Drainage Capacity and Flood Risk Assessment of Georgetown, Guyana

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Abstract: This study quantifies the drainage capacity and flood risk of Georgetown, Guyana, through field measurements and hydraulic analysis covering the city's catchment area of 28.5 km^2. Field visits to the city's sluices and pumps between 2016 and 2025 provided measurements of channel width, depth, and operational characteristics. Using the Chezy-Manning equation, a unified Sluice Drainage Coefficient Equation was derived to compute theoretical daily drainage capacity directly from sluice geometry and site parameters. Results indicate a total gravity drainage coefficient of approximately 61 mm/day (2.5 mm/hr) from the ten sluices, increasing to about 131 mm/day (5.5 mm/hr) when combined with the twelve drainage pumps. Rainfall data from 2011–2026 were analysed using the Weibull method to estimate return periods and exceedance probabilities. The analysis shows that temporary flooding occurs whenever rainfall intensity exceeds about 5.5 mm/hr, even when the system is fully operational. Recent rain-induced floods – such as 69.2 mm in four hours (December 2025) and 96.7 mm in four hours (February 2026) – produced intensities 3 – 5 times higher than the system's hourly discharge rate, resulting in temporary flooding until low-tide gravity drainage resumed. These findings confirm that Georgetown's flooding is governed primarily by its physical and tidal limitations rather than maintenance deficiencies. The integrated drainage-coefficient model developed in this study provides a practical tool for assessing and upgrading tidal drainage systems. It highlights the need to assess rainfall not only by daily totals but also by hourly intensity to guide realistic design standards for coastal urban drainage infrastructure.

Keywords: *Catchment Area, Chart Datum (CD), Conveyance, Discharge Capacity, Drainage Coefficient, Exceedance Probability, Flood Risk, Rainfall Intensity, Return Period, Runoff Coefficient, Stormwater Storage.*

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I. INTRODUCTION

Georgetown, the capital city of Guyana, is situated at the estuary of the Demerara River on its eastern bank on a flat alluvial coastal plain. Its boundary on the Atlantic Ocean extends from Kingston to Turkeyen for 6.0 km, on the Demerara River from Kingston to Thirst Park for 4.05 km, on the southern boundary with Meadowbank for 5.73 km, and the eastern boundary with Cummingslodge for 5.38 km. The city covers an area of 28.5 square km. The average elevation of the city is about 1.8 m above Chart Datum (CD), corresponding approximately to mean sea level. At the lowest astronomical tide (0.17 m CD), the city surface is about 1.6 metres above sea level, and at the highest astronomical tide (3.37 m CD), about 1.6 metres below sea level. It is protected on the north from the Atlantic Ocean by a reinforced concrete seawall (crest height 4.84 m CD) and on the west from the Demerara River by earthen dikes mostly covered over by wharves and other buildings (Guyana Tide Tables and List of Lights, 2025; Moray House Trust, 2014; Carter, 2014a).

There are 10 sluice sites and nine mobile pumps along the riverside, and three permanent drainage pump stations on the ocean side. Depending on the state of the tidal cycle, the sluices open for about 4 – 5 hours at low tide to drain the city twice in 24 hours, giving a total daily gravity drainage duration of 8 – 10 hours (Japan International Cooperation Agency, 2017; U.S. Army Corps of Engineers, 1998). The sluices are manually operated by gears and pulley mechanism, and the sluice operators are given up-to-date tide tables to know the opening and closing times for the sluice gates. In the event of heavy rainfall, the pumps provide drainage when the sluices are closed at high tides. If the rainfall runoff exceeds the combined drainage capacity of the sluices and pumps, flooding of the city or sections of it can happen. Flooding, with water levels ranging from several inches to about two feet, is likely to occur when rainfall exceeds 50 mm to 65 mm per day, or when there is short-duration high-intensity rainfall, such as 40 mm in one to two hours (Persaud & Forsythe, 1980; Ramraj, 1996).

This paper therefore evaluates Georgetown's flood risk by relating rainfall intensity and duration to the city's measured drainage capacity, providing an updated, field-calibrated assessment of its drainage performance.

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II. LITERATURE REVIEW

➢ *Historical Development of Georgetown's Drainage System*

Georgetown was originally established as a small town called Stabroek by the Dutch in the 1750s between Plantation Werk-en-Rust and Plantation Vlissengen. These were among several sugar plantations managed by the Dutch in the colonies of Demerara and Essequibo. Over the years, while it grew in area and population to encompass the plantations and other estates such as Eve Leary, Kingston, and La Repentir, the town changed hands between Dutch, French, and British rule.

In 1812, the town came under permanent British rule and was renamed Georgetown in honour of King George III and became the capital city of British Guiana (National Trust of Guyana, 2022). As the city expanded, all the sugar plantations in its boundaries were eventually converted into residential, commercial and industrial areas. The systems of canals and sluices that irrigated and drained the former sugar plantations were linked to form the city's drainage infrastructure that has endured, with modifications, expansions and infilling of some canals, to this day (Kupi Travel Guide, 2026; Moray House Trust, 2014; Carter, 2014b; Carter, 2014c).

Over decades of engineering evolution and construction, the system was designed to have a drainage coefficient of 50–65 mm/day. Government drainage authorities consistently cite a drainage capacity of about 2.5 in/day (63.5 mm/day) as the design drainage coefficient for Georgetown (Kaieteur News, 2015; Guyana Chronicle, 2016a, 2020; Stabroek News, 2016; Ministry of Agriculture, 2020).

However, field observations in this study indicate that the effective drainage coefficient varies widely with tidal conditions, sluice and pump functionality, operational response, and siltation. Over time, additional pumped drainage was added to the system with temporary mobile pumps placed at each sluice site as needed, including three permanent pump stations being built at Kitty in 1968 and Liliendaal in 1973 and 2025 (DRRT, 2016; Stabroek News, 2025a).

➢ *Post-Independence Challenges and Data Gaps*

In its post-independence years, Georgetown's drainage system started to deteriorate under the pressure of rapid urbanisation, in many cases unplanned and uncontrolled, as Pelling (1997, pp. 204-205) noted: "*Impervious areas within Georgetown increased by 50 per cent between 1963 and 1993 raising the volume of run-off channelled through Georgetown's drainage system. At the same time, drainage capacity has been reduced due to the infilling of drains, inadequate maintenance of existing drainage, the use of drains for informal refuse disposal and the use of drainage reserves for informal housing and peti-agriculture. Since 1989, uncontrolled urban expansion into unserviced areas has similarly increased city vulnerability to flooding from high rainfall events. A rise in sea levels will further reduce the efficiency of the city's gravity drainage, and may induce a rise in groundwater level*."

Pelling's assessment highlights many of the same issues that persist today – low infiltration, urban encroachment on drainage reserves, and the compounding effect of sea-level rise – all of which continue to affect the city's drainage performance.

One of the major challenges to improving Guyana's drainage systems is the lack, insufficiency, or inaccessibility of hydrological data needed for effective planning and design. This limitation was noted by the U.S. Army Corps of Engineers (1998) in its *Water Resources Assessment of Guyana*, which recommended the establishment of a National Clearinghouse for the collection, organisation, and management of hydrological data inter alia. The Corps advised that such an institution should be legally mandated to ensure continuity and inter-agency data sharing.

➢ *Modern Studies and Drainage Capacity Estimates*

In late 2015, the four-member Dutch Risk Reduction Team (DRRT) assessed Georgetown's flood vulnerability and drainage infrastructure over a period of four days. They highlighted the same deficiency – particularly the absence of updated data on the condition and capacity of the drainage system. Based on available data and brief field observations, the team estimated the city's drainage coefficient of ten sluices and eight pumps at 101 mm/day, while noting that the result was tentative because the sluice dimensions and site parameters were not directly measured (DRRT, 2016).

Later in 2016, a follow-up team of seven MSc Civil Engineering students from Delft University of Technology visited Georgetown for seven weeks and did a detailed analysis of the drainage network in the southern section of the city, an area of 3.36 square km, about 12% of the city's area (Guyana Chronicle, 2016b). From historic rainfall data and field measurements of canals, culverts, and hydrological parameters, they developed a hydraulic drainage model to predict the flood vulnerability of the area. The team presented its model and report to the local drainage authority to use to further develop drainage analyses of the rest of Georgetown.

While the team did valuable work, it did not directly measure sluice dimensions and site parameters to determine quantitative discharge capacities and drainage coefficients. It also did not account for the underlying impervious clay soils of Georgetown that hinder the infiltration of rainwater and may have underestimated runoff coefficients, leading to an underestimation of runoff volumes and an overestimation of the drainage characteristics of the area (Remmers et al., 2016).

In 2017, the Japan International Cooperation Agency (JICA) & CTI Engineering International incorporated the Dutch findings, adopting the same estimated drainage coefficient of 101 mm/day for Georgetown, and proposed system upgrades aimed at increasing it to 134 mm/day (JICA, 2017). Although they did not measure sluice dimensions, they conducted soil borings to better understand the impervious

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nature of the clay soils underlying Georgetown, which severely hinder infiltration, thereby giving a more realistic estimation of the runoff coefficient.

Earlier work by Rowe (1970), titled *A Report on Declared Drainage and Irrigation Areas in Guyana*, assessed the drainage capacities of coastal systems designated as Declared Drainage and Irrigation (DDI) Areas. However, Georgetown was not included in that study, as it is not classified as a DDI area. Rowe's study focused on agricultural drainage and irrigation schemes along the coastlands of Essequibo, Demerara, and Berbice.

While Rowe provided qualitative descriptions of the performance of these systems and reported some quantitative data for them, he did not report measured data of the dimensions or hydraulic parameters of sluices or canals. Consequently, his findings could not be used to find accurate discharge capacities for gravity drainage sluices. To date, no studies have been identified that provide direct measurements of sluice gate dimensions; however, estimates of sluice drainage capacity have been found in some studies.

➢ *Rainfall-Flood Analysis*

Persaud & Forsythe (1980) and Ramraj (1996) both emphasised that rainfall-flood analysis in Guyana cannot be reliably performed on a daily basis using the conventional daily drainage coefficient. They observed that most flood events in coastal Guyana are caused by short-duration, high-intensity rainfall, which temporarily overwhelms the drainage system even when total daily rainfall remains within design limits. This observation is particularly relevant to Georgetown, where the current drainage coefficient of 131 mm/day (5.5 mm/hr) can be exceeded during a storm producing 48 mm of rain in four hours (12 mm/hr). Under such conditions, rainfall temporarily exceeds the drainage capacity per hour, resulting in temporary flooding despite an adequate system designed on the basis of a daily drainage coefficient.

