Gorakhpur Environmental
Action Group

# Technical Feasibility Study for a Low Cost and Low Energy Drainage System in Rasoolpur, Gorakhpur, India

Draft Report (Rev. 00)

**October 2010**




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Job number 207105

ARUP



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|---|---|---|---|
| Job title | Technical Feasibility Study for a Low Cost and Low Energy Drainage System in Rasoolpur, Gorakhpur, India | Job number<br>207105 | |
| Document title | Draft Report (Rev. 00) | File reference | |
| Document ref | 207105-REP-001-00 | | |

| Revision | Date | Filename | Draft Report (Rev. 00).doc | | |
|---|---|---|---|---|---|
| 00 | 07/10/2010 | Description | First Issue | | |
| | | | Prepared by | Checked by | Approved by |
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# 1 Introduction

## 1.1 The Project Background

Many low-income communities in developing countries such as in this case, consider stormwater drainage to be their most urgent need as far as urban infrastructure is concerned. This is partly because their houses are often built on unsuitable land subjected to frequent flooding. The land prices in areas sufficiently close to the city centre for the journey to work tend to be beyond their means. The only land they can afford, or on which the owners will allow them to stay as squatters, is land that is unsuitable for other purposes. This is often on steep hillsides subject to erosion and landslides, or it is low-lying, marshy land often subject to flooding.

Lack of adequate drainage system causes damage to lives and property which will take years to repair and everybody could not afford. Rainwater is not the only problem. Leaking water mains, wastewater from washing and bathing, and the sewage from overflowing septic tanks and blocked sewers constitute health hazards, damage buildings, and can cause flooding if an adequate drainage system does not exist.

The lack of drainage is especially serious problem where the ground is very flat such as in Gorakhpur. In cases the land is flat; in cities such as Gorakhpur, Bangkok, Calcutta, Colombo, Dar es Salaam, Jakarta, Guayaquil, Lagos, Manila and Recife, many neighbourhoods are flooded at least once or twice a year, and people have to learn to cope with water inside their dwellings. Sometimes people build their houses on stilts and connect them by elevated pathways. However, their construction is rickety, and it is very easy to lose balance and fall into the muddy, polluted water underneath.

This report was prepared as part of a technical assistance role that Arup is providing as part of the Asian Cities Climate Change Resilience Network (ACCCRN). ACCCRN is funded by the Rockefeller Foundation, and Gorakhpur is one of 10 cities seeking to understand climate change impacts as part of this network, in order to build urban resilience to the shocks and stresses that are likely to be introduced or enhanced by climate change.

## 1.2 Objectives and Structure of this Report

The key objective of this report is to describe the findings of the preliminary assessment and submit preliminary proposals to mitigate the existing flooding problem in Rasoolpur village. The assessments in sections 2 of the report are based on information collected from various sources including site visit described below in Section 1.4.

As a first aid measures, the mitigation measures are recommended to implemented as soon as possible to minimise the risk to loss of life and property to the habitants of the village. Apart from this, short term mitigation measures are also recommended to be completed as soon as possible. As the short term works need to complete as soon and therefore the proposed works must not be complicated and must be practical and simple to construct.

Apart from the first aid and short term mitigation measures, a long term mitigation measures are also recommended to improve the flooding condition in the pilot study area.

The conclusions reached and the recommendation for next steps is presented in Sections 3.

## 1.3 Information Sources

The following information received from various sources has been used in the compilation of this report:

Drainage Improvement Works by UP Jal Nigam Ltd, India.

Geo-hydrological Study of Gorakhpur City, UP India, DDU, Gorakhpur University.

Vulnerability Analysis, Gorakhpur City

Site photographs

## 1.4 Standards

There is no standard or guideline to design the drainage system in developing countries similar to this. Therefore, a review of international practice for the preliminary design of low cost drainage system was carried out to put forward the recommendation. Some of these references are listed in Section 4 of this report.

Apart from this, an Appendix B is also prepared from the review of international practice for the planning, design and maintenance of low cost energy efficient drainage system not only for Rasoolpur village but also for other locations.

## 1.5 International Practice

Arup has been involved for the planning, design and construction of flood mitigation measures for low lying village not only in developing countries but also in developed countries. One of the main reasons of flooding for those areas is lower site formation level as compared to surrounding. During storm events, storm water could not be drained to nearby drainage system and therefore require polder scheme comprise of storage and pumping. The experience from those projects is used for proposing the mitigation measures for Rasoolpur ward in Gorakhpur. Below are some of the schemes implemented by Hong Kong Government to mitigate the frequent flooding:

**Village Flood Pumping Scheme in Ma Tin Tsuen, Hong Kong**


**Reed Pond in San Tin, Hong Kong mitigates the flooding and enriches the ecology.**

# 2 Broad Assessment

## 2.1 General

Generally, the storm water from low income areas is discharged into main drains maintained by local public authorities. The separate system with a separate collection of wastewater and storm water is at present generally accepted in the developing and developed world to improve the water quality and public health.

However, a combined system is still a very common for existing development in developing countries due to lack of sewerage infrastructure. In United Kingdom, there is combined system in London and many other places.

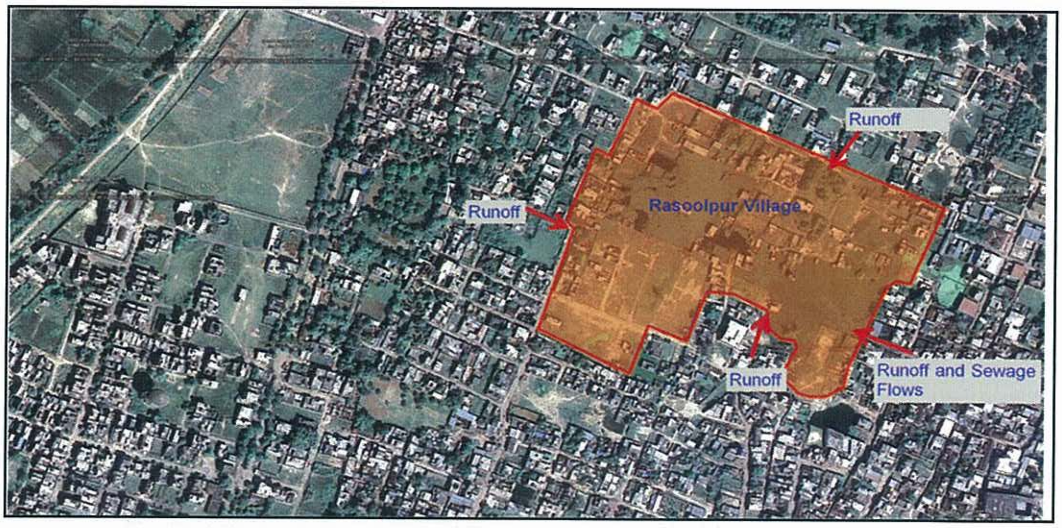
This section sets out the overall assessment methodology and assumptions adopted in carrying out preliminary assessment to draw up the mitigation measures.

## 2.2 Site Location and Description

The pilot study area known as Rasoolpur village is located in Gorakhpur city, Uttar Pradesh, India. The site is low lying areas inhabitant by people from low income group.

Based upon the discussion with the local habitants, there used to be a brick kiln plant. The low lying site is formed due to earth material excavated to make bricks. Subsequently, the area was sold to poor people who built up the houses in ignorance without knowing the fact that the area will be flooded during wet season.

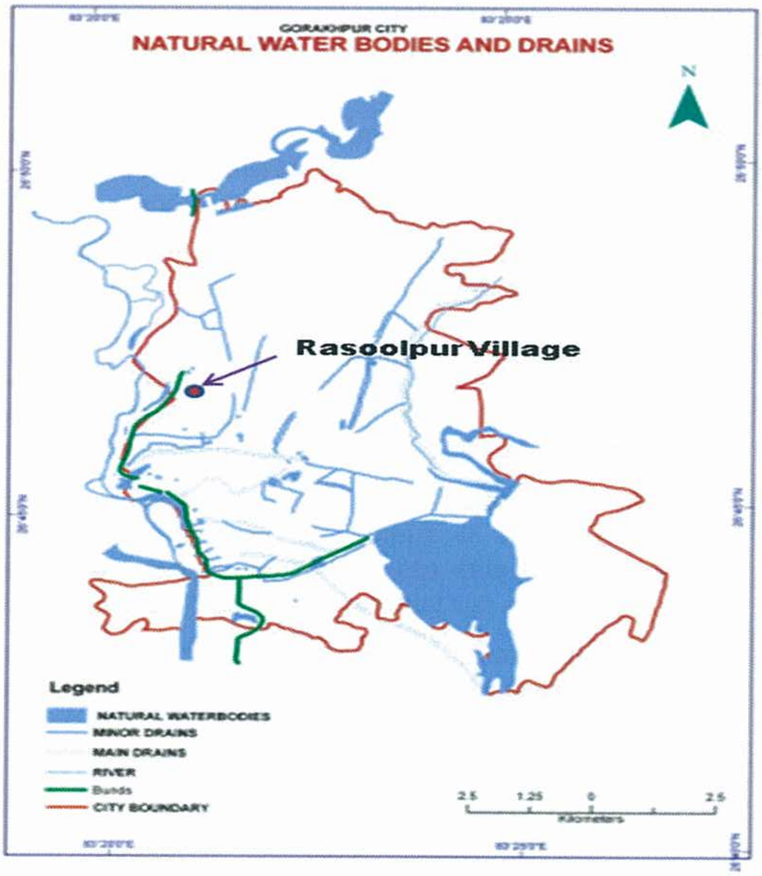
In order to appreciate the problem, a site visit has been undertaken on 24th and 25th May 2010. The discussions were also held with the locals about the severity of the flooding problem in the past during wet season.




**Location Plan of Rasoolpur Village**

The majority of the Rasoolpur village already build up in the form of huts without any consideration of sanitation. The construction in the remaining areas is also in progress. Under the existing condition, the runoff including sewage water from the surrounding is discharged into Rasoolpur village.

The following map shows river system and major drains around Gorakhpur. It can be seen that city has high risk of flooding during monsoon season. In view of the lower ground levels as compared to water levels along the river, a flood protection bund is constructed to protect the city. The storm runoff from the city is pumped to the river during high water levels along the river.




