Nile Equatorial Lakes Subsidiary Action Program

FEASIBILITY STUDY AND PREPARATION OF AN INTEGRATED WATERSHED MANAGEMENT PROGRAM AND INVESTMENT PROPOSAL FOR SIO-MALABA-MALAKISI SUB BASIN

Final Report

Annex 3B - Storm Water Drainage Master Plans for Bungoma and Lwakhakha

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Executive Summary

INTRODUCTION

The basic objective of the Sio Malaba Malakisi River Basin Regional Integrated Watershed Management Master Plan is to outline a programme which, when implemented, will improve the facilities for the management of stormwater at developed areas of the Bungoma in a manner adequate to contribute towards reversal of the current trend of catchments degradation by addressing the issues of sediment load and pollution of the river system. The Master Plan addresses the assessment of the performance of existing drainage system; outline strategies for storm water management and prepare storm water drainage master plans.

The general criteria that were followed during the development of the Drainage Master Plan are:

- Maximize the use of natural features as natural watercourses to accommodate the runoff
- Maximize the use of existing facilities for the collection and diversion of storm runoff to minimize cost and correct deficiencies in the existing system
- Use of open channel drains.

LOCATION

Bungoma Municipality is located approximately 500 km North - West of Nairobi between latitudes 00 32'S and 00 35'S and longitude 340 33' E and 340 34'E 30 km east of Malaba town, along the Kenya - Uganda border, and 61km west of Kakamega town, the provincial headquarters of Western Province.

The town covers an area of 57 sq. Km and extends between Sibembe to the South, and Kanduyi to the north. It borders Rivers Khalaba to east and Sio to the west. Administratively it is divided into two locations namely; Township and Musikoma locations. It has four sub-locations and eight electoral wards. The eight wards are Namasanda, Sio, Siritanyi, Sinoko, Mjini, Musikoma, Stadium, and Khalaba.

DRAINAGE DESIGN CRITERIA

For the purposes of the study, minor drainage system will be defined as one that is designed to accommodate floods storms with a return period of 2 to 5 years while a major system is defined by flow paths for runoff from less frequent storms, up to the 20 year return.

Floods of 5 and 10 Year Return Period were considered as appropriate for the Bungoma town Design. These gave flows of Q2 = 22.21 m3/s, Q5 = 28.61 m3/s and Q10 = 33.37 m3/s. Bungoma town falls within sub catchment number 4.

From the observations made during the reconnaissance field survey, most of the drainage channels have developed over a period of time from the natural path taken by the storm water. It is recommended that these be improved by adopting a trapezoidal section which will be more appropriate for the unlined channels and easier to maintain. Structurally, this will also give a more stable section.

CONSTRUCTION COST

The estimated cost of implementation is about Kshs. 247,665,600.00 (US $ 2,966,055.11 at the current exchange rate of Ksh. 83.50/US $). This includes 20% and 15% respectively for Project Management and Supervision costs and Contingencies.

OPERATION ET MAINTENANCE

The mandate of the management of stormwater is under the Ministry of Local Government and by extension the Bungoma Municipal Council.

Bungoma Municipal Council will therefore be responsible for overseeing the operation, routine maintenance and rehabilitation of all Storm Water facilities in both Central Business District and the outlying Wards. The Municipal Council shall establish performance standards, clearly describing the Storm Water facilities, and explain how each facility is intended to function and operate over time governed by the laws, regulations and Acts of Parliament of the Republic of Kenya that directly and indirectly touch on drainage aspects. These standards should be strictly enforced and all stakeholders within the municipality boundaries made to observe them.

RECOMMENDATION

The stormwater Master Plan and the redevelopment and construction of storm water drainage infrastructure will offer considerable benefits to the community within the Bungoma Municipality and could form a basis for more enhanced economic activities and access to other enterprises that could benefit from the development.

The enforcement of the by-laws and regulations for the proper maintenance of Storm Water Facilities and best management practices will requires the cooperation and support of all the stakeholders operating within the Municipality. Without the cooperation and commitment from all stakeholders involved, the reconstruction measures and efforts put in place are bound to fail.

Judicious operation of the stormwater drainage infrastructure can significantly reduce interruption of activities within the municipality and at the same time improve the water quality and reduce the pollution levels for the river systems. Without these measures being implemented, the consequences can be far reaching.

It is therefore proposed that The Municipal Council puts in place mechanisms that ensure an effective Participatory Process of storm water management involving all stakeholders such as communities, Landlords, Business people and Council Staff.

Any process of forming a stakeholder's Association will need to be streamlined and be all inclusive comprising of representatives from the Business community, landlords and the Municipal Council officials with no apparent external interference. Each representative should have the mandate to take decisions on behalf of the people he/she represents.

A detailed topographic survey of the town will have to be carried out to collect data and information on levels for all drainage channels.

Future plans for expansion of roads and drains need to be planned, designed and constructed together so that there is a proper linkage between them and they serve the purpose of not only drainage the collection of surface water on the roads and also facilitate road sweeping and separate collection of solid waste.

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ACRONYMS AND ABBREVIATIONS

CBD	Central Business District
NBI	Nile Basin Initiative
NELSAP	Nile Equatorial Lakes Subsidiary Action Program
O&M	Operation and Maintenance
SMM	Sio-Malaba-Malakisi
TRRL	Transport and Road Research Laboratory (UK Department of the Environment)

CHAPTER 1.INTRODUCTION

1.1 Background

The Sio-Malaba-Malakisi (SMM) River Basin Management Project is one of the three transboundary integrated water resources management and development projects being implemented within the framework of the Nile Equatorial Lakes Subsidiary Action Program (NELSAP), an investment program of the Nile Basin Initiative.

As the Municipality of Bungoma experience growth, the Stormwater Masterplan will provide guidance on its core area of service delivery spelt out in the council's strategic plans to develop, rehabilitate and maintain drainage systems and contribute to the water quality and pollution control for the rivers system. This Masterplan is considered as a general guideline from which the town, can prepare and implement short term development plans to address the specific drainage needs while at the same time addressing the twin problem of water quality and pollution control for the river system.

1.2 Purpose of the Master Plan

The purpose of the Stormwater Masterplan is to provide a long term management plan for the storm water management strategies which minimize problems associated with flooding while ensuring that water quality and pollution control in Khalaba and Sio Rivers is maintained to acceptable standards.

This long term plan will help the municipality manage stormwater resources and identify, evaluate, improve the existing drainage infrastructure and provide a future plan for the expansion of the drainage systems in line with the Municipality's growth. This Master plan is developed in line with the challenges the Municipal Council is facing in managing stormwater in its area of jurisdiction.

The Study is expected to provide guidelines on the following:

- Reduced Flood occurrence in Bungoma Town.
- Reduced Risk of Flood Damage to Property and Infrastructure and result in time and cost saving Transport Operations both in the town and outlying areas.
- Improved hygiene Conditions and general cleanliness of Bungoma Town.
- Reduced Silt Load in Khalaba and Sio Rivers leading to reduced Turbidity in the River
- Serve as a vehicle for building the Institutional and Managerial Capability of Bungoma for Planning, Implementing and instituting measures to ensure coordinated Future planning of Projects and improvement of Commercial and Industrial Activities and Land Use.

1.3 Standards

As discussed above, the mandate of the management of stormwater is under the Ministry of Local Government. The laws, regulations and Acts of Parliament of the Republic of Kenya that directly and indirectly touch on drainage aspects are listed below.

- The Environmental Management and Co-ordination Act, 1999
- The Water Act, 2002
- The Environmental Management and Co-Ordination (Water Quality) Regulations, 2006
- The Public Health Act, Chapter 242
- The Local Government Act, Chapter 265
- The Streets Adoption Act, Chapter 406
- The Community Service Orders Act, 1998
- The Environmental (Impact Assessment and Audit) Regulations, 2003
- The Trust Lands Act, Chapter 288
- The Physical Planning Act, Chapter 286
- Environmental Management and Co-Ordination (Waste Management) Regulations, 2006
- The Public Roads and Roads of Access Act, Chapter 399
- The Land Control Act, Chapter 302
- The Land Adjudication Act, Chapter 284
- The Land Acquisition Act, Chapter 295

1.4 Goal of the Master Plan

The main goal of the Masterplan is to provide stormwater drainage facilities at a level adequate to protect private and public property against any damage and ensure public health and safety and at the same time address the twin problem of water quality and pollution control of the river system.

1.5 Drainage standards, systems & terminology

In every location there are two stormwater drainage systems that must be considered; the minor system and the major system. Three factors influence the design of these systems; flooding; public safety; and, water quality and pollution control.

The purpose of the minor drainage system, which is designed for the 2 to 5-year storm event, is to remove stormwater from areas such as streets and sidewalks for public safety reasons. This system consists of inlets, street and roadway gutters, roadside ditches, small channels and small underground pipe systems which collect stormwater runoff and transport it to the major drainage system (i.e., natural waterways, large man-made conduits, and large water impoundments). If the minor system is exceeded during a storm event, the major system is then utilized.

The major system is defined by flow paths for runoff from less frequent storms, up to the 10 year frequency in this case. It consists of natural waterways, large man-made conduits, and large water impoundments. In addition, the major system includes some less obvious drainage ways such as infrequent temporary ponding areas. The major system includes not only the trunk line system that receives the water from the minor system, but also the natural backup system which functions in case of overflow from or failure of the minor system. Overland relief must not flood or damage houses, buildings or other property.

From the review of the existing storm water drainage system and the anticipated discharge capacities and the inherent cost of upgrading the system, the Design Return Period of 10 years is recommended for the Major System.

1.6 Design criteria

The design storm frequencies adopted for design are given in the Table 1-1.

Table 1-1: Storm frequencies for minor systems

Land use	Recommended Design Storm Return Period (Years)
Residential	2 to 5
Institutions	2 to 5
Commercial and Industrial	5
Central Business District (CBD)	5 to 10

1.7 Urban storm water runoff components

1.7.1 General

Rainfall runoff in an urban environment effectively takes place instantly for areas served by traditional drainage systems and nearly all the rain that falls on impermeable surfaces runs off. The rate of runoff and the volume of runoff are both important components in analysing the performance of a network. For storms above a certain magnitude the performance of the network downstream may be exceeded.

Rainfall-related flooding of the drainage network, simply defined, is the concentration of stormwater to a point from which it cannot escape quickly enough to avoid ponding or passing on as overland flow. In addition to the hydraulic behaviour of traditional drainage systems, their water quality management characteristics are poor and this problem is now recognised as a major issue in terms of polluting receiving waters.

1.7.2 Stormwater sewers

Stormwater sewers are designed to collect all run-off from paved areas and exclude foul sewage. Storm drain pipe systems, sometimes referred to as storm sewers or lateral closed systems, are pipe conveyances used in the minor stormwater drainage system for transporting runoff from the roadway and other inlets to outfalls and receiving waters. Pipe drain systems are suitable mainly for medium to high-density residential and commercial/industrial development where the use of natural drainage ways and/or vegetated open channels is not feasible.

When storm sewers are over-loaded, flooding can occur and this is particularly serious when internal flooding of properties takes place. The level of service provided by stormwater sewers is often much less than the initial design intended due to additional developments taking place either by in-filling existing urban areas or being extended upstream.

The polluting effects of stormwater runoff in streams or flooding in houses is not significantly different to flooding from foul sewers. The contaminated silts and other detritus from urban areas and the occasional illicit foul connection make the impact of internal flooding equally unpleasant and damaging.

The high runoff rates which can occur, if unchecked, can cause erosion problems in receiving streams and also re-entrain polluted sediment from the riverbed. It is now recognised that surface water systems are a major cause of river pollution.

1.7.3 Open Channels

Open channel systems and their design are an integral part of stormwater drainage design, particularly for development sites utilizing better site design practices and open channel outfall structures. Open channels include drainage ditches, grass channels, riprap channels and concrete-lined channels.

The three main classifications of open channel types according to channel linings are vegetated, flexible and rigid. Vegetated linings include grass with mulch, sod and lapped sod, and wetland channels. Riprap and some forms of flexible man-made linings or gabions are examples of flexible linings, while rigid linings are generally concrete or rigid block.

- **Vegetative Linings**

Vegetation, where practical, is the most desirable lining for an artificial channel. It stabilizes the channel body, consolidates the soil mass of the bed, checks erosion on the channel surface provides habitat and provides water quality benefits. Conditions under which vegetation may not be acceptable include but are not limited to:

- high velocities;
- continuously flowing water;
- lack of regular maintenance necessary to prevent growth of taller or woody vegetation;
- lack of nutrients and inadequate topsoil; and/or,
- Excessive shade.

Proper seeding, mulching and soil preparation are required during construction to assure establishment of healthy vegetation.

- **Flexible Linings**

Rock riprap, including rubble, is the most common type of flexible lining for channels. It presents a rough surface that can dissipate energy and mitigate increases in erosive velocity. These linings are usually less expensive than rigid linings and have self-healing qualities that reduce maintenance. However, they may require the use of a filter fabric depending on the underlying soils, and the growth of grass and weeds may present maintenance problems.

- **Rigid Linings**

Rigid linings are generally constructed of concrete and used where high flow capacity is required. Higher velocities, however, create the potential for scour at channel lining transitions and channel head cutting.

1.7.4 Culverts

A culvert is a short, closed (covered) conduit that conveys stormwater runoff under an embankment, usually a roadway. The primary purpose of a culvert is to convey surface water, but properly designed it may also be used to restrict flow and reduce downstream peak flows. In addition to the hydraulic function, a culvert must also support the embankment and/or roadway, and protect traffic and adjacent property owners from flood hazards to the extent practicable.

The design of a culvert should take into account many different engineering and technical aspects at the culvert site and adjacent areas. The list below presents the key considerations for the design of culverts.

- Culverts can serve double duty as flow retarding structures in grass channel design. Care should be taken to design them as storage control structures if flow depths exceed several feet, and to ensure public safety.

- Improved inlet designs can absorb considerable energy for steeper sloped and skewed inlet condition designs, thus helping to protect channels.

Both minimum and maximum velocities shall be considered when designing a culvert. The maximum velocity shall be consistent with channel stability requirements at the culvert outlet. The maximum allowable velocity is 0.38 metres per second. Outlet protection shall be provided where discharge velocities will cause erosion problems. To ensure self-cleaning during partial depth flow, culverts shall have a minimum velocity of 0.064 metres per second at design flow or lower, with a minimum slope of 0.5%.

Buoyancy protection shall be provided for all flexible culverts. This can be provided through the use of headwalls, end walls, slope paving or other means of anchoring.

The culvert length and slope shall be chosen to approximate existing topography. To the degree practicable, the culvert invert should be aligned with the channel bottom and the skew angle of the stream, and the culvert entrance should match the geometry of the roadway embankment.

For maintenance purposes, the minimum recommended size for a culvert up to 30m long is 900mm diameter, or 750mm wide x 450mm high, and for culverts longer than 30m, a diameter of 1200mm, or 900mm wide x 450mm high would be more appropriate. However 600mm may be provided for Access Culverts.

1.7.5 Stormwater inlets

Inlets are drainage structures used to collect surface water through grate or kerb openings and convey it to storm drains or direct outlet to culverts. This can only be considered at the moment for the bituminous standard roads within the CBD. Grate inlets subject to traffic should be bicycle safe and be load-bearing adequate. Appropriate frames should be provided.

Inlets recommended for use for the drainage of bituminous surfaces for Bungoma town can be divided into three major classes:

- Grate Inlets – These inlets consist of an opening in the gutter covered by one or more grates, and slotted inlets consisting of a pipe cut along the longitudinal axis with a grate or spacer bars to form slot openings.
- Kerb-Opening Inlets – These inlets are vertical openings in the kerb covered by a top slab.
- Combination Inlets – These inlets usually consist of both a kerb-opening inlet and a grate inlet placed in a side-by-side configuration, but the kerb opening may be located in part upstream of the grate.

Inlets may be classified as being on a continuous grade or in a sump. The term "continuous grade" refers to an inlet located on the street with a continuous slope past the inlet with water entering from one direction. The "sump" condition exists when the inlet is located at a low point and water enters from both directions.

Where significant ponding can occur, in locations such as underpasses and in sag vertical curves in depressed sections, it is good engineering practice to place flanking inlets on each side of the inlet at the low point in the sag. The flanking inlets should be placed so that they will limit spread on low gradient approaches to the level point and act in relief of the inlet at the low point if it should become clogged or if the design spread is exceeded.

The design of grate, kerb and combination inlets are not considered any further since the roads on which drainage channels are to be improved within Bungoma Town are gravel running surface and only side channels are appropriate.

CHAPTER 2.FIELD SURVEYS AND DATA COLLECTION

2.1 Review of existing data and desk studies

A site reconnaissance visit was conducted as shown below in order to familiarize with the site conditions and the existing storm water drainage system and town layout.

The key dates for the mission were as follows:-

24th January 2011	Travel from Nairobi to Kakamega
25th January	Travel from Kakamega to Bungoma in the company of the Project officer, NBI, and Meeting with the Bungoma Municipal Council and Bungoma County Council
25th January	Reconnaissance survey of the Bungoma storm water drainage system in the company of the Town officials.
27th January	Return to Nairobi

Meetings were held with Bungoma Municipal Council Officials for the purposes of ascertaining the availability of any existing information and data within the council offices.

The following data and information was provided:

- Bungoma Municipality, Strategic Urban Development Plan 2008 – 2030.
- Base Maps

A follow up field visit was conducted between 21st and 24th March 2011 to confirm some of the information collected earlier and collect additional data and information.

