IMPROVING THE HYDRAULIC CONVEYANCE OF A ROAD DRAINAGE: A CASE STUDY OF NALUUMA ROAD, NANSANA-NABWERU

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A FINAL YEAR RESEARCH AND DESIGN PROJECT REPORT SUBMITTED TO THE FACULTY OF ENGINEERING, DESIGN AND TECHNOLOGY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A DEGREE OF BACHELOR OF SCIENCE IN CIVIL AND ENVIRONMENTAL ENGINEERING OF UGANDA CHRISTIAN UNIVERSITY

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ABSTRACT

This research project focused on improving the hydraulic conveyance of Naluuma road drainage channel in Nansana-Nabweru, Uganda. The study involved determining the existing conditions of the road drainage channel, determining the peak discharge of the catchment, sufficiently sizing the drainage channel through hydraulic calculations and providing suitable cost estimates with a bill of quantities (BOQ)

To achieve these objectives, site visits and topographic surveys were conducted, channel measurements were taken and the catchment area was demarcated using ArcGIS, QGIS and a Digital Elevation Model (DEM). Rainfall data was acquired from Uganda National Meteorological Association (UNMA) to generate intensity duration frequency (IDF) curves, utilizing the theoretical extreme value (EV) distribution, which were used to determine the design storm and estimate rainfall events hence arriving at rainfall intensities. Using the rational method, the peak discharges were calculated. A bill of quantities was also generated in reference to prices and benefits of the various materials or equipment used.

A total channel length of 803m was divided into three sections based on terrain slope and flow characteristics. Parameters such as runoff coefficients, rainfall intensities and catchment areas were determined to finally come up with peak discharges for the respective sections the uphill section(330m), midhill(300m) and downhill(180m). Results obtained from the third objective such as top and bottom widths, flow depth, and discharges from objective two were input into HECRAS software to run a supercritical hydraulic simulation of the modified channel. The results highlighted sections of the channel that were prone to overflow under extreme discharge scenarios. Based on these findings, recommendations were made on channel

dimensions and possible lining materials to enhance flow capacity and reduce erosion risk hence mitigating the flooding problem of Naluuma

DECLARATION

I **OBBO AUSTIN**, **S20B32/257** hereby declare that this is entirely my work and it has never been submitted to any other institution.

Signature: ……………………………………

Date: ……………………………………………

APPROVAL

This is to confirm that this final year report by **OBBO AUSTIN** has been completed, and reviewed approved under my supervision and has been submitted for approval.

Signature: ……………………………………………………

Mr. BRIAN SEMPIJJA BAAGALA

ACADEMIC SUPERVISOR

ACKNOWLEDGEMENT

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My sincere appreciation goes to my project supervisor, Mr. Brian Sempijja Baagala whose professional advice, timely feedback and patient guidance have been instrumental from the start to the end of this research, my project partner Akampurira A Timothy for his unwavering moral support, shared ideas and thoughtful discussions which helped refine my approach and broaden my perspective.

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LIST OF ABBREVIATIONS

UNMA	Uganda National Meteorological Authority
BCR	Benefit Cost Ratio
DEM	Digital Elevation Model
CBA	Cost Benefit Analysis
EV	Extreme Value
Fr	Froude's Number
ft	Feet
Km	Kilometer
GPS	Global Positioning System
IDF	Intensity duration frequency
Km^2	Square kilometer
RTK	Real Time Kinematic
SI	International System of Units
UGX	Ugandan Shillings
LULC	LAND-Use Land Cover
m	Meter
m^2	Square Meters
m^3/s	Cubic meters per second
mm/hr	millimeter per hour

MoWT	Ministry of Works and Transport
NPV	Net Present Valu

CHAPTER 1: INTRODUCTION

1.1 Background

Drainage is a critical component of road infrastructure that involves the interception, collection, and removal of water from both above and below the road surface. It is typically classified into two main types; Surface drainage, which manages runoff on the road surface and adjacent areas, and subsurface drainage, which addresses water removal beneath the pavement structure.

Both drainage-types play a significant role in preserving the structural integrity, longevity, and safety of roads, making effective drainage design a key consideration in highway construction (Smith, 2022).

Proper drainage facilities are essential to protect roads from water-induced damage, which can create hazardous driving conditions and accelerate pavement deterioration (Williams & Chen, 2021). Inadequate drainage compromises the serviceability and lifespan of road infrastructure (Taylor et al., 2023). Effective drainage systems typically integrate both natural and engineered features such as ditches, culverts, pipes, curbs, and storm channels to ensure the safe and efficient conveyance of stormwater.

The success of drainage construction depends heavily on factors like choosing appropriate materials that align with system requirements for collection, conveyance, and discharge, adhering to sound engineering practices, and conducting regular maintenance, all of which are essential for enhancing the performance and reliability of drainage systems (Roberts, 2023).

In Uganda, a landlocked country in East Africa, roads are the primary mode of transport and play a vital role in supporting the national economy by facilitating the movement of goods and people. The Uganda National Roads Authority (UNRA), established in July 2008 by an Act of Parliament, is responsible for development and maintenance of national roads, management of road machinery, oversight of axle load control, strategic planning for sustainable road infrastructure.

One of the persistent challenges facing Uganda's road infrastructure is poor or inadequate drainage, often manifested as undersized drains, complete absence of drainage facilities, or blocked channels. These deficiencies are a direct cause of urban flooding, especially during intense storm events when large volumes of stormwater runoff overwhelm the drainage capacity, leading to flooding and property damage in nearby communities (ActionAid, 2006).

Inadequate drainage channels can result in multiple issues, including frequent flooding, soil erosion, water pollution, and infrastructure degradation (EPA, 2019; NOAA, 2019).

If not properly designed or maintained, drainage systems can become blocked, damaged, or overwhelmed, particularly during high-intensity rainfall. Additionally, poorly constructed or unlined channels are highly susceptible to erosion, where high-velocity water flows scour the channel beds and banks. This erosion leads to sediment deposition downstream, and the formation of sinkholes, which pose serious risks to both pedestrians and vehicles (USACE, 2014).

This study focuses on the Naluuma Road (approximately 1.2 km in length), located in the Nansana-Nabweru Town Council in Wakiso District, Central Uganda. The road is situated near Hoima Road and serves as a critical access route for residents of

Nabweru Cell 2, facilitating both local transport and commercial activities. However, the road has been severely impacted by a poor drainage network, leading to frequent flooding and reduced accessibility. This underscores the urgent need for the design and rehabilitation of an efficient roadside drainage system to support local socio-economic development and improve the resilience of transport infrastructure in the area.

1.2 Problem Statement

The side drainage along Naluuma Road that is an access road connecting to Hoima Road, is severely silted due to frequent erosion of the earthen channel embankments. This sedimentation has significantly reduced the channel's conveyance capacity resulting in the recurring flooding events during periods of heavy rainfall.

These flooding occurrences have continuously contributed to the destruction of the road surface since infiltration and groundwater recharge weaken the pavement structure. This process leads to the formation of potholes which then makes transportation difficult and compromises pedestrian safety (H. Lugeye, personal communication, Municipal Engineer, December 2024).

The current open channel design suffers from geometric and hydraulic deficiencies, including inadequate cross-sectional shape, slope, and size at certain locations. These flaws reduce the hydraulic efficiency of the drainage system, making it incapable of effectively conveying runoff, especially during high-intensity storms.

Despite these challenges, no empirical upgrades have been implemented to cover come the drainage problems. Therefore, this study aims at bridging the existing design gap by focusing on improving the hydraulic conveyance capacity of the drainage system along Naluuma Road. This will help to mitigate the flooding problem, enhance road accessibility, and also support sustainable infrastructure development in Nabweru.

1.3 Main objectives

To improve the hydraulic conveyance of Naluuma road drainage.

1.4 Specific objectives

1. To determine the existing conditions of the road drainage channel
2. To conduct a hydrological and hydraulic analysis of the catchment
3. To sufficiently size the drainage channel through hydraulic calculations
4. To determine an economic analysis of the modified channel

1.5 Research questions

1. What kind of drainage system exists in the catchment?
2. What is the cause of the poor drainage system?
3. What are the effects of a poor drainage system on the community?
4. What design improvements can be made to the existing channel?

1.6 Justification

Naluuma catchment has experienced significant urbanization, shown by the expansion of residential settlements and commercial activities. This growth has led to increase in impervious surfaces hence resulting in generation of higher volumes of surface runoff that exceed the conveyance capacity of the existing drainage system

Absence of an effective and well-planned drainage infrastructure has also led to persistent flooding along Naluuma Road in Nabweru hence posing serious risks to public safety, property, and transportation. This issue arises from the lack of an efficient drainage design that prioritizes flood mitigation under the various land use and climatic conditions.

Therefore, the purpose of this study is to assess the state of the roadside drainage channel and to create a drainage channel design that is flood resilient. The study's findings will improve the roads infrastructures functionality and safety while also offering a sustainable way to manage runoff and lessen the frequency and effects of flooding

Figure 1. 1 ***Current condition of the roadside drainage***

1.7 Significance of the Project

This research project addresses the problem of flooding in the settlements along Naluuma Road. The study will provide a comprehensive solution by proposing a new side drainage layout that meets the modern drainage design standards. The improved drainage will effectively divert excess surface runoff from road shoulders and pavement edges hence reducing water related damage and improving roads durability. The proposed drainage design will also enhance pedestrian safety, especially for those using walkways adjacent to the drainage channel by mitigating waterlogging and also minimizing slip hazards.

1.8 Content Scope

Hydraulic performance analysis of Naluuma roadside channel in relation to precipitation patterns, runoff volumes and time of concentration across the catchment

Hydraulic modeling focusing on the estimation and management of peak discharges within the drainage network using simulation tools to assess current and proposed performance of the channel

1.9 Time Scope

the project was initiated in September 2024 and is scheduled for completion in March 2025.this time frame was planned to ensure the attainment of the main objective and fulfillment of all specific objectives outlined in the study

1.10 Geographical Scope

The study is geographically confined to Naluuma road located in the Nabweru South ward, within Nansana municipality Uganda. The site lies at coordinates 0.34904N, 32.54101E. the location is part of a rapidly urbanizing region where efficient stormwater management is crucial due to increasing impervious surface areas and frequent flooding incidents.

Figure 1. 2 Location of Naluuma Road (Source: Google Earth)

CHAPTER TWO: LITERATURE REVIEW.

2.1 Flooding

Flooding as applied to roads, refers to the inundation of roadways due to excessive rainfall, river overflow or storm surges, leading to significant damage and disruption of transportation networks.

A flood can be defined as the overflow of large amounts of water beyond the prescribed limits. Some causes of floods include heavy rainfall, high melting of snow and ice, failures of water storage or water-diverging structures etc. The floods can lead to various communicable diseases, damage the infrastructure and property, damage any plants or wildlife that come in its path and contaminate habitats.

2.1.1 Factors that cause flooding

Flooding is a complex phenomenon influenced by a variety of natural and anthropogenic factors. Below is an outline of the primary factors contributing to flooding;

2.1.1.1 Natural factors

Rainfall; excessive rainfall is a significant trigger for flooding.in regions like Kotabaru, Indonesia, moderate rainfall accounts for 73.3% of flood events (UMMIYATI et al., 2024)

Geographical conditions; low lying topography and proximity to rivers as seen in Tunggal Irang llir village increase vulnerability to flooding (Yati et al., 2024)

Climate change; changes in climate patterns including increased wet conditions, exacerbate flood risks, particularly in areas like northwestern Ethiopia (Teshome Nigatu et al., 2023)

2.1.1.2 Anthropogenic Factors

Urban Planning; poor urban planning and inadequate drainage systems are prevalent in cities like Harper City, Liberia, leading to increased flood risks (Baddianaah, 2023)

Land Use Changes; deforestation and land degradation contribute to flooding by reducing the land's ability to absorb rainfall (Teshome Nigatu et al., 2023)

Waste Management; ineffective solid waste management can block drainage systems, worsening flood conditions (Baddianaah, 2023)

While natural factors are significant, the role of human activities in exacerbating flooding cannot be overlooked. Addressing these anthropogenic causes through improved urban planning and environmental management is essential for reducing flood risks.

2.2 The Hydrological cycle

The hydrological cycle plays a crucial role in understanding flooding dynamics, particularly in how water movement and management can mitigate flood risks. This cycle involves the continuous movement of water through evaporation, condensation, precipitation, and infiltration, which can significantly influence flood events. However, flood control measures, such as constructing floodways, may inadvertently reduce groundwater storage, highlighting the need for balanced flood management strategies (Pratoomchai et al., 2022)

This gigantic system, powered by energy from the Sun, is a continuous exchange of moisture between the oceans, the atmosphere, and the land. Studies have revealed that evaporation, the process by which water changes from a liquid to a gas from oceans, seas, and other bodies of water (lakes, rivers, streams) provides nearly 90%

of the moisture in our atmosphere. Most of the remaining 10% found in the atmosphere is released by plants through transpiration. Plants take in water through their roots, then release it through small pores on the underside of their leaves. In addition, a very small portion of water vapor enters the atmosphere through sublimation, the process by which water changes directly from a solid (ice or snow) to a gas. The gradual shrinking of snow banks in cases when the temperature remains below freezing results from sublimation.

After the water enters the lower atmosphere, rising air currents carry it upward, often high into the atmosphere, where the air is cooler. In the cool air, water vapor is more likely to condense from a gas to a liquid to form cloud droplets. Cloud droplets can grow and produce precipitation (including rain, snow, sleet, freezing rain, and hail), which is the primary mechanism for transporting water from the atmosphere back to the Earth's surface.

When precipitation falls over the land surface, it follows various routes in its subsequent paths. Some of it evaporates, returning to the atmosphere; some seeps into the ground as soil moisture or groundwater; and some runs off into rivers and streams. Almost all of the water eventually flows into the oceans or other bodies of water, where the cycle continues. At different stages of the cycle, some of the water is intercepted by humans or other life forms for drinking, washing, irrigating, and a large variety of other uses (Paul Przyborski, no date)

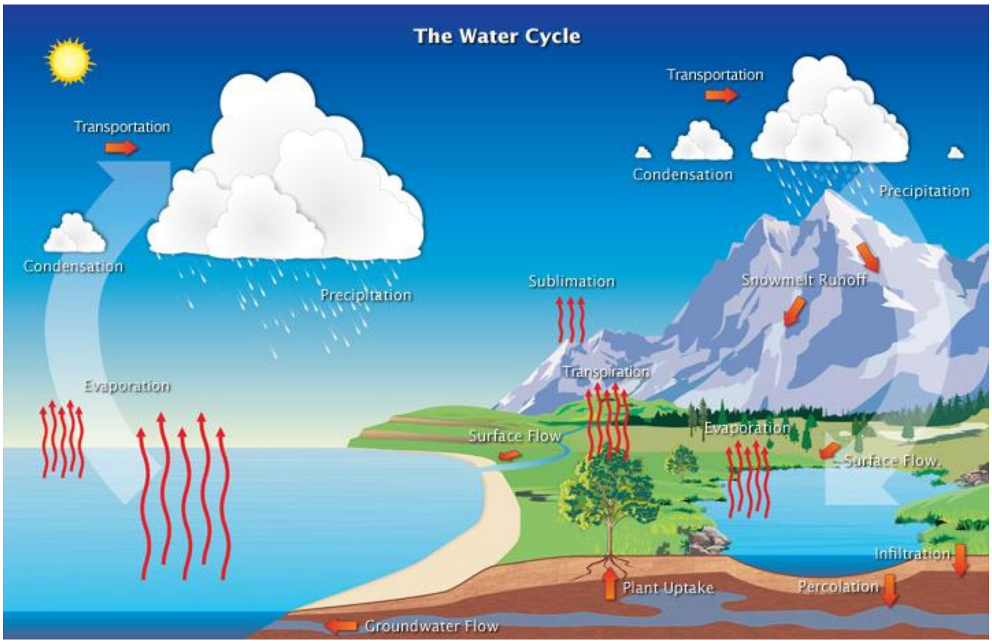


Figure 2. 1 Hydrological cycle

2.3 Channel geometry

Channel geometry plays a pivotal role in design and analysis of open channel flows, directly influencing flow capacity, velocity, and overall hydraulic efficiency. These properties are essential for effective water conveyance

2.3.1 Cross sectional shape

Rectangular channels; common in engineered structures due to ease of construction and analysis. They offer good balance between efficient fluid flow and adaptability to various conditions

Trapezoidal channels; often used in irrigation and drainage systems for stability and efficient flow especially in situations with limited land availability. They offer a good balance between maximizing waterflow capacity while minimizing the amount of material needed for construction

Triangular channels; typically found in natural formations or specific design scenarios. They are used in situations where maximizing flow velocity with minimal water volume is desired because its design concentrates flow towards the center of the channel leading to high flow rates with a relatively small cross-sectional area

Circular channels. These are preferred due to their ability to minimize flow resistance due to their unique geometry that allows for the smoothest fluid movement with the less friction against the channel walls

The cross-sectional area of the stream is determined by multiplying channel depth by channel width along a transverse section of the stream. For a hypothetical stream with a rectangular cross-sectional shape (a stream with a flat bottom and vertical sides) the cross-sectional area (A) is simply the width multiplied by the depth:

$$\mathbf{A = (b * y)}$$

Wetted perimeter; this is simply the total length of the channel walls that are in contact with the liquid(water)

The wetted perimeter, P is the width, b plus twice the depth, y that the water touches:

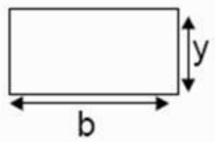
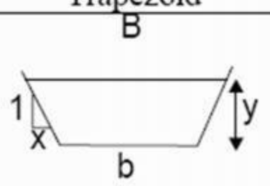
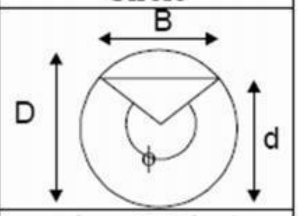
$$\mathbf{P = b + 2y}$$

The greater the cross-sectional area in comparison to the wetted perimeter, the more freely flowing will the stream be because less of the water is in proximity to the frictional bed. So as hydraulic radius increases so will velocity (all other factors being equal).

