

Preparation of the Stormwater Drainage Management Plan for Matara Municipal Council

N.T.S. Wijesekera and K.M.P.S. Bandara

Abstract: Matara Municipal Council area had been experiencing stormwater drainage problems causing inconvenience to public, interruption to work and damage to property. Though the Matara Municipal Council (MMC) had carried out a project in 2001 to develop its drainage canals, there were many cases of flooding within its boundary limits. In order to achieve a suitable plan for stormwater drainage management, the present work carried out an analysis of the associated stormwater drainage system. Systematic field data collection activities were done to identify the flood problem of the area, and to capture sufficient details of terrain and drainages. GPS surveys were conducted to identify the road and drainage alignments. A main feature of the study was the conduct of a road drainage survey which among many other details captured drainage directions along and across the roads. This survey helped to rationally identify the undulations in the terrain to generate the digital terrain model for the generation of stream network and delineation of watersheds. The 1:10,000 elevation data supported by the field work information showed the capability to generate a representative topography for stormwater drainage assessments. Analysis also used a simple Geographic Information System to prioritize critical flood affected areas and enabled identification of critical watersheds for engineering interventions. The present canal system was evaluated with that generated by the model and several sections were identified for early drainage designs these locations were verified in the field. Present work identified that in the MMC area 42% of roads coincide with the stream network indicating a loading of street stormwater drains with runoff generation as a result of terrain changes affected at individual compounds. 164 identified flood locations were analysed with drainage directions and surrounding elevations supported by detailed engineering inspections at specific locations to provide short term solutions. The study made recommendations with respect to development plan approval procedures, preparation of a suitable stormwater drainage database and the need of guidelines for developers to mitigate stormwater drainage problems as part of the long term solutions.

Keywords: Urban, Stormwater, Drainage, Management, Terrain Model, GIS, Flood, Field Survey.

1. Introduction

Urban areas often experience drainage problems causing flooding to disrupt human activities and leading to numerous environmental problems such as creating mosquito breeding grounds, washing away of garbage to undesirable places, creating stagnant water holes generating unpleasant odour and deteriorating road surfaces. Urban area flooding is usually attributed to new developments blocking the natural waterways, land filling creating changes to drainage directions, filling of flood retention and detention areas, and diversion of natural streams to road side drains etc. In near coast urban centres the low-lying lands also cause drainage problems thereby leading to flood situations when land use changes are conducive to higher runoff generation than that were previously experienced.

The Matara Municipality Area (Figure 1) had been experiencing stormwater drainage problems causing inconvenience to public, interruption to work and damage to property. The reasons cited for poor stormwater drainage had been given as, the non existence of natural drainage to the sea because most of the lands are either below the sea level or at the same level, many buildings and boundary walls have come up obstructing the natural drainage paths, uncontrolled landfills creating obstacles for flood water flow and storage, lack of proper drainage of stormwater as a result of

Eng. (Prof.) N.T.S. Wijesekera, B.Sc. Eng. Hons, (Sri Lanka), P.G.Dip(Moratuwa), M.Eng.(Tokyo), D.Eng.(Tokyo), C.Eng. FIE(Sri Lanka), MICE(London), Senior Professor of Civil Engineering, Department of Civil Engineering, University of Moratuwa.

Eng. (Dr.) K.M.P.S. Bandara, B.Sc.Eng. (Sri Lanka), M.Sc (Geoinformatics-Netherlands), PhD(Netherlands), MBA (Colombo), C.Eng, FIE(Sri Lanka), MICE(London), Director of Engineering Service Board, Ministry of Public Administration & Home Affairs.



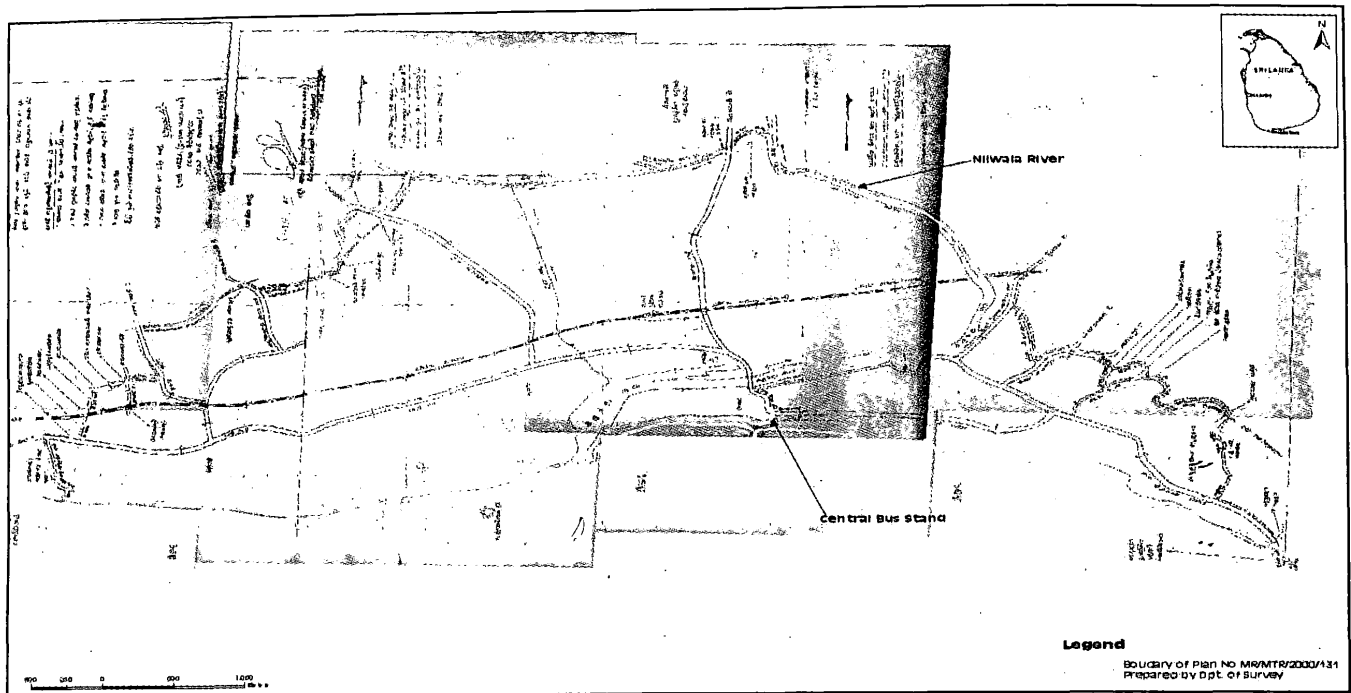


Figure 1 - Survey Department Map of Matara Municipal Council Area

construction activities without proper plans or control and also issues such as land filling activities without making provision for natural streams and drainage paths. In order to identify the stormwater drainage issues and to carry out necessary mitigatory activities, the present work was undertaken to prepare a stormwater management plan for the Matara Municipal Council (MMC) area.

The present work describes the preparation of a stormwater management plan based on field work and mathematical modelling, the details of field work carried out, along with engineering and management options recommended as short term and long term solutions.

2. Objective and Specific Objectives

2.1. Objective

The objective of the present work was to analyse the stormwater drainage system and to recommend stormwater management options for the Matara Municipal Council area.

2.2. Specific Objectives

- I. Characterization and delineation of Matara Municipal Council (MMC) area watersheds
- II. Characterization of land use conditions affecting the runoff generation

- III. Characterization of Drainage Patterns
- IV. Identification of stormwater drainage canal infrastructure within the MMC area and the surrounding areas
- V. Identification of existing problems in the stormwater conveyance system
- VI. Identification of the stormwater runoff discharge problems through the existing storm drainage system and the associated canals
- VII. Identification of potential alternatives and a strategy for long and short term management of stormwater drainage in the Matara Municipal Council area

3. Methodology

Overall methodology used for the plan preparation is schematically shown in Figure 2. Data was collected to capture the background to the problem and also to perform a situation assessment. Activities carried out to achieve the specific objectives are as indicated below.

- Agency Data Collection, Reviewing Data and Information of Study Area
- Watershed delineation, land use and physical parameter characterization
- Characterization of the drainage, stream banks and associated environmental conditions through a detailed survey and other fieldwork

- Identification of the stormwater drainage system infrastructure locations and dimensions, and survey of key parameters

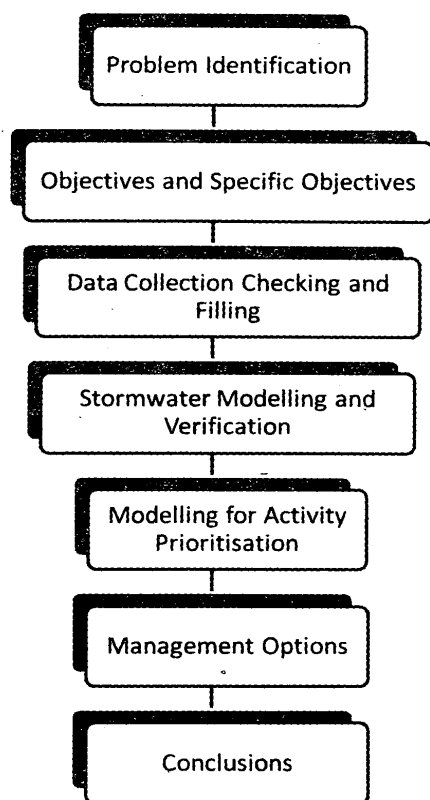


Figure 2 - Methodology Flow Chart

- Terrain model development, runoff system generation and associated field verification
- Development of a Geographic Information System to carryout spatial analysis of stormwater drainage problems
- Identification and evaluation of stormwater management alternatives
- Meetings and Coordination to perform progress review, management and coordination of activities between the field staff and managers, inter agency discussions etc.
- Preparation of outputs and associated documents such as results of the stream assessments, maps of drainage patterns, present locations, problem areas, proposed structures, model and outputs.

