A Study of the Drainage Capacity, Flood Risks and Mitigation Measures for Selected Areas in Guyana's Coastal and Riverine Regions: Williamsburg-Hampshire, Kilcoy-Chesney and Mabaruma-Kumaka-Barabina

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Abstract:- This research investigates the drainage challenges and flood risks in three areas of Guyana: Williamsburg-Hampshire, Kilcoy-Chesney, and Mabaruma-Kumaka-Barabina. These drainage areas are characterised by low-lying terrain, proximity to waterways, and inadequate drainage infrastructure. The study identifies how these factors lead to frequent and sometimes costly flooding, especially during periods of peak rainfall and high tides that prevent the opening of drainage sluices.

Using rainfall and runoff data, with the analysis of drainage coefficients and discharge capacities, the study examines the existing drainage systems in these regions. It highlights the inefficiencies of undersized drainage structures, inadequate maintenance, and the growing pressure from urbanisation, which has led to the expansion of impervious surfaces, thus increasing runoff. In the case of Mabaruma-Kumaka-Barabina, under-maintained sluices, narrow bridge culverts, and low earthen dams exacerbate the area's flood vulnerabilities.

To address these issues, the study recommends several key interventions. These include upgrading drainage infrastructure by widening internal drains, replacing narrow culverts, installing additional sluices, and using modern technologies like automated pumps and self-actuated sluices. The construction of higher, vegetated embankments and raising the earthen river dams are also recommended to prevent erosion and overtopping during high tides. Monitoring water levels and rainfall data regularly is proposed to inform drainage maintenance and flood prevention efforts. The findings underscore the need for public-private partnerships to maintain drainage systems while engaging the community in flood risk mitigation. By implementing these recommendations, these regions can better manage water flow, reduce the impact of flooding, and improve the quality of life for residents, particularly as climate change continues to pose greater challenges for water management in Guyana.

Keywords:- *Drainage Coefficient, Exceedance Probability, Flooding, Hydraulic Resistance, Permeability, Polder, Recurrence Interval, Runoff, Self-Actuated Sluices, Saturation, Storage Capacity.*

I. INTRODUCTION

Approximately 90% of Guyana's population resides on the low-lying alluvial coastal plain, which stretches for about 400 km in length and averages 16 km in width. Except for the slightly elevated sand reef areas, much of the coastal plain lies below sea level during high tides, making it highly vulnerable to flooding from the sea (Ishmael, 2005). The coastal plain also receives fresh water from the interior highlands through numerous creeks and the four main rivers: the Corentyne, Berbice, Demerara, and Essequibo. This topography and the tropical climate expose the coastal plain to flood risk from the sea, inland freshwater, and rainfall. The significance of the coastal plain to Guyana cannot be overstated, as it contains the country's most fertile soils, supporting the majority of agricultural activities and other economic sectors (Sattaur 1990; U.S. Army Corps of Engineers, 1998).

During over two centuries of European colonization in Guyana, starting around 1750 by the Dutch and followed in 1814 by the British, a complex network of polders, back dams, sea dams, interconnected sideline canals, and gravity drainage sluices was constructed to manage water flow (Case, 1920). This empoldered system had a dual purpose: mitigating flooding and supplying water for agricultural and human needs. During low tide, sluices leading to rivers and the ocean are opened for 2 to 6 hours, depending on tidal cycles, allowing excess water to drain from the land by gravity. Given that there are two low tides per day, the total daily opening times for sluices range from 4 to 12 hours. When the tide rises, the sluices are closed to prevent seawater intrusion. When heavy rainfall coincides with high tide and the sluices cannot be opened, hydraulic lift pumps, where available, are used to pump the excess water over the seawall and into the ocean (U.S. Army Corps of Engineers, 1998).

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The operation of the sluice doors is determined by the tidal cycle, which ranges from 11 to 13 hours, with an average of 12 hours and 25 minutes from one high tide to the next. This system is not automated and relies on manual operation by sluice workers, who must be present to control the opening and closing mechanisms or to activate the pumps. Tide tables are provided to these workers to ensure they arrive on time to operate the sluices or pumps. The coastal drainage systems are designed to handle 1.5 to 2.5 inches (38.1 to 63.5 mm) of rainfall within 24 hours without flooding. However, rainfall exceeding 2.5 inches in that period can lead to flooding, particularly in the capital city of Georgetown (Carter, 2014).

Over the years, the drainage system has sometimes proved inadequate in preventing flooding in certain areas during heavy rainfall. In addition to flooding, some areas experience stagnation of water due to poor drainage, which breeds water-borne disease organisms. This is largely due to poor maintenance, lethargic improvements, or neglect of parts of the system. The system's effectiveness may also be compromised by climate change impacts, such as rising sea levels, increased rainfall, and shifts in seasonal rainfall patterns. During high tides, sluice doors are subjected to intense hydrostatic pressure from the tide and dynamic pressure from waves, occasionally leading to door failures that result in coastal flooding and property damage. In some instances, the use of substandard construction materials further weakens the sluice doors, contributing to their failure (Majeed, 2008).

In January 2005, the worst flooding in recent years happened after prolonged heavy rainfall, followed by a breach in the East Demerara Water Conservancy. The flood caused 36 deaths due to water-borne diseases and drowning. Moreover, it damaged agriculture and businesses along the East Coast of Demerara (ECD) and in the capital city of Georgetown, with estimated damage at nearly 60% of the country's GDP. Due to its inundated campus grounds, the University of Guyana at Turkeyen had to be closed for several weeks (Global Facility for Disaster Reduction and Recovery, 2016; Sutherland, 2020). In response, from 2010 to 2015, the government constructed the Hope Canal and Eight-Door Sluice Project, which has since alleviated rainfall-induced flooding along the ECD that might have caused the water level in the conservancy to rise to dangerous levels (Kaieteur News, 2010; Kaieteur News, 2015).

Many areas in the coastal region of Guyana continue to suffer low-level flood events during heavy rainfall, affecting lives, communities, and the local economy. Consequently, residents, businesses, agriculture, and industries in those areas suffer damage and destruction of property and assets totaling millions of dollars. Undrained stagnant water also provides a breeding ground for vector-borne and other diseases and poses the risk of drowning. There is a need for quantitative technical knowledge of the drainage capacities of these areas to devise mitigation measures for flood events. (Liu, 2014; Seegobin, 2015). This research focuses on three locations in Guyana that have been affected by rainfall-induced flooding; the first two are in the East Berbice-Corentyne region, and the third is in the Barima-Waini region: (1) Williamsburg-Hampshire Housing Scheme, (2) Kilcoy-Chesney Housing Scheme, and (3) Mabaruma-Kumaka-Barabina Township.

II. LITERATURE REVIEW

A. Historical Context and Development of Drainage Infrastructure

The complex interaction between Guyana's drainage infrastructure, rainfall patterns, the sea, and flood risk management has been extensively studied, reflecting the critical need for effective strategies to mitigate the impacts of relentless sea and extreme weather events. The struggle to reclaim and protect Guyana's narrow coastal plain from oceanic and atmospheric phenomena has been a defining feature of its history. As Rodway (1891) described, "Every acre at present under cultivation has been the scene of a struggle with the sea in front and the flood behind. As a result of this arduous labour through two centuries, a narrow strip of land along the coast has been rescued from the mangrove swamp by an elaborate system of dams and dykes."

This historical battle against nature has shaped the landscape and established a legacy of engineering experimentation to meet environmental challenges. The early efforts to establish sugar plantations along the coast exemplified this struggle, with the construction of an extensive network of dams, canals, sluices, and conservancies. Ishmael (2005) notes, "Before 1838, all of these waterways were dug by the slaves using shovels as their tools. After this period, paid African labour and Indian indentured workers carried out the excavation works. For every square mile of land used for sugar-cane cultivation, about 49 miles of drainage and 16 miles of irrigation trenches, were dug. In the process of digging canals and trenches on the sugar plantations, over 100 million tons of earth were excavated." These early efforts laid the foundation for the current drainage infrastructure, which remains vital in managing the threats posed by rain and the sea.

B. Current Infrastructure and Challenges

After the slaves were emancipated in 1838, many of them purchased villages on the coast along with their drainage and irrigation infrastructure from British plantation owners. However, a significant problem arose from the periodic build-up of huge mudbanks in front of the sluices that hindered drainage when the sluices were opened at low tides. The wealthier plantation owners utilized expensive steam-driven pumps to drain water from their lands, but the villagers could not do the same (Khemraj, 2015). This issue has persisted into the 21st century, with diesel-driven pumps now used to assist drainage when sluices are blocked by the slowly moving mudbanks.

Another stressor on the drainage system is sea level rise caused by climate change. The World Meteorological Organization (2023) reported, "The rate of global mean sea level rise has doubled between the first decade of the satellite record (1993-2002, 2.27 mm/yr) and the last (2013-2022, 4.62 mm/yr)." This accelerating rise in sea level reduces the opening times for sluices at low tides and can exacerbate flooding, necessitating the need for more drainage pumps.

C. Effectiveness of Drainage Infrastructure: Case Studies

Over the years, studies of the drainage infrastructure have been conducted to assess its effectiveness. One such study was Rowe's "A Report on Declared Drainage and Irrigation [DDI] Area in Guyana" (1970), which reported on coastal areas of Guyana. Among the areas examined were the Fyrish DDI area and the Courtland-Gibraltar DDI, which are both immediately west of the Kilcoy-Chesney Housing Scheme, one of the focus study areas of this research.

D. Fyrish DDI Area

Rowe describes the Fyrish DDI thus: "*A system of main drains provides gravity drainage via the North façade drain, which can discharge through a check sluice into the Gibraltar- Courtland Drainage & Irrigation area façade drain and thence to sea through the Gibraltar Sea Sluice. The façade drain can also discharge through a G.H. [gravity head] Box into the façade drain of Albion Sugar Estate at Kilcoy. Drainage is poor. The main drains need reconditioning. Fyrish is somewhat low and tends to flood. Good drainage would be obtained by providing pumps at Gibraltar* ..." While Rowe gives a good qualitative assessment of this area's condition and drainage, quantitative data, such as dimensions of drainage structures, discharge capacities, and drainage coefficients, are lacking.

