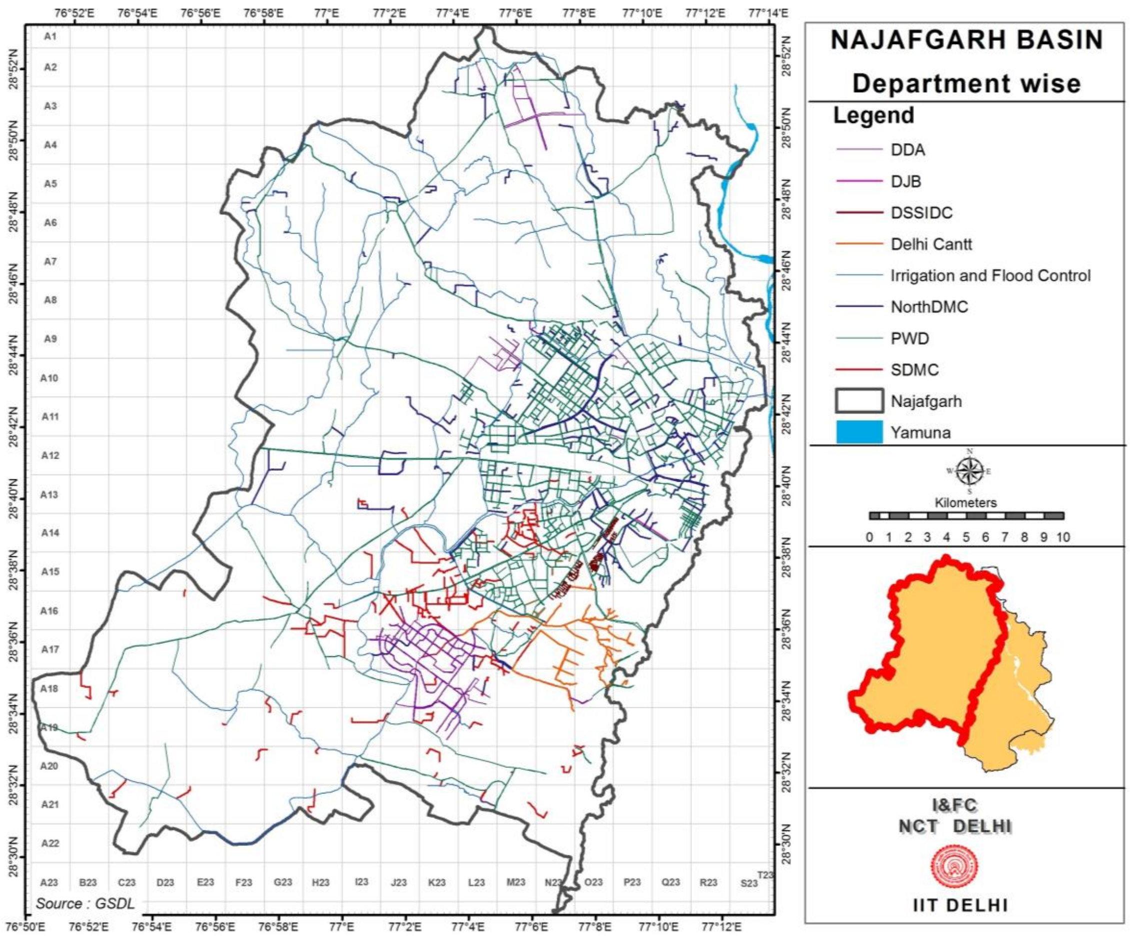
3.3. Najafgarh Basin

3.3.1. Introduction

3.3.1.1. Basin characteristics

The Najafgarh drain is the biggest drain in National Capital Territory (NCT) of Delhi. It enters South-West corner of Delhi from Haryana. It traverses a length of 57.489 km before joining river Yamuna, downstream of Wazirabad barrage. In its initial stage through South-West district of National Capital Territory of Delhi, the drain carries flood water, wastewater from Haryana and surface runoff from the adjoining catchment. A map of the general characteristics of the region with the major roads and storm drains is given in Figure 3.3-1.

Figure 3.3-1: General Characteristics of Najafgarh Basin

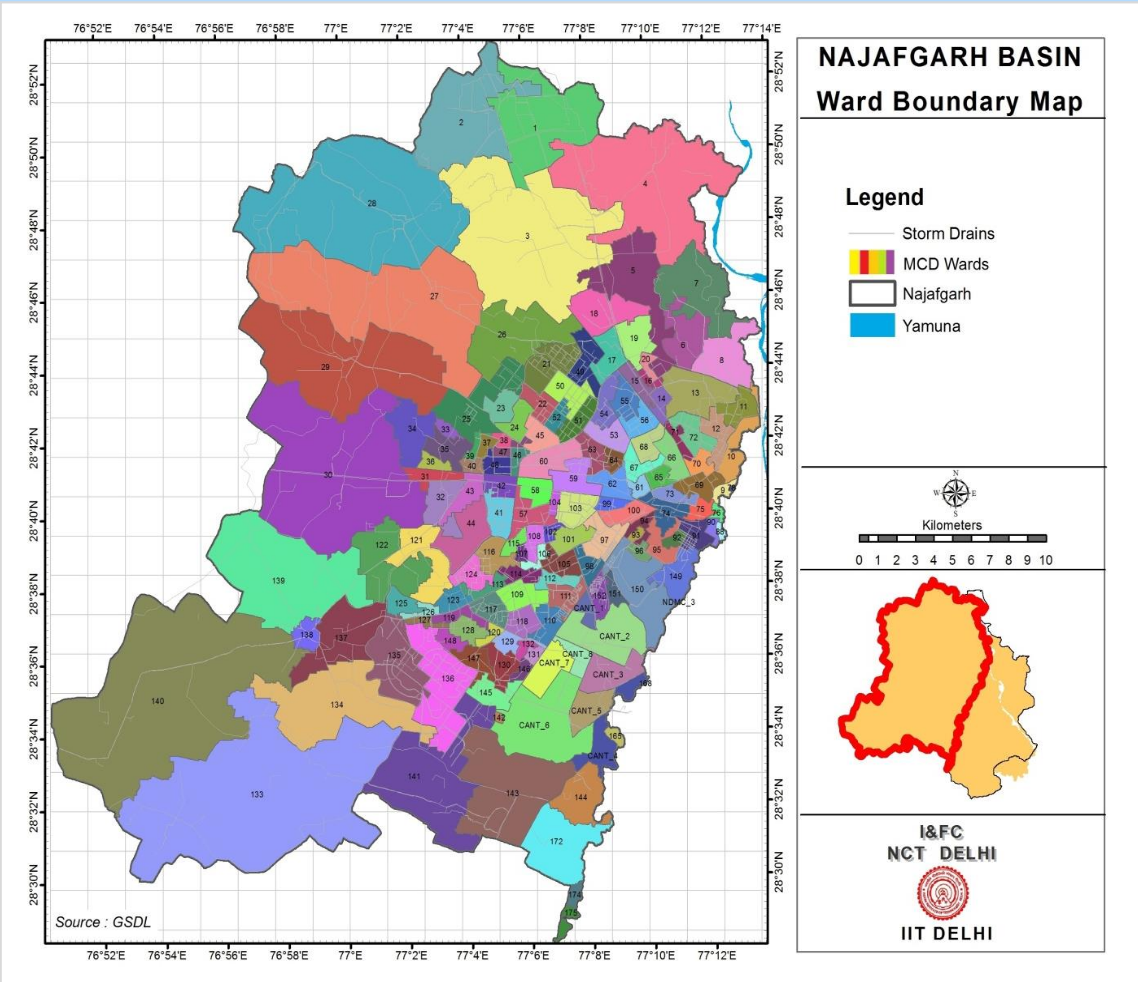


Out of the 57.489 km stretch of the drain, nearly 30.943 km stretch of the drain passes through South-West district from near Dhansa to Kakraula. Thus, nearly 53.82% of the length of Najafgarh drain flows through south-west district of National Capital Territory (NCT) of Delhi. Moreover, from Dhansa to Kakraula regulator, 28 small drains join this big drain and subsequently after Kakraula, nearly 74 big and small drains join Najafgarh drain. Supplementary drain is the second largest drain which joins the Najafgarh drain just before its outfall into Yamuna river and total 71 small drains join the supplementary drain. The Najafgarh drain comprises three major blocks, namely, Alipur, Kanjhawala, Najafgarh and some urban part of South-West Delhi. The total catchment area of Najafgarh drain is around 977.26 sq.km. within NCT of Delhi.

3.3.1.2. Population statistics

According to the 2011 census, total population in the region is around 87.838 lakhs. It can be observed from the census 2011 data that south-west and north-west districts are comparatively less densely populated than central and west Delhi. A map showing the location of wards in the Najafgarh basin is given in Figure 3.3-2.

Figure 3.3-2: Details of wards in Najafgarh basin



District areas and population are given in Table 3.3-1

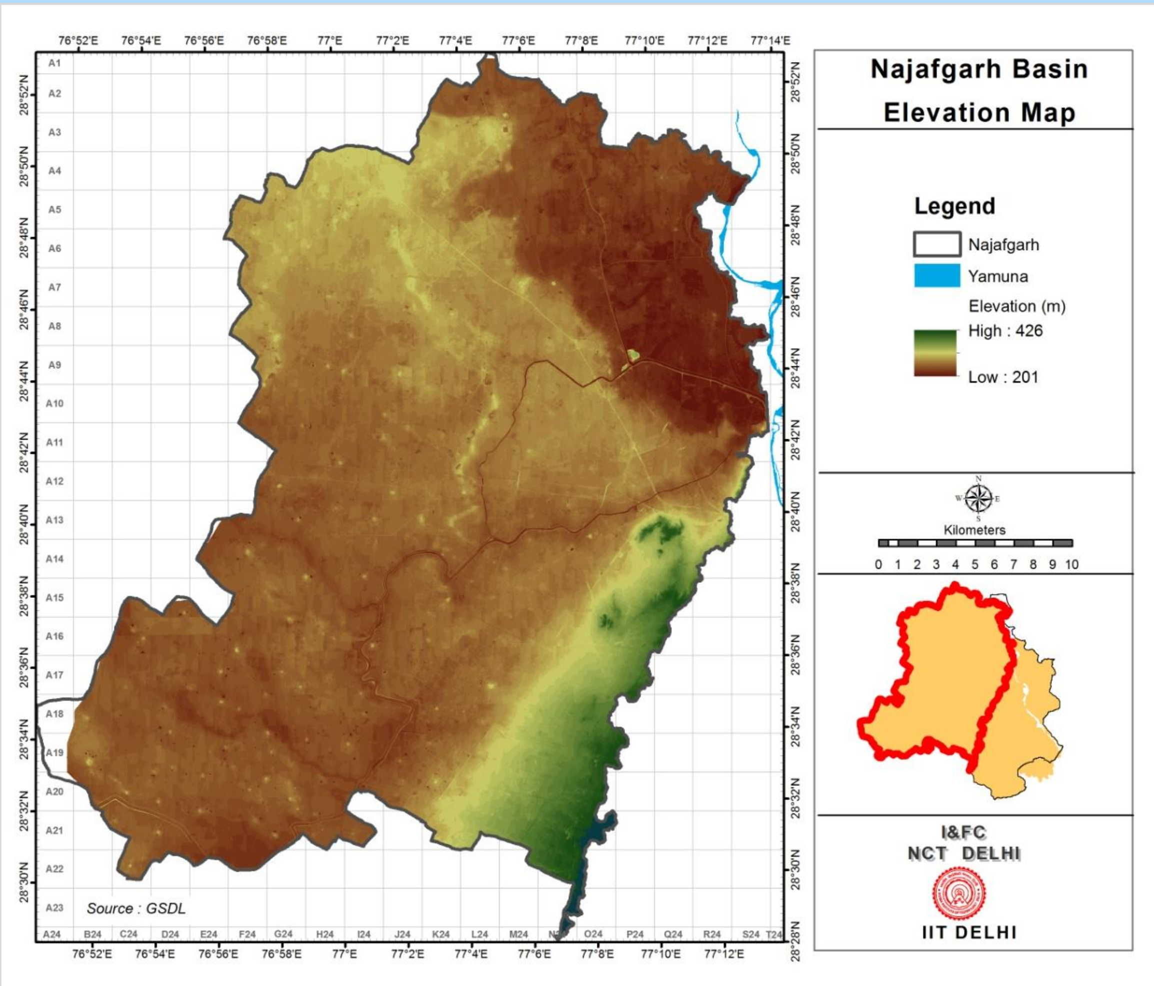
Table 3.3-1: Population Statistics - Najafgarh Basin

District	% Area in the Najafgarh Basin	Population within Najafgarh Basin	Density (person per sq. km.)
Central Delhi	24.62662	142507	23149
North Delhi	55.60949	491264	14973
North West Delhi	95.59602	3490460	8298
South Delhi	0.23281	6364	10935
South West Delhi	85.81488	1967189	5445
West Delhi	99.90546	2529190	19625
Total Population		**8626974**	

3.3.1.3. Topography and land use

The digital elevation model (DEM) map of the Najafgarh region is shown in Figure 3.3-3.

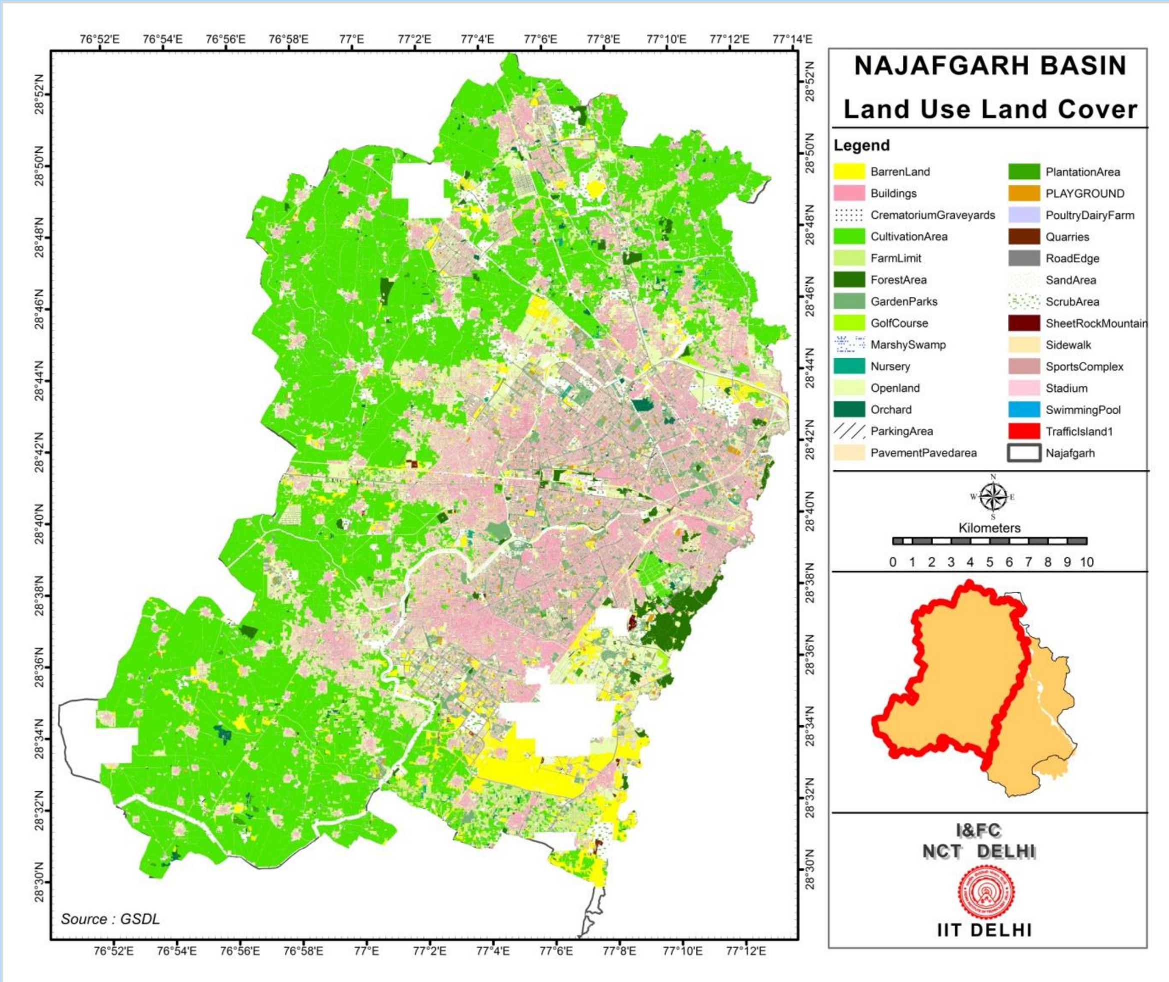
Figure 3.3-3: Digital Elevation Model (DEM) map of Najafgarh Basin



The surface elevation lies between 201 m to 426 m above m.s.l. Natural flow direction of this region is towards river Yamuna. The land use of the region is broadly divided into crop land, urban, forest, water bodies, grass and fallow lands. Najafgarh basin covers a very large part of Delhi. Najafgarh basin has a natural depression called Najafgarh Jheel. It receives the spill from Delhi, as well as from Haryana and Rajasthan Territories. Najafgarh Jheel earlier used to be a big water body.

