Guyana Power and Light Incorporated

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

BLOCK 37, LINDEN – FLOOD RISK REPORT

2022-008

Report includes a preliminary identification of flood mitigation measures

1-Apr-22

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Block 37, 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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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 Block 37, Linden (Region 10) Solar Photovoltaic Farm (SPVF) (Area = 13.9 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 greenfield Block 37 site to be unaffected by external elements, namely the Demerara River and a Tributary 2.5km south of the site during extreme flood conditions. This is attributed to the 14m difference in elevation between the project site at 54m AMSL and the banks of the tributary at 40m AMSL. These values were taken from Google Earth terrain data and are pending confirmation when GPL supplies the site topographical data that is currently underway by others. The condition used for risk assessment was the flood extent of a historical FWSE =15m AMSL in the Demerara River based on reported flood depths from previous flood events. The investigations herein indicate that the site is classified as a low risk level in Scenario 1 described below accordingly to a flood depth - flood risk transformation framework published by the US Federal Emergency Management Agency (FEMA 2020).

No.	Scenario	[1]Estimated FWD (m) On Project Site	FWSE (m)	Risk Category
1	Extreme Demerara River Floodplain at FWSE = 15m AMSL	0	15	**LOW**
2	Flooding from the 10 Yr., 50 Yr. and 100 Yr. R.I. peak flow conditions within the site	Topographical/geometric data is required to estimate flood depths for the peak flows summarized below and categorize risk levels. This spatial information is required to ascertain the acreage and locations of the site at low/medium risk to flooding in the various R.I.s.		

10 Yr.	50 Yr.	100 Yr.
7.49 m^3/s	12.84 m^3/s	20.74 m^3/s

[1] Using an Average Site Elevation of 54m AMSL (based on Google Earth terrain data).

The main risk at this site is the impact of saturated conditions from potential ponding of internal site runoff in the depressed areas across the site which can lead to damage to the structures/panels/ foundations, financial losses and periods of plant downtime for repair/reconstruction. Peak flows for the existing site were estimated for the 10 Yr., 50 Yr. and 100 Yr. R.I. rainstorm events. The latter for the proposed substantially grassed surface cover is in the order of 20m^3/s. Corresponding water surface elevations within the site for these flows require spatial/geometric data, including the topographical survey for the site, to be simulated and mapped. When this data is supplied, hydraulic checks will be conducted at the site outfall(s) to ensure that surface runoff from the site is naturally drained in the localized 50 Yr. R.I. storm event. In the absence of the topographical data and other employer-defined aspects of the SPVS, the preliminary recommendation is to place solar panels within the higher elevations/low risk areas (for which a conceptual schematic is included herein to be revisited when relevant data is supplied). The actual SPV footprint can be used, when supplied, to assess the risk, develop mitigation measures and conduct a cost-benefit analysis to determine the feasibility of utilizing medium/high risk areas. Topographical data is a key criterion for finalization of the analyses and recommendations made herein. The latter will be subject to review in the next version of this report.

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 **Block 37, 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 28SE from Item 2 above			The elevation spot heights from sample data are sparsely distributed and hence insufficient to generate contours for the site.
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:

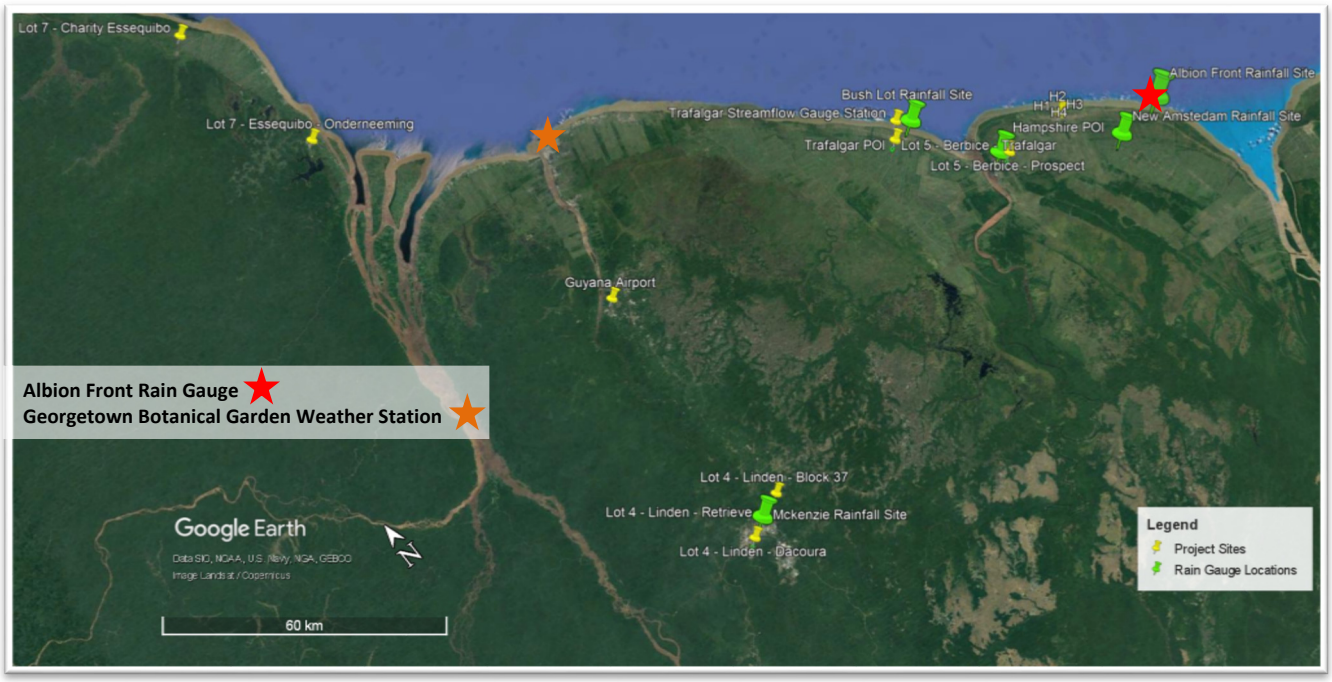


Figure 4-1: Rain Gauge Locations

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).

