MINISTRY OF ENVIRONMENT AND ENERGY
REPUBLIC OF SEYCHELLES

THE STUDY
FOR
COASTAL EROSION
AND FLOOD CONTROL MANAGEMENT
IN
THE REPUBLIC OF SEYCHELLES

FINAL REPORT

MARCH 2014

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

CENTRAL CONSULTANT INC.
CTI ENGINEERING INTERNATIONAL CO., LTD.

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Summary

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1. Introduction

The Republic of Seychelles consists of over 115 islands scattered in the Western Indian Ocean and has a total land area of 452 km^2. The population was estimated at 87,000 in 2011 with over 90% concentrated in the narrow coastal strips around the three main islands of Mahe, Praslin and La Digue. The country depends on its coastal zone for most of its economic activities such as tourism and fishing. About 200,000 tourists visit the Seychelles annually.

The coastal zone has been affected by several disasters in recent years, such as the coastal erosion of Anse Kerlan on Praslin since 1986, disasters caused by the Indian Ocean Tsunami in 2004, three days of inundation in Victoria in 2004, and flooding in the southeast of Mahe in January 2013. Because of the sea level rise and increased rainfall intensity caused by climate change, the risk of natural disasters is increasing, alongside anthropogenic influence such as tourism and housing development in the coastal zone.

The study was conducted to formulate a coastal conservation plan and flood management plan to mitigate coastal erosion and flooding in the coastal zone, implement pilot projects which are applicable to the conditions in the Seychelles and undertake the related technology transfer.

2. Present Condition of Coastal Erosion and Flooding

The extent of coastal erosion was investigated from old maps, aerial photos and field investigations and classified into (1) coasts with long-term erosion, (2) coasts with seasonal changes by wave conditions, (3) coasts with erosion and accretion caused by the construction of structures, and (4) stable coasts. At North East Point and Baie Lazare the coast has been eroded presumably by offshore sediment transport caused by longshore transport or flooding though the reef channel. At North East Point and Beau Vallon in Mahe and Anse Kerlan in Praslin, the coast changes seasonally. If the coast has a wide beach which can accept the seasonal variations, there are no erosion problems. The groynes at Anse Kerlan and breakwaters at La Passe have caused erosion and accretion around the structures.

Past flooding was investigated from the records of disasters, analysis of the hydraulic conditions and field investigations and classified into (1) improper drainage, (2) increased run-off caused by urbanisation, (3) development of lowland areas, and (4) river mouth problems. At Victoria drainage problems were caused in some areas by reclamation fronting the old town and urbanisation. The development of lowland areas such as the construction of schools, public facilities and housing has caused inundation problems because of the limited flat land in the Seychelles. The reclamation for the international airport has caused inundation problems. The development of the wetland at Anse Au Pins, Au Cap and Anse Royale in Mahe and in La Digue brings inundation of those areas. Drainage from lowland to the sea is also made difficult because of accumulation of sand at the mouth by waves.

The main strategies related to coastal conservation and flood management in the Seychelles are the

Seychelles Sustainable Development Strategy (SSDS 2012-2020), National Climate Change Strategy (2009), and National Disaster Management Policy (2011). These strategies include an integrated coastal zone management plan and related action plans. Laws for the management of disasters include the Town and Country Act (1975), Town and Country Planning Act (1972), Environment Protection Act (1994), Beach Control Act (1971) and Removal of Sand and Gravel Act (1991). Environmental impact assessment (EIA) is also established by the regulations (1996).

The main organisations for coastal disaster management are the Ministry of Environment and Energy, Ministry of Land Use and Housing and Ministry of Community Development, Social Affairs and Sports. In the Department of Environment of the Ministry of Environment and Energy, the Climate Affairs, Adaptation and Information Division, National Meteorological Services and Coastal Adaptation and Management Section deal with coastal zone management which includes coastal erosion and flooding problems. The Divisions of Risk and Disaster Management in the Department is responsible for disaster response and disaster risk management. The Ministry of Land Use and Housing has authority regarding land use planning and regulation.

The main issues are:

- Coastal erosion and flood damage in lowland areas are caused by the construction of roads, breakwaters, houses and schools without consideration for the natural characteristics.
- The system and organisation of coastal management and EIA do not function effectively because of the lack of manpower and experience.
- There have been few past disasters and public interest in disasters is scarce due to limited basic information.
- The existing disaster management plan does not fully address the characteristics and limitations of the Seychelles.
- New types of disaster are expected due to further national economic development and climate change in the future in the coastal zone.

3. Coastal Management Plan

The coastal conservation plan and flood management plan were formulated based on the management cycle of (1) issue identification and baseline assessment, (2) management plan preparation and adoption, (3) action plan and project implementation and (4) monitoring and evaluation. Information management and education are also considered.

The objectives of the management plan are:

- To mitigate the damage to human lives and property from coastal erosion, flooding, tides, waves and tsunamis.
- To harmonise the mitigation measures with nature conservation and the use of coastal areas, wetlands and rivers.
- To contribute to coastal zone development and climate change adaptation for sustainable development in the future.
- To promote awareness and understanding of the value of the coasts and rivers and bring

together stakeholders.

The target year and design return period for the plan were decided as shown in Table 1.

Table 1: Target Year and Design Period

	Short Term	**Medium Term**	**Long Term**
Target Year	2020	2050	2100
Design Return Period			
Area	**Small Scale**	**Medium Scale**	**Large Scale**
Victoria Town	10 years	25 years	100 years
Others	5 years	25 years	100 years

The coastal or flood risk areas were classified and the risks evaluated. The measures were investigated from several alternatives for protection, accommodation and retreat. Sand nourishment and groyne construction for coastal erosion and drainage improvement and river improvement for flood control were selected as structural measures. As accommodation, measures such as land use regulations, warnings, emergency operation, public awareness and EIA were selected. The implementation schedule is from short to medium term for structural measures and from short to long term for non-structural measures.

The coastal conservation and flood management plans were formulated for the priority coasts or areas as action plans. The priority areas were selected based on necessity, urgency, technical characteristics and future development. The selected areas are North East Point and Baie Lazare in Mahe, Anse Kerlan in Praslin and La Passe in La Digue for coastal conservation and Victoria, Point Larue, Anse Au Pins, Au Cap and Anse Royale in Mahe for flood management.

4. Coastal Conservation Plan for Priority Coasts

North East Point

The 2km-long coast is located in the northeast part of Mahe and is protected by a narrow coral reef and beach rock. Waves come from the northwest from November to April and from the southeast from May to October. A coastal road and houses are located along the coast and the beach is used by local residents for recreation. The problems are erosion and wave run-up at high tide on the coastal road that affects traffic. The beach was eroded for 30m in width from 1960 to 2011 and the seasonal variation was about 20 m. The possible causes of the long-term erosion are offshore transport.

The proposed measures are sand nourishment for 20m in width for a 2 km stretch of the beach with maintenance nourishment. Sand or gravel nourishment is selected to compensate for the loss of sand and to keep beach use even the needs of maintenance nourishment because revetments cause loss of sand in front of the revetment.

Baie Lazare

The coast is located on the southwest coast of Mahe and is partly protected by a coral reef. Wetland has formed behind the sand bar where a coastal road and houses are located. The Baie Lazare River flows into the wetland and flushes out the sand bar in times of flooding. This possibly causes the loss of sand from the beach.

The problems are coastal erosion and wave run-up that affects the coastal road, shops and houses along the beach. Coastal erosion started two or three years before 2008. Wave run-up and coral debris were reported during the high tide in May 2007. Stone and wooden pile revetments were constructed in the past and today broken revetments remain.

The proposed measures are sand nourishment for 20m in width for a 400 m stretch of the beach with maintenance nourishment. It is necessary to monitor the beach profile to estimate the causes of erosion and the necessary sand volume for maintenance. Maintenance of the beach by sand nourishment is better than direct protection by revetments because revetments cause loss of sand from the beach. The prevention of sand loss during flooding by a submerged reef fronting the channel is not feasible because of cost. Traffic control at high tide is not reliable and other measures are necessary to combat the future sea level rise.

Anse Kerlan

The coast is located in the west part of Praslin and is protected by a coral reef. It receives waves from the northwest in winter and from the south in summer which causes seasonal changes in longshore sediment transport.

Along the coast, hotels and restaurants have been developed for tourism activities. The coast has one of the best beaches in Praslin.

The problem is that erosion causes the loss of property and use of the sandy beach for tourism. Originally at Anse Kerlan the beach sand was transported from the north to the south and deposited at Grand Anse. After the erosion became severe, five groynes were constructed in 1990 and they prevent the return of sediment from the south. The coastal road was shifted inland due to the erosion.

The proposed measures are three groynes and sand nourishment for 20m in width for a 1,000 m stretch of the beach with maintenance nourishment for stabilisation. Because the beach is important for tourism, sand nourishment and groyne construction are appropriate for recovering the beach and reducing longshore transport. Revetments may cause loss of beach sand.

La Passe

The coast is located in the west part of La Digue and is protected by a wide coral reef and Praslin Island to the west. Therefore, waves come from the north and south and not from the west. A jetty is provided for the ferry to Praslin. The anchorage is protected by three breakwaters.

The problem is that the breakwaters at the jetty cause accretion in the anchorage and erosion on the south beach. Erosion causes loss of land and wave overtopping onto the hospital grounds. The anchorage is difficult to use and needs dredging.

The proposed measures are one groyne and sand bypass of 1,000 m^3 of sand from the anchorage to the south beach. To reduce the accumulation of sediment in the sheltered area, a groyne with sand bypass from the anchorage to the eroded beach was proposed. The rearrangement of the breakwaters and groynes is one alternative. However, it would be necessary to conduct a detailed study and that is not within the action plan. The arrangement of the groynes was considered for future development based on the existing proposed plan.

5. Flood Management Plan for Priority Areas

Victoria Town

The town has been developed and urbanised in the seaward direction by reclamation. The ground level of the reclaimed land is higher than that of the old town. The problem is that the flow capacity of the drains and rivers is not enough for flood water.

The short-term plan involves drainage improvement of 8 drainage channels with a total length of 1.3km to provide a 40% increase in capacity. The channels are located at Olivier Maradan (88m), Market Street (108m), Huteau Lane (179m), Palm Street (121m), Benezet Street (125m), State House Avenue (96m), Independence Avenue (223m) and Francis Rachel (321m). The medium-term plan involves river improvement of five rivers by 1,080m-long bed excavation, widening of 340 m and construction of a 780m-long wall and 28m-long elevating dike. The five rivers are the River Anglaise, River Moosa, River Maintry, River St. Louis and River La Poudriere. As the cause is the lack of proper drainage, direct improvement or extension is more appropriate than reducing flood discharge by construction of retarding basins.

Point Larue

At one time the road ran along the coast and small rivers ran out to the sea. The Seychelles International Airport and main highway were developed on reclaimed land fronting the old coastal road. The problem is that the reclamation obstructs the river flow and drainage from the road. Flooding on the road makes it difficult to access the airport from Victoria Town. Also, drainage problems are severe at three lowland sites.

The proposed short-term measures are drainage improvement by a culvert (30m) under the road, extension of the drainage channel (40m) to the wetland and widening of the existing channels. The proposed medium- term measure is enlargement of the existing 8m-long culvert

Anse Au Pins

Wetland was formed along the coast and was at one time used to store flood water. The lowland around the wetland has been developed for housing or public facilities such as the district administrate office. The problem is that the deposition of sand at the outlet by waves causes flooding of the residential lowland area. At Chetty Flat the drainage does not work well due to lack of management.

At Chetty Flat the proposed short-term measure is the construction of a new 120m-long drainage channel to the sea. The proposed medium-term measure is improvement near the mouth of the river. One proposal is river bed excavation for 300m and the other is widening of the river for 200 m with construction of a new box culvert. At Chetty Flat the improvement of the existing channel involves a long distance and requires land acquisition. The proposed new channel is short and easy to maintain. The improvement of the rivers was considered according to the characteristics of each river and appropriate improvement was selected.

Au Cap

Wetland was formed along the coast and was at one time used to store flood water. The lowland around the wetland has been developed for a housing estate and public facilities such as schools. The problem is that the deposition of sand at the outlet by waves causes flooding of the residential lowland area. New measures using pipes have been introduced but the flow capacity is not enough.

The proposed short-term measure is improvement of the drainage. The proposed medium-term measures are improvement near the mouth of the river by widening of the river (620m) and construction of two bridges together with widening of the river mouth (230m). Flooding is caused by the lack of flow capacity at the mouth. Therefore, increasing the capacity by widening or dredging of the river and maintenance of the river mouth is appropriate.

Anse Royale

Wetland was formed along the coast and was at one time used to store flood water. The lowland around the wetland has been developed for housing or public facilities such as schools. The problem is that the deposition of sand at the outlet by waves causes flooding of the residential lowland area.

The proposed measure is a 120m-long drainage ditch for the short term. The proposed measures for the medium term are improvement near the mouth of two rivers by widening of the rivers (170m), river bed excavation (1400m) and construction of a bridge together with widening of the river mouth (130m). Flooding is caused by the lack of flow capacity at the mouth. Therefore, increasing the capacity by widening or dredging of the river and maintenance of the river mouth is appropriate.

6. Pilot Projects

The pilot projects were implemented from among the selected plans to clarify the effectiveness of the plans, acquire the necessary technology and improve the plans. The projects were selected in view of urgency, importance, applicability to the Seychelles and the scale of the project. The selected projects are sand nourishment at North East Point, groyne construction and sand bypass at La Passe, culvert and channel construction at Point Larue and outlet improvement at Au Cap. However, the culvert at Point Larue was cancelled because the permission of landowner was not obtained within the study period.

North East Point

The pilot project at North East Point was intended to introduce sand nourishment to the Seychelles as a mitigation measure against coastal erosion, to evaluate the effectiveness and to identify the mechanism and amount of erosion. 4,000m^3 of sand was nourished on the 400m-long southern part of the beach. From the beach monitoring results after one year, the beach changes seasonally and it is difficult to estimate the loss of sand. It is necessary to continue beach monitoring. The nourished sand moved and accumulated at the north where the risk of wave overtopping is high. At present, the nourished sand is effective for the protection of the beach.

La Passe

The purpose of the project at La Passe was to mitigate the impact of the construction of breakwaters which cause the accumulation of sediment at the anchorage and erosion on the south side of the port. A 50m groyne was constructed to prevent longshore sediment movement from south to north. Also, a sand bypass system was provided from the anchorage to the eroded beach.

From the beach monitoring results, longshore movement decreased and the beach became stable. The submerged groyne appeared due to dredging and serves to reduce longshore movement together with the new. Beach was created for the use of local people and tourist.

At present the effect of groyne is clear sediment movement though long-term monitoring is necessary. The nourished beach will contribute to beach use.

Development of La Passe Port is planned and conservation of beach is important as tourism resources. The pilot project shows a kind of mitigation measures to the impact of breakwaters. The results can be applied to the development of the port as sustainable manner.

Au Cap

The project intended to improve the flow capacity at the river mouth and develop new measures which can be applied at the outlet from the wetland to the sea. The capacity development of DOE was also intended in the design and management of this kind of outlet. A 25m-long outlet was constructed to ensure smooth flood flow and prevent sand accumulation in the channel.

The monitoring results show that the flow capacity improved compared with before the construction though some dredging work is necessary. In future, this kind of structure will be one of the measures for river mouth problems. DOE is planning to apply the results to other outlet and has begun to implement.

7. Technical Transfer

Technology transfer was conducted by improvement of the technical guidelines, OJT (on-the-job training), workshops, seminars and training in Japan. The guidelines for EIA, drainage design, beach monitoring and others were improved. OJT was implemented in the taking of aerial photographs, coastal investigations, flood damage surveys, GIS training and others. In the seminars, Japan's disaster management, pilot projects and technology exchange with Mauritius were explained and discussed. Coastal conservation measures and flood management were studied in the training in Japan. The results were applied to the disaster recovery works after the floods in January 2013 and 2014.

8. Conclusion and Recommendations

In order to mitigate the disasters caused by coastal erosion and flooding, the coastal conservation plan and flood management plan were formulated after detailed study, issue identification and evaluation of alternatives. Sand nourishment and groyne construction were proposed to retain the sandy beaches as important resources for tourism in the coastal conservation plan. Pilot projects were implemented to study the applicability of the plan and show its effectiveness, though long-term monitoring is necessary. Drainage and river improvements were proposed to mitigate inundation problems as the flood management plan. The river improvements include increasing the flow capacity from the wetland to the sea. An outlet was constructed as a pilot project and showed its effectiveness together with suggestions for improvement.

The capacity of the relevant officials was developed during the study through OJT and training. The planning, designing and procurement of the pilot projects were conducted in collaboration with the counterparts and contributed to their capacity development.

At the end of the study, flood disasters occurred in January 2013 and 2014 in the southeast of Mahe and La Digue. As the recovery work, river improvement works were started based on the flood management plan proposed in the study. Not only the plan but the outlet constructed in the pilot project were applied and the experience of the pilot projects was utilised. The construction works will continue for several years. The results of the study will be applied and contribute to mitigating coastal and flood disasters and to developing engineering capacity in the Seychelles.

From the study the recommendations are:

- Review of plans at certain intervals with the use of the adaptive management system
- Development and enhancement of land use regulations in risk areas
- Allocation of a budget for implementation of the plan and maintenance
- Reinforcement of EIA in areas at high risk of coastal erosion and flooding
- Beach monitoring of eroding coasts and water level monitoring of rivers and wetlands
- Improvement of the disaster response manual based on past experiences
- Recording of past experiences and informing of future generations

Table of Contents

Chapter 3 Component 2: Formulation of Management Plan 3-1

Chapter 7 Technical Transfer 7-1

Chapter 8 Recommendation 8-1

Appendix

List of Tables

List of Figures

Abbreviations and acronyms

AfDB	African Development Bank
CAAID	Climate Affaires, Adaptation and Information Division
CAMS	Coastal Adaptation and Management Section
CESD	Climate and Environment Service Division
CFTC	Commonwealth Found for Technical Cooperation
COP2	Second Conference of the Parties
CRU	Climate Research Unit, United Kingdom
DA	District Administrator
DOE	Department of Environment
DOT	Department of Transport
DMP	Disaster Management Plan
DRDM	Divisions of Risk and Disaster Management
DRR	Disaster Risk Reduction
EEWS	Environment Engineering and Wetland Section
EIA	Environmental Impact Assessment
EMPS	Environment Management Plan in Seychelles
GCM	Global Climate Model
GDP	Gross Domestic Product
GEF	Global Environment Facility
GIS	Geographical Information System
GOJ	Government of Japan
GOS	Government of the Republic of Seychelles
GPS	Global Positioning System
GUI	Graphical User Interface
HEC-RAS	Hydrologic Engineering Centers-River Analysis System
IOC (UNESCO)	International Oceanographic Commission
IPCC	International Panel on Climate Change
ISDR	International Strategy for Disaster Reduction
JICA	Japan International Cooperation Agency
MCDY	Ministry of Community Development and Youth
MEE	Ministry of Environment and Energy
MHAETE	Ministry of Home Affairs, Environment, Transport and Energy
MLUH	Ministry of Land Use and Housing
MND	Ministry of National Development
MSLD	Mean Sea Level Datum
NBS	National Bureau of Statistics
NDC	National Disaster Committee
NGO	Non-Governmental Organization

NMS	National Meteorological Services
NOAA	National Oceanic and Atmospheric Administration
NTB	National Tender Board
OJT	On the Job Training
POU	Procurement Oversight Unit
PUC	Public Utilities Corporation
QGIS	Quantum Geographical Information System
RECOMAP	Regional Coastal Management Programme
SCR/SR	Seychellois Rupee
SEA	Strategic Environmental Assessment
SSDS	Seychelles Sustainable Development Strategy
SST	Sea Surface Temperature
TCPA	Town and Country Planning Act
TSZ	Tidal Staff Zero
UNESCO	United Nations Educational, Economical, Scientific and Cultural Organization
UNFCC	United Nations Framework Convention on Climate Change
UNDP	United Nations Development Programme

Chapter 1 Introduction

Chapter 1 Introduction

1-1 Background

The Republic of Seychelles consists of over 115 islands scattered in the Western Indian Ocean and has a total land area of 452 km^2. The population was estimated at 87,000 in 2011 with over 90% concentrated in the narrow coastal strips around the three main islands of Mahe, Praslin and La Digue. The country depends on its coastal zone for most of its economic activities such as tourism and fishing. About 200,000 tourists visit the Seychelles annually.

The coastal zone has been affected by several disasters in recent years, such as the coastal erosion of Anse Kerlan on Praslin since 1986, disasters caused by the Indian Ocean Tsunami in 2004, three days of inundation in Victoria in 2004, and tidal flooding in the north of Mahe in 2007. Because of the sea level rise and increased rainfall intensity caused by climate change, the risk of natural disasters is increasing, alongside anthropogenic influence such as tourism and housing development in the coastal zone.

The Government of the Republic of the Seychelles (hereinafter referred to as GOS) prioritised the issues of coastal erosion and flooding during preparation of the Seychelles' Second National Communication to the United Nations Framework Convention on Climate Change (UNFCC). Thereafter, GOS prepared a report on coastal erosion and flooding in 2008 with the support of UNDP/GEF. In the report, a number of recommendations were put forward to mitigate the vulnerability of the coastal sector.

After the establishment of the Cool Earth Partnership by GOS and the Government of Japan (hereinafter referred to as GOJ) in September 2008, the Japan International Cooperation Agency (hereinafter referred to as JICA) held a dialogue with the Ministry of Environment, Natural Resources and Transport in February 2009. After a preparatory study by JICA in June 2009, GOS officially requested the Study for Coastal Erosion and Flood Control Management in the Republic of the Seychelles (hereinafter referred to as the Study) and GOJ decided to conduct the Study. In June 2010 the Detailed Planning Survey Team of JICA and the Department of Environment (hereinafter referred to as DOE) in the Ministry of Home Affairs, Environment and Transport agreed and signed the Scope of Work for the Study. The Study was launched with the explanation of the inception report in February 2011 as a three-year project until March 2014.

1-2 Objectives and Study Area

The objectives of the study are as follows:

1) To formulate a coastal conservation plan with regard to disasters to enhance coastal management;
2) To formulate a flood management plan to reduce flood risks;
3) To implement pilot projects for coastal conservation and flood management, in order to confirm the effectiveness of the measures to be taken and to enhance the capacity of the relevant personnel engaged in coastal conservation and flood control management;
4) To undertake technology transfer to the relevant personnel through the joint activities of the

Study as well as trainings and workshops.

The Study area is as follows:

1) For coastal conservation with regard to disasters:
   Coasts of the islands of Mahe, Praslin and La Digue;
2) For flood management:
   Town of Victoria and other flood risk areas on the islands of Mahe, Praslin and La Digue.

The map of the Study area is shown in Figure 1-2-1 and Figure 1-2-2.

1-3 Basic Policies

The basic policies of the study are: focus on the characteristics of the Seychelles, coordination with related organisations and the public, and utilisation of the information obtained.

The Seychelles Strategy, Seychelles Climate Change Strategy and Seychelles Sustainable Development Strategy (SSDS) 2012-2020 are existing documents while the Disaster Management Plan (DMP) is being prepared. However, in the field of coastal erosion and flooding, there is a shortage of information, cause analysis, and practical mitigation measures and plans.

The types of coastal erosion and flooding are rather limited because of the natural conditions. The coastal erosion is related to littoral drift caused by south-easterly waves during the north-west monsoon and north-westerly waves during the south-east trade winds. The flooding is flash floods at the foot of the mountains where the coastal lowland is located. Man-made activities such as lowland development, construction of structures and coral sand mining are one of the causes in addition to the natural conditions.

There are several organisations executing disaster mitigation activities. They are the DOE, Department of Community Development of the Ministry of Community Development and Youth (MCDY), Ministry of National Development (MND), District Administration Office and so on. For disaster mitigation, coordination is necessary between these organisations.

Shortage of information is also a problem. If people have enough experience, they can prepare for disasters. Because disasters are very rare in the Seychelles, information exchange is very important.

1-4 Study Components and Methods

The executed Study was divided into four components, namely basic study, formulation of plans, implementation of pilot projects and technology transfer in coastal conservation and flood management.

Component 1: Basic Study

The basic study consists of the collection of existing data, surveying and monitoring of coastal and flood risk areas, and analysis of coastal erosion and flooding. In the basic study, the conditions and causes of coastal erosion and flooding were analysed based on the corrected data and surveyed results. Past EIA reports were collected and evaluated under the present conditions to improve the EIA manual. The performance of existing structures for coastal and flood disaster prevention was analysed to improve the design guidelines.

Component 2: Formulation of plans for coastal conservation and flood management

The plan for coastal conservation to prevent disasters was formulated for several priority coasts which were selected from the whole coastline of the three islands according to natural characteristics and severity of damage. The plan for flood management was divided into a plan for Victoria Town and a plan for other flood risk areas. The plan for other flood risk areas was formulated for several priority areas which were selected according to local characteristics and severity of damage.

The plans were formulated under the national strategy and related higher plans such as EMP. The basic concept of the plan was selected based on five positions, namely do-nothing, accommodation, working with the natural process, protection and positive action considering abilities and future expenses. The realisation of the plan was also considered by making clear the necessity and priority of the projects and the understanding of local people.

Because resources are limited in the Seychelles, the appropriate technology was applied to correspond with the natural and socio-economic conditions, the magnitude of damage and future development. The structures were made of local materials such as stones and wood and constructed with local skills. Nature-friendly measures were applied such as sand nourishment which mitigates coastal erosion.

In elaborating the plans, small-scale countermeasures and non-structural measures, except for large-scale projects, were recommended in consideration of the Seychelles' socio-economic characteristics.

Component 3: Pilot Projects

The pilot projects were implemented from the selected plans to clarify the effectiveness of the plans, to acquire the necessary technology and to improve the plans. The projects were executed by considering EIA procedures, procurement procedures and the participation of local people through discussions.

Component 4: Technical Transfer

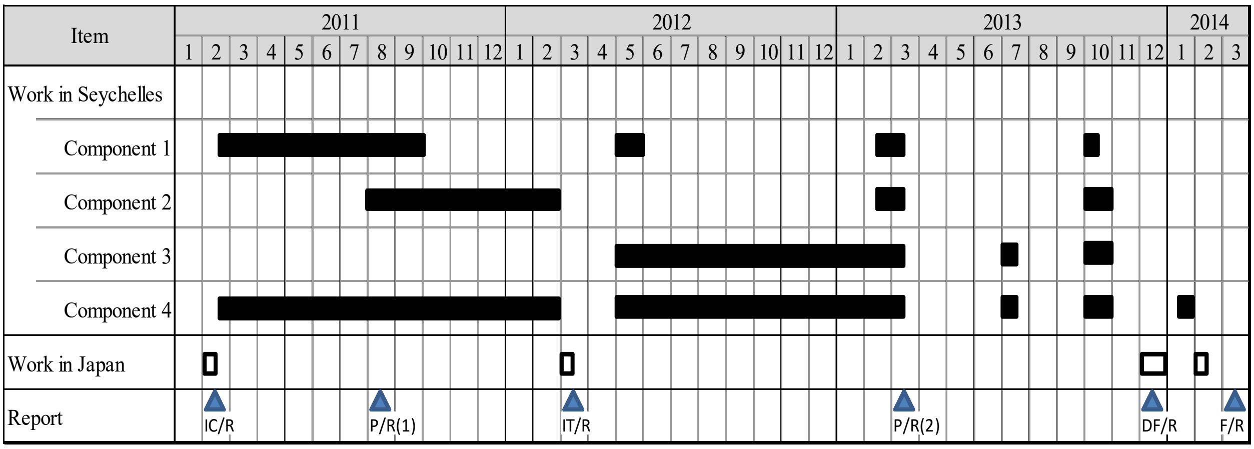
As the main purpose of the study was to enhance the capacity to mitigate the risks of coastal erosion and flooding, technology transfer was conducted to the related government officials in the fields of coastal erosion and flooding by OJT (on-the-job training), workshops, seminars and training in Japan. The capacity development of NGOs, contractors and consultants was also considered.

Because it is difficult to estimate future climate change and economic development, adaptive management is necessary. The ability to conduct the processes including monitoring of conditions and improvement of the plans was enhanced during the Study. Technical guidelines were established and improved based on the results of the Study.

1-5 Study Schedule

The schedule of the Study is shown in Table 1-5-1.

Table 1-5-1: Study Schedule



Note: IC/R: Inception Report, P/R: Progress Report, IT/R: Interim Report, DF/R: Draft Final Report, F/R: Final Report

1-6 Composition of Report

This report explains the final results of the project as the final report. As an introduction, the background, objectives and components of the study are explained in Chapter 1.

In Chapter 2 the results of the basic study are explained. The natural conditions, socio-economic conditions and policies, legal framework and organisation are included as basic conditions. The analysis of coastal erosion problems and flooding and drainage problems was also explained.

In Chapter 3 the management plan for coastal conservation and flood management is explained. At first, the procedure for formulation of the plan is explained. The planning cycle covers issue identification, preparation and adoption of the management plan, implementation, monitoring and evaluation. The management plan is formulated after alternative measures are discussed.

In Chapter 4 the coastal conservation plan for the priority coasts is explained. The selected priority coasts were North East Point and Baie Lazare in Mahe, Anse Kerlan in Praslin and La Passe in La Digue. The erosion problems on each coast were summarised and measures were selected from several alternatives.

Chapter 5 explains the flood management plan for the priority areas. The areas are Victoria Town, Pointe Larue, Anse aux Pins, Au Cap and Anse Royale. The flood management plan is explained based on the drainage and flood analysis. The main measures are drainage improvements and non-structural measures for future climate change and economic development.

In Chapter 6 the selection of pilot projects, the planning and design of the projects and the results are explained. North East Point and La Passe were selected as the sites for coastal works and Pointe Larue and Au Cap for flood mitigation works. The detailed plan and design of each project, procurement, construction and supervision, and monitoring plan are explained in this chapter.

In Chapter 7 the contents and results of technology transfer are explained. The transfer involves preparing of guidelines, on-the-job training, training in Japan, workshops and seminars. Two seminars and three workshops were held in Victoria Town. During the execution of the project, OJT was conducted for the C/P and others in the monitoring, planning and designing of structures.

In Chapter 8 for the implementation of the plans and mitigation of coastal and flood damages several recommendations are explained from the execution of the Study. Those are related to the management plan, laws and organization, financial action, EIA, monitoring, disaster response and public communication.

