STRENGTHENING FLOOD RESILIENCE IN DATA-SPARSE AGRICULTURAL REGIONS: A PLANNING APPROACH FOR COASTAL GUYANA

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Abstract. Coastal Guyana concentrates most of the country's population and agricultural production in low-lying polder landscapes that are increasingly exposed to flooding from intense rainfall, sea-level rise, and deterioration of drainage and irrigation infrastructure. Engineering design and resilience planning in these settings are often constrained by limited hydrometric monitoring (discharge, water levels), incomplete documented drainage network, and restricted access to institutional datasets. This paper presents the value of using a low-information framework for flood resilience planning and preliminary hydraulic design in data-sparse agricultural regions, using the 364 km^2 part of Guyana's Mahaica–Mahaicony catchment as a case study. The framework integrates (i) rainfall frequency analysis from long-term gauge records, (ii) remote sensing and global datasets (DEM and land-use/land-cover) to delineate sub-basins and screen flood impact, (iii) simplified runoff and volume-based drainage calculations consistent with rice-field storage and saturated soils, and (iv) structured stakeholder engagement to identify flood-prone areas, operational constraints, and feasible interventions. Six-sub-basins are used for developing a routing strategy to distribute runoff volumes and to explicitly incorporate upstream detention in the wetlands, thereby reducing peak flows conveyed northward through constrained canal corridors. High-level drainage canals, dedicated conveyance paths for critical sub-basins, and dual-purpose drains supporting both drainage and irrigation storage are used to determine preliminary cross-section designs, which are then assessed with 1D hydraulic modelling under tidal boundary conditions. The approach supports phased investment planning that improves flood safety, protects livelihoods, and increases agricultural reliability while aligning with national adaptation priorities.

Key words: Flood resilience; data-sparse environments; coastal drainage; dual-purpose canals; Guyana

1. INTRODUCTION

Guyana's geographical and climatic conditions present specific challenges for infrastructure design, particularly in water management and agricultural systems. The country's coastal regions are predominantly below sea level, making effective drainage and irrigation systems important for both flood prevention and agricultural productivity. This geographical particularity determined the way design approaches are developed in the region, taking into account the need for solutions that address the complex relationship between water management and agricultural development.

The climate of Guyana is characterized by high rainfall intensity and significant seasonal variations, which requires a drainage infrastructure capable of handling extreme weather events while simultaneously supporting all year-round agricultural activities. Agriculture needs reliable irrigation systems that must function in tandem with drainage requirements. However, resource constraints in the region require that design approaches balance technical effectiveness with economic feasibility and local maintenance capabilities, presenting a significant challenge for engineers and planners.

Traditional design approaches in Guyana focus on separate systems for drainage and irrigation, treating these functions as independent infrastructure requirements. However, recent literature suggests a paradigm shift toward integrated designs that optimize land use, reduce infrastructure costs, and improve overall system efficiency (Njoroge, 2025). Dual-purpose channels, which are designed for both drainage and irrigation functions, are welcomed in regions like Guyana where both needs are important for sustainable development. These integrated systems represent a novel approach, different from conventional single-purpose infrastructure, requiring design principles that account for the competing and sometimes contradictory requirements of drainage and irrigation operations.

The hydraulic design of dual-purpose channels must ensure adequate capacity to manage peak drainage flows during heavy rainfall events while maintaining appropriate water levels for irrigation during dry periods. This requires careful consideration of channel geometry, with cross-sectional dimensions that can accommodate the widely varying flow rates and water levels associated with both functions. Control structures, including gates, weirs, and regulators, play a significant role in enabling the system to switch between drainage and irrigation modes depending on seasonal requirements and operational priorities.

Water quality management emerges as an added consideration in the dual-purpose systems, as drainage water may contain sediments, agricultural runoff, or other contaminants that could compromise the suitability of water for irrigation purposes. Design approaches must therefore incorporate features that prevent contamination of irrigation water from drainage sources, such as separation mechanisms, settling basins, or treatment components integrated into the channel network.

Guyana's exposure to flooding is not new, and its roots lie as much in the historical transformation of the coastal landscape as in present-day climatic pressures. Empoldering historically converted mangrove swamp into a „second nature" of sea walls, canals, and drained agricultural land that depends on continuous human maintenance to remain habitable (Pelling, 1999). When that maintenance lags behind the pace of infrastructure deterioration and sea-level rise, vulnerability increases sharply. Current estimates indicate that the majority of Guyana's coastal agricultural land and approximately two-thirds of its coastal urban areas are exposed to flooding and erosion, with potential losses equivalent to a large share of national GDP (World Bank, 2024). These figures emphasize why engineering interventions in this setting cannot be postponed until dense monitoring networks are established. More broadly, the difficulty of characterizing hydrological response without long, spatially distributed discharge and water-level records is not unique to Guyana: it reflects the wider challenge identified by the hydrological sciences community under the Prediction in Ungauged Basins initiative, which called for methods that make defensible use of the sparse, heterogeneous data typically available in most of the world's catchments (Sivapalan *et al.*, 2003). The framework developed in this paper combines statistical analysis of the available rainfall records, globally available remote-sensing and terrain datasets, simplified but physically grounded runoff and routing calculations, and structured local knowledge, rather than developing a fully calibrated model that, in absence of good data is having a lot of uncertainties.