The following data and information was collected with the assistance of the Municipality officials;

- Inventory on Storm water drainage channels
- Current construction rates for works carried out within the Municipality

The Municipal staff was helpful in providing the said information and in helping conduct a condition survey of the drainage channels within the municipality.

The data and information was useful in providing the Consultant with reference material on which to build and identify gaps that required additional surveys.

2.2 Situation analysis of the existing system

2.2.1 General

As outlined above, the Consultant carried out detailed field Surveys on the 21st to 24th March 2011 to assess the Existing Storm Water Drainage system in Bungoma Town. Discussions held with Town Officials also provided useful insights on the deficiency and challenges of the Existing Drainage System in the Town including:

- Heavy Flooding experienced in the Town during the rainy season. Most of the Storm Water is as a result of the localized rainfall within the town and outlying areas.
- Blocked Culverts and Channels due to uncontrolled Solid Waste Disposal within the Town.
- Siltation of the Existing Storm Water Drainage Channels from road sweepings and sediments carried by runoff from the unsurfaced roads.
- A number of the Businesses have been established either on or along the drainage channels thereby blocking or interfering with the flow of Storm Water.
- The said businesses contribute heavily to the solid waste that eventually finds its way into the drainage channels.
- Discharge of poorly treated sewage effluent from the treatment works into the Khalaba River.
- Surface Water Pollution essentially due to lack of Sanitary Systems and unsatisfactory Sanitation in the Area
- Poor Maintenance of the Drainage System in the Town Council.

During the said survey the Consultant had the opportunity to observe firsthand the performance of the Storm Water Drainage System as it had been raining for the last few days. It was observed that apart from the Central Business District (CBD), most of the storm water drainage channels are not designed and have been formed as a result of drainage water trying to find its way when it rains. As a result the road network suffers from poor Storm Water Drainage both in capacity and design leading to flooding of vast areas for a long time. The section that is worst affected is the Bungoma Mumias road (C33) near the bus park. It was noted that it was only along the Moi Avenue that the drainage channels were lined. Drainage channels in other parts of the town are unlined and in most cases improved natural channels.

2.2.2 Road transport

The Road Network within the CBD in Bungoma Town consists of both bitumen standard and gravel roads. Among the former are as follows:

- Moi Avenue
- Crossroads Road
- Simba Road
- Chemist Road
- Mama Fanta Street
- KNTC Street
- Site and Services Road
- Tourist Road
- A section of the C33 that cuts through the town
- A section of the A104 road that passes on the northern flank of the town

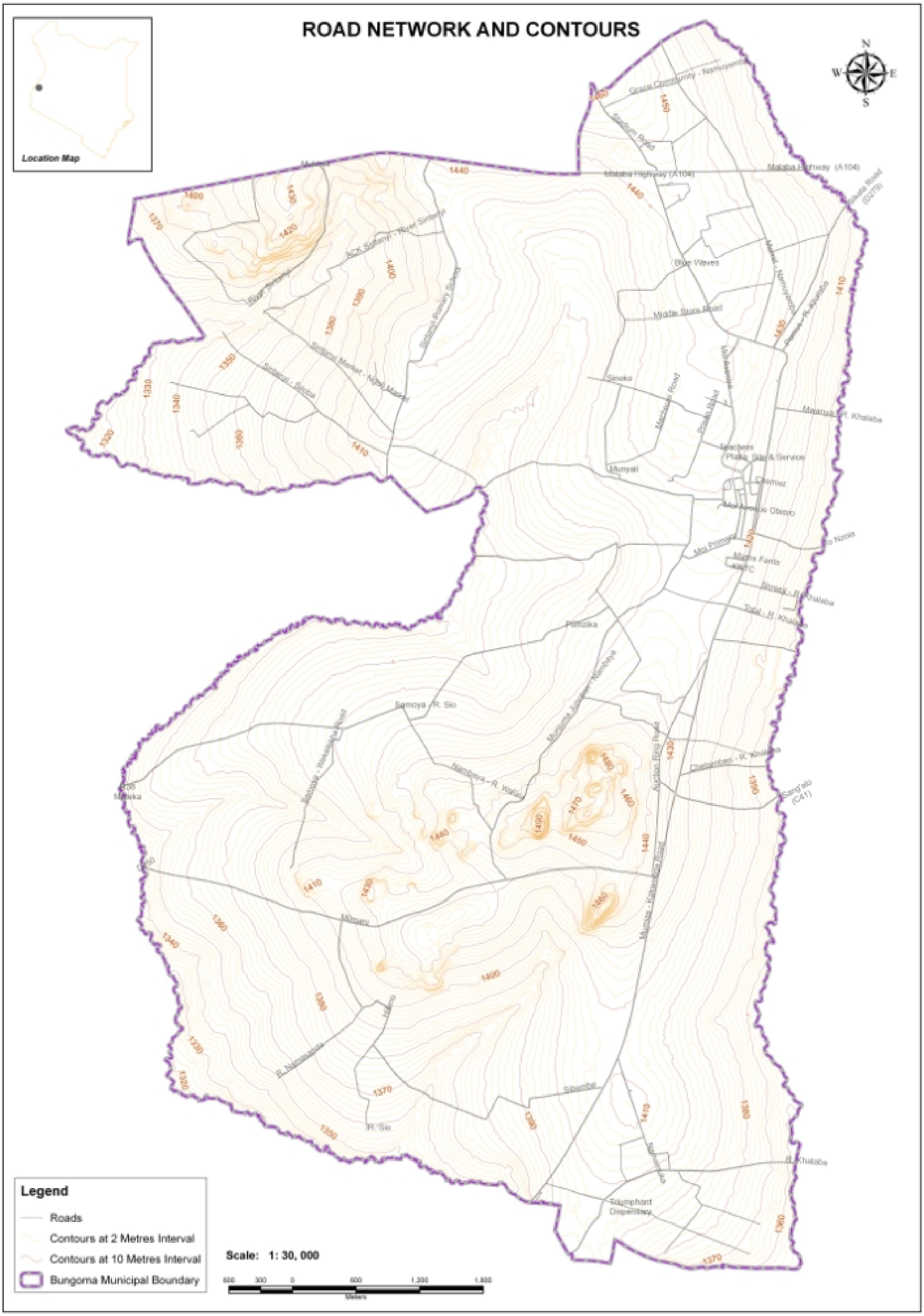
Gravel roads within the CBD include the following:

- Slaughter House Road
- Oldrex Road
- Moi Primary Street
- Market Road

Roads within Bungoma town fall into three broad categories:

- Classified highways under the Kenya National Highways Authority (KeNHA),
- Classified rural roads under the Kenya Rural Roads Authority (KeRRA), and
- Urban roads under the Kenya Urban Roads Authority (KURA) and Municipal Council of Bungoma.

The above two categories of roads provide access between Bungoma and its hinterland as well as linking the town with other important neighboring towns like Kakamega, Busia, Mumias, Malaba, Kitale, Kimilili, Webuye, Eldoret and Kisumu. The rehabilitation and maintenance of the drainage system for these roads is not the responsibility of the Municipal Council of Bungoma, but contributes to the effective evacuation of storm water for the town.



Map 2-1: Road Network in Bungoma Municipality

Table 2-1 shows the inventory of the Existing Drains and type in each ward.

Table 2-1: Existing Drains in Bungoma Municipality in each Ward

	Ward	Route description	Length of drain (km)	Type
1	Mjini	Moi Avenue	4.8 (both sides)	Lined
		Simba Street	0.5 (one side)	Lined
		Mama Fanta	0.2 (one side)	Lined
		KNTC Street	0.2 (one side)	Lined
		Khetia's back street	0.4 (both sides)	Unlined
		Moi Primary Street	1.0 (both sides)	Unlined
		Site and Service	1.2 (both sides)	Lined
		Moi Avenue Obiero Road	0.6 (both sides)	Unlined
		Tourist Road	0.3 (both sides)	Lined
		Total	**17.5**	
2	Sio	Oldrex-River Sio	5.0 (both sides)	Unlined
		Munyali-River Sio	2.0 (both sides)	Unlined
		Pumzika-River Sio (R38)	4.0 (both sides)	Unlined
		Oldrex-River Walala	6.0 (both sides)	Unlined
		Total	**34.0**	
3	Khalaba	Pamus-River Khalaba	1.8 (both sides)	Unlined
		Mwanya-River Khalaba	1.8 (both sides)	Unlined
		Elgon View-River Khalaba	1.8 (both sides)	Unlined
		Mukhaweli-River Khalaba	1.8 (both sides)	Unlined
		Slaughter House Road	1.8 (both sides)	Unlined
		Shreeji-River Khalaba	1.8 (both sides)	Unlined
		Mateso-River Khalaba	1.8 (both sides)	Unlined
		Total-River Khalaba	1.8 (both sides)	Unlined
		KCC-River Khalaba	1.8 (both sides)	Unlined
		Chebembe-River Khalaba	1.8 (both sides)	Unlined
		Total	**36.0**	
4	Stadium	Sikota Road	2.0 (both sides)	Unlined
		Marell-Namuyemba Road	2.0 (both sides)	Unlined
		Sunrise Road	1.0 (both sides)	Unlined
		Grace Community-Namuyemba B	1.0 (both sides)	Unlined
		Total	**12.0**	
5	Namasanda	Samoya Mkt-River Sio	4.0 (both sides)	Unlined
		Samoya-Wekelekha	3.6 (both sides)	Unlined
		Mlimani-Namasanda	4.0 (both sides)	Unlined
		Namasanda-River Sio	2.6(both sides)	Unlined
		Namamuka-Triumphant-River Khalaba	2.0 (both sides)	Unlined

		Sibembe-Namamuka-River Khalaba	1.5 (both sides)	Unlined
		Total	**35.4**	
6	Musikoma	Munjuma Junction-Nambaya	6.0 (both sides)	Unlined
		Fremos-Musikoma-bakery-River Khalaba	3.0 (both sides)	Unlined
		Total	**18.0**	
7	Siritanyi	Siritanyi Mkt-River Sio	2.0 (both sides)	Unlined
		A104-Siritanyi Mkt	4.0 (both sides)	Unlined
		MK-River Siritanyi	3.6 (both sides)	Unlined
		Siritanyi-Ng'oli Mkt	6.0 (both sides)	Unlined
		Siritanyi-Siloba-River Sio	4.0 (both sides)	Unlined
		Mukholi-River Siritanyi	2.0 (both sides)	Unlined
		Total	**43.2**	
8	Sinoko	Mkova Street	1.0 (both sides)	Unlined
		Teachers Plaza-River Sio	4.0 (both sides)	Unlined
		Blue Waves-Sinoko-Munyali	2.8 (both sides)	Unlined
		Middle Store	1.0 (both sides)	Unlined
		Total	**17.6**	

While evaluating part of the present drainage situation, the following issues were observed:

- Undersized or nonexistent roadside Drainage in many parts of the Town
- Maintenance of the Drainage System seems to be restricted to the lined channels along the Moi Avenue. Maintenance for the natural unlined channels consists of cleaning and removal of solid waste. This has led to changes to the hydraulic properties of the channels rendering the existing system less effective than it could be.
- Information from the town officials indicated that flooding is severe in the lower end of the Moi Avenue at the point where it joins the Mkhavo Street. This results in the section next to the petrol station and the C33 road being completely inundated for long periods.
- Blocked Culverts and Channels due to uncontrolled Solid Waste Disposal within the Town. This was evident on Moi Avenue downstream of the junction with CrossRoads Road to the point where it joins the C33 Road.
- Siltation of existing Storm Water Drainage channels and access culverts due to road sweepings and erosion from unsurfaced roads, examples of which are along Moi Primary and Market Roads.
- Encroachment on the right-of-way of the Drainage Channels such as blockage of the Channel Alignment by business people and in some cases, construction on the channels.

The photographs included in Annex A indicate the extent of the problem.

2.2.3 Drainage infrastructure

- **Closed drains**

Bungoma Municipality's drainage structures do not incorporate closed buried drains in any of its infrastructural arrangement.

Closed drains are commonly used in areas that are fully developed and with limited space. With the expansion and development of the municipality as foreseen in the Strategic Urban Development Plan 2008 – 2030, this category of infrastructure could be used in areas such as described above.

- **Advantages and disadvantages**

Closed drains are buried underground. They are not exposed and are safe to the general public. Hygienically, closed drains are convenient to the public because in case of any illegal connections, exposure to foul smell is only through manholes and therefore minimal. Also closed drains require minimal cleaning due to the designed self-cleansing velocity and catch pits. Just as open drain is illegally used by the community as solid waste dumping ground; closed drain is immune except one that has broken manholes.

However, closed drains are very expensive to construct and requires substantial finances. Also due to its unexposed nature, closed drain can be used by notorious illegal connectors to carry foul sewer. Occasionally, closed drain can be difficult to clean when the drain is poorly designed by providing slope that does not allow self-cleansing and when broken manholes are not repaired immediately and acts as a passage of silt and solid waste to the drain.

- **Open drains**

Open drains exists in all the zones of the Municipality. Within the Central Business District (CBD) lined drains run along the Moi Avenue. Other drains within the Municipality are natural unlined open channels.

The existing 2.6km existing drain in the Municipality comprises of 1.2km lined with the remainder being unlined natural channels which have been improved over time.

Open drains are appropriate in areas with enough space and less developed.

- **Advantages and disadvantages**

Open drains are normally laid along either side of the road or streets or along boundary walls of houses and provide a cheap and economical arrangements of collecting surface runoff. However, open drains are potential danger zones due to the possibility of falling into them. They are also less hygienic particularly when it carries foul sewer due to uncontrolled effluent discharge. In addition, open drains are potential ground for dumping of solid waste and therefore requiring regular cleaning.

- **Problem statement and development challenges**

Bungoma Town drainage problems have compounded primarily due to continued rapid growth, lack of funding for maintenance, rehabilitation of the existing infrastructure and construction of the new drainage system. In addition, the lack of any designed system has contributed to the flooding problems in the Municipality with the drains contributing heavily to the BOD levels in both the Sio and Khalaba Rivers. Other primary issues that have contributed to drainage problems in Bungoma are as follows:

- **Road related problems**

For effective storm drainage within the Municipality, road construction and maintenance within the jurisdiction of the Municipality should be well managed. However, the depending on the class of the road such as the C33 traversing the town, this responsibility rest with the Roads Authorities. Close liaison between the Municipal Council and the Roads Authorities is highly recommended.

- **Topography related problems**

The flat topography within which the Municipality is located requires properly designed channels to enable them drain the surface runoff that accumulates and floods during the rainy season.

- **Lack of sufficient criteria for drainage development**

No storm drainage Master plan for Bungoma Municipality has been developed. As a result a number of challenges are faced by the Municipality in addressing the issue such as:-

- Inadequate maintenance resources reducing the effectiveness of the existing systems.
- Incorrect construction resulting in drainage bypassing catch pit’s or gulley’s inlets that are high for stormwater to get in.
- Illegal practices of the residents that induce flooding in the localized area
- Lack of a stormwater drainage treatment facility before discharge into the river courses of Sio and Khalaba.

2.3 Reference maps

As part of the data and information gathering by the Consultant, the following were collected both in Nairobi and Bungoma:

- Maps showing different development alternatives of the Bungoma Town and current road network prepared by Matrix Development Consultants for the Strategic Urban Development Plan 2008 - 2030. These Maps have been used to generate a detailed layout map showing the existing road network.
- The Municipal Physical Planner also provided the Consultant with a hard copy of the Bungoma Town Layout Map on scale 1:2,500.

- Topographical Map of Bungoma District (Sheet 88/3 of scale 1:50,000 covering the areas of Bungoma Municipal Council were obtained from the Survey of Kenya offices in Nairobi. The Map was used for the general location of Bungoma Municipality.
- The Topographical Map gave an appreciation of the general land surface including rivers into which storm water drainage is channeled to. The map gives countour intervals of 20 metres.

