Guyana Power and Light Incorporated

Guyana Utility Scale Solar Photovoltaic Program - Lot 7 - Flood Risk Assessments for Eight (8) Project Sites

RETRIEVE, LINDEN – FLOOD RISK REPORT

2022-008

Demerara River, Retrieve Linden

Demerara River, Retrieve Linden

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Report includes a preliminary identification of flood mitigation measures

29-Mar-22

Retrieve, Linden
Flood Risk Report

Guyana Utility Scale Solar Photovoltaic Program
Lot 7 - Flood Risk Assessments for Solar Photovoltaic Farm Project Sites

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DOCUMENT CONTROL SHEET

PROJECT DETAILS	
Project Name:	Guyana Utility Scale Solar Photovoltaic Program - Lot 7 - Flood Risk Assessments for Eight (8) Project Sites
Project No.:	2022 - 008
Client:	Guyana Power and Light Inc.
Country:	Guyana

REPORT DETAILS		
Report Name:	**RETRIEVE, LINDEN – FLOOD RISK REPORT**	
Deliverable No.:	5 (Retrieve)	
Date:	29-Mar-22	
Report Status	**REPORT**	EXECUTIVE REPORT
REPORT COMMITTEE		
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REVISION DETAILS		
Revision No.:		
Comments Provided By (Personnel):		
Comments Received On (Date):		
Summary of Changes Made:		
Revised By:		
Approved By:		

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LIST OF ABBREVIATIONS

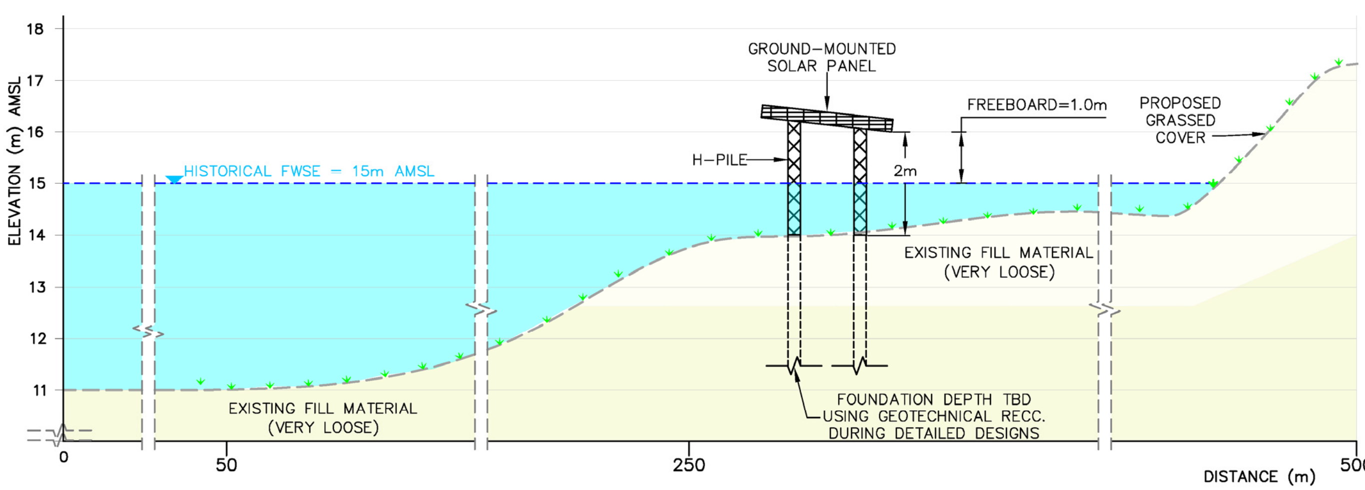
AFRG – Albion Front Rain Gauge
AMSL – Above Mean Sea Level
CC – Climate Change
CI – Confidence Interval
DDF – Depth-Duration-Frequency
DEM – Digital Elevation Model
DRG – Donor Rain Gauge
ENSO - El Niño-Southern Oscillation
FIE –Flood Impact Extent
FWD – Flood Water Depth
FWSE – Flood water Surface Elevation
GEV – Generalized Extreme Value
GIS – Global Information Systems
IDF – Intensity-Duration-Frequency
IMD – Indian Meteorological Department
MK – Mann-Kendall
IMD – Indian Meteorological Department
MK – Mann-Kendall
NSA – North Southern America
PFE –Precipitation Frequency Estimates
PV – Photovoltaic
RCP - Representative Concentration Pathway
RG – Rain Gauge
RI – Recurrence Interval
SDVF – Solar Photovoltaic Farm
SDVS – Solar Photovoltaic System
ToR – Terms of Reference
TRFQ - Tide-Rainfall Flood Quotient
TRG – Target Rain Gauge
UoG - University of Guyana
WB – World Bank
WSE – Water Surface Elevation

EXECUTIVE SUMMARY

This report comprises the preliminary investigations, findings and recommendations for the proposed Retrieve, Linden (Region 10) Solar Photovoltaic Farm (SPVF) (Area = 10.7 Ha.) based on a preliminary flood risk assessment. It includes a section for rainfall frequency and climate change analyses to bridge the data gap of applicable IDF Curves for use in hydrological modelling. Preliminary screening/classification revealed the Retrieve site to be impacted by the Demerara River when it is in extreme flood stage, using a historical FWSE =15m AMSL based on flood depth reports from previous flood events. The contributing area for this hydrological point of interest relative to the site is in the order of 33,000 Ha. in the Demerara Watershed and involves manifold integrated physical processes which require, inter alia, extensive topographical data, discretized and otherwise, to efficiently compute peak flood flows and simulate flood water surface elevations with a high confidence level. This data is not presently available within the domain of this study to derive realistic outputs for the Retrieve project site. Hence, a probable scenario on the basis of a historical flood depth was used to assess the flood risk at this site. The results are summarized in the table below together with a risk category transformed from the flood depth. The values shown are based on an assumed average site level of 14.5m AMSL using Google Earth terrain data. All elevations used herein are pending confirmation when GPL supplies the site topographical data that is currently underway by others. Data/information on the hydraulic performance, operation and maintenance of existing defence structures is not presently available to determine the current and future modulation of floods (Region 5 shapefiles from the NDIA provide locations only). The investigations herein indicate that the Retrieve site is impacted by Scenario 1 at a medium risk level.

No.	Scenario	Est. FWD (m)	FWSE (m)	Risk Category
1	Historical FWSE in Demerara River Based on Reported Flood Depths from Historical Storm Events in Excess of a 10 Yr. R.I. 24-Hr. magnitude	0.5 *Assuming Avg. Site Elev. – 14.5m AMSL*	15	**MEDIUM**

The main risk at this site is damage to the structures/panels from saturated conditions which can result in damage to the foundations, financial losses and periods of plant downtime for repair/reconstruction, as evidenced in the vulnerability assessment performed herein. The same presents a specific framework in the form of a Stage-Damage Function for damage assessment at this site. The preliminary recommendation is to elevate the panel frames by 2m above the existing ground to provide protection from Scenario 1 above with a 1m freeboard for probable marginal increases in FWSE from freshwater input (rainfall excess) within the site. This is shown in the schematic below. All values herein can be revisited when relevant data/information is provided or confirmed by GPL.



1. INTRODUCTION

Guyana Power & Light Inc. (GPL) is undertaking the planning, design, and construction of ground-mounted solar photovoltaic systems (SPVS) at various project sites across Guyana. A flood risk report is required for each Solar Photovoltaic Farm (SPVF) Project Site to allow risk and liability to be minimized while maximizing the potential for an economic and safe design for the service life of the project.

Alpha Engineering & Design (2012) Ltd (Alpha) was contracted by Guyana Power & Light Inc. (GPL) to conduct flood risks assessments and produce a flood risk report for eight (8) solar PV project sites that comprise Lot 7 in **Table 1-1** below.

Table 1-1: Lot 7 - Solar PV Farm Project Areas

No.	Project Site	Region	No.	Project Site	Region
1	Dacoura	Linden	5	Prospect	Berbice
2	**Retrieve**	**Linden**	6	Hampshire	Berbice
3	Block 37	Linden	7	Onderneeming	Essequibo
4	Trafalgar	Berbice	8	Charity	Essequibo

Presented hereunder is the **Flood Risk Report** for **Retrieve, Linden** which includes, inter alia, rainfall frequency and climate change analyses, a methodology for flood impact assessment based on the leading cause of flooding at the site, derivation of flood water depths (FWDs) and flood water surface elevations (FWSEs) for probable scenarios, a preliminary flood risk assessment and recommended mitigation measures.

This Disaster Risk Assessment will form the basis of the executive Disaster Risk Management Plan (which will include the assessments already made and any necessary updates).

For expedience, this report is issued using ***estimated topographical data*** and will be adjusted accordingly as it relates to derived flood levels, when the site-specific topographical reports (ongoing by others) are provided by GPL.

2. SCOPE OF REPORT

This report covers the following:

i. The quality/quantity of available data for hydrological and hydraulic analyses and data gaps;

ii. Rainfall frequency and climate change analyses conducted as follows:

   a. A frequency analysis of the rainfall data series using a Generalized Extreme Value (GEV) Type I Distribution;

   b. Development of IDF & DDF Curves for 2Yr., 10 Yr., 25 Yr., 50 Yr., & 100 Yr. R.I.s;

   c. Trend detection in the data series using the Mann-Kendall (M-K) Statistical Test to potentially guide the selection of suitable factors to be applied to the point precipitation frequency estimates (PFEs) derived in **Item ii (b)** above;

   d. Enhancement of the IDF & DDF Curves for the R.I.s and storm durations listed above taking into consideration a factor of 20% for the expected intensification of extreme rainfall events as this study relates to flood risk assessment.

iii. Determination of the main source of flooding from preliminary screening and site classification based on elevation, proximity to watercourses and tidal influence;

iv. Flood impact assessment to derive FWDs and FWSEs at the SPVF site for probable scenarios;

v. A flood risk assessment considering potential consequences and mitigation measures based on the findings of **Item** iv above;

vi. Recommendation of mitigation measures for consideration in the detailed design of the system by others.

3. DATA COLLECTION & PROCESSING

Table 3-1 below summarizes the available data for use in analyses for this project site.

Table 3-1: Description of Available Datasets

No.	Category	Description	Source	Date	Remarks Based on Processing/Utility
1	Elevation	1:50,000 PSAD Topographical Maps (50 ft. contour interval)	Guyana Lands and Surveys Commission (GLSC)	1973	Maps are in pdf/tiff format and do not have digitized features or elevation data. Therefore, attempts to generate contours for the various catchments using GIS tools were unsuccessful as outputs at 1m, 2m and 5m contour intervals were deemed to be inaccurate and inconsistent with the general terrain.
2		1:1,000,000 PSAD Topographic Sheet Index		2005	The map is in pdf/tiff format and contains digitized features including river networks and roads. However, there is no elevation data for extraction.
3		Shapefiles for Block 37NW from Item 2 above			As per the Topographic Sheet Index, digital data with digitized features, in the form of shapefiles or other, is not available for this block.
4	Rainfall	Daily Data from ARFG & Daily Data from Adjacent Gauges to fill data gaps	Hydrometeorological Service, Ministry of Agriculture, Guyana	1974 -2021	Data used to execute rainfall frequency and climate change analyses and ultimately produce IDF Curves for input in hydrological modelling of the catchments.
5	Features	Shapefiles for main rivers, catchments and channels in Region 5	National Drainage & Irrigation Authority, Ministry of Agriculture, Guyana	Received 22-Mar-2022	The Region 5 geopackage received contains shapefiles of digitized locations of catchments, channels and main sluices and pumps in Region 5. Data/ information on the hydraulic performance, operation and maintenance of existing defense structures as well as plans for future upgrades is not presently available to determine the current and future modulation of floods.