E. Courtland-Gibraltar DDI Area

Rowe provides a somewhat similar qualitative and non-quantitative description of the adjacent Courtland-Gibraltar DDI thus: "*Gravity drainage is provided by a system of main drains and a R.C. [reinforced concrete] Sea Sluice on the outfall end of Gibraltar West sideline [canal] ... The main and internal drains need to be reconditioned. Drainage is poor, foreshore conditions impeding discharge through the Sluice. The lands on both sides of, and adjacent to, the Public Road are low and are subject to flooding. These areas would still be poorly drained even if the foreshore conditions were good. This D & I area would greatly benefit by the provision of pumped drainage*."

Following Rowe's recommendation and also to benefit drainage for sugar cane cultivation, the Guyana Sugar Corporation (GuySuCo) later installed a permanent drainage pump adjacent to the sea sluice. This helped to reduce the frequency and severity of flooding in the area, though flooding still occurred in the event of high-intensity rainfall, such as in the May-June 2021 rainfall. (Table 1 below).

F. Rose Hall DDI Area

In other areas where pumps are provided, Rowe offers quantitative descriptions of discharge capacities, gravity head, and drainage coefficients, such as the Rose Hall DDI, which is immediately east of the Williamsburg-Hampshire House Scheme, another focus area of this research. He reported*: "The area is provided with pumped drainage by one Vickers Gill single Stage Axial Flow Pump, with a design point of 120 tons per minute (72 cusecs) at 10 ft total head. Allowing for 20 hours maximum pumping per day, the provision of 72 cusecs pumping capacity for 906 acres is equivalent to a drainage coefficient of 1.57 inches in 24 hours. This is ample for sugar cane. However, drainage is imperfect, as the main drains need remodeling in order that the pump can be supplied with water to its rated capacity. As the situation stands, the drains are undersized and pumping is intermittent on that account*." The quantitative data reported is noteworthy as it gives insight into the effectiveness of the pump. The pump later fell into disrepair and, in 2014, was replaced by a pump with a greater discharge capacity, thereby increasing the drainage coefficient and reducing flooding in Rose Hall.

G. Black Bush Polder DDI Area

In some areas, Rowe did report quantitative data for drainage coefficients, such as the Black Bush Polder (BBP) DDI, the largest drainage system in the East Berbice-Corentyne region, which he describes thus, "*Gravity drainage is provided by a complete network of main and subsidiary drains. The drainage system was designed using a drainage coefficient of 1 ½ inches in 24 hours which is more than adequate for rice cultivation. The three main drainage sluices, however, are sited on the Public Road and have outfall channels about 1 mile long on the average. Due to siltation of these channels the design coefficient has not been realized. In recent times, however, the amount of siltation has decreased due to improved foreshore conditions, and although the drainage coefficient is not being fully realized, it is probably safe to say, that more than 1 inch in 24 hours is obtained. The solution would appear to lie in auxiliary pumped drainage*." Over the years, temporary small pumps, and recently, permanent larger pumps, have been installed at these three sluices. Consequently, flooding has been reduced in the BBP DDI area, though in the event of high-intensity rainfall, flooding still occurs, such as on May 29, 2021 and May 3, 2022 (Table 1 below).

It seems that Rowe had good access to pump discharge data but limited access to similar data for drainage boxes, pipes, or sluices. Planning and designing canals and effective gravity drainage structures would be difficult without such quantitative data for the entire drainage network. This researcher contends that field measurements of dimensions of the gravity drainage structures and the use of the Chezy-Manning equation for open channel flow (Potter, 2009), along with data on the drainage acreage, would give reasonable estimates of discharge capacities and drainage coefficients. This would enable the construction of adequate infrastructure to manage rainfall-induced flooding. It is precisely these quantitative data that this research attempts to obtain for the selected areas of study to make recommendations for possible flood mitigation measures.

H. Dutch Risk Reduction Team's Drainage and Flood Risk Assessment

The most recent drainage and flood risk assessment of the entire empoldered coastland from the Corentyne River in the east to the Pomeroon River in the west was done by a four-member Dutch Risk Reduction Team at the request of the Guyana government in 2015. Over four days, they inspected drainage works in Georgetown, did flyovers of the coastland,

and conducted interviews with local engineers, technical persons, and involved stakeholders. Due to the brevity of their visit, the Team did not collect field measurements of drainage infrastructure, rather, they relied on available data, inspection of structures, and interviews conducted. They admitted to the tentative nature of their description of "the technical state of inspected hydraulic structures" (Dutch Risk Reduction Team, 2016). In this regard, the assessment of the Team was limited due to its lack of field measurements.

Although the Team analysed only Georgetown's rainfall records from 1886 to 2015 to rank the ten most extreme rainfall events in the capital, it is notable that the highest recorded rainfall in Guyana was 224 mm at Strathavon in 2014 (Guyana Chronicle, 2014). Strathavon is 15 miles east-southeast of Georgetown at the northeastern corner of the East Demerara Water Conservancy, which was breached following heavy rainfall and contributed to the 2005 floods. Apart from the Strathavon event, the Team found that three of the top ten rainfall events occurred in the last decade, highlighting that the effects of climate change are already manifesting through more frequent and intense weather events. In view of this, Guyana should prioritise improving its drainage system and constructing more robust, adaptable infrastructure to manage the increasing risks of extreme rainfall and mitigate future flood hazards in vulnerable areas.

The Team observed many unplanned modifications in the drainage system and opined, "*These adjustments all resulted in an increase in the hydraulic resistance and therefore decrease of the conveyance capacity. There are no quantitative data on how much the conveyance capacity (in m^3 /s per cross-section) has decreased in each part of the overall drainage system. It is however very likely that due to the ... modifications, the flood probability in certain urban areas has increased as a result ...*" (Ibid, 2016). They also noted, "*measures have been taken to increase the conveyance capacity or to increase the redundancy of the drainage system.*" They adjudged these measures to have improved parts of the drainage system. They also recognised that "*many operations and policies, both technical and managerial, are adequate and do not need to be changed*," and declared these are good things to maintain. However, the Team noted a glaring weakness in the system, "*The lack of a knowledge infrastructure and institutional memory may well be the largest barrier for improvement of the Guyanese water systems. A lot of knowledge is available in the heads of the people involved but it is not combined, it is not accessible to others and there are no foundations laid for further knowledge development.*" Hence, there is a critical need for an organized and permanent knowledge repository of the drainage infrastructure data to guide future developments and the ability to address flood risks. This research is an attempt to add to that repository.

I. Impact of Tropical Rainfall on Drainage Effectiveness

Guyana's climatic conditions, particularly the extreme rainfall intensity that characterises the region, continually challenge the effectiveness of the drainage infrastructure. A particular climatic phenomenon in the tropics is extreme rainfall intensity over very short periods. This phenomenon in Guyana and its implications have been addressed by Persaud and Forsythe (1980), who noted that relatively long periods (over 24 hours or more) of continuous rainfall seldom occur in the tropics, but that "short duration high-intensity rainfall" occurs more frequently and often leads to flooding.

Most of these types of rainstorms occur during the pre-dawn hours, but a few continue beyond 8:00 a.m. As mentioned in the Introduction above, in Guyana, flooding is likely to happen when rainfall exceeds 38.1 mm to 63.5 mm. Ramraj (1996) gives an example of the four-hour downpour of November 1, 1974, during which 174 mm of rain fell, leading to significant flooding. The next highest recorded rainfall that caused flooding happened on November 12, 1995, when 153 mm of rain fell over 24 hours (Pelling, 1997). The table below shows a few examples of intense rainfall that resulted in flooding in the last ten years (Guyana Chronicle, 2014; Hoppie, 2015; Hydromet Weather Briefs, 2024).

Table 1: Examples of Daily Rainfall that Resulted in Flooding

Date	Location	Rainfall (mm)
November 19, 2014	Strathavon, East Coast Demerara	244.0
November 19, 2014	Georgetown, Demerara River	186.0
July 15, 2015	Georgetown, Demerara River	209.8
June 22, 2017	John's Village, East Berbice	188.7
September 1, 2017	New Amsterdam, Berbice River	42.0
July 1, 2019	Wales, West Bank Demerara	51.2
July 11, 2019	John's Village, East Berbice	52.0
May 24, 2021	Johanna, Black Bush Polder	70.6
May 25, 2021	Kumaka, Aruka River	138.7
May 26, 2021	Good Success, Wakenaam	148.8
May 27, 2021	Whim, East Berbice	102.0
May 29, 2021	Johanna, Black Bush Polder	120.2
May 3, 2022	Lesbeholden, Black Bush Polder	145.5
April 25, 2023	Blairmont, West Bank Berbice	175.5
June 8, 2023	Georgetown, Demerara River	101.6
July 17, 2024	New Amsterdam, Berbice River	113.2

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After the rainstorm of July 15, 2015, it took three to four days for Georgetown to be drained by sluices and pumps, indicating an average daily drainage capacity of about 60 mm. Similarly, flooding in New Amsterdam after the September 1, 2017 rainfall demonstrated that its drainage capacity was close to the colonial-inherited drainage coefficient of 38.1 mm (1.5 inches) for sluices (Lacey, 1953). Drainage pumps were installed in 2023 to provide the town with assisted drainage for the sluices (Guyana Chronicle, 2023). However, it still experienced flooding from the higher rainfall on July 17, 2024, indicating only a marginal improvement in drainage capacity.

The rainfall in May-June 2021 was so intense that by the end of May 2021, all ten administrative regions in Guyana were affected by various levels of flooding (Newsroom, 2021). On June 13, 2021, the President of Guyana declared flooding a national disaster, enabling the emergency release of funds and resources to aid flood-affected areas and flood victims (Kaieteur News, 2021).

Such high intensity, short-duration rainfall events have frequently overwhelmed the existing drainage system, leading to flooding. With climate change leading to more intense and variable weather patterns, the frequency and severity of such events are expected to increase, further straining the infrastructure. As such, it is imperative to assess the current drainage capacity to determine improvements to manage future challenges.