2.4 Climatic data

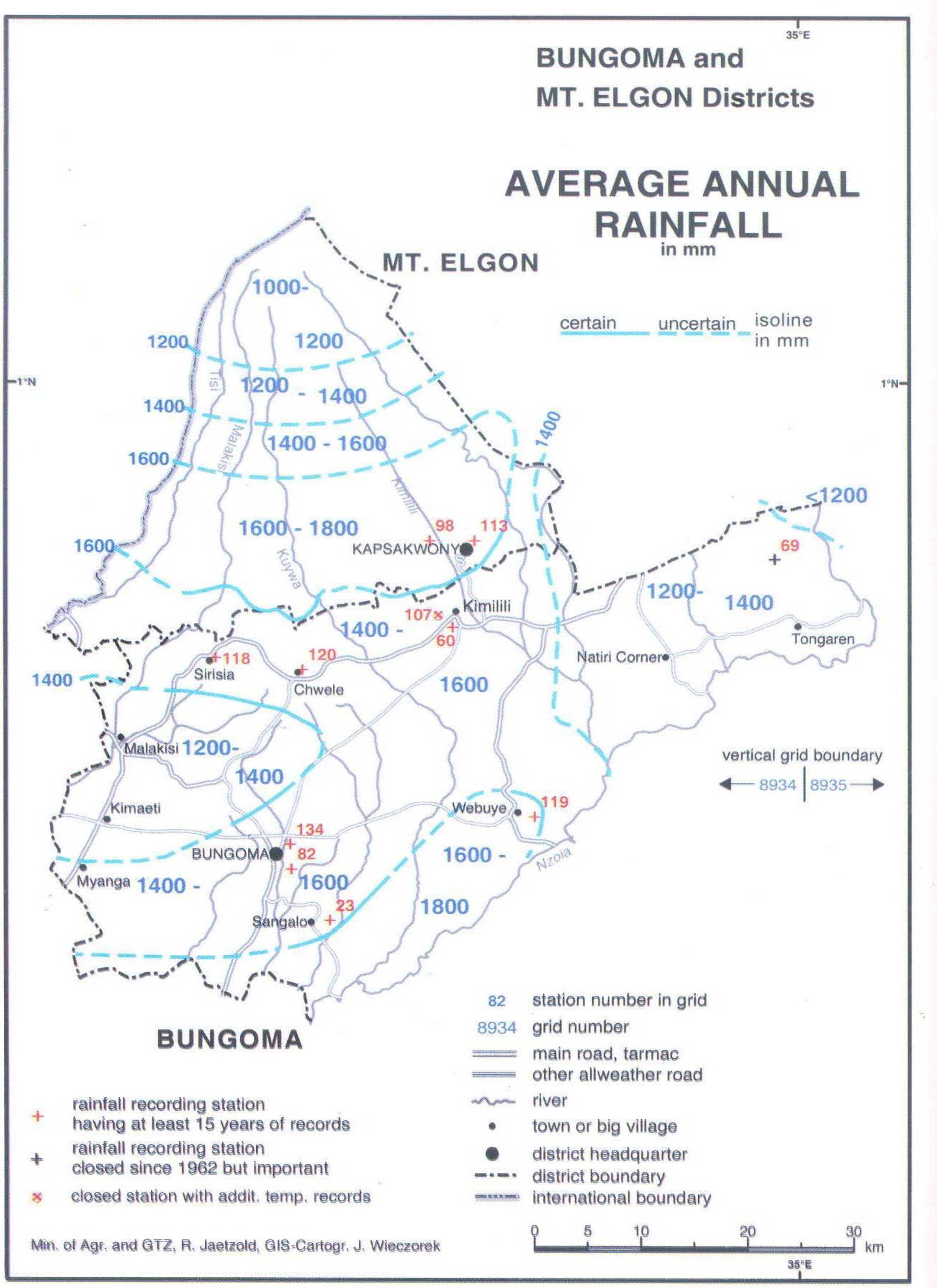
The area is characterized by bimodal rainfall of long and short rains. Long rains normally start in March to July while short rains start in August to October. The mean annual rainfall ranges from 1250mm to 1800mm with the heaviest rains between April and May. This is the period when the town has to contend with the most storm water flows. The mean annual temperatures range from 21^0 - 23^0 C with the hottest temperatures falling between December to February and low temperatures between April to July.

Daily Rainfall Records for Bungoma Gauge Station were collected from the Lake Victoria North Catchment Area offices in Kakamega town. Bungoma Weather Station No. 8934134 is the nearest station to Bungoma Town. Peak Daily Rainfall Data for a period of about 17 years ranging from 1994 to July 2010 was obtained. This data is useful in the Hydrological Analysis.

The Parameters obtained included:

- Peak Daily Rainfall (mm)
- Mean Monthly Rainfall (mm)
- Rainfall Intensity
- Rainfall Duration

The Rainfall Data obtained captures the critical periods that experienced severe rains of El-Nino in 1996 and 1998. The Annual Distribution of Rainfall is shown in Figure 2-1, expressed in terms of Mean Monthly Rainfall compiled from available Daily Rainfall Data.



Map 2-2: Average Annual Rainfall (mm) – Source: Ministry of Agriculture, Bungoma Farm Management Handbook

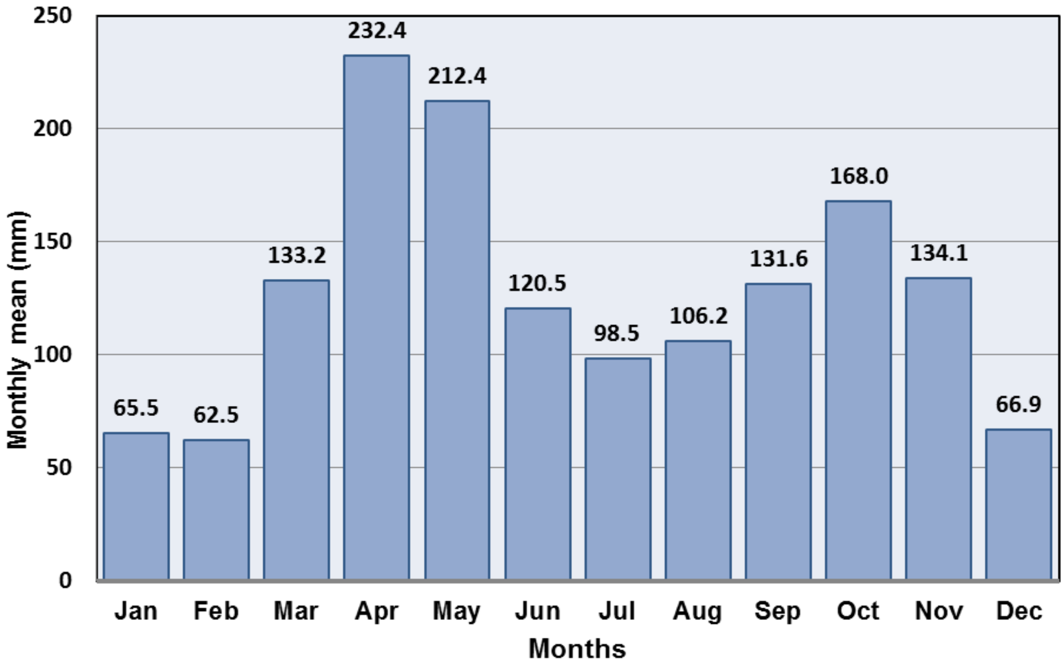


Figure 2-1: Bungoma 24 HR Maximum Rainfall in mm/month. Weather Station No. 8934134.

2.5 Drainage and relief

The area within which the municipality is located is part of Lake Victoria drainage basin. Rivers drain from Mt. Elgon to Lake Victoria. The rivers traversing the municipality include rivers Khalaba and Sio. Sinoko swamp in Sinoko ward was identified as a source of several streams which join the main river.

Because of the relatively flat nature of the terrain, drainage is poor in many areas including the built up areas, which easily floods with storm water. Flooding is a perennial problem within the municipality because of lack of and blocked storm drainage system.

The natural terrain of Bungoma town is well drained by Khalaba and Sio Rivers. Most of the roads however do not have adequate drainage. The section that is worst affected is the Bungoma-Mumias road (C33) near the bus park. The section is a low lying area and the problem is aggravated by solid waste which is washed from the surrounding areas from business premises. Some of the refuse is swept down from the CBD along the existing drainage channels and blocks the drains on the road thereby causing flooding. There is need therefore to ensure efficient collection of waste to minimize incidences of blocking of drains. Maintenance of drains should also be prioritized.

CHAPTER 3.STUDY AREA CHARACTERISTICS

3.1 Historical background

The history of Bungoma town dates back to over 80 years during the construction of the Kenya –Uganda railway line. The railway line reached Bungoma town in 1926. Makeshift structures were then built at the present Central Business District (CBD) to house Indian labourers who settled as traders.

Agricultural activity in the surrounding area by the local inhabitants became a source of trade between the Africans and the newly settled Indians. Produce such as maize, sim sim and cotton was traded between the two communities with some of it finding its way to India. Hence, the town developed into a market centre encouraging other economic activities to be established. With increased economic opportunities and being already a major transit point, Bungoma has grown from a market centre into a municipality today. It is both the Headquarters of Bungoma South District and is inhabited by mostly the Bukusu community.

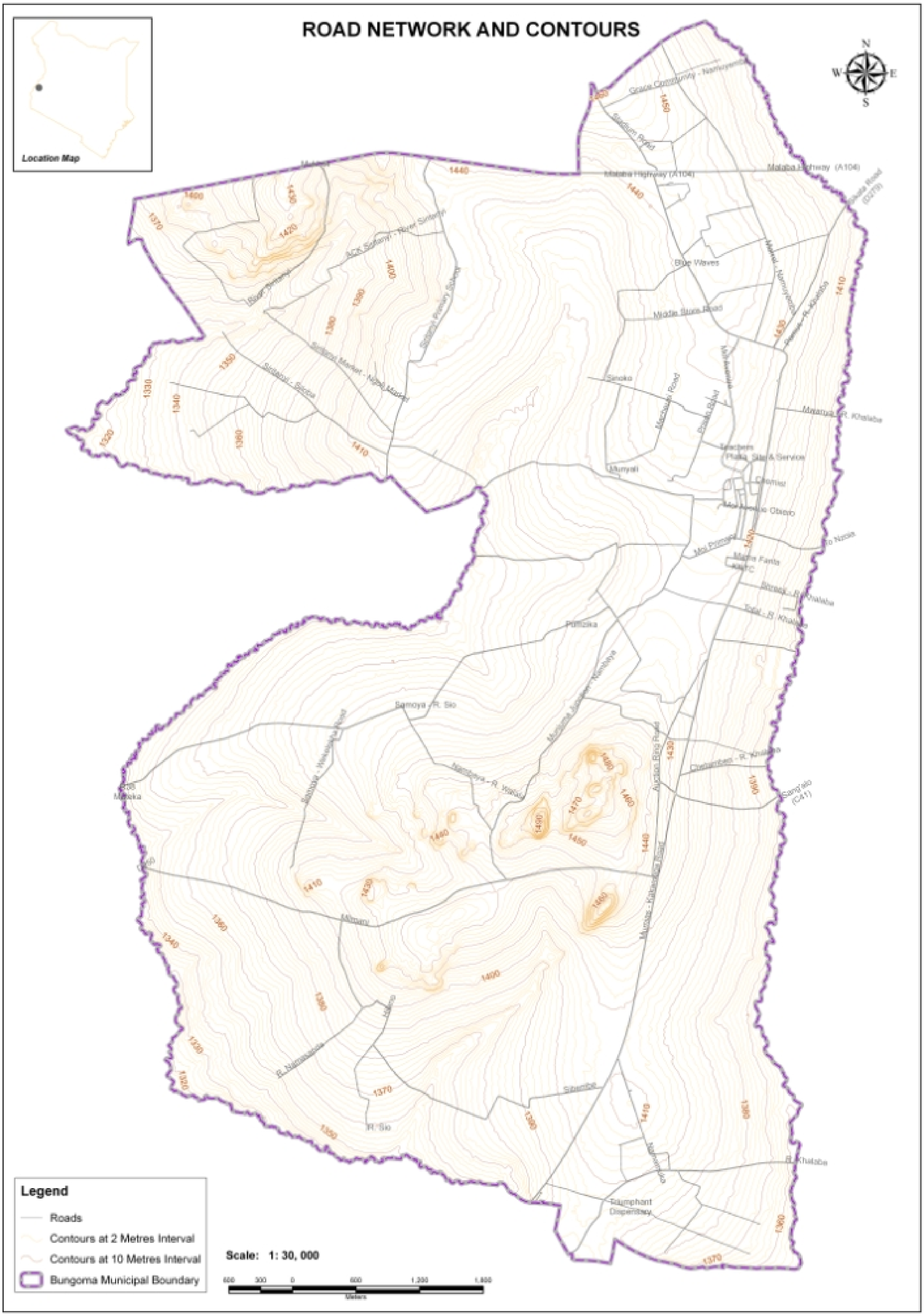
3.2 Location

Bungoma Municipality is located approximately 500 km North - West of Nairobi and km east of Malaba town, along the Kenya - Uganda border, and 61km west of Kakamega town, the provincial headquarters of Western Province.

The town covers an area of 57 sq. Km and extends between Sibembe to the South, and Kanduyi to the north. It borders Rivers Khalaba to east and Sio to the west .The town is situated in North and South Bukusu adjudication area. Administratively it is divided into two locations namely, Township and Musikoma locations. It has four sub-locations and eight electoral wards as listed below:

- Namasanda,
- Sio,
- Siritanyi,
- Sinoko,
- Mjini,
- Musikoma,
- Stadium, and
- Khalaba.

Map 3-1 shows the municipal and ward boundaries.



Map 3-1: Municipal Ward and Boundaries for Bungoma

CHAPTER 4.DRAINAGE DESIGN

4.1 Review of Bungoma Town Structure Plan

The Strategic Urban Development Plan 2008 – 2030 for Bungoma Municipality prepared by Matrix Consultants was used as the basis for the preparation of maps used for the preliminary design of the Storm Water Open Channel Reticulation Network. AutoCAD and ArcGIS software was used in preparing the maps of Bungoma Town and surroundings areas and served as the basis for the Hydrological Analysis and estimation of Peak Discharges expected through Town.

4.2 Major problems of the existing drainage system

The entire road network in Bungoma Town, with the exception of the main Moi Avenue and a few other connecting roads which cuts across the Central Business District (CBD) and the C33, is gravel surface. Problems affecting the storm water drainage management within Bungoma Town, as observed during field investigations and discussions with the Municipal Council Officials are:-

- Poor Maintenance of Existing Drains
- Undersized Culverts and Channels
- Inadequate and sometimes Non Existent Road Side Drainage
- Siltation and Blockage of Drainage Facilities due to uncontrolled Urban Litter Disposal.

4.3 Hydrologic and hydraulic analysis

4.3.1 Drainage catchments

The first step in undertaking any kind of hydrologic modeling involves the pre-processing of the various datasets and surface models before delineating streams and watersheds, and getting some basic watershed properties such as area, slope, flow length, and stream network density.

Bungoma Municipality has a relatively flat topography and rises gradually towards the Sinoko swamp and therefore developing the drainage catchments requires the use of high resolution surface model to yield better result.

For purposes of this Study, Major Catchments over the entire Bungoma Municipality were delineated using the above mentioned software. Sub Catchments within Bungoma Town were further delineated using ArcGIS. Onto these were overlaid the Topographical Survey of the Existing Road Network to ensure greater accuracy.

Field inspection Surveys were undertaken to evaluate and confirm specific characteristics of delineated Sub Catchments such as General Slope, Land Use and Runoff Coefficients.

In line with Proposed Design Standards adopted in this Report, the following Return Periods were selected:

Residential	5 years
Institutions and Schools	5 years
General Commercial and Industrial	5 years
Central Business District (CBD)	10 years

However for a Comparative Analysis of Runoff Volumes, 25 Year Peak Flood Flows were also evaluated.

4.3.2 Drainage basins

A hydrologic and hydraulic analysis of Bungoma Municipality was undertaken to define drainage basins in order to develop the capital outlay for the proposed drainage infrastructure.

In hydrologic and hydraulic analysis, peak flows and volumes were determined and shall be used to size the storm drainage structures.

The drainage basin analysis involved establishment of major basins by modelling the entire study area into catchments through a GIS based programme. The catchments shall be based on direction of flow, topography and discharge points were used to initially identify major basins. After these the minor and major basins shall be mapped, the low point of each major basin shall be identified.

4.3.3 Design storm frequency

The design rainfall frequency is the period during which, on average, a rainstorm of the design magnitude will occur or be exceeded just once. Although in reality there is no such thing as the design storm, it does nevertheless represent a useful concept, and over a long period of time it is a fair statistical representation of what happens at the prescribed frequency.

In most urban situations a design frequency of storm is set which takes account of environmental considerations and the cost implications of possible damage during greater storms versus the cost of providing a more substantial system. In normal practice return periods to be used in design of the drainage structures should be those that take into account of the high flood regimes. Return periods to be specified for each of the following:

- Checking the design of existing systems
- Extensions, rehabilitations and minor amendments to existing system;
- Minor culverts
- Major culverts
- Box culverts

4.3.4 Rainfall Intensity Duration Frequency relationship

The purpose of an urban storm water drainage system is to remove excess surface water from roofs, roads, and other paved surfaces at a rate sufficient to prevent the accumulation of water in puddles or floods. In a separate storm water drainage system such as in Bungoma, the only significant source of water entering the system is from storm rainfall runoff, and the rate of such inflow is obviously dependent on the rate of rainfall. It is therefore important to be able to establish a design rate, or intensity, of rainfall in order to derive the rate of water inflow to the drainage system under design conditions. The following sub-sections consider how rainfall intensity is estimated.

Generally, when one considers a series of individual rainstorms, the maximum average rainfall decreases with the duration of rainfall. There is also a relationship between intensity and the frequency of recurrence, or return period. When considering drainage hydrology, it is normal practice to derive a relationship between rainfall intensity, duration and frequency of recurrence for any given locality, and to plot this relationship as a set of intensity-duration-frequency curves (or i-d-f curves).

This relationship may be derived statistically, based on measured rainfall records for storms at the site over a period of years. Ideally, such data would be taken using a continuously recording rain gauge, which provides a full intensity-time record during all storms. Such data is actually seldom available in that form, and is more normally available only as daily readings, which note only the total depth of rainfall in a twenty four hour period. Therefore, statistically derived empirical formulae are often used to adjust the daily rate to shorter durations of storm.

Although the use of data from a single gauge within the drainage area is acceptable, given enough years of record, there is another method available for deriving i-d-f curves. Considerable work has been carried out by the Transport and Road Research Laboratory (TRRL) of the UK Department of the Environment, using many years of rainfall records from about a hundred gauging stations throughout Kenya. On the strength of this large statistical database they have been able to derive more generalised formulae applicable, with suitable local constants, to eight different climatic zones throughout the region. This is referred to as the TRRL East African Model, and it is proposed, for its simplicity, that this would be used to determine Peak Flood Flows for 2, 5, 10 and 25 Year Return Periods. However in the Design of Bungoma Storm Water Master Plan, only the 5 and 10 Year Flood Flows were used in the sizing of the Drainage System Components. The model uses three simple empirically derived relationships to build up I-D-F curves.