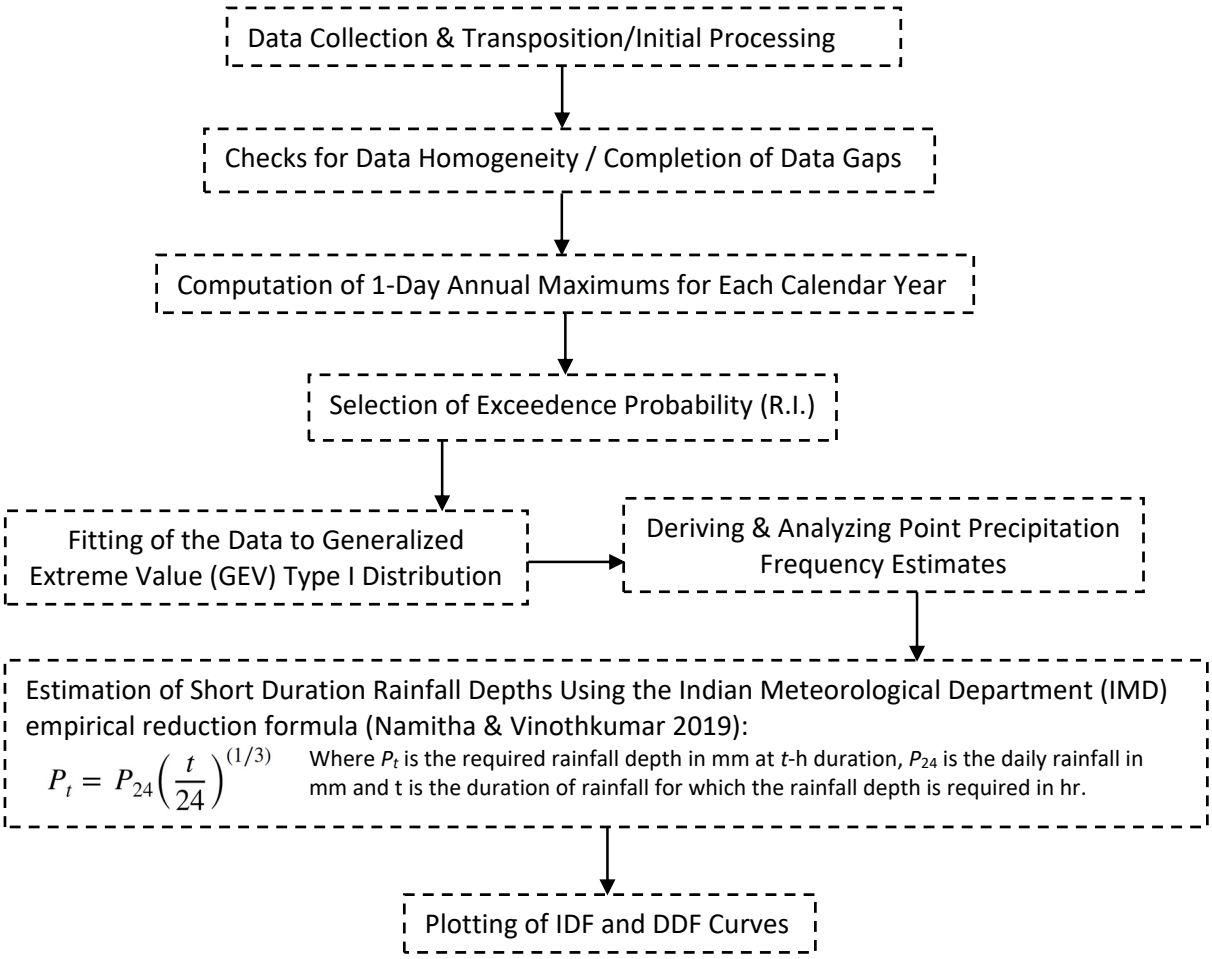


Figure 4-2: Outline of the Main Steps Used in the Development of IDF/DDF Curves

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

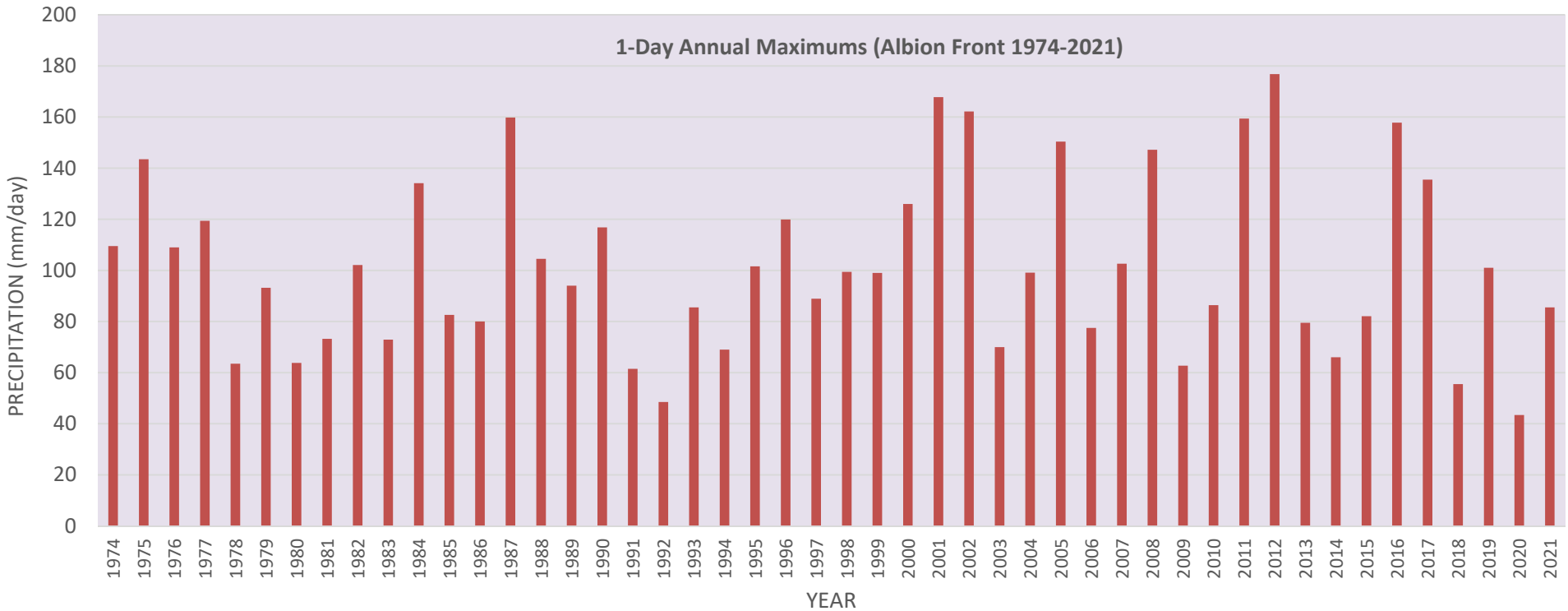


Figure 4-3: 1-Day Annual Maximums Plot

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.