**Major River and Drainage System around Gorakhpur City**

## 2.3 Catchment Characteristics

All the information received from various sources was reviewed to identify the reason for flooding. The information reviewed includes the drainage master plan for the Gorakhpur City which does not propose any mitigation measures for Rasoolpur village. In view of the limited information and to appreciate the problem, a site visit was undertaken to appreciate the problem on site. After carrying out spot on site survey, it was concluded that the runoff from surrounding areas also convey runoff to the Rasoolpur village. In view of the limited information on topographical survey, it is difficult to identify the catchment conveying runoff to Rasoolpur village and therefore further investigation is required for the design of mitigation measures.

However, the boundary of Rasoolpur village subjected to this investigation can be established fairly. It can be seen from the photographs below that Rasoolpur village is surrounded by high level roads and other developments.

**Photograph: Existing Condition in Rasoolpur Village**

## 2.4 Likely Causes of Flooding

Based upon review of existing information, site visit and discussion with the inhabitants of Rasoolpur village, the following are the main reasons for the current flood inundation.

**Low Lying Areas**

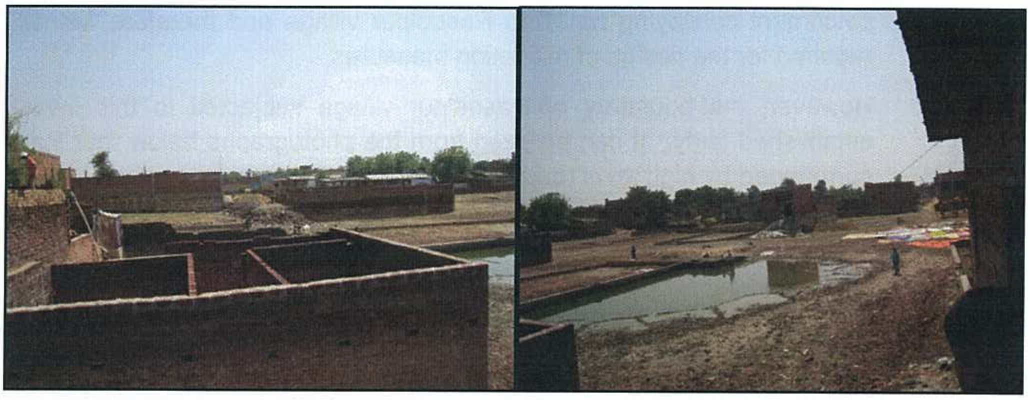
As mentioned in previous paragraph and can be seen from the photographs below, one of the main reason for flooding is the low lying areas of Rasoolpur village. Because of this, runoff could not be drained through gravity from the village to public drains which are running along the road.

**Photograph: Showing relative elevation of houses in Rasoolpur Village compared to surroundings**

**Inadequate Drainage System**

Apart from being low lying areas, there is no drainage system within the village. The houses/huts are being built without taking into any engineering consideration and of future risk to life and property due to flood inundation. Even though, this is low lying areas, there should be an internal drainage system for collection and its subsequent pumping to public drain.

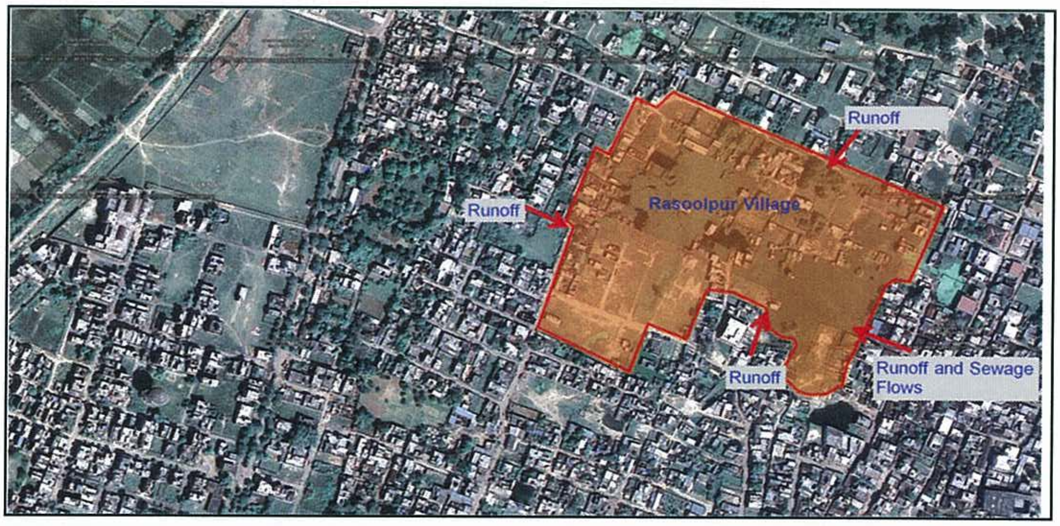
Based upon existing developments/construction practice, it seems there is no control on the process of development. Therefore, there is a need for the planning of drainage infrastructure within the village so as to minimise the water logging in the future.



**Photograph: Runoff could not be drained to public drains**

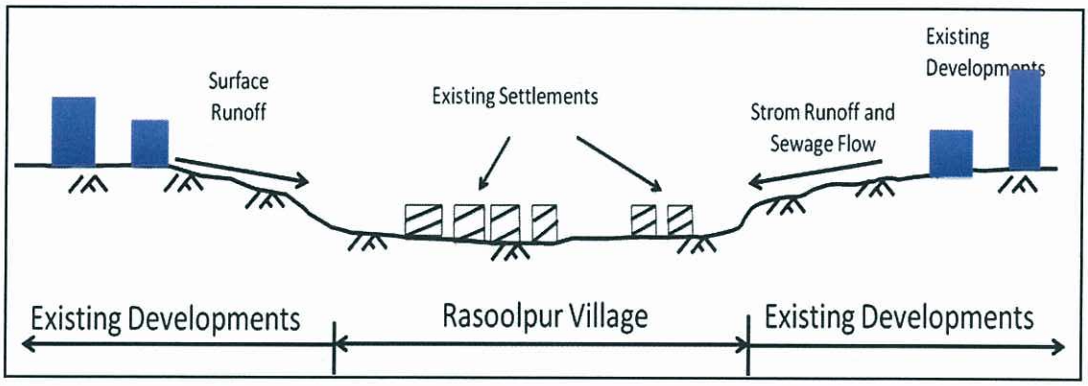
**Storm Runoff from the Surrounding**

The site visit was undertaken to appreciate the issues and to identify prime reason for flooding. It was noticed that stormwater from the surrounding areas is also discharged into Rasoolpur village and making the things worse. In view of limited scope of this study, it is difficult to establish catchment boundary of the areas currently draining into Rasoolpur village.




**Satellite Image Showing Runoff from Surrounding Discharged to Rasoolpur Village**

**Photos Showing Runoff from the Surrounding Discharge to Rasoolpur Village**




**Existing Condition around Rasoolpur Village**

## Dry Weather Flow from the Surrounding

During the discussion with local inhabitants, this came to our attention that there are lots of health issues. As people are extracting ground water for water supply purpose and therefore there is a possibility of ground water pollution due to lack of sewerage system. This is the case similar to noticed in developing world as mentioned in Appendix B.

Therefore, in-depth site reconnance survey was undertaken to identify, if sewage is discharged to the subjected site during site visit. It was found that sewage flows from some of the surrounding areas are discharged to the concerned site.

It can be seen from the photo below that dry weather flow from the surrounding areas is discharged into the site. As ground water table is relatively shallow and therefore water table get polluted and causing water borne diseases within the local community.

**Photograph: Sewage from outside Areas discharge into Rasoolpur Village**

The above photographs were taken on 24th May 2010 which is long spell of dry period. It can be seen there is lots of polluted water in some of the location in Rasoolpur village which is due to discharging of dry weather flow into the subjected site. The rate of incoming dry weather flow is more than the infiltration capacity and therefore ponding of water is taking place. Apart from this city waste is also being dumped into the site. In summary, this results in environmental and health issues within and in the vicinity of Rasoolpur village.

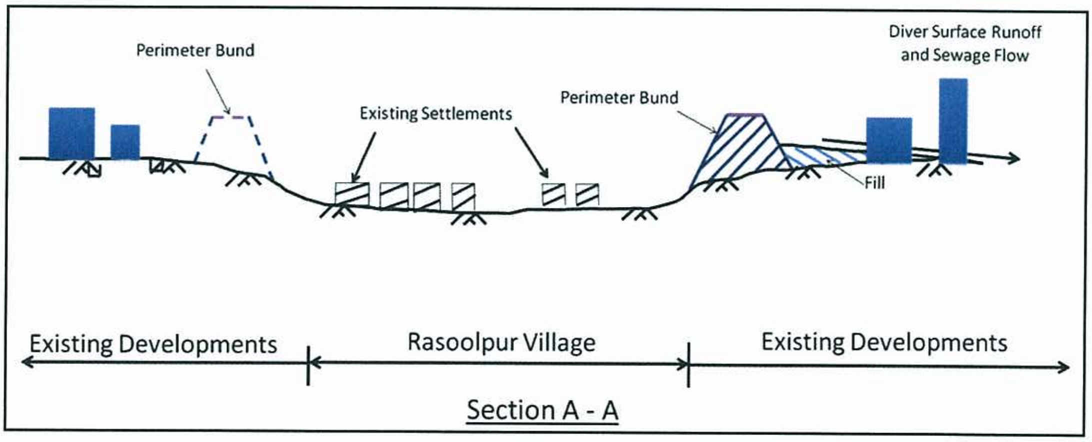
## 2.5 Proposed Mitigation Measures

### 2.5.1 First Aid Measures

**Sewage Flow Diversion**

One of the main objectives of this study is to design/suggest measures which can provide immediate relief or reduce the severity of the problem within the pilot study area. As mentioned in previous paragraph, dry weather flow and storm runoff from nearby areas discharge into the subjected site such as shown below even in dry season. This not only cause water inundation but also pollution of ground water table.