The hydraulic radius, R, is defined as the ratio of the cross-sectional area of the flow, A, to the wetted perimeter of the channel, P:

$$\mathbf{R} = \frac{\mathbf{A}}{\mathbf{P}}$$

Channel slope or Gradient; this is the difference in elevation between two points on a stream divided by the distance between them measured along the stream channel. The flow velocity, and thus power of the stream to do work is also directly related to the slope of the channel, the steeper the slope, the faster the velocity of flow.

	Rectangle	Trapezoid	Circle
			
Area, A	by	$(b+xy)y$	$\frac{1}{8}(\phi - \sin\phi)D^2$
Wetted perimeter P	$b+2y$	$b+2y\sqrt{1+x^2}$	$\frac{1}{2}\phi D$
Top width B	b	$b+2xy$	$(\sin\phi/2)D$
Hydraulic radius R	$by/(b+2y)$	$\frac{(b+xy)y}{b+2y\sqrt{1+x^2}}$	$\frac{1}{4}\left(1-\frac{\sin\phi}{\phi}\right)D$
Hydraulic mean depth D_m	y	$\frac{(b+xy)y}{b+2xy}$	$\frac{1}{8}\left(\frac{\phi-\sin\phi}{\sin(1/2\phi)}\right)D$

2.4 Open channel flow classification

2.4.1 Steady and unsteady flow

A steady flow occurs when the flow properties, such as the depth or discharge at a section, do not change with time. As a corollary, if the depth or discharge changes with time, the flow is termed unsteady. In practical applications, due to the turbulent nature of the flow and the interaction of various forces, such as wind, surface tension, etc., at the surface, there will always be some fluctuations in the flow properties with respect to time. To account for these, the definition of steady flow is somewhat generalized, and the classification is done on the basis of gross characteristics of the flow.

2.4.2 Laminar and turbulent flow

In open channel flow, when the Reynolds number exceeds 500, the flow is known as turbulent flow and when it is lower than 500, the flow is called laminar flow.

So laminar flow in open channel occurs when Reynolds number is lower than 500.

2.4.3 Critical, Subcritical and Supercritical Flow in Open Channel

This classification is based on the Froude's Number. In open channel flow, critical flow occurs when the flow velocity equals the wave speed, maintaining a stable water surface. Subcritical flow is slower than the wave speed, resulting in tranquil water conditions, while supercritical flow is faster, causing disturbances like waves and rapids. The classification is as follows

$F < 1$; Subcritical flow

$F = 1$; Critical flow

$F > 1$; Supercritical flow

The velocity of flow at any channel section is not uniformly distributed due to the presence of free surface and the frictional resistance offered to free flow of water by the boundary of the channel.

The velocity distribution in a channel section depends upon various factors such as the shape of the section, roughness of the boundary of the channel and the alignment of the channel (Murugappan.A, 2020)

2.4.4 Factors affecting velocity of flow

Alignment of channel

The velocity of flow in the channel also depends on the alignment of the channel. If the channel is straight there will be no change in velocity with respect to alignment. In straight channels, maximum velocity generally occurs at 0.05 to 0.15 m depth from the free water surface. If it is sinuous or meandering, the velocity will vary at bends. At bends, due to centrifugal action of flow, the velocity becomes more on the convex side compared to the concave side.

Slope of Channel bed

Slope of channel bed or gradient of the channel will also affect the velocity of flow in open channels. At steeper gradients, velocity increases while at normal gradients velocity decreases.

Roughness of channel

Roughness of channel is the measure of the amount of frictional resistance offered by channel bed material against the flow of water. In natural channels, the flow velocity is affected by the presence of large angular boulders as bed material, vegetation, obstructions etc. If the channel is made of smooth clay or silt, its roughness is very low and water flows faster. In the case of artificial channels, smooth finishing is required to maintain the required flow velocity. The average velocity in open channels can be calculated using manning's formula mentioned below.

$$\mathbf{V} = \frac{\mathbf{1}}{\mathbf{n}} * \mathbf{R}^{\frac{2}{3}} * \mathbf{S}^{\frac{1}{2}}$$

Where,

V = Average velocity of channel

R = hydraulic radius of channel

S = Slope of channel

n = Manning's roughness coefficient.

CHAPTER 3: METHODOLOGY

3.0 Introduction

This chapter outlines the various steps taken to develop the proposed designs. Relevant data was collected through a review of existing literature and analysis of historical rainfall records within the contributing areas. It also involved the generation of Intensity-Duration-Frequency (IDF) curves, which were essential in estimating rainfall intensity for the specific catchments

Key activities carried out included field inspections, conducting topographic surveys along the road alignment, and reviewing academic and online resources related to drainage.

The design process followed a standardized approach guided by established design manuals. Software tools such as ArcMap 10.1 and QGIS 3.38.2 were used to analyze catchment characteristics and patterns of land use. Civil 3D software further assisted in estimating catchment areas by utilizing GPS coordinates collected during fieldwork.

3.1 To determine the existing conditions of the road drainage channel

A field investigation was conducted to understand the present condition of the drainage channel along the road. It involved an initial reconnaissance survey to get a clear picture of the site and also determine the most appropriate design strategy. The process also included a topographic survey and the delineation of the relevant catchment area.

3.1.1 Field Reconnaissance

A site visit was conducted by walking the full stretch of the drainage channel, this helped to observe the surrounding environment, analyze the existing channel alignment, and also determine the natural flow direction along with some of the physical aspects of the catchment. During the walk-through, features such as land use types, settlement patterns, and alignment characteristics were recorded.

The approach taken was based on transect walks by moving between two specific points in order to systematically cross through the local community. This exercise later included sketching a map that reflected the observations like potential hazards, and key features in place.

This activity also involved interacting with local residents to gather information through informal conversations. These discussions together with active observation helped in identification of important community assets, risks, and livelihood patterns.

3.1.2 Topographic Survey

A detailed topographic survey was conducted along the entire length of the drainage channel from its point of entry to the outlet using Real-Time Kinematic (RTK) Global Positioning System (GPS) equipment. During the process, both the centerline and side coordinates, together with their respective elevation points were recorded at various chainages along the channel. Elevation data for ground surfaces, bridge structures, and culverts with their exact coordinates were also collected and documented.

The following steps were followed;

- A temporary benchmark was established at the beginning of the channel, and appropriate instrument stations were positioned at intervals along the route.
- The RTK base station was installed at the benchmark to ensure optimal satellite signal coverage and enable the transmission of real-time correction data.
- Elevation points and coordinates of the ground surface, the channel bed, crossing structures, and spot heights were measured after every 20 meters along both sides and the center of the channel by using a measuring tape.
- All the coordinates obtained were input into Microsoft Excel from the original field notes and later imported into Civil 3D software. This data was then used to produce a topographic representation of the drainage channel and its associated features.

3.1.3 Measurement of the Channel

The dimensions of the drainage channel were established using standard surveying techniques with the help of instruments such as GNSS RTK equipment and measuring tapes. The objective of this activity was to determine geometric parameters of the channel such as the cross-sectional area, widths, depth, and elevation in order to evaluaate its flow capacity.

Once the field measurements were collected, the data was extracted from the equipment, compiled and organized in Microsoft Excel. From there, the information was imported into Civil 3D software and later into AutoCAD, where it was utilized to assist in the design and delineation of the relevant catchment area.

The slope of the channel was calculated using the elevation values recorded at both the inlet and outlet, along with the total measured length of the channel. The slope was determined using the following formula:

$$\textbf{Channel slope} = \frac{\textbf{Inlet elevation} - \textbf{Outlet elevation}}{\textbf{Total length of the channel}}$$

3.2 To conduct a hydrological and hydraulic analysis of the catchment

To analyze the flow and drainage characteristics of the catchment area, a comprehensive hydrological and hydraulic evaluation was performed.

3.2.1 Catchment Area Delineation

The catchment area contributing to the roadside drainage along Naluuma Road was mapped using ArcGIS software. A satellite image of the area was combined with a Digital Elevation Model (DEM), which provides elevation data for various points. Because both datasets shared the same coordinate reference system, the merging process was seamless.

To prepare the DEM for analysis, the “Fill” tool found in the spatial analysis toolbox was applied to eliminate surface depressions and irregularities. Flow direction for each grid cell in the DEM was then determined using the “Flow Direction” tool and followed by the “Flow Accumulation” tool used to trace the accumulation paths.

A pour point to represent the outlet was defined to assist in outlining of the watershed boundaries and identifying stream networks. The “Watershed” tool was then used to delineate the specific area draining into the defined pour point. A visual representation of the corresponding catchment area on the map was then generated.

Land use and landcover (LULC) data from the study area was also analyzed and ArcGIS software was used to calculate the percentage of each land use category within the watershed. The analyzed data helped in the estimation of the catchment's weighted runoff contribution to the Naluuma drainage system.

3.2.2 Design Storm

Data on the highest annual rainfall was obtained from the Uganda National Meteorological Authority (UNMA), located in Luzira was used to analyze extreme rainfall patterns for the catchment area.

3.2.3 Development of IDF Curves

To establish Intensity-Duration-Frequency (IDF) curves, the Gumbel Type I distribution a type of Extreme Value (EV) distribution was applied to the historical rainfall data. This approach allowed for estimation of rainfall intensities associated with specific exceedance probabilities over various durations.

Procedure Followed:

Data Collection and Organization; Historical rainfall records, particularly peak rainfall values, were gathered and categorized by year and time intervals to prepare for analysis.

Selection of a Distribution Type; Different statistical distributions such as Gumbel, Fréchet, and Weibull were fitted to the data to determine which best represented the observed values. After comparison, the Gumbel distribution was selected due to its better fit based on statistical evaluation.

Estimating distribution parameters; Parameters of the chosen distribution were calculated using statistical techniques like the method of moments and maximum likelihood estimation, based on the historical rainfall dataset.

Return period; The return period representing the average time between events of a certain magnitude was derived using the estimated distribution parameters and historical records.

Uncertainty evaluation; Confidence intervals were also calculated to assess the uncertainty linked to the estimated parameters and return periods.

This statistical method provided a reliable way to estimate the likelihood of extreme rainfall events which is essential for designing effective drainage system. The raw data and full process used to produce the IDF curves are documented in Appendix B.

Table 3. 1 Maximum yearly rainfall (2012-2024)

Year	Maximum rainfall (mm)
2012	258.9
2013	198.4
2014	199.5
2015	301.4
2016	345.6
2017	176.6
2018	219.0
2019	293.8
2020	304.1
2021	295.2
2022	250.7
2023	342.0
2024	200.5

Table 3. 2 Calculated Mean and Standard Deviation for Each Return Period (2012-2024)

Construction of IDF (intensity-duration-frequency) curve for different recurrence interval (Gumbel)								
Ep = p(t/24) ^ (1/3)								
	5mins	**10mins**	**15mins**	**30mins**	**60mins**	**120mins**	**720mins**	**1440mins**
	39.20438	49.39442	56.5425	71.23908	89.75562	113.085	205.4891	258.9
	30.04306	37.85188	43.32959	54.59186	68.78144	86.65918	157.4702	198.4
	30.20963	38.06175	43.56983	54.89454	69.16279	87.13965	158.3433	199.5
	45.64001	57.50281	65.82429	82.93341	104.4895	131.6486	239.2213	301.4
	52.33307	65.93554	75.47735	95.0955	119.8128	150.9547	274.3029	345.6
	26.74196	33.69276	38.56858	48.59336	61.2238	77.13716	140.1675	176.6
	33.16245	41.78207	47.82853	60.26017	75.92306	95.65706	173.8204	219
	44.48917	56.05284	64.16449	80.84219	101.8548	128.329	233.1892	293.8
	46.04886	58.01793	66.41395	83.67634	105.4256	132.8279	241.3643	304.1
	44.70117	56.31994	64.47024	81.22741	102.3401	128.9405	234.3004	295.2
	37.96268	47.82998	54.75166	68.98276	86.91284	109.5033	198.9807	250.7
	51.78794	65.24871	74.69113	94.10493	118.5648	149.3823	271.4456	342
	30.36106	38.25253	43.78822	55.1697	69.50947	87.57644	159.137	200.5
Mean	39.43734	49.68794	56.87849	71.6624	90.28897	113.757	206.7101	260.4385
standard deviation	8.721665	10.98861	12.57882	15.84832	19.96763	25.15764	45.71446	57.59661

Table 3. 3 Rainfall depths for each return period.

X_t (mm) = mean + SD*K_t								
			2 years	10 year	25 year	50 year	75year	100year
time(mins)	Mean	STD	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
5mins	39.437	8.7216	39.43734	54.68663	62.98028	69.13298	72.70916	75.24025
10mins	49.687	10.988	49.68794	68.90084	79.35018	87.10209	91.6078	94.79677
15mins	56.878	12.578	56.87849	78.87177	90.83328	99.70701	104.8648	108.5152
30mins	71.662	15.848	71.6624	99.3722	114.4428	125.623	132.1213	136.7206
60mins	90.288	19.967	90.28897	125.2011	144.1888	158.275	166.4624	172.2572
120mins	113.757	25.157	113.757	157.7435	181.6666	199.414	209.7295	217.0304
720mins	206.710	45.714	206.7101	286.639	330.11	362.3593	381.1038	394.3705
1440mins	260.438	57.596	260.4385	361.1425	415.9126	456.5441	480.1607	496.8756

Table 3. 3 Rainfall depths for each return period.

Table 3. 4 Rainfall intensity for each Return Period

	2 year	10 year	25 year	50 year	75year	100year
time(hours)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)
0.083333	458.5021	656.2398	755.7636	829.5961	872.5103	902.8833
0.166667	288.8381	413.405	476.101	522.6125	549.6468	568.7806
0.25	220.4247	315.4871	363.3331	398.828	419.459	434.0609
0.5	138.8589	198.7444	228.8855	251.2459	264.2426	273.4412
1	87.47562	125.2011	144.1888	158.275	166.4624	172.2572
2	55.10619	78.87177	90.83328	99.70701	104.8648	108.5152
12	16.6891	23.88659	27.50917	30.19661	31.75865	32.8642
24	10.51347	15.04761	17.32969	19.02267	20.0067	20.70315

3.2.4 Time of Concentration

To determine the design storm, the time of concentration was computed using Kirpich's formula:

Tc = $\boldsymbol{KL^{0.770}S^{-0.385}}$

Where:

T = Time of concentration (minutes)

K = Conversion factor (0.0195 for SI units, 0.0078 for US units)

L = The longest flow path of runoff (meters)

S = Slope of the drainage channel

Calculations

For Section 1,

Tc = $KL^{0.770}S^{-0.385}$

Tc = $0.0195 \ * \ 330^{0.770} * 0.0196^{-0.385}$

Tc = 7.70 minutes

For Section 2,

Tc = $KL^{0.770}S^{-0.385}$

Tc = $0.0195 * \ 330^{0.770} * 0.0456^{-0.385}$

Tc = 5.17 minutes

For Section 3,

Tc = $KL^{0.770}S^{-0.385}$

Tc = $0.0195 * 173.472^{0.770} * 0.0057^{-0.385}$

Tc = 7.86 minutes

By utilizing Kirpich's equation, these computations provided insight into how quickly runoff moves through the drainage system, aiding in stormwater design and flood management planning.

3.2.5 Runoff Coefficient

For areas with varying land use types, a weighted runoff coefficient is necessary to accurately represent runoff characteristics. In general, the runoff coefficient encapsulates all other influences on surface runoff, excluding rainfall intensity and catchment area.

The weighted runoff coefficient is obtained using the formula:

$$\mathbf{Cw} = \frac{(\boldsymbol{A1C1+A2\ C2+\cdots+AnCn})}{\boldsymbol{A}}$$

Where:

A1, A2, An = Land areas with similar surface characteristics within the catchment area A

C1, C2, Cn = Respective runoff coefficients for each land area.

Weighted Runoff Coefficient Calculation:

$$\mathbf{Cw} = \frac{(\mathbf{0.34 * 0.50 + 0.10 * 0.60 + 0.20 * 0.15})}{\mathbf{0.64}}$$

$$\mathbf{Cw = 0.41}$$

This computed value, 0.41 is an estimate of the fraction of rainfall expected to contribute to runoff within the given catchment.

3.2.6 Estimation of Peak Runoff

Peak runoff refers to the highest discharge rate of stormwater at a given point during a rainfall event. To estimate peak runoff, historical annual rainfall data spanning over a decade was analyzed to determine expected runoff values for the channel. This data was then used to generate Intensity-Duration-Frequency (IDF) curves which help in attaining rainfall intensity for different durations.

The Rational Method was employed to calculate surface runoff. The peak runoff rate was estimated using the formula:

$$\mathbf{Q} = \frac{\mathbf{CIA}}{\mathbf{360}}$$

Where:

Q = Peak discharge (m^3/s)

C = Runoff coefficient

I = Rainfall intensity (mm/hr)

A = Catchment area (hectares)

Peak Runoff Calculations:

Section 1:

$$Q = \frac{(0.41*96*0.34)}{360} = 3.72 \text{ m}^3/\text{s}$$

Section 2:

$$Q = \frac{(0.41*110*0.10)}{360} = 1.25 \text{ m}^3/\text{s}$$

Section 3:

$$Q = \frac{(0.41*95*0.20)}{360} = 2.16\text{m}^3/\text{s}$$

3.3 To sufficiently size the drainage channel through hydraulic calculations

A structured approach was used to estimate the expected flow rate and determine suitable channel dimensions to ensure efficient water conveyance.

The following steps were taken in the estimation:

- Estimation of design flow rate; The anticipated runoff volume and intensities were assessed using the HEC-RAS software while incorporating rainfall data and other parameters derived in objective 2
- Selection of channel slope; An appropriate longitudinal slope was chosen while balancing the need for adequate flow velocity while preventing excessive erosion.
- Basing on availability of space and expected flow, different channel shapes (trapezoidal, rectangular, and circular) were considered. The trapezoidal channel was then selected due to its larger wetted perimeter which enhances water conveyance.
- Using the selected slope and flow rate, key channel parameters such as depth, bottom width, and side slopes were also determined.
- Flow Velocity Assessment; The computed dimensions were verified to ensure that the flow velocity remained within acceptable limits to prevent erosion. This analysis was conducted using the HEC-RAS hydraulic model.
- Consideration of Inflow and Outflow Conditions; The design ensured that the channel could accommodate anticipated flow without causing flooding or structural instability.