4. Reconnaissance

Floods in an area at close proximity to a major river and its floodplain can be due to two reasons. One is due to floods arising from river overflow as a result of rainfall experienced in

the upstream watersheds and the other is due to inadequate drainage as a result of rainfall that directly falls in to the project area (Mays 2004). During the study, an assessment of the present flood drainage system of the MMC area was carried out. In the MMC area two distinct flood bund sections are in existence to prevent flood water of the Nilwala river reaching the MMC area. A pumping station is in operation to discharge drainage water of the Thudawe Ela to the Nilwala river. Gravitational flow of drainage water from the MMC area and close to the bunds had been restricted due to the construction of bunds. In this area a fresh path for the gravitational drainage had been facilitated through a canal linking the restricted area to the upstream of pumping station. A Major drainage canal network had been designed and developed in 2001 under a project called "Improvements to Stormwater drainage in Matara Urban Council Area". Development activities are taking place in most of the area. Many evidence of clearing land cover and earth filling could be observed. These locations were even visible in the available satellite imagery. Major drainage canals in the MMC area that had been improved recently are included in the Figure 3.

4.1. Field Visits and Discussions

Field visits and discussions with officials and public were carried out to identify the functioning of the drainage network and the associated problems. Initial discussions with MMC officials enabled the identification of fifteen locations of reported flood problems. Visits to each of the sites revealed that some were significant and others were insignificant. Significant problem locations were identified as the locations which inundated the roads and property causing unbearable inconvenience to public. Field visits and discussions with public at various locations revealed that the major canal network draining surface water generating from within the city area, did not function as expected and hence either flooding was taking place or there were stagnant water with unpleasant water quality. At places near the flood bunds, the public indicated that the natural streams which were initially draining across the bund alignment are now forced to drain in a different direction. There were complaints that the new canals do not function as expected.



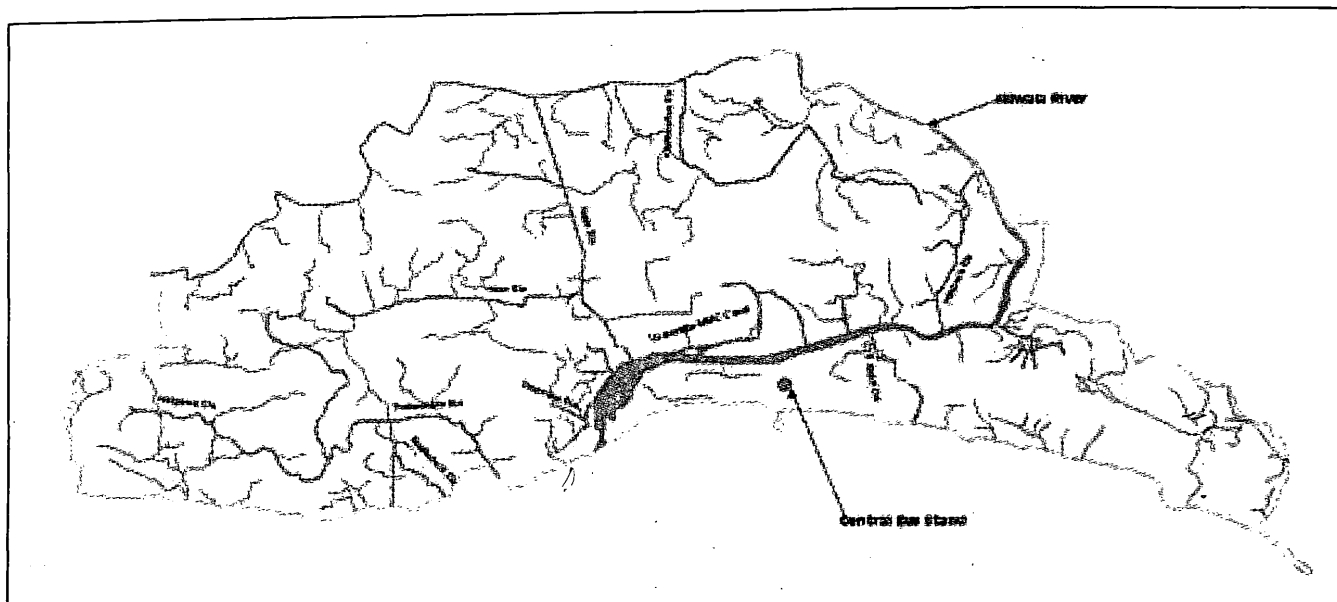


Figure 3 – Major Drainage Canals

In many of the canals there was significant pollution due to stagnant water. Nearby residents complained about the foul odour. The elderly indicated that when they were children, they had bathed in these canals which then carried clear water. At the field visits it could be identified that the drainage canals were not even a bearable sight. At many locations, public complained about increased flood inundations experienced year after year. City dwellers blamed the new property constructions and disposal of stormwater from homesteads on to the roads as the cause for increased inundation and poor drainage. On many occasions and at many locations it could be observed that land filling was taking place. In almost all houses, stormwater drainage from compounds were directly connected to the road drains or to the nearby low lands. Houses constructed at lower elevations had weirs constructed at the entrances in order to obstruct the natural flow of water over the terrain. Construction of boundary walls blocking natural drains was a common sight. Public were of the opinion that the remedy to the flooding of a land is to raise the elevation of that particular land. If the land filling is not practicable then the public would seek excavating or cleaning drains through other lands or along roads. Those who are unable to do any of the above, were suffering and were resorting to making complaints to the public bodies and officials.

These initial field visits and discussions with public revealed that the Matara Municipal area

stormwater drainage problems are not due to the Niwala river water flooding the MMC area but because of issues that rise in the process of draining local rain water out of the dwelling and commuting area.

5. Data Collection, Checking and Filling

5.1. Field Data Collection

Available map and report data (Table 1) had to be satisfactorily updated and strengthened in order to identify stormwater management issues pertaining to the drainage of water from the catchments within the MMC area. For this purpose, updated road and canal layouts and elevation details were identified as necessary to support the stormwater modelling.

Field work were undertaken to update the road network. A GPS survey was carried out to capture the road alignments, points of drainages that were intersecting the roads, drainage alignments, culvert locations, and reported flooding areas. A separate field survey was carried out to capture the drainage pattern along the roads, relative elevation of lands with respect to roads, drainage structure details, flooding information along the road network, and nature of built up area along the roads of the MMC area.

5.2. GPS Survey of Roads and Culverts

Magellon Triton 2000 and Magellon 600 hand held GPS mounted on vehicles were used to-

Table 1 - Map and Report Data Availability

Item	Data Type	Data Details	Remarks
1	Boundary Maps	Map of Municipality available with the MMC Map of MMC in the Greater Matara Development Plan of Urban Development Authority Survey plan MTR/2000/131 of 31 st March 2000 done under the directive of Surveyor General.	Boundaries of these maps did not match with each other
2	Topographic Data	Survey Department Data made available by the MMC. Scale 1:10,000, Buildings, Contours and Spot Heights of the project area Survey Department Topographic Maps of 1:50,000	Consisted of Four Sheets which required edge matching. Hard copies scanned and Georeferenced.
3	Engineering Survey Sheets	Engineering Survey(ES) sheets of Survey Department, 1995, Scale 1:5000, spot heights, building and roads	Blue Prints, scanned and Georeferenced
4	Satellite Imagery	Satellite imagery of 2001 and 2007, in Picture format, resolution approximately 0.5 meters, color.	Georeferenced to the project area
5	Internet Map Extract	Google internet site imagery, screen capture, JPEG format	Mosaic prepared and Georeferenced
6	Project Report	Stormwater System Improvement, Urban Development and Low Income Housing Project, Funded by Asian Development Bank, Design rainfall values and runoff coefficients, design drawings.	
	Development Plan	Plans for the Urban Development Area of Greater Matara (Volume 1 and 2), UDA development plan, 2005 Guidelines for future development, development regulations, zonal information and urban planning targets	

track the road network at a longitudinal resolution of 20 meter. Capturing of important points such as road beginning and end; junction and structure locations was supported with specific waypoints. The GPS data captured through this methodology were verified with plots on satellite imagery and through field testing of sample areas. Culverts for significant drainage that cross the roads were captured during the same field survey.