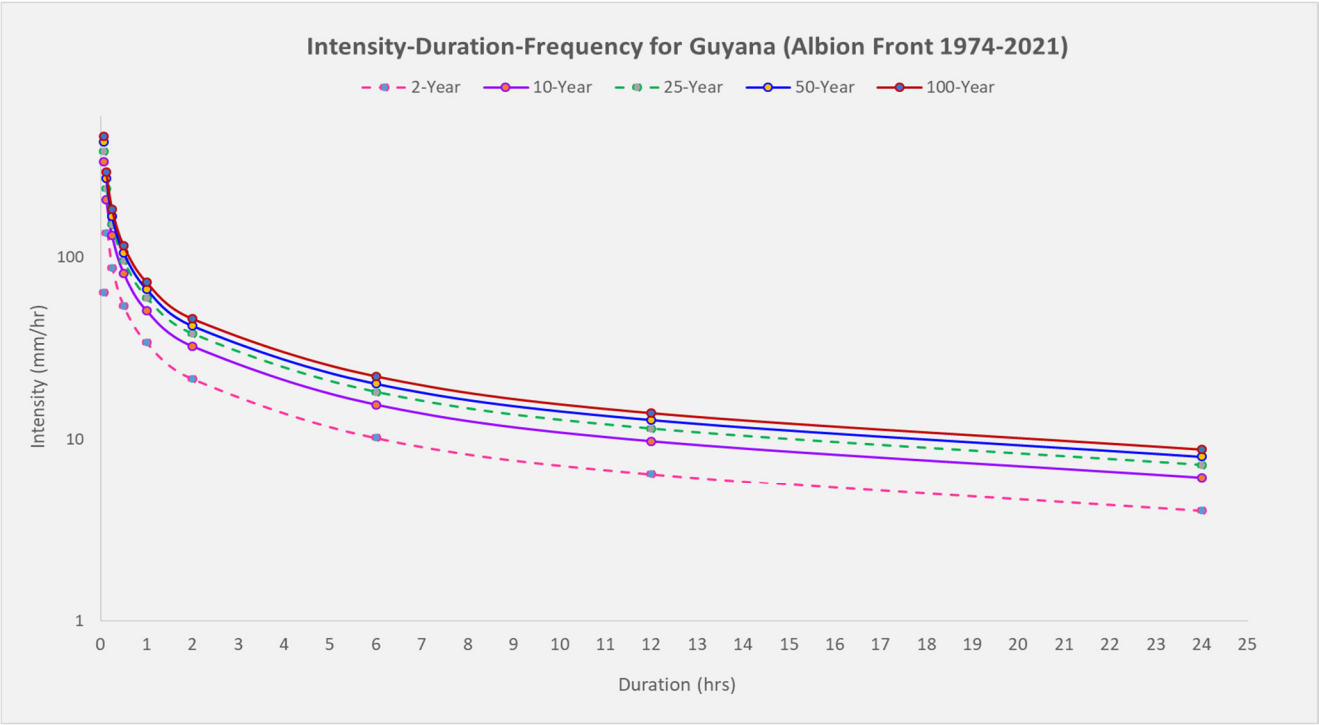


Figure 4-4: IDF Curves for Guyana Using Rainfall Data from Albion Front for 1974-2021

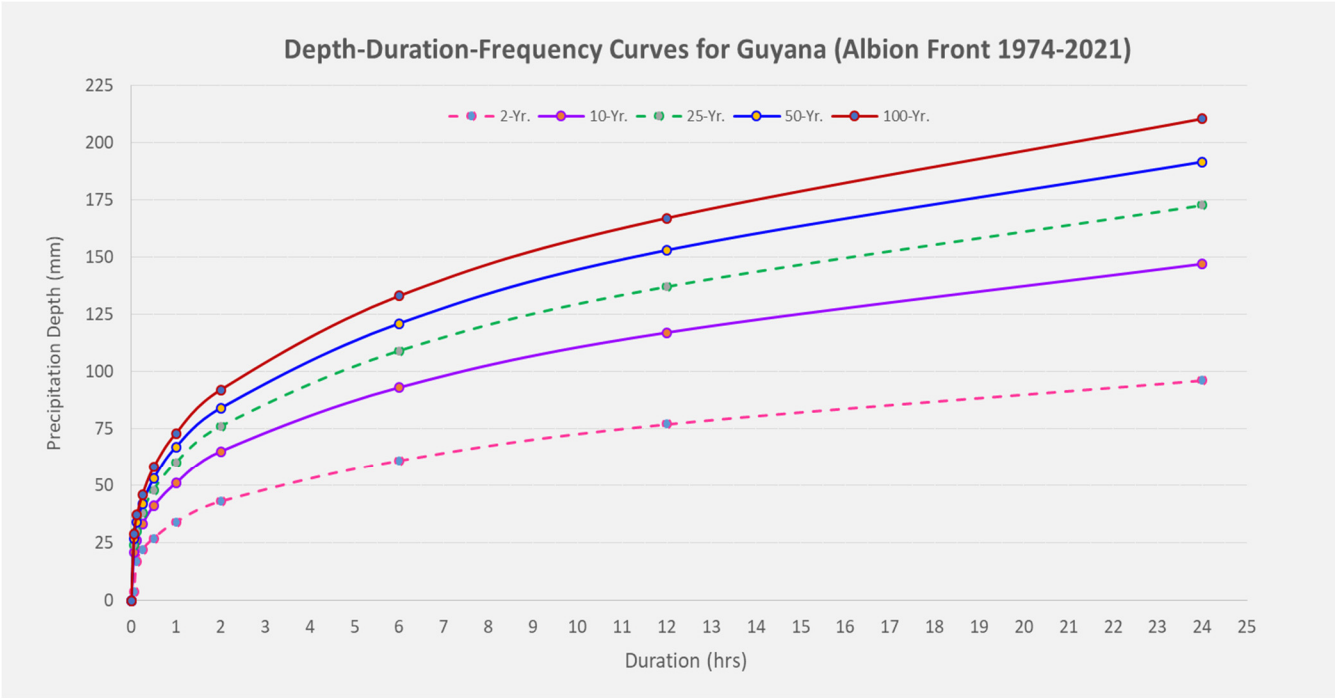


Figure 4-5: DDF Curves for Guyana Using Rainfall Data from Albion Front for 1974-2021

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 $\alpha = 0.05$, 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 $\alpha = 0.05$, 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.

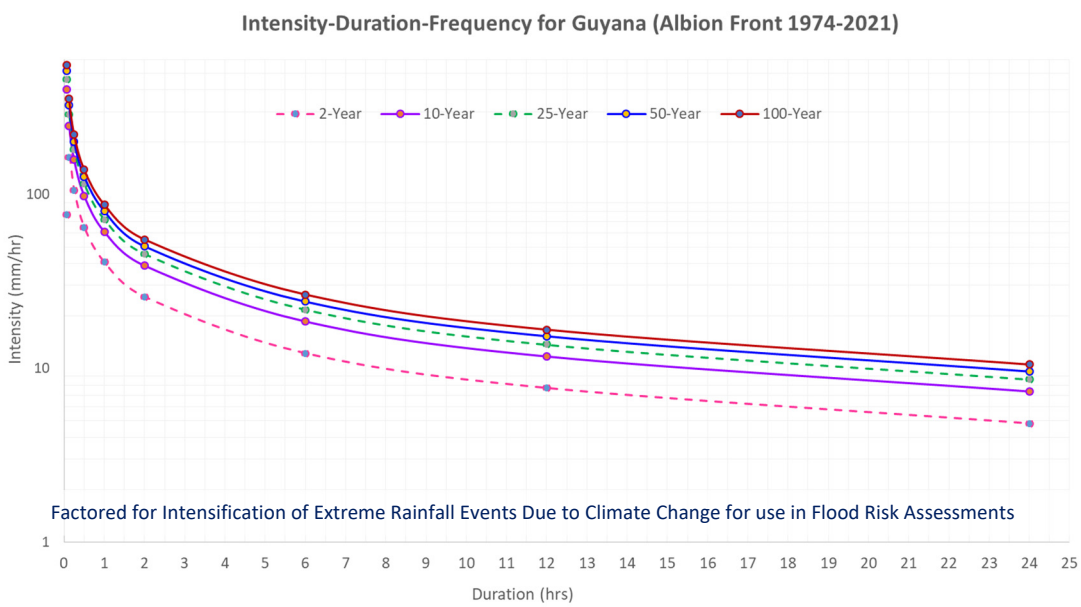


Figure 4-6: Enhanced IDF Curves for Guyana Using Rainfall Data from Albion Front for 1974-2021