Channel Design Using Manning's Equation

The Manning's Equation was used to determine the necessary channel dimensions:

$$Q = \frac{AR^{2/3}S^{1/2}}{nP^{5/3}}$$

Where:

Q = Design discharge (m^3/s)

A = Cross-sectional area of the channel (m^2)

R = Hydraulic radius (m)

S = Channel slope

P = Wetted perimeter (m)

n = Manning's roughness coefficient

Additional Considerations in Channel Design included constraints due to seasonal variations; the channel's performance would be affected by seasonal changes and maintenance conditions over time and spatial restrictions; the channel's top width was constrained to fit within the available right-of-way.

By substituting known values of V, S, Q and n into the Manning's equation, key design parameters such as cross-sectional area (A) and hydraulic radius (R) were determined.

3.3.1 Determination of Flow Depth

To establish an appropriate flow depth, field measurements were conducted which involved inserting a probe into the channel until it reached the channel bed. These measurements provided baseline data, which together with hydraulic analysis, helped in determining the most suitable depth for the drainage system.

3.3.2 Side Slope

Recommended side slopes are shown in the table below.

Table 3. 5 Recommended channel side slope.

Material	Side slope
Rock	Nearly vertical
Muck and pear soils	¼ : 1
Stiff clay and earth with concrete lining	½ 1 to 1:1
Earth with stone lining	1:1
Firm clay or earth for small ditches	1 ½:1
Loose, sandy earth	2:1
Sandy loam or porous clay	3:1

3.3.3 Longitudinal Channel Slope

The longitudinal slope of a drainage channel refers to the vertical gradient between the channel start and end points. This slope determines how water flows along the channel and directly influences its flow velocity and conveyance efficiency.

To calculate this gradient, the elevation difference between the inlet and outlet of the channel is first established. The length of the channel is then used alongside the elevation difference to compute the slope using the formula:

$$\textbf{Channel slope} = \frac{\textbf{Difference in channel elevation}}{\textbf{Length of channel}}$$

NB: It's important to distinguish between the longitudinal slope, which describes the incline along the length of the channel, and the side slope, which pertains to the inclination of the channel's side walls.

3.3.4 Channel Lining Material

The choice of channel lining material is a crucial component in the design of a drainage system because it helps to protect the channel against erosion, minimizes sedimentation, and ensures long-term structural performance of the drainage system. It also supports stable flow conditions especially during periods of high discharge and on steep slopes. Selection of a suitable lining material is influenced by several factors such as flow velocity, gradient of the channel, composition of soil and budgetary constraints

The commonly used materials in channel lining include reinforced concrete, asphalt, riprap (rock armor), vegetative cover, and geotextile materials.

To ensure a systematic and effective selection and design of the channel lining, the following approach was adopted:

- An initial site investigation was performed as in the first objective to understand the channel's characteristics, hydrological characteristics, and ground conditions.
- With these insights, the most appropriate lining material was chosen one that can handle the predicted flow rates, withstand the terrain's slope, and is compatible with the local soil type. Considerations also included cost-efficiency, availability of materials, and environmental impact.
- The design phase involved defining geometric parameters like as slope, alignment, and cross-sectional shape while ensuring that the lining would be effective and durable under operational conditions.
- Installation feasibility and maintenance requirements were taken into account during the implementation planning to ensure sustainability and ease of upkeep over time.

3.3.5 Channel Dimensions

The dimensions of a drainage channel are key component in ensuring its ability to handle the designed flow rates efficiently and without failure. These dimensions are influenced by multiple factors such as the expected peak discharge, sediment load characteristics, and the available physical spce for channel construction.

To achieve an optimal design, calculations were based on the geometry of a trapezoidal channel, which offers a balance between flow efficiency and structural stability, especially for open channel systems. The Manning's equation was used in conjunction with the geometric formulas to determine critical flow parameters.

The following design parameters were calculated;

Bottom width (b)

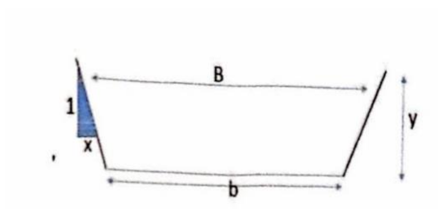
Cross-sectional area (A)

Wetted perimeter (P)

Hydraulic radius (R = A/P)

Top width (T)

Flow velocity (V) using Manning's equation



Area, A

A= $(b + xy) * y$

Wetted perimeter, P

P= b + 2y$\sqrt{(1 + x^2)}$

Hydraulic Radius, R_h

$$R_h = \frac{\text{Area}}{\text{Wetted perimeter}}$$

$$R_h = \frac{A}{P} = \frac{(\text{b} + \text{xy})*\text{y}}{\text{b} + 2\text{y}\sqrt{(1+x^2)}}$$

Top Width, B

B = b + 2xy

Velocity of flow, V

From Q_{peak} = AV

Hence, the flow velocity is determined by

$$V = \frac{\text{Qpeak}}{Area} = \frac{\text{Qpeak}}{(\text{b} + \text{xy})*\text{y}}$$

Froude's number, F_r

$$F_r = \frac{V}{\sqrt{(gD_m)}}$$

$$\text{Where } D_m = \frac{A}{B}$$

Calculations;

Area for each Section.

For Section 1,

A= $(b + xy) * y$

A= $(0.622 + 1 \text{ x } 0.2435) * 0.2435$

A= $(0.622 + 0.2435) * 0.2435$

A = 0.210 m^3

For Section 2,

A= $(0.684 + 1 \text{ x } 0.245) * 0.245$

A= $(0.684 + 0.245) * 0.245$

A = 0.228 m^3

For Section 3,

A= $(b + xy) * y$

A= $(1.255 + 1 \text{ x } 0.269) * 0.269$

A= $(1.255 + 0.269) * 0.269$

A = 0.410 m^3

Wetted perimeter or each Section

For Section 1,

P= b + 2y$\sqrt{(1 + x^2)}$

P= 0.622 + 2 x 0.2435$\sqrt{(1 + 1^2)}$

P = 1.310 m

For Section 2,

P= b + 2y$\sqrt{(1 + x^2)}$

P= 0.684 + 2 x 0.245$\sqrt{(1 + 1^2)}$

P= 1.377 m

For Section 3,

P= b + 2y$\sqrt{(1 + x^2)}$

P= 1.255 + 2 x 0.269$\sqrt{(1 + 1^2)}$

P= 2.016 m

Velocty of flow for each Section.

assuming a Manning's roughness coefficient n= 0.025 for an earthen channel.

For Section 1,

$$V = \frac{R^{2/3} S^{1/2}}{n}$$

$$V = \frac{0.160^{2/3} * 0.0262822^{1/2}}{0.025}$$

V = 1.956 m^3/s

For Section 2,

$$V = \frac{R^{2/3} * S^{1/2}}{n}$$

$$V = \frac{0.165^{2/3} * 0.0262822^{1/2}}{0.025}$$

V = 1.994 m^3/s

For Section 3,

$$V = \frac{R^{2/3} * S^{1/2}}{n}$$

$$V = \frac{0.203^{2/3} * 0.0262822^{1/2}}{0.025}$$

V = 2.242 m^3/s

Froude's number for each Section

For Section 1,

$F_r = \frac{V}{\sqrt{(gD_m)}}$, where g = 9.81 **m³/s**

$F_r = \frac{1.956}{\sqrt{(9.81\ x\ 0.2435)}}$

$\mathbf{F_r = 1.266}$

For Section 2,

$F_r = \frac{V}{\sqrt{(gD_m)}}$

$F_r = \frac{1.994}{\sqrt{(9.81\ x\ 0.245)}}$

$\mathbf{F_r = 1.287}$

For Section 3;

$F_r = \frac{V}{\sqrt{(gD_m)}}$

$F_r = \frac{2.242}{\sqrt{(9.81\ x\ 0.269)}}$

$\mathbf{F_r = 1.379}$

3.3.6 HEC-RAS 1-D Flow Hydraulic Analysis

Hydraulic analysis was carried out using the HEC-RAS software. This tool was selected due to its capability in simulating steady and unsteady flow conditions n open channels and its wide adoption in drainage and river engineering applications.

The software providedd a variety of computational tools that were applied to perform hydraulic analysis of the Naluuma roadside drainage channel. This analysis enabled the assesment of water surface profiles, flow depths, velocities, and energy gradients along the channel that helped to verify that the prposed modified channel dimensions would adequately convey the expected runoff without issues of overtopping or erosion.

3.4 To determine an economic analysis of the modified channel

3.4.1 Bill of Quantities (BOQ)

To assess the economic viability of the proposed upgrade of the Naluuma roadside drainage channel, a Bill of Quantities (BOQ) was prepared. This involved estimating of all construction costs, including materials, labor, and other associated expenses.

Procedure:

- The initial step involved completion of the channel design based on the hydrologic and hydraulic analysis. Factors such as catchment area, topography, soil characteristics, and rainfall intensity were also incorporated. The finalized design was then drafted using AutoCAD that served as the basis for quantity estimation.

- The channel design was then divided into structural components such as the channel lining, bed, side walls, and inlets. For each component, formulas and reference tables were used to calculate the required material quantities including concrete, reinforcement bars, geotextile linings, and excavation volumes.
- Unit prices for materials were obtained through market surveys from local suppliers, manufacturers, and registered contractors. Where available, recent government rates and standard cost references were used to ensure market-aligned costing.
- Labor requirements were estimated based on the scope and complexity of work. This included calculating the number of skilled and unskilled workers required, expected productivity rates, and local wage rates. Industry benchmarks and regional construction norms guided the wage estimation process.
- In addition to material and labor costs, other necessary expenditures were considered, such as; site clearance and preparation, resettlement and compensation costs, contingency allowances, overheads and profit margins
- A comprehensive Bill of Quantities was then compiled. This document listed each work item with its description, quantity, unit of measurement, unit rate, total cost
- The BOQ underwent thorough review to ensure that all cost items were covered. Adjustments were made to account for design revisions, price fluctuations, or

scope changes. The final BOQ proviided a clear picture of the total estimated cost of constructing the proposed drainage channel.

3.4.2 Cost-Benefit Analysis (CBA)

A Cost-Benefit Analysis (CBA) was conducted to assess the economic justification for the proposed upgrade of the Naluuma roadside drainage channel. This analysis measured the economic rate of return by comparing the expected costs, with the quantifiable and qualitative benefits derived from the improved drainage channel.

The primary focus of the analysis was on cost savings and economic gains, which were anticipated to accrue over the lifetime of the drainage system. These benefits include reduced maintenance costs, improved public health, increased land value, and prevention of floodrelated losses.

Identified Economic Benefits: The economic benefits were assessed based on the reduction of community losses and improved living conditions. These benefits were grouped into the following key categories:

Reduction in Property Damage: By minimizing flood risks, the drainage system reduces the frequency and severity of water damage to residential and commercial structures.

Savings in Health and Medical Costs: Standing water and poor drainage are associated with vector-borne diseases. Improved drainage reduces the incidence of such health issues, resulting in lower treatment costs for residents.

Decrease in Road Rehabilitation and Maintenance Costs: Flooding contributes significantly to the degradation of road infrastructure. The proposed channel improves water management, reducing road damage and the need for frequent repairs.

Increased Land and Property Value:

Residential Areas: Previously flood-prone zones become suitable for habitation and expansion, raising the real estate value.

Commercial Areas: Improved access and reduced inventory risk enhance business opportunities and rental value.

Economic Evaluation Method:

To calculate the present value of expected future benefits, the Present Value (PV) formula was used:

$$\text{PV} = \frac{(1+r)^n - 1}{r\,(1+r)}$$

Where:

PV = Present Value of future benefits

FV = Future Value (estimated benefit in a given year)

r = Discount rate

n = Number of years the benefit is expected to be realized

By applying this formula, each benefit was discounted back to its present worth, allowing for a comprehensive comparison against the project's initial and ongoing costs.

3.4.3 Quantification of Economic Benefit – Property Value Increase

To evaluate the economic benefit of the proposed drainage improvement project, an analysis was conducted to estimate the annual increase in land property value within the affected flood-prone area. The improved drainage is expected to lead to enhanced land usability and attractiveness, thereby raising land values.

$Estimated\ flood-affected\ area$ = (150 × 805) = 120,750 $m2$

But 1 $m2$ = 10.764 $ft2$

$Estimated\ area$ = (120,750 × 10.764) = 1,299,753 $ft2$

$Area\ of\ Plot$ = (100 × 50) = 5,000 $ft2$

$No.\ of\ plots\ affected = \frac{1,299,753}{5000}$

= 259.95 ~260 $plots$ ($considering\ public\ land$)

$Annual\ increase\ in\ property\ value$ = 923,000 × 260 = UGX 240,000,000

b) Improved Sanitation and Public Health

Flooding often results in the accumulation of stagnant water, which serves as a breeding ground for mosquitoes and contributes to the spread of diseases such as malaria and cholera. These conditions place both economic and health burdens on the affected population. The construction of a functional drainage channel is expected to:

- Significantly reduce mosquito breeding grounds
- Lower healthcare costs related to flood-induced diseases

Quantifying the Benefit

- Data Collection: About 160 cases of malaria and cholera annually. A reduction of 30% in such illnesses is assumed with the construction of the new drain. This translates to 112 annual cases.
- Medical Cost Estimation: Consultation with local health officials estimates a UGX 30,000 cost for treatment.

Annual savings from improved public health

$Saving\ cases$ = (160 − 112) = 48 $cases$

$Savings$ = (30,000 × 48) = UGX 1,440,000

c) Enhanced Pedestrian and Road User Safety

Flooding along Naluuma Road not only disrupts transportation but also increases the risk of accidents for pedestrians and motorists. Poor drainage results in slippery surfaces, obscured potholes, and reduced visibility, all contributing to unsafe conditions. The improved drainage channel is expected to:

- Reduce the number of pedestrian-related accidents
- Lower the cost of accident-related treatments
- Improve overall mobility and safety

Quantifying the Benefit

15% reduction in road maintenance costs due to damage.

$Savings$ = (135,356,000 - 23,886,000) = UGX 159,242,000.

d) Enhanced Road Durability

Flooding along roads can lead to water stagnation that seeps into and beneath the pavement layers, gradually weakening the subgrade and surface. This contributes to:

- Formation of potholes, cracks, and surface degradation
- Increased maintenance frequency and costs
- Shortened road lifespan

The construction of the improved drainage channel is expected to:

- Mitigate water pooling on and near the road surface
- Reduce long-term damage to the pavement
- Lower overall maintenance costs

Quantifying the Benefit

15% reduction in road maintenance costs due to damage.

$Savings$ = (135,356,000 - 23,886,000) = UGX 159,242,000.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.0 Introduction

This chapter presents the findings from the investigation into the drainage capacity of the Naluuma roadside drainage system and its impact on flooding in Naluuma, Nabweru-Nansana, Uganda.

A combination of site visits, catchment studies, and topographic surveys were conducted. These assessments confirmed that the existing roadside channel is undersized and unable to handle stormwater runoff during periods of heavy rainfall. As a result, frequent flooding occurs along Naluuma Road.

The following sections of this chapter provide a detailed discussion of the findings, analyze their implications, and highlight the proposed improvements in drainage sizing aimed at mitigating the flooding issue.

4.1 To Determine the Existing Conditions of the Road Drainage Channel

4.1.1 Site Visits

A detailed reconnaissance of the study area was conducted with the assistance of a local guide appointed by the LC1 chairperson. Observations from the site visit revealed that the drainage issues within the catchment area primarily stem from the current inadequate condition of the drainage system, blockage of channels due to accumulation of solid waste (rubbish), encroachment and construction within the floodplain, high rainfall intensity overwhelming the drainage capacity, lack of regular maintenance of the existing drainage system

The investigation highlighted that the existing channels are mostly unlined and appear to be undesigned, with only a few lined sections near residential perimeter walls. These conditions increase the likelihood of erosion, sedimentation, and flow inefficiencies all of which contribute to flooding and public safety concerns.

Visual documentation of the site, including maps and photographs of key drainage sections, support these observations and provide a clearer picture of the drainage challenges currently faced in the area.

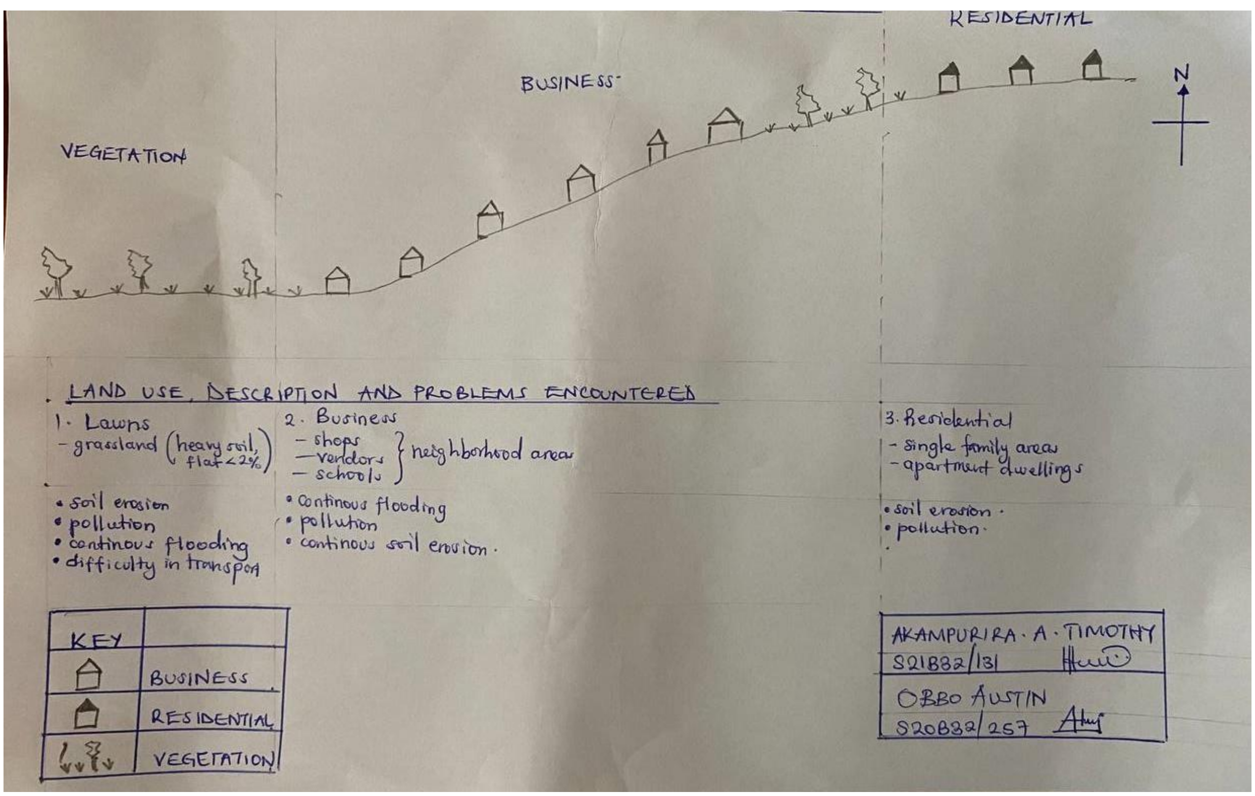


Figure 4. 1 A transect map of Naluuma (catchment)

Figure 4. 2 Visual representation of existing situation

The areas adjacent to the roadside drainage channel are comprised of a mixture of residential units, business establishments, and lawns, all of which significantly contribute to surface runoff and, in some instances, sewage discharge into the drainage system.