5.3. Road Drainage Survey

A detailed field survey of road network at approximately 30 meter longitudinal resolution captured information pertaining to stormwater drainage characteristics and flooding information. A datasheet was prepared for the survey to enable easy recording of data. Some data collected were based on measurements whereas some numerical records were based on visual approximations. Survey data collectors were trained at both off and on site locations. The developed datasheet was tested with pilot surveys. The data sheet used is shown in the Annex 1. This datasheet was carefully designed and field tested using numerous trials, to capture details on a sketch which required minimum recording during field work. Details

were captured from both sides of the roads. Culvert details, flood inundation depths and durations, availability of boundary walls, relative elevation of adjoining lands, percentage of built up area, drainage directions along the road and drainage directions across the road were the data collected at each road section of approximately 100 feet (~30m). Collected field survey data were checked for position and the alignment with the use of satellite images. GPS survey of roads was also used to check data compatibility. Random checking of data capturing sheets verified the accuracy of field data collection. Survey data collectors were given a briefing prior to data collection missions. Each team of data collectors consisted of three persons with one for recording on the sheet and the other two to capture information pertaining to the road and also to make necessary measurements. Surveyed data were mapped on to 1:5,000 scale sheets of base datasets. Road survey was carried out for almost all roads except short private roads leading to specific dwelling units. A total of 165 kilometres of roads were surveyed at the said resolution



5.4. Drainage Detail and Status Survey

A field survey was conducted to capture the locations which had attracted public complaints about poor stormwater drainage. These locations were visited and details were collected including discussions with residents and collection of location photographs. Flood problems were cited with local name of the drainage canals and therefore needed comparison with map data for clarification. A detailed drainage line field survey was conducted to assess the field situation of the drainage canals and to capture other relevant details.

5.5. Data Checking and Filling

All maps were scanned and georeferenced to the Kandawala datum enabling the features to be extracted and were utilized for GIS based computations. Data layers were then printed to a scale of 1:5000 and random field checks of reported information was performed. Data were checked for consistency, and accuracy. In case of elevations when absolute values were not known, a relative comparison of either the data from the same dataset or from different datasets was done to identify disparities. Data showing inconsistency were taken out and wherever possible missing data were given reasonable values considering the surrounding values supported with field visit information. Where the canals had been rehabilitated but the elevations were not available, design gradients in the drawings were used to compute approximate elevations. In cases where canal bank elevations were not available, the ground levels from the topographic maps were taken as the bank elevations. In case elevations of only one bank was available, then the elevations of both banks were considered equal. The drainage and stream alignment were checked closely with the satellite imagery and the traces were adjusted to suit the tracks shown in the satellite imagery. Road traces were also checked, field verified and adjusted in a similar manner. The data checking activity was combined with field visits to ensure data accuracy suitable for computations.

6. Stormwater Modelling

6.1. Terrain Model Development

The assessment of stormwater drainage issues requires identifying the geography of the MMC area in sufficient detail and hence a satisfactory digital terrain model of the study area is

required. A terrain model for the assessment of drainage in MMC needs to ensure necessary terrain features for watershed delineation in a flat terrain. Also this terrain model needs to be of sufficiently high resolution to capture the localized flooding issues reported by the public and the Municipality officials. Stormwater generation is highly dependent upon the built up and non-built up area. Therefore it is also necessary to capture the land cover information with adequate representation of the built up area. Accordingly terrain model development was commenced with the use of collected information from maps and reports.

6.1.1. Spatial Resolution

In order to model the stormwater drainage in the project area, various spatial resolutions were taken into consideration (Maidment and Djokic 2000). A spatial resolution of 5m was selected by considering the adequacy of details for a management plan, and also considering the computational time required for high resolution data processing (Dutta, Herath and Wijesekera, 2002). Modelling work were also carried out to compare 35m and 50m spatial resolutions and it was noted that such coarse resolutions prevented the reflection of finer details required for stormwater modelling in urban flat terrain.

6.1.2. Elevation Data Adequacy

An attempt was taken to develop the terrain model using available spot heights and contour information of the 1:10,000 scale maps in order to capture terrain and associated changes that had taken place since 2002. The available major drainage canal bed and bank elevations from design drawings, identified railway embankment and the flood bunds, and Nilwala river details etc., were incorporated to prepare the digital terrain model pertaining to the year 2002. MMC area at a data scale pertaining to 1:10,000 reflected only the general flat terrain outline with a very limited hilly area in the western side and in the eastern side of the project area (Figure 4). The only hilly area within the flood plain and at close proximity to the Nilwala river is approximately in the North Eastern side of the MMC area and this patch of high land had been used to bridge the two flood bunds presently protecting the city from a Nilwala river waters. These mapping efforts revealed that spot heights and contours of topographic maps were of a resolution incapable of reflecting the undulations that would lead to interpret the present stormwater drainage problems.

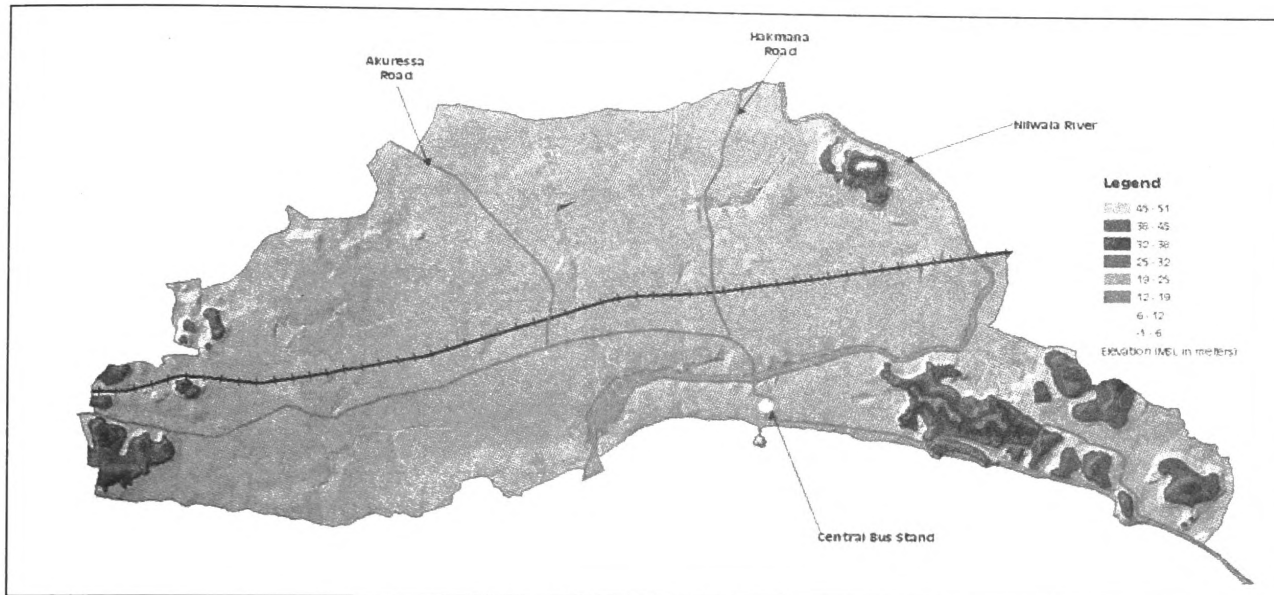


Figure 4 - Digital Terrain Model with Major Features, Canals and the 1:10,000 Elevation Data

Watershed generation efforts with digital terrain models indicated flat triangles due to lack of data (Maidment 2002). Hence available elevation data needed enhancement to carryout modelling to suit the MMC objectives.

6.1.3. Elevation Data Enhancement

Elevation data available from 1:10,000 maps were improved using the relative information of adjacent lands which were identified during the road drainage survey. Initially natural stream network alignments were captured from the terrain mapping carried out using the 1:10,000 maps. These data were then compared with the satellite image information pertaining to land

features, vegetation and with subsequently collected field data in order to capture the streams as at present. A common terrain depression was then imposed on the stream lines to suit site conditions so that valley lines in the terrain could be captured through stream network burning (Saunders 1999). Relative measurements from drainage field survey data were plotted to identify drainage directions along and across the roads (Figure 5). Road alignments captured by the project specific work were also overlaid on the available terrain and then adjusted to suit the drainage directions.