- The East African regression equation relating once in two year 24 hour rainfall to average annual rainfall:

Y_2 = 0.018 MAR – 0.016 ALT + 69.5

Where:

Y_2 = the 2 year 24 hour rainfall (mm)
MAR = the mean annual rainfall (mm)
ALT = the station altitude (m)

For Bungoma,
MAR = 1525 mm (Overall mean, Bungoma Town 1950 – 2004)
ALT = 1440 metres a.m.s.l.

Therefore, Y_2 = 73.91 mm

- Bell's equation is used to adjust the two-year 24-hour depth to other frequencies:

T: 10 year ratio = 0.21 log T + 0.52

or, alternatively,

T: 2 year ratio = (0.21 log T + 0.52)/0.666

This yields 24 hour rainfall depths for T year return periods in Bungoma as shown in Table 4-1.

Table 4-1: 24 Hour Rainfall in Bungoma at various Frequencies

Return Period T years	T year 24 hr Rainfall Depth (mm)
1	57.71
2	73.91
5	95.22
10	111.37
25	132.72
50	148.90

- The 24 hour rainfall may be adjusted to different durations using the formula:

$$RR = \frac{t}{24}\frac{(24+b)^n}{(t+b)}$$

Where: RR = rainfall ratio

b = constant taken as 0.33 for East Africa

n = zone index, taken as 0.96 for the region

This relationship yields the depth-duration-frequency curves, tabulated in Table 4-2 and Table 4-3 also show the corresponding intensity-duration-frequency curves obtained using the basic definition that Average intensity = Depth/Duration

Table 4-2: Rainfall Depth-Duration-Frequency Relationship for Bungoma

Duration	Rainfall Depths (mm) at Return Periods of:					
	1 year	2 years	5 years	10 years	25 years	50 years
5 mn	9.98	12.79	16.47	19.27	22.96	25.76
10 mn	16.85	21.58	27.80	32.52	38.75	43.48
15 mn	21.70	27.79	35.80	41.88	49.90	55.99
30 mn	30.82	39.47	50.85	59.47	70.87	79.51
1 h	39.19	50.18	64.65	75.62	90.12	101.10
2 h	45.72	58.55	75.43	88.23	105.14	117.96
4 h	50.44	64.60	83.22	97.34	116.00	130.14
8 h	53.84	68.96	88.84	103.91	123.83	138.92

Table 4-3: Rainfall Intensity-Duration-Frequency Relationship for Bungoma

Duration	Rainfall Intensities (mm/h) at Return Periods of:					
	1 year	2 years	5 years	10 years	25 years	50 years
5 mn	119.8	153.5	197.6	231.2	275.5	309.1
10 mn	101.1	129.5	166.8	195.1	232.5	260.9
15 mn	86.8	111.2	143.2	167.5	199.6	224.0
30 mn	61.6	78.9	101.7	118.9	141.7	159.0
1 h	39.2	50.2	64.7	75.6	90.1	101.1
2 h	22.9	29.3	37.7	44.1	52.6	59.0
4 h	12.6	16.2	20.8	24.3	29.0	32.5
8 h	6.7	8.6	11.1	13.0	15.5	17.4

4.3.5 Runoff coefficients

Run-off calculations are based on the Rational method which is widely used in urban drainage studies and gives satisfactory results for small catchment areas (up to 15km²) typical of drainage basins in an urban environment.

Rainfall in urban areas can land on three types of surface:

- Roads and pavements,
- Roofs,
- Permeable surfaces such as gardens and undeveloped land

Each surface type shall have its own characteristics, which determine how much and how quickly rainfall landing on the ground is converted to runoff water entering the drainage system. In Bungoma, typical characteristics are as follows:

- Roads, pavements and paved areas in general are fairly flat. Often they are of a broken nature or undulated or potholed, all of which lead to relatively high depression storage (i.e. tendency to puddles) and moderately slow runoff.
- Roofs may or may not be connected to downpipes, but even where they are, they tend not to be connected directly to the drainage system. However, in heavily developed areas they often discharge onto pavements, and thus indirectly into gutters and the drainage system. Elsewhere, in less heavily developed areas, roofs typically drain to soakaways or just straight on to the ground surface. In these instances, roof drainage typically does not contribute to the flows entering the drainage system.
- The remaining undeveloped land or gardens and open surfaces in Bungoma are usually rather flat, and except where the soil is of a silty nature, the ground is reasonably, or even very, permeable. Generally, there shall be little runoff from undeveloped land surfaces.

Detailed analyses of drainage systems normally employ separate assessment of the proportional areas for the three surface types, and the application of three separate runoff coefficients. Local practice to date, however, has advocated an overall runoff coefficient and time of entry selected according to various types of land use and population densities. Suggested coefficients are presented in the Table 4-4.

Table 4-4: Runoff Coefficients

Description of area	Runoff coefficient
Town Centres	0.6 – 0.8
District Centres	0.4 – 0.6
Industrial	0.4 – 0.5
Public Purpose	0.2 – 0.5
Residential, high density	0.3 – 0.5
Residential, medium density	0.2 – 0.3
Residential, low density	0.1 – 0.3
Parks, gardens, sports grounds, etc.	0.1 – 0.25
Undeveloped, bush or forest	0.01 – 0.2

4.3.6 Time of concentration (T_c)

Rainfall landing on the ground or paved surfaces takes a finite length of time to enter the designed drainage system. This is of significance since it affects the manner in which flows accumulate and aggregate within the drainage system. The time water takes to enter the system, usually at a gulley or an open drain, is a function of:

- The nature and roughness of the surface,
- The steepness of the surface

The time of concentration Tc is defined as the time for runoff to travel from the hydraulically most distant point in the drainage basin to the outlet or point of interest. For small drainage basins of less than 15 km^2, the time tp peak is regarded as being equal to the time of concentration. This relationship is based on the Rational Method (Chow 1964) which is used in for the purposes of this assignment.

Quite a number of formulas exist for deriving Tc from the physical characteristics of a drainage basin. One of the empirical formulas is given by Kirpich (1940)

Tc = 0.02 L0.77 S-0.385

Where: Tc = time of concentration (min)

L = Maximum length of travel (m)

S = slope, equal to H/L where H is the difference in elevation between the most remote point in the basin and the outlet

4.3.7 Estimation of runoff

In order to be able to size a drain, an estimate must be made of the peak rate of flow entering it during a design storm. There are different methods available for making such estimates and in this particular case the empirical formula approach will be used and is described in the following section.

4.3.8 Rational method

The Rational Method is a purely empirical formula which is very simple and quick to apply. Larry W. Mays records that criticism has been raised on the adequacy but it is still in continued use for sewer design where high accuracy runoff rate is not essential. In its fundamental form the Rational Formula is:

$$Q = K.C.I.A$$

Where/ Q = Peak runoff rate, m3/s

K = Constant, 0.28 in SI units

C = Runoff coefficient (depends on the characteristics of the surface)

I = Average rainfall intensity in mm/hr obtained from the intensity – duration - frequency relationship curves.

A = Area of the drainage basin in km²

A drainage area will normally consist of sub-catchments with different surface characteristics. In consideration of the composite analysis, Larry W. Mays (2005) gives the peak runoff using the rational formula as:

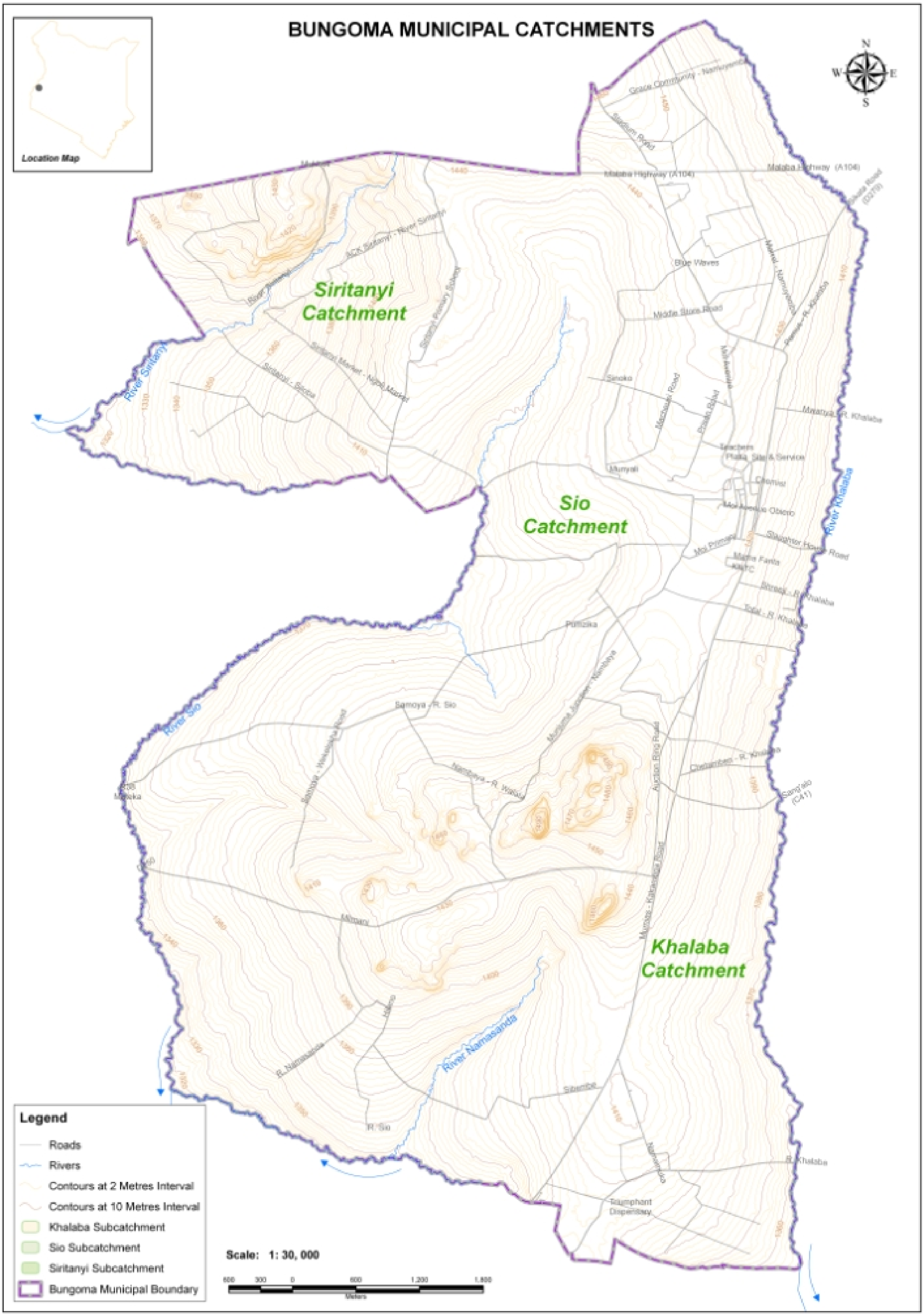
$$Q = Ki\sum_{j=1}^{m} CjAj$$

Where : m = the number of sub-catchments drained by the storm structure

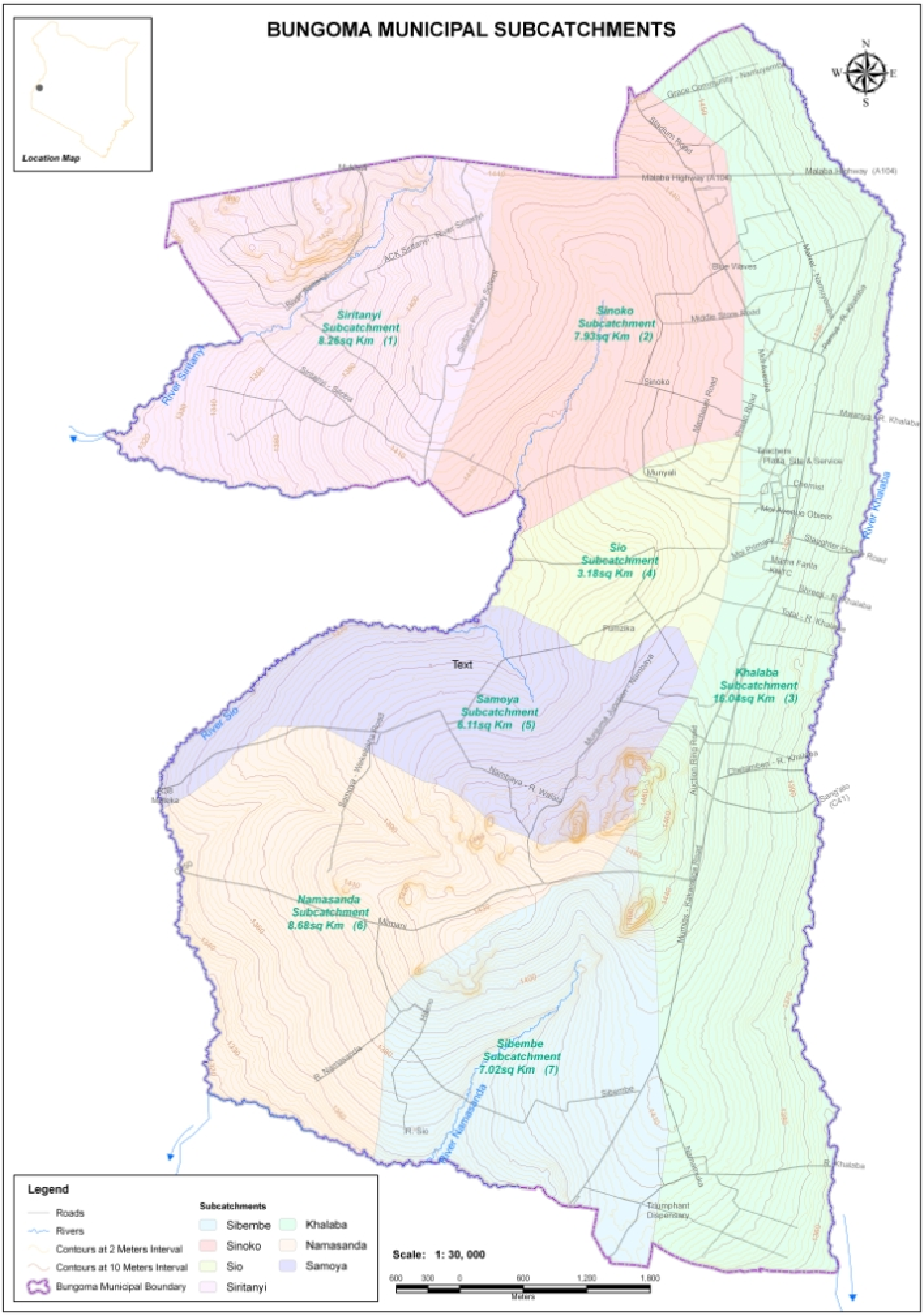
The duration of the rainfall is normally taken as the time of concentration Tc of the drainage area. This is the time associated with the peak runoff from the watershed to the point of interest. Runoff from a watershed usually reaches a peak at the time when the entire watershed is contributing. It is the time for a drop of water to flow from the remotest point in the watershed to the point of interest.

Table 4-5: Peak Discharge for Sub-Catchments

Sub-Catchment Basin	1	2	3	4	5	6	7
Catchment area	8.26	7.93	16.04	3.18	6.11	8.68	7.02
Maximum length of travel, L (m)	2,530	3,500	12,500	2,460	2,320	3,720	3,100
Difference in Elevation, H (m)	100	42	72	46	76	88	42
Slope, S = H/L	0.040	0.012	0.0058	0.019	0.033	0.024	0.014
Concentration Time, Tc (mn)	29	77	207	38	29	47	50
Average Rainfall intensity (mm/h)							
2 Years Return Period, Q2	78.94	44.33	19.76	71.27	78.74	62.64	59.77
5 Years Return Period, Q5	101.70	57.11	25.46	91.82	101.7	80.71	77.00
10 Years Return Period, Q10	118.94	66.80	29.78	107.39	118.94	94.39	90.06
25 Years Return Period, Q25	141.74	79.61	35.48	127.97	141.74	112.49	107.33
Design Discharge (m^3/s)							
2 Years Return Period, Q2	63.90	34.45	31.06	22.21	47.15	53.28	41.12
5 Years Return Period, Q5	82.32	44.38	40.02	28.61	60.90	68.66	52.97
10 Years Return Period, Q10	96.28	51.91	46.81	33.47	71.22	80.29	61.96
25 Years Return Period, Q25	114.74	61.87	55.77	39.88	84.87	95.69	73.84



Map 4-1: Bungoma Municipal Catchments



Map 4-2: Bungoma Municipal Sub-Catchments

4.4 Proposed drainage option

4.4.1 General

As mentioned earlier, some of the roads within the Bungoma Municipality are of gravel running surface. It is mostly on these roads that drainage will either have to be provided or the existing channels improved. In view of this, a Drainage Reticulation Network based on Open Channels both lined and unlined as necessary is foreseen with culverts where appropriate. These roads include among others:

- Slaughter House Road
- Stadium Road
- Moi Primary Street
- Market Road

The following roads have a bituminous running surface:-

- Moi Avenue
- Crossroads Road
- Simba Road
- A section of the C33 that cuts through the town
- A section of the A104 road that passes on the northern flank of the town

The responsibility of provision and maintenance of stormwater drainage for the last two falls under the Kenya National Highways Authority. The Bungoma Municipality therefore plays a very limited role of clearance of debris and vegetation since this system contributes to the evacuation of the town's stormwater.

The first three roads have lined open channels running alongside the road for evacuation of storm water.