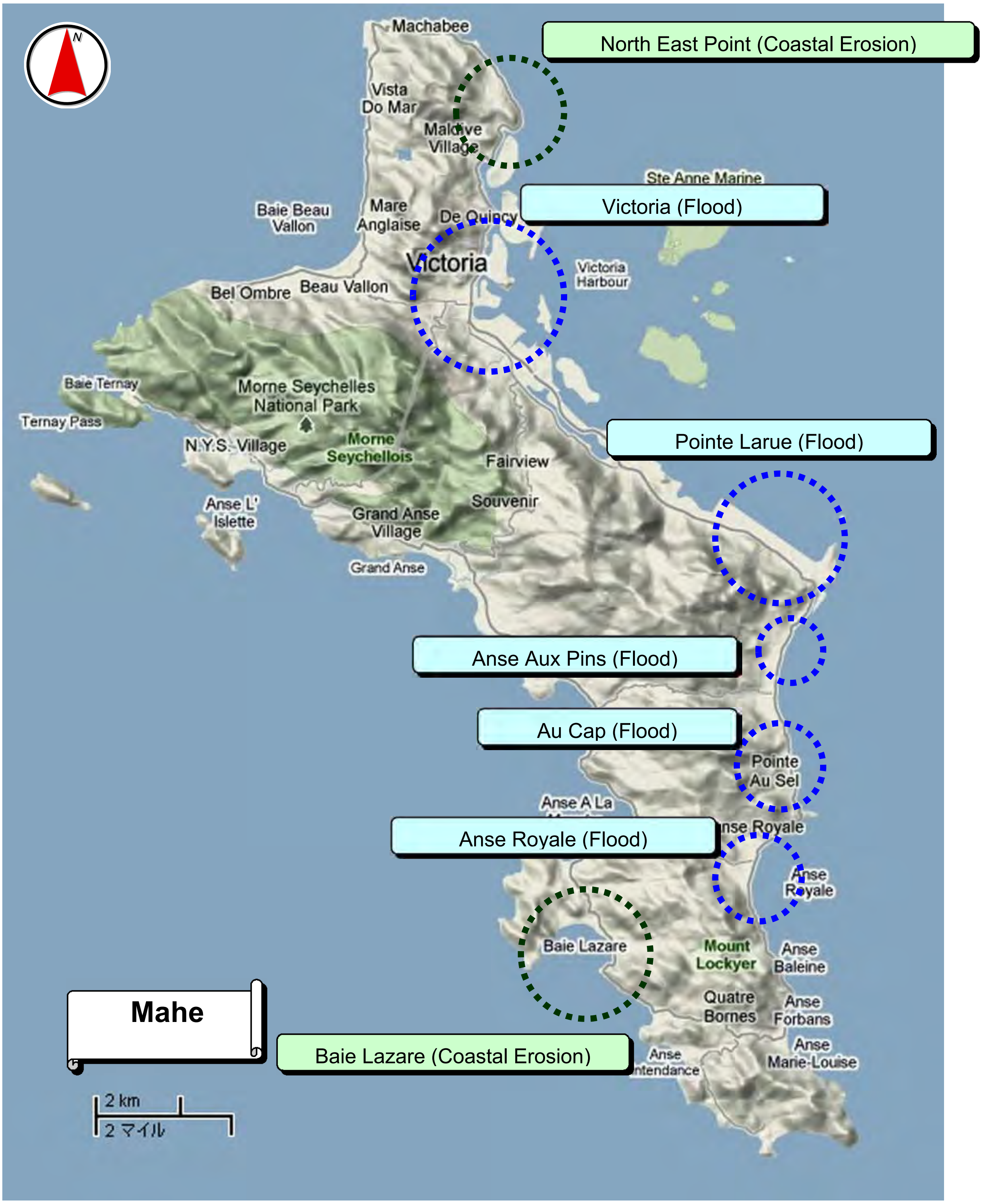


Figure 1-2-1: Map of the Study Area (Mahe)

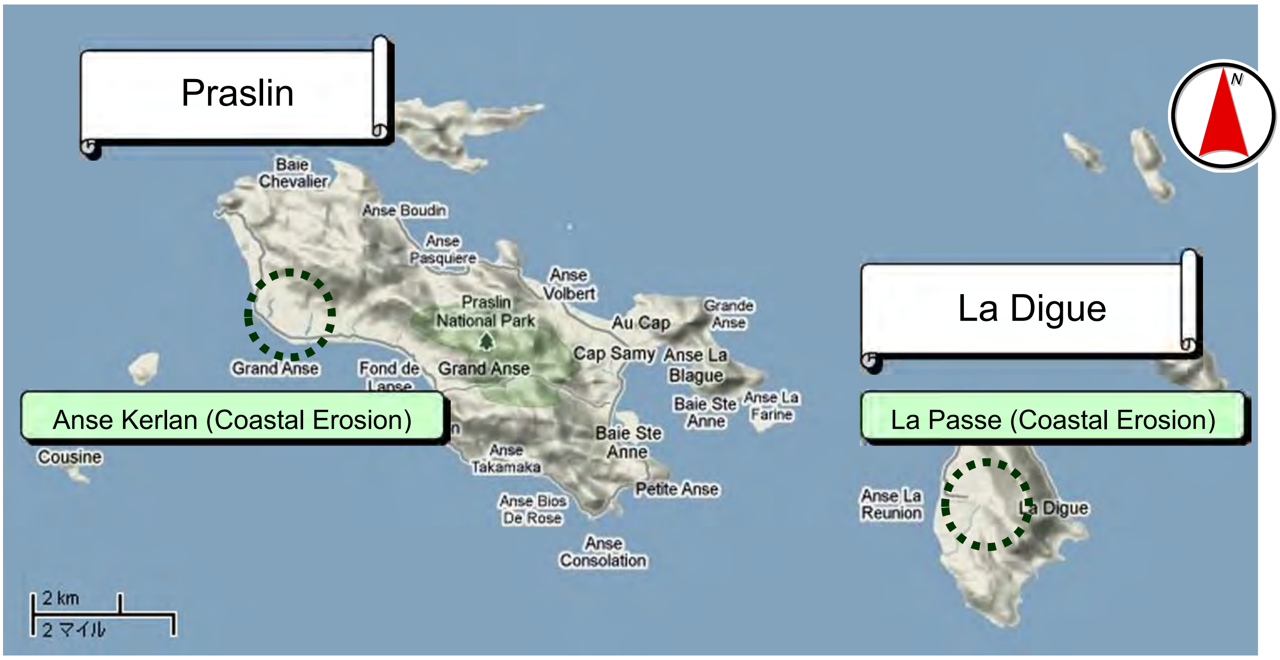


Figure 1-2-2: Map of the Study Area (Praslin and La Digue)

Chapter 2 Component 1: Basic Study

Chapter 2 Component 1: Basic Study

2-1 Natural Conditions

2-1-1 Geography

The Republic of the Seychelles consists of over 115 islands scattered over 1 million km^2 of sea in the middle of the Western Indian Ocean with a total terrestrial area of 445 km^2 and an Exclusive Economic Zone of 1.3 million km^2. The Seychelles' archipelago is divided into two distinct groups: the Mahe group, 43 inner islands in all, composed of granitic rock with high mountains; and the coralline group numbering 73 or more islands, for the most part only a little above sea-level. Mahe, the most important island, lies at latitude 4 degrees south and longitude 55 degrees south-east. It is 27 km long and 11 km wide with a land area of 148 km^2, rising abruptly from the sea to a maximum altitude of 905 m at the peak of Morne Seychellois. Two other islands of major importance as regards size and population are Praslin, 33.6 km from Mahe, and La Digue, 48 km away (Seychelles in Figures, 2011 ed., National Bureau of Statistics (NBS)).The granitic islands are of Precambrian age (650 million years old) and were created 135 million years ago during the break-up of Gondwanaland.

2-1-2 Climate

The Seychelles' climate is always warm without extremes. The temperature seldom drops below 24ºC or rises above 32ºC. During the north-west monsoon from October to March, the sea is generally calm and the weather is warm and humid, with average winds of 8-12 knots. During January and February the islands receive rain, rejuvenating the rivers and streams. The months between May and September bring drier and cooler weather, with winds of 10-20 knots. The table below is a summary of the statistical averages at Seychelles International Airport from 1972 to 2010.

Table 2-1-1: Climate Conditions

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	402.6	283.2	194.9	186.7	151.6	105.1	76.6	119.3	154.0	189.7	206.3	302.8
Temperature (ºC)	26.9	27.4	27.8	28.1	27.8	26.7	26.0	26.0	26.5	26.9	26.9	26.9
Humidity (%)	82	80	80	80	79	79	80	80	79	79	80	82
Wind Direction	NW	NW	NW	SW-NW	SE	SE	SE	SE	SE	SE	SW-NW	NW
Wind Speed (knots)	6.3	6.3	5.2	4.9	7.8	10.4	11.4	12.1	11.3	7.9	5.4	5.4

(http://www.seychelles.com/en/about_seychelles/climate.php)

2-2 Socio-economic Conditions

2-2-1 Population

The total population was about 90,000 in 2011 with 86% living on Mahe as shown in Table 2-1-1. The average family size is five and 20% of the population is under the age of 15. The life expectancy at birth is 72.6 years for both sexes; 68 years for men and 78 years for women (Seychelles in Figures, 2012 ed., NBS).

Table 2-2-1: Population and GDP

Item	2006	2007	2008	2009	2010	2011
Total Population (thousand)	84.6	85.0	87.0	87.3	89.7	87.4
Male	42.9	43.2	45.0	45.0	45.9	43.1
Female	41.7	41.8	42.0	42.3	43.8	44.3
Geographical Distribution (thousand)						
Mahe	73.9	74.3	76.0	76.3	77.5	75.6
Praslin	7.4	7.4	7.4	7.6	8.5	8.3
La Digue & Outer Islands	3.3	3.3	3.5	3.5	3.7	3.5
Gross Domestic Product						
GDP (million rupees)	5,600	6,962	9,100	11,450	11,621	13.119
Per capita GDP (thousand rupees)	66.2	81.9	104.7	131.2	129.5	150.0

(Seychelles in Figures, 2012 ed., NBS)

2-2-2 Economic Activities

The Seychelles' economy depends largely on tourism and fishing, which is chiefly based on tuna, as earners of foreign exchange. Over 128,000 tourists visited the islands in 2005 and 194,500 in 2011 as shown in Table 2-2-2. Agriculture provides a limited amount of food for local consumption, restricted arable land being one of the controlling factors.

Since 1971, with the opening of the international airport, tourism has been the major earner of foreign exchange, with the tourist industry employing a large percentage of the population. Some 75% of visitors come from Europe, namely France, Italy, Germany and others, while 13% come from Africa.

Fishing and related activities are a major component of the Seychelles' economy. The main fisheries sectors are local fishery which targets reef fishes, and the multinational tuna fishery which targets tuna in the extensive waters of the Seychelles' Exclusive Economic Zone.

The early local economy of the Seychelles was based on the production of cinnamon, copra and coconut oil. Nowadays vegetables are grown around the narrow coastal plains of Anse Royale and Anse Boileau on Mahe. Local industry is poorly developed. With the exception of the tuna processing plant, a paint factory and the manufacturing of beer and soft drinks, there is little manufacturing in the Seychelles.

Table 2-2-2: Trends in Visitor Arrivals

Item	2006	2007	2008	2009	2010	2011
Total Visitor Arrivals (*1,000)	140.6	161.3	159.0	157.5	174.5	194.5

(Seychelles in Figures, 2012 edition, NBS)

2-2-3 Land Use

In Mahe almost half of the land is forest and protected areas, and residential areas are increasing with urban development (Zoran Vuksanovic (2008): Ile Perseverance, a new town in the Seychelles has an innovative way of avoiding urban sprawl, 44th ISOCARP Congress).

Table 2-2-3: Land Use on Mahe

Land Use	Area km^2	%
Residential areas	32	20.1
Protected areas	16	10.0
Agriculture	26	16.7
Built-up non residential	12	7.7
Forest area	59	38.6
Total	155	100

(Zoran Vuksanovic (2008): Ile Perseverance, a new town in the Seychelles has an innovative way of avoiding urban sprawl, 44th ISOCARP Congress: Included unknown 10km^2 and 6.5%)

2-3 Policy, Legal Framework and Organisation

The Seychelles Strategy 2017, Strategy for Climate Change in Seychelles, Seychelles Sustainable Development Strategy 2012-2020 and Seychelles Sustainable Development Strategy 2021-2030 are current strategic development documents. The contents are general and do not fully address the characteristics and limitations of the Seychelles.

2-3-1 National Policy

There are three strategies and one policy related to coastal erosion and flood mitigation. They are the Seychelles Strategy 2017, Strategy for Climate Change in Seychelles, Seychelles Sustainable Development Strategy 2012-2020 and National Disaster Management Policy.

(1) Seychelles Strategy

In the Seychelles Strategy 2017 (2007), the Government of the Seychelles is committed to doubling the country’s gross domestic product (GDP) by 2017 in order to improve the standard of living through focused fisheries and tourism expansion programmes. In 2007 the population had a per capita GDP of US$ 8,722.

Government policies to enhance the construction industry will focus on bolstering human resources capacity and reviewing technical and architectural specifications. The transport situation will be improved through enhanced road planning and upgrading of the public transport infrastructure. Careful land management plans will be developed focused on deriving the maximum utility from land allocation, with a detailed assessment of future land needs and an assessment of possible areas for reclamation. Programmes will also be introduced to raise public awareness of and contribute to environmental protection. The people of the Seychelles will also be encouraged to view themselves as environmental stakeholders (Seychelles Strategy 2017 (2007)).

The AfDB report in 2011 stated that the Seychelles’ economy had undergone a major transformation in the previous two years. Before 2009, recurrent expansionary fiscal and monetary policies, coupled with mismatched trade and exchange rate policies, produced serious macro-economic imbalances. The economy became so fragile that, at the end of 2008, it defaulted on its foreign debt repayment. Because of a comprehensive reform programme that the Government put in place with the support of major development partners, the economy has recorded a significant turn-around. Over this period, the country improved its creditworthiness and demonstrated a good track record in reforms (African Development Bank (AfDB): Seychelles - Country Strategy Paper 2011-2015, 2011).

(2) Initial National Communication

As for climate change, the Seychelles Initial National Communication was prepared based on the guidelines provided by Decision 10/CP.2 of the Second Conference of the Parties (COP2) in 2000. It is composed of five chapters: (1) National circumstances; (2) Greenhouse gas inventory: Sources and sinks; (3) Technologies and measures for mitigation; (4) Vulnerability, impact and adaptation options; and (5) Capacity building needs and priorities.

The communication reported that natural habitats and biodiversity, the coastal zone and human settlements, agriculture, water resources, fisheries, human health, natural disasters and insurance were the key socio-economic sectors that were considered for sensitivity and vulnerability to climate change.

For the coastal zone and human settlements, a rise in sea level, as envisaged in the IPCC reports, will particularly affect tourism and fisheries, which are the pillars of the economy. About 85% of human settlement and infrastructure in the Seychelles is located along the coast. A rise in sea level will result in the displacement of a large proportion of the population. Coastline recession will also adversely affect infrastructure and biodiversity. Several low-lying coral islands and sand cays could disappear. There would be enhanced coastal flooding, particularly associated with severe storms or abnormal high tides, resulting in erosion of shorelines and tourist beaches. This would be exacerbated by the fact that the steep slopes of the main granitic islands are prone to landslides, while the very narrow strip of coastal plain is prone to flooding. The quantity and quality of water resources are also expected to be affected.

Adaptation options include planned retreat strategies, accommodation strategies, defence strategies and the adoption of integrated coastal management when there are recurring opportunities to adapt to sea level changes. Capacity building in these areas is also an important factor in adaptation.

For natural disasters, as the sea surface temperature rises, the ocean area, which can spawn tropical cyclones, may bring the increased probability of extreme events in the Seychelles. A feeder-band within an active convergence zone passing over Mahe could bring strong gusts in excess of 50 knots (100 km/hr), with torrential rain causing flash floods. With warming of the ocean, there could be changes in the frequency, intensity and locality of tropical cyclones, making the Seychelles islands far more vulnerable. Storm tides and extreme wave actions pose the greatest threat to tourism activities in low-lying coastal areas. Intense conventional storms may be localised, but the resulting flood waves could move rapidly down the valleys resulting in coastal flooding and landslides (Ministry of Environment and Transport: Seychelles Initial National Communication under the United Nations Framework Convention on Climate Change, 2000).

(3) Seychelles Sustainable Development Strategy 2012-2020

The overall objective of the EMPS 1990-2000 and EMPS 2000-2100, despite being called the Environment Management Plan, was to promote, coordinate and integrate sustainable development in the Seychelles. The EMPS 2000-2010 review concluded that due to a lack of suitable indicators, proper evaluation of the effectiveness of the plan with regard to development in the Seychelles could not be made. It further elaborated that the EMPS 2000-2010, whilst well-coordinated overall, lacked appropriate integration across all sectors. Therefore, there is now a shift in environment planning to a sustainable development strategy (SSDS).

The vision of the SSDS is to realise a knowledge-led and innovation-driven approach to sustainable development that guarantees an increasing quality of life inclusive of the natural environment, and to achieve a balance between the social and economic needs of present and future generations whilst conserving the integrity of natural capital.

The action plan brings together thirteen thematic areas identified to implement the strategy. The estimated cost of implementing the action plan is USD 704 million. In the SSDS, there are 13 thematic goals. In the goals there are six sub-goals aimed at the formulation of coastal conservation and flood management plans as follows:

- Development of the necessary structures and policy framework to integrate social development and sustainable use of resources.
- Long-term national development and land use management strategies for sustainable land management.
- Effective and integrated national coastal zone management framework.
- Enhanced actions on mitigation of climate change.
- Provision of life-long learning experiences at all levels of society to adopt environmentally sustainable practices.
- Strengthening of the capacity to effectively manage the environment of the Seychelles and establish an effective environmental information management system.

(Seychelles Sustainable Development Strategy, 2012-2020)

(4) Seychelles National Climate Change Strategy

In the national climate change strategy, the vision is to minimise the impacts of climate change through concerted and proactive actions at all levels of society.

To address these issues, the following five strategic priority objectives are proposed:

1) To advance understanding of climate change, its impacts and appropriate responses;
2) To put in place measures to adapt, build resilience and minimise vulnerability to the impacts of climate change;
3) To achieve sustainable energy security through reduction of greenhouse gas emissions;
4) To mainstream climate change considerations into national policies, strategies and plans;
5) To build capacity and social empowerment at all levels to adequately respond to climate change.

From these objectives, the following action plan is defined and related to coastal erosion and flood management. It covers a very wide range of actions as follows:

- Establishment of long-term monitoring of oceanographic parameters, including sea level rise and sea surface temperature;
- Consolidation of the existing beach and wetland monitoring programmes;
- Access to high-resolution regional and global ocean and coastal datasets;
- Establishment of sea level rise/tidal changes;

- Expansion of the rainfall monitoring network for the development of appropriate predictive and design tools;
- Evaluation of potential coastal risk zones, vulnerabilities and level of protection in place;
- Development of legally binding coastal land-use plans (incorporating the impact of climate change and natural changes in coastal processes);
- Establishment of basic design specifications, incorporating climate change considerations into coastal drainage, coastal protection, road and other infrastructure development projects;
- Establishment and strengthening of the role of EIA and SEA in climate change adaptation and risk/impact reduction;
- Development and implementation, on a pilot scale, of effective adaptation measures and tools at community level, including coastal restoration approaches;
- Research and development of alternative coastal designs which accommodate sea level rise;
- Demonstration of adaptation technology implementation, with a focus on nature-based methods;
- Identification and undertaking of a review of the main institutions involved in responding to climate change, identification of conflicts or complementary efforts and exploration of networking and synergies;
- Review of key procedures, guidelines and specifications to include climate change adaptation considerations into national planning;
- Engagement of government with the scientific community for input of climate risk information into the formulation of national development strategies, policies and laws;
- Identification of key stakeholders and development of policies for involvement of key stakeholders in climate change adaptation through a multi-stakeholder coordination committee;
- Introduction of climate change research and adaptation training at university level;
- Development and maintenance of a knowledge base and use of case studies for climate risk reduction;
- Integration and adaptation of leadership training in climate change, climate variability and coastal security.

(Seychelles National Climate Change Committee: Seychelles National Climate Change Strategy, 2009)

(5) Seychelles National Disaster Management Policy

The Government of the Seychelles recognises that the building of resilience to disaster is an on-going process of iterative review and improvement to meet changing circumstances. It furthermore recognises the International Strategy for Disaster Reduction (ISDR) and the *Hyogo Framework for Action 2005-2015* as providing a sound, comprehensive framework for the elaboration of national initiatives and programmes to integrate Disaster Risk Reduction (DRR) across development sectors and enable the effective elaboration and implementation of the disaster management cycle in the Seychelles.

This policy document provides a means for the Government to set out concisely its intent and proposed course of action in pursuit of the desired objectives. This policy is intended to provide the parameters for the subsequent development of detailed action plans, procedures and protocols to address DRR needs in the various sectors and scenarios present in the Seychelles.

The policy is founded on a Mission Statement and sets out the Government's intentions, as resources and circumstance may allow, in the context of five objectives and activities logically derived therefrom. It is intended that the policy be reviewed as circumstances may require but not less than every 5 years regardless.

Mission Statement

To establish and continually review and improve the capacities, mechanisms and procedures to enable the optimal reduction of disaster risk and vulnerability in the context of the people of the Seychelles, their security, health and socio-economic well-being.

Objectives

1) To provide a strong institutional basis for the implementation of Disaster Risk Reduction at local and national level;
2) To identify, assess and monitor disaster risks and enhance early warning;
3) To develop a culture of safety and resilience at all levels through targeted and effective dissemination of information;
4) To reduce underlying risk factors;
5) To enable effective response capacities by strengthening disaster preparedness at all levels.

2-3-2 Legal Framework

There are several laws and regulations with aspects relevant to coastal conservation and flood management. They are the Town and Country Act, 1975; Town and Country Planning Act, 1972; Environment Protection Act, 1994; Beach Control Act, 1971; Removal of Sand and Gravel Act, 1991 and others.

(1) Town and Country Act

The Town and Country Planning Act, 1975 formed the basis for granting or refusing building permits. The Act contains provisions for most of the basic environmental provisions (sewage, rainwater management, garbage collection, landscaping, etc.).

(2) Town and Country Planning Act, 1972 (Cap 237, TCPA)

Permission is required for the development of any land, including the coastal plateau for tourism purposes. Building operations must comply with the rules and codes of practice laid out in Sections 7 to 83 of the Regulations.

(3) Environment Protection Act, 1994

The Act provides for, inter alia, the environmental impact assessment process, establishment of sensitive areas, coastal zone management, waste management and standards, and makes provision for prevention, control and abatement of pollution. The Act grants powers to the responsible authority to prepare coastal zone management plans (Section 11) which include evaluation of the coastal ecosystem and areas of scenic and outstanding beauty, and evaluation of the impact of coastal erosion and the causes and sources of coastal pollution and degradation.

(4) Environment Protection (Standards) Regulations, 1995

The effluent quality standard is prescribed for the discharge of effluents to a recipient system from any industry, operation or process.

(5) Environment Protection (Impact Assessment) Regulations, 1996

The Regulations specify the preparation of an impact assessment report for any project or activity such as mining, hotel industry (hotels, restaurants and tourism activities), roads and coastal defences, land reclamation and housing development. They also provide limits to development, with protected areas or ecologically sensitive areas such as beaches and intertidal zones, coastal strips, small and outlying islands and unique natural habitats not protected as legally protected areas.

(6) Beach Control Act, 1971 and Subsidiary Regulations, 1991

The Act provides specific provisions for regulation of the use of pleasure boats and limits on water sports to within inshore waters and (Cap 14) grants powers to the designated authority regarding specific areas of the beach to allow several activities without endangering the environment or public safety. To date, two areas (Beau Vallon and Port Launay) have been zoned in accordance with these regulations.

(7) Removal of Sand and Gravel Act, 1991 Chapter 203

The Act regulates the removal of sand and gravel from rivers, streams and coastal areas.

(8) Others

▪ Maritime Zones Act (1997) and Maritime Zones (Maritime Pollution) Regulations (1981)

The act defines maritime zone, territorial sea, continental shelf and Exclusive Economic Zone and regulates offences and penalties. The regulations provide for the protection and preservation of the marine environment as well as the prevention and control of marine pollution.

▪ National Parks and Nature Conservancy Act (1969)

The act defines the regulations for the National Parks for the management of protected area. The Park is defined an area set aside for the propagation, protection and preservation for wildlife or the preservation of places of aesthetic, geological, prehistoric, historical, archaeological or other scientific interest for the benefit and enjoyment of the general public.

▪ Protected Areas Act (1967)

The act is used primarily for reasons of national and internal security to exclude persons or public access from certain areas, but it has however also been utilised to designate an area for environmental reasons.

▪ Land Reclamation Act (1961)

The act lays down the procedure to follow for reclamation of land by filling any foreshore. A person, who believes that the proposed reclamation may adversely affect either the property owned, or public rights or the natural beauty of the coastal area may object to the reclamation.

2-3-3 Organisation

The government organisations of the Seychelles consist of the Office of the President, Office of the Vice

President, eleven ministries and constitutional bodies. The ministries are:

- Ministry of Community Development, Social Affairs & Sports;
- Ministry of Home Affairs and Transport;
- Ministry of Education;
- Ministry of Foreign Affairs;
- Ministry of Natural Resources & Industry;
- Ministry of Finance, Trade & Investment;
- Ministry of Environment & Energy;
- Ministry of Tourism & Culture;
- Ministry of Land Use & Habitat;
- Ministry of Health;
- Ministry of Employment and Human Resource Development.

The counterpart organisation in the JICA project is the Department of Environment (DOE) which belongs to the Ministry of Environment and Energy.

(1) Ministry of Environment and Energy

The ministry has two departments, namely the Department of Environment and the Department of Energy. Figure 2-3-1 shows the organisation chart of the ministry.

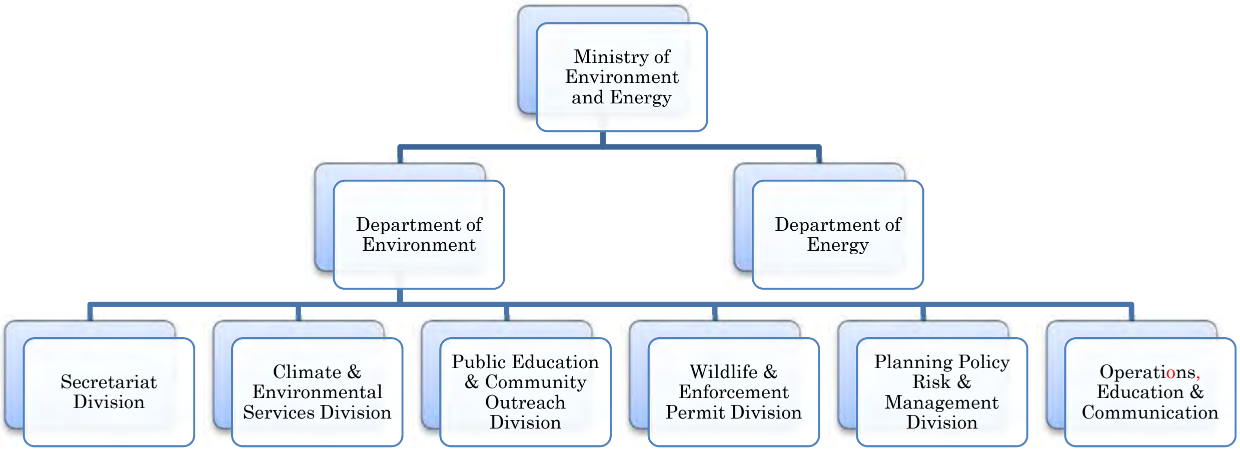


Figure 2-3-1: Organisation Chart of the Ministry of Environment and Energy

(2) Department of Environment

The Department of Environment (DOE) primarily safeguards the natural environment of the Seychelles and ensures that all developments are properly planned and executed in a sustainable manner. Through various mechanisms and tools, it regulates and controls pollution and the negative impact of human activities. In addition, it promotes positive behaviour of the general population towards the environment.

The department manages a network of protected areas and provides support to local non-governmental organisations and private agencies engaged in environmental matters. The Department of Environment comprises six divisions which together provide the necessary institutional capacity for effective implementation of environmental programmes to regulate activities impacting on the natural environment and resources.

(Department of Public Administration: Public Sector Function Manual, 2008)

(3) Climate and Environment Services Division

This division covers the environment-related fields of wetlands, rivers and coasts along with planning of environmental impact assessments. The organisation is shown in Figure 2-3-2

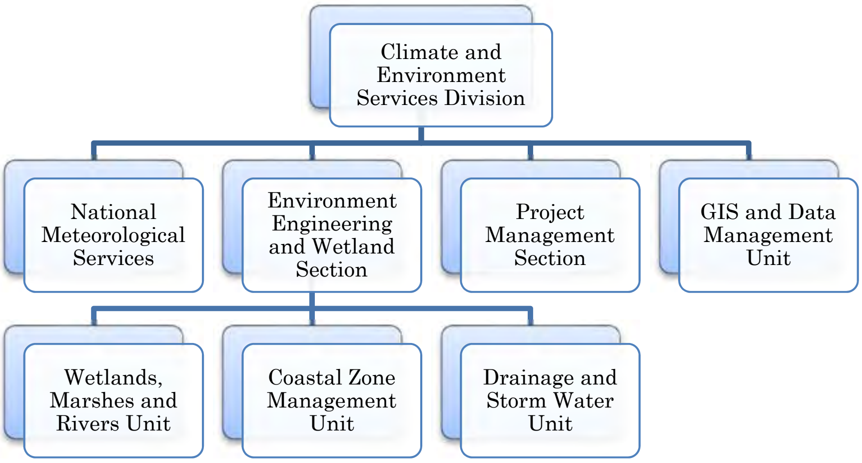


Figure 2-3-2: Organisation Chart of Climate and Environment Services Division

(a) National Meteorological Services

The National Meteorological Services observe and attempt to understand the Seychelles' weather and climate and provide meteorological data in support of international obligations.

(b) Project Management Section

This section is responsible for coordinating and ensuring effective and timely implementation of environmental programmes and large projects and for monitoring implementation of the Environment Management Plans of 2000-2010 and 2011-2020.

(c) Environment Engineering and Wetland Section

This section is responsible for overseeing and coordinating all drainage management, flood control, and coastal zone management issues and matters on a national basis. Its mission is to promote, educate and ensure implementation of effective storm water management, flood control and coastal zone management practices in the Seychelles.

The section has three units, namely the Wetlands, Marshes and Rivers Unit, Coastal Zone Management Unit and Storm Water and Drainage Unit.

The Wetlands, Marshes and Rivers Unit deals with the following:

- Conservation, protection and management of wetlands and rivers;
- Education of the wider public in sustainable practices and flood mitigation;
- Contracting out of periodic cleaning and wetland restoration to ensure healthy ecological niches.

The Coastal Zone Management Unit deals with the following:

- Management, protection and conservation of coastal zones;
- Supervision, coordination of and advice on coastal based developments;
- Identification and implementation of integrated coastal zone management;
- Dissemination of best coastal zone management practices to the wider public

The Storm Water and Drainage Unit deals with the following:

- Design, implementation and monitoring of drainage networks;
- Collection of hydrology and catchment data;
- Reduction of flood risk vulnerability on a national level.

(4) Divisions of Risk and Disaster Management

The National Disaster Committee (NDC) was established in 1997 as the national platform for coordination and policy guidance on disaster risk reduction. In 2006, the NDC secretariat was upgraded to the Division of Risk and Disaster Management (DRDM) so as to form the operational body of the NDC and to oversee the day-to-day comprehensive implementation of the disaster management cycle. As of 1st July 2010, the DRDM was re-organised into two divisions and named the Divisions of Risk and Disaster Management, under the mandate of the Department of Environment. Figure 2-3-3 shows the organisation chart of DRDM.

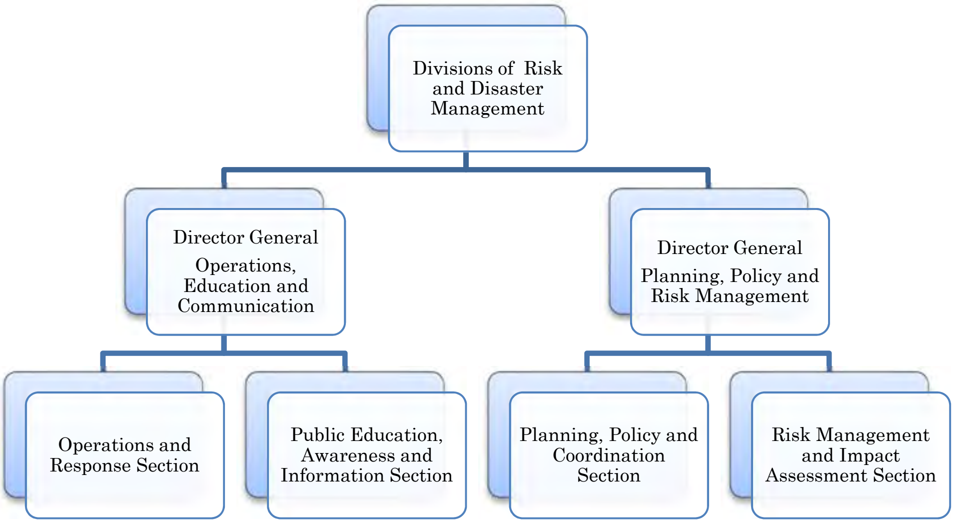


Figure 2-3-3: Organisation Chart of the Divisions of Risk and Disaster Management

The function of each section is as follows:

Operations and Response Section

- Major emergency response, rapid response team, case management, drill/exercises, coordination, district/community preparedness and early warning dissemination

Public Education, Awareness and Information Section

- Training, education, awareness, advocacy, programme development, public information, public relations document centre

Planning, Policy and Coordination Section

- General planning and policy, legal affairs, scenario planning and visioning, local and international cooperation, national preparedness, contingency planning, early warning planning and research

Risk Management and Impact Assessment Section

- Risk management, hazard identification/analysis, mapping risk assessment, mitigation planning, mitigation projects and scoping exercises

In an emergency, the Disaster Response Headquarters will be established in the National Emergency Operations Centre.

(5) Other Relevant Organisations

Other relevant organisations are the Ministry of Foreign Affairs, Ministry of Land Use and Housing, Ministry of Community Development, Youth and Sports, Seychelles Port Authority and Seychelles Coast Guard.

2-4 Analysis of Coastal Conservation

The coastline of the Seychelles falls into two basic types, rocky granite cliffs and coralline coastlines backed by coastal plains and fronted by fringing coral reefs. The fringing reef breaks the waves sufficiently to enable settlement and development of the coastal plains. The reefs provide the primary infrastructure that supports the Seychelles' tourism industry. The area and length of the coast are shown in Table 2-4-1.

Table 2-4-1: Main Islands in the Seychelles

Name of Island	**Land Area (m^2)**	**Coast Length (km)**
Mahe	154	105
Praslin	38	43
La Digue	10	-
Others	250	-
Total	452	-

(STATISTICAL ABSTRACT 2007, NSB)

The outline of the tides in the Seychelles is shown in Table 2-4-2. The long-term sea level rise was 0.66 cm/year from 1993 to 2010.

Table 2-4-2: Tidal Range

Spring Range	**Mean Range**	**Neap Range**
1.15 m	0.88 m	0.45 m

Most waves come from the SE to S generated by the southeast trade winds in the dry season. In the rainy season waves are brought by the northwest monsoon. The maximum significant wave height is estimated to be 6 m with a 30-year return period.

Incoming waves break and dissipate on the reef. In general, the wave height on the reef is affected by the incoming wave height and is related to the water depth which changes according to the tidal level as follows: $H=0.5*(h+0.1*H_s)$

where H: significant wave height on the reef (m), h: water depth (m) and H_s: incident significant wave height (m) on the reef.