4. RAINFALL & CLIMATE CHANGE ANALYSES

This chapter addresses the data gap of applicable Guyana-based IDF Curves for the project site by presenting rainfall frequency and climate change analyses conducted on forty-eight (48) years of daily local rainfall data from the Albion Front Rain Gauge (AFRG) in Guyana to produce IDF and DDF curves that are suitable for providing rainfall intensity/depth estimates for the respective hydrological models. The missing gaps in the raw dataset were filled with recorded data from adjacent rain gauges for the corresponding period. The daily data was fitted to a Generalized Extreme Value (GEV) Type I Distribution and an empirical reduction formula was used to estimate rainfall depths for sub-daily durations. Neither an increasing nor decreasing trend was found in the data using the Mann-Kendall (MK) statistical test. Notwithstanding, a factor of 20% was applied to all point precipitation frequency estimates (PFEs) to produce enhanced curves that cater for the potential intensification of extreme precipitation due to climate change for the purpose of flood estimation and risk assessment in this study. The result was a set of IDF curves to be used as the main rainfall input in the hydrological analysis. A comparison of the unadjusted curves developed herein with IDF curves for Georgetown Botanical Gardens showed comparable results as the difference in PFEs are within a -1 to +2 mm margin for the 10 Yr. and 50 Yr. R.Is. Details of the analyses are included in the sub-chapters below.

4.1 CLIMATE DESCRIPTION & CLIMATE CHANGE IMPACT

Guyana's climate generally comprises of two climatic conditions (rainy and dry). The two significant rainy seasons are **April to August** and **November to January**. Annual rainfall varies from roughly 2285 mm on the east coast to 3556 mm in the rainforest areas in the west/southwest (EES Inc. 2022). While climate projections for Guyana indicate a decrease in the mean annual precipitation (IPCC 2014), the intensity and frequency of extreme precipitation and pluvial floods are projected to increase at the medium confidence level for the 2°C global warming level and higher (IPCC 2021). Sea Level Rise (SLR) is also a significant threat to the relatively flat and heavily populated coastal region. Local tide gauge data for the period 1951 to 1979 indicated a mean relative sea level rise of 10.2 mm per year (Van Doimen 2013). The projections made by IPCC (2014) and World Bank (2021) are in the same order and suggest an increasing severity of impacts from storm surges and increased flood levels in the future which is concerning for the project sites in the low-lying coastal areas.

Rainfall distributions across the country are associated with the El Niño-Southern Oscillation (ENSO) of which El Niño and La Niña events are the extreme phases on the ESNO cycle. The El Niño phenomenon has produced unprecedented drought conditions throughout Guyana (Wahlström and Weber 1998) while a La Niña event is likely to result in significantly higher than normal precipitation (Wardlaw et al. 2007).

Some historical events on record provide context of the climatic situation in Guyana. On the dry side of the spectrum, the strongest El Niño cycle in Guyana's recorded history produced a drought in March 1997 – 1998 during which there were more than 40-day periods with zero rainfall based on raw rainfall data recorded at the AFRG on the east coast. The impacts of this event included the drying up of rivers and saline intrusion of dams 48 – 64 km upstream of the coastal rivers (Vaughn 2018).

On the other side, more relevant to this project, the storm events between December 2004 and February 2005 resulted in over 1500mm of cumulative rainfall flooding Guyana's Atlantic coast (Blommestein et al. 2005). This was an unprecedented occurrence compared to the average monthly rainfall of 230mm for these months.

4.2 DESCRIPTION OF RAINFALL DATASETS

The rainfall data used in this study has a daily resolution and was procured from the Hydro-meteorological Service (Hydromet) of the Ministry of Agriculture, Guyana recorded at the Albion Front Rain Gauge (AFRG) (Lat. 6.15; Long. -57.22). The location of this rain gauge is shown in **Figure 4-1** below:

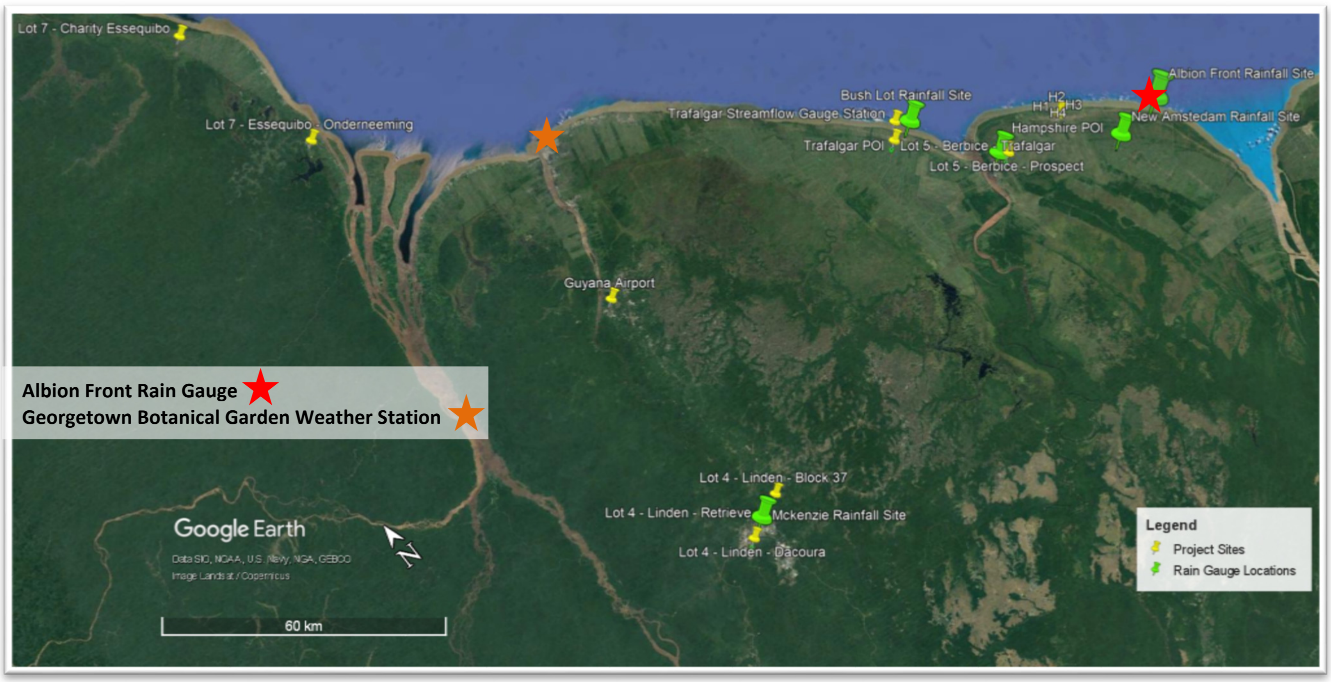


Figure 4-1: Rain Gauge Locations

This dataset was selected as the most feasible option from the list of available data provided by Hydromet for the following reasons:

1. The available dataset includes forty-eight (48) years of daily rainfall data that is generally continuous with a few gaps;
2. A relevant corroboration is made with the point precipitation frequency estimates (PFEs) from the IDF curves for Georgetown;
3. The AFRG is situated in coastal hinterland (~3km) and the impact of the wind on the gauge measurements, if any, likely results in an upward skew of the total rainfall measured, as sea spray is known, through investigation, to increase rainfall measurements with increased wind speeds (Okachi et al. 2020);

4. High-intensity tropical storms reduce as they move inland losing speed and moisture so this phenomenon generally results in an increase in extreme rainfall events in coastal regions.

Considering these factors, the AFRG data is considered to be a suitable candidate for the development of IDF curves, erring on the conservative side in the case of points 3 and 4 above.

Table 4-1: Data Gaps in the TRG and Respective DRGs

No.	Missing Periods in Albion Front (TRG)	No. of Days	Donor Rain Gauge (DRG)	Distance from DRG to TRG (km)
1	Dec 2019	31	Canje Forestry	34.39
2	Dec 2017	31		
3	Oct 2013	31	New Amsterdam	10.3
4	18-30 Sep 2013	13		
5	Dec 2012	31		
6	Feb-Sept 2001	242		
7	July-August 2000	62		
8	Dec 1999	31		
9	Apr-May 1999	61		
10	June 1991	30	McKenzie	125.31
11	May 1990	31	New Amsterdam	10.3
12	Oct 1989	31		
13	Aug 1989	31		
14	Feb 1988	29		
15	Jun- July 1988	61		
16	14-17 Dec 1988	4		
17	Sept 1986	30		

The missing gaps of data from the AFRG are listed in **Table 4-1**. Due to the debilitating effect that significant data gaps can have on the resulting IDF curves, observations from neighboring rain gauges were chosen to bridge these gaps for the corresponding periods in accordance with Adilah & Hannani (2021). The donor rain gauges (DRGs) are also listed in **Table 4-1** based on straight-line distance from the target rain gauge (TRG) "AFRG" and availability of data from Hydromet. The locations of the DRGs are also shown in **Figure 4-1** above.

Given that rainfall data from all adjacent gauges have missing gaps in the datasets, the following assumptions were made:

1. The normal yearly totals at Canje Forestry and New Amsterdam rain gauges (RGs) are within 10% of the normal annual precipitation (Adilah & Hannani 2021) at Albion Front, and so they are representative of the observations from the AFRG due to proximity (34.39 km and 10.3km respectively) and topographical condition, and hence do not need to be factored to account for differences;
2. The 1-month data record (June 1991) imported from the RG at McKenzie, positioned 125.31 km away will have a negligible impact, if any, on the output IDF/DDF Curves due to the relatively short gap and similarity of the imported estimates with other June rainfall values at the AFRG.

4.3 INTENSITY-FREQUENCY-DURATION ANALYSIS

Rainfall intensities are key inputs for the hydrological models to be developed as part of the flood risk assessment for the project areas in Lot 7. The scope of work (as per the Terms of Reference) require hydrological analyses for the 50 Yr. and 100 Yr. R.I.s and it was further agreed at the Kick-Off Meeting that the same will be done for the 10 Yr. R.I. The sub-chapters below present the rainfall frequency analyses conducted by Alpha to derive rainfall intensities/depths for use in the modelling process.

4.3.1 METHODOLOGY

Figure 4-2 below shows the main steps used to develop IDF & DDF Curves for the 2 Yr., 10 Yr., 25 Yr., 50 Yr. and 100 Yr. Recurrence Intervals (R.I.s) in accordance with DHV Consultants BV & Delft Hydraulics (2002) and Namitha and Vinothkumar (2019).