➢ *Contribution of the Present Study*

The current research therefore extends beyond the study of Rowe and others by directly measuring sluice dimensions, evaluating site parameters and runoff coefficients, and applying hydraulic equations, including an integrated Sluice Drainage Coefficient Equation, to quantify more accurately the drainage capacity and flood risk of Georgetown. This study seeks to address those data gaps by conducting more detailed field measurements of the Georgetown system. Incorporating these data with the city's recorded rainfall patterns allows for a flood-risk assessment by comparing available daily and hourly drainage rate with the recurrence of high-intensity rainfall events. To quantify the city's drainage performance under these tidal and hydraulic constraints, field measurements and analytical derivations were undertaken as described below.

III. METHODOLOGY

➢ *Rainfall and Assessing Flood Risk*

Rainfall records corresponding to flooding caused by intense precipitation were compiled using data from the Hydrometeorological Service of Guyana (Hydromet), along with information from government and media reports. Generally, flooding occurs when rainfall magnitude exceeds the city's drainage capacity. More specifically, flooding begins when the hourly runoff rate surpasses the hourly drainage rate, both expressed in millimetres per hour. This occurs most often during short-duration, high-intensity storms, as observed by Persaud & Forsythe (1980) and Ramraj (1996), rather than during prolonged rainfall, which is spread over the day and can be managed more effectively by the drainage system.

This study assesses flood risk both on a daily basis and an hourly basis, since Guyana's rainfall is dominated by short, intense storms rather than prolonged daily rainfall. The city's theoretical drainage capacity of 131 mm/day (5.5 mm/hr) implies that any rainfall event exceeding the hourly rate will produce temporary flooding. For example, a downpour yielding 28 mm of rainfall in two hours (14 mm/hr) is more than twice the city's hourly drainage rate. The resulting runoff volume would require approximately five hours of continuous drainage to remove, assuming ideal conditions of unobstructed flow and optimal sluice and pump operation.

➢ *Rainfall-Flood Criteria*

- *Criterion Using Runoff: Flooding Occurs if* $CR > D$,

Where

C = runoff coefficient (dimensionless)

R = rainfall intensity (mm/hr)

D = hourly drainage rate (mm/hr)

This compares the hourly runoff rate with the hourly drainage rate.

- *Criterion Including Reductions in Usable Capacity: Flooding Occurs if* $CR > kD_0$,

Where

D_0 = theoretical maximum hourly drainage rate (mm/hr) under ideal conditions,

k = availability factor ($0 < k \leq 1$) that accounts for reduced capacity due to high tides, blocked drains, or delayed operation. Use $k < 1$ when sluices are closed, canals are obstructed, or pumps are partly offline. If the left side exceeds the right, incoming runoff is faster than removal and ponding will occur until the imbalance is removed.

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- *Quick Georgetown Example*

- ✓ C = 0.85, R = 96.7 mm in 4 hr = 24.2 mm/hr → CR = 20.6 mm/hr
- ✓ Theoretical D_0 = 5.5 mm/hr
- ✓ If sluices or pumps are partly unavailable (e.g. k = 0.5), usable drainage rate kD_0 = 2.75 mm/hr.
- ✓ Since 20.6 mm/hr >> 2.75 mm/hr, flooding is inevitable.

- *Runoff Estimation*

The rate of surface runoff was estimated using the Rational Method (Nathanson, 2008), which expresses the peak discharge as

$$Q_r = C\,R\,A \quad \text{(Eq. 1)}$$

Where

Q_r = peak rate of runoff (m³/hr)

C = runoff coefficient for the drainage area (dimensionless, $0 < C < 1$)

R = rainfall intensity (m/hr)

A = drainage area (m²)

To express the runoff as a depth per unit area, Eq. 1 can be rearranged as

$$\frac{Q_r}{A} = C\,R \quad \text{(Eq. 2)}$$

Let the runoff depth rate r (m/hr) = Q_r/A, then

$$r = C\,R \quad \text{(Eq. 3)}$$

Multiplying both sides of Eq. 3 by 1,000 and averaging over a 24-hour period yields the average daily runoff (mm/day), which can be directly compared with the daily drainage coefficient of a catchment to assess its flood-risk potential (Hackett, 2024). The Rational Method is appropriate for urban and suburban basins with uniform land cover and limited infiltration – conditions that are comparable to the built-up areas and layout of Georgetown (Nathanson, 2008).

- *Selection of Runoff Coefficient for Georgetown*

The runoff coefficient (C) represents the fraction of rainfall that becomes direct surface runoff within a drainage area. Values of C obtained from standard runoff coefficient tables indicate that woodland areas range from 0.01– 0.20, residential areas from 0.30 – 0.75, and commercial districts from 0.70 – 0.95 (Nathanson, 2008).

Georgetown is a low-lying coastal city with dense urban development, paved roads, concrete drains, and limited green space. Most surfaces are impervious, except for small more pervious zones such as the Botanical Gardens, Bourda, and parts of, Liliendaal, Turkeyen and Sophia. Moreover, ground infiltration of rainwater is hindered by the impervious clay layers underlying the city, so absorption is limited mostly to the topsoil (Pelling, 1997; JICA, 2017). Based on these land-use and soil characteristics and standard runoff coefficient tables a representative value of C = 0.85 was used. This reflects the city's predominantly built environment and soil characteristics and aligns with coefficients of 0.70-0.95 used for high-density urban areas. Although local variations exist, C = 0.85 gives a realistic citywide average for estimating runoff and assessing Georgetown's overall drainage capacity and flood susceptibility.

- *Return Period and Exceedance Probability*

The return period (T_r) and exceedance probability (Pr) of rainstorms were estimated using the Weibull method:

$$T_r = \frac{n+1}{m} \quad \text{(Eq. 4)}$$

Where,

n = number of years

m = rank of rainstorm

$$P\,r(P \geq P_m) = \frac{1}{T_r} \times 100\% \quad \text{(Eq. 5)}$$

Where,

P = precipitation

P_m = amount or intensity of precipitation

(Viessman & Lewis, 2003; Persaud & Forsythe, 1980).

The return period and exceedance probability are used to assess flood risk and to plan drainage design. By relating rainfall magnitude and frequency to the catchment's drainage capacity, storm events that exceed system capacity can be identified. Because short-duration rainfall often exceeds the hourly discharge capacity even when daily totals are moderate, both daily and hourly rainfall intensities were analysed to ensure realistic assessment of flood risk and design capacity.

- *Field Visits*

The sluice and pump locations in the city were visited, and measurements done of the width and water depth of the rectangular channels of the sluices and observations made of site conditions, approach canals and outfall channels. The field data used in this study were collected over multiple visits spanning 2016-2025, with the final site visits done in 2025 to ensure the most current representation of the city's drainage system.

Figure 1 shows the locations of the sluices and pumps in Georgetown where field measurements and site observations were conducted.

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Fig 1 Map of Georgetown Showing Locations of Sluices and Pump Stations Where Field Data Were Collected. Base Map from Google Earth Satellite Imagery (Google, 2025), August 24, 2025. Field Data and Annotations by the Author (2016–2025).

- *Detection of Sluice Bed Levels and Field Safety*

Water depths and bed elevations of the sluices were determined using a graduated line marked at 0.05 m intervals and fitted with a weighted plumb bob, which was lowered vertically into the water column until firm contact was felt with the hard sluice bed at the bottom. The transition from soft silt to a resistant base was noted by the change in line tension, allowing the true bed depth to be distinguished from silted layers. At several locations, fixed depth sticks installed near the sluices were used to verify the readings, and at the Princess Street site, a measuring stick provided by the operator was employed. The precision of the depth measurements is estimated at ±0.05 m, based on repeated readings and visual referencing from the sluice base. Depths were successfully measured at eight of the ten sluices, with partial data at the remaining two due to heavy siltation.

Field measurements were conducted with due attention to safety and hygiene, as sluice sites often lacked guard rails, sometimes had slippery surfaces, and have water depths that can exceed a person's height even at low tide. In addition, the inlets and approach canals are frequently polluted with garbage and debris. Although the city has a dedicated sewerage network, much domestic and commercial wastewater still enters the drainage system, creating unhygienic conditions at sluice sites. These factors make field measurements physically challenging and may explain the scarcity of sluice dimension data in previous studies. During fieldwork, appropriate safety precautions were taken, including the use of a life jacket, high-grip field boots, and hand sanitisation after each visit. Figure 2 shows the layout of a typical Georgetown drainage sluice and elevations in Georgetown Datum (GD) relative to other proximate coastal structures.