The Government of Guyana's initiation of the Hope-like Canal (HLC) series of projects continues the success of the Hope Canal, which was implemented between 2011 and 2023 to provide flood relief in Demerara-Mahaica region. The new initiatives are referred to as „Hope-like Canal" projects and will function as the main conveyance channels in the area of the project. A key component of this projects is the dual-purpose of the Hope-like Drainage Canals (HLDCs): (i) Flood management: To maximize gravity flow into the Atlantic Ocean after water is mechanically lifted by pumps, particularly in the wetlands; and (ii) Water storage: To store freshwater to meet irrigation demands, especially to support rice cultivation (JICA, 2017; World Bank, 2024).

Present paper takes a study case of the HLC project in the Mahaica-Mahaicony area of administrative region no. 5 of Guyana and addresses the following research questions:

RQ1. How can a framework for the study areas be developed under conditions of limited data availability?

RQ2. How can structured stakeholder engagement be incorporated to parameterize and validate key assumptions – such as flood hotspots, storage practices, and operational constraints – in simplified hydrological calculations and/or 1D hydraulic modelling?

The article is organized as follows: Section 2 describes the study area and data sources. Section 3 presents the low-information framework, including design storm estimation, runoff and drainage volume calculations, sub-basin routing, cross-section development, and hydraulic modelling approach. Section 4 reports results (flood impact screening, flow allocation, preliminary geometry feasibility, and operational sensitivities). Section 5 concludes with recommendations for phased implementation and monitoring upgrades.

2. STUDY AREA

The study area spans over approximately 364 km^2, located within the mid to lower reaches of the Mahaica - Mahaicony catchment, bounded by the Mahaica River (west), Mahaicony River (east) and the Atlantic coastal plain of Guyana (Fig. 1).

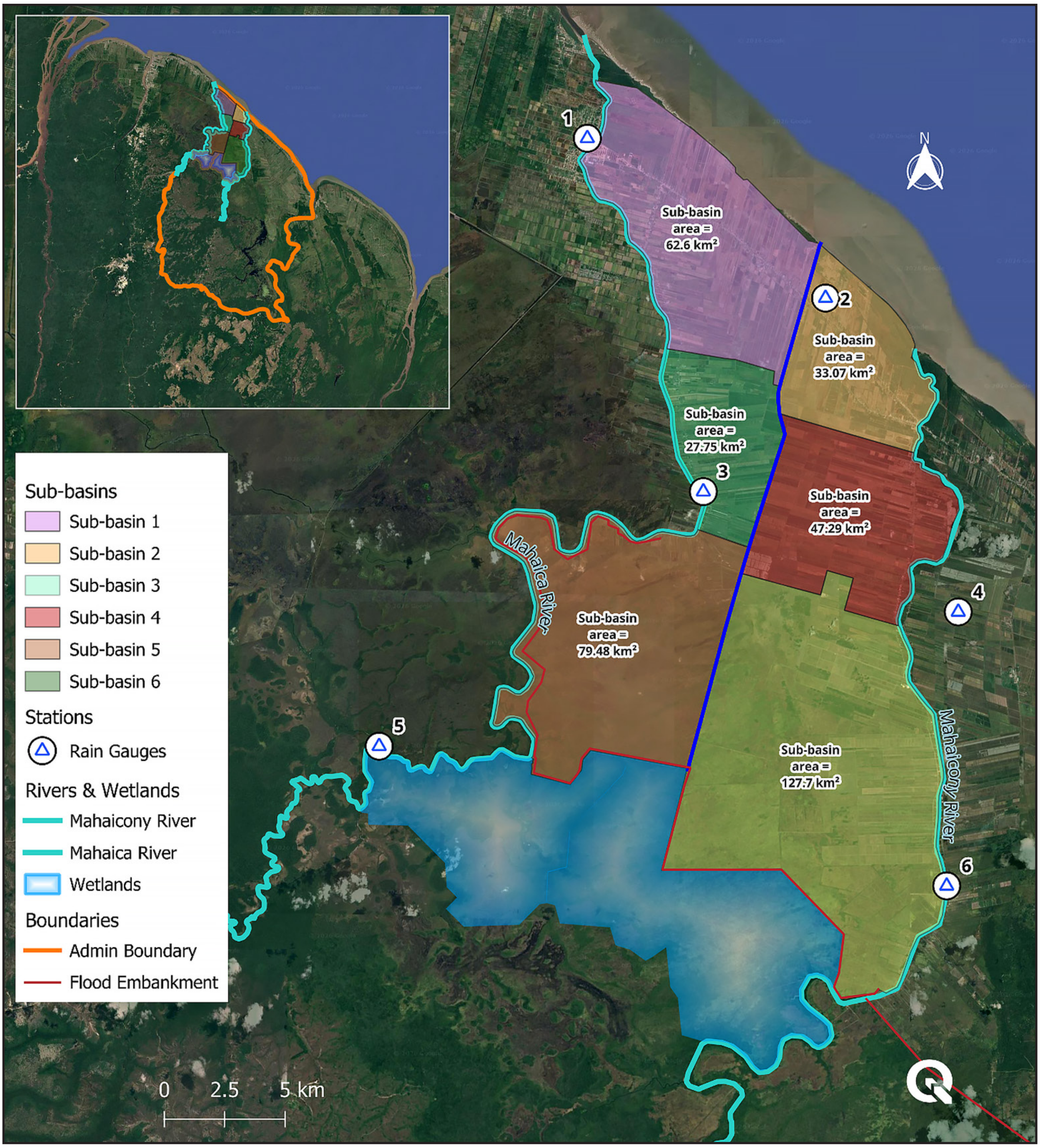

Fig. 1. Mahaica–Mahaicony study area and delineated sub-basins (1–6) and positions of primary canals, gauge locations, and coastal outfalls.