From the preceding description of the drainage system in Guyana and its frequent ineffectiveness in dealing with flooding, it is the considered opinion of this researcher that the drainage infrastructure inherited from the Dutch and British was designed for climatic conditions over 200 years ago and has not been significantly improved by the post-colonial governments to address the challenges of climate change. It is only within the last fifteen years that serious efforts have been initiated to do so, notably the Hope Canal and Eight-Door Sluice Project, which has proved its value in reducing flooding on the East Coast of Demerara, as mentioned in the Introduction. Also, in early 2024, the government announced plans to build Hope-like canals and sluices in vulnerable coastal areas (Oosman, 2024). In July 2024, one such project started in the East Berbice-Corentyne area. Previously, much of the work done on the inherited drainage infrastructure was to maintain it and not to improve it, and many areas suffered from poor maintenance or neglect.

J. Conclusion of Literature Review - Research Aims and Methodology

This brief review highlights the historical evolution of Guyana's drainage infrastructure, ongoing challenges, and the need for modern, adaptive solutions to manage flood risks. Early colonial efforts laid the foundation, but climate change, antiquated systems, and inadequate data collection continue to strain the infrastructure. The DDI cases reviewed emphasise the importance of improved maintenance and infrastructure upgrades. The Dutch Risk Reduction Team recommends precise field-based data, modernised systems, and a centralised knowledge repository to enhance future planning and flood risk management.

This research aims to reduce the knowledge gap by providing quantitative assessments of the drainage capacity of the selected areas. The study estimates discharge capacities and drainage coefficients of existing infrastructure through field measurements and hydrological and hydraulic analyses. These data will be critical in developing recommendations for upgrading and maintaining the drainage systems to mitigate the impacts of future extreme rainfall events and rising sea levels.

III. METHODOLOGY - THEORY AND PRINCIPLES INVOLVED

A. Brief Overview of Conduct of Study

Field visits were carried out in the three study areas to assess their drainage infrastructure and flow regimes by taking measurements of the dimensions of canals and drainage structures and applying the Chezy-Manning equation for open channel flow and pump and pipe discharge equations to estimate discharge capacities and water flow speeds. The current state of drainage structures, channels, and flood defences in the catchment area was observed and assessed for structural vulnerabilities and restrictions to drainage. Google Earth Satellite Maps with up-to-date high-resolution images of the coastal regions and mapping tools were used to help determine features, terrain, and dimensions of the study areas. Estimates of the rainfall-runoff coefficients of the catchment areas were made by observation of the terrain and consulting the relevant runoff coefficient tables. Recurrence intervals for peak rainfall events and floods were determined from historical rainfall data and recurrence interval graphs.

B. A Brief Explanation for Flooding

When it rains on a drainage area on Guyana’s flat coastal plain (average gradient of 1/5,000), the ground absorbs some rainwater depending on its porosity and the permeability of its surface. Some rainwater will flow into drainage canals, some will evaporate, and some will pool on the land and become runoff.

Viessman and Lewis (2003) define runoff, “The term runoff normally applies to flow over a surface… Rain falling on a surface in quantities exceeding the soil or vegetation uptake becomes surface runoff. Water infiltrating the soil may eventually return to a stream and combine with surface runoff in forming the total drainage of the basin.”

It is also possible that infiltration of rainwater into the ground can be so slow as to be negligible and lead to surface pooling, especially in high-intensity short-duration rainfall. In this flat terrain, runoff will be slower, increasing the likelihood of pooling. Eventually, if the canals are filled to overflowing, the ground becomes saturated, and the runoff starts to rise, then flooding will occur unless the water can be drained out quickly enough through sluices and pumps. If the runoff, especially from peak flows, exceeds the combined drainage capacity of the sluices and pumps, the drainage

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system will be overwhelmed, leading to flooding. Since some rainwater will be absorbed, evaporated, and stored, the runoff that remains pooled on the land will always be less than rainfall, unless the ground is already saturated and storage spaces are already filled before the rainfall event. Hence, rainfall is typically greater than runoff, except when the ground is saturated and storage is full, in which case, runoff will closely match rainfall.

C. Rainfall Data Collection

Rainfall data were obtained from the rain gauge set up at John's Village on September 20, 2013, by the Ministry of Agriculture's Hydrometeorological Service (Hydromet). Since then, it has been monitored daily by the researcher, who is a rainfall observer for Hydromet. The researcher also set up rain gauges at Rose Hall Town on March 1, 2020, and at Williamsburg on May 18, 2024, and monitored daily rainfall since those dates. Information on the highest daily recorded rainfall in Guyana and other weather-related information were obtained from Hydromet's website, URL https://hydromet.gov.gy.

D. Drainage Coefficient and Rainfall Formulas

Drainage capacity is usually expressed as the drainage coefficient (D. C.) in millimetres (mm).

$$D.C. = \frac{\text{Daily Drainage Volume, } V\ (\text{m}^3)}{\text{Drainage Area, } A\ (\text{m}^2)} \times 1{,}000 \qquad (1)$$

(Rowe, 1970)

A more useful formula to calculate D. C. is given by:

$$D.C. = \frac{Q(m^3/s) \times t(hr) \times 3{,}600}{A(km^2) \times 1{,}000} \qquad (2)$$

Q = discharge capacity or volume flow rate of sluice or pump;
t = daily drainage time;
A = Drainage area

When expressed in mm, this enables the drainage coefficient to be compared with rainfall, which is directly measured in mm using a rain gauge.

$$\text{Rainfall} = \frac{\text{Daily Rainfall Volume } (\text{m}^3)}{\text{Rainfall Area } (\text{m}^2)} \times 1{,}000 \qquad (3)$$

If needed, the volume of rainfall in the drainage area (assuming uniform rainfall distribution) can be found using the formula:

$$V_r = R \times A \times 1{,}000 \qquad (4)$$

V_r = rainfall volume (m^3); R = rainfall (mm); A = drainage area (km^2)

E. Runoff Formula

The runoff, or the amount of rainwater that remains on the land surface as surface flow after absorption, storage, and evaporation, can be estimated using the rational method formula (Nathanson, 2008):

$$Q_r = C \times R \times A \qquad (5)$$

Q_r = peak or maximum rate of runoff (m^3/hour)
C = dimensionless runoff coefficient for drainage area, ($0 < C < 1$)
R = rainfall intensity (m/hour)
A = drainage area (m^2)

To give runoff in units of m/hour, Eq. (5) can be expressed thus:

$$\frac{Q_r\ (\text{m}^3/\text{hour})}{A\ (\text{m}^2)} = C \times R\ (\text{m/hour}) \qquad (6)$$

Let runoff, $r = Q_r/A$, and Eq. (6) can be written simpler:

$$r = C \times R \qquad (7)$$

By multiplying both sides of Eq. (7) by 1000, runoff can be more conveniently expressed in mm/hour or even in mm by cancelling hour from both sides. This simplifies the relation between rainfall and runoff for a drainage area with a given runoff coefficient. It can be used to estimate runoff for any peak rainfall event lasting up to several hours and to estimate average daily runoff. This formula is applicable to urban and suburban areas up to about 5 square miles (13 square km), which aligns with the size and terrain of the three study areas in this research (Nathanson, 2008).

F. Runoff Coefficient

The runoff coefficient, C, is the fraction of rainfall that becomes runoff in the drainage area. Its value depends on ground absorption, storage spaces, evaporation, transpiration, terrain, slope, and land use. When $C = 1$, all the runoff is rainfall, as happens if the ground is totally impermeable. But as there is always some absorption, C is always less than 1, and so $0 < C < 1$. Values of C are obtained from runoff coefficient tables and are selected based on the physical characteristics of the drainage area, e.g. for woodland areas, C = 0.01 to 0.20; for business areas, C = 0.70 to 0.95 (Ibid.)

G. Recurrence Interval

The recurrence interval or return period, T_r, is the average expected time for a storm or flood event of a particular intensity or greater to recur (Nathanson, 2008). Recurrence intervals are determined from the historical rainfall data of a drainage area. The highest rainstorm for each year is obtained for n number of years, and they are ranked from $m = 1$ (highest) to $m = n$ (lowest). The recurrence interval for the peak event in each year is found using the Weibull equation (Persaud & Forsythe, 1980; Viessman & Lewis, 2003):

$$T_r = \frac{n+1}{m} \qquad (8)$$

The exceedance probability, *Pr*, of an event of a given intensity or greater, $P \geq P_m$, occurring in a given year, is found using the equation (Ibid, 1980 & 2003):

$$Pr(P \geq P_m) = \frac{1}{T_r} \times 100\% \quad (9)$$

For example, if a rainstorm event has a 100-year recurrence interval, then there is a 1% probability that an event of that magnitude or greater will occur in any given year.

By comparing the storm's magnitude and recurrence interval, with an area's drainage capacity and coefficient, the likelihood and intensity of flooding in the area can be estimated, and, if necessary, improvements can be made in the design of the drainage infrastructure. For instance, the Dutch Risk Reduction Team (2016) estimated a flood recurrence interval of two years for Georgetown, based on a drainage coefficient of 101 mm/day. Generally, if the rainfall runoff is less than the drainage coefficient for a given day, flooding is unlikely to occur. However, if the runoff surpasses the drainage coefficient, flooding becomes more likely.

H. Discharge capacity of Sluices and Channels

The Chezy-Manning equation for open channel flow (Potter, 2009) is used to find the discharge capacity (Q) of sluices:

$$Q = \frac{A(R^{2/3})(S^{1/2})}{n} \quad (10)$$

A = Cross-section area of flow (m^2) = wd, for w = width (m);
d = depth (m) of rectangular sluice
R = Hydraulic radius (m) = cross-section area/wetted perimeter = $(wd)/(w + 2d)$
S = Slope or gradient (dimensionless) = 0.0002 for average of coastal plain (Merrill, 1993)
n = Manning coefficient = 0.014 $s/m^{1/3}$ for unfinished concrete sluice wall (Potter, 2009)

Alternatively, the flow speed, v, of water can be computed from Equation (6) using the continuity equation:

$$Q = Av \quad or\ v = Q/A \quad (11)$$

Yielding: $$v = \frac{(R^{2/3})(S^{1/2})}{n} \quad (12)$$

This can be used to determine the flow speed through drainage pipes, gravity head boxes, and channels, knowing their Manning coefficient and hydraulic radius of flow. The volume flow rate is found using the continuity equation (11). Flow speeds can also be obtained from observations and field measurements. Water flow speeds in coastal channels in Guyana are observed to be around 1 m/s or even less due to the flat terrain and shallow gradient. The researcher used Equation (12) to confirm this value for the flow speed. Discharge capacities of pumps can be estimated in a similar manner or from technical specifications in the relevant literature.