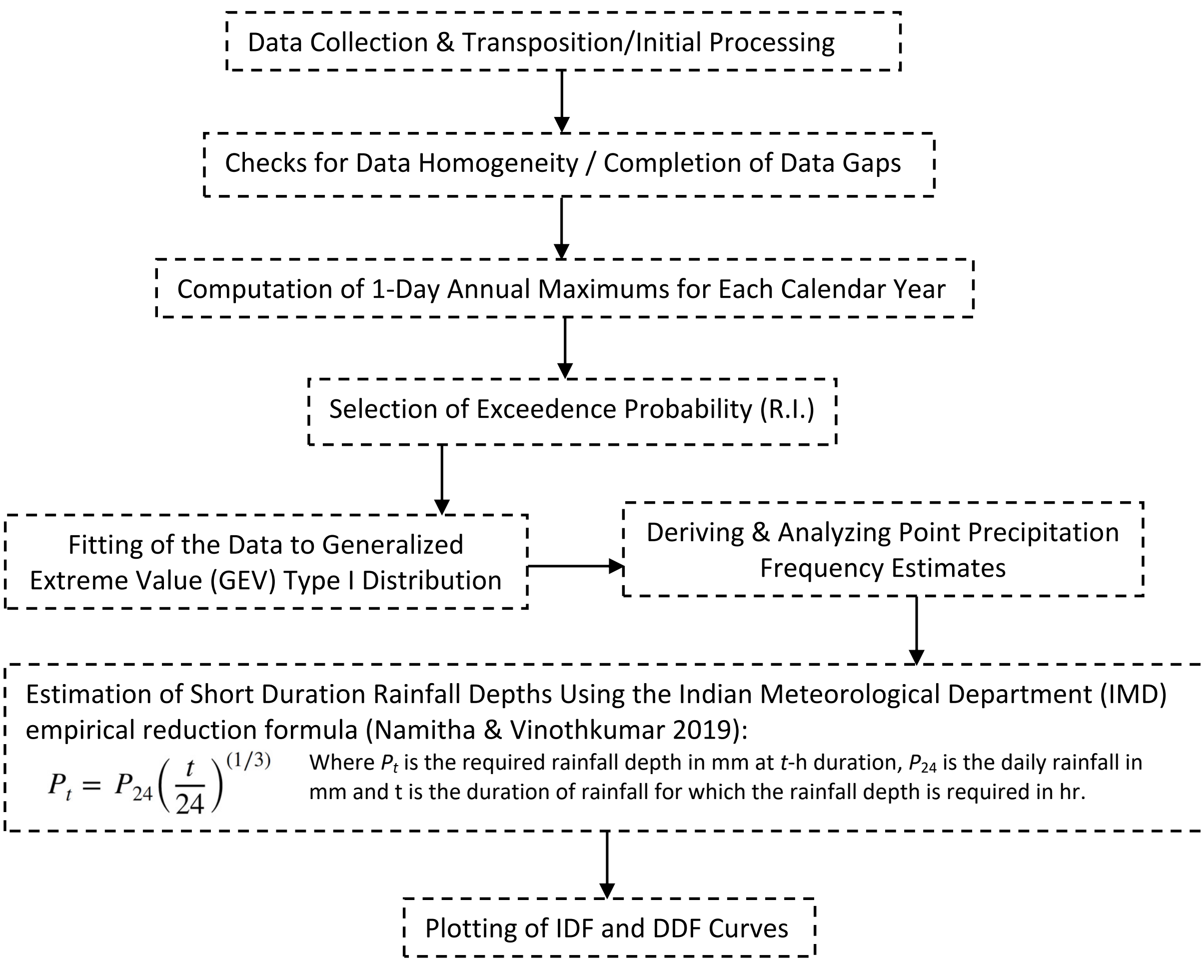


Figure 4-2: Outline of the Main Steps Used in the Development of IDF/DDF Curves

4.3.2 TABLE OF MAXIMUMS

Table 4-2 below shows the maximums computed for each calendar year using the daily rainfall dataset described above from the AFRG.

Table 4-2: 1-Day Annual Maximums

Year	1-Day Maximum	Year	1-Day Maximum	Year	1-Day Maximum	Year	1-Day Maximum	Year	1-Day Maximum	Year	1-Day Maximum
1974	109.5	1982	102.1	1990	116.8	1998	99.4	2006	77.5	2014	66
1975	143.5	1983	72.9	1991	61.5	1999	99	2007	102.6	2015	82.1
1976	109	1984	134.1	1992	48.5	2000	126	2008	147.2	2016	157.8
1977	119.4	1985	82.6	1993	85.5	2001	167.8	2009	62.7	2017	135.5
1978	63.5	1986	80	1994	69	2002	162.2	2010	86.4	2018	55.5
1979	93.2	1987	159.8	1995	101.6	2003	70	2011	159.4	2019	101
1980	63.8	1988	104.5	1996	119.9	2004	99.1	**2012**	**176.8**	2020	43.4
1981	73.2	1989	94	1997	88.9	2005	150.4	2013	79.5	2021	85.5

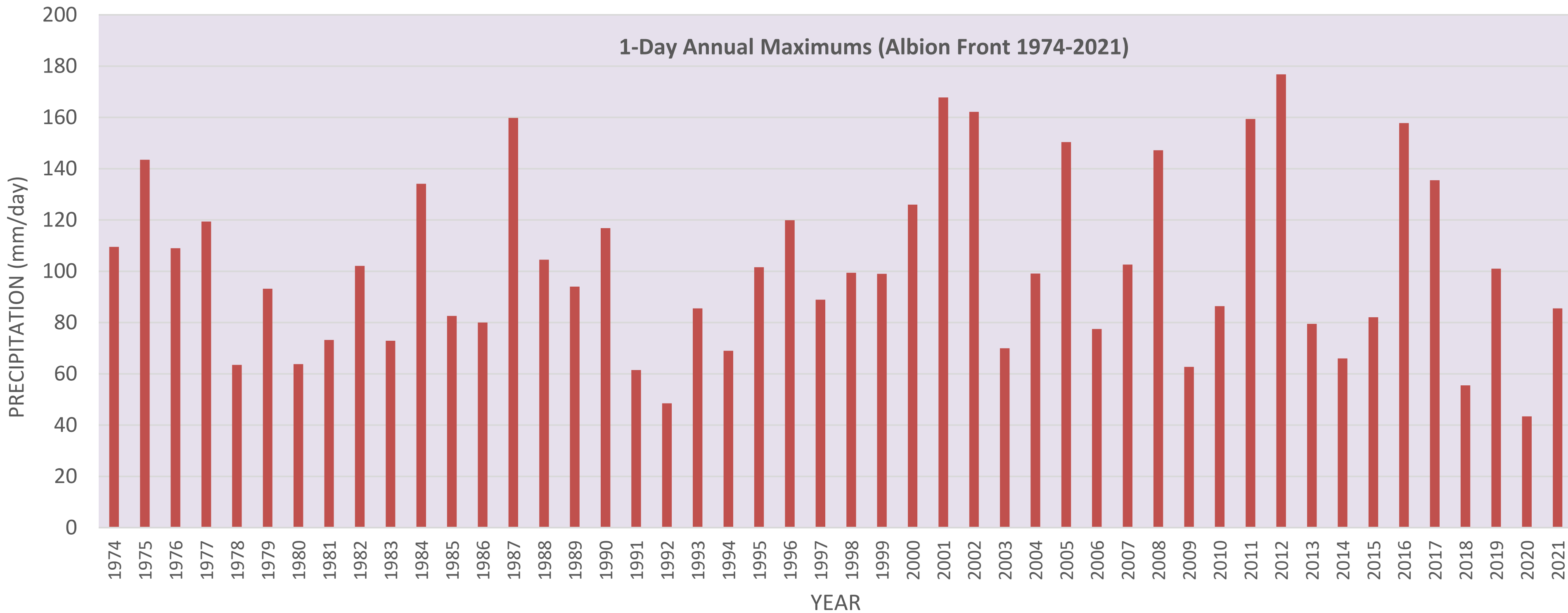


Figure 4-3: 1-Day Annual Maximums Plot

4.3.3 IDF/DDF CURVES

Figure 4-4 and **Figure 4-5** below show the IDF and DDF Curves generated using the Albion Front Rainfall Dataset.

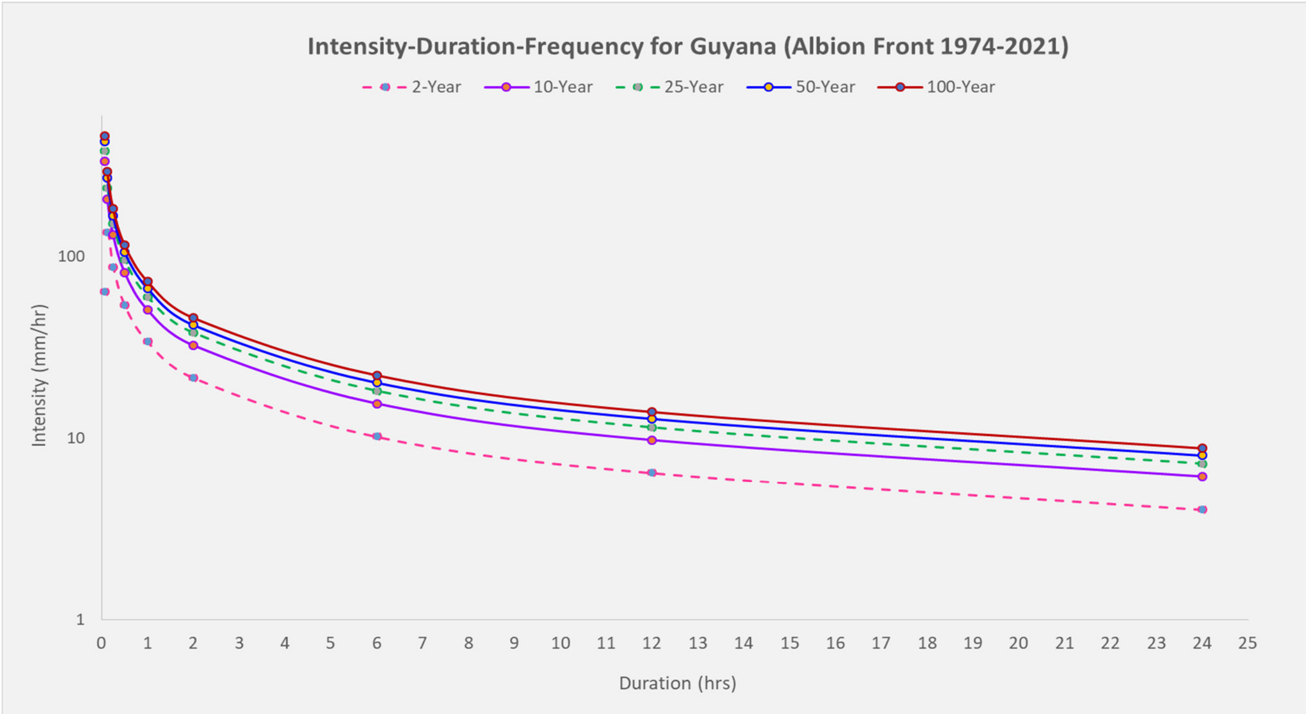


Figure 4-4: IDF Curves for Guyana Using Rainfall Data from Albion Front for 1974-2021

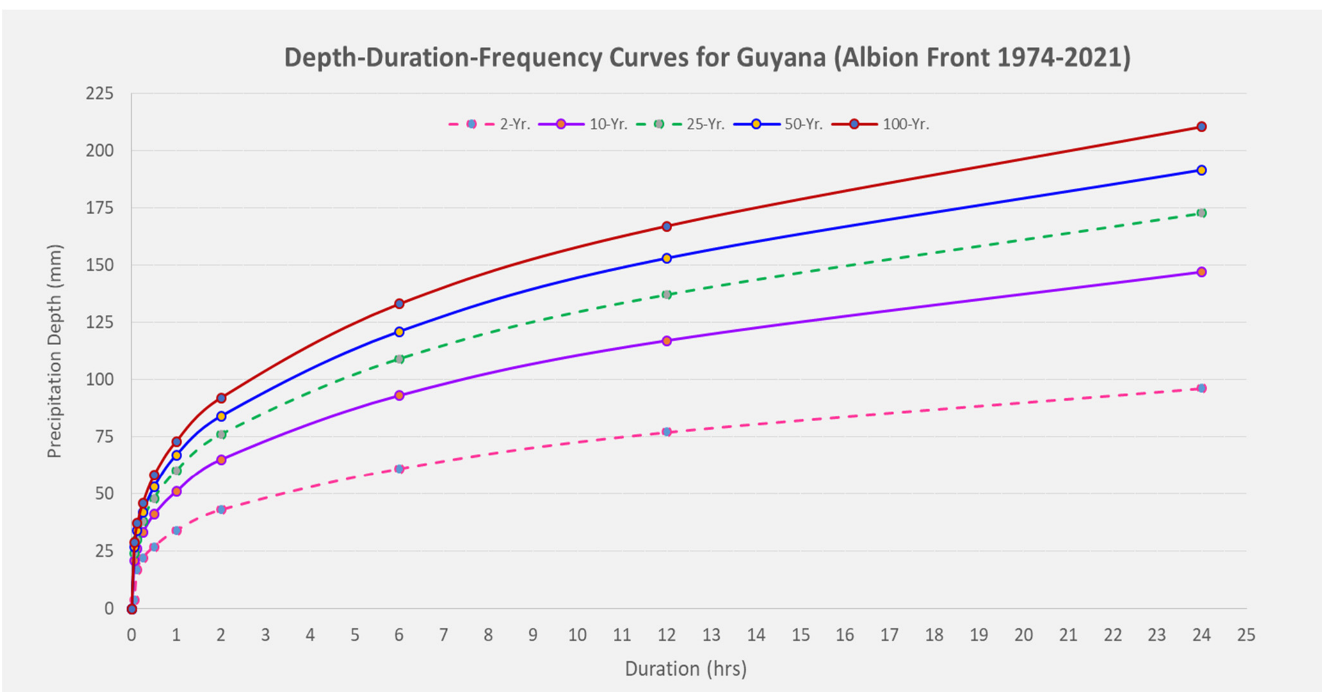


Figure 4-5: DDF Curves for Guyana Using Rainfall Data from Albion Front for 1974-2021

4.4 TRENDS IN DATA

Rainfall frequency and intensity estimates were extracted from the historical local records through statistical analyses in the previous section. Given all the climate change indicators and projections being developed by the IPCC on a global scale, the daily rainfall totals and 1-day annual maximums were tested using the Mann-Kendall (MK) statistical test to determine whether a true trend exists or there is no trend detected in the dataset (Wang et al. 2020).