The domain is divided into six sub-basins delineated by primary drainage canals and natural/engineered divides. The southern boundary is defined by an engineered flood embankment associated with the upstream drainage control strategy for sub-basins 5 and 6 (Fig. 1).

In terms of elevation, the lands vary between 16.0 to 16.5 m GD (which means reference to the Guyana Georgetown datum). The Georgetown Datum (GD) is an imaginary plane with the 0.00 GD reference level set at approximately 15.559 m below mean sea level (MSL). The coastal plain of Guyana is mostly flat and the slope of the land is mild. As a result, the overland and channel flows are slow.

The study area is part of a low-lying coastal drainage region which is subjected to semi-diurnal tides. The existing network comprises both natural elements and the existing man-made drainage channels (canals and drains). The region is characterized by extensive rice cultivation, cattle rearing, and smaller-scale cash crops. Land use derived from Sentinel-2/ESRI LULC (2023) indicates dominant classes of crops and rangeland (Table 1).

Table 1. Land use/land cover summary (Sentinel-2 / ESRI LULC, 2023).

Land Use/Cover	Area (km²)
Water	0.94
Trees	26.46
Flooded Vegetation	2.02
Crops	183.52
Built-up Area	8.79
Bare Ground	0.05
Rangeland	155.88

The man-made channels in the study area typically have invert levels around 14.0 m GD and very mild bed slopes (reported as 2 inches per mile, approximately 3.175×10^{-5} m/m). The embankments and channels are designed with side slopes of 1:2.5 or 1:3 due to the soil type which consists primarily of coastal alluvial and marine clay deposits.

The available data sets for the study include long-term daily rainfall records from four gauges (record lengths 49-76 years); DEM coverage (*e.g.*, SRTM 30 m); satellite imagery for land use and flood extent screening (Sentinel-2 Level-2A); limited field cross-sections and reconnaissance of key canals/outfalls; stakeholder knowledge on flood hotspots, drainage timing, rice-field storage practices, and operational constraints. Key limitations include the absence of continuous discharge/water-level monitoring, incomplete bathymetry and network records, and constraints in accessing institutional datasets for calibration. The SRTM DEM (Farr *et al.*, 2007), while globally consistent and freely available, is known to carry a positive vertical bias over vegetated and low-relief terrain that can be significant relative to the sub-metre elevation differences that control drainage direction on a near-flat coastal plain (Kulp and Strauss, 2019); this constraint was partly compensated for in the present study through cross-referencing with field cross-sections, canal invert surveys, and local knowledge of flow directions at confluences and outfalls.

3. METHODOLOGY

The applied methodology for the study is presented in figure 2. Data collection feeds two parallel analyses that converge on the hydraulic design, which is tested and refined through iterative modelling.

Each of the methodological steps are further detailed:

1. Design storm estimation (HEC-SSP): A rainfall frequency analysis is performed using HEC-SSP on long-term gauge data. Candidate distributions (*e.g.*, Gumbel, GEV, Log-Pearson III) are fitted using robust estimators (*e.g.*, L-moments, following Hosking and Wallis, 1997), with goodness-of-fit evaluated (*e.g.*, Kolmogorov–Smirnov). L-moment-based fitting is preferred over conventional moments in this context because it is less sensitive to the small sample sizes and occasional outliers that are common even in relatively long tropical rainfall series, and it performs reliably when only single-site records rather than a dense regional network are available (USACE, 2019). A 100-year event is selected as a conservative design basis for screening and preliminary sizing. It is important to note that the assessment, analysis and design of storm drains, canals and sluices, rely on international standards including those of the American Association of State Highway and Transportation Officials (AASHTO), the American Society for Testing and Materials (ASTM), American Concrete Institute (ACI), British Standards, and European Standards since Guyana does not have its own national drainage design standards.

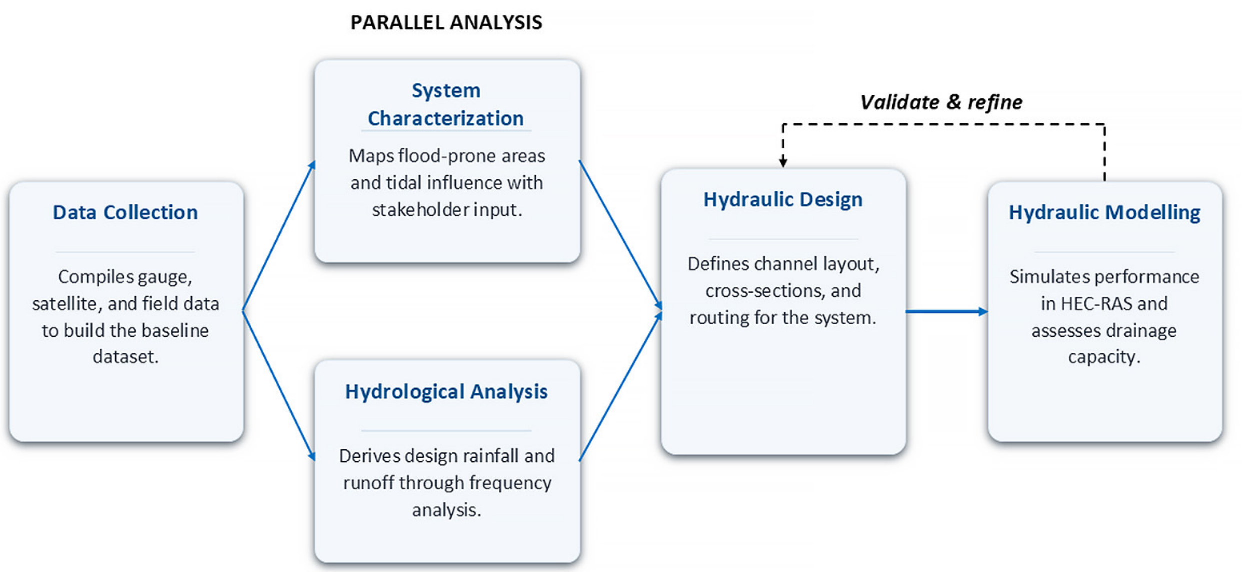

Fig. 2. Applied methodology.