I. Discharge Capacity of Pumps

If the pump's discharge capacity cannot be obtained as previously described, the following equation may be used, provided the power input of the pump and head are known:

$$Q = \frac{\eta P}{\rho g H} \quad (13)$$

η = efficiency of the pump (usually between 0.6 and 0.9)
P = power input of pump (W),
ρ = density of water (1000 kg/m^3),
g = acceleration due to gravity (9.81 m/s^2),
H = head (m)

Equation (13) is derived from the basic principles of fluid mechanics and energy conservation applied to fluids (Potter, 2009). The derivation follows.

J. Derivation of Equation (13) for Discharge Capacity of a Pump

Work done, W, to lift a mass, m, of water through a height, H, is given by $W = mgH$

For volume, V, and density, ρ of water, $m = V\rho$

Therefore, $W = V\rho g H$

From the definition of power, $P = \frac{W}{t} = \frac{V\rho g H}{t}$

From the definition of volume flow rate or discharge, $Q = \frac{V}{t}$

Hence, $P = Q\rho g H$

Expressing as $Q = \frac{P}{\rho g H}$, which gives the discharge for an ideal 100% efficient pump.

Since no pump is 100% efficient, then $Q = \frac{\eta P}{\rho g H}$, where η = energy efficiency of the pump,

with $0.6 < \eta < 0.9$.

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If the information on the power input of the pump is unavailable, then assuming the discharge occurs from a horizontal pipe and the horizontal displacement and vertical fall height of the discharge stream can be measured, the following equation may be used,

$$Q = kAx\sqrt{\frac{g}{2y}} \qquad (14)$$

k = dimensionless air resistance factor ($0.5 < k < 0.9$)
A = cross-section area of flow at exit from pipe (m^2)
x = horizontal displacement of discharge stream (m)
y = vertical fall height of discharge stream (m)
g = acceleration due to gravity (9.81 m/s^2)

Equation (14) is derived from the continuity equation (11) and the principle of projectile motion applied to water (Halliday, Resnick & Walker, 1993; Cutnell & Johnson, 2012). The derivation follows.

K. *Derivation of Equation (14) for Discharge Capacity of a Pump*

For a discharge stream exiting a pipe horizontally with speed, v, vertical fall height, y, and horizontal displacement, x, the vertical fall height is given by $y = ½\, gt^2$ and the horizontal displacement by $x = vt$.

Eliminate t from both equations: $y = \frac{g}{2}\left(\frac{x}{v}\right)^2 = \frac{gx^2}{2v^2}$

Making v the subject: $v^2 = \frac{gx^2}{2y} \Rightarrow v = \frac{x\sqrt{g}}{\sqrt{2y}} = x\sqrt{\frac{g}{2y}}$

From $Q = Av \Rightarrow Q = Ax\sqrt{\frac{g}{2y}}$, which gives the discharge for zero air resistance.

Since there is air resistance, then $Q = kAx\sqrt{\frac{g}{2y}}$, where k = air resistance factor,

with $0.75 < k < 0.95$. Figure 1 illustrates the arrangement and dimensions to be measured.

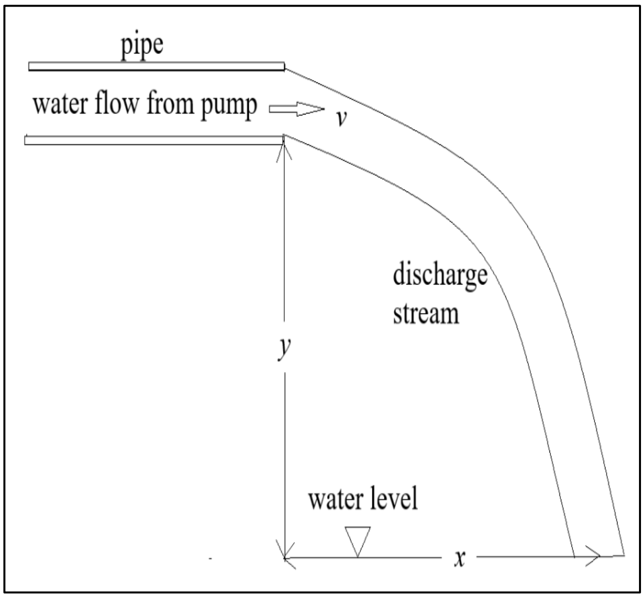

Fig 1: Discharge Stream Exiting a Horizontal Pipe

L. *Assumptions and Limitations of Study*

This study assumes that during a high-intensity short-duration rainfall event (i) ground infiltration is so slow that it is negligible, (ii) ground storage for water has been filled, and

(iii) evaporation is so low that it is negligible. Hence, flooding will be from water that has not otherwise been removed from the surface terrain and constitutes runoff. It is useful to make these assumptions in a tropical climate, especially on Guyana's flat coastal plain with an average gradient of 1 in 5,000, where heavy and fast rainfall can quickly inundate the ground and fill storage spaces, after which flooding can happen from the runoff of a high flow event.

Measurements by GuySuCo indicate that evaporation in Guyana ranges from five to seven mm of water daily (Stabroek News, 2016; Kaieteur News, 2016). Evaporation will come into effect after the rainfall has stopped and will provide some water removal from the drainage area, though not very significant over one day.

Comparing rainfall intensity with the drainage coefficient will then determine the flood risk of the area. Drainage infrastructure can be designed with this in mind. This may lead to some over-design and cost overruns in the drainage infrastructure as they will be designed for rainfall rather than runoff and may be viewed as a limitation of this study. However, drainage infrastructure with high capacity would be better in the long term in the face of climate change and uncertainty in the variability of weather patterns and sea level rise. Inevitably, though, every drainage system has its maximum drainage capacity, and flooding is likely to occur once this capacity is exceeded by heavy rainfall. The authorities must exercise prudence in determining the acceptable level and frequency of flooding while designing adequate drainage systems within budgetary constraints.

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IV. OBSERVATIONS, RESULTS, ANALYSIS & RECOMMENDATIONS

A. Brief Description of the East Berbice-Corentyne Drainage and Irrigation System

The East Berbice-Corentyne Drainage and Irrigation (D&I) System serves a two-fold purpose: (1) to prevent or minimise flooding of agricultural and inhabited lands during the rainy seasons and high tides and (2) to provide fresh water for irrigation throughout the year. The system is supplied with water during the rainy seasons and fresh water from the upper Berbice River via the Torani Canal, which flows into the Canje River, from which various canals, sluices, and pumps convey the water into the D&I system (Lacey, 1953; Guyana Sugar Corporation, 2023). Excess water, including rainfall runoff, is fed into the sideline canals to eventually discharge into the sea via sea sluices and drainage pumps.

During the dry season, sluice doors are rarely opened as there is no need to discharge excess water due to flooding, but to retain the fresh water in the system. Hence, fresh water in the D&I system is prevented from flowing into the sea via the sideline canals and recirculated to the agricultural backlands for irrigation. The non-flow of water in the sideline canals results in sedimentation in the lee of sluice doors, where large amounts of silt are deposited. Sedimentation also occurs in the seaward section of the closed sluice door, where the tidal cycles deposit massive amounts of silt in front of the sluice door. This is compounded by the cyclical mudbanks that block outfall channels on the seashore.

When the rainy season starts, mechanical excavators are used to remove the silt around the sluice doors to allow the free flow of water to the sea. This is a costly operation as funds must be expended to operate the excavators. Two of the study areas for this research, the Williamsburg-Hampshire and Kilcoy-Chesney Housing Schemes, are located in the East Berbice-Corentyne region and share many of the challenges faced by the broader D&I system.

B. Brief Description of the Williamsburg-Hampshire Housing Scheme Drainage Area

Fig 2: Satellite Map of Fyrish to Port Mourant, showing the Williamsburg-Hampshire and Kilcoy-Chesney Housing Schemes and a Simplified Layout of Their Drainage Networks (Google Earth Satellite Maps, 2024).

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The Williamsburg-Hampshire housing scheme, in Figure 2 above, was established in 2022. It covers 0.63 square km (155 acres) of flat, low-lying grasslands and slightly elevated inland sand reefs. It is between Rose Hall Town and Belvedere Village, at Latitude 6° 16' N, Longitude 57° 21.7' W. In 2022, the Ministry of Housing constructed 100 housing units in the northwestern section covering about 0.07 sq km (18 acres), and by August 2024, most were occupied. The eastern portion of the scheme is still mostly unoccupied, but house lots have been allocated, and a few residents have started building their homes. The southern part is occupied by a government agency, 0.04 sq km (11 acres), a private construction company, 0.07 sq km (18 acres), and a place of worship, 0.02 sq km (4 acres). The remaining approximately 0.4 sq km (100 acres) is yet to be unoccupied by houses. The drainage area forms a trapezoidal shape with an average length of 1.08 km and an average width of 0.62 km. These areas and distances were found using the area measurer and distance measurer tools in Google Earth Satellite Maps (2024).

The catchment area is empoldered by low earthen embankments that double as roads, with a single culvert draining into the Hampshire-Belvedere main canal along its western boundary. This main canal was previously drained into the Atlantic Ocean via a reinforced concrete 7-ft wide sluice, but due to significant siltation of the outfall channel, the sluice has been shut down and blocked off. During the rainy season, a temporary pump is installed to provide assisted drainage, but it is removed during the dry season. Drainage has since been rerouted to an east-west façade canal, which runs 2.3 kilometres from Williamsburg to the main canals of the Albion Sugar Factory. These main canals, in turn, are drained by the Albion-Chesney pumps and sluices, located 1.3 kilometres north, which discharge into the Atlantic.