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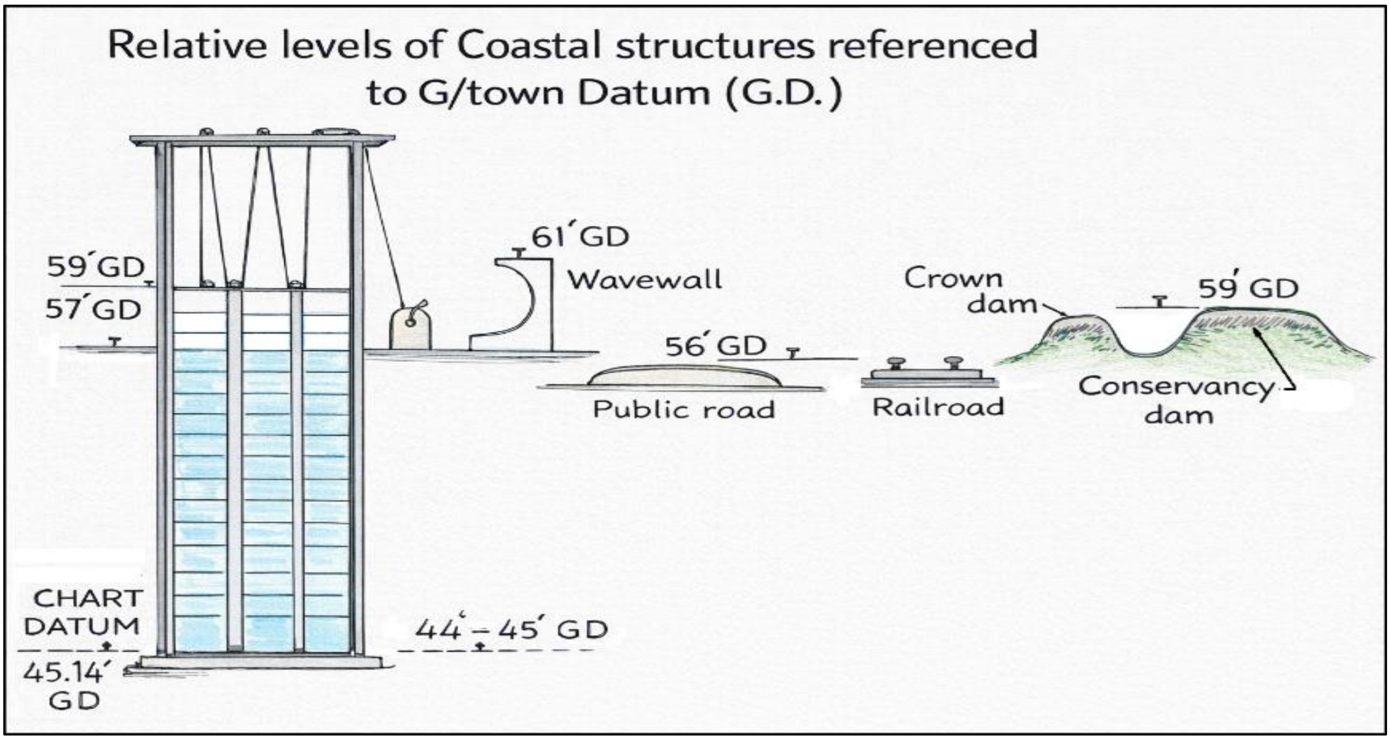

Fig 2 Relative Levels of Georgetown's Coastal Drainage and Defence Structures Referenced to Georgetown Datum (GD). Adapted from Bert Carter (2014a), "Coastal Structures," (Moray House Trust, 2014).

- *Sluice Operations*

Examination of tide tables for the Demerara Bar shows that the sluices can be opened for a range of 8–10 hours per day, consistent with estimates by JICA (2017). However, the effective duration varies with tidal state. During spring tides, when the low water level falls to about 0.3–0.5 m CD, sluices can remain open for 5–6 hours per tidal cycle (10–12 hours per day), but during neap tides, when the low-water level rises to 0.9–1.1 m CD, the opening period shortens to 3–4 hours per cycle (6–8 hours per day) (Guyana Tide Tables and List of Lights, 2016 & 2025). This variation affects the hydraulic head available for gravity drainage, reducing discharge capacity during neap tides.

For computation of drainage coefficients, a representative daily sluice opening duration of 8 hours was used, representing the long-term average between spring and neap tide conditions, along with 16 hours of pumped drainage, assuming ideal transition between sluice and pumped drainage. The drainage coefficient of pumps was calculated using the drainage coefficient equation relating discharge capacity, drainage area, and operational time (Eq. 8). A worked example of the calculation is presented in Table 7 for the new Liliendaal pump station. The total drainage coefficient is therefore the sum of the contributions from the sluices and the pumps.

To relate tidal elevations from the tide tables (referenced to Chart Datum) with local sluice elevations (referenced to Georgetown Datum), the conversions shown in Table 1 were used.

Table 1 Conversion Between Chart Datum (CD) and Georgetown Datum (GD) Elevations for Georgetown, Guyana.

Description	CD (metres)	GD (feet)
Zero of Georgetown Datum	-13.76	0.00
Zero of Chart Datum & Sluice bed	0.00	45.14
Lowest astronomical tide March 9, 2016	0.17	45.70
Highest low spring	0.48	46.71
Mean low tide	0.80	47.76
Mean sea level	1.80	51.05
Lowest high spring	2.74	54.13
Mean high tide	2.75	54.16
Highest astronomical tide April 8, 2016	3.36	56.16
Benchmark on Kingston Lighthouse & Sluice top	3.65	57.11
2nd highest recorded tide	3.70	57.28
Highest observed tide October 16 & 18, 2020	3.73	57.38
Crest of seawall/wavewall	4.84	61.00

Source: Adapted from Carter (2014a) and Guyana Tide Tables (2016; 2025).

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Conversion equations used were:

GD (ft) = [CD (m) /0.3048] + 45.14 ft, and CD (m) = [GD (ft) – 45.14 ft] × 0.3048.

The main elevations of a typical Georgetown sluice relative to Georgetown Datum (GD) and Chart Datum (CD) are shown in Figure 3, illustrating the positions of the sluice top, sluice bed, and characteristic tidal levels.

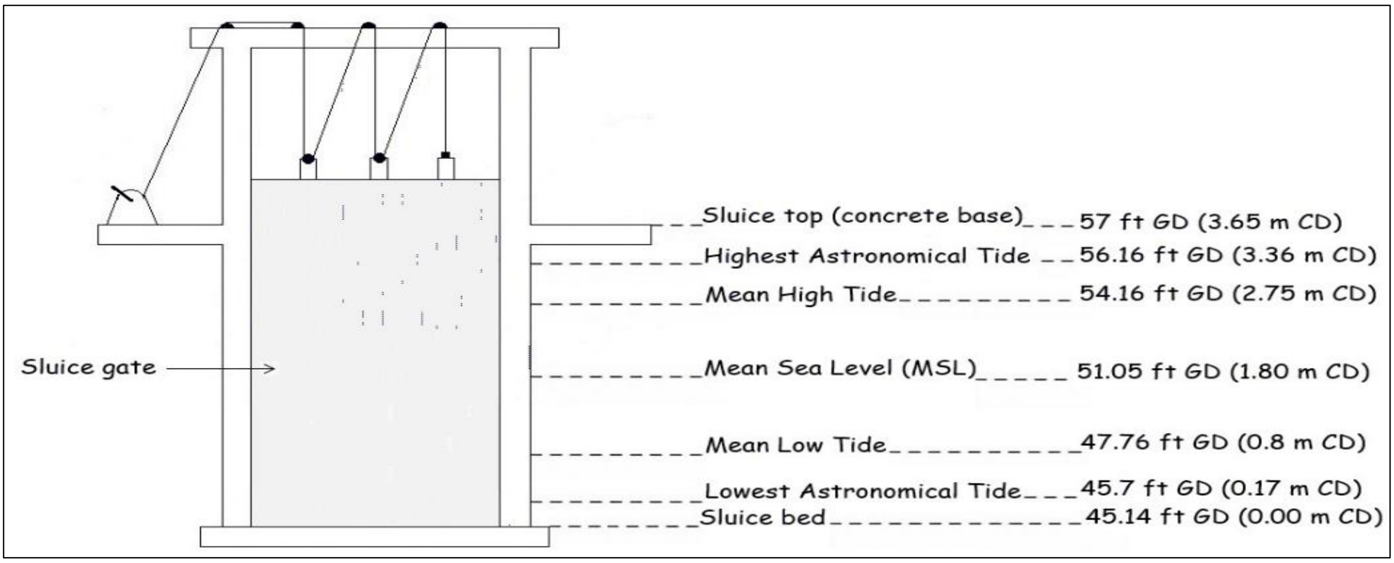

Fig 3 Relative Elevations of a Typical Georgetown Sluice Showing Key Levels Referenced to Georgetown Datum (GD) and Chart Datum (CD).

The elevations shown in Figure 3 define the hydraulic limits within which Georgetown's sluices operate. The sluice bed, at approximately 45.14 ft GD (0.00 m CD), represents the base elevation for drainage discharge, while the sluice top or concrete base at 57 ft GD (3.65 m CD) corresponds to the structural crest used as a benchmark on tide gauges at sluice sites. Mean Sea Level (MSL), at 51.05 ft GD (1.80 m CD), lies roughly midway between the mean high and mean low tides, delineating the point at which sluices are typically opened or closed during balanced tidal conditions. This elevation outline provides the reference for determining typical flow depth and sluice operational timing within each tidal cycle.

➢ *Estimating Discharge Capacities of Sluices and Pumps*

The Chezy-Manning equation for open-channel flow in a rectangular channel was used to estimate the volume flow rate or discharge capacity of the sluices. In Georgetown, sluice gates are normally raised fully during operation so that the bottom of the gate clears the water surface, ensuring that discharge occurs as free, open-channel flow rather than as submerged flow (Potter 2009). Sluice operators are instructed to raise the gate sufficiently high to avoid partial submergence and the resultant loss in discharge capacity. Consequently, flow through Georgetown's sluices is largely governed by the geometry of the approach canals and outfall channels and can be reasonably represented by the Chezy–Manning equation.

Discharge capacities of pumps were obtained from the manufacturer's specifications or the relevant literature. The operational duration of the sluices was estimated from the tidal cycles obtained from local tide tables. Since the pumps are used during periods of high tide when the sluices are closed, their daily operational times would provide about 14 to 16 hours of pumped drainage. Hence, during high day-long rainfall, the system ideally should be able to provide 24 hours of combined gravity and pumped drainage.

One hydrological equation was used to determine the daily drainage coefficient of each sluice and pump, based on their discharge capacity, drainage area, and operational times. To improve computational efficiency, the Chezy–Manning equation and the drainage coefficient equation were combined to yield a single integrated equation for sluice drainage coefficient.

➢ *Derivation of an Integrated Sluice Drainage Coefficient Equation*

The drainage efficiency of Georgetown, a tidal coastal city, is determined largely by the discharge capacities of its sluices and pumps, which are dependent on tidal cycles and hydraulic parameters. Traditional capacity estimates use separate equations for channel flow (e.g., Chezy-Manning) and for catchment drainage coefficient (DC). For practical engineering assessment, these relations were combined to derive a unified equation to allow direct computation of the DC from sluice parameters.

➢ *Assumptions*

- Each sluice performs as a rectangular open channel of width b (m) and water depth d (m) under steady flow conditions.
- Flow is governed by the Chezy-Manning relationship with Manning's roughness coefficient n and channel slope S.
- Sluices are fully open during operation. Entrance, contraction, and submergence losses are either negligible or incorporated in the effective value of n.

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- Each sluice opens for t hours per day, contributing to the drainage of a catchment area A (km²).
- All quantities are expressed in SI units, and the drainage coefficient (DC) is expressed in millimetres per day.