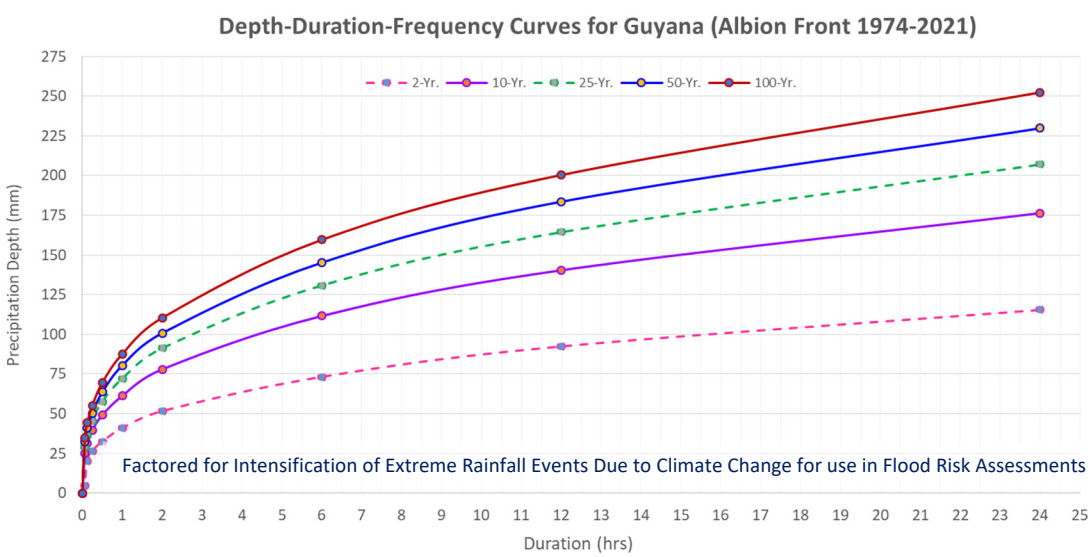


Figure 4-7: Enhanced DDF Curves for Guyana Using Rainfall Data from Albion Front for 1974-2021

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

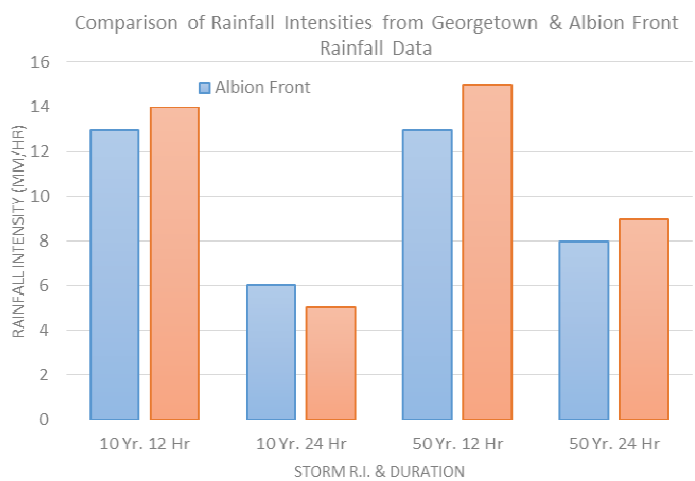


Figure 4-8: Comparison of Rainfall Intensities

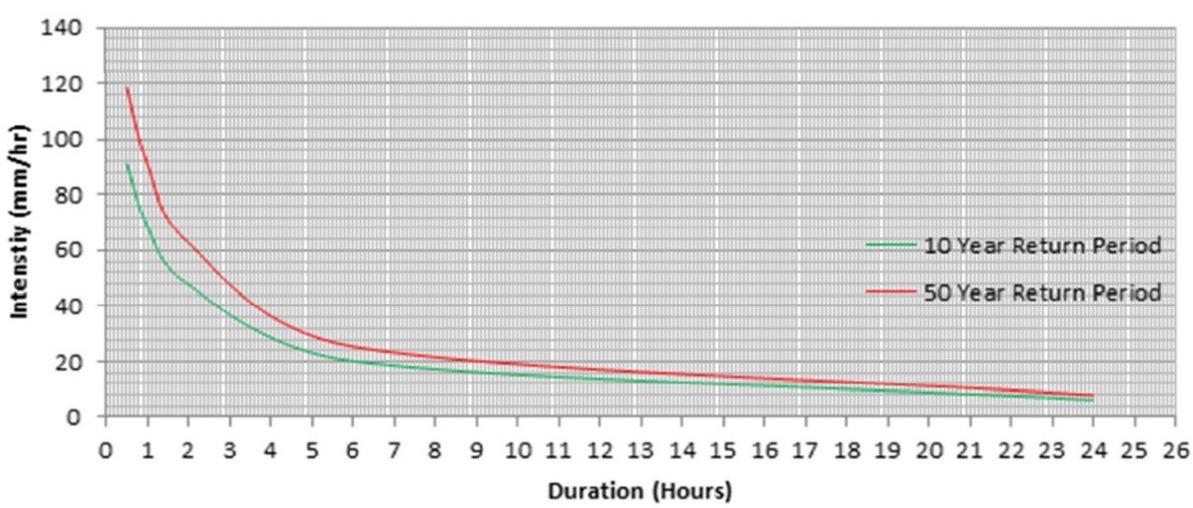


Figure 4-9: IDF Curves Developed by the Joint Venture of HYDEA/RPA/EMO Consultants (2014) Using Rainfall Data from Georgetown Botanical Garden Weather Station

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	**Block 37, Linden**		
Site Description	The project site in Block 37, Linden has an area of 13.9 Ha. and is gently undulating terrain with a medium degree of ponding. The surface cover of the site is thick vegetation.		
Potential Cause of Flooding	Should flooding occur on this site, the main cause would likely be ponding in depressed areas and/or inadequate drainage within the site itself.		
Main Source of Flooding	**INTERNAL PROJECT SITE**	EXTERNAL ELEMENTS	COMBINATION
Description of Source of Flooding	The nearest watercourse is a tributary of the Demerara River and has a straight-line distance of 2.5km from the project site. The latter is significantly elevated relative to the banks of the adjacent/receiving water bodies downstream (i.e. in excess of 10m of elevation difference).		
Prelim. Flood Risk Classification	**LOW**		

