Climate Change Adaptation Case Study:

Sea Level Rise in Trinidad and Tobago

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Abbreviations and Acronyms

AAGR	Average Annual Growth Rate
AOGCM	Atmosphere-Ocean General Circulation Model
CARICOM	Caribbean Community
DEM	Digital Elevation Model
DTM	Digital Terrain Model
GCM	Global Circulation Model
GHG	Green House Gas
GIS	Geographical Information System
HDC	Housing Development Corporation
ICZM	Integrated Coastal Zone Management
IDB	Inter-American Development Bank
IMS	Information Management System
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resources Management
LAC	Latin America and the Caribbean
NAO	North Atlantic Oscillation
POS	Port of Spain
SIDS	Small Island Development States
SIDS	Small Island Development States
SRES	Special Report on Emission Scenarios issues
T&T	Trinidad and Tobago
UK	United Kingdom
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
USAID	US Agency for International Development
WASA	Water and Sewerage Authority
GDP	Gross Domestic Product
NA	North Atlantic

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1 Introduction

1.1 Background

The Inter-American Development Bank (IDB) has contracted DHI to conduct climate change and adaptation studies under the Bank's "Knowledge and Capacity Building Product" project.

The overall objective of the project is the development of an initial portfolio of adaptation case studies allowing IDB to respond to requirements and needs of its member countries in establishing specific policies of adaptation to climate change with respect to impacts on water resources.

The case studies are based on on-going IDB activities in the Latin American region and they are aiming at providing local information and analyses assisting the local water resources managers in coping with Climate Change challenges but also to prepare guidelines on how to mainstream adaptation to climate change into implementation of Bank-funded projects and to recognize explicitly the impact of adaptation measures.

Four case studies have been identified by the bank to address different types of climate change impacts.

The case study in this report concerns Sea Level Rise in Trinidad and Tobago with the following overall objectives:

Define, in terms of measurable quantitative variables, the vulnerability of the water and sanitation sector in Trinidad and Tobago with respect to sea level rise.

Contribute to strengthen the capacity of the water and sanitation sector to adaptively respond to sea level rise through climate change in terms of the development planning and reducing the vulnerability in Trinidad and Tobago.

Contribute to the establishment of guidelines for “best practices” in adaptation to climate change with respect to potential effects of sea level rise in the water and sanitation sector in Latin America and the Caribbean (LAC) through this case study in Trinidad and Tobago.

Contribute to the Bank’s across-the-board efforts to classify, monitor and evaluate its investments in reducing the vulnerability of climate change in the region.

The three other cases are:

- Montevideo, Uruguay (increased hydrological extreme events)
- Quito, Ecuador (glacier melting)
- Trujillo, Peru (droughts/desertification)

These cases have been documented in separate reports.

1.2 The Case Study

This case study is discussing possible impacts from sea level rise in Trinidad and Tobago, with particular focus on issues and areas of concern in the island of Trinidad. Methods applied and adaptation measures discussed would however be applicable for similar conditions in Tobago.

1.2.1 Location and Territory

Trinidad and Tobago are the southernmost islands of the Caribbean archipelago, located close to the South American mainland some 15 km east of the Venezuelan coast at its closest (Figure 11). The land area comprises 5,126 km^2, with Trinidad covering 4,826 km^2 and Tobago 300 km^2. The coastline for the two islands totals 362 km.

The two islands are located on the continental shelf of South America roughly between 10°N and 11.5°N latitude and between 60°W and 62°W longitude. Trinidad and Tobago’s exclusive economic zone is estimated to approximately 104,000 km^2.

Figure 1.1 Caribbean archipelago with Trinidad and Tobago located as the southernmost island close to the Venezuelan Coast (Google Earth Image dated 1/1 1970)

1.2.2 Topography

Trinidad has three mountainous areas. The Northern Range is running east to west along the northern boundary of the island with elevations up to 900 metres, which is the eastern extension of the Andean Mountain System. The Central Range runs from northeast to southwest forming an area of rolling hills across the centre with many limestone peaks and a maximum elevation of 300 metres. The Southern Range to the southeast is composed of low hills. The three ranges separate the area into two fertile plains, the Northern Basin lying between the Northern and Central Ranges and the low lying Southern Basin (Figure 12).

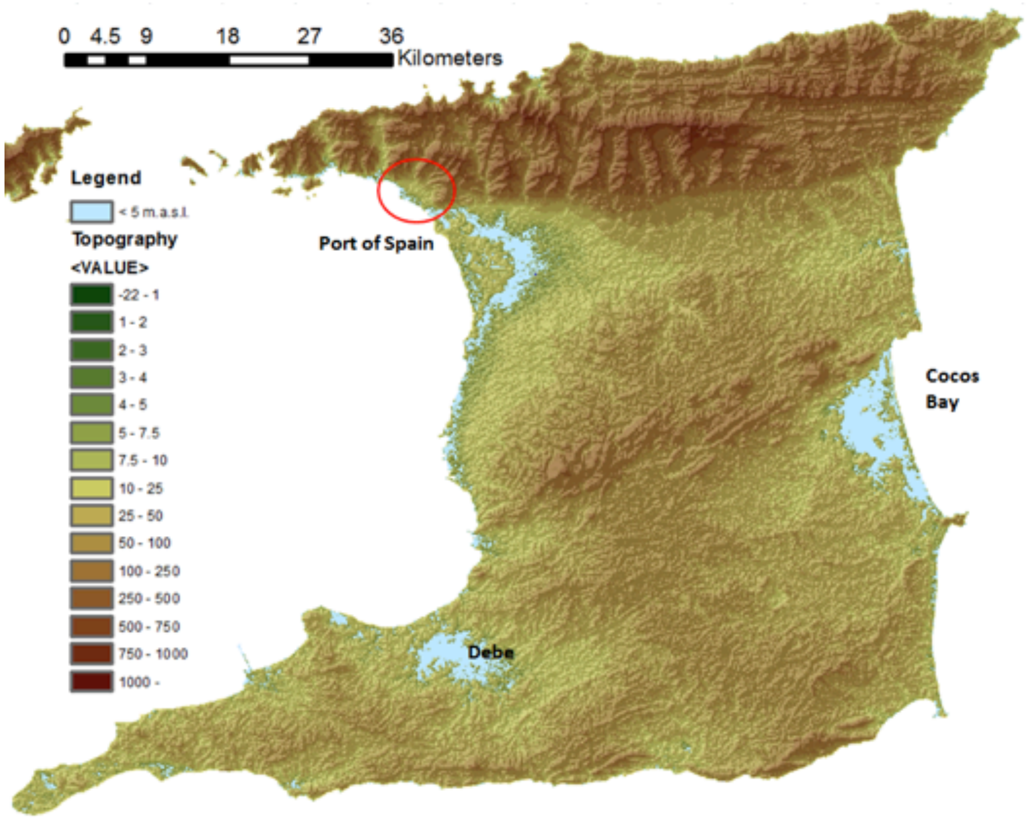
Detailed digital terrain models are very strong tools for evaluating possible impacts of sea level rise.

Such models are often established by LIDAR measurements from airplanes or from vehicles and can nowadays be produced with quite high resolution. No such detailed terrain models have been available for the present study. Instead NASA's SRTM model (Nasa 2000) has been applied to provide an overview of the low lying areas of Trinidad that may be influenced by sea level rise (Figure 13).

The SRTM model is freely available on the internet and has a resolution of 90 m by 90 m horizontally and 1 m vertically. The fact that the low horizontal resolution averaging levels over 90 m tiles and that the model has been established by satellite radar measurements, meaning that buildings and to a certain extent heavy vegetation, may influence the "terrain" levels. This is observed in Port of Spain, where the levels of the reclaimed harbour area seem to be higher than expected and in the swamp southeast of the City where vegetation seems to influence the data.

Figure 1.2 Physical Map of Trinidad and Tobago (downloaded from http://www.ezilon.com/maps/north-america/trinidad-and-tobago-physical-maps.html - Copy Right implications to be examined before dissemination or map to be replaced by other physical map)

Figure 1.3 Topography of Trinidad from NASA's SRTM dataset with areas below 5 m.a.s.l. marked in blue



The areas below 5 m.a.s.l. are concentrated in the wetland southeast of Port of Spain, in the area around Cocos Bay on the eastside of the Island and at Debe in the southern part. Furthermore, a large number of more isolated plains are scattered along the coastline. Among the more important ones of these are the low areas of Port of Spain. The areas below 5 m.a.s.l. constitute 164 km^2 or 3.2% of the Island's total area.

1.2.3 Climate

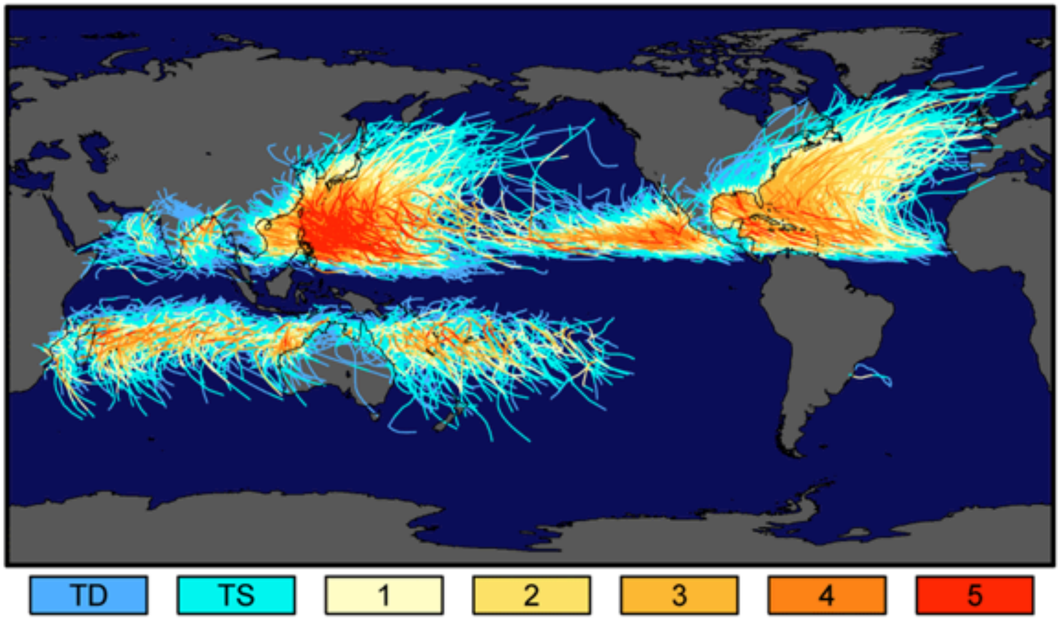
Trinidad and Tobago have a tropical climate with a dry season from January to May and a rainy season from June to December with monthly rainfall between 200 and 250 mm. Tobago to the North experiences more desiccated dry seasons while Trinidad to the South has wetter rainy seasons. The average annual rainfall in Trinidad is unevenly distributed reaching above 3000 mm on the northern ridge and below 1500 mm in the plains areas.

The mean temperature is around 26°C dropping a degree or two in the cooler months of December to February.

The inter-annual variability in the climate is strongly influenced by the El Niño Southern Oscillation (ENSO), resulting in drier and warmer conditions during El Niño episodes and colder and wetter conditions during La Niña episodes.

The islands lie on the southern margins of the Atlantic Hurricane belt and normally escape the passages of cyclones and hurricanes (Figure 14 and Figure 15).

Figure 1.4 Paths and intensity of tropical cyclones since 1860 (Ref. 42)



Escala de intensidad del huracanes Saffir-Simpson

Figure 1.5 Tracks of all Tropical cyclones which formed worldwide from 1985 to 2005 (ref 43). The points show the locations of the storms at six-hourly intervals and use the colour scheme shown in The Saffir-Simpson Hurricane Wind Scale referred to in Figure 1-4 and Figure 1-5 above is a 1 to 5 rating based on a hurricane's sustained wind speed. This scale estimates potential property damage. Hurricanes reaching Category 3 and higher are considered major hurricanes because of their potential for significant loss of life and damage. Category 1 and 2 are still dangerous, however, and require preventative measures (Table 1-1).

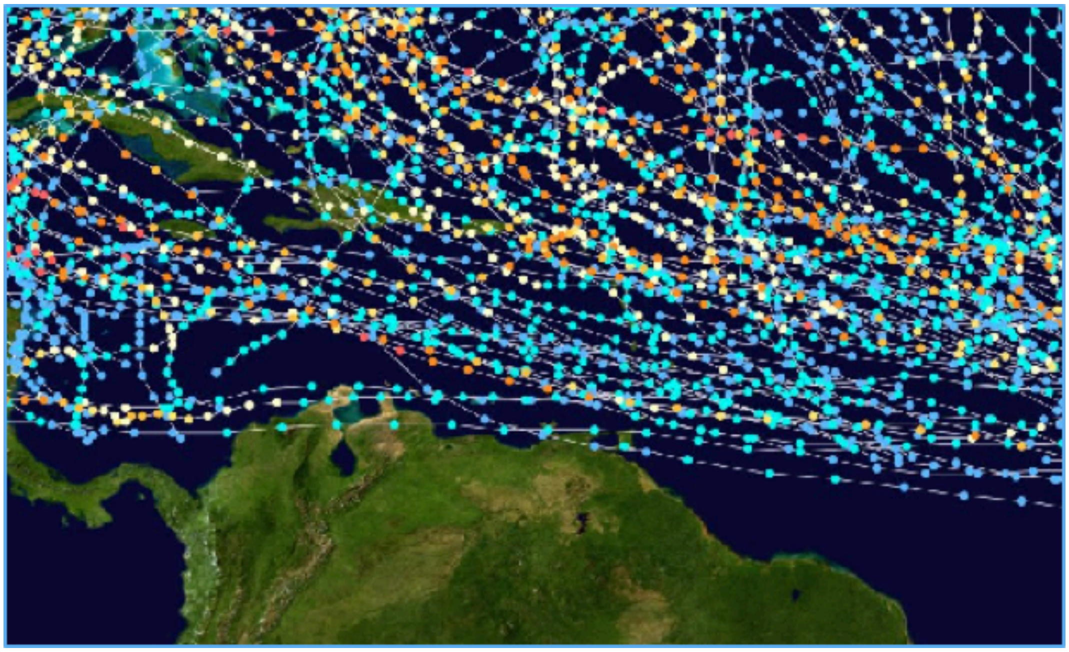


Table 1.1 Saffir-Simpson Intensity Scale for Hurricanes (Ref. 43)

Type	Category	Pressure (mb)	Winds (mph)	Winds (kmph)	Surge (meters)
Tropical Depression	TD	-	< 39	< 62	-
Tropical Storm	TS	-	39-73	63-118	-
Hurricane	1	> 980	74-95	119-153	1.2-1.5
Hurricane	2	965-980	96-110	154-177	1-6-2.4
Hurricane	3	945-965	111-130	178-209	2.5-3.6
Hurricane	4	920-945	131-155	210-250	3.7-5.4
Hurricane	5	< 920	> 155	> 250	> 5.4

The Caribbean Hurricane Network, also known as "stormCARIB," since 1996 operates a website providing detailed information and tools on hurricanes threatening the islands of the Caribbean, including the Greater and Lesser Antilles . Historical records on tropical storms and hurricanes from this website are given for Trinidad in Table 12 and for Tobago in Table 13.

Table 1.2 Tropical storm and hurricane occurrence for Trinidad 1851 - 2010 (extracted from ref.: 53).

Date	Maximum wind speed (mph)	Category (Saffir-Simpson)	Category (Saffir-Simpson) Closest point of approach (miles)	Name
02 Sep 1878	92	Hurricane 1	29	Not named
07 Oct 1892	81	Hurricane 1	33	Not named
27 Nov 1896	46	Tropical Storm	26	Not named
27 Jun 1933	81	Hurricane 1	48	Not named
20 Jul 1961	52	Tropical Storm	69	Anna
01 Oct 1963	127	Hurricane 3	51	Flora
14 Aug 1974	46	Tropical Storm	27	Alma
25 Jul 1990	52	Tropical Storm	69	Arthur
14 Aug 1990	40	Tropical Storm	29	Fran
07 Aug 1993	58	Tropical Storm	9	Bret
01 Oct 2000	40	Tropical Storm	53	Joyce

Tropical systems passing within 60nm (= 69mi.) of the island. Used latitude/longitude coordinates (10.62N, 61.35W) is from Port of Spain. Wind/category reported is the maximum measured while the system moved through the region. Winds are in miles per hour. Also listed is how close the centre of the storm came to the island, the so-called closest point of approach (cpoa, in miles).

Table 1.3 Tropical storm and hurricane occurrence for Tobago 1851 - 2010 (extracted from ref.: 53).

Date	Wind speed (mph)	Categoría (Saffir-Simpson)	Category (Saffir-Simpson)	Name
13 Aug 1856	81	Hurricane 1	65	Not named
22 Sep 1877	81	Hurricane 1	45	Not named
2 Sep 1878	92	Hurricane 1	20	Not named
6 Oct 1892	75	Hurricane 1	3	Not named
27 Nov 1896	46	Tropical storm	25	Not named
8 Sep 1921	92	Hurricane 1	41	Not named
17 Aug1933	40	Tropical storm	47	Not named
10 Aug 1938	46	Tropical storm	36	Not named
20 Jul 1961	40	Tropical storm	29	Anna
30 Sep 1963	121	Hurricane 3	6	Flora
14 Aug 1974	46	Tropical storm	64	Alma
11 Aug 1978	52	Tropical storm	59	Cora
14 Oct 1988	52	Tropical storm	58	Joan
25 Jul 1990	52	Tropical storm	21	Arthur
7 Ago 1993	58	Tropical storm	30	Bret
1 Oct 2000	40	Tropical storm	9	Joyce
15 Aug 2004	52	Tropical storm	45	Earl
7 Sep 2004	121	Hurricane 3	42	Ivan
14 Jul 2005	86	Hurricane 1	40	Emily
1 Sep 2007	46	Tropical storm	65	Félix

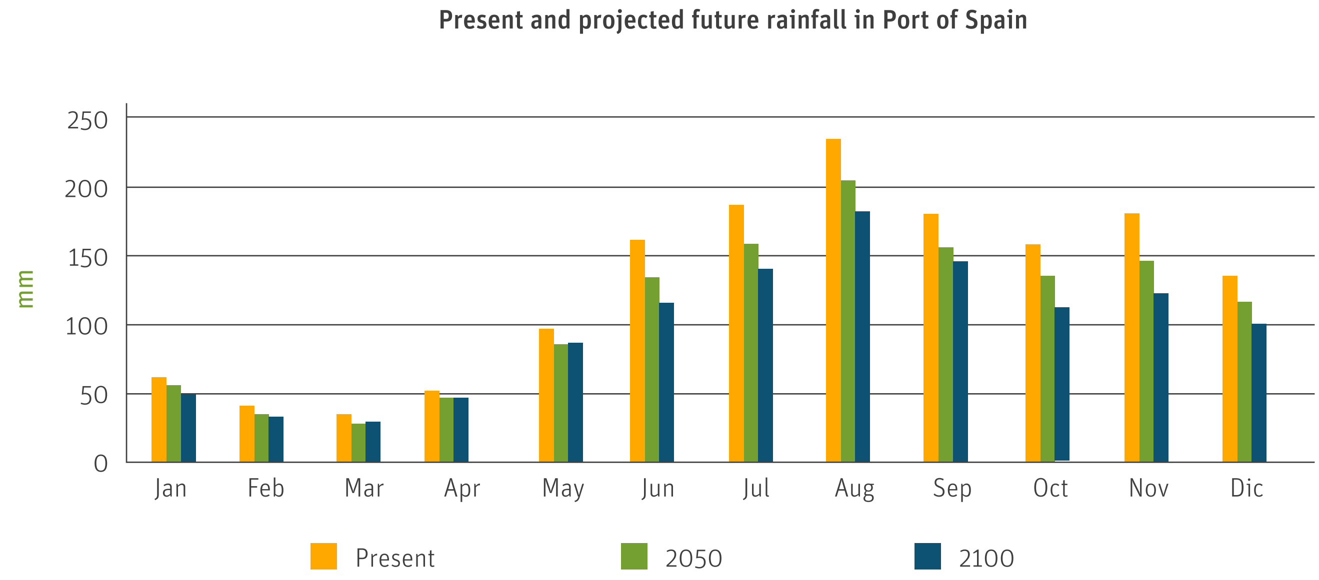
Tropical systems passing within 60nm (= 69mi.) of the island. Used latitude/longitude coordinates (11.15N, 60.83W) is from the island weather station the airport at Sandy Bay. Wind/category reported is the maximum measured while the system moved through the region. Winds are in miles per hour. Also listed is how close the centre of the storm came to the island, the so-called closest point of approach (cpoa, in miles).

Tropical storms only occur infrequently in Trinidad and Tobago and rarely develop into hurricanes. The highest hurricane level recorded within 60 nautical miles is 3 on one occasion in Trinidad in 1963 (Flora) and on two occasions in Tobago in 1963 (Flora) and in 2004 (Ivan).

1.2.3.1 Climate Change

Detailed projections of Climate change for Trinidad and Tobacco have not been available for this study. A rapid assessment has therefore been made by this project of changes in monthly changes in rainfall and evaporation in Port of Spain as projected by various global climate circulation models (See Appendix A). As illustrated in Figure 16. The annual precipitation is projected to decrease by 14% by 2050 and by 21% by 2100. Similarly, increases in potential evaporation of 5% and 8% are expected by 2050 and 2100, respectively.

Figure 1.6 Projected changes in Rainfall in Port of Prince in 2050 and 2100 (average of predictions of 21 different global circulation models (emission scenario SRA1B)).



1.2.4 Demography

Trinidad and Tobago had a population of 1,241,296 in 2010 according to the latest population census. The population has been decreasing slightly between 2000 and 2010 at an average annual growth rate of -0.17% (Table 14). The 2012 estimate of population growth for the country is - 0.086% (Ref. 9). The negative population growth is caused by a net migration out of Trinidad and Tobago estimated at -6.76 migrant(s)/1000 population (Ref. 9).

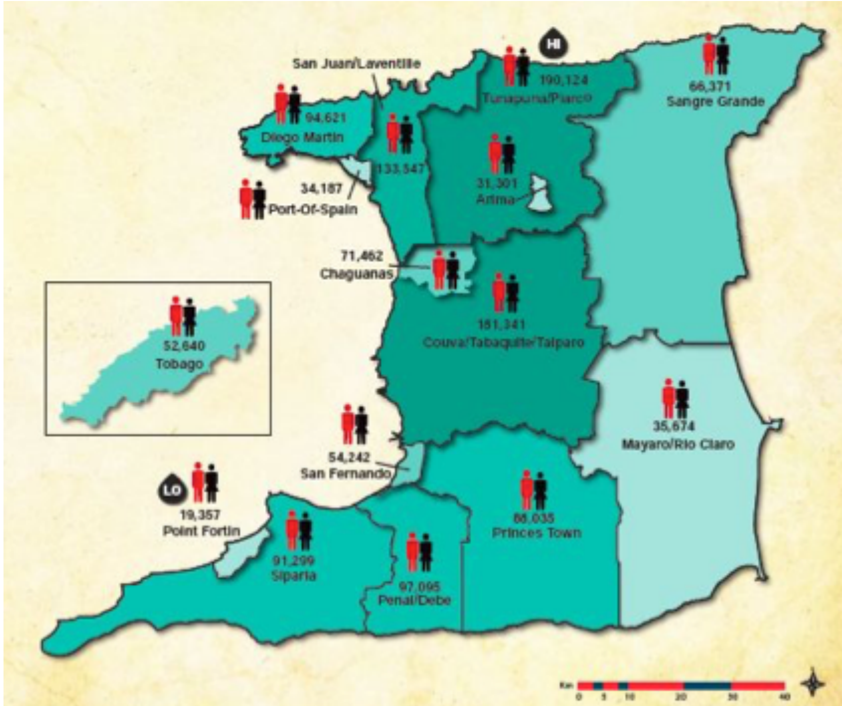
The population is unevenly distributed with highest concentrations in low laying coastal areas. The urban population in 2010 was at 14% and the annual rate of change in urban population between 2010 and 2015 is estimated at 3% (Ref. 9).

Table 1.4 Population data for Trinidad and Tobago.

Name	Status	Area km²	Population 2000	Population 2010	AAGR %	Population Density 2010
Trinidad	**Isla**	**4,852**	**1,208,282**	**1,188, 656**	**-0.16%**	**249**
Port of Spain	City	13	49,031	34,187	-3.61%	3,772
Mayaro/Rio Claro	Region	853	32,143	35,674	1.04%	38
Sangre Grande	Region	899	65,680	66,371	0.10%	73
Princess Town	Region	621	91,947	88,035	-0.43%	148
Penal/Debe	Region	247	83,609	97,095	1.50%	338
Siparia	Region	510	81,917	91,299	1.08%	161
San Fernando	City	19	55,419	54,242	-0.21%	2,917
Arima	Borough	11	32,278	31,301	-0.31%	2,934
Chaguanas	Borough	60	67,433	71,462	0.58%	1,124
Point Fortin	Borough	24	19,056	19,357	0.16%	794
Diego Martín	Region	128	105,720	94,621	-1.11%	826
San Juan/Laventille	Region	220	157,295	133,547	-1.64%	715
Tunapuna/Piarco	Region	527	203,975	190,124	-0.70%	387
Couva/Tabaqite/Talparo	Region	720	162,779	181,341	1.08%	226
Tobago	**Island**	**303**	**54,084**	**52,640**	**-0.27%**	**178**
TOTAL	**Country**	**5,155**	**1,262,366**	**1,241,296**	**-0.17%**	**245**

AAGR = Average Annual Growth Rate. Population 2010 (Ref. 6). Population 2000 and areas (http://www.citypopulation.de/Trinidad.html). Original source of popula-tion data for 2010 and 2000 are Census data from Central Statistical Office.

Figure 1.7 Population distribution in Trinidad and Tobago 2010 (Ref. 6)



1.2.5 Economy

The economic growth between 2000 and 2007 averaged slightly over 8%, significantly above the regional average of about 3.7% for that same period. The growth in GDP has slowed down since then and contracted during 2009-2011. The GDP in 2011 has been estimated by the Ministry of Finance at 20,596 Million USD (per capita GDP at 15,843 USD) placing Trinidad and Tobago as one of the most prosperous Caribbean states (Ref. 12).

Trinidad and Tobago is the leading Caribbean producer of oil and gas, and its economy is heavily dependent upon these resources but it also supplies manufactured goods, notably food products and beverages, as well as cement to the Caribbean region. Oil and gas account for about 40% of GDP and 80% of exports, but only 5% of employment. The country is a regional financial centre, and tourism is a growing sector, although it is not as important domestically as it is to many other Caribbean islands.

Trinidad and Tobago's energy sector faces a number of important challenges in the medium and long-term. Recent estimates project that stocks of oil and gas reserves are nearing exhaustion[1]. Moreover, production of crude oil has been declining substantially in recent years (32% since 2006), as some

1 At current extraction rates, proven natural gas reserves are estimated at 10 to 15 years and oil reserves at around 20 years (Reference to Ryder Scott Report 2010 in Ref.12).

of the country's oil fields are maturing. Gas production has remained relatively stable, but uncertainty remains with respect to the price of this commodity, due to developments in new extraction technologies (such as those related to shale gas), and expected supply increases associated with several worldwide investments to come on-stream in the future. These trends in the gas industry, combined with increasingly high exploration and extraction costs in Trinidad and Tobago, have led to a decrease in the level of investment in the energy sector (Ref.12).