The Indian Ocean Tsunami in 2004 reached the Seychelles. The highest flood levels on Mahe ranged from 1.6 m to more than 4.4 m above mean sea level. On Praslin, they ranged from 1.8 m to 3.6 m.

The past coastal disasters are summarised in Table 2-4-3.

Table 2-4-3: Past Record of Coastal Disasters

Name of Coast	Type of Disaster	Date	Damages
Anse Kerlan	Coastal Erosion	From 1989	Land loss of 30m
La Passe	Coastal Erosion	From 1991	Land loss of more than 5m
All Islands	Tsunami	Dec. 2004	Collapse of bridge and inundation

The analysis of past coastal erosion on the three islands of Mahe, Praslin and La Digue shows that the causes of erosion are thought to be as follows:

- The coastline tends to shift because of the seasonal variations in wave direction caused by the north-west monsoon and the south-east trade winds;
- Coastal structures such as revetments on roads, groynes and breakwaters affect sediment movement and cause erosion and accretion around them;
- Coral sand was lost by past sand mining activities and was also transported offshore through channels in the reef;
- EIA has been conducted in the past, but functions and regulations are lacking, especially for probable eroding coasts.

On the coastline there are several coastal structures. They are revetments and groynes for coastal protection and breakwaters for harbours and fishing ports.

Table 2-4-4: Existing Coastal Structures

Type of Structure	Name of Place
Coastal Revetment	Au Cap, Anse Royale
Wooden Pile Revetment	Baie Lazare, Anse a la Mouche
Groyne	Anse Kerlan, La Passe
Breakwater	Bel Ombre, La Passe

2-4-1 Coastal Topography

The coastline of the Seychelles’ granitic islands consists of two basic types: granitic coastlines where waves break directly onto granite rocks and steeply sloping cliffs; and coralline coastlines backed by coastal plains and fronted by fringing coral reefs. On the coralline coastlines, the fringing reef crests break the waves sufficiently to enable settlement and development of the coastal plains. Between the reef crest and the shoreline, sheltered lagoons may exist, backed by fine sand beaches. The flat land, calm lagoons and ocean access of the coralline shorelines have attracted settlement and development, supporting a large proportion of the agriculture, urban development and tourism of the Seychelles. Channels through the fringing reefs provide access to the ocean from safe harbours for artisanal fishing boats and pleasure crafts. The same coral reefs provide the primary infrastructure that supports the Seychelles' tourism industry, providing beaches and sites for snorkelling and scuba diving. The coral reefs and sea grass beds have important socio-economic benefits and are used extensively as fishing grounds by local fishermen.

The coastal zone of the granitic islands consists of elevated terraces known locally as "plateau", as well as marshy areas. The plateau which is about 2m above sea level consists of calcareous reef material which builds up as sand dunes and pocket beaches known as *anses*. The sandy deposits have accumulated in the last six thousand years. In contrast, the low-lying areas around the river mouths are marshy and characterised by sediment of fine clay and quartz. Port Victoria, the capital, is built on such sediment. The main island of Mahe is 27km long and 6km wide with a land area of 148km^2. The coastline runs for about 105km in length and there are 36km of sandy beaches. The second largest island, Praslin, has a 43km-long coastline and 21km of beaches. The La Digue plateau covers about 167 ha, and on Praslin the total plateau area is about 193 ha.

The coastal marine areas of the granitic islands can be systematically zoned into rocky shores or sandy beaches, rippled sand zone, marine grass beds, radial zone, algal ridge, reef edge and outer slopes. Fringing reefs are found in only a few parts of the granitic island coastline and extend as uneven belts reaching 1500m in width on the north-western coast of Mahe. The largest continuous fringing reef in the granitic islands, stretching about 27 km in the northeast bay to Anse Marie Louise on Mahe, has now been interrupted by east coast land reclamation and the Seychelles International Airport. Sea grass beds and the standing stock of algae are still very extensive and deserve particular attention especially as wave energy buffers and erosion mitigating zones (Status of the Marine Environment Report, Seychelles, 2008, UNEP-GEF).

2-4-2 Tides

In the Seychelles, the tide has been measured at Pointe Larue under the management of the Seychelles Meteorological Services since 1993. In the past, the tide was measured at Port Victoria (Hodoul, A&B), Aldabra and Praslin. The tidal observation data are available and can be accessed on the internet via the following link: (http://www.soest.hawaii.edu/UHSLC).

The outline of the tide in the Seychelles is as follows:

- Astronomical tide: 2.10 m
- Mean high water spring: 1.63 m
- Mean high water: 1.45 m
- Mean high water neap: 1.27 m
- Mean level: 1.10 m
- Mean low water neap: 0.81 m
- Mean low water: 0.63 m
- Mean low water spring 0.45 m
- Lowest astronomical tide: 0.20 m

(Macharia J., http://www.odinafrica.org/index.php/learn-about-odinafrica/81-seychelles)

Harmonic analysis was conducted of the tidal data for 2006. The results show that the spring range is 1.15m, the neap range is 0.45m and the mean range is 0.88m. The major constituents, amplitudes and phases are shown in Table 2-4-5.

Table 2-4-5: Major Constituents, Amplitudes and Phases at Pointe Larue

Symbol	Constituent	Amplitude (cm)	Phase (deg)
M2	Principal lunar semi-diurnal	40.11	13.98
S2	Principal solar semi-diurnal	17.75	52.55
N2	Larger lunar elliptic semi-diurnal	8.22	350.27
K1	Luni-solar declinational diurnal	18.27	0.01
P1	Solar diurnal	5.40	357.94
O1	Lunar declinational diurnal	10.44	4.55

(Charles M.: TIDAL ANALYSIS AND PREDICTION IN THE WESTERN INDIAN OCEAN, REGIONAL REPORT, WIOMSA&IOC, 2008.)

The long-term sea level changes and the probability of maximum tides were analysed from the data obtained at Pointe Larue from 1993 to 2010 to estimate the influence of climate change and plan coastal defences. Because the incoming waves are not high and break on the reefs in the Seychelles, the tidal level is important and affects the wave run-up on structures.

The yearly changes in minimum, mean and maximum sea level are shown in Figure 2-4-1. The mean sea level has risen in recent years at a rate of 0.66cm/year. Before 2004 the changes in sea level were not so great.

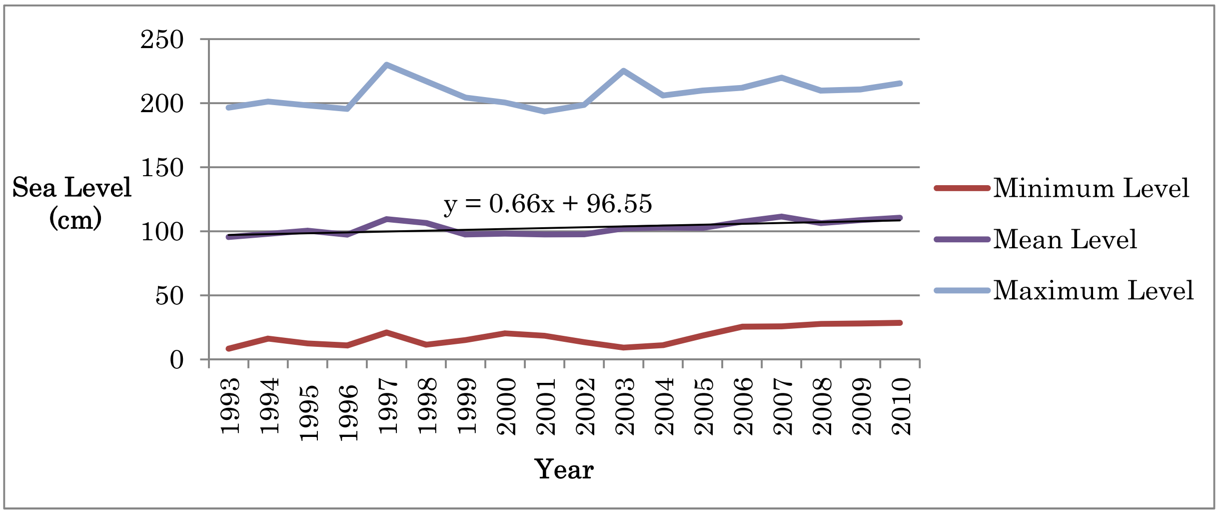


Figure 2-4-1: Yearly Changes in Sea Level

2-4-3 Waves

(1) Wind Waves

There is no wave observation station in the Seychelles. The only available information is the wave atlas at http://www.knmi.nl/waveatlas compiled by the European Centre for Medium-Range Weather Forecasts as ERA-40 dataset from September 1957 to August 2002 (45 years).The results are available on a global 1.5*1.5grid. Surface plots of the monthly mean in the Indian Ocean (with the respective mean wave direction given by superimposed arrows) are shown in Figure 2. The monthly mean maps present the mean significant wave height, period and direction with 6-hourly values from 1971-2000 for the specified month. The wave is wind wave and does not include swell.

In the Seychelles, the wave height ranges from 1.0m to 1.5m in January and February and from 2.0m to 2.5m in July and August. Most waves come from the south-east or the south.

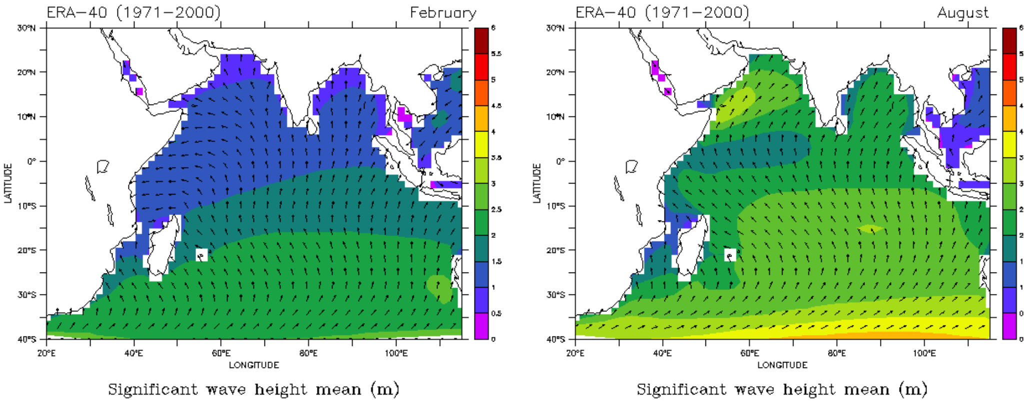


Figure 2-4-2: Monthly Mean Significant Wave Height (m): February and August

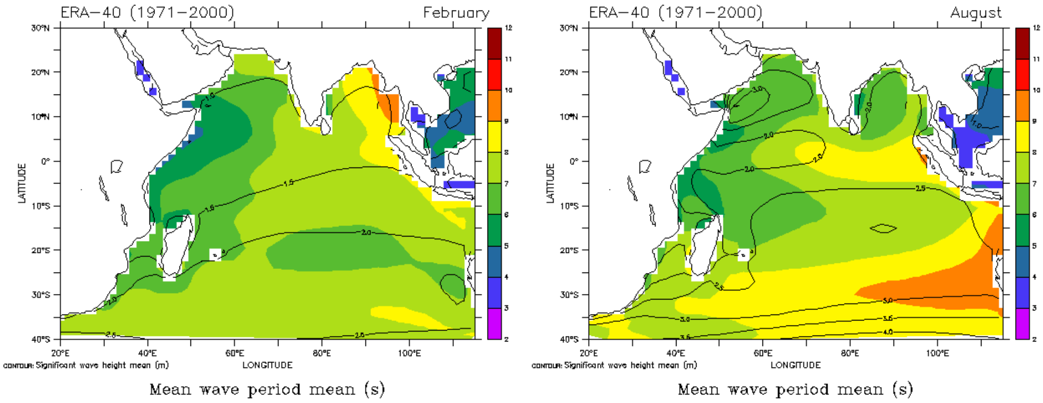


Figure 2-4-3: Monthly Mean Significant Wave Period (s): February and August

The distribution of the wave height for each wave direction is classified into two categories. When waves come from NNW (315 degrees) to E (90 degrees) through N (0 degree), over 95% of the height is concentrated from 1 m to 2 m. From E to NNW through S (180 degrees), the height is concentrated from 1 m to 2 m with about 20% from 2 m to 3 m.

The distribution of the wave period for each wave direction shows gradual changes. From W (279 degrees) to NW (45 degrees) through N (0 degree), the period ranges from 4s to 6s and from NW to S (180 degrees) the wave period increases up to 9s. From S to SW the period is from 5s to 9s and has a wide range. This corresponds to the increased swell generated by the south-east trade winds.

The wave conditions characterise the movement of sediment. The coast facing north to northwest receives waves generated by local winds. The coast facing east to west through south receives longer waves generated by the trade winds.

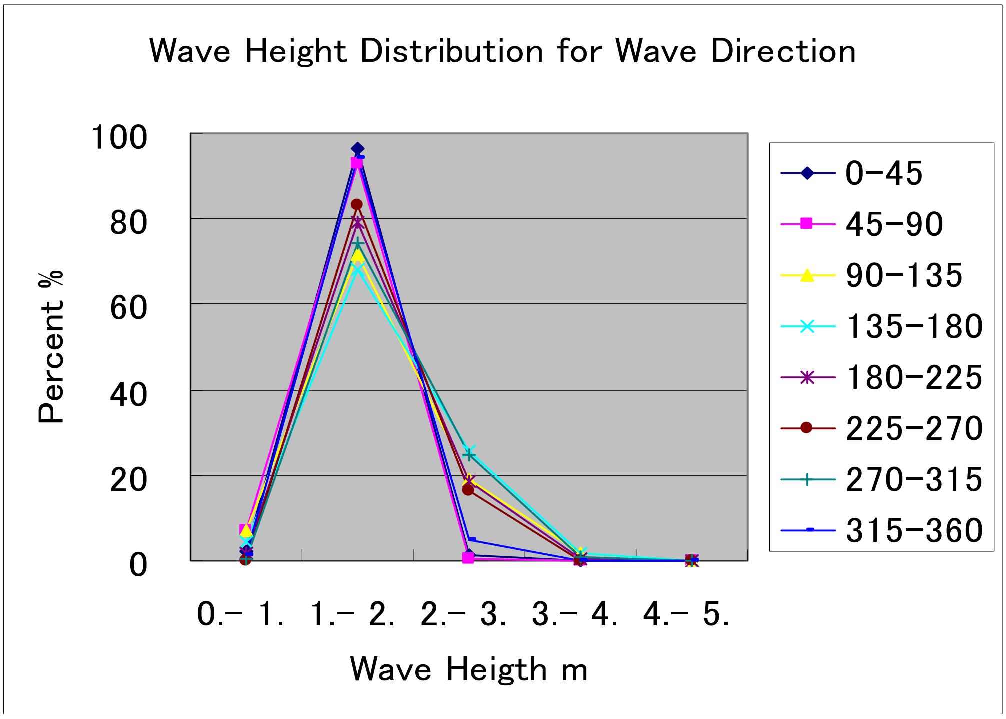


Figure 2-4-4: Wave Height Distribution for Wave Direction

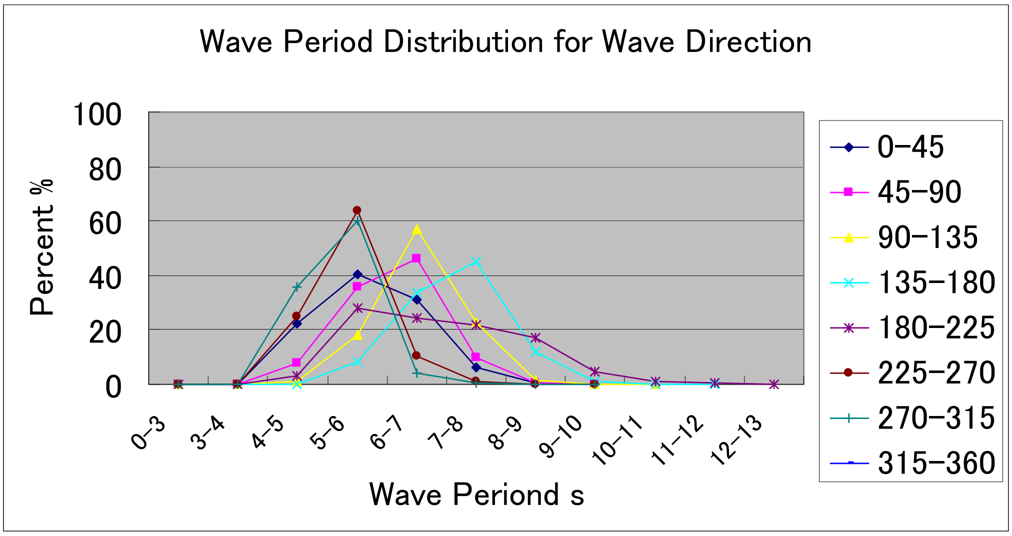


Figure 2-4-5: Wave Period Distribution for Wave Direction

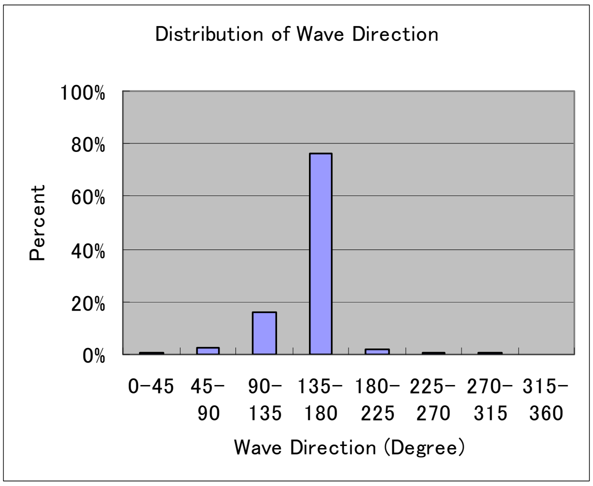


Figure 2-4-6: Wave Direction Distribution

Incoming waves break and dissipate on the reef. In general, the wave height on the reef is affected by the incoming wave height and the water depth which changes according to the tidal level. High tide brings high waves and low tide brings low waves as shown in Figure 2-4-7

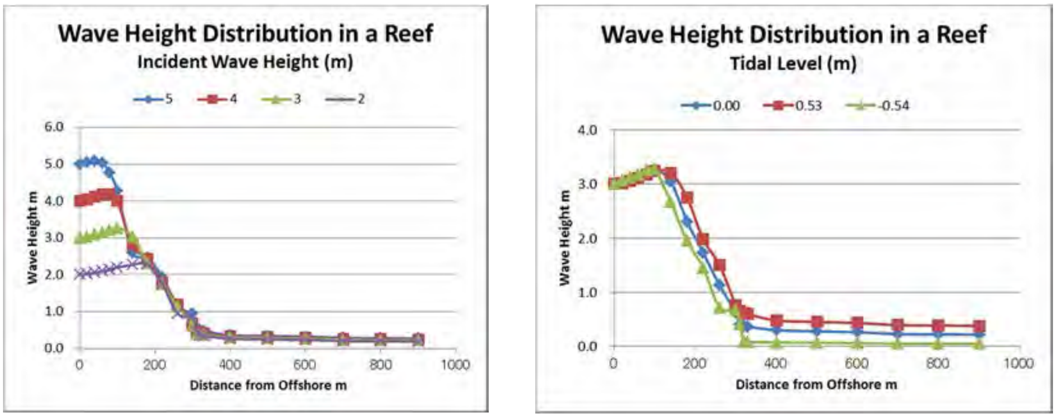


Figure 2-4-7: Wave Height Deformation: High tide brings high wave on the beach

The changes in wave height on the reef are estimated using wave deformation calculations. From the results, a simplified useful relation is derived as follows:

$$H=0.5*(h+0.1*H_s)$$

where H: significant wave height on the reef or in front of a structure (m), h: water depth (m) measured from tidal level, and H_s: incident significant wave height (m) on the reef. The equation is derived from a simple assumption of the wave height inside the reef as proportional to the water depth. The depth is determined by the tidal level and the wave set-up caused by incident waves. The wave set-up is assumed to be 10% of the incident wave height.

(2) Tsunami

The Indian Ocean Tsunami in 2004 reached the Seychelles. The highest flood levels on Mahe ranged from 1.6 m to more than 4.4 m above mean sea level. On Praslin, they ranged from 1.8 m to 3.6 m. The maximum withdrawal of water was not recorded by the tide gauge at Mahe because the stilling well went dry, but there is evidence from observers that it dropped as far as 4 m below mean sea level.

The tsunami run-up height is shown in Figure 3 and was investigated by a team from the Geological Survey of Canada.

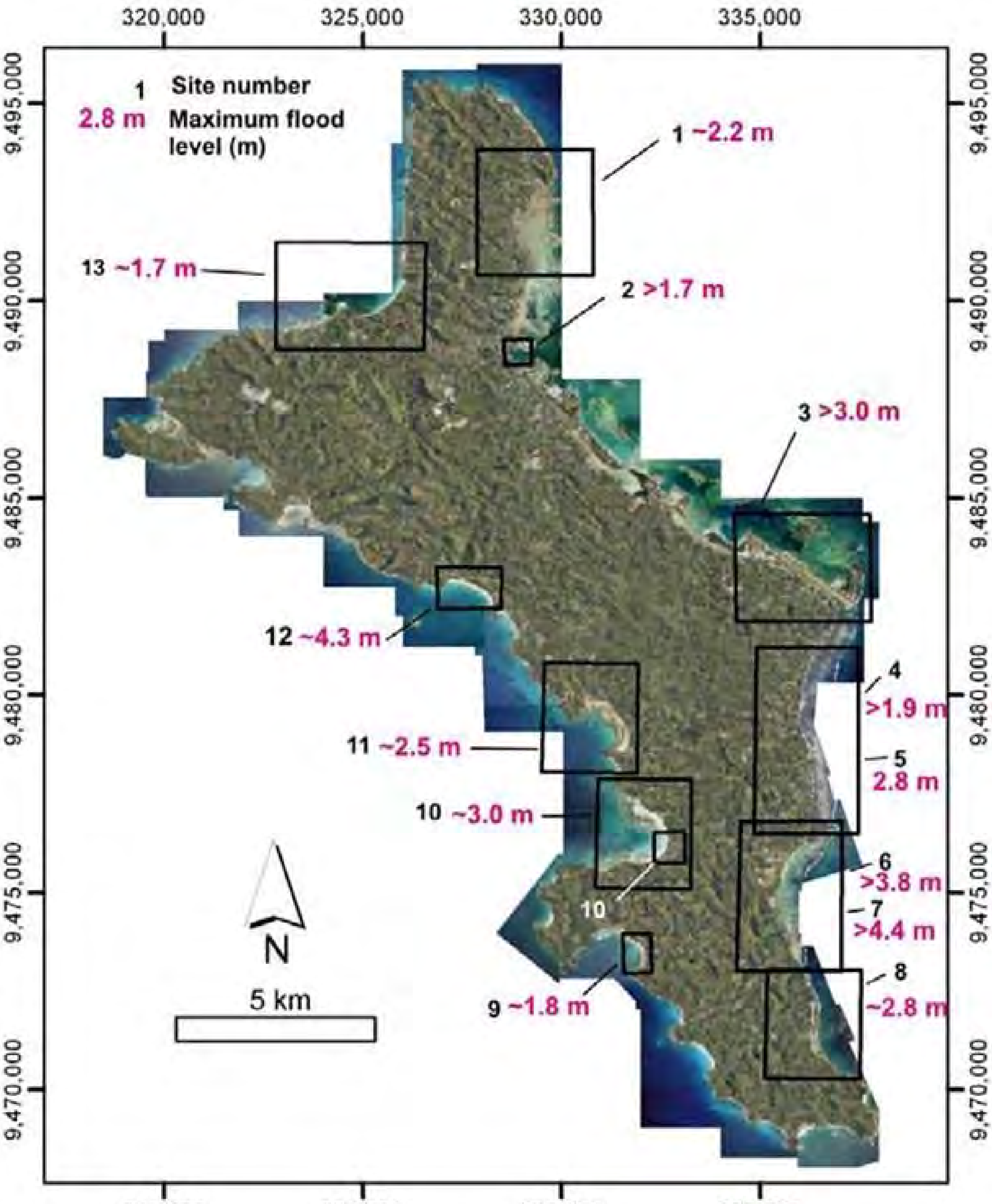


Figure 2-4-8: Tsunami Run-up Height on Mahé Island

The red numbers refer to the maximum water level above mean sea level at each location

(Jackson, L.E., Jr., Barrie, J.V., Forbes, D.L., Shaw, J., Manson, G.K., Schmidt, M.: Effects of the 26 December 2004 Indian Ocean tsunami in the Republic of Seychelles. Report of the Canada-UNESCO Indian Ocean Tsunami Expedition, Geological Survey of Canada, 2005.)

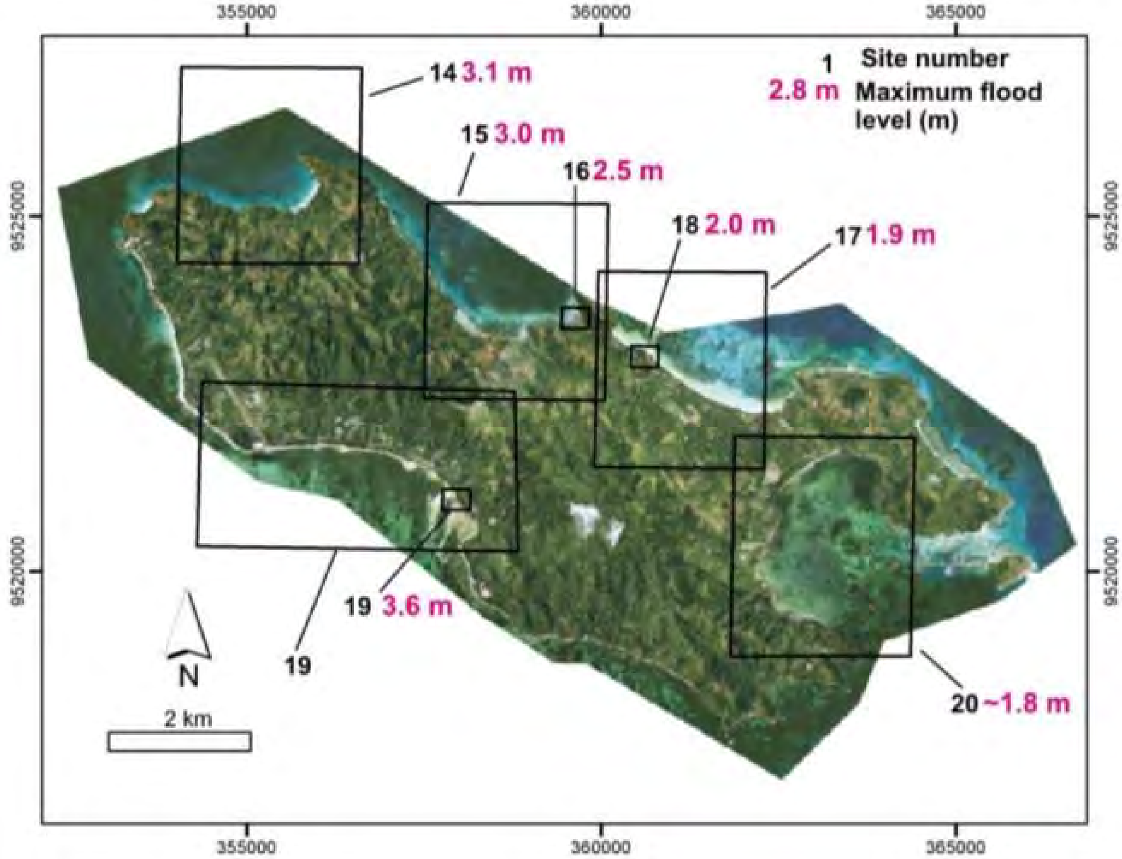


Figure 2-4-9: Tsunami Run-up Height on Praslin Island

The red numbers refer to the maximum water level above mean sea level at each location.

(Jackson, L.E., Jr., Barrie, J.V., Forbes, D.L., Shaw, J., Manson, G.K., Schmidt, M.: Effects of the 26 December 2004 Indian Ocean tsunami in the Republic of Seychelles. Report of the Canada-UNESCO Indian Ocean Tsunami Expedition, Geological Survey of Canada, 2005.)

2-4-4 Past Coastal Disasters

The past record of coastal disasters is very limited. The only records are of coastal erosion at Anse Kerlan on Praslin, erosion and accretion at La Passe on La Digue, and the Indian Ocean Tsunami disaster. The reports explain the situations and possible causes. However, detailed quantitative analysis has not been conducted yet. For the management of disasters, it is necessary to make clear what actually happened as well as the causes. The report provides the basic information for the analysis.

(1) Coastal Erosion at Anse Kerlan

An article in the Seychelles Nation in 1998 explains the coastal erosion at Anse Kerlan as follows. A fierce battle is ranging between the land and the sea at Anse Corbigeau, on the main road from Amitie to Anse Kerlan, Praslin. The sea has pushed the beach further back inland along the coast nearer to Amitie, although its advance has been somewhat checked by the construction of groynes.

A resident of Anse Kerlan estimates that the sea has washed away some 10,000 m^2 of the coastline. The beach has been pushed back some 30 m. This has caused the diversion of the road inland. The sea is now gnawing at the base of the road in the Anse Corbigeau area.

At high tide the waves pound the beach. Trees that had been playing games with the wind, including the tall casuarina, spreading takamaka and scenic coconut palms, are the first casualties. After losing their anchoring in the sand, the trees fall down one by one and die.

The construction of groynes is part of the government's actions to arrest coastal erosion at Anse Kerlan. But not all is lost, if the Anse Kerlan resident is to be believed. Whilst part of the Anse Kerlan coast was washed away, sand was piling up at Nouvelle Decouverte, adjoining Joseph Albert's property. Land lost at Anse Kerlan is land gained at Nouvelle Decouverte.

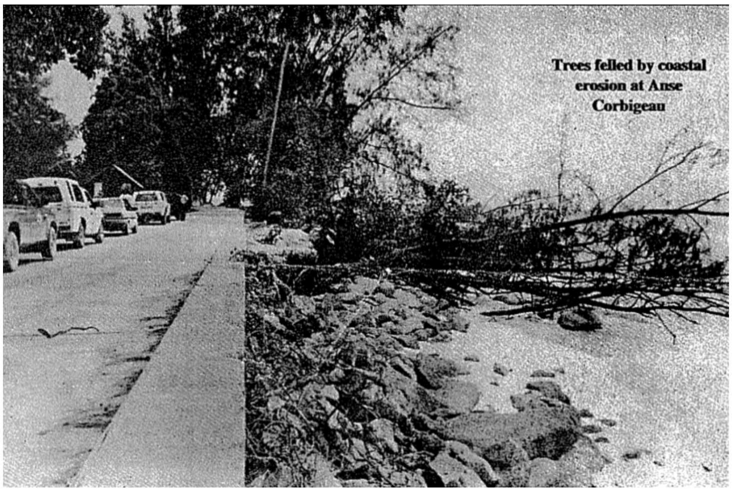


Figure 2-4-10: Coastal Erosion at Anse Kerlan (Seychelles Nation, May 18, 1998)

Another report was written by Shah as follows. The beaches of Anse Kerlan and adjoining Amitie on Praslin Island are probably the most spectacular examples of shoreline recession in the granitic islands. The area has a narrow reef barrier which offers little protection. The proximate cause of the beach receding is due to a combination of wave action and longshore drift. Simultaneously, the southerly beach at Grand Anse has been growing due to accretion. This process is reputed to have taken place during the last 15 to 25 years. Apparently, a delicate balance previously existed between the two biannual littoral drifts: one in a general north-westerly direction during the south-east trade winds and the other in a general south-easterly direction during the northwest monsoon. This balance has now been upset with the result that there is a net littoral drift in a south-easterly direction away from Anse Kerlan without a sufficient return of beach material. The reasons for this are not clear, but it is thought that both natural and man-made causes play a part. It is the opinion of a professional coastal engineer that unwise development has disturbed the balance; development of the beach and sand dunes includes reclamation, houses, seawalls, roads and solid landing piers. There has been no attempt to monitor the beach profiles or the reef and therefore no quantitative data is available. Erosion is so severe that the coastal road has had to be diverted.

Over the years, attempts have been made to protect the shoreline by the construction of seawalls. The seawalls have accelerated the erosion and scouring of the sand due to increased wave reflection has led to destruction of the seawalls. Rip-rap armouring of the backshore has also been attempted. Five granite block groynes were constructed in December 1990 to provide protection for the shrinking coastline at Anse Kerlan. It is clear from the above that littoral drift traps sand during the north-west monsoon and deprives downstream beaches such as Anse Korbiso (where there have been complaints of erosion) of its seasonal replenishment. During the south-east monsoon the action may be reversed but at the expense of the adjacent northern beaches. Erosion is still continuing at Anse Kerlan although the beach between the groynes has stabilised. (Shah, N. J.: Seychelles National Report, Coastal Erosion, Sea-level Changes and their Impacts, IOC Workshop Report No.96-Supplement 1, UNESCO, 1994)

(2) Erosion at La Passe

The report written by Shah also explains the erosion at La Passe as follows. Erosion has become pronounced at La Passe where La Digue port and landing pier are located. The present day beach to the south of the granite headland at Cap Barbu comprises carbonate and quartz sand mixed with coarse fragmented biogenic carbonate material from nearby dredging operations. This is banked against an erosional scar up to 1 m high in the older beach sands. The shore faces west-north-west. In 1991, a Fish Collection Centre located on the backshore beach and flattened dunes in front of the yacht and schooner basin was endangered by shoreline erosion. The sea had undermined the land beneath the Centre and nearby coconut trees had been uprooted.