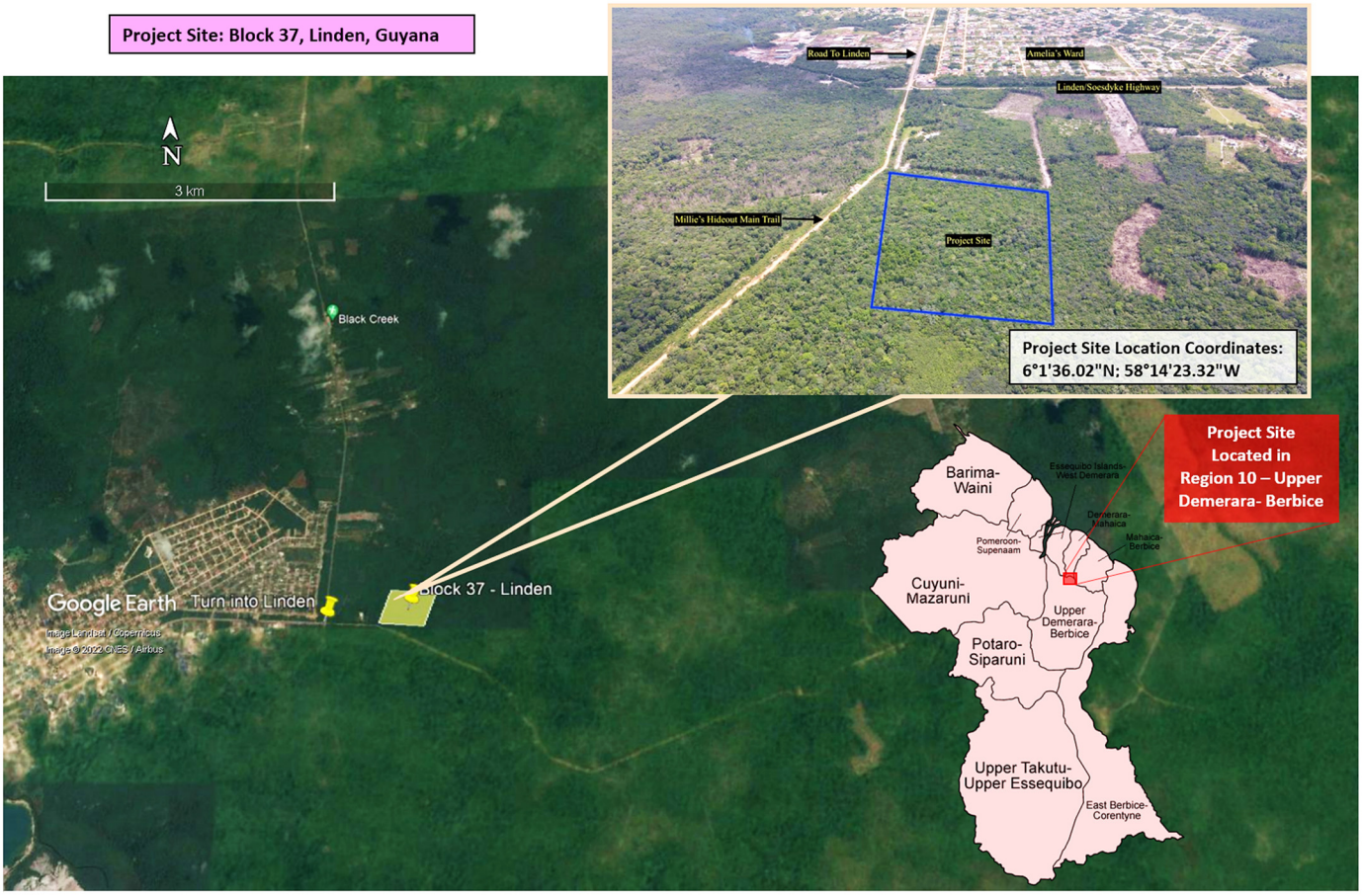


Figure 5-1: Block 37, Linden Project Site Location Plan

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.

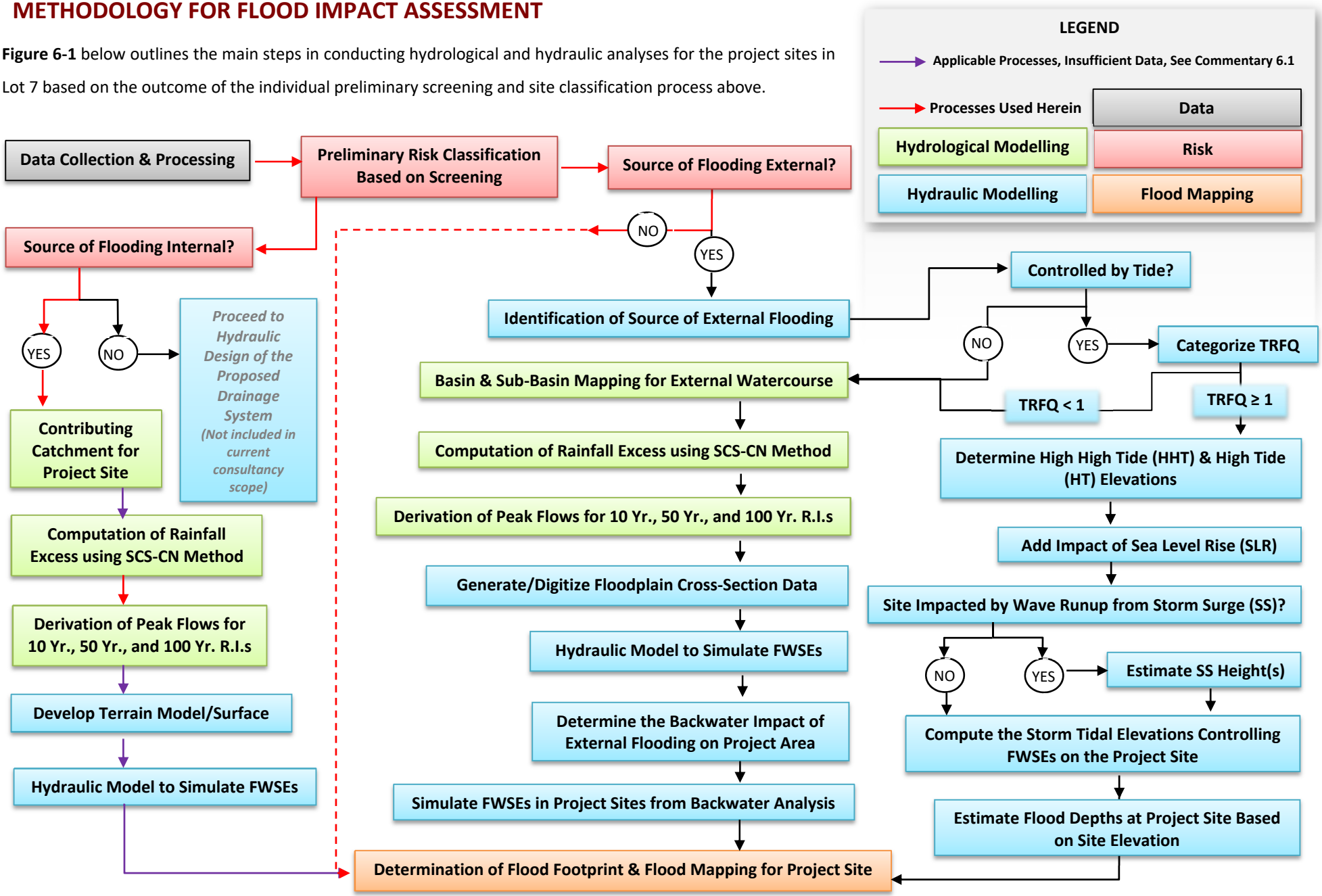


Figure 6-1: Outline of Methodology for the Modelling Process

Commentary 6.1

These processes (→) are all applicable for hydrological and hydraulic modelling of the project site to derive peak storm flows for various R.Is to simulate flood water surface elevations and thus categorize the various levels of risk to the proposed SPVF for each R.I. The following notes are pertinent to the methodology and preliminary recommendations made herein:

i. Google Earth terrain data was used for estimating the contributing catchment for this site as well as assuming the longest flow path due to the unavailability of contour data as per Data Item No. 3 of **Table 3-1** above. The drainage pattern and various flow regimes (e.g. shallow-concentrated or channelized) in the catchment are not known and can only be assumed in the absence of this data. Therefore, these require revision when spatial geometric data/contours for this location are available;

ii. Peak flows were then estimated using the Rational Method as:

   a. key site-specific input data to guide the selection of factors required by the SCS-CN Method are not presently available;

   b. the Block 37 Catchment (Area = 51.3 Ha.) is within the accepted area criterion of 80 Ha. (200 Ac.) for use of this rainfall-runoff model;

   c. the catchment was modelled as a single catchment because sufficient data including existing flow paths and the proposed layout of the SPVF are not available for sub-division into sub-catchments.

iii. The required input data including a field topographical survey is not presently available to develop a Terrain Model/Surface for the site from which geometric data is needed to simulate Flood Water Surface Elevations.

When the required data including the site topographical survey and proposed SPVF layout are provided, flood water surface elevations for the 10 Yr., 50 Yr. and 100 Yr., R.I.s at hydrological points of interest within the site will be determined using channel geometry. Hydraulic checks will then be conducted at the site outfall(s) to ensure that surface runoff from the site is naturally drained in the localized 50 Yr. R.I. storm event and the preliminary flood mitigation measures/recommendations made herein can be finalized.