Apart from river Yamuna, numerous pockets of water bodies are also present in the basin like Najafgarh Jheel, Balswa lake etc.. Land use map of Najafgarh is shown in Figure 3.3-4.

Figure 3.3-4: Built-Up area of Najafgarh Basin



The percentage area of each land use in the region is given in Table 3.3-2.

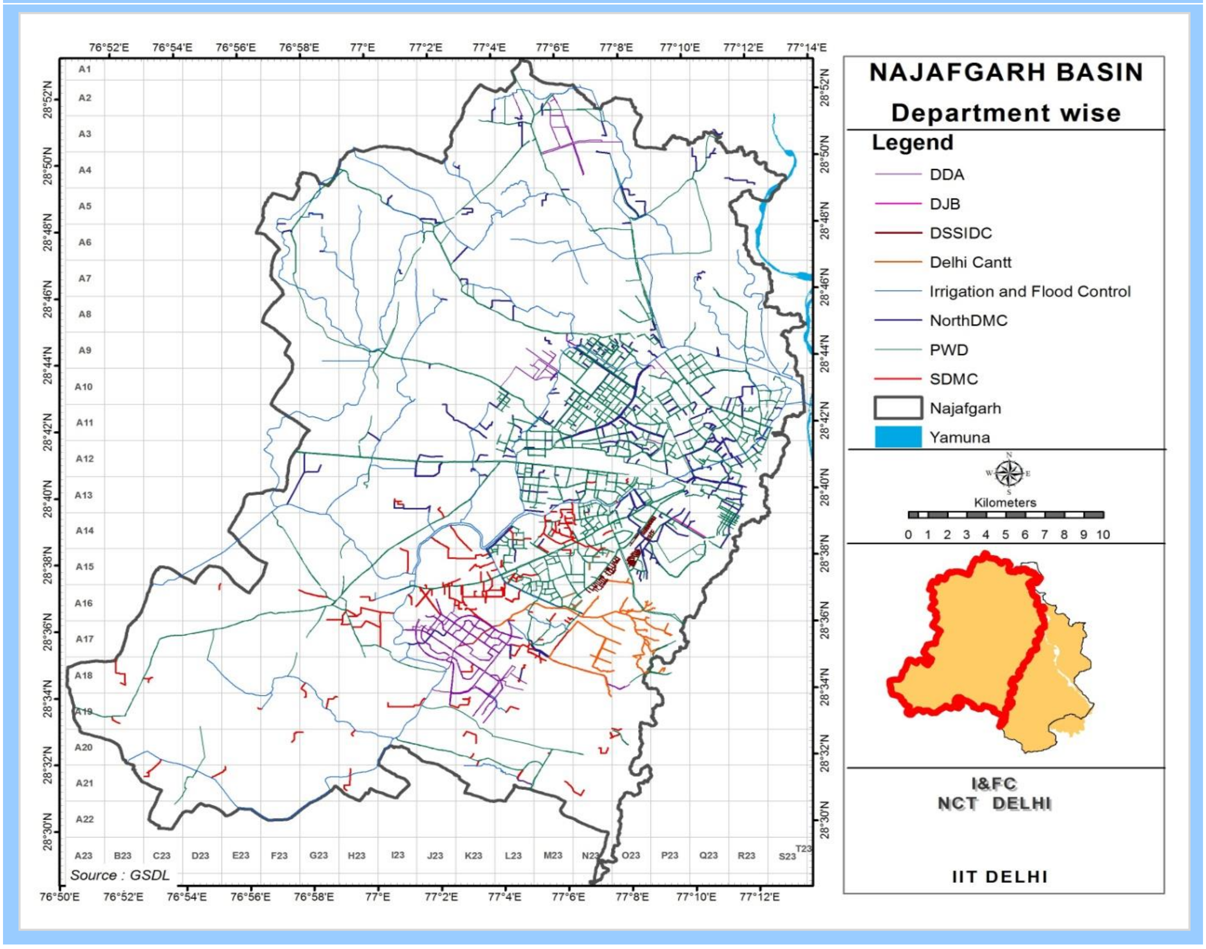
Table 3.3-2: Area (in sq. km. and in percentage) of each land use - Najafgarh Basin

S.No	Land Use	Sub Divisions	Area (sq. km.)	Percentage of Total Area (%)
1	Rural/Crop Land	Cultivation Area, Farm limit, Plantation Area	404.798	44.077
2	Urban	Building Full, Parking, Paved Area, Poultry Dairy Farm, Road, Sports Complex, Traffic Islands etc.	192.419	20.952
3	Grass	Golf Course, Garden Parks, Marshy Swamps, Nursery, Playground	45.739	4.98
4	Fallow	Barren Land, Open Land, Orchard, Quarries, Sand Area	209.867	22.85
5	Deciduous	Forest Area, Scrub Area, Sheet Rock	65.55	7.13

3.3.2. Details of existing drainage network

Storm drains of various agencies are combined together to form complete storm network in Najafgarh region. Map depicting the storm drainage network and respective agencies is shown in Figure 3.3-5.

Figure 3.3-5: Department wise drainage map of Najafgarh Basin

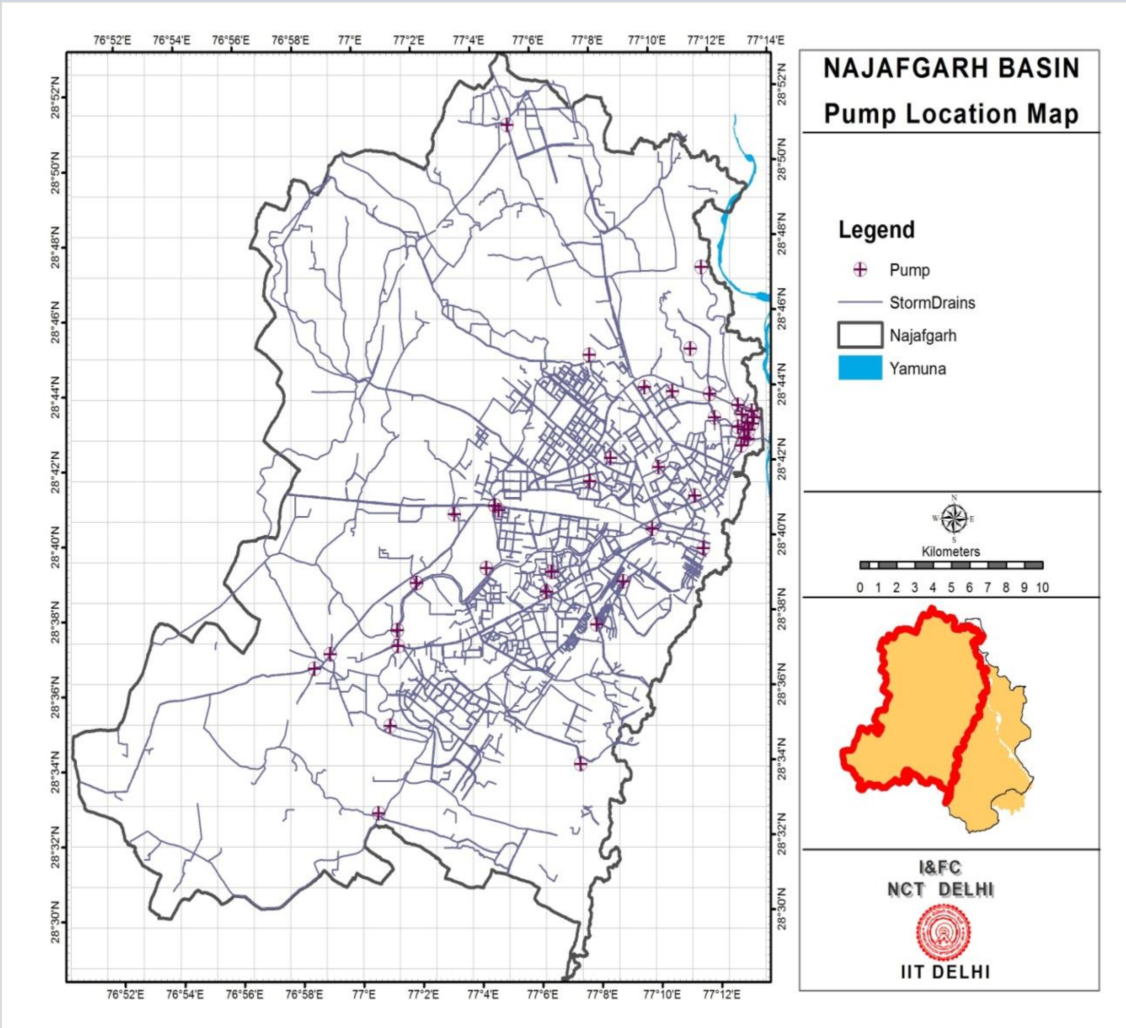


3.3.3. Major drainage problems in the region

The water logging and drainage problem in the Najafgarh basin can be generally categorised as follows:

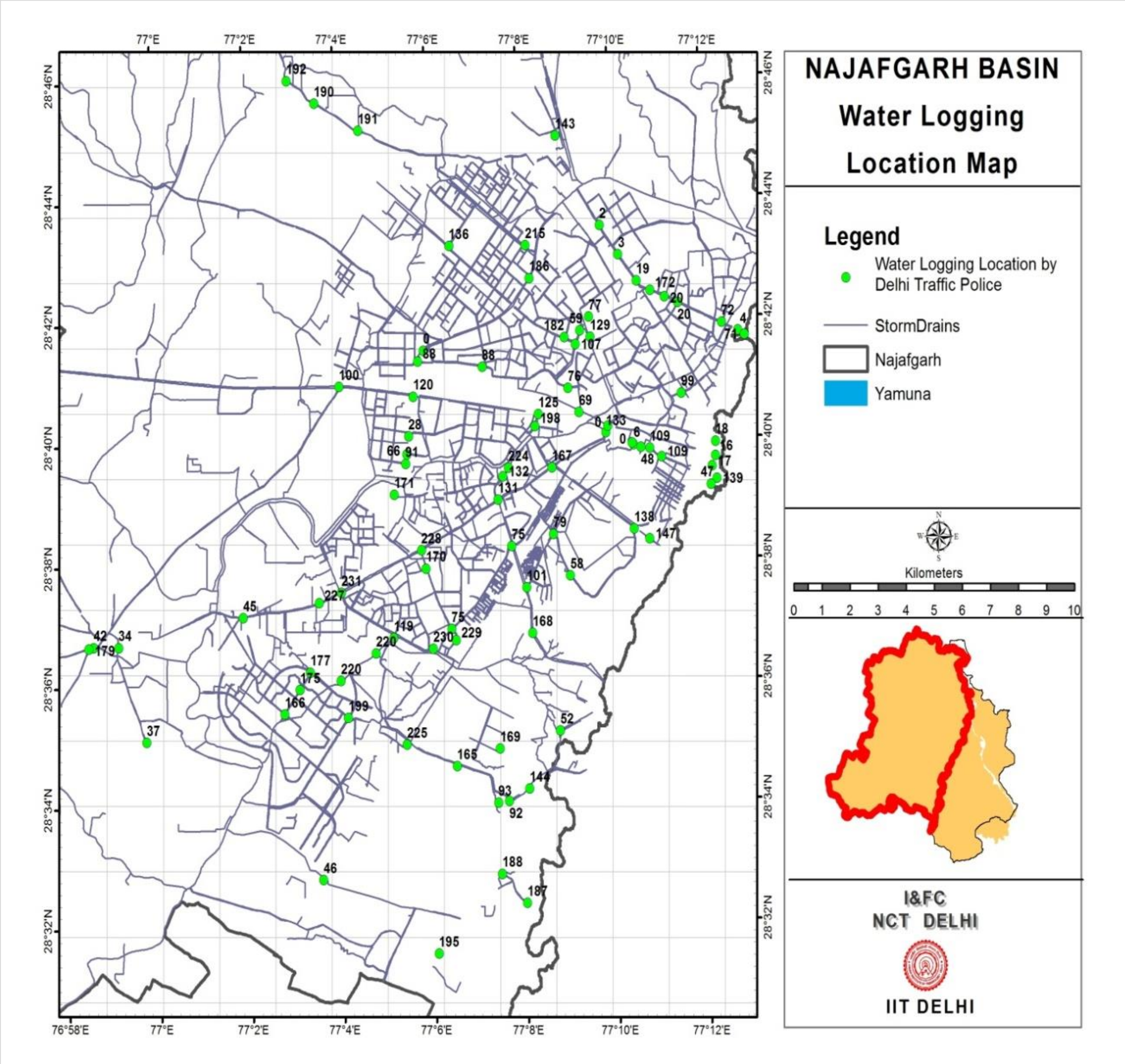
- Drainage Congestion: On account of depressions at numerous places in the basin, the storm water from the nearby areas collect during the rainy season in these depressions.
- Drains carrying storm water from outside Delhi: Drains (such as Najafgarh and Mungeshpur) which have their origin in the other states and carry considerable discharges into Delhi.
- Failure in Pumping: Pumps have been installed at various locations by the government to pump out the storm water into the Najafgarh drain. Location details of installed pumps are shown in Figure 3.3-6. The failure of these pumps leads to drainage congestion in these areas. In addition, constant usage of mobile pumps to pump out the surplus amount of water into nearby drains, whenever required, affects the capacity of the drain and causes flooding in the downstream areas.

Figure 3.3-6: Location details of pumps installed in Najafgarh Region



Many places have been identified by the Delhi Traffic Police where water logging conditions occur predominantly (Figure 3.3-7). Apart from these, interior built-up areas have also been reported to be affected by water logging conditions, especially during monsoon period.

Figure 3.3-7: Areas facing frequent water logging as reported by Delhi Traffic Police - Najafgarh Basin



3.3.4. Simulation scenarios

The following modelling scenarios have been generated for Najafgarh basins with rainfall event of 15 minutes interval and 2 year return period at Palam station. The detailed comparative analysis of simulation for the total network of Najafgarh basin is provided in APPENDIX XIII.

3.3.4.1. Scenario 1 – with data provided by the departments

This is the scenario to generate the flooding conditions with respect to the data provided by various organizations to supposedly represent the present condition of the drainage system. The model has been setup to check the performance of the existing infrastructure of storm water drains which IIT Delhi received from various departments/ agencies. It was unfortunate that the various departments passed on the survey data without vetting the data properly. Therefore, the authenticity of the data provided has been to certain extent indirectly vetted through this scenario.

After analyzing results of simulation of scenario 1 (scenario with invert levels and cross sections provided by agencies), there are around 3854 nodes flooded (APPENDIX XIII). The results of this simulation run on a segment of Hastsal Ranhola Road Nallah (from Commander Chowk to N.G.drain) taken as sample which is provided in Table 3.3-3. The table depicts the junctions that are flooded along with the duration of flood and total flooded volume. Similar details on flooding time and flood volume for all segments of the drainage network are available as part of the detailed outputs provided in the working model of the basin not only for this scenario but all the subsequent scenarios as well.

Table 3.3-3: Flood volume of nodes in a sample segment of Hastsal Ranhola Road Nallah after simulation of scenario 1

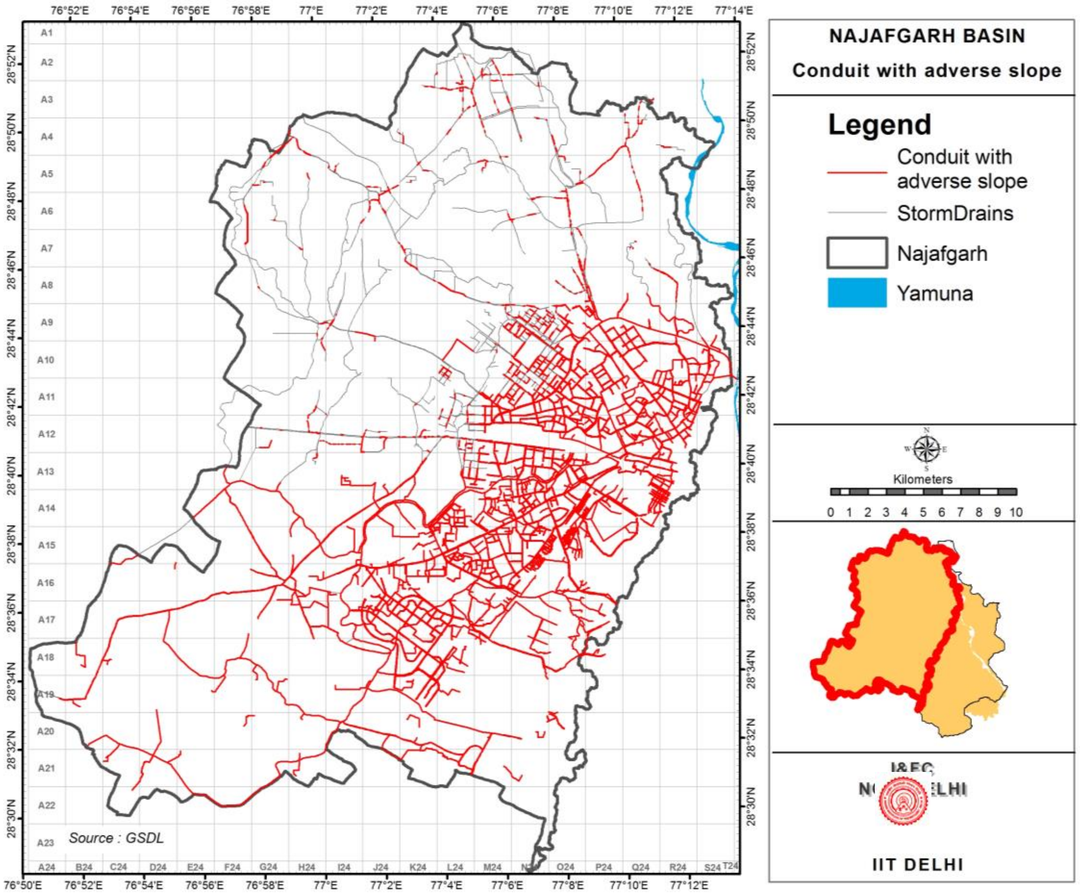
Node	Flooding Hours (in hours)	Flood volume (m^3)
J_4160	32	5486
J_4182	2	811
J_4216	0	0
J_4258	0	0
J_4301	1	2049
J_4325	0	0

3.3.4.2. Scenario 2 – with changes made to cross-sections

Scenario 2 represents the incorporation of changes made in the cross-sections wherever adverse slopes has been encountered by changing the Invert Levels and width of the Cross Section in case if constriction is encountered. There are 441 segments with adverse slope encountered out of 1667 conduits in Alipur. Similarly, the number of segments with adverse slope in Kanjawala are 1012 out of 4221 and in Najafgarh it is 3539 segments out of 14035. A total of 4992 conduits with adverse slope in entire Najafgarh basin are shown in Figure 3.3-8

The invert levels have been corrected keeping in mind the slope of the preceding drain and also the elevation taken from Digital Elevation Model of NCT Delhi provided by Geo Spatial Delhi Limited. Along with the corrections made to the Invert Levels in the segments with adverse slope, the width of the cross section has also been changed wherever a constriction in width has been encountered and the junction is flooded (APPENDIX VII). The simulation has been made after incorporating these changes and 2794 junctions have been found flooded (APPENDIX XIII).