➢ *Derivation*

For a rectangular sluice:

$$\text{Flow area}, A = b\ d\ (\text{m}^2)$$

$$\text{Wetted perimeter}, P = b + 2d\ \ (\text{m})$$

$$\text{Hydraulic radius}, R = \frac{A}{P} = \frac{b\ d}{b + 2d}\ (\text{m})$$

The Chezy-Manning equation for uniform open-channel flow is:

$$Q = \frac{A\ R^{2/3}\ S^{1/2}}{n} \qquad \text{(Eq. 6)}$$

Where Q is the volume flow rate or discharge capacity (m³/s).

Substituting for A and R,

$$Q = \frac{b\ d}{n}\left(\frac{b\ d}{b + 2d}\right)^{2/3} S^{1/2} \qquad \text{(Eq. 7)}$$

The drainage coefficient (depth of water drained from the catchment per day) is defined as:

$$\text{DC (mm)} = \frac{3{,}600\ Q\ t}{1{,}000\ A} \qquad \text{(Eq. 8)}$$

(Rowe, 1970)

Where t is the daily operating time in hours, A is the catchment area in km², 3,600 converts hours to seconds and 1,000 converts metres to millimetres. These conversions ensure that the drainage coefficient is in millimetres.

Combining both expressions yields a unified Sluice Drainage Coefficient Equation:

$$\text{DC (mm)} = \frac{3.6\ t}{A} \cdot \frac{b\ d}{n}\left(\frac{b\ d}{b + 2d}\right)^{2/3} S^{1/2}$$

$$\text{DC (mm)} = \frac{3.6\ t\ S^{1/2}}{A\ n} \frac{(b\ d)^{5/3}}{(b + 2d)^{2/3}} \qquad \text{(Eq. 9)}$$

This equation gives the theoretical daily drainage coefficient in mm directly from sluice geometry and site parameters. This general form can be input in spreadsheet or computational software and the variables and hydraulic parameters adjusted as required for different sluice and site characteristics and operational duration.

➢ *Georgetown-Specific Form*

Substituting the measured and estimated parameters for the Georgetown sluices: n = 0.014 s/m$^{1/3}$, S = 0.0002, t = 8 hr, A = 28.5 km^2, the coefficient simplifies to a single empirical constant K:

$$K = \frac{3.6\ t\ S^{1/2}}{A\ n} = \frac{3.6 \times 8 \times 0.0002^{1/2}}{28.5 \times 0.014} = 1.0208\ \text{m}^{-5/3}$$

Hence, the per-sluice daily drainage coefficient for Georgetown becomes:

$$\text{DC (mm)} = 1.0208\ (b\ d)\left(\frac{b\ d}{b + 2d}\right)^{2/3} = \frac{1.0208\ (b\ d)^{5/3}}{(b + 2d)^{2/3}} \qquad \text{(Eq. 10)}$$

This simplified form allows direct computation of each sluice's daily drainage contribution in mm for a catchment area using only its measured width and depth.

The entire city was treated as a single catchment area of 28.5 km², since some areas are interconnected by culverts and drainage pipes that allow the sluices or pumps in one area to assist drainage in another area, thereby providing redundancy to the system (DRRT, 2016). The contribution of each pump or sluice to the total drainage coefficient of the entire city was then calculated.

➢ *Validation of the Integrated Sluice Drainage Coefficient Equation*

Table 2 shows the predicted discharge Q and DC values for the Georgetown sluices using the unified equation, from field-derived measurements and observations obtained in 2016 and 2025. The results, graphed in Figure 4, show a linear relation (R^2 = 1) between Q and DC, consistent with the expected linear relationship between discharge capacity and drainage coefficient predicted by Eq. 9, and confirming its suitability for drainage coefficient assessments under uniform flow conditions.

Table 2 Predicted Discharge and Drainage Coefficients of Georgetown's Sluices

	Sluices	**Width (m)**	**Flow Depth (m)**	**Discharge (m^3/s)**	**DC (mm)**
1	Young St.	4.76	1.20	4.96	5.0
2	Cummings	5.45	1.70	9.65	9.8
3	Lamaha St.	3.05	1.25	3.00	3.0
4	Church St.	3.17	1.70	4.77	4.8
5	Commerce St.	2.26	1.50	2.56	2.6
6	Princess St.	4.36	1.70	7.26	7.3
7	Sussex St.	3.68	1.50	4.91	5.0
8	LaPenitence (North gate)	4.32	2.50	12.04	12.2
	LaPenitence (South gate)	4.26	0.90	2.85	2.9

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9	Ruimveldt North (Riverview)	2.47	2.30	4.96	5.0
10	Ruimveldt South (Caneview)	2.40	1.80	3.51	3.5
			Avg = 1.64	Tot = 60.5	Tot = 61.1

The discharge capacity and drainage coefficient data listed in Table 2 is graphically illustrated in Figure 4.

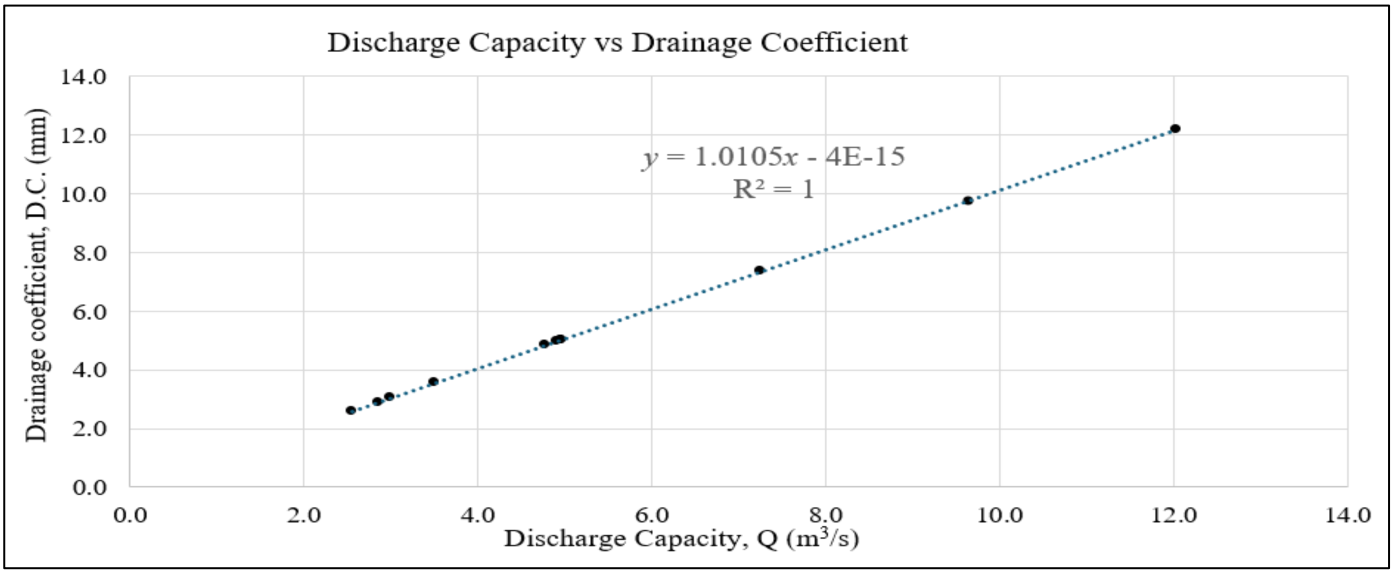

Fig 4 Graph Showing Linear Relation Between Discharge Capacity and Drainage Coefficient

➤ *Applicability and Limitations*

- The equation assumes free outflow (unsubmerged conditions). Under partial submergence or high downstream tide levels, discharge is reduced.
- The uniform channel slope *S* and Manning coefficient *n* should be adjusted if sluice roughness or geometry differs.
- The operating time *t* should reflect actual sluice-opening hours per daily tidal cycle.
- The formula is most accurate for trapezoidal or rectangular sluices draining flat, low-gradient coastal catchment areas like Georgetown's.

➤ *Selection of Typical Flow Depth*

Because the hydraulic head across the sluices varies during the tidal cycle, the average flow depth of 1.64 m (Table 2) was used to represent typical depth conditions during sluice opening at low tide. The sluice drainage coefficient rises only slightly to 61.6 mm/day when 1.64 m is used for all sluices, hence the more conservative estimate of 61.1 mm/day is retained. Since the typical sluice bed is at 0.00 m CD elevation and Mean Sea Level at 1.80 m CD (Figure 3), a depth of 1.64 m at the sluice would correspond to 1.64 m CD, and is therefore a reasonable estimate for the average depth conditions during the tidal cycle.

➤ *Selection of Manning's Roughness Coefficient*

A Manning roughness coefficient of *n* = 0.014 was used for the sluices in this study. According to Potter (2009), typical values range from 0.012 for finished concrete to 0.022 for earth channels. Georgetown's sluices are constructed of reinforced cast concrete, but most are unfinished and exposed to wear, algae growth, and minor surface irregularities, which slightly increase roughness above that of smooth finished concrete. The selected value therefore represents a realistic intermediate roughness appropriate for unfinished concrete sluice walls that form the controlling sections of the city's drainage outlets. It also reflects field conditions observed during sluice visits, where flow surfaces were concrete but not hydraulically smooth.

The approach canal and outfalls, which often have earthen sides and vegetation, would exhibit higher effective roughness; however, as the sluices govern discharge, *n* = 0.014 provides a suitable representative value for estimating the city's drainage coefficient.

The sensitivity analysis in Table 3 shows the effect of varying Manning's roughness coefficient (*n*) around the baseline value of 0.014 s/m$^{1/3}$ on the total sluice drainage coefficient.

Table 3 Effect of Manning Roughness Coefficient on Total Sluice Drainage Coefficient

Manning coefficient, *n* (s/m$^{1/3}$)	**Total Sluice Drainage Coefficient, DC (mm)**	**% Changes in DC relative to *n* = 0.014**
0.012	67.4	+10.3
0.014	61.1	0.0
0.016	50.6	-17.2
0.018	45.0	-26.4
0.020	40.4	-33.9

The results show that a 14 % decrease in *n* (from 0.014 to 0.012) increases the total drainage coefficient by about 10 %, whereas a 14 % increase in *n* (from 0.014 to 0.016) reduces it by about 17%, showing the inverse relationship between *n* and DC.