Further observations revealed the presence of makeshift crossings over the drainage channel, a clear indication of inadequate infrastructure planning. These informal structures impede the natural flow of water and may contribute to blockages, especially during periods of heavy rain.

There was extensive evidence of poor solid waste disposal, with debris and garbage being dumped into the channel. This improper waste management practice leads to clogging at culvert crossings, thereby reducing the conveyance capacity of the drainage system and heightening the risk of flooding.

In several low-lying sections, the channel exhibited significant silt deposition. This accumulation of sediment reduces the effective cross-sectional area available for water flow, which consequently diminishes the hydraulic efficiency of the drainage.

Some sections of the channel showed signs of vegetative overgrowth acting as a natural lining. While vegetation can offer some erosion control, in this case, it contributed obstruction of water flow, leading to stagnation. Stagnant water poses serious public health risks, serving as a breeding ground for mosquitoes and increasing the potential for malaria and other vector-borne diseases.

4.1.2 Surveying

A topographic survey was conducted along the roadside drainage channel using an RTK machine. The survey data included coordinates such as Northings, Eastings, and Elevations collected at various chainage points, which allowed for the development of an accurate channel profile.

From the surveyed data, key channel parameters like channel depth, bed width, and slopes were extracted.

The analysis of the topographic data revealed that the longitudinal slope of the section of the roadside channel is approximately 0.0262822 (2.63%). While this slope suggests a certain degree of gradient for flow, it still indicates that the area is relatively low-lying, especially when considered in context with siltation and poor drainage management observed during site visits.

This low slope also increases the likelihood of ponding or stagnant water, particularly during intense rainfall events, and further highlights the need for channel redesign and proper lining to enhance flow efficiency and reduce flood risks.

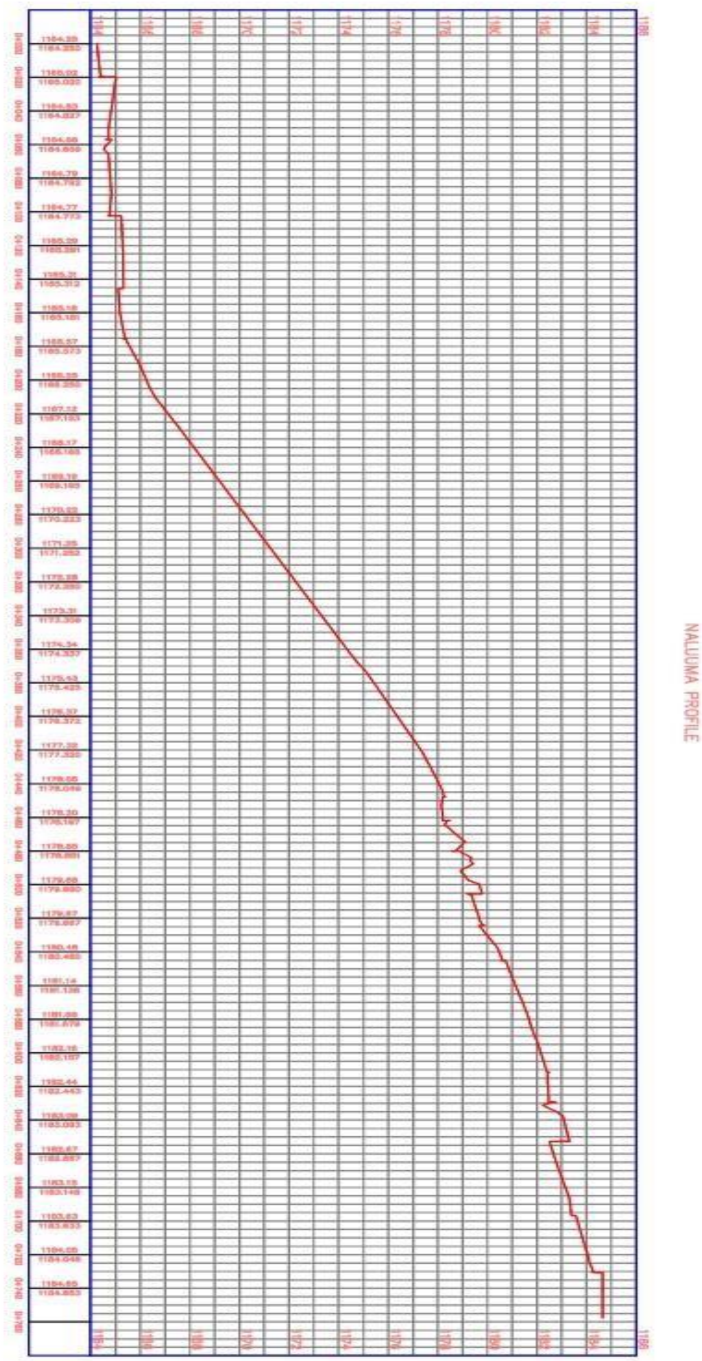


Figure 4. 3 Alignment profile of Naluuma (Catchment)

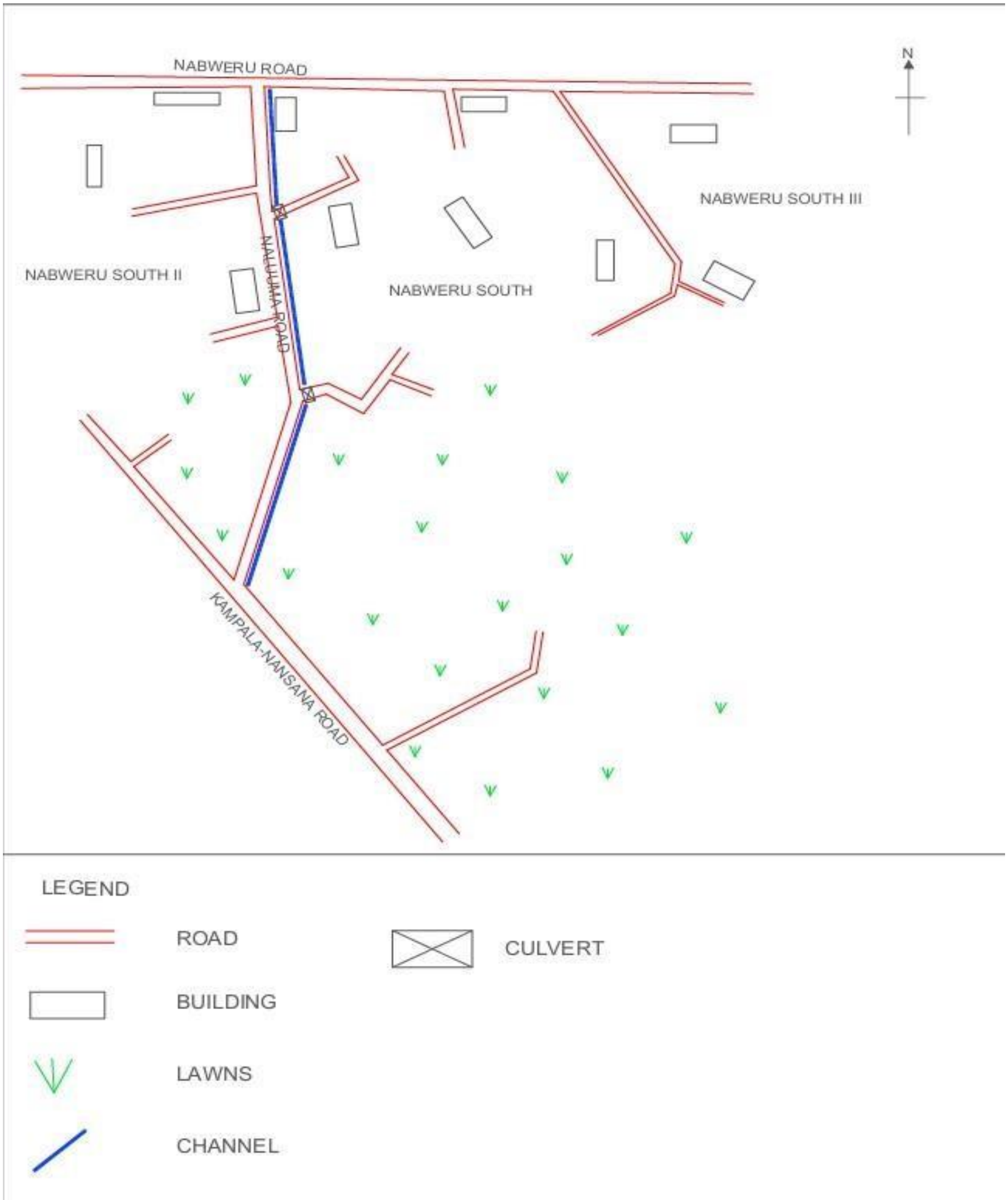


Figure 4. 4 Topographic map of Naluuma(Source: Civil3D)

4.1.3 Channel Measurements

Channel measurements to establish the cross-sectional dimensions, width, length, change in height were carried out and slope was obtained by the GNSS RTK equipment.

Table 4. 1 Channel measurements (Source; RTK machine)

Length of the channel = 803.4722m
Inlet elevation (0 + 000) = 1185.313m
Outlet elevation (0 +810) = 1164.196m
Change in height = 21.117m
Slope, S = 0.0262822

Section	Top width (m)	Bottom width (m)	Height (m)
1	1.109	0.622	0.244
2	1.174	0.684	0.245
3	1.793	1.255	0.269

4.2 To Conduct a Hydrological and Hydraulic Analysis of the Catchment

4.2.1 Catchment Studies

4.2.1.1 Catchment Area

The catchment area contributing surface runoff to the drainage outlet along Naluuma Road was determined through topographic analysis and field verification. The delineated watershed covers an estimated area of 0.64 km^2, which lies well within the threshold for applying the Rational Method as outlined in the Ministry of Works and Transport (MoWT) Drainage Design Manual (2010).

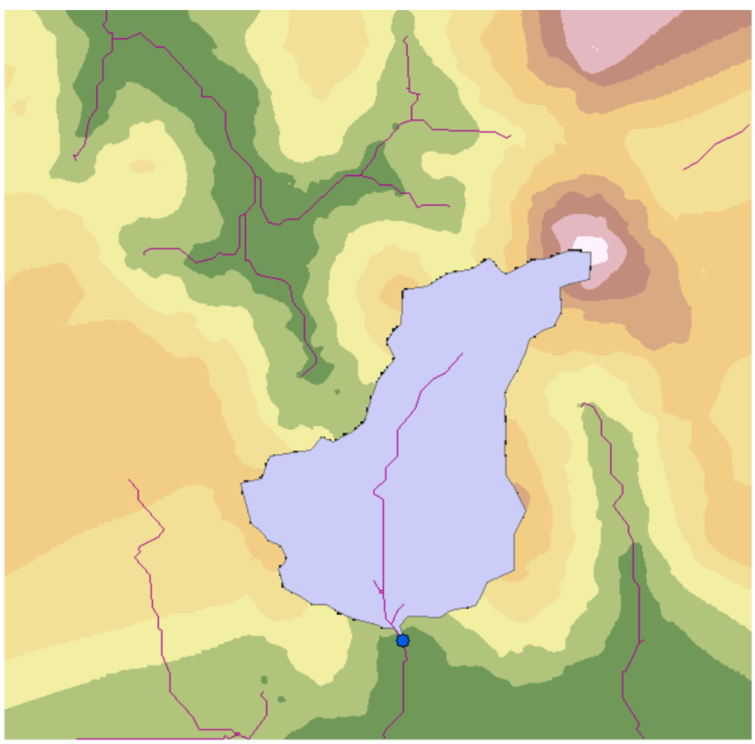


Figure 4. 5 Delineation of the watershed (Source: ArcGIS software)

4.2.1.2 Land-Use Land-Cover (LULC)

The land use types in Naluuma, Nansana-Nabweru south II were classified into three major group which significantly impact the hydrological processes;

Table 4. 2 The distribution of the land use types

LAND USE	AREA (Km^2)	PERCENTAGE
Residential areas	0.34	53.13%
Business	0.10	15.63%
Vegetation	0.20	31.24%

4.2.2 Design storm

The maximum monthly data for 13 years (2012-2024) used was acquired from Uganda National Meteorological Authority UNMA offices in Luzira.

4.2.3 Generation of IDF Curves

The Gumbel Type 1 Extreme Value (EV) distribution method generated intensity duration frequency curve for the catchment as shown below.

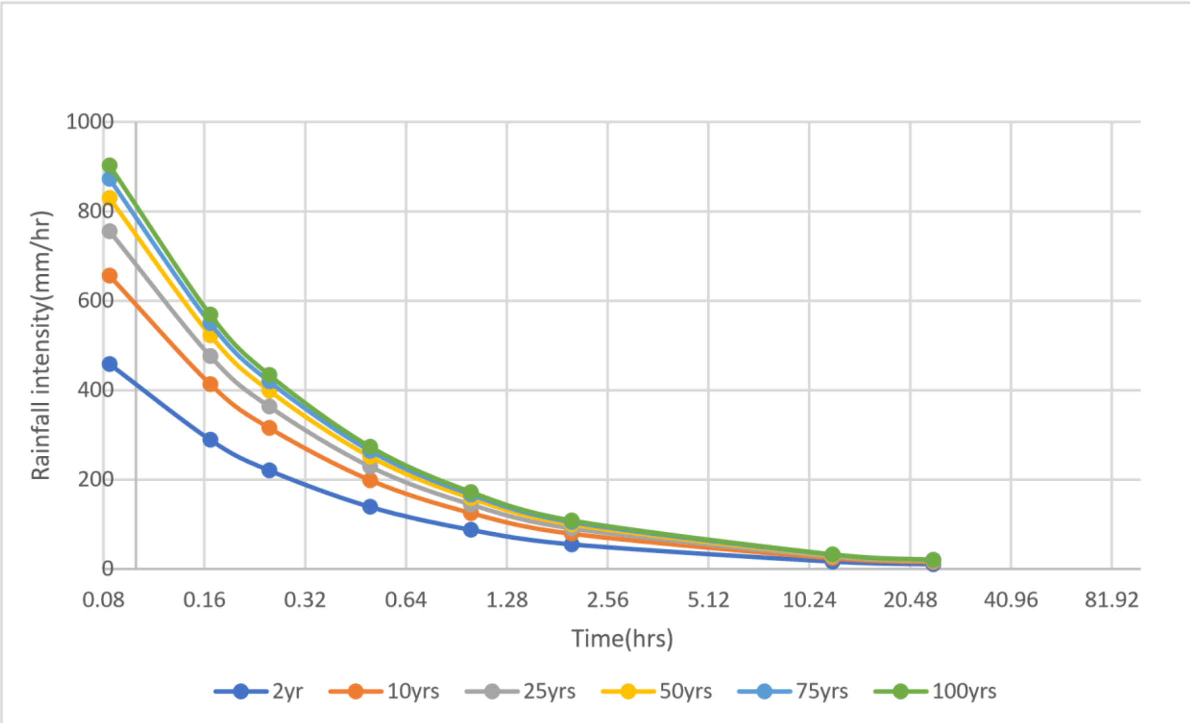


Figure 4. 6 IDF Curves for Nansana Nabweru

From the above curves, the longer rainfall events have lower intensities, while shorter events have high intensity rainfall. The findings agree with those done by Chen et al., (2017) that state as the duration of a rainfall event increases, the intensity of the rainfall decreases which is often coupled with a decrease in infiltration rate.

4.2.4 Time of concentration

Table 4. 3 Time of concentration for each section

Section	Maximum length (m)	Outlet elevation point, Ho (m)	Inlet elevation point, Hi (m)	Difference in elevation H = Ho - Hi (m)	Slope H/L	Time of Concentration (mins)
1	330	1185.313	1178.85	6.64	0.0196	7.70
2	300	1178.85	1165.18	13.67	0.0456	5.17
3	173.472	1165.18	1164.19	0.99	0.0057	7.86

Section 1 exhibits a high time of concentration due to its gentle slope. This area is predominantly composed of residential settlements, which contribute a high pollutant load carried by the surface runoff. The gentle slope causes slower movement of runoff, hence the longer Tc.

Section 2 has the lowest time of concentration among all Sections. This is attributed to the steeper gradient, as observed from the channel profile in the first objective. The steeper incline promotes faster runoff movement, reducing the Tc significantly.

Section 3 records has highest time of concentration. This Section is relatively flat, and its location within a dense mix of commercial and residential activities leads to an increase in impervious surfaces and pollutant loads. These characteristics slow down the movement of runoff and result in a longer Tc.

The variation in time of concentration across the Sections highlights the diversity of flow characteristics within the catchment. The overall analysis indicates that the catchment contributes substantial runoff, increasing the risk of flooding during heavy rainfall events.

Table 4. 4 Rainfall intensity for a 25-year period

Section	**Time of concentration**	**Rainfall intensity (mm/hr)**
1	7.70	96
2	5.17	110
3	7.86	95

From the data presented above, the rainfall intensities were obtained directly from the IDF curves for a 25-year return period, in line with the guidelines provided in the Ministry of Works and Transport Drainage Design Manual (2010). The intensities correspond to the respective time of concentration values for each Section.