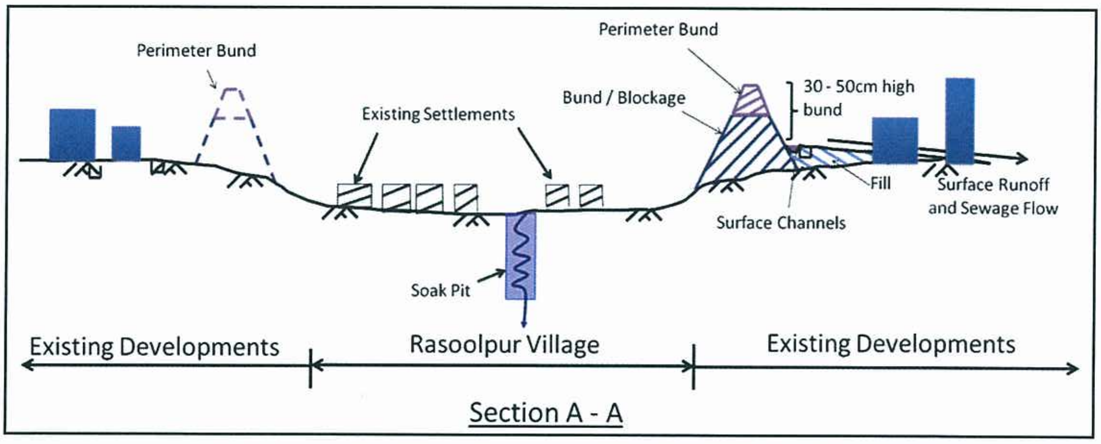

**Drains heading towards Rasoolpur village require diversion**

It is recommended to divert all those dry weather flow to public sewerage system. Therefore, further discussions are recommended between Gorakhpur Municipality and UP Jal Nigam to implement the first aid measures.

### 2.5.2 Short and Medium Term Measures

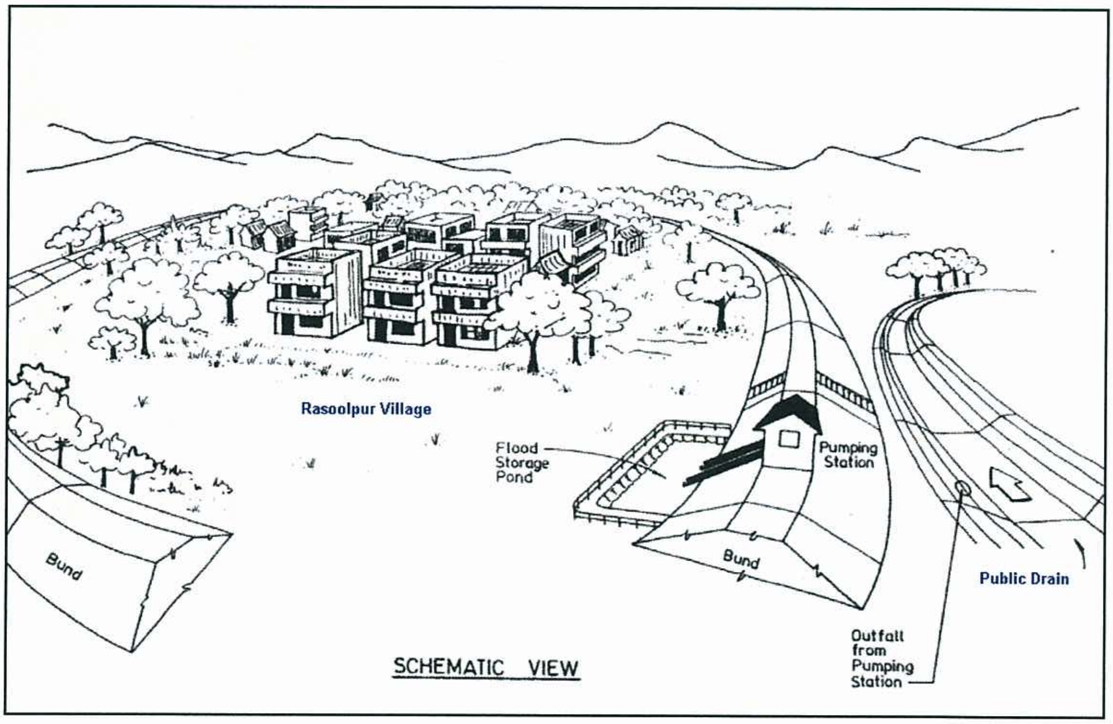
**Village Perimeter Bund**

As mentioned before, Rasoolpur village is a low lying area surrounded by urban environment. Because of general topography, the runoff from the surrounding areas discharges to Rasoolpur village and cause flood inundation even during a small storm event. Therefore, a flood protection wall around the village is recommended varying in height from 30cm to 50cm. The exact height of the wall needs to be determined after carrying out further investigation especially the catchment boundary of surrounding areas, ground levels and capacity of the existing drainage system.

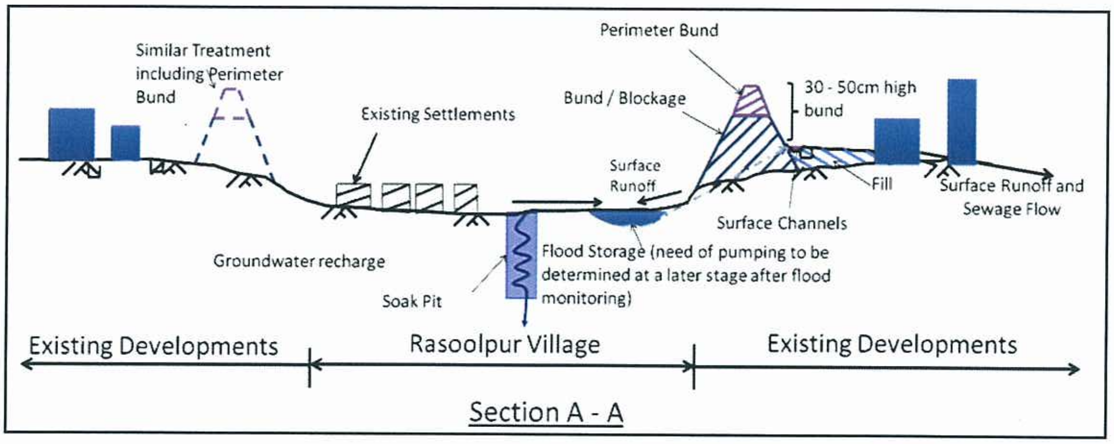



**Flood Storage and Pumping (if required)**

As Rasoolpur village is a low lying areas and therefore storm runoff from the area could not be conveyed to public drains by gravity. Therefore, there is a need of flood storage at number of places in the village and if required a pump to convey the storm water to nearby public drainage system. It is recommended that pump shall only come into operation once water level into pond reaches more than the design limit and pose a risk to life and property to the inhabitant of village. The conceptual plan of scheme is provided below.



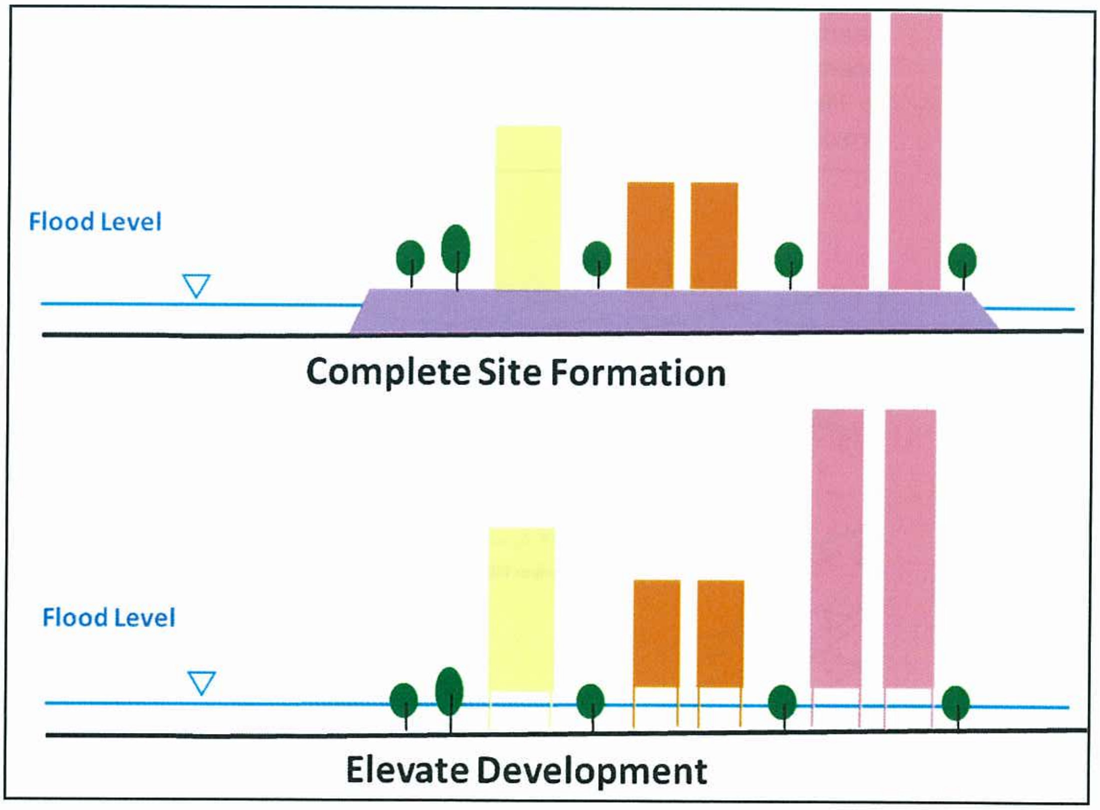
**Schematic View of Flood Storage for Rasoolpur Village**




**Sectional View through Rasoolpur Village and Surrounding Developments**

## Raise the Site Formation Level

The area of the Rasoolpur village is significant with part of the village already developed in the form of huts or small houses without taking into consideration drainage aspects. In order to minimise the flooding risk and to safe guard the life and property, it is recommended to raise the site formation level of future developments. The cost of raising the site formation level of the houses will be low as compared to reconstruction of houses at a later stage. Further discussions with City Municipality are recommended to dispose the construction waste in these areas.