➢ *Selection of Channel Slope*

A channel slope of $S = 0.0002$ was used to represent the average gradient of Georgetown's drainage canals. This value corresponds to the mean surface gradient of Guyana's low-lying coastal zone, as reported by Merrill (1993), and is consistent with the city's topography where elevations range only about 1.5 to 2.0 metres above mean sea level over several kilometres. Field observations confirm that both the internal canals and outfall channels have very mild slopes characteristic of tidal lowlands with flow speeds generally below 1.0 m/s and rarely exceeding 1.5 m/s. The slope *S* represents the effective hydraulic gradient, or water-surface slope, between the drainage canal and the river during periods of sluice discharge at low tide. The adopted value of $S = 0.0002$ gives a realistic approximation of the average energy slope governing gravity drainage at the sluices and is suitable for use in the Chezy–Manning formulation of the Integrated Drainage Coefficient Equation. Local slope variations exist, and sensitivity calculations ($S = 0.0001$– 0.0004) were done to assess the effect on the drainage coefficient.

The sensitivity Table 4 shows sluice drainage coefficient against channel slope for ±50% changes around $S = 0.0002$.

Table 4 Effect of Channel Slope on Drainage Coefficient

Channel Slope, *S*	**Sluice Drainage Coefficient, DC (mm)**	**% changes in DC from *S* = 0.0002**
0.0001	43.2	-29.3
0.0002	61.1	0.0
0.0003	74.8	+22.4
0.0004	86.4	+41.4

➢ *Summary*

The derived equation combines hydraulic flow theory with catchment drainage assessment to give a single, practical design and evaluation tool for Georgetown's sluices. This integrated Sluice Drainage Coefficient Equation, while grounded in the classical Chezy-Manning approach, gives a simplified yet empirically validated method to estimate the city's theoretical daily drainage capacity directly from measurable sluice dimensions and site parameters.

Using the methodology described above, the discharge capacities of the sluices and pumps and the resulting drainage coefficients were calculated. The measured data and the results of these calculations are presented in the following section.

IV. RESULTS AND ANALYSIS

Table 5 shows the measured sluice bed depths and water depths at the sluices, together with field observations on siltation conditions.

Table 5 Field Measurements of Bed Depth, Water Depth and Siltation Conditions at Georgetown Sluices.

No.	**Sluice**	**Bed to Sluice Top (m)**	**Water Depth (m)**	**Notes**
1	Young St.	3.88	1.20	Little siltation. Clear inlet and outfall
2	Cummings	4.55	1.70	Possible bed contact. Canal heavily silted lee of sluice
3	Lamaha St.	>3.82	1.25	Totally silted outfall
4	Church St.	3.47	1.7	Possible bed contact, uncertain due to debris; some siltation
5	Commerce St.	>3.4	1.5	Gate open, flow seen; bed not visible
6	Princess St.	3.89	1.70	Hard bed confirmed with operator's stick. Silt depth 0.19 m; riverside 0.47 m
7	Sussex St.	3.88–4.03	1.50	Depth stick confirmed firm base. Silt depth lee 0.89 m; riverside 0.27 m
8	La Penitence (North Gate)	4.38	2.50	Hard bed distinct; silt depth 0.33 m lee
	La Penitence (South Gate)	4.38	0.90	Heavily silted inlet. Silt depth leeward 2.21 m; riverside 0.63 m
9	Ruimveldt North (Riverview)	~ 4.62	2.3	Possible bed detected; little siltation
10	Ruimveldt South (Caneview)	3.65	1.80	Hard bed distinct; little siltation

Significant siltation was observed at several sluices, particularly at Lamaha Street and the south gate of La Penitence, where the sluice bed could not be detected and siltation depths exceeded two metres. This reduces effective flow depth and discharge capacity, indicating that the actual

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drainage coefficient of the Georgetown system may be lower than the calculated theoretical 131 mm/day.

Table 6 shows the detailed calculations for discharge capacity and drainage coefficient of a representative sluice, which are incorporated into the Integrated Sluice Drainage Coefficient Equation for computational efficiency.

Table 6 Discharge Capacity and Drainage Coefficient Calculations for Young St. Sluice

Parameter	**Value**	**Equations**
Width, *W* (m)	4.76	$Q = \frac{A(R^{2/3})(S^{1/2})}{n} = \frac{5.71(0.798^{2/3})(0.0002^{1/2})}{0.014}$ = 4.96 m^3/s
Depth, *D* (m)	1.20	
Area, *A* (m^2)	5.71	
Wetted perimeter, $P = W + 2D$ (m)	7.16	
Hydraulic radius, $R = A/P$ (m)	0.798	
Slope, *S*	0.0002	
Manning coefficient, *n* ($s/m^{1/3}$)	0.014	
Flow speed, *v* (m/s)	0.87	$D.C. = \frac{3{,}600\ Qt}{1{,}000A} = \frac{3{,}600(4.96)(8)}{1{,}000(28.5)}$ = 5.0 mm
Discharge capacity, *Q* (m^3/s)	4.96	
Duration of opening of sluice, *t* (hr)	8	
Daily drainage volume, *D* (m^3)	142,848	
Drainage area of Georgetown, *A* (km^2)	28.5	
Drainage coefficient, DC (mm)	5.0	

Table 7 shows the detailed calculation of drainage coefficient for the two new pumps at Liliendaal using the drainage coefficient equation with each pump having a reported capacity of 4.3 m^3/s and average pump operating duration of 16 hours per day.

Table 7 Daily Drainage Coefficient for Liliendaal New Pumps

Parameter	**Value**	**Drainage coefficient equation**
Discharge capacity for 1 pump Q_1 (m^3/s)	4.3	$D.C. = \frac{3{,}600\ Q_2\ t}{1{,}000\ A} = \frac{3{,}600(8.6)(16)}{1{,}000(28.5)}$ = 17.4 mm
Discharge capacity for 2 pumps, Q_2 (m^3/s)	8.6	
Duration of operation of pumps, *t* (hr)	16	
Daily drainage volume, *D* (m^3)	495,360	
Drainage area of Georgetown, *A* (km^2)	28.5	
Drainage coefficient (mm)	17.4	

Table 8 shows the calculated discharge capacity and drainage coefficients of the sluices using the Chezy–Manning equation and assuming a channel slope of *S* = 0.0002, Manning roughness coefficient *n* = 0.014, and an average sluice operating duration of 8 hours per day.

Table 8 Calculated Discharge Capacity and Drainage Coefficients of Georgetown Sluices

No.	**Sluices**	**Breadth, b (m)**	**Depth, *d* (m)**	**Flow speed, *v* (m/s)**	**Discharge, Q (m^3/s)**	**Drainage Coefficient, DC (mm/day)**
1	Young St.	4.76	1.20	0.87	4.96	5.0
2	Cummings	5.45	1.70	1.04	9.65	9.8
3	Lamaha St.	3.05	1.25	0.79	3.00	3.0
4	Church St.	3.17	1.70	0.89	4.77	4.8
5	Commerce St.	2.26	1.50	0.75	2.56	2.6
6	Princess St.	4.36	1.70	0.98	7.26	7.3
7	Sussex St.	3.68	1.50	0.89	4.91	5.0
8	LaPenitence (North gate)	4.32	2.50	1.11	12.04	12.2
	LaPenitence (South gate)	4.26	0.90	0.74	2.85	2.9
9	Ruimveldt North (Riverview)	2.47	2.30	0.87	4.96	5.0
10	Ruimveldt South (Caneview)	2.40	1.80	0.81	3.51	3.5
	Average	3.65	1.64	0.89	5.50	5.6
	Total	-	-	-	60.5	61.1

When the average flow depth of 1.64 m in Table 8 is used for all the sluices, allowing for tidal variation during sluice opening, the drainage coefficient rises only slightly to 61.6 mm/day. Hence, the value of 61.1 mm/day is a reasonable estimate for the drainage coefficient provided by the sluices.

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Table 9 shows the reported discharge capacities and corresponding calculated drainage coefficients of the pumps operating for an average of 16 hours per day. Together, the results of Tables 8 and 9 give the total drainage coefficient of the Georgetown system.

Table 9 Pumps Discharge Capacity and Drainage Coefficients

No.	Pump	Discharge (ft^3/s)	Discharge, Q(m^3/s)	DC (mm)
1	Young St.	40	1.13	2.3
2	Cummings	80	2.27	4.6
3	Lamaha St	40	1.13	2.3
4	Church St	40	1.13	2.3
5	Commerce St	40	1.13	2.3
6	Princess St	40	1.13	2.3
7	Sussex St.	80	2.27	4.6
-	LaPenitence (No pump)	0	0.00	0.0
8	Ruimveldt North (Riverview)	40	1.13	2.3
9	Ruimveldt South (Caneview)	80	2.27	4.6
10	Kitty	152	4.30	8.7
11	Liliendaal – old	300	8.50	17.2
12	Liliendaal – new	304	8.60	17.4
	Average	103	2.92	5.9
	Total	1,236	35.00	70.7

The results in Table 9 show that the pumps provide a drainage coefficient of 70.7 mm/day, which, when added to the 61.1 mm/day provided by the sluices (Table 8), yields a total theoretical drainage capacity of 131.8 mm/day for the city, which is rounded down to 131 mm/day for a slightly conservative estimate. This figure is very close to the 134 mm/day target set by JICA (2017) for its proposed system upgrades. The increase in drainage capacity over the past decade therefore seems to result mainly from the addition of four pumps to the system.

The Kitty and Liliendaal pump stations do not have sluices and so can operate independently of the tides, allowing 24 hours operation during heavy rainfall. While this could raise the city's drainage capacity to a maximum of 153 mm/day (6.4 mm/hr) – beyond the conservative estimate above – operational factors such as equipment wear, maintenance needs, pump rotation practices, and costs may limit sustained continuous use. Even with continuous pumping, short, intense rainfall may still exceed this rate, so temporary flooding can still occur. The main benefit would be that floodwater would recede two to three hours sooner.

➢ *Rainfall and Flood Events in Georgetown*

Table 10 lists recorded major rainfall events that caused flooding in Georgetown from 2011-2026 and the corresponding rainfall totals used in this study.