Investigations showed that the *original* coastline had already receded by approximately 4.5 m prior to the construction of the Fish Collection Centre in early 1986. This was presumed to have been the result of previous dredging operations in the yacht basin and the destruction of the protective reef platform and coral. Following more dredging operations in May 1990, further erosion of the beach was accelerated with a recession of approximately 5 m. This left only 4 to 6 m of flattened dunes behind the Fish Collection Centre The short-term cause was identified by local experts as an open trench for a high tension electric cable dug between the shoreline and the Fish Collection Centre which had not been backfilled and served as a conduit for backwash at high tide. However, the main problem is thought to be the existing pier which is a solid structure, except for two narrow culverts, and acts as a groyne trapping longshore drift sand. The yacht basin therefore needs periodic dredging which is partly a cause of the beach erosion and shoreline recession. Arthurton, who visited the area on 8th April 1992, believes the recession may be due to a net southward or south-westward drift caused by relative enhancement of the north-east monsoon over the last 20 years or so (Arthurton 1992).

Detailed recommendations were proposed by a senior engineer from the Ministry of Community Development and experts from the Division of Environment for remedial action. Nevertheless, a sea wall has been constructed to protect the Fish Collection Centre, contrary to the experts' advice (Shah, N. J.: Seychelles National Report, Coastal Erosion, Sea-level Changes and their Impacts, IOC Workshop Report No.96-Supplement 1, UNESCO, 1994).

(3) Indian Ocean Tsunami

The damage to the coastal infrastructure on both the eastern and western shores was most severe where the natural coasts had been modified, i.e. where the natural beach berms had been removed from the surface of the beach, where roads were immediately adjacent to the beach, and where hotel structures were either adjacent to the high water mark or projected seaward over the beach. In some instances, a berm no more than 0.65 m high protected houses from inundation. In one case, a hotel with no berm was flooded, while the houses 50-100 m away behind a natural berm were not.

There were two deaths in the entire Seychelles' archipelago. Both occurred on Mahe: one person fishing near North East Point died immediately; another was caught in the waves at Anse Royale and died some time later from injuries. Tragic as this was for the families of those individuals, the casualty figure was very small compared to the total elsewhere in the Indian Ocean basin. The Seychelles was spared a higher death toll because the initial and largest tsunami waves occurred at low tide. Had the waves occurred at high tide and during a normal weekday, when the docks would have been busy and schools along the coast occupied, it is believed that the loss of life would have been far higher.

Most damage was experienced at hotels and restaurants, these establishments being deliberately located on coastal embayment adjacent to beaches. In some places, homes were flooded and some incurred structural damage. Dock structures were damaged in Port Victoria, causeway bridges collapsed between Victoria and the airport, and coastal roads were damaged in a number of places (Jackson, L.E., Jr., Barrie, J.V., Forbes, D.L., Shaw, J., Manson, G.K., Schmidt, M.: Effects of the 26 December 2004 Indian Ocean tsunami in the Republic of Seychelles. Report of the Canada-UNESCO Indian Ocean Tsunami Expedition, Geological Survey of Canada, 2005).

(4) Other Types of Coastal Erosion

The report written by Shah explains other types of coastal erosion, namely sand extraction, destruction of protective coral reefs, removal of coastal vegetation, building on sand dunes and construction of sea walls, groynes, breakwaters and piers ((Shah, N. J.: Seychelles National Report, Coastal Erosion, Sea-level Changes and their Impacts, IOC Workshop Report No.96-Supplement 1, UNESCO, 1994).

2-4-5 Coastal Erosion

The coastal changes were analysed mainly on the sandy coasts of the three islands where erosion was reported. They were North East Point, Anse Aux Pins, Au Cap and Baie Lazare on Mahe, Anse Kerlan on Praslin and La Passe on La Digue. The data sources were old maps, old aerial photographs, GIS data, Google Earth and aerial photographs taken by helicopter.

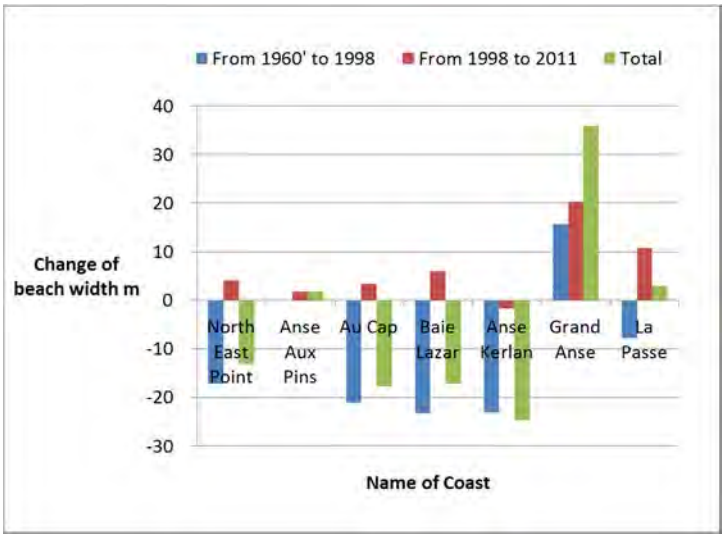


Figure 2-4-11: Changes in Beach Width from 1960 to 2011

The long-term changes in the beach from the 1960s to 1998 and from 1998 to 2011 were estimated as shown in Figure 2-4-11. The data for the 1960s were obtained from old maps, for 1998 from GIS data and for 2011 from aerial photos. Here beach means sandy beach in front of a vegetation line which itself is found in front of a line of structures. In the estimate there is uncertainty in the range of about 5m caused by tidal changes at the location where the photo was taken.

From the 1960s to 1998 the average beach width decreased by about 20m on the coast at North East Point, Au Cap, Baie Lazare and Anse Kerlan. After 1998 the change is not very remarkable. The erosion on the coast of Anse Kerlan corresponds to the accretion at Grand Anse. The erosion from the 1960s to 1998 is estimated to have been mainly caused by sand mining from the beach. However, because the data on beach changes and the records of coastal erosion by sand mining are limited, it is difficult to analyse the changes in the beaches and their causes. The beach changes on each coast are explained in the following.

(1) North East Point (Mahe)

The 1.7km-long coast is located in the northern part of Mahe and receives moderate waves from north to east in the northwest monsoon period. Because the beach alignment is convex, alongshore sediment movement is predominant. In front of the beach there exists a coral reef and beach rock. The coral reef has a slope of about 1/30 at a depth of 10m and there is no reef flat. Incoming waves break on the reef and dissipate. Therefore, on the beach, the wave height is affected by the incoming wave height and the tidal level. The beach width ranges from 10m to 40m and is about 20m on average. On the coast, there is a coastal road, a bus stop and a rehabilitation centre.

From the analysis of coastal changes as shown in Figure 2-4-12, the beach has eroded continuously since the 1960s, at a rate of 0.5m per year on average. In Figure 2-4-12 the yellow colour shows the beach in the 1960s and the red colour as it was in 2011. It can be clearly seen that the beach is eroded, especially in the southern part. The causes of erosion are thought to be the offshore movement of sediment along with sand mining. The beach rock seems to act as some kind of resistance against coastal erosion but it promotes offshore transportation. Longshore sediment movement due to seasonal changes in wave direction is also predominant, bringing about 20m of beach fluctuations.

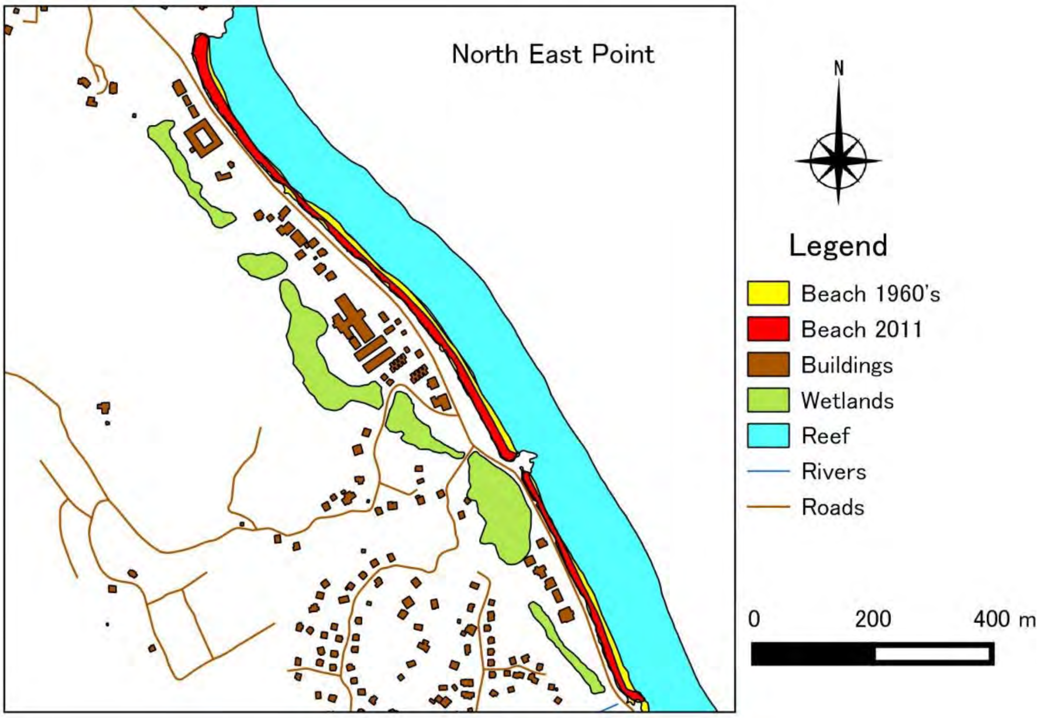


Figure 2-4-12: Beach Changes at North East Point from the 1960s to 2011

The beach is narrow and the coastal road is located along the beach. Rock armouring was placed along the road in some places. Sometimes the road is affected by wave overtopping and sand accumulation at high tide. In 2004 the road, a bus stop and a rehabilitation centre experienced some damage. The photos below show the condition of the beach and sand run-up over the road in front of the rehabilitation centre.

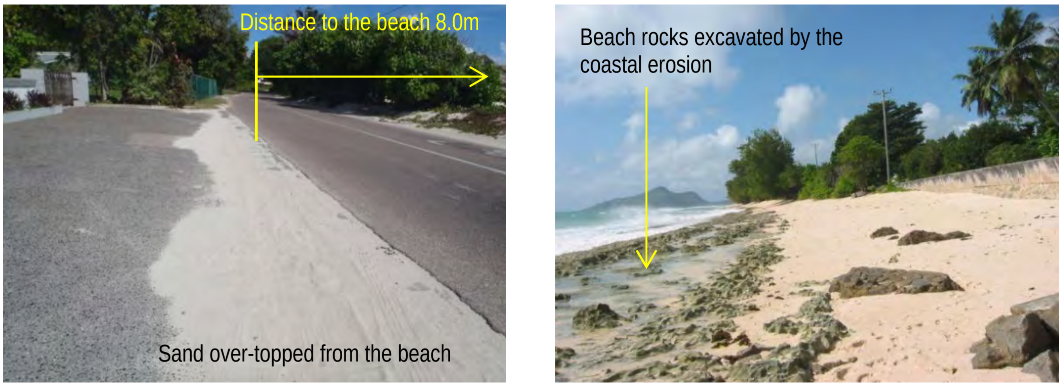


Photo 2-4-1: Eroded Beach and Sand Run-up over the Road at North East Point

In summary, long-term erosion occurred for about 30m from the 1960s to 2011 or 0.5m/y on average, and the seasonal variations in the coastline extend for about 20m. Wave and sand run-up at high tide on the coastal road is also a problem. The possible causes of the long-term erosion are offshore transport and sand mining.

(2) Anse Aux Pins

The 1.5km east-facing coast is located south of the international airport, from Anse Faure to the district boundary in the south. To the north, a reclaimed island and a breakwater were constructed in 2003. There exists a nearly 100m-wide reef on the ocean side of the island. Therefore, the beach is protected by the reef and these structures. The only waves come from two gaps and diffract to the sheltered area.

Coastal erosion was reported and was thought to be caused by the change in wave diffraction through the opening caused by the construction of the reclaimed island and the breakwater. At the market site, beach material was transported to the north by incident waves from the opening and deposited there. The beach area in the lagoon increased from 6,300m^2 in 2004 to 9,200m^2 in 2011. Therefore, the erosion in the lagoon seems to be caused partially by the decreased waves which bring no recovery to the beach in front of the beach scarp or the coastal wall.

The coast is located behind the reclaimed land, named Ile Soleil, and the breakwater. Before the reclamation, scattered beaches existed along the coastal road and in front of the coastal revetments. After the reclamation, local people complained that coastal erosion had occurred in some places. There is no record of any detailed analysis and the only available data are maps and aerial photographs.

Analysis of the 1960s maps, 1984 aerial photos, 1998 GIS data, recent Google Earth in 2004 and aerial photos taken from a helicopter in 2011 shows sediment accumulation in the lagoon between Ile Soleil and the coast. Figure 2-4-13 shows the increase in the beach area from 1998 to 2011. Detailed investigation shows that there is a partly eroded place, as in Photo 2-4-2, near the market site.

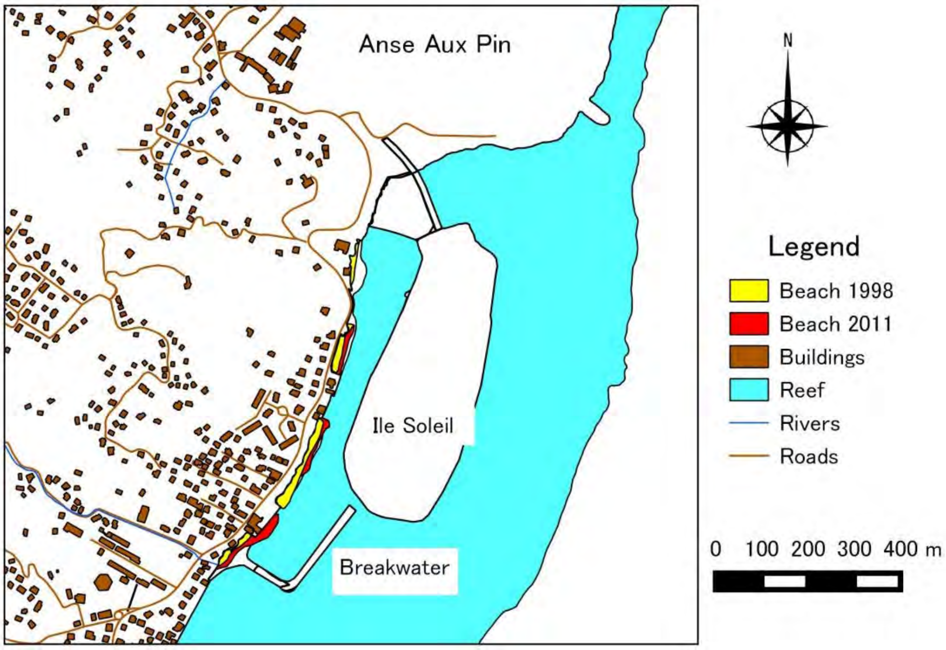


Figure 2-4-13: Beach Changes at Anse Aux Pins from the 1998 to 2011

Photo 2-4-2: Eroded Beach at Anse Aux Pins (Left: Beach carp is clearly seen, Right: Revetment was constructed at market site against erosion)

On average, sediment accumulates on the coast and in the lagoon because of the decreased wave height and tidal action. The diffracted waves from the two gaps in the breakwater transport beach material alongshore and cause accretion and erosion.

Another reason is that the decreased waves only attack the foot of the beach and do not bring sediment to high places. Therefore, a small erosion scarp was seen to develop. Eroded sediment moves offshore and the beach becomes flat. Usually it is very rare for waves to cause erosion. However, the beach is easily scoured when waves just break in front of it. Because of small incident waves, it is easy to protect the beach using some kind of materials.

(3) Au Cap (Mahe)

The 1km-long east-facing coast is made of coral sand and is located south-east of Mahe, with a 400m-wide coral reef fronting the beach. High waves come during the south-east trade winds from April to October. Waves break on the coral and the variation in wave height is rather small. However, the seasonal variation in wave direction is large, varying between the north-east monsoon and the south-east trade winds. The variation in tides is rather high compared to the wave height, ranging from 2.1 m at high tide to 0.4 m at low tide.

A comparison of the 1963 beach (yellow) and the 2011 beach (red) shows severe erosion along about 20m of the whole coast as shown in Figure 2-4-14. From 1998 to 2011 erosion also occurred but was not as remarkable as before. There were four groynes at Au Cap. Google Earth in 2004 shows longshore sediment transport from south to north causing accretion to the south and erosion to the north of the groynes. The causes of the erosion are not clear but it is difficult to think that it is caused only by natural phenomena.

The coastal road runs from Au Cap in the north through La Plaine St. Andre Estate to the mouth of the Theodore Butler River south of Anse Aux Courbes. Therefore, sometimes the coastal road from Au Cap to Pointe Au Sel suffers wave overtopping, especially at high tide. This contributes to some extent to the erosion in front of the road. The vertical structure also makes the situation worse because of the loss of sediment due to the increased wave action.

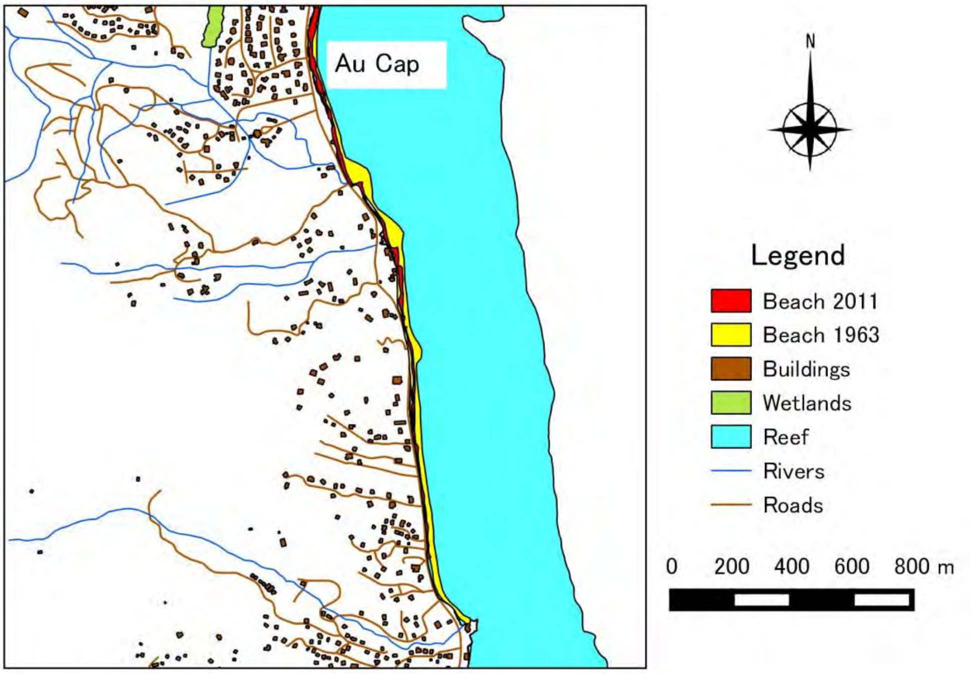


Figure 2-4-14: Beach Changes at Au Cap from the 1963 to 2011

(4) Anse Royale (Mahe)

The 2.5km-long coast is located on the south-east coast of Mahe with headlands on both sides. It faces the east, with a reef from 500m to 800m wide and a channel. A more than 2m-high scarp was reported, caused by reef blasting for fishing boats. The information provided is based on observations, interviews with local people and photos. The results of beach monitoring from 2003 to 2008 show no continuous erosion but rather temporary changes in the beach.

A comparison of the beach on the 1963 map and the 2011 aerial photos shows erosion as in Figure 2-4-15. In the north and south, erosion is very evident while in the middle erosion is not severe. In the centre of the beach, the wide channel in the reef is clear. Therefore, offshore transport through the channel is a possible reason for the erosion of the beach.

Along the coast there are groynes constructed from the 1960s to the 1970s along with concrete revetments constructed in the 1980s. Some of them are partially broken. The beach is narrow, 15 to 20m wide, and sometimes there is no beach. Recently the beach was protected by rock armouring. The damage to the coastal revetments and the remains of the rock armouring are shown in Photo 2-4-3.

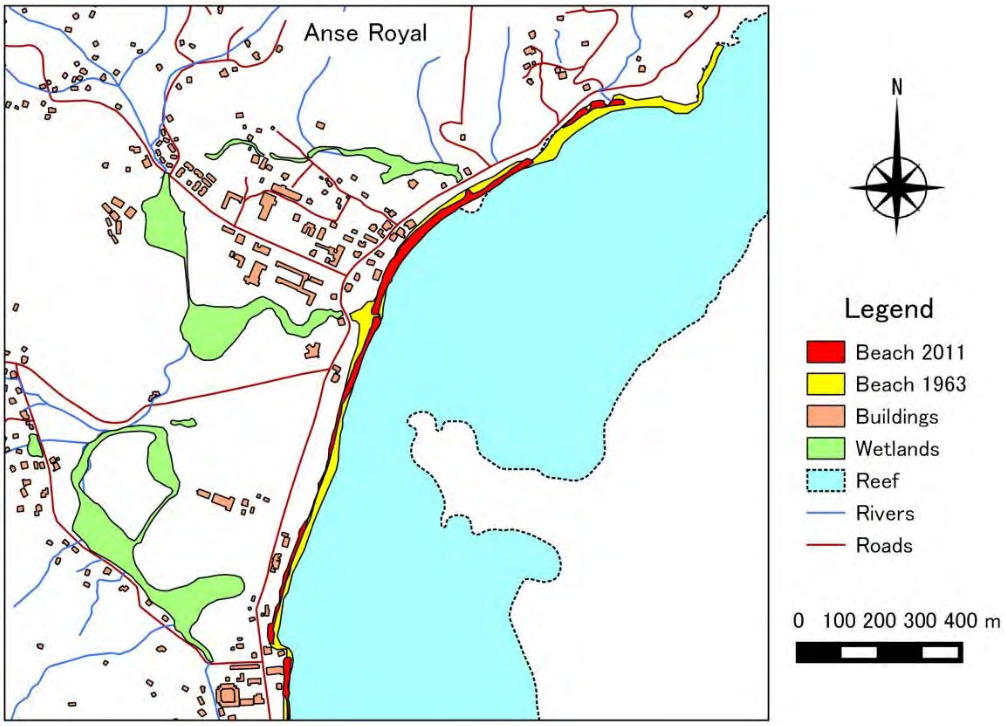


Figure 2-4-15: Beach Changes at Anse Royale from the 1963 to 2011

Photo 2-4-3: Damaged Revetments and Scattered Rock Armouring at Anse Royale

(5) Baie Lazare (Mahe)

The 2.2km-long coast is located on the west coast of Mahe, at the bottom of a bay named Baie Lazare or Anse Gaulettes. The coast faces south and west, with a reef about 100m wide. In the middle of the coast, the Baie Lazare River flows into the sea. The reef is not actively developing because of the fresh, muddy water from the river. Long waves from the south are predominant. Along the coast there is a road, some houses and shops.

To the north of the coast the Baie Lazare River flows into the sea. The beach changes from the 1963 map to the 2011 aerial photos show clear erosion as in Figure 2-4-16. A comparison of the 1978 map and the 1998 GIS data shows little erosion. The erosion was caused before 1978 mainly around the outlet of the Baie Lazare River. This means that the sediment moves offshore during floods and sometimes acts as a jetty, preventing sediment movement along the coast and causing accretion near the outlet.

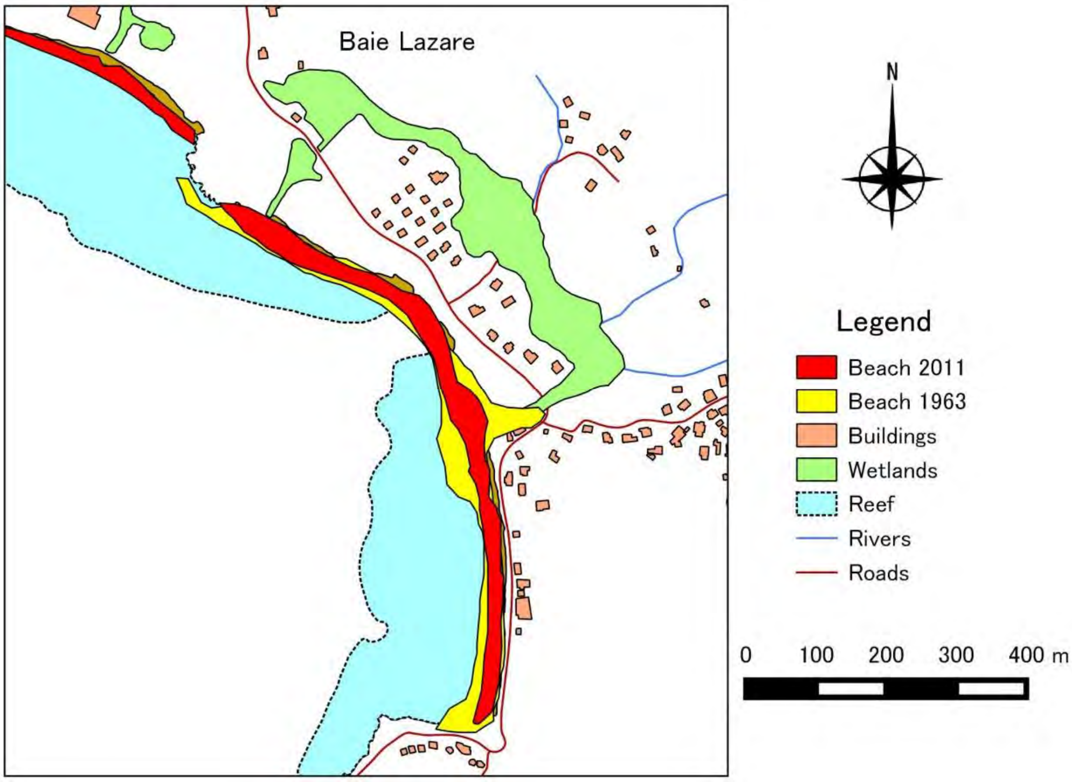


Figure 2-4-16: Beach Changes at Baie Lazare from the 1963 to 2011

Wave run-up and coral blocks were reported at the high tide in May 2007 (UNFCC (2008)). Coastal erosion started 2 or 3 years earlier and a 300m-long beach scarp 0.5m to 1.0m high was seen along the coast in the preliminary study.

Stone and wooden pile revetments were constructed in the past and the half-broken remains are left as seen in Photo 2-4-4. Recently, a channel for fishing boats was excavated through the reef. The impact of the channel on the beach is not clear.

Photo 2-4-4: Beach Scarp and Remains of Revetments and Wooden Piles at Baie Lazare

(6) Anse a La Mouche (Mahe)

The 2.5km-long, west-facing coast is made of coral sandy beach materials and is located in the south-west of Mahe Island, with a coral reef some 100m wide fronting the beach.

It is part of the coast of Anse a La Mouche which extends from Roche Soleil to the headland at Anse a La Mouche to the south of Anse Louis. The waves come from WNW because of the bay formation.

The direction of littoral sediment is from west to east and from south to north along the curved coastline. This is clear from the 1963 map of Mahe. There was a sand spit which extended to the east along the beach, with accretion to the south and erosion to the north of the river mouth, near the junction with the road. In the map the road runs parallel to the coast.

On the 1978 map of Mahe, there is reclaimed land in the sand spit, with a groyne and a jetty at the outlet of the Bouechreau River. Near each structure, there is accretion to the west and erosion to the east. This causes erosion in front of the road. On the map, the distance between the shoreline and the road is wide on the north side and narrow on the south side because of erosion to the south. The long-term beach changes are shown in Figure 2-4-17 by comparison of the 1963 map with the 2011 aerial photos. There is accretion overall, with some accretion to the west and erosion near the structures.

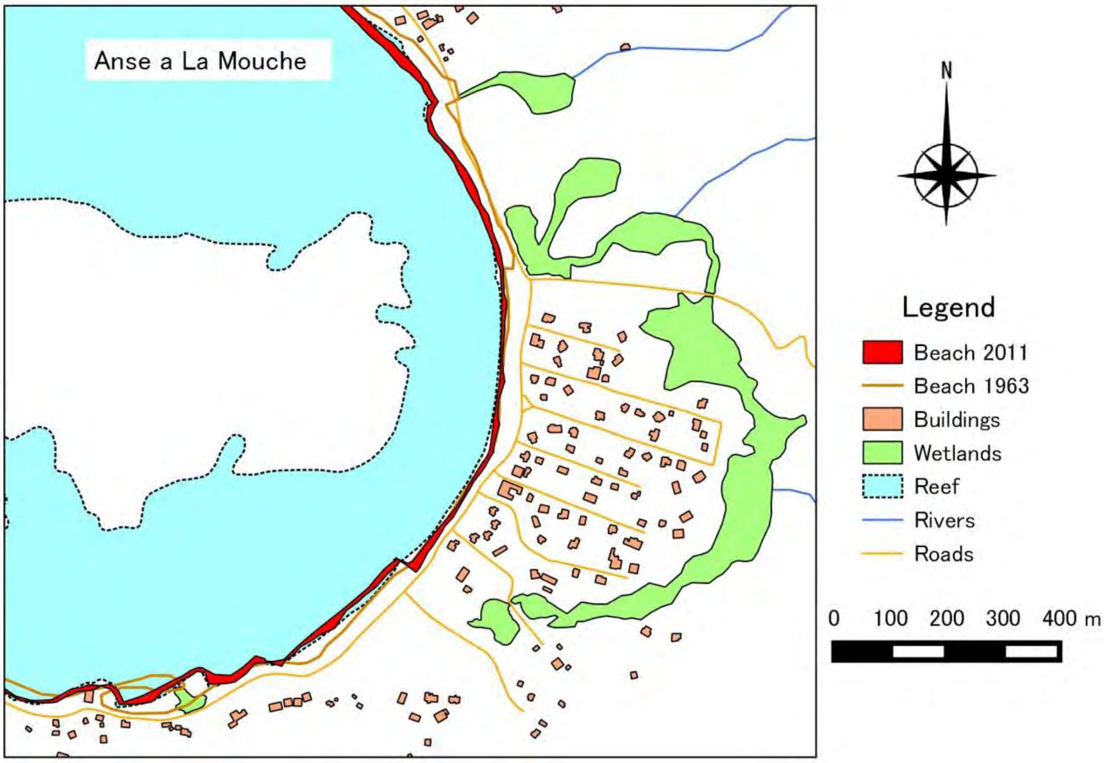


Figure 2-4-17: Beach Changes at Anse a La Mouche from the 1963 to 2011

The main cause of erosion is the decrease in sediment supply from the west due to the construction of the jetty at the outlet. The loss of sediment in the offshore direction also seems to be one of the causes. The erosion in front of the road increases the wave run-up onto the road and brings traffic problems.

(7) Anse Kerlan (Praslin)

At Anse Kerlan on Praslin, the littoral cell extends from St Marie’s Point to Roche Curet and is about 7km long. It includes Anse Kerlan and Grand Anse. The coast is convex and faces east on the north side and south on the south side. The road is located along the coast. Fronting the coast there is a wide reef extending 400m to the north and 3.0km to the south.

Coastal erosion was already reported in the newspaper (Nation, 18th March 1989). Local people explained that 12,000 m^2 of land was lost already and the coast had eroded by 30m. At that time, trees fell over on the coast at high tide and the construction of groynes was started. Also, it was explained that the erosion at Anse Kerlan corresponded with accretion at Anse Corbigeau, located to the south.

The changes in the beach between the 1960s maps and the 2011aerial photos are clearly shown in Figure 2-4-18 with erosion at Anse Kerlan and in Figure 2-4-19 with accretion at Grand Anse. A comparison of the 1990s maps and the 1998 GIS data also shows the same trend. There is erosion from 10m to 50m in the north in the area named Anse Kerlan. A comparison of the 1967 map and the 1998 GIS data of shows accretion for about 30m in the south in the area named Grand Anse. This means that the beach changes occurred mainly before 1998. There is erosion in the north and accretion in the south, and sediment is transported from the north to the south. The recent changes in the coast which were observed when the 1998 GIS data and the 2011 aerial photographs were compared are not clear.