Given the outlook for its energy sector, and the dependence of the non-energy sector of the economy on Government support, Trinidad and Tobago faces the significant development challenge of transitioning its economy into a post-hydrocarbon model, while continuing to improve its standard of living.

1.2.6 Water Sector[2]

The Water and Sewerage Authority (WASA), which was created under the WASA Act 1965, is the statutory body responsible for carrying out the Government policies related to water and wastewater and for the provision of water and wastewater services in T&T.

WASA has approximately 340,000 customers. While it is estimated that 92% of T&T's population have access to a piped water supply, the water supply system operates under constant challenges, mostly related to aging pipes and lack of the adequate maintenance. These problems have led to a gradual deterioration of the network, high level of non-revenue water (as high as 44%), and low service levels (only 20% of the population in Trinidad and 58% in Tobago have access to continuous water supply). The water sector is also heavily affected by the poor performance of the wastewater treatment plants as they impact the quality of surface and ground water sources - representing 62% and 27% of the total water supply respectively.

Trinidad & Tobago introduced centralized sewer and wastewater treatment systems in the 1960s. Since then, the sewage collection and treatment infrastructure has grown to an estimated 560 km of sewers and 243 wastewater facilities in both Trinidad and Tobago. However, this infrastructure only covers approximately 30% of T&T's population (about 400,000 persons serviced by centralized systems), with the remaining 70% serviced by septic tanks and pit latrines. The main sewered areas include Port of Spain, San Fernando and Arima in Trinidad and Scarborough in Tobago.

Current WASA statistics for wastewater can be summarized as follows: (i) only 20% of the total population serviced by WASA's centralized sewerage system; (ii) operation of 40 wastewater treatment plants[3] and 32 lift stations; and (iii) average wastewater flows treated of 130Ml/d.

Overall, the wastewater sector faces the following challenges: (i) limited expansion of the central sewers; (ii) tariffs below the cost of providing sewerage services; (iii) limited financial and human resources; (iv) poor infrastructure designs; and (v) poor maintenance of the existing infrastructure. As a consequence, the sewerage system is currently in a state of despair and in urgent need of rehabilitation.

2 The discussion of the Water Sector is based on Ref 11.
3 The remaining wastewater treatment plants are owned by Housing Development Corporation (HDC)

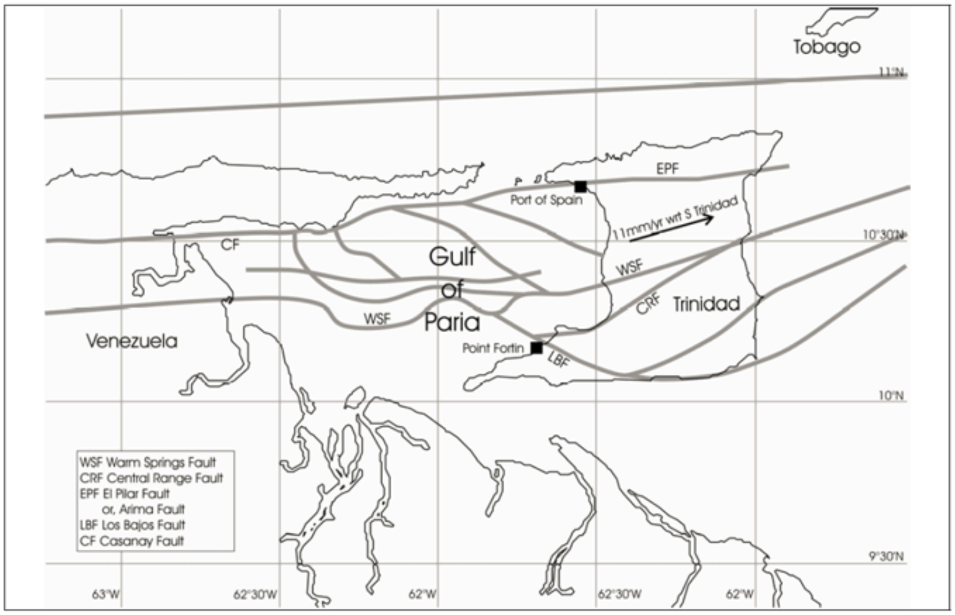
1.2.7 Tectonics

Trinidad and Tobago lies within a plate boundary zone near the south-eastern margin of the Caribbean Plate. The Caribbean plate is bounded on its eastern margin by a portion of the North American (NA) Plate. At about 200 kilometres east of the chain of volcanic islands in the eastern Caribbean the NA Plate is being sub-ducted beneath the Caribbean plate. Along the northern and southern boundaries the Caribbean plate slides past the NA and South American Plates in an easterly direction at a rate of about 2 cm/year. Rather than moving continuously, the plates tend to become locked along planar fault segments, accumulate strain and then rupture in zones.

The fault zone of the East West lateral strike slip between the Caribbean and the South American tectonic plates has created the Gulf of Paria, which now separates Trinidad from Venezuela. The fault zone extends across Trinidad in its entirety, with three major faults extending East West. It has been determined, that in recent times, it is the fault across the centre of the island that has been active, moving at a rate of 11mm a year. This fault runs North South in the Gulf of Paria before turning west again along the North coast of Venezuela. It is hypothesised that the East West movement on the North South line has caused Trinidad to separate from Venezuela and created the Gulf of Paria as a pull-apart basin (Figure 18, Ref. 5).

It is apparent that the rate of sea level rise in South West Trinidad is about four times that in the North West. The difference is likely to be due to the subsidence of South West Trinidad into the pull-apart basin of the Gulf of Paria.

Figure 1.8 The Fault Zone across Trinidad (Ref. 5)



1.3 Approach to the Case Study

In the reconnaissance mission to Trinidad and Tobago carried out in January/February 2012 a detailed scope for the case study was not provided and no specific linkage was made to an existing project. Instead four areas of concern related to climate change induced sea level rise were identified linked to urban drainage (Port of Spain), salinization of coastal aquifers (water supply), flooding of low lying coastal areas (West Coast) and impact on shoreline dynamics (South Coast). To address these four areas in depth is a major undertaking and beyond the resources available to the Trinidad and Tobago case study.

The approach to addressing the four areas of sea level rise concern has been:

1. The impact of sea level rise on the sewerage and drainage systems in Port of Spain. This was IDB's initial point of entry as the basis for the case study. During the reconnaissance visit to Port of Spain and discussions with local stakeholders, they expressed that the potential impact from the sea level rise is not considered significant for the drainage, in comparison with other factors such as the changes of rainfall patterns, further urbanization and other changes of land uses in hinterland catchments. This is probably the case at present, with acute drainage problems, including frequent flooding incidents in some parts of the town, associated with relatively short, high intensity rainstorms, combined with under capacitated and poorly maintained drainage infrastructure.

   But, it seems as if, under the urgent pressure of currently existing conditions, the potential impact of sea level rise as an additional threat in the future has received limited consideration. Valuable parts of the town's commercial center are built up in the coastal zone, on a low-lying reclaimed land. It is on the fringes of this zone, current flooding problems occur due to insufficient capacity of natural and man-made storm water drains. It is inevitable that due to the anticipated rise of the average sea level and increased storm surges in the future, drainage conditions in this area will deteriorate. Therefore, sea level rise must be included in the drainage system rehabilitation and augmentation studies.

   It is not possible to assess the scale of this potential threat without studying hydraulic conditions in the downstream sections of storm water drains, close to the coast. Such studies may be successfully executed by using appropriate hydrodynamic models for the affected parts of storm drainage network. The case study in Montevideo has engaged in a modeling approach that includes boundary conditions defined by sea level rise scenarios. The Montevideo case study therefore exemplifies an approach, which may be applied also in the context of Port of Spain, not only addressing sea level rise but also demonstrating the type of integrated modelling required, encompassing the hydrology in the contributing catchments, hydraulics in the drainage system and the anticipated sea level rise.

   Due to the lack of essential data, the Trinidad and Tobago case study has refrained from addressing the impact of sea level rise on urban drainage in Port of Spain through a modeling study. Instead, the possible approach is outlined in this report, with the Montevideo case taken as a baseline approach, appropriately adapted for the case of Port of Spain.

2. There are potential impacts of sea level rise on the salinization of coastal aquifers which are important sources of freshwater supply at present. The safeguarding of freshwater resources is a concern expressed by WASA. Whereas sea level rise may have an impact on the interaction between sea water and coastal aquifers, on-going extraction and patterns of land uses in upstream catchments are also likely to be important due to their potential impact on aquifer recharge.

   In order to consider the importance of sea level rise WASA has been requested to provide details of salinity intrusion problems in coastal aquifers, preferable confined to a specific local aquifer[4].

3. Sea level rise poses threats to development in low lying coastal areas with focus on the West Coast, where petrochemical and chemical industries are of particular concern and where flooding from the sea is already a management challenge. Concern about the investments in the oil and gas industry along the West coast has sparked vulnerability studies that reveal the severity of climate change impacts while demonstrating an approach to sea level rise vulnerability assessments. The study amongst others emphasize the importance of mainstreaming climate change vulnerability assessments into long term planning and emphasizes the need for integrated approaches to planning in the coastal areas.

4. Impacts of sea level rise are expected on shorelines and coastal processes (erosion/accretion) with focus on the southern and western coast of Trinidad already experiencing shoreline management challenges. The Institute of Maritime Affairs is currently compiling information on sea levels and coastal profiles which will enable outlining a conceptual approach to addressing the impact of sea level rise on shoreline processes from a management and planning point of view[5].

   A structured approach to address shoreline concerns would be to engage in a more comprehensive shoreline management study applying sediment cell and management unit analyses to inform spatial planning. Shoreline vulnerability assessments would look at the coastal profiles in combination with sea level rise scenarios. Although a shoreline management study is outside the resources and scope of the present case study such a study is recommended for the entire coast to support planning decisions.

In conclusion the Trinidad and Tobago case study will not address concern 1 above. Instead the Montevideo case should be disseminated as an example of a possible approach for Port of Spain.

For concerns 2, 3 and 4 the Trinidad and Tobago case will provide more narrative and conceptual discussions in a broader development management perspective.

The approach used in all the case studies is inspired by a stepwise approach to incorporate climate change adaptation and resilience into development projects, as developed by USAID. The approach has been modified to fit this project both in terms of scope and focus. Where the original approach is dealing with particular infrastructure projects, the focus of the case studies carried out during the

4 This material reached DHI too late in the preparation period to be considered in any degree of detail.
5 This information is still pending and thus not available for the case study.

present project have been more diverse and focusing on the sustainability of water supply or drainage systems to the case study cities, and in this case study for Trinidad and Tobago, even on more general spatial development along the coast. The approach is illustrated in Figure 19.

Figure 1.9 Stepwise approach used in the case study

1
- **Vulnerability Screening**
- Is the system vulnerable to sea level rise?
- If not leave here

2
- **Quantify possible sea level rise impacts on the system**

3
- **Evaluate the sensitivity of the system to sea level impacts**
- Compare with impacts of other pressures

4
- **Identify possible Adaptation measures**
- Are these no-regret options and are there adverse effects
- Further studies to be carried out

5
- Suggest adaptation plan or process

This case study for Trinidad and Tobago has been developed in a participatory process including two stakeholder dialogues. The first took place in January 2012 during a reconnaissance visit where stakeholders extensively discussed the scope for the case on adaptation to sea level rise in the country and agreed on addressing the four areas of concern covered in the case study. The first draft was circulated to stakeholders in Trinidad and Tobago in September 2012 allowing comments to be addressed in a second draft that was presented at a final stakeholder dialogue held in Port of Spain in March 2013.

2 Summary, Conclusions and Recommendations

2.1 Vulnerability Screening

As a small island state, Trinidad and Tobago, with limited land areas, high population and economic pressure on coastal areas, is particularly vulnerable to impacts of climate changes. This vulnerability is perhaps less pronounced compared to other Small Island Developing States (SIDS) as the country through its economic status has better adaptation capability. This capability, however, may eventually come under threat due to the country's high dependency on the energy sector, where extractable oil resources are likely to diminish over the next period of time.

This case study is focusing on sea level rise in particular and four areas of particular concern identified by key stakeholders are addressed. As discussed in Chapter 1 the case study confirms the vulnerability of Trinidad to:

1. The impact of sea level rise on the sewerage and drainage systems in Port of Spain
2. The impacts of sea level rise on the salinization of coastal aquifers
3. The impacts of sea level rise pose on low lying coastal areas, particularly on the west coast of the island where there is high population density and considerable economic development.
4. The impact of sea level rise along the coast in the form of erosion particularly where the shores have flat profiles and consist of unconsolidated material (beach areas).

Sea level rise will have an aggravating influence on all four areas and should therefore be carefully considered in measures taken addressing these challenges.

2.2 Sea Level Rise Projections for Trinidad

The relative change in sea level at a given location is a result of several contributing factors which can be expressed as $\Delta RSL = \Delta SL_G + \Delta SL_{RM} + \Delta SL_{RG} + \Delta SL_{VML}$, where is the relative change in sea levels, ΔSL_G is the contribution from global sea level rise, ΔSL_{RM} is the contribution from differences in meteo-oceanographic factors, is the contribution due to differences in regional gravity field, and ΔSL_{VML} is the contribution from vertical land movements (Ref. 31).

The projections in relative sea level rise have large uncertainties and while these uncertainties are being addressed it is recommended to apply a range of sea level rises depending on potential impacts. In the current case a central estimate of 1.25 m and a high estimate of 2.15 m relative sea level rise by 2100 have been applied. These levels have not included a meteo-oceanographic deviation as this at present is considered negligible in the Trinidad region.

As Trinidad is located in the southernmost margin of the Atlantic hurricane belt, occurrences of tropical storms are infrequent and cyclones are rare compared to other parts of the Caribbean and occurrences tend to be less severe. Since 1851 the highest hurricane level recorded within a radius of 60 nautical miles from either the airport of Tobago or from Port of Spain was three. Level three-huricanes were recorded on two occasions in Tobago (Flora in 1963, 6 nautical miles away, and Ivan in 2004, 42 nautical miles away) and on one occasion in Trinidad (Flora in 1963, 52 nautical miles away). All other hurricanes recorded have been at level 1. Details on tropical storm and hurricane occurrences have been provided in Section 1.2.3 Climate (Table 12 and Table 13).

Based on the history of cyclone events in Trinidad it appears that storm surges are unlikely to exceed 3 m corresponding to a category 3 cyclone. More dependable assessments of likely storm surges in Trinidad would, however, require a cyclone study, where local conditions can be duly taken into account.

2.3 Impacts from Sea Level Rise on the Drainage of Port of Spain

The present drainage problems in Port of Spain have been found to be a result of many issues not related to climatic change such as:

- Increased and faster runoff due to intensive urban developments and removal of vegetation of the upstream hill slopes;
- Inadequate drainage infrastructure;
- Sediment deposition and accumulated solid waste in the lower drainage segments;

Occurrences of heavy rain storms and high tides already aggravate the flooding situation since the lower parts of the City are located only a few meters above present mean sea level. A general rise of this level will further aggravate the situation and such a rise needs to be taken into consideration as part of an expansion/re-design of the drainage network.

2.4 Impacts from Sea Level Rise on the Salinization of Coastal Aquifers

The study has focused on two aquifers close to and under Port of Spain namely the Port of Spain Gravels and Northern Gravels. A full-fledged detailed hydrogeological modeling study of these aquifers as required for a quantification of the potential future salinity intrusion is out of the scope of the present study.

Analyses of the received hydrogeological information on the aquifers and the historical water quality and pumping information have revealed that:

- Salinity intrusion in these aquifers has been experienced earlier, although it is now under control.
- Generally lower amounts of rainfall combined with increased potential evaporation in Port of Spain as projected by a large number of global circulation models will lead to decreased recharge rates, which will further lower the sustainable pumping rates from the aquifers.
- Increased sea water levels will pose a serious threat and require further measures (reduced pumping or implementation of more advanced ways of pumping enforcing seawards gradients or potential barriers) in order to avoid further salinity intrusion.

2.5 Impact from Sea Level Rise on low lying Coastal Areas

Low lying coastal areas are exposed to flooding from the sea during extreme weather conditions such as surges during tropical storms and cyclones. Sea level rise is exacerbating these impacts with inundation potentially reaching further inland areas. This poses threats to vulnerable areas including population centres, infrastructure, economic activities, and natural resources.

2.6 Impact from Sea Level Rise on Shorelines

Erosion is observed at many beaches along the coast of Trinidad and as recorded in beach profiling at selected locations since 1991. Analyses of such profiles have shown evidence of coastal erosion at a number of locations at a rate of 1 to 2 metres per year on average. The shoreline retreat in these places may well be an indication of sea level rises although it may also be a result of chronic erosion caused by local patterns of current and wave impact.

Increased sea levels will expose a larger portion of coasts to wave action and current. At erodible shores this will lead to increased erosion, so some of the coasts are vulnerable to the anticipated sea level rise.

2.7 Adaptation Measures and Outline Adaptation Plan

For each of the four focus issues a number of possible adaptation measures have been identified and ranked in a scoring matrix considering their win/win and regret/no regret characteristics, their flexibility, resilience, urgency, political acceptability and implementation costs (Chapter 1). No attempt has been made to rank options across the four focus areas i.e. suggesting one of the issues to be more important than the others.

Based on the ranking outline adaptation plans for each of the four focus issues have been prepared for the consideration of and discussion amongst the stakeholders (Chapter 7).

The identified adaptation measures are summarised below.

2.7.1 General measures

The information base required for decision support pertaining to management of the complex and dynamic coastal areas is weak and there is a need to establish and through monitoring continuously maintain a shared structured management information system.

There is a need to embark on more integrated approaches to development management in the coastal areas. Integrated coastal zone management (ICZM) and integrated water resources management (IWRM) have been developed over the past many decades and are now by the international community increasingly embraced as effective tools in addressing climate change challenges and sustainable development.

The dynamic interface between land and sea that is moving landwards due to sea level rise calls for specialised studies and planning to develop policies and strategies for land uses along the shoreline to feed into spatial planning.

Vulnerabilities to climate change and sea level rise need to be duly addressed/mitigated in spatial planning and the on-going review of the national spatial development plan in Trinidad offers an entry point for mainstreaming climate change into spatial planning. Directions/guidelines need to be developed for environmental assessments to consider climate change mitigation particularly for development and projects in vulnerable areas.

Contingency plans need to be developed where settlements and economic activities remain in vulnerable areas, including early warning and response measures for extreme events such as storms and associated surges.

2.7.2 Port of Spain drainage

Full understanding of the flooding in Port of Spain problems at present time and in the future, requires a comprehensive study applying state-of-the-art analytical tools (digital terrain models (DTMs), satellite and aerial imagery, GIS, dynamic simulation models, etc.) and the incorporation of the climate change impacts, including sea level rise.

Such a comprehensive study, along with urgent remediation of local acute problems, should be the first undertaking of the massive investments in the storm drainage sector, repeatedly announced by the city's political leaders. If properly conducted, the study would secure correct and economically efficient solutions.

Further recommendations on such a study are given in Section 6 of this report.

2.7.3 Salinization of coastal aquifers

A number of possible alleviation measures have been identified including: Freshwater injection barriers, creation of outwards gradients by increased near coast pumping, modification of present pumping practice and possible relocation of wells, artificially increased recharge, and prevention of salinity intrusion in estuaries.

As prerequisites to the assessment of the feasibility of such measures a detailed integrated hydrogeological model bust be established to further reveal the aquifer characteristics and the possible measures analysed; an improved monitoring program must be established and a testing program for the most promising pumping scenarios must be implemented.

In parallel other options for supply of drinking water should be investigated (e.g. increased use of surface water and possible desalination) and possible savings by water demand management should be analysed. The analyses could be integrated in a general water supply management plan.

2.7.4 Inundation

Low lying coastal areas are vulnerable to flooding from the sea particularly during storm surges. This vulnerability is exacerbated through sea level rise. Possible adaptation pathways include protecting areas at risk implying defending vulnerable areas, accommodating to impacts implying remaining in vulnerable areas while changing land uses, construction methods and improving preparedness and retreat, which is a planned abandonment of areas and relocation to areas that are not vulnerable to sea level rise.

The choice of pathway or combination of pathways relies on careful consideration of vulnerabilities in spatial analyses where areas at risk are measured against the array of themes that are considered in physical planning, including demography, infrastructure, socio-economy, economy, natural resources and more. A prerequisite for such analyses on one side is that credible vulnerability assessment are achieved and on the other that good information is available and accessible in a shared information management system as outlined under decision support measures above.

An important adaptation measure is therefore to ensure a better ability to determine areas at risk. Measures to this end include establishing a detailed Digital Elevation Model (DEM) for the coastal areas, quantification of the contribution to relative sea level rise due to vertical land movements, a cyclone study to assess frequency of tropical storms and cyclones and associated surges in Trinidad, and assessments of vulnerability to inundation as themes that can interact in spatial analyses supporting spatial development planning.

An important tool in development management is physical planning. An important adaptation measure is therefore to mainstream climate change into the National Spatial Development Planning. The National Spatial Development Strategy currently under formulation needs to incorporate vulnerabilities to climate change in general and to sea level rise to ensure that strategic guidance duly incorporates climate change resilience in the arrangements of major infrastructure and the location of major facilities, and in the national urban development strategy.

Finally, it is recommended to engage in long term reform processes targeting sustainable climate resilient development through Integrated Coastal and Water Resources Management.

2.7.5 Erosion

The erosion experienced along the coasts of Trinidad may be caused by natural and/or anthropogenic causes, including winds, waves, tides, storm and surge conditions, sea level rise and land subsidence and may have severe consequences on natural and man-made environments.

The contribution to coastal erosion from sea level rise can be assessed using the Bruun rule, which establishes a relation between shoreline retreat, relative sea level rise and the slope of the beach profile. In Trinidad erosion rates of 1 to 2 m per year have been attributed to sea level rise at several locations.

To determine appropriate management responses to erosion requires an analysis of actual and potential shoreline erosion against planned and existing development activities at the coast. It is recommended to undertake a systematic shoreline management planning process in Trinidad to produce appropriate policies and strategies for adaptation to coastal erosion.

3 Sensitivity and Vulnerability to Climate Change and Sea Level Rise

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli.

Adaptive capacity is the ability of a system to adjust to climate change, including climate variability and extremes, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. Hereby, adaptive capacity depends on socio-economic factors, technology and infrastructure.

Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.

As is the case for most Small Island Development States (SIDS) Trinidad and Tobago is particularly vulnerable to climate change due to:

- A concentration of population, socio-economic activities, and infrastructure along the coastal zone.
- High population densities. The average population density in Trinidad and Tobago was at 245 persons per km^2 in 2010 with highest densities in urbanised coastal areas (Table 14, page 8).
- Limited physical size, effectively eliminating some adaptation options to climate change and sea-level rise.
- Susceptibility to frequent and more intense tropical cyclones and to associated storm surge, droughts, tsunamis and volcanic eruptions. Trinidad and Tobago is located at the southernmost outskirt of the Atlantic hurricane belt, and is as such to some extent subject to tropical storms and hurricanes6. Trinidad and Tobago is also located on the Circum-Caribbean Tectonic Belt, which has produced several earthquakes in magnitudes exceeding 7.0 since 1900. Trinidad and Tobago is also subject to floods (Ref. 11).
- Dependence on water resources for freshwater supply that are sensitive to sea-level changes. Approximately 70% of Trinidad and Tobago's water supply is derived from surface water sources, while the remainder 30% is provided from groundwater sources (Ref. 22).

Compared to most SIDS, Trinidad and Tobago has a greater adaptation capacity due to a stronger economy, more developed infrastructure and access to professional services. The economy's high dependence on the energy sector may, however, erode this adaptation strength.

The present case study has its focus on sea level rise and will therefore not deal with other climate changes factors in any degree of detail. Such factors are considered in more detail in the three other case studies.

3.1 General

Global warming leads to rising sea levels due to thermal expansion of the oceans and to melting of land based ice including the Arctic/Antarctic ice caps and glaciers. The rapid reduction in the area of arctic sea ice experienced during summer time further contributes to the thermal expansion due to increased absorption of heat.

Global mean sea level change is one of the more certain impacts of human induced global warming and one which is expected to continue for centuries due to the time scales associated with climate processes and feedbacks even if greenhouse gas (GHG) emissions and concentrations were to be stabilised. Given the large and growing concentration of population and economic activity in the coastal zone, as well as the importance of coastal ecosystems, the potential impacts of sea-level change have evoked widespread concern for more than two decades (Ref. 31).

6 Tropical storms are infrequent and only seldom develop into hurricanes within 60 nautical miles of Trinidad and Tobago. The highest recorded hurricane level recorded since 1851 has been 3 on one occasion in Trinidad (Flora, 1963) and on two occasions in Tobago (Flora 1963, Ivan 2004). More details on occurrences of tropical storms and hurricanes in Trinidad and Tobago are provided in Section 1.2.3 Climate (Table 12 and Table 13).

Sea level changes vary regionally due to differences in the rates of oceanic thermal expansion, changes in wind and atmospheric pressure and changes in ocean circulation as well as changes in the Earth's gravity field due to melting of polar ice.

Changes in storm characteristics may influence the frequency and magnitude of storm surges.

Non-climate processes such as glacial isostatic adjustments, tectonics, and subsidence (e.g. by over-exploitation of groundwater) may add to the relative change of sea levels.

Rising sea levels can have significant impact on water resources including increased risk of flooding from the sea during storm surges, fluvial flooding due to backwater effects, wetland losses, shoreline changes, saltwater intrusion of both surface and groundwater, and impeded drainage and increase in the groundwater table (Table 31).

Table 3.1 The main physical impacts of relative sea level rise, which require sea level rise scenarios for their analysis (Ref.31)

Physical Impacts	
• Inundation, flood and storm damage	a. Surge (sea)
	b. Backwater effect (river and storm drains)
• Long-term wetland loss (and change)	
• Altered patterns of erosion and accretion (direct and indirect morphological change)	
• Saltwater intrusion	a. Surface waters
	b. Ground water
• Rising water tables / impeded drainage	

Sea levels have risen over the last century and over the past decades at an increased rate. A rising sea level is not a catastrophic event in itself but a gradual process allowing time for adaptation. Adaptation avenues are often well known as they are similar to the adaptation measures used to cope with effects of climate variability, such as flooding due to storm surges and shoreline erosion.

The consequences of a rise in sea level however, on the frequency and severity of extreme events such as flooding during storm surges may be catastrophic and thus demand preparedness.

Relative sea level can change over a wide range of timescales from seconds to centuries. For instance, significant sea-level variability can occur over years or even several decades due to a range of processes and large-scale atmospheric circulation changes such as the El Niño-Southern Oscillation (ENSO) phenomenon or the North Atlantic Oscillation (NAO), depending on the location (Ref. 31).