Table 10 Major Rainfall Events that Caused Flooding in Georgetown

No.	Date	Rainfall (mm)	Source
1	February 20, 2011	127.0	Kaieteur News, 2011
2	February 28, 2012	130.0	Kaieteur News, 2012
3	November 27, 2013	128.9	Kaieteur News, 2013
4	November 19, 2014	186.0	Guyana Chronicle, 2014
5	June 18, 2015	106.3	Guyana Chronicle, 2015
6	July 15, 2015	209.8	Kaieteur News, 2015
7	December 23, 2016	101.6	Stabroek News, 2016
8	July 2, 2019	76.2	Stabroek News, 2019
9	November 3, 2020	120.3	Guyana Chronicle, 2020
10	June 15, 2021	137.4	Hydromet, 2021
11	December 26, 2021	88.9	Guyana Standard, 2021
12	July 24, 2022	102.1	Hydromet, 2022
13	November 22, 2022	101.6	Stabroek News, 2022
14	June 8, 2023	101.6	Kaieteur News, 2023
15	December 5, 2025	69.2	Hydromet, 2025
16	February 12, 2026	96.7	Hydromet, 2026

The rainfall totals recorded for these flood events are generally close to or exceed the estimated drainage capacity of Georgetown – 101 mm/day from the DRRT report (2016) or 131 mm/day from this current study – supporting the conclusion that rainfall approaching or exceeding this threshold is likely to cause flooding.

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Table 11 summarises the quantitative relationship between rainfall intensity, runoff, and drainage coefficient during four major flood events. It shows that each event produced rainfall intensities significantly exceeding the city's drainage rate, resulting in temporary flooding until low tide allowed sluice operation.

Table 11 Rainfall Intensity, Runoff, and Drainage Coefficient Relationships for Flood Events with Known Rainfall Duration in Georgetown.

Date	**November 27, 2013**	**June 19, 2015**	**December 5, 2025**	**February 12, 2026**
Total (mm)	128.9	27.9	69.2	96.7
Duration (hr)	6	2	4	4
Intensity (mm/hr)	21.5	14.0	17.3	24.2
Runoff (mm)	109.6	23.7	58.8	82.2
Runoff rate (mm/hr)	18.3	11.9	14.7	20.6
Drainage coefficient (mm/day)	75	101	131	131
Drainage rate (mm/hr)	3.1	4.2	5.5	5.5
Exceedance (mm/hr)	15.2	7.7	9.2	15.1
Drainage time (hr)	35.3	5.6	10.7	14.9

- Note: Calculations are based on rainfall and runoff data for representative flood events in Georgetown. Rainfall intensity (I) = total rainfall / duration; runoff (R_o) = $I \times$ runoff coefficient ($C = 0.85$); drainage coefficient values from field-derived analyses of sluices and pumps; drainage rate = drainage coefficient / 24; exceedance = (runoff rate – drainage rate); drainage time = runoff/drainage rate, all under ideal conditions. Results show that flooding occurs when hourly rainfall intensity exceeds the city's hourly drainage rate, as in this case: "*According to the Hydro-meteorological Office, Central Georgetown recorded 27.9 mm of rainfall between 08:00hrs and 10:00hrs* [on June 19, 2015]" (Guyana Chronicle, 2015).

➢ *Case Example – February 20, 2011 Flood Event*

On February 20, 2011, Georgetown received approximately 127 mm of rainfall within 24 hours – over three times the city's then design capacity of 38–50 mm per day (Kaieteur News, 2011). City officials reported that ten sluices and five pumps were operational, though two pumps serving the southern catchments were temporarily offline. Despite ongoing desilting of major canals, flooding occurred in multiple wards as high tide and silted outfall channels along the Demerara River restricted sluice drainage. This event illustrated that even a functional system is governed by a physical limitation where rainfall intensity exceeding the drainage coefficient inevitably produces temporary ponding until tide levels fall and sluices reopen.

➢ *Case Example – November 27, 2013 Flood Event*

On November 27, 2013, the city experienced one of the most intense rainfall events on record, with 128.9 mm of rainfall measured within six hours (21.5 mm/hr) at the Botanical Gardens gauge (Kaieteur News, 2013). The event inundated approximately 75% of the city, forcing the closure of 42 schools and numerous businesses. During the period of rainfall, two of the seven pumps were reported inoperative, and sluices were closed due to high tide, significantly reducing the city's drainage discharge capacity. The rainfall intensity exceeded the city's estimated hourly drainage rate (4.2 mm/hr) at that time by nearly fourfold, illustrating the physical limitation of the system when rainfall inflow exceeds outflow potential. Although poor maintenance and temporary pump failures contributed to localised retention, the primary cause of flooding was the extreme short-duration, high-intensity rainfall relative to the city's available drainage coefficient.

➢ *Case Example – July 24, 2022 Flood Event*

Heavy rainfall on July 24, 2022, contributed to localised flooding in parts of Georgetown, particularly in low-lying areas such as South Ruimveldt. According to the *Daily Weather Brief* issued by the Hydromet Service (2022, July 25), South Ruimveldt recorded the highest 24-hour rainfall total of 102.1 mm in the country for that day. This observation aligns with field reports of temporary street inundation and elevated canal levels within the city's catchment area. Such rainfall quantities often exceed the city's daily drainage capacity, especially when combined with high tides.

➢ *Case Example – December 5, 2025 Flood Event*

On December 5, 2025, the city experienced a period of short-duration high-intensity rainfall that resulted in localised flooding across several areas of the city. Streets in the central business district, including Regent, Camp, Wellington, and Robb Streets, were temporarily flooded following heavy rainfall during the morning hours (Guyana Chronicle, 2025; Stabroek News, 2025b). According to the *Daily Weather Brief* issued by the Hydromet Service (2025, December 6), 69.2 mm of rainfall was recorded in Georgetown for the 24-hour period ending 08:00 hours (See Appendix). Field reports indicate that most of this rainfall occurred within approximately four hours, producing an average rainfall intensity of about 17.3 mm/hr.

This rainfall intensity significantly exceeded the combined drainage capacity of Georgetown's 10 sluices and 12 pumps, estimated at 131 mm/day (5.5 mm/hr). Consequently, rainfall was entering the drainage system at a rate 11.8 mm/hr greater than the system's hourly drainage rate, leading to temporary ponding and localised flooding. Although the city's drainage capacity has increased by approximately 30% over the past decade – from about 101 mm/day (4.2 mm/hr) when only eight pumps were operational – the flat, tidal-coastal topography of Georgetown means that runoff cannot be drained rapidly when hourly rainfall intensity exceeds hourly drainage rate. Under such conditions, ponded water typically requires several hours to drain once rainfall ceases and sluice discharge resumes during low tide.

➢ *Case Example – February 12, 2026 Flood Event*

On February 12, 2026, Georgetown experienced 96.7 mm of rainfall in four hours during the early morning. With sluices closed due to the morning high tide and pumps operating at full capacity, widespread street flooding occurred across the city. The rainfall intensity – about 24.2 mm/hr – exceeded the city's drainage capacity of 131 mm/day (5.5 mm/hr), resulting in temporary inundation of streets and business areas. The event exceeded the system's hourly drainage rate by 18.7 mm/hr, explaining the observed temporary inundation. It was estimated that approximately 15 hours would be required for the accumulated runoff to drain from the catchment. The event illustrates that when short-duration rainfall intensity exceeds the city's drainage coefficient of 5.5 mm/hr, temporary flooding becomes inevitable, particularly during high-tide conditions when sluice drainage is restricted.

Across the 2011–2026 record, every major flood coincided with rainfall intensities exceeding 2–5 times the city's hourly drainage rate, confirming that short-duration, high-intensity rainfall is the dominant cause for flooding in Georgetown.

Table 12 shows the ranked rainfall events and the corresponding return periods and exceedance probabilities used to assess the likelihood of intense rainstorms that cause flooding in Georgetown.

Table 12 Ranked Rainfall Events with Estimated Return Periods and Exceedance Probabilities for Georgetown.

Rank	Date	Rainfall (mm)	Estimated Return Period T_r (years)	Exceedance Probability P_r (%)
1	15 Jul 2015	209.8	15.00	6.7
2	19 Nov 2014	186.0	7.50	13.3
3	15 Jun 2021	137.4	5.00	20.0
4	28 Feb 2012	130.0	3.75	26.7
5	27 Nov 2013	128.9	3.00	33.3
6	20 Feb 2011	127.0	2.50	40.0
7	3 Nov 2020	120.3	2.14	46.7
8	18 Jun 2015	106.3	1.88	53.3
9	24 Jul 2022	102.1	1.67	60.0
10	23 Dec 2016	101.6	1.50	66.7
11	22 Nov 2022	101.6	1.36	73.3
12	8 Jun 2023	101.6	1.25	80.0
13	12 Feb 2026	96.7	1.15	86.7
14	26 Dec 2021	88.9	1.07	93.3
15	2 Jul 2019	76.2	1.00	100.0
16	5 Dec 2025	69.2	0.94	106.7*

- *Note: Probabilities exceeding 100% indicate events with an expected frequency greater than once per year, that is, the return period is shorter than one year.

The data listed in Table 12 are graphed in Figure 5, showing the relationship between rainfall magnitude and estimated return period for the Georgetown rainstorms of 2011–2026.

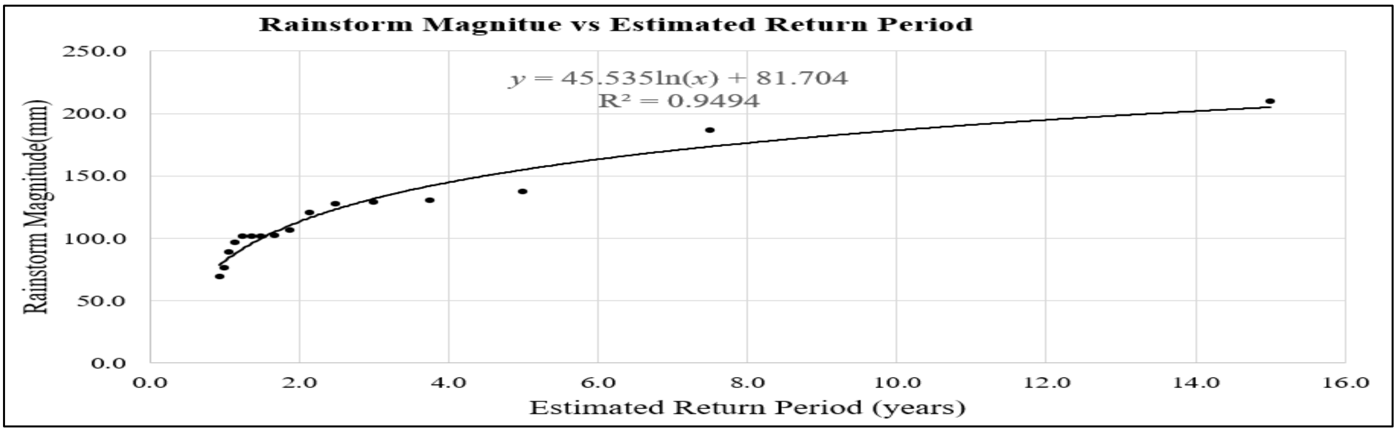

Fig 5 Return Period for Rainstorms from 2011 to 2026.