7. FLOOD IMPACT ASSESSMENT

7.1 FLOOD IMPACT

The Block 37 Project site is situated at an approximate elevation of 54m AMSL 2.5km north of a tributary to the Demerara River which has a bank elevation of 40m AMSL as shown in **Figure 7-1** below. Using historical flood depths reported by Kaieteur News (2021) of 12 ft., a historical **FWSE =15m AMSL** was estimated for the Demerara River in this region. The required data is not presently available to simulate FWSEs in the tributary for various R.I.s. However, given the average 14m difference in elevation between the tributary banks and the project site using Google Earth terrain data, the project site will not be impacted by flooding, even in extreme conditions, from these watercourses. Any flooding within the site will be related to internal runoff deficiencies such as ponding in depressed areas and/or inadequate drainage.

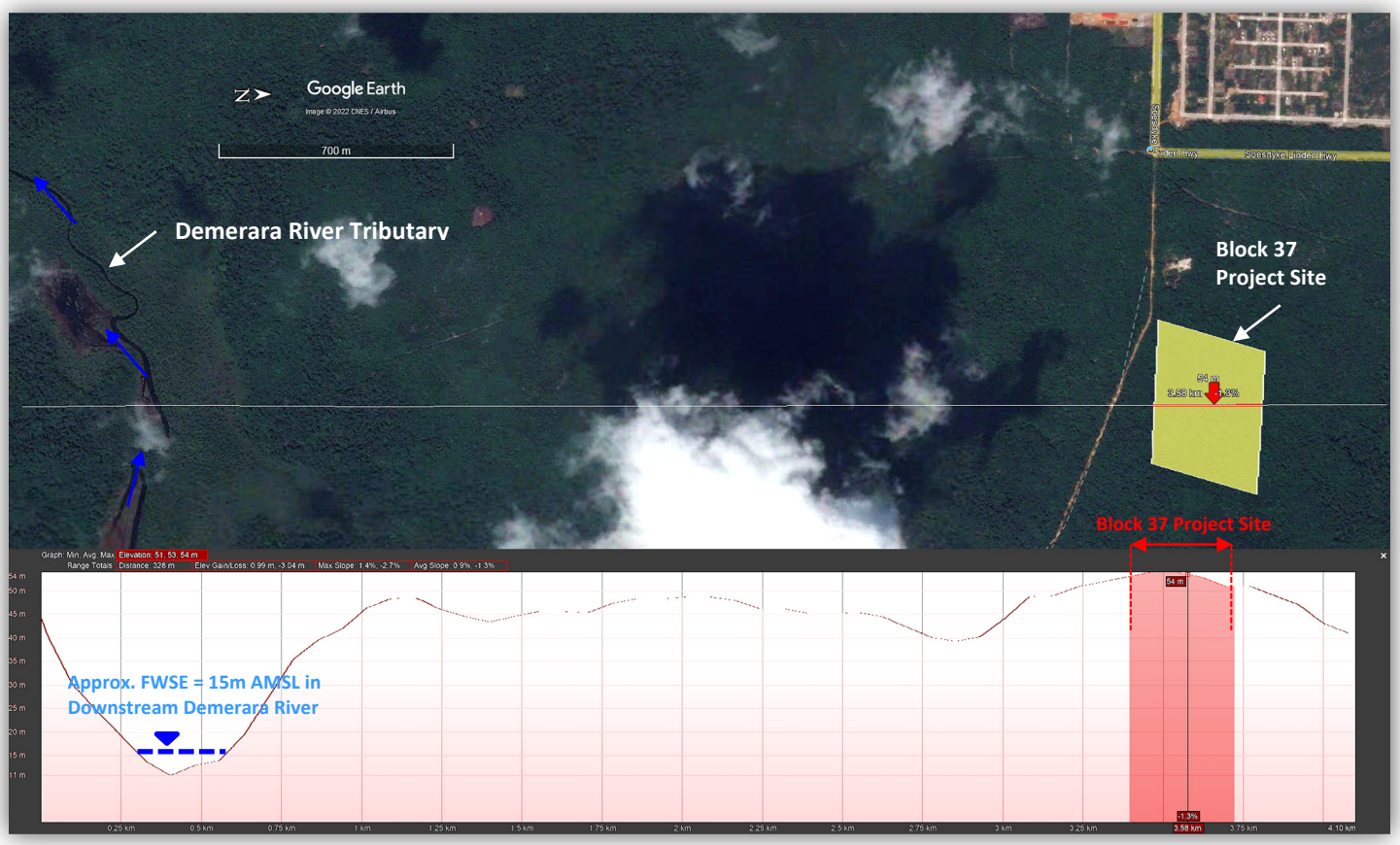


Figure 7-1: Block 37 Project Site Relative to Demerara River Tributary

7.2 INTERNAL FLOOD MODELLING

It was established at the preliminary screening phase that internal site factors are likely to be the main source of flooding at the Block 37 site. This is a greenfield site that may require general grading and filling of depressed areas depending on where the solar panels are placed.

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.

As per **Commentary 6.1** above, peak flows for the existing condition of the site were estimated using Google Earth terrain data and the Rational Method as detailed below. The catchment and assumed "channelized" longest flow path are shown in **Figure 7-2** below. The peak flows derived for the existing "forest" condition are presented in **Table 7-1** below. The same for the proposed "grassed" surface cover (as per the preliminary recommendations in the following chapters) are shown in **Table 7-2**. These values are for the purpose of order of magnitude only and require revision when relevant data is provided.