There are three principles which need to be taken into consideration in the selection of design criteria. These are:

- Sustainability;
- level of service;
- cost-effectiveness
- Sustainability in terms of drainage can be interpreted as:
- Drainage systems should utilise natural resources which can be reused and are energy efficient in terms of constituent products and construction process;
- Drainage systems should aim to replicate the natural characteristics of rainfall runoff for any site;
- The environmental impact of man should be minimised.

The principal objective of drainage is to provide protection from flooding due to rainfall on an area. The level of service provided is a function of society's expectations as well as the cost-benefit of the system based on the damage consequences due to flooding. For expansive areas such as large cities, Design criteria normally require that no flooding occurs up to the 30 year return period for new developments, and properties are protected against flooding for the 100 year return period. The level of service for existing systems is usually a lower standard and as pointed earlier 5 years is being considered as a minimum requirement for Bungoma Town.

Drainage design should aim to provide the most cost-effective solution particularly in terms of maintenance requirements. In view of this, the recommended Drainage Reticulation Network will be based on open channels utilizing as much as possible the natural characteristics of rainfall runoff hence the existing natural drainage channels within the town. Where velocities are considered high and could possibly lead to channel erosion lined channels will be a preferred option with requisite culverts where necessary.

4.4.2 Hydraulic design of open channels

The list below presents the key considerations for the design of open channels.

- Open channels provide opportunities for reduction of flow peaks and pollution loads. They may be designed as dry or grass channels.
- Channels can be designed with natural meanders improving both aesthetics and pollution removal through increased contact time.
- Grass channels generally provide better habitat than hardened channel sections, though studies have shown that riprap interstices provide significant habitat as well. Velocities should be carefully checked at design flows and the outer banks at bends should be specifically designed for increased shear stress.
- Flow control structures can be placed in the channels to increase residence time. Channel slope stability can also be ensured through the use of grade control structures that can serve as pollution reduction enhancements if they are set above the channel bottom. Regular maintenance is necessary to remove sediment and prevent aggradation and the loss of channel capacity.
- Open channels shall be designed to follow natural drainage alignments whenever possible.
- Channel side slopes shall be stable throughout the entire length and the side slope shall depend on the channel material. A maximum of 2:1 shall be used for channel side slopes, unless otherwise justified by calculations. Roadside ditches shall have a maximum side slope of 3:1.
- The design of artificial channels shall consider the frequency and type of maintenance required, and shall make allowances for access of maintenance equipment.

- Trapezoidal cross sections are preferred over triangular shapes for artificial channel designs.
- The final design of artificial open channels shall be consistent with the velocity limitations for the selected channel lining. Maximum velocity values for selected lining categories are presented in Table 4-6.

Table 4-6: Table showing Maximum Velocities for Comparison of Lining Materials – Source: AASHTO, 1991

Material	Maximum Velocity (m/s)
Sand	0.61
Silt	1.07
Firm Loam	1.07
Fine Gravel	1.52
Stiff Clay	1.52
Graded Loam or Silt	1.52
Cobbles	1.83
Coarse Gravel	1.83

4.4.3 Flow calculation formula

The Manning's formula is acceptable for open channel flow, where there are no other suitable methods, but is regarded as insufficiently reliable for calculation of flows in full or part-full pipes.

The Manning's formula states that:

$$Q = 1/n \cdot A \cdot R^{2/3} \cdot S^{1/2}$$

Where: Q = Discharge Rate for Design conditions, in m^3/s

R = hydraulic mean radius, i.e. cross-sectional flow area divided by the wetted perimeter (A/P), in m

S = Slope of energy grade line

n = Manning's roughness coefficient

A = Cross sectional area, in m^2

For prismatic channels, in the absence of backwater conditions, the slope of the energy grade line, water surface and channel bottom are assumed to be equal.

The Manning's "n" value is an important variable in open channel flow computations. Variation in this variable can significantly affect discharge, depth, and velocity estimates. Since Manning's "n" values depend on many different physical characteristics of natural and man-made channels, care and good engineering judgment must be exercised in the selection process.

Recommended Manning's "n" values for artificial channels with rigid, unlined, temporary, and riprap linings are given in Table 4-7.

Table 4-7: Manning's Roughness Coefficients (n) for Artificial Channels – Source USDOT, 1996

Category	Lining Type	Depth Ranges		
		0 – 0.15 m	0.15 – 0.61 m	> 0.61 m
Rigid	Concrete	0.015	0.013	0.013
	Grouted Riprap	0.040	0.030	0.028
	Stone Masonry	0.042	0.032	0.030
	Soil Cement	0.025	0.022	0.020
	Asphalt	0.018	0.016	0.016
Unlined	Bare Soil	0.023	0.020	0.020
	Rock cut	0.045	0.035	0.025
Temporary	Woven Paper Net	0.016	0.015	0.015
	Jute Net	0.028	0.022	0.019
	Synthetic Mat	0.036	0.025	0.021

Recommended Manning's values for natural channels that are either excavated or dredged and natural are given in Table 4-8. For natural channels, Manning's "n" values should be estimated using experienced judgment and information presented in publications such as the Guide for selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains (USDOT, 1984).

Table 4-8: Uniform Flow Values of Roughness Coefficient n – Source USDOT, 1996

Type of Channel and Description	Minimum	Normal	Maximum
a. Earth, Straight and Uniform			
1. Clean, recently completed	0.018	0.022	0.025
2. Clean after weathering	0.022	0.025	0.030
3. Gravel, uniform section, clean	0.022	0.027	0.033
b. Earth, Winding and sluggish			
1. No vegetation	0.023	0.025	0.030
2. Grass, some weeds	0.025	0.030	0.033
3. Dense weeds/plants in deep channel	0.030	0.035	0.040
4. Earth bottom and rubble sides	0.025	0.030	0.035
5. Stony bottom and weedy sides	0.025	0.035	0.045
c. Channel not maintained, weeds and bush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120
2. Clean bottom, bush on sides	0.040	0.050	0.080
3. Same, highest stage of flow	0.045	0.070	0.110
4. Dense bush, high stage	0.080	0.100	0.140

4.4.4 Geometric relationships

Area, wetted perimeter, hydraulic radius, and channel top width for standard channel cross sections can be calculated from geometric dimensions. Irregular channel cross sections (i.e., those with a narrow deep main channel and a wide shallow overbank channel) must be subdivided into segments so that the flow can be computed separately for the main channel and overbank portions. This same process of subdivision may be used when different parts of the channel cross section have different roughness coefficients. When computing the hydraulic radius of the subsections, the water depth common to the two adjacent subsections is not counted as wetted perimeter.

CHAPTER 5.COST ESTIMATES

5.1 Basis for cost estimates

Estimating costs for civil engineering works within the project area is not a challenging exercise since there exists a well established local construction industry. Prices of materials including fuel are fairly stable and depend largely on market forces countrywide dictated by supply and demand. However, at this preliminary stage, it is only possible to put an approximate order of costs on the proposed redevelopment and construction works. The following rates and prices (Table 5-1) were obtained from works of a similar nature carried out previously within the project area and have been used for guidance in developing the cost estimates. A rate of 1US $ to KShs. 83.50 has been adopted as the current exchange rate.

Table 5-1: Basic cost information for Bungoma Town

Type of Channel and Description	Unit	Rate (US$)
General Site Clearance of Work Areas	m^2	0.06
Excavation of soil	m^3	1.8
Excavation in rock	m^3	4.79
Concrete Grade 25/20	m^3	119.80
Concrete Grade 25/30	m^3	167.66
Concrete Grade E (Blinding)	m^3	95.81
Formwork, plane horizontal	m^2	4.79
Formwork curved	m^2	7.19
Reinforcement: High Yield Bars Diameter up to 20 mm	Kg/m^3	2.40
Mesh Fabric, 6 – 7 Kg/m^2	Kg	5.39
Concrete pipe 450 diameter	m	71.86
Concrete pipe 600 diameter	m	119.80
Concrete pipe 900 diameter	m	167.66

5.2 Availability of plant, labour and materials

Since it is foreseen that the redevelopment and construction of the drainage system will have to go hand in hand with road rehabilitation, appropriate construction equipment in the project area is bound to be limited and will have to probably be sourced from the region in towns such as Kakamega and Kisumu. It is recommended that manual labour be used where appropriate as this will also encourage community participation and create employment. In situations where only machinery is usable, the contracts with the Contractors should be well structured contracts for a specified quantity of work and payments made on certified work by the Engineer.

Manual labour is likely to be available but the works will need proper supervision if the quality is to be ensured. Skilled labour such as surveyors and technicians is bound to be available even from surrounding areas so long as the pay is attractive.

The supply of basic construction material in the area is bound to be available in adequate quantities as the transport network is good and reliable. Locally available materials such as masonry are expected to be of good quality and this is mined from the surrounding deposits. Supply of good quality aggregate is adequate with coarse aggregate coming from Eldoret while supply for river sand is available from Malaba.

However, majority of the works for rehabilitation will involve earthworks and will not require much in the way of materials.

5.3 Redevelopment and construction cost estimate

The quantities and rates used for the cost estimate shown in Table 5-1 are based on the information gathered from the Municipal Works Officer at the time of the field investigation survey and are therefore susceptible to fluctuation and should therefore be applied with caution.

The cost estimate aims to reflect the major cost items in particular and is broken down to various components to differentiate type of works. These are given in Table 5-2.

Table 5-2: Estimated redevelopment and construction costs

Description	Amount (US$)
Topographical Survey	11,065.87
General Site Clearance	23,952.10
Earthworks	311,377.25
Mass Concrete	5,173.65
Reinforced Concrete	5,029.94
Mesh Reinforcement	239.94
Precast Concrete Pipes	25,868.26
Town roads and drainage channels	1,796,407.20
Masonry and Gabion mattresses	17,964.07
SUB TOTAL	**2,197,077.86**
Project Management and Supervision (20%)	439,415.57
Contingencies (15%)	329,561.68
GRAND TOTAL	**2,966,055.11**

CHAPTER 6.OPERATION AND MAINTENANCE

6.1 General

The Storm Water Master Plan provides a guideline that Bungoma Municipal Council could adopt for the management of storm water in order to achieve the objectives laid down for the system.

Proper Maintenance of Storm Water Facilities and best management practices are important factors in the long-term performance and effectiveness of a Storm Water Master Plan. An effective Operation and Maintenance (O&M) programme ensures that the system continues to provide the required service at the expected levels of performance. The O&M Plan should therefore aim at establishing an effective Site-Specific Maintenance Programme that emphasises on preventive measures thus prolonging the service life of Storm Water Facilities, minimize expensive repairs, and ensure its continued safe, effective and reliable performance.

Pile of solid waste probably contributed by business premises in the background

The Municipal Council has to put in place mechanisms that ensure an effective Participatory Process of storm water management involving all stakeholders such as communities, Landlords, Business people and Council Staff.

6.2 Situation analysis

During the field reconnaissance visit, it was observed that O&M arrangements for the existing drainage system especially outside the Central Business District are very poor or nonexistent with the exception of drainage channels along the Moi Avenue next to the Municipal Council offices. Many of the unlined natural drainage channels near the Bus Park are blocked with solid waste and uncontrolled weed growth. Lined channels along the lower section of Moi Avenue and along Simba Street are clogged with sediments and solid waste.

Uncontrolled solid waste disposal next to flooded area

Most of the solid waste is due to uncontrolled disposal by the Town residents and failure on the part of the Municipal Council to enforce the necessary by-laws and regulations. Blockages along the drainage channels due to the above circumstances lead to uncontrolled flow of storm water and flooding of low lying areas within the town as shown in the picture.

The sections below provide requirements to ensure successful performance of stormwater control facilities once they have been constructed. Included in this section are requirements for as-built surveys, facility inspection and maintenance, and maintenance and access easement requirements to allow for maintenance in an around stormwater facilities.

It is assumed that the Municipal Council will adopt a preventive approach in maintenance and operation of the system and the drainage structures will not be left to deteriorate or be rendered obsolete.

6.3 Stormwater control facility maintenance responsibility

It is essential that any approved stormwater control facility be properly maintained in order to assure its performance. The Municipal Council will maintain eligible infrastructure constructed and designed to serve the town developments. To be eligible for Municipal Council maintenance services, developers who provide part of the stormwater infrastructure must:

- Have established approved vegetation or paving within and around the facility, if applicable,
- Have designed and constructed the facility in accordance with Municipality standards and proven by As-built Surveys,
- Have the facilities in proper working order at the time the Municipal Council accepts maintenance responsibilities, and
- Provide to the Municipal Council specific, dedicated easement rights sufficient to perform required maintenance.

Onsite facilities in residential and institutional developments, shall be maintained by the Property Owner or, if applicable, a homeowners association. Onsite facilities constructed to serve privately-owned developments (i.e., multi family, commercial, industrial, etc.) shall be maintained by the Property Owner.

6.4 Stormwater control facility easement and access requirements

For stormwater control facilities that are to be operated and maintained by the Municipal Council, the Property Owner shall provide the Municipal Council with an easement to the area of the stormwater facilities, appurtenances to the facilities such risers, outlet pipes, etc., and a minimum width of 6 metres next to the facilities. A dedicated access easement, having a minimum width of 6 metres, shall also be provided that extends from the facility easement to the nearest public right-of-way.

For facilities that are to be maintained by a homeowners association or institutions, the developer shall provide to the Municipal Council a minimum 6 metres wide easement for such inlet and outlet pipes, etc., conveying stormwater to a public conveyance system.

For stormwater control facilities that are to be operated and maintained by the Municipal Council, the Property Owner shall provide the Municipal Council with a maintenance vehicle accessway having a minimum width of 6 metres. The vehicle accessway shall be stabilized with suitable materials (e.g., concrete, gravel, or other suitable means of stabilization) adequate to prevent rutting by the maintenance vehicles. All access routes shall be designed to allow the turn-around of maintenance vehicles.

6.5 Stormwater control facility maintenance plan

A maintenance plan for privately-owned stormwater controls and for stormwater controls that are to be maintained by a homeowners association or institutions must be prepared and submitted for review and approval by the Municipal Council during the Plan approval process. At a minimum, maintenance plans for stormwater controls shall include a method and frequency for the following activities:

- Inspection of all permanent structures,
- Debris/clogging control through appropriate removal and disposal,
- Vegetation control (mowing, harvesting, wetland plants),
- Erosion repair,
- Non-routine maintenance should include pollutant and sediment removal and the “rejuvenation” or replacement of filters and appropriate soils,
- Disposal of solid waste, sediments, and other debris in accordance with Municipality regulations, and
- Mosquito monitoring and abatement, encompassing inspections for conditions conducive to mosquito breeding, routine (e.g., vegetation control, debris and sediment removal) and non-routine (e.g., restoration of grade to eliminate ponding) activities to address these conditions, and conditions where the use of insecticides may be warranted.

6.6 Maintenance inspection and reporting requirements

The Property Owner, its administrators, executors, successors, heirs or assigns shall maintain the stormwater control facility or facilities in good working condition acceptable to the Municipal Council and in accordance with the schedule of long term maintenance activities provided in the approved stormwater control facility maintenance plan for the stormwater control facility or facilities. Maintained infrastructure shall include all pipes and channels built to convey stormwater, as well as all structures, improvements, and vegetation provided to control the quantity and quality of the stormwater. ”Maintain” is herein defined as good working condition so that these facilities are performing their design functions.

The purpose of maintenance inspections is to assure safe and proper functioning of the stormwater control facilities. The Property Owner shall perform periodic inspections of the stormwater control facility and its appurtenances at a frequency stipulated in the approved stormwater control facility maintenance plan. Inspections shall cover all elements for the stormwater control facility as defined in the stormwater control facility maintenance plan.

Inspections shall include the completion of dated and signed inspection checklists provided in the stormwater control facility maintenance plan and the notation of all deficiencies observed during the inspection. The Property Owner shall maintain copies of complete dated and signed inspection checklists in a maintenance inspection log, along with recorded dates and descriptions of maintenance activities performed by the Property Owner to remedy the deficiencies observed during prior inspections. The maintenance inspection log shall be kept on the property and shall be made available to the Municipal Council upon request.

A copy of the Maintenance Inspection Log shall be submitted annually by 31st December each year to the Town Engineer, Division of Sewerage and Drainage.

CHAPTER 7.RECOMMENDATIONS

While the Terms of Reference for this study were aimed at the preparation of a stormwater management Master Plan for Bungoma town as one of the approaches of controlling water quality and pollution control of the Lake Victoria River Basin, the Consultant noted that there are other activities that contribute to the problem throughout the entire Sio and Khalaba river systems. The photographs highlight the observation.

At the time of implementing the redevelopment and construction of the drainage plan, it will be necessary to carry out a detailed overview of the overall drainage situation in Bungoma Town and translate this into a workable comprehensive drainage plan.

Khalaba River as seen from the Slaughter House Road Bridge. Note the condition of water with photo taken during dry season with no

Detailed information regarding the topography of the whole town, invert levels of all the natural and man-made drains, invert levels of the corresponding sewer lines, information about any linkage of underground sewer drains and storm water drains would be required through a meticulous survey.

Roads and drains need to be planned, designed and constructed together so that there is a proper linkage between them and they serve the purpose of not only drainage and collection of surface water on the roads but also facilitate road sweeping and separate collection of solid waste.

Property Developers should be encouraged to incorporate rainwater harvesting in their designs as a strategy to supplement on the municipal water supply and at the same time reduce on the amount of runoff that finds itself in the stormwater drainage system.

There should be strict instructions to the construction agencies and developers to clear all debris and construction material from within the drains before covering the slabs. This is crucial for proper functioning of the drains.