The results are summarized in

Table 4-4 below and show that a trend was not detected in both cases at a 95% Confidence Interval (CI) for this picture-in-time. If the P-value is less than the significance level α = 0.05, the null hypothesis H_0 is rejected, indicating that there is a trend in the time series (Karmeshu 2012). Hence, accepting H_0 indicates that a trend is not detected. Since the computed P-value is greater than the significance level α = 0.05, the null hypothesis H_0 is accepted in this case. Therefore, the test did not detect an increasing or decreasing trend in the data.

Table 4-3: Summary of Statistics Computed for M-K Trend Test

Dataset	Variable	No. of Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. Deviation
1-Day Annual Max.	109.5	47	0	47	43.400	176.800	101.704	34.949
Daily Totals	0	17854	0	17854	0.000	176.800	4.703	11.746

Table 4-4: Output of M-K Trend Test

M-K Statistical Output	1-Day Annual Max.	Daily Totals
Significance Level, α	**5%**	**5%**
Kendall's Tau	0.009	-0.006
S value	10.000	-748144.000
Var (S)	1.2×10^4	5.3×10^{11}
P-value (Two-tailed)	0.934	0.305
Hypothesis	H_0	H_0
Trend Detection	None	None

4.5 ADJUSTED IDF/DDF CURVES

Notwithstanding that neither an upward nor downward trend was observed in the dataset examined herein, there is no guarantee that a trend will not develop in future time series. Therefore, for the purpose of estimating flood hydrologic response of the eight solar PV project areas, a factor of 20% was applied to the PFEs derived above to enhance the IDF/DDF Curves to cater for a potential intensification of extreme rainfall events, in line with the IPCC's prediction that the intensity and frequency of extreme precipitation and pluvial floods are projected to increase (medium confidence) for 2°C of global warming level and above for the Northern South America (NSA) region in which Guyana is situated (IPCC 2021). The two sets of enhanced curves are shown in **Figure 4-6** and **Figure 4-7** below and will be used in the hydrological modeling of all catchments in the project scope.

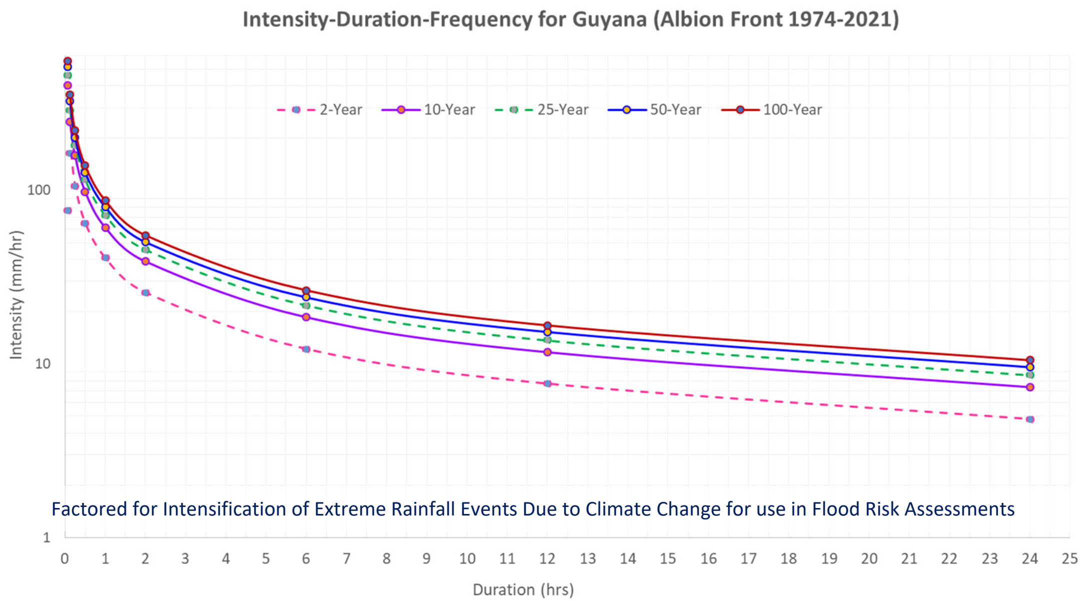


Figure 4-6: Enhanced IDF Curves for Guyana Using Rainfall Data from Albion Front for 1974-2021

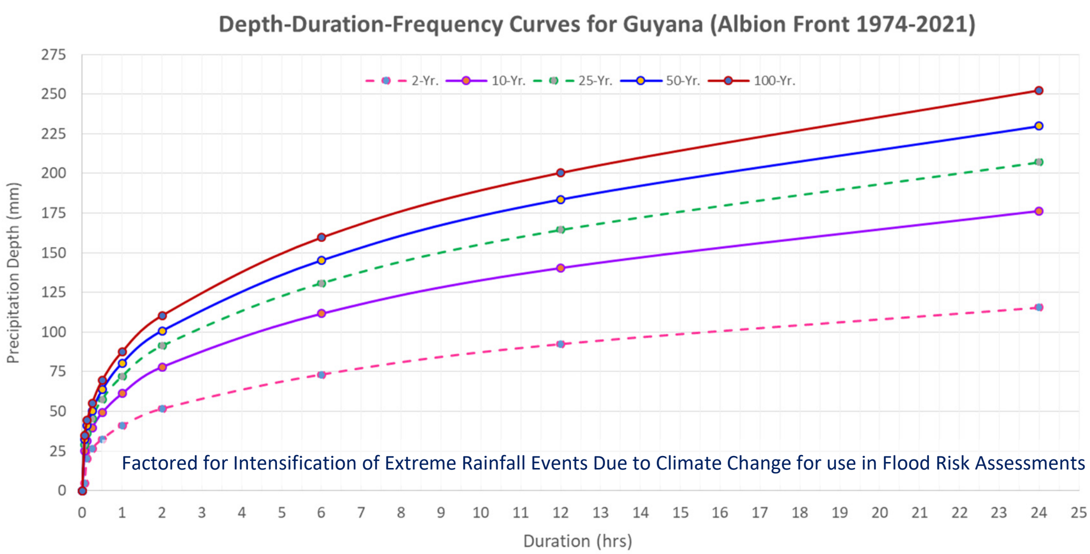


Figure 4-7: Enhanced DDF Curves for Guyana Using Rainfall Data from Albion Front for 1974-2021

4.6 COMPARISON OF RAINFALL INTENSITIES

The IDF curves for the 10 Yr. and 50 Yr. R.I.s were developed by a Joint Venture of HYDEA/RPA/EMO Consultants (2014) for the University of Guyana Science and Technology Support Project using rainfall data recorded at the Georgetown Botanical Garden Weather Station from Ministry of Agriculture's Hydrometeorological Service. These curves are shown in **Figure 4-9** below. The gauging station is situated approximately 115km northwest of the AFRG (as shown in **Figure 4-1** above) and is situated within a similar topographical region. Therefore, a relevant comparison of the PFEs provided by the IDF curves from these two gauging stations (***not factored for CC***) can be made for corroboration of the reliability of the IDF Curves developed herein, in the absence of a wider range of data/local-based studies for further analyses. As shown in **Figure 4-8** below, the difference in PFEs are within a -1 to +2 mm margin for the storm events compared.

Storm Event	Comparison of Rainfall Intensities (mm/hr)		
	[1]IDF Curves for Albion Front	[2]IDF Curves for Georgetown	Difference (mm/hr)
10 Yr. 12-Hr.	13	14	1
10 Yr. 24-Hr.	6	5	-1
50 Yr. 12-Hr.	13	15	2
50 Yr. 24-Hr.	8	9	1

[1]Developed Herein
[2]Ref. Joint Venture of HYDEA/RPA/EMO Consultants (2014) for UoG

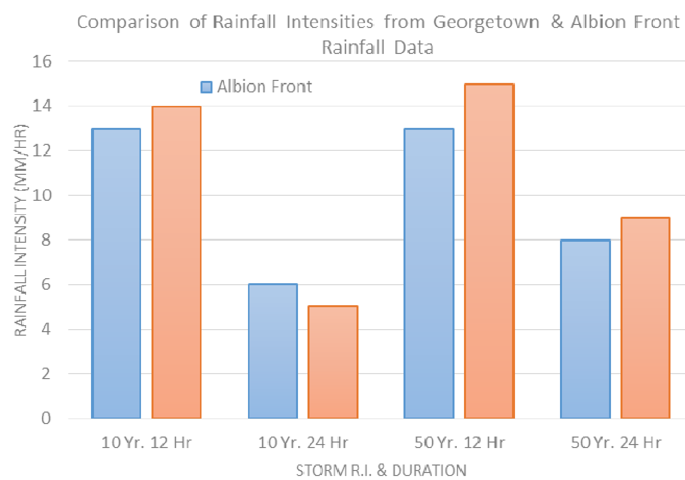


Figure 4-8: Comparison of Rainfall Intensities

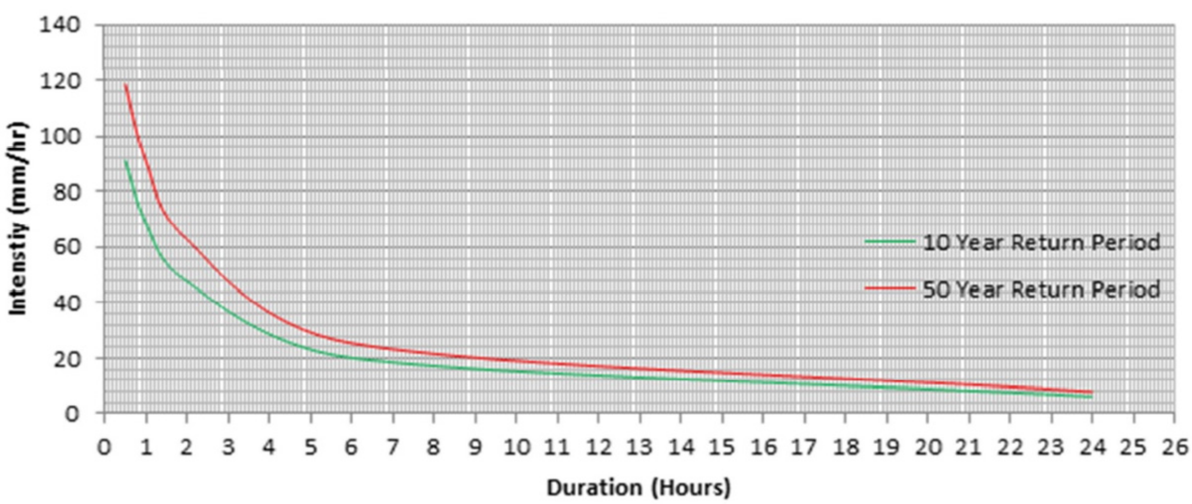


Figure 4-9: IDF Curves Developed by the Joint Venture of HYDEA/RPA/EMO Consultants (2014) Using Rainfall Data from Georgetown Botanical Garden Weather Station

5. SCREENING & SITE CLASSIFICATION

A preliminary screening and classification of the site in relation to flood risk is summarized in **Table 5-1** below to determine the most suitable methodology for flood impact assessment in the next chapter.