From Section 1 to Section 2, there is an increase in rainfall intensity (from 96 mm/hr to 110 mm/hr). This suggests that as the channel progresses, particularly through residential zones with more structured drainage, the velocity of runoff increases due to steeper slopes and less infiltration.

From Section 2 to Section 3, the rainfall intensity slightly decreases (from 110 mm/hr to 95 mm/hr), but this does not necessarily mean improved drainage. In fact, Section 3, which includes a mix of business premises and dense settlements, has a flat slope and high pollutant load, contributing to slower runoff movement and a higher likelihood of flooding and water stagnation.

These observations highlight Section 3 as a critical section prone to drainage challenges, where water stagnation and recurrent flooding are expected during heavy rainfall events. The hydrologic response in this Section reflects a need for targeted design interventions to improve flow conveyance and reduce flood risks.

4.2.4 The coefficient of discharge

Table 4. 5 Existing land use conditions with Rational Coefficients

LAND USE	AREA (Km^2)	PERCENTAGE	RUNOFF COEFFICIENT (C)
Residential	0.34	53.13%	0.50
Business	0.10	15.63%	0.60
Vegetation	0.20	31.24%	0.15
TOTAL	0.64	100%	Cw = 0.41

The runoff coefficients used in the hydrological analysis were derived from Table **4.7-(a)** of the Ministry of Works and Transport **(**MoWT**)** Drainage Design Manual **(**2010**)**. These coefficients, specific to various land use types and surface conditions, were utilized to compute the weighted runoff coefficient **(Cw)** for the entire catchment area.

The computed **Cw =** 0.41, as detailed in Chapter **3**, indicates that approximately 41% of rainfall in the area is converted into surface runoff. This relatively high runoff **coefficient** underscores the urbanized nature of the catchment, which includes impervious surfaces such as rooftops, roads, and compacted ground surfaces, all of which limit infiltration and accelerate surface water movement.

The catchment's shape and size also contribute to the magnitude of runoff, affecting both the **volume** and **velocity** of water entering the drainage channel. The elongated and developed nature of the catchment leads to a quicker and higher peak discharge, particularly during intense storm events.

Based on these parameters, the peak flow rate can now be calculated using the Rational Method.

4.2.5 Determination of peak runoff

Table 4. 6 Peak Discharges for the Sections.

Section	**Discharge, Q (m^3/s)**
1	3.72
2	1.25
3	2.16

Section 1 records the highest peak discharge. Despite its gentle slope, this Section features extensive impervious surfaces such as pavements and rooftops, which reduce infiltration and promote surface runoff. The mild gradient allows runoff to accumulate over time, increasing the total discharge volume.

Section 2, situated on a steeper incline, exhibits a lower peak discharge. The steepness causes rapid runoff, which limits the time for water to accumulate, thereby reducing the peak flow. This Section acts as a conduit, quickly channeling water downstream.

Section 3, characterized by a flat slope, receives runoff from the upstream Sections. While one might expect the peak discharge here to be highest due to accumulation, the excessive vegetative cover, occasional ponding, and localized infiltration reduce the velocity of flow, moderating the peak discharge values.

These variations highlight the influence of topography, land cover, and infrastructure on runoff behavior. The flatter, low-lying areas act as collection points, while the steeper areas function as efficient conveyors of stormwater. Such analysis is critical for designing targeted drainage improvements that account for spatial variability within the catchment.

4.2.6 HEC-RAS 1-D Hydraulic Analysis of the Naluuma road side drainage.

The existing road side channel had the following channel dimensions as shown in the **Table** below;

Table 4. 7 Existing channel Froude's number.

Section	Bottom width (m)	Top width (m)	Depth (m)	Area	Wetted Perimeter	Velocity of flow	Froude's number
1	0.622	1.109	0.244	0.210	1.310	1.956	1.266
2	0.684	1.174	0.245	0.228	1.377	1.994	1.287
3	1.255	1.793	0.269	0.410	2.016	2.242	1.379

A 1-D steady flow simulation of the Naluuma roadside drainage channel revealed a supercritical flow regime, as indicated by a Froude number ($Fr > 1$) throughout the channel. This suggests that the flow velocity exceeds the wave celerity, and the flow depth is less than the critical depth, a typical condition for channels with comparatively steep slopes.

The upstream, midstream, and downstream cross sections, derived from the Civil 3D survey data, are presented below along with their respective water surface elevations. These cross-sections provide a clear picture of the flow profile, identifying points of potential constriction, ponding, or flow acceleration.

4.2.3 Upstream Flow Conditions and Design Interventions

The water surface level at the upstream section was recorded at approximately 0.9 meters above the channel bed, aligning well with field observations during peak flow periods. This correlation reinforces the accuracy of the hydraulic simulation and confirms the severity of potential flooding at downstream locations.

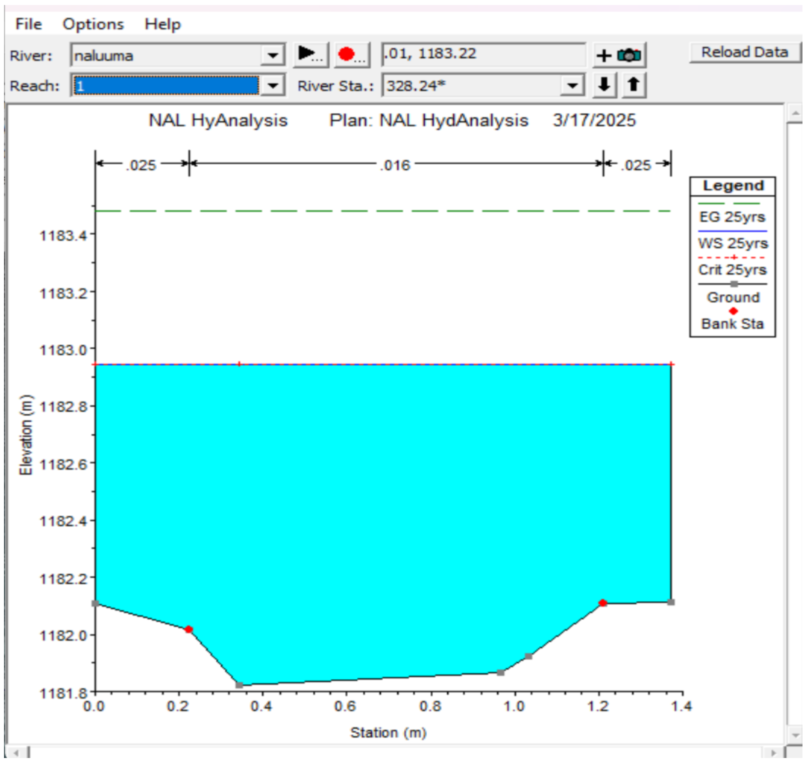


Figure 4. 7 Upstream water surface level of the existing channel (Source: HEC-RAS Software)

Mid-Stream Flow Conditions

In the mid-stream stretch of the Naluuma roadside drainage, the water surface level was found to be approximately 0.8 meters above the channel bed, consistent with field observations recorded during storm events. This section of the drainage channel passes through mixed-use zones comprising both business and residential communities.

The waterway in this Section is characterized by an irregular cross-section, which significantly limits the hydraulic efficiency of the system. The uneven geometry reduces the effective flow area, causing flow constriction and potential backwater effects. Combined with high runoff generation from surrounding impervious surfaces, this results in inadequate transport capacity, making the area especially vulnerable to localized flooding and water stagnation during high-intensity rainfall.

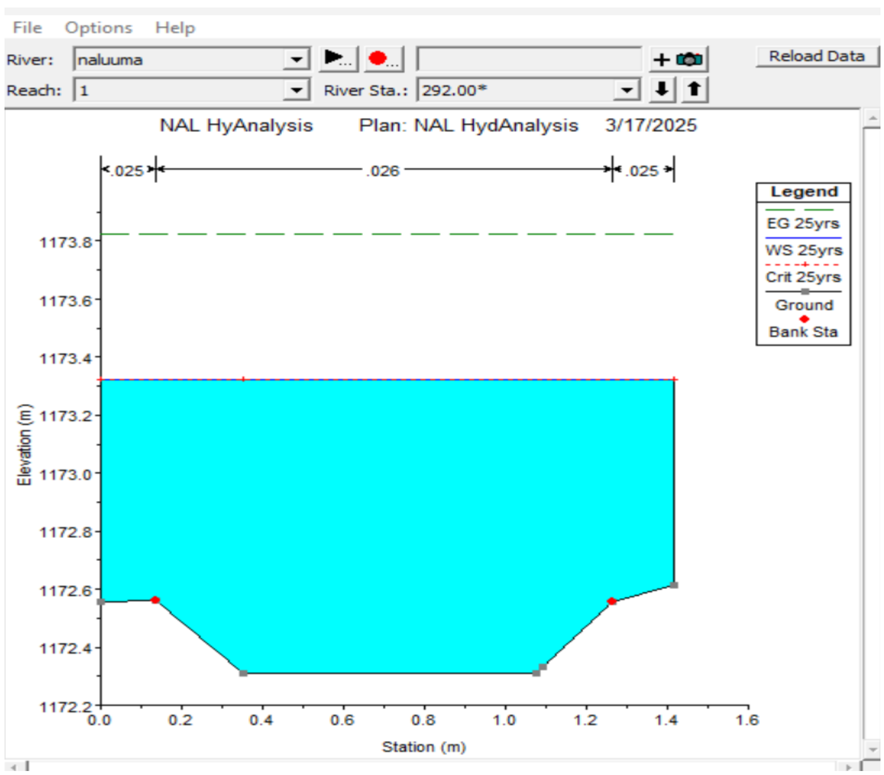


Figure 4. 8 Mid-stream water surface level of the existing channel (Source: HEC-RAS Software)

Downstream Flow Conditions

In the downstream section of the Naluuma roadside drainage, the water surface level is approximately 0.5 meters above the channel bed, which correlates well with the data observed during field inspections. This area is situated adjacent to a vegetative lawn, located at the outlet of the road drainage system.

The presence of vegetative cover at the outlet contributes to slight resistance to flow, potentially promoting localized ponding during peak discharge. However, the relatively lower water surface elevation in this section suggests that flow energy has dissipated downstream, supporting the transition from supercritical to subcritical flow conditions. The outlet vegetation may also provide some natural filtration benefits but requires maintenance to prevent excessive obstruction of flow.

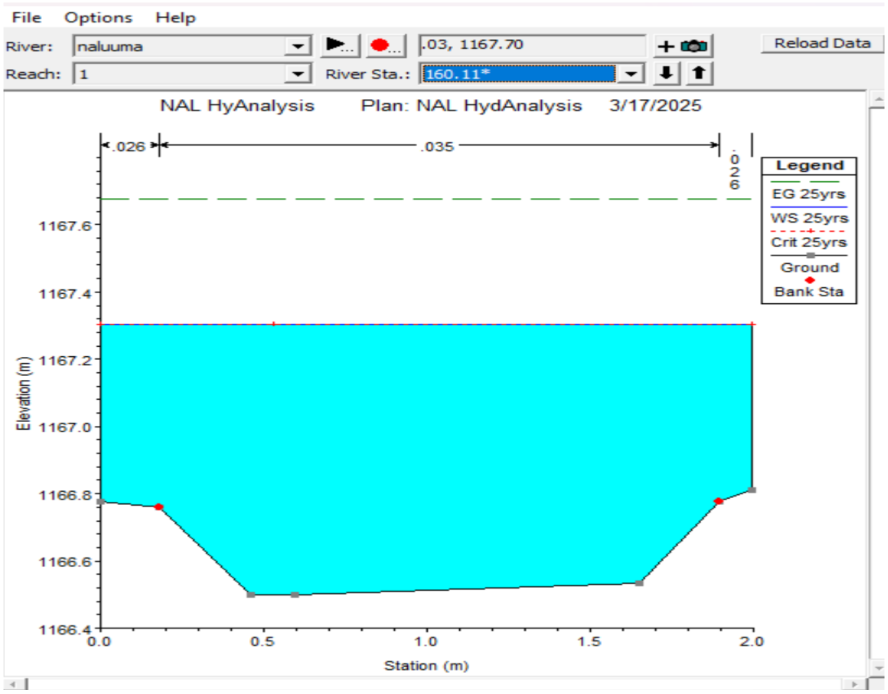


Figure 4. 9 Downstream water surface level of the existing channel (Source: HEC-RAS Software)

4.3 To Sufficiently Size the Drainage Channel

4.3.1 Modified Channel Design

Due to the identified shortcomings of the current Naluuma roadside drainage, modifications to the channel geometry were implemented, as illustrated in the figure below. These changes aim to improve conveyance, minimize flooding, and facilitate routine maintenance.

4.3.2 Depth of Flow

To ensure adequate drainage capacity and ease of maintenance, the design flow depths for the modified channel were set as follows:

- Section 1: 1.0 m
- Section 2: 1.0 m
- Section 3: 0.9 m

These dimensions offer sufficient storage volume, accommodate expected peak flows, and allow for simple cleaning access.

4.3.3 Side Slope

A 1:1 side slope was selected based on V.T. Chow's recommendations (1956) for earth channels with concrete lining. This slope ensures structural stability and reduces the risk of erosion.

4.3.4 Channel Slope

The existing slope of 0.0262822 (2.63%) was retained for the modified design, as it supports supercritical flow conditions and facilitates self-cleansing velocity during peak runoff.

4.3.5 Channel Lining Material

The modified channel will be lined with concrete, as recommended for channels with steep side slopes (1:1 or greater). According to standard guidelines, a Manning's roughness coefficient (n) of 0.015 was adopted for hydraulic computations.

4.4 HEC-RAS 1-D Flow Hydraulic Analysis of the Modified Channel

The HEC-RAS 1-D steady flow simulation for the 25-year return period showed that the water surface levels in Section 1 remained within the channel boundaries, indicating that the modified geometry effectively contains peak discharges.

A comparison of flow profiles between the existing and modified channels demonstrates enhanced hydraulic performance in the redesigned channel, particularly in mitigating overflow and improving flow conveyance.

Upstream section

During the 25-year return period, the water surface levels in the modified Section 1 remained within the channel boundaries, indicating that the revised geometry successfully accommodates design flows without overtopping.

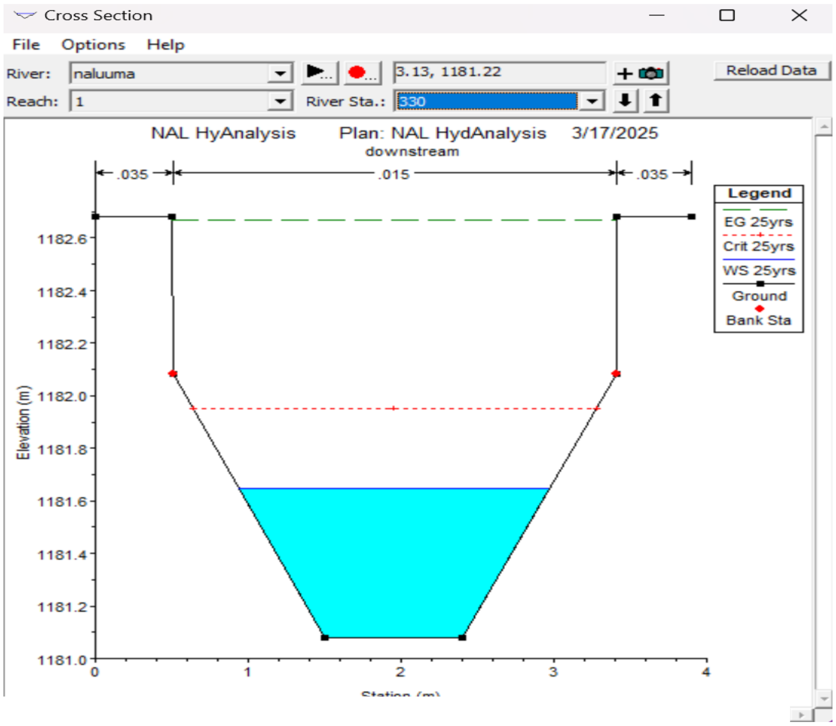


Figure 4. 10 Up-stream section of the modified channel (Source HEC-RAS Software

Midstream section

During the 25-year return period, the water surface levels in the modified Section 2 remained within the channel boundaries, indicating that the revised geometry successfully accommodates design flows without overtopping.

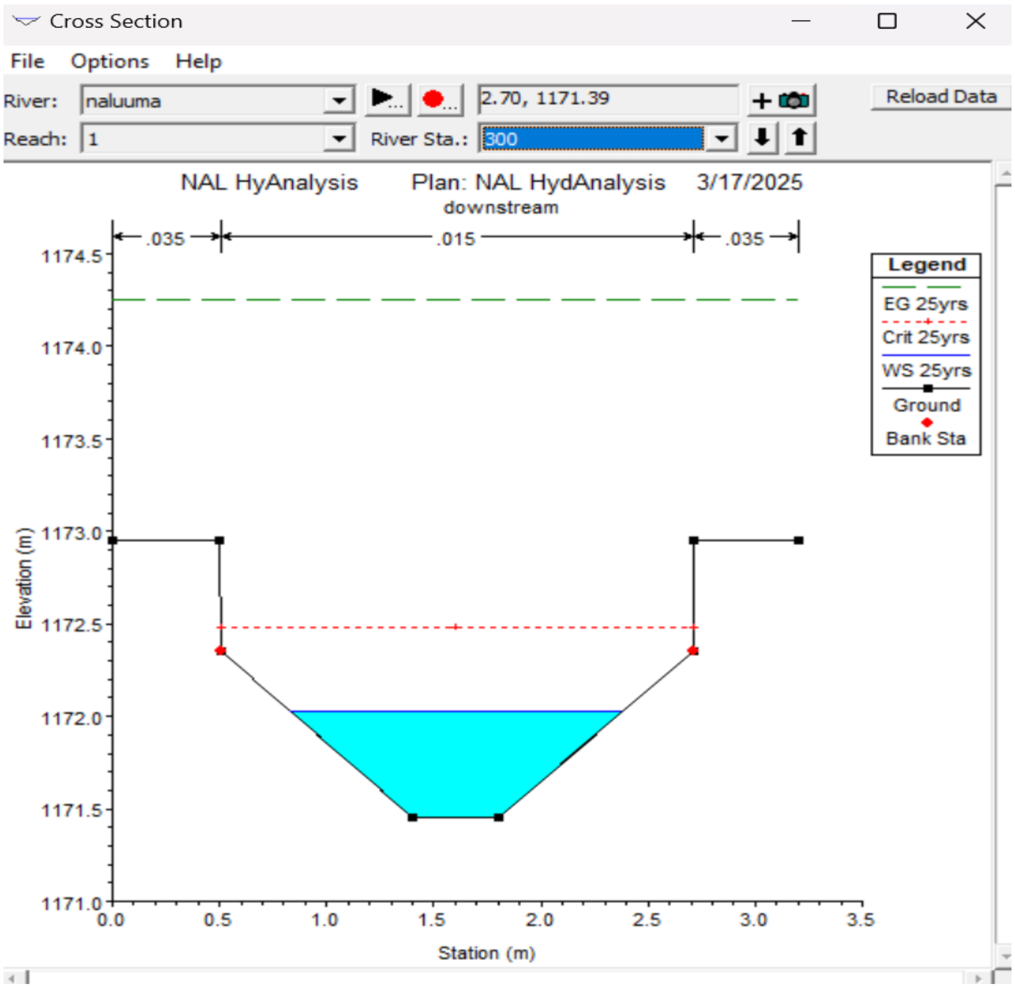


Figure 4. 11 Mid-stream section of the modified channel (Source HEC-RAS Software)

Downstream section

During the 25-year return period, the water surface levels in Section 3 of the modified channel remained within the channel boundaries, confirming the adequacy of the redesign in handling peak discharge without causing flooding.