3.2 Is the Urban Drainage in Port of Spain vulnerable to Sea Level Rise?

Port of Spain (POS) is located at the southern coast of the north-western peninsula of Trinidad on the foothills of the Northern Range. Settlements in east Port of Spain occur on slopes and ridges, but most of the city is situated on land which slopes gently toward the sea. Reclamation from the sea has taken place over the past two hundred years and the water front and port area of the city is located on reclaimed land. It is this low-lying land, with port facilities and other valuable urban contents, which is subject to flooding.

Although the flooding is influenced by a large number of factors, as further described in Section 3.3 below, a projected increase of the sea level of up to 1.25 m (central estimate) by the end of the 21st century will significantly change hydraulic condition in the lower reaches of the Port of Spain's urban rivers and in low parts of the storm drainage network which is therefore vulnerable to such change.

3.3 Are Coastal Aquifers vulnerable to Sea Level Rise?

In an unconfined aquifer that contacts the sea at the shoreline or seaward, the freshwater, which is less dense than seawater, floats as a lens-shaped layer on top of seawater (Figure 31), and the weight of the overlying freshwater depresses the seawater below sea level.

Under natural conditions with no or little groundwater pumping rising sea levels will lead to a rise both in the groundwater tables and in the level of the interface between the fresh and the saline water, which in cases with thick water bearing formations should not pose serious problems.

In Port of Spain the terrain is, however, very close to the sea level and an increase of the groundwater levels may bring these very close to the surface, where they may create problems for the infrastructure in the area. Furthermore, the groundwater is heavily exploited and salinity intrusion is already experienced (Table 32). It seems, however, that the salinity intrusion is presently kept under control by adjustment of the pumping rates and controlling the drawdown at acceptable levels (see Figure 32 which shows a rather constant drawdown and compare with Table 32 indicating that salinity levels are under control). Rising sea water levels may increase the pressure gradients from the sea to the boreholes which can aggravate the salinity intrusion. The coastal aquifers are therefore quite vulnerable to such rise.

Figure 3.1 Simplified freshwater - saltwater interface in a coastal water - table aquifer. Illustrating the Ghyben-Herzberg Principle (Ref. 28)

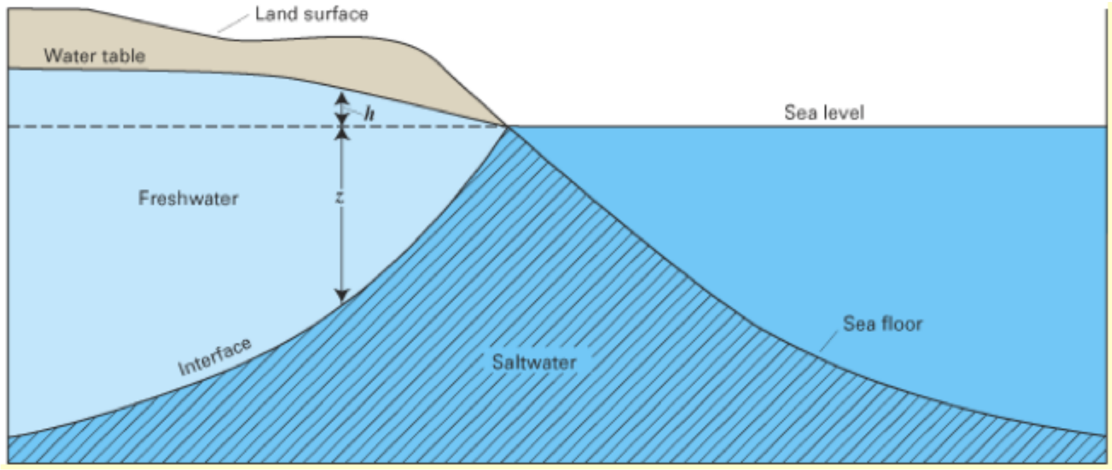


Figure 3.2 Draw-down (reduced water levels (m)) in the Port of Spain Queen's Park Savannah and Botanic Garden well-fields. Source: WASA (2012)

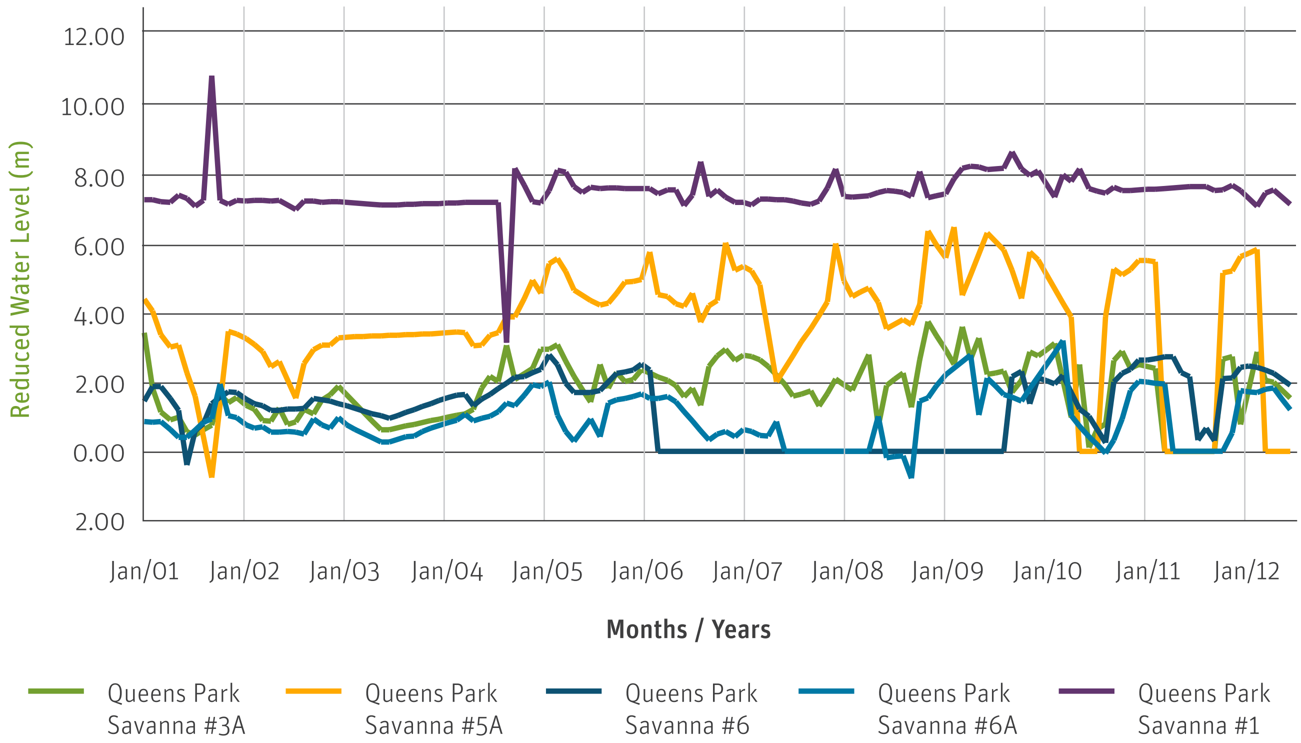


Table 3.2 Water Quality Parameters for the Port of Spain Well-field (1979-2009). Source: WASA

Well name	Well type	Date	Chloride (mg/l)	Total disolved solids (mg/l)
N.F.M. Borehole (2168 Ps)	Observation		274	778
			80	370
			156	530
		09-Oct-79	286	830
		02-Aug-82	540	1099
		02-Oct-82	395	955
		02-Nov-82	330	745
		30-Nov-90		
T&TEC #10 (2326 Ps)	Production	31-Dec-89	101	
		30-Jun-90	107	
Country Club (767 Ps)	Production	17-Mar-89	30	233
		16-Mar-90	29	248
		25-Jan-91	22	150
Queens Park Hotel #1 (2297 Ps)	Production	24-Feb-89	38	234
		16-Mar-90	45	293
		25-Jan-91	43	219
Electric Ice #2 (749 Ps)	Production	29-Jul-85	157	616
		10-Apr-89	168	577
		09-May-90	138	589
Dock site (763 Ps)	Observation	26-Jun-85	2106	4209
Electric Ice #1 (750 Ps)	Production	29-Jul-85	169	650
		10-Apr-89	153	585
		09-May-90	142	591
Dock site #1 (762 Ps)	Observation	08-Jul-09	220	

3.4 Are low-lying Coastal Areas vulnerable to Sea Level Rise?

Low-lying coastal areas in Trinidad will be inundated as a direct result of sea level rise unless remediating measures are undertaken. Furthermore, storm surges with increasing sea levels would impact further into the coastal areas as compared to the current situation expanding the population and investments at risk.

Such concerns have been raised in Trinidad and amongst others sparked more detailed vulnerability assessments on the west coast, focusing on oil and gas facilities and associated infrastructure on the west coast of Trinidad. These studies examined the impact of a sea level rise in the Vessigny-Cap de Ville area based on two coupled atmosphere-ocean general circulation models (Canadian CGCM2 and British HadCM3), while also discussing storm surges and erosion. The results of the study showed that infrastructure such as access roads, pipelines, storage tanks, jetties, harbours, and administrative buildings would be at severe risk of inundation and erosion derived from sea level rise and storm surges (Refs.: 16 and 49).

A study carried out covering CARICOM Member States has attempted to quantify the transformational impacts of sea level rise in the Caribbean, based on GIS analyses. Table 33 provides the study's assessment of the impacts on a number of parameters in Trinidad and Tobago from sea level rises of 1 m and 2 m.

Table 3.3 Impacts of sea level rise (SLR) of 1 and 2 m in Trinidad and Tobago (Adapted from Ref.:36).

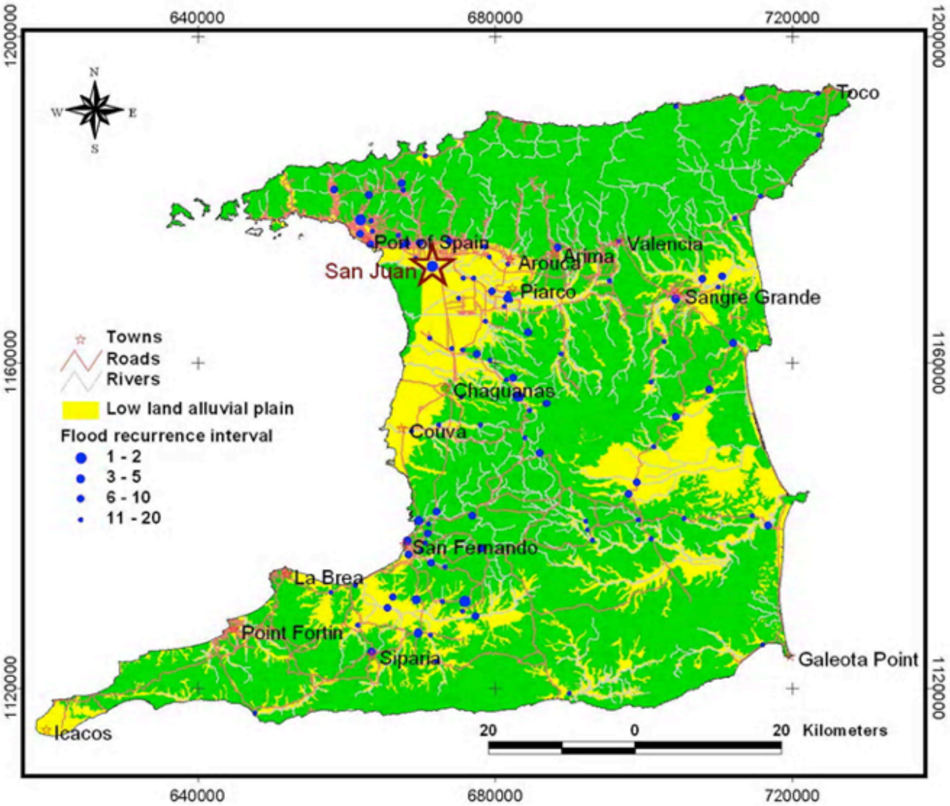
	1 m SLR	2 m SLR
Land area	1 %	2 %
Population	1 %	2 %
Urban area	1 %	2 %
Wetland	< 1 %	< 1 %
Agricultural land	3 %	6 %
Crop and plantation	*	*
Major tourism resorts	33 %	63 %
Airports	50 %	50 %
Road Network	1 %	2 %
Protected areas	0 %	0 %
Sea turtle nests	15 %	24 %
Power plants	0 %	0 %
Ports	100 %	100 %

*Data restrictions

In addition, low lying areas are frequently and increasingly subjected to flooding and sea level rise will have an aggravating impact on the severity of flooding as the drainage of impacted areas will become more difficult and slower.

In conclusion, the answer to the posed question is that low lying coastal areas in Trinidad are indeed vulnerable to sea level rise. As there is a general concentration of people and investments in these areas development planning and management is required to incorporate the impact of sea level rise.

Figure 3.3 Flood prone areas and flood locations in Trinidad (Ref. 32). Based on flood occurrences over 20 years, between 1986 and 2006. Flood occurrences 10 - 13, 4 - 9, 2 - 3 and 1 times were categorized into 1 - 2, 3 - 5, 6 - 10 and 11 - 20 flood recurrent interval classes respectively.



3.5 Are the Shorelines in Trinidad and Tobago vulnerable to Sea Level Rise?

Erosion is observed at many beaches along the coast of Trinidad and as recorded in beach profiling at selected locations since 1991 (Ref. 26). Analyses of such profiles from 1991 to 2001 showed evidence of coastal erosion at a number of locations at a rate of 1 to 2 metres per year on average (Ref. 25). The shoreline retreat in these places may well be an indication of sea level rises during this period although it may also be a result of chronic erosion caused by local patterns of current and wave impact.

Increased sea levels will expose a larger portion of coasts to wave action and current. At erodible shores this will lead to increased erosion, so some of the coasts are vulnerable to the anticipated sea level rise.

4 Projected Sea Level Rise

As discussed in Section 3 the relative change in sea level at a given location is a result of several contributing factors, which can be expressed as:

$$\Delta RSL = \Delta SL_G + \Delta SL_{RM} + \Delta SL_{RG} + \Delta SL_{VML}$$

Where is the relative change in sea levels, ΔSL_G is the contribution from global sea level rise, ΔSL_{RM} is the contribution from differences in meteo-oceanographic factors, ΔSL_{RG} is the contribution due to differences in regional gravity field, and ΔSL_{VML} is the contribution from vertical land movements (Ref. 31).

4.1 Global Sea Level Rise Projections

The global sea level rise (ΔSL_G)) is a result of an increase in the global volume of water due to thermal expansion of warming surface waters, the melting of glaciers and ice caps and changes in the mass balance of the Greenland and Antarctic sheets (Ref. 31).

The IPCC 4th Assessment Report for the six SRES (Special Report on Emission Scenarios) in 2007 gave 2100 projections for surface warming in the range of 1.1 – 6.4°C and for global sea level rise in the range of 0.18 - 0.59 m (Table 41). The major part of the projected sea level rise is due to thermal expansion with the remaining stemming from melting of ice caps and glaciers. These projections, however, adopted linear projections of melting and did not include more rapid processes related to accelerated ice-sheet discharges observed in Greenland and Antarctica.

Table 4.1 Table SPM.3 from Ref. 35. The Physical Science Base (WGI). Projected global average surface warming and sea level rise at the end of the 21st century. The projected sea level rise from the different scenarios is given as the 5% to 95% range in metres.

	Temperature change		**Sea level rise**
	(°C at 2090-2099 relative to 1980-1999)		(m at 2090-2099 rela-tive to 1980-1999)
Case	Best estimate	Likely range	Model-based range ex-cluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations	0.6	0.3-0.9	NA
B1 scenario	1.8	1.1-2.9	0.18-0.38
A1T scenario	2.4	1.4-3.8	0.20-0.45
B2 scenario	2.4	1.4-3.8	0.20-0.43
A1B scenario	2.8	1.7-4.4	0.21-0.48
A2 scenario	3.4	2.0-5.4	0.23-0.51
A1F1 scenario	4.0	2.4-6.4	0.26-0.59

Newer studies following the IPCC 4th Assessment Report indicate higher sea level rises by 2100.

Table 42 provides a summary of the most recent projections of global sea level rises over the 21st century and compares these studies to the projections in the IPCC 4th Assessment Report and continuation of current trends.

Table 4.2 Summary of global sea level rise projections for 21st century. (Source: Ref 36)

	2050*	2100		
		Low range	central estimate	High range
Continuation of current trend (3.4 mm/ year)	13.6 cm	-	30.6 cm	-
IPCC AR4 (2007)	8.9 cm a 23.8 cm	18 cm	-	59 cm
Rahmstorf (2007)	17 cm a 32 cm	50 cm	90 cm	140 cm
Horton et al. (2008)	~ 30 cm		100 cm	
Vermeer and Rahmstorf (2009)	~ 40 cm	75 cm	124 cm	180 cm
Grindstead et al. (2009)	-	40 cm	125 cm	215 cm
Jevrejeva et al. (2010)		60 cm	120 cm	175 cm

The more recent studies all project high range global sea level rise of more than 140 cm by 2100 and central estimates of more than 90 cm. Although the central estimate is the more likely scenario at present, applying the precautionary principle in the absence of scientific certainty would require that the high range projections are not discounted (Ref. 36).

With respect to the temporal evolution of the global sea level rise it has been suggested to use a quadratic function[7].

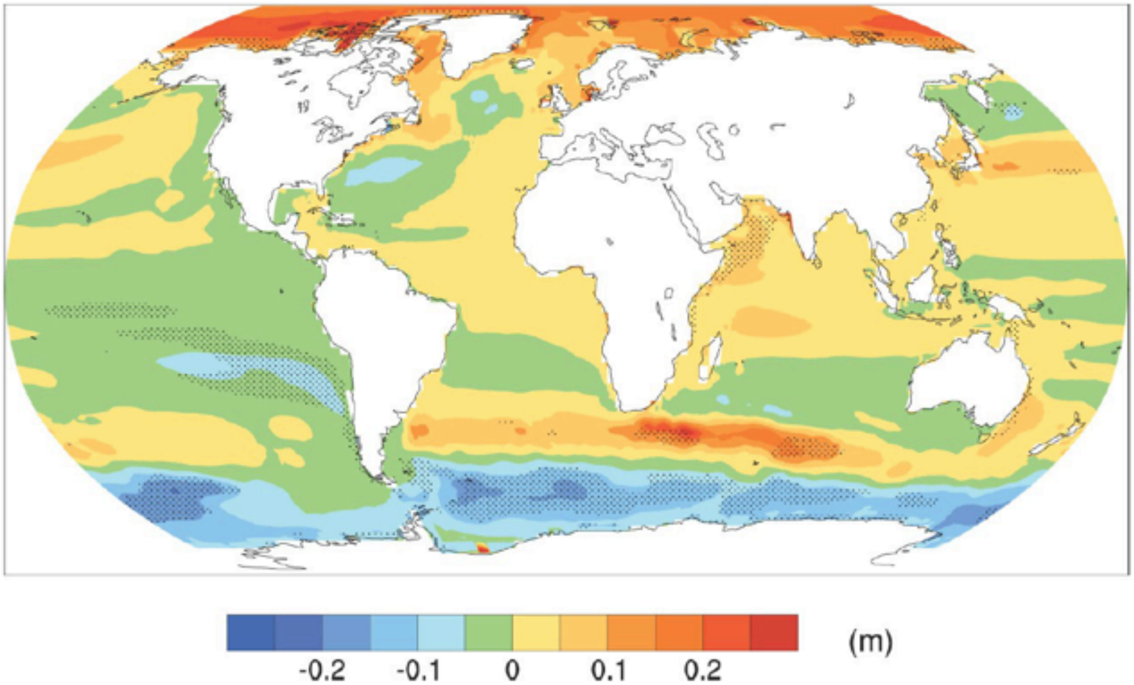
4.2 Deviations to the Global Model in the Caribbean

Meteo-oceanographic factors (ΔSL_{RM}), including differences in the rates of oceanic thermal expansion, changes in long-term wind and atmospheric pressure, and changes in ocean circulation could be significant, causing large regional departures from the global average value for the thermal expansion component of sea-level change. In the IPCC 4th Assessment Report ensembles of outputs from coupled Atmosphere-Ocean General Circulation Models (AOGCMs) show regional variations in local sea level change due to ocean density and circulation (Ref 44) that are lower than average on the southern hemisphere and higher than average in the Arctic. The variation, however, in the Trinidad region from global average appears very small and less than 5 cm (Figure 41) or less than 4 % of a global central estimate of 1.25 m.

7 To project the evolution over time in global sea level rise until 2100 the following simple quadratic function has been found to give a good fit assuming sea level is 0 in 1990: , where is the change in global sea level since 1990, is the number of years since 1990, is the trend in sea level change and is the change in the rate of the sea level change (Ref. 31).

Changes in the regional gravity field of the Earth (ΔSL_{RG}) due to ice melting (caused by redistribution of mass away from Greenland, Antarctica as well as small glaciers). If a polar ice sheet melts, then the volume of water in the oceans increases, but at the same time, the gravitational pull from the ice sheet on the oceans close to the ice sheet falls. The net effect of these processes is that sea-level rise occurs faster in areas further away from the ice sheets. For example, in the case of melting Greenland ice, there would be less sea-level rise than the global average in the North Atlantic, near to Greenland, progressing to an enhanced sea-level rise (compared to the global eustatic value) at low latitudes and in the southern oceans. Regional variations of sea level rise caused by changes in the gravity field have yet to be studied in detail, but the effect could be significant, potentially increasing the sea levels experienced in the Trinidad region.

Figure 4.1 Local sea level change caused by changes in ocean density and circulation relative to the global average sea level rise calculated as the difference between 2080-2099 and 1980-1999, as an ensemble average over 16 AOGCMs forced with the SRES A1B scenario



4.3 Sea Levels in Trinidad and Tobago

Vertical land movements (uplift and subsidence) (ΔSL_{VML}), due to various natural and human-induced geological processes). Vertical land movement occurs in most places. Natural causes include: (1) neo-tectonics, (2) glacio-isostatic adjustment (GIA), and (3) sediment compaction/consolidation. These changes can be regional, slow and steady, as in the case of GIA, but also localised, large and abrupt, for example as associated with earthquakes.

In addition, human activity has often influenced rates of subsidence in susceptible coastal lowlands such as deltas by land reclamation and by lowering water tables through water extraction and improved drainage. These human-enhanced processes are generally localised to Holocene-age deposits and can locally exceed the magnitude of changes expected due to climate change through the 21st Century.

It is apparent that the rate of sea level rise in South West Trinidad is about four times that in the North West. The difference is likely to be due to the subsidence of South West Trinidad into the pull-apart basin of the Gulf of Paria (Ref.5).

4.4 Sea Level Rise Projections for Trinidad and Tobago

Projections of sea level rise in Trinidad and Tobago components are summarised in Table 43.

The projections in relative sea level rise have large uncertainties and while these uncertainties are being addressed it is recommended to apply a range of sea level rises depending on potential impacts. In the current case a central estimate of 1.25 m and a high estimate of 2.15 m relative sea level rise by 2100 have been applied. These levels have not included a meteo-oceanographic deviation as this at present is considered negligible in the Trinidad region.

The selected sea level rises are in the higher end and should be adjusted as more credible forecasts become available and incorporating assessments of local vertical land movements, which will differ along the coast.

At the same time the predictions from the global model must be closely followed as they will provide more dependable estimates of climate change contributions to sea level rise according to different scenarios.

Table 4.3 Summary of relative sea level change components in Trinidad. Relative changes in 2100 as compared to 1990.

Relative Sea Level Change (ΔRSL)		Current assessment	Requirements	Adaptation action
Global sea level change	ΔSL_G	Central estimate 1.25 m High es-imate 2.15 m	Update according to best information	Monitor progress intenationally
Meteooceanographic driven de-viation from global sea level change	ΔSL_{RM}	Less than 5 % of global sea level change to be added	Update according to best information	Seek and apply qulified as-sessments and tools
Corrections for gravity effects	ΔSL_{LG}	Assume globally uniform eustatic sea level rise	Update according to best information	Seek and apply qulified as-sessments and tools
Natural vertical land movement	$\Delta SL_{VML}l$	Local variations due to tectonics Assume no change	Urgent local asessment required	Identify hotspots and conduct study/initiate monitor-ing
Human induced vertical land movement	$\Delta SL_{VML}l$	Local var-iations due to wa-ter and hydro-carbon extraction Assume no change	Urgent local asessment required	Identify hotspots and conduct study/initiate monitor-ing
Changes in storm surge		Assume no change	Detailed modeling using regional models or statistical downcal-ing driven by climate change.	

4.5 Storm Surges

Under extreme events such as during tropical storms and cyclones storm surges will build up due to high winds pushing on the surface, which causes water to pile up higher than normal sea levels. A secondary smaller addition to the wind driven surge arises from the low pressure in the centre of these weather systems. The extent of storm surges is influenced by the bathymetry. It is this combined effect of low pressure and persistent wind over a shallow water body which is the most common cause of storm surge flooding problems, particularly when it coincides with high tides.