Table 5-1: Preliminary Screening & Site Classification

Project Site	**Retrieve, Linden**		
Site Description	The project site in Retrieve, Linden has an area of **10.7 Ha**. and is generally elevated (2-4m) above surrounding areas. The surface cover of the site is mostly light underbrush with small clusters of thick vegetation.		
Potential Cause of Flooding	Demerara River when in extreme flood stage		
Main Source of Flooding	INTERNAL PROJECT SITE	**EXTERNAL ELEMENTS**	COMBINATION
Description of Source of Flooding	The Demerara River banks are at approximately 11m AMSL and flow northward 1.3km west of the project site. The latter is at an approximate elevation of 14.5m AMSL and is considered to be within the floodplain region of the Demerara River under extreme conditions.		
Prelim. Flood Risk Classification	**MEDIUM**		

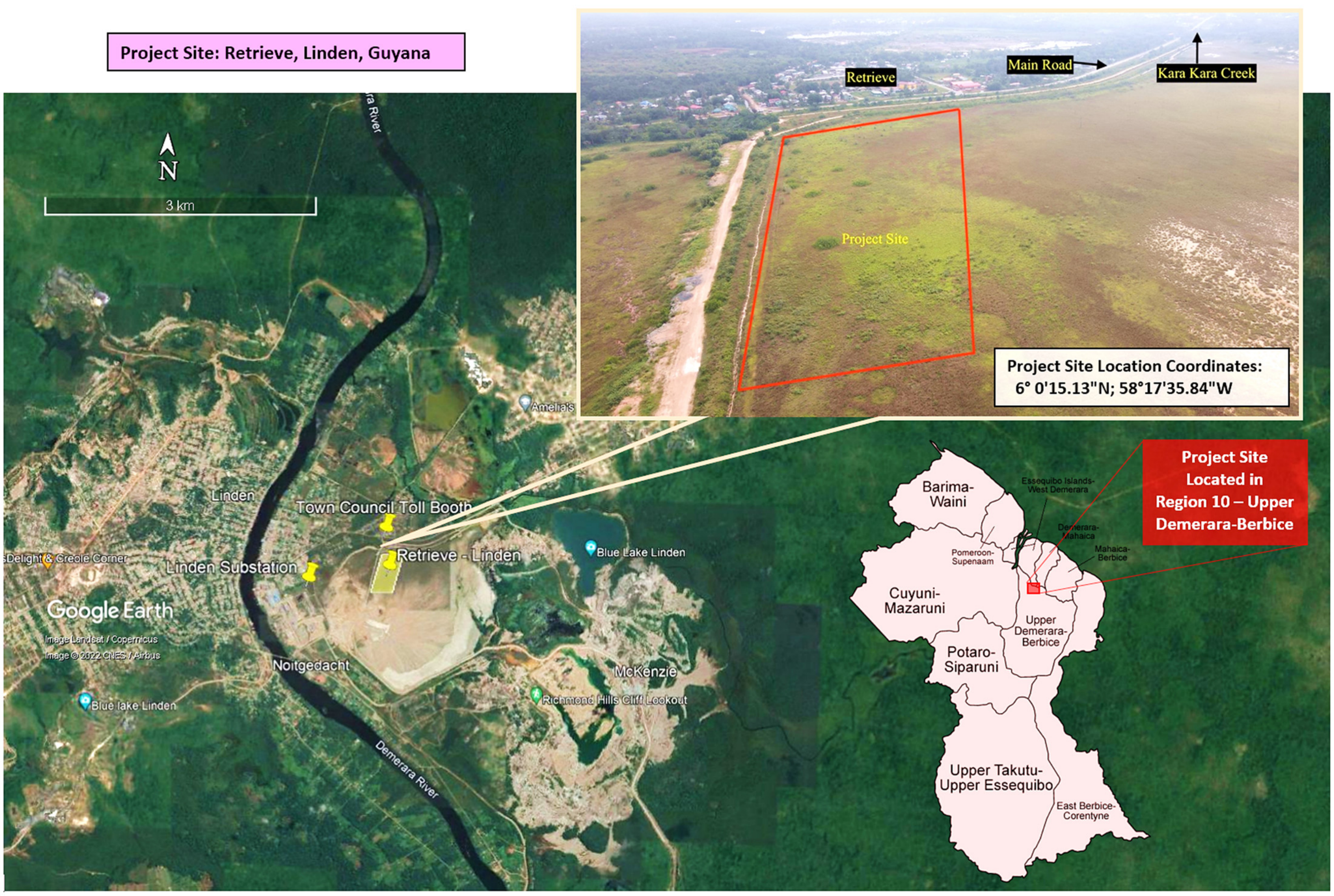


Figure 5-1: Retrieve, Linden Project Site Location Plan

6. METHODOLOGY FOR FLOOD IMPACT ASSESSMENT

Figure 6-1 below outlines the main steps in conducting hydrological and hydraulic analyses for the project sites in Lot 7 based on the outcome of the individual preliminary screening and site classification process above.

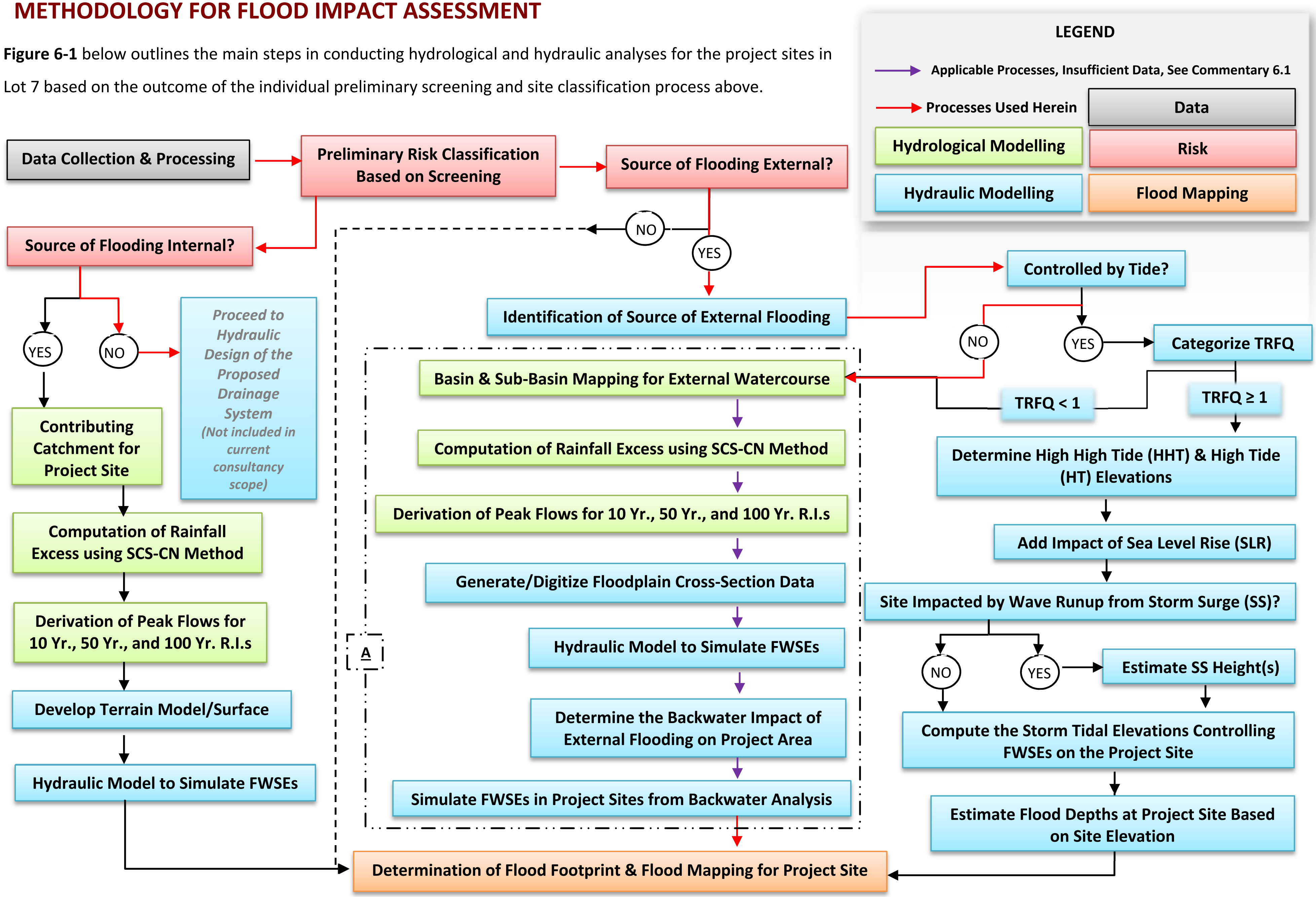


Figure 6-1: Outline of Methodology for the Modelling Process

Commentary 6.1

The processes in Group A above are all applicable for modelling the Demerara River to derive peak storm flows for various R.Is and simulate flood water surface elevations at the hydrological point of interest with respect to the Retrieve project site. The contributing area for this point is the upper Demerara River Watershed, shown in **Figure 6-2** below on the Major Watershed Maps by GLSC (2006), and has an area in the order of 33,000 Ha. This watershed involves manifold integrated physical processes that result in a complex hydrological condition. In general, applicable flood routing methods need to be chosen with respect to the modelling purpose as well as available data (Hellmers and Fröhle 2021). Notwithstanding the purpose of modelling, topographical data for the contributing area is necessary for providing a geometric description of the river/floodplains and thus achieving realistic outputs in terms of flood depths, durations and impact extents (i.e flood mapping). Faridani et al. (2020) articulates the reality of data paucity for flood mapping and in return, presents an innovative procedure for estimating flood extent and depth, which requires a DEM as the primary input data. While the same is not available for this current study, the work of these authors corroborate the essential nature of elevation data on accurately estimating flood depths. Further, the aforementioned study indicates that the model developed, namely Geomorphic Flood Index, is not fit for modeling flood wave propagation to determine, inter alia, times and durations of peak floods.

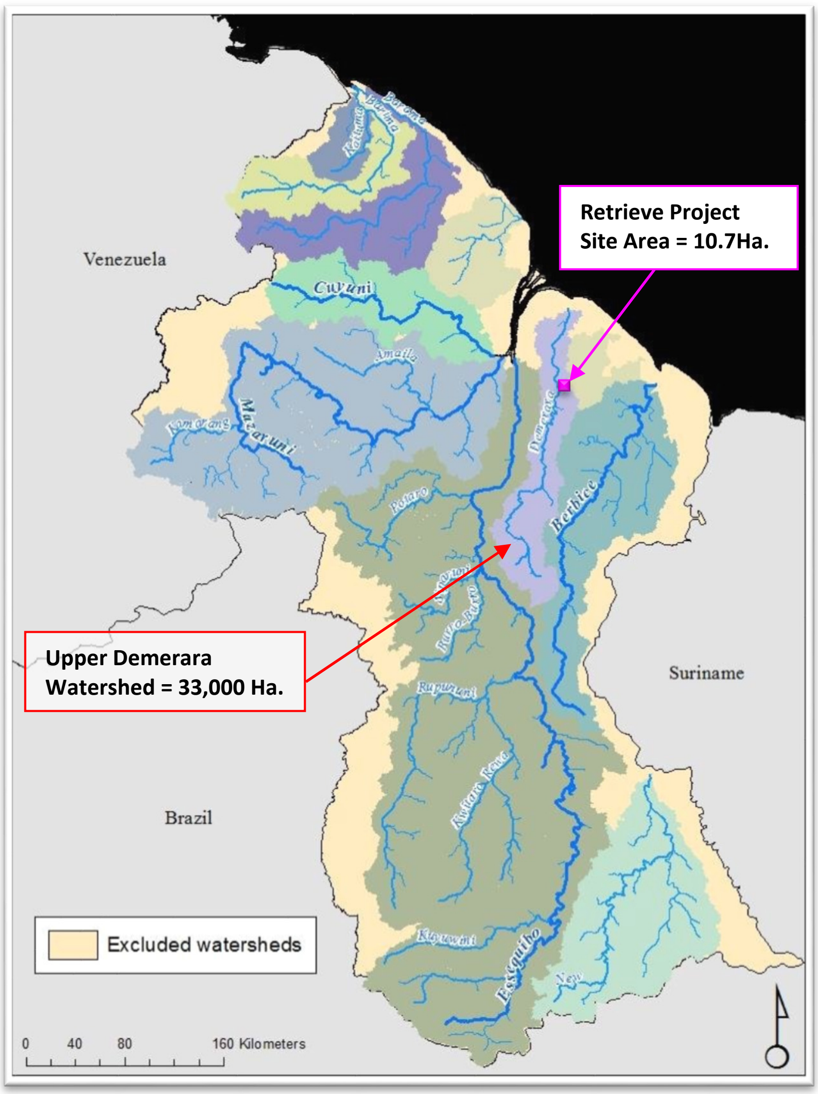


Figure 6-2: Retrieve Project Site in Demerara River Watershed (Source Map – GLSC 2006 Major Watersheds)

Section 3 above summarizes data availability and utility for this study, including a list of available elevation data sources. The lack of the same creates a computational limitation with respect to the derivation of peak flows with a high confidence level. Therefore, a scenario considering a historical flood level is discussed below.