The redevelopment of the drains should consist of the hydraulic modification of the cross section of the drains as outlined in section 4.4.3 of this report. This should be prepared for all the drains mentioned in Table 2-1 so that the problem can be solved from the very root in a long term sustainable way.

The Engineering Department of the Municipal Council should be fully empowered to deal with all sewer, storm water and natural drains within the Municipality area in a comprehensive manner.

APPENDIX: 24 HOUR MEAN MONTHLY RAINFALL 1994 – 2010

				BUNGOMA 24 HR MAXIMUM RAINFALL IN MM/MONTH									
					WEATHER STATION No. 8934134								
YEAR	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**August**	**Sept**	**October**	**Nov**	**Dec**	**Annual Maximum mm**
1994	33.4	29.2	90.8	159.9	202.7	88.1	60.9	81.1	36.5	86.4	198.4	45.1	202.7
1995	18.4	24.6	95.8	196.3	70.5	76.1	64.5	78.2	88.4	104.5	133.9	25.3	196.3
1996	42.2	187.6	165.9	369.2	329.5	127.0	145.2	86.0	278.1	170.2	174.2	33.1	369.2
1997	36.2	0.0	132.2	242.0	230.7	118.3	151.3	138.8	60.2	276.0	275.6	189.2	276.0
1998	217.3	140.7	116.7	260.7	140.0	242.7	233.9	146.8	140.6	270.8	142.4	9.2	270.8
1999	129.5	11.0	313.5	307.8	255.3	103.2	105.9	187.5	144.7	378.3	48.5	35.2	378.3
2000	98.8	0.0	68.8	176.9	147.9	74.6	99.0	58.1	76.0	163.5	91.7	27.9	176.9
2001	58.1	47.3	95.8	250.0	130.2	13.8	51.1	50.2	45.4	75.0	58.0	0.0	250.0
2002	11.7	15.1	55.6	153.3	237.4	50.2	10.7	17.8	76.3	99.1	122.1	130.2	237.4
2003	6.7	56.0	213.0	250.6	385.8	152.4	151.5	145.7	96.0	56.4	88.6	28.5	385.8
2004													0.0
2005			74.1	238.8	177.5	124.1	88.1	91.9	95.1	170.9	54.1	29.4	238.8
2006	65.1	76.7	255.1	345.3	113.9	184.5	87.1	125.2	164.5	133.7	317.6	222.9	345.3
2007	3.6	66.9	86.8	163.3									163.3
2008	64.4	53.3	178.1	179.1	253.1	159.0	100.2	178.0	174.6	285.9	119.3	31.8	285.9
2009	94.8	35.2	23.6	232.7	333.0	171.3	22.3	111.2	225.9	80.7	53.2	129.4	333.0
2010	103.0	193.7	164.7	193.1	178.1	121.5	105.2	96.8	271.6				271.6
Monthly Mean	**65.5**	**62.5**	**133.2**	**232.4**	**212.4**	**120.5**	**98.5**	**106.2**	**131.6**	**168.0**	**134.1**	**66.9**	**232.4**

Annex 3B2. Storm Water Drainage Master Plan for the town of Lwakhakha

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ACRONYMS AND ABBREVIATIONS

CBD	Central Business District
NBI	Nile Basin Initiative
NELSAP	Nile Equatorial Lakes Subsidiary Action Program
O&M	Operation and Maintenance
SMM	Sio-Malaba-Malakisi
TRRL	Transport and Road Research Laboratory (UK Department of the Environment)

CHAPTER 1.INTRODUCTION

1.1 Background

The Sio-Malaba-Malakisi (SMM) River Basin Management Project is one of the three transboundary integrated water resources management and development projects being implemented within the framework of the Nile Equatorial Lakes Subsidiary Action Program (NELSAP), an investment program of the Nile Basin Initiative. One of the components of the project is the preparation of a Stormwater Master Plan for Lwakhakha town.

As the town of Lwakhakha experience growth, the Stormwater Master Plan should provide guidance on the need to protect existing natural stormwater resources, convey and control stormwater in a safe and responsible manner, and meet water quality goals. Lwakhakha town's core area of service delivery must be to develop, rehabilitate and maintain drainage systems and contribute to the water quality and pollution control for the Lwakhakha River.

Lwakhakha River as seen from the Kenyan side

This report is considered as a general guideline from which the town can prepare a Master Plan and implement both short and long term development plans to address the specific drainage needs while at the same time addressing the twin problem of water quality and pollution control for the river Lwakhakha.

Stormwater management, particularly in the area of stormwater quality management, is an evolving science. The goal of the town should therefore be to be responsive to changes in stormwater policy and monitor new developments and initiatives brought forth by the natural progression of the industry. As such, the Master Plan will have to be updated as necessary to reflect accepted standard practice in stormwater management.

1.2 Drainage standards, systems & terminology

In every location there are two stormwater drainage systems that must be considered; the minor system and the major system. Three factors influence the design of these systems; flooding; public safety; and, water quality and pollution control.

The purpose of the minor drainage system, which is designed for the 2 to 5-year storm event, is to remove stormwater from areas such as streets and sidewalks for public safety reasons. This system consists of inlets, street and roadway gutters, roadside ditches, small channels and small underground pipe systems which collect stormwater runoff and transport it to the major drainage system (i.e., natural waterways, large man-made conduits, and large water impoundments). If the minor system is exceeded during a storm event, the major system is then utilized.

The major system is defined by flow paths for runoff from less frequent storms, up to the 10 year frequency in this case. It consists of natural waterways, large man-made conduits, and large water impoundments. In addition, the major system includes some less obvious drainage ways such as infrequent temporary ponding areas. The major system includes not only the trunk line system that receives the water from the minor system, but also the natural backup system which functions in case of overflow from or failure of the minor system. Overland relief must not flood or damage houses, buildings or other property.

From the review of the existing storm water drainage system for Lwakhakha town and the anticipated discharge capacities and the inherent cost of upgrading the system, the Design Return Period of 10 years is recommended for the Major System.

A section of the drainage channel along the main road on the Kenyan side

A section of the main drainage channel alongside the main road on Uganda side. Note well maintained cross culvert

Design criteria

The design storm frequencies adopted for design are given in the Table 1-1.

Table 1-1: Storm frequencies for minor systems

Land use	Recommended Design Storm Return Period (Years)
Residential	2 to 5
Institutions	2 to 5
Commercial and Industrial	5
Central Business District (CBD)	5 to 10

1.3 Urban storm water runoff components

1.3.1 General

Rainfall runoff in an urban environment effectively takes place instantly for areas served by traditional drainage systems and nearly all the rain that falls on impermeable surfaces runs off. The rate of runoff and the volume of runoff are both important components in analysing the performance of a network. For storms above a certain magnitude the performance of the network downstream may be exceeded.

Rainfall-related flooding of the drainage network, simply defined, is the concentration of stormwater to a point from which it cannot escape quickly enough to avoid ponding or passing on as overland flow. In addition to the hydraulic behaviour of traditional drainage systems, their water quality management characteristics are poor and this problem is now recognised as a major issue in terms of polluting receiving waters.

The development of Lwakhakha town is not foreseen adopting closed drainage system any time in the future and as such only the relevant components that would be suitably adopted are outlined and discussed below.

1.3.2 Open Channels

Open channel systems and their design are an integral part of stormwater drainage design, particularly for development sites utilizing better site design practices and open channel outfall structures. Open channels include drainage ditches, grass channels, riprap channels and concrete-lined channels.

The three main classifications of open channel types according to channel linings are vegetated, flexible and rigid. Vegetated linings include grass with mulch, sod and lapped sod, and wetland channels. Riprap and some forms of flexible man-made linings or gabions are examples of flexible linings, while rigid linings are generally concrete or rigid block.

- **Vegetative Linings**

Vegetation, where practical, is the most desirable lining for an artificial channel. It stabilizes the channel body, consolidates the soil mass of the bed, checks erosion on the channel surface provides habitat and provides water quality benefits. Conditions under which vegetation may not be acceptable include but are not limited to:

A grassed drainage channel on the Ugandan side

- high velocities;
- continuously flowing water;
- lack of regular maintenance necessary

to prevent growth of taller or woody vegetation;

- lack of nutrients and inadequate topsoil; and/or,
- Excessive shade.

Proper seeding, mulching and soil preparation are required during construction to assure establishment of healthy vegetation.

- **Flexible Linings**

Rock riprap, including rubble, is the most common type of flexible lining for channels. It presents a rough surface that can dissipate energy and mitigate increases in erosive velocity. These linings are usually less expensive than rigid linings and have self-healing qualities that reduce maintenance. However, they may require the use of a filter fabric depending on the underlying soils, and the growth of grass and weeds may present maintenance problems.

A drainage channel with flexible lining on the Ugandan side

- **Rigid Linings**

Rigid linings are generally constructed of concrete and used where high flow capacity is required. Higher velocities, however, create the potential for scour at channel lining transitions and channel head cutting.

1.3.3 Culverts

A culvert is a short, closed (covered) conduit that conveys stormwater runoff under an embankment, usually a roadway. The primary purpose of a culvert is to convey surface water, but properly designed it may also be used to restrict flow and reduce downstream peak flows. In addition to the hydraulic function, a culvert must also support the embankment and/or roadway, and protect traffic and adjacent property owners from flood hazards to the extent practicable.

The design of a culvert should take into account many different engineering and technical aspects at the culvert site and adjacent areas. The list below presents the key considerations for the design of culverts.

- Culverts can serve double duty as flow retarding structures in grass channel design. Care should be taken to design them as storage control structures if flow depths exceed several feet, and to ensure public safety.
- Improved inlet designs can absorb considerable energy for steeper sloped and skewed inlet condition designs, thus helping to protect channels.

Both minimum and maximum velocities shall be considered when designing a culvert. The maximum velocity shall be consistent with channel stability requirements at the culvert outlet. The maximum allowable velocity is 0.38 metres per second. Outlet protection shall be provided where discharge velocities will cause erosion problems. To ensure self-cleaning during partial depth flow, culverts shall have a minimum velocity of 0.064 metres per second at design flow or lower, with a minimum slope of 0.5%.

A poorly maintained undersized cross culvert on the Ugandan side.

Buoyancy protection shall be provided for all flexible culverts. This can be provided through the use of headwalls, end walls, slope paving or other means of anchoring.

The culvert length and slope shall be chosen to approximate existing topography. To the degree practicable, the culvert invert should be aligned with the channel bottom and the skew angle of the stream, and the culvert entrance should match the geometry of the roadway embankment.

For maintenance purposes, the minimum recommended size for a culvert up to 30m long is 900mm diameter, or 750mm wide x 450mm high, and for culverts longer than 30m, a diameter of 1200mm, or 900mm wide x 450mm high would be more appropriate. However 600mm may be provided for Access Culverts.

CHAPTER 2.FIELD SURVEYS AND DATA COLLECTION

2.1 Review of existing data and desk studies

A site reconnaissance visit was conducted as shown below in order to familiarize with the site conditions and the existing storm water drainage system and town layout.

The key dates for the mission were as follows:-

24th January 2011	Travel from Nairobi to Kakamega
25th January	Travel from Kakamega to Lwakhakha in the company of the Project officer, NBI, and meeting with the Bungoma County Council officials, Kenya and Lwakhakha County Council Chairman, Uganda.
25th January	Reconnaissance survey of the Lwakhakha storm water drainage system in the company of the Town officials.
27th January	Return to Nairobi

Meetings were held with Lwakhakha County Council Officials Chairman of the town council on the Ugandan side for the purposes of ascertaining the availability of any existing information and data.

From the discussions with the council officials it was apparent that no data and information was available from their offices. This presented a challenge for the Consultant since no plans could be prepared without the relevant maps.

2.2 Situation analysis of the existing system

2.2.1 General

The Consultant carried out detailed field Surveys on the 21st to 24th March 2011 to assess the Existing Storm Water Drainage system in Lwakhakha Town. Discussions held with Town Officials also provided useful insights on the deficiency and challenges of the Existing Drainage System in the Town. The following issues were brought up and observations also made during the field visit.

- Heavy Flooding experienced in the Kenyan side of the Town during the rainy season. This is because no conventional storm water drainage system exists apart from the poorly maintained channel along the main road. Runoff from storms is normally channelled through natural drains which have been formed over time by the runoff. On the Ugandan side, there exists a fairly elaborate drainage system consisting of both lined and unlined channels that is well maintained.

- The few culverts along the drainage channel along the main road on the Kenyan side are blocked due to uncontrolled Solid Waste Disposal and sediment eroded from the gravel surface road and surrounding areas.
- There seems to be a maintenance programme for drainage infrastructure on the Ugandan side.
- Siltation of the Existing Storm Water Drainage Channels from road sweepings and sediments carried by runoff from the unsurfaced roads.
- The businesses contribute heavily to the solid waste that eventually finds its way into the drainage channels.
- Surface Water Pollution essentially due to lack of Sanitary Systems and unsatisfactory Sanitation in the Area
- Poor Maintenance of the Drainage System in the Kenyan side of the Town.

Conventional storm water drainage for Lwakhakha town on Kenyan side is virtual nonexistent consisting mainly of a combination of a number of natural and one man-made drainage systems. However, most of the water collected through different drainage system finally gets discharged into the river Lwakhakha. The main road surface is such that in some areas the levels do not provide proper drainage of the runoff and this has contributed heavily to the problem.

A natural drainage channel directing stormwater to River Lwakhakha from the main road on the Kenyan side

Flooding of the town centre and water logging of the outlying areas, even with showers of medium intensity, is quite common, leading to difficult living conditions, inconvenience and interruption of business activities.

It appears that a comprehensive overview of the situation is lacking and only piecemeal solutions have been attempted at different points of development of the town. This is amply demonstrated by the lack of a Physical Development Plan for the town.

Keeping in view the inadequacy of storm water drainage, particularly in the unplanned outlying areas of the town, which is highlighted during the rains every year, a Physical Development Plan needs to be prepared at the earliest to form a basis on which to plan for the stormwater drainage Master Plan. This Development Plan should possibly consider urbanization limits till 2030 in line with the Government policy of vision 2030.

At the same time the extent of urbanization and industrialization have to be ascertained from the various Government agencies.

Road surface susceptible to erosion by runoff during storms

One of the fundamental issues that is obviously neglected in the town is the comprehensive design of roads, drains, sewers and other utility network like water pipe, electric and communication cables etc. and their careful and meticulous execution. Instead, the foundations as well as the surface of the roads are not proper leading to early damage due to movement and weather conditions.

Due to the nature of the road surface storm runoff has led to erosion of the running surface and other debris including road sweepings causing further damage to the infrastructure. At least part of this eroded material and debris end up into the adjacent drains and eventually into the river system.

The existing drainage system along the main road on the Ugandan side is made of stone-pitched, trapezoid shaped drainage channels in different sizes. In the outlying areas the drainage channels are unlined and in some cases, created by the storm run-off. The stone pitched channels depth ranges from 500 to 1000 mm, the bottom width from 300 to 750 mm with side slopes of 1:1.5. Culverts depending on their function vary I diameter between 450 mm and 900 mm.

Stone pitched open drainage channel on the Uganda side of the town

2.2.2 Existing drainage system

Without the required maps it is not possible to delineate the town into the different sub-catchments draining into the Lwakhakha River. However, from the physical assessment it was possible to get an indication of the limited drainage channels available within the Kenyan side of the town.

The length of main drainage channel along the main road is approximately 200 m. This is supplemented by a number of natural drainage channels emanating from the upper part of the town and crossing the road and finally discharging into the river. The length of the existing drainage channels, classified in different categories is shown in Table 2-1.

Table 2-1: Existing drains in Lwakhakha Town

Category	Length of Channel (m)
Main road side channel	200
Natural drains	1,250

2.3 Climatic data

The area is characterized by bimodal rainfall of long and short rains. Long rains normally start in March to July while short rains start in August to October. The mean annual rainfall is approximately 1494mm with the heaviest rains between April and May. This is the period when the town has to contend with the most storm water flows. The mean annual temperatures range from 21^0 - 23^0C with the hottest temperatures occurring between December to February and low temperatures between April to July.

Daily Rainfall Records for Sirisia Chief's camp were obtained from the Ministry of Agriculture Farm Management Handbook. Weather Station No. 89341118 at an altitude of 1615 m and has been adopted as being representative to rainfall patterns experienced in Lwakhakha Town.