One of the most recent studies conducted by the Japan International Cooperation Agency JICA in 2017 used AASHTO and ACI standards in their analysis due to the lack of national guidelines. Similarly, AASHTO drainage manuals and the U.S. Federal Highway Administration (FHWA) Hydraulic Design Series (HDS-5 Culverts) are often referenced in the Ministry of Public Infrastructure Road and Roadside Drain Projects and Engineering Reports.

2. Runoff depth and effective drainage volume (rice-field storage): Because soils are frequently saturated and rice cultivation practices include standing water, a simplified runoff estimate is adopted for screening-level design. This treatment is consistent with the broader literature on the flood-mitigation function of paddy fields, which shows that ponded rice land can retain a substantial fraction of incident rainfall before contributing to downstream runoff, effectively acting as a distributed, farmer-operated detention system (Masumoto *et al.*, 2006; Matsuno *et al.*, 2006):
   - Runoff coefficient (Rc) representing saturated fields (*e.g.*, (Rc approx 0.9)).
   - Field storage allowance consistent with farmer practice (*e.g.*, ≈ 76.2 mm).
   - Effective runoff depth (h_{eff}) after storage and losses (currently ≈ 103.8 mm).

3. Drainage window and required average discharge: For a drainage window (T_d) (*e.g.*, 72 hours), the average discharge needed to remove (h_{eff}) over area (A) is:

$$Q_{avg} = \frac{A \times h_{eff}}{T_d}$$

   which is 145.8 m^3/s for the study under consideration.

4. Sub-basin routing concept and detention strategy: The six-sub-basin structure is used to distribute volumes and define routing principles, as follows:
   - direct conveyance from critical flooded sub-basins,
   - distributed drainage through multiple corridors, and
   - peak attenuation via upstream detention/storage in sub-basins 5 & 6.

   The operational state is that the channels only accommodate up to ~16 m^3/s routed north. The remaining volumes are directed west/east via pumping to Mahaica/Mahaicony River and/or routed to wetlands/south storage where appropriate. Shapefiles showing drainage and irrigation networks for the study areas were created using satellite imagery, and through identification from field work.

5. Cross-section development: Preliminary channel geometries are developed using Manning-based capacity checks under target discharges and allowable water levels, subject to:
   - limited footprint widths,
   - embankment stability slopes (1:2.5–1:3),
   - invert constraints near 14.0 m GD,
   - low slope and sedimentation considerations, and
   - tidal backwater at the outfall.

6. 1D hydraulic modelling (HEC-RAS) and boundary conditions: A 1D model (steady for screening and/or unsteady for operational checks), built following USACE (2023) modelling guidance, is used to evaluate: capacity of existing cross-sections, sensitivity to downstream stage (tide), and effectiveness of possible interventions, such as relief channels, HLDCs, gates/weirs, or pumps. Prescribing the downstream boundary as a tidal stage series rather than a fixed normal-depth condition is consistent with established practice for 1D models of channels in the tidally influenced transition zone between fluvial and estuarine regimes, where downstream water levels – rather than channel capacity alone – often control conveyance (Mashriqui *et al.*, 2014).

7. Participatory inputs: Meetings with stakeholder were carried out to determine flood hotspot polygons/points, flood duration categories, operational timing (gate opening, pumping practices, tidal awareness), rice-field storage practices and acceptable inundation periods, planned land expansion areas and constraints. Embedding local knowledge in this way follows established guidance on participatory modelling, which treats stakeholders not merely as sources of anecdotal information but as active contributors whose operational understanding of the system can constrain, validate, and, where instrumented data are absent, substitute for missing quantitative inputs (Voinov and Bousquet, 2010).

4. RESULTS AND DISCUSSION

4.1. Data collection of flood impact

Extreme flood events occurred in 2005 (economic impact on the country's GDP of approximately 59%) and the second extreme event occurred in the 2021 floods.

The recent 2021 flood event was selected as a representative case to understand how flooding manifests within the catchment and to assess system performance under stress. A record of flood depths could not be established for the catchment due to insufficient ground-truth data. To address this gap, Sentinel-2 Level 2A imagery (res: 26m x 26m) from June 2021 (Fig. 3) was analysed to evaluate flood extent and identify bottlenecks in the existing drainage system, using surface-water indices in the spirit of the Normalized Difference Water Index and its modified form (McFeeters, 1996; Xu, 2006) to separate standing water from vegetated and built-up land cover. Figure 3 contains also the calculated flood impact, which was classified into five categories: very low, low, medium, high, and very high. Because optical imagery cannot see through cloud cover, which is frequent during the rainy-season events that generate the most severe flooding, the resulting map should be interpreted as a screening-level indicator of relative impact rather than a fully validated inundation extent; this is a recognised limitation of single-date optical flood mapping relative to radar-based or multi-temporal approaches.