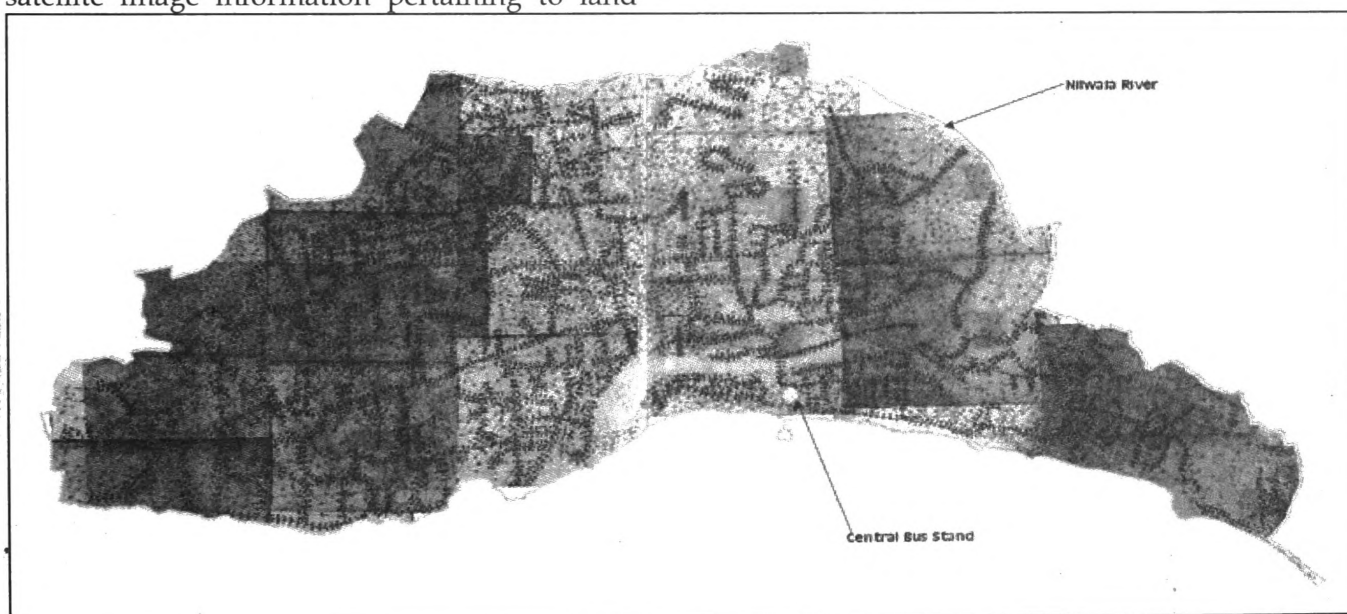


Figure 5 - Drainage Directions Identified by Field Surveys

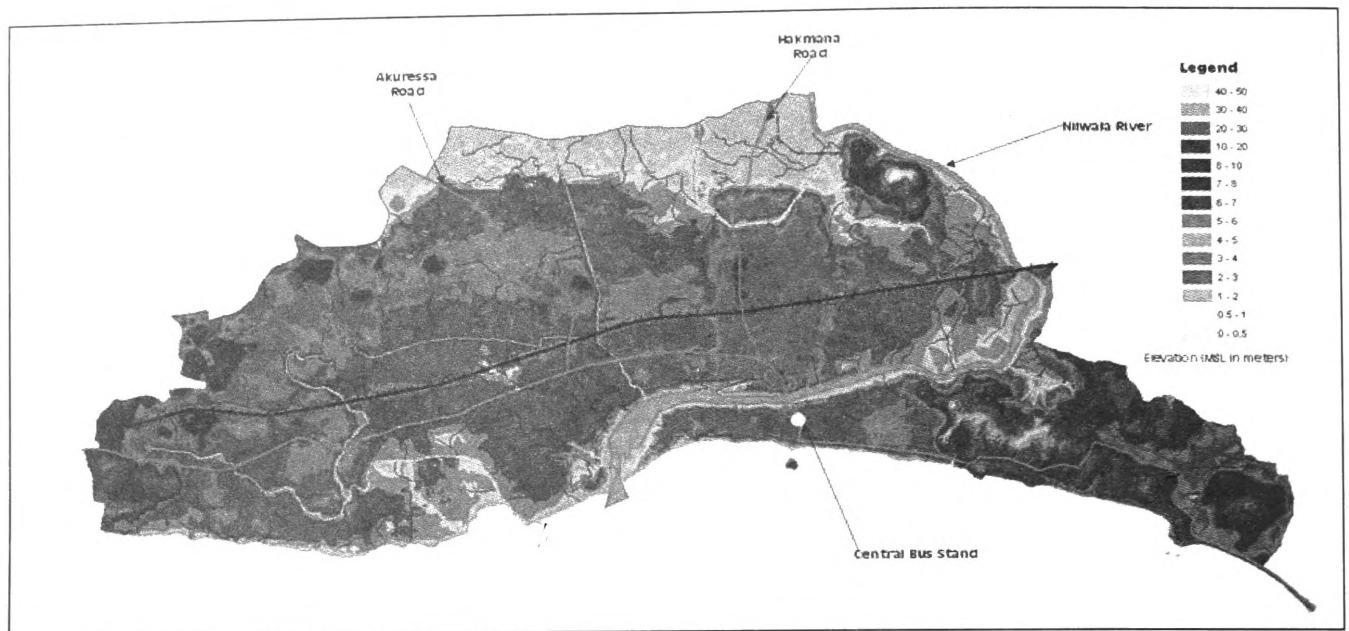


Figure 6- Digital Terrain Model with Major Features, Canals and the 1:10,000 Elevation Data

The finalized road elevation data were used to establish the near road terrain that had been captured from the field data collected as part of road drainage survey. Incorporation of road and adjacent drainage direction details enabled the generation of supplementary spot elevations. This effort made it possible to enhance the terrain model digital data from the original 15,900 spot heights to 34,500 spot heights. The digital terrain model for the present data set is shown in Figure 6. The terrain model with enhanced elevation data reflected the surface details adjacent to the roads. Since the road network was quite dense, the road survey provided sufficient details to enhance the terrain data to a sufficient geographic coverage

6.2. Watershed Modelling

Watershed modelling for the stormwater management options in the MMC area consisted of two parts. They are (i) Modelling of terrain to capture the stream network and carryout watershed delineation using the digital elevation model in order to assess the drainage areas that drain the stormwater either to the sea or to the Nilwala river, and (ii) Modelling of the flooded area to prioritize the watersheds for management activities through the identification of critical parameters and then carrying out a spatial modelling exercise to determine priority basins and associated characteristics.

6.2.1. Terrain Model

The terrain model development for the year 2008, utilized a Triangular Irregular Network (TIN) model developed to a spatial resolution of 5m with the spot heights of the terrain, roads and adjoining lands, streams and major drainage channels, Nilwala river and the sea coast details. This terrain model was then filtered for irregularities initially by digital checking of data and then by visual and manual smoothening to capture and remove unrealistic representations due to data overshoots or undershoots. The terrain model which was shown in the Figure 6 represented the finer details adequate for a watershed assessment purpose. TIN model development was an iterative process with the incorporation of various data resolutions and data corrections to achieve a realistic representation of the terrain. Terrain verification was done with checks on the representation of selected and known locations. However several irregularities indicated the need of higher resolution data for a smoother terrain model.

6.2.2. Stream Network: Flow Accumulation Modelling

TIN model developed for the enhanced dataset pertaining to the year 2008 was converted to a raster format data of 5 meter grid resolution to capture elevation information of the terrain. Slope and aspect maps for the terrain enabled the generation of the flow direction and flow accumulation maps. Generation of flow direction maps were verified manually using a sample grid developed with the drainage survey data. Flow direction model filtered by

filling the sinks was used to capture the flow accumulation model for the project area. Stream network was delineated with various threshold values for flow accumulation. Trial and error computations indicated that a threshold value of 100 showed the best detailed stream network. Considering the available dataset and while considering the issues pertaining to generating streams in a flat terrain without detailed elevation data, this threshold value presented a highly acceptable stream network map. Streams thus generated were checked for the matching with known terrain and field data. Subsequently the stream network data were compared at selected field locations and was found reliably representative. Field testing locations for the stream network were the flood complaint locations. Stream network generated through the model on most occasions followed the trace of the major drains. However in case of secondary and tertiary drainages, the matching showed a deviation from the terrain depressions that were naturally present in the spot height dataset and also indicated by the vegetation observed in the satellite imagery. The stream network also reflected the drainage direction concerns mentioned by the public. The Nupe Ela and the Kithulampitiya (Weragampita) Canals which were captured from the satellite imagery and rehabilitation plans deviate from the generated ones indicating a different flow direction than that had been anticipated. During field visits and discussion with public verified that the model results are closer to the reality.

6.2.3. Modelling for Watershed Delineation

Watersheds for the generated streams, were delineated to capture the surface area at the drainage outlets. Watershed draining points were either at the Nilwala river banks or at the MMC boundary. Generation of watersheds (drainage basins) through the model indicated 3088 individual basins draining either to the river or to the boundary of the MMC area. These generated basins were grouped into four classes based on the surface area. The four classes are, (i) Area less than 5 ha, (ii) 5-10 ha, (iii) 10-100 ha, and (iv) >100ha. 3044 of the basins were having less than 5 ha in extent and these were located either in the riparian zone of the Nilwala or located at very close proximity to the sea shore. These were grouped as one and the rest of the basins were numbered in the ascending order of surface area (Figure 7). Significant number of very small basins indicated the sensitive nature of the extent represented by those basins which contribute to stormwater discharge from the MMC area in a distributed manner.

Though these basins would not significantly impact the stormwater drainage within MMC area because of the nature of their location and the size, these will contribute significantly for the water quality issues of the draining water bodies. The project area showed that there are three major basins, namely the No 1, 2 and 3.