At the Williamsburg end of the east-west façade canal, a 3-ft diameter drainage pipe connects to the west Rose Hall Town sideline canal, which is drained by the Rose Hall Town pump into the sea. Although the Williamsburg-Hampshire housing scheme benefits from the drainage system maintained by GuySuCo and Rose Hall Town, it remains vulnerable to flooding due to its lone drainage culvert linking to the Hampshire-Belvedere canal and its flat low elevation.

C. *Williamsburg-Hampshire Housing Scheme Drainage Area Technical Details*

Area = 0.63 km^2 ; Number of Sluices: 1 (non-functional & blocked); Number of pumps: 1 (portable Hydroflow pump with discharge pipe diameter 1 ft & currently removed); Number of culverts: 1 with one 3-ft diameter gravity drainage pipe; Rainfall runoff coefficient = 0.5.

Tables 2 and 3 below give the discharge capacity and the drainage coefficient of the area for the drainage pump only.

Table 2: Volume Flow Rate Calculations for Hampshire-Belvedere Pump

Parameter	Value	Volume flow rate calculations
Radius of circular pipe, (m)	0.15	$Q = Av = 3.14 \times (0.15)^2 \times 3.00$ = 0.212 m^3/s
Area, *A* (m^2)	0.0707	
Flow speed *v* (m/s)	3.00	
Volume flow rate, *Q* (m^3/s)	0.212	

The volume flow rate of water discharged by the pump was estimated using Equation (14) for discharge from a horizontal pipe given the horizontal shift, x = 2 m, and vertical height, y = 1.5 m of the discharge stream, with an estimated dimensionless air resistance factor, k = 0.85.

Table 3: Daily Drainage Coefficient for Hampshire-Belvedere Scheme with pump

Parameter	Value	Drainage coefficient equation
Volume flow rate for pump, *Q* (m^3/s)	0.212	$D.C. = \frac{Q \times t \times 3,600}{A \times 1,000}$ $= \frac{0.212 \times 18 \times 3,600}{0.63 \times 1,000}$ = 22 mm
Duration of operation, *t* (hr)	18	
Daily drainage volume, *D* (m^3)	137,376	
Drainage area, *A* (km^2)	0.63	
Drainage coefficient (mm)	22	
Drainage coefficient, *D.C.* (inch)	0.87 in	

Tables 4 and 5 give the total discharge capacity and the drainage coefficient of the area for the 3-ft diameter culvert pipe.

Table 4: Volume Flow Rate Calculations for Williamsburg-Hampshire 3-ft Diameter Culvert Pipe

Parameter	Value	Volume flow rate equation
Radius, *r* (m)	0.457	$Q = Av = 3.14 \times (0.457)^2 \times 1.00$ = 0.656 m^3/s
Area, *A* (m^2)	0.656	
Flow speed *v* (m/s)	1.00	
Volume flow rate, Q_1 (m^3/s)	0.656	

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Table 5: Daily Drainage Coefficient for Williamsburg-Hampshire Housing Scheme with Culvert Pipe

Parameter	Value	Drainage coefficient equation
Volume flow rate for 1 pipe, Q_1 (m^3/s)	0.656	$D.C. = \frac{Q_1 \times t \times 3{,}600}{A \times 1{,}000}$ $= \frac{0.656 \times 24 \times 3{,}600}{0.63 \times 1{,}000}$ = 90 mm
Duration of draining, *t* (hr)	24	
Daily drainage volume, *D* (m^3)	566,784	
Drainage area, *A* (km^2)	0.63	
Drainage coefficient (mm)	90	
Drainage coefficient, *D.C.* (inch)	3.54	

Provided the internal drains are unobstructed and free of debris and conveyance to the drainage structure is good, the area should manage a daily rainfall-runoff equivalent to the combined drainage coefficient of 112 mm (4.4 inches) of the drainage pipe and pump with minimal flooding in 24 hours. Only if runoff exceeds this figure will flooding occur. Note that in the absence of the pump, this figure will drop to 90 mm (3.54 inches) with an increased likelihood of flooding should runoff exceed this lower value. However, if the ground is saturated and all surface storage spaces are filled by previous rainfall, continuous rainfall that exceeds the drainage coefficient is more likely to cause flooding. With the peak rainfall event of 188.7 mm on June 22, 2017, at John’s Village (Table 1), the runoff for this area (C = 0.5 and using Equation 7) should be 94.4 mm. This runoff will tax the drainage infrastructure and cause flooding unless an adequate pump is present to provide assisted drainage.

During the annual May-July rainy season in 2024, Williamsburg-Hampshire experienced instances of flooding. On June 25, 2024, after receiving 55.4 mm of rainfall, low-lying areas were inundated. Nearby Rose Hall Town, located to the east, recorded 66.1 mm of rainfall, while John's Village, 5 km to the southeast, received 100.4 mm. Although no flooding was reported in Rose Hall Town, low-lying areas in John's Village were affected. All three areas had experienced steady but less intense rainfall for the previous nine days, which likely contributed to ground saturation in Williamsburg-Hampshire, making it more vulnerable to flooding.

Field observations revealed that many internal drains and culverts in Williamsburg-Hampshire are undersized and clogged with aquatic vegetation, which increases hydraulic resistance and reduces the conveyance capacity to the sole drainage culvert leading to the Hampshire-Belvedere canal. Vegetation, silt, and debris obstructing internal drainage systems is a widespread issue in many drainage areas across Guyana.

Residents have complained about the slothfulness of local authorities in cleaning, de-silting, and maintaining the drainage structures. This problem is further exacerbated by the fact that many internal drains and canals are undersized due to unplanned, and in some cases, planned modifications.

D. Effects Of Reducing The Size Of A Drainage Canal

A brief description of the consequences of reducing a drainage canal width from 10 ft to 1.5 ft is now discussed. According to the Chezy-Manning equation, a 1.5-foot-wide (0.46 m) concrete drain will convey eight times less water per second than a 10-foot-wide (3.05 m) earthen side canal. Lining the bottom and sides of the 10-foot canal with finished concrete (n = 0.012) increases its conveyance capacity by 80%. Table 6 below compares the two conveyances, assuming a rectangular cross-section. To match the volume conveyed by the earthen canal (n = 0.022), the concrete drain must be at least 6.25 feet wide. In summary, reducing the width of a drainage canal from 10 feet to 1.5 feet increases the flood risk by a factor of eight.

Table 6: Comparison of Drainage Parameters for Earthen Side Canal and Concrete Drain.

Parameter	Earthen side canal	Small concrete drain
Width, *w* (m)	3.05	0.46
Depth, *d* (m)	1.00	1.00
Cross Section Area, *A* (m^2)	3.05	0.46
Wetted Perimeter, *P* (m)	5.05	2.46
Hydraulic radius, *R* (m)	0.604	0.186
Slope, *S*	0.0002	0.0002
Manning coefficient, *n*	0.022	0.012
Volume flow rate, *Q* (m^3/s)	1.40	0.18
Volume flow rate (ft^3/s)	49.5	6.20

The table was created in MS Excel with inputs for width, depth, slope, and Manning coefficient for the channel. The appropriate formulas in Excel were set up, including the Chezy-Manning equation, to calculate the other parameters and determine the volume flow rate or conveyance capacity of the channel. Once the table and formulas are created, the inputs in the table can be easily changed to see what would be the variations in the other parameters and the discharge rate.

E. Recommendations for Williamsburg-Hampshire

The existing culvert should be enhanced by installing another 3-ft diameter drainage pipe to allow for increased drainage into the Hampshire-Belvedere canal. This would double the drainage coefficient of the area, enabling it to

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better handle peak rainfall events such as the 188.7 mm rainfall on June 22, 2017.

The old non-functional 7-ft wide sluice at this canal was built too far inland with a 1.2-km outfall channel to the Atlantic Ocean that made the channel prone to siltation and blockage by the periodic mudbanks moving along the seashore. A new sluice, twice the width of the old one, should be built closer to the ocean with a short outfall channel not longer than 200 m to reduce siltation in the channel but far enough away from the shore to minimise wave impacts on the sluice. Its discharge capacity will be about 2.5 times greater, and this increased flow will also help keep the outfall channel clear of silt and mud. This new sluice will significantly improve the drainage coefficient by about 100 mm for the entire 2 square km of villages from Williamsburg to Albion north of the Corentyne main road and will assist the drainage systems at Albion-Chesney and Rose Hall Town.

A permanent pump with adequate discharge capacity should be installed alongside the recommended new sluice to provide assisted drainage during heavy rainfall when the tide is high and the sluice cannot be opened.

The local governing authority of the surrounding communities should ensure that all canals, culverts, and drainage infrastructure are regularly cleared of debris, silt, and vegetation to prevent blockages and to maintain their conveyance effectiveness. The internal drains need refurbishing and resizing to increase their storage and conveyance capacities.

Given that about 100 acres of the housing scheme are still occupied with space for probably 500 additional residential lots, the local authority needs to be proactive and plan for the future development of the drainage system to improve its efficiency. The construction of new houses and roads will increase the impervious areas, reducing water infiltration into the soil and causing the runoff coefficient to rise, thus increasing the flood vulnerability of the scheme to peak rainfall events.

F. Brief Description of the Kilcoy-Chesney Housing Scheme Drainage Area

This new housing scheme, in Figure 2 above, established from 2012 to 2015, covers 258 acres (1.0 square km) of flat, low-lying grasslands between the villages of Albion and Fyrish. It is located about 0.5 km northwest of GuySuCo's Albion Sugar Factory at Latitude 6° 15.8' N, Longitude 57° 23.1' W. It lies directly north of and contiguous with the older Chesney Housing Scheme, which sits on a slightly elevated inland high sand reef (Ishmael, 2005). Due to this elevation, the old scheme is less prone to flooding than the new one. The new scheme forms an approximate rectangular shape, measuring 1.74 km in length and 0.63 km in width. It is empoldered by low earthen embankments and drained via several culverts into GuySuCo's main No. 4 canal along its eastern boundary. The embankments also serve as roads for the community. The main canal is drained by GuySuCo's Albion-Chesney pumps and sluices, located 1.62 km north, discharging into the Atlantic Ocean. So far, by August 2024, over 50% of the scheme has been occupied by residential houses. Although the new scheme benefits from this main canal drainage, it suffers from inadequate culvert linkage to the canal, its naturally low elevation, and under-maintenance of its internal drains, which makes it more susceptible to flooding.