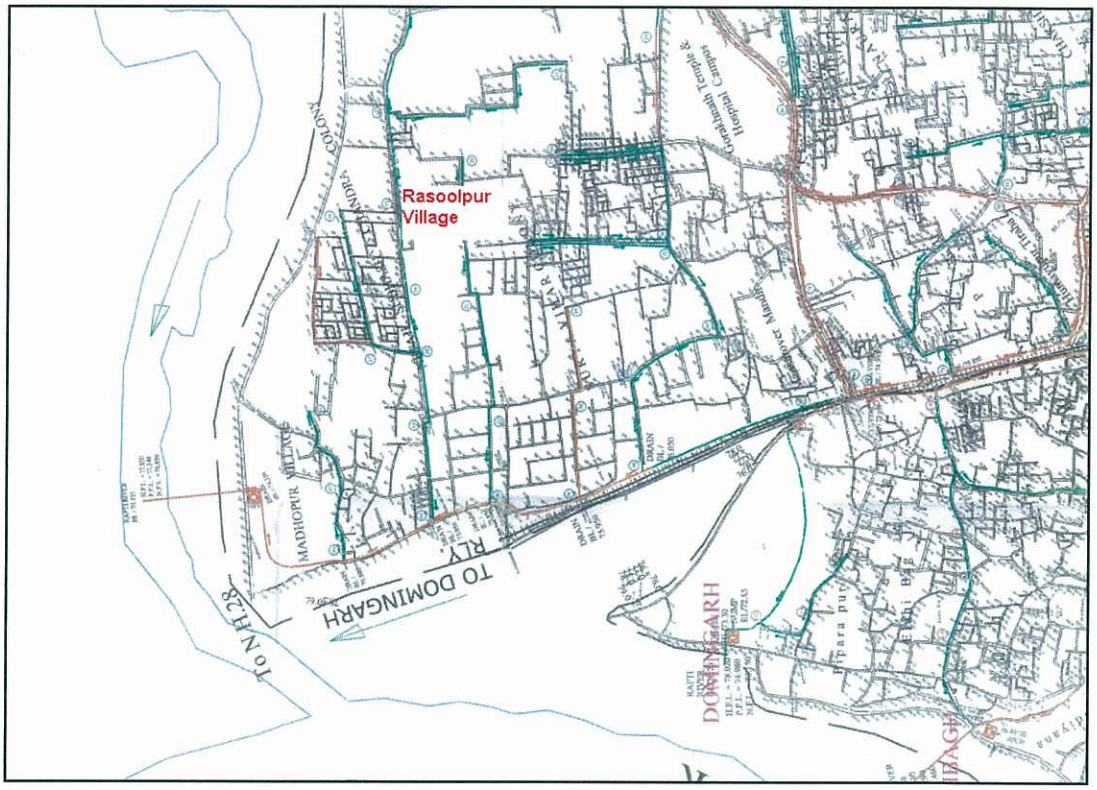



**Site Formation for Future Development**

Based upon recent site visit, it was noticed that solid waste is dumped into the open areas village to fill in the areas. It is recommended that Gorakhpur municipality should play a role to regulate the construction of future houses.

**Improvement of Public Drainage System**

During site visit, this was noticed either there is no public drainage system around the village periphery or existing drainage system is silted. There is a need to review the adequacy of existing drainage system both in terms of its hydraulic capacity and routine maintenance. The plan below shows the proposed drainage improvement works in Gorakhpur City.




**Drainage Master Plan for Gorakhpur City by UP Jal Nigam**

### 2.5.3 Energy and Cost Effectiveness of Mitigation Measures

The proposed mitigation measures range from first-aid to short and long term measures. The following Table provide a brief comparison in terms of their effectiveness and also a comparison in terms of cost and energy with respect to Rasoolpur village.

| Measures | Energy Consumption | Cost | Effectiveness in Reducing Flood Inundation | Time for Construction |
|---|---|---|---|---|
| **First Aid** | | | | |
| Flow diversion | Nil | L | H | S |
| **Short and Medium Term** | | | | |
| Perimeter Bund | Nil | M | H | H |
| Village Storage Pond | Nil | L | M | S |
| Raise the Site Formation Level | Nil | H | H | H |

| Measures | Energy Consumption | Cost | Effectiveness in Reducing Flood Inundation | Time for Construction |
|---|---|---|---|---|
| Improvement of Public Drainage System | Nil | H | H | H |
| Pump for pumping extra water | M | M | H | M |

L- Low, M- Medium, H – High, S - Small

These measures can be implemented in phases. Although, the main objective of this study is to identify and propose low cost and low energy drainage mitigation measures but due to Rasoolpur Village located in low lying areas, runoff from the site could not be conveyed to nearby public drainage system by gravity. Therefore, in long term a polder scheme including a small pumping station may be required. The necessity of polder scheme should be determined after assessing the effectiveness of flow diversion and flood protection bund around the Rasoolpur village.

In order to minimise the construction and energy cost, the mitigation measures are recommended in the following order for implementation:

- Flow diversion;
- Perimeter bund;
- Village flood storage pond;
- Raise the site formation level;
- Improve the public drainage system;
- Pumps to empty flood storage pond.

### 2.5.4 Maintenance of Drainage System

The proper maintenance of the drainage system is essential to achieve its designated objectives. The method and maintenance requirements vary from type of drains and flooding risk associated. Generally, storm drains are cleaned before the onset of monsoon and also during the monsoon season depending upon visual inspection of drains interms of silt deposition and blocking.

### 2.5.5 Community/Institution Participation and Involvement

The involvement of Institutions is very important from the planning and design stage to the operation of drainage system. Apart from this, support of institutions is also required for formulating the policies in relation to drainage and sewerage system. Whereas, participation of local community is important for the operation and maintenance of local drainage system.

For this pilot study, the support of UP Jal Nigam and City Municipality is required for the implementation of planned drainage improvement works which will mitigate the flooding of Rasoolpur village to certain extent especially by intercepting the storm flow from outside the Rasoolpur village. Whereas, support from local community is required for the implementation and operation of proposed mitigation measures within the Rasoolpur village.

# 3 Conclusion and Recommendations

### 3.1.1 Conclusion

The in-depth study has been undertaken to understand and appreciate the issues and reason behind the frequent flooding in Rasoolpur village. The main reason for the frequent flooding are low lying areas of the concerned site, in adequate drainage system within and outside the site and the runoff discharge to the site from the surroundings areas.

### 3.1.2 Recommendations

The following mitigation measures are recommended in sequential order to minimise the loss of life and property due to reoccurrence of flooding:

- Carry out the sewage flow diversion from the surrounding areas which is currently discharge into the concerned site to minimise the flooding and also to eliminate ground water contamination;
- Construct a perimeter bund to stop entry of stormwater from surrounding during extreme events;
- Construct a flood storage ponds within Rasoolpur village to collect storm water for infiltration and evaporation;
- Raise the site formation of existing developments and ensure future developments are constructed above the maximum flood level;
- Improve the public drainage system in whole city to safeguard the city against any flooding;
- Construct a pump for pumping of excess storm water to nearby public drainage system, if required;
- The pumping arrangement shall only be undertaken if flow diversion, perimeter bund and flood storage pond is not adequate.

# 4 References

1. Surface Water Drainage for Low Income Communities – *Published by World Health Organisation in collaboration with United Nations Environmental programme.*
2. Surface Water Drainage – How Evaluation Can Improve Performance.
3. Low Cost Sewerage by *Duncan Mara.*
4. Low Cost Sewerage and Drainage *by L. A. van Duijl.*
5. Performance Indicators for Urban Storm Drainage in developing countries by *Pete Kolsky and David Butler.*
6. Storm Drainage – An engineering guide to low-cost evaluation of system performance by *Pete Kolsky.*