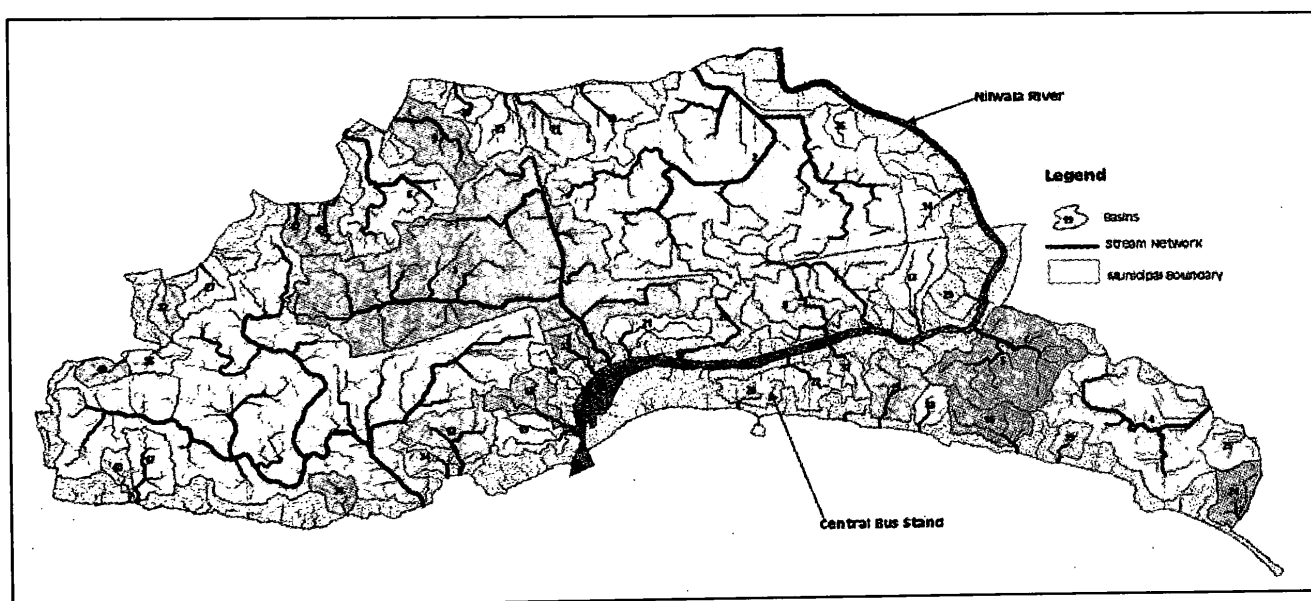


Figure 7- Watersheds Delineated from the Terrain Model with Streams at a Threshold of 100

The No 1 is draining to the sea, No 2 is draining to the Thudawe Ela and the No 3 is draining to the Niwala river.

6.2.4. Modelling of Drainage Patterns

Major drainage line network was compared with the rehabilitated canal system for the capability to drain stormwater from respective areas. Generated canal network with enhanced terrain inputs showed a very good match at most of the locations. The digital terrain model showed that terrain elevations and boundary conditions which were input to the model were satisfactorily represented in the mathematical interpolations. A comparison of drainage patterns was made with the input canal network and the generated system. As shown in the Figure 8, there were several locations which indicated flow of water generated by the mathematical model deviating from the major drainages which were on ground. The changed locations were verified with the source data which were input for model computations. Field visits were also conducted to identify the issues and needs pertaining to the deviation of the generated stream network from that physically existed on ground. Other locations with respect to the major drainages were well represented in the terrain model.

7. Modelling Mitigation Activity Prioritisation

Management of Stormwater related issues pertaining to a large spatial extent would consist of a significant number of parameters that vary geographically. In case of stormwater management, it is necessary to carryout planning, management, implementation and monitoring of related activities. In case of managing the activities at a set of locations with a wide spatial variation pertaining to the magnitude of the event and also pertaining to the geography of the locality, there should be a tool to facilitate the prioritisation of such activities. This need arises when the finances or other resources required for the management actions gets restricted. Considering the above, a Geographic Information System (GIS) was developed and modelling was carried out to identify the priority of stormwater management locations that require early attention. In this work as part of prioritisation, GIS modelling was carried out to prioritise the reported flood locations for the incorporation of either mitigatory activities or effecting preventive action within the concerned area.

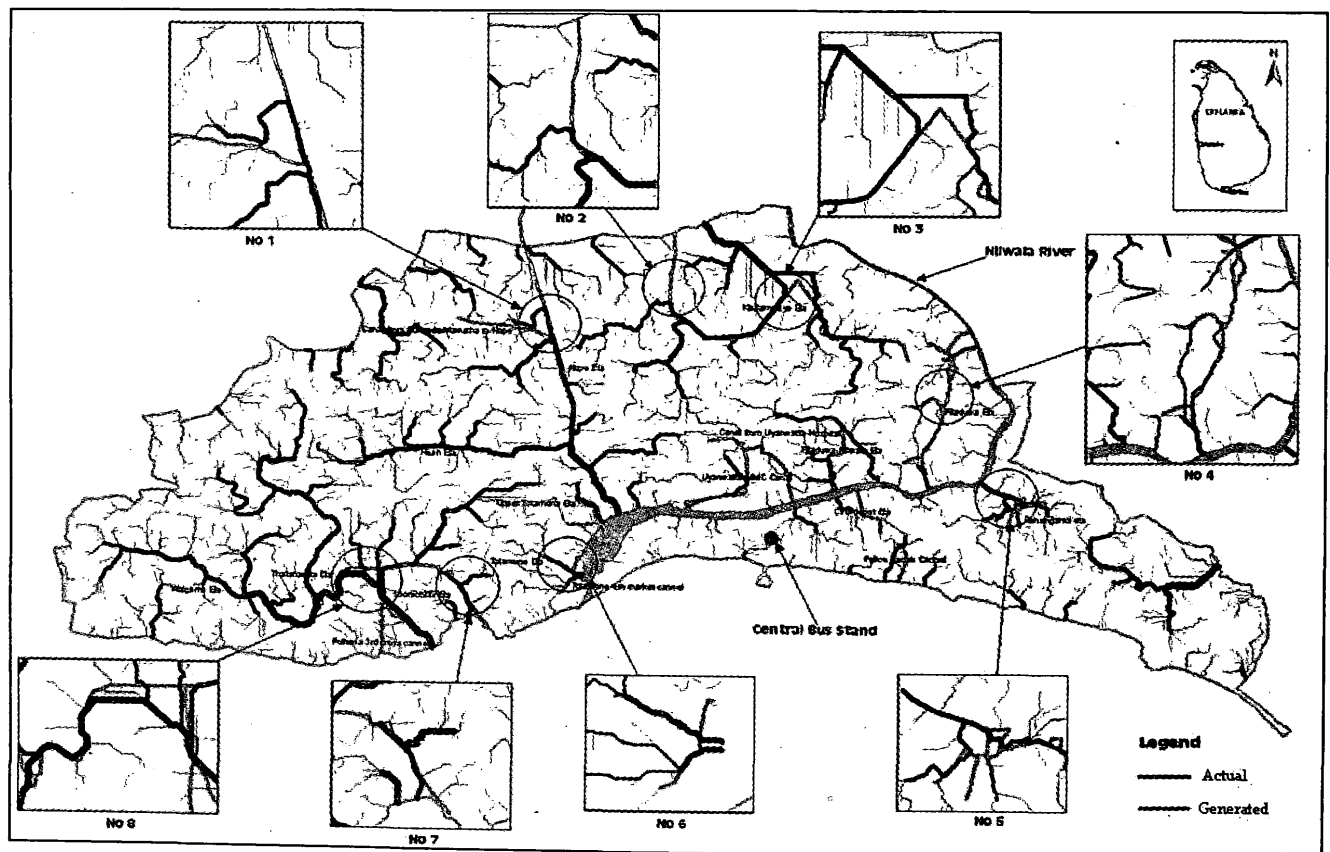


Figure 8 - Comparison of Generated Canal Network and Major Drainage Network

GIS modelling was then carried out to perform a spatial aggregation in order to identify prominent sections of the MMC area where the stormwater drainage paths mostly concentrated.

7.1. Priority Locations for Mitigation

Field surveys were carried out in the project area to identify the issues pertaining to the 14 locations cited by the MMC officials. Apart from these, the project specific flood survey along the road network identified 577 locations which were captured as 30 meter stretches of flooded road sections. This indicated that approximately 17 kilometres of road length in the MMC area were experiencing floods. Surveys also captured the inundation depth and duration at each location. Each of these reported flood locations was also studied in detail to identify engineering options available to mitigate the flooding impacts at each location.

A spatial model was developed to identify the flooding areas that have most impact on public. The GIS based spatial decision making tool was based on the objective function which considered that the high impact flood locations are those which are (i) at places mostly used by the public, (ii) which are in clusters of other flooding points, which have (iii) significant inundation depths and (iv) prolonged inundation durations. Geographic data layers representing these were then overlaid to obtain the impact zoning map. In the analysis, the concentration of public was considered to be represented by the building density and the flooding location clusters were computed from the density of road lengths that were undergoing floods. Inundation depths and inundation time were assigned to each road element. Each layer was classified in to five classes and each class were assigned numerical values ranging from 1-5. The classes assigned were based on modified natural breaks of the geographic dataset. Values used for classification are shown in Table 2.

Model output ranked the spatial extent of the MMC according to the criticality of a particular area determined by the above four parameters. This GIS enables a manager to filter the results to select a number of sites according to a priority criterion.

Table 2 - Classification of Parameters to Flood Area Prioritisation GIS Model

Class Value	Inundation Duration (Hr)	Inundation Depth (ft)	Building Density (area/unit area)	Flood Location Density (m/100 sqm)
1	<1	<0.5	<0.2	< 0.001
2	1-6	0.5-1	0.2-0.4	0.001-0.004
3	6-12	1-2	0.4-0.6	0.004-0.007
4	12-24	2-4	0.6-0.8	0.007-0.012
5	>24	>4	>0.8	>0.012

The final result was reclassified to identify the region according to four zones, namely, Very High Priority, High Priority, Critical and Less Critical. The reported flood points were classified according to the above classes and there were 34, 58, 90 and 395 locations in each of the Very High Priority, High Priority, Critical and Less Critical classes respectively (Figure 9). Model output locations were verified with the MMC identified flood locations and the results indicated a very good match of the results corresponding to the complaints received. There were many other locations that were identified during the field survey and the model outputs revealed that some such locations also require priority attention.