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A logarithmic trend line (R^2 = 0.9404) gave a better fit than a linear trend line (R^2 = 0.8513) (Figure 5). The logarithmic rainfall-return period equation obtained is $y = 45.535\ln(x) + 81.704$, where y = magnitude of rainstorm and x = return period. This equation was used to determine the return period for rainstorms that exceed the drainage coefficient of the city. For coefficient of 131 mm/day, the return period is approximately 3 years, with annual exceedance probability of about 33%. This means that there is a one-in-three chance in any given year that rainfall will exceed the city's drainage capacity, or that such an event occurs on average once every three years.

The DRRT report (2016) found that the return period for their 101 mm/day drainage estimate was 2 years with a 50% exceedance probability. Using the log equation obtained above, the return period for a 101 mm/day event is 1.5 years with exceedance probability of 65%. The current data therefore indicates that the chance of a 101 mm/day event now occurring in any one year has risen from one-in-two to one-in-one and half, a 33% increase. This means that rainstorms of that magnitude or greater are more likely to occur now than they were ten years ago with the consequential increase in flood events.

Moreover, Table 12 lists four rainstorms with magnitudes less than 101 mm/day that still resulted in flooding. For example, on December 5, 2025, 69.2 mm of rainfall fell in 4 hours, producing an average rainfall intensity of 17.3 mm/hr and an estimated runoff rate of 14.7 mm/hr, which significantly exceeded the system's current drainage rate of 5.5 mm/hr (Table 11).

The log equation shows that the return period of a rainstorm of 69.2 mm is approximately 0.76 year or about 9 months, meaning an expected frequency of occurrence more than once per year on average, or about once every 9 months. Even if such a storm were to last for 8 - 10 hours, its hourly runoff rate would still exceed the hourly drainage rate, and the city is likely to experience temporary flooding. Consequently, the city is highly susceptible to flooding at least once per year from such short, intense rainstorm events.

These results indicate that flood risk in Georgetown arises not only from extreme daily rainfall totals associated with longer return periods, but more importantly from short-duration, high-intensity rainfall events whose hourly runoff rates exceed the system's effective hourly drainage rate, resulting in temporary flooding even when the total daily rainfall remains below the estimated daily drainage coefficient. The types of short, intense storms have shorter return periods.

Since the current drainage coefficient of 131 mm/day corresponds to an effective drainage rate of approximately 5.5 mm/hr, any rainfall intensity exceeding this rate will produce temporary flooding until rainfall ceases and sluice drainage resumes. Consequently, effective flood risk management in Georgetown must consider not only the total daily rainfall relative to the drainage coefficient, but also the rainfall intensity and duration that determine whether runoff rates temporarily exceed the system's effective drainage capacity.

V. DISCUSSION

As mentioned in the literature review, historic design statements commonly quote 2.5 in/day (63.5 mm/day) as the intended sluice and pumped drainage coefficient for Georgetown, however, this study's results show that the realised drainage coefficient depends on several dynamic factors and thus can vary widely. First, tidal state determines sluice opening and hydraulic head; spring lows allow longer higher-volume sluice discharge whereas neap tides shorten the drainage window and reduce discharge. Second, the mechanical condition and operational readiness of sluices and pumps (including the response time that operators can open sluices or bring pumps online) determine whether that tidal window is utilised. Third, siltation at sluices, approach canals and outfall channels reduces flow depth and increases roughness, lowering discharge for a given head. Combined, these effects mean the drainage coefficient should be expressed as a range (minimum to maximum, e.g., 101 – 153 mm/day), with a long-term average (e.g., 131 mm/day), rather than a single deterministic number. This implies two things for flood management: (1) even a fully functional system with current pump and sluice capacities cannot prevent temporary flooding from high intensity storms – it can only limit flood depth and speed up removal; and (2) maintaining high operational availability (regular desilting, rapid pump deployment, fast-response or self-actuated sluice opening, and pre-storm removal of water) can reduce both the depth and duration of flooding when high-intensity rainfall occurs.

Further, the manual operation of the sluices is dependent on tides and hydraulic pressure. Sluices are typically opened during the falling tide near mid-tide, when water levels are equal and the pressure differential is low, and remain open for about four to six hours. They are closed on the following rising tide, again near mid-tide, to prevent backflow. This operation demands accurate timing and considerable physical effort to operate the sluice mechanism, especially when the sluice is operated late and the head difference increases. During spring tides, sluices can remain open longer, while during neap tides the drainage window is shorter. These limitations show the potential value of automated or self-actuated sluices, provided such structures are designed to withstand the high hydrostatic pressures associated with spring tides and can operate reliably under local conditions.

The findings of this study confirm the earlier observations of Persaud & Forsythe (1980) and Ramraj (1996) that the dominant short-duration, high-intensity rainfall in Guyana renders daily drainage coefficients an incomplete measure of flood resilience. Even with a theoretical capacity of 131 mm/day, Georgetown experiences temporary flooding whenever rainfall intensity exceeds 5.5 mm/hr. For instance, the 69.2 mm rainfall of December 5, 2025, over four hours (17 mm/hr) produced temporary ponding that lasted for about 14 hours before complete drainage. Such analysis shows the importance of evaluating

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drainage performance in hourly terms, particularly for low-lying, tidal coastal cities such as Georgetown.

During the February 12, 2026 event, 96.7 mm of rainfall in four hours produced an average intensity of 24 mm/hr, compared with the city's drainage capacity of 131 mm/day (5.5 mm/hr). Under such conditions, inflow to the drainage system inevitably exceeds its discharge rate, leading to temporary surface flooding even when pumps and sluices are fully operational.

Blockages and narrowed drains prolong flooding by reducing internal conveyance and lengthening drainage time, but they are secondary factors compared with the physical limit imposed by rainfall intensity exceeding the system's drainage capacity. The essential role of maintenance is to reduce the duration of flooding, ensuring that accumulated runoff drains out as quickly as possible once rainfall subsides and low tide allow sluice operation.

Although Georgetown's total drainage capacity has gradually increased since 2015 – from approximately 101 mm/day (4.0 mm/hr) with ten sluices and eight pumps to about 131 mm/day (5.5 mm/hr) with ten sluices and twelve pumps by 2025 – short-duration, high-intensity rainfall continues to exceed system capacity. During such events, rainfall intensity often exceeds the system's hourly drainage rate by three to five times. This recurrent imbalance between inflow and outflow gives the appearance of system failure to the general public, even though the drainage system functions as designed and the ponded water drains away once rainfall ceases and sluices reopen at low tide.

The logarithmic rainfall-return period equation indicates that rainfall magnitude increases slowly with increasing return period (Figure 5). As a result, even substantial increases in drainage capacity would only modestly increase the return period of rainstorms capable of exceeding drainage capacity. This means that flood mitigation in Georgetown cannot rely solely on increasing drainage capacity, but must also consider enhanced stormwater storage and improved internal conveyance to the sluices and pumps.

Public perception often attributes flooding in Georgetown primarily to blockages within the drainage system. While obstructions in tertiary and secondary drains can delay the removal of accumulated water, they are not the fundamental cause of flooding during intense rainfall. The underlying hydrological principle is that temporary flooding occurs whenever the hourly runoff rate exceeds the city's available hourly drainage rate, regardless of how clean or well-maintained the system may be.

Analysing rainfall solely by daily totals and long return periods can underestimate flood risk; when rainfall intensity over a few hours exceeds the catchment's hourly drainage rate, temporary flooding becomes inevitable. Therefore, comparing a rainstorm's hourly intensity and short-term recurrence with the area's hourly drainage coefficient provides a more realistic assessment and better guides system management and improvement.

VI. RECOMMENDATIONS

- *Maintenance and Operation of Sluices and Pumps*

All sluices and pumps must be maintained in good and safe working condition and operated at optimum tidal and rainfall periods during storm events. Adequate standby or mobile pumps should be available to provide redundancy whenever units are taken offline for regularly scheduled servicing or repair.

- *Desilting*

The approach canals and outfall channels adjoining each sluice should be desilted regularly to prevent backwater effects that reduce head differences and discharge capacity. Priority attention should be given to sluices where siltation historically limits outflow, e.g., the Lamaha and Cummings sluices.

- *Operator Safety and Training*

Sluice and pump operators should be provided with protective railings, lighting, and life jackets at all sites, and trained in emergency response to ensure safe and efficient drainage management.

- *System Modernisation and Automation*

The city's drainage system should be progressively modernised and automated, incorporating electric sluice actuators, automatic pump start-up systems, water level sensors, and real-time rainfall gauges linked to a centralised computer-based monitoring and control network. Such automation will improve operational response times during storm events, reducing flood impacts and accelerating the removal of ponded water.

- *Hydraulic Conveyance and Flow Efficiency*

Main and secondary canals, internal drains, culverts, and all conveyance structures must be kept free of blockages, including garbage, construction materials, and any other obstructions that impede flow. Enforcement of anti-dumping regulations is essential to maintain system performance.

- *Urban Planning and Canal Preservation*

The narrowing or infilling of canals and drains for road construction or urban development should be strictly prohibited, as these practices increase hydraulic resistance, reduce conveyance capacity, and diminish the stormwater storage volume available. Preserving the original canal and drain geometry is critical for maintaining the system's stormwater storage and drainage performance.

- *Canal Lining and Flow Improvement*

Earthen canal and drain surfaces should be lined with finished concrete to reduce Manning's roughness coefficient, increase conveyance efficiency, and minimise siltation. Concrete lining also reduces long-term maintenance costs and desilting frequency. The practice of using in-water piles to support revetments at sluice inlets and outlets should be phased out as this increases roughness and reduces discharge.