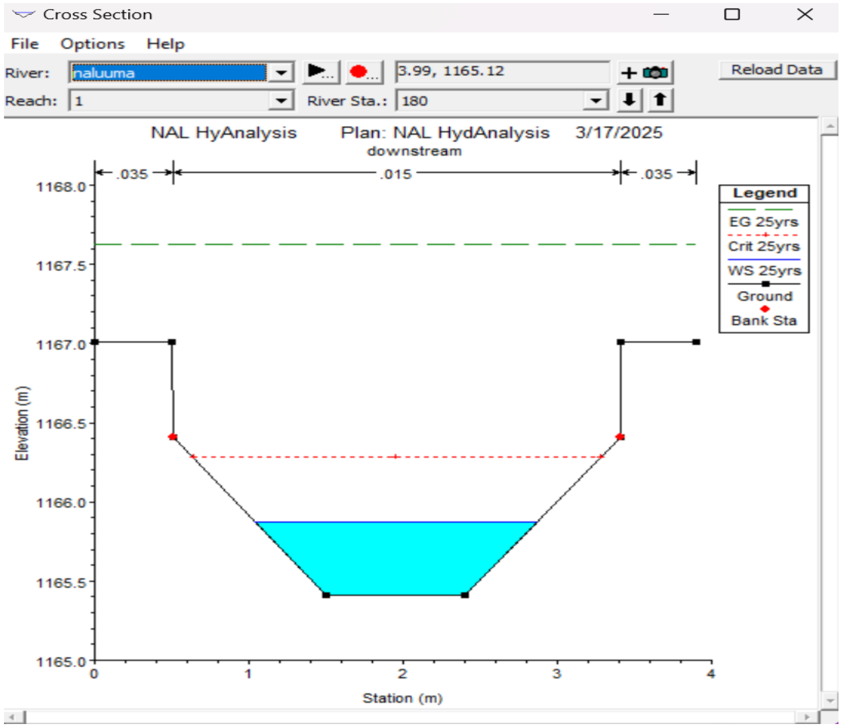


Figure 4. 12 Downstream section of the modified channel (Source HEC-RAS Software)

During the 25-year return period, the water surface levels across all three Sections of the modified channel remained within the channel boundaries for the simulated flow, indicating successful hydraulic performance. The flow regime in the redesigned channels was found to be supercritical (Froude number, Fr > 1), as determined by the hydraulic analysis.

While subcritical or near-critical flows are typically preferred in drainage design due to their stability and predictability, supercritical flow offers several advantages, especially in constrained urban environments. It supports higher flow velocities, which reduces the risk of overflow and flooding. Additionally, supercritical flow allows for narrower channel widths for the same discharge rate, which can result in significant savings in land use and construction costs.

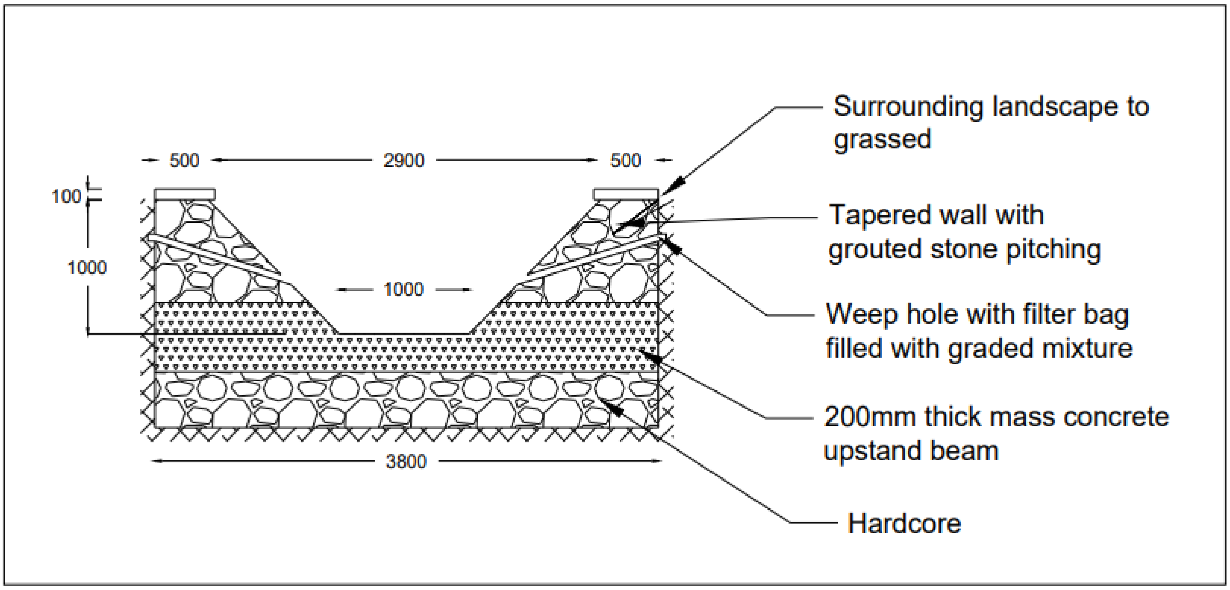
HEC-RAS Plan: 1 River: naluuma Reach: 1 Profile: 25yrs

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
1	330	25yrs	3.72	1181.08	1181.65	1181.95	1182.67	0.019610	4.48	0.83	2.03	2.24
1	328.24*	25yrs	3.72	1181.82	1182.95	1182.95	1183.48	0.003426	3.34	1.38	1.37	1.04
1	326.47*	25yrs	3.72	1181.25	1181.99	1182.37	1183.28	0.015050	5.19	0.85	1.37	2.02
1	324.71*	25yrs	3.72	1180.68	1181.36	1181.79	1182.90	0.023063	5.67	0.77	1.37	2.31
1	322.94*	25yrs	3.72	1180.11	1180.76	1181.22	1182.42	0.025872	5.86	0.74	1.37	2.44
1	321.18*	25yrs	3.72	1179.54	1180.18	1180.64	1181.87	0.030338	5.93	0.72	1.37	2.49
1	319.41*	25yrs	3.72	1178.97	1179.62	1180.06	1181.25	0.032194	5.82	0.73	1.37	2.43
1	317.65*	25yrs	3.72	1178.40	1179.06	1179.48	1180.62	0.030210	5.71	0.75	1.37	2.36
1	315.88*	25yrs	3.72	1177.83	1178.49	1178.92	1180.00	0.031864	5.61	0.76	1.37	2.31
1	314.12*	25yrs	3.72	1177.26	1177.93	1178.35	1179.39	0.030041	5.50	0.77	1.37	2.24
1	312.35*	25yrs	3.72	1176.70	1177.37	1177.77	1178.77	0.031545	5.40	0.78	1.37	2.19
1	310.59*	25yrs	3.72	1176.13	1176.81	1177.20	1178.16	0.029821	5.31	0.79	1.37	2.14
1	308.82*	25yrs	3.72	1175.56	1176.24	1176.63	1177.55	0.031391	5.22	0.80	1.37	2.10
1	307.06*	25yrs	3.72	1174.99	1175.68	1176.05	1176.92	0.031281	5.07	0.82	1.37	2.01
1	305.29*	25yrs	3.72	1174.42	1175.12	1175.47	1176.32	0.029594	4.97	0.84	1.37	1.96
1	303.53*	25yrs	3.72	1173.85	1174.56	1174.90	1175.72	0.031214	4.91	0.85	1.37	1.93
1	301.76*	25yrs	3.72	1173.28	1174.00	1174.33	1175.12	0.029400	4.81	0.86	1.37	1.87
1	300	25yrs	1.25	1171.45	1171.72	1172.07	1174.22	0.133176	7.00	0.18	0.93	5.12
1	292.00*	25yrs	1.25	1172.31	1172.84	1172.84	1173.07	0.011009	2.18	0.62	1.41	1.01
1	284.00*	25yrs	1.25	1171.91	1172.32	1172.43	1172.72	0.027552	2.86	0.46	1.46	1.52
1	276.00*	25yrs	1.25	1171.51	1171.97	1172.02	1172.25	0.017263	2.40	0.55	1.50	1.19
1	268.00*	25yrs	1.25	1171.11	1171.54	1171.61	1171.85	0.022801	2.53	0.52	1.54	1.31
1	260.00*	25yrs	1.25	1170.72	1171.16	1171.21	1171.43	0.018793	2.36	0.56	1.58	1.20
1	252.00*	25yrs	1.25	1170.32	1170.74	1170.80	1171.02	0.021873	2.40	0.55	1.62	1.25
1	244.00*	25yrs	1.25	1169.92	1170.35	1170.39	1170.60	0.019392	2.24	0.58	1.66	1.15
1	236.00*	25yrs	1.25	1169.52	1169.94	1169.99	1170.20	0.021092	2.28	0.57	1.70	1.19
1	228.00*	25yrs	1.25	1169.12	1169.55	1169.58	1169.78	0.019819	2.17	0.60	1.74	1.12
1	220.00*	25yrs	1.25	1168.72	1169.14	1169.18	1169.37	0.021045	2.15	0.60	1.79	1.12
1	212.00*	25yrs	1.25	1168.32	1168.75	1168.77	1168.96	0.019556	2.08	0.62	1.83	1.09
1	204.00*	25yrs	1.25	1167.93	1168.34	1168.37	1168.56	0.021369	2.08	0.62	1.87	1.10
1	196.00*	25yrs	1.25	1167.53	1167.95	1167.97	1168.15	0.019142	1.96	0.66	1.91	1.02
1	188.00*	25yrs	1.25	1167.13	1167.54	1167.56	1167.74	0.021093	2.01	0.64	1.95	1.06
1	180	25yrs	2.16	1165.41	1165.76	1166.06	1167.02	0.039454	4.98	0.43	1.60	3.05
1	160.11*	25yrs	2.16	1166.50	1167.08	1167.08	1167.34	0.017875	2.30	0.98	1.99	1.02
1	140.22*	25yrs	2.16	1166.27	1166.85	1166.85	1167.11	0.017203	2.28	0.99	1.99	1.00
1	120.33*	25yrs	2.16	1166.03	1166.62	1166.62	1166.88	0.017086	2.28	1.00	1.99	1.00
1	100.44*	25yrs	2.16	1165.80	1166.39	1166.39	1166.65	0.016965	2.27	1.00	1.99	1.00
1	80.56*	25yrs	2.16	1165.57	1166.16	1166.16	1166.41	0.016789	2.27	1.00	1.99	1.00
1	60.67*	25yrs	2.16	1165.34	1165.92	1165.92	1166.18	0.016849	2.27	1.00	1.99	1.00
1	40.78*	25yrs	2.16	1165.11	1165.68	1165.68	1165.94	0.016973	2.27	1.00	1.99	1.00
1	20.89*	25yrs	2.16	1164.87	1165.44	1165.44	1165.70	0.017289	2.27	0.99	1.99	1.00
1	1	25yrs	2.16	1164.64	1165.20	1165.20	1165.46	0.017530	2.27	0.99	1.99	1.00

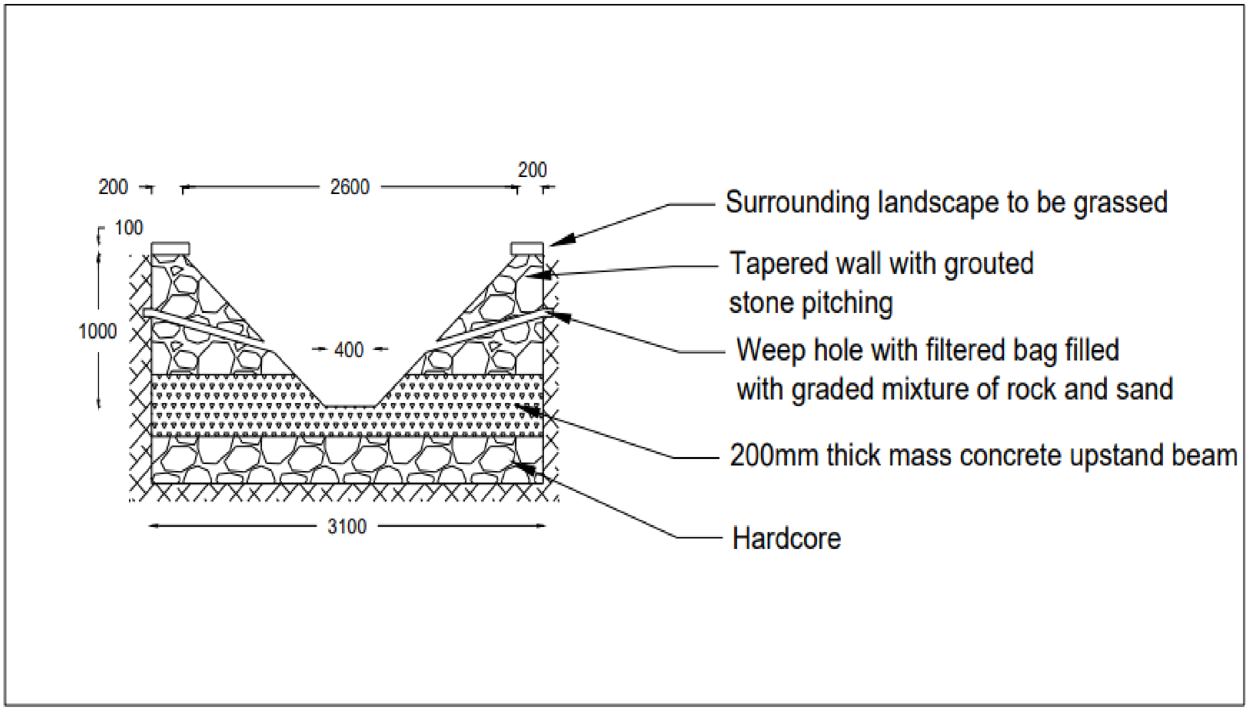
Figure 4. 13 Profile output of hydraulic analysis of modified channel (Source: HECRAS Software)

4.4.1 Design engineering drawings of the Modified channel for the various Sections.

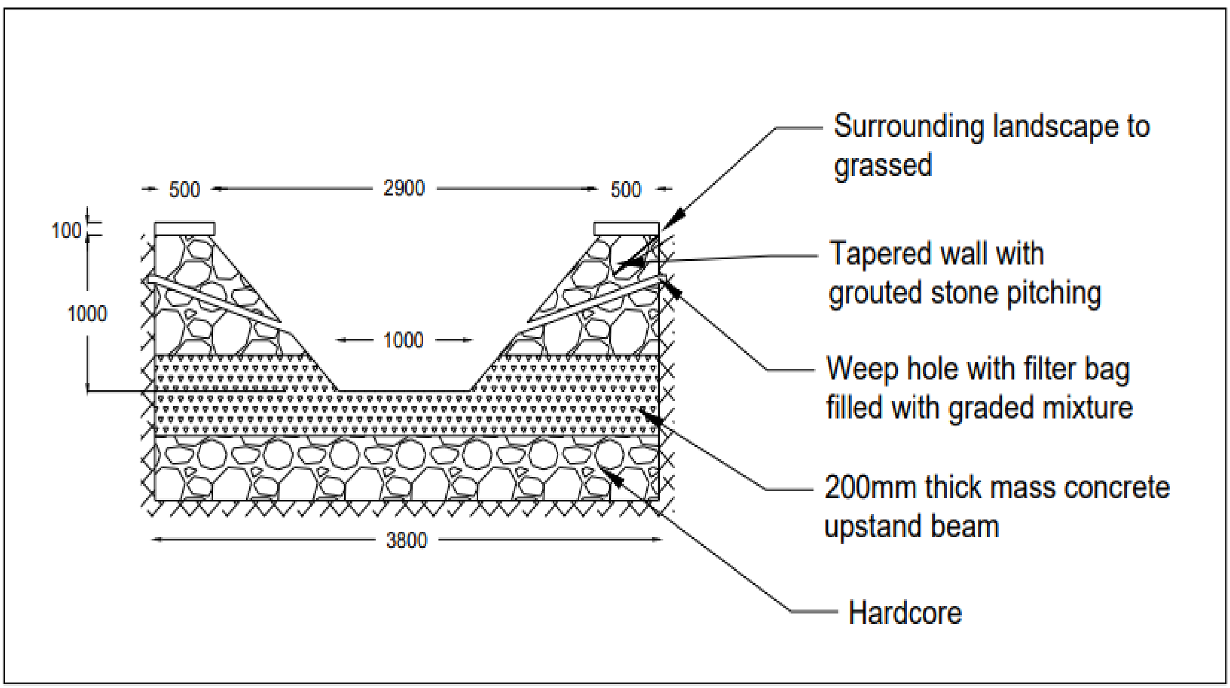
FOR SEGEMENT 1



SECTION 1



SECTION 2



SECTION 3

4.5 To Provide a Suitable Cost Estimate with a Bill of Quantities (BOQ)

4.5.1 Economic Analysis for the Improved Drainage System

The economic evaluation conducted for the proposed improvements to the Naluuma Road side drainage system estimated the total construction cost at UGX 1,376,914,000. Based on the quantified social, environmental, and infrastructural benefits, the project achieved a Cost-Benefit Ratio (CBR) of 1.1.