Figure 3.3-8: Conduits with adverse slope in Najafgarh basin

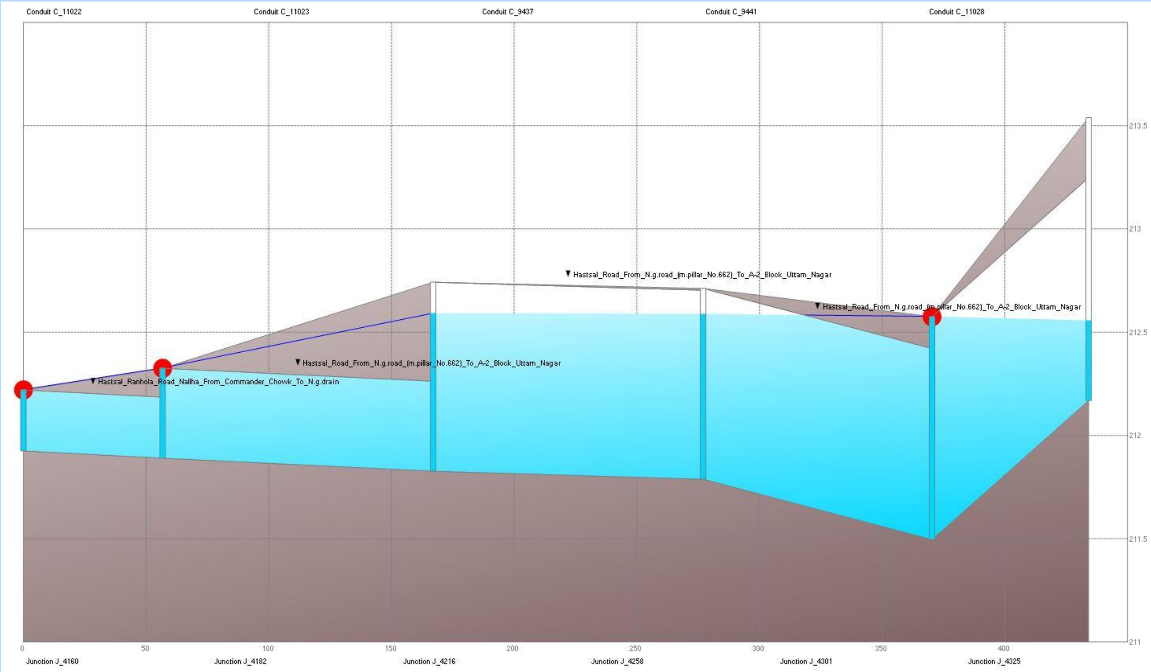


Following are some of the generic observations from simulation of scenario 2 as compared with the simulation of scenario 1 are:

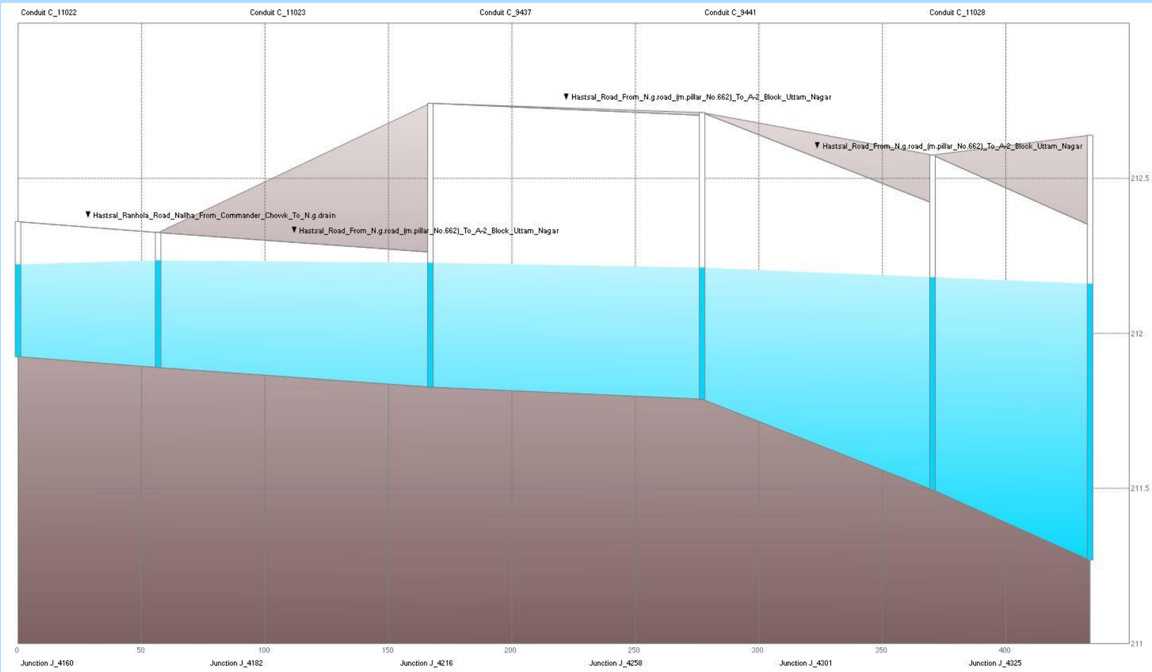
- In some cases, the flooding has considerably reduced and at some junctions the flooding is totally removed.
- In other cases, flooding has moved to upstream or downstream of flooded junctions as shown earlier in Figure 3.1-10. This has been observed because the levelling of bottom of drain led to removal of depression storages, which were earlier able to store water.

Comparison of water profiles in the segment of Hastsal Ranhola Road Nallah (from Commander Chowk to N.G.drain) after simulation of scenario 1 and scenario 2 has been shown in Figure 3.3-9.

Figure 3.3-9: Comparison of water profiles in the segment of drain after simulation of scenario 1 and scenario 2



Scenario 1: With data provided by the departments



Scenario 2: With changes made to cross-sections

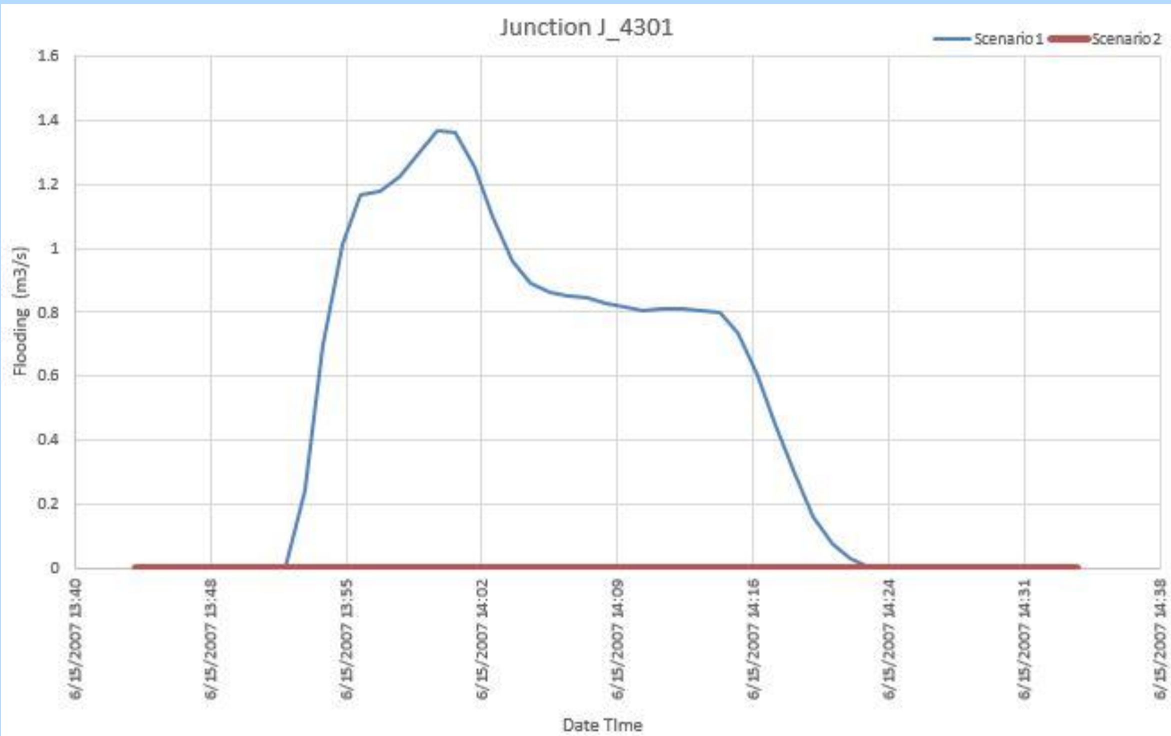
There is a huge decrease in volume of surplus water in some drains. Following is an example of the reduction of flood volume at different junctions in the sample drain (Table 3.3-4).

Table 3.3-4: Comparison between the flood volume at nodes of a segment of drain after simulation of scenario 1 and scenario 2

Node	Flood volume (m³)	
	Scenario 1	Scenario 2
J_4160	5486	99
J_4182	811	0
J_4216	0	0
J_4258	0	0
J_4301	2049	3866
J_4325	0	0

Change in flood volume of water at one of the nodes of Table 3.3-4 can be seen in Figure 3.3-10, which depicts the extent of flooding as well as the duration of flooding . The graph shows that J_4301 was originally flooded with 2049 m^3 volume of excess water over a period of 1 hour 45 minutes, while in the scenario 2 after changing the Invert Levels the flooding gets totally removed.

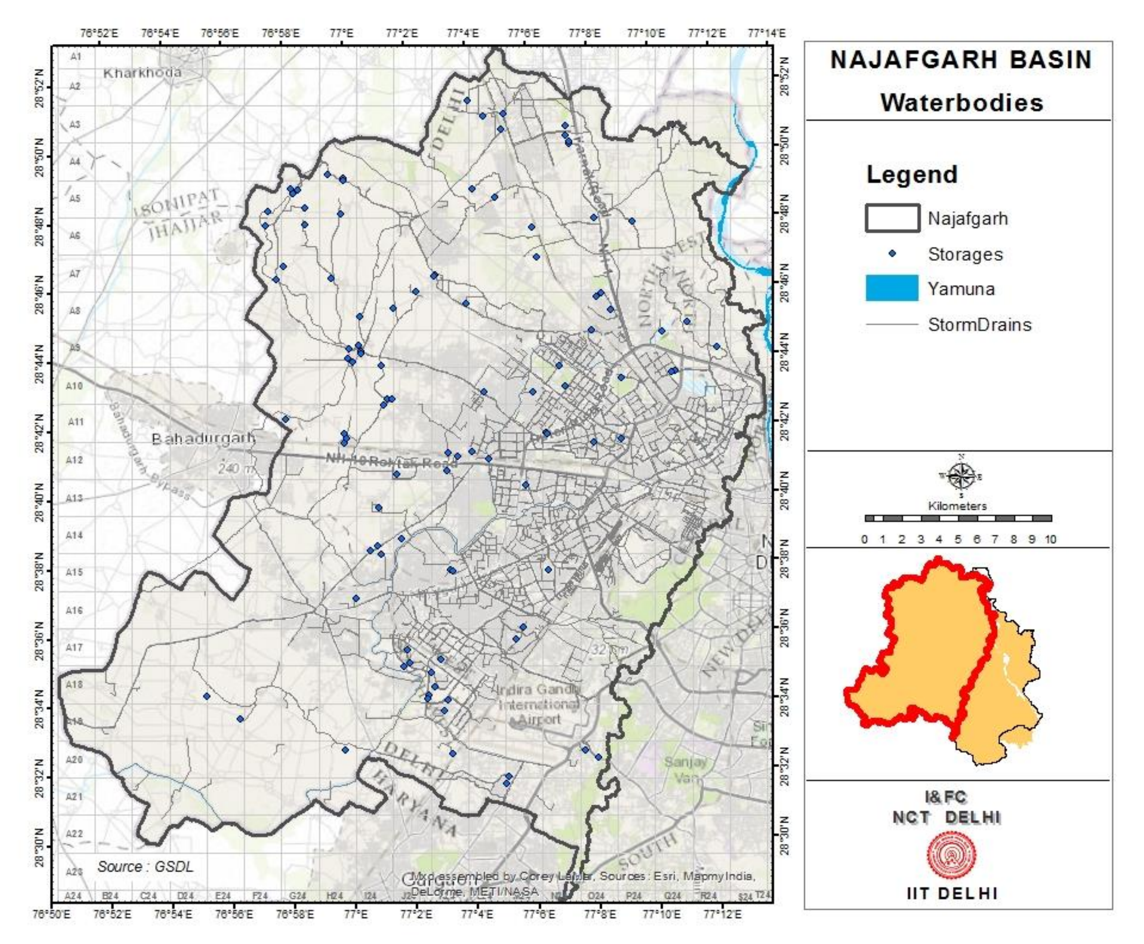
Figure 3.3-10: Comparison between the flood volumeat a sample junction after simulation of scenario 1 and scenario 2



3.3.4.3. Scenario 3 – Simulation with rejuvenation of water bodies

This scenario has been formulated by incorporating the water bodies into the scenario 2, so as to absorb some of the excess runoff generated from the sub catchments and rejuvenating the water bodies. In Najafgarh basin, there are total 140 water bodies, which have been incorporated and treated as storages in the model (Figure 3.3-11). The runoff from the sub catchment is first routed towards the water bodies and then proceeds ahead towards the nearby junction, and secondly from the junctions to water bodies. This reduces the total flood volumeat the junction. Najafgarh being the largest basin in Delhi region contains large number of water bodies including Bhalswa Lake, Swarna Jayanti Lake, Sardar Patel Lake, Najafgarh Jheel and many other small water bodies. In accordance to the suggestion from departments, the average depth of the water bodies has been kept as 2 meters. APPENDIX X presents all the water bodies connected to junctions in Najafgarh basin along with the new conduits joining flooded junction to water bodies.