G. Kilcoy-Chesney Housing Scheme Drainage Area Technical Details

Area = 1.0 km^2 Number of culverts: 3 & 4 gravity drainage pipes of 2-ft (0.61-m) diameter; Estimated rainfall runoff coefficient = 0.7.

Tables 7 and 8 below give the total discharge capacity and the drainage coefficient of the area, assuming that all drainage structures are fully operational and clear of obstacles.

Table 7: Volume Flow Rate Calculations for Kilcoy-Chesney Drainage Culvert Pipe

Parameter	Value	Volume flow rate equation
Radius, r (m)	0.305	$Q = Av = 3.14 \times (0.305)^2 \times 1.00$ $= 0.292$ m^3/s
Area, A (m^2)	0.292	
Flow speed v (m/s)	1.00	
Volume flow rate, Q_1 (m^3/s)	0.292	
Volume flow rate, Q_4 (m^3/s)	1.17	

Table 8: Daily Drainage Coefficient for Kilcoy-Chesney Housing Scheme

Parameter	Value	Drainage coefficient equation
Volume flow rate for 4 pipes, Q_4 (m^3/s)	1.17	$D.C. = \frac{Q_6 \times t \times 3{,}600}{A \times 1{,}000} = \frac{1.17 \times 24 \times 3{,}600}{1.0 \times 1{,}000} = 101$ mm
Maximum duration of draining, t (hr)	24	
Daily drainage volume, D (m^3)	101,088	
Drainage area, A (km^2)	1.0	
Drainage coefficient(mm)	101	
Drainage coefficient, $D.C.$ (inch)	4.0	

The 24-hour drainage coefficient (101 mm) of the Kilcoy-Chesney Housing Scheme is similar to that of the Williamsburg-Hampshire Scheme (90 mm) for the drainage pipe alone. Hence, similar inferences can be drawn: this area should be able to manage a rainfall runoff of 101 mm with little flooding but is likely to flood with higher runoff, in which event pumps will be required to assist drainage. As with the Williamsburg-Hampshire area, this scheme is flood-vulnerable due to inadequate culvert linkage to the main canal, its flat low elevation, and subpar maintenance of structures. Gravity drainage pipes are inadequate for extreme rainfall events, and two of the four culvert pipes are partially blocked by debris and vegetation. This partial blockage can decrease the drainage capacity by at least 25%, thus reducing the drainage coefficient to 76 mm or even less.

This housing scheme was flooded on June 1, 2021, after one week of total rainfall of 238.9 mm was recorded at John's Village and 256.9 mm at Rose Hall Town. Portable pumps were temporarily installed to provide assisted drainage but have since been removed and allocated elsewhere.

On May 24, 2021, Johanna, Black Bush Polder recorded the highest daily rainfall in Guyana with 70.6 mm, followed by an even greater figure of 145.5 mm on May 29. Black Bush Polder was flooded. By the end of May, many other areas in East Berbice-Corentyne were inundated following that week of rainfall all across the region.

According to Hydromet, the intense rainfall was primarily caused by the activation of the Inter-Tropical Convergence Zone (ITCZ) over Central and Southern Guyana, which created unstable atmospheric conditions. The presence of an atmospheric tropical wave further exacerbated the instability, leading to heavy downpours. These weather systems prolonged the rainy conditions, resulting in widespread flooding across East Berbice-Corentyne (Hydromet Weather Briefs, 2024).

H. Recurrence Interval for John's Village and Surrounding Areas

Daily rainfall data collected over eleven years (2013–2023) from the Hydromet rain gauge at John's, East Berbice, were used to identify the peak rainfall event for each year. From these data, the recurrence interval and the probability of a peak event recurring were calculated, as outlined previously. These results are presented in Table 9.

Table 9: Rank, Recurrence Interval, and Exceedance Probability of Peak Rainfall at John's, East Berbice

Year	Peak Rainfall (mm)	Rank	Recurrence Interval (yr)	Exceedance Probability (%)
2017	188.7	1	12.0	8.3
2016	138.2	2	6.0	16.7
2021	107.3	3	4.0	25.0
2023	100.4	4	3.0	33.3
2015	89.8	5	2.4	41.7
2019	84.1	6	2.0	50.0
2013	82.6	7	1.7	58.3
2020	82.5	8	1.5	66.7
2022	81.4	9	1.3	75.0
2018	78.0	10	1.2	83.3
2014	58.9	11	1.1	92.0

The John's Village rain gauge is located 4.3 km from the Williamsburg-Hampshire and 6.6 km from the Kilcoy-Chesney housing schemes. While rainfall and flooding in the East Berbice region can be localised, extreme events tend to impact the entire area, as occurred during the May–June 2021 rainfall and flooding. Therefore, it is reasonable to use the calculated recurrence values to assess the flood risk of the two locations, given their drainage capacity.

The information in Table 8 is shown in the graph in Figure 3 below for the return period (x) versus annual peak rainfall (y) at John's Village.

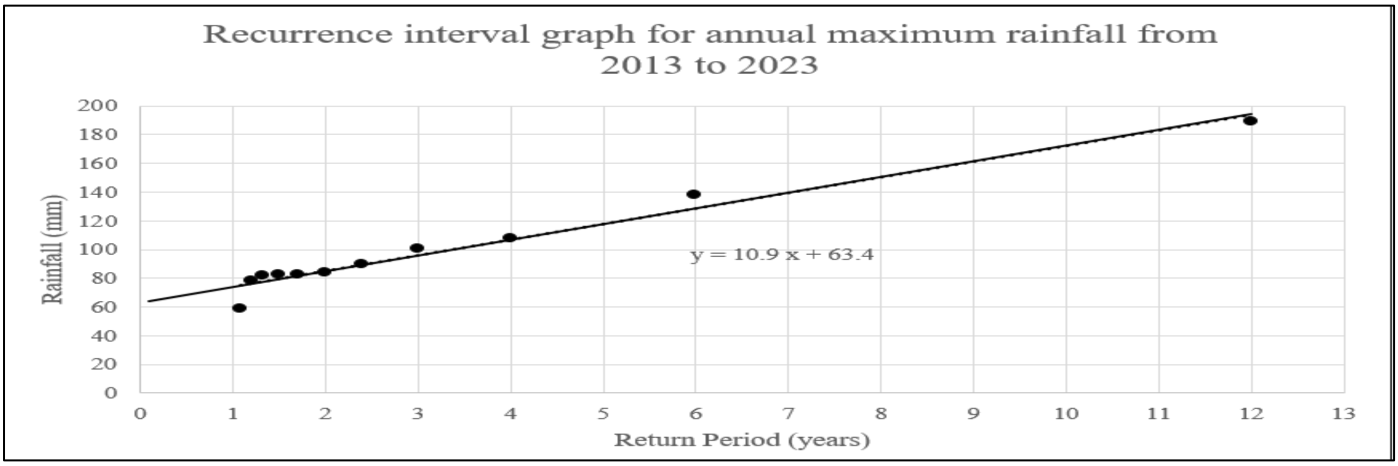

Fig 3: Recurrence Interval Graph for Annual Maximum Rainfall from 2013 to 2023

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The equation of the trend line, $y = 10.9\,x + 63.4$, is used to determine the flood recurrence interval given the drainage coefficient of the drainage area. Since the two areas' drainage coefficients are so close, at 90 mm and 92 mm respectively, we can substitute $y = 91$ mm into the equation and solve for x to obtain the flood recurrence interval. This yields $x = (91 - 63.4)/10.9 = 2.5$ years. Thus, the flood recurrence interval for a rainstorm of 91 mm or greater is $T_r = 2.5$ years. Using Equation (9), the probability of a flood of this magnitude or greater occurring in a given year is $Pr\ (P \geq 91\ \text{mm}) = 40\%$. Therefore, the likelihood of a rainstorm producing 91 mm or more rainfall in Johns's area and its surroundings is 40%. This result is consistent with the estimate provided by the Dutch Risk Reduction Team (2016), which predicted a flood recurrence interval of two years for Georgetown, based on a drainage coefficient of 101 mm. The similarity in results is expected, given the comparable rainfall patterns and drainage infrastructure along Guyana's coast.

I. Recommendations for Kilcoy-Chesney

To increase the recurrence interval and reduce the probability of flooding to specified values, the drainage infrastructure of the areas should be improved appropriately. For example, to double the recurrence interval and halve the probability of flooding, the drainage coefficient should be increased to $D.C. = y = 10.9 \times (5) + 63.4 = 118$ mm. This can be achieved by installing the requisite pumps to provide assisted drainage or constructing additional drainage culverts to the required drainage capacity. Increasing the number of culverts or their size to accommodate greater water flow would help this scheme. Specifically, upgrading the 2-ft diameter pipes to 3-ft diameter would double the drainage capacity of the area.

Similar recommendations made for Williamsburg-Hampshire would apply to Kilcoy-Chesney due to the similar topology of the land. Related local governments maintain the drainage systems of both areas under the Regional Democratic Council for East Berbice-Corentyne, which can provide additional flood management resources when necessary, and both areas benefit from the drainage provided by GuySuCo.