7.2. Priority Locations for Prevention

A stormwater manager needs to identify locations which would create the most impact with regards to stormwater generation. Since stormwater generation is directly proportional to the land changes, it is necessary for a manager to identify the locations that would most likely influence the critical flooding points due to changes affected to the land in the concerned area. Therefore it is important to identify the critical watersheds and their land cover parameters in order to assess and monitor any forthcoming development activities. This identification would also enable a manager to affect restoration programmes depending on the status of each watershed. The Geographic Information System developed for the study enabled the extraction of the watersheds pertaining to the critical flood localities and to carry out a comparative analysis enabling a stormwater manager to take preventive (or restorative) decisions regarding



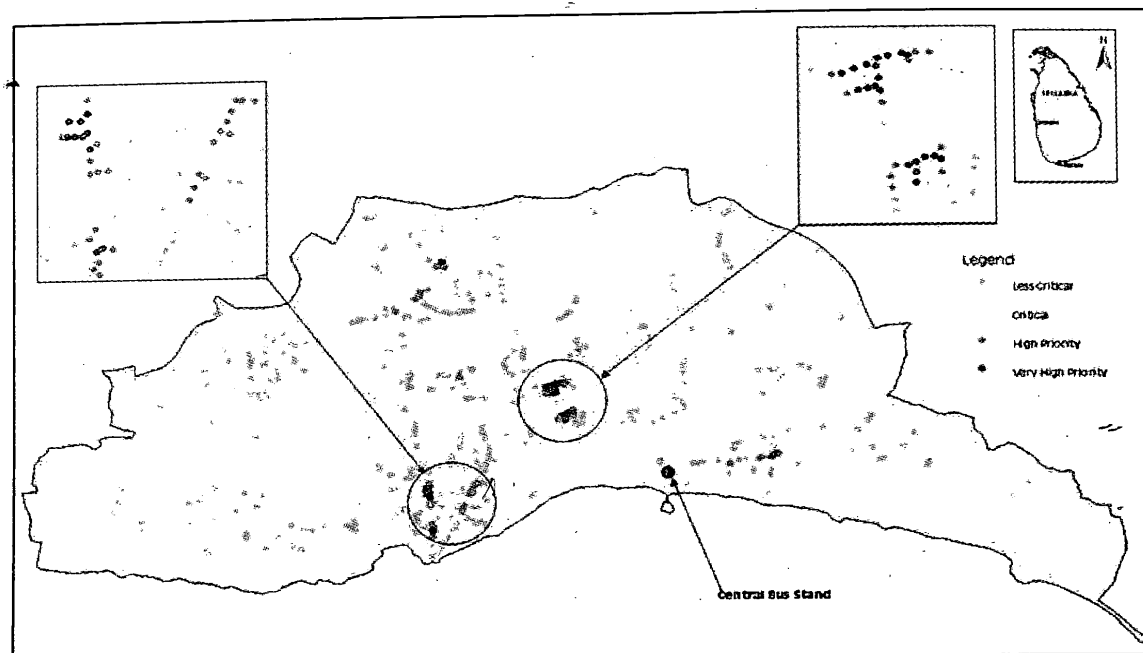


Figure 9 - Priority Locations out of the Reported Flooding Locations

the development activities on a watershed basis.

Another common problem in urban area is the changes to land parcels which result in loading the road drainage network with stormwater that otherwise would have either got infiltrated at individual compounds or would have drained in another direction. Such property changes would require a manager to strengthen the stormwater drainage infrastructure in that particular area and hence it is important to identify the locations where most of the roadways coincide with the waterways.

The present work also carried out a GIS modelling effort to identify the geographic locations where such road sections are mostly concentrated. Once such locations are identified a manager could assess the infrastructure at those areas and carryout strengthening where necessary. These two GIS modelling activities and results are described below.

7.2.1. Critical Watersheds

The zones which were identified during the priority flooding areas showed 26 locations with varying importance and pertaining to three zones. These points were demarcated on the terrain model to capture the stormwater drainage lines contributing to the flooding at the identified priority points. Then the terrain model was used to capture the watersheds that need to be managed to mitigate the critical

flood points. 29 watersheds were identified as critical watersheds that were contributing to the priority flooding area. Landuse values were extracted in each of the watersheds for the years 2002 and 2008 in order to assess the change to built-up area in each watershed.

Critical watersheds showed a marked difference in the high runoff land use percentage when compared with the same for the Matara MMC in general. The high runoff land use for 2008 in critical basins was 41% compared to the MMC average High runoff land use value of 28%. Results points to another interesting information. The 2002 high runoff land cover/use percentage in critical basins is equal to the 2008 high runoff land use average for the MMC area. This shows that rest of the area would also become rapidly urbanised similar to the critical basins. Therefore the MMC need to effect early action to establish proper stormwater management strategies.

7.2.2. Critical Drainage Network

The most common complain encountered during the field visits was that the stormwater from individual allotments are drained directly on to the road or to road drains and as a result, the roads become waterways. In such occasions the road drains have to be expanded to a sufficient capacity for the disposal of stormwater. This was very well reflected in the generated streamline network. At those locations the road drains should have a good

connectivity to the nearest drainage line while ensuring the capacity of the road drain to dispose the water without overflowing on to the road. Computations were carried out to capture road sections where the streamlines fall on the road alignment. Such locations were captured through the model and were verified manually with on screen comparisons incorporating field observations. The model results provide valuable information for a manager to carryout stormwater drainage management within the MMC area. Model results have to be filtered to ensure that the problem causing sections are highlighted. Therefore from the model outputs it is necessary that the road sections which are already in operation with a suitable drainage canal by the side needs to be filtered from the rest of the area. Nupe Ela is one such canal. Model computations filtered the major drainage canals with roads and the results for roads that coincide with significant streamlines.

The identification of road sections that coincide with stormwater streamlines provides a manager with the capability to capture critical road sections and then to plan and effect stormwater management actions for critical areas (Figure 10).

These results from the present work indicate only the sections that are longer than 30 meters. However depending on the management requirements the computations on a Geographic Information System (GIS) can highlight the road sections of a desired length. Therefore a manager could carry out work prioritisation in case of resource limitations.

The GIS computations revealed that a total of 75 km long road sections out of an entire road network of 177km, carry stormwater along the roads. This is mainly because the public carryout earth filling to maintain their land elevations higher than the roads so that the stormwater could be directly discharged to the road drain. This type of behaviour in urban areas changes most of the roadways to waterways. Coinciding of waterways with roadways was shown approximately as 42 % of the total road length for the MMC area. The diversion of household drainage water directly to the street drains appears as the greatest challenge for the stormwater manager. Spatial variation of the density of such critical road sections were calculated considering the length-weighted distribution of such sections in the vicinity. Since these density maps indicate the sections common to stream network and the roads, a manager should combine this information with the slope of terrain to separate the stormwater management issue from drainage and erosion.

7.3. Runoff Characteristics

Stormwater generation depends on the increase of impervious areas in a particular land extent. In an urban area, the runoff generation increases mainly due to construction of buildings, roads and due to paving of land surfaces.

In this study calculations were done to determine the building and road area

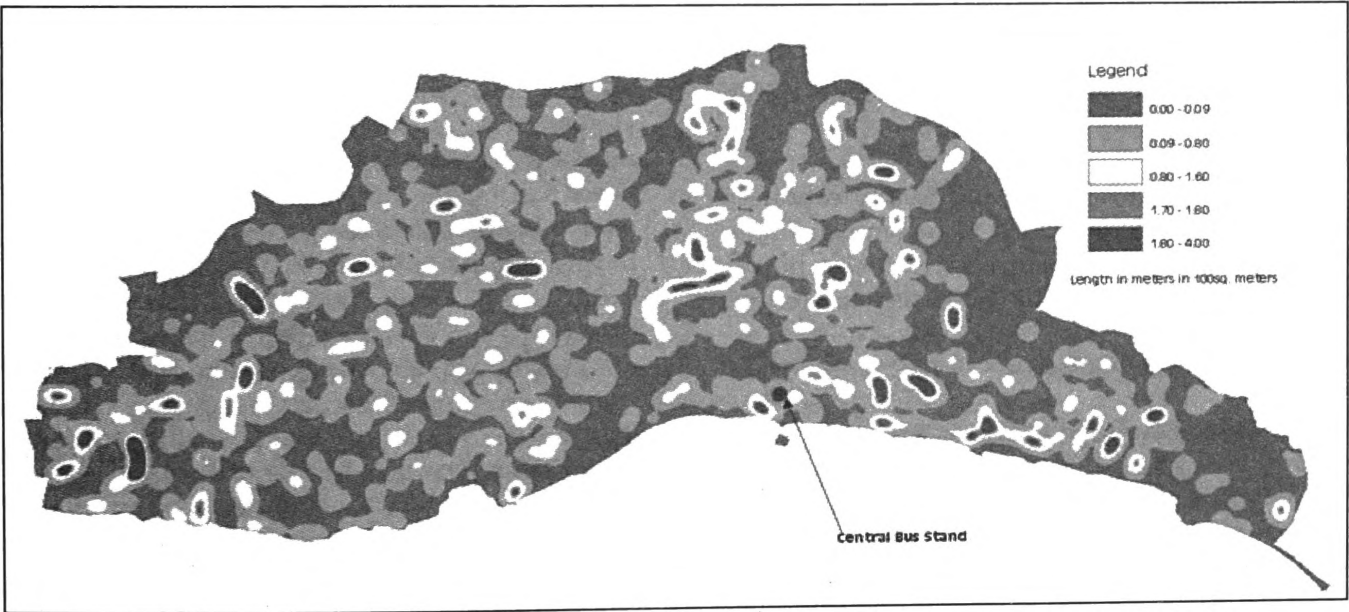


Figure 10 - Density of Road Sections that Coincides with the Drainage Network Generated the DTM

in the two datasets corresponding to 2002 and 2008. Roads which were in the 1:10,000 scale had subjected to many changes. Roads and Buildings of each year was overlaid on the landuse map of 2002 and each land use type was extracted using the Geographic Information System. These land use categories were then classified into two broad groups as high runoff generating and low runoff generating. Watersheds in general showed an increase in the impervious land cover indicating a high runoff land use percentage of approximately 28% as against a value of 17% for high runoff land cover corresponding to the year 2002. The land use changes of watersheds incorporating average runoff coefficients of 0.7 and 0.25 for high runoff generating and low runoff generating land uses respectively show that the generation of stormwater has increased by 14% from the year 2002 to year 2008. The same computations for a high runoff value of 0.8 and with the same low runoff value of 0.25 would increase the runoff by 16%.