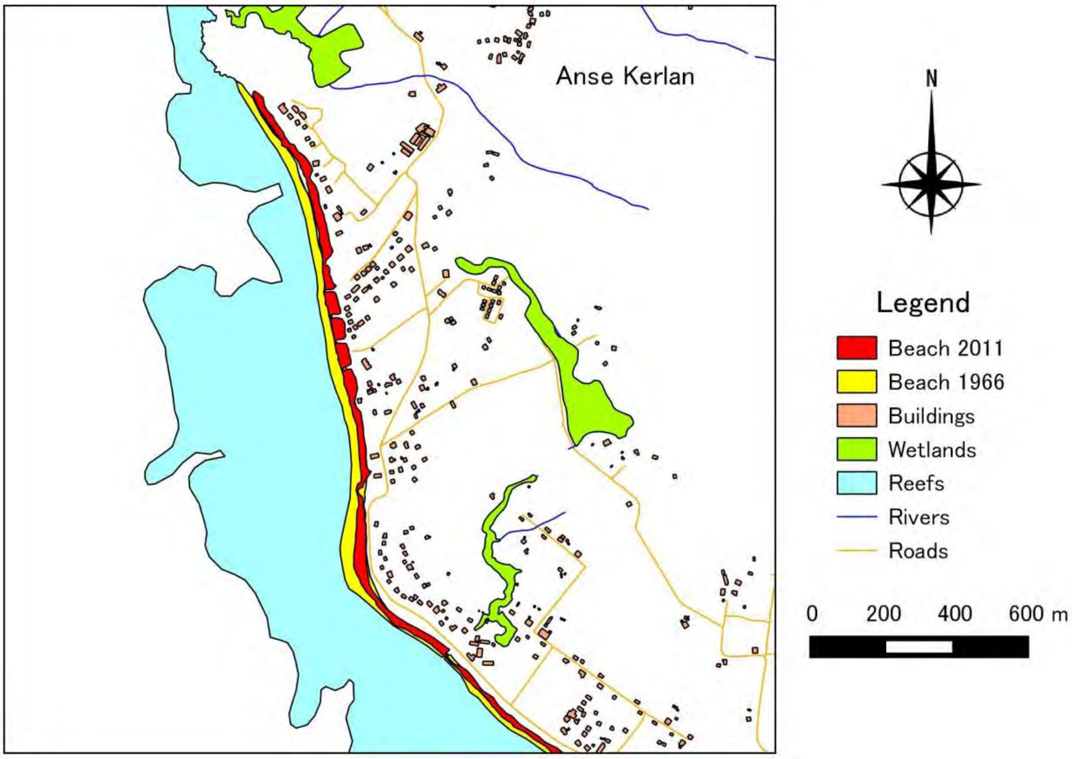


Figure 2-4-18: Beach Changes at Anse Kerlan from the 1966 to 2011

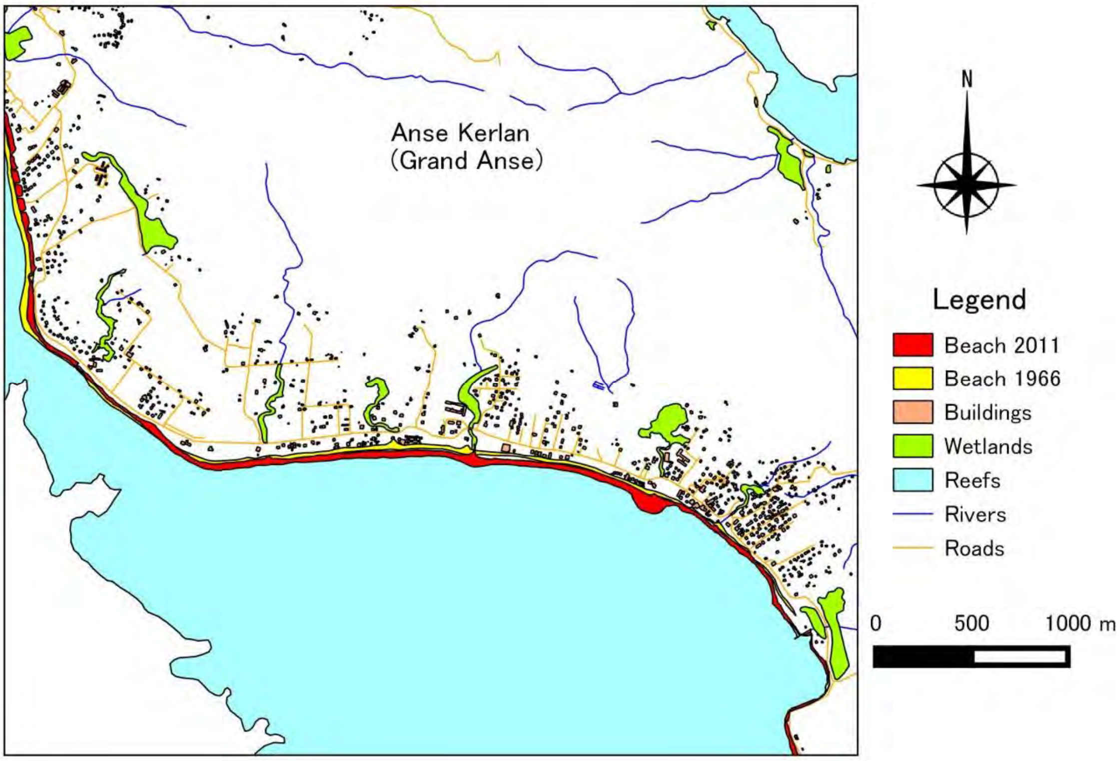


Figure 2-4-19: Beach Changes at Anse Kerlan (Grand Anse) from the 1966 to 2011

Five groynes were constructed in 1990 and another two groynes were built in 1999. The groynes were possibly constructed on an eroded beach and hence prevented the beach from recovering sediment. Also, groynes increase offshore sediment movement along the structures. A recently eroded beach and groyne field are shown in Photo 2-4-5.

Photo 2-4-5: Recent Erosion and Groyne Field at Anse Kerlan

(8) La Passe (La Digue)

The coast is located in the western part of La Digue, with a coral reef about 300m wide, and receives waves from the north-west and the south-west because Praslin is located on the west side of the island. The coast is located near the anchorage and a pier for ferries which connect La Digue to the other islands. It was reported that the Fish Collection Centre was in danger and the land was eroded and coconut trees were uprooted. The beach had eroded by 4.5m since the time of construction of the Centre in 1991 (IOC Workshop Report No.96).

A comparison between the coastline as featured on the 1964 map and the 2011 aerial photographs taken by helicopter shows erosion and accretion around the pier as in Figure 2-4-20. As coastal structures, there was only a short jetty located in front of the police station, and the beach stretched from north to south with a width of between 20m to 50m in 1964. In 2011 the beach was eroded in the north due to heavy accretion to the south of the pier. The accretion is about 50m long and 50m wide just near the pier. To the south of the pier, accretion is also seen around the reclaimed island. Between the pier and the island the beach is eroded. It is estimated that the sediment moves from the south to the pier and from both sides to the reclaimed island.

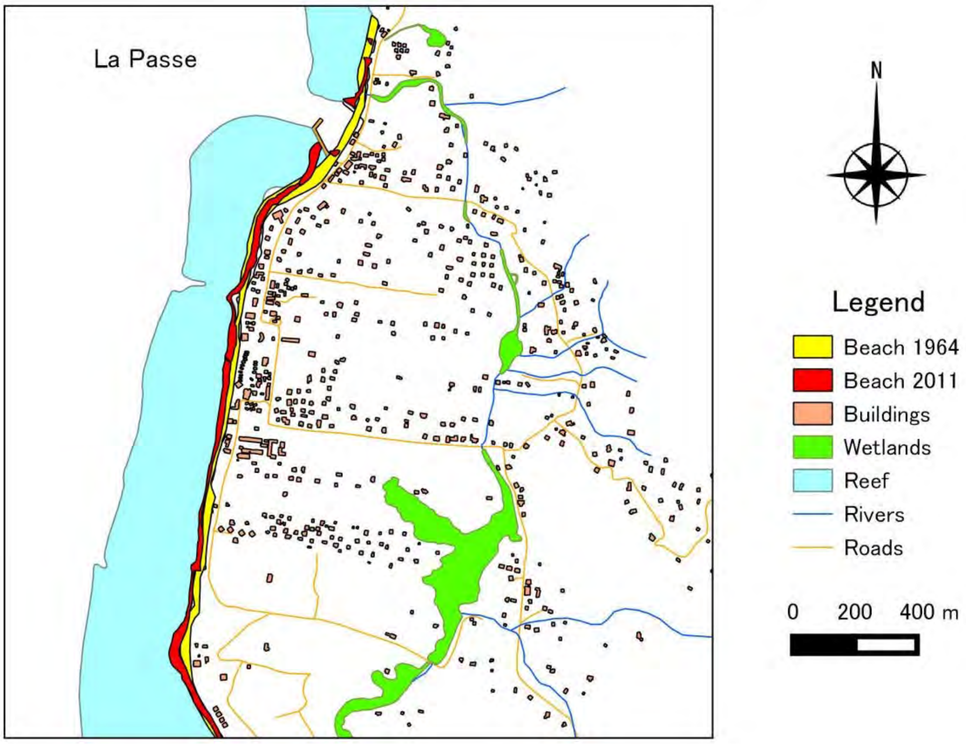


Figure 2-4-20: Beach Changes at La Passe from the 1964 to 2011

The construction of breakwaters changes the wave pattern and the coastline changes according to the new pattern. The newly built breakwaters prevent waves from the south, and the beach is accreted in the area sheltered from the northerly waves. The sediment comes from the south, and the beach is eroded as shown in Figure 2-4-21. A hospital was in danger and rock armouring was installed. The accretion continues to occur because there is no mechanism to move the sediment to the south.

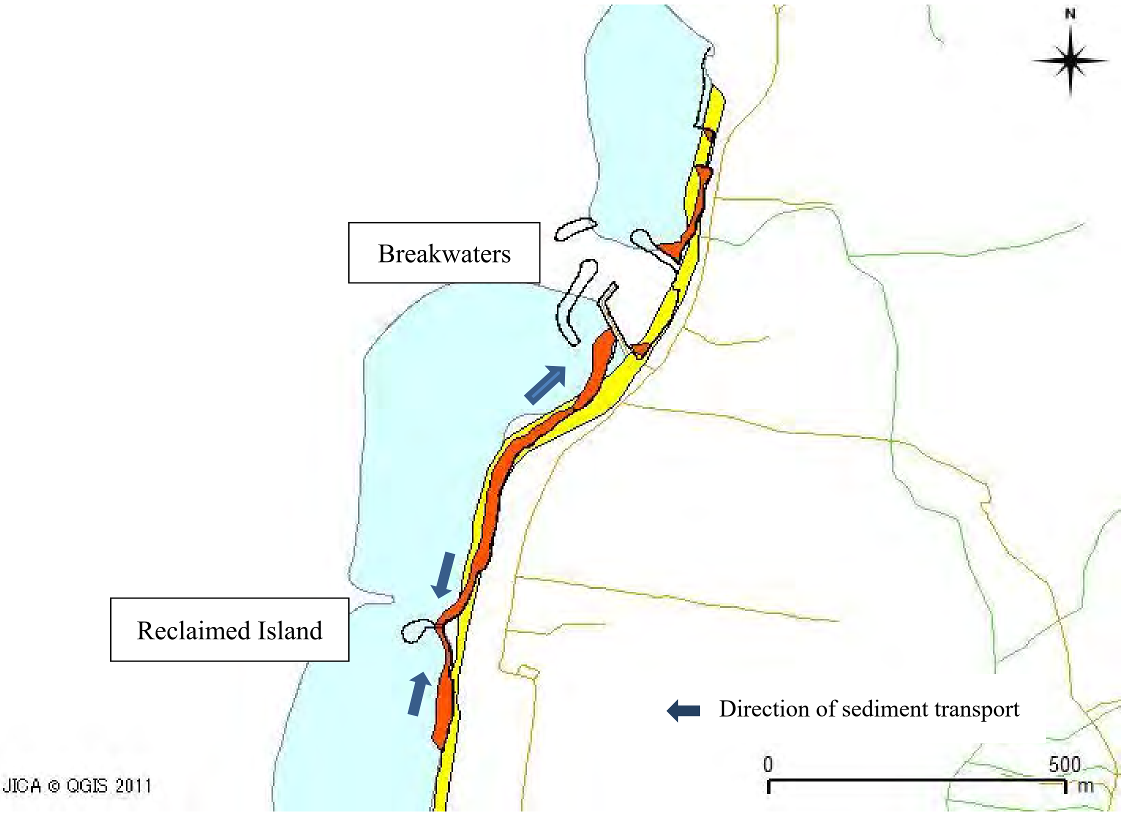


Figure 2-4-21: Sediment Movement at La Passe

Photo 2-4-6: Accretion at the Anchorage and Eroded Coast with Dead Trees

(9) Summary

On the three islands of Mahe, Praslin and La Digue, coastal roads, hotels and residents on the narrow coastal plain are affected by coastal erosion. The causes of erosion are thought to be as follows:

- The coastline tends to shift because of the seasonal variation in wave direction caused by the north-west monsoon and the south-east trade winds;
- Coastal structures such as revetments of roads, groynes and breakwaters affect sediment movement and cause erosion and accretion around them;
- Coral sand was lost due to past sand mining activities and was also transported offshore through channels through the reefs;
- EIA has been conducted in the past, but functions and regulations are lacking, especially on the probably eroding coasts.

2-4-6 Existing Coastal Structures

There are several coastal structures on the coastline. They are revetments and groynes for coastal protection, breakwaters for harbours and fishing ports and outlets for drainage improvement. Because the number of structures is limited, it is easy to investigate the effects and impact on coastal processes for improvement of performance.

(1) Revetments

The coastal road is protected by revetments made of concrete at Au Cap or wooden piles at Anse Boileau. Sometimes armoured revetments are used such as at North East Point. They are 2m to 3m high and the ground level in front of the revetments is above mean sea water level. Other types of revetments such as the armoured type are used for the protection of reclaimed land and the coral reef along the east coast of Mahe.

Photo 2-4-7: Concrete revetment at Au Cap

Photo 2-4-8: Wooden pile revetment at Anse Boileau

Photo 2-4-9: Armoured revetment at North East Point

(2) Groynes

Groynes are mostly used at Anse Kerlan on Praslin, while on Mahe some are found at Au Cap and they are intended for the control of beach erosion. The groynes at Anse Kerlan are 100 m to 200 m long and are made of rock armour. The materials are local products such as granite rock and wooden piles.

Photo 2-4-10: Groynes at Anse Kerlan on Praslin

(3) Breakwaters

There are two breakwaters at La Passe on La Digue. There are breakwaters at the fishing port at Bel Ombre and at Anse Cimetiere on Mahe. They are made of rock armouring with a length of 100m to 200m.

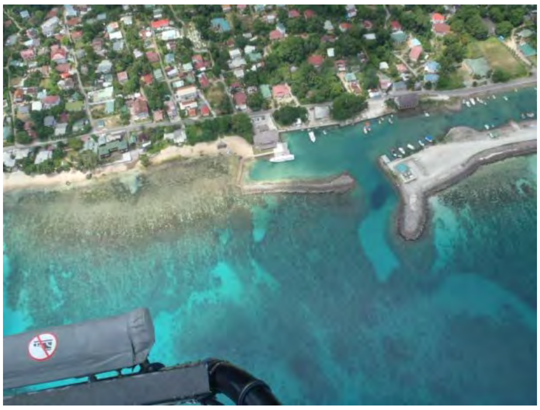


Photo 2-4-11: Breakwater at Bel Ombre

Photo 2-4-12: Breakwater at Anse Cimetiere

2-5 Analysis of Flood Management

2-5-1 General

(1) The river basin is divided into east and west by the mountain range in the centre of Mahe Island and more than 100 small rivers are distributed within the area. Most of the river catchment areas on Mahe Island are less than 1.0 km^2.

(2) Based on collected data and the inventory survey, most of the flooding was caused by short-term rainfall within a few hours. However, in the Seychelles short-term rainfall data have been observed only at Seychelles international airport.

(3) In this Study, the JICA Study Team installed three rainfall gauges and eight water level gauges in order to collect basic hydrological data. Rainfall gauges were installed around Victoria Town and the first data collection started in June 2011. Four water level gauges were installed permanently in Victoria Town and the remaining four were installed in other priority districts. The latter four gauges are removable and can be installed for certain periods in some locations and then relocated to other locations.

(4) Based on the available rainfall data, Mahe Island can be divided into three locations, north, centre and south, according to spatial distribution of the rainfall intensities and topography. In this study, the probable rainfall at these 3 locations was estimated by multiplying the following ratios by the rainfall intensity curve at Seychelles airport station where hourly rainfall data exist.

Figure 2-5-1: Correction Factors to the Rainfall Intensity Curve

Area	North area	Central area	South area
Ratio	1.1	1.0	0.9

(5) Flood discharge analysis was carried out based on the Storm Water Drainage Design Guidelines. However, there were difficulties in determining the value of some coefficients due to the lack of basic hydrological data. Therefore, some of the coefficients were set based on assumptions utilising past Japanese experience. In future, these coefficients should be reviewed after a sufficient amount of sample data has been collected.

(6) Flood inundation analysis was conducted using HEC-RAS software. Records of previous flood events were not properly archived by the concerned agencies which made verification of the hydraulic model developed in this study difficult. Model verification was carried out by reproducing the past flood situation discerned from photographs.

(7) 13 flood damage records were found for the past 25 years in local newspapers. However, only information on the location and a general damage report were provided. There was no detailed information on rainfall volume, flooding interval and depth. According to the articles, the flooding caused landslides which disrupted traffic in some locations. No human injuries were reported.

(8) The Government of the Seychelles conducted a preliminary study of drainage problems as undertaken by the drainage task force. Some countermeasures have been implemented based on the proposals of the drainage task force reports since 2005.

ydrological and hydraulic analyses are conducted in accordance with the following flowchart.

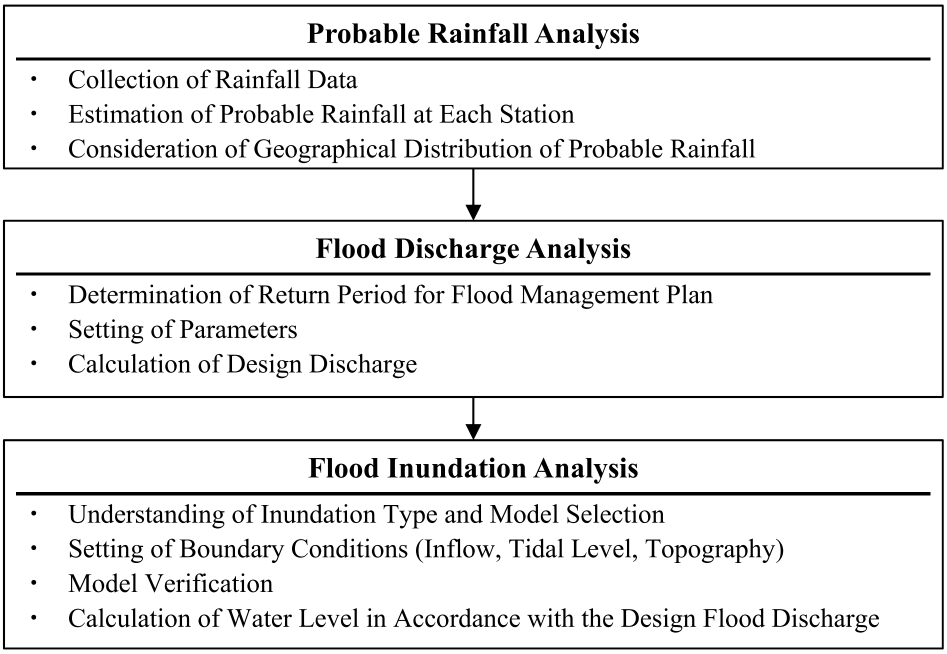


Figure 2-5-1: Procedures of Flood Analysis

The calculation results and evaluation of the water level for the flood management plan are shown in Chapter 5.

2-5-2 River Characteristics

The river basin is divided into east and west by the mountain range in the centre of Mahe Island and more than 100 small rivers are distributed within the area (refer to Figure 2.5-2). The maximum catchment area of the main river is 2.3km^2 and only 13 catchments have an area over 1.0km^2. Indeed, most of the catchments of the rivers on Mahe Island are less than 1.0km^2. Rainwater flows for a short time to the flat area along the coastline and most flows into the sea via the wetlands. The rivers in the flat area have a gradient of 1/1,000 to 1/2,000, width of 3m to 8m, and maximum water depth of about 2m.

Except for the central part of Victoria Town and the river mouths, almost all the areas are in a natural state. Since most of the rivers are lower than ground height, revetment walls were partially built at those sections. Clogging of the river mouths on the south and west side of Mahe occurs in the dry season and requires maintenance work.

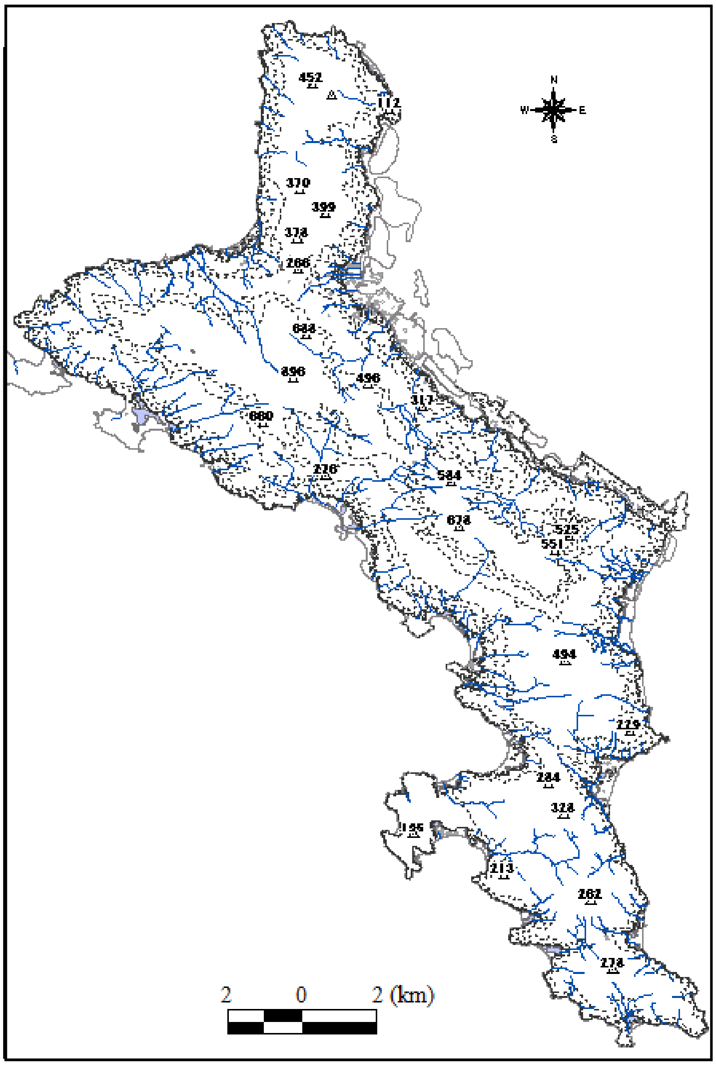
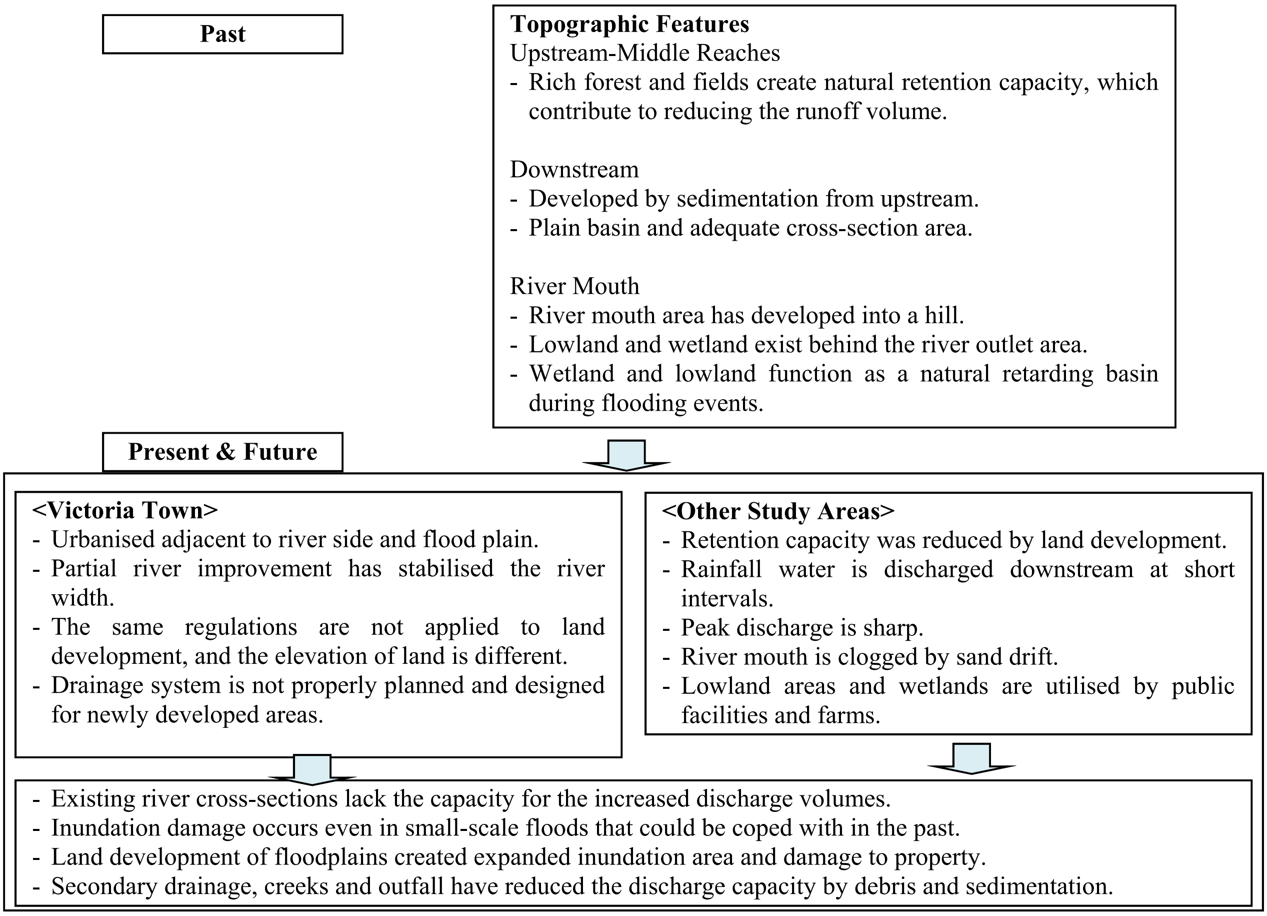


Figure 2-5-2: River Network in Mahe Island

Based on the initial survey, the river characteristics and problems can be summarised as in Figure 2-5-3.



Past

Topographic Features

Upstream-Middle Reaches
- Rich forest and fields create natural retention capacity, which contribute to reducing the runoff volume.

Downstream
- Developed by sedimentation from upstream.
- Plain basin and adequate cross-section area.

River Mouth
- River mouth area has developed into a hill.
- Lowland and wetland exist behind the river outlet area.
- Wetland and lowland function as a natural retarding basin during flooding events.

Present & Future

<Victoria Town>
- Urbanised adjacent to river side and flood plain.
- Partial river improvement has stabilised the river width.
- The same regulations are not applied to land development, and the elevation of land is different.
- Drainage system is not properly planned and designed for newly developed areas.

<Other Study Areas>
- Retention capacity was reduced by land development.
- Rainfall water is discharged downstream at short intervals.
- Peak discharge is sharp.
- River mouth is clogged by sand drift.
- Lowland areas and wetlands are utilised by public facilities and farms.

- Existing river cross-sections lack the capacity for the increased discharge volumes.
- Inundation damage occurs even in small-scale floods that could be coped with in the past.
- Land development of floodplains created expanded inundation area and damage to property.
- Secondary drainage, creeks and outfall have reduced the discharge capacity by debris and sedimentation.

Figure 2-5-3: General Idea of River Characteristics and Problems

Based on the collected data and the inventory survey of the flood risk areas, it is planned to classify the flood patterns based on local characteristics, with consideration given to the severity of damage when preparing the flood management plan. The classification corresponds to the measures to be taken. The expected classifications are as follows.

1) Urban flood;
2) Improper drainage;
3) Lowland development;
4) River with wetland.

The former three are caused by human activities and the last is a natural phenomenon.

The drainage problem in Victoria Town is characterised as a kind of urban flood. In Victoria the natural rivers flow into urban areas which have been extended to the sea as a result of land reclamation. The river gathers flood water through the drainage system such as road drains and side drains. With increased runoff associated with recent development over the years, the flow capacities of the drains have become inadequate, together with the increase in flood discharge. The measures which can be applied are the usual flood control measures in view of the specific conditions of Victoria Town.

Usually, flooding is caused somehow by ignoring the proper planning or designing of the drainage system. For example, at Pointe Larue the reclamation for the international airport obstructed the existing drainage from the coastal road to the sea without considering landward flooding. The measures to be applied should be a properly designed drainage system.

Because the available land in the Seychelles is limited, the lowland where flooding occurs is sometimes developed for housing projects or is used for public facilities. Lowland development therefore is one of the causes of flooding. The rivers flow from the mountains to the sea through the lowland where a lagoon or wetland is formed behind the coastal sand dunes. The reclamation of the lagoon sometimes aggravates the situation because the lagoon has the function of keeping the river outlet open to the sea. The measures to be applied are accommodation, regulation of land use and structural measures.

In the Seychelles, as a natural phenomenon, most storm water is discharged into the nearby wetland before reaching the sea because sand dunes along the coast prevent smooth flow of the water. River and wetland systems are natural systems which cause flooding around the wetland. The measures to be applied are do-nothing, accommodate and use structural measures.

2-5-3 Hydrological Observations

(1) Rainfall

The only existing rainfall station that measures short-term rainfall is currently located at Seychelles International Airport. In order to analyse the meteorological impact of torrential rainfall in Victoria City, the distance between the two sites is considered to be too far. Therefore, it is necessary to install new equipment for rainfall measurement in Victoria Town.

In this study, three rainfall gauges are installed near Victoria, two in the mountain area and one on low-lying land. The sites for rainfall gauge installation are shown in Table 2-5- and the location map is shown in Figure 2-5-4.

Table 2-5-2: Sites for Rainfall Gauge Installation

Location Name	No.61, St. Louis	No.58, Hermitage	English River Secondary School
Location	St. Louis LAT: 4° 37’ 7.83’’ LONG: 55° 26’ 22.98’’	Hermitage Water Works LAT: 4° 37’ 54.28’’ LONG: 55° 27’ 10’’	Victoria LAT: 4° 37’ 7.84’’ LONG: 55° 27’ 20.53’’
Owner of property	Cable & Wireless	PUC	Victoria Town (school)
Status	• Basically agreed on installation of new gauge. (April 26, 2011) • Need official letter from PUC to the company	• Discussed with PUC (21 April 2011) • Agreed on installation, no need further documentation. • Location already fixed • 20 June 2011 finished installation.	• Basically agreed on installation of RG. (5 May 2011) • Need one more discussion before installation
Photo			
Maintenance	NMS	PUC	NMS
Remarks	Need to prepare an official letter.	After arrival of equipment, discuss again with PUC how to install the equipment on the tank	After arrival of equipment, discuss again how to install equipment Require an official letter

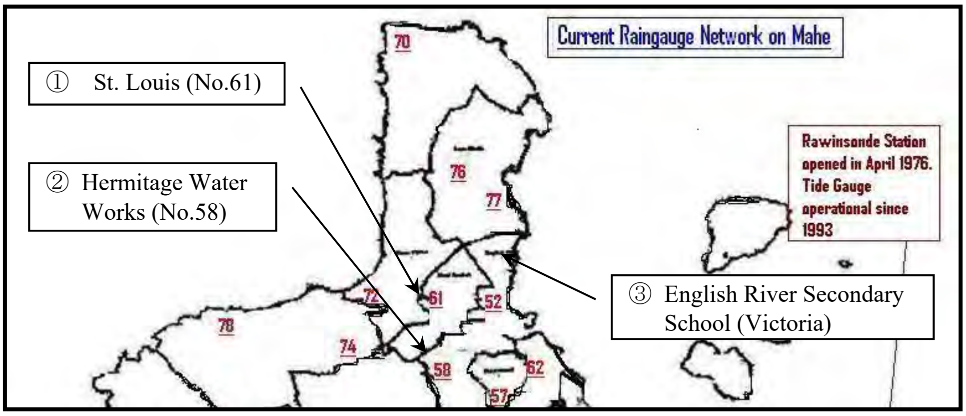


Figure 2-5-4: Location Map of Sites for Rainfall Gauge Installation

Figure 2-5-5:
Installing Rainfall Gauge
(Hermitage, PUC)

The monitoring procedure at the rainfall station is as follows:

1) Open the outer cover and connect the PC to the rain gauge with the RS232 cable

Figure2-5-6 Connection of Rainfall Gauge and PC

2) PC Software Operation (Refer to the Rainfall Logging System in the user manual)

- Display the current rain gauge status
- Download the data
- Check the downloaded data
- Initialise the rain gauge

3) Maintenance

- Periodically check for debris in the funnel and blockage of the inlet and outlet ports. Remove any debris and clean the meshes.
- The water outlet on the underside of the funnel can be unscrewed to allow the inlet mesh to be removed and cleaned.
- If necessary, the bucket surface can be cleaned using a mild detergent solution.
- Unexpected debris or refuse (e.g. branches, dead leaves, bird droppings, insects, etc.)
- Maintenance at a desirable timing.