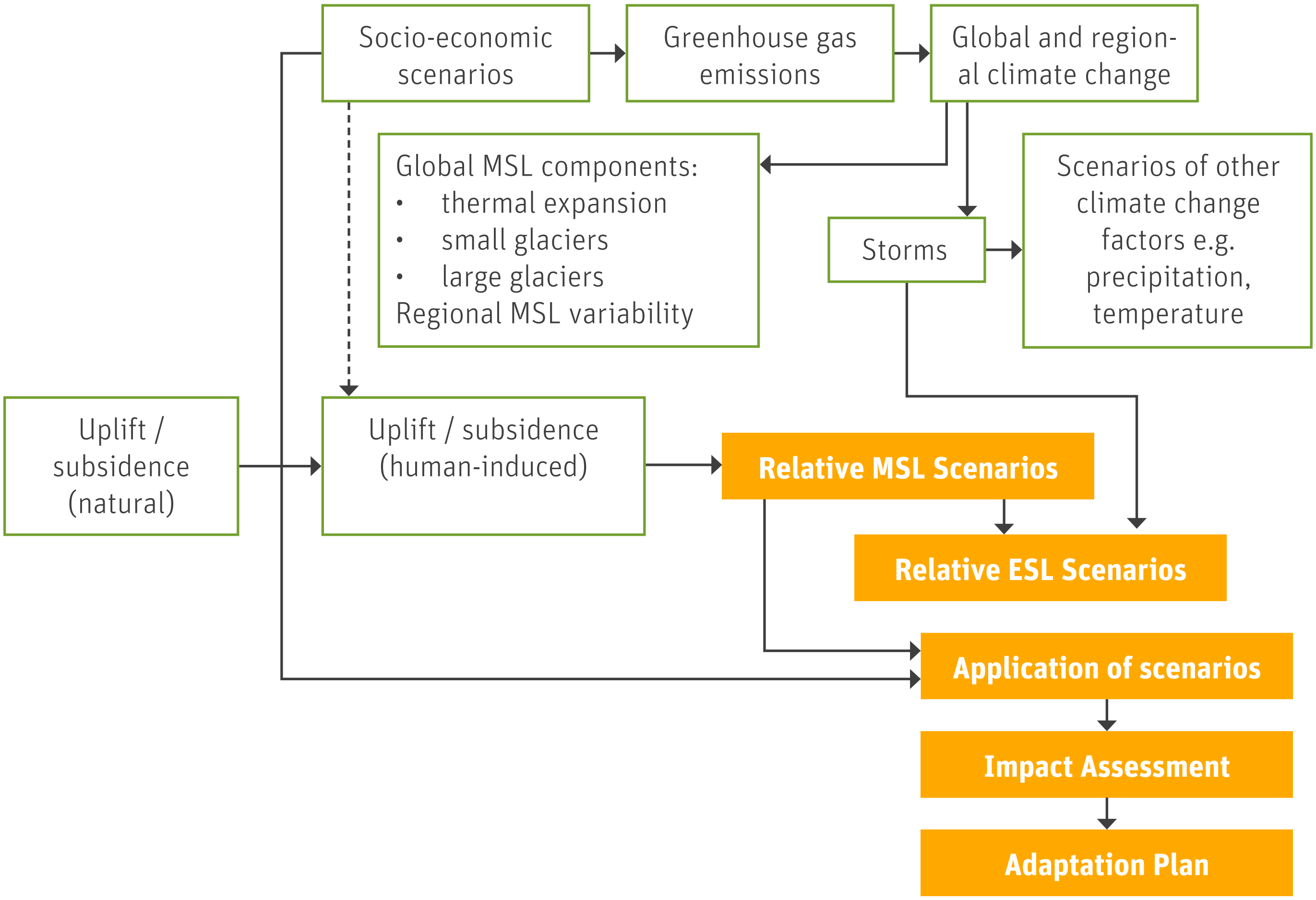
As Trinidad is located in the southernmost margin of the Atlantic hurricane belt occurrences of tropical storms and cyclones are rare compared to other parts of the Caribbean, and occurrences tend to be less severe as illustrated in Figure 14 (page 5) and Figure 15 (page 5). In (page 6) storm surge levels associated with the different cyclone categories Saffir-Simpson Hurricane Scale have been indicated. Based on the history of cyclone events in Trinidad it appears that storm surges are unlikely to exceed 3 m corresponding to a category 3 cyclone (Table 12, page 6 and Table 13, page 7). More dependable assessments of likely storm surges in Trinidad would, however, require a cyclone study, where local conditions can be duly taken into account.

5 Sea Level Rise Impacts on the Water Sector in Trinidad and Tobago

5.1 General Development and Climate change Aspects

The standard approach to climate change impact assessments may be described as top-down because it starts with long term global socio-economic and greenhouse gas emission scenarios, that drives the climate models, which are subsequently downscaled from global to the local scale. Through a series of analytical steps the resulting changed local climate parameters are taken through biophysical impacts towards local socio-economic impact assessment. As part of this framework it is necessary to determine *relative* sea-level change which is composed of the sum of global, regional and local trends related to changing oceans and land levels (see Section 3.1). These components and their drivers are commonly linked within an impact assessment as illustrated in Figure 51.

Figure 5.1 Summary of a methodology commonly applied for developing sea-level scenarios for impact assessment and adaptation planning. MSL – mean sea level; ESL – extreme sea level (Source: Ref. 31).



Section 4 on Projected Sea Level Rise provided a more detailed discussion of relative sea levels and it was recommended that a central estimate of 1.25 m and a high estimate of 2.15 m relative sea level rise by 2100 be applied in Trinidad for this case study. In the discussions it was further assessed that storm surges exceeding 2 m corresponding to a category 2 cyclone was unlikely to occur, although a more comprehensive cyclone study is required to substantiate this.

The development over time in relative sea level is gradual with more pronounced levels in the last part of the period following a quadratic function. Adaptation measures related to projects and plans therefore have to be developed carefully considering the lifetimes of investments against progress in sea level rise and magnitude and frequency of severe planning events.

As also discussed in Section 3 there is a considerable development pressure on land, water and other resources in the coastal areas of Trinidad, which over time has created serious management issues that needs to address, including degradation of wetlands, salinization of aquifers, erosion, flooding and more. It is important to realise that sea level rise is only one of several challenges to be dealt with in the land use and resource planning of the country. Hence, the sea level rise and its implications can probably not be solved in insolation. Given the high population and development pressure and the complexity of the coastal environments more integrated and coordinated approaches to development management are required for the coastal areas. It is essential that climate change adaptation be mainstreamed into such management and important adaptation measures identified for addressing impacts of sea level rise is therefore to engage in shoreline management planning (SMP), integrated coastal zone management (ICZM) that accounts for the linkages between the coastal areas and the catchment and integrated water resources management (IWRM).

5.2 Impacts on Storm Drainage and Flooding in Port of Spain

5.2.1 General on storm drainage and flooding in Port of Spain

Flooding occurs frequently in the City of Port of Spain, particularly in the low-lying zones between the Maraval River on the West and St. Anne River in the East.

The flooding is the result of a number of factors (Ref. 38), such as:

Intensive urban developments and removal of vegetation of the hillsides north of Port of Spain, causing increased volumes of surface waters and faster runoff concentration (i.e. short term steep peaks).

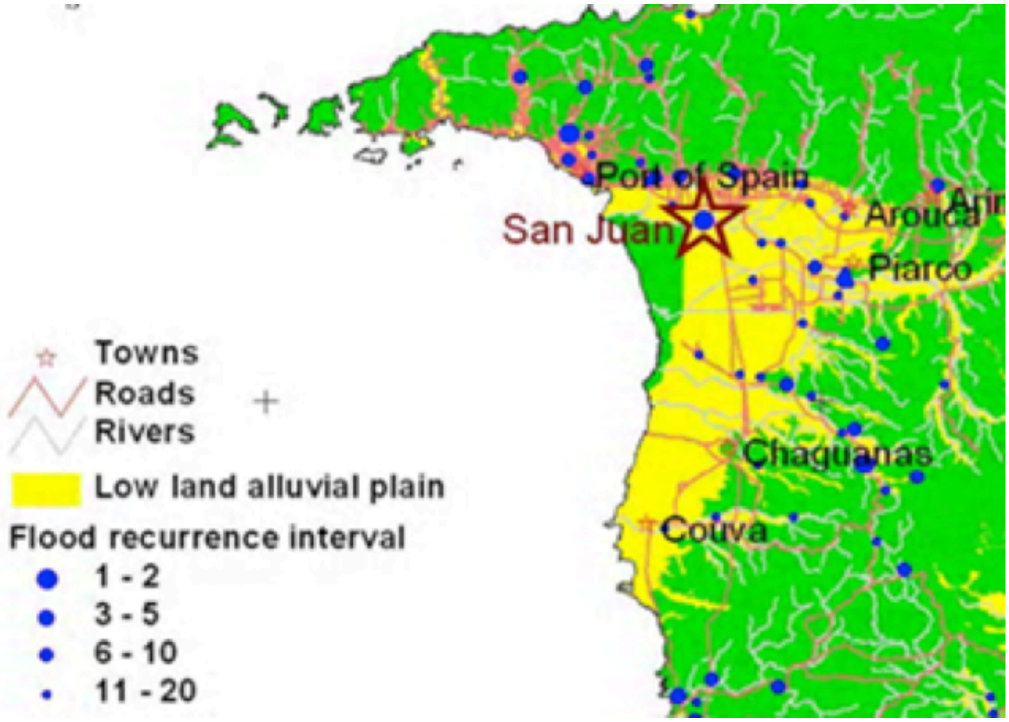
Inadequate drainage infrastructure: The present drainage infrastructure was built in the 1960s. Since then, there has not been any systematic reengineering of the system, except patchwork repairs and ad-hoc efforts of keeping deteriorating drains in operation. Under extreme conditions, the system now carries volumes, which it was never designed for.

Increased erosion in the upstream catchments and sediment deposition in the lower segments of river channels, and drains and the accumulated solid waste and in absence of regular maintenance reduces the rivers' and drains' effective hydraulic conveyance.

Occurrences of heavy rain storms and high tides aggravate the flooding situation.

Figure 52 below shows the major flood locations in the Greater Port of Spain area. (Refs. 32, 33).

Figure 5.2 Flood locations in the greater Port of Spain Area. The size of the blue dots is a measure of the frequency of flooding. Based on flood occurrences over 20 years, between 1986 and 2006. Flood occurrences 10 - 13, 4 - 9, 2 - 3 and 1 times were categorized into 1 - 2, 3 - 5, 6 - 10 and 11 - 20 flood recurrent interval classes respectively. Capture from Figure 3 3 (page 19).



Flooding occurs at locations where the channel gradients change abruptly, typically where old land meets reclaimed land. In the downtown area, known flooding locations include Wrightson Road, South Quay, Henry Street and the Brian Lara Promenade. The flooding occurs after short and intensive rainfall and usually recedes after about an hour, which indicates that the overall cause of the flooding is related to insufficient storm water evacuation capacity into the sea from the area.

As a consequence of serious underground erosion and dysfunctional drains during heavy storms, dangerous sink-holes have opened at several locations, endangering human lives causing serious traffic disruptions and losses (see Figure 54).

The rivers in Port of Spain do not have a record of frequent floods. There is, however, historical evidence that the East Dry River did cause a flooding, presumably due to clogged river channel by deposits of sediments and solid waste.

Figure 5.3 Flooding in downtown Port of Spain, with surcharging storm water drains during a heavy downpour.

Figure 5.4 A massive sink-hole on Beetham Highway (Port of Spain) caused by underground erosion due to dysfunctional storm drainage.

5.2.2 Solutions to the storm drainage problems in Port of Spain

Recently, after repeated flooding incidents, a project has been initiated, under the title "The Port of Spain Flood Alleviation Project". This project, with the principal objective to mitigate flooding in the capital city, includes nine packages, and represents the materialization of the promises that the flooding problems will be solved (Ref. 37 and Ref. 41).

Figure 5.5 Temporary detention pond on South Quay, result of the on-going project "The Port of Spain Flood Alleviation Project"

These on-going activities are being criticized (e.g. Ref. 40) for lacking the holistic approach to this complex situation. Piecemeal solutions as those currently pursued will certainly mitigate actual local problems, but will fail to provide long-term sustainable solution.

An inspiration for the solution is sought in the last known comprehensive attempt to solve the storm drainage problems in Port of Spain, which dates more than 30 years back. It was a study performed in 1981, known as Dr. Millette's report, whose validity for the solution of the drainage problems has not been disputed, and which is repeatedly brought into discussions among stakeholders as an example of a good approach to this complex problem (Ref. 39).

Now, more than 30 years later, the report can probably be used as an outset for a new comprehensive study, based on the actual situation, the present state-of-the-art analytical tools and the knowledge on possible climate change impacts.

Dr. Millette's study has recorded the existing state (i.e. of 1981) of the individual drainage systems in the city and outlined the solutions for the identified deficiencies. Among others, the downstream areas of the city were identified as the problematic areas for flooding.

As the probable main causes of flooding, the study included the dumping of debris, sediment, illegal raw sewage connections made into the storm water system, the restriction of new open drainage channels under entrances at some new developments and the inadequate pipe size and drain inlets from the slippers.

The report suggested several possible solutions for alleviating the problem, including:

- Cleaning the silt deposits from the existing system, that were present in significant amounts;
- Introducing measures aimed at preventing the silting of drains;
- Improving the solid waste management system, aiming at reducing the likelihood of blockage by debris;
- Incorporating a parallel relief drain for excess flows;
- Installation of a new trunk collector, possibly linking more than one catchment area, taking excess flows to a different discharge point;
- Active usage of existing storage and introducing additional storage for excess flows.

Further, the report recommended installation of pumping stations incorporating various degrees of storage, near Murray Street, Charles Street, South Quay east of the St Ann's River, South Quay/Beetham Highway and Independence Square.

The St Ann's and Maraval rivers – two major river systems which flow through the Port of Spain area, were also identified as objects for essential improvement, through a series of specific actions.

5.2.3 Sea level rise contribution to the flooding problem

The factors responsible for flooding, listed above and elaborated in the Dr. Millette's study, at present by far surpass the importance of gradual sea level rise, and immediate remediation of the acute flooding problem should be based on addressing these factors.

In a long-term perspective, however, the sea level rise will impact on storm water drainage from Port of Spain and act as an additional complicating factor. A forecasted increase of the sea level of up to 1.25 m (central estimate) by the end of the 21st century will significantly change hydraulic condition in the lower reaches of the Port of Spain's urban rivers and in low parts of the storm drainage network. As the scale and significance of this impact is unknown, it has to be taken into account when studying the remediation efforts.

The findings of the Dr. Millette's study have confirmed that, in addition to the inadequate structural and functional conditions of the drainage system and the growing load pressures, even back in 1981, a part of flooding problem in the downtown Port of Spain could be attributed to the storm water evacuation conditions into the sea. The solution proposed was an augmentation of the gravitational capacity and the introduction of pumping stations.

This issue is equally important today and is likely to play an even more important role in future. Future average sea levels, increased possibly by 1.25 m, will fundamentally change possibilities for gravitational evacuation of storm water, potentially reducing the drainage efficiency in the critical areas.

Therefore, any new study of the storm water drainage system in Port of Spain must take the impact of sea level rise seriously. An example of the application of this methodology for the City of Montevideo is given in Ref. 47.

In conclusion, sea level rise is an unavoidable issue which must be included in the study of storm water drainage problems in Port of Spain.

5.3 Aquifer Salinization

The water supply in Trinidad is to a large extent based on groundwater and the national water resource authorities are concerned about the potential impact from future sea level rise related to climate change.

Hydrogeological data on some of the most important Coastal aquifers (Port of Spain Gravels and Northern Gravels) have been received from WASA and this chapter focuses on these locations. The data are in the form of hydrogeological maps, well field locations interpolated transects of the aquifers time series of draw down at various boreholes and some water quality measurements. Furthermore, older reports of the saline intrusion (ref. 45) and overall description of the aquifer systems (ref. 46) have been received. The data were received at a late stage of the report preparation and although such data, when supplemented with further hydrological and hydrogeological information, can be used to establish detailed hydrogeological models of the aquifers, such modelling is out of the scope of the present study, which has to be limited to a more overall assessment of the problem.

The Port of Spain Gravels and Northern Gravels Aquifers, being the main aquifers for the water supply of Port of Spain, are both located in deep sediment deposits intersected by more or less horizontal clay lenses of lower permeability. Both aquifers seem to be in direct contact with the sea water along the shore line and probably also off shore (see transects in Appendix B)

General aspects of sea water intrusion in aquifers with ground water exploitation but without consideration of sea level rise are summarised in Textbox A below. In cases, where the sea constitute the downstream pressure boundary of a *natural undisturbed* profound aquifer, a rise in the mean sea level would normally lead to a rise in the ground water levels of the same magnitude as the sea level rise. Such cases are not likely to lead to significant salinity intrusion. However, in both of the considered aquifers large scale pumping has lowered the water table to levels very close to or under the present mean sea level. The drawdown may have been aggravated by land use changes in the contributing watersheds e.g. in the form of urbanisation leading to decrease in aquifer recharge rates (Ref. 30). The aquifers can therefore not be considered undisturbed.

Contamination by salt water intrusion has already been experienced in the groundwater systems of both the Northwest Peninsula Gravels (Port of Spain/Cocorite), the Northern Gravels (El Socorro) where significant pumping takes place close to the sea and also in the Mayaro Sandstone (East Coast of Trinidad). The Port of Spain Gravels has a steeply formed salt-water wedge and salinity intrusion has been found to be by horizontal “in-coning” rather than vertical “up-coning” (Ref. 45). The salinity levels close to the sea respond quickly to any variation in abstraction rates. Furthermore, wells pumping from depth of 30-100m are found generally to have lower salinity levels than those pumping from the upper 10-20 m.

In the Northwest Peninsula Gravels (Port of Spain/Cocorite) and in the Northern Gravels (El Socorro) significant pumping takes place close to the sea and the ground water levels are monitored (Figure 32) and controlled to reduce salinity intrusion, which, as mentioned, have previously been a problem in some of the wells (See Table 32).

If groundwater levels are maintained at today’s level in a situation with higher mean sea level, the salinity intrusion is likely to increase, since the gradient between the sea and the nearest boreholes will steepen. In principle this could be prevented by allowing the groundwater levels to rise at the same pace as the mean sea level. Assuming that the aquifer recharge would be unchanged in the future this should be possible by maintaining todays pumping rates. Two factors may, however, make such a scenario problematic:

a) The groundwater levels are already at present very close to the surface in the coastal areas of Port of Spain (see Appendix B). Further rise in groundwater levels could lead to structural problems for low lying infrastructure such as roads or buildings with poor foundations. It may be, however, that the lowest terrain levels of the reclaimed land will have to be increased anyway to prevent flooding from the increased sea levels.

b) With projected decreases in the annual rainfall in Port of Spain by 14% in 2050 and by 21% in 2100 (see Appendix A) in combination with increases in potential evaporation of 5% (2050) and 8% (2100), the recharge rates to the aquifers is likely to decrease in the future, if all other factors (catchment permeability and land cover etc.) are unchanged. Therefore the present pumping rates are not likely to be sustainable without introduction of additional measures to combat aquifer salinization.

Text Box A: Salinity Intrusion into Aquifers, General Aspects

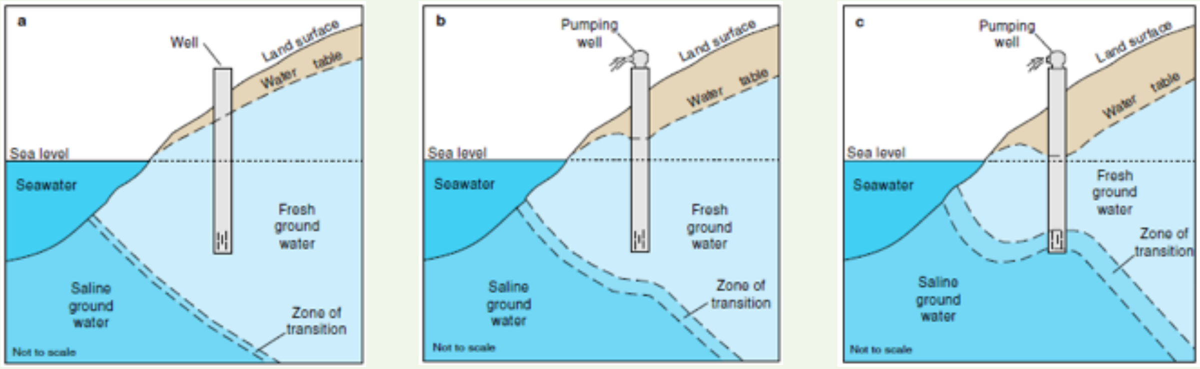
In natural coastal aquifers the higher groundwater levels on the land side originating from the aquifer recharge, maintains an equilibrium interface to the heavier saline groundwater under the sea. Pumping out fresh ground water reduces the weight of the overlying freshwater, which in turn can decrease or even reverse the seaward flow so that seawater moves landward into the freshwater aquifer. This migration of seawater into the freshwater aquifer is known as seawater intrusion.

The interface between the salty ground water below and fresh ground water above is a transition zone () of gradually mixing fresh and salt waters. Under natural, undeveloped conditions, the location of this zone will move slightly as the tide rises or falls and as recharge fluctuates seasonally. Likewise this zone and the freshwater zone will move upwards with increasing sea levels, which may eventually cause the fresh groundwater to surface and thus lead to flooding of low lying areas, and limit the possible groundwater level above sea level (h), which in turn may lead the interface to move further inland.

However, when a well pumps fresh ground water from near the transition zone, the equilibrium can be disturbed and the ground-water flow pattern changed (Figure a below). As water is pumped out of the water-bearing zone, the transition zone moves upward towards the well (Figure b below). Prolonged or large-scale pumping can raise the transition zone to the well, which may then draw in salty water (figure c below).

The location of the transition zone depends on several natural and human-made conditions: the relative densities of seawater and freshwater; the tides; the pumping from wells; the rate of ground-water recharge; sea level rise; and the hydraulic characteristics of the aquifer. Because these conditions vary locally, the depth to the transition zone below sea level differs from one place to another.

and patterns of land uses in upstream catchments may be of even greater importance due to their potential impact on aquifer recharge.



Non-pumping well in an unconfined aquifer under conditions of equilibrium – no intrusion has occurred

Well pumping from an unconfined aquifer – sea water intrusion not affect-ing salinity of pumped water

Well pumping from an un-confined aquifer – sea water intrusion affecting sa-linity of pumped water

Future changes in climate, e.g. precipitation, temperature and sea level, are expected to affect negatively the quantity and quality of the groundwater resources. However, the hydrogeological behaviour of the aquifers is complex and it will only be possible to make reliable quantitative assessments of such impacts by application of detailed integrated hydrological and groundwater models. Such models are normally used to evaluate the consequences of climate changes and may be used to investigate the effects of various adaptation measures such as the ones proposed in Section 1 below. It is therefore highly recommended to initiate such modelling for the Port of Spain and Northern Gravel aquifers.

In order to support both the modelling and the future management of the aquifer it is highly recommended that the coastal groundwater aquifers are carefully and continuously monitored with respect to: Pumping rates, water quality, ground water levels and sea water level.

5.4 Inundation Impacts

The inundation impacts of various sea level rise scenarios have been illustrated in Figure 57 below based on a GIS analysis using a course 90 m Digital Elevation Model (DEM). The calculated impacted areas have been listed in Table 51.

Table 5.1 Areas of Trinidad located below certain contour levels (Hypsometric Table). The table thus provides an indication of the % of land that would be inundation at various sea level rises.

Contour	Area below contour	
(m.a.s.l.)	(km^2)	(% of total area)
1	18.1	0.4
2	42.2	0.8
3	78.2	1.5
4	118.8	2.3
5	164.3	3.2
7	262.6	5.1
10	417.0	8.1
25	1239.3	24.2
50	2669.6	52.1
100	3919.0	76.5
250	4617.8	90.1
500	5003.2	97.6
750	5105.3	99.6
1000	5125.5	100.0
Total island	**5125.7**	**100.0**

The 1m and 2m scenario result in relatively little impact in terms of area as compared to Trinidad's overall area. The use of the coarse elevation model may, however, underestimate these areas, (see Section 1). More importantly, many of these areas are intensively populated and heavily developed and considerable investments and livelihoods may therefore be at risk if they are affected. The 3m and 5m scenarios provide an indication of the possible impact of sea level rise combined with storm surges, but also indicate areas that to some extent may be subjected to drainage congestion in case of raised sea levels. The 10 m scenario is considered an upper (improbable) limit of areas that could be affected by a severe sea level rise and storm surge event. It can be seen that considerable areas are at risk. Even though storm surge scenarios are only with short duration, as storm surges will recede, the livelihood and economic implications associated with such flooding may be considerably.

Sea level rise will increase the risk for coastal flooding of low lying coastal areas through the rise of extreme storm surge levels. The sea level rise in itself will normally not cause disastrous flooding, However, the rising sea levels may very well lead to serious drainage congestion in low lying areas presently inhabited or in use for agricultural activities. This could very well become a serious problem for the agricultural areas around Debe in the south and around Cocos Bay.

Furthermore, the raised sea level will increase the extreme water levels caused by storm surges, or in other words, the sea level rise will decrease the recurrence interval of storm surge events, see Figure 56. The example show a rise in the sea level of 50 cm along the Danish Wadden Sea coast decreases the recurrence period from 100 years to 20 years for flooding of a dike, which is designed for a water level of 340 cm. The shift in recurrence period is dependent of the slope of the extreme water level exceedance curve, and a flatter slope will introduce even more drastic reductions in the recurrence period for design events. This is evident from the example from Sri Lanka in Figure B-1, where a 50-cm rise in sea level introduces a decrease in the recurrence period from 100 years to less than 2 years for exceedance of the water level 150 cm (Ref. 14).

Lack of statistical information about extreme water levels in Trinidad has prevented illustrating the impact of sea level rise on recurrences of extreme water levels.

As mentioned in Section 3 the Petroleum Company of Trinidad and Tobago (PETROTRIN) in 2006 assessed the vulnerability of its oil and gas facilities to climate driven sea level rise and storm surges, focusing on the coast stretching from Vessigny River in the North to Cap-de-Ville in the South. Based on sea level rise projections from AOGCMs and surge estimates the study used a digital elevation model to assess land losses and infrastructure facilities at risk for inundation and erosion. The study based its assessments on simulated sea level rise by 2071 between 25 and 51 cm and superimposed storm surges of 2 and 5 m respectively. The results predicted moderate to severe land losses threatening existing installations and infrastructure. Furthermore most offshore well platforms would experience inundation during storm surges and furthermore be at risk from wind and wave impact (Ref.: 16).

Minimum recommendations given by the study amongst others included that retrofitting and/or design of installations and infrastructure in areas at risk should accommodate a one and half metre rise in sea level and storm surges up to 5 metres as well as the erosion of the coastline associated with such sea level rise and extreme weather conditions. It was found highly advisable to develop a coastal zone management plan, integrating the various land uses to accommodate climate change and sea level rise (Ref.: 16).

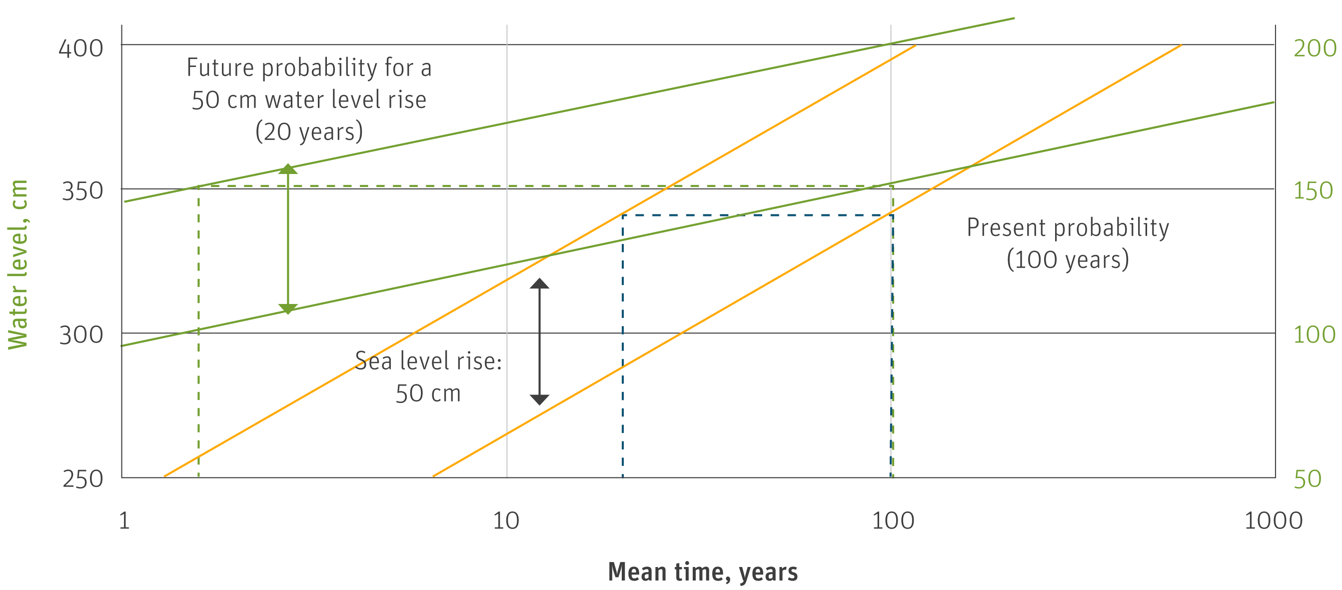
As discussed in Section 4 newer prediction suggest higher sea level rises than the ones used in the study. On the other hand the storm surges applied are associated with cyclone strengths beyond the levels experienced in the Trinidad area. While underpinning the need to develop a better information base for vulnerability assessments, the scenarios used by the study combining sea level rise and storm surge are at levels comparable to the ones discussed above.