Figure 3.3-11: Water bodies connected to junction to divert the excess water

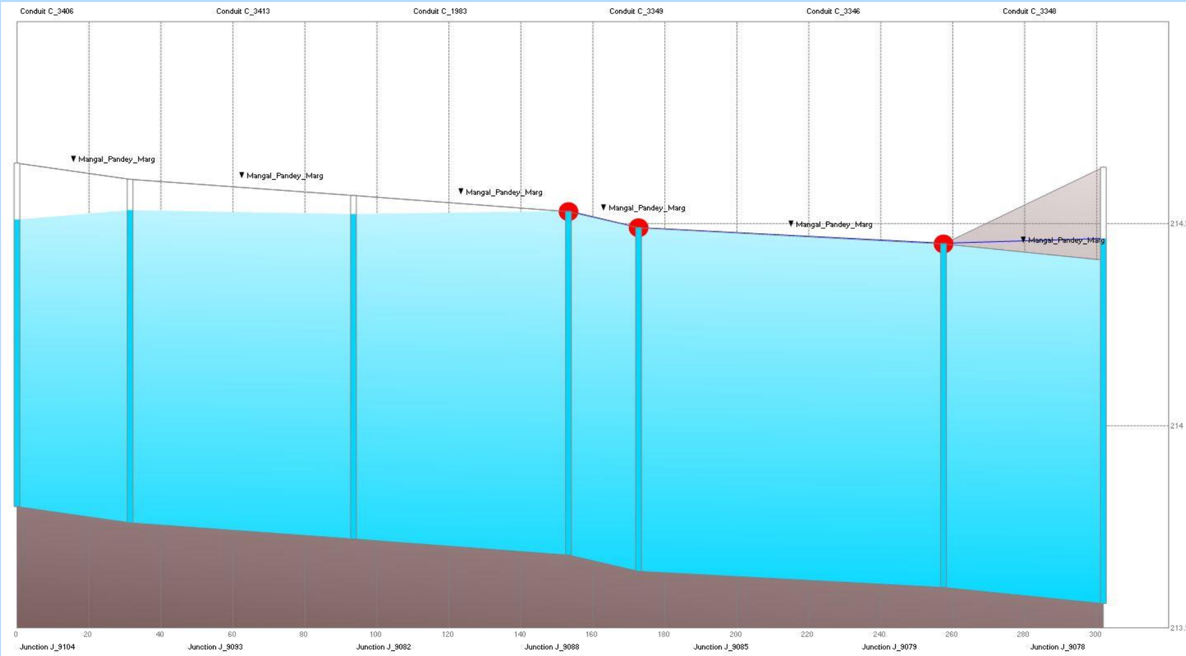


Following are some of the generic observations from simulation of scenario 3 as compared with the simulation of scenario 2 are:

- In some cases, water bodies captivate the flooded volume of water and thus removing the flood at some of the junctions or reducing the volume at others
- Additional length of conduits has been provided to connect water bodies and nearby junctions for transfer of excess water in water bodies after they have been filled up with water coming from the subcatchment.

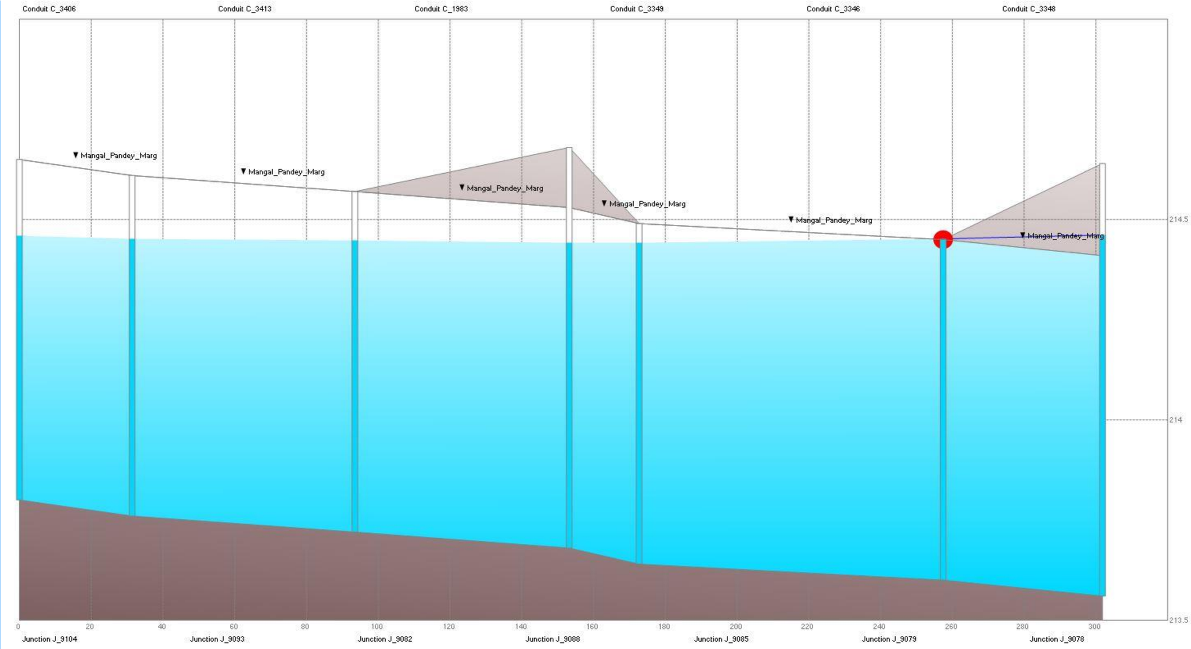
Comparison of water profiles in the segment of drain after simulation of scenario 2 and scenario 3 has been shown in Figure 3.3-12 .

Figure 3.3-12: Comparison of water profiles in the segment of drain after simulation of scenario 2 and scenario 3



Scenario 2: before inclusion of water body in basin

Figure 3.3-12: Comparison of water profiles in the segment of drain after simulation of scenario 2 and scenario 3



Scenario 3: after inclusion of water body

An example of the reduction of flood volume at different junctions in the sample drain is shown below in In scenario 3, the runoff from the sub-catchment is first made to flow into the water body with a depth of 2 metres, which could store a huge amount of volume and thus preventing the junction from flooding.

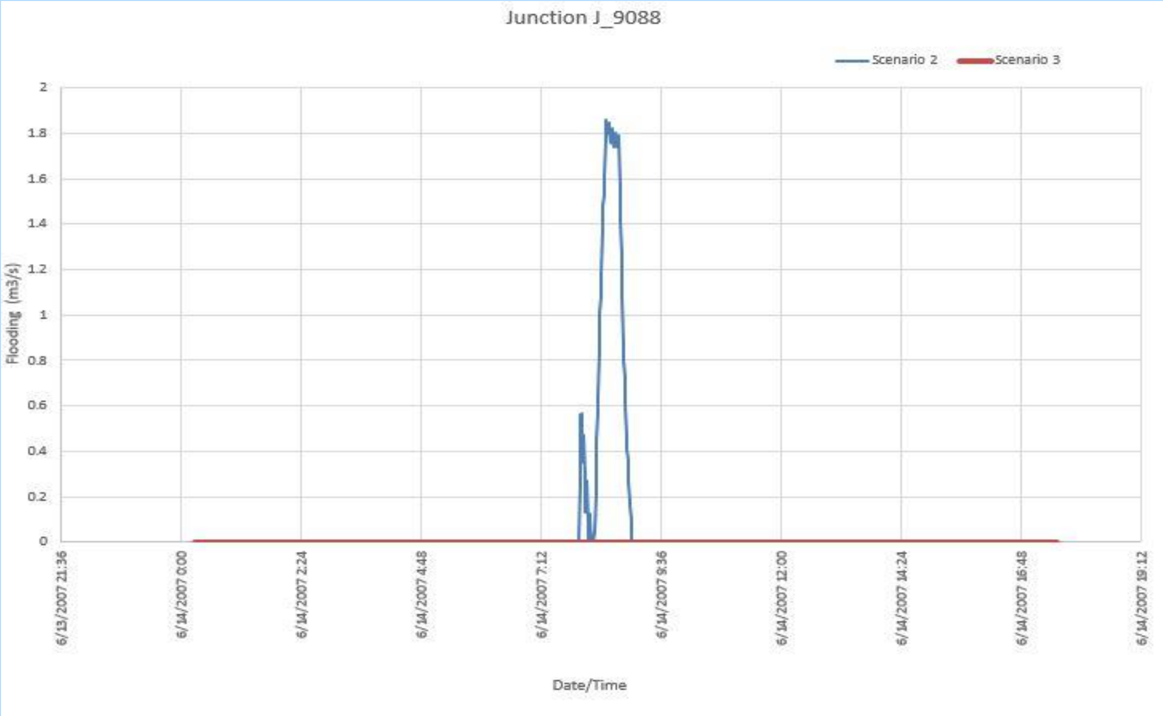
Table 3.3-5. In scenario 3, the runoff from the sub-catchment is first made to flow into the water body with a depth of 2 metres, which could store a huge amount of volume and thus preventing the junction from flooding.

Table 3.3-5 Comparison between the flood volume at junctions of a segment of drain after simulation of scenario 2 and scenario 3

Junctions	Flood volume (m^3)	
	Scenario 2	Scenario 3
J_9104	0	0
J_9093	0	0
J_9082	0	0
J_9088(water body)	9775	0
J_9085	0	0
J_9079	1570	365

Change in flooded volume of water at a single junction can be seen in Figure 3.3-13. In the present example, the Junction J_9088 was catering to the runoff from a big sub catchment and thus was flooded after simulation of scenario 2. The graph shows the reduction in the flooding at Junction J_9088 after incorporating water body at this junction.

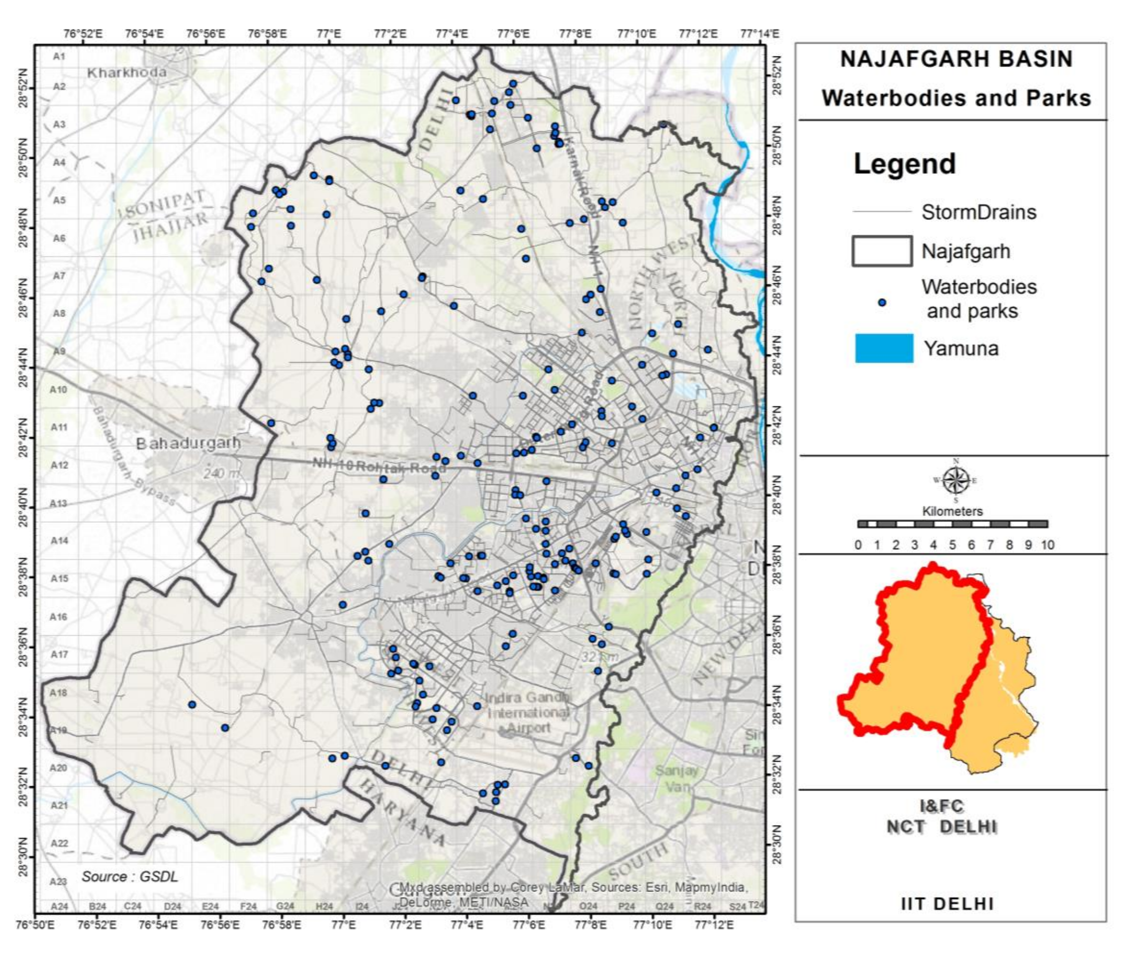
Figure 3.3-13: Comparison between the flood volumeat a sample junction after simulation of scenario 2 and scenario 3



3.3.4.4. Scenario 4 - with public parks as recharge zones

After including water bodies to the basin (scenario 3), scenario 4 has been designed to divert the excess volume of water from the junction, water bodies to the parks and other open areas. DDA parks and other parks have been incorporated in the basin with a standard depth of 1 feet (0.3 meters) and a uniform area along the depth. APPENDIX X presents all the junctions connected to parks in Najafgarh basin along with the new conduits joining flooded junction to parks.

Figure 3.3-14: Parks connected to junction to divert the excess water

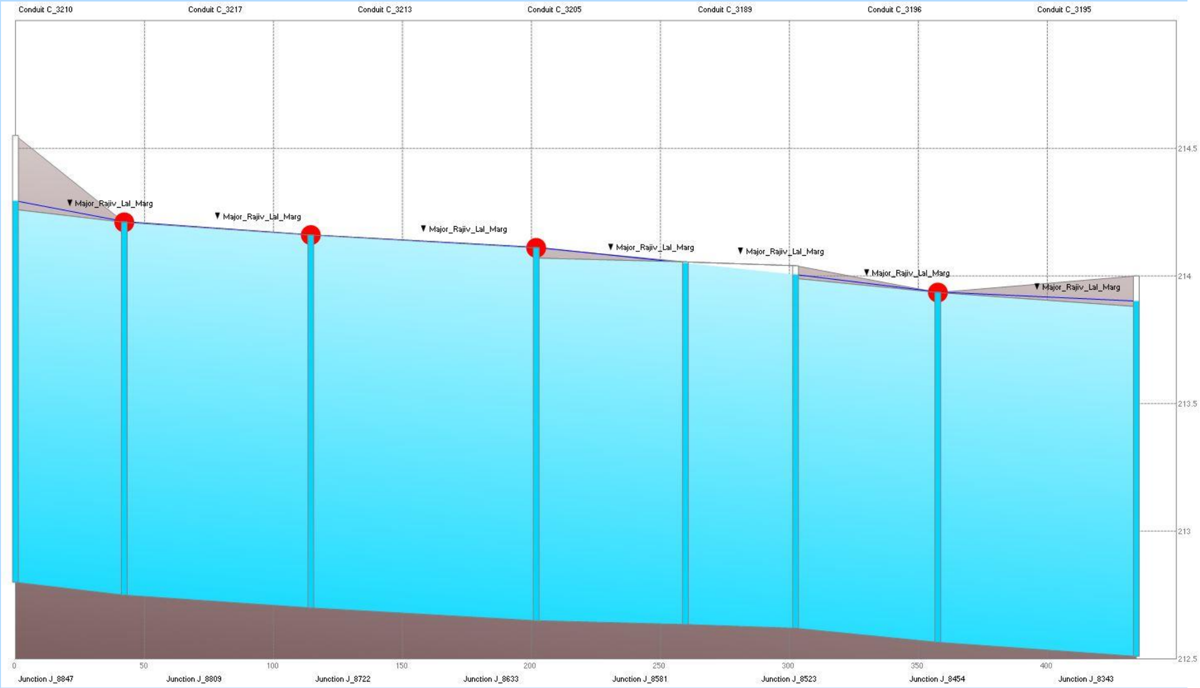


Following are some of the generic observations from simulation of scenario 4 as compared with the simulation of scenario 3 are:

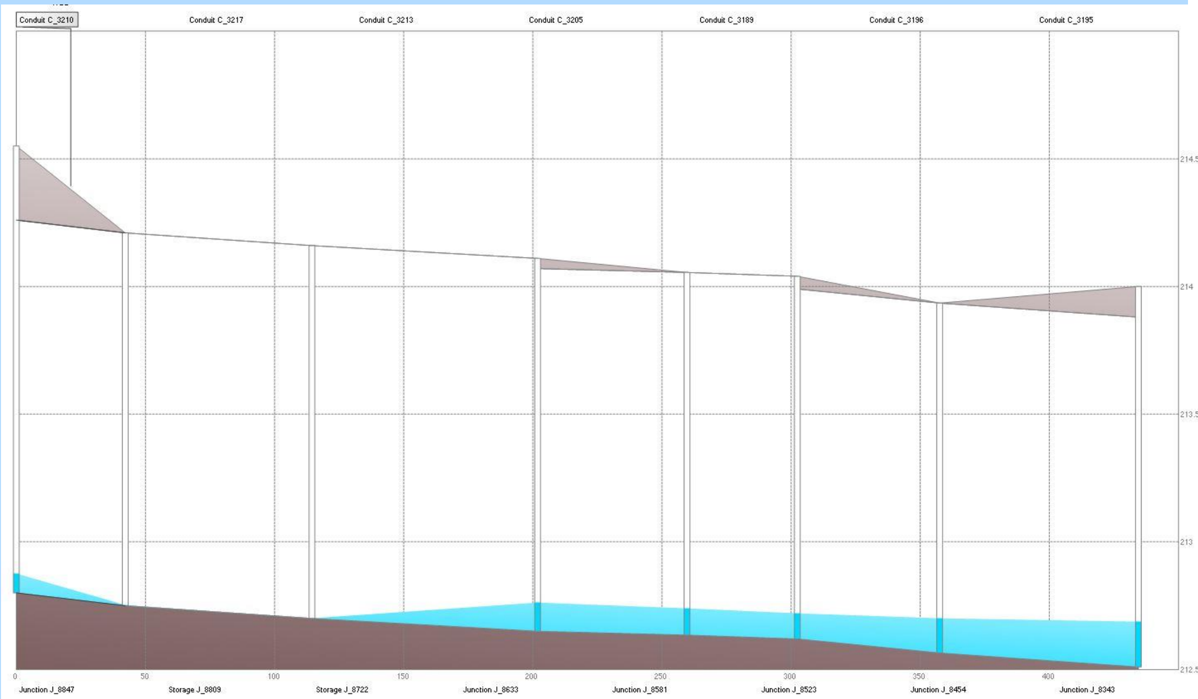
- In some cases, the flooded volume of water from the junction is diverted to nearest parks and open spaces removing the flood at some of the junctions or reducing the volume at others.
- Additional length of conduits has been provided to connect the flooded junctions and nearby parks for transfer of excess water from junctions.