Periodically

- At least once every 3 months (Dry season)
- At least once a month (Rainy season)

Irregularity

- When it rains continually for about 1 week

(Logger capacity: Memory=64kb: stops logging when full, Records=13,000:1 minute of rainfall per record).

It is expected that hourly rainfall data which is required for flood analysis will be obtained continuously in the future.

(2) Water Level (Victoria)

In this study, eight water level gauges were installed in the selected areas. Four gauges were installed permanently in the town of Victoria and the others were installed at the outlets of rivers or at the inlets and outlets of marsh areas to monitor water movement. The sites for water level gauge installation are shown in Table 2-5-1 and the location map is shown in Figure 2-5-5.

Table 2-5-1: Sites for Water Level Gauge Installation in Victoria

River Name	Anglaise	Moosa	Maintry	St. Louis
Location	Right side Downstream of the bridge	Right side next to the Youth Club	Right side Upstream of the road	Right side Upstream of the road
Owner of property	Private	Private	Private	Private
Status	Installed	Installed	Installed	Installed
Photo				
Remarks	Installation will be carried out after desilting by DOE	Installation will be carried out after desilting by DOE	• Installation will be carried out after clearing • DOE will clear the vegetation on the site	• Need to clear the installation site • DOE will clear the vegetation on the site

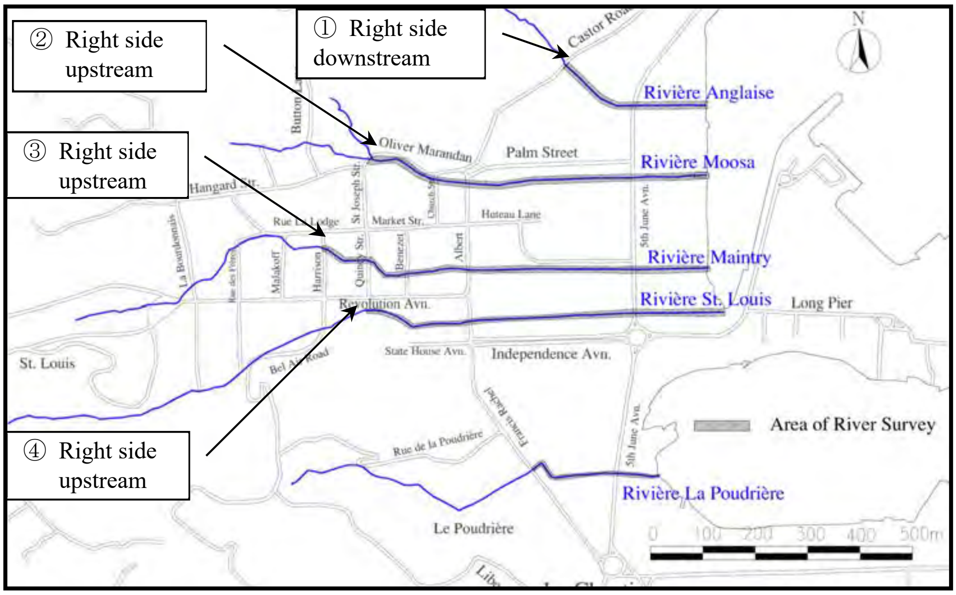


Figure 2-5-5: Location Map of Sites for Water Level Gauge Installation in Victoria

(3) Water Level (Others)

Four gauges in other areas were installed at the outlets of rivers or at the inlets and outlets of marsh areas to monitor water movement. Two gauges were installed at each location in Pointe Larue, Anse Aux Pins, Au Cap and Anse Royale (one midstream and the other at the river mouth) and observations implemented of the first two months. Currently, continuous observations are conducted.

2-5-4 Probable Rainfall Analysis

(1) Collection of Rainfall Data

There are 26 rain gauge stations operating at present on Mahe Island and rainfall data collected over 20 years are available from 22 locations. Hourly rainfall data are limited to Seychelles international airport since the other observatories only measure daily rainfall data. Hence the data necessary for analysis of the flood conditions are insufficient. Table 2-5-2 and Figure 2-5-6 show the location of rain gauge stations.

Table 2-5-2: Table of Rain Gauge Stations

NO	Name	Height (m)
1	Seychelles Airport	2
2	Rawinsonde	2
6	Cascade	110
7	La Misere (Fairview)	342
16	Anse Royale PUC	80
17	Anse Royale Police Stn	2
19	Quatre Bornes	85
21	Anse Soleil	8
22	Pointe Au Sel	38
23	Anse Forbans	5
32	Anse Boileau	5
33	Grand Anse Waterworks	2
37	Tea Factory	390
41	Bon Espoir	240
45	La Misere (Mr. Rose)	455
57	Rochon Waterworks	200
58	Hermitage Waterworks	80
61	St Louis	182
74	Le Niol Waterworks	22
76	La Gogue	120
77	Ma Constance(North East)	112
78	Belombre	25
	Additional Data	

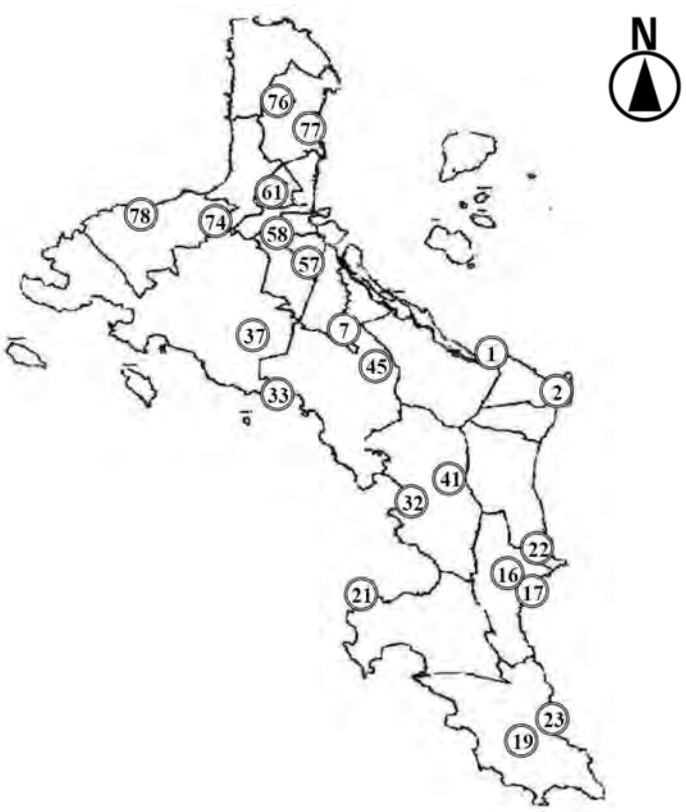


Figure 2-5-6: Location of Rain Gauge Stations

(2) Estimation of Probable Rainfall

Based on the annual maximum daily rainfall at each station, the results by Gumbel's law which is generally employed for hydrological statistics are shown in Table 2-5-3.

Table 2-5-3: Probable Annual Maximum Daily Rainfall

St.No	Name/Return Period	100	50	20	10	5	3	2
1	Seychelles Airport	287	262	229	203	177	156	136
2	Rawinsonde	232	208	177	153	128	108	90
6	Cascade	250	225	193	167	141	120	101
7	La Misere (Fairview)	271	245	210	183	155	133	113
16	Anse Royale PUC	288	262	228	201	174	152	132
17	Anse Royale Police Stn	229	209	182	162	140	123	108
19	Quatre Bornes	170	153	132	115	98	84	72
21	Anse Soleil	202	184	159	140	119	103	89
22	Pointe Au Sel	256	234	204	181	157	138	121
23	Anse Forbans	178	163	142	125	109	95	83
32	Anse Boileau	227	204	175	152	128	109	92
33	Grand Anse Waterworks	281	254	216	187	157	133	112
37	Tea Factory	289	260	221	191	159	134	112
41	Bon Espoir	242	219	188	164	139	120	102
45	La Misere (Mr. Rose)	335	299	252	216	178	147	120
57	Rochon Waterworks	287	258	219	189	158	133	110
58	Hermitage Waterworks	349	318	276	243	210	183	158
61	St Louis	313	282	241	210	177	150	127
74	Le Niol Waterworks	291	265	230	203	175	153	133
76	La Gogue	269	241	202	172	141	117	95
77	Ma Constance(North East)	293	263	223	192	160	134	111
78	Belombre	290	260	221	190	158	133	111

(3) Consideration of Geographical Distribution of Probable Rainfall

(a) Rainfall Distribution

Since hourly rainfall data are obtained only at Seychelles International Airport, the probable rainfall intensity curve is only available there. Therefore, the rainfall intensity curves at other areas are prepared by correcting the curve at the international airport station according to the ratio of maximum rainfall at each gauge station.

According to the distribution of the past maximum rainfall and the probable daily rainfall in the 10-year return period, the southward area has less rain compared with the northward area, and this tendency can also be seen in the annual total rainfall distribution in the past results.

Based on the past results for probable rainfall (Disaster risk profile of the Republic of the Seychelles July 2008, UNDP), the geographical distribution is divided into two, the north and the south of Mahe Island.

Considering the height of the mountains and isohyet distribution, it is reasonable to divide the whole area into 3 parts: northern, central and southern. The probable rainfall in the 3 parts is shown in the following table.

Table 2-5-4: Probable Rainfall in Each Return Period

Area	St.No	Name / Return Period	400	200	150	100	80	50	30	20	10	5	3	2	1.5
North	58	Hermitage Waterworks	412	381	368	349	339	318	295	276	243	210	183	158	138
	61	St Louis	374	344	331	313	303	282	259	241	210	177	150	127	106
	74	Le Niol Waterworks	343	317	306	291	282	265	245	230	203	175	153	133	116
	77	Ma Constance(North East)	353	323	310	293	283	263	241	223	192	160	134	111	92
	37	Tea Factory	348	319	306	289	280	260	238	221	191	159	134	112	93
	78	Belombre	348	319	307	290	280	260	238	221	190	158	133	111	91
	57	Rochon Waterworks	345	316	304	287	278	258	236	219	189	158	133	110	91
	76	La Gogue	327	298	286	269	260	241	219	202	172	141	117	95	76
Center	45	La Misere (Mr. Rose)	405	370	355	335	323	299	273	252	216	178	147	120	97
	1	Seychelles Airport	337	312	302	287	279	262	244	229	203	177	156	136	120
	33	Grand Anse Waterworks	337	309	298	281	272	254	233	216	187	157	133	112	93
	7	La Misere (Fairview)	323	297	287	271	263	245	226	210	183	155	133	113	95
	6	Cascade	299	274	264	250	242	225	207	193	167	141	120	101	85
	41	Bon Espoir	288	265	255	242	234	219	202	188	164	139	120	102	87
	2	Rawinsonde	278	255	245	232	224	208	191	177	153	128	108	90	75
	32	Anse Boileau	271	249	239	227	219	204	188	175	152	128	109	92	78
South	16	Anse Royale PUC	340	314	303	288	280	262	243	228	201	174	152	132	115
	22	Pointe Au Sel	301	279	269	256	249	234	218	204	181	157	138	121	106
	17	Anse Royale Police Stn	269	249	241	229	223	209	194	182	162	140	123	108	95
	21	Anse Soleil	240	221	213	202	196	184	170	159	140	119	103	89	77
	23	Anse Forbans	210	194	188	178	173	163	151	142	125	109	95	83	73
	19	Quatre Bornes	202	186	179	170	164	153	141	132	115	98	84	72	61

(b) Rainfall Intensity Curve

To compare the maximum rainfall data for each part with that of the airport station where only hourly rainfall data exists, the average rainfall using 3 higher rank spots (considering the reliability of the plan) is calculated.

The probable rainfall at the airport station is approximately the same as that of the central area. The probable rainfall in the northern area is 108% compared to that at the airport station and the probable rainfall in the southern area is 89% compared to that at the airport station.

Table 2-5-5: Probable Rainfall and Ratio at Airport in Each Return Period

Area / Return Period	400	200	150	100	80	50	30	20	10	5	3	2	1.5
North Area(3)	376	347	335	318	308	288	266	249	219	187	162	139	120
Center Area(3)	360	330	318	301	292	272	250	232	202	171	145	123	103
South Area(3)	303	281	271	258	251	235	218	205	181	157	138	120	105
N Area Ratio of Airport	1.12	1.11	1.11	1.11	1.10	1.10	1.09	1.09	1.08	1.06	1.04	1.02	1.00
C Area Ratio of Airport	1.07	1.06	1.05	1.05	1.04	1.04	1.02	1.01	0.99	0.96	0.93	0.90	0.86
S Area Ratio of Airport	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.89	0.89	0.89	0.89	0.88	0.88

Considering the long-term planning, the probable rainfall in the 3 areas is determined as follows.

North Area	1.1 (110%)
Central Area	1.0 (100%)
South Area	0.9 (90%)

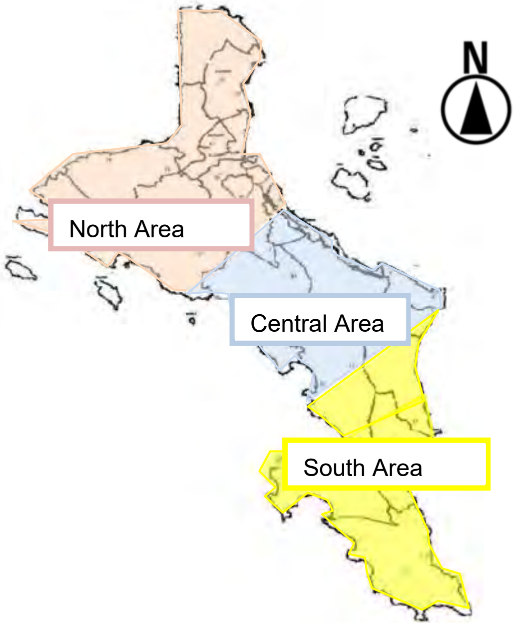


Figure 2-5-7: Compensation Coefficient Rainfall in 3 Areas

Consequently, the following coefficient values (shown in Table 2-5-6) are applied when preparing the probable rainfall intensity curve in the case of the design discharge calculations.

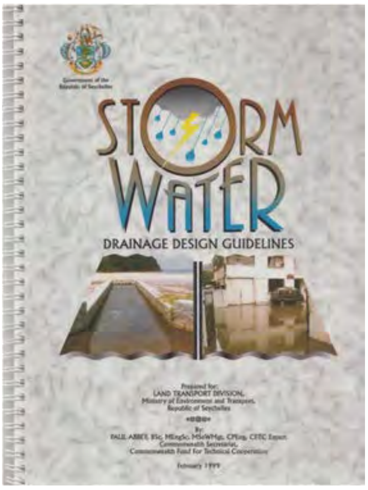
Table 2-5-6: Coefficient Value Applied to Probable Rainfall Intensity Curve

Study Area	Coefficient Value Applied to Probable Rainfall Intensity Curve
Victoria Town	1.1
Pointe Larue	1.0
Anse Aux Pins	0.9
Au Cap	0.9
Anse Royale	0.9

2-5-5 Flood Discharge Analysis

(1) General

The *Storm Water Drainage Design Guidelines* were prepared in 1999 by the Commonwealth Fund for Technical Cooperation (CFTC). The document aims to provide a basic reference for MHAETE engineers when planning and designing urban drainage and related structures. Therefore, these guidelines will be adopted for the design and evaluation of the drainage system in this study.



STORM WATER

DRAINAGE DESIGN GUIDELINES

Figure 2-5-8: Cover of Storm Water Drainage Design Guidelines

Discussed hereunder are the items considered when calculating the discharge.

- Topographic data and existing drainage network from GIS data
- Site investigation
- Results of the *Preliminary Study of the Flooding Problems in Victoria Town* in 2005
- Results of the *Preliminary Study of the Drainage Problems in Various Districts, Drainage Task Force Committee, October 2004*
- Results of *The Flooding Problem at Au Cap - A Study of the Drainage Pattern and Recommendations for Corrective Actions*

(2) Determination of Return Period for Flood Management Plan

A 10-year return period was adopted for the drainage structures in Victoria Town and other areas in the Drainage Design Guidelines as shown below:

Table 2-5-7: Recommended Return Period for Design

Category	Return Period
Central Business – Victoria City	10 years
Commercial & Industrial	5 years
High Density Residential – more than 35 dwelling units/hectare	10 years
Medium Density Residential – 25 to 35 dwelling units/hectare	5–10 years
Low Residential – less than 25 dwelling units/hectare	5 years
Culvert Structures – Major roads	25 years
– Minor roads	2–5 years
Major natural drainage channels	25 years

In this study, the target return periods are set as shown below, consisting of three phases in each area: Short-Term Plan as the target to be implemented immediately, Medium-Term Plan as the target for the time being, and Long-Term Plan as the target for the future taking into consideration factors such as climate change.

Target Return Period

	Short Term	Medium Term	Long Term
Victoria	**10**	**25**	**100**
Others	**5**	**25**	**100**

As for the other 4 areas except Victoria town, the short-term target return period is set at 5 years considering the land use conditions, including Commercial & Industrial and Low Residential – less than 25 dwelling units/hectare.

(3) Catchment Areas

The catchment areas are divided based on a 2m contour line which was incorporated into the existing GIS in addition to the results of site investigation. The details are shown in the Supporting Report.

(4) Calculation Formula

The Design Guidelines recommend the rational method for estimating the design discharge. The rational method is used for drainage areas of 20 km^2 or less. Considering its simplicity and applicability, the rational formula is deemed most appropriate and is therefore adopted for calculation of the discharge. The rational formula is expressed as

$$Q = \frac{1}{3.6} C_y I_y A$$

where

Q = design discharge, m^3/sec

C_y = runoff coefficient

I_y = rainfall intensity, mm/hr

A = catchment area, km^2

(5) Setting of Parameters

The two parameters used in the rational formula (Runoff Coefficient C_y and I_y) are set as shown in Table 2-5-8.

Table 2-5-8: Setting of Parameters of Rational Formula (Runoff Coefficient C_y and I_y)

	Victoria City	**Other Areas**	**Remarks**
f_i (Coefficient reflecting the land use conditions)	1.0	0.9	”*Storm Water Drainage Design Guidelines*”
C_{10} (Runoff Coefficient applied to 10-year return period)	0.65	0.63	Calculation Formula : $C_{10} = 0.45 + 0.2\ f_i$ ”*Storm Water Drainage Design Guidelines*”
C_y (Runoff Coefficient applied to target return period)	0.65	0.60	Calculation Formula : $C_y = F_y \times C_{10}$ (F_y is a coefficient relating to return period) ”*Storm Water Drainage Design Guidelines*”
I_y(Rainfall Intensity) T_c (Time of Concentration)	Shown in Supporting Report		Coefficients shown in Table 2-5-6 are applied to Probable Rainfall Intensity Formula Table 2-5-9.

Table 2-5-9: Probable Rainfall Intensity Formula

Coefficient of Formura	Return Period					
	2	5	10	25	50	100
	$r = \frac{a}{t^n + b}$					
n	0.74	0.82	0.91	0.93	0.96	0.98
a	1,401	3,247	7,346	9,847	13,922	17,790
b	8	22	54	68	91	109

*Coefficients of formula are set according to the curve shown in “*Storm Water Drainage Design Guidelines*”

(6) Design Discharge

In the design discharge plan flow rate which was calculated based on the above conditions, the design discharges are shown in Table 2-5-10.

Table 2-5-10: Design Discharge

			Return Period											
	Name	Area	5			10			25			100		
		(ha)	Cy	Iy	Qy	Cy	Iy	Qy	Cy	Iy	Qy	Cy	Iy	Qy
Victoria	Anglaise	57.0	0.62	86.4	8.5	0.65	100.1	10.3	0.69	112.0	12.2	0.79	136.4	17.1
	Moosa	135.0	0.62	80.7	18.8	0.65	94.7	23.1	0.69	106.4	27.6	0.79	130.6	38.7
	Maintry	33.0	0.62	79.2	4.5	0.65	93.3	5.6	0.69	105.0	6.6	0.79	129.1	9.4
	St Louis	118.0	0.62	80.7	16.4	0.65	94.7	20.2	0.69	106.4	24.1	0.79	130.6	33.8
	La Poudrie	38.0	0.62	88.3	5.8	0.65	101.8	7.0	0.69	113.7	8.3	0.79	138.2	11.5
Point Larue	PL-1	59.0	0.60	82.9	8.2	0.63	94.9	9.8	0.67	105.8	11.6	0.76	128.1	16.0
	PL-2	29.0	0.60	75.5	3.7	0.63	88.1	4.5	0.67	98.9	5.3	0.76	121.0	7.4
	PL-3	12.0	0.60	77.8	1.6	0.63	90.3	1.9	0.67	101.0	2.3	0.76	123.3	3.1
	PL-4	28.0	0.60	82.9	3.9	0.63	94.9	4.7	0.67	105.8	5.5	0.76	128.1	7.6
	PL-5	6.0	0.60	82.0	0.8	0.63	94.1	1.0	0.67	104.9	1.2	0.76	127.3	1.6
	PL-6_1～3	86.0	0.60	79.4	11.4	0.63	91.7	13.8	0.67	102.6	16.4	0.76	124.8	22.7
	PL-7	38.0	0.60	66.1	4.2	0.63	79.0	5.3	0.67	89.3	6.3	0.76	110.7	8.9
	PL-8	24.0	0.60	66.1	2.6	0.63	79.0	3.3	0.67	89.3	4.0	0.76	110.7	5.6
Anse Au Pinn	AAP-1	18.0	0.60	74.6	2.2	0.63	85.4	2.7	0.67	95.2	3.2	0.76	115.3	4.4
	AAP-2	34.0	0.60	74.6	4.2	0.63	85.4	5.1	0.67	95.2	6.0	0.76	115.3	8.3
	AAP-3	58.0	0.60	72.2	7.0	0.63	83.3	8.5	0.67	93.0	10.0	0.76	113.1	13.9
	AAP-4	55.0	0.60	70.0	6.4	0.63	81.2	7.8	0.67	90.9	9.3	0.76	110.9	12.9
	AAP-5	101.0	0.60	55.5	9.3	0.63	67.0	11.9	0.67	76.1	14.3	0.76	94.9	20.3
	AAP-6	16.0	0.60	66.6	1.8	0.63	78.1	2.2	0.67	87.7	2.6	0.76	107.5	3.6
	AAP-7	33.0	0.60	52.4	2.9	0.63	63.8	3.7	0.67	72.6	4.5	0.76	91.0	6.3
Aux Cap	AC-1	41.0	0.60	67.3	4.6	0.63	78.7	5.7	0.67	88.3	6.7	0.76	108.2	9.4
	AC-2	95.0	0.60	69.3	11.0	0.63	80.6	13.4	0.67	90.3	16.0	0.76	110.2	22.1
	AC-3	27.0	0.60	63.6	2.9	0.63	75.2	3.6	0.67	84.7	4.3	0.76	104.4	6.0
	AC-4	54.0	0.60	61.5	5.5	0.63	73.1	6.9	0.67	82.5	8.3	0.76	101.9	11.6
	AC-5	58.0	0.60	61.5	5.9	0.63	73.1	7.4	0.67	82.5	8.9	0.76	101.9	12.5
	AC-6	50.0	0.60	61.5	5.1	0.63	73.1	6.4	0.67	82.5	7.7	0.76	101.9	10.8
	AC-7	46.0	0.60	61.5	4.7	0.63	73.1	5.9	0.67	82.5	7.1	0.76	101.9	9.9
	AC-8	31.0	0.60	62.5	3.2	0.63	74.2	4.0	0.67	83.6	4.8	0.76	103.1	6.8
	AC-9	25.0	0.60	66.6	2.8	0.63	78.1	3.4	0.67	87.7	4.1	0.76	107.5	5.7
Anse Royal	AR-1	51.0	0.60	66.0	5.6	0.63	77.5	6.9	0.67	87.1	8.3	0.76	106.9	11.5
	AR-2	162.0	0.60	55.5	15.0	0.63	67.0	19.0	0.67	76.1	23.0	0.76	94.9	32.5
	AR-3	41.0	0.60	61.0	4.2	0.63	72.6	5.2	0.67	82.0	6.3	0.76	101.4	8.8
	AR-4	84.0	0.60	52.1	7.3	0.63	63.4	9.3	0.67	72.2	11.3	0.76	90.5	16.1
	AR-5	49.0	0.60	56.3	4.6	0.63	67.9	5.8	0.67	77.0	7.0	0.76	95.9	9.9
	AR-6	82.0	0.60	59.0	8.1	0.63	70.6	10.1	0.67	79.9	12.2	0.76	99.1	17.2
	AR-7	23.0	0.60	72.2	2.8	0.63	83.3	3.4	0.67	93.0	4.0	0.76	113.1	5.5

2-5-6 Flood Inundation Analysis

(1) Basic Policy

The patterns of inundation by river floods are classified into three types depending on the condition of the river channel and the topography of the inundation area. These are, namely flood channel type, diffusion type and storage type. According to the topographic features of the target area, it is projected that inundation water flows down the river and does not extend widely onto the flood plain. Therefore, the flood channel type is a good description of this type of inundation condition.

In this study, a one-dimensional analysis model is employed for calculation of the water level and establishment of the flood management plan. As for the tidal level at the river mouth, the probable tidal level is set as the boundary condition.

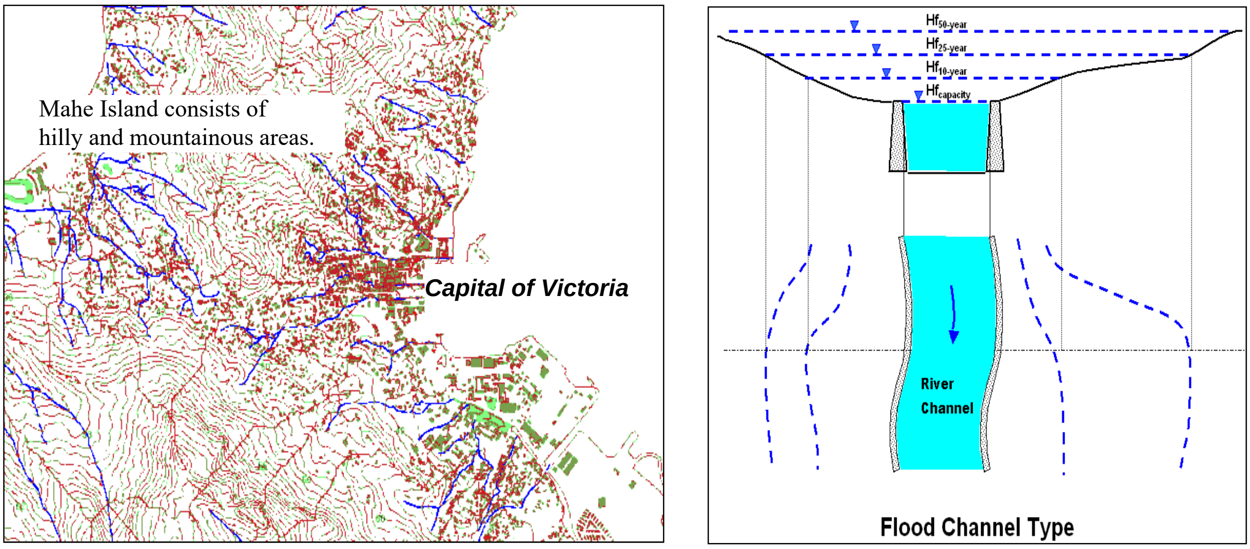
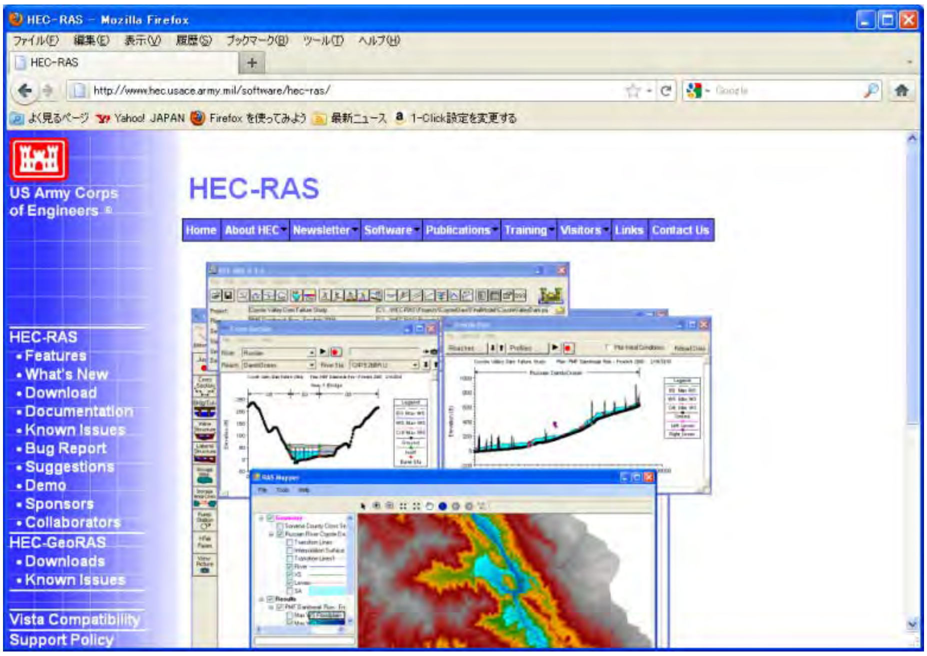


Figure 2-5-9: Flooding Type

From the point of view of technology transfer to the counterparts, easily obtainable and user-friendly software is employed. In this study, HEC-RAS developed by the US Army Corps of Engineers is used for analysis. This programme can be obtained free from the following website (Figure 2-5-10).



http://www.hec.usace.army.mil/software/hec-ras/

Figure 2-5-10: HEC RAS Website

(2) Analysis Conditions

(a) River Cross Section

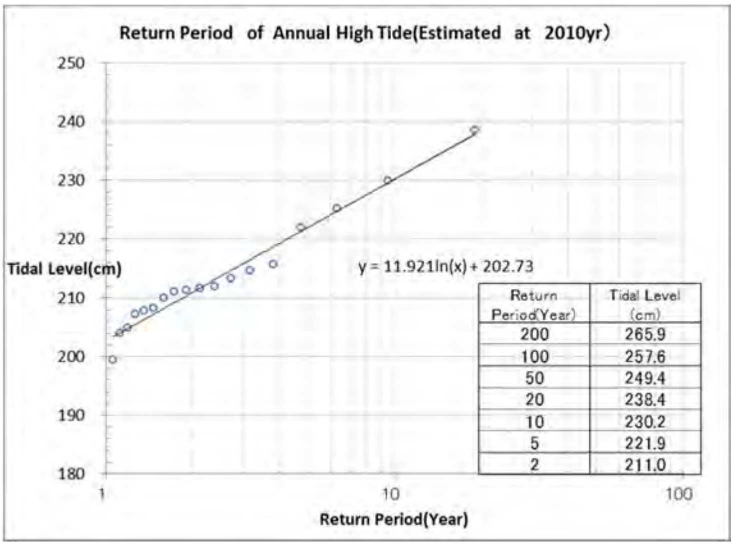
Since there was no available data on the river cross section, on-site surveys were conducted in this study. The results are used as the topographical conditions for the analysis.

(b) Discharge from Upstream

Discharges from each river at each cross section are given according to the results of runoff calculation using the rational formula explained above (Table 2-5-10). The catchment areas of the Moosa River and Maintry River are divided into smaller sub-basins because these two rivers are located in the Victoria urban area and their catchment areas include the area where flooding has occurred in the past.

(c) Tidal Level at River Mouth

According to the observed tidal level at the airport, the recent mean-sea-level is rising at a rate of about 6 mm per year. The probability distribution of the annual maximum tidal level is estimated considering the sea level variation by comparing 2010 with a rate of 6 mm per year. The results are shown in Figure 2-5-11 and Table 2-5-11.



*plotting position: Weibull plotting

Figure 2-5-11: Probability Distribution of Tidal Level

Table 2-5-11: Design Tidal Level with a Return Period of 10, 25, and 100 years

Item	Return Period (Years)	Tidal Level above TSZ (cm)	Tidal Level above MSLD (cm)
Short Term	10	230	133
Medium Term	25	241	144
Long Term	100	258	161
TSZ: Tidal Staff Zero, MSLD: Mean Sea Level Datum, 97cm above TSZ, CD: Chart Datum, 7cm above TSZ			

(3) Model Verification (2004 Flood)

To prove the reasonability of the model, model calibration is conducted by comparing the calculated water levels of the Maintry River with the observed water levels. In the study, the 2004 flood is employed as the target flood.