Addressing vulnerability to inundation from sea level rise in Trinidad requires:

- The construction and updating of more precise digital elevation models generally for the country and more urgently in low lying coastal areas under population and economic development pressure.
- Continuous attention to the predictions of global sea level rise while seeking a better quantification of the local contribution to sea level rise from tectonic and subsidence processes along the coastal areas.
- Better storm surge assessments for the country based on cyclone study.

Meeting these requirements will enable the more precise identification of areas along the coast vulnerable to inundation from general sea level rise and during extreme flooding events that is required to assess the risks for people and investments and to take decisions on measures to take to address these risks. As sea level rise is a gradual process the risk pattern change with time and decisions on adaptation measures needs to be taken in short, medium and longer term perspective.

Figure 5.6 Example of extreme water level analysis, flooding levels vs. recurrence interval in years for the Danish Wadden Sea Coast and for Sri Lanka. The influence of a 0.50-m rise in sea level is shown.



Orange y **blue**: Example from Denmark (100 years to 20 years)
Green: Example from Sri Lanka (100 years to 2 years)

There are basically three adaptation directions or pathways that can be considered separately or in combination (Ref.: 23):

Protect areas at risk from sea level rise. This implies defending vulnerable areas, including population centres, economic activities and natural resources

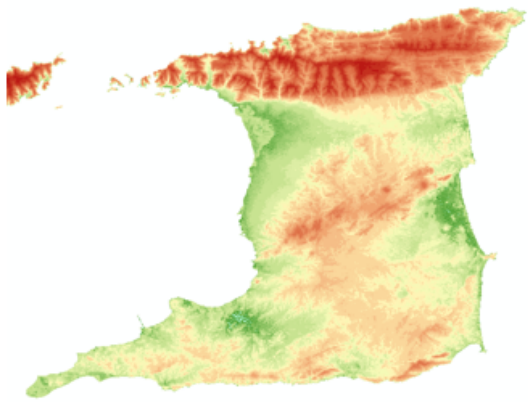
Accommodate to the impacts of sea level rise. This implies a continuation of occupying vulnerable areas accepting degree and frequency of flooding and responding by changing land uses, construction methods and improving preparedness and responses to extreme events.

Retreat. The planned abandonment of developed areas and relocation to areas, that are not vulnerable to sea level rise.

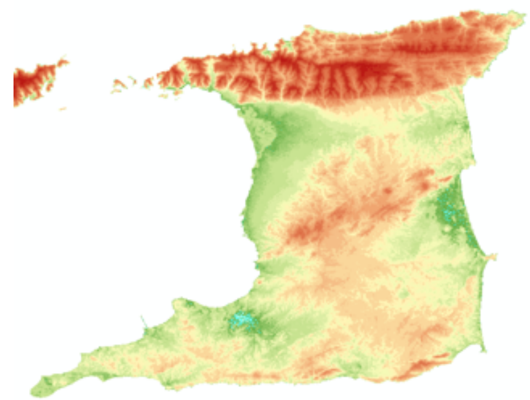
Pathways 1 and 2 can be considered reactive and as such are often taken when applying measures in a shorter and medium term perspective. Such measures may well turn out costly in a longer perspective where pathway 3 would be more cost effective. Finding a suitable strategy for balancing adaptation measures between these pathways rely on the mainstreaming of climate change and indeed sea level rise into planning systems. As discussed in Section 5.1 above traditional sector planning has proven inadequate to address the special challenges in managing the development in the complex coastal areas and it is recognised in Trinidad and elsewhere that more holistic and integrated approaches to development planning is required as for example offered in ICZM and IWRM approaches. The spatial planning dimension plays a key role and physical planning therefore becomes an important element in management reform processes. Vulnerabilities related to inundation should be integrated as an important theme in spatial analyses for land use planning. It is important that such analyses take due consideration to the changes in risk patterns linked to gradual sea level rise.

The Ministry of Planning and the Economy in Trinidad and Tobago is preparing for a new National Physical Development Plan (NPDP) as the current plan form the mid-1970s is no longer considered a relevant articulation of the country's development direction. Part of the new planning framework will be a National Spatial Development Strategy which shall enunciate the spatial dimensions of major land uses, national and sectoral goals, give strategic guidance on the arrangements of major infrastructure and the location of major facilities, and will articulate the national urban development strategy (Ref.: 50). The spatial development plan and the guiding spatial development plan are crucial entry points for mainstreaming climate change adaptation measures into national planning.

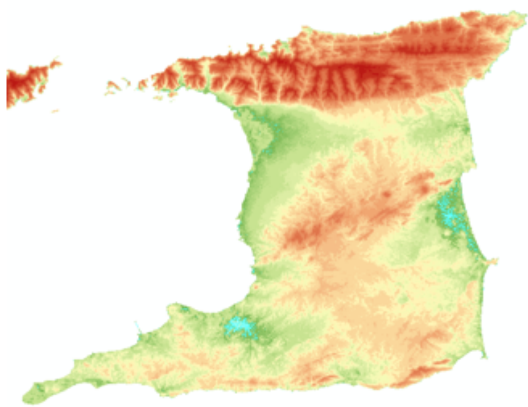
Figure 5.7 Visualisation of different SLR scenarios based on 90 m DEM for Trinidad. The higher SLR (3m, 4m, 5m and 10m) scenarios are not realistic. They have however been included to illustrate the potential combined impact of SLR and storm surges. Please refer to appendix 1 for higher resolution maps.



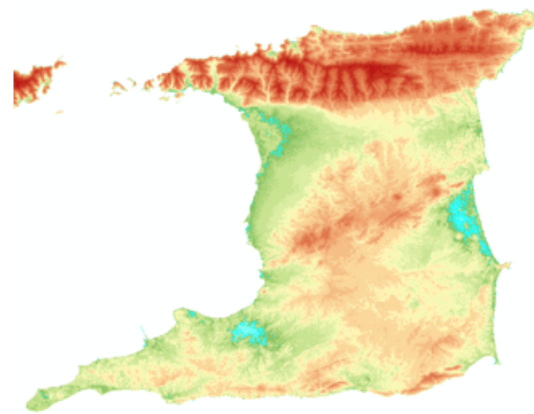
Trinidad present 90 m DEM



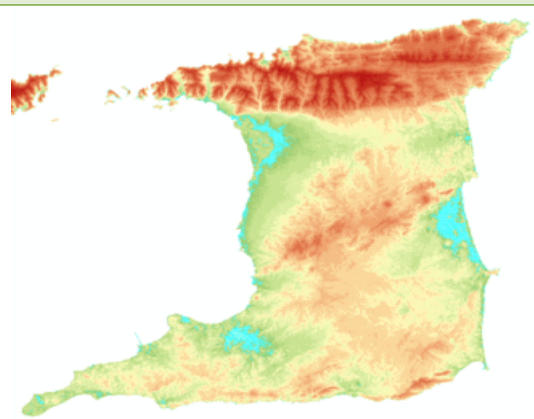
Trinidad 1m SLR



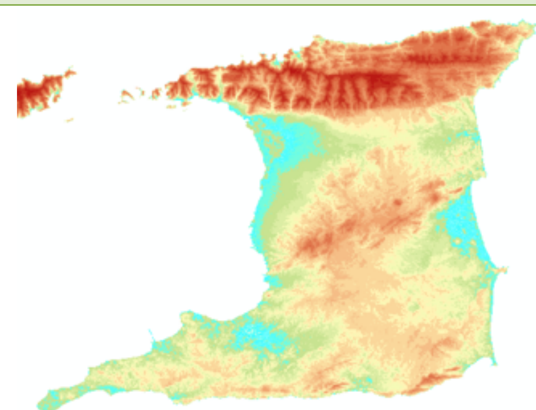
Trinidad 2m SLR



Trinidad 3m SLR



Trinidad 5m SLR



Trinidad 10m SLR

5.5 Impacts on Shorelines – Erosion

Shoreline erosion and accretion are natural processes shaping coastlines where land meets the sea. Influencing factors include winds, waves, currents, tides, storm and surge conditions, sea level rise, land subsidence and sediment supply from rivers. Anthropogenic interference with underlying processes may significantly alter the rates of accretion or sedimentation. This could be through land use changes in catchments, which may impact on sedimentation processes that play a role in shoreline morphology. It may also alter the hydrological regime which can impact on erosion/accretion patterns along the sea adjacent to estuaries. Interference with the shoreline itself by infrastructure development can also influence erosion and accretion long distances along the coast.

Impacts of sea level rise on shoreline retreat is often assessed using the Bruun rule which gives a relation between the relative sea level rise, the slope of the shoreline and the retreat (Text Box B below). Where beaches have gentle slopes coastal retreats caused by a relative sea level rise of 1 m can be up to 100 to 200 metres.

Studies of beach profiles monitored around Trinidad (1990-2001) have shown that severe coastal erosion is taking place at several locations especially at Icacos-Corral Point, Quinam and Cocos South with average retreat rates of 1 – 2 meters per year (ref. 52). The Institute of Marine Affairs has since then systematically monitored beach profiles at several locations and is expected to provide further details on shoreline retreat rates in reporting currently taking place. The present case study has not had access to this material.

The study commissioned by the Petroleum Company of Trinidad and Tobago in 2006 used the Bruun rule in vulnerability assessments to sea level rises and storm surges on the west coast of Trinidad and found that considerable areas would be lost to erosion.

To determine appropriate management responses to erosion requires an analysis of actual and potential shoreline erosion against planned and existing development activities at the coast. It is recommended to undertake a systematic shoreline management planning process in Trinidad to produce appropriate policies and strategies for adaptation to coastal erosion.

A Shoreline Management Plan normally covers an area along the coast described as a sediment cell. A sediment cell is a section of the coastline in which the physical processes are relatively independent from processes operating in adjacent sediment cells. The boundary of a sediment cell generally coincides with larger estuaries or prominent headlands.

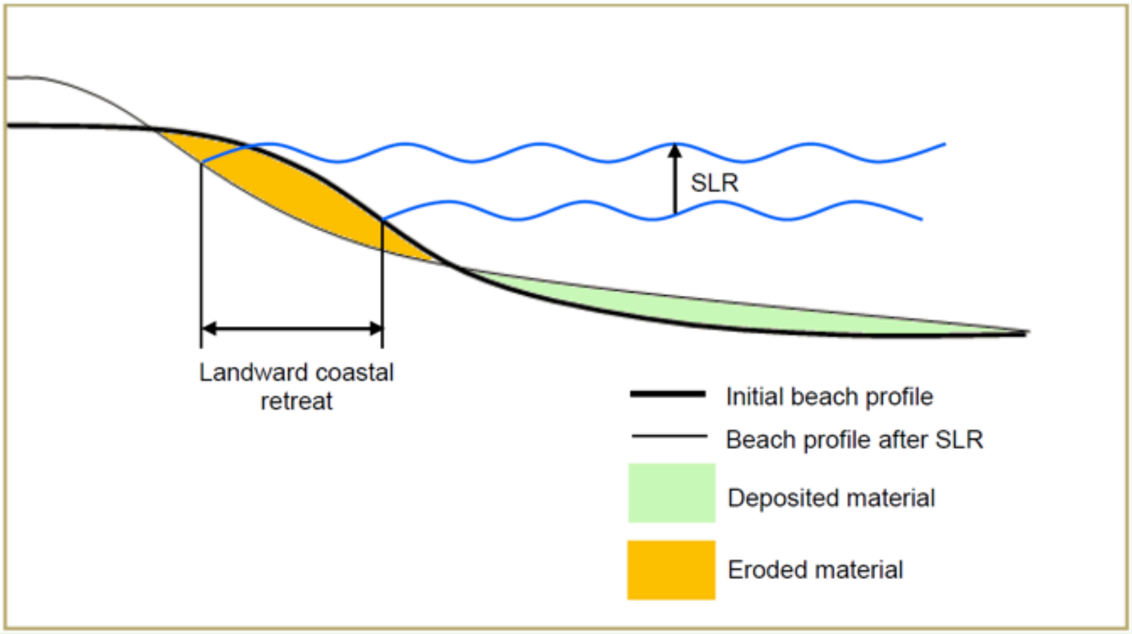
A detailed discussion on shoreline management planning is provided in Appendix C which also contains an outline of the content of a Shoreline Management Plan.

Text Box B: Shoreline Retreat due to Sea Level Rise – The Bruun Rule

Erosion is a process where sediment is moved away from the coast due to wave and current actions. Sea level rise will promote the offshore transport of sediment.

A model widely applied to describe the shoreline retreat caused by sea level rise was offered by Bruun in 1962. Depending on the slope of a beach profile the "Bruun Rule" suggests a retreat of 50 to 100 times the rise in relative sea level and is due to the beach's desire to maintain an equilibrium beach profile. As illustrated in the equilibrium beach profile is maintained through the removal of sediment from the shoreline which is subsequently deposited offshore (Ref. 23).

Figure 5.8 Simplified model of landward coastal retreat under SLR (based on the Bruun Rule). Source: (Ref. 23)



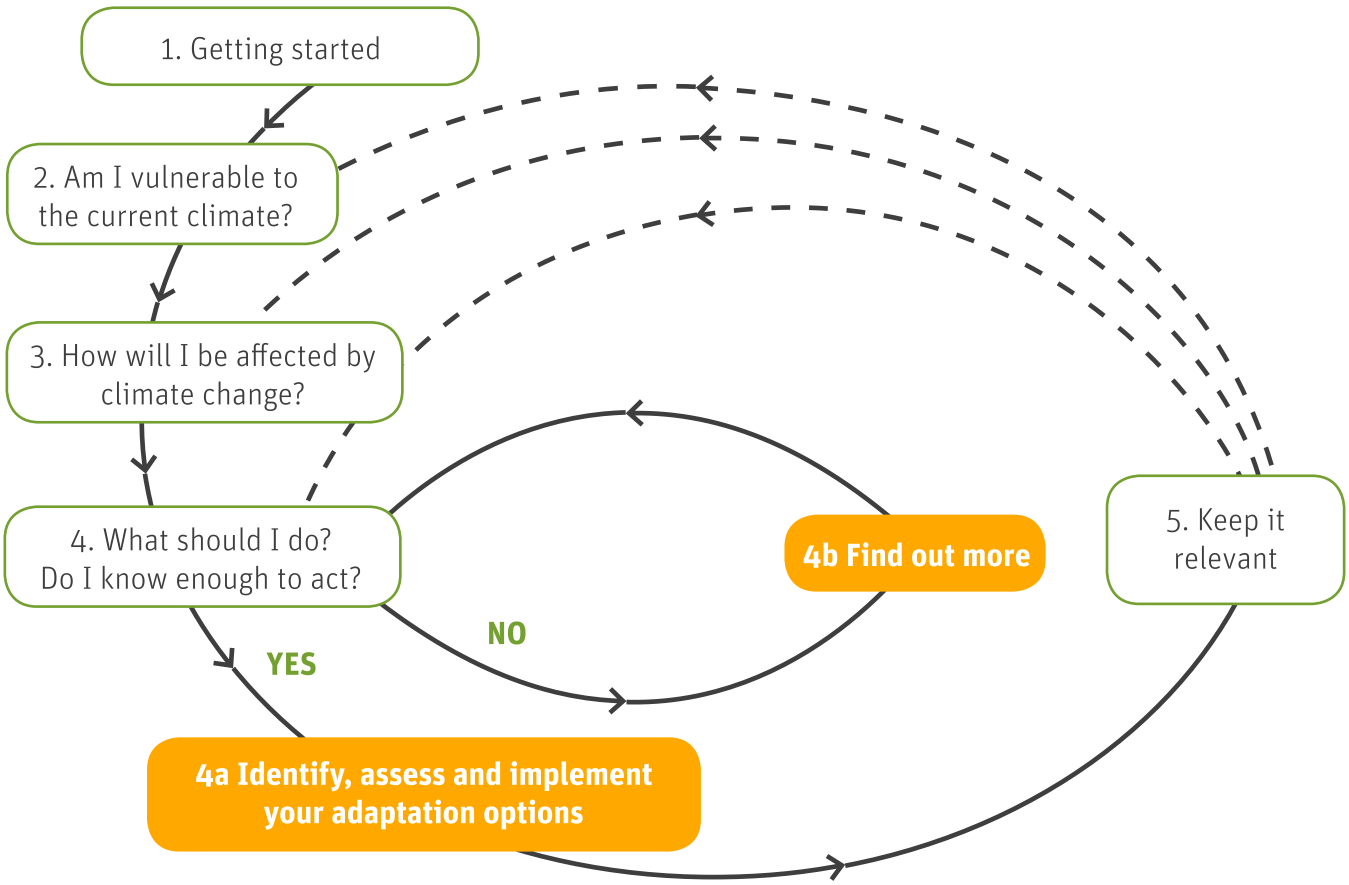
A sandy beach with a slope of the active coastal profile of s (typically s = 1/50 to 1/100) exposed to sea level rise of h_{SLR} will experience a shoreline retreat $R = \frac{h_{SLR}}{s}$ (Bruun Rule). Thus, a coastal profile with a slope $s = \frac{1}{100}$ exposed to a sea level rise of 1 m will experience a shoreline retreat of 100 m.

6 The Adaptation Process

Measures for adaptation to climate induced changes in water resources flooding/drainage or coastal protection issues will in nature not differ from those already known from dealing with historical Climate variations. But climate change challenges will be over layered all other uncertainties. On the other hand designing for climate change can often not be done by using the historical records of rainfall and runoff since the changing climate may be associated with more intensive rain events or with changed catchment responses to rainfall. Hence, it will normally not be sufficient to base one's planning on historical records alone.

The UK Climate Impact Program suggests a stepwise yet cyclic approach to adaptation planning as indicated in Figure 61. To avoid stalling of the process it is important at an early stage to identify win-win and no-regret scenarios i.e. scenarios that will benefit the system in other ways than just climate adaptation and scenarios that would be beneficial independently of how the climate actually will develop. Therefore, the adaptation measures outlined below will focus on studies aiming at reducing uncertainty, win-win scenarios and no-regret measures.

Figure 6.1 The UKCIP Adaptation Wizard v 2.0. UKCIP, Oxford (Ref. 7).



6.1 Adaptation Measures

General measures to adapt to raising sea levels have been identified with regard to improving decision support and with regard to planning and reform processes.

With respect to the four areas of concern addressed in this case study adaptation measures of particular relevance have been listed for each under separate headings below. Some of these are overall measures already discussed under general measures.

6.1.1 General Measures

Decision Support

Development management decisions in complex settings such as is the case in Trinidad's coastal zone need to be based on a solid information base that enables analyses across many dimensions, including socioeconomic, economic, natural resources, land uses, and indeed climate. Climate change adaptation measures in general and in this case measures to adapt to sea level rise must be defined based on analyses spanning these dimensions. A crucial adaptation measure is therefore to ensure that a solid information base is continually available as decision support for planning, that systematic monitoring is carried out to maintain the information base updated and that mechanisms are in place that ensures shared access to information and systematic dissemination of information on the management situation through state reporting:

- Information Management System (IMS)
- Monitoring satisfying the requirements of the IMS
- State Reporting/Information Sharing

Important themes for decision support vis-à-vis sea level rise are vulnerability and risk mapping related to erosion and inundation.

Planning

Traditional sector planning has fallen short in coping with the complex development situation in the coastal areas, which has contributed to unsustainable land uses, and it is recognised that more integrated approaches are required for development management. Such approaches have matured internationally over the past decades and are increasingly embraced by the international community and considered particularly suited to address the challenges of addressing climate change.

- Integrated Coastal Zone Management
- Integrated Water Resources Management

There is a particular requirement to address the dynamic environment where land meets the sea, not the least in a situation where sea level rise exert pressure to move this area land wards. A systematic study of the shoreline and the forces that shape it is required to develop policies and strategies for land uses along the shores. Hence an important adaptation measure is to undertake a comprehensive shoreline management study delivering information to be used in land use decision making, i.e. physical planning. Key deliveries include vulnerability and risk mapping to guide land use and contingency planning.

- Shoreline Management Planning

Spatial planning is a powerful instrument to give strategic guidance on the arrangements of major infrastructure and the location of major facilities, and to articulate strategy for urban development. The spatial development plan and the guiding spatial strategy are therefore important entry points for mainstreaming climate change adaptation measures into national planning. In the context of sea level rise, vulnerability and risk mapping vis-à-vis erosion and inundation become significant themes in spatial analyses. Mainstreamed spatial plans needs to be accompanied by directions and or guidelines for environmental impact assessments for development in vulnerable areas ensuring that climate change mitigation measures are incorporated in plan and project design and implementation.

- Land Use (Spatial) Planning

The risk mapping will identify areas where settlements and economic activities remain in vulnerable areas and the shoreline management planning and spatial planning will provide direction and guidance for development in these areas including measures to mitigate the identified risks. An important element in addressing risks will be to establish contingency plans with response strategies for extreme events such as storms and associated surges where protective measures may not prevent direct impact on property and people. Such responses may include early warning systems and strategies for avoidance (shelters, evacuation).

- Contingency Planning

6.1.2 Adaptation Measures to Improve the Drainage of Port of Spain

Full understanding of the flooding in Port of Spain problems at present time and in future, requires a comprehensive approach, similar to the one applied in Dr. Millette's study in 1981. However, this must be modernized through employment of the state-of-the-art analytical tools (digital terrain models (DTMs), satellite and aerial imagery, GIS, dynamic simulation models, etc.) and the incorporation of the climate change impacts, including sea level rise.

Such a comprehensive study, along with urgent remediation of local acute problems, should be the first undertaking of the massive investments in the storm drainage sector, repeatedly announced by the city's political leaders. If properly conducted, the study would secure correct and economically efficient solutions.

An outline of the study could be:

1. Geographical extent: the study should include entire area of contributing urban and rural catchments for natural water courses draining through the city of Port of Spain
2. Hydrological study:
    a) Present and future land use, by compiling information from urban planning documents, satellite and aerial imagery.
    b) Review of the existing system and proposal for the expansion of the hydrometric network (rain gauging stations, local-area rainfall radar, flow meters in the main rivers).

c) Review and analysis of long-term historical rainfall records and rainfall statistics

d) Establishment of a hydrological model of contributing catchments, including calibration against historical observations. If necessary, monitoring campaign should be planned and conducted to provide the necessary set of data.

3. Study of climate change impacts on relevant forcing of the storm water drainage system for the period until year 2100.

e) Analysis of climate change impacts on extreme rainfalls, i.e. increase of peak intensities and frequencies.

f) Analysis of the average sea level rise and storm surge projections.

4. Development of GIS database of natural watercourses and storm drainage infrastructure. The database shall be based on existing databases of watercourses and related drainage infrastructure across Trinidad and Tonago.
5. Development of an integrated simulation model of storm drainage, including contributing catchments, natural water courses, piped and open drains, culverts, ponds, retention basins, pumping station and sea outlets. The model should capture the essential functional elements of the system with sufficient accuracy to make it representative for the actual system functionality.
6. Simulation of various development scenarios under future hydrological and oceanographic conditions, i.e. including anticipated climate change.
7. Identification of the area under flooding risk and development of possible adaptation structural measures, such as detention ponds, new drains, silt traps, trash racks, erosion-control measures, etc. as well as a range of adequate “soft” measures aimed at increased resilience to flooding.
8. Development of a comprehensive long-term solution.
9. Verification of the solution efficiency by the simulation model.

6.1.3 Measure to Prevent Salinization of Coastal Aquifers

The following Measures to prevent salinization of coastal aquifers from rise in sea level have been identified.

1. *Assess present and future capacity of coastal aquifers.* Establish and calibrate detailed and distributed groundwater models with capacity for gravity flow and integrated with distributed physically based hydrological models. The latter should be capable of simulate dynamically both present aquifer recharge and the effects on such recharge for changed rainfall and temperature patterns. Salinity intrusion in the estuaries of the rivers south of Port of Spain will be essential to provide plausible downstream boundaries for the important well-fields in El Socorro.
2. *Assess present and future water demand.*

3. *Analyse Pumping scenarios.* Analyse by means of mathematical modelling various pumping scenarios to prevent or alleviate salinity intrusion e.g.:
   a. Freshwater injection barriers through injection or (deep-well) infiltration of fresh (purified sewage) water near the shoreline. This is already applied in Israel, at Long Island and in Los Angeles;
   b. Extraction of saline and brackish groundwater. Creating an outward gradient in the indland aquifer. This might be combined with desalination of the pumped brakish water;
   c. Modifying pumping practice through reduction of withdrawal rates or adequate relocation of extraction wells;
   d. Increase of (artificial) recharge in upland areas to enlarge the outflow of fresh groundwater through the coastal aquifer;
   e. Consider preventing salinity intrusion in estuaries and wetlands by seawards dikes and pumping or tidal drainage of the river water.
4. *Review and improve monitoring program for coastal aquifers*. Carefull monitoring and storing of piezometric heads, pumping rates and water quality and storing of these numbers for the individual boreholes in a database. Current analysis of the collected data.
5. *Test pumping scenarios*. Test pumping of the most promissing of the strategies under point 2.
6. *Investigate water supply alternatives*. Assess the technical and economic feasibility of using alternative sources of water supply, surface water, rainwater harvesting, desalination. It should be kept in mind that surface water resources may also become more scarce as a qonsequence of Climate Change (ref. Appendix A).
7. *Water demand management*. The unaccounted water seem quite high in Trinidad (44%), by metering and leak fixing significant savings in the raw water supply can often be made.
8. *Prepare water supply Management Plan*. Prepare a plan for sustainable management of the Water supply ot hte city built on a sustainable use of the aquifers and the other water resources. Closely coordinated with other IWRM and ICZM plans for the country.

6.1.4 Measures to Adapt to Inundation of Low Laying Coastal Areas

Addressing the risk of inundation in low lying areas requires spatial analyses based on credible scenarios for relative sea level rise and storm surges on one side and on the other detailed information within various dimensions including topography, meteorology, land and water uses, socio-economy, natural resources, demography and more. The adaptation measures identified in this context are primarily addressing the decision support basis as this is a prerequisite for applying the spatial analyses necessary for determining the vulnerability to inundation in the coastal areas.