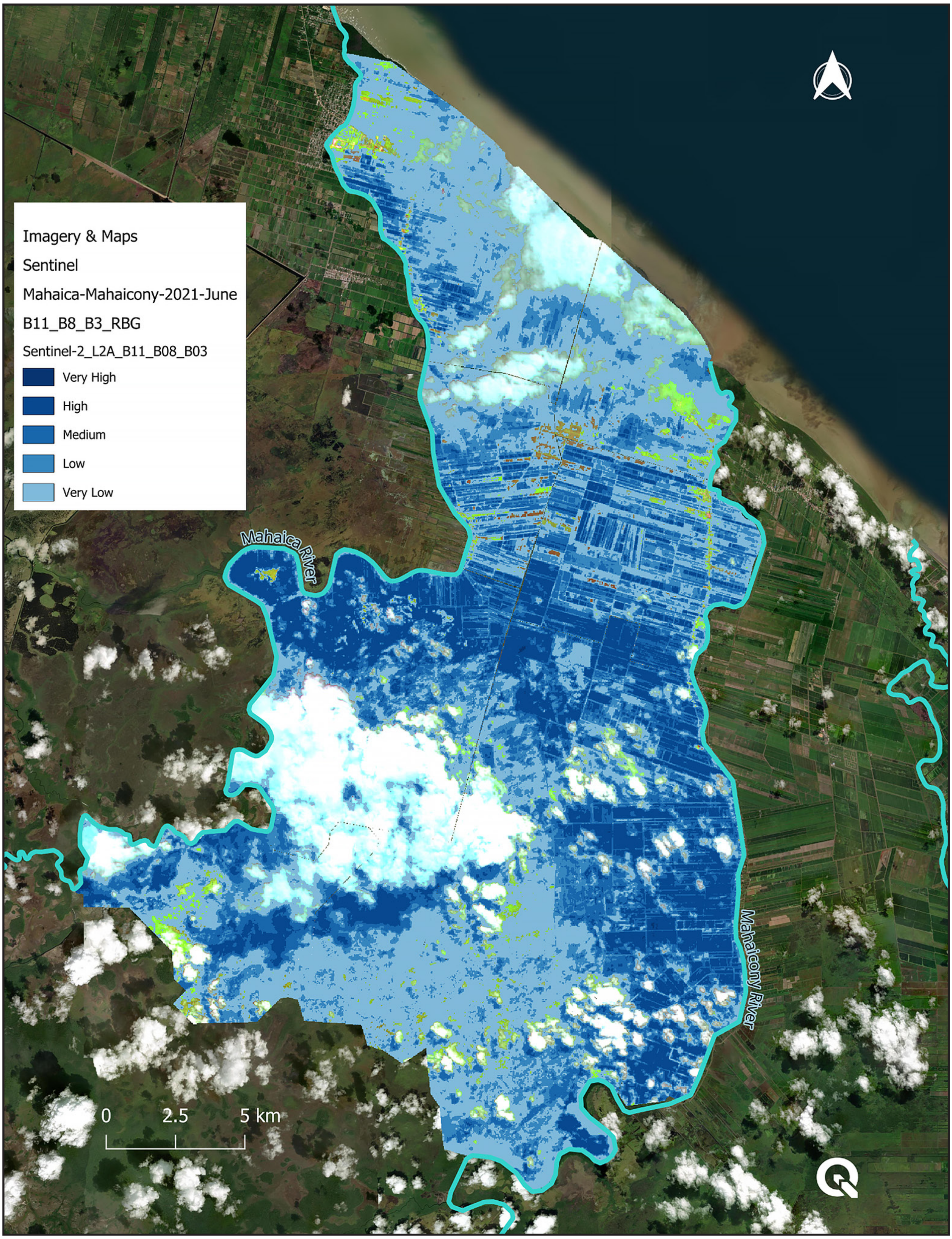

Fig. 3. Remote-sensing-derived 2021 flood impact screening map (Base imagery derived from Sentinel-2 Level-2A data obtained through the Copernicus Data Space Ecosystem).

4.2. Hydrological analysis

Given the scarcity of long-term hydrometeorological records in the study area, we conducted a rainfall frequency analysis using the UASCE HEC-SSP tool (the Hydrologic Engineering Center's Statistical Software Package) with Hydrometeorological Service gauge data from four stations (Cane Grove Back, Cane Grove Front, Mahaicony Railway, and MARDS - see Figure 1), with record lengths of 76, 49, 73, and 67 years, respectively.

Table 2: Rain gauge stations

ID	Gauge Location
1	Helenano
2	Cane Grove (back)
3	Little Biaboo
4	Railway Mahaicony
5	Maduni
6	Pine Ground

Results of the analysis are shown in figure 4, which show that maximum are of 1-to 3-days.

4.3. Runoff depth and drainage discharge targets

Runoff depth was estimated using a SWAT rainfall-runoff approach (Neitsch *et al.*, 2011) that considers agricultural storage and saturated soil conditions typical of rice cultivation. Runoff coefficient (Rc) = 0.9 to reflect saturated fields.

Additionally, rice fields/lands were considered to be capable of storing approximately 76.2 mm of rainfall. This water depth is typically required inches of depth water (rain) is typically required by the paddy for germination according to the farmers. After accounting for storage and losses, the effective runoff depth used for design was approximately 103.8 mm.