(a) Status of Flood

According to the recent disaster information database, FLOOD is included as a single disaster type, but with information related only to occurrence date and the affected district's name. Hence quantitative information such as details of rainfall, depth of flood, area, duration and details of damage is unclear. Photographs of the flood in central Victoria in past reports are material from which the extent of the flood can be comprehended though no information about time or depth is obtained (See Photo 2-5-1).

Photo 2-5-1: Photo of Centre of Victoria Town in the 2004 Flood

The flood occurred on 28th and 29th December 2004. The inundation depth is estimated to be 30 cm according to Photo 2-5-1. In other areas, the extent of the flooding is unclear due to lack of information.

(b) Analysis Conditions

1) Evaluation of Rainfall

In the rainfall event which occurred in 2004, there was less rainfall in the southern region than in the northern region where Victoria Town is located. The daily rainfall measured at the airport station was 68 mm with a maximum hourly rainfall of 25mm on 29th December while at the Hermitage station which is located in the neighbourhood of Victoria it was 169 mm.

The hourly rainfall distribution at the Hermitage station was prepared by enlarging the rainfall distribution at the airport station by an enlargement ratio equivalent to the ratio of daily rainfall at the Hermitage station to that at the airport station.

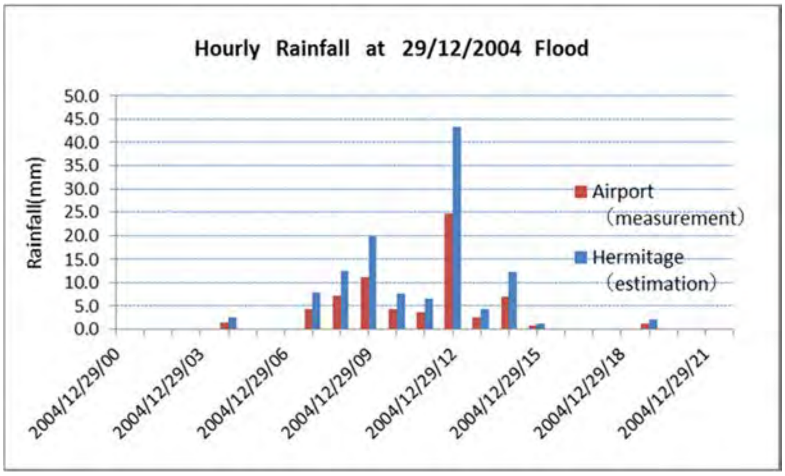


Figure 2-5-12: Hourly Rainfall on 29 December 2004

The return period of 6 hours (equivalent to the duration time) of rainfall is estimated to be 5 years according to the rainfall intensity curve shown in the guidelines.

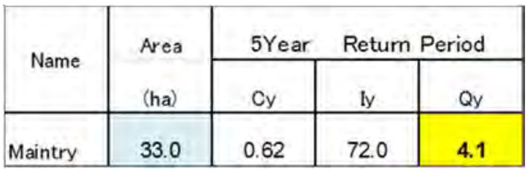
- Recorded 6-hour rainfall at the airport station: 55.3 mm
- Enlarged 6-hour rainfall at the Hermitage station: 136.7 mm

・Six-hour rainfall corresponding to the 5-year return period obtained from the rainfall intensity curve: 132.7 mm

2) Discharge from Upstream

Since the return period of this event is estimated to be 5 years, the discharge from upstream calculated by the rational formula is as follows.

Table 2-5-12: Estimated Discharge of Maintry River in 2004 Flood



Name	Area	5Year Return Period		
	(ha)	Cy	Iy	Qy
Maintry	33.0	0.62	72.0	4.1

Since the enlarged 6-hour rainfall at the Hermitage station (136.7mm) is equivalent to 103 % of probable rainfall corresponding to the 5-year return period at the airport station, the discharge from upstream calculated by the rational formula increases by 3 %. As a result, a discharge of 4.2m^3/s is applied as the upstream boundary condition.

3) River Cross Section

The cross section data obtained in the on-site survey are used as the geometrical conditions. In addition, the influence of river bed excavation about 20cm conducted after the 2004 flood is taken into consideration.

4) Tidal Level

The observed tidal level on 28-29 October 2004 is shown in Figure 2-5-13. The maximum tidal level of 0.74m (MSL) is applied as the downstream boundary condition.

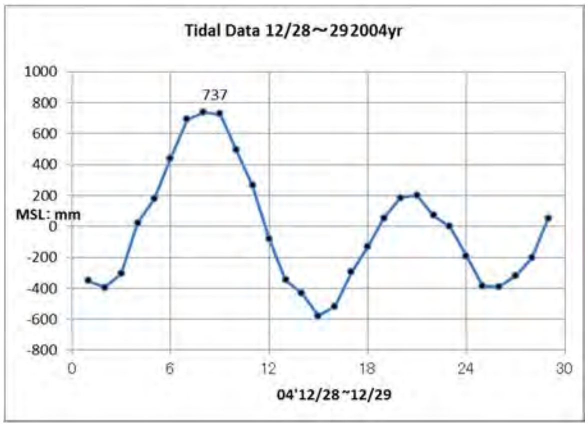


Figure 2-5-13: Observed Tidal Level on 28-29 October 2004

(c) Results

The calculation result for the Maintry River is shown below.

The flooded photo site shown below is near L=450 m and is equivalent to the neighbourhood shown in broken lines in the road survey results and the following figure which combined cross section of the

Maintry River. As of 2011, about 20 cm of river-bed excavation had been implemented. Therefore, the cross section profile in 2004 was 20 cm higher than the existing state.

Figure 2-5-14 shows the existing cross section and the results contrast with those from 2004.

The minimum road height near the photographed site was about 1.6 EL.m, and the calculation result in 2004 was 1.9EL.m, and it is estimated that the flood depth was about 30 cm.

The flood water height in the photograph is around the floor of the building, and as for the water depth, the outline agrees with the calculation result.

Though there are some issues such as uncertainty as to whether or not the photograph represents the maximum flood water level and the assumption that the cross section of the river was uniformly excavated by 20 cm, it is possible to judge that there is no problem with application of the one-dimensional non-uniform flow computation by HEC-RAS.

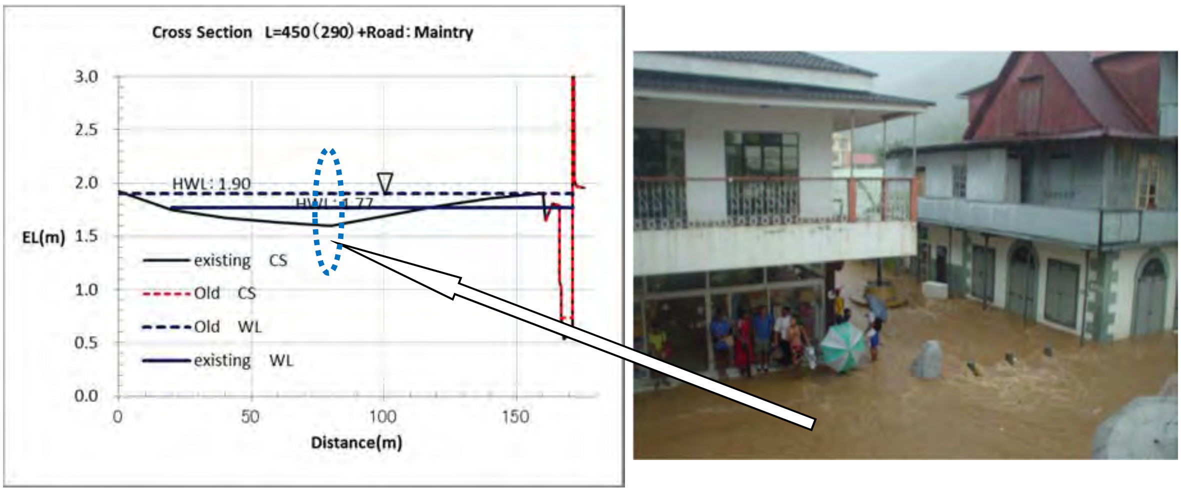


Figure 2-5-14: Photo and Cross Section of Maintry River in the 2004 Flood

(4) Analysis of 2013 Flood

To comprehend the extent of the 2013 flood, data collection and on-site investigation are conducted. In addition, hydraulic analysis is conducted using the collected data to comprehend the characteristics of the flood. The target areas are Anse Aux Pins and Au Cap where flooding was reported.

(a) Analysis Conditions

1) Evaluation of Rainfall Scale

The evaluation of rainfall probability during the period from 25th to 29th January when the target flood occurred is as shown in Figure 2-5-15, in which the 6-hour rainfall on 25th January and 12-hour rainfall on 28th are plotted on the rainfall intensity curve. The probability of a rainfall event in January 2013 is estimated to be 2 years from Figure 2-5-15.

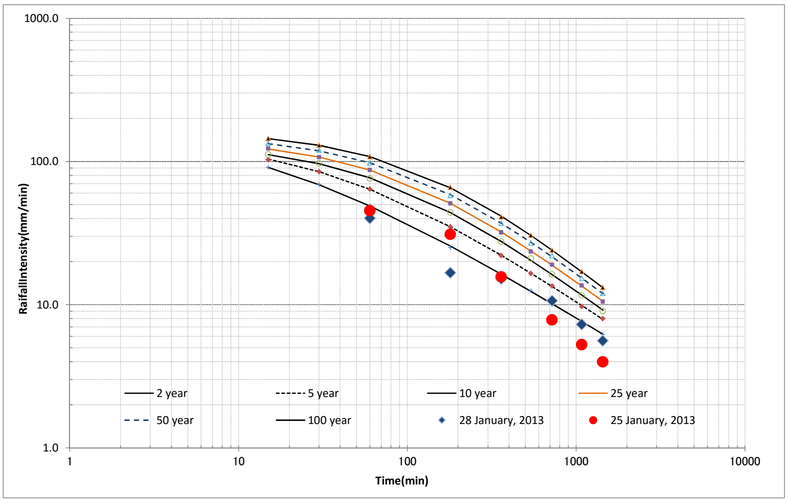


Figure 2-5-15: Evaluation of Rainfall Probability of 2013 Flood

2) Upstream Discharge

The maximum hourly rainfall was 41mm/h, which occurred at 16:00 on 28th January. Runoff discharges from the catchment areas at Au Cap and Anse Aux Pins are calculated using the rational formula with the maximum hourly rainfall as an input condition. The runoff coefficient is set at 0.54 considering that the return period of the rainfall event is estimated to be 2 years.

Table 2-5-13: Estimated Discharges in 2013 Flood

	Au Cap									
	AC-1	AC-2	AC-3	AC-4	AC-5	AC-6	AC-7	AC-8	AC-9	Total Area
Area (ha)	41.0	95.0	27.0	54.0	58.0	50.0	46.0	31.0	25.0	427.0
Discharge (m^3/s)	2.5	5.7	1.6	3.2	3.5	3.0	2.8	1.9	1.5	25.7

	Anse Au Pins							
	AAP-1	AAP -2	AAP -3	AAP -4	AAP -5	AAP -6	AAP -7	Total Area
Area (ha)	18.0	34.0	58.0	55.0	101.0	16.0	33.0	315.0
Discharge (m^3/s)	1.1	2.0	3.5	3.3	6.1	1.0	2.0	18.9

3) River Cross Section

Cross section data obtained in the on-site survey are used as the geometrical conditions.

4) Tidal Level

The downstream tidal level is set as high water (0.53MSLD) which occurred right after the maximum hourly rainfall occurred.

Table 2-5-14: Tidal Data (28 January 2013)

		Tidal Level (TSZ)	Tidal Level (MSLD)
28 Jan	5:13	1.8	0.83
28 Jan	12:00	0.4	-0.57
28 Jan	17:49	1.5	0.53
28 Jan	23:42	0.6	-0.37

(b) Results

The calculated river water levels at each cross section are shown below with the results of the questionnaire survey conducted in July 2013 to grasp the extent of the flooding.

The outline of the questionnaire survey is as follows.

【Survey Period】6th July 2013

【Survey Method】Questionnaire

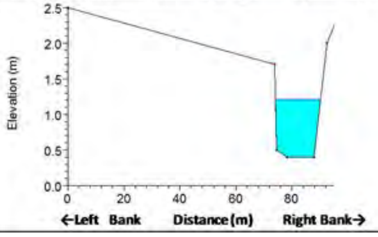
【Survey Items】Depth and Duration

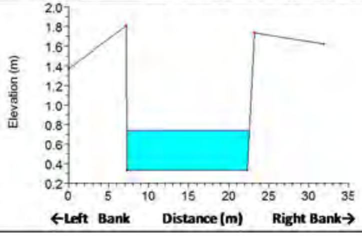
The calculated water levels by and large agree with the results of the questionnaire survey. At least, identification of the spots where the flow capacity is low is possible with the hydraulic model developed in this study.

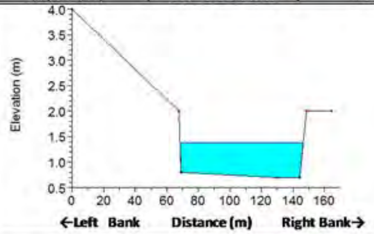
The following can be deduced from the calculation results and survey results.

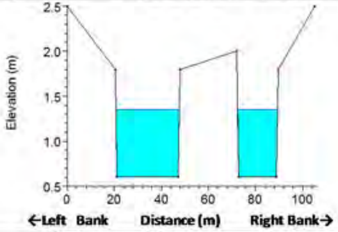
・At the Au Cap River, the flow capacity near the mouth is small, causing flooding in the upstream area. Therefore, increased capacity by widening or dredging of the river and maintenance of the river mouth is appropriate. In addition, the right bank of the channel for around 500m to 600m from the mouth is widely inundated. Therefore, measures such as improvement of drainage or widening of the river are required in view of the survey results which show that inundation of these areas is caused by rainwater.

・At the Anse Aux Pins River, the residential area around the wetland is basically a lowland area which is always inundated largely by rainwater. Floodwater gathers in the wetland before flowing out through the river mouth, so the storage capacity of the wetland can be utilised for flood control if the safety of residents is secured. In addition, widening of the river channel near the mouth is required since flooding near the mouth is caused by the lack of flow capacity at the mouth.

River Name	Au Cap River A	A2	
Distance from River Mouth	L = 85.2 m		
		Left Bank Side	Right Bank Side
Result of Survey	Photo	 *at the right side of the river	
	Inundation Type*	I	I
	Depth (m)	30cm	30cm
Result of Calculation			

River Name	Au Cap River A	A1	
Distance from River Mouth	L = 0 m		
		Left Bank Side	Right Bank Side
Result of Survey	Photo	—	
	Inundation Type*	—	—
	Depth (m)	No Overflow	No Overflow
Result of Calculation			

River Name	Au Cap River A	A4	
Distance from River Mouth	L = 248.6 m		
		Left Bank Side	Right Bank Side
Result of Survey	Photo	 *at the right side of the river	
	Inundation Type*	—	F
	Depth (m)	No Overflow	40cm
Result of Calculation			

River Name	Au Cap River A	A3	
Distance from River Mouth	L = 179.2 m		
		Left Bank Side	Right Bank Side
Result of Survey	Photo	—	
	Inundation Type*	—	—
	Depth (m)	No Overflow	No Overflow
Result of Calculation			

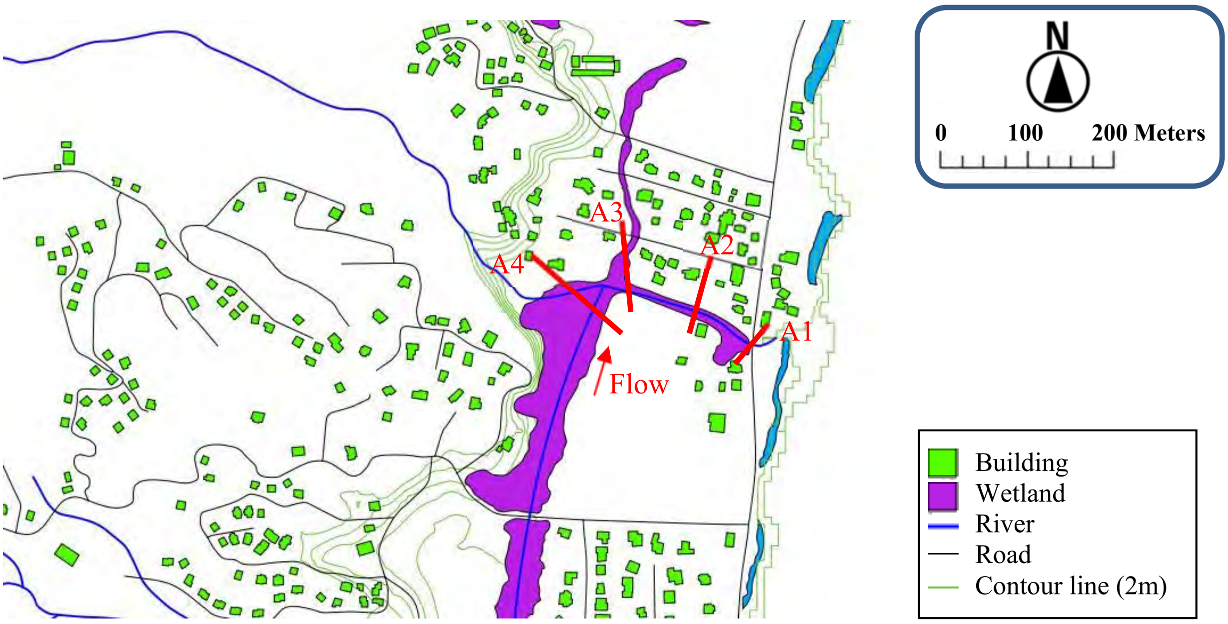
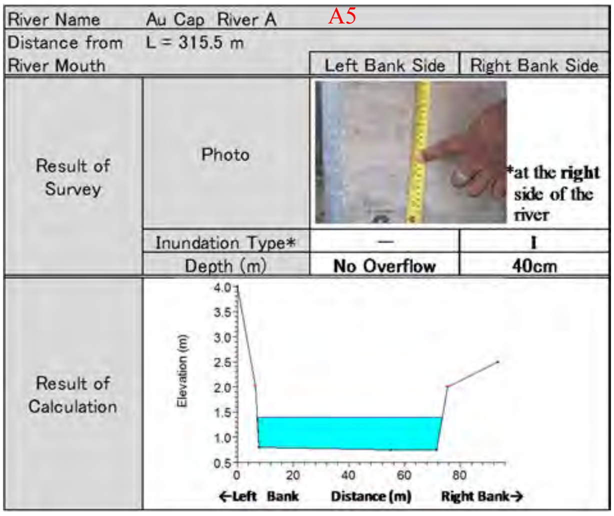
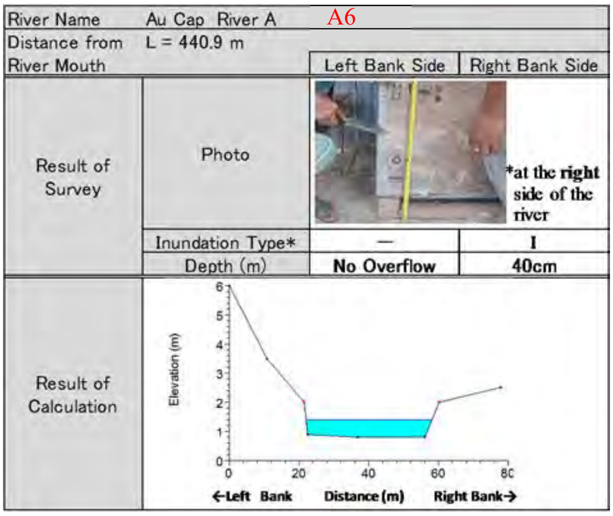


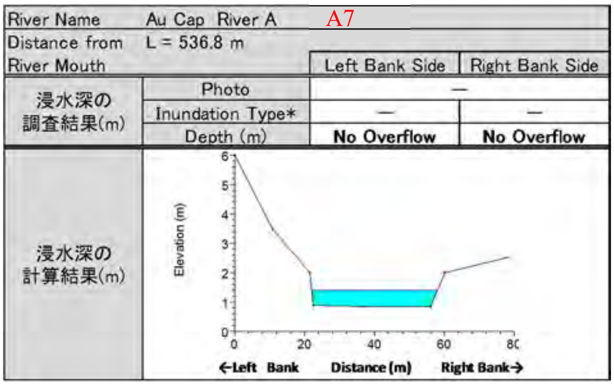
Figure 2-5-16: Comparison of Calculation Results and Survey Results at Au Cap (1/4)



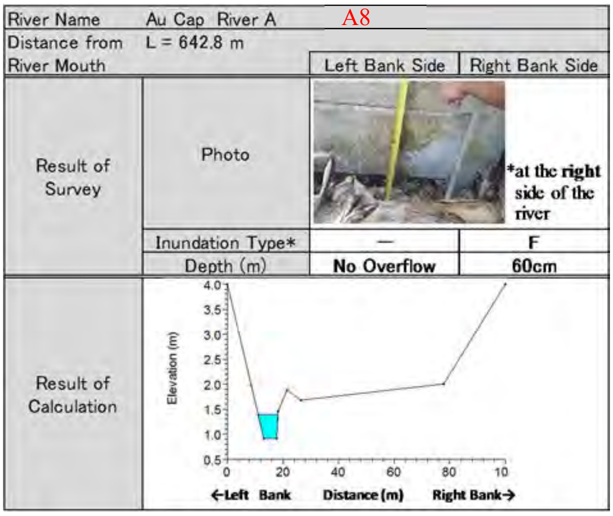
River Name	Au Cap River A	A5	
Distance from River Mouth	L = 315.5 m	Left Bank Side	Right Bank Side
Result of Survey	Photo		*at the right side of the river
	Inundation Type*	—	I
	Depth (m)	No Overflow	40cm
Result of Calculation			



River Name	Au Cap River A	A6	
Distance from River Mouth	L = 440.9 m	Left Bank Side	Right Bank Side
Result of Survey	Photo		*at the right side of the river
	Inundation Type*	—	I
	Depth (m)	No Overflow	40cm
Result of Calculation			



River Name	Au Cap River A	A7	
Distance from River Mouth	L = 536.8 m	Left Bank Side	Right Bank Side
浸水深の調査結果(m)	Photo	—	
	Inundation Type*	—	—
	Depth (m)	No Overflow	No Overflow
浸水深の計算結果(m)			



River Name	Au Cap River A	A8	
Distance from River Mouth	L = 642.8 m	Left Bank Side	Right Bank Side
Result of Survey	Photo		*at the right side of the river
	Inundation Type*	—	F
	Depth (m)	No Overflow	60cm
Result of Calculation			

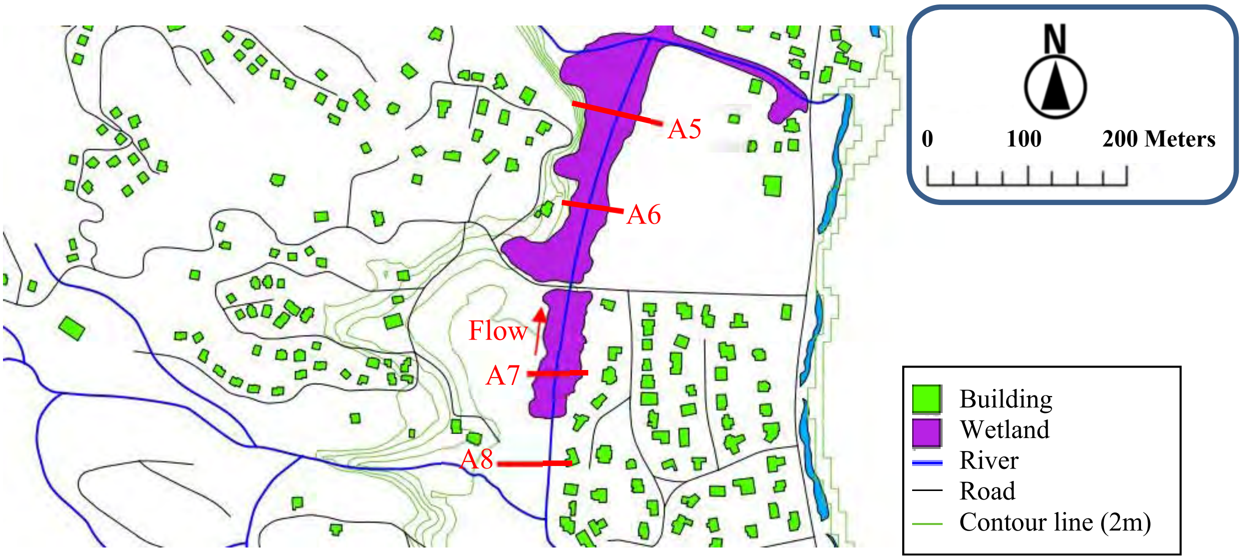
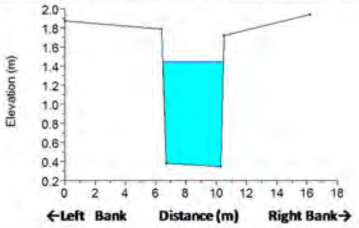
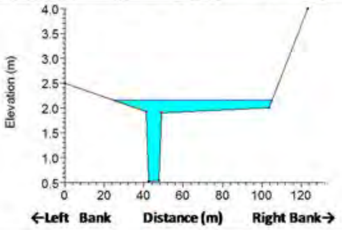
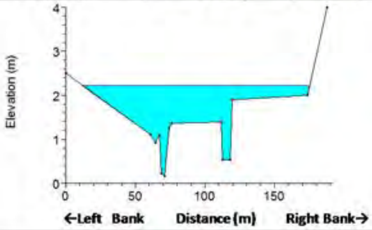
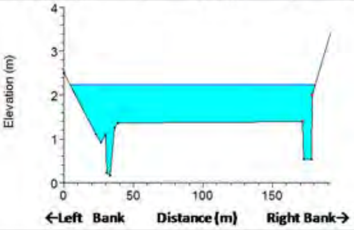


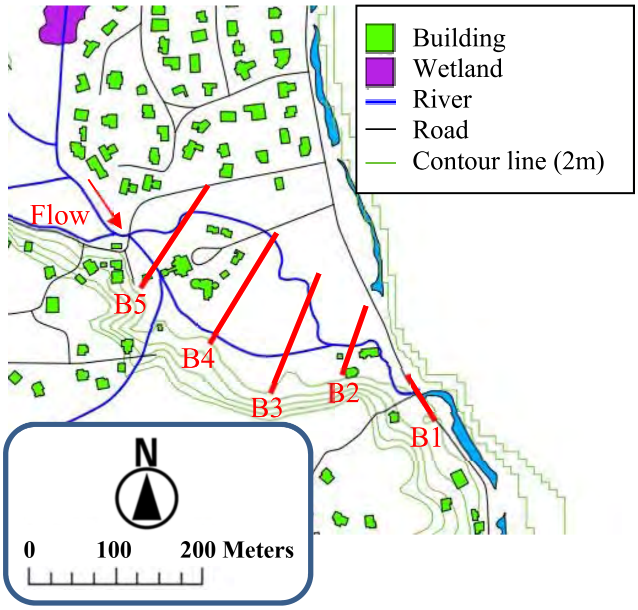
Figure 2-5-17: Comparison of Calculation Results and Survey Results at Au Cap (2/4)

River Name	Au Cap River B	B1	
Distance from River Mouth	L = 0 m	Left Bank Side	Right Bank Side
Result of Survey	Photo		*at the right side of the river
	Inundation Type*	—	I
	Depth (m)	No Overflow	15cm
Result of Calculation			

River Name	Au Cap River B	B2	
Distance from River Mouth	L = 90.6 m	Left Bank Side	Right Bank Side
Result of Survey	Photo		*at the right side of the river
	Inundation Type*	I	I
	Depth (m)	60cm	60cm
Result of Calculation			

River Name	Au Cap River B	B3	
Distance from River Mouth	L = 177.0 m	Left Bank Side	Right Bank Side
Result of Survey	Photo	—	
	Inundation Type*	F	I
	Depth (m)	30cm	40cm
Result of Calculation			

River Name	Au Cap River B	B4	
Distance from River Mouth	L = 272.3 m	Left Bank Side	Right Bank Side
Result of Survey	Photo		*at the Left side of the river
	Inundation Type*	I	I
	Depth (m)	80cm	100cm
Result of Calculation			



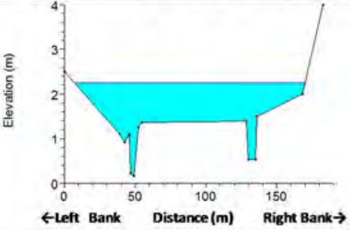
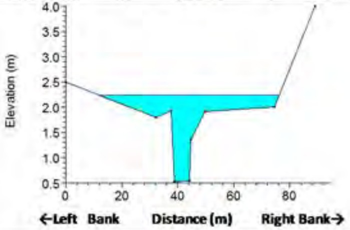
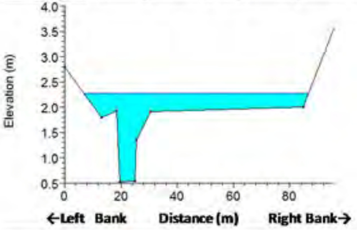
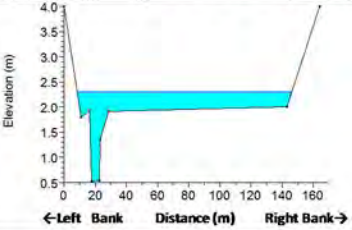
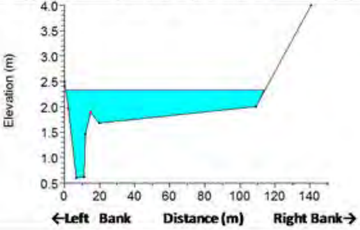
River Name	Au Cap River B	B5	
Distance from River Mouth	L = 379.0 m	Left Bank Side	Right Bank Side
Result of Survey	Photo		*at the right side of the river
	Inundation Type*	Not allowed to enter the site	I
	Depth (m)		80cm
Result of Calculation			

Figure 2-5-18: Comparison of Calculation Results and Survey Results at Au Cap (3/4)

River Name	Au Cap River B	B5	
Distance from River Mouth	L = 448.3 m	Left Bank Side	Right Bank Side
Result of Survey	Photo		*at the Left side of the river
	Inundation Type*	F	I
	Depth (m)	20cm	50cm
Result of Calculation			

River Name	Au Cap River B	B6	
Distance from River Mouth	L = 512.6 m	Left Bank Side	Right Bank Side
Result of Survey	Photo		*at the right side of the river
	Inundation Type*	I	I
	Depth (m)	60cm	60cm
Result of Calculation			

River Name	Au Cap River B	B7	
Distance from River Mouth	L = 579.1 m	Left Bank Side	Right Bank Side
Result of Survey	Photo		*at the right side of the river
	Inundation Type*	Not allowed to enter the site	I
	Depth (m)		35cm
Result of Calculation			

River Name	Au Cap River B	B8	
Distance from River Mouth	L = 654.0 m	Left Bank Side	Right Bank Side
Result of Survey	Photo		*at the right side of the river
	Inundation Type*	—	F
	Depth (m)	No Overflow	60cm
Result of Calculation			

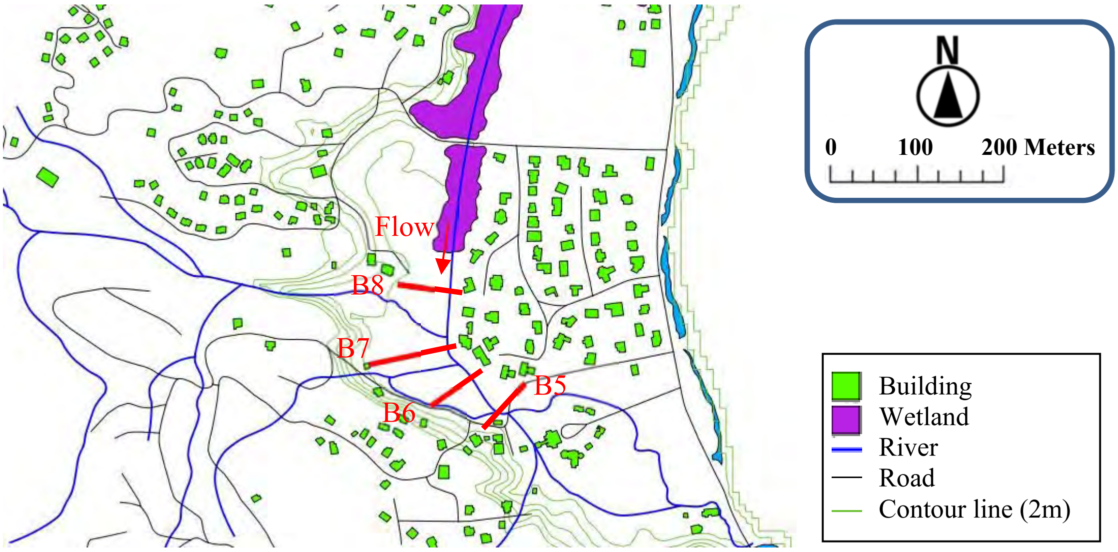
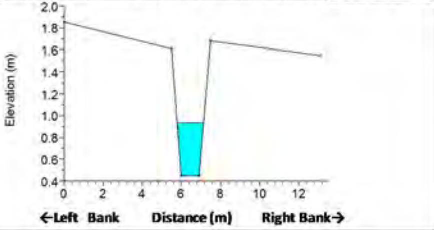
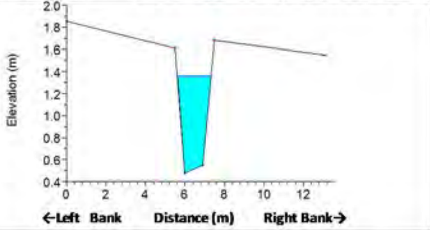
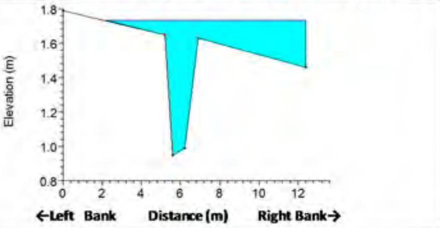
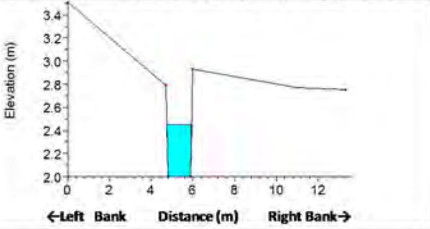