7. FLOOD IMPACT ASSESSMENT

7.1 FLOOD IMPACT

The Retrieve Project site is situated at an approximate elevation of 14.5m AMSL 1.3km east of the Demerara River which has a bank elevation of 11m AMSL as shown in **Figure 7-1** below. Using historical flood depths reported by Kaieteur News (2021) of 12 ft for the region, a historical **FWSE =15m AMSL** was estimated at this location. These events are relevant as they proved widespread extraordinary flooding experienced by the villages/communities from pluvial inputs exceeding the rainfall intensity associated with a 10 Yr. R.I. across 24-hours. Based on Google Earth terrain data, the resulting floodplain extends eastward impacting the project site with a flood water depth of 0.5m.

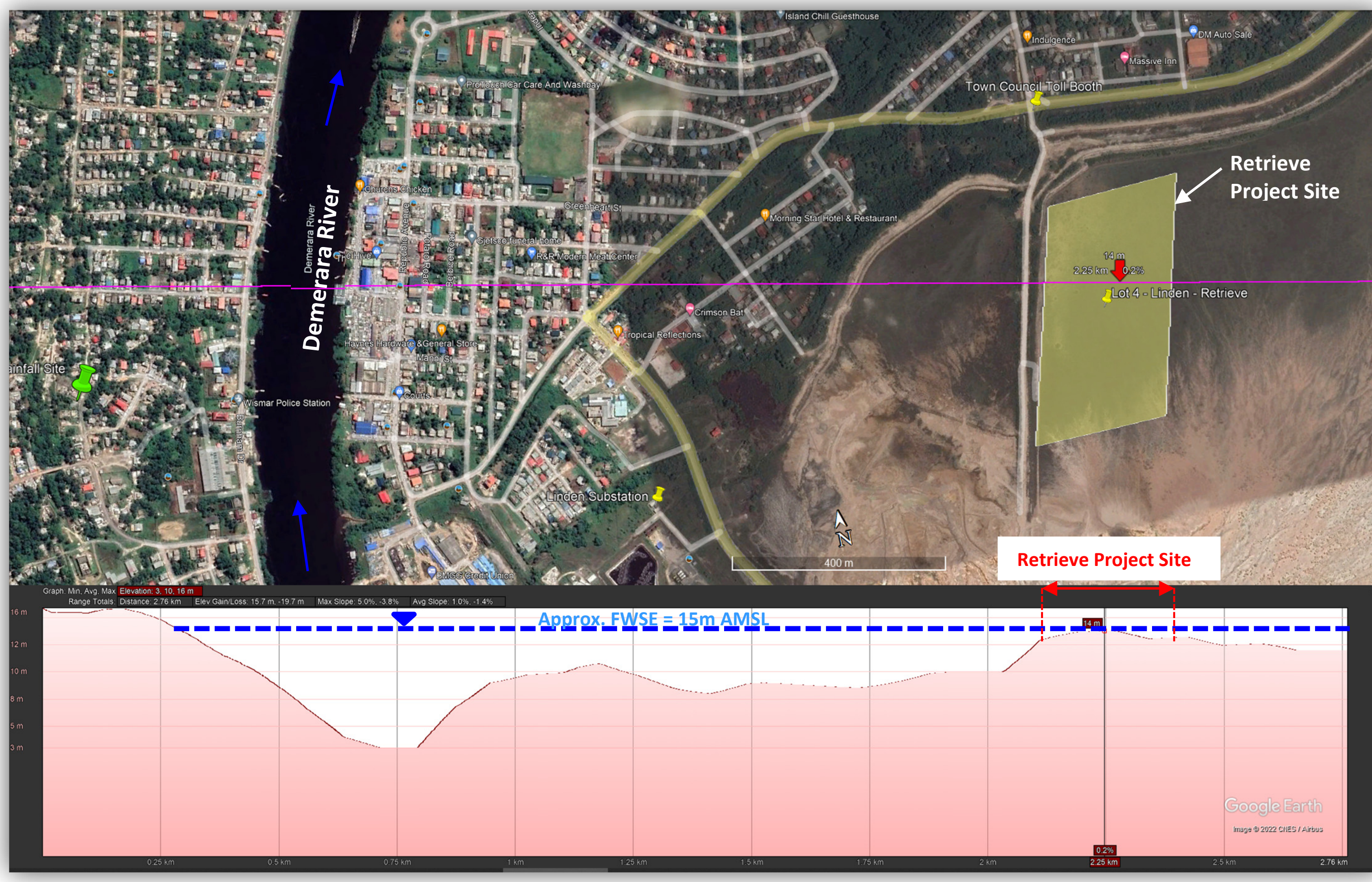


Figure 7-1: Retrieve Project Site Relative to Demerara River

The modulation of historical floods by existing kokers/sluices and/or pumps is not presently known as data for analyzing the same is not currently available. Similarly, assessing their impact on floods for future scenarios requires data/information on the hydraulic performance, operation and maintenance of existing defense structures and plans for future upgrades. This is partially because multiple events of failure have occurred in the recent past in the Demerara/Mahaica region resulting in water forcefully rushing inward and flooding adjacent communities. Some of these are reported firsthand by iNews

Guyana (2022), Stabroek News (2020) and Stabroek News (2009). The structures are, in many cases, hydraulically and structurally inefficient and cannot effectively drain the floodwater into main rivers whenever there is a deluge (Kaieteur News 2021).

7.2 INTERNAL FLOOD MODELLING

It was established at the preliminary screening phase that internal site factors are not the main source of flooding at the Retrieve site. Internal flood modelling is based on the level of flooding within the project site in the post-developed condition from surface runoff generating from the site area itself and is required at the detailed design phase when the layout of the system is established.

7.3 FLOOD FOOTPRINT

In the absence of high resolution topographical rasters to produce a Water Surface Elevation (WSE) Raster using a grid cell analysis, the historical/assumed flood depths stated above were mapped using an elevation model from https://www.floodmap.net/pro/ to demonstrate the inundation across the site in both cases.

In **Figure 7-2** at FWSE = 15m, the flooded areas within the Demerara River floodplain impact the northern section of the project site. This is based on historical flooding depths reported in the region.

The map shown below is included herein solely for the purpose of illustrating flood extents based on elevations. Other critical factors that modulate flood events are not catered for in the flood extents shown in this map. As such, it is not meant for extracting flood depths to prepare detailed designs or evaluate flood risk as they have not been calibrated or verified.

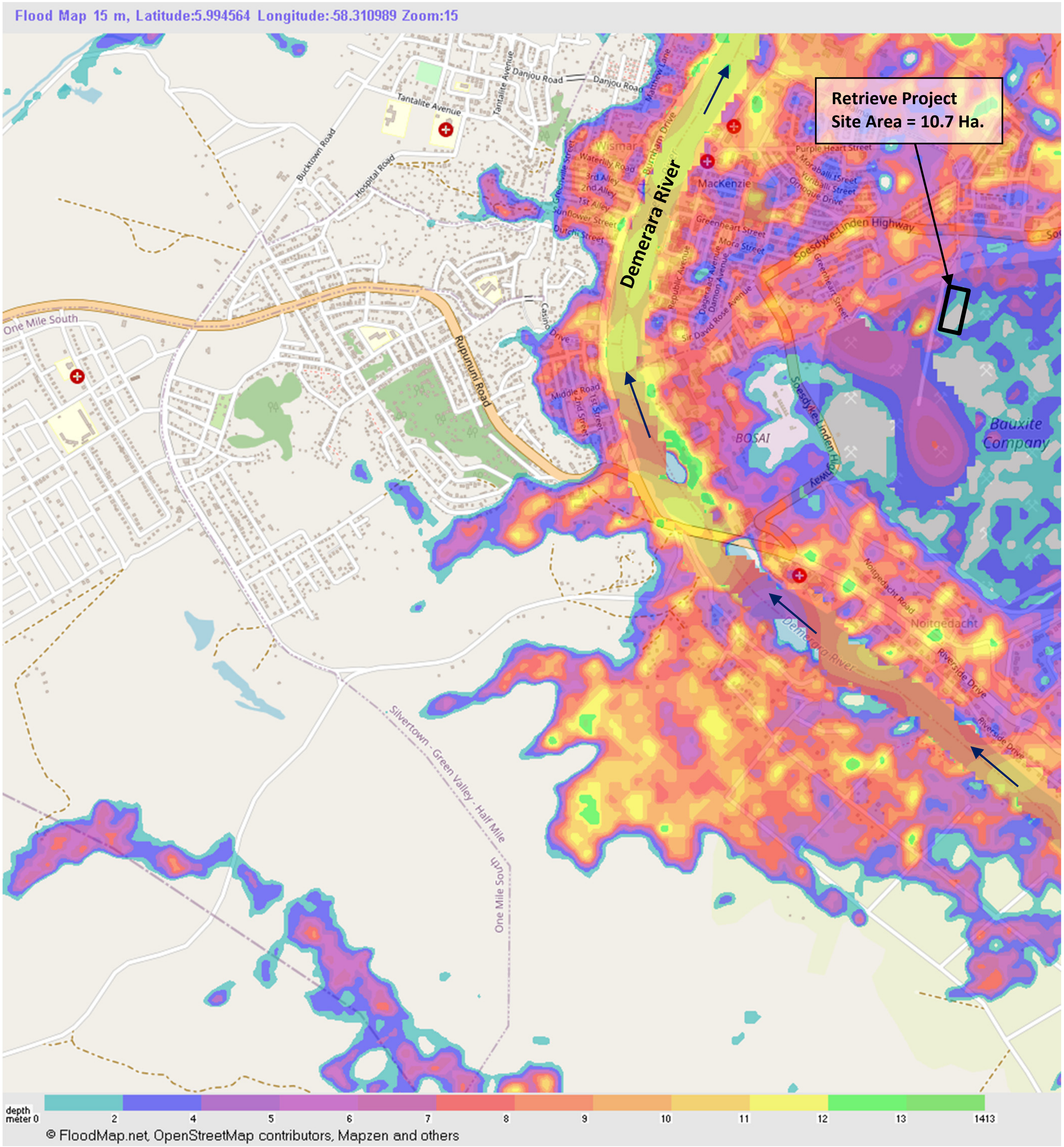


Figure 7-2: Flood Inundation Map for Retrieve, Linden at FWSE = 15m AMSL

8. FLOOD RISK ASSESSMENT

The Retrieve site (area = 10.7 Ha.) is proposed for a ground-mounted solar photovoltaic system (SPVS). Flood mitigation measures stemming from a flood risk assessment for the proposed preliminary post-development condition at this location is critical to ultimately achieve the objective of energy independence and autarky within the communities/facilities to be supplied during extreme weather conditions considering the impacts of climate change.

The risk category shown in **Table 8-1** (FEMA 2020) was used to categorize the flood risks at the Retrieve Site for the scenario presented above using the flood depth derived in the flood impact assessment.

Table 8-2 below shows that there is a **medium** flood risk in the case of the historical FWSE. As such, mitigation measures to reduce the associated risks are discussed below.