The resulted total discharge required to drain the catchment was computed using:

- Catchment area = 364 km^2
- Net runoff depth = 103.8 mm
- Drainage period = 72 hours

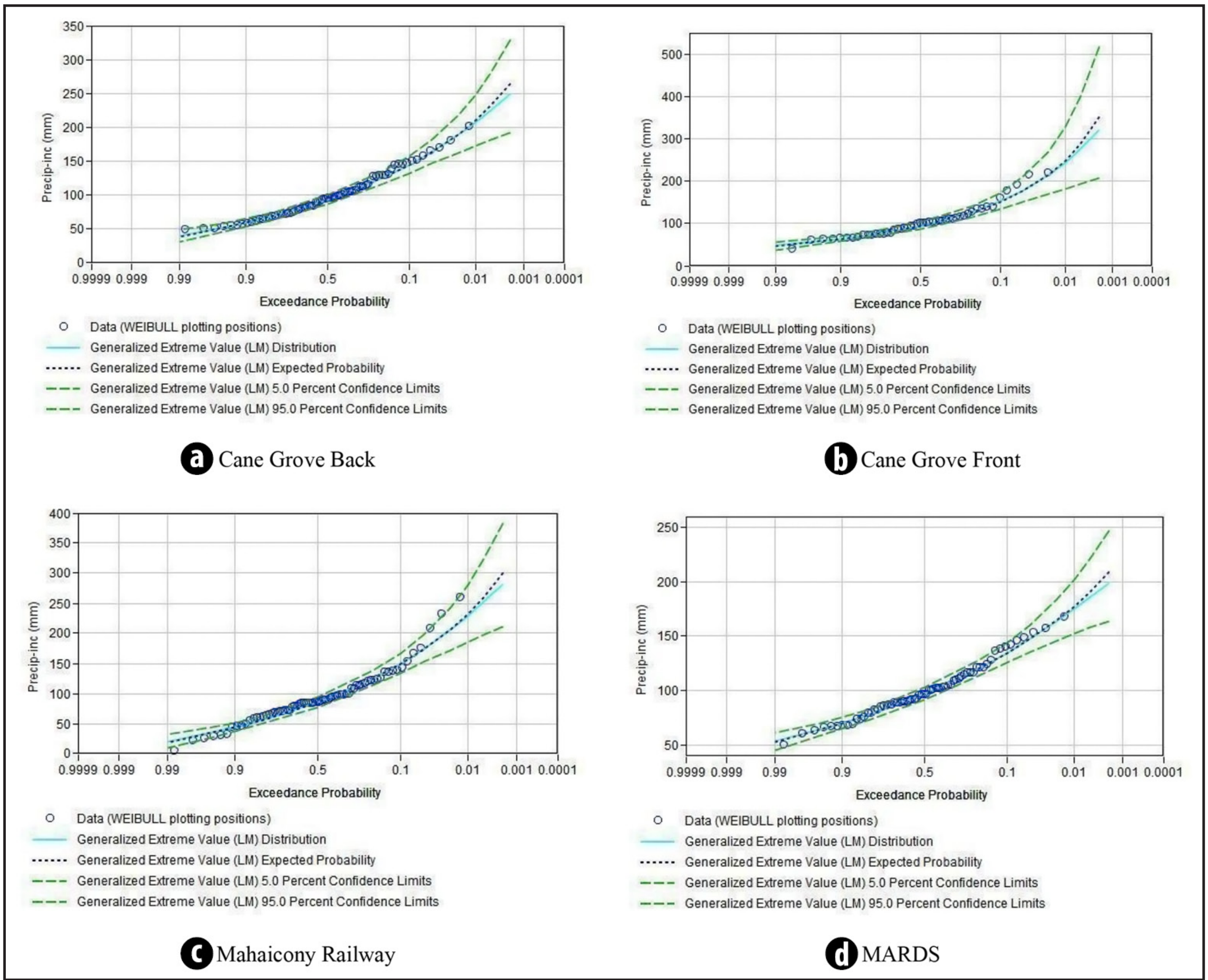

Fig. 4. Rainfall frequency analysis results for selected gauges (HEC-SSP): fitted distributions and return-period rainfall depths.

Based on these parameters, the drainage system needed to convey approximately 145.8 m^3/s during the drainage window. However, due to the existing infrastructure, drainage network, rice lands, designing canals with cross-sections to convey these large velocities was impossible.

4.4. Flow Routing over each sub-basin

The catchment of 364 km^2 was subdivided into six hydrological sub-basins (Fig. 1) to distribute flows across the drainage network.

Three routing principles (Fig. 5) used are:

1. Direct conveyance from flood-prone sub-basins.
2. Distributed drainage through multiple channels.
3. Peak flow attenuation through upstream storage (basins 5 & 6).

The drainage network of sub-basins 5 & 6 were designed to detain 1.75 inches of rainfall in addition to the 3 inches retained for the rice paddy. This strategy resulted in 31 m^3/s of average discharge to be detained upstream before controlled release, reducing downstream flood peaks.

Computed volume is based on the formula:

$$V = (B + S \times H) \times H \times L$$

where V is the storage volume, B – bottom with of the channel, S – the side slope of the cross-section, H – water depth and L – the length of the channel.

At the water board level there was an agreement that only up to 16 m^3/s inflow from the backlands will be routed north to avoid overloading the network. Remaining flows are pumped into the Mahaica and Mahaicony River (routed west and east) and into the wetlands (routed south).