Figure 2-5-19: Comparison of Calculation Results and Survey Results at Au Cap (4/4)

River Name	Anse Aux Pins River A	A1	
Distance from River Mouth	L = 0 m	Left Bank Side	Right Bank Side
Result of Survey	Photo	—	
	Inundation Type*	—	—
	Depth (m)	No Overflow	No Overflow
Result of Calculation			

River Name	Anse Aux Pins River A	A2	
Distance from River Mouth	L = 40.4 m	Left Bank Side	Right Bank Side
Result of Survey	Photo	—	
	Inundation Type*	—	—
	Depth (m)	No Overflow	No Overflow
Result of Calculation			

River Name	Anse Aux Pins River A	A3	
Distance from River Mouth	L = 165.0 m	Left Bank Side	Right Bank Side
Result of Survey	Photo	 *at the right side of the river	
	Inundation Type*	I	I
	Depth (m)	No Overflow	No Overflow
Result of Calculation			

River Name	Anse Aux Pins River A	A4	
Distance from River Mouth	L = 292.7 m	Left Bank Side	Right Bank Side
Result of Survey	Photo	—	
	Inundation Type*	—	—
	Depth (m)	No Overflow	No Overflow
Result of Calculation			

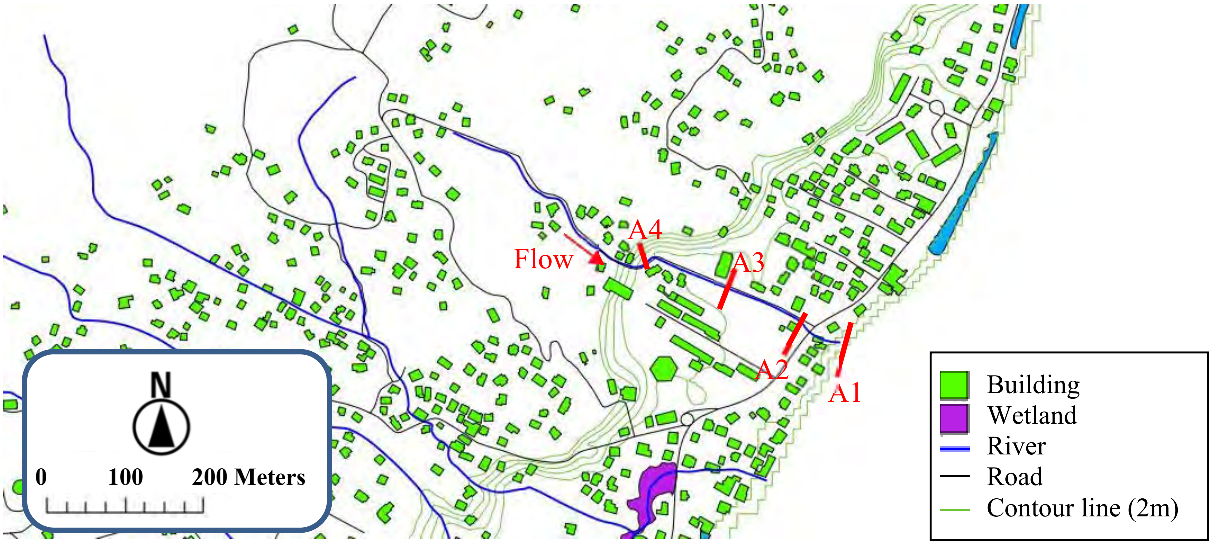
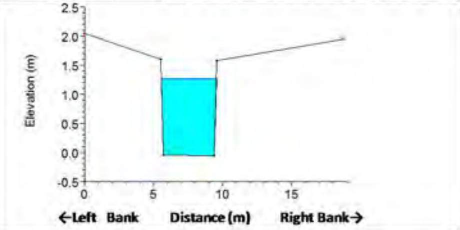
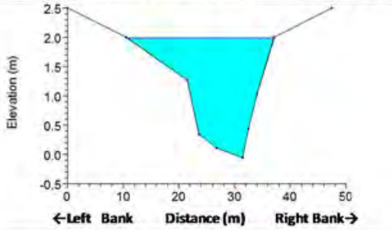
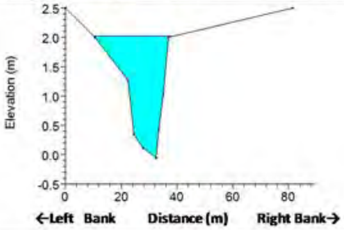
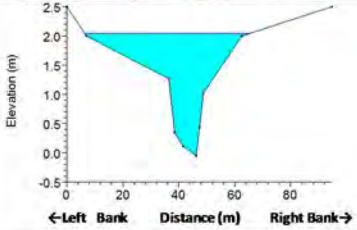


Figure 2-5-20: Comparison of Calculation Results and Survey Results at Anse Aux Pins (1/5)

River Name	Anse Aux Pins River B B1		
Distance from River Mouth	L = 0 m	Left Bank Side	Right Bank Side
Result of Survey	Photo	—	
	Inundation Type*	—	—
	Depth (m)	**No Overflow**	**No Overflow**
Result of Calculation			

River Name	Anse Aux Pins River B B2		
Distance from River Mouth	L = 51.2 m	Left Bank Side	Right Bank Side
Result of Survey	Photo	 ***at the Left side of the river**	
	Inundation Type*	**F and I**	—
	Depth (m)	**60cm**	**No Overflow**
Result of Calculation			

River Name	Anse Aux Pins River B B3		
Distance from River Mouth	L = 141.6 m	Left Bank Side	Right Bank Side
Result of Survey	Photo	 ***at the Left side of the river**	
	Inundation Type*	**F**	**F**
	Depth (m)	**60cm**	**90cm**
Result of Calculation			

River Name	Anse Aux Pins River B B4		
Distance from River Mouth	L = 226.9 m	Left Bank Side	Right Bank Side
Result of Survey	Photo	 ***at the Left side of the river**	
	Inundation Type*	**F**	**No resident**
	Depth (m)	**70cm**	
Result of Calculation			

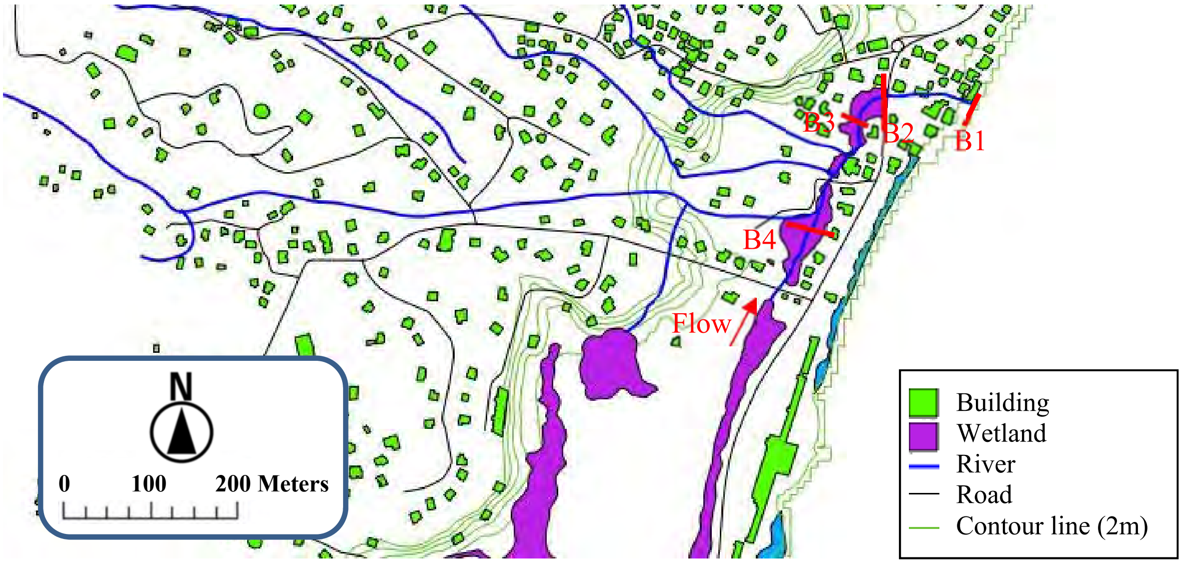
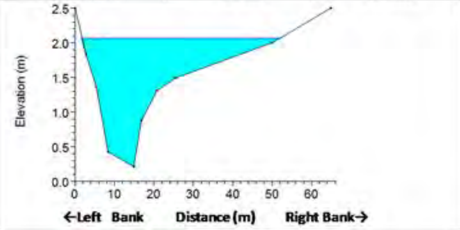
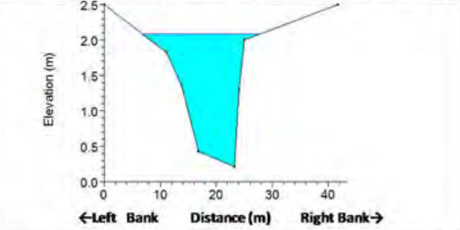
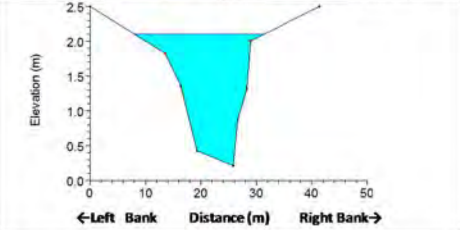
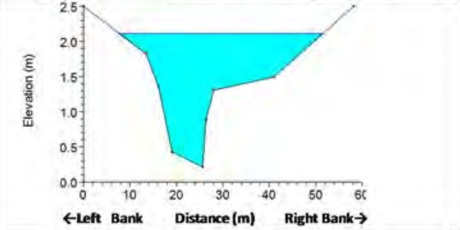


Figure 2-5-21: Comparison of Calculation Results and Survey Results at Anse Aux Pins (2/5)

River Name	Anse Aux Pins River B B5		
Distance from River Mouth	L = 373.4 m	Left Bank Side	Right Bank Side
Result of Survey	Photo		*at the Left side of the river
	Inundation Type*	F and I	F and I
	Depth (m)	65cm	65cm
Result of Calculation			

River Name	Anse Aux Pins River B B6		
Distance from River Mouth	L = 536.5 m	Left Bank Side	Right Bank Side
Result of Survey	Photo		*at the Left side of the river
	Inundation Type*	F and I	F and I
	Depth (m)	40cm	10cm
Result of Calculation			

River Name	Anse Aux Pins River B B7		
Distance from River Mouth	L = 669.8 m	Left Bank Side	Right Bank Side
Result of Survey	Photo		*at the Left side of the river
	Inundation Type*	F and I	F and I
	Depth (m)	90cm	60cm
Result of Calculation			

River Name	Anse Aux Pins River B B8		
Distance from River Mouth	L = 762.5 m	Left Bank Side	Right Bank Side
Result of Survey	Photo	—	
	Inundation Type*	F and I	F and I
	Depth (m)	40cm	40cm
Result of Calculation			

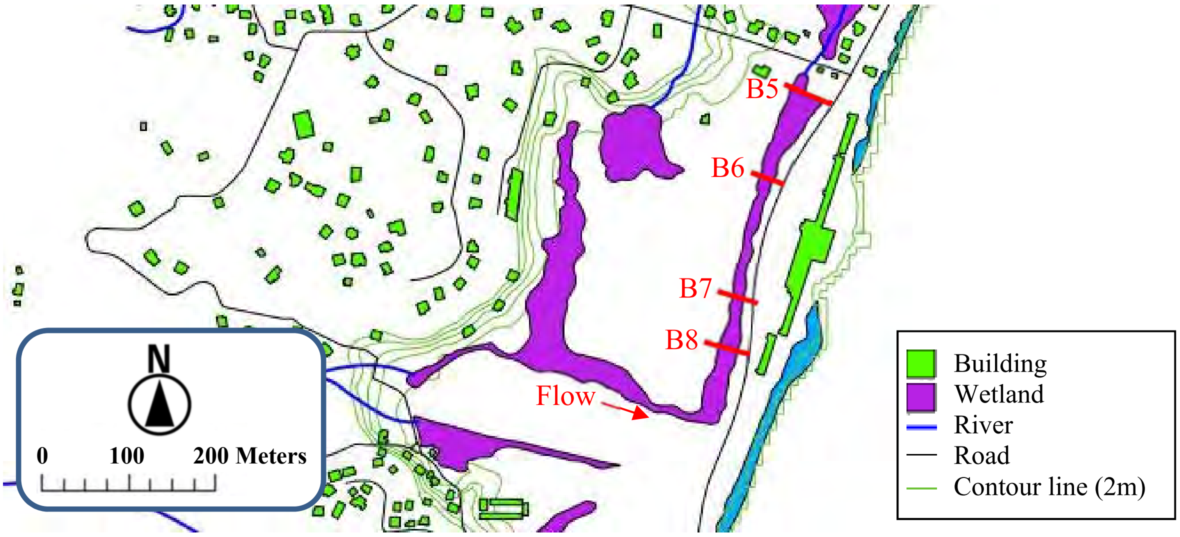
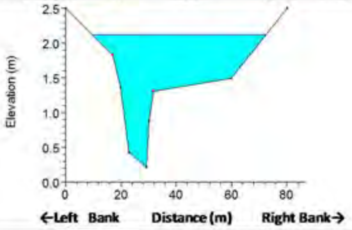
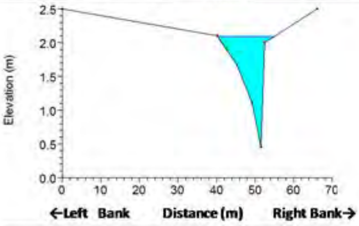
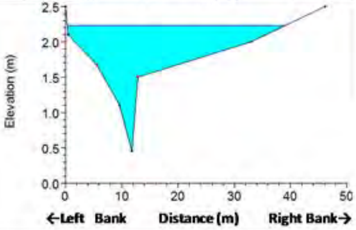
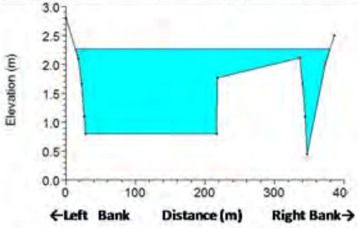


Figure 2-5-22: Comparison of Calculation Results and Survey Results at Anse Aux Pins (3/5)

River Name	Anse Aux Pins River B	B9	
Distance from River Mouth	L = 824.9 m	Left Bank Side	Right Bank Side
Result of Survey	Photo	—	
	Inundation Type*	F and I	F and I
	Depth (m)	60cm	60cm
Result of Calculation			

River Name	Anse Aux Pins River B	B10	
Distance from River Mouth	L = 875.1 m	Left Bank Side	Right Bank Side
Result of Survey	Photo		*at the Left side of the river
	Inundation Type*	F and I	F and I
	Depth (m)	60cm	60cm
Result of Calculation			

River Name	Anse Aux Pins River B	B11	
Distance from River Mouth	L = 977.0 m	Left Bank Side	Right Bank Side
Result of Survey	Photo		*at the Left side of the river
	Inundation Type*	F and I	F and I
	Depth (m)	50cm	65cm
Result of Calculation			

River Name	Anse Aux Pins River B	B12	
Distance from River Mouth	L = 1029.5 m	Left Bank Side	Right Bank Side
Result of Survey	Photo		*at the Left side of the river
	Inundation Type*	I	F
	Depth (m)	50cm	20cm
Result of Calculation			

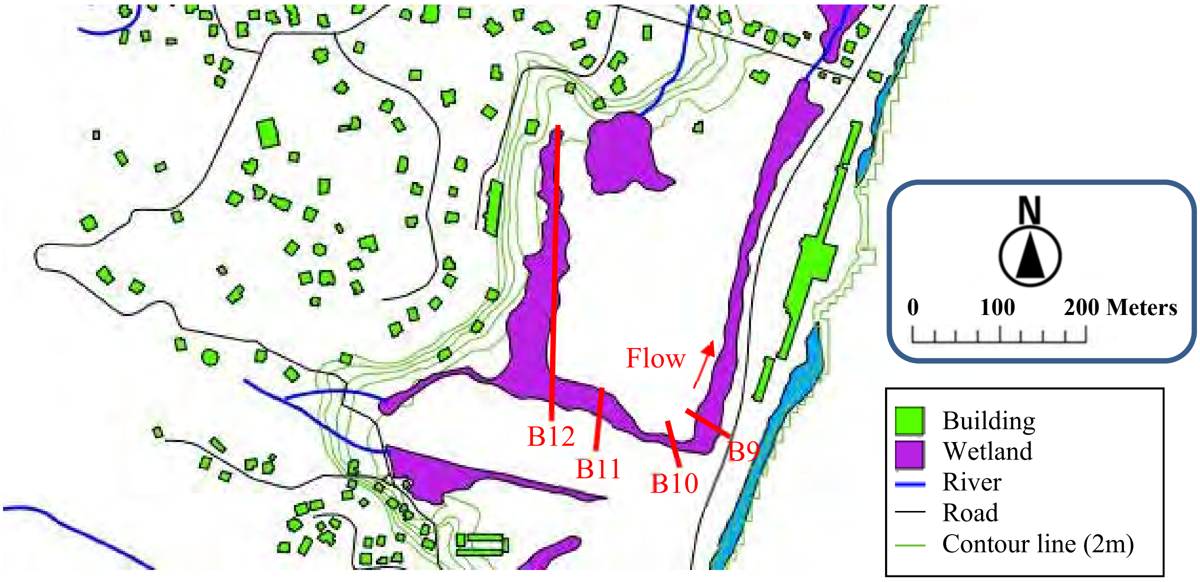
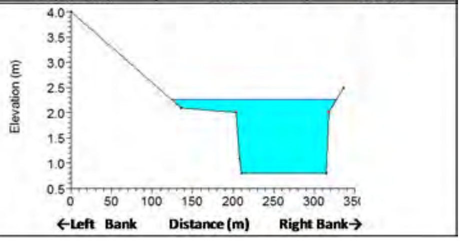
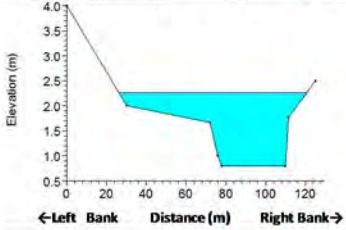
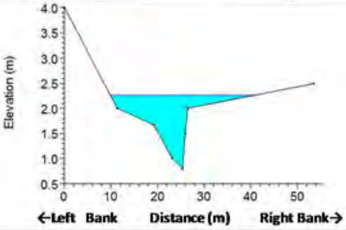
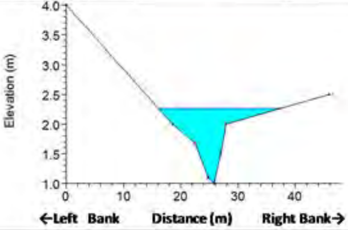


Figure 2-5-23: Comparison of Calculation Results and Survey Results at Anse Aux Pins (4/5)

River Name	Anse Aux Pins River B B13		
Distance from River Mouth	L = 1064.9 m	Left Bank Side	Right Bank Side
Result of Survey	Photo	 *at the Left side of the river	
	Inundation Type*	F	F
	Depth (m)	30cm	55cm
Result of Calculation			

River Name	Anse Aux Pins River B B14		
Distance from River Mouth	L = 1095.9 m	Left Bank Side	Right Bank Side
Result of Survey	Photo	 *at the Left side of the river	
	Inundation Type*	F	F
	Depth (m)	50cm	30cm
Result of Calculation			

River Name	Anse Aux Pins River B B15		
Distance from River Mouth	L = 1165.3 m	Left Bank Side	Right Bank Side
Result of Survey	Photo	—	
	Inundation Type*	—	—
	Depth (m)	—	—
Result of Calculation			

River Name	Anse Aux Pins River B B16		
Distance from River Mouth	L = 1222.0 m	Left Bank Side	Right Bank Side
Result of Survey	Photo	—	
	Inundation Type*	—	—
	Depth (m)	—	—
Result of Calculation			

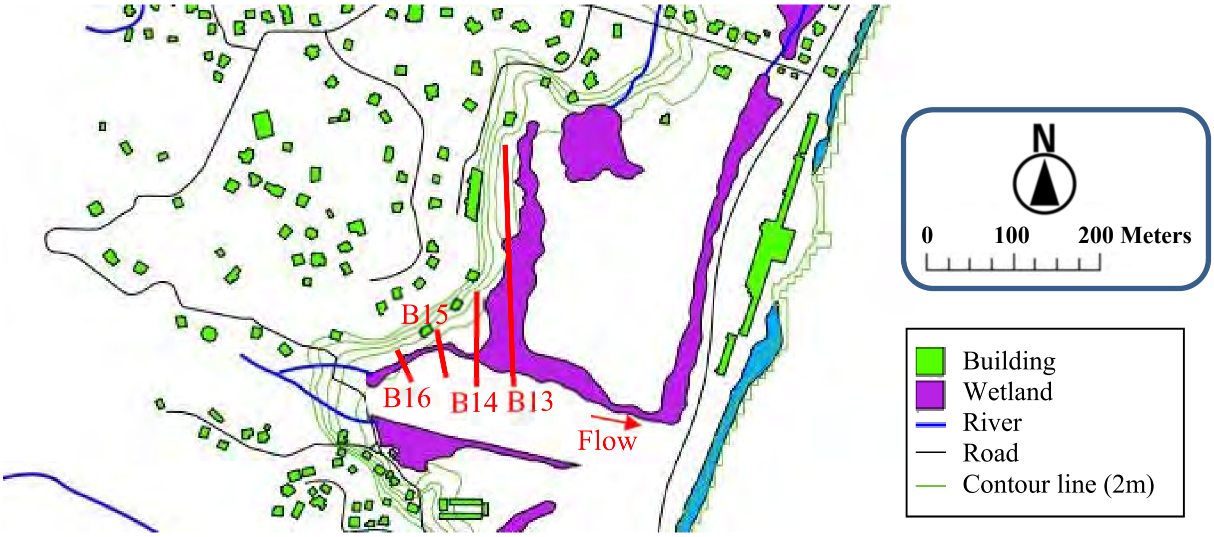


Figure 2-5-24: Comparison of Calculation Results and Survey Results at Anse Aux Pins (5/5)

2-5-7 Past Flood Disasters

In the Seychelles, there is no monitoring system for flood conditions such as inundation depth and inundation duration, therefore past records of flood disasters are limited.

The JICA Study Team browsed through old newspapers to gain a better understanding of the flood situation in the last 25 years. A summary of the flood disasters in the last 25 years is shown in Table 2-5-15. According to the newspaper articles, heavy rainfall caused landslides, inundation and flooding which damaged roads, houses and other facilities. However, there are no reports of human casualties. Residents stayed indoors for a few hours until the water level subsided. The detailed flood damage record is sourced from the National Archives (http://www.sna.gov.sc/).

Table 2-5-15 Summary of Past Flood Disasters in the Last 25 Years

Date	Area	Location	Description
31st July 1989	Mahe	Anse Aux Pins, Pointe Larue	Flooding
28th January 1990	Mahe	Belonie, La Louise, Beau Vallon	Flooding / landslide
18th-19th February 1990	Mahe	Victoria Town, Anse Etoile, Pointe Larue, Mont Fleuri and Bel Eau	Flooding / overflow / damage to houses
18th-22nd May 1990	Mahe	Mont Buxton, Port Glaud, Les Mamelles, Anse aux Pins	Flooding / landslide/ damage to houses
16th February 1993	Mahe	Victoria, Albert Street	Flooding
18th February 1993	La Digue	La Passe, Anse Reunion	Flooding / mud / damage to drainage and roads
10th-13th January 1997	Mahe	Mont Fleuri, Roche Caiman, Foret Noire, Bel Air	Flooding / landslide
9th-12th February 1997	Mahe	Foret noire, Plaisance. Mont Fleuri	Flooding / landslide
13th-17th August 1997	Mahe La Digue	Victoria Town, Beau Vallon, Pointe Conan, Takamaka	Flooding / overflow / collapsed roads, 5 killed, 1237 affected.
5th November 1997	Praslin	Grand Anse, Baie Ste Anne	Flooding
29th-30th December 2004	Mahe	Northern regions of Mahe, Victoria Town, Beau Vallon	Flooding / inundated houses / damage to public infrastructure
8th-12th June 2005	Mahe	Grand Anse, Anse Boileau, Port Glaud, Anse Royale, Le Niol	Flooding / landslide / falling of trees
4th-5th January 2006	Mahe	North Mahe, Pointe Conan, Beau Vallon and Mont Buxton	Flooding / landslide / collapsed roads

Source: "Seychelles NATION" Newspaper in Seychelles, Rainfall Data of National Meteorological Services,
EM-DAT "Number of killed and affected"

2-5-8 Past Mitigation Measures

Past flood disasters in the Seychelles are listed in Table 2-5-15. For other flood risk areas, some studies were carried out by the Drainage Task Force Committee in early 2004. The task force conducted a preliminary study of the flooding and drainage problems on Mahe, Praslin and La Digue; however, there was no quantitative analysis of flood damage in the reports. Three reports were collected by the team, namely:

1. Preliminary Study of the Drainage Problems in Various Districts: October 2004
2. Preliminary Study of the Drainage Problems in North Mahe (incomplete): December 2005
3. The Flooding Problems at Au Cap, A Study of Drainage Patterns and Recommendations for Corrective Actions

2-5-8-1 Past Mitigation Measures in Victoria Town

Since the tsunami in December 2004 was followed by other natural disasters and successive flooding, the President of the Seychelles decided to form a Drainage Task Force in January 2005. The taskforce conducted a preliminary study of the flooding and drainage problems in Victoria.

In the study, 11 projects were proposed and prioritised for action. All of the projects focused on drainage problems and did not consider river improvements. The status of implementation of each action plan is as listed in Table 2-5-16.

Table 2-5-16: Status of Implementation of Mitigation Measures

No.	Project Location	Project Cost (SR)	Priority	Status
1	Market Street and Church Street	1,890,000	2	Partially Completed
2	Albert Street	684,000	3	Partially Completed
3	State House Avenue	1,234,000	4	Completed
4	Francis Rachel Street	1,382,000	6	Partially Completed
5	Independence Avenue	1,085,000	5	Completed
6	Huteau Lane	485,000	9	Not yet in action
7	Ste Elizabeth Convent	519,000	1B	Not yet in action
8	English River	988,000	7	Not yet in action
9	Vilaz Trezor	1,000,000	1A	Not yet in action
10	Mont Fleuri	683,000	1C	Not yet in action
11	Mont Buxton	450,000	8	Completed

Source: The Preliminary Study of the Flooding Problems in Victoria, June 2005

The study report mentions the proposed solutions for each drainage problem area. However, no specific proposed plan or design of drainage facilities is put forward. According to the report, the estimated costs were based on rates used to carry out drainage works at the time by various ministries and organisations, but no breakdown of the costs is provided. Regarding priority, it was stated that the extent of damage to property and the level of risk to human lives were the elements/criteria used to prioritise the action plans . However, there is no detailed explanation of the specific elements and criteria.

2-5-8-2 Other Districts

In the study report from October 2004, several projects were prioritised into four action plans (immediate, short-term, medium-term and long-term). Each action plan contained more than 10 projects and some of them were already implemented within 6 years (2005-2011). The affected areas were ranked as per district priority in consultation with the district authorities as follows:

1. Immediate Plan – Risk to human lives, sanitation, damage to property, calamity-prone areas and overdue maintenance works
2. Short-Term Plan – Protection of property, population density, intensity of the problem and the cost of implementation
3. Medium-Term Plan – Preventive measures, cost implications, resource needs and mobilisation
4. Long-Term Plan – Preventive measures

The status of implementation of each action plan is as listed in Table 2-5-17. The total project cost is based on the amount proposed in the study.

Table 2-5-17: Status of Implementation of Mitigation Measures within 6 Years

Action Plan	Proposed Projects	Completed Projects	Partially Completed	Total Cost (SCR)		Ratio of Implementation Cost
				Proposed	Implemented	
Immediate Action	12	9	1	1,710,140.0	1,526,030	89.2%
Short-Term Action	14	6	1	3,803,246.0	2,070,596.0	54.4%
Medium-Term Action	17	3	0	5,025,172.0	366,500.0	7.3%
Long-Term Action	17	0	0	10,237,015.0	-	-

The total implementation cost for 6 years from 2005 to 2011 is calculated at SCR 3.96 million. Therefore, the annual implementation cost is estimated to be SCR 0.66 million.

The number of proposed and completed projects by district is listed in Table 2-5-18.

Table 2-5-18: Number of Proposed and Completed Projects by District

	Immediate			Short			Medium			Long		Total Cost
District	Plan	Complete	Cost	Plan	Complete	Cost	Plan	Complete	Cost	Plan	Complete	SCR
Baie Lazare	1	1	746,910	3	1	100,900	1	0	0	3	0	847,810
Baie Ste. Anne	5	4	329,030	3	1	77,500	4	0	0	0	0	406,530
Point Larue	2	2	62,220	2	1.5	890,000	2	1	150,000	0	0	1,102,220
Anse Royale	1	1	177,870	3	2	443,400	4	2	216,500	4	0	837,770
La Digue	2	1.5	210,000	2	0.5	177,500	2	0	0	4	0	387,500
Anse Boileau	1	0	0	1	1	381,296	4	0	0	6	0	381,296
Total	12	9.5	1,526,030	14	7	2,070,596	17	3	366,500	17	0	3,963,126

Based on the report of the flooding problems at Au Cap, the proposed solutions were divided into Immediate Actions and Longer Term Actions. The project costs were SCR 1.74 million and SCR 1.926 million respectively. However, DOE has not elaborated on the status of the projects at Au Cap.

2-6 Analysis of Future Climate Change

2-6-1 General

Although the Seychelles consists of over 115 granitic or coral islands, the population mainly inhabits the three granitic inner islands targeted in this Study. Almost all of the population and economic activities are located in the narrow coastal flatlands on these three islands. Due to the steep land conditions and lack of suitable land for infrastructure, extensive areas have been reclaimed on the east coast of Mahe Island, the largest inhabited island in the group (Seychelles National Climate Change Strategy (2009)). These conditions have made the Seychelles vulnerable to possible future climate change as it is typically thought that small islands are prone to be affected by sea level rises. (Source: The Seychelles National Climate Change Committee, 2009. *Seychelles National Climate Change Strategy*, p.96)

This section deals with climate change issues closely related to coastal erosion and flooding. To reflect the extent of the variability or the impacts of future climate change in the coastal erosion and flood management plans, quantitative local information on climate change specific to the three targeted islands, Mahe, Praslin and La Digue, has been collected and reviewed as much as possible from existing literature and reports. However, the information is so limited that only qualitative or regional information is described for some items.

In addition to the above limited information, the projections of future climate change shown below involve uncertainties. In particular, the uncertainties are expected to increase over time. It is necessary for climate change adaptation to recognise the uncertainties associated with the climate change projections. In this regard, the following activities should be further enhanced in future:

- better understanding of the changing climate (monitoring & analysis),
- improved projection techniques, and
- adjustment of coastal/flood management systems to changing future impacts.

2-6-2 Sea Level Rise and Wave Climate

(1) Sea Level Rise

According to the IPCC 4thReport, the global average sea level is projected to rise by the end of this century as shown in Table 2-6-1.

Table 2-6-1: Projected Global Average Sea Level Rise by End of 21st Century (2090-2099) (relative to the 1980-1999 average)

SRES Scenario	**B2**	**A1F1**
Sea Level Rise (m)	0.20 ~ 0.43	0.26 ~ 0.59
Rate of Sea Level Rise (mm/yr) during 2090-2099	2.1 ~ 5.6	3.0 ~ 9.7

(Source: IPCC 4th Report (WG I))

As a regional climate projection for small islands, the IPCC 4th Report states that the sea level is likely to continue to rise on average during this century around the small islands in the Indian Ocean and that the rise will not be geographically uniform, but large deviation among the models makes regional estimates across the Indian