## PICTURES


**Photo : Location of Rasoolpur Village**

**Photo: Showing lack of Internal Drainage System**

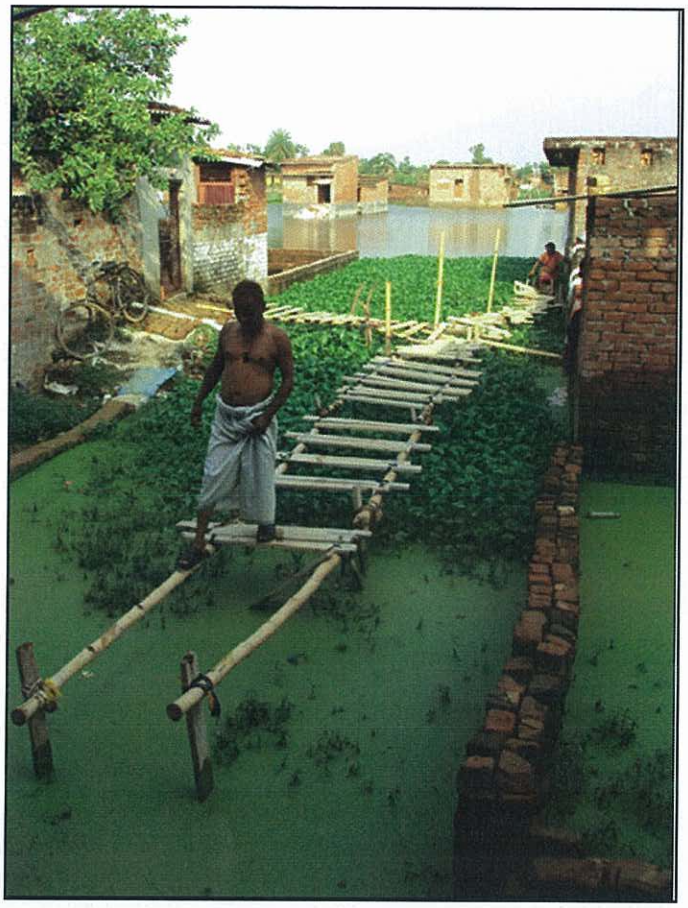


**Photo: Showing the Flooding in Past**

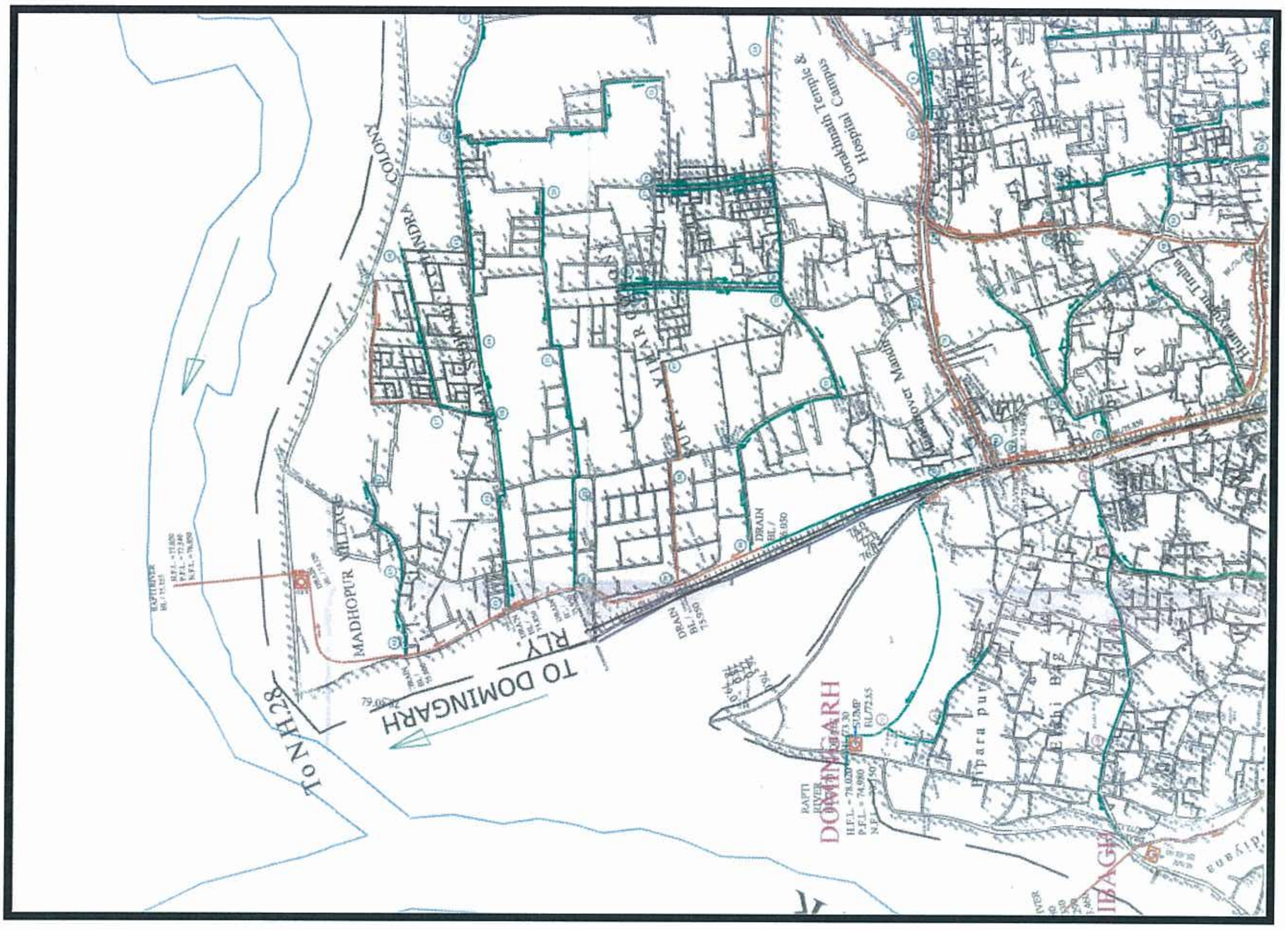
**Photo: Showing the Flooding in Past**

**Photo: Showing Flooding in Past along the Street**

**Photo: Showing Sewage Collected within the Village**

Appendix A

## Figures




**Drainage Master Plan by UP Jal Nigam for Gorakhpur City**

Appendix B

# Planning, Investigation and Design of Low Cost Energy Efficient Drainage Systems

# B1 Drainage Systems, Flooding and Performance

## B1.1 Surface Water Drainage and Public Health

Drainage is the process to remove unwanted water which can be in many forms and therefore envisaged a variety of drainage requirements. Runoff, also called stormwater, is the fraction of rainfall that runs off the surface of the ground, and leads to flooding. Frequent small floods damage roads and housing, disrupt business, and represent a basic threat to human health, life and property.

During a flood, runoff mixes with human wastes from sewers, drains, and latrines, and spreads them through the streets and homes of the community. These wastes carry the bacteria, viruses, and parasites responsible for a wide number of gastro-intestinal infections, including diarrhoea, typhoid, cholera and intestinal worm infections.

All sanitation systems need good drainage; none can function effectively during a flood. A number of studies have been carried out especially in slums where storm drains combined with sewerage system and found that surface water drainage reduced the odds of frequent diarrhoea by more than 50 percent. Apart from this, surface water drainage combined with low-cost sewerage reduced the rate even further.

Most soil provides an ideal environment in which worm eggs, passed in the human waste, can mature and spread to new victims. Poorly drained and unpaved sites, such as the Rasoolpur village, may thus promote the spread of a number of worm infections, such as roundworm, hookworm, and whipworm. These infections can lead to anaemia, stunting, and poor nutrition, as the worms grew at the expense of the infected child. A number of past studies concluded, that an increase in roundworm infection may have been caused by frequent flooding of sewer during storms, due to inadequate surface water drainage such as in Rasoolpur village. Therefore, improving the drainage system in slums will improve the health conditions as well.

The safety of drinking water can also be affected by drainage especially due to pollution of ground water table and water supply mains. This is frequently cited as a cause of disease outbreak in developing countries during flooding due to entrant of flood water into water pipe when watermains are not pressurised. As flood waters are usually contaminated with human wastes, this can lead to severe pollution of the water supply.

Ponding and blocked drains often provide breeding grounds for mosquitoes and habitat for snails. Poor drainage is therefore often associated with malaria and schistosomiasis, although nature of these problems depends very much upon local conditions.

## B1.2 Factors that Affect Performance

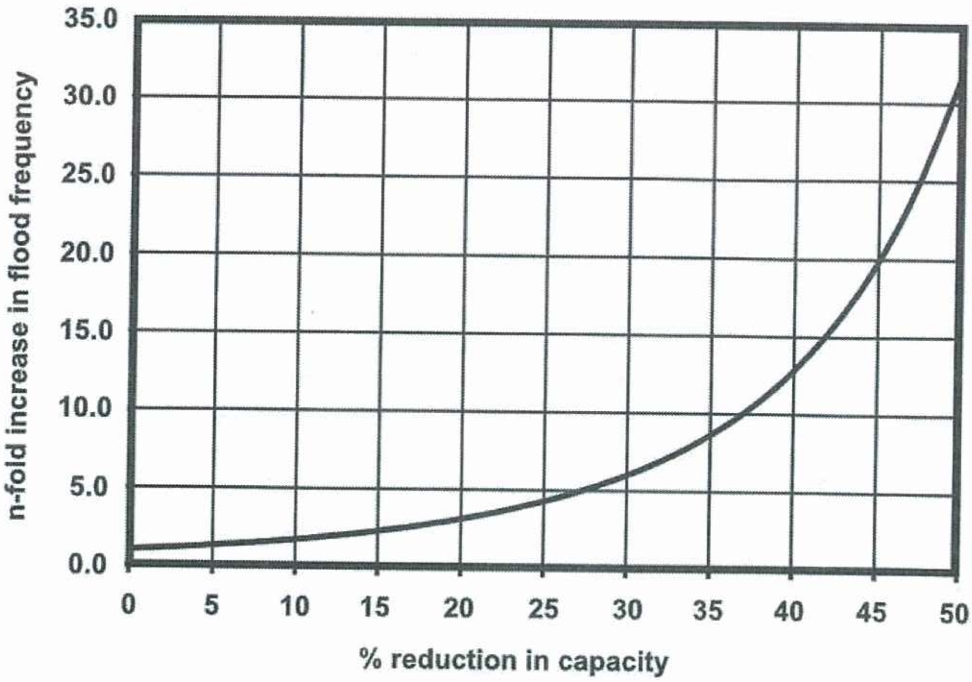
For either the planning or investigation, it is important to know the factors that affect the performance of the drainage system. The following are some of the important factors that affect the hydraulic performance of existing drainage system and recommended to be taken into consideration for the planning, design and construction of drainage system:

**<u>Type of Drainage System</u>**

Major or Minor Drainage – generally, every drainage system has major and minor drainage system. Minor drainage system is designed to convey moderate flows whereas major drains are designed to convey the flows due to extreme events when minor drains could not convey all stormwater to discharge point. Apart from this, major drains collect the storm runoff from number of minor drains. In almost all cases, the major system of roads and open space has not been designed or systematically considered, despite its critical role during flooding. Conventional designs focus on reducing the nuisance of relatively small and frequent storms by removing their runoff from the service area before significant flooding occurs. The weakness of this approach is not enough attention is given to what happens when floods do occur.

**Hydraulic Capacity**

The hydraulic capacity is one of the important elements affected by design consideration and also by construction and maintenance schedule. In developing countries, debris left in drains and trigger a process of solid build up which will reduce the hydraulic capacity and cause the flooding. Similarly, poor maintenance which leads to the build of solids over time is one of the main reasons for flooding apart from under size of drains. Sometime, design errors also become one of main reason for flooding. It can be seen from the following graphs that flood frequency increases with the reduction in hydraulic capacity. Similarly, depth, area and duration of flooding increase with the reduction in hydraulic capacity.




**Flood frequency increases if flow capacity is reduced**

**Street Grading**

The grading of street has a profound impact on depth, area and duration of flooding. Some engineers use street as surface drains during extreme storm events in developing countries especially in slums with serious reservation from the designer in developed countries.

**Inlets**

Generally, there is open and closed type of drains depending upon area to be drained. Open drains generally intercept runoff from open ground such as u-channels and easier to maintain as compared to closed drain. Whereas, closed type of drains convey the storm runoff within urban environment and they are difficult to maintain. The close drains generally runs along the public roads. The big advantage of closed drain is decreasing the entry of solids by reducing the number of inlet points and hence preserving the hydraulic capacity by minimising the deposition of solids. However, design of inlet points is very important to intercept storm runoff and thus minimise the chances of any flooding. Thus, inlets can easily become weakest link in the chain of closed drainage system.

**Catchment Surface and Storage**

The effects of urbanisation on runoff have been extensively studied by researchers and professional engineers. While the precise effects are difficult to estimate, the principal effects are in increasing the total volume of runoff, as the surface changes from a less permeable to a more permeable area, and the flow of runoff are accelerated due to directing flow in channels and reducing storage.

Table below shows the variation in runoff coefficient with different type of land use and slopes; the runoff factor can roughly be taken as 1.0 for paved surface. Urbanisation thus has a major impact on runoff through the conversion of relatively permeable areas to impermeable areas in form of paved surface. Therefore, the existing and future land uses have to be considered to assess the hydraulic capacity of existing and planned drainage system.

**Table: Runoff Coefficient**

| **Land Use Type** | **Runoff Coefficient** |
|---|---|
| Asphalt | 0.70-0.95 |
| Concrete | 0.08-0.95 |
| Brick | 0.70-0.85 |
| Grassland (heavy soil) | |
| Flat | 0.13-0.25 |
| Steep | 0.25-0.35 |
| Grassland (sandy soil) | |
| Flat | 0.05-0.15 |
| Steep | 0.15-0.20 |

Further, the ponds and depression are filled as part of urbanisation process which shortened the length of drainage path. This is reflected in variation in the time of concentration, generally defined as the time taken for water to reach the outlet from most remote part of the catchment. Therefore, urbanisation process shortened the time of concentration and hence runoff reaches earlier and results in higher peak discharge.