Comparison of water profiles in the segment of drain after simulation of scenario 3 and scenario 4 is shown in Figure 3.3-15.

Figure 3.3-15: Comparison of water profiles in the segment of drain after simulation of scenario 3 and scenario 4



Scenario 3: Without including any recharge zones



Scenario 4: With public parks as recharge zones

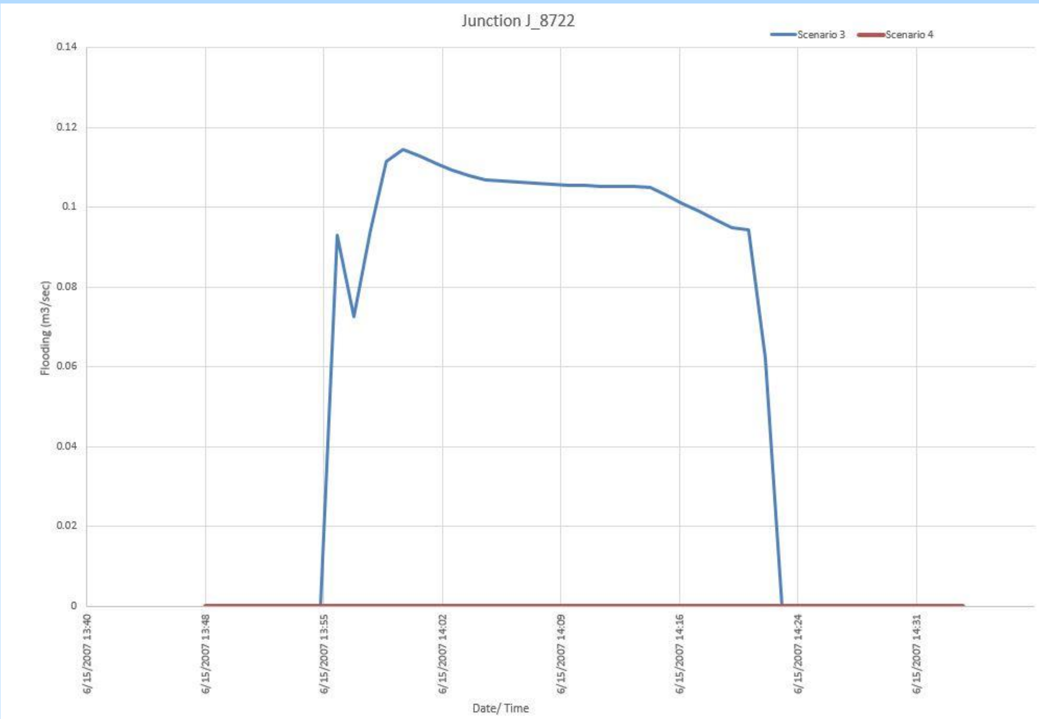
An example of the reduction of flood volume at different junctions in the sample drain is shown below in Table 3.3-6. In the present example, the Junction J_8722 was flooded after simulation of scenario 3. In scenario 4, the flood volume at J_8722 has been made to flow into the nearest park which could store a huge volume of water and thus preventing the node from flooding.

Table 3.3-6 Comparison between the flood volume at junctions of a segment of drain after simulation of scenario 3 and scenario 4

Junctions	Flood volume (m^3)	
	Scenario 3	Scenario 4
J_8847	0	0
J_8809	830	0
J_8722	161	0
J_8633	3400	0
J_8581	0	0
J_8523	0	0
J_8454	1204	0
J_8343	0	0

Change in flooded volume of water at a single junction can be seen in Figure 3.3-16. The graph shows the reduction in the flooding at Junction J_8722 after diverting the excess water from it to the nearest park.

Figure 3.3-16: Comparison between the flood volumeat a sample junction after simulation of scenario 3 and scenario 4



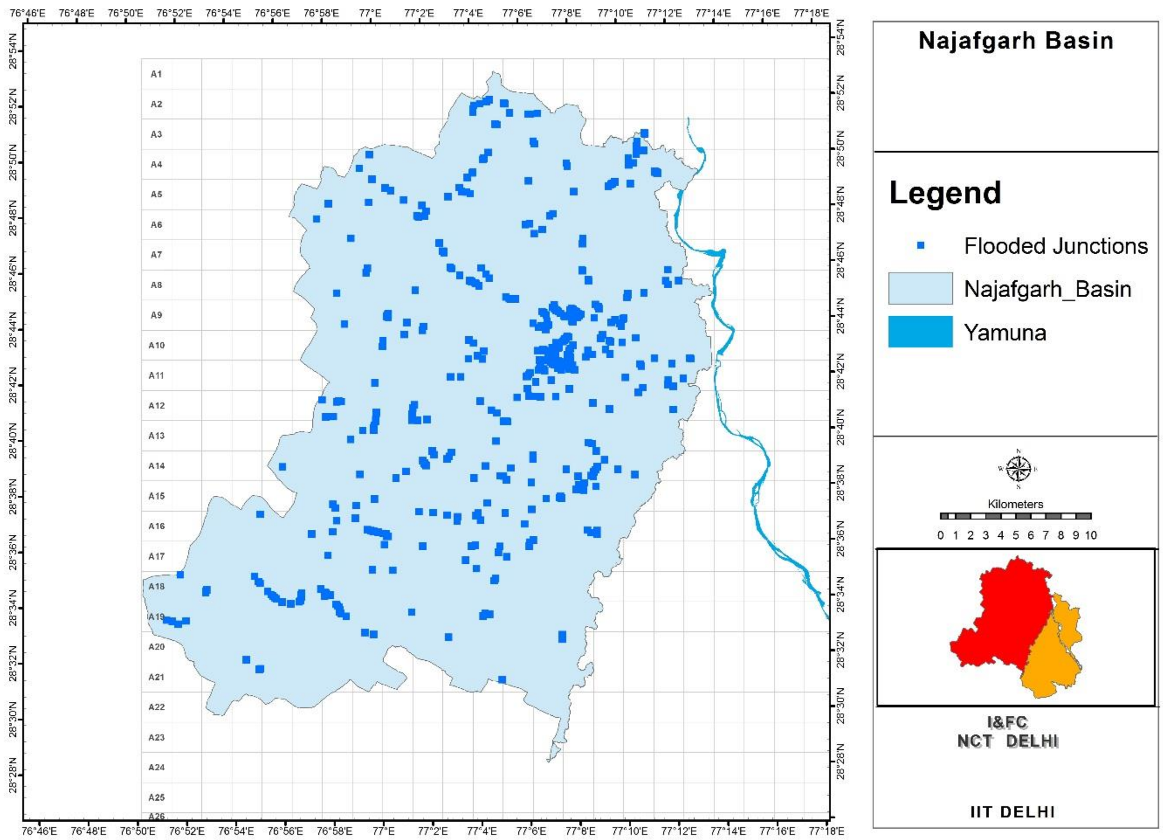
3.3.4.5. Scenario 5 - Towards no flooding junction for 2 year return period storm

For each subbasin suitable LIDs can be identified and the effectiveness of the same can be established through simulation and the consequent reduction as well as unaccounted surplus runoff volume can be quantified.

While formulating scenario 5 another decision has been taken to consider all the junctions that are getting flooded for a duration of more than 15 minutes.

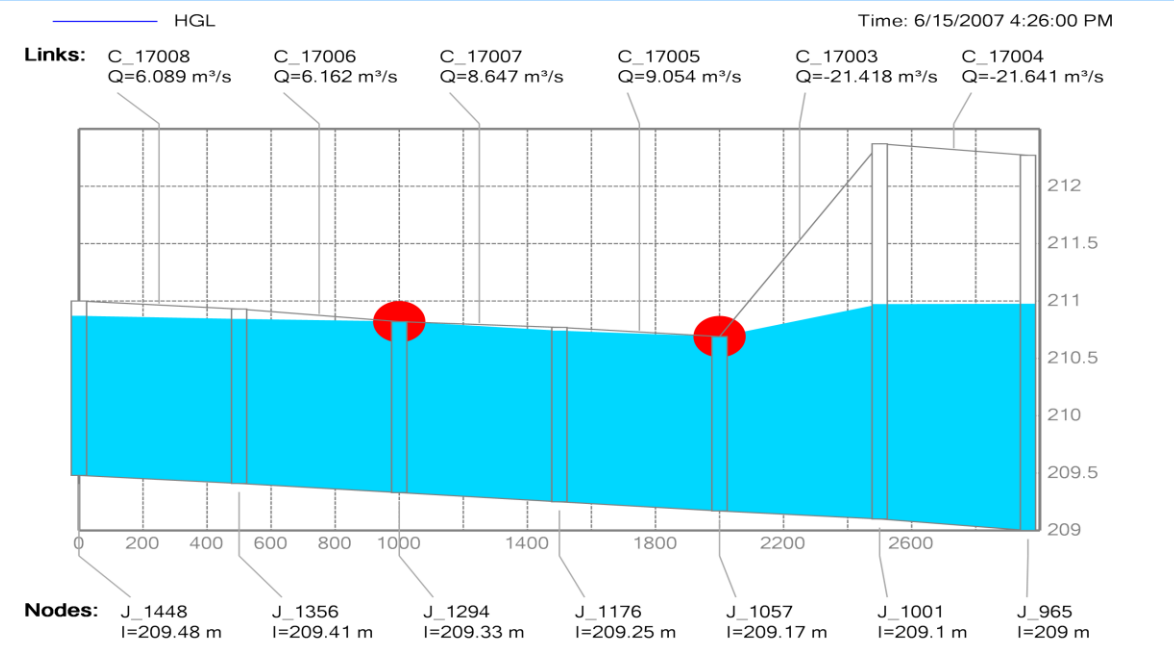
Total 1618 number of junctions (**Figure 3.3-17**) which were flooded were transformed into the storages, taking care of the excess volume of water in the basin. However, these storages may be replaced by other LID structures if feasible. Based on ground realities suitable LIDs are implemented in a case study.

Figure 3.3-17: Flooded junctions were transferred into Storages

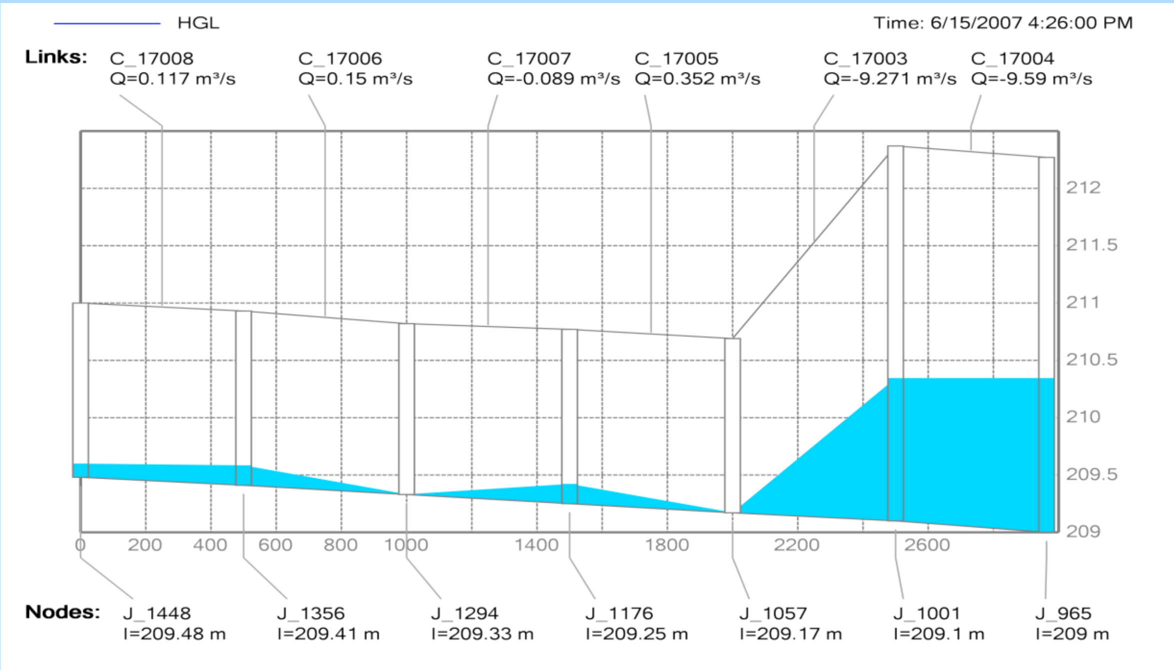


Comparison of water profiles in the segment of drain after simulation of scenario 4 and scenario 5 has been shown in **Figure 3.3-18**.

Figure 3.3-18: Comparison of water profile in the segment of the drain after scenario 4 and 5



Scenario 4: Before the application of storage junctions



Scenario 5: After the application of storage junctions

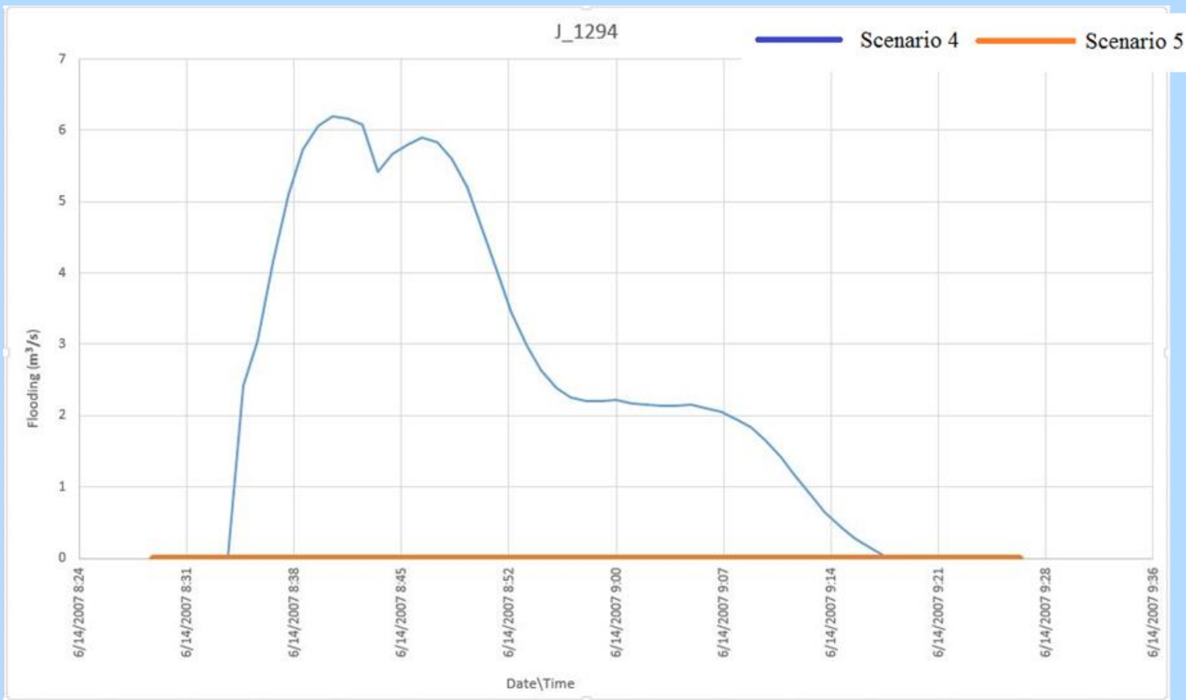
An example of the reduction of flood volume at different junctions in the sample drain is shown below in Table 3.3-7. In the present example, the Junction J_1294 was flooded after simulation of scenario 4. In scenario 5, the flood volume at J_1294 has been made to store in the retention tank/ detention tank/ LID structure which could store a desired amount of volume and thus preventing the junction from flooding.

Table 3.3-7: Comparison between the flood volume at junctions of a segment of the drain after simulation of scenario 4 and scenario 5

Node	Flood volume (m3)	
	Scenario 4	Scenario 5
J_1448	507	0
J_1356	1356	0
J_1294	71808	0
J_1176	4907	0
J_1057	606820	588
J_1001	0	0
J_965	0	0

Change in flooded volume of water at a single junction can be seen in **Error! Reference source not ound.**. In the present example, the Junction J_1294 was catering to the runoff from a big sub catchment and thus was flooded after simulation of Scenario 4. The graph shows the reduction in the flooding at Junction J_1294 after incorporating storage at this junction.