8. Management Recommendations

The MMC stormwater drainage system which has many similarities to other urban areas along the coast of Sri Lanka lies on a flat terrain. The main common characteristic is that the public directly discharge stormwater from their properties to the roadway drains. Paved areas in the city are increasing with time due to pressure of dwelling needs in the urban community.

The present work of stormwater system analysis indicated the options for stormwater management. The options can be broadly divided into long term and short term. The long term ones would be the preventive actions and good management practices whereas short term ones would be to ease the problems which are presently being experienced.

The present work led to the identification of problem areas and goes on to recommend how such areas could be dealt with and also how a manager could determine the areas of priority.

8.1. Short Term Solutions

8.1.1. Major Drainage Lines

The mathematical modelling and field work identified that the generated major streams reflected a different behaviour when compared with what had been anticipated during the previous designs and construction. This

indicated that the functioning of the drainage canals at certain points need detailed studies in order to identify the appropriate drainage canal trace, size, slope and other parameters.

The stream network generation by the model follows a system which initially identifies the flow directions and then picks up sinks where pools of water results in sets of cells with undetermined flow directions. In the model such pools are filled and then calculations are carried out to identify the flow directions to compute the stream network. An iterative process fills the terrain sinks to produce the final stream network. Stream network generated by the model reflects the functioning of the drainage direction once the pools are filled and hence the direction in which the flood waters would recede. However in reality, when the rains are inadequate then the flow will stop at the sinks creating pools of water. This means that even if the flood is receding there will be pools of water at the locations where the terrain indicate sinks. A close scrutiny of the major canals identified several key issues pertaining to the major canals. Their locations are shown in Figure 8 and descriptions are given thereafter.

No.1: In the generated stream network, the Nupe canal is shown as two sections flowing in two directions. A major section is flowing southwards and a smaller section is draining towards the northern boundary. This behaviour shows that even when the surface depressions had been incorporated for the terrain model indicating the presence of a canal, the functioning in reality is different or in other words the flow in the canal is not in one direction. Terrain model has indicated that canal elevation inputs have not supported water flow through the canal alignment. However it is noteworthy that the terrain model represents the behaviour of the canal as described by the officials and the public. Site visits also revealed the presence of a regulator to raise the parent canal head so that the water could flow along the Nupe canal in the direction from North to South. This regulator does not appear to be in operation as at present. Also the recent constructions raising the bed level of the Nupe canal indicates that for the regulator to be useful then the water level would have to be raised to significant elevations.

No 2: In the Kithulampitiya canal too there is a section which behaves similarly to Nupe Ela.

The physical inputs show a canal construction but the terrain model shows flow in two separate directions. This indicates the problem when attempting to drain water through the Kithulampitiya canal in the direction of Thudawa.

No 3: Kithulampitiya canal is expected to drain water from regions inside the flood bunds at the western edge of the MMC area to the Thudawe Ela at the Northern end. However the model indicates that instead of flowing along the canal trace the drainage flow deviates to lower terrain at a location close to the Mathugala Bund (Wella). Water from the Harischandra properties also drain towards the Mathugama Wella contradicting the flow direction expected from the canal. These behaviour matches with the observations of the public and the complaints made by them indicating that the canal levels need checking because it appears that the canal has been constructed to push the flow in the upstream direction. The terrain model developed for the study has successfully indicated the geographic features that support the drainage of stormwater along this canal system.

No 4 at Piladuwa Ela shows two section of the Ela draining in two separate directions while having a ridge close to the railway line. This indicates that the elevations do not permit water to flow along the canal though the ends are linked to form a single canal. The stream network generated by the model clearly reflects the behaviour of the canal system as described by the public during field surveys.

At Nos 5,6, 7 and 8 too, the flow directions deviate from the physically excavated canal alignments. This indicates that the terrain does not facilitate the flow directly into the canals which have been rehabilitated. It also means that at the deviations there will be locations of flooding and water collecting pools prior to draining excess water through the stream network as identified by the model.

This detailed comparison of model outputs with the physically existing canal system points to the problem locations which are having difficulties in draining stormwater to ensure flood mitigation. Therefore the terrain model output has indicated its strong potential to capture critical locations in the main drainages so that a manager could commence action to pursue detailed engineering studies in the model identified locations to identify the exact

behaviour and then to execute engineering solutions.

The generated stream network was categorised according to stream order of tributaries and this enables a manager to initially identify the problem area in the high stream order locations and then to move towards less order streams. In case the terrain details that have been fed to the model are of finer resolution then it is possible to satisfactorily capture the drainage issues even in the level 1 stream order canals.

The model has identified locations of incompatibility in the existing drainage system. This enables the stormwater manager to commence action to carryout detailed studies and identify locality specific engineering designs for implementation as indicated above.

8.1.2. Identified Flooding Locations

Each of the flooding locations identified during field surveys and at discussions with MMC officials were inspected to identify the best management options. The observations were studied with the terrain model and the generated streamlines to provide options for easing the stormwater drainage problem as at present. Engineering field inspections of the surrounding environment were made at each of the identified flood complaint locations. At most occasions it was identified that either the natural stormwater discharge path had been obstructed by a land or had been over loaded due to large stormwater contributions from surrounding urbanised land. The proposals whilst using site inspection details and satellite imagery recommend the most suitable path for stormwater disposal. However engineering surveys at the recommended vicinity should be carried out prior to construction work. Importantly, long term solutions should be incorporated for each and every critical location to ensure the sustainability of these solutions. Specific solutions were given for the identified 164 locations and a sample is shown in the Figure 11.

8.2. Long Term Solutions

8.2.1. Development Planning and Approval

The study identified that the major issue for stormwater management in the long run would be to control the stormwater generation from the urban lands and also to control the simultaneous discharge of the stormwater to the street drainage network. Blockage of natural drainage paths were also identified as a



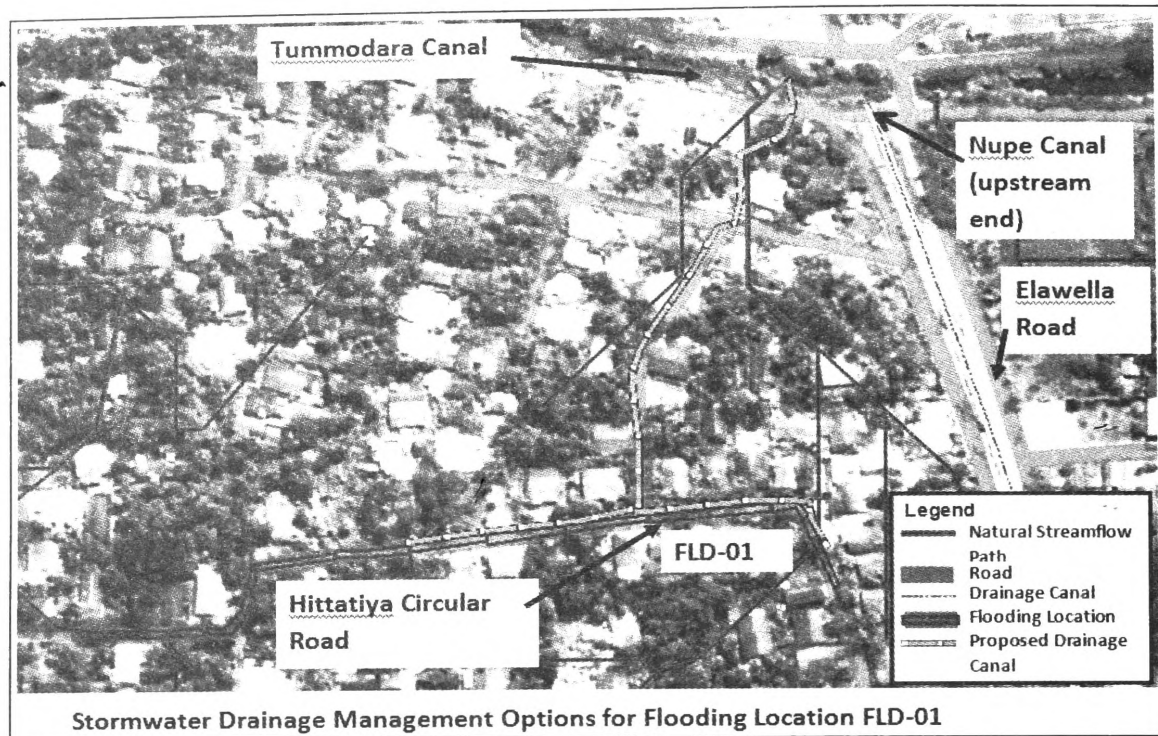


Figure 11- Specific Short Term Solutions Provided through Field Verifications

major cause for the change of drainage directions and this has to be carefully controlled to ensure that no blockage of drainage water would take place leading to enhanced flood situations. Construction of walls has prevented natural flow of water across boundaries. It is important that the MMC identifies a methodology to ensure that the development plan approval procedure in future would satisfactorily cater to the above needs. The best option would be to impose conditions and to incorporate the needs that have to be fulfilled when granting the development approval. Study revealed the problems caused due to obstruction of natural drainages. Though the short term solutions have been proposed, the MMC should take adequate steps to demarcate and declare reservations for natural drainages so that the stormwater could be properly managed in the years to come.