By contrast, storage in ponds, gardens, green spaces, and flat roofs cab substantially reduce peak flows. Rasoolpur village is the lowest point by considering the surroundings and the runoff from the surrounding discharge into the village. Apart from frequent flood inundation of Rasoolpur village, this also increases the chances of flooding in other parts of the city due to the loss of flood storage as a result of its development.

Storage in ponds, gardens, green spaces, and flat roofs cab substantially reduce peak flows. The detention basin often designed to reduce the peak flow at downstream of the basin; their effect on the flow hydrographs sketched in Figure below. While storage will not substantially alter the total runoff volume, it counteracts the effects of channelization, and allows the same volume to drain over a longer time.

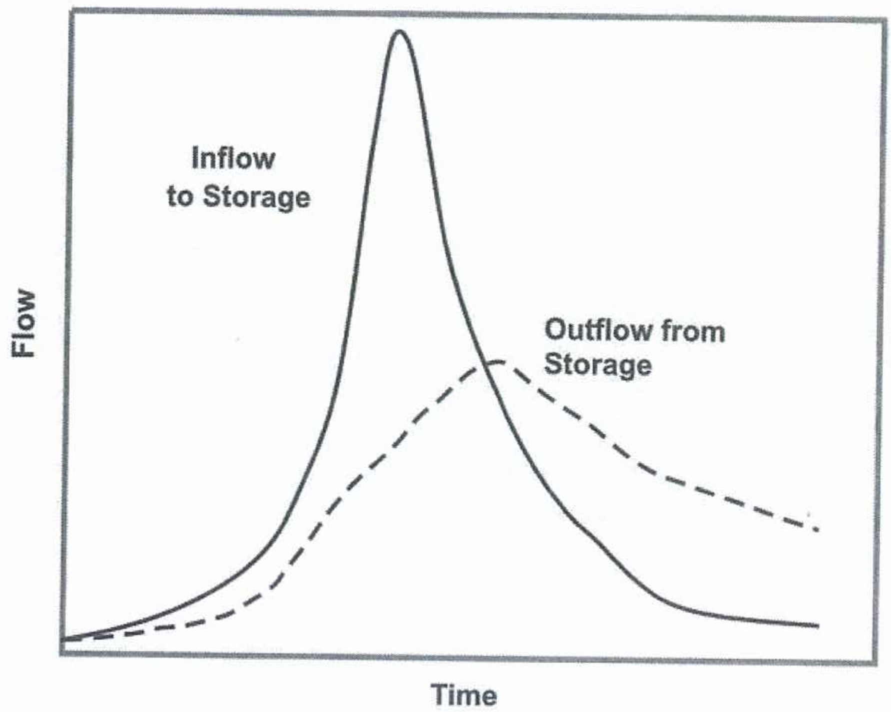



**Figure: Storage reduces the peak, but not the volume, of runoff**

Land use changes which fill in large open areas that become pond during rains will have exactly the opposite effect. They reduce the storage within the system and thus concentrate runoff discharge into a shorter interval at a higher flow. This can easily increase flow and make flooding worse.

## B1.3 Drainage Evaluations

The drainage evaluations will depend upon purpose of the evaluation. The following table describe a broad approach towards evaluation of the drainage system. Generally, the following are the three indicators to determine the performance of the drainage system:

- Performance measurement;
- Performance indicators;
- Process indicators.

Generally, an evaluation of the entire drainage system of a city is often required for funding or planning decisions about where and how much to invest in new facilities. Such an evaluation needs to take place on several levels, generally, this more focus on primary drains but less on the secondary or tertiary network. The focus on primary drainage is natural because of the complexity of drainage and the need to keep the scope of the study within the bounds. The problem of this approach is that many flooding incidents occur upstreams of primary drainage and flooding on those locations will not be reduced by improvement to primary drainage system. Therefore, it is necessary to evaluate at different levels.

Regarding who shall do the evaluation of the drainage system, it is hard to answer but generally it should be the one working with the system. A system wide drainage system evaluation should probably involve the following stages, although may not be carried out in strict sequence:

- Gather background data;
- Gather and review existing topographical and drainage system data and reports;
- Identify preliminary questions
- Identify information gaps;
- Perform field work;
- Gather additional data;
- Analyse the data; and
- Writing up the findings.

## B1.4 Studying the Catchment and Assessing Flooding as a Problem

The studying of the catchment involves estimating the runoff and performance of the drainage system within the catchment. This will require topographical data for the following purpose:

- to define the catchment area, and its sub-catchments;
- to determine the direction of flow in both natural and artificial systems;
- to compute flows and capacities in combination with other data;
- to identify bottlenecks or control points, which determine drainage patterns for the whole area.

Any evaluation based on inadequate topographic work will miss some of the most important constraints on the drainage system. There are no substitutes for good topographical data and no shortcuts to the work needed to obtain them.

***Level of accuracy***

It is impossible to prescribe universal requirements of accuracy. At the very least, topographic data should be at least as good as those that are normally used for design. In many cases, 'design' consists of simply specifying a lining for an existing ditch which flows by gravity, so that many drains are 'designed' without accurate topographical information. To evaluate the drainage system, however, someone must estimate its capacity, and will therefore need to know the slopes and levels. If the catchment is steep, topographic accuracy is less critical; and vice versa.

It is good practice to establish a series of benchmarks throughout the catchment with which to close traverses. Benchmarks must naturally be determined with greater precision than other levels, as any errors in them will be compounded in any measurements derived from them.

***Data to Collect***

It is important to obtain the following data in relation to catchment surface:

- spot elevations and locations at road junctions;
- elevations of road and roadside (is adjacent land above or below the road?);
- elevations and general topography of open areas;
- low and high spots.

In areas where flooding is experienced or expected, it is important to gather data on housing plinth levels and the levels at which water can enter the house as part of detailed investigation to identify the reason for flooding. In addition to gathering specific data at points of interest, the topographical data should be collected with a view sketching ground contours at suitable contour intervals, to show the general lay of the land, and to estimate the direction of flow.

The detailed analysis will also require information on invert level at junctions of drainage system and points where there is a change in slope, shape or dimensions of drain and length.

***Analysis***

As part of the studying the catchment, the following should be extracted for further analysis:

- the catchment boundary;
- drainage network location and relevant links and nodes (conduits and junctions);
- numbering of conduits and nodes;
- street identification;
- a scale of the plan;
- orientation.

***Profiles***

Once information on open channel or pipe sections and levels are gathered, the profiles of the drainage system can be plotted up. These are invaluable as a graphic description for the slope of the system, and often pinpoint problem areas, where subsidence or poor construction practice has created depression in the system, where silt and debris accumulate. Figure below shows a profile of a surface water drain, developed from structural survey; note the 'depression' in the pipe where sediment is likely to be trapped. Such a profile cannot be based simply on 'distances from ground level', but must use accurate survey work to allow for variations in ground level.

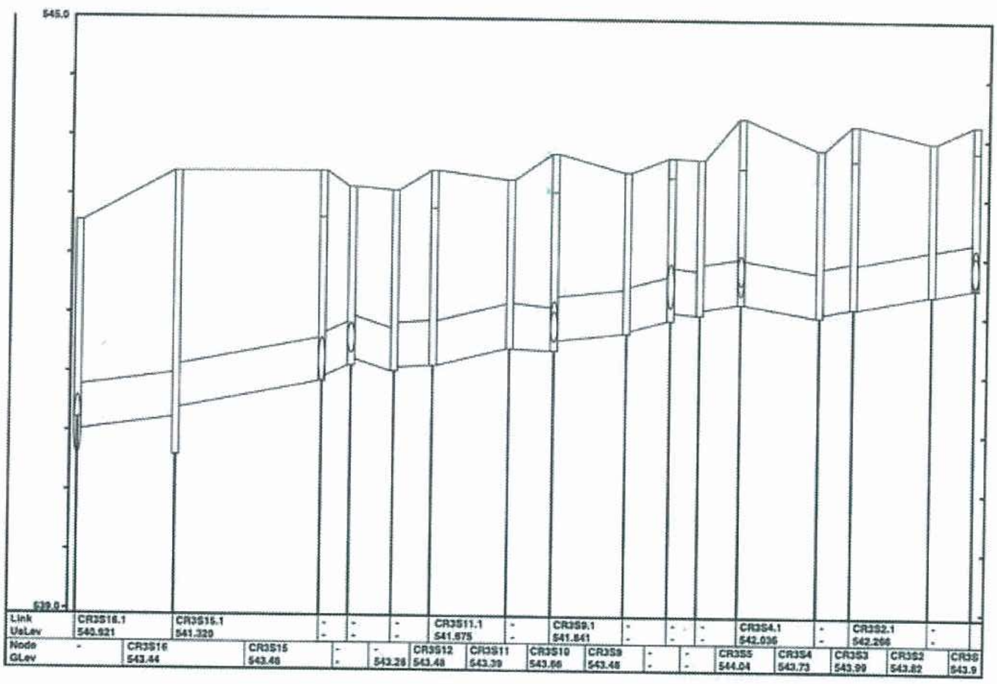



**Figure: Vertical Profile of the Drain**

***Defining a catchment***

As discussed previously, a catchment is simply the area that contributes runoff flowing past a specific point of interest. Thus the overall catchment is defined as the total area contributing to flow at the outlet of the entire system; subcatchments are defined for specific points further upstream along the main or tributary drains.

Defining a catchment seems a straightforward task, but there are often both practical and conceptual difficulties. One practical difficulty is that catchments are defined by topography and drainage networks, not by convenient ward, district, or contract site boundaries; that means it will probably be necessary to patch together several maps of different areas (often drawn to different scales!) to cover the whole catchment, and there may well be some portions that are unmapped. The conceptual difficulties arise in flat areas, where boundaries are unclear, and often determined by small drainage paths rather than topography.

These difficulties are real, but can be managed well enough for the purposes of practical evaluation. The main principle is to use the understanding of the topography and drainage network to define the areas contributing flows to different portions of the network. Once the outlines are sketched on a map, it is important to walk through the boundaries during a storm, to see if runoff is indeed flowing in the expected way; sometimes alternative drainage routes emerged (e.g. small drainage conduits, back alleys, or routes over properties) which may divert runoff away from the natural slope of the land. In particular, note the levels of roads in the catchment relative to the adjacent terrain. Are they at the same level and therefore simply part of the catchment? Are they set above the surrounding land, so that they act as subcatchment boundaries? Or are they set below the surrounding land, so that they act as drains for the adjacent terrain? This will vary from site to site within the catchment, but noting the difference between the road levels and surrounding ground levels is critical to understanding how the catchment behaves.