Table 3. Sub-basin statistics, effective runoff volumes, routing pathways, and target corridor flows (including detention assumptions)

Description	Area (km^2)	Rainfall (mm)	Rc	Total Runoff (mm)	Retention (mm)	Net Runoff (mm)	Volume (m^3)	Q 1-day (m^3/s)	Q 2-day (m^3/s)	Q 3-day (m^3/s)
Sub-basin 1	61.58	200	0.90	180	76.2	103.8	6,392,212	74.0	37.0	24.7
Sub-basin 2	32.73	200	0.90	180	76.2	103.8	3,396,959	39.3	19.7	13.1
Sub-basin 3	27.75	200	0.90	180	76.2	103.8	2,880,450	33.3	16.7	11.1
Sub-basin 4	47.29	200	0.90	180	76.2	103.8	4,908,702	56.8	28.4	18.9
Sub-basin 5	67.00	200	0.90	180	76.2	103.8	6,954,600	80.5	40.2	26.8
Sub-basin 6	127.70	200	0.90	180	76.2	103.8	13,255,260	153.4	76.7	51.1
Total	**364.05**						**37,788,182**	**437.4**	**218.7**	**145.8**

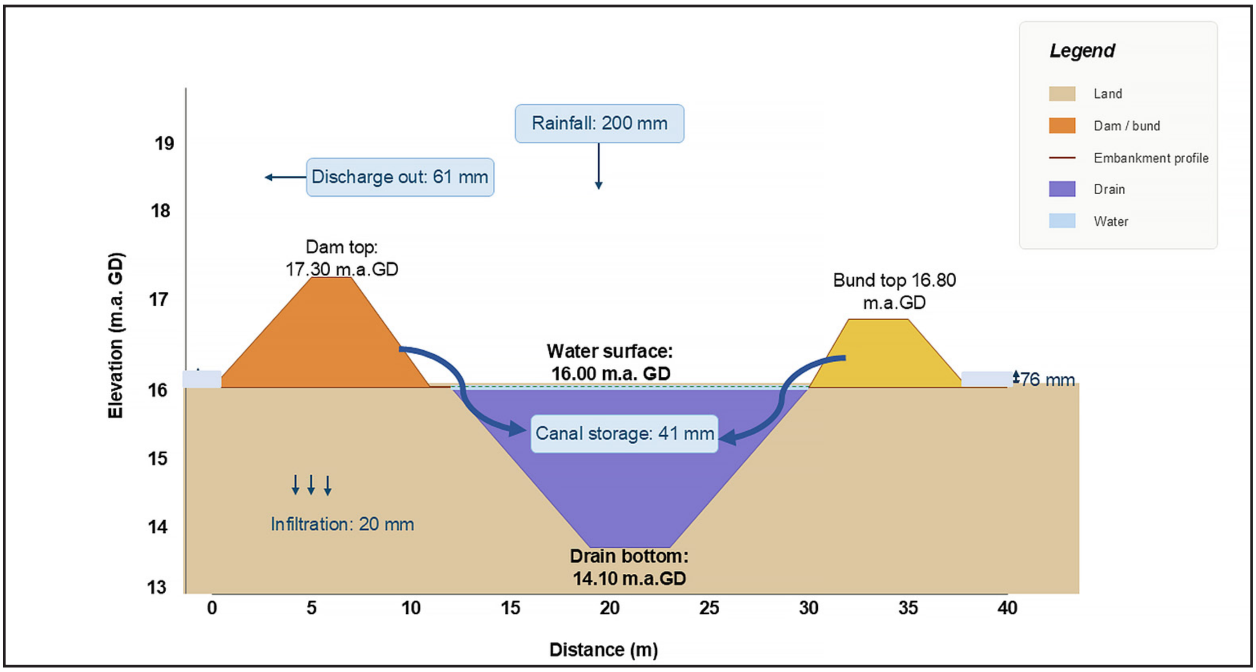

Fig. 5. Routing schematic.

The four primary design components are:

(a) Sub-Basin 3 Drainage Strategy: Direct Conveyance to Bellamy Canal

Sub-basin 3 was identified through remote sensing as the most impacted area during the recent 2021 floods. Field observations and system evaluation suggest that drainage performance is currently constrained by the elevated downstream stages in the Industry Canal and Planters Hall/ Cottage Drain.

To mitigate this constraint, the proposed design establishes a dedicated drainage path for sub-basin 3.

(b) Perth Biabu HLDC Strategy: Conveyance of Midlands & Backlands Flows

A high-level drainage channel (HLDC) with a dam crest elevation of 18.0 m GD is proposed along the existing alignment of the Perth Biabu Canal to function as the primary outflow path from the midlands and backlands toward the Bellamy Canal for discharge into the Atlantic Ocean. The total length of the Perth Biabu HLDC is approximately 16.4 km.

(c) Wash Clothes 900 HLDC Strategy: Enhancing Backland Drainage

A HLDC is also proposed along the alignment of the Wash Clothes 900 Cross Drain HLDC to enhance the drainage system.

The objective of design proposal is to reduce a significant portion of the flows which are directed towards Bellamy Canal since there is a bottleneck at the main road which leads into the Sarah/Drill Drain.

(d) Dual Purpose Drains in Sub-Basins 5 & 6

The implementation of a network of dual-purpose drains in sub-basins 5 & 6 for enhancing backlands storage and for reducing peak flows. Storage accommodates ~ 38 mm of rainfall.

Local stakeholder knowledge was used to identify flood-prone areas and validate system behaviour, addressing information gaps (consistent with participatory flood modelling approaches). The resulted position of the canals is shown in figure 6.

5. CONCLUSIONS

This study demonstrates that flood resilience planning and preliminary drainage-irrigation design can proceed in data-sparse coastal agricultural settings by integrating gauge-based frequency analysis, remote-sensing screening, simplified runoff/volume calculations consistent with local agricultural storage practices, and structured stakeholder knowledge.