Table 8-1: Flood Risk Categories (FEMA 2020)

Flood Depth Range (D)	Risk Category
D(m) < 0.4	LOW
0.4 < D(m) < 0.75	MEDIUM
0.75 < D(m) < 1.75	HIGH
1.75 < D(m) < 3.0	VERY HIGH
D (m) > 3.0	EXTREME

Table 8-2: Flood Risk Categories for the Retrieve Project Site

No.	Scenario	[1]Estimated FWD (m) On Project Site	FWSE (m)	Risk Category
1	Historical FWSE in Demerara River	0.5	15	MEDIUM

[1] Using an Average Site Elevation of 14.5m AMSL as it varies from 11-18m AMSL across the site (based on Google Earth terrain data).

The potential risks to the solar photovoltaic system at the Retrieve SPVF are discussed in **Table 8-4** below. The impact of the possible consequences associated with each risk is based on using a 1-5 scale having the definitions shown in **Table 8-3** below and the impact ratings applied in **Table 8-4** are based on an estimation of these parameters.

Table 8-3: Impact Criteria for Potential Consequences

Level	Descriptor	Description		
		Financial Loss Estimated FLI (USD) to Restore Operation	Rehabilitation Work Envisaged to Restore Operation	Estimated SPVF Downtime (DT)
1	Insignificant	. None	None	-- Remains Operational
2	Minor	FLI < $1,000.00 (Negligible)	Minor	DT < 1 day
3	Moderate	$1,000 ≤ FLI < $5,000 (Considerable)	Routine	1 day ≤ DT < 1 week
4	Major	$5,000 ≤ FLI < $20,000 (Major)	Major (Req. significant resources)	1 week ≤ DT (days) < 3 months
5	Severe	FLI ≥ $20,000 (Massive)	Reconstruction of the existing infrastructure/proposed works required to restore operation	DT ≥ 3 months

Figures stated here are arbitrary for the purpose of presenting a specific framework for quantitative risk assessment of the SPVS and need to be reviewed when relevant information is supplied by GPL.

The impacts of flooding on the SPVF, as ranked in **Table 8-3** above, is related to damage to the solar photovoltaic system (SPVS) since:

- In any flood event, damage to the SPVS is expected to be high compared to the damage to civil infrastructure which is likely to be on the minimal end;
- In a low impact event, no automatic or manual shutdown of the SPVF is envisaged;
- Partial or full shut down of the SPVF is considered in direct proportion to the length of shutdown that can occur.

Additional information relating to the acreage to be occupied, the general layout of the SPVF and the main technical and financial aspects of the detailed designs are required to conduct a quantitative risk assessment whereby the vulnerability, hazard, risk, risk tolerability and technical and economic viability can be evaluated as per Barandiarán et al. (2019).

When this information is supplied, any new potential risks, the likelihood of occurrence of the risks identified herein and the residual risks after mitigation measures have been catered for in the designs can be assessed.

Table 8-4: Potential Risks & Mitigation Measures

No.	Potential Risks	Potential Consequence	Impact (1-5)	[1]Mitigation Measures
1	Uplift of solar panels under saturated conditions	Extended periods of plant downtime	4	Grassing the surface cover of the project site and elevating the solar panels by 2m above the existing ground level.
		Damage to elements	5	
		Upthrust force on foundations	4	
2	Settlement of module mounting structure (MMS) due to soil erosion or saturation	Acceleration of structural failure of the main elements	3	Soil type is predominantly loose fill material based on preliminary soil investigations by GeoPro (2022). Geotechnical recommendations for the site to guide the design of foundations based on borehole data and soil properties.
3	Formation of flow vortices around the MMS and fences creating localized scouring during runoff conveyance		3	Placement and maintenance of grassed surfaces will contribute to reduced flow velocities and provide scour protection for the footings and fences

[1]Responsibility of the Implementing Agency to ensure the minimum design standards and risk tolerability for the Design & Build of the SPVF

9. PRELIMINARY FLOOD MITIGATION MEASURES RECCOMMENDED

It is our understanding that solar panels will generally occupy the higher southern portion of the site. As such, the following are recommended for consideration in the detailed designs at this site:

i. Found the solar panels on Structural Steel Galvanized or Aluminium H-Piles with panel frames elevated 2m above the existing ground to have a 1m freeboard above the historical FWSE of 15m AMSL;

ii. Use a grass cover for the surface of the site and ensure spatial access for periodic maintenance using small equipment, and to resist localized erosion during flood water recession;

iii. Design the internal drainage considering grassed swales sized for the 50 Yr. R.I. plus a 0.3m freeboard.

The schematic in **Figure 9-2** below illustrates the recommendations made above and is based on GE terrain data. The preliminary residual risks are summarized **Table 9-1** below, all of which can be addressed during routine maintenance procedures after a flood event and will not result in any downtime of the SPVS.

Table 9-1: Identification and Impact of Residual Risks

No.	Residual Risks	Impact (1-5)
1	Silt/debris deposits around the MMS and fences	1
2	Damaged fences	1
3	Loss/damage to grassed areas	1

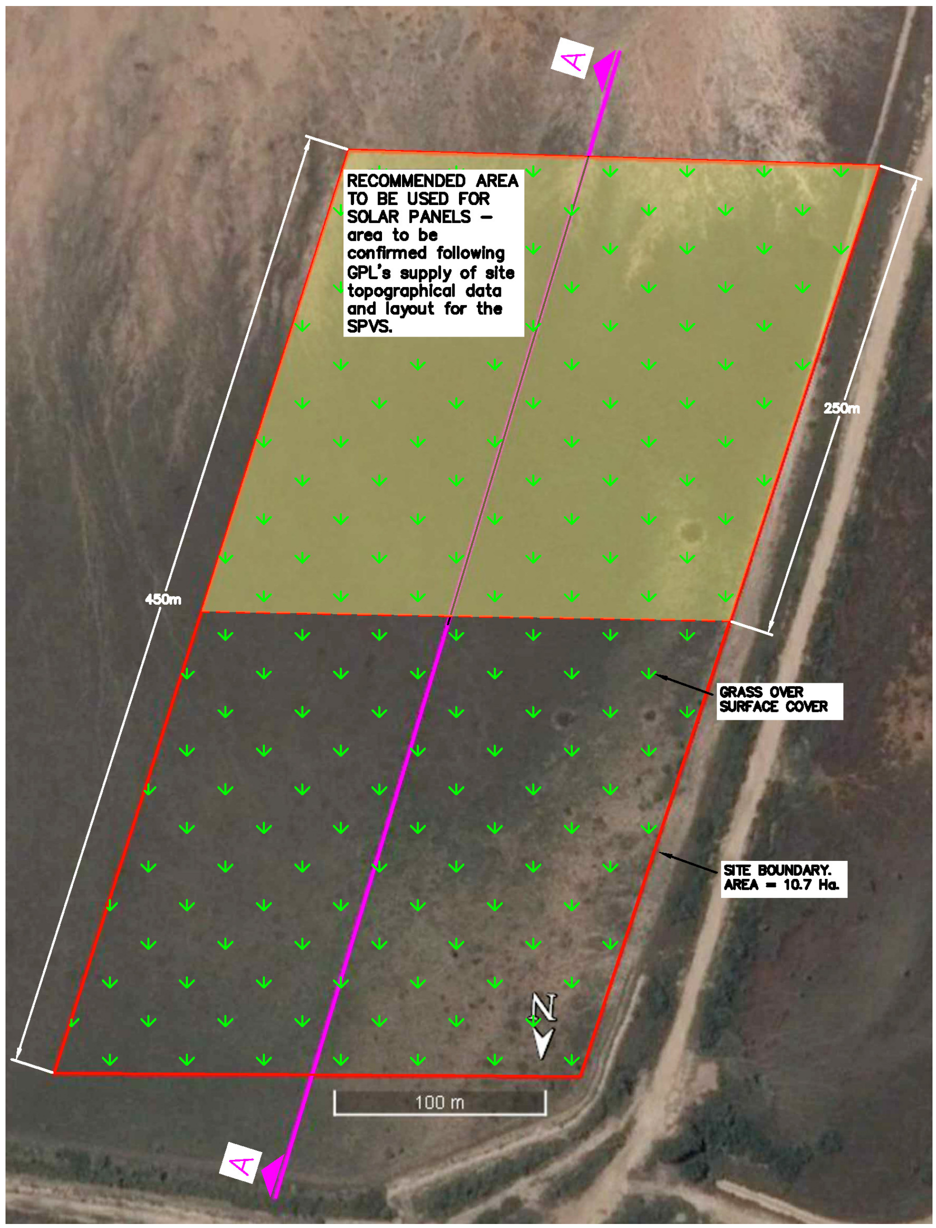
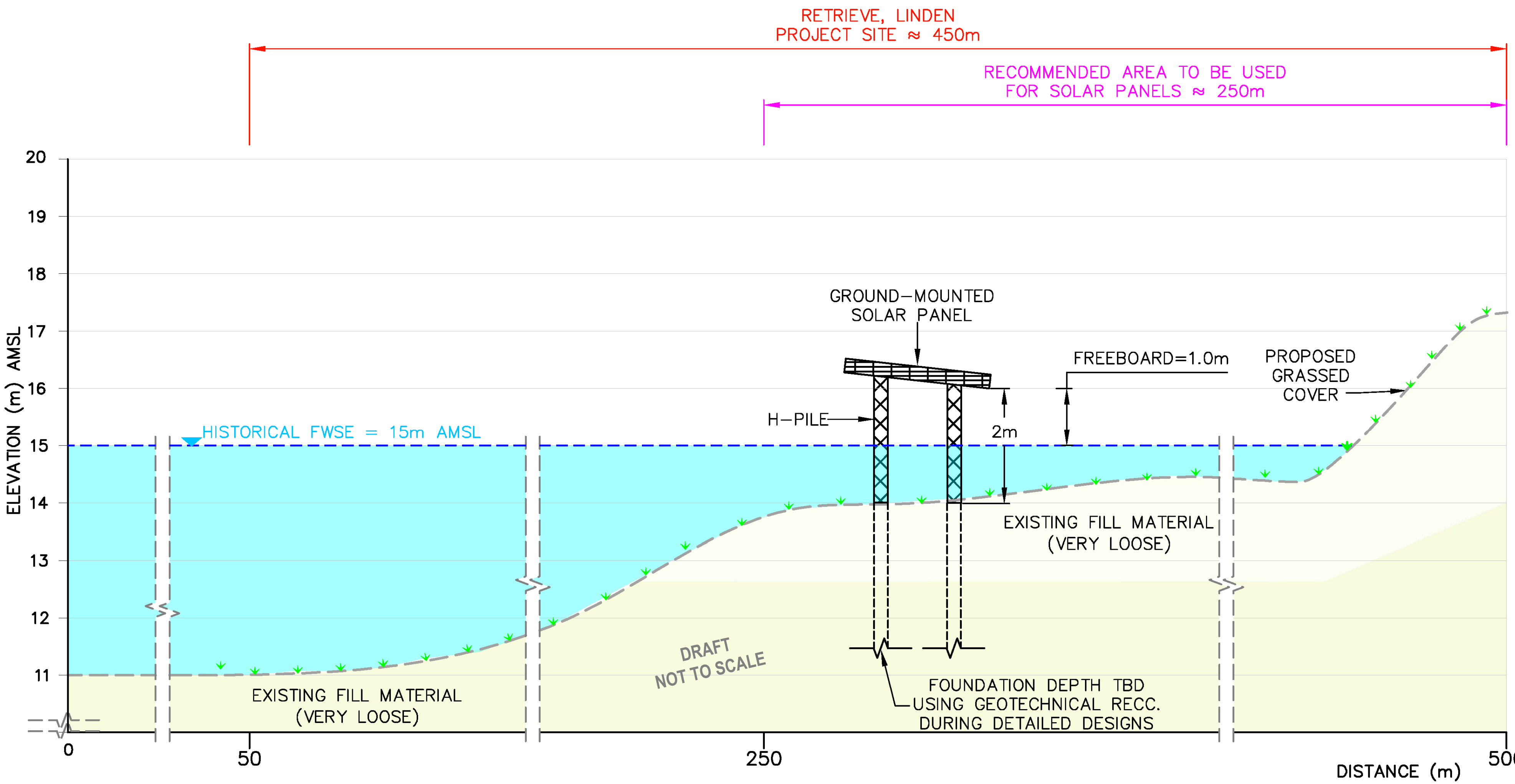


Figure 9-1: Plan Showing Location of Schematic XS A-A (Site Location: Lat Long: 5.986988° -58.322083°)



GUYANA – RETRIEVE LINDEN
SCHEMATIC X–SECTION A–A

NOTES:
1. Not to Scale
2. Sub–surface according to Alpha/GeoPro preliminary geotechnical report dated 2022.03.17;
3. Site topographical report pending for finalization;
4. Based on preliminary information supplied by GPL, the higher areas within the site will be occupied by the solar photovoltaic system. An assumption was made herein and will be updated when further information is provided;
5. Existing ground to be graded for positive surface drainage toward the outfall – recommendation to be developed when the topographical data inclusive of outfall information is provided by GPL.

