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"Climate Change Impacts and Adaptation for Coastal Transport Infrastructure in the Caribbean"

Applying the operational thresholds method

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UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT
PROSPERITY FOR ALL

Applying the thresholds method/approach

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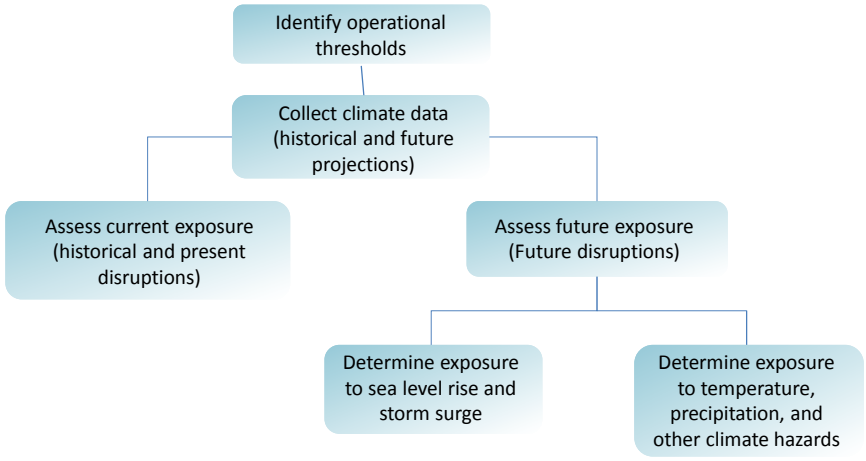
Synopsis

1. The operational thresholds method

2. Application of the threshold method
   - 2.1 Identification of the operational thresholds
   - 2.2 Collection of climate data
   - 2.3 Estimation of historical and future disruptions

3. Some thoughts

The operational thresholds method



Application of the threshold method

Critical assets

The major transportation assets in Saint Lucia are:

- ***Hewanorra International Airport (HIA)***
- ***George F. L. Charles Airport (GCIA)***
- ***Castries Seaport (CSP)***
- ***Vieux Fort Seaport (VFSP)***

The major transportation assets in Jamaica are:

- ***Donald Sangster International Airport (DSIA)***
- ***Historic Falmouth Cruise Port (HFCP)***
- ***Norman Manley International Airport (NMIA)***
- ***Kingston Freeport and Container Terminal (KCT)***

Application of the threshold method

Identification of the operational thresholds

Employee ability to work safely outdoors and heat index

Heat index is provided at http://www.nws.noaa.gov/om/heat/heat_index.shtml

NOAA's National Weather Service

Heat Index

Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution | Extreme Caution | Danger | Extreme Danger

Generic thresholds:

Heat Index over 103 °F is "high" risk

Heat Index over 115 °F is "very high" risk

Application of the threshold method

Identification of the operational thresholds

Employee ability to work safely outdoors and heat index

For example the threshold of heat index equal 115 °F will be exceeded if the temperature is over 92 °F and at the same time humidity is over 75%.

	Combinations of temperature and relative humidity						
Humidity / Heat index thresholds	70%	75%	80%	85%	90%	95%	100%
Heat Index over 39.4 C (103 °F) is "high" risk	32.2 °C (89.9 °F)	31.4 °C (88.5 °F)	30.8 °C (87.5 °F)	30.4 °C (86.8 °F)	29.9 °C (85.8 °F)	29.4 °C (85 °F)	28.9 °C (84 °F)
Heat Index over 46 C (115 °F) is "very high" risk	34 °C (93.2 °F)	33.3 °C (92 °F)	32.6 °C (90.7 °F)	32.1 °C (89.7 °F)	31.5 °C (88.7 °F)	31.1 °C (87.9 °F)	30.4 °C (86.7 °F)

All combinations of Temperature and Humidity were compared with climate data and it was found that most disruptions are likely to be associated with relative humidity of 80 %.

Application of the threshold method

Identification of the operational thresholds

Aircraft Runway Length Requirements and Temperature

Takeoff length requirements vary by aircraft type, and are available from aircraft manufacturers.

For Boeing aircrafts this information is available at:
Source: Boeing, 2013
(http://www.boeing.com/assets/pdf/commercial/airports/acaps/737.pdf).

This manual (Boeing, 2013) provides Takeoff Runway Length Requirements, in a series of charts.