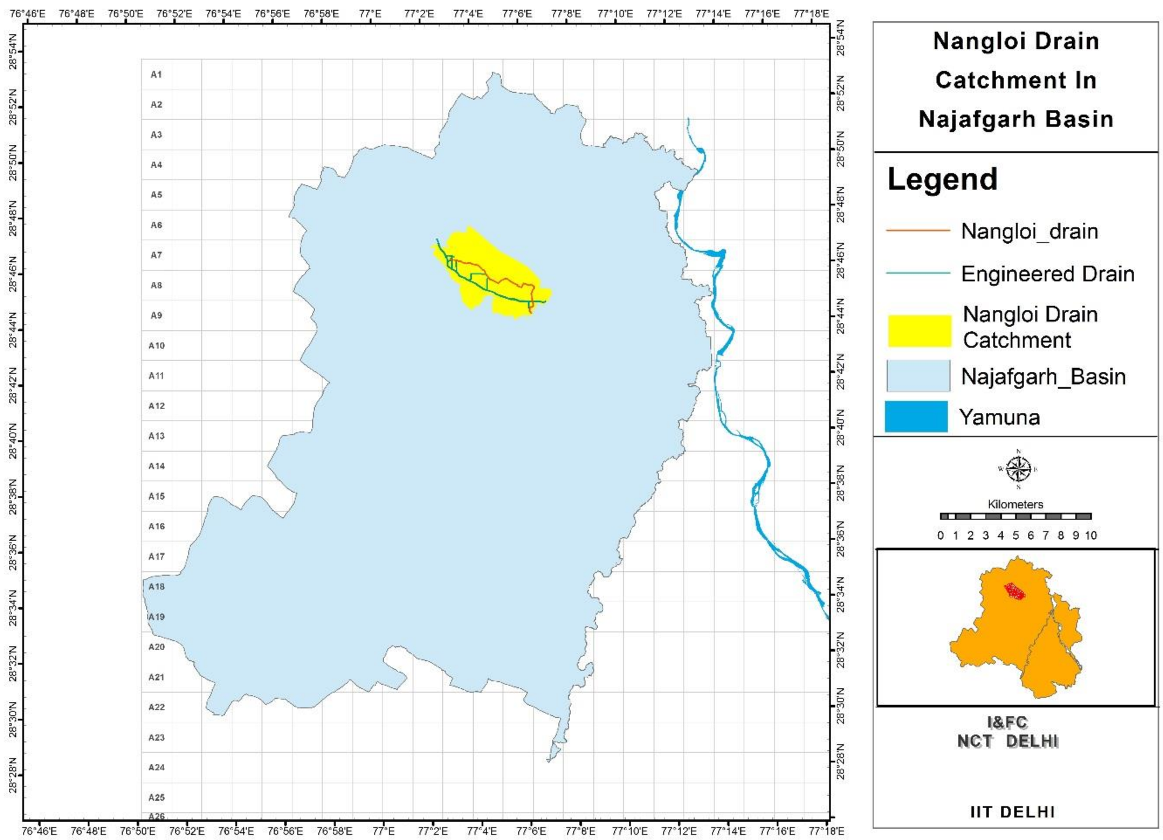
Figure 3.3 19: Comparison between the flood volumeat a sample junction after simulation of Scenario 4 and Scenario 5



CASE STUDY FOR LID IMPLEMENTATION

A catchment of Nangloi drain (Najafgarh basin) has been considered as shown in **Figure 3.3-19**, for demonstrating how the LIDs can be identified and implemented for further reduction of flooding. Nangloi Drain is nearly 9 km long which spreads its catchment in Najafgarh basin. The drain outfalls into Supplementary Drain in the Najafgarh Basin.

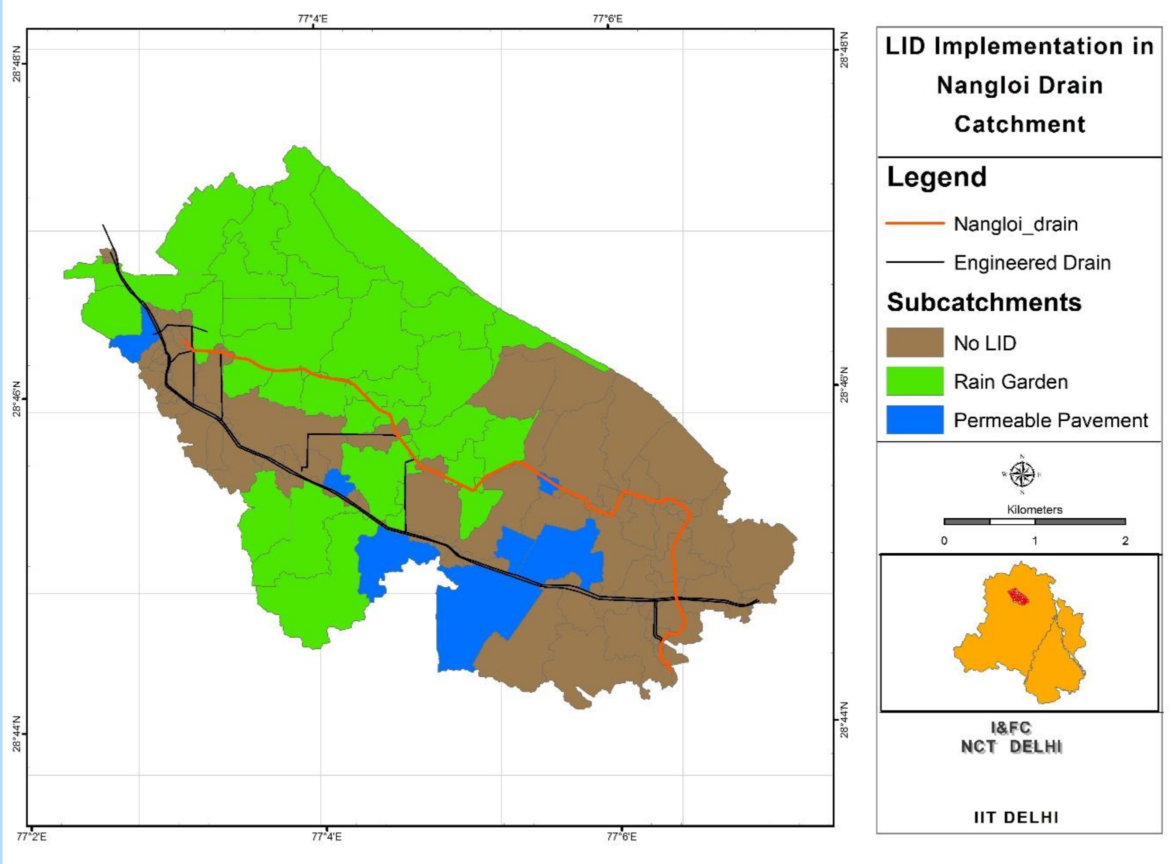
Figure 3.3-19: Nangloi drain catchment in Najfgarh basin



After studying the landuse, geography of the area and the soil properties of the Delhi region, only two types of LIDs were identified and implemented; (a) Permeable Pavement and, (b) Rain Garden as shown in figure 3.3-21.

The simulations are then performed to quantify the effectiveness of the selected LID(Permeable Pavement and Rain Garden) which have been established through the model results which show significant reduction in the flood volumes at the junctions.

Figure 3.3-20: LID Implementation in Nangloi Drain Catchment



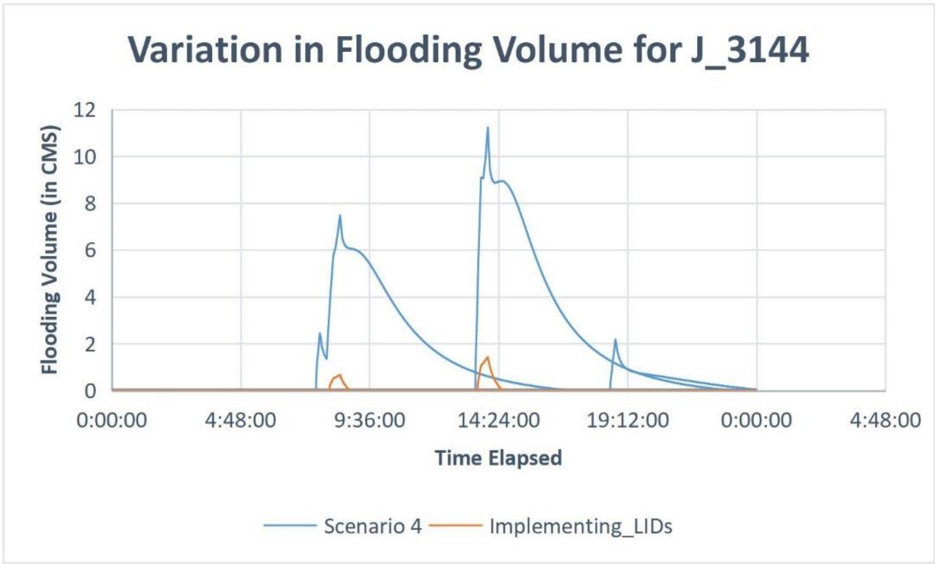
The comparison of flood volume between scenario 4 and after implementing LID is shown inTable 3.3-8

Table 3.3-8: : The comparison of flood volume between scenario 4 and after implementing LID in Nangloi catchment

Node	Flood volume (10^6 ltr)	
	Scenario 4	Implementing LID
J_2967	0	0
J_2987	0	0
J_3144	172880	3460
J_3170	0	0
J_3203	0	0

For some Junctions these flooding values have reduced so much that they can be considered as a flood free junction. If these junctions, with very low flood volumes, were considered as a flood free junction, then there would remain only 29 flooded junction. A tremendous drop in flood volume was observed in Junction J_3144 after the implementation of LIDs in the sub-catchment poured its runoff to this junction. The graph in **Figure 3.3-21** reflects the considerable drop in volume after the implementation of LIDs:

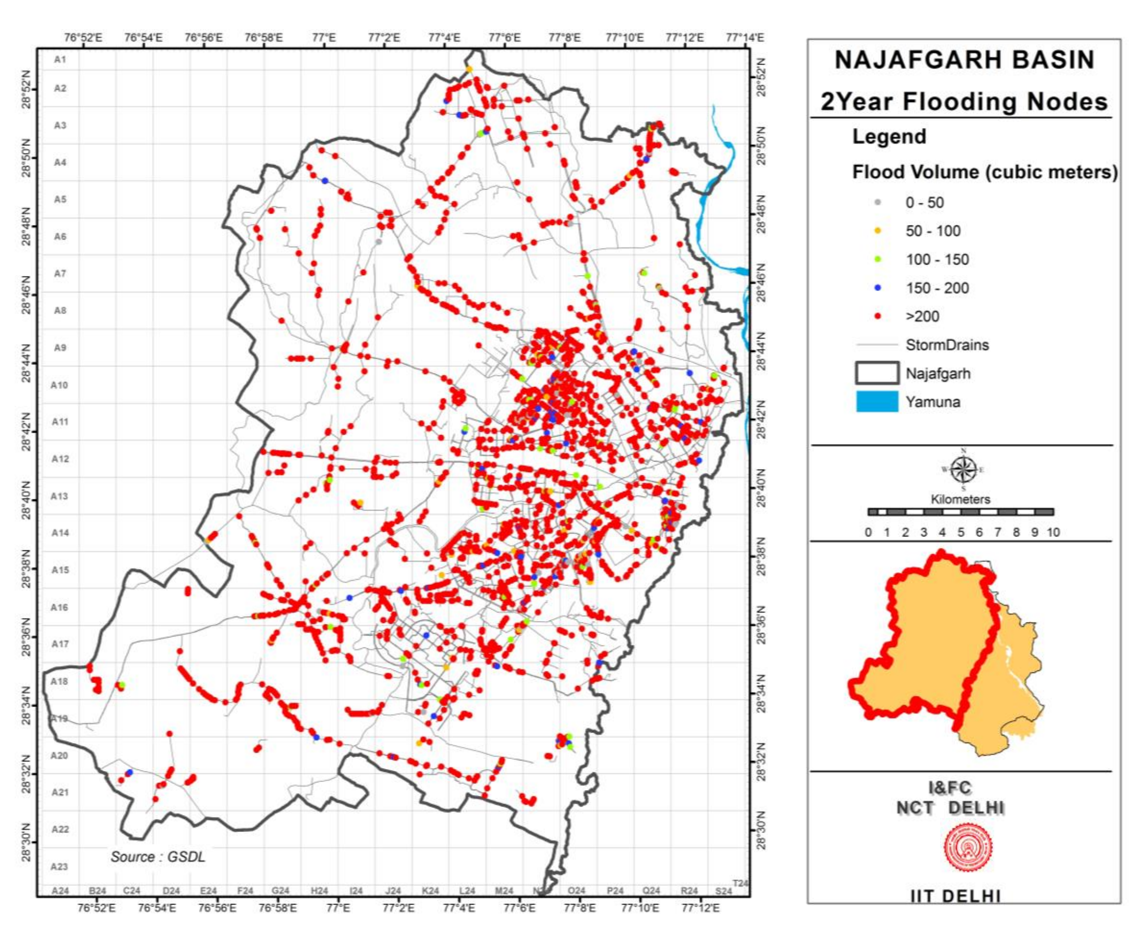
Figure 3.3-21: Graph reflecting the change in Flood volume for J_3144



3.3.4.6. Comparison of Simulations with 2 year and 5 year return period rainfall events

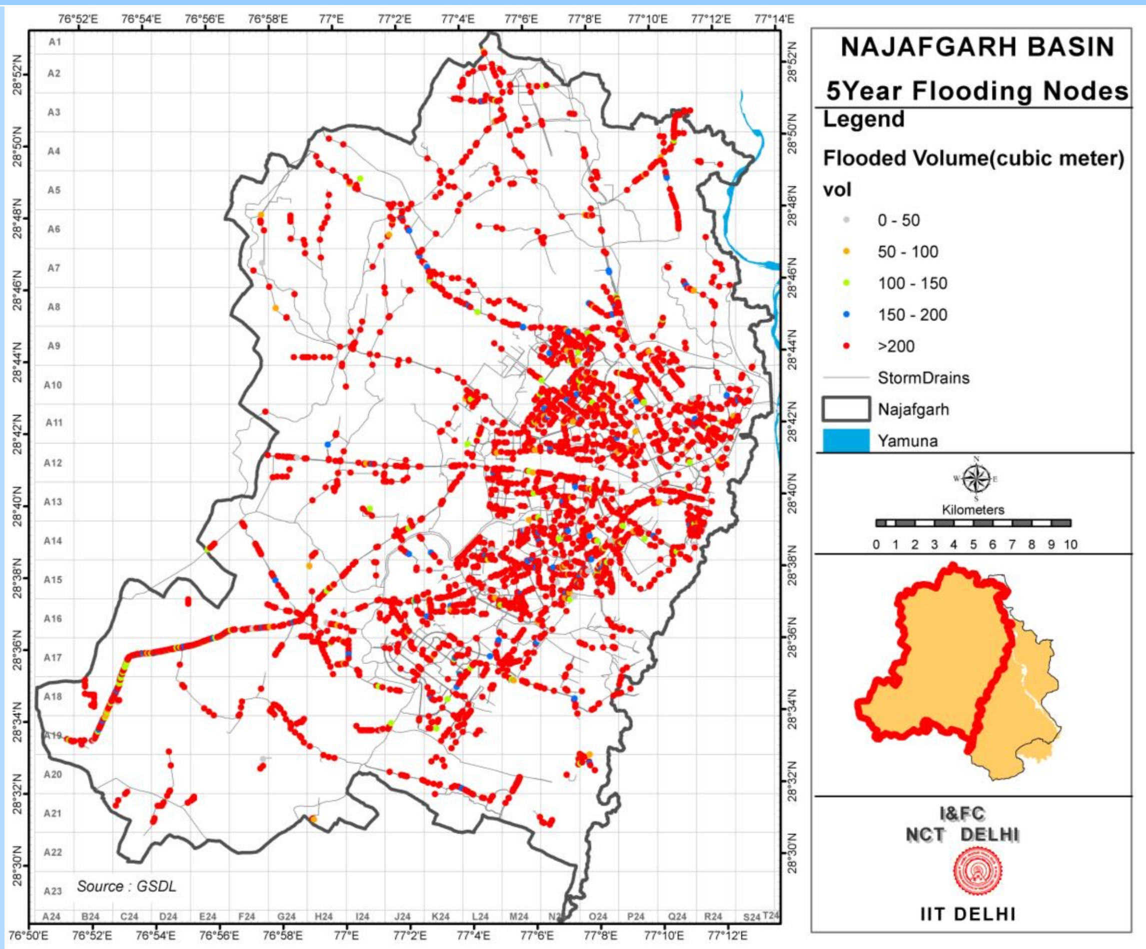
Exhaustive simulations of the stormwater drainage network have been done using the rainfall events for 2 year return period and 5 year return period rainfall events. Figure 3.3-23— shows the number of junctions flooded on the basis of 2 year and 5 year return period rainfall events.