This ratio indicates that the anticipated benefits outweigh the projected costs, confirming that the proposed drainage upgrades represent a viable and economically sound investment. The results support implementation, as the improvements will lead to long-term gains in public health, road durability, flood reduction, and pedestrian safety.

4.5.2 Bill of Quantities (BOQ)

Table 4. 8 Bill of Quantities of the improved channel.

Item	Description	Unit Cost	Quantity	Total Price (Ugx)
Earthworks	Clearing	1000/m^2	805	805,000
	Excavation and Disposal	30,000 UGX/m^2	590	17,700,000
Base Layer	Hardcore stones	90,000 UGX/m^3	1207	108,630,000
Preparation of subgrade and blinding	Excavation and blinding of 1:3:6 mix	250,000UGX/m^3	40.5	10,125,000
Weep hole pipes	150m of pipes with a	60,000UGX for each pipe of 6m	41	2,460,000

	diameter of 50mm			
Side walls	Reinforced concrete of C25 of mix ratio 1:2:4	800,000UGX/m^3	574	459,200,000
Drainage Channel Lining	Reinforced concrete lining (30cm thick)	800,000UGX/m^3	810.4	648,320,000
Labour	Unskilled Labour	10,000 UGX/day	200	2,000,000
	Skilled Labour	25,000 UGX/day	100	2,500,000
Contingency (10% of Total cost)				125,174,000
TOTAL				1,376,914,000

4.5.3 Cost Benefit Analysis

Table 4. 9 Cost Benefit Analysis of the improved channel

Benefit Category	Description of the method applied	Rate Estimates	Annual Benefit	Present Value (Discount Rate 10%)
An improvement in the value of land	The reduction in flooding results in a rise in property value	The value of lands increased by 2% as a result of less flooding. Per plot, the average cost is	240,000,000 UGX	1,121,810,000 UGX

		100,000,000 UGX		
Improved Sanitation and Public Health	Reduced illness rate	A reduction in flood related illnesses by 20%, Average cost/ illness = 30,000 UGX	1,440,000	1,309,000 UGX
Enhanced Pedestrian Safety	Reduced accidents along the road	10% reduction in pedestrian accidents and average cost estimate = 50,000 UGX	2,500,000	2,272,000 UGX
Enhanced road durability	Reduced risk of potholes, cracks and other forms of road damage	15% reduction in road maintenance costs due to damage.	159,242,000	1,447,650,000 UGX
TOTAL				**2,573,041,000 UGX**

Item	**Amount (UGX)**
Construction cost	1,376,914,000
Total Benefits	2,573,041,000
Benefit cost ratio (BCR)	1.867
(B-C)	1,196,127,000 UGX

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In the southern division of Nansana–Nabweru, the 805-meter Naluuma roadside drainage stretch in Nabweru Cell 2 is prone to flooding due to heavy siltation, irregularly lined sections, and inconsistent cross-sectional dimensions. These deficiencies have significantly reduced the channel's capacity to convey stormwater, thereby making its rehabilitation both necessary and urgent.

A GNSS RTK system was employed for the topographic survey, yielding a channel slope of 0.0262833 (2.63%). Using ArcGIS, a Digital Elevation Model (DEM) of the area was generated, and catchment delineation revealed a contributing watershed area of 0.64 km^2, consisting of 31.24% vegetation, 15.63% business zones, and 53.13% residential areas.

This composition contributes to significant surface runoff, exacerbated by insufficient drainage capacity, especially during heavy rainfall.

From Table 4.7-(a) of the MoWT Design Manual (2010), the weighted runoff coefficient (Cw) was determined to be 0.41, indicating that a substantial portion of rainfall converts to surface runoff.

Using 13 years of daily rainfall data, IDF curves were developed, yielding critical rainfall intensities of 96 mm/hr (Section 1, Tc = 7.70 min), 110 mm/hr (Section 2, Tc = 5.17 min), and 95 mm/hr (Section 3, Tc = 7.76 min) for a 25-year return period design storm. The corresponding peak discharges, calculated using the Rational Method, were 3.72 m^3/s (Section 1), 1.25 m^3/s (Section 2), 2.16 m^3/s (Section 3).

Hydraulic analysis, conducted using HEC-RAS 1-D Flow Simulation, revealed that the existing channel overtops during peak flow events by 0.5 m at the downstream section, 0.8 m at midstream, and 0.9 m at upstream. To address this, the channel was redesigned as a concrete-lined trapezoidal section with side slopes of 1:1 (per V.T. Chow, 1956), Manning's roughness coefficient, n = 0.015, and construction in C-25 reinforced concrete.

Additionally, scour checks at 20-meter intervals are proposed to mitigate flow velocities and reduce erosion risks.

The estimated rehabilitation cost is UGX 1.37 billion, while quantified benefits amount to UGX 1.19 billion, yielding a Benefit-Cost Ratio (BCR) of 1.1. This confirms the project's economic viability and supports the implementation of the proposed drainage improvements.

5.2 Recommendations

Recommendations to Nansana Municipality

Promote Rainwater Harvesting; The municipality should actively encourage residents to adopt rainwater harvesting systems for household use. This initiative would help reduce the volume of surface runoff generated during rainfall events, thereby decreasing the risk of overloading the drainage system and contributing to flood mitigation efforts.

Improve Solid Waste Management; To address the issue of improper solid waste disposal into the drainage channel, the municipality should establish strategically located solid waste collection points. These points must be routinely and promptly emptied to ensure the uninterrupted and efficient flow of runoff within the drainage system, thereby enhancing the overall performance of the infrastructure.

Recommendations for Further Investigation Sediment Transport Analysis

A detailed sediment transport study should be conducted to evaluate the rate of sediment deposition within the Naluuma roadside drainage system and assess the impacts of erosion on its conveyance capacity. This investigation would help identify critical deposition zones, predict erosion-prone areas, and determine the maintenance frequency and strategies required to enhance hydraulic performance and sustain long-term functionality of the drainage infrastructure.

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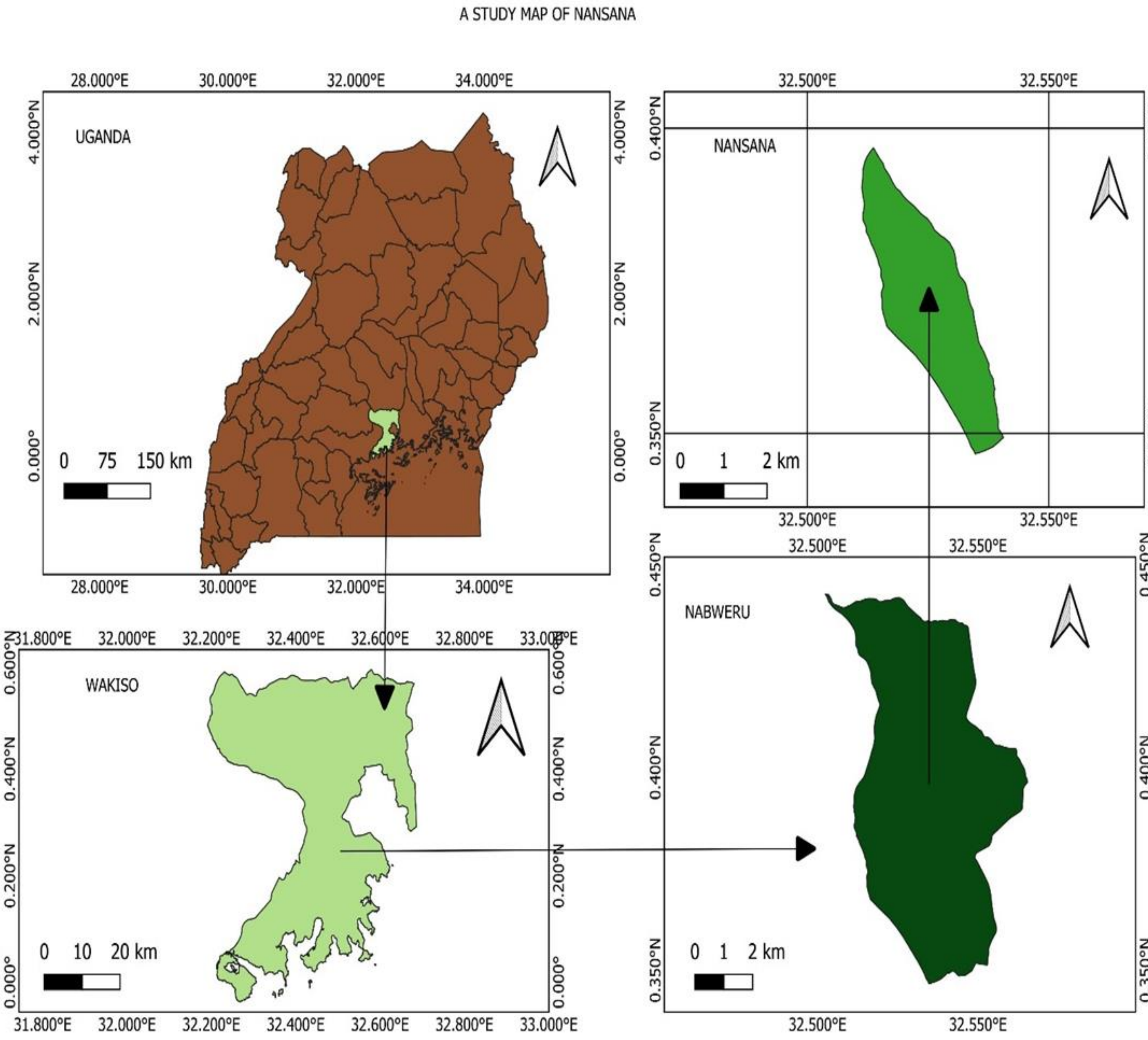
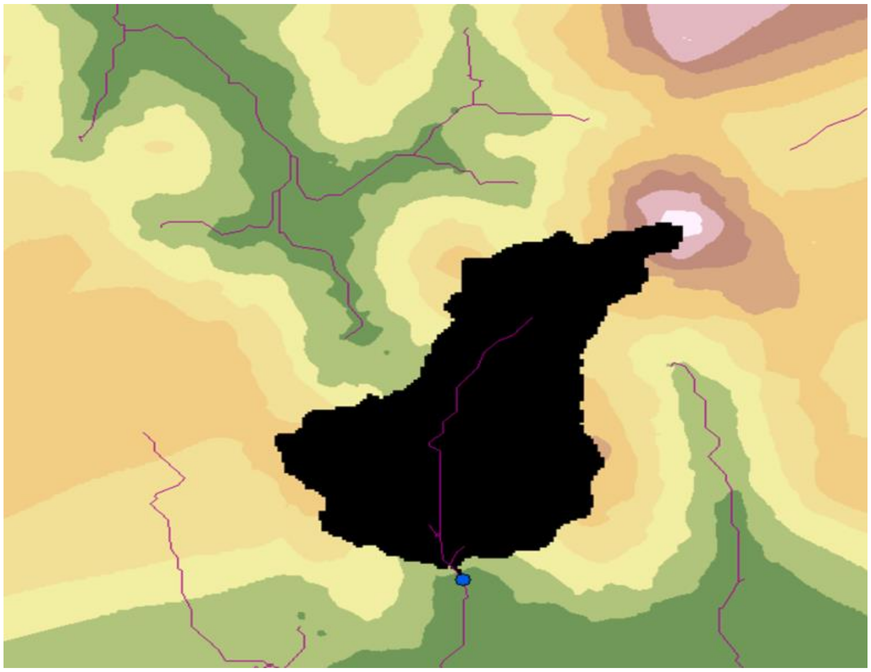
APPENDICES

APPENDIX A: CATCHMENT AREA MAPS FROM THE DEM



Study maps (Source: QGIS software)



DEM of Naluuma Nabweru southward, Nansana (Source: ArcGIS)

APPENDIX B: RAINFALL TABULATIONS.

Yearly maximum rainfall.

Year	Maximum rainfall (mm)
2012	258.9
2013	198.4
2014	199.5
2015	301.4
2016	345.6
2017	176.6
2018	219.0
2019	293.8
2020	304.1
2021	295.2
2022	250.7
2023	342.0
2024	200.5

Raw data for the monthly rainfall for Nansana

Monthly Rainfall(mm) for Nansana												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2012	4.8	40.2	106.0	209.8	202.4	74.6	0.5	42.6	65.5	79.0	177.9	258.9
2013	70.1	90.3	182.6	188.7	198.4	16.7	121.4	112.9	117.2	85.7	103.0	106.5
2014	0.0	0.5	176.8	160.2	136.6	158.0	52.2	133.0	199.5	138.5	82.6	34.2
2015	1.8	61.8	118.0	144.8	202.3	101.8	24.0	92.4	115.7	301.4	262.8	110.8
2016	98.6	36.6	56.4	345.6	153.2	76.3	23.7	43.4	162.8	112.7	120.4	17.0
2017	44.3	90.2	146.5	172.9	105.8	64.9	94.4	114.2	173.7	95.2	176.6	55.0
2018	44.2	76.4	143.5	219.0	39.0	110.1	65.1	108.9	31.6	121.8	203.6	174.9
2019	94.8	76.0	90.1	159.9	181.3	170.7	25.4	83.9	173.6	293.8	175.7	232.2
2020	92.7	131.2	304.1	169.0	203.4	40.7	87.7	139.8	127.5	177.6	284.5	137.2
2021	105.0	48.8	147.8	191.9	295.2	40.1	56.2	210.2	117.7	105.6	177.3	97.1
2022	20.7	170.6	143.9	105.4	83.1	27.7	58.0	82.4	222.9	250.7	203.6	181.1
2023	10.0	94.9	293.7	211.2	76.0	142.1	48.9	143.7	190.3	342.0	251.0	126.3
2024	83.0	105.0	127.2	200.5	82.2	78.4	72.6	110.9	91.3	132.2	161.0	127.7

Calculated Mean and Standard Deviation for Each Return Period (2012-2024)

Construction of IDF (intensity-duration-frequency) curve for different recurrence interval (Gumbel)								
Ep = p(t/24) ^ (1/3)								
	5mins	**10mins**	**15mins**	**30mins**	**60mins**	**120mins**	**720mins**	**1440mins**
	39.20438	49.39442	56.5425	71.23908	89.75562	113.085	205.4891	258.9
	30.04306	37.85188	43.32959	54.59186	68.78144	86.65918	157.4702	198.4
	30.20963	38.06175	43.56983	54.89454	69.16279	87.13965	158.3433	199.5
	45.64001	57.50281	65.82429	82.93341	104.4895	131.6486	239.2213	301.4
	52.33307	65.93554	75.47735	95.0955	119.8128	150.9547	274.3029	345.6
	26.74196	33.69276	38.56858	48.59336	61.2238	77.13716	140.1675	176.6
	33.16245	41.78207	47.82853	60.26017	75.92306	95.65706	173.8204	219
	44.48917	56.05284	64.16449	80.84219	101.8548	128.329	233.1892	293.8
	46.04886	58.01793	66.41395	83.67634	105.4256	132.8279	241.3643	304.1
	44.70117	56.31994	64.47024	81.22741	102.3401	128.9405	234.3004	295.2
	37.96268	47.82998	54.75166	68.98276	86.91284	109.5033	198.9807	250.7
	51.78794	65.24871	74.69113	94.10493	118.5648	149.3823	271.4456	342
	30.36106	38.25253	43.78822	55.1697	69.50947	87.57644	159.137	200.5
Mean	39.43734	49.68794	56.87849	71.6624	90.28897	113.757	206.7101	260.4385
standard deviation	8.721665	10.98861	12.57882	15.84832	19.96763	25.15764	45.71446	57.59661

Calculating the Frequency Factor for Each Return Period.

P = m/(n+1)	Return Period	KT= (YT-YN)/SN	YT=-LN(LN(t/t-1))	QT
0.076923	2	-0.1409	0.366513	252.3233
0.142857	10	1.748438	2.250367	361.1425
0.214286	25	2.699362	3.198534	415.9126
0.285714	50	3.404813	3.901939	456.5441
0.357143	75	3.814847	4.310784	480.1607
0.428571	100	4.105054	4.600149	496.8756

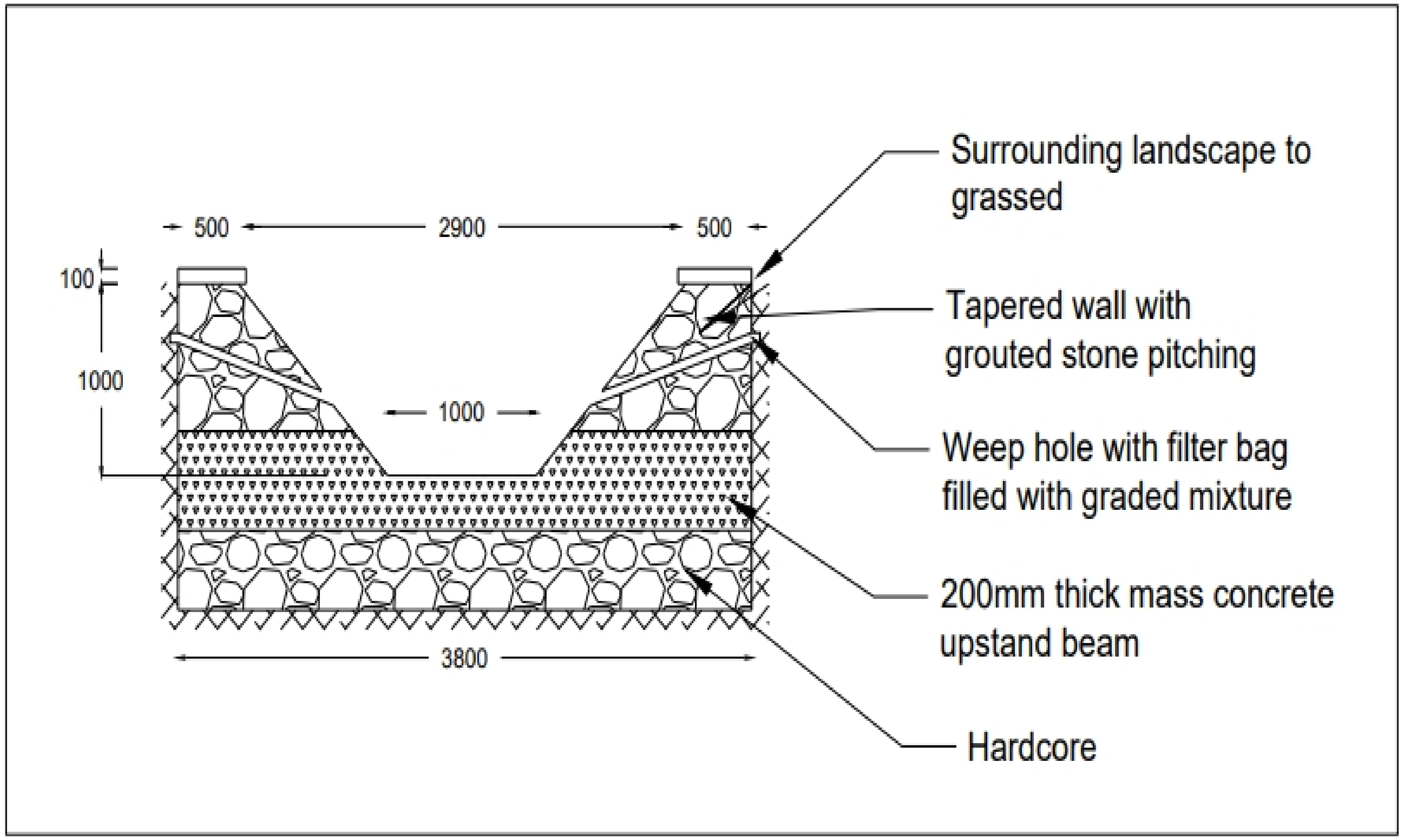
The Rainfall Depth for each Return Period.