The following adaptation measures have been identified:

1. Establish a detailed Digital Elevation Model DEM for the coastal areas. The course DEMs applied in the present case study and in other assessments has only been useful in demonstrating approaches and providing indications of inundation vulnerabilities to sea level rise. More detailed elevation modelling is required filtering out vegetation and higher resolution is necessary differentiate buildings and adjacent surface areas. The required resolution will vary from place depending on natural and manmade topographic features. The DEM should be integrated with spatial planning GIS.
2. Quantification of the contribution to relative sea level rise due to vertical land movements. Efforts to be given to determine the impact of tectonics on vertical land movements at different locations along the coast. Efforts to be given to determine the impact of development activities and human activities on subsidence along the coast.
3. Conduct a cyclone study to assess frequency of tropical storms and cyclones and associated surges. Efforts should be made to establish the history extreme water levels along the country's coastline.
4. Develop assessments of vulnerability to inundation as themes that can interact in spatial analyses supporting spatial development planning.
5. Mainstreaming climate change (including sea level rise) into the National Spatial Development Planning. The National Spatial Development Strategy needs to incorporate vulnerabilities to climate change in general and to sea level rise to ensure that strategic guidance duly incorporates climate change resilience in the arrangements of major infrastructure and the location of major facilities, and in the national urban development strategy.
6. Engage in long term reform processes targeting sustainable climate resilient development through Integrated Coastal and Water Resources Management.

6.1.5 Shoreline Erosion

Addressing erosion along the coast of Trinidad requires a systematic examination of shoreline processes including sea level rise and analysing this against existing and planned land uses in the areas behind the shoreline.

The following adaptation measures have been identified:

1. Map and describe sediment cells and sub-cells along the coastline as basis for determining boundaries for Shoreline Management Planning areas and identify vulnerable areas for detailed shoreline management planning. Further discussion on sediment cell delineation is provided in Appendix C.
2. Vulnerability assessment through Shoreline Management Study and Plan. Identify and quantify erosion/accretion along the coast and translate into management policies and strategies taking projected sea level rise into account. Further details on Shoreline Management Planning are provided in Appendix C.
3. Mainstream shoreline management planning into land use/local planning.

6.2 Screening Matrices

The adaptation measures outlined above have been entered into screening matrices (Table 61, page 55) and subjected to an initial evaluation based on general knowledge and site-specific conditions. This is a qualitative evaluation, where each measure is narratively evaluated against the following criteria:

Win/win[8]. Does the adaptation measure have positive impact on other management challenges or opportunities?

Regret/No Regret[9]. Is the adaptation measure beneficial without climate change impact? The present case is focusing on sea level rise which is a climate change impact that is recognized to continue in the foreseeable future, even beyond 2100.

Flexibility. Is the adaptation measure receptive for adjustments according to new knowledge? The predictions of climate change impacts are at present associated with high degree of uncertainty and new knowledge and information may require adjusted or different adaptation measures.

Resilience[10]. Does the adaptation measure make the management system more robust in responding to climate change impacts?

Urgency. How will the implementation of the adaptation measure be influenced if it is delayed? Sea level rise in itself is not a catastrophic event, but develops gradually. As the impact however may influence decisions/structures with long lifetimes (planning horizons), lack of actions can eventually have huge implications on adaptation options and costs.

Political acceptability. Does the adaptation measure require awareness raising and sensitization of the political process or has it already been addressed in policies.

Costs. Are huge investments associated with the adaptation measure?

In an attempt to provide a prioritized assessment, each narrative evaluation has been translated into scores ranging from "**+ + +**" for the best positive score, through "**0**" as neutral, to "**- - -**" as the worst score. Positive and negative scores are added separately allowing the following rating of the implementation measures:

High positive score = high priority in implementation

High negative score = a high level of controversy, high cost or otherwise problematic measure.

8 Where everyone gains an advantage – in this case: initiatives that benefits more than one aspect/interest group.

9 'No-regrets solutions' are those which are feasible and beneficial even if the climate does not change as expected (or does not change at all, for that sake). They are attractive in a context where action is required, but set against a background of incomplete financial resources and uncertainty about exactly how the climate will change in the time to come.

10 Climate resilience is the ability to withstand a climate-related pressure, or to recover from an adverse climate-related event. Climate resilience is an important cross-cutting development goal in a context of high vulnerability and increasing exposure to climate-related pressures and events.

In the matrices the adaptation measures have been ranked according to the level of positive scoring. The negative score, if any, for a given adaptation measure emphasizes that careful planning and design must be carried out specifically seeking to minimize these negative aspects prior to implementation.

The currently evaluated measures, the evaluation criteria and the actual scores might be incomplete and may not reflect the actual situation in a fully objective manner. Therefore the screening matrices need to be updated and / or extended appropriately through interactive participation of local stakeholders.

Table 6.1 Assessment Matrix - Do Nothing

ID	Adaptation Measure	Win/Win	Regret/No Regret	Flexible	High Resilience	Urgency	Political Acceptability	Costs	Score	Rank
Do Nothing										
00		- - - No wins. Sea levels will rise and cause losses if not addressed.	- - - Adaptation measures take time - speeding up or alternatives are costly.	- - - Not addressing planning requirements will render later solutions less flexible.	- - - No resilience vis-à-vis sea level rise. No action will increase vulnerability.	0	- - - Climate change adaptation is already on the political agenda including adaptation to sea level rise.	- - - Not addressing potential impact of sea level rise on land uses will increase costs for adaptation at a later date.	00+/18-	

Table 6.2 Assessment Matrix-Decision Support Measures

ID	Adaptation Measure	Win/Win	Regret/No Regret	Flexible	High Resilience	Urgency	Political Acceptability	Costs	Score	Rank
Decision Support Measures										
01	Information Management National coordinated and shared information management system (IMS) using GIS for geo-referenced data. Enables analysis across different themes indispensable for coordinated adaptation responses.	+ + + Access to updated and shared information system establishes common reference in all decision making.	+ + + All management will benefit from structured updated information with or without climate change.	+ + Structured and shared information management accommodates revisions/expansions more expediently.	+ + Updated, expanded information base widens response.	+ + + Urgent to inform a wide range of decision makers / planners.	+ + / - - - There is an acknowledgement that information should be coordinated and shared. There may be opposition against rearranging information management. Clear policies for data exchange need to be established including cost recovery.	+ + The information management system in itself not very costly. Its maintenance and continuous updating is costly, but not necessarily beyond existing information acquisition costs.	17+/03-	3

ID	Adaptation Measure	Win/Win	Regret/No Regret	Flexible	High Resilience	Urgency	Political Acceptability	Costs	Score	Rank
02	Monitoring A systematic monitoring system to ensure that information management is based on updated baselines. Monitoring to satisfy requirement defined in the shared IMS.	+ + + Will support all decision making.	+ + + Management will benefit from structured updated information with or without climate change.	+ + + Continuously updated information and trends in indicators strengthen decision support and sharpens response basis. Shared IMS enables fast and agreed revisions/ expansion in monitoring coverage.	+ + Updated, expanded information base widens response.	+ + + Urgent to provide more informed management.	+ + + / - A streamlined structural monitoring will strengthen decision making. Rearrangement of responsibilities may be met with resistance.	+ / - - Possible savings through streamlining of current efforts. Can become costly especially with new parameters, denser and more frequent acquisition.	18+/03-	1
03	State Reporting/ Information Sharing Periodic reporting as basis for planning and evaluation.	+ + + Systematic holistic information dissemination will support qualified response to management	+ + + Informed managers and public at large facilitates effective management in general	+ + + Flexibility as in IMS and monitoring.	+ + Improved awareness reduces response time among stakeholders.	+ + + Urgent to promote alertness among mangers and the public.	- - Increases transparency in decision making may expose decision makers. Clear policies for data exchange need to be established including cost recovery.	+ + + Low costs, particularly if reporting is automatized and internet based.	17+/02-	2

ID	Adaptation Measure	Win/Win	Regret/No Regret	Flexible	High Resilience	Urgency	Political Acceptability	Costs	Score	Rank
04	Sea level monitoring Needs particular attention to validate management intervention and as basis for continuous planning.	+ + Provides better basis for development planning and control. Improves risk assessments.	+ + + Sea levels are also changing due to local non-climatic phenomena and needs to be followed.	+ + Provides informed basis for more diverse land use strategies accommodating different project lifetimes.	+ Provides informed basis for more diverse land use strategies accommodating different project lifetimes.	+ Urgent to assist future management decisions.	+ + + Politically acceptable	+ + Low costs although local differences in sea level rise may necessitate many monitoring sites.	14+/00-	4
05	Improve the spatial detail and reduce uncertainties in climate change and sea level rise assessments for Trinidad and Tobago	+ + Provides better basis for development planning. Improves risk assessments	+ + No regret	+ + Provides improved basis for decision making	0 It will in itself not increase resilience	+ + + Urgent to assist future management decisions.	+ + Politically acceptable	+ + Low costs	13+/00-	5

Table 6.3 Assessment Matrix-Planning Measures

ID	Adaptation Measure	Win/Win	Regret/No Regret	Flexible	High Resilience	Urgency	Political Acceptability	Costs	Score	Rank
Planning Measures										
06	Integrated Coastal Zone Management (ICZM) Institutional reform targeting sustainable management of coastal areas through improved coordination and integration	+ + + ICZM is an important approach to addressing development pressure in coastal areas.	+ + + No regret as ICZM addresses other development challenges than those imposed by climate change.	+ + + ICZM is targeting better coordination between decision makers and integration of stakeholders lowering rigidity from traditional sector management.	+ + + Coordinated management will enhance resilience.	+ + + Urgent as institutional reforms take time.	+ + / - - - ICZM Committee has been established to develop policies. May meet some institutional resistance.	+ + / - - Low costs to plan for institutional reforms. Reform processes may be costly.	19+/05-	1
07	Integrated Water Resources Management (IWRM) Institutional reform targeting sustainable management of water resources through improved coordination and integration.	+ + + IWRM is an important approach to addressing development pressure in catchments.	+ + + No regret as IWRM addresses other development challenges than those imposed by climate change.	+ + + IWRM is targeting better coordination between decision makers and integration of stakeholders lowering rigidity from traditional sector management.	+ + + Coordinated management will enhance resilience	+ + + Urgent as institutional reforms take time.	+ + / - - - IWRM Policy approved by Government. Planning and implementation may meet institutional resistance.	+ + / - - Low costs to plan for institutional reforms. Reform processes may be costly.	19+/05-	1

08	Shoreline Management Planning Land use policies at the shore based on systematic assessment of shoreline and near shore vulnerabilities.	+ + + Shoreline management planning is required to address effects from the sea on shorelines and near shore coastal land.	+ + + Shoreline management planning is required to address effects from the sea on shorelines and near shore coastal land.	+ Some flexibility in its provision of strategic options.	+ + Shoreline management will enhance resilience by providing strategic options to spatial planning.	+ + + Urgent to inform planning in general and land use planning in particular.	+ +/- - Political awareness about requirements for shoreline planning. May meet institutional and private sector resistance.	+ / - - Costly to systematically assess vulnerability throughout the coast (studies and modelling). The plan itself not so costly.	15+/04-	3
09	Integrated Spatial Planning Updated structure, regional and local plans addressing vulnerability to climate change and sea level rise.	+ + + A prerequisite for development planning and control	+ + + No regret as it is urgently required in complex management challenges in the coastal areas.	+ Flexibility incorporated if cyclic planning is adhered to.	+ Systematic and cyclic spatial planning can have resilient measures built in.	+ + + Urgent to control the comprehensive development along the coast and to minimise sea level impacts on high life time investments.	+ + + / - - Government has initiated the reviewing of the National Physical Development Plan of 1984. Adaptation measures (resettlement, relocation) may meet resistance.	+ / - - - Implementation of updated plan over time may involve costly measures (protection, relocation). Delayed planning will increase costs.	15+/05-	4

10	Contingency Planning Responding to risks associated with land uses in areas vulnerable to climate variability, change and sea level rise.	+ + Provides responses to vulnerabilities associated with climate variability.	+ + + Provides responses to vulnerabilities associated with climate variability.	+ + + Increases adaptation flexibility by defining acceptable land uses in vulnerable areas and contingency actions for such uses.	+ Some resilience provided by defining acceptable land uses in vulnerable areas	+ Urgent to address impacts already experienced (flooding) and to increase preparedness for expected impacts.	+ + + Politically acceptable as it would define and protect acceptable land uses in vulnerable areas.	+ + Not costly	15+/OO-	2

ID	Adaptation Measure	Win/Win	Regret/No Regret	Flexible	High Resilience	Urgency	Political Acceptability	Costs	Score	Rank
Port of Spain Flooding Measures										
11	Comprehensive study of the present and future drainage conditions Including sequenced sub tasks.	++ This would benefit both the present and future drainage conditions and the urban planning in general	+++ No Regret	+++ Very flexible and prerequisite for introducing flexibility in the planning	+ Some resilience improving the knowledge on the existing system will improve possibility to restore it after damage.	+++ Very urgent since problems are already experienced at present.	+++ Politically acceptable	+++ Cheap prerequisite for optimal investment planning.	18+/O-	No Ranking

Table 6.4 Assessment Matrix – Salinity Intrusion Measures

ID	Adaptation Measure	Win/Win	Regret/No Regret	Flexible	High Resilience	Urgency	Political Acceptability	Costs	Score	Rank
Salinity Intrusion Measures										
12	Assess present and future capacity of coastal aquifers	++ Benefit both aquifer management and water supply in general	+++ No regret	+++ Keeps all doors open	0 Not in itself resilience creating	+++ It is urgent to know the boundaries and develop tools	+++ Very acceptable	+++ Low Costs	17+/0-	3
13	Assess the present and future water demand	+++ Benefit both aquifer management and water supply in general	+++ No regret	+++ Keeps all doors open	0 Not in itself resilience creating	+++ It is urgent to know the demands	+++ Very acceptable	+++ Low Costs	18+/0-	1
14	Analyse pumping scenarios (depends on #17)	+ Benefit general water supply management	+++ No regret	+++ Keeps all doors open	+ Resilience creating	++ It is urgent to know the possibilities	+++ Very acceptable	+++ Low Costs	17+/0-	4
15	Review and improve monitoring program for coastal aquifers	+ Benefit pumping management with or without climate change	+++ No regret	+++ Keeps all doors open	+ Resilience creating	++ It is urgent to know the possibilities	+++ Very acceptable	++ Rather Low Costs	16+/0-	5

ID	Adaptation Measure	Win/Win	Regret/No Regret	Flexible	High Resilience	Urgency	Political Acceptability	Costs	Score	Rank
16	Test Pumping Scenarios	+ Benefit pump-ing manage-ment with or without climate change	++ No regret	+++ Keeps all doors open	++ Resilience creating	++	++/-- Acceptable But may have temporary implications for existing users.	++ Rather Low Costs	15+/2-	6
17	Investigate water supply alterna-tives	+++ Benefit both aquifer man-agement and water supply in general	+++ No regret	++ Keeps all doors open	++ Resilience creating	++ It is urgent to know the possibilities	+++ Very acceptable	+++ Low Costs	18+/0-	2
18	Water demand management.	+++ This will benefit both the stress on the aquifer and the treat-ment and distri-bution system in general	+++ No regret	++ Saving water does not rule out imple-mentation of other measures.	++ Creates resilience by lowering the reliance on the aquifers.	++ Urgent to start the process which will need some time to implement	-- May imply costs to privates and may meet resistance	+ Fixing leaks in the distribution may be costly and saving water in the households may cost moey for the population	13+/2-	7

Table 6.5 Assessment Matrix-Inundation Measures

ID	Adaptation Measure	Win/Win	Regret/No Regret	Flexible	High Resilience	Urgency	Political Acceptability	Costs	Score	Rank
Inundation Measures										
19	Establish a detailed Digital Elevation Model DEM for the coastal areas and make available for spatial planning GIS	+ + + Important theme for planning in general	+ + + No regret	+++ Keeps all doors open	0 Not in itself resilience creating	+ + + Urgent to inform planning in general and land use planning in particular.	+ ++ Very acceptable	+++ Low costs	18+/0-	1
20	Quantification of the contribution to relative sea level rise due to vertical land movements.	+ + + Important theme for planning in general	+ + + No regret	+++ Keeps all doors open	0 Not in itself resilience creating	+ + + Urgent to arrive at credible sea level rise projections	+ ++ Very acceptable	+++ Low costs	18+/0-	1
21	Conduct a cyclone study to assess frequency of tropical storms and cyclones and associated surges.	+ + + Important theme for planning in general	+ + + No regret	+++ Keeps all doors open	0 Not in itself resilience creating	+ + + Urgent to arrive at credible storm surge risks	+ ++ Very acceptable	+++ Low costs	18+/0-	1

ID	Adaptation Measure	Win/Win	Regret/No Regret	Flexible	High Resilience	Urgency	Political Acceptability	Costs	Score	Rank
22	Develop assessments of vulnerability to inundation as themes that can interact in spatial analyses supporting spatial development planning.	+ + + Important theme for planning in general	+ + + No regret	+++ Keeps all doors open	0 Not in itself resilience creating	+ + + Urgent	+ ++ Very acceptable	+++ Low costs	18+/0-	1
23	Mainstreaming climate change (including sea level rise) into the National Spatial Development Planning.	+ + + A prerequisite for development planning and control	+ + + No regret as it is urgently required in complex management challenges in the coastal areas.	+ Flexibility incorporated if cyclic planning is adhered to.	+ Systematic and cyclic spatial planning can have resilient measures built in.	+ + + Urgent to control the comprehensive development along the coast and to minimise sea level impacts on high life time investments.	+ + + / - - Government has initiated the reviewing of the National Physical Development Plan of 1984. Adaptation measures (resettlement, relocation) may meet resistance.	+ / - - - Implementation of updated plan over time may involve costly measures (protection, relocation). Delayed planning will increase costs.	15+/5-	2

ID	Adaptation Measure	Win/Win	Regret/No Regret	Flexible	High Resilience	Urgency	Political Acceptability	Costs	Score	Rank
24	Engage in long term reform processes targeting sustainable climate resilient development through Integrated Coastal and Water Resources Management.	+ + + Important theme for planning in general	+ + + No regret	+ Flexibility incorporated if cyclic planning is adhered to.	+ Systematic and cyclic spatial planning can have resilient measures built in.	+ + + Urgent to control the comprehensive development along the coast and to minimise sea level impacts on high life time investments.	+ + / - - - ICZM Committee has been established to develop policies. May meet some institutional resistance. IWRM Policy approved by Government. Planning and implementation may meet institutional resistance.	+ + / - - Low costs to plan for institutional reforms. Reform processes may be costly	15+/5-	2

Table 6.6 Assessment Matrix-Shoreline Erosion Measures

ID	Adaptation Measure	Win/Win	Regret/No Regret	Flexible	High Resilience	Urgency	Political Acceptability	Costs	Score	Rank
					Shoreline Erosion Measures					
	Map and describe sediment cells and sub-cells along the Trinidad coast, determine boundaries for Shoreline Management Planning areas and identify vulnerable areas for detailed shoreline management planning.	+ + + Important theme for planning in general	+ + + No regret	+++ Keeps all doors open	0 Not in itself resilience creating	+ + + Urgent to inform planning in general and land use planning in particular.	+ ++ Very acceptable	+++ Low costs	18+/0-	1

ID	Adaptation Measure	Win/Win	Regret/No Regret	Flexible	High Resilience	Urgency	Political Acceptability	Costs	Score	Rank
25	Vulnerability assessment through Shoreline Management Study and Plan Identify and quantify erosion/accretion along the coast and translate into management policies and strategies taking projected sea level rise into account.	+ + + Provides management tools that can guide development planning in near shore areas.	+ + + Shoreline management planning is required to address effects from the sea on shorelines and near shore coastal land.	+ Some flexibility in its provision of strategic options.	+ + Shoreline management will enhance resilience by providing strategic options to spatial planning.	+ + + Urgent to inform planning in general and land use planning in particular.	+ +/- - Political awareness about requirements for shoreline planning. May meet institutional and private sector resistance.	+ / - - Costly to systematically assess vulnerability throughout the coast (studies and modelling). The plan itself not so costly.	15+/5-	2
26	Mainstream policies and strategies into land use/local planning	+ + + A prerequisite for development planning and control	+ + + No regret as it is urgently required in complex management challenges in the coastal areas.	+ Flexibility incorporated if cyclic planning is adhered to.	+ Systematic and cyclic spatial planning can have resilient measures built in.	+ + + Urgent to control the comprehensive development along the coast and to minimise sea level impacts on high life time investments.	+ + + / - - Government has initiated the reviewing of the National Physical Development Plan of 1984. Adaptation measures (resettlement, relocation) may meet resistance.	+ / - - - Implementation of updated plan over time may involve costly measures (protection, relocation). Delayed planning will increase costs.	15+/5-	2

7 Outline Adaptation Plan

The screening matrices provide ranked outlines of adaptation measures that can reduce the vulnerability to the impacts of sea level rise. The outlines need to be validated with stakeholders in Trinidad and Tobago after which efforts can be given to further detailing such measures into concrete actions, allocating institutional responsibilities, establishing time frames for implementation, quantifying financing requirements and identifying funding sources.

The preliminary ranked list of adaptation measures are grouped in the matrices and below at the level of decision support, the level of planning and the levels of the four areas of particular concern. Many of the measures discussed are important management requirement generally but where climate change impacts have underpinned the urgency of carrying out the measures.

An indication of urgency has been given for each adaptation measure and time required for implementation has been assessed as applicable.

7.1 Decision Support

Climate changes impact across sectors and management interventions need to be based upon comprehensive and complex information, covering many dimensions including economic, socio-economic, environmental, natural resources, water resources, land uses, land capabilities, topographic, climatic and more.

The ramifications of climate change must be addressed in an integrated manner coordinating responses among many stakeholders. A prerequisite for such coordination is a comprehensive and shared information base. Good management decisions further require that the information base is continuously updated enabling state reporting and assessments of the effectiveness of management interventions.

Information Management System

Impressions from the initial visit to Trinidad and Tobago and from subsequent information gathering are that whereas considerable information may be available from numerous government as well as non-government sources, some is not up-to-date, is incomplete in geographical coverage and is not readily interchanged between information suppliers. Much information is produced as part of studies thus representing one-off focused data acquisition efforts, where data may escape integration into government information management systems.

Management needs to be based on good information (accurate to the required level, distributed (resolution), and updated (varying frequency depending on parameter)). An information management system should be identified that fulfils the requirements for planning, development and environment control, monitoring and situational reporting. Approach should be structural to avoid data duplication and data corruption.

There is a need for developing a national shared system for information management that will enable coordinated and well informed planning and to ensure that vulnerability assessments with respect to climate change are included. The implications of sea level rise in terms of land use impact from sea level rise associated with flooding and storm surges need to be interacting with spatial planning themes.

Cross-sector and sector planning management will benefit substantially from access to a shared management information system and the efforts towards developing a shared information management infrastructure is a no regret investment that will improve the basis for coordinated development planning in general, while at the same time being required to host climate change risk information. It is therefore recommended as an urgent requirement. The establishment of a shared information management system is a demanding task relying on structural rearrangements that may influence many actors. The development in information technology over the past decades has removed many of the technical obstacles experienced earlier and it is today more a question of defining and agreeing on mandates and responsibilities associated with information management. Achieving a fully implemented shared information management infrastructure is a lengthy process where traditional data and information management has to be reviewed and assessed and where agreements have to be made and translated into legal provisions. A first recommended step is the development of a meta description of indicators that needs monitoring as decision support for management. Considerations and initiatives along this line is normally inherent as early activities in Integrated Water Resources Management (IWRM) and Integrated Coastal Zone Management (ICZM) processes where state of the catchment or state of the coastal zone reporting systems are considered. With dedicated efforts a first meta description of a shared information management systems can be developed within a period of ½-1 year allowing for cross sector coordination.

Monitoring

The indicators contained in the structured information management system needs to be systematically monitored to ensure that trends and baselines are updated to a level satisfying planning and other management requirements. The spatial resolution, frequency and accuracy of the monitoring will vary with parameters and should be defined in the meta-descriptions of the management information system.

Data themes of specific importance to sea level rise (sea level monitoring, meteorological, oceanographic, parameters etc.), cannot on their own support decision making but need to interact with various other themes. Monitoring systems will therefore have to satisfy the quality requirements (frequency, resolution, accuracy, timeliness) for all themes that are interacting in climate change adaptation analyses.

The meta description of the shared information management system discussed above shall include data themes pertinent for decision support related to climate change adaptation. Fields in the meta description must amongst others define accuracy, geographical resolution, and frequency for monitoring and identify responsibility for monitoring and maintenance of the indicator in the information system.

The monitoring requirements will thus emerge from the meta-description and a structured overview could be established within the period of ½ to 1 year indicated above. Resources and capabilities at this point in time will determine the timescale for implementing monitoring programs for all identified indicators.

Sea level monitoring

The sea level projections for Trinidad and Tobago are associated with development presumptions that may change over time and represent possible magnitudes with high levels of uncertainty. Whereas ensembles of global models will become more accurate in their projections over time local conditions in Trinidad and Tobago impact significantly on sea levels amongst others due to subsidence, which vary between coastal areas. In order to support management decisions there is a particular need to monitor the actual sea level movements at various locations along the coast and a systematic program should be set up ensuring that local differences are duly captured.

Task 1: Sea level rise study

The study should compile existing knowledge about the different contributing factors to sea level rise in Trinidad and Tobago with the view of identifying key locations for establishing a continuous monitoring programme. The study should be carried out as a matter of urgency to allow for a structured monitoring of sea level rise. Depending on resources the study could be completed with ½-1 year.

Task 2: Initiate monitoring programme

Based on the recommendations arising from task 1 a systematic monitoring of sea levels can be started at the identified key locations.

Improve the spatial detail and reduce uncertainties in climate change scenarios for Trinidad and Tobago

7.2 Planning Measures

Proactive adaptation to climate change and sea level rise requires mainstreaming into planning. The four areas of concern discussed in the case on sea level rise for Trinidad and Tobago have identified the following tasks as particularly important for addressing sea level rise in development management in the coastal areas:

Task 1: Shoreline Management Planning

Develop land use policies at the shore based on systematic assessment of shoreline and near shore vulnerabilities. Inform land use planning.

The systematic assessment of the shorelines in Trinidad and Tobago to determine vulnerabilities related to erosion and inundation is a matter of urgency to develop local policies that can be incorporated/mainstreamed into development planning and at the same time consider impacts of climate variability and change. A full shoreline management plan for each island can be completed in 1 to 2 years' time adopting an approach as exemplified in Appendix C.

Task 2: Mainstream climate change and Sea Level Rise adaptation into Land Use Planning

Update structure, regional and local plans addressing vulnerability to climate change and sea level rise. Responding to risks associated with land uses in areas vulnerable to climate variability, change and sea level rise.

Themes on shoreline vulnerability will be produced as an outcome of Task 1 together with local policies at sediment cell and management unit ready for inclusion into spatial planning to guide development control. The timing for such inclusion will rely on a review schedule for local plans where the most vulnerable areas should get the highest priority.

Task 3: Engage in reforms towards integrated development management in the coastal areas.

Integrated Coastal Zone Management incorporating Institutional reform targeting sustainable management of coastal areas through improved coordination and integration.

Integrated Water Resources Management Institutional reform targeting sustainable management of water resources through improved coordination and integration.

Task 4: Increase preparedness in vulnerable areas through contingency planning.

Use high end sea level rise scenario to assess catastrophic impacts as a basis for contingency planning.