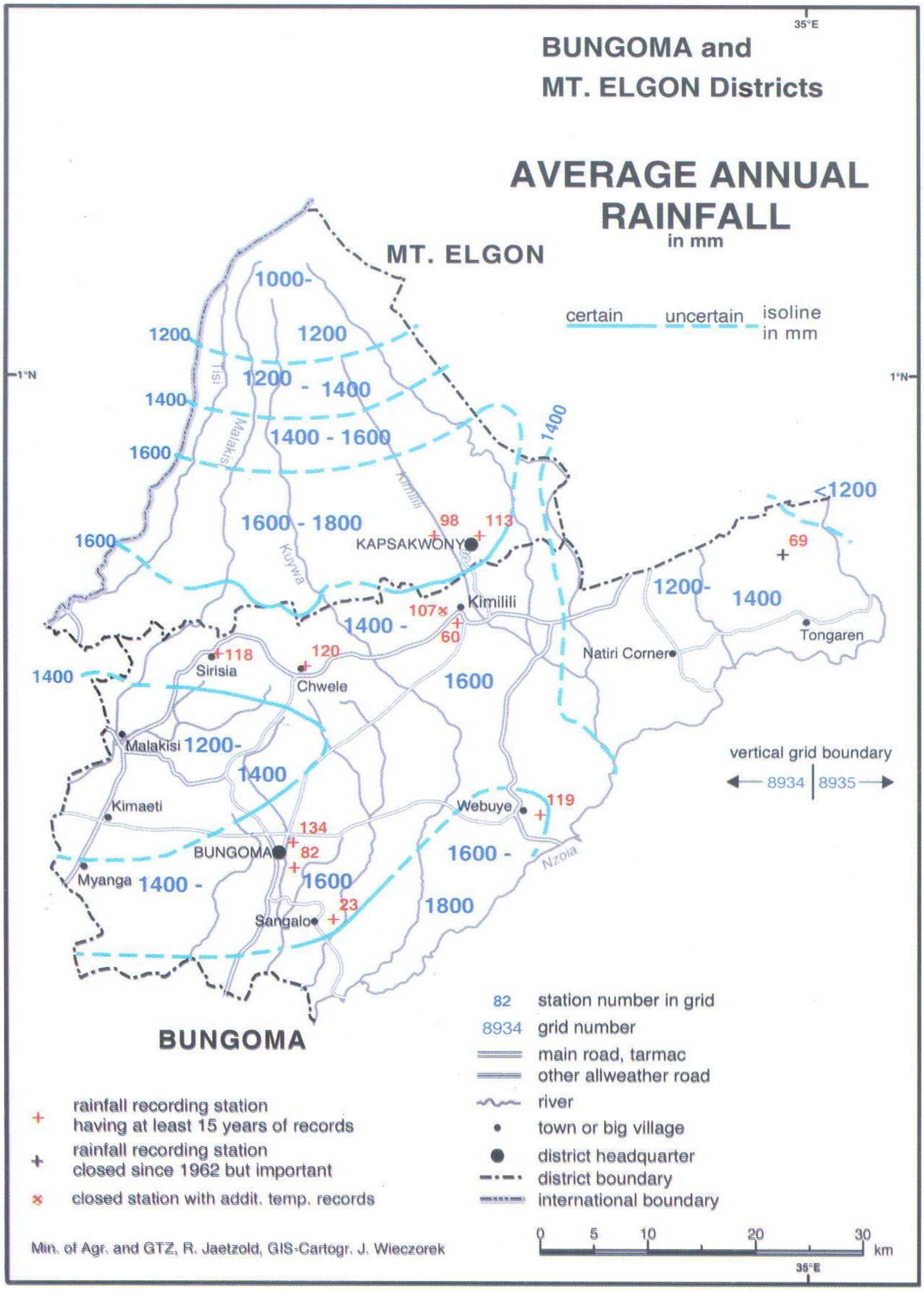
The Rainfall Data obtained represents records for at least 15 years. The Annual Distribution of Rainfall is shown in The area is characterized by bimodal rainfall of long and short rains. Long rains normally start in March to July while short rains start in August to October. The mean annual rainfall ranges from 1250mm to 1800mm with the heaviest rains between April and May. This is the period when the town has to contend with the most storm water flows. The mean annual temperatures range from 210 - 230 C with the hottest temperatures falling between December to February and low temperatures between April to July.

Daily Rainfall Records for Bungoma Gauge Station were collected from the Lake Victoria North Catchment Area offices in Kakamega town. Bungoma Weather Station No. 8934134 is the nearest station to Bungoma Town. Peak Daily Rainfall Data for a period of about 17 years ranging from 1994 to July 2010 was obtained. This data is useful in the Hydrological Analysis.

The Parameters obtained included:

- Peak Daily Rainfall (mm)
- Mean Monthly Rainfall (mm)
- Rainfall Intensity
- Rainfall Duration

The Rainfall Data obtained captures the critical periods that experienced severe rains of El-Nino in 1996 and 1998. The Annual Distribution of Rainfall is shown in Figure 2-1, expressed in terms of Mean Monthly Rainfall compiled from available Daily Rainfall Data.



Map 2-2: Average Annual Rainfall (mm) – Source: Ministry of Agriculture, Bungoma Farm Management Handbook

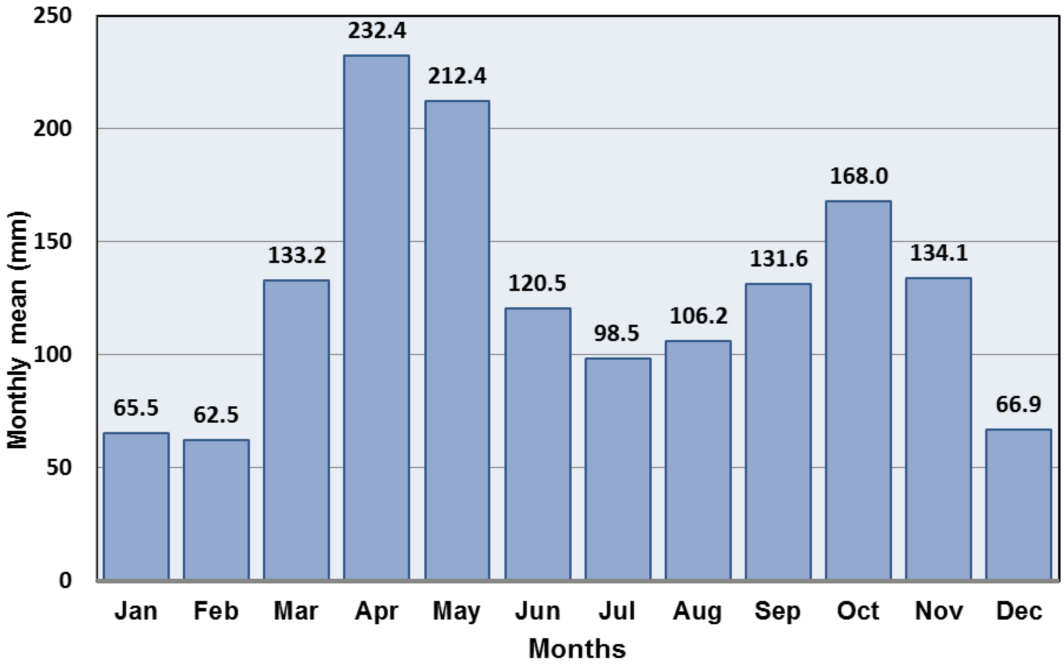


Figure 2-1 Mean Monthly Rainfall compiled from available Daily Rainfall Data.

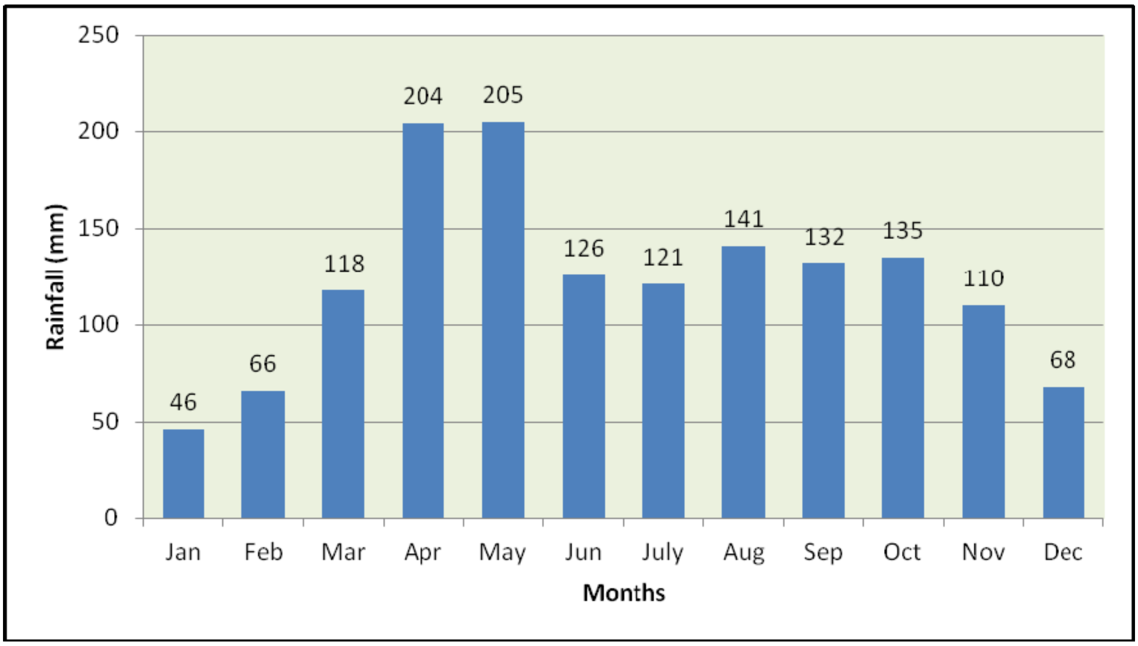


Figure 2-2: Average Mean Monthly Rainfall in mm, Weather Station No. 8934118, Sirisia.

2.4 Drainage and relief

The area within which the town is located is part of Lake Victoria drainage basin.

The natural terrain of Lwakhakha town is well drained by the Lwakhakha River since the topography slopes towards the river. There is only one road which cuts across the town towards the border crossing. The rest are paths which do not qualify to be classified as roads and seem to have expanded naturally due to usage.

There exists an open side drainage channel on the right side of the road that carries water to the river. The channel is however poorly maintained and in some sections nonexistent. Storm runoff has over the years created natural drainage channels towards the river that act as the town's drainage system.

Solid waste has aggravated the drainage problem when washed from the surrounding areas from business premises. Since all the road surfaces are of gravel material and susceptible to erosion, sediment load is high and this contributes to the blocking of whatever exists as drainage channels and culverts when washed off by runoff. There is need therefore to ensure efficient collection of waste to minimize incidences of blocking of drains. Maintenance of drains should also be prioritized.

2.5 Major problems of the existing drainage system

The main road in Lwakhakha Town including other connecting roads which cuts across the town is gravel surface. Problems affecting the storm water drainage management within Lwakhakha Town, as observed during field investigations and discussions with the town Council Officials are:

- Lack of a conventional drainage system on the Kenyan side
- Lack of Maintenance and improvement of existing natural Drains
- Undersized Culverts and Channels
- Lack of cross and access culverts to direct runoff into the appropriate channels
- Inadequate and sometimes nonexistent road side drainage
- Siltation and blockage of drainage facilities due to uncontrolled urban litter disposal.

CHAPTER 3.STORMWATER CONVEYANCE

3.1 General

It is not possible at this stage to carry out design of the various components of the stormwater system required for Lwakhakha town due to lack of adequate data and information. This section will however outline the requirements and steps necessary for the design of a conventional stormwater drainage system envisaged for the town.

This section describes the criteria and methodologies that should be used to plan and design stormwater conveyance systems within the town of Lwakhakha.

Subsections include:

- Hydrology Requirements
- Design Storm Frequency
- Rainfall Intensity-Duration-Frequency Relationship

The Town's stormwater management goals should be to prevent hazardous or detrimental flooding, erosion and water quality degradation that may result from stormwater runoff from developments and business premises.

3.2 Hydrology requirements

The first step in undertaking any kind of hydrologic modelling involves the pre-processing of the various datasets and surface models before delineating streams and watersheds, and getting some basic watershed properties such as area, slope, flow length, and stream network density. The hydrology requirements are then used to determine the volume and discharge rate of stormwater from land areas.

Lwakhakha Town has a relatively steep topography and drops gradually towards the Lwakhakha River and therefore developing the drainage catchments on which to carryout hydrological analysis requires the use of high resolution topographic maps to yield better result.

No development plans have been prepared for the town and therefore such maps are not available and this poses a challenge for development of any drainage master plan.

In line with Proposed Design Standards for any storm water master plan, the following Return Periods are recommended for future planning of a proper drainage system for Lwakhakha town:

- Residential 5 years
- Institutions and Schools 5 years
- General Commercial and Industrial 5 years
- Central Business District (CBD) 10 years

3.3 Design storm frequency

The design rainfall frequency is the period during which, on average, a rainstorm of the design magnitude will occur or be exceeded just once. Although in reality there is no such thing as the design storm, it does nevertheless represent a useful concept, and over a long period of time it is a fair statistical representation of what happens at the prescribed frequency.

The stormwater master plan for Lwakhakha should be prepared with the Physical Development Plan in mind. This will ensure that the master plan will take into consideration the anticipated growth of the town and hence be able to address the long term solutions. As expected in most urban situations a design frequency of storm is set which takes account of environmental considerations and the cost implications of possible damage during greater storms versus the cost of providing a more substantial system. In normal practice return periods to be used in design of the drainage structures should be those that take into account of the high flood regimes. Return periods will then be specified for each of the following:

- Checking the design of existing systems
- Extensions, rehabilitations and minor amendments to existing system;
- Minor culverts
- Major culverts
- Box culverts

3.4 Rainfall Intensity Duration Frequency relationship

The purpose of an urban storm water drainage system is to remove excess surface water from roofs, roads, and other paved surfaces at a rate sufficient to prevent the accumulation of water in puddles or floods. Since no conventional sewerage system exists in Lwakhakha, the only significant source of water entering the system will be from storm rainfall runoff, and the rate of such inflow will obviously be dependent on the rate of rainfall. It is therefore important to be able to establish a design rate, or intensity, of rainfall in order to derive the rate of water inflow to the drainage system under design conditions.

When the Physical Development Plan for the town is prepared, the drainage hydrology will have to be carried out in deriving a relationship between rainfall intensity, duration and frequency of recurrence for the area. Normally this information is presented in form of a plot as a set of intensity-duration-frequency curves (or i-d-f curves).

Using the relevant maps delineating Sub Catchments, the Transport and Road Research Laboratory (TRRL) of the UK Department of the Environment method should be used in the Hydrological Analysis. 2 and 5 Year Peak Flows can then be determined for sizing the stormwater reticulation system.

3.5 Proposed drainage option

3.5.1 General

Lwakhakha town has only one main road with gravel running surface that cuts across the centre of the town. The rest are widened tracks that join the main road at different points from the outlying areas. This is more pronounced on the Kenyan side. The Ugandan side boasts of a more improved road system that appears well maintained. It is mostly on these roads that drainage will either have to be provided or the existing channels improved. In view of this, a Drainage Reticulation Network based on Open Channels both lined and unlined as necessary is foreseen with culverts where appropriate.

There are three principles which need to be taken into consideration in the selection of design criteria. These are:

- Sustainability;
- level of service;
- cost-effectiveness

Sustainability in terms of drainage can be interpreted as:

- Drainage systems should utilise natural resources which can be reused and are energy efficient in terms of constituent products and construction process;
- Drainage systems should aim to replicate the natural characteristics of rainfall runoff for any site;
- The environmental impact of man should be minimised.

Drainage design should aim to provide the most cost-effective solution particularly in terms of maintenance requirements. In view of this, the recommended Drainage Reticulation Network should be based on open channels utilizing as much as possible the natural characteristics of rainfall runoff hence the existing natural drainage channels within the town. A number of these natural drainage channels exist and are predominant in providing storm water drainage for the town. Where velocities are considered high and could possibly lead to channel erosion lined channels will be a preferred option with requisite culverts where necessary.

A natural drainage channel that could be remodeled to the required standards

3.5.2 Hydraulic design of open channels

The list below presents the key considerations for the design of open channels.

- Open channels provide opportunities for reduction of flow peaks and pollution loads. They may be designed as dry or grass channels.
- Channels can be designed with natural meanders improving both aesthetics and pollution removal through increased contact time.
- Grass channels generally provide better habitat than hardened channel sections, though studies have shown that riprap interstices provide significant habitat as well. Velocities should be carefully checked at design flows and the outer banks at bends should be specifically designed for increased shear stress.
- Flow control structures can be placed in the channels to increase residence time. Channel slope stability can also be ensured through the use of grade control structures that can serve as pollution reduction enhancements if they are set above the channel bottom. Regular maintenance is necessary to remove sediment and prevent aggradations and the loss of channel capacity.
- Open channels shall be designed to follow natural drainage alignments whenever possible.
- Channel side slopes shall be stable throughout the entire length and the side slope shall depend on the channel material. A maximum of 2:1 shall be used for channel side slopes, unless otherwise justified by calculations. Roadside ditches shall have a maximum side slope of 3:1.
- The design of artificial channels shall consider the frequency and type of maintenance required, and shall make allowances for access of maintenance equipment.
- Trapezoidal cross sections are preferred over triangular shapes for artificial channel designs.
- The final design of artificial open channels shall be consistent with the velocity limitations for the selected channel lining.
- Identification of priority areas/catchments
- Detailed stakeholder analysis in areas concerned
- Contacting communities and awareness creation
- Joint data collection and baseline assessment
- Agreement on interventions and training of individuals and relevant working groups
- Preparation of an overall implementation program
- Preparation of an annual work plan
- Defining responsibilities for tasks to be performed and making related institutional arrangements

- Implementation
- Joint evaluation of implementation
- If necessary, adaptation of overall work plan

3.5.3 Estimation of runoff

In order to be able to size a drain, an estimate must be made of the peak rate of flow entering it during a design storm. There are different methods available for making such estimates and in this particular case the empirical formula approach will be used and is described in the following section.

3.5.4 Rational method

The Rational Method is a purely empirical formula which is very simple and quick to apply. Larry W. Mays records that criticism has been raised on the adequacy but it is still in continued use for sewer design where high accuracy runoff rate is not essential. In its fundamental form the Rational Formula is:

$$Q = K.C.I.A$$

Where: Q = Peak runoff rate, in m^3/s

K = Constant, 0.28 in SI units

C = Runoff coefficient, (depends on the characteristics of the surface)

I = Average rainfall intensity obtained from the intensity - duration frequency relationship curves, in mm/hr

A = Area of the drainage basin in km2

A drainage area will normally consist of sub-catchments with different surface characteristics. In consideration of the composite analysis, Larry W. Mays (2005) gives the peak runoff using the rational formula as:

$$Q = Ki\sum_{j=1}^{m} CjAj$$

Where: m = the number of sub-catchments drained by the storm structure

3.5.5 Flow calculation formula

The Manning's formula is acceptable for open channel flow, where there are no other suitable methods, but is regarded as insufficiently reliable for calculation of flows in full or part-full pipes.