Figure 9-2: Schematic Cross-Section of the Recommended Mitigation Measures at Retrieve, Linden

10. VULNERABILITY ASSESSMENT

A stage-damage function can be developed for the Retrieve site in the absence of a detailed design and relevant damage data as shown in **Figure 10-1** below, whereby rising floodwater (i.e. FWSE (m AMSL)) and estimated percentage of the SPVS to be damaged (i.e. Damage %) were correlated for the existing and recommended scenarios.

The Damage % is dependent on the detailed design and thus is presented here to be used as a preliminary framework for the impact of various flood depths on the SPVS. This vulnerability assessment can be updated when detailed designs are completed. Due to the specific hydraulic analyses and site specific data used herein for derivation of FWDs, these curves are not spatially transferrable for other SPVFs.

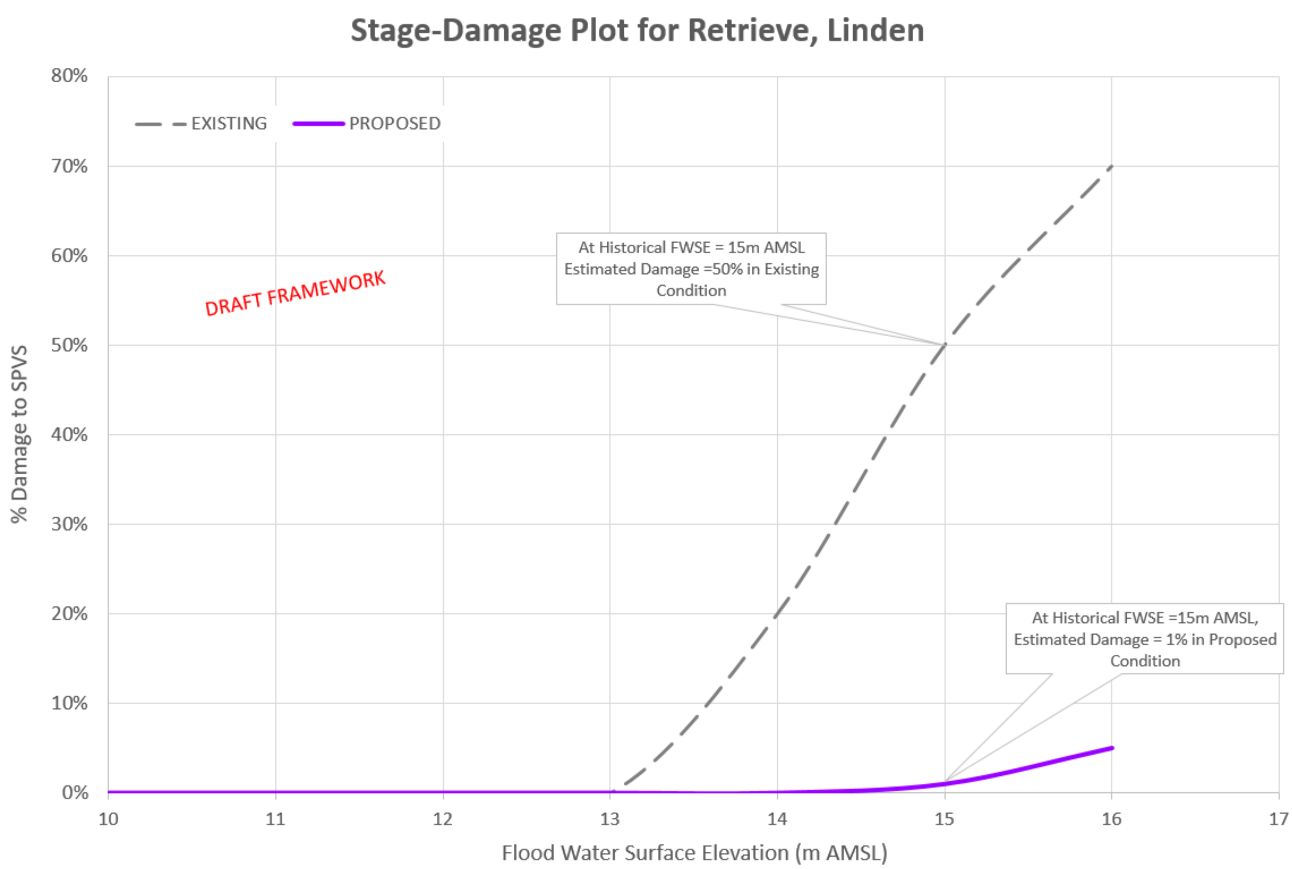


Figure 10-1: Stage-Damage Plot for Retrieve, Linden

11. THE WAY FORWARD

The key findings of the flood risk report are as follows:

i. The proposed project site at Retrieve, Linden in Region 10 for a solar photovoltaic system (SPVS) can be impacted by flooding from the Demerara River under extreme conditions based on a Historical FWSE = 15m AMSL;
ii. The main risk to the SPVS at this site is the impact of saturated conditions from floodwater on the solar panel foundations which could result in permanent damage to the elements, financial losses and periods of plant downtime for reconstruction. As such, the most feasible flood mitigation measure involves elevating the solar panel frames by 2m above the existing ground to an elevation of 16m AMSL, in which case there will be a 1m freeboard above the Historical FWSE = 15m AMSL.

The following are required in order to verify these preliminary findings and conclude the flood risk assessment for this site:

i. Additional information relating to:
    a. the general layout of the SPVF;
    b. the main technical and financial aspects of the detailed designs inclusive of panel configuration/tilt angle, etc;
ii. A Preliminary Operational Risk Profile inclusive of the desired level of protection for the power generation site;
iii. Data/information on the hydraulic performance, operation and maintenance of any kokers/sluice gates/pumps in downstream of the site;
iv. Any major implementation plans for upgrades to the existing upstream and downstream drainage and defence systems for climate change resilience.

REFERENCES

Adilah, A. and H. Hananni. 2021. "Comparison of Methods to Estimate Missing Rainfall Data for Short Term Period at UMP Gambang." *IOP Conf. Series: Earth and Environmental Science 682.* Doi:10.1088/1755-1315/682/1/012027.

Barandiarán, M. et al. *Disaster and Climate Change Risk Assessment Methodology for IDB Projects - A Technical Reference Document for IDB Project Teams.* Inter-American Development Bank.

Blommestein, E. et al. 2005. *Guyana Socio-Economic Assessment Of The Damages And Losses Caused By The January-February 2005 Flooding.* UN ECLAC & IICA.

DHV Consultants BV & DELFT Hydraulics. 2002. *How to Analyse Rainfall Data.* Hydrology Project Training Module. World Bank & Government of the Netherlands.

Environmental Engineering Solutions (EES) Inc. 2022. *Environmental and Social Analysis (ESA) Solar PV Projects-Guyana.* Implementation of Utility Scale Solar PV Projects through the Guyana Redd+ Investment Fund (Guysol). IDB.

Faridani, F. et al. 2020. "Estimating Flood Characteristics Using Geomorphologic Flood Index with Regards to Rainfall Intensity-Duration-Frequency-Area Curves and CADDIES-2D Model in Three Iranian Basins." *Sustainability, 12, 7371*. Doi:10.3390/su12187371.

Federal Emergency Management Agency (FEMA). 2020. *Guidance for Flood Risk Analysis and Mapping - Flood Depth and Analysis Rasters.* Guidance Document 14.

FloodMap.net. 2022. Interactive Flood Map / Elevation Map for Guyana. Accessed 27-Mar-2022. https://www.floodmap.net/pro/.

GeoPro Ltd. 2022. *Preliminary Geotechnical Report for Retrieve, Linden*. Guyana Power and Light Ltd. Lot 4 - Guyana Utility Scale Solar Photovoltaic Program Geotechnical investigations.

Guyana lands & Surveys Commission (GLSC). 2006. *Major Watersheds Map.*

Hellmers, S. and P. Fröhle. 2021. "Computation of backwater effects in surface waters of tidal lowland catchments including control structures – An efficient and re-usable method implemented in the hydrological open source model Kalypso- NA (4.0)." *Geoscientific Model Development EGU.*

HYDEA, RPA and EMO Joint Venture. 2014. *Rehabilitation of UG Drainage System.* Consultancy for the Design and Supervision of Civil Works - C. No.UG/QCBS/02/2013. Government of Guyana – World Bank Credit No. 4969-GY; Project ID No.: P125288.

iNews Guyana. 2022. "Houses, Farmlands Flooded As Koker Door Collapses At Better Success." February 3, 2022. https://www.inewsguyana.com/houses-farmlands-flooded-as-koker-door-collapses-at-better-success/.

Intergovernmental Panel on Climate Change (IPCC). 2014. *Climate Change 2014: The Physical Science Basis.* Fifth Assessment Report (AR5). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Intergovernmental Panel on Climate Change (IPCC). 2021. *Regional fact sheet – Central and South America.*

Sixth Assessment Report (AR6). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Kaieteur News. 2021. “Region 10 communities hit by severe flooding.” May 29, 2021. https://www.kaieteurnewsonline.com/2021/05/29/region-10-communities-hit-by-severe-flooding/.

Karmeshu, N. 2012. “Trend Detection in Annual Temperature & Precipitation using the Mann Kendall Test – A Case Study to Assess Climate Change on Select States in the Northeastern United States.” Master of Environmental Studies Capstone Projects. 47. University of Pennsylvania.

Namitha, M. R. and V. Vinothkumar. 2018. “Derivation of the Intensity-Duration-Frequency Curve for Annual Maxima Rainfall using Generalised Extreme Value Distribution.” *International Journal of Current Microbiology and Applied Sciences 8(1): 2626-2632.*

Okachi, H. et al. 2020. “Characteristics of Rain and Sea Spray Droplet Size Distribution at a Marine Tower.” *Atmosphere 11: 1210.* Doi:10.3390/atmos11111210.

Stabroek News. 2009. “Torrential rainfall causes flooding at Linden.” Cathy Richards, September 17, 2009. https://www.stabroeknews.com/2009/09/17/news/guyana/torrential-rainfall-causes-flooding-at-linden/.

Stabroek News. 2020. “Broken sluice floods East Bank Demerara homes.” Staff Editor, August 20, 2020. https://www.stabroeknews.com/2020/08/20/news/guyana/broken-sluice-floods-east-bank-demerara-homes/.

Vaughn, S. E. 2018. “The Political Economy of Regions - Climate Change and Dams in Guyana.” *MARHO: The Radical Historians’ Organization, Inc. 131*. Doi: 10.1215/01636545-4355157.

Wahlström, M. and G. Weber. “Guyana: El 22 April 1998 Niño Drought.” *Appeal no: 14/98.*

Wang, S. et al. 2020. “Interpreting Rainfall Anomalies Using Rainfall’s Nonnegative Nature.” *Geophysical Research Letters, 46, 426–434*. Doi. org/10.1029/2018GL081190.

Wardlaw, R., D. Jaigopaul and Z. Rahaman. 2007. “Influence of El Nino on rainfall in Guyana and Uganda.” *Institution of Civil Engineers, Water Management 160:135–143.* Doi: 10.1680/wama.2007.160.3.135.

Zhu, Z. et al. 2018. “The Impact of Rainfall Space-Tine Structure in Flood Frequency Analysis.” *Water Resources Research, 54: 8983-8998.* Doi. 10.1029/2018WR023550.