7.3 Port of Spain Flooding

Various measures can be implemented to improve the drainage situation of Port of Spain and to safeguard the drainage towards impacts from sea level rise. However, the identification, efficiency assessment and pricing of such measures require a better and more quantitative understanding of the flooding problems in Port of Spain, at present time and in future. Such understanding are most efficiently established by state-of-the-art analytical tools (digital terrain models (DTMs), satellite and aerial imagery, GIS, dynamic simulation models, etc.) as described in Section 6. Establishment of such tools scores high when evaluated according to the criteria selected in Section 6. This suggests the task to be both cost effective and non-controversial and since it is a prerequisite for cost efficient interventions and improvements it should be the first task in a drainage adaptation plan for Port of Spain. The subsequent task should be to use the established tools to identify, cost and rank the detailed alleviation measures and to initiate the implementation of the most urgent ones.

Task 1 Establish the decision tools:

Hydrological study

Task 1 Assessment of the climate change impacts on the design parameters for the period until year 2100.

Development of GIS database of natural watercourses and storm drainage infrastructure.

Development of an integrated simulation model of storm drainage, including contributing catchments, natural water courses, piped and open drains, culverts, ponds, retention basins, pumping station and sea outlets. The model should capture the essential functional elements of the system with sufficient accuracy to make it representative for the actual system functionality.

Task 2 Identify and test various alleviation options:

Simulation of various development scenarios under future hydrological and oceanographic conditions, i.e. including anticipated climate change.

Identification of the area under flooding risk and development of possible adaptation structural measures, such as detention ponds, new drains, silt traps, trash racks, erosion-control measures, etc. as well as a range of adequate "soft" measures aimed at increased resilience to flooding.

Development of a comprehensive long-term solution. By selection the most cost effective a politically acceptable solutions that fulfils the long term targets.

Verification of the solution efficiency by the simulation model.

Task 3 Start implementing the most urgent and efficient measures.

7.4 Salinity Intrusion

In Section 6 a number of measures to prevent salinization of the two selected aquifers have been identified, evaluated and ranked in a scoring matrix.

Based on this ranking the following outline adaptation plan is suggested to deal with the salinization of aquifers under Climate change.

Task 1: Assess the present and future water demand.

Such assessment has not been available to the present study. It is a prerequisite for other activities. Hence, if it is not already available it needs to be prepared urgently.

Task 2: Investigate water supply alternatives.

This is a high priority task that may be implemented in parallel to the tasks above. It is important to investigate if cheaper solutions exists to the possible scarcity problems than squeezing more water out of the aquifers. Obvious candidates could be impoundment of surfacewater or desalination of sea water or brakish water form the coast near boreholes.

Task 3: Assess present and future capacity of coastal aquifers

The establishment of detailed hydrological and hydrogeological models is necessary to further analyse the present and future capacity and for task 4.

Task 4 Analyse pumping scenarios

The established models will be used to identify and test various pumping scenarios, new well fields, filter settings etc.

Task 5 Review and improve monitoring program for coastal aquifers

This task can be implemented in parallel with the former tasks, but the model analyses are likely to point to new important aspects to monitor and verify

Task 6 Test Pumping Scenarios

If or when promising pumping scenarios have been identified and analysed, such scenario have to be tested either by use of existing bore holes (preferable) or by introduction of new test wells to confirm the scenarios. This task can be quite costly.

Task 7 Implementation of water demand management.

With 44 % of the water unaccounted for, substantial savings should be possible by fixing leaks in supply network and by metering. Water pricing policies has in developed countries lead to large reduction in the per capita consumption and may also be considered here, although such measures may face political opposition. Water demand management may be implemented in parallel to the other tasks. Its implementation may take some time.

Task 8 Prepare water supply management plan.

The findings of the above tasks should be formulated in an official plan for sustainable management of the water supply ot the city built on a sustainable use of the aquifers and the other water resources.

7.5 Low Land Inundation

Task 1: Develop the tools required for vulnerably assessments.

(a) Establish a detailed Digital Elevation Model DEM for the coastal areas. The DEM should be integrated with spatial planning GIS.

The Digital Elevation Model (based on 90 m grid) used to visualise vulnerability to sea level rise in low lying areas in Trinidad in Figure 57 is far too rough as decision and planning support and more detailed models are required for areas of particular concern. High resolution DEMs can be established using readily available LiDAR technology. It is expected that the timing for developing more detailed DEMs for vulnerable coastal areas will be coordinated with other planning efforts targeting these areas, such as the preparation and or updating of local and special area plans or in connection with feasibility studies for major infrastructure or other investments. Procedures and guidelines for developing detailed DEMs should however be prepared and maintained to ensure that such DEMs satisfy the requirements from structured uses (incorporation into applied GIS, development planning, spatial planning, vulnerability assessments). The development of guidelines and procedures is a matter of urgency and could be completed within ½ to 1 year, possibly as part of a pilot project demonstrating the practical use of a DEM in vulnerability assessments.

(b) Quantification of the contribution to relative sea level rise due to vertical land movements due to tectonics and due to human activities respectively.

The sea level rise study discussed in Section 7.1 will provide an assessment of contributing factors to effective sea level rise in various parts of Trinidad and Tobago based on existing information and assist in identifying monitoring requirements for selected locations. With time monitoring programmes at these sites will provide more detailed information about the relative importance of vertical land movements to sea level rise.

(c) Conduct a cyclone study to assess frequency of tropical storms and cyclones and associated surges.

A comprehensive cyclone study can be carried out within ½ year to better assess the probabilities, characteristics and likely pathways for cyclones in Trinidad and Tobago. It would be appropriate to undertake the study as a regional Caribbean effort.

Task 2: Develop assessments of vulnerability to inundation as themes that can interact in spatial analyses supporting spatial development planning.

Use detailed DEMs to identify areas vulnerable to sea level rise, including storm surges associated with cyclone storm events and develop risk maps. Vulnerability and risk maps should be prepared as themes that enable interaction with themes used in spatial planning. Procedures and guidelines for developing local vulnerability and risk themes should be prepared and maintained to ensure that such themes satisfy the requirements from structured uses (incorporation into applied GIS, development planning, and spatial planning). The development of guidelines and procedures is a matter of urgency and could be completed within 1 to 2 years, possibly as part of a pilot project demonstrating the practical use of vulnerability and risk themes in spatial planning.

Task 3: Mainstreaming climate change (including sea level rise) into the National Spatial Development Planning.

Structure planning, regional planning and local planning need to include assessments of vulnerability and risks associated with climate variability and climate change. Applying themes produced as indicated under Task 2 in spatial planning will allow identification of areas at risk and analyses of development scenarios involving these areas. It is important to have scenarios developed and considered at all planning levels (national/structural, regional/land uses, and local /cadastral). The National Spatial Development Strategy currently under formulation would be an obvious point of entry for mainstreaming climate variability and change into spatial planning processes. Full integration however is a longer term effort to defined/targeted as part of the Spatial Development Strategy.

Task 4: Engage in long term reform processes targeting sustainable climate resilient development through Integrated Coastal and Water Resources Management.

The need for integrated approaches to development management has been acknowledged in Trinidad and Tobago and efforts have already been undertaken towards integrated water resources management (IWRM) and integrated coastal zone management (ICZM). Whereas these approaches address much required reforms there is an increasing appreciation of the need to better coordinate such processes recognising the linkage between catchment management and coastal area management. Considering the impact from climate change on water resources and on coastal areas it is required that the reform processes incorporates climate change adaptation.

7.6 Shoreline Erosion

The following adaptation plan is proposed:

Task 1: Map and describe sediment cells and sub-cells along the coastline as basis for determining boundaries for Shoreline Management Planning areas and identify vulnerable areas for detailed shoreline management planning.

Task 2: Vulnerability assessment through Shoreline Management Study and Plan. Identify and quantify erosion/accretion along the coast and translate into management policies and strategies taking projected sea level rise into account.

Task 3: Mainstream shoreline management planning into land use/local planning

A detailed presentation of the approach is provided in Appendix C on Shoreline Management Planning.

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Appendices

Appendix A

Climate Change projections for Port of Spain, Trinidad & Tobacco

Climate Change Projections Port of Spain. Rapid Assessment

A Rapid assessment of the projected changes in Rainfall and Evaporation in Port if Spain has been made to suplement the discussions of the sea water intrusion in the coastal aquifer in the Main Report.

Monthly projected change factors of rainfall and Evaporation have been extracted from the results of 21 Global circulation models using DHI's Climate Change assessment facility in the Mike 11 modelling package (ref A-1) the models included in the analyses are listed in Table A.

The package extracts data from three scenarios SRA1B, SRA2 and SRB1. No information has been received on any official decision on which emission scenario to be used for Trinidad and Tobacco. For this analysis the emission scenario SRA1B has been selected. Comparing the three above scenarios SRA1B provides a central estimate of rainfall for the end of the 21st century while it gives lower rainfall than the two other for the mid-century (seeFi) .

Rainfall Projections

In general prediction of changes in rainfall is more uncertain than the predictions of changes in temperatures and large variation in the predictions of the various models are often experienced. Figure A illustrates this variation for Scenario SRA1B for the projected rainfall changes by the end of the 21st century. It is noted that 80% of the 21 models agree on the negative trend in the rainfall amounts and that more than 50% of the model agree on this decrease to appear in all months of the year

In average the 21 models predicts an annual decrease of rainfall of 14% and 21% by the year 2050 and 2100, respectively.

It must be emphasised that while the projected general decrease in monthly rainfall as a consequence of the global climate changes may be used to indicate changes in the overall hydrological patterns such as general recharge to groundwater aquifers, it should not be used to draw conclusions on the intensity and duration of single rainstorms, which are relevant parameters for the design of urban drainage works. Such events are predicted to become more severe in many parts of the world. More detailed extreme value analyses on the basis of regional climate models with finer resolution than the global ones are required to improve the design parameters for the urban drainage.

Table A-1 Models included in the assessment

ID	Model	ID	Model	ID	Model
1	BCM2	8	GFCM20	15	IPCM4
2	CGHR	9	GFCM21	16	MIHR
3	CGMR	10	GIAOM	17	MIMR
4	CNCM3	11	GIEH	18	MPEH5
5	CSMK3	12	HADCM3	19	MRCGCM
6	ECHOG	13	HADGEM	20	NCCCSM
7	FGOALS	14	INCM3	21	NCPCM

A long term records of rainfall from the Botanic Garden in Port of Spain has been available to this study (Table A). This series has been used to illustrate the projected future rainfall in the City (Figure A)

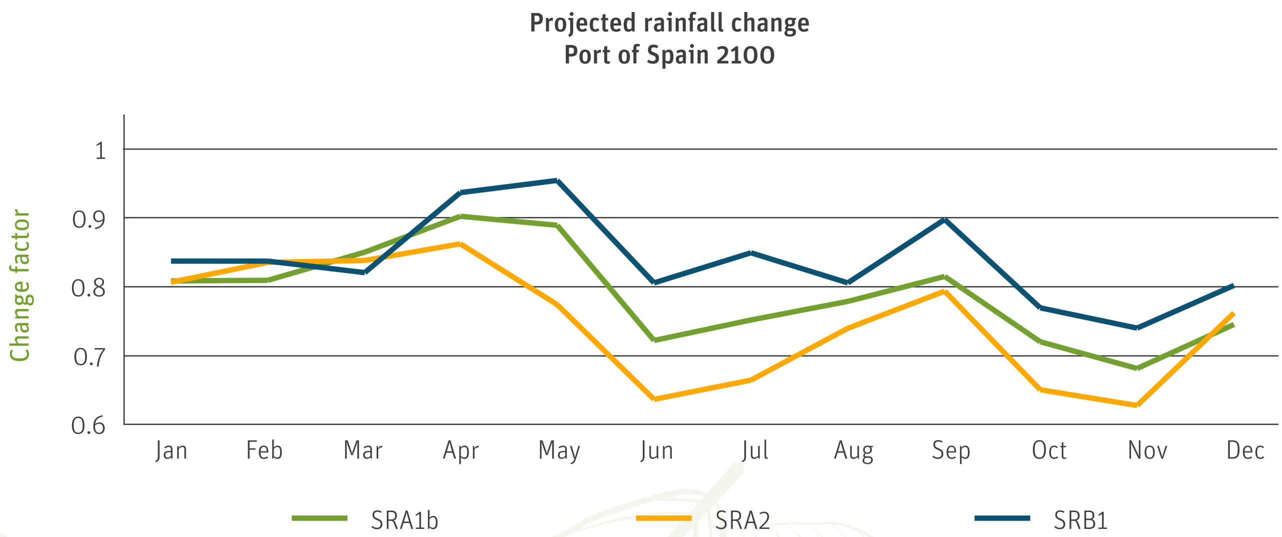
The series provides a rather long and undisrupted series from 1921 to 1981. After 1981 the series contains more gaps and since a professional gap-filling exercise has been considered out of scope for this study the data up to 1981 has been used as representative for the present climate in the City.

Projection of Potential Evaporation

The potential evaporation as predicted by the 21 Climate models is illustrated in Figure A4.

The models all agrees that potential evaporation will rise and that the percentage rise will be almost constant over the year. In average increases in Potential evaporation of 5% and 8% are predicted by 2050 and by 2100, respectively.

Figure A-1 Comparison of rainfall projections for Port of Spain under three different emission scenarios. Average Prediction of 21 models



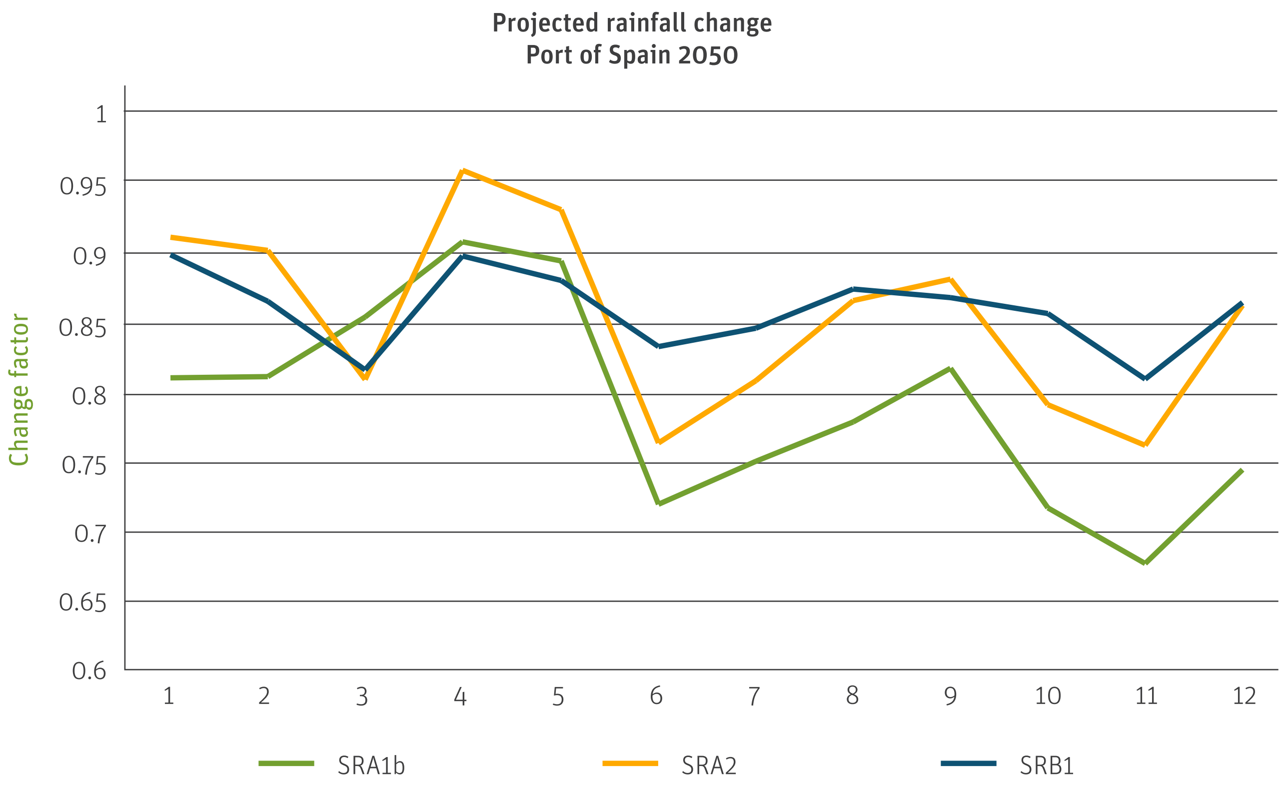


Figure A-2 Statistics of rainfall projections for Port of Spain year 2100.

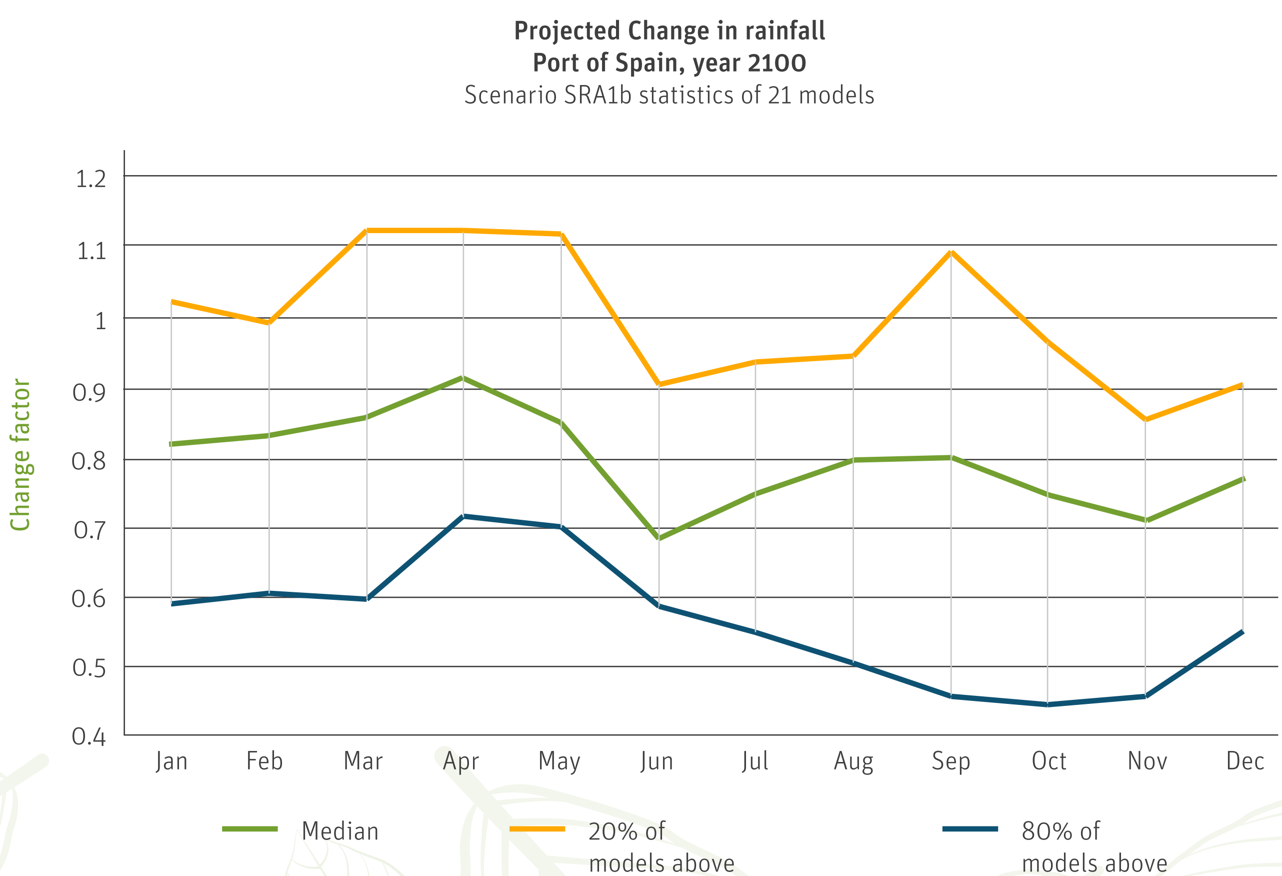


Figure A-3 Long term historical rainfall in Port of Spain (1921-1981) assumed representative for present conditions and projected changes by 2050 and 2100,

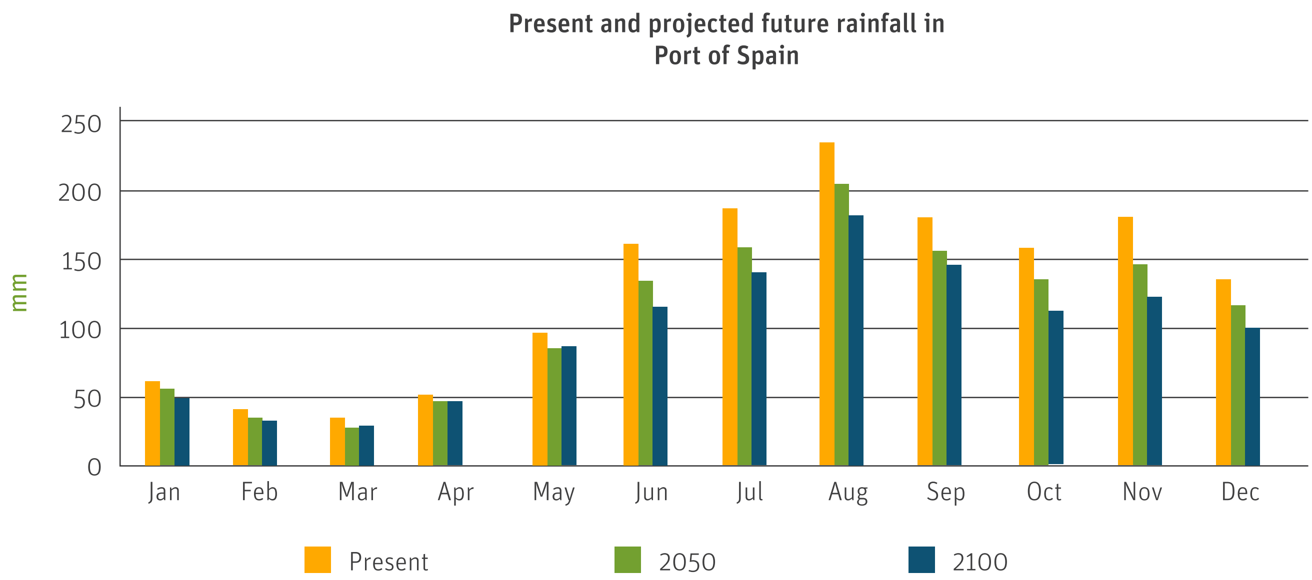


Figure A-4 Projection of changes in Potential Evaporation in Port of Spain by 2100.

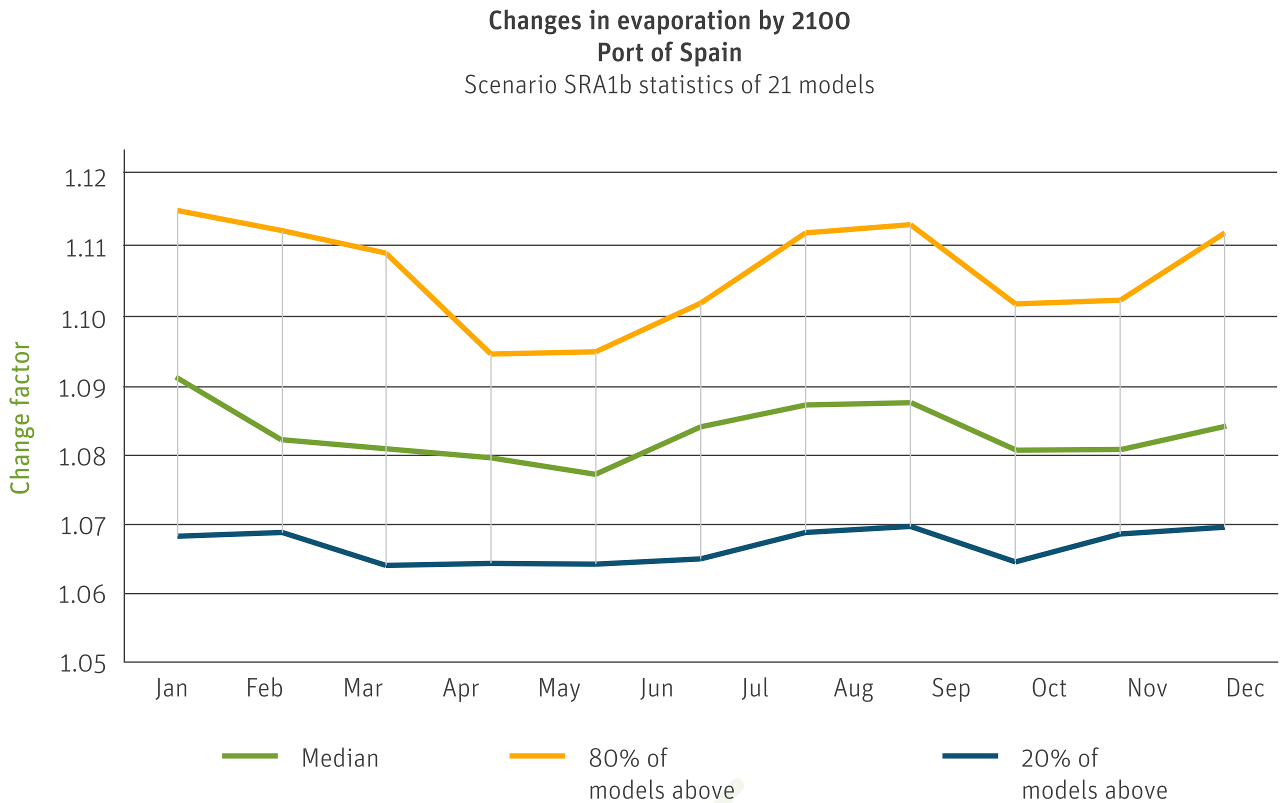


Table A-2 Monthly Rainfall From Port of Spain (Botanic Garden) 1927-1981.