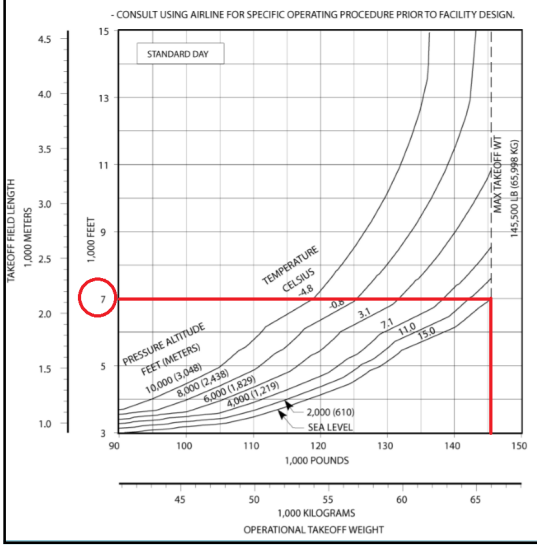
Each chart shows the runway length requirements for a different air temperature starting from the "Standard Day" (STD) temperature of 15 °C.

The temperatures that Boeing aircrafts will require a runway longer than the existing runway of HIA (St Lucia), DSIA and NMIA (Jamaica) were estimated and used as thresholds.

Application of the threshold method

Identification of the operational thresholds

Aircraft Runway Length Requirements and Temperature



Takeoff Runway Length Requirements
737-600 (CFM56-7B18/-7B20)

Assuming the following conditions:

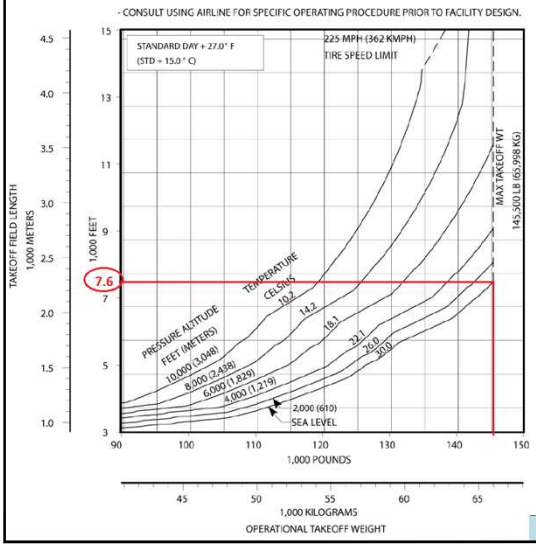
- maximum aircraft takeoff weight
- sea level
- dry runway
- zero wind
- zero runway gradient
- air conditioning off
- and optimum flap setting

The Takeoff length requirement for STD temperature (15 °C) is 7000 ft.

Application of the threshold method

Identification of the operational thresholds

Aircraft Runway Length Requirements and Temperature



Takeoff Runway Length Requirements
737-600 (CFM56-7B18/-7B20)

Assuming the following conditions:

- maximum aircraft takeoff weight
- sea level
- dry runway
- zero wind
- zero runway gradient
- air conditioning off
- and optimum flap setting

The Takeoff length requirement for STD + 15 °C temperature (30 °C) is 7600 ft.

Application of the threshold method

Identification of the operational thresholds

Aircraft Runway Length Requirements and Temperature

Using the charts, takeoff runway length requirements for different types of Boeing aircraft under multiple temperature conditions were estimated.

Hewanorra International Airport (HIA) has a runway length of 2,744 m (9,003 ft)

	Maximum daily temperature				
	STD*	STD + 15 °C	STD + 22.2 °C	STD + 25 °C	**Threshold temperature for 2,744 runway length of HIA**
	15 °C (59 °F)	30 °C (86 °F)	37.2 °C (99 °F)	40 °C (104 °F)	
Boeing 737-600	2,134 m (7,000 ft)	2,316 m (7,600 ft)	**3,048 m (10,000 ft)**	n/a	**34.2 °C**
Boeing 737-800/-800W/BBJ2	2,377 m (7,800 ft)	2,469 m (8,100 ft)	n/a	**3,078 m (10,100 ft)**	**34 °C**
Boeing 737-500	2,469 m (8,100 ft)	2,652 m (8,700 ft)	n/a	n/a	**31.2 °C**
Boeing 737-400	2,530 m (8,300 ft)	2,682 m (8,800 ft)	n/a	n/a	**31 °C**

Application of the threshold method

Identification of the operational thresholds

Aircraft Runway Length Requirements and Temperature

Takeoff length requirements by aircraft type and temperature for Jamaican airports.