J. Brief Overview of the Mabaruma-Kumaka-Barabina Township Drainage Area

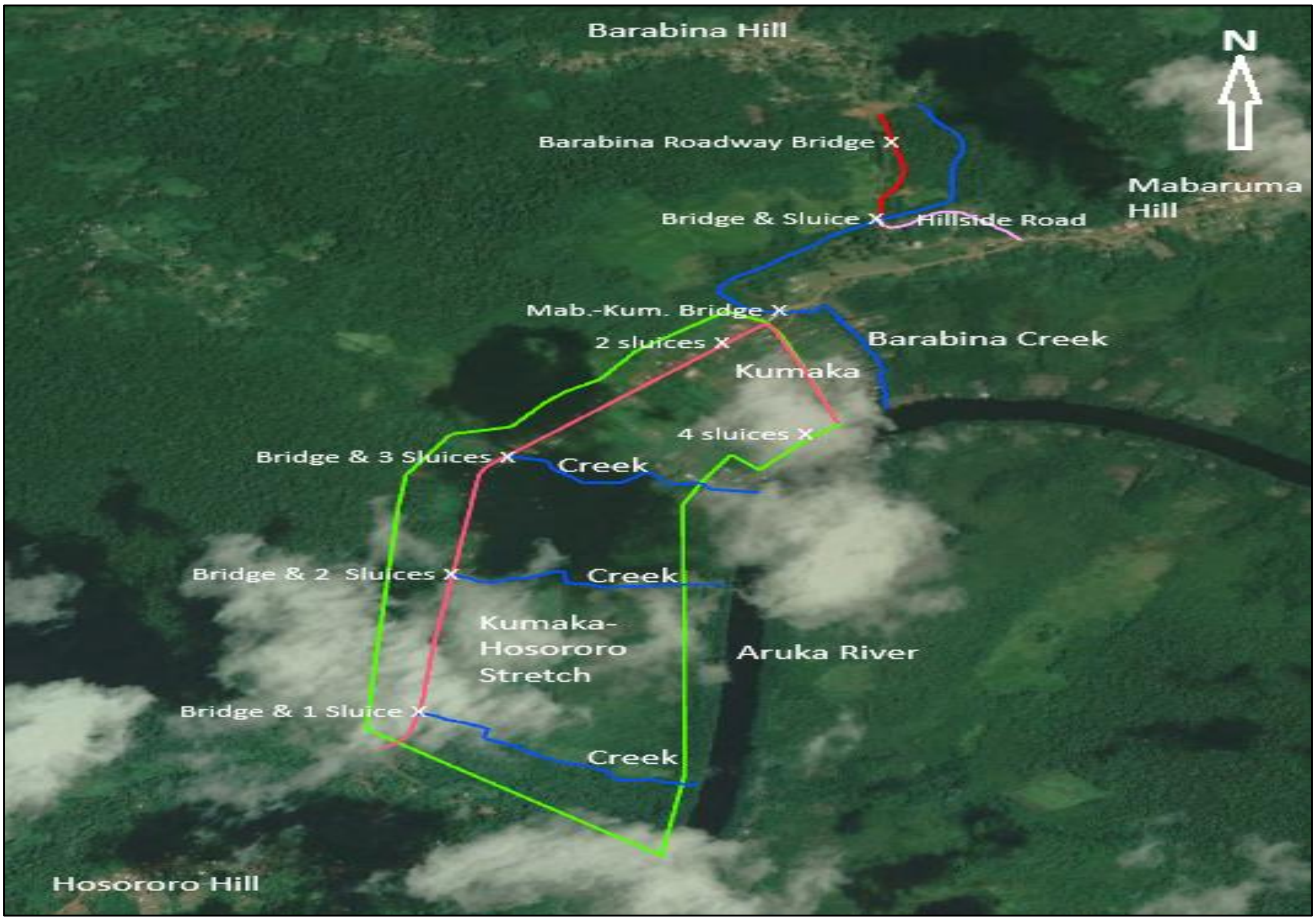

Fig 4: Satellite Map of Hosororo Hill to Barabina Hill, showing the Kumaka-Hosororo Stretch, Kumaka, and the Barabina Roadway Area and a Simplified Layout of their Drainage Systems (Google Earth Satellite Maps, 2024).

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The Mabaruma-Kumaka-Barabina Township (Figure 4 above) is a riverine community in the hilly and forested Barima-Waini region of northwestern Guyana. It is situated on the west bank of the Aruka River, approximately 32 km from the Atlantic Ocean, at Latitude 8° 11.8' N, Longitude 59° 47.9' W. The Aruka River is hydraulically connected to the ocean via the Barima River, Mora Passage, and Waini River, allowing the tidal cycle to affect the riversides of the study area. The township has several inhabited hills with elevations between 20 m and 100 m, with Hosororo Hill, Mabaruma Hill, and Barabina Hill being the most notable. Mabaruma serves as the administrative hub of the town and is home to Broomes Airfield, which hosts regular flights to Georgetown and the country's interior.

Kumaka is a low-lying riverside area situated between Hosororo Hill in the south and Mabaruma Hill in the north. Along the northern boundary of Kumaka, flows the Barabina Creek which joins the Aruka River north of the Kumaka waterfront. Kumaka forms the commercial and residential part of the town and has a wharf that accommodates a weekly ferry from Georgetown and smaller boats servicing the region’s interior.

The business and wharf areas are protected from the river by 1-m high steel sheet pilings revetments. Beyond the businesses and wharf, private individuals have built a 2-ft high earthen embankment river defence. The less-populated area between Mabaruma and Hosororo is locally referred to as Kumaka-Hosororo Stretch and has a road linking Hosororo, Kumaka, and Mabaruma. This road is flanked by two canals that join the Barabina Creek at the Mabaruma-Kumaka junction bridge.

The Kumaka drainage area extends 2.3 km along the west bank of the Aruka River, starting from the foothills of Hosororo and reaching Barabina Creek at the base of Mabaruma. With an average width of 0.74 km, it covers an area of 1.64 square km and is divided into two sections: the commercial-residential area, Kumaka, and the Kumaka-Hosororo stretch.

Another, but separate, low-lying area, with several houses, is located between Barabina Hill in the west and Mabaruma Hill in the east and has a roadway linking the two hills. Kumaka and Barabina roadway are slightly elevated approximately 1.5 m above the level of the Aruka River at low tide and are protected by 2-ft high earthen river dams at high tide. They are drained by self-actuated sluices that flow into the river and creeks linked to the river. These sluices are privately owned and maintained by individuals and business persons in the community. The elevations mentioned above were estimated from the Guyana Tide Tables & List of Lights (2023) and observations of the Aruka River.

The primary waterway draining the Barabina roadway area of the waters that flow down Barabina Hill and Mabaruma Hill is Barabina Creek, which passes immediately north of Kumaka before flowing into the Aruka River (Solomon, 2019). The northern section of Kumaka drains into Barabina Creek. These low-elevation areas are prone to flooding caused by heavy rainfall and high tides, exacerbated by inadequate and under-maintained drainage infrastructure.

K. Kumaka and Kumaka-Hosororo Stretch Drainage Area Technical Details

Area = 1.64 km^2; Number of self-actuated creek sluices: 8 functional, 2 non-functional; Number of self-actuated river sluices: 4 functional, 1 non-functional. Total number of functional sluices: 12. The sluices are constructed from wood frames and wood doors with 3-ft diameter high-density polyethylene (HDPE) drainage pipes (Figure 5 below). Rainfall-runoff coefficient of area = 0.5.

Tables 10 and 11 below give the total discharge capacity and the drainage coefficient of the area for 12 functional sluices. The flow speed of water through the sluices was observed to be about 0.5 m/s. This slow flow speed is due to the flat terrain of Kumaka and the elevated water level of the river even at low tide. The self-actuated sluice doors, which open and close gradually with the changing tides, also tend to reduce the flow speed of water and shorten the opening duration of the sluices, which is estimated to be 10 hours daily.

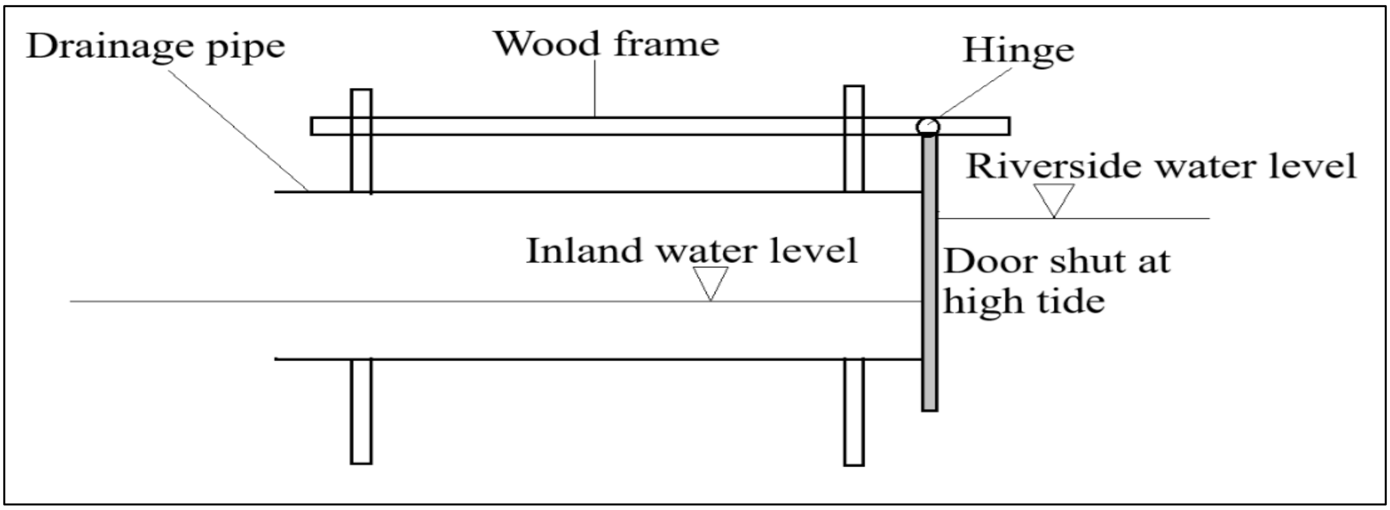

Fig 5: Diagram Showing a Self-Actuated Sluice used in Barima-Waini

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Table 10: Volume Flow Rate Calculations for Kumaka 3-ft Diameter Sluice Pipes

Parameter	Value	Volume flow rate equation
Radius W (m)	0.457	$Q = Av = 3.14 \times (0.457)^2 \times 0.5$ $= 0.328$ m^3/s
Area, A (m^2)	0.656	
Flow speed v (m/s)	0.50	
Volume flow rate, Q_1 (m^3/s)	0.328	
Volume flow rate, Q_{12} (m^3/s)	3.94	

Table 11: Daily Drainage Coefficient for Kumaka

Parameter	Value	Drainage coefficient equation
Volume flow rate, Q_{12}(m^3/s)	3.94	$D.C. = \frac{Q_3 \times t \times 3{,}600}{A \times 1{,}000} = \frac{3.94 \times 10 \times 3{,}600}{1.64 \times 1{,}000} = 86.5$ mm
Maximum duration of draining, t (hr)	10	
Daily drainage volume, D (m^3)	141,840	
Drainage area, A (km^2)	1.64	
Drainage coefficient(mm)	86.5	
Drainage coefficient, $D.C.$ (inch)	3.4	

Kumaka and Barabina roadway areas were flooded on May 25, 2021, after recording the highest rainfall of 138.7 mm in Guyana for that day (International Federation of Red Cross And Red Crescent Societies, 2021; Hydromet Weather Brief, 2021). With an estimated runoff coefficient of C = 0.5 for that area, the runoff for 138.7 mm of rainfall would have been 69.4 mm. The rainfall alone would have challenged the system, given that the ground would have already been saturated by the several days of past rainfall. The situation was exacerbated by the proximity of the location to the riverbank, its low, flat elevation, and high tides that prevented the opening of the self-actuated sluices. Hence, it was inevitable that the area experienced flooding.