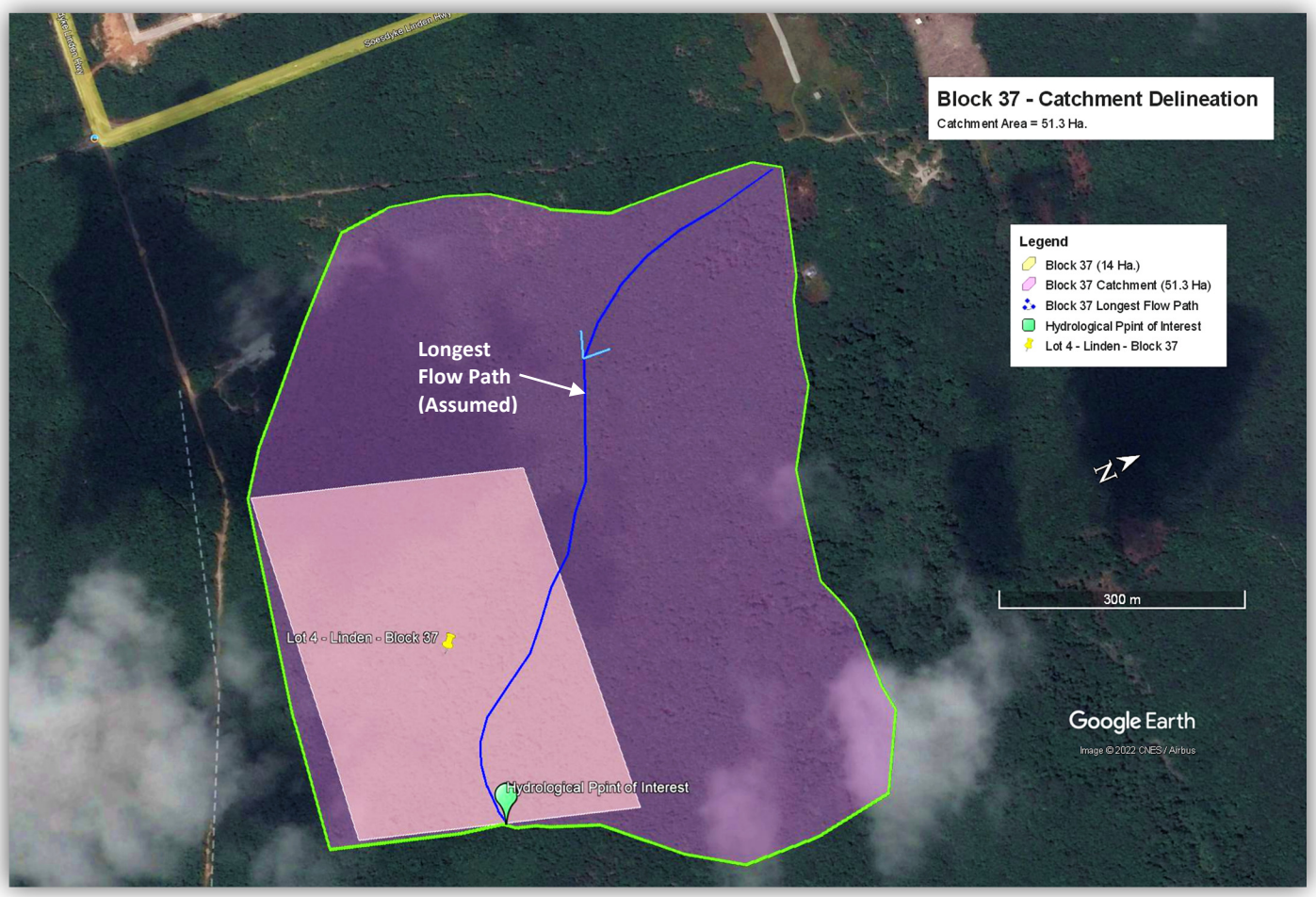


Figure 7-2: Block 37 Catchment Delineation Using Google Earth Terrain Data

Table 7-1: Peak Flows for the Existing Surface Cover Condition of Block 37 Using the Rational Method

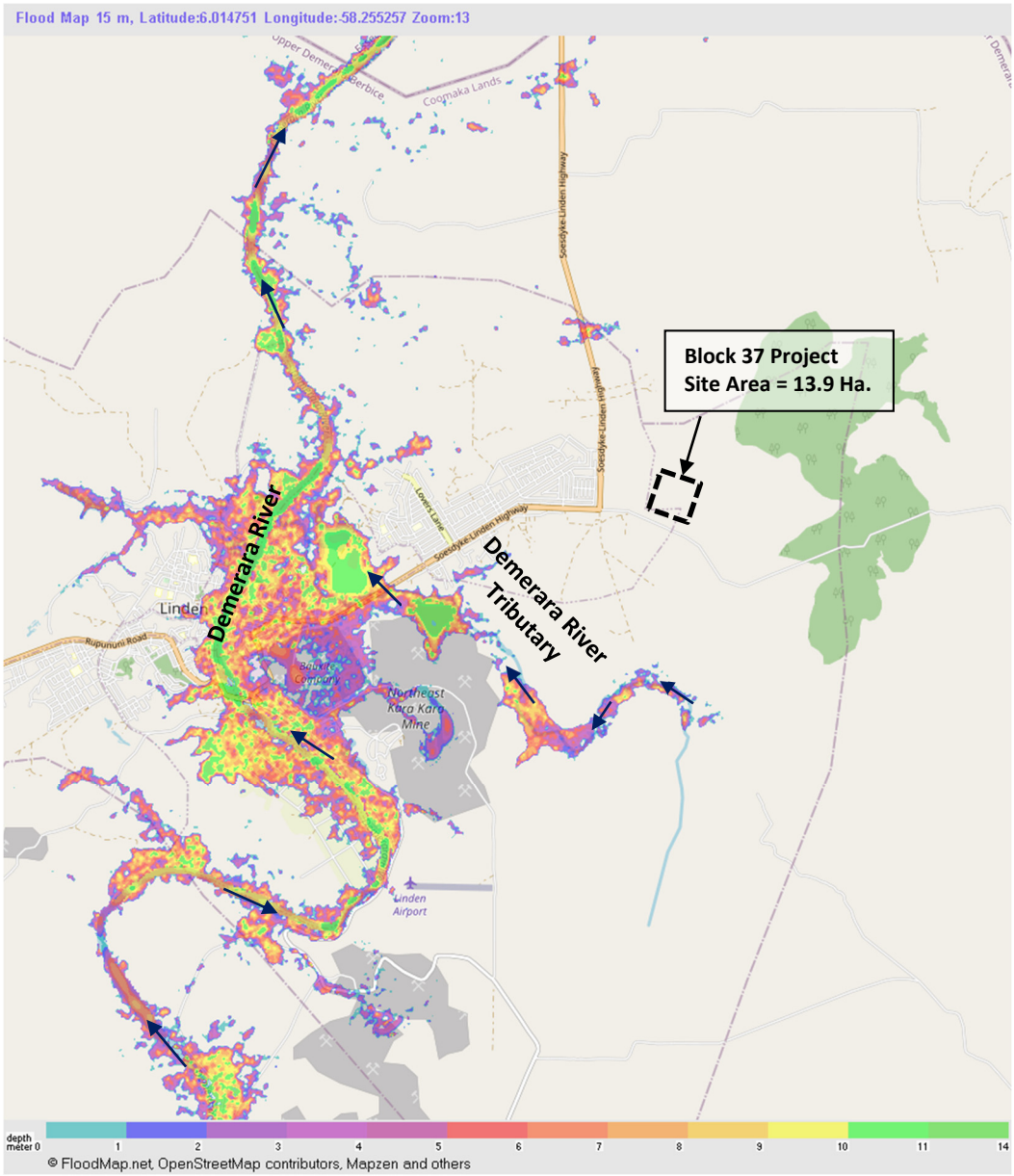
Reference	**Block 37 - Rational Methods for Peak Flows**		**Units**	**Calculation**		
Google Earth (2022) Terrain Data	Upper Elevation	E_1 =	m	55		
	Lower Elevation	E_2 =	m	50		
	Longest Flow Path Length	L =	m	945		
	Slope	S =	m/m	0.005291		
Kirpich Formula	Time of Concentration $t_{ch} = KL^{0.770}S^{-0.385}$	t_{ch}=	min	29		
	Catchment Area	A =	Ha	51.3		
				Recurrence Interval		
				10 Yr.	**50 Yr.**	**100 Yr.**
IDF Curves Report Section 4	Rainfall Intensity for D = t_{ch}	I =	mm/hr.	105	150	205
Site Aerial Photos from GPL (2022), Chow (1969)	Runoff Coefficient	C =		0.25	0.35	0.45
Rational Method	Peak Discharge = 0.00278 * C * I * A	**Q =**	**m^3/s**	**3.74**	**7.49**	**13.16**

Table 7-2: Peak Flows for the Proposed Surface Cover Condition of Block 37 Using the Rational Method

Reference	**Block 37 - Rational Methods for Peak Flows**		**Units**	**Calculation**		
Google Earth (2022) Terrain Data	Upper Elevation	E_1 =	m	55		
	Lower Elevation	E_2 =	m	50		
	Longest Flow Path Length	L =	m	945		
	Slope	S =	m/m	0.005291		
Kirpich Formula	Time of Concentration $t_{ch} = KL^{0.770}S^{-0.385}$	t_{ch}=	min	29		
	Catchment Area	A =	Ha	51.3		
				Recurrence Interval		
				10 Yr.	**50 Yr.**	**100 Yr.**
IDF Curves Report Section 4	Rainfall Intensity for D = t_{ch}	I =	mm/hr.	105	150	205
Site Aerial Photos from GPL (2022), Chow (1969)	Runoff Coefficient	C =		0.5	0.6	0.7
Rational Method	Peak Discharge = 0.00278 * C * I * A	**Q =**	**m^3/s**	**7.49**	**12.84**	**20.74**

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 depth stated above was mapped using an elevation model from https://www.floodmap.net/pro/ to demonstrate that there is no inundation across the site from a FWSE = 15m in the Demerara River floodplain, inclusive of the Tributary. This is shown in **Figure 7-3** below. As shown, the project site is not impacted by either of these watercourses in extreme hydrological conditions. 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. 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. The map is also not intended to show the flooding extent across the site in the various R.I.s / peak flow conditions computed above.