The Manning's formula states that:

$$Q = 1/n \,.\, A \,.\, R^{2/3} \,.\, S^{1/2}$$

Where: Q = Discharge Rate for Design conditions, in m^3/s

R = hydraulic mean radius, i.e. cross-sectional flow area divided by the wetted perimeter (A/P), in m

S = Slope of energy grade line

n = Manning's roughness coefficient

A = Cross sectional area, in m^2

For prismatic channels, in the absence of backwater conditions, the slope of the energy grade line, water surface and channel bottom are assumed to be equal.

The Manning's "n" value is an important variable in open channel flow computations. Variation in this variable can significantly affect discharge, depth, and velocity estimates. Since Manning's "n" values depend on many different physical characteristics of natural and man-made channels, care and good engineering judgment must be exercised in the selection process.

Recommended Manning's "n" values for artificial channels with rigid, unlined, temporary, and riprap linings are given in Table 4-7.

Table 3-1: Manning's Roughness Coefficients (n) for Artificial Channels – Source USDOT, 1996

Category	Lining Type	Depth Ranges		
		0 – 0.15 m	0.15 – 0.61 m	> 0.61 m
Rigid	Concrete	0.015	0.013	0.013
	Grouted Riprap	0.040	0.030	0.028
	Stone Masonry	0.042	0.032	0.030
	Soil Cement	0.025	0.022	0.020
	Asphalt	0.018	0.016	0.016
Unlined	Bare Soil	0.023	0.020	0.020
	Rock cut	0.045	0.035	0.025
Temporary	Woven Paper Net	0.016	0.015	0.015
	Jute Net	0.028	0.022	0.019
	Synthetic Mat	0.036	0.025	0.021

3.5.6 Geometric relationships

Area, wetted perimeter, hydraulic radius, and channel top width for standard channel cross sections can be calculated from geometric dimensions. Irregular channel cross sections (i.e., those with a narrow deep main channel and a wide shallow overbank channel) must be subdivided into segments so that the flow can be computed separately for the main channel and overbank portions. This same process of subdivision may be used when different parts of the channel cross section have different roughness coefficients. When computing the hydraulic radius of the subsections, the water depth common to the two adjacent subsections is not counted as wetted perimeter.

CHAPTER 4.COST ESTIMATES

4.1 Basis for cost estimates

Estimating costs for civil engineering works within the project area is not a challenging exercise since there exists a well established local construction industry. Prices of materials including fuel are fairly stable and depend largely on market forces countrywide dictated by supply and demand. However, at this preliminary stage, it is only possible to put an approximate order of costs on the proposed redevelopment and construction works. The following rates and prices (Estimating costs for civil engineering works within the project area is not a challenging exercise since there exists a well established local construction industry. Prices of materials including fuel are fairly stable and depend largely on market forces countrywide dictated by supply and demand. However, at this preliminary stage, it is only possible to put an approximate order of costs on the proposed redevelopment and construction works. The following rates and prices (Table 5-1) were obtained from works of a similar nature carried out previously within the project area and have been used for guidance in developing the cost estimates. A rate of 1US $ to KShs. 83.50 has been adopted as the current exchange rate.

Table 5-1

Table 4-1: Basic cost information for Lwakhakha Town

Type of Channel and Description	Unit	Rate (US$)
General Site Clearance of Work Areas	m^2	0.06
Excavation of soil	m^3	1.8
Excavation in rock	m^3	4.79
Concrete Grade 25/20	m^3	119.80
Concrete Grade 25/30	m^3	167.66
Concrete Grade E (Blinding)	m^3	95.81
Formwork, plane horizontal	m^2	4.79
Formwork curved	m^2	7.19
Reinforcement: High Yield Bars Diameter up to 20 mm	Kg/m^3	2.40
Mesh Fabric, 6 – 7 Kg/m^2	Kg	5.39
Concrete pipe 450 diameter	m	71.86
Concrete pipe 600 diameter	m	119.80
Concrete pipe 900 diameter	m	167.66

4.2 Availability of plant, labour and materials

Since it is foreseen that the redevelopment and construction of the drainage system will have to go hand in hand with road rehabilitation, appropriate construction equipment in the project area is bound to be limited and will have to probably be sourced from the region in towns such as Kakamega and Kisumu. It is recommended that manual labour be used where appropriate as this will also encourage community participation and create employment. In situations where only machinery is usable, the contracts with the Contractors should be well structured contracts for a specified quantity of work and payments made on certified work by the Engineer.

Manual labour is likely to be available but the works will need proper supervision if the quality is to be ensured. Skilled labour such as surveyors and technicians is bound to be available even from surrounding areas so long as the pay is attractive.

The supply of basic construction material in the area is bound to be available in adequate quantities as the transport network is good and reliable. Locally available materials such as masonry are expected to be of good quality and this is mined from the surrounding deposits. Supply of good quality aggregate is adequate with coarse aggregate coming from Eldoret while supply for river sand is available from Malaba.

However, majority of the works for rehabilitation will involve earthworks and will not require much in the way of materials.

4.3 Rehabilitation cost estimate

As stated above the rates used for the cost estimate shown in Estimating costs for civil engineering works within the project area is not a challenging exercise since there exists a well established local construction industry. Prices of materials including fuel are fairly stable and depend largely on market forces countrywide dictated by supply and demand. However, at this preliminary stage, it is only possible to put an approximate order of costs on the proposed redevelopment and construction works. The following rates and prices (Table 5-1) were obtained from works of a similar nature carried out previously within the project area and have been used for guidance in developing the cost estimates. A rate of 1US $ to KShs. 83.50 has been adopted as the current exchange rate.

Table 5-1 are based on the information for Bungoma and are therefore susceptible to fluctuation and should therefore be applied with caution.

The cost estimate aims to reflect the major cost items in particular and is broken down to various components to differentiate type of works. It is also important to note that the estimate at this stage is preliminary since additional data will require to be collected and collated to be able to arrive at a comprehensive overview of the situation.

The cost estimate aims to reflect the major cost items in particular and is broken down to various components to differentiate type of works. These are given in The quantities and rates used for the cost estimate shown in Table 5-1 are based on the information gathered from the Municipal Works Officer at the time of the field investigation survey and are therefore susceptible to fluctuation and should therefore be applied with caution.

The cost estimate aims to reflect the major cost items in particular and is broken down to various components to differentiate type of works. These are given in Table 5-2.

Table 5-2

Table 4-2: Estimated redevelopment and construction costs

Description	Amount (US$)
Topographical Survey	52,622.75
General Site Clearance	2,395.21
Earthworks	10,419.16
Mass Concrete	2,395.21
Reinforced Concrete	15,808.38
Mesh Reinforcement	658.68
Precast Concrete Pipes	21,844.31
Town roads and drainage channels	52,095.81
Masonry and Gabion mattresses	20,958.10
SUB TOTAL	**179,197.61**
Project Management and Supervision (20%)	35,839.52
Contingencies (15%)	26,879.64
GRAND TOTAL	**241,916.77**

CHAPTER 5.OPERATION AND MAINTENANCE

5.1 General

This Report provides a guideline on what measures the Storm Water Master Plan for Lwakhakha town could adopt for the management of storm water in order to achieve the objectives laid down for the system.

Proper Maintenance of Storm Water Facilities and best management practices are important factors in the long-term performance and effectiveness of a Storm Water Master Plan. An effective Operation and Maintenance (O&M) programme ensures that the system continues to provide the required service at the expected levels of performance. The O&M Plan should therefore aim at establishing an effective Site-Specific Maintenance Programme that emphasises on preventive measures thus prolonging the service life of Storm Water Facilities, minimize expensive repairs, and ensure its continued safe, effective and reliable performance.

Solid waste swept into the drainage channel from business premises in the background on the Ugandan side

The town Councils have to put in place mechanisms that ensure an effective Participatory Process of storm water management involving all stakeholders such as communities, Landlords, Business people, Government Agencies and Council Staff.

5.2 Situation analysis

During the field reconnaissance visit, it was observed that O&M arrangements for the limited existing drainage system on the Kenyan side are very poor or nonexistent. The Ugandan side of the town seems to have a well coordinated maintenance arrangement as observed with the fairly well maintained drainage channels. All of the unlined natural drainage channels are formed by runoff and therefore have cross sections that do not meet the right hydraulic properties to enable the evacuation of even showers of medium intensity, leading to overflowing of stormwater and uncontrolled weed growth.

Most of the solid waste is due to uncontrolled disposal by the Town residents and failure on the part of the Councils to enforce the necessary by-laws and regulations. Blockages along the drainage channels due to the above circumstances lead to uncontrolled flow of storm water and flooding of low lying areas within the town.

The sections 5.4 to 5.7 below provide requirements to ensure successful performance of stormwater control facilities once they have been constructed. The requirements might appear stringent for a town the size of Lwakhakha. However, the town needs to take advantage of this stage of development to ensure that the storm water infrastructure for both short and long term evolves with developing stages of storm water management.

Included in these sections are requirements for as-built surveys, facility inspection and maintenance, and maintenance and access easement requirements to allow for maintenance in and around stormwater facilities.

It is assumed that the Councils will adopt a preventive approach in maintenance and operation of the system and the drainage structures will not be left to deteriorate or be rendered obsolete.

5.3 Current operation and maintenance challenges

Ideally maintenance of the storm drainage system should include:

- Cleaning and repairing damage to storm drain lines and catch basins to maintain as much as possible the hydraulic properties of the channels
- Inspecting and maintaining grit traps and storm drain outlets
- Removal and proper disposal of sediment (mostly sand and silt) from storm drain structures. Catch basins and grit traps should be cleaned many times each year at regular intervals to remove trash and other materials.
- Removal of vegetative and weed growth along unlined drainage channels

It was however observed that very little of maintenance is carried out on the drainage infrastructure on the Kenyan side of the town. Sediments and solid waste has been left to accumulate along the drains thus causing blockages and resulting in overflow of storm runoff.

A poorly maintained access culvert on the Kenyan side

The above scenario could be attributed to a number of factors namely:

- Lack of adequate and trained labour
- Inadequate allocation of financial resources to ensure successful drainage operation and maintenance
- Lack of suitable and adequate equipment
- Lack of a proper set out institutional arrangement responsible for programming and implementation of regular inspection and maintenance programme of the drainage system

The situation is slightly different on the Ugandan side of the town. The storm water drainage infrastructure seems to be in a fairly well maintained and operated condition apart from a few sections of the lined channels whose stone pitching has collapsed.

A fairly well maintained lined channel and cross culvert on the Ugandan side

5.4 Stormwater control facility maintenance responsibility

It is essential that any approved stormwater control facility be properly maintained in order to ensure its performance. The Councils will maintain eligible infrastructure constructed and designed to serve the town developments. To be eligible for Council maintenance services, developers who provide part of the stormwater infrastructure must:

- Have established approved vegetation or paving within and around the facility, if applicable,
- Have designed and constructed the facility in accordance with Council standards and proven by As-built Surveys,
- Have the facilities in proper working order at the time the Council accepts maintenance responsibilities, and
- Provide to the Council specific, dedicated easement rights sufficient to perform required maintenance.

Onsite facilities in residential and institutional developments, shall be maintained by the Property Owner or, if applicable, a homeowners association. Onsite facilities constructed to serve privately-owned developments (i.e., multi family, commercial, industrial, etc.) shall be maintained by the Property Owner.

5.5 Stormwater control facility easement and access requirements

For stormwater control facilities that are to be operated and maintained by the Council, the Property Owner shall provide the Council with an easement to the area of the stormwater facilities, appurtenances to the facilities such risers, outlet pipes, etc., and a minimum width of 6 metres next to the facilities. A dedicated access easement, having a minimum width of 6 metres, shall also be provided that extends from the facility easement to the nearest public right-of-way.

For facilities that are to be maintained by a homeowners association or institutions, the developer shall provide to the Council a minimum 6 metres wide easement for such inlet and outlet pipes, etc., conveying stormwater to a public conveyance system.

For stormwater control facilities that are to be operated and maintained by the Council, the Property Owner shall provide the Council with a maintenance vehicle access way having a minimum width of 6 metres. The vehicle access way shall be stabilized with suitable materials (e.g., concrete, gravel, or other suitable means of stabilization) adequate to prevent rutting by the maintenance vehicles. All access routes shall be designed to allow the turn-around of maintenance vehicles.

5.6 Stormwater control facility maintenance plan

A maintenance plan for privately-owned stormwater controls and for stormwater controls that are to be maintained by a homeowners association or institutions must be prepared and submitted for review and approval by the Council during the Plan approval process. At a minimum, maintenance plans for stormwater controls shall include a method and frequency for the following activities:

- Inspection of all permanent structures,
- Debris/clogging control through appropriate removal and disposal,
- Vegetation control (mowing, harvesting, wetland plants),
- Erosion repair,
- Non-routine maintenance should include pollutant and sediment removal and the "rejuvenation" or replacement of filters and appropriate soils,
- Disposal of solid waste, sediments, and other debris in accordance with Municipality regulations, and
- Mosquito monitoring and abatement, encompassing inspections for conditions conducive to mosquito breeding, routine (e.g., vegetation control, debris and sediment removal) and non-routine (e.g., restoration of grade to eliminate ponding) activities to address these conditions, and conditions where the use of insecticides may be warranted.

5.7 Maintenance inspection and reporting requirements

The Property Owner, its administrators, executors, successors, heirs or assigns shall maintain the stormwater control facility or facilities in good working condition acceptable to the Municipal Council and in accordance with the schedule of long term maintenance activities provided in the approved stormwater control facility maintenance plan for the stormwater control facility or facilities. Maintained infrastructure shall include all pipes and channels built to convey stormwater, as well as all structures, improvements, and vegetation provided to control the quantity and quality of the stormwater. ”Maintain” is herein defined as good working condition so that these facilities are performing their design functions.

The purpose of maintenance inspections is to assure safe and proper functioning of the stormwater control facilities. The Property Owner shall perform periodic inspections of the stormwater control facility and its appurtenances at a frequency stipulated in the approved stormwater control facility maintenance plan. Inspections shall cover all elements for the stormwater control facility as defined in the stormwater control facility maintenance plan.

Inspections shall include the completion of dated and signed inspection checklists provided in the stormwater control facility maintenance plan and the notation of all deficiencies observed during the inspection. The Property Owner shall maintain copies of complete dated and signed inspection checklists in a maintenance inspection log, along with recorded dates and descriptions of maintenance activities performed by the Property Owner to remedy the deficiencies observed during prior inspections. The maintenance inspection log shall be kept on the property and shall be made available to the Municipal Council upon request.

A copy of the Maintenance Inspection Log shall be submitted annually by 31st December each year to the Town Engineer, Division of Sewerage and Drainage.

CHAPTER 6.RECOMMENDATIONS

A faster growth of Lwakhakha town should be anticipated especially with the creation of County Governments which could spur economic growth and the Government's vision 2030 strategy. This would be an opportune time to prepare both the Physical Development Plan and the Storm water Master Plan before any unplanned developments interfere with the natural drainage paths. The exercise would be less complex task and would present a detailed overview of the overall drainage situation and translate this into a workable comprehensive drainage plan. This master plan should consider urbanization limits till 2030.

There is also a need to develop run-off norms for Lwakhakha town before commencement of the preparation of the Master Plan. A Committee of Experts may be set up under the Chairmanship of Nile Basin Initiative, Engineers from Bungoma County Council and Lwakhakha Town Council on the Uganda side and Government Agencies operating within the town to finalize the run-off norms and also the detailed terms of reference for the preparation of the master plan for storm water drainage in Lwakhakha.

At the same time the extent of urbanization will have to be ascertained from the Councils together with the Government Agencies etc.

One of the fundamental issues that should not be neglected is the comprehensive design of roads, drains, sewers and other utility network like water pipe, electric and communication cables etc. and their careful and meticulous execution. Road foundations as well as the running surface should be such that it doesn't lead to early damage due to movement and weather conditions.

It is inevitable for a gravel surface of the road that more dust and debris during road sweepings would result to further damage to the surface. Some of this dust and debris is what finds its way into the adjacent drains causing blockage. At the same time suitable ducts / pipes should be provided under the foot path to accommodate cables, pipes etc. so that the road is not dug up time and again.

Since the drainage system for Lwakhakha town is virtually nonexistent, Stormwater systems should be designed to conform to natural drainage patterns and discharge to natural drainage paths within a drainage basin where practicable. These natural drainage paths should be modified as necessary to contain and safely convey the peak flows generated within the town.

Detailed information regarding the topography of the whole town, invert levels of all the natural and man-made drains, information about any linkage of underground utilities and storm water drains would be required through a meticulous survey which should be part of the terms of reference to be developed for the preparation of the Master Plan.

There should be strict instructions to the construction agencies and developers to clear all debris and construction material from within the drains before covering the slabs. This is crucial for proper functioning of the drains.

The remodelling of the natural drains should consist of the hydraulic modification of the cross section of the drains as outlined in section 3.5.5 of this report. This should be replicated for all the drains mentioned in Table 2-1 so that the problem can be solved from the very root in a long term sustainable way.

The Engineering Departments for the respective Councils should be fully empowered to deal with all sewer and waste water, storm water and natural drains within the town area in a comprehensive manner.