***Surface Type survey***

In addition to data on levels, evaluation will require study of the surface type in the catchment area to estimate the runoff coefficient. To keep the analysis simple and manageable, it is a good idea to reduce the number of land use types that considered for the estimation of runoff. In Rasoolpur, it is recommended to consider the following three types of areas:

- blocks or areas surrounded by roads with houses and buildings;
- roads; and
- open spaces.

It may be easier to tackle a survey of each of these separately. Good maps will make this work much easier, so the land use type survey should follow the topographic work. With good maps, the fraction of the catchment taken up by roads can be estimated as a desk study, with spot checks in the field to ensure the quality of the mapping. The main field work will then be to determine how much of the open or developed land is paved or covered with housing, and what other kinds of cover are present.

**Assessing Flooding as a Problem**

Regarding flooding assessment as a problem, there are generally five methods for assessment of drainage performance and the nature of flooding:

- resident surveys of the community about flooding;
- direct observation during rain storms;
- a resident gauges which are local landmarks (e.g. telephone poles/boundary wall) marked as scales by which local residents can observe flooding depth and duration;
- chalk gauges which are chalk-coated metre sticks, installed in protective boxes into which flood waters may enter;
- electronic level gauges, which record the water level with respect to time.

In general, resident surveys and direct observation are more than adequate to describe flooding problem, and together represent reasonable performance indicators. The other methods are more direct performance measurements, but are also more difficult to manage, and are unlikely to be of much practical use except as a research tool.

## B1.5 Flow Estimation

The volume and rate of runoff depend upon catchment area, land use type and rainfall pattern. It is important to have an estimate of peak discharge to assess the hydraulic performance of an existing drainage system or for planning and design of future drainage system. In simplified term, the peak discharge from the catchment can be estimated by using Rational Method as the following:

Q = 2.78CIA, where;

Q is peak discharge (litre/second),

C is a dimensionless runoff coefficient depend upon landuse type,

i is rainfall intensity in mm/hr, and

A is catchment area in hectares.

### Catchment Area and Landuse Types

The Rational Method provides peak discharge to the drainage system. But, this method has certain limitations such as only providing the peak discharge from the catchment. Further, the effects of land use type will have significant bearing on peak discharge from the catchment. The topographic and land use survey should allow estimates of both contributing areas and land use types at various critical points in the system. Sometime 'effective area' is used which is simply the product of the runoff coefficient and the catchment area being considered.

As the urban community develops, the open grounds have been filled for housing and transformed into impervious areas. This results in increase in runoff. Such analysis is helpful when considering plans for future developments, and assessing their impacts upon existing and planned drainage systems.

### Rainfall intensity

The other great influence on flow, besides total area and land use type is the rainfall intensity. This is one of the most uncertain aspects of drainage evaluation. There are several approaches that can be used, depending upon both the data and resources available. These include:

- Use of a full set of intensity-duration-frequency (IDF) curves derived from locally available rainfall data recorded continuously through a rain gauge.
- Use of an approximate IDF curve derived from limited local rainfall data (e.g. hourly or daily rainfall data).
- Use of a single design intensity, e.g. 25 mm/hr (possibly varying with duration or catchment area), from a handbook. This may vary from place to place.

Most hydrology and drainage textbooks describe the use of IDF curves. These curves show how the intensity of rainfall decreases with both duration and frequency. The maximum intensity of rainfall over 10 minutes is much higher than the maximum intensity of rainfall over an hour, for a given return period; the most intense hour often includes the most intense 10 minutes, along with 50 minutes of less intense rainfall, and this automatically brings down the average.

Figure below shows some typical curves extracted from relevant text books. It is important to understand that these curves do not describe the rainfall pattern of individual storms. These simple IDF curves are a rational and practical way to estimate design flows for comparison with system hydraulic capacity.

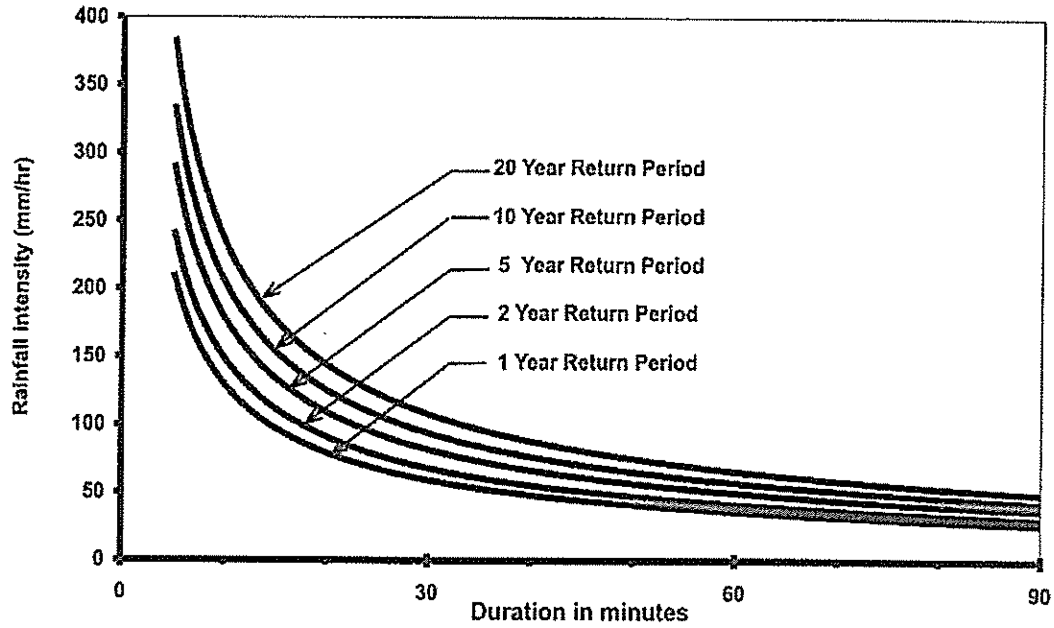



**Figure: Example of Intensity Duration Frequency Curves**

## Using IDF curves to estimate flows

Intensity Duration and Frequency (IDF) curves are the relation developed after analysing the past rainfall data. In a drainage design, the chosen return period reflects some judgement about the relative costs of drainage works and flood protection. The ideal return period shall be chosen such that any additional investment in flood protection will cost more than the extra flood damage it prevents. In practice, performing such an analysis is too complicated, uncertain, and time consuming to be undertaken on a regular basis. Judgement, experience and common practice are usually substituted for rigorous economics. Common criteria include the selection of a five-year return period for business districts, and a two-year return period for residential areas from country to country. There are strong arguments for using short return periods in developing countries such as in India where the money available for investment in drainage is very limited. Unfortunately, development of IDF curves showing return periods of less than a year is not a common practice. Whereas in some well developed cities such as Hong Kong, trunk drains are designed from 1 in 50 years to 1 in 200 year return period events depending upon land use type.

Most IDF curves are based on the largest event of each year, and these cannot easily be extrapolated below the I-year level of return period; as noted earlier, the pattern of variation within years is likely to be quite different from the pattern of variation between years.

In practice, it may be worth evaluating systems at a range of return periods. Where time is limited, it is recommended to start with a very short return period of one year or less, as this will identify the most frequent shortcomings. As we have seen earlier, the variation of intensity with return period is slight compared to the variation of runoff with land use type, so it is more important to put effort into assessing the land use type.

## Rainfall Duration

In Rational Method of runoff estimation, the peak discharge is generally predicted for rainfall duration equal to the time of concentration tc. The time of concentration is generally the time it takes for water from the most remote portion of the catchment to reach the point where flow is being estimated. If duration longer than this is chosen, the intensity will diminish, thus yielding a lower flow. If a shorter duration is chosen, more intense rainfall will be assumed, but the farthest reaches of the catchment will not have time to contribute to the flow. Where flows are combined from catchments of different sizes and times of concentration, it may be necessary to check the times of concentration for different subcatchments. This is because a subcatchment with a large area and a short time of concentration could yield more flow than the entire catchment with a longer time of concentration determined by a very small but distant subcatchment. The time of concentration ($t_c$) has two components: the time it takes to enter the drainage system (inlet time $t_i$ and the travel time $t_t$ it takes to travel through the drainage network to the point under consideration at which flow is being estimated). The inlet time is often taken as 15 minutes minimum for very small catchment which may result in small time of concentration and high intensity.

## B1.6 Assessing Drainage Capacity

This section describes how to estimate hydraulic capacity for comparison with estimated flows into the drainage system.

**Concepts of capacity**

What do engineers mean when they refer to the 'capacity' of a drainage network? In general usage, the capacity is the largest flow that can pass through the network without causing flooding. There are a number of aspects to this definition that need to be thought about carefully.

In the above definition, capacity appears to be defined precisely in terms of a single value of flow. In fact the capacity of a network is not fixed, but will vary with circumstances. One obvious example is a drainage system that discharges to a river; the capacity is reduced when the river level submerges the outlet of the drainage system. Alternatively, the discharge capacity may increase with the hydraulic slope when the upstream water levels 'back up' above the crown of the pipe, but the outlet remains free. Drainage systems can also manage higher flows at the beginning of a storm (as empty channels and pipes fill) than they can later on when all storage is filled. Given these and other variations in hydraulic conditions, it becomes clear that no single number can define the maximum rate of runoff that may be managed.

A drainage network is like a chain; it is only as strong as its weakest link. The capacity of a network can therefore be assessed only by determining the capacity of its individual sections. This means looking not only at the capacity of the pipes or conduits, but also at the capacity of inlets.

**Three types of capacity estimation**

There are three types of capacity worth considering in a drainage evaluation: design capacity, as-built capacity and actual capacity. These capacities can be understood as the following:

**Design capacity**

- is based on design drawings;
- is relatively straightforward to compute;
- may easily identify bottlenecks;
- serves as an initial estimate of the upper limit of capacity for the drainage system.

**As-built capacity**

- is based on estimation using 'as-built' dimensions and levels;
- is usually less than design capacity;

- does not consider blockages or obstruction by solids;
- serves as a more realistic upper limit of capacity without major construction changes.