The Barabina roadway, which lies in a valley between Mabaruma Hill and Barabina Hill, is flood-prone due to the Barabina Creek 180 m to the east, the flat elevation of that area, and two concrete bridges with narrow culverts that span the creek at Barabina and at Mabaruma-Kumaka junction. The narrow bridge culverts slow water outflow during low tide, causing the Barabina roadway area to remain water-saturated. Previously, wooden bridges spanned Barabina Creek at the roadway and at the Mabaruma-Kumaka junction, and the creek maintained its natural width, allowing for better drainage.

Efforts to properly maintain the wooden road bridge connecting Mabaruma and Barabina have been hindered as foundation piles repeatedly subside into the saturated soil or misalign over time. It was observed that soil was removed from the hillside of Mabaruma alongside the road going downhill to the Barabina roadway to be used as filling material for the water-saturated road bridge, but that did not solve the problem, as subsidence and misalignment of foundation piles continued to happen.

As of July 27, 2024, the road bridge is impassable to vehicles and undergoing repairs by building a corduroy log road on the bridge's southern approach to stabilise the soil and support the road. A wooden footbridge built about 50 m west of the road bridge some years ago has partially collapsed due to the water-saturated conditions. Barabina residents have made makeshift repairs to the footbridge to maintain the vital link with Mabaruma. The self-actuated sluice near the Barabina concrete bridge is non-functional and open to tidal flows, and no additional sluices are in place to manage the tide from the Aruka River into Barabina roadway.

L. Recommendations for Mabaruma-Kumaka-Barabina

The low earthen river dams protecting Kumaka from the Aruka River must be raised by at least 0.46 m (1.5 ft) with a proportional widening of the base to prevent overtopping during high spring tides. Bioengineering and the regrowth of native vegetation should be implemented on the dams to enhance stability and prevent erosion. Additionally, all non-functional sluices should be repaired, made fully operational, and subjected to regular inspections and maintenance. This is critical given that the sluices and doors are wood-constructed and use HDPE drainage pipes. The Mayor & Town Council should form public-private partnerships with the owners of the private sluices and dams to oversee these efforts and provide funding or subsidies for the inspection, repairs, and maintenance of these structures, as they provide a vital service for the entire community. Engaging the residents, the business community, and other stakeholders in collaborative discussions is also crucial to raise awareness about the urgent need for improved river defences and drainage infrastructure in Kumaka and Barabina roadway.

The culverts under the two concrete bridges spanning Barabina Creek should be widened or deepened and kept clear to allow water to flow freely through them into the Aruka River at low tide. The creek should be cleared of vegetation to reduce hydraulic resistance, improve its conveyance capacity, and help the roadway and surrounding areas drain faster, particularly after heavy rains or high tides. An additional self-actuated sluice should be installed near the Barabina concrete bridge opposite the existing sluice to drain the area on the other side of the roadway during low tide and to prevent water inflow during high tides. A sufficiently elevated earthen embankment, stabilised by protective vegetation, should be constructed along the banks of Barabina Creek near the roadway area to prevent water overtopping during the high spring tides.

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The town authority should consider installing permanent adequate pumps at both Kumaka and Barabina roadway areas to provide assisted drainage when water accumulates in those areas due to heavy rainfall or when the sluices cannot be opened at high tides. Pumps will help to move excess water out of these low-lying areas when natural drainage is insufficient.

Since the Hydromet Service already has rain gauges established at Mabaruma, Hosororo, and Kumaka, the long-term rainfall data can be analysed by Hydromet in collaboration with the Town Council's engineering department to determine the recurrence intervals for peak rainfall and flood events to better plan, design and maintain the river defences and drainage infrastructure of the township. A water depth gauge should be established in the Barabina Creek at the Mabaruma-Kumaka junction bridge and a daily record maintained of water levels. This is a critical spot where the two road canals from the Kumaka-Hosororo Stretch meet the creek before it flows into the Aruka River. A correlation of the rainfall data with water levels can be maintained to assist in decision-making related to drainage and flood issues affecting the community.

Removing soil from the Mabaruma hillside to be used as filling material for the Barabina roadway bridge is an inadvisable practice as this could weaken the slope and increase the risk of slope failure or landslides and block the hillside road. Filling materials should be sourced from elsewhere without the risk of destabilising the hillside, even though that might be more costly. The risk and expense of a landslide would be much greater if the practice of hillside soil removal is continued. The excavated hillside should no longer be used as a source for filling material but be allowed to revegetate naturally to re-stabilise itself.

Further research needs to be done in the hydrology of the Barabina area to determine other more specific measures that need to be implemented to stabilise the roadway and surrounding areas.

V. GENERAL DISCUSSION

Williamsburg-Hampshire, Kilcoy-Chesney, and Mabaruma-Kumaka-Barabina face similar but regionally specific flooding-related challenges. These communities, characterised by low-lying terrain, proximity to natural and artificial waterways, the Atlantic Ocean, and inadequate drainage infrastructure, experience regular and occasionally severe flood events, especially during high-intensity short-duration rainfall. This research emphasises how inadequate and under-maintained drainage systems exacerbate the flood risks for these regions. Even moderate rainfall can overwhelm the existing infrastructure, especially when compounded by high tides, which prevents the opening of sluices.

The common theme across these regions is the lack of resilient, modern infrastructure to manage water effectively. A consistent problem in each area is the lack of regular maintenance of drainage infrastructure by the responsible local government bodies. The current reliance on undersized and under-maintained structures creates vulnerability, particularly during extreme weather events. Across the regions, the undersizing of drainage structures, construction of impervious surfaces, and degradation of permeable surfaces have hindered water movements in both natural and artificial drainage systems.

All three regions need significant upgrades to their drainage system, including widening internal drains, installing new sluices and pumps, and upgrading culverts to better manage both tidal and rainfall-induced flooding. The focus should be on increasing the capacity of these systems to handle peak water flow and implementing modern technologies such as self-actuated sluices and automated pumps to ensure efficient drainage.

VI. GENERAL RECOMMENDATIONS

It would be engineering prudence to design drainage infrastructure for rainfall rather than runoff since runoff = $C \times$ rainfall, where $C < 1$, so rainfall is greater than runoff, although this would be more costly. So, a compromise would have to be made to design infrastructure for magnitudes between rainfall and runoff to provide adequate drainage. However, this would mean accepting a minimal level of flooding that should be quickly drained after a peak rainfall event is over. Cost-benefit ratios for drainage infrastructures would need to be estimated to decide the design and capacity of the structures.

Increasing urbanisation is creating more impervious surfaces and fewer green spaces to absorb water. As a result, runoff in urban areas will increase, putting greater pressure on drainage systems and increasing flood risks. To mitigate against this, drainage systems need to be re-engineered with enhanced conveyance and discharge capacities to manage the higher runoff and reduce flood vulnerability in newly developed areas. Urban planners must also avoid reducing the size of drainage infrastructure when adding new impervious surfaces such as roads, pavements, parking lots, and residential or commercial areas. Landscaping of urban areas must ensure the creation or restoration of sufficient permeable and green spaces to absorb rainwater. Effective urban planning should incorporate quantitative assessments of drainage capacity, storm, and flood recurrence intervals based on rainfall data, and runoff coefficients, as outlined in this research, to ensure the construction of resilient and adequate drainage systems.

Continuous monitoring of water levels in key waterways along with rainfall data from Hydromet's stations is essential for making informed decisions about flood management. Water depth gauges and rain gauges should be installed at critical points in the drainage systems, and the data should be analysed regularly to predict and prepare for extreme weather events.

Public-private partnerships should be established where residents, businesses, and local authorities collaborate to maintain and repair drainage structures. Residents should be educated about the importance of maintaining drainage infrastructure and how their actions, such as improper waste disposal, deforestation, and removal of green spaces, can contribute to flooding. Community-driven efforts, combined with governmental support, will create a more sustainable approach to flood risk reduction.

VII. CONCLUSION

Flooding in the Williamsburg-Hampshire, Kilcoy-Chesney, and Mabaruma-Kumaka-Barabina areas ranges from an occasional to regular but costly issue, primarily due to inadequate drainage infrastructure, subpar maintenance, and the natural meteorology and hydrology of these regions compounded by the effects of climate change. Mitigating these flood risks requires a multifaceted approach involving infrastructure upgrades, regular maintenance, community involvement, and the adoption of modern drainage and water management techniques. By implementing the recommendations proposed in this research, these areas, and other similar areas in Guyana, should be able to reduce their vulnerability to flooding, protect livelihoods, and improve the quality of life for residents.

The Government of Guyana has announced plans for significant improvements to the drainage systems of East Berbice-Corentyne. The first phase of those improvements has already started in the Upper Corentyne area. It is hoped that the findings of this research will play some useful role in guiding those efforts to design and construct resilient drainage systems to meet the challenges of the local coastal and riverine environments as the country moves forward into the 21st century and beyond.

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