Figure 3.3-23—: Junctions flooded with respect to 2 year and 5 year return period rainfall events



Junctions flooded in rainfall event of 2 year return period

Figure 3.3-23—: Junctions flooded with respect to 2 year and 5 year return period rainfall events



Junctions flooded in rainfall event of 5 year return period

4. DESIGN PARAMETERS

4.1. MANNING'S ROUGHNESS COEFFICIENT, n

Hydraulic roughness is the measure of the amount of frictional resistance water experiences when passing over land and channel features [[8]]. Manning's roughness coefficient, n, is used extensively around the world to predict the degree of roughness. Values of Manning's roughness coefficient, n, are known for the channel flow, but for overland flow, the values of n are not well defined because of the considerable variability in landscape features, transitions between laminar and turbulent flow, very small flow depths, etc. The following Table 4.1-1 (source: SWMM Manual) has been referred for estimation of effective roughness coefficients for overland flow.

Table 4.1-1 Manning's Roughness Coefficient for overland flow

Sources	Ground Cover	Manning's n	Range
Crawford and Linsley (1966)	Smooth asphalt	0.01	
	Asphalt of concrete paving	0.014	
	Packed clay	0.03	
	Light turf	0.20	
	Dense turf	0.35	
	Dense shrubbery and forest litter	0.4	
Yen (2001)	Smooth asphalt pavement	0.012	0.01-0.015
	Smooth impervious surface	0.013	0.011-0.015
	Tar and sand pavement	0.014	0.012-0.016
	Concrete pavement	0.017	0.014-0.020
	Rough impervious surface	0.019	0.015-0.023
	Smooth bare packed soil	0.021	0.017-0.025
	Moderate bare packed soil	0.03	0.025-0.035
	Rough bare packed soil	0.038	0.032-0.045
	Gravel soil	0.032	0.025-0.045
	Mowed poor grass	0.038	0.030-0.045
	Average grass, closely clipped soil	0.050	0.040-0.060
	Pasture	0.055	0.040-0.070
	Timberland	0.090	0.060-0.120
	Dense grass	0.090	0.060-0.120
	Shrubs and bushes	0.120	0.080-0.18
	Business land use	0.022	0.014-0.035
	Semi business land use	0.035	0.022-0.050
	Industrial land use	0.035	0.020-0.050
	Dense residential land use	0.040	0.025-0.060
	Suburban residential land use	0.055	0.030-0.080
	Parks and lawns	0.075	0.040-0.12

[8] Vieux, B.E. 2004. Distributed Hydrologic Modeling Using GIS. Springer. p. 14.

The following Table 4.1-2 (source: SWMM Manual) has been referred for estimation of effective roughness coefficients for closed conduits.

Table 4.1-2 Manning's Roughness coefficient for closed conduits

Conduit Material	Manning's n
Asbestos-cement pipe	0.011-0.015
Brick	0.013-0.017
Cast iron pipe **Cement-lined and seal coated**	0.011-0.015
Concrete (monolithic) **Smooth form** **Rough form**	 0.012-0.014 0.015-0.017
Concrete pipe	0.011-0.015
Corrugated-metal pipe **Plain** **Paved invert** **Spun asphalt**	 0.022-0.026 0.018-0.022 0.011-0.015
Plastic pipe (smooth)	0.011-0.015
Vitrified clay **Pipes** **Linters plates**	 0.011-0.015 0.013-0.017

Finally, the values of Manning's Roughness coefficient taken for the simulations are given in Table 4.1-3.

Table 4.1-3 Manning's Roughness coefficient value considered for the simulations in the present study

Drain Type	Manning's n
Impervious smooth surface	0.014
RCC Box Drain	0.012
Circular drain	0.013
Irregular, open drain	0.025

4.2. DEPRESSION STORAGE

Depression storage of depth, ds, stores a volume that must be filled prior to the occurrence of runoff in both pervious and impervious areas.

In the SWMM rainfall-runoff algorithm, water stored as depression storage on pervious areas is subject to infiltration (and evaporation), so that available storage capacity is continuously and rapidly replenished. Water stored in depression storage on impervious areas is depleted only by evaporation and therefore it takes much longer to empty such storage once filled to its full capacity.

The American Society of Civil Engineers (1992) suggests depression storage of **1/16 inch or 1.5875 mm for impervious areas** and **1/4 inch or 6.35 mm for pervious areas**.

4.2.1. Percentage Zero-Imperviousness

The input parameter '% Zero Impervious', determines what fraction of a sub catchment's impervious area has no depression storage. A percent of the impervious area is assigned zero depression storage in order to promote immediate runoff.

4.2.2. Ponded Area

Area occupied by ponded water atop the junction after flooding occurs (sq. feet or sq. m.). If the 'allow ponding simulation' option is turned on, a non-zero value of this parameter will allow ponded water to be stored and subsequently returned to the conveyance system when capacity exists.

4.3. Horton infiltration method

Infiltration from pervious areas may be computed by the Horton equation described below. Infiltration capacity as a function of time, as given by Horton, is:

$$f_p = f_\infty + (f_o - f_\infty)e^{-kt}$$

Where: f_p= Infiltration capacity into soil (m/sec),

f_∞= minimum or equilibrium value of infiltration capacity (m/sec),

f_o= maximum or initial value of infiltration capacity (m/sec),

t= Time from beginning of storm (sec) and

k= Decay coefficient (sec^{-1})

Minimum Infiltration Capacity ($f\infty$)

f_∞= the minimum or equilibrium infiltration capacity (m/sec)

To help select a value within the range given for each soil group, the user should consider the texture of the layer of least hydraulic conductivity in the profile. Depending on whether that layer is sand, loam, or clay, the $f\infty$ value should be chosen near the top, middle, and bottom of the range respectively

Using the NBSS soil data, the texture of the soil is **loam** and lies in the **D** Hydrologic Soil Group. So, the minimum infiltration value taken is .025 in/hr or 0.635 mm/hr.

Table 4.3-1 Values of minimum or equilibrium value of infiltration capacity, f∞ for Hydrologic Soils Groups[9]

Hydrologic Group	f∞ (in/hr)
A	0.45-0.30
B	0.30-0.15
C	0.15-0.05
D	0.05-0

Initial Infiltration Capacity (f_o)

The initial infiltration capacity, f_o depends primarily on soil type, initial moisture content, and surface vegetation conditions.

Table 4.3-2 Representative value of maximum or initial value of infiltration capacity, f_o

A.Dry soils (with little or no vegetation):	
Sandy Soil Loam Soil	5 in/hr 3 in/hr
B. Dry soils(with dense vegetation): Multiply values given A by 2 [10]	
C. Moist soils (change from dry f_o value required for single event simulation only) Soils which have drained but not dried out (i.e. field capacity: divide values from A and B by 3) Soil close to saturation: Choose values close to f_∞ value Soils which have partially dried out: divide values from A and B by 1.5-2.5	

The value for initial infiltration capacity, f_o *is assumed to be 3 in/hr or 76.2 mm/hr.*

Decay Coefficient (kd)

For any field infiltration test, the rate of decrease (or "decay") of infiltration capacity from the initial value depends on the initial moisture content. Thus, k_d determined for the same soil will vary from test to test. Finally, k_d taken for the simulations is given in Table 4.3-3.

Table 4.3-3 Decay coefficient, *kd* considered for the simulations in the present study

Decay coefficient, k_d	*4 per hour*

[9] Musgrave, G.W. 1955. "How Much Water Enters the Soils," U. S. D. A. Yearbook, U. S. Department of Agriculture, Washington, DC, pp. 151-159.
[10] Jens, S. W. and McPherson, M.B. 1964. "Hydrology of Urban Areas," in Handbook of Applied Hydrology, V.T. Chow, ed., McGraw-Hill, New York.

4.4. Rainfall Characteristics

Knowledge of rainfall characteristics is necessary for hydrologic studies related to planning, design, and management of water based infrastructure. In particular, knowledge of extreme storm events is critical for planning and design of hydraulic systems designed to be used for regulation and control of natural flows. Similarly, knowledge of extreme storm events is also critical for design of hydraulic conveyance systems.

For a particular site for which sufficient rainfall data are available, a comprehensive frequency analysis of these data can be performed to obtain estimates of return period corresponding to various precipitation rates that occur for a specified duration and over a given area. These results are commonly summarized as 'Intensity-Duration-Frequency' or IDF relationship. The number of rain gauges within NCT of Delhi for which long term sub-hourly rainfall records are available, is limited to only two meteorological stations, namely, Palam Airport and Safdarjung Airport. Hence, IDF relationships have been derived for these two stations.

The equations[11] used for frequency analysis are:

$$I = \mu + \alpha Y_T$$

$$\mu = b_0 - 0.5772\alpha$$

$$\alpha = [\frac{2 * b1 - b0}{ln2}]$$

$$b0 = 1/N[\sum_{j=1}^{N} Xj$$

$$b1 = 1/N \sum_{j=2}^{N} [(j-1)(Xj)]/(N-1)$$

where,

1. Y_T is the T-year EV1 reduced variate and estimated as

Y_T = - ln {-ln (1- 1/T)}

2. T is the return period in years
3. b_0 is mean
4. b_1 is variance
5. I is the rainfall intensity in mm/hr

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[11] Greenwood, Landwehr, J.M., Matalas, N.C., Wallis, J.R., 1979. Probability weighted moments: definition and relation to parameters of several distributions expressible in inverse form. Water Resour. Res. 15 (5), 1049–1054.

6. μ and α statistical Probability Weighted Moments parameters corresponding to measures of location and scale respectively
7. N is length of data in years
8. j = 1,2,3,4….,N

4.4.1. IDF equation for Safdarjung station

The 15 minute rainfall frequency analysis (Table 4.4-1) for Safdarjung station has been done using the data available for 30 years, from 1979 to 2008. Out of which, data for 1983, 1987, 1988, 1990 and 1993 were missing.

Table 4.4-1:15 minute rainfal frequency analysis for 30 years

Year	15 minutes Rainfall (mm)	j	15 minutes Rainfall (mm)	Intensity (X_j)	j-1	Intensity*(j-1)
1979	21.5	1	10.6	42.4	0	0
1980	16.5	2	13.5	54	1	54
1981	13.5	3	16.5	66	2	132
1982	21	4	18	72	3	216
1984	10.6	5	18	72	4	288
1985	27	6	18.5	74	5	370
1986	18.8	7	18.5	74	6	444
1989	21.5	8	18.8	75.2	7	526.4
1991	18.5	9	19	76	8	608
1992	20.2	10	20	80	9	720
1994	22	11	20.2	80.8	10	808
1995	35.8	12	20.7	82.8	11	910.8
1996	20.7	13	21	84	12	1008
1997	22	14	21.5	86	13	1118
1998	18.5	15	21.5	86	14	1204
1999	41	16	22	88	15	1320
2000	19	17	22	88	16	1408
2001	18	18	27	108	17	1836
2002	34	19	27	108	18	1944
2003	30	20	29	116	19	2204
2004	18	21	30	120	20	2400
2005	20	22	30	120	21	2520
2006	27	23	34	136	22	2992
2007	29	24	35.8	143.2	23	3293.6
2008	30	25	41	164	24	3936

Following calculations have been performed to determine the intensity for 2 year and 5 year return period:

$b0 = 1/N[\sum_{j=1}^{n} Xj$, So b0= 91.856 for N=25. (N=number of record available)

$b1 = 1/N \sum_{j=2}^{n}[(j-1)(Xj)]/(N-1)$, b1=53.768

$\alpha = [\frac{2*b1-b0}{ln2}]$, α=22.071

$\mu = b0 - 0.5772\alpha$, μ=79.116

So, for return period, T= 2 Year

$$I = \mu + \alpha Y_T$$

*I=79.116+22.071*0.366*

So, Intensity for 15 minutes duration for 2 year return period= 87.205 mm/hr.

Similarly, for T=5 Year

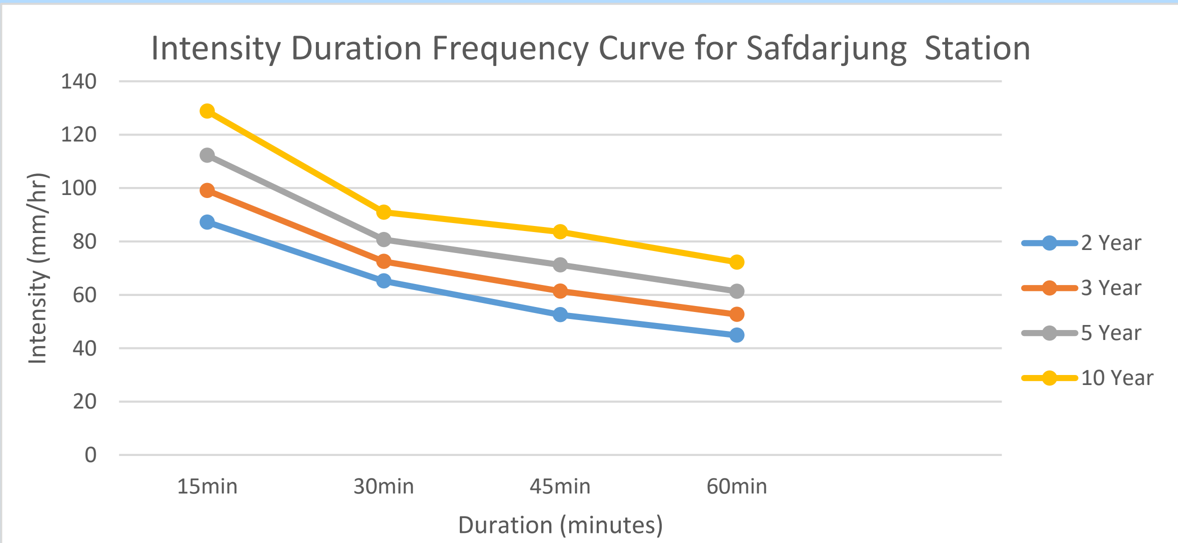
*I=79.116+22.071*1.499*

So, intensity for 15 minutes duration for 5 year return period =112.22 mm/hr.

Similarly the calculations have been done for 30 minutes, 45 minutes and 60 minutes duration.

Figure 4.4-1 shows Intensity Duration Frequency Curve for 2 year, 3 year, 5 year and 10 year return period based on 15 minutes rainfall data.

Figure 4.4-1: Intensity Duration Frequency curve for Safdarjung station



4.4.2. IDF equation for Palam station

The rainfall frequency analysis for Palam station has been done for the data available for 32 years, from 1977 to 2008. Out of which, data for 1979, 1980, 1983, 1990 and 1993 were missing.

Table 4.4-2: 15 minute rainfal frequency analysis for 30 years

Year	15 minutes Rainfall (mm)
1977	20
1978	23.5
1981	13.5
1982	18
1984	14
1985	15
1986	14
1987	20
1988	24
1989	20.5
1991	18
1992	22
1994	19
1995	24.5
1996	22
1997	20
1998	24
1999	20
2000	24.5
2001	26
2002	20.4
2003	30
2004	16
2005	16.4
2006	22
2007	20
2008	30

j	15 minutes Rainfall (mm)	Intensity (X_j)	j-1	Intensity*(j-1)
1	13.5	54	0	0
2	14	56	1	56
3	14	56	2	112
4	15	60	3	180
5	16	64	4	256
6	16.4	65.6	5	328
7	18	72	6	432
8	18	72	7	504
9	19	76	8	608
10	20	80	9	720
11	20	80	10	800
12	20	80	11	880
13	20	80	12	960
14	20	80	13	1040
15	20.4	81.6	14	1142.4
16	20.5	82	15	1230
17	22	88	16	1408
18	22	88	17	1496
19	22	88	18	1584
20	23.5	94	19	1786
21	24	96	20	1920
22	24	96	21	2016
23	24.5	98	22	2156
24	24.5	98	23	2254
25	26	104	24	2496
26	30	120	25	3000
27	30	120	26	3120

$b0$=82.56

$b0 = 1/N[\sum_{j=1}^{n} Xj$, So b0= 82.56 for N=27(N=number of records available)

$b1 = 1/N \sum_{j=2}^{n}[(j-1)(Xj)]/(N-1)$, b1=46.27

$\alpha = [\frac{2*b1-b0}{ln2}]$, α=14.39

$\mu = b0 - 0.5772\alpha,$ μ=74.24

So, for return period, T= 2 Year

$$I = \mu + \alpha Y_T$$

I=74.24+14.39*0.366

So, intensity for 15 minutes duration for 2 year return period= 79.52 mm/hr.