**Actual capacity**

- makes explicit allowance for solids levels, and actual blockages;
- requires significant field work and judgement;
- is more approximate, but more meaningful, than other measures.

In capacity evaluation, much depends upon the quality and quantity of information already available. The computation of design capacity makes sense only where good clear drawings are readily available. The other capacity estimates are always more meaningful, but if good drawings are available, a quick estimate of design capacity may help identify areas worth studying in greater details. Where good design drawings are not available, it makes sense to move directly to as-built and actual capacities.

## B1.7 Drainage Network Structural and Maintenance Survey

As mentioned in the previous section, it is useful to separate 'as-built' capacity from other capacity caused by temporary blockages or solids deposition. These constraints need different types of solutions to improve performance. If the drain laid on a flat gradient, the solids deposit along the invert of the drain. This may appear to be a 'maintenance' problem, when it is actually caused by poor design, poor construction, or both.

This section describes survey techniques to check the structural conditions which limit as-built capacity. This section will focus on measurement of maintenance and solids that further reduce capacity. The maintenance surveys are generally repeated depending upon public complaints or for monitoring purpose, to see how deposition of solids and debris change with time.

As the drainage system gets older, it is important to assess the structural condition of the system through the survey. In those circumstances, the structural and maintenance survey combined together for evaluation of existing drainage system can minimise the cost and the inconvenience to general public by closing the roads as well.

**Conduit Measurements**

*Dimensions*

The dimensions of cross-sectional area and length of the various conduits are critical for capacity estimation, and can be measured simply with a tape. It is important to let surveyor knows exactly what is to be measured. For a trapezoidal channel, it is important to measure top and bottom width apart from depth. Figure below shows some common definitions of terms and measurement of the drains to be taken for analysis.

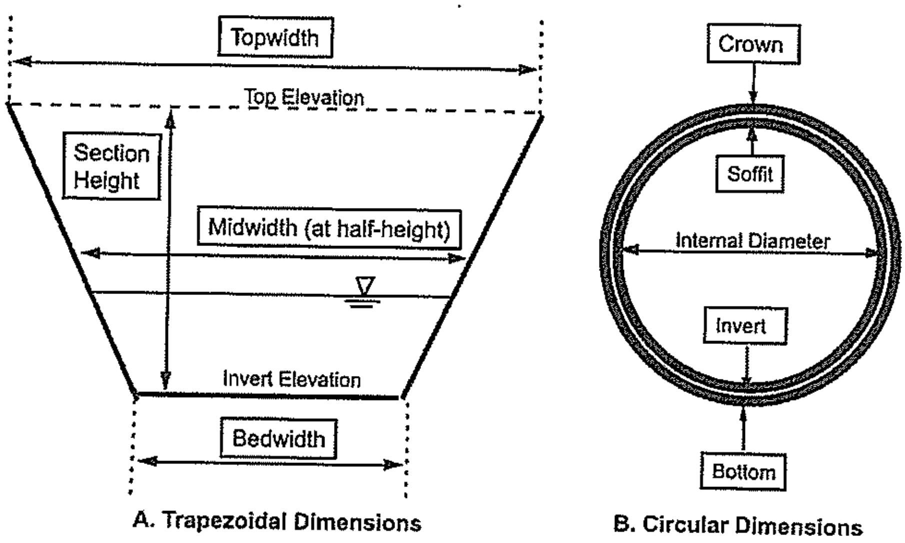



**Figure: Main Conduit Dimensions and Elevations**

From hydraulic perspective, the inner dimensions of the conduit are the important ones. Whereas from structural perspective, the outer dimensions are important. No level is required to gather dimensions, but measurements of 'relative elevations' of soffits or inverts must be made with respect to a fixed point for which the level may be easily found. Field workers sometimes prefer to measure the outside dimensions of a pipe, as these are often more accessible. If this is done, the pipe thickness must be measured.

*Levels*

Levels are critical in determining hydraulic capacities of the drainage system. The invert levels and cover levels are important to assess the hydraulic capacity and to assess free board available at junctions. Surveys therefore should involve measuring dimensions such as 'depth to pipe invert' from the ground surface. Closed conduit systems are particularly troublesome because surveyors can observe the conduits details only at manholes.

## Condition of Conduits

*Open Conduits*

It is relatively easy to inspect open drains to determine their structural condition, slopes, and any blockages. The easiest case is that of a clean surface water drain containing no sewage or sullage in which simple visual inspection of the channel is sufficient. Where solids cover the bottom of the drain, these must be cleared to measure the depth and assess the structural condition of the bottom. Where the drain carries sewage or sullage, inspection is more difficult, and is best done during the low flow condition.

*Closed Conduits*

It is much more difficult to evaluate the condition of closed conduit storm drains as compared to open drains. For open drains, inspection is easiest where drains are truly separate. Even in this case, however, unless the closed drain is very large, or manhole spacing is unusually frequent, it is difficult to assess the condition, except by spot checks at manholes. However, with the advancement of technology, closed circuit television (CCTV) technology is used to assess the condition of closed conduits between manholes. Unfortunately, CCTV technology is expensive and therefore not widely adopted in developing countries.

Safety is an issue when working in drains and especially in closed drains entering into deep manholes. Certain basic precautions as per regulations shall always be followed which can be found in health and safety regulation.

*Manhole Inspections*

Often there is no alternative but simply to get down to the bottom of the manhole for manhole inspection. Many drains are too small and shallow to allow the survey workers to inspect along the drains from manholes and therefore recommended to carry a mirror to reflect the view from the mouth of pipe. To identify any blockage, an illuminated lamp can be lowered down from other manhole and blockage can be viewed through the mirror. Alternatively, the photographs can be taken from a camera but will require entering into the manhole to record the condition along the pipe. In order to document the record for reference in future, it is important to record the location of manholes and photographs nos on a sketch.

Apart from pipe/conduit, the manhole inspection also serves the purpose to inspect the structural condition of the manhole and any blockage. Further, the hydraulic condition of the manhole is different as compared to a conduit. The manholes are designed at junctions of drains or for change in flow direction which result in reduced velocity and result in deposition of solids. In order to avoid deposition of sediment in conduit, the manholes are designed to trap the silt/sediment similar to the arrangement as below.

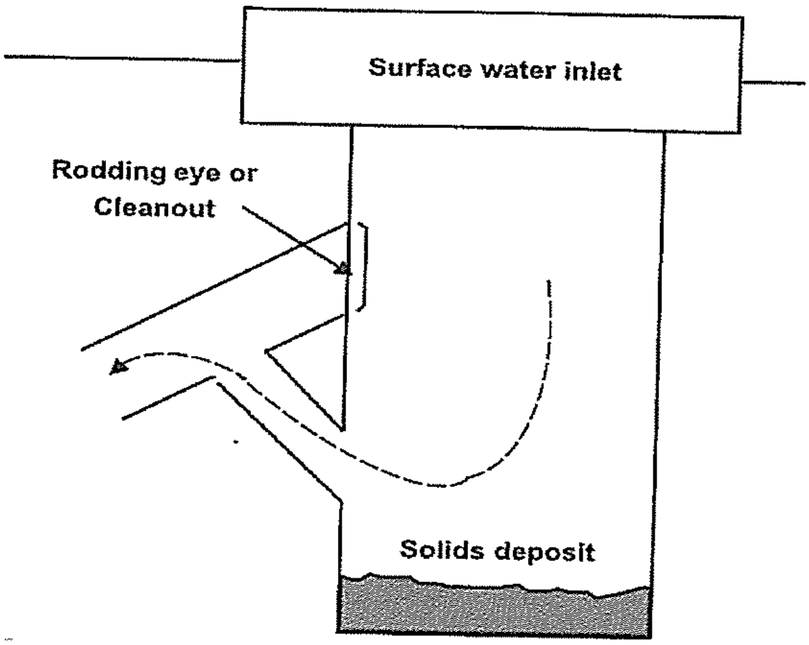



**Figure: A gully pot installation to trap solids before their entry to the drain**

**Drainage Maintenance Survey**

The routine drainage maintenance survey consists of (i) periodic removal of solids deposits and blockage from the network and (ii) to perform the routine repairs. It is easier to assess the deposition and removal of solids from open drains as compared to closed drains. In closed drains, the deposition of solids at manhole will provide a relative magnitude of deposition problem along the drainage system without quantifying deposition along the conduit.

In open drains, visual inspection and solids levels provide estimation on the silt deposition for the planning of maintenance work. In addition, this also helps to assess the operational hydraulic capacity of the drainage system.

Apart from the level of solids in the drainage network at a particular time, it is worth knowing how quickly the solids accumulate. If a clean drain gradually fills up over a year, then an annual cleaning, just before the onset of rains, is adequate. If the drain fills up in a month then drain need to be cleaned more frequently especially after every rain storm. If slopes are good and solids don't accumulate, then cleaning need not be scheduled at all, and can be done only in response to complaints as when they arise.

## B1.8 Studying Drainage System in Action

The best way to understand the actual behaviours of a drainage system is to start monitoring the hydraulic behaviour during rain storm. This is difficult and does not produce the same kind of data as can be obtained through the flow survey measurement. Specifically, wet weather studies are the most effective way for the engineer to assess:

- Catchment and sub-catchment boundaries;
- The nature of flooding in flood prone areas;
- The hydraulic performance of total drainage system;
- The surface flow routes followed by runoff during floods;
- The public nuisance, hazard, and damage associated with flooding.

It is also possible to collect time variation of water level and discharge which is important for the calibration of the hydraulic model. There is a tremendous difficulty and great benefit in doing the wet weather flow monitoring but should be aimed with a clear objective because of significant investment involved.

Generally at the interface of two catchments with relatively flat land and not adequate topographical survey data available, it is difficult to identify flow pattern. In these areas, minor variations in levels can lead to substantial changes in contributing areas, and flow may enter the drainage network at unlikely locations. For pipe system, for example, some inlets may end up intercepting little or no flow because of irregularities in topography.

In flood plane areas, the nature of flooding will vary from place to place. However, it is useful to collect information how frequently a particular site flood in rainy season such as Rasoolpur village for planning of the resources. Further, observation of flood prone areas often clarifies the cause of flooding, such as inflows from other areas, or inlet capacities.

Apart from this, the best way to see the difference between the design capacity and actual capacity of a drainage system is through a systematic survey during rain storm. Such a survey can establish:

- overflow locations;
- bottlenecks and high head losses e.g., culverts
- obstructed entry to drain, either by inlet blockage, poor inlet design, or poor surface grading.