8.2.2. Detailed Database and Tools

Stormwater management monitoring and decision making requires a detailed database. The database should include a high resolution elevation dataset, land cover details, property boundaries, stream network, drainage canals etc. The present work in order to assess the situation and propose solutions used various techniques such as, field surveys and interpretation of satellite imagery. However a

sufficiently detailed dataset is preferred. In the present work many rational approximations were done to overcome a data scarce situation and time barriers for carrying out detailed data capturing. MMC needs to commence collecting requisite data in digital form to support long term sustainability of stormwater drainage management.

Present study also demonstrated the methods and availability of tools to prioritise the locations that need to be attended in case of resource limitations. This included the prioritisation of the flooding locations using a geographic information model that considers four parameters namely, the building density, flooded area density, flood duration and depth of inundation. These types of tools should be available with trained staff capable of providing necessary outputs to enable satisfactory stormwater management. MMC should take necessary steps to develop management tools to prioritise the stormwater management activities and also to monitor the status of the associated watersheds. Staff training would be an essential component with regards to sustainability of the use of tools.

8.2.3. Engineering Solutions and Guidelines

In the country the common practise is to discharge the stormwater from one's own property to the closest road drain. This has been identified as the primary cause for

flooding and especially flash flooding. The MMC needs to ensure that such discharges are carried out within engineering limits imposed by considering the load that can be undertaken by a reasonable drainage infrastructure system. Since the increase of stormwater on the drainage system requires financial inputs to sustain the infrastructure, it may be appropriate for the MMC to consider imposing a levy on those properties that have not constructed stormwater retention or detention facilities.

In order to ensure that the public are properly assisted to incorporate stormwater retention and detention, it is necessary that the MMC establishes guidelines for the developers as to what should be constructed, what type and size should be used etc. It is recommended that a handbook for the design and building of such facilities should be made available at the MMC for public use.

9. Conclusions

1. The present study carried out systematic field and desk studies and clearly identified the long term and short term solutions for rational stormwater management.
2. Watershed delineation efforts for flat terrain requires high resolution elevation data, but in the absence of such survey data, it is possible to use field drainage surveys to create representative digital elevation models using 1:10,000 topographic map elevation data with satellite map interpretations.
3. Simple Geographic Information System incorporating flood inundation level, inundation duration, proximity to populated area, and nearby flood location density enabled the prioritisation of critical locations for management interventions.
4. The present work compared the terrain, the generated stream network, the constructed drainage canals and carried out field inspection of specific locations to successfully propose practically feasible short term solutions for Stormwater drainage management
5. The generated stream network developed for the present situation confirmed that the road drains have become the major drainage water disposal route as a result of landfills and drainage closures. The GIS

enabled the identification of such road section clusters enabling a manager to propose adequate interventions.

6. Eight critical locations in the major drainage network were identified and recommendations were made to ensure proper drainage of stormwater using the existing drainage canal network.
7. Individual flooding locations which were identified during field surveys were grouped in to 164 localities. These locations were inspected, analysed for suitable options, and solutions for proper stormwater disposal have been made while taking efforts to address each individual case and its surroundings.
8. The flood locations identified were spatially modelled using a GIS to identify 34 No of Very High Priority, 58 No of High Priority, and 90 No of Critical flooding locations for implementation of mitigatory action especially in resource limited situations.
9. 29 Critical watersheds pertaining to the priority given to flooding locations were identified with its landuse components facilitating a stormwater manager to monitor and control the development activities in a sustainable manner.
10. A Total of 75 kilometres of road sections which is approximately 42% of the MMC roads, that carry significant stormwater either in its side drains or on the road surface were identified, mapped and prioritised for effecting suitable stormwater management programs.

References

1. Maidment, David and Djokic, Dean "Hydrologic and Hydraulic Modelling Support with Geographic Information Systems", Maidment, David and Djokic, Dean Editors, Environmental Systems Research Institute, Inc., Redlands, California, ISBN 1-879102-80-3, 2000.
2. Dutta D., Herath, S., Wijesekera, N.T.S., "Understanding The Impacts of Spatial Data Resolution in Flood Risk Modelling", Proceedings of the International Symposium on Geoinformatics for Spatial Infrastructure Development in Earth and Allied Sciences, GISIDEAS, Hanoi, Vietnam, September, 2002.



3. Saunders, William., "Preparation of DEMs for Use in Environmental Modelling Analysis", ESRI User Conference, July 24-30, San Diego, California, 1999.
4. Mays, Larry. W., "Floodplain Management, Water Resources Engineering", Replika Press Pvt. Ltd., India, ISBN 9812-53-116-5, 2004
5. Maidment David., "Arc Hydro, GIS for Water Resources", David Maidment Editor, Environmental Systems Research Institute, Inc., Redlands, California, ISBN 1-58948-034-1, 2002.



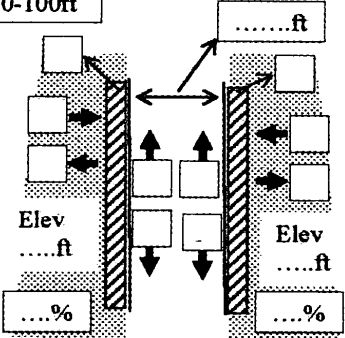
Annex 1 - Data Sheet for Field Data Collection During the Road Drainage Surveys

Official Ref. No.

Road Name:..... Ward No:.....

Description of Starting Point

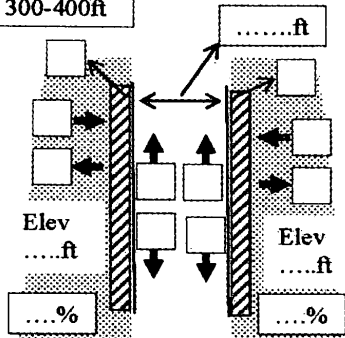
0-100ft



Culvert
 L.....ft
 W.....ft
 Dia.....ft
 No.....

Flooding
 No
 Yes
 Level....
 Hr.....

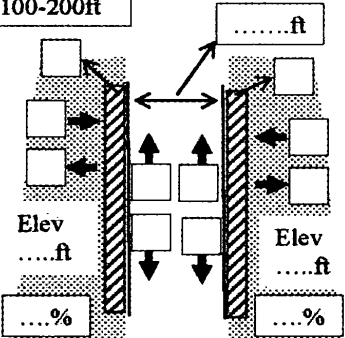
300-400ft



Culvert
 L.....ft
 W.....ft
 Dia.....ft
 No.....

Flooding
 No
 Yes
 Level....
 Hr.....

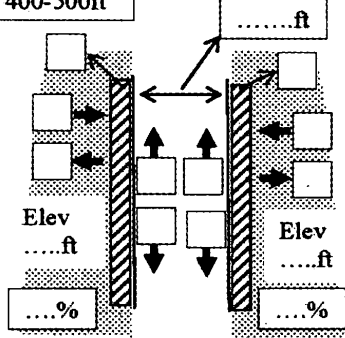
100-200ft



Culvert
 L.....ft
 W.....ft
 Dia.....ft
 No.....

Flooding
 No
 Yes
 Level....
 Hr.....

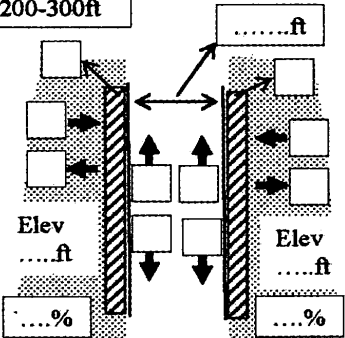
400-500ft



Culvert
 L.....ft
 W.....ft
 Dia.....ft
 No.....

Flooding
 No
 Yes
 Level....
 Hr.....

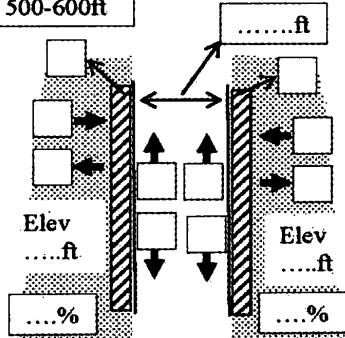
200-300ft



Culvert
 L.....ft
 W.....ft
 Dia.....ft
 No.....

Flooding
 No
 Yes
 Level....
 Hr.....

500-600ft



Culvert
 L.....ft
 W.....ft
 Dia.....ft
 No.....

Flooding
 No
 Yes
 Level....
 Hr.....

Name:..... Signature..... Date