The same cannot be determined as spatial geometric data for the site, both in the existing and proposed conditions, are not presently known.

Therefore, the spread of the peak flows computed above cannot be positively mapped in order to classify flood risk.

Figure 7-3: Flood Inundation Map for Block 37, Linden at FWSE = 15m AMSL

8. FLOOD RISK ASSESSMENT

The Block 37 site (area = 13.9 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 Block 37 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 **low** flood risk in Scenario 1 described below. As such, generic recommendations for the internal site drainage/layout are proposed below to mitigate localized flooding.

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 Block 37 Project Site

No.	Scenario	[1]Estimated FWD (m) On Project Site	FWSE (m)	Risk Category
1	Extreme Demerara River Floodplain at FWSE = 15m AMSL	0	15	LOW
2	Flooding from the 10 Yr., 50 Yr. and 100 Yr. R.I. peak flow conditions within the site	Topographical/geometric data is required to estimate flood depths for the peak flows shown above (summarized below) and categorize risk levels. 10 Yr. 7.49 m^3/s; 50 Yr. 12.84 m^3/s; 100 Yr. 20.74 m^3/s This spatial information is required to ascertain the acreage and locations of the site at low/medium risk to flooding in the various R.I.s.		

[1] Using an Average Site Elevation of 54m AMSL (based on Google Earth terrain data).

The potential risks to the solar photovoltaic system at the Block 37 SPVF are discussed in **Table 8-4** below, based on the preliminary analyses above in the absence of spatial/geometric data and the proposed SPVF layout at this site. 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, was developed specifically for this project and 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 from localized flooding in depressed areas	Extended periods of plant downtime	4	• Maintaining a grassed surface cover across the project site; • Elevating the solar panels by at least 1m above the existing ground level; • Filling any depressed areas that will be occupied by solar panels and grading the site to have positive drainage toward the established outfall.
		Damage to elements	5	
		Upthrust force on foundations	4	
2	Settlement of module mounting structure (MMS) due saturation	Acceleration of structural failure of the main elements	3	Soil type is predominantly sand (loose-very dense) up to a depth of 12.8m 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 conveyance		3	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

In the absence of a proposed SPVS layout/footprint, it is our understanding, based on discussions with GPL on 22-Mar-2022, that solar panels will generally occupy the higher areas within the site. As such, the following are recommended in abstract terms for consideration in the detailed designs at this site:

i. Limit the placement of solar panels to the low-risk areas. A schematic representation of High/Medium/Low Risk areas is shown in **Figure 9-1** below and require confirmation when the relevant data is provided. At present, it appears, from Google Earth, that the site has a high degree of ponding and it is uncertain whether or not there is an inflow-outflow drainage pattern across the site;

ii. If additional acreage is then required for the SPVS, the footprint/layout information is needed to assess the risk, develop mitigation measures to avoid ponding/saturated conditions and ensure positive drainage, and prepare a cost-benefit analysis to determine whether these areas should be used;

iii. Found all solar panels on Structural Steel Galvanized or Aluminium H-Piles with panel frames elevated 1m above the existing ground;

iv. Maintain a grass cover for the surface of the site and ensure spatial access for periodic maintenance using small equipment;

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

The preliminary residual risks are summarized in **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

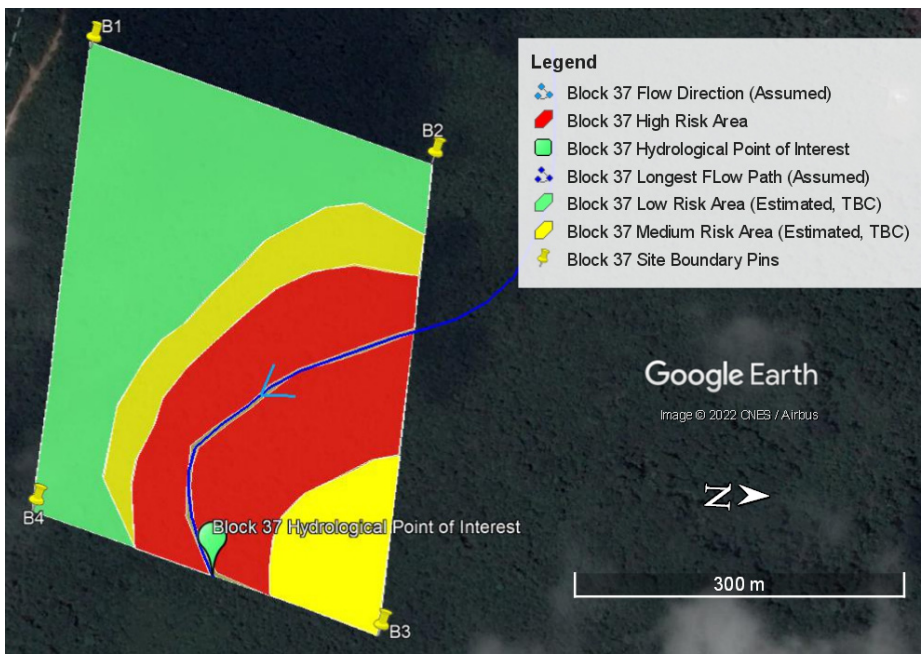


Figure 9-1:Approximate High/Medium/Low Risk Areas within the Site

A stage-damage function can also be developed for the Block 37 site using water surface elevations derived from the internal site modelling when the site layout/footprint is established.

10. THE WAY FORWARD

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

i. The proposed project site at Block 37, Linden in Region 10 for a solar photovoltaic system (SPVS) is not impacted by flooding from the Demerara River or the Tributary under extreme conditions based on a Historical FWSE = 15m AMSL. There is potential for flooding within the site due to off-site areas contributing surface runoff to the site and existing depressed areas.

ii. The main risk to the SPVS at this site is the impact of saturated conditions from potential ponding of internal site runoff in the depressed areas across the site. As such, the most feasible flood mitigation measure involves utilizing the low risk areas within the site (to be determined from topographical data) for the placement of solar panels. If additional acreage is then required, the footprint/layout information of the SPVS is needed to assess the risk , develop mitigation measures and prepare a cost-benefit analysis to determine if it is feasible to utilize other areas.

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

i. Detailed topographical data inclusive of adjacent downstream drainage flow paths/outfalls. *It is our understanding that this is ongoing by others and will be supplied by GPL when completed*;

ii. Additional information relating to:
    a. the general layout of the SPVF in order to estimate the acreage of site that is actually required to determine which of the preliminary measures apply;
    b. the main technical and financial aspects of the detailed designs inclusive of panel configuration/tilt angle, etc;

iii. A Preliminary Operational Risk Profile inclusive of the desired level of protection for the power generation site to inform risk profile assumptions made in this report.

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