	Maximum daily temperature				
	STD*	STD + 15 °C	STD + 25 °C	**Threshold temperature for 2,662.4 m runway length of DSIA**	**Threshold temperature for 2,716 m runway length of NMIA**
	15 °C (59 °F)	30 °C (86 °F)	40 °C (104 °F)		
Boeing 777	2,439 m (8,000 ft)	2,561 m (8,400 ft)	n/a	**32.8 °C**	**31.8 °C**
Boeing 737-800	2,377 m (7,800 ft)	2,469 m (8,100 ft)	3,078 m (10,100 ft)	**33.2 °C**	**34.1 °C**

Application of the threshold method

Identification of the operational thresholds

Increase of Energy cost and Temperature

Extreme heat can raise energy costs for cooling. According to generic standard 1°C warming will result to 5% increase in energy costs.

Using historical data mean temperature for the period 1986-2005 was estimated to be 26.8 °C in Saint Lucia and 29.5 °C in Jamaica.

The threshold temperatures were estimated for 0.8, 1.3 and 3 °C temperature increases since 1986-2005; for these increases the energy cost will raise by 4%, 6.5% and 15% respectively.

Application of the threshold method

Identification of the operational thresholds

Other Generic thresholds

Climate Hazard	Sensitivity	Example Threshold	Source
Ports			
Precipitation	Low visibility inhibits crane operation	In Manzanillo, intense rainfall > 20 mm within 24 hours reduces visibility enough to impair operations	IDB, 2015b
		Very heavy rainfall (e.g. >50 mm/day)	IDB, 2015b
Wind Speeds	Ability to berth ships (due to waves)	Varies by facility. For example, at Kingston Container Terminals (KCT) in Jamaica: • Winds ≥ 18 m/s (40.3 mph, 35 knots) force operational shutdown • With winds of 12.8-18 m/s (28.8-40.3 mph, 25-35 knots), discretion is applied	Smith Warner, 2017
Airports			
Wind Speeds	Inability of aircraft to land or take off	Commercial airports: sustained winds of 20 m/s (45 mph, 39 knots) or frequent gusts of 26 m/s (58 mph, 50.4 knots) General Aviation airports: 11.2 m/s (25 mph, 21.7 knots)	ACRP Report 160

Application of the threshold method

Collection of climate data

The database of the Caribbean Community Climate Change Centre (CCCCC) was used as a source, since it provides daily-scale climate data.

Daily-scale climate data from the Regional Climate Model (PRECIS) for the period 1970 - 2100 were obtained.

The available projections were based on the A1B scenario which is compatible with the RCP 6.0.

Application of the threshold method

Assess current exposure

Historical data in a daily scale, from the CCCCC database were used.

The data were compared with thresholds and the number of days that the operational thresholds have been exceeded historically, was estimated.

Application of the threshold method

Assess future exposure

(temperature, precipitation, and other climate hazards)

- Compare the projected climate data with the operational thresholds.
- Estimate the number of times the operational thresholds will be exceeded in the future

Application of the threshold method

Assess future exposure

Determine exposure to temperature, precipitation, and other climate hazards

Days of disruptions for airports and seaports in Saint Lucia.

Climate Stressor	Sensitivity	Threshold	Disruptions (average days/year)					
			1986-2005	2006-2030	2030	2031-2055	2056-2080	2081-2100
Extreme Heat	Employee ability to work safely outdoors in airports and seaports	Heat Index (NOAA) over 30.8 °C (87.5 °F) with relative humidity 80% is "high" risk	1.25	1.96	***2.00***	11.86	29.13	55.33
		Heat Index (NOAA) over 32.9 °C (90.7 °F) with relative humidity 80 is "very high" risk	0.00	0.00	***0.00***	0.59	2.42	9.06
	Aircraft take-off length requirements	Boeing 737-500 aircraft would not be able to take off from HIA if the temperature exceeds 31.2°C	0.55	0.96	***0.00***	10.64	31.38	69.72
		Boeing 737-800 aircraft would not be able to take off from HIA if the temperature exceeds 34.5°C	0.00	0.00	***0.00***	0.00	0.04	1.33
	Energy costs in seaports	0.8°C = 4% increase if temperature exceeds 27.6°C (1986-2005 average: 26.8 °C)	80.55	114.32	***168.00***	225.50	322.13	355.72
		1.3°C warming = 6.5% increase if temperature exceeds 28.1°C	49.05	71.76	***113.00***	161.59	279.58	343.61
		3°C warming = 15% increase if temperature exceeds 29.8°C	5.90	9.72	***18.00***	40.32	98.54	182.78
Precipitation	Inhibits crane operation in seaports	Intense rainfall (e.g., > 20 mm/day)	48.20	44.60	***51.00***	45.55	46.88	48.00
		Very heavy rainfall (e.g. >50 mm/day)	0.45	0.72	***1.00***	1.05	0.54	0.83