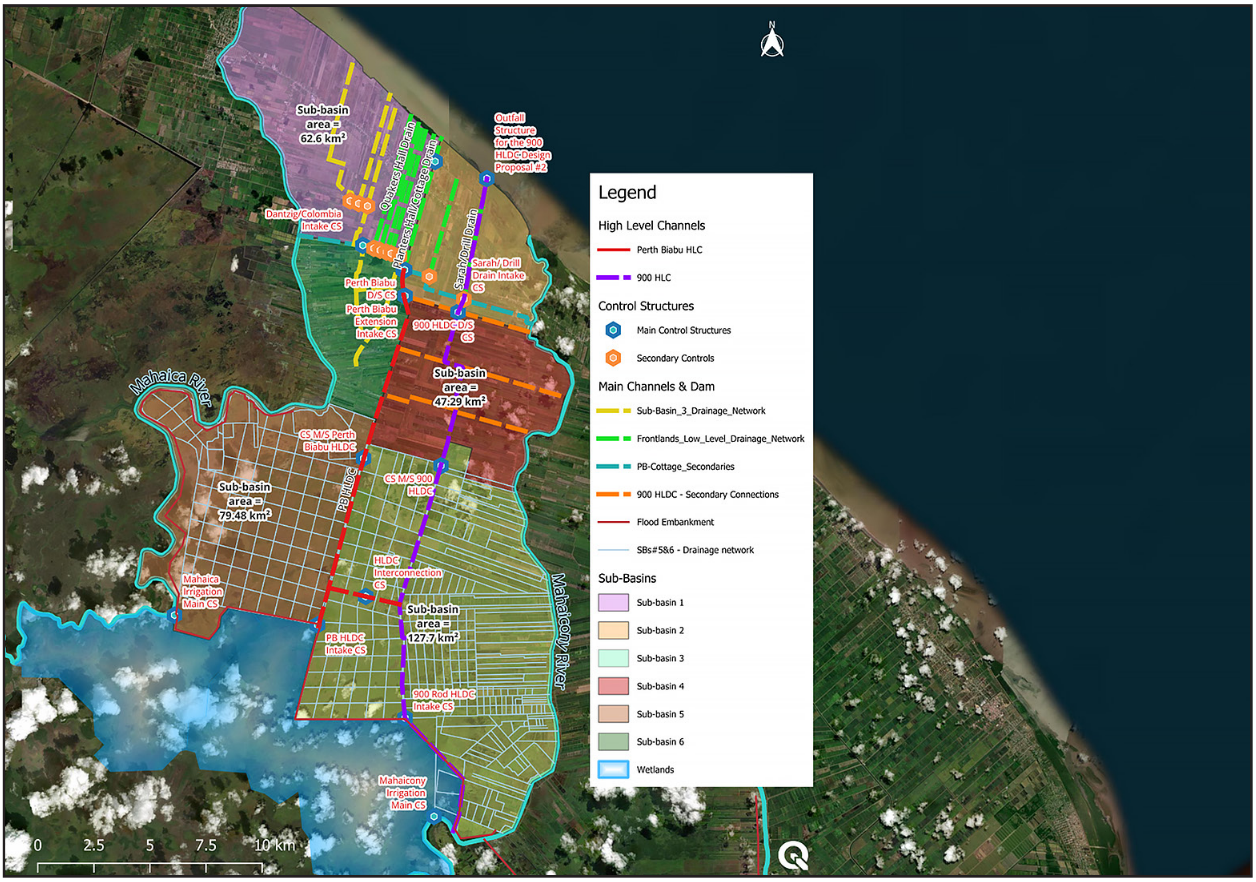

Fig. 6. Layout of the proposed integrated drainage and irrigation network within the study area.

Applied to the Mahaica–Mahaicony catchment in coastal Guyana, the approach supports a sub-basin routing strategy that limits northward conveyance through constrained canal corridors and instead combines targeted high-level drainage canals, dedicated conveyance for critical sub-basins, and upstream detention in backlands. Screening-level 1D hydraulic modelling under tidal boundary conditions highlights the central role of downstream stage control and operational rules (gate/weir settings and pumping) in determining drainage performance. While the framework cannot replace detailed calibration in the absence of monitoring, it enables prioritization of interventions and defines a staged pathway for refinement through focused surveys and monitoring upgrades. The resulting phased strategy can strengthen flood safety, protect livelihoods, and improve agricultural reliability while aligning with national climate adaptation objectives.

Beyond the specific case of the Mahaica–Mahaicony catchment, the value of the framework lies in its transferability to the many other low-lying, agriculturally dependent, and historically empoldered coastlines that share Guyana's combination of flat terrain, tidal influence, and constrained hydrometric monitoring — a challenge long recognised in the wider hydrological sciences literature on planning under data scarcity (Sivapalan *et al.*, 2003). The approach deliberately favours transparent, auditable assumptions — an explicit runoff coefficient, a stated drainage window, simple storage-volume relationships, and clearly documented routing rules — over more data-intensive distributed or fully coupled hydrodynamic models that, however desirable in principle, would not currently be supportable by the available data or institutional capacity. This choice carries trade-offs: the results are best understood as a first-order, screening-level basis for prioritizing investment and sequencing field investigations, not as a substitute for calibrated design once discharge, water-level, and bathymetric surveys become available. Future work should prioritize the installation of a minimal but strategically located monitoring network (water-level loggers at key control structures and canal confluences, together with periodic discharge measurements), which would allow the presently assumed parameters – the runoff coefficient, the effective drainage window, and the assumed detention performance of sub-basins 5 and 6 — to be progressively verified and refined, and would support extension of the current steady/quasi-steady screening analysis toward fully unsteady, calibrated simulation of the integrated drainage–irrigation network.

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