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The original width and depth of canals should be retained to preserve stormwater storage capacity.

➢ *Data Collection and Monitoring*

A continuous hydrological and hydraulic data collection programme should be established to monitor rainfall, tide levels, pump discharge rates, and sluice operations. This information should feed into a centralised drainage management system to support decision-making and early warning during heavy rainfall.

➢ *Policy and Institutional Coordination*

Agencies responsible for drainage and flood management should coordinate through a national or municipal data-clearinghouse, as previously recommended by the U.S. Army Corps of Engineers, to ensure consistent data sharing and system planning.

➢ *Further Research and Capacity Building*

Continued field studies should measure the hydraulic performance of sluices, pumps, and canals under varying rainfall and tidal conditions. Updated drainage coefficients should be periodically derived to reflect system upgrades, land-use changes, and sea-level rise.

VII. CONCLUSION

This study quantified the drainage capacity and flood risk of Georgetown through direct field measurement, hydraulic analysis, and rainfall–flood assessment. Using measured sluice dimensions and the Chezy–Manning equation, a unified Sluice Drainage Coefficient Equation was derived to calculate the theoretical daily drainage capacity from geometric and hydraulic parameters. Application of this equation to Georgetown's ten sluices yielded a total gravity drainage coefficient of approximately 61 mm/day, equivalent to 2.5 mm/hr. When combined with the city's twelve drainage pumps, the overall drainage capacity increases to about 131 mm/day, or 5.5 mm/hr, under ideal operating conditions.

Comparison of these drainage capacities with historical and recent rainfall events shows that temporary flooding occurs whenever rainfall intensity exceeds approximately 5.5 mm/hr, confirming earlier observations by Persaud & Forsythe (1980) and Ramraj (1996) that short-duration, high-intensity rainfall rather than daily totals governs flood occurrence in coastal Guyana. Recent flood events – such as 69.2 mm in four hours on December 5, 2025, and 96.7 mm in four hours on February 12, 2026 – produced intensities several times higher than the city's hourly drainage rate, resulting in temporary flooding even when all pumps and sluices were functional.

These findings demonstrate that Georgetown's flood vulnerability arises not primarily from maintenance failures but from a physical mismatch between rainfall intensity and drainage rate. While blockages extend flood duration, they are secondary to the city's hydrological and tidal limitations.

The integrated Sluice Drainage Coefficient Equation developed here provides a practical tool for evaluating and upgrading coastal drainage systems, and its application can guide future improvements in sluice design, pump scheduling, and flood prediction. Continued field measurement, hydrological data management, and maintenance of drainage structures remain essential to enhance the city's resilience against increasingly intense rainfall events.

While Georgetown's drainage infrastructure has steadily improved over the past decade, its capacity remains limited by the city's flat topography and tidal dependence. Flooding during intense rainfall does not necessarily indicate system failure but rather reflects the physical limitation that rainfall intensity can temporarily exceed the city's available drainage rate.

Future studies should examine the effects of canal infilling and narrowing, land-use change, tidal backflow, and siltation on the city's residual stormwater storage and drainage-conveyance capacities.

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APPENDIX:

Hydromet's Weather Brief for December 6, 2025

HYDROMETEOROLOGICAL SERVICE
MINISTRY OF AGRICULTURE

Weather Brief for Saturday, 06 December 2025 from the Hydrometeorological Service, Guyana
Rainfall records for the past 24 hours, measured at 08:00hrs Saturday, 06 December 2025 were available for most of the stations. Georgetown in Region 4 recorded the highest rainfall of 69.2 mm.

Marine Advisory: Rough seas will likely produce hazardous sea conditions, coupled with spring tides can lead to over-topping and damage of river and sea defences along low-lying and riverine areas. Persons are advised to exercise caution to protect their lives and property.

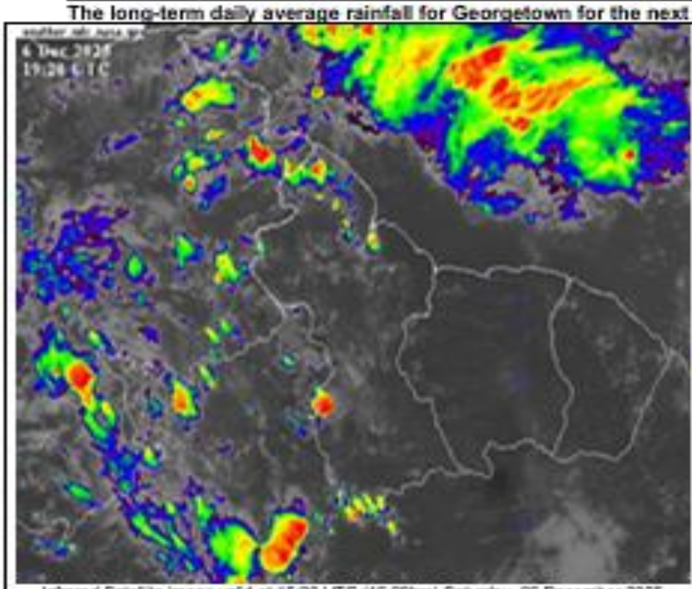
Synopsis: Apart from weak confluence at low levels, which produced some instabilities over regions 1 and 2. Stable conditions dominated in most of the forecast area due to an increase in Saharan Dust concentrations and dry air transport from southeasterly flows. Model projection shows a gradual development of the ITCZ along the coast of Guyana in the new week.

Today's weather review: Apart from scattered showers over regions 1, 2, and 7, partly cloudy and sunny skies dominated the forecast area.

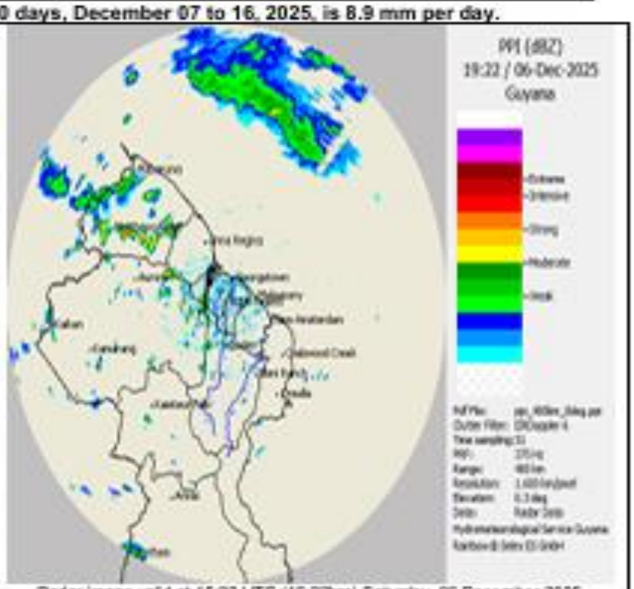
Table # 1 Weather forecast for the next twenty-four hours

Saturday, 06 December 2025 (19:00 hrs – 07:00 hrs)			Sunday, 07 December 2025 (07:00 hrs – 19:00 hrs)		
Regions	Weather Conditions	Cloudy skies with occasional showers over regions 1, 2, and 7. Elsewhere, morning cloudy spells with passing showers. Winds: Moderate to fresh easterly breeze. Minimum temperatures: Coast: 22 °C – 26°C Hinterland: 19 °C – 24 °C	Regions	Weather Conditions	Mostly cloudy skies with frequent showers and isolated thundershowers over regions 1 to 3, 7, and 10. Elsewhere, cloudy spells with scattered showers. Winds: Moderate to fresh easterly breeze. Gusting before and during heavy downpours/thundershowers. Maximum temperatures: Coast: 28 °C – 32 °C Hinterland: 29 °C – 33 °C
Regions 1, 2 & 7.	Rainfall between 5 & 15 mm.		Regions 1 to 3, 7 & 10.	Rainfall between 10 & 30 mm.	
Other regions.	Rainfall between 0 & 5 mm.		Other regions.	Rainfall between 0 & 15 mm.	

The long-term daily average rainfall for Georgetown for the next 10 days, December 07 to 16, 2025, is 8.9 mm per day.



Infrared Satellite image valid at 15:20 UTC (15:20hrs) Saturday, 06 December 2025.



Radar image valid at 15:22 UTC (15:22hrs) Saturday, 06 December 2025.

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Table # 2 Occurrences of high and low tides for the next 24 hours and the times for sunrise and sunset.

Tonight (December 06, 2025)	Morning (December 07, 2025)		Afternoon (December 07, 2025)
Low Tide 23:25hrs Tide Height 0.41m	High Tide 05:57hrs Tide Height 2.84m Low Tide 11:30hrs Tide Height 0.67m		High Tide 17:32hrs Tide Height 3.07m
Sunrise:	05:50hrs	Sunset:	17:35hrs

Spring Tide Advisory: The spring tide is in effect and will continue until December 9, 2025.

Sea conditions:
-Moderate to rough northeasterly seas with swells reaching 2.5 to 3.0 meters in open waters.
-These waves will likely have periods of between 8 and 9 seconds.
- Moderate to fresh easterly breeze.

Extended Forecast

Monday and Tuesday: Mostly cloudy skies with frequent showers and isolated thundershowers over regions 1 to 3, 7, and 10. Elsewhere, cloudy spells with scattered showers. Rainfall is expected between 10 mm and 30 mm over regions 1 to 3, 7, and 10, elsewhere between 0 mm and 15 mm within 24 hours.

Wednesday through Friday: Southern regions 6 and 9 can expect partly cloudy skies with scattered showers, elsewhere cloudy to overcast skies with rain and thundershowers. Rainfall is expected between 0 mm and 15 mm over southern regions 6 and 9, and the remaining regions between 30 mm and 70 mm within 24 hours.

For the Current Regional climate forecast, please see the latest Seasonal Climate Outlook, which is available on the Hydrometeorological Service's website https://hydromet.gov.gy

An update in the bulletin is provided daily by the Hydromet Service.
Specialist Meteorologist: Doodnauth Ramlakhan

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Archived copies of all cited *Daily Weather Briefs* are retained by the author (PDF downloads from the Hydrometeorological Service of Guyana website: https://hydromet.gov.gy/weather/weather-brief/). These documents correspond to the dates referenced in the main text and contain the official daily rainfall, temperature, and forecast data issued by the Hydrometeorological Service of Guyana.