X_t (mm) = mean + SD*K_t								
			2 years	10 year	25 year	50 year	75year	100year
time(mins)	Mean	STD	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
5mins	39.437	8.7216	39.43734	54.68663	62.98028	69.13298	72.70916	75.24025
10mins	49.687	10.988	49.68794	68.90084	79.35018	87.10209	91.6078	94.79677
15mins	56.878	12.578	56.87849	78.87177	90.83328	99.70701	104.8648	108.5152
30mins	71.662	15.848	71.6624	99.3722	114.4428	125.623	132.1213	136.7206
60mins	90.288	19.967	90.28897	125.2011	144.1888	158.275	166.4624	172.2572
120mins	113.757	25.157	113.757	157.7435	181.6666	199.414	209.7295	217.0304
720mins	206.710	45.714	206.7101	286.639	330.11	362.3593	381.1038	394.3705
1440mins	260.438	57.596	260.4385	361.1425	415.9126	456.5441	480.1607	496.8756

Rainfall intensity for each Return Period.

Rainfall intensity (mm/hr) = rainfall depth / time in hours						
	2 year	10 year	25 year	50 year	75year	100year
time(hours)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)
0.083333	458.5021	656.2398	755.7636	829.5961	872.5103	902.8833
0.166667	288.8381	413.405	476.101	522.6125	549.6468	568.7806
0.25	220.4247	315.4871	363.3331	398.828	419.459	434.0609
0.5	138.8589	198.7444	228.8855	251.2459	264.2426	273.4412
1	87.47562	125.2011	144.1888	158.275	166.4624	172.2572
2	55.10619	78.87177	90.83328	99.70701	104.8648	108.5152
12	16.6891	23.88659	27.50917	30.19661	31.75865	32.8642
24	10.51347	15.04761	17.32969	19.02267	20.0067	20.70315

APPENDIX C: ENGINNERING DESIGN DRAWINGS.



SECTION 1

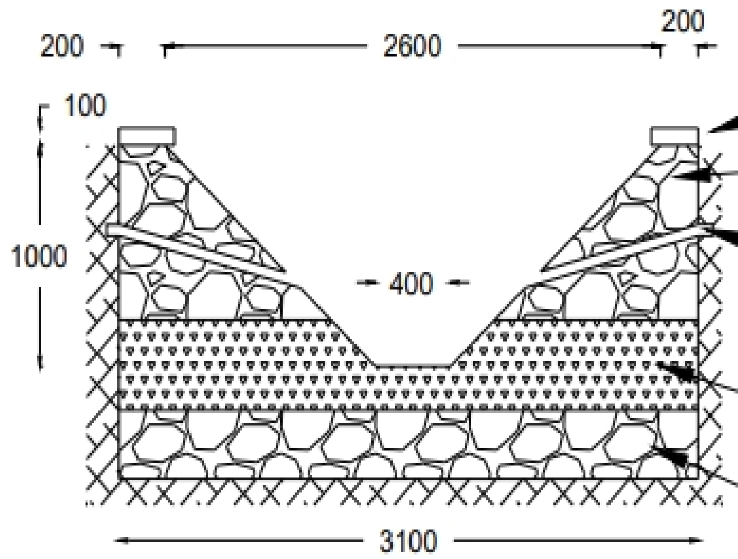
BSCEE 4
FINAL YEAR RESEARCH AND DESIGN PROJECT

PROJECT TITLE:
IMPROVING THE HYDRAULIC CONVEYANCE OF NALUUMA ROAD DRAINAGE

DRAWING TITLE:
PROPOSED DESIGN FOR THE DRAINAGE CHANNEL

SCALE: 1:100

BY:
TIMOTHY. A. AKAMPURIRA
AUSTIN OBBO



SECTION 2

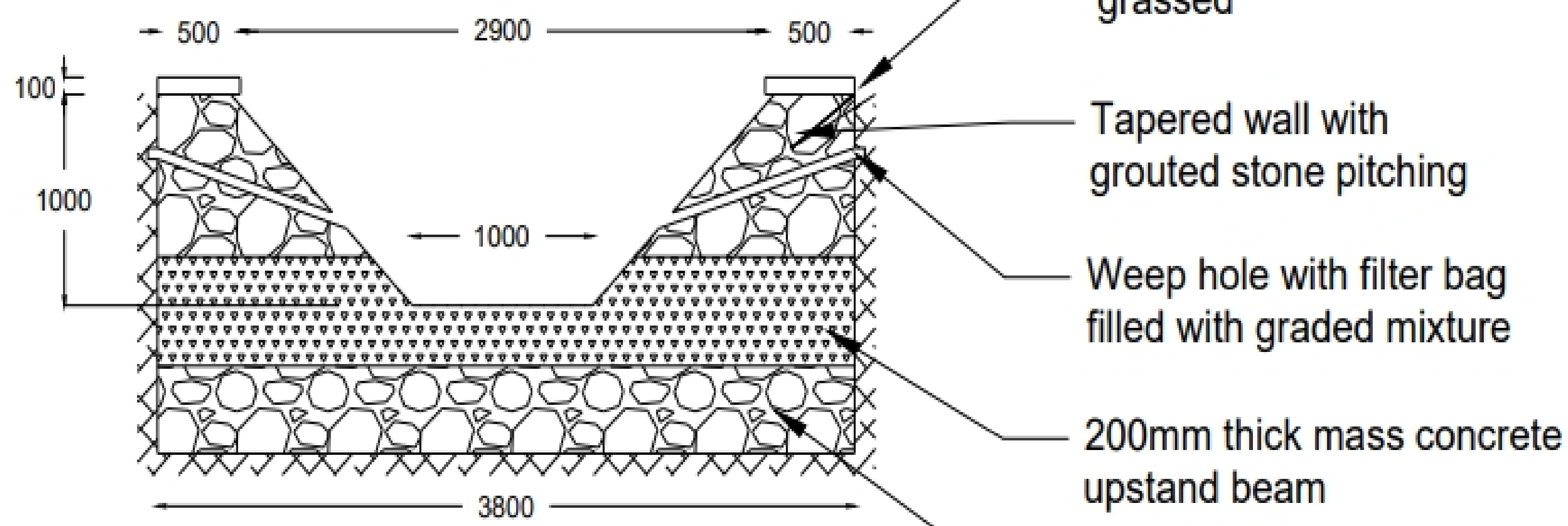
BSCEE 4
FINAL YEAR RESEARCH AND DESIGN PROJECT

PROJECT TITLE:
IMPROVING THE HYDRAULIC CONVEYANCE OF NALUUMA ROAD DRAINAGE

DRAWING TITLE:
PROPOSED DESIGN FOR THE DRAINAGE CHANNEL

SCALE: 1:100

BY:
TIMOTHY. A. AKAMPURIRA
AUSTIN OBBO



SECTION 3

BSCEE 4
FINAL YEAR RESEARCH AND DESIGN PROJECT

PROJECT TITLE:
IMPROVING THE HYDRAULIC CONVEYANCE OF NALUUMA ROAD DRAINAGE

DRAWING TITLE:
PROPOSED DESIGN FOR THE DRAINAGE CHANNEL

SCALE: 1:100

BY:
TIMOTHY. A. AKAMPURIRA
AUSTIN OBBO

APPENDIX D: HEC– 1D HYDRAULIC ANALYSIS

HEC-RAS Plan: 1 River: naluuma Reach: 1 Profile: 25yrs

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
1	330	25yrs	3.72	1181.08	1181.65	1181.95	1182.67	0.019610	4.48	0.83	2.03	2.24
1	328.24*	25yrs	3.72	1181.82	1182.95	1182.95	1183.48	0.003426	3.34	1.38	1.37	1.04
1	326.47*	25yrs	3.72	1181.25	1181.99	1182.37	1183.28	0.015050	5.19	0.85	1.37	2.02
1	324.71*	25yrs	3.72	1180.68	1181.36	1181.79	1182.90	0.023063	5.67	0.77	1.37	2.31
1	322.94*	25yrs	3.72	1180.11	1180.76	1181.22	1182.42	0.025872	5.86	0.74	1.37	2.44
1	321.18*	25yrs	3.72	1179.54	1180.18	1180.64	1181.87	0.030338	5.93	0.72	1.37	2.49
1	319.41*	25yrs	3.72	1178.97	1179.62	1180.06	1181.25	0.032194	5.82	0.73	1.37	2.43
1	317.65*	25yrs	3.72	1178.40	1179.06	1179.48	1180.62	0.030210	5.71	0.75	1.37	2.36
1	315.88*	25yrs	3.72	1177.83	1178.49	1178.92	1180.00	0.031864	5.61	0.76	1.37	2.31
1	314.12*	25yrs	3.72	1177.26	1177.93	1178.35	1179.39	0.030041	5.50	0.77	1.37	2.24
1	312.35*	25yrs	3.72	1176.70	1177.37	1177.77	1178.77	0.031545	5.40	0.78	1.37	2.19
1	310.59*	25yrs	3.72	1176.13	1176.81	1177.20	1178.16	0.029821	5.31	0.79	1.37	2.14
1	308.82*	25yrs	3.72	1175.56	1176.24	1176.63	1177.55	0.031391	5.22	0.80	1.37	2.10
1	307.06*	25yrs	3.72	1174.99	1175.68	1176.05	1176.92	0.031281	5.07	0.82	1.37	2.01
1	305.29*	25yrs	3.72	1174.42	1175.12	1175.47	1176.32	0.029594	4.97	0.84	1.37	1.96
1	303.53*	25yrs	3.72	1173.85	1174.56	1174.90	1175.72	0.031214	4.91	0.85	1.37	1.93
1	301.76*	25yrs	3.72	1173.28	1174.00	1174.33	1175.12	0.029400	4.81	0.86	1.37	1.87
1	300	25yrs	1.25	1171.45	1171.72	1172.07	1174.22	0.133176	7.00	0.18	0.93	5.12
1	292.00*	25yrs	1.25	1172.31	1172.84	1172.84	1173.07	0.011009	2.18	0.62	1.41	1.01
1	284.00*	25yrs	1.25	1171.91	1172.32	1172.43	1172.72	0.027552	2.86	0.46	1.46	1.52
1	276.00*	25yrs	1.25	1171.51	1171.97	1172.02	1172.25	0.017263	2.40	0.55	1.50	1.19
1	268.00*	25yrs	1.25	1171.11	1171.54	1171.61	1171.85	0.022801	2.53	0.52	1.54	1.31
1	260.00*	25yrs	1.25	1170.72	1171.16	1171.21	1171.43	0.018793	2.36	0.56	1.58	1.20
1	252.00*	25yrs	1.25	1170.32	1170.74	1170.80	1171.02	0.021873	2.40	0.55	1.62	1.25
1	244.00*	25yrs	1.25	1169.92	1170.35	1170.39	1170.60	0.019392	2.24	0.58	1.66	1.15
1	236.00*	25yrs	1.25	1169.52	1169.94	1169.99	1170.20	0.021092	2.28	0.57	1.70	1.19
1	228.00*	25yrs	1.25	1169.12	1169.55	1169.58	1169.78	0.019819	2.17	0.60	1.74	1.12
1	220.00*	25yrs	1.25	1168.72	1169.14	1169.18	1169.37	0.021045	2.15	0.60	1.79	1.12
1	212.00*	25yrs	1.25	1168.32	1168.75	1168.77	1168.96	0.019556	2.08	0.62	1.83	1.09
1	204.00*	25yrs	1.25	1167.93	1168.34	1168.37	1168.56	0.021369	2.08	0.62	1.87	1.10
1	196.00*	25yrs	1.25	1167.53	1167.95	1167.97	1168.15	0.019142	1.96	0.66	1.91	1.02
1	188.00*	25yrs	1.25	1167.13	1167.54	1167.56	1167.74	0.021093	2.01	0.64	1.95	1.06
1	180	25yrs	2.16	1165.41	1165.76	1166.06	1167.02	0.039454	4.98	0.43	1.60	3.05
1	160.11*	25yrs	2.16	1166.50	1167.08	1167.08	1167.34	0.017875	2.30	0.98	1.99	1.02
1	140.22*	25yrs	2.16	1166.27	1166.85	1166.85	1167.11	0.017203	2.28	0.99	1.99	1.00
1	120.33*	25yrs	2.16	1166.03	1166.62	1166.62	1166.88	0.017086	2.28	1.00	1.99	1.00
1	100.44*	25yrs	2.16	1165.80	1166.39	1166.39	1166.65	0.016965	2.27	1.00	1.99	1.00
1	80.56*	25yrs	2.16	1165.57	1166.16	1166.16	1166.41	0.016789	2.27	1.00	1.99	1.00
1	60.67*	25yrs	2.16	1165.34	1165.92	1165.92	1166.18	0.016849	2.27	1.00	1.99	1.00
1	40.78*	25yrs	2.16	1165.11	1165.68	1165.68	1165.94	0.016973	2.27	1.00	1.99	1.00
1	20.89*	25yrs	2.16	1164.87	1165.44	1165.44	1165.70	0.017289	2.27	0.99	1.99	1.00
1	1	25yrs	2.16	1164.64	1165.20	1165.20	1165.46	0.017530	2.27	0.99	1.99	1.00

APPENDIX E: APPROVED INTRODUCTORY LETTERS

UGANDA CHRISTIAN UNIVERSITY
A Centre of Excellence in the Heart of Africa

Received
Segoe 19/12/2024

FACULTY OF ENGINEERING, DESIGN, AND TECHNOLOGY
Department of Engineering Design and Technology

18/12/2024

The Municipal Engineer
Nansana Municipality

Dear Sir/Madam,

RE: INTRODUCTORY LETTER FOR AKAMPURIRA Timothy & Obbo Austin

This is to introduce the above named students of Uganda Christian University, pursuing a ***Bachelor of Science Degree in Civil and Environmental Engineering***, currently in Fourth Year Semester One.

Mr. Akampurira and Mr. Obbo are working on a project of improving the Hydraulic Convergence of Naluuma Rd Drainage. These students are seeking for permission to do channel measurements

The information obtained is entirely for educational purposes, not shared for public consumption, and will be treated with the highest level of confidentiality.

Any help rendered to them will be highly appreciated as they go through their learning process.

In case of any questions, contact the undersigned.

Thank You

Yours sincerely,

UGANDA CHRISTIAN UNIVERSITY
H.O.D
19 DEC 2024
DEPARTMENT OF ENGINEERING AND ENVIRONMENT

Mr. Rodgers Tayebwa
Head of Department Engineering and Environment
Uganda Christian University
<u>email</u> : rtayebwa@ucu.ac.ug of contact: 0703-860281

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PO Box 4, Mukono, Uganda | Tel: (+256) 312 350 898 | (+256) 772 194 147 |Email: hodengenv@ucu.ac.ug | eng.envt@ucu.ac.ug | Web: www.ucu.ac.ug

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UGANDA CHRISTIAN UNIVERSITY
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FACULTY OF ENGINEERING, DESIGN, AND TECHNOLOGY
Department of Engineering and Environment

ACA
pls handle as required.
07/02/2025

Kisiri / Glorious
Establish the availability of data & process for the client
07/02/25

Date: 6th February 2025

The Uganda National Metrological Center
Portbell Rd
Luziira

Dear Sir/Madam,

RAINFALL DATA

RE: INTRODUCTORY LETTER FOR AKAMPURIRA TIMOTHY & OBBO AUSTIN

This is to introduce the above-named students of Uganda Christian University, pursuing a ***Bachelor of Science Degree in Civil and Environmental Engineering***, currently in Fourth Year Semester Two.

Mr. Akampurira and Mr. Obbo are working on a project of improving the Hydraulic conveyance of Naluuma Road drainage Nabweru Nansana

The information obtained is entirely for educational purposes, not shared for public consumption, and will be treated with the highest level of confidentiality.

Any help rendered to them will be highly appreciated as they go through their learning process.

In case of any questions, contact the undersigned.

Thank You

Yours sincerely,

UGANDA CHRISTIAN UNIVERSITY
H.O.D
06 FEB 2025
DEPARTMENT OF ENGINEERING AND ENVIRONMENT

Mr. Tom Mark Mwanje
Head of Department Engineering and Environment
Faculty of Engineering, Design and Technology
Contact 0785-057593 0700-181522
Email tmwanje@ucu.ac.ug

DEPARTMENT OF METEOROLOGY
07 FEB 2025
RECEIVED
P.O.BOX 7025, KAMPALA, UGANDA

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APPENDIX F: SURVEYING