	Jan	Feb	Mar	Aor	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Promedio	**62.3**	**40.6**	**34.0**	**52.1**	**97.1**	**161.4**	**187.3**	**234.5**	**180.3**	**157.9**	**181.4**	**135.1**	**1513**
1927		112.8	91.9	128	181.8	176.2	239	296.5	231.5	155.6	143.3	183.3	
1928	107.2	17.6	33.3	51.3	16.5	146.1	204.9	220	187	232.2	213.8	150.9	**1581**
1929	158.5	21.4	45.1	20.6	186.1	178.6	129.4	322.9	132.3	86.4	236	38.6	**1556**
1930	68.6	2	7.8	60.6	47.1	161.4	180.7	125.4	148	159.2	66	124.1	**1151**
1931	42.6	28.3	1.8	7.4	28.5	176.2	278.4	225.8	123.3	167.3	201.6		
1932	142.5	43.7	110.6	101.4	235.1	267.6	147.2	407.4	97.9	117	259.7	203.5	**2134**
1933	98.2	31.7	48.6	34.5		258.9	277.6	408.3	292.6	188.3	136.7	159.7	
1934	65.2	22.8	18.8	4.3	20.8	77.6	239.7	183.7	166.3	216.1	256.1	134.9	**1406**
1935	13.5	14.4	31.2	10.7	128.2	60	186.7	335.7	294.9	96.9	286	87.9	**1546**
1936	29.7	7.2	2.8	61.6	142.8	267.2	272.7	150.7	206.6	125.9	179.5	140.7	**1587**
1937	92	31.8	17.8	65.8	5.1	110.1	180.1		137.5	106	306.9	200.3	
1938	88.9	66.8		164.4		149.1	245.2	257.7	269.7	190.2	262.5	298	
1939	27.4	60	23.8	47.3	71.8	136.9	191.5	213.7	214.7	251.5	81.1	124.2	**1444**
1940	32	6.8	41.1	12.5		135.4	108.5	274.9	152.6	142.7	245.1	108.4	
1948	155.5	20.1	53	93.4	100.7	315.7	369.1	221.4	244.4	195.4	130.2	36.6	**1936**
1949	16.7	49.5	22.6	14.2	92	167.7	176.2			78.5	207.6	218.6	
1950	122	139.5	48.3	78.7	49.7	265	192	314.8	148.8	178.3	67.2	108.3	**1713**
1951	135.9	240.6	108.8	53.8	162.6	246.6	180.2	382.5	279.1	198.6	188.4	94.9	**2272**
1952	33.6	41.8	9.4	54.5	58	173.8	200.1	243.3	287.8	170.5	132.9	154.2	**1560**
1953	63.6	35.6	30.2	30.9	142	120.8	215.1	213.8	239.6	132.4	180.9	106.1	**1511**
1954	54.9	16.8	37.7	74.7	50.8	183.3	185.5	269.3	226	185.6	257.4	154.5	**1697**
1955	59.8	36.9	43.2	31.9	33.3	285.4	239.6		49.5	314.2	241.6	120.7	
1956	110.9	78.5	56.9	49	55.5	144.8	86	196.2	193.1	237.3	115.9	120.8	**1445**
1957	63.1	24.9	8.7	72.7	34.9	130.6	175.8	120.5	138.4	77.1	236.3	154.3	**1237**
1958	28.6	26.3	82.8	134.3	183.5	311.4	274.6	240.2	223.6	131.5	184	122.2	**1943**
1959	10.1	30.6	2.8	11	42.7	118.6	59.1	129.2	218.2	148.7	150.8	172.9	**1095**
1960	27.5	25.3	6.7	30	35.4	70.2	109.5	34.2					
1962	53.3	67	57.9	14.7	52.1	237.7	272.2	317.1	199.3	88.1	112.1	120.7	**1592**
1963	69	52.1	44.6	26.5	524.8	198.3	215.1	209.5		104.8			
1971	57	31.1	27.3	4.4	60.9	92.9	84.6	254.6	142.8	356.6	202.2	138	**1452**
1972							134.3	93.7	98.1	130.6	76.5	97.7	
1973	27.9	9.8	21.1	49.2	44.6	93.5	78.6	282.3	125.7	59.6	184.8	101.9	**1079**
1974	86.5	38.9	31.7	26.5	43.5	86.2	215.4						
1975	34.9	15.4	19.8	66.7	79.1	71.2	119.2	474.2	218.5	160.9	143.3	214.6	**1618**
1976	38	47.2	46.2	54.7	34.2	163.2	173.2	90.9	91.2	42.9	151.7	160.4	**1094**
1977	14.1	20.5	18.1	20.1	14.3		141.1	184.8	108	182.2	110.8	17.7	
1978	30.6	1.3	15.2	9.4	80.6	82.5	346.4	172.8	124.1	91.2	37.9	13.8	**1006**
1979	18.8	5.1	9.4	34.5	12.3	70.9	136.8	100.2	119.6	182.2	210.1	266.2	**1166**
1980	20.4	5.8	1.2	6.4	308.7	60.7	42.3	252.7		158.8	334.4	106.5	
1981	67.3	57.2	12.5	218.2	135	140.5		222.7				107.5	

Appendix B

Hydrogeological profiles of the Northwest Peninsula Gravels Aquifer (Port of Spain/Cocorite)

Summary

This Appendix summarises the information received from WASA on the Port of Spain Coastal Aquifers.

By comparing the locations on the map (Figure B-1) with the Cross sections (Figure B-2 to B-5) it is noted that the terrain levels close to the coastline are very close to present mean sea level and that the dynamic water levels in the wells are very close to and sometimes under the present mean sea level.

The Cross sections shows deep sedimentary deposits and suggest good hydraulic contact with the seawater at the coastline of off the shore. It is not possible from this information to assess the magnitude of aquifer freshwater recharge neither horizontally via local infiltration nor laterally from the upstream hilly areas.

High levels of salinity have previously been reported but seem to be under control and the drawdown in the various boreholes seems to be stable (see Table 3-2, and Figure 3-2 of the Main Report).

Figure B-1 Plan of pumping and observation wells in the Northwest Peninsular Gravels under Port of Spain with locations of the transects shown in the following figures.

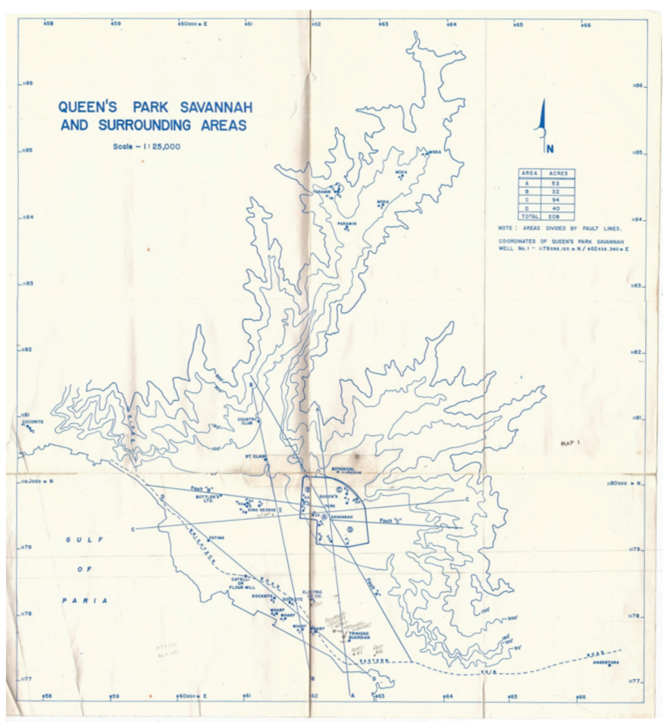


Figure B-2 Cross section A-A (Location in figure B-1) Of the Aquifer

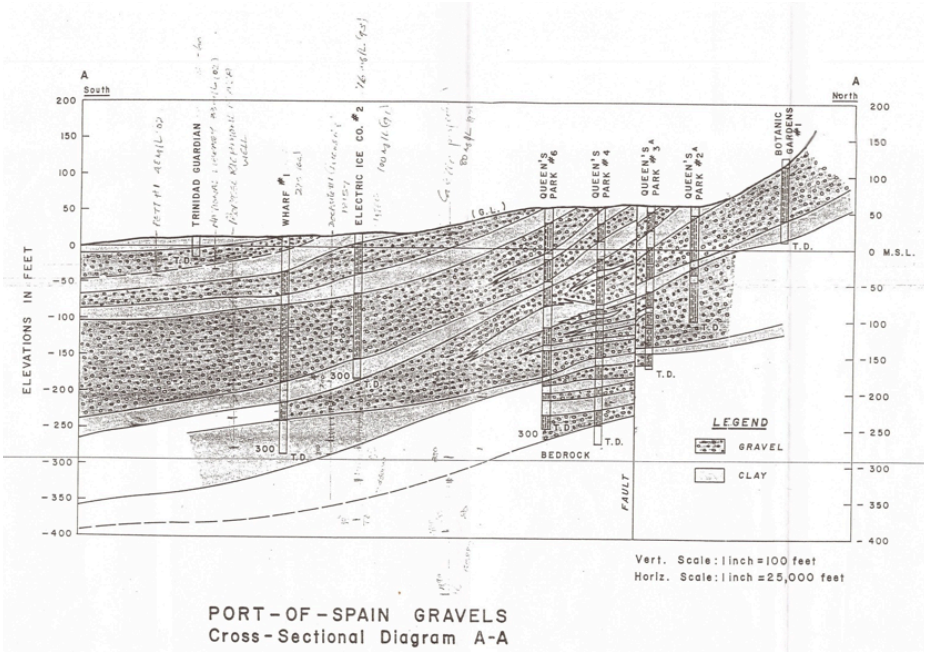


Figure B-3 Cross section B-B (Location in figure B-1) Of the Aquifer

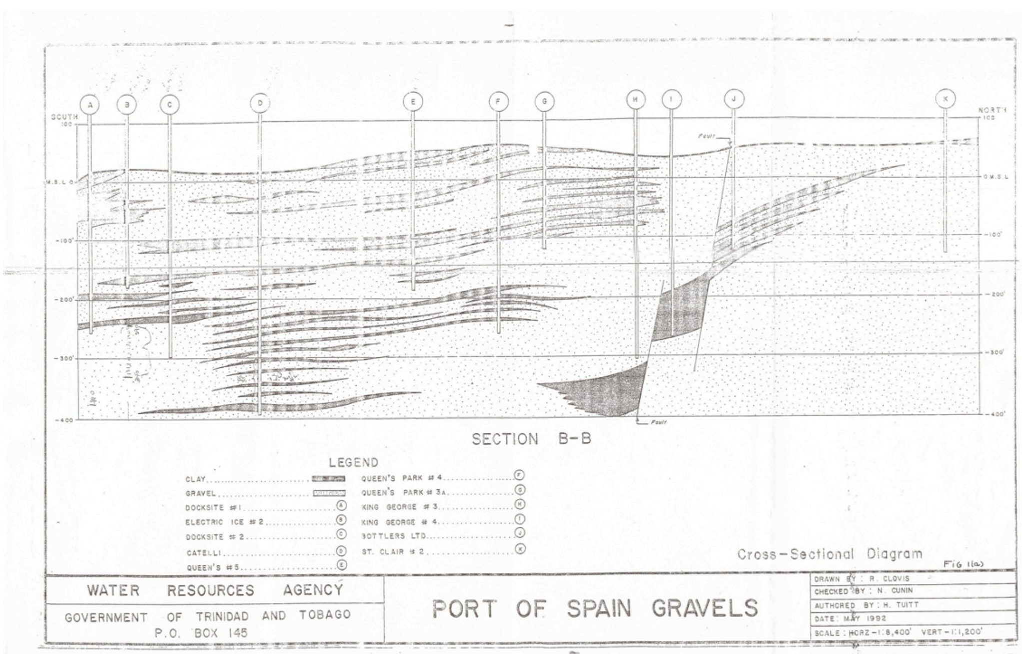


Figure B-4 Cross section C-C (Location in figure B-1) of the Aquifer

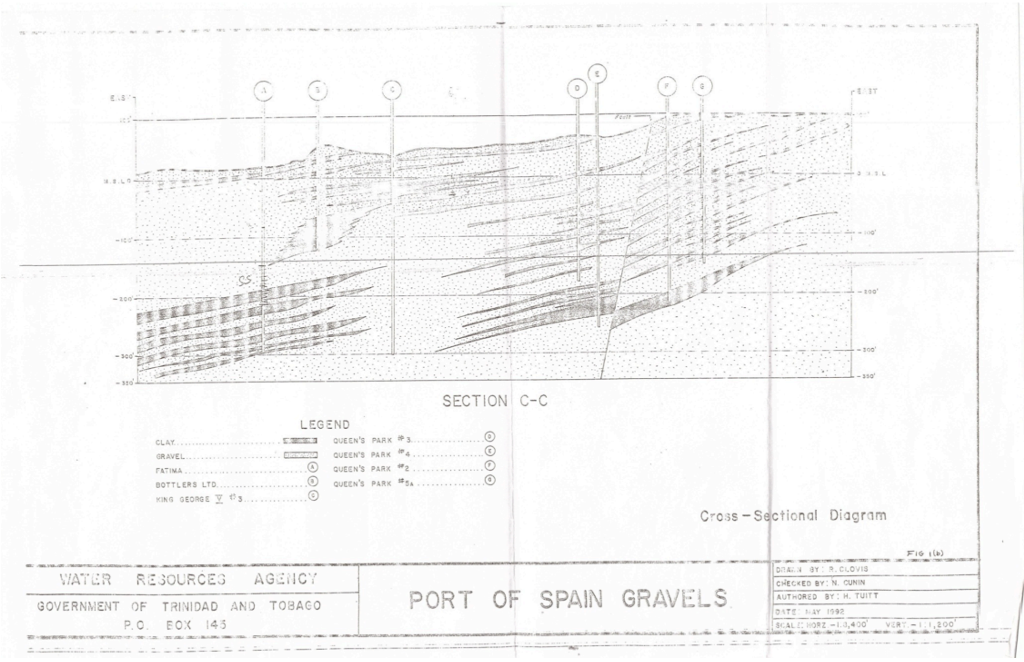
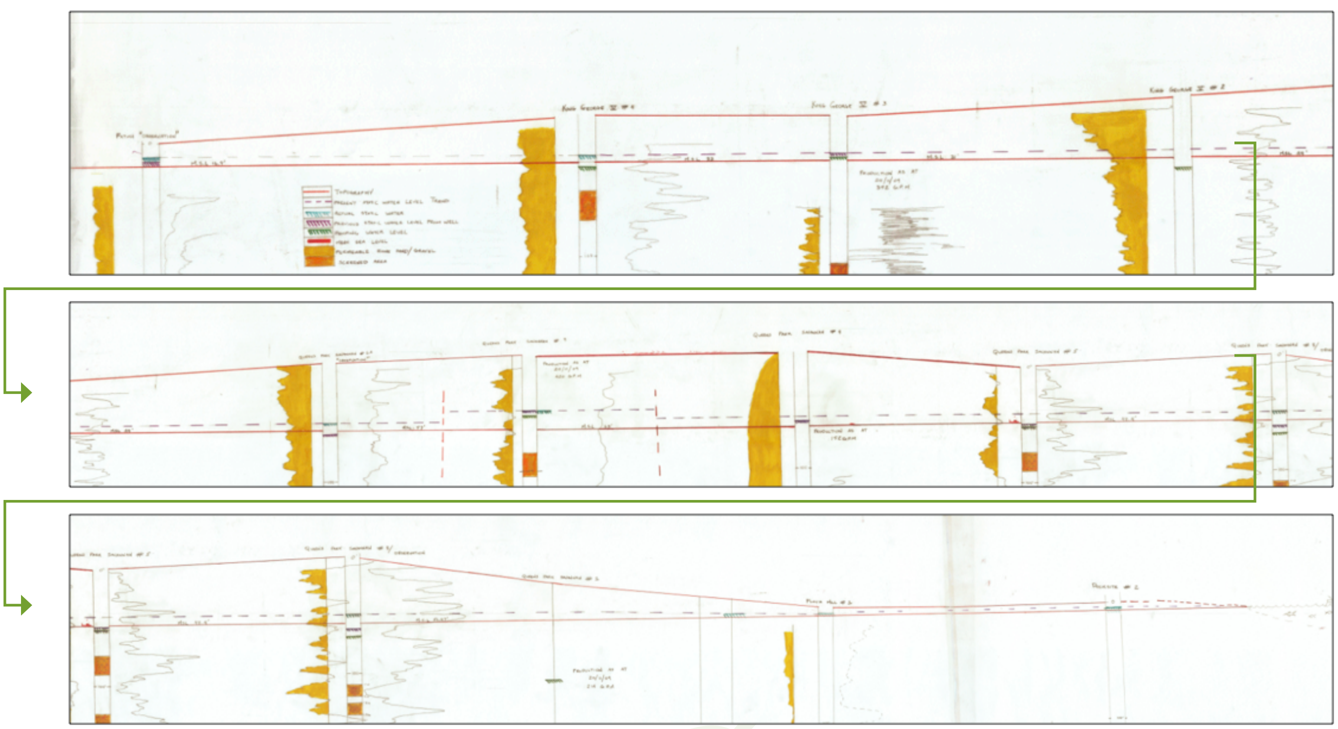


Figure B-5 Zigzagged section of the Port of Spain Aquifer with indication of Stationary and Dynamic water levels in the various wells. Source: Received from WASA.



Appendix C

Shoreline Management Planning (Extracted from Ref. 51)

Shoreline Management Planning

The purpose of Shoreline Management Planning is to identify the resources and assets in the coastal area now and in the future and through that minimise negative consequences from the interaction between the various interests, i.e. tourist and economical development, coastal protection, natural dynamics etc.

Shoreline Management Planning is the part of the Integrated Coastal Zone Management that deals with the interaction between the actual and potential coastal evolution and the existing and planned activities in the coastal area.

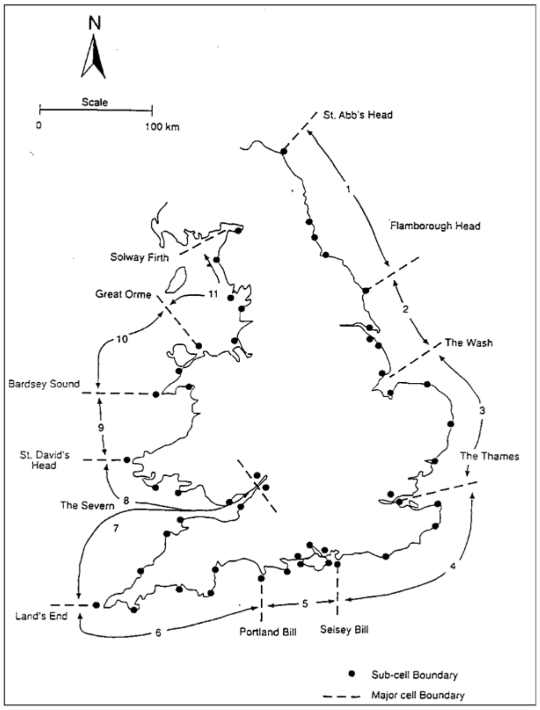
The aim of a *Shoreline Management Plan* (SMP) is to provide the basis for the implementation of overall sustainable shoreline management policies and strategies – a management strategy - for a well-defined region and to set the framework for the future management of conflicts in the coastal area.

A Shoreline Management Plan is a strategy document that delivers a broad-brush assessment of the coastal resources, conflicts, opportunities and constraints. The plan must therefore contain reference to the adopted policies and to the adopted regulatory system as well as to the Coastal Zone Management Plan.

The SMP shall address, in broad terms, whether to defend, or continue to defend, assets with coastal defences or manage the risks through other means. The plan shall be based on a strategic assessment of conditions within the plan area rather than detailed studies of individual sites.

A Shoreline Management Plan normally covers an area along the coast described as a *Sediment Cell*. A sediment cell is a section of the coastline in which the physical processes are relatively independent from processes operating in adjacent sediment cells. The boundary of a sediment cell generally coincides with larger estuaries or prominent headlands. An example from the UK is presented in Figure C-1.

Figure C-1 Boundaries of major sediment cells in the UK



In many cases, however, sub-cells or groups of sub-cells provide a more practical basis for the production of plans because they have a more manageable size. The boundaries of sub-cells, also shown in Figure C-1, are not definitive; they are based on the best available knowledge of large-scale processes, and may need to be revised as further information becomes available.

Shoreline Management Planning has become increasingly important with the accelerated development pressure in the coastal areas and the relatively strict sector requirements for preservation and restoration of the natural resources, which have been implemented in the legislation in most countries over the last decades. The challenge in this context is to combine the following interests:

- Public interests: Shore protection, resource preservation, development of infrastructure and public utilities etc.
- Private interests: Development of projects and coast protection
- Industry interests: Industrial development, navigation, raw material utilisation etc.

There are often inherent conflicts of interests in e.g. coast protection projects, both with respect to the objectives and with respect to the sharing of the costs. Resolving these planning matters is often as difficult as it is to find a suitable technical solution. The following aspects are equally important in this planning process:

- Openness through public participation via dissemination of the planning concepts and public hearings.

- Balanced weighting of conflicting interests, such as requirements for sustainable development, environmental protection and preservation of the natural coastal landscape versus requirements to protection etc. This can be implemented through well-planned optimised projects.
- Fair distribution of cost between all involved parties. The main two types of parties are:
  a) Landowners, who directly benefit from the project, e.g. in form of obtaining protection of property, and
  b) Sector Authorities, who introduce requirements to sustainability and nature preservation, which often leads to increased cost of the project

It is normally the responsibility of the regional authority or a sector authority, such as the Coastal Authority, to develop Shoreline Management Plans. It is important that experts in the fields of coastal morphology, coastal engineering, landscape architecture and planning, and environmental management participate in the elaboration of the Shoreline Management Plan.

In the following the overall content of a **Shoreline Management Plan** for a specific Sediment Cell is listed and described. The administrative procedures in connection with the planning process are also included in the description.

1. Reference to related plans and to the legal and institutional framework

- Summary of planning requirements for the Sediment Cell from existing regional and local spatial plans. Discussion of possible requirements for amendments to these plans in order to make room for possible new development
- Summary of sector requirements for the Sediment Cell from existing sector acts and from a possible Coastal Zone Management Plan
- Description of the institutional set-up and procedures in relation to elaboration and approval of the SMP

2. Historically updated information about the coastal area

- Description of the shore- and coastline development based on historic data (old surveys, aerial photographs, charts, maps and other local/national information)
- Description of existing coastal and harbour structures (and how they have changed through time), including dredging. In relation to the above-mentioned the impact on the coastal development should be deduced
- Meteomarine conditions (wave climate, currents, wind, temperature, and water levels). If wave and water level data are not available it will be possible through numerical modelling to generate useable information
- Bathymetric and topographic information
- Geological and morphological information. Description of coastal landscape and recent development. Information on existing marine sand layers onshore and matching grain size distribution, which is required for calculation of the littoral drift budget

- Mapping of existing land use: Housing and habitation areas, agriculture, industry, major infrastructure and nature areas (forests, bare land, recreational areas)
- Biodiversity, nature conservation and environmental aspects
- Historic environment (important local or national historic locations, archaeology remains, historic buildings, parks, gardens, landscapes)
- Landscape issues (landscapes designated for their importance, national parks and world heritage)

3. Establish the littoral drift budget, classify the shoreline and categorise sections of shoreline for sensitivity

- Collection of necessary additional data
- Establish the littoral drift budget for the Sediment Cell by numerical modelling and by analysis of historic shoreline development data. The littoral drift budget is decisive for the erosion or accretion of the natural coast and for understanding impacts from man-made structures, existing or planned
- Establish shoreline classification. This is important for understanding of morphological features and for evaluation of suitable protection measures
- Categorise sections of shoreline for sensitivity to erosion and accretion based on the sediment budget

4. Identification of bindings (natural or man-made) in the coastal area, present and future

- Description of the shoreline development.
- Description of land use in a broad sense (present and future (planned development)). Land use in characteristic categories: Habitation, industry, major infrastructure, recreation and nature protected areas
- Analysing conflicts between shoreline development, land use and environmental requirements

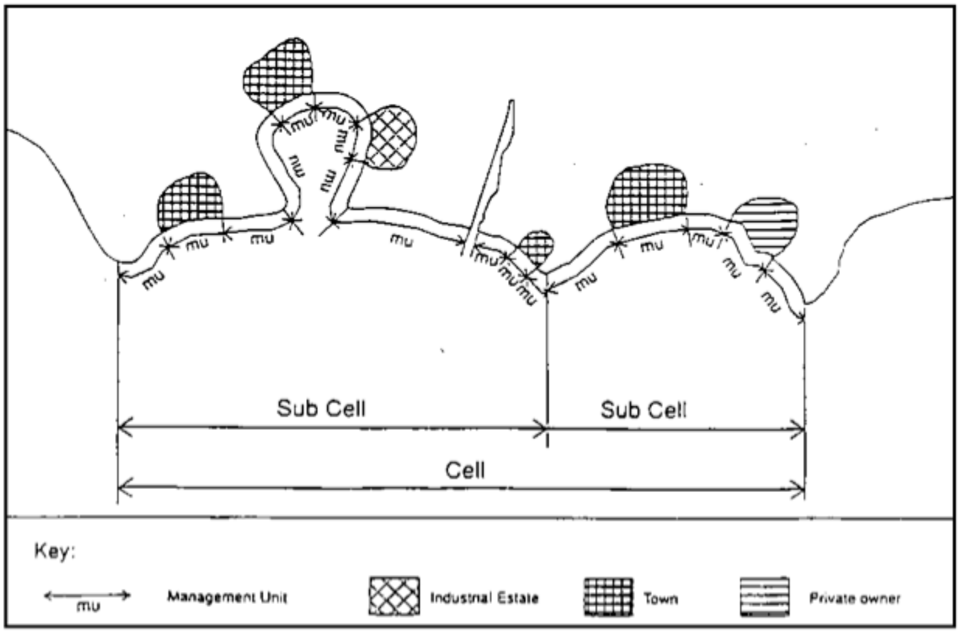
5. Strategy developed and accepted by stakeholders

- Establish draft sustainable shoreline management strategy for future development and protection, e.g. where can development be accepted and whether to defend, or continue to defend, assets with coast protection or shore protection measures or manage the risks through other means
- Part of the management strategy is the establishment of a cost sharing distribution for different types of developments and protection principles
- Publish the draft shoreline management strategy and circulate among relevant authorities for consideration and carry through public hearing process
- Establish consensus via the circulation and public hearing processes, formulate the agreed shoreline management plan and publish

6. Identification of Management Units

Identify *Management Units* within the plan area – the Sediment Cell or the Sediment Sub-Cell. Management Units represent a practical subdivision of the Sediment Cell into lengths that follow sediment cell principles and represents sections of homogeneous land use. Management Units are suitably sized sections of coasts to form the basis for Master Plans for conceptual design of shore development/protection schemes, the so-called Shoreline Master Plan (SMasP). An illustration of the relationship between Management Units and Sediment (Sub) Cells is shown in Figure C-2.

Figure C-2 Example of Sediment Cell, Sediment Sub-cells and Management Units.



7. Establish a Monitoring Plan and a Database

- Identified data gaps shall be filled by surveys, samplings and recordings as required to ensure that future plans will make use of the best and newest information.
- The development in the area shall be monitored through a monitoring programme, which can contain the following types of activities:
  - Monitoring of shoreline development and coastal profiles by regular surveys
  - Monitoring of hydrographic data, such as water levels and waves
  - Registration of coastal structures, nourishment and maintenance dredging etc.
- Establish a GIS based data base for storing and easy access to all relevant data

The Shoreline Management Plan thus provides the decision-makers with the necessary information about consequences in deciding on the future development and identifies manageable units (Management Units) within the Shoreline Management Plan area.

Knowing that a Shoreline Management Plan has a limited life span due to fast development of society and possible change in preference and to ensure that all relevant aspects always are included, it is advisable to revise the plan on a regularly basis.

The interval between plan revisions should be co-ordinated with the other involved/concerned planning authorities with respect to when they revise their plans (a suggestion is every 4 -5 years).

Inter-American
Development Bank