Similarly, for T=5 Year

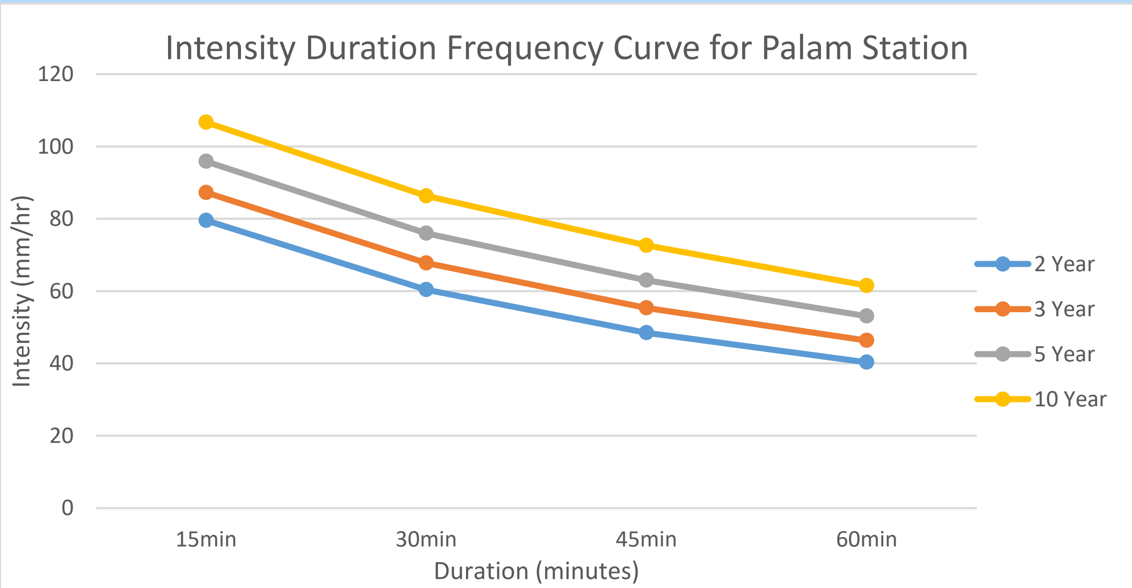
I=74.24+14.39*1.499

Intensity for 15 minutes duration for 5 year return period 95.84 mm/hr.

Similarly, the calculations have been done for 30 minutes, 45 minutes and 60 minutes duration.

Figure 4.4-2 shows Intensity Duration Frequency Curve for 2 year,3 year,5 year and 10 year return period based on 15 minutes rainfall data.

Figure 4.4-2: Intensity Duration Frequency curve for Palam station



4.4.3. Selection of Design Storm from existing data

The number of rain gauges within NCT of Delhi for which long term sub-hourly rainfall records are available, is limited to only two meteorological stations namely Palam Airport and Safdarjung Airport. Hence, IDF relationships have been derived for these two stations. Subsequently, 2 year and 5 year return period rain intensities have been derived, which have been decided to be used as design storms for NCT of Delhi.

4.4.3.1. Safdarjung

Out of the three basins of NCT of Delhi, two basins (Barapullah and Trans Yamuna) are under the influence of Safdarjung rain gauge station. The precipitation events have been used in the Storm Water Management Model (SWMM/PCSWMM) to simulate the corresponding flooding, if any, in these basins of NCT of Delhi. The event has been selected on the basis of the 15 minute frequency analysis. The intensity for 2 year return period for 15 minute duration is 87.20 mm/hr. The event of 9/13/1997 whose 15 minutes annual maximum frequency is 88mm/hr has been selected. The motivation behind selecting the time series in this manner is to utilize the already existing rainfall event which have occurred in the past. Similarly, for 5 year return period, the event of 06/27/2006 has been selected.

4.4.3.2. Palam

The Najafgarh basin is considered to be under the influence of Palam rain gauge station. The precipitation events have been used in the Storm Water Management Model (SWMM/ PCSWMM) to simulate the corresponding flooding, if any, in the Najafgarh basins of NCT of Delhi. The event has been selected on the basis of the 15 minute frequency analysis. The intensity for 2 year return period for 15 minute duration is 79.52 mm/hr. The event of 06/15/2007 whose 15 minutes annual maximum frequency is 80mm/hr has been selected. The motivation behind selecting the time series in this manner is to utilize the already existing rainfall event which have occurred in the past. Similarly, for 5 year return period, the event of 06/30/1998 has been selected.

5. SUMMARY AND CONCLUSIONS

Pre-requisite for a reliable analysis of the existing storm drainage infrastructure towards its adequacy for draining the respective areas effectively, is the availability of an equally reliable data on the infrastructure in terms of cross-sections and invert levels of the drains. It would have been much easier for the consultants to design afresh the required infrastructure to drain the respective areas by totally ignoring the existing infrastructure in view of the fact that the data on the existing infrastructure was not captured despite indulging in a gigantic exercise to digitize the whole Delhi. The Consultant was conscious of the fact that the Delhi Drainage Master Plan can only be successfully and economically implemented if the existing system is accurately captured and analysed. Therefore, they were left with no choice but to engage in processing of the drainage data that was decided to be captured through fresh exercise by various agencies by deploying their contractors, although it was the responsibility of the Government of Delhi to provide duly authenticated and validated data on drainage system to the consultant. The consultant was also left to assess for connectivity, flow directions and missing/erroneous attributes like outfalls, invert levels, dimensions, etc. In addition, data on the locations of pumps and sumps, their capacity, operation policies, etc. were added to the networks with lot of iterations with the respective departments. Also, extensive efforts were made by sending IIT Delhi representatives in field to verify the connectivity of some of the crucial drains and thus make the drainage data suitable for the purpose of analysis through modelling. Thus, a massive exercise of co-ordination of data collection and correction was taken up by IIT Delhi. Bulk of the time went into data collection and processing activity, and that in a way over exhausted the budget earmarked for the study. It is important to convey that under some situations, recourse to interpolation, engineering judgment, etc., was taken to make the data worthy of simulation.

Using the processed datasets, the SWMM model has been setup in the present study for each of the drainage basins of Delhi to simulate the inundation depths as well as their spatial locations. The model results have been validated to certain extent through the flooding location data provided by the Delhi Traffic Police. However, it has been found that despite all our efforts there have been a large number of discrepancies that are still being observed in the drainage network. These have been very systematically depicted in the Report by drawing the schematics of all the networks along with their longitudinal profiles (APPENDIX V, VI, VII).

Various scenarios have been generated to analyze the adequacy of the drainage system to start with and subsequently exploring various options to reduce the volume of runoff generated or to detain the volume of runoff. Incorporation of water bodies and other water retention zones in the drainage system can have a significant impact on flood reduction. Proper maintenance of the water bodies improves infiltration and water retention capability.

The consultant has deliberately not provided the complete implementation strategy for ensuring that there is no flooding in any part of the NCT of Delhi, but on the contrary has quantified for every drain as to what is the surplus runoff that needs to be handled using various mechanisms such that ultimately there is no flooding. In the process, a sequential procedure, through number of steps have been identified via a number of scenarios generated through modelling, wherein the effectiveness of each step has also been quantified. Herein, it is import to understand that some of these steps such as rectifying the drainage infrastructure that is technically incorrect and thus unacceptable, has to be the first priority. On implementing this step, it shall be possible to evaluate the effectiveness of this step and also to verify the ground realities once again.

The subsequent steps of implementation recognised through the respective scenarios shall need detailed investigations about the possible locations to be used for LIDs. Once that is done then the proposed implementation can be used in the simulation to foresee their impact. Therefore, the framework that has been created in the present study is a boon to plan the range of implementations to work towards a sustainable solution for handling the problem of flooding in the NCT of Delhi.

6. Recommendations

To alleviate the flooding conditions in various parts of the city, the stormwater infrastructure has to be made efficient. So, it is pertinent to apply corrective measures to the faulty drainage infrastructure, and introduce low cost flood preventing measures such as water bodies rejuvenation, rainwater harvesting using parks and Low Impact Development options. Further, the solid waste and the sewage has been managed in such a way that they do not interfere with the storm water drainage. Following are the recommendations that can make a storm drainage system to work in an efficient manner:

No encroachments on storm drains

- Storm drains should be treated as key public assets and no encroachment should be allowed. Any encroachment of the drain should be immediately removed and reported back. Department managing the storm drain should be made responsible for keeping drain encroachment-free. Special drives to remove encroachments from the storm drains should be taken up.

No sewage in storm drains

- No natural or artificial storm drain should be allowed to carry any sewage. Only treated sewage of acceptable quality as per CPCB norms should be allowed in storm drains.
- All drains that are entering into NCT of Delhi (from Haryana, U. P., etc.) should be only carrying storm water and treated sewage of acceptable quality as per CPCB norms.
- Current practice of DJB of puncturing sewer lines and draining sewage into storm drain in the event of blockage should be stopped. DJB should resort to using latest mechanisms such as supper suckers for de-clogging the sewer lines.
- No sewage should be allowed to enter the storm drains even from unauthorized colonies; interceptor sewers should be set-up wherever required by DJB to trap the sewage coming out of such colonies and take it to the nearest sewer line or STP.

No Solid Waste or C&D waste be allowed into storm drains

- No silt from the road (before or after road sweeping – manual or otherwise) be allowed to be dumped into bell-mouths/drains. Road sweeping process should be completely overhauled. Weight/volume of silt received after street sweeping should be recorded. Segments of road from where more silt is being received should be reviewed and reason of the same ascertained. If need be, possible afforestation exercise should be taken up to reduce silt on the road segment.
- No solid waste should be allowed to be dumped into storm drains.
- Construction & Demolition (C&D) waste should not be allowed to be dumped in storm drains or depressions. Amount of waste likely to be generated from a construction or demolition site should be assessed by the contractor in advance (along with the permission to construct/modify house). C&D waste should be lifted by government appointed contractors and dumped at C&D processing site.

Effectiveness of desilting of storm drains

- It has been seen that many drains are covered fully/partially. It has been noticed that most of the covered drains do not have access for desilting. If desilting is not carried out under the covered potion, effectiveness of desilting of rest of the drain is reduced significantly. Therefore, access points, if they are not there, should be provided at appropriate distance so that desilting can be carried out.

- Schedule of desilting should be publically displayed and in a manner that is understood clearly by general public. GSDL should use the GIS layout of the drainage network made by IIT Delhi with cross-section and L-section to capture and display the schedule of desilting by the contractors segment-wise and jurisdiction-wise. Crucial details such as time schedule of desilting and the amount of silt/debris removed should also be captured and displayed.
- Certification that desilting is completely and satisfactorily done, be made by the concerned agency. On this certification, local public shall be notified that work is completed and public suggestions/feedback shall be sought (through an App that allows the user to send geo-tagged photos of the concerned issue). Received public complaints should be looked into by the department within a stipulated time.
- Some of the drains are managed by multiple departments/sub-divisions within departments. Extra care is required in such cases because if desilting is not carried out in proper co-ordination (there is gap in schedule of departments/sub-division or one portion is not desilted), effectiveness of the work carried out reduces significantly.
- Weight & quality of silt removed should be mandatory to be certified from the way-bridge of receiving agency (Municipality SWM site). This information shall be recorded diligently segment-wise and displayed on GIS by GSDL and should be analyzed with year-on-year goal to reduce the amount of silt that is coming to the respective storm drains.
- Effort should be made to put all the storm water drains under single agency that shall take care of many issues identified above.

No storm water should be drained into sewer systems

- No storm drain should ever outfall into sewer system at any cost since they are never designed for such situation and shall therefore result in surcharge of sewerage network and may flood some of the areas with sewage. All such cases should be identified and immediately addressed. No such cases (temporary or permanent) should ever be allowed.
- Practice of opening sewer man-holes to discharge local storm water should be banned. Adequate system to discharge storm water should be put in place and public awareness should be increased towards ill-effects of diverting storm water into sewer lines.
- Similarly, house-holds draining storm water into the sewer lines should be penalized. Locality level storm drains should be revived or as an alternative GW recharging mechanism should be put in place by individual household – at own cost. Awareness campaign should be carried out to sensitize public in this regard.

No construction should be allowed inside any storm drains. There are two specific violations that are usually happening:

- Utilities are laid inside the storm drains
- Pillars of elevated roads/metro are built inside the storm drains.

No such activity should be allowed. Also, in the locations such compromise of the section has happened, adequate measures should be taken immediately to restore the original carrying capacity of the storm drain.

Design of new storm drains should not be done in isolation

- Overall impact of any new drain on the existing storm drainage system should be studied.
- Data collected and modelling system deployed as part of this study should be used for checking design feasibility of any new drains.
- Retention cum Harvesting corridors can be laid along the road to capture the runoff generated from the surface. This will enhance the ground water recharging.
- Different scenarios have been envisaged and presented in this report to simulate the prevailing conditions as well as the interventions required to alleviate the flooding conditions in various parts of the city. After implementing the recommended practices, more scenarios can be later introduced, further enhancing the efficiency of the drainage network of the city.

Rejuvenation of water bodies

Many of the water bodies have become redundant over the years and are not even properly connected to their catchments. Once rejuvenated, these water bodies can play a pivotal role in reducing the flooding as they act as detention and recharge basins. They should be continuously monitored and maintained in order to reduce runoff into storm drains.

- Dumping of waste into water bodies should be prohibited to maintain ambient water quality.
- Regular desilting should be undertaken to avoid reduction in storage capacity of the water bodies.
- No encroachment or unauthorised construction in wetlands should be permitted.

Low Impact Development (LID) Options

In order to explore additional options for disposal of the remaining excess water, it is advisable to explore the local conditions in a comprehensive manner and wherever feasible, identify various Low Impact Development (LID) options such as infiltration trenches, rain gardens, bio-retention ponds, bio-swales, etc. in respective contributing areas of each of the drains.

Flood monitoring using sensors to improve flood management

Monitoring of extent of flood at locations which are perpetually getting flooded. This can be achieved by installing low cost sensors which can also serve the purpose of issuing appropriate warning. This data shall also be useful in evlauting the performance of various flood reduction measures.

Effective administrative management

There should be a single institution that bears an overall responsibility of the management of the total storm water drainage system within NCT of Delhi.

Additional recommendations

It is proposed that the government should enact a law that prohibits:

- **Sidewalk and pavement hawking**. There is a natural temptation to dispose of wastes into available storm water collection system with impunity. Use of garbage disposal bags should be made mandatory for businesses along road carriageways.
- **Roadside delis and other eating places that do not have a hygienic and an organized pantry system within the premises for cleaning and washing of utensils.** Enforcement should be rigorous and non-compliance should carry compensatory as well as punitive penalty. Further,

the license to operate should also be incumbent on a demonstrable infrastructure for an orderly disposal of solid and liquid wastes.

- **Roadside auto service and repair shops as these require sophisticated waste handling, storage, stowing and disposal infrastructure.** It is commonly observed that chemical wastes are routinely disposed off into the nearest available storm water systems.
- **Roadside auto dealerships that cater to both new as well as pre-owned vehicles.** These businesses invariably utilise public space for parking and display of goods on sale and the damage to roadside infrastructure is indeed inevitable.
- **Collection and stacking of construction related building and other wastes on public spaces.** No completion certificate should be granted unless a public inspection of the sites is able to verify compliance and adherence to building waste management norms.
- **Roadside piling of dirt and other solid wastes (road sweep) resulting from road, sidewalks and service roads.** It is a common observation that dirt is routinely swept off and stacked in front of roadside bell mouths.
- **Weekly markets without an installable (temporary) infrastructure to collect, store and safely stow business wastes prior to its disposal at formally designated locations and in accordance with formalized protocol.** Failure to comply should result in levying punitive penalty on the organizers, individually and/or collectively.
- **Direct access to businesses from the roadside.** As part of masterplan for the future, all access to proposed community centres, markets and business centres that are planned along road carriageways should be planned with no direct access from the roadside and should be planned with basement parking. Access to shops for customers as well as delivery of stock and other inventory from/to these businesses should only be from the rear and off the main road as shown in the Figure R1.
- Firm rules and policies (no tolerance zone, no parking, etc.) should be designed and executed to evade the effect of rapid urbanization on storm water infrastructure of the city.

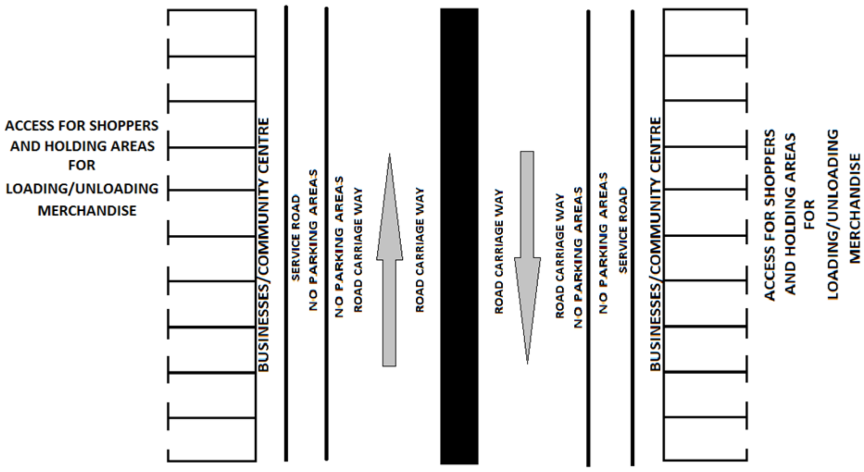


Figure R1: Schematic of proposed road plan

Recommendations may not be effective if not implemented properly. Therefore, it is important to understand that implementation of the recommendations has to be sequential for better efficacy since it is possible that many of the data elements that have not been independently validated by the respective departments may be different on ground than the digital reality captured and used in the model.

So till the time the full system is not deployed and handed over, all new storm drains designs should be sent to IIT Delhi for checking their feasibility.

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FEEDBACK

The feedback on the draft report received from various organizations and our response has been compiled in APPENDIX XXI.

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APPENDICES

Flooded junctions (flooding hours above 15 minutes) for 5 year return period in Najafgarh basin after scenario 4

APPENDIX XX

Initiatives by IIT Delhi and some observations from field visits

APPENDIX XXI

Feedback