Application of the threshold method

Assess future exposure

Determine exposure to temperature, precipitation, and other climate hazards

Days of disruptions for airports and seaports in Jamaica.

Climate Stressor	Sensitivity	Threshold	Disruptions (average days/year)					
			1986-2005	2006-2030	2030	2031-2055	2056-2080	2081-2100
Extreme Heat	Employee ability to work safely outdoors in airports and seaports	Heat Index (NOAA) over 30.8 °C (87.5 °F) with relative humidity 80% is "high" risk	4.40	5.76	***5.00***	13.45	22.21	29.67
		Heat Index (NOAA) over 32.9 °C (90.7 °F) with relative humidity 80% is "very high" risk	0.05	0.12	***1.00***	1.95	4.88	10.89
	Aircraft take-off length requirements	Boeing 737-800 aircraft would not be able to take off from DSIA if the temperature exceeds 33.2°C	23.70	44.92	***65.00***	84.91	138.75	183.78
		Boeing 737-800 aircraft would not be able to take off from NMIA if the temperature exceeds 34.1°C	5.35	14.64	***24.00***	44.41	99.25	146.00
	Energy costs in seaports	0.8°C warming = 4% increase if temperature exceeds 30.3°C (1986-2005 average: 29.5 °C)	145.20	177.36	***214.00***	216.73	271.46	303.44
		1.3°C warming = 6.5% increase if temperature exceeds 30.8°C	121.50	153.44	***182.00***	196.41	248.50	286.61
		3°C warming = 15% increase if temperature exceeds 32.5°C	47.25	74.92	***97.00***	117.95	168.96	214.83
Precipitation	Inhibits crane operation in seaports	Intense rainfall (e.g. > 20 mm/day)	3.70	3.60	***0.00***	4.59	4.00	3.11
		Very heavy rainfall (e.g. >50 mm/day)	0.90	0.64	***0.00***	1.45	0.92	0.89

Application of the threshold method

Assess future exposure

Determine exposure to sea level rise and storm surge

Coastal flooding is induced due to Extreme Sea Levels ESLs.

- ESLs were estimated for Saint Lucia and Jamaica. In order to assess the impacts of a Caribbean hurricane, the effects of cyclones were taken into consideration on the ESL projections.

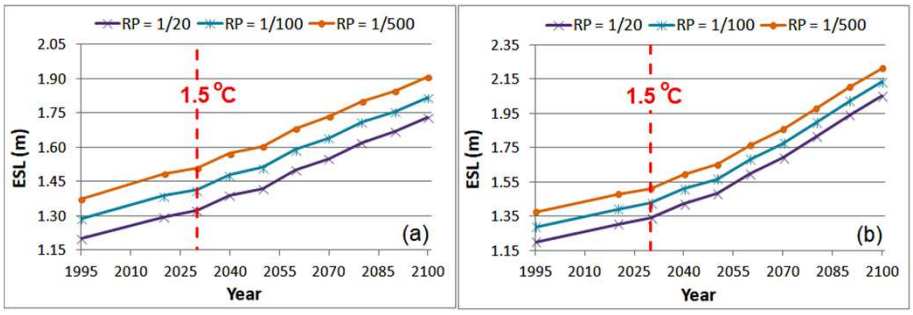
- Flood/inundation was assessed (This work is made by the collaborating institute Joint Research Centre (JRC-EC), using dynamic inundation modeling (LISFLOOD-ACC)

Application of the threshold method

Assess future exposure

Determine exposure to sea level rise and storm surge

Extreme Sea levels for Saint Lucia (MSL + tide + storm surge + wave set up + cyclones) from JRC:

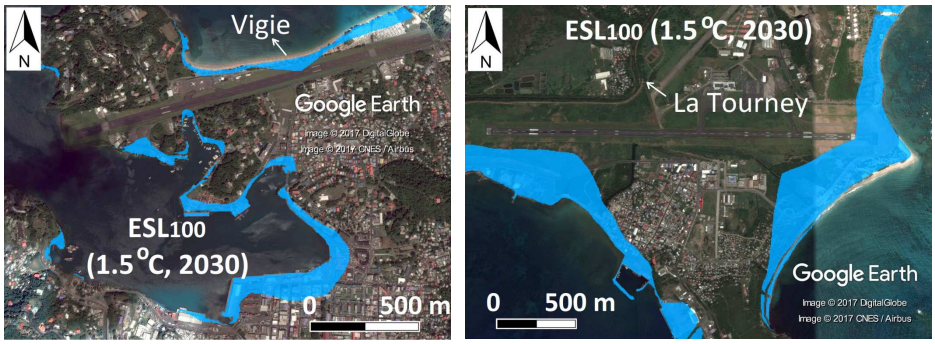


Time evolution of ESLs for 3 return periods (RP) and according with the RCP scenarios (a) 4.5 and (b) 8.5. The red stippled line represents the projected date year of the 1.5 °C temperature increase since the pre-industrial period

Application of the threshold method

Assess future exposure

Determine exposure to sea level rise and storm surge and hurricane

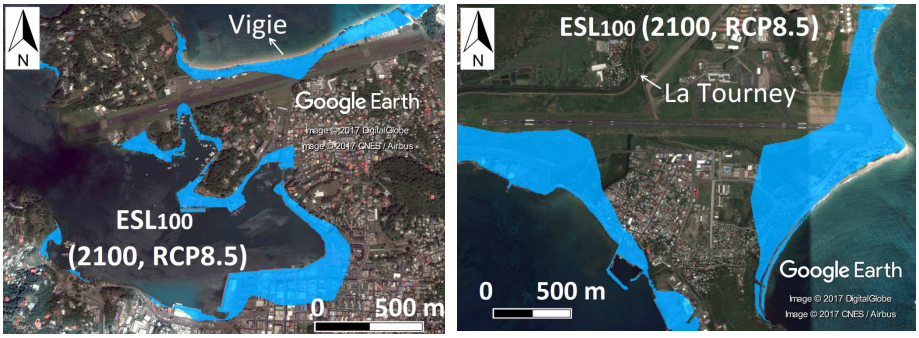


Inundation of GCIA, CSP, HIA and VFSP under ESL_{100} (1.5 °C, 2030)

Application of the threshold method

Assess future exposure

Determine exposure to sea level rise and storm surge and hurricane



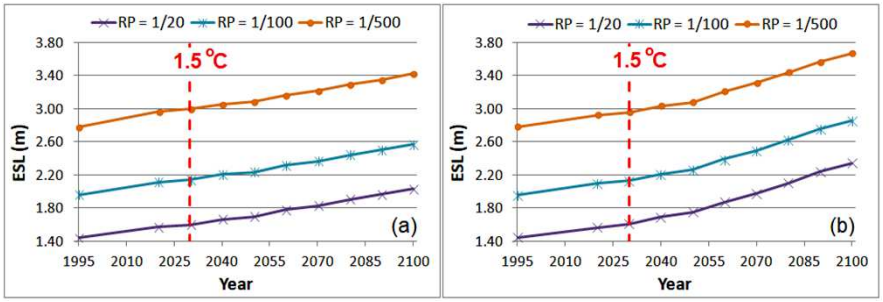
Inundation of GCIA, CSP, HIA and VFSP under ESL_{100} (2100, RCP8.5)

Application of the threshold method

Assess future exposure

Determine exposure to sea level rise and storm surge

Extreme Sea levels for Jamaica (MSL + tide + storm surge + wave set up + cyclones) from JRC:



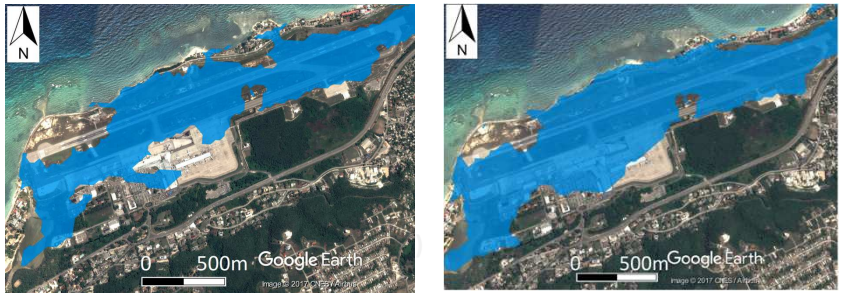
Time evolution of ESLs for 3 return periods (RP) and according with the RCP scenarios (a) 4.5 and (b) 8.5. The red stippled line represents the projected date year of the 1.5 °C temperature increase since the pre-industrial period

Application of the threshold method

Assess future exposure

Determine exposure to sea level rise and storm surge and hurricane

Donald Sangster International Airport
(Runway elevation = 1.37 m)



Inundation maps under (a) a 100-year ESL 2030 (ESL = 2.14 m) and (b) a 100-year ESL RCP 8.5, 2100 (ESL = 2.86 m)

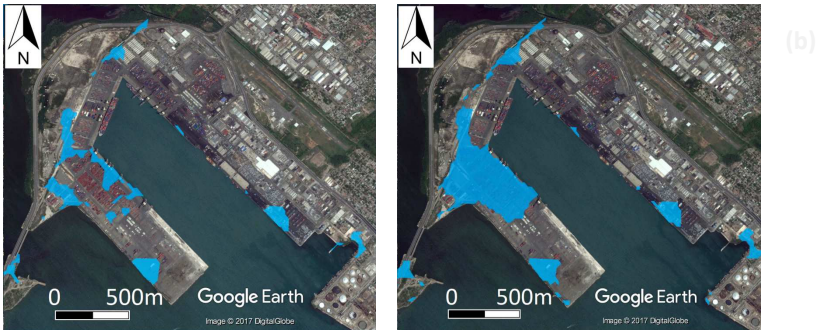
Application of the threshold method

Assess future exposure

Determine exposure to sea level rise and storm surge and hurricane

Kingston Freeport and Container Terminal

(Port elevation = 4 m)



Inundation maps under a 100-year ESL (a) 2030 (ESL = 2.14 m) and (b) RCP 8.5, 2100 (ESL = 2.86 m)

Application of the threshold method

Assess future exposure

Determine exposure to sea level rise and storm surge and hurricane

Table summarizing the impacts on major transportation assets of St Lucia and Jamaica due to coastal flooding. 0: no impacts, 1: Low impact, 2: medium impact, 3: high impact.

Scenarios	ESLs (St. Lucia)	Graded impacts on the Major Assets				ESLs (Jamaica)				
		HIA	GCIA	VFSP	CSP		DSIA	NMIA	KCT	HFCP
RCP 4.5 – 2050 (RP=1/10)	1.38	1	0	3	3	1.39	2	0	1	0
RCP 4.5 – 2050 (RP=1/50)	1.47	1	1	3	3	1.97	3	0	1	0
RCP 4.5 – 2050 (RP=1/100)	1.51	1	1	3	3	2.23	3	0	1	0
RCP 8.5 – 2050 (RP=1/10)	1.44	1	0	3	3	1.59	3	0	1	0
RCP 8.5 – 2050 (RP=1/50)	1.53	1	1	3	3	2.01	3	0	1	0
RCP 8.5 – 2050 (RP=1/100)	1.57	1	1	3	3	2.27	3	0	2	0
RCP 4.5 – 2100 (RP=1/10)	1.69	1	1	3	3	1.86	3	0	1	0
RCP 4.5 – 2100 (RP=1/50)	1.78	2	2	3	3	2.31	3	0	2	0
RCP 4.5 – 2100 (RP=1/100)	1.82	2	2	3	3	2.57	3	0	2	1
RCP 8.5 – 2100 (RP=1/10)	2.01	2	2	3	3	2.19	3	0	2	0
RCP 8.5 – 2100 (RP=1/50)	2.10	3	2	3	3	2.61	3	1	2	1
RCP 8.5 – 2100 (RP=1/100)	2.13	3	2	3	3	2.86	3	1	2	1

Some thoughts

Using the operational threshold method the historical and future disruptions can be determined

Through the inundation mapping the locations which are most likely to be inundated can be determined

The results of the application can be improved if the following information is available:

- Facility-specific operational thresholds
- DEM or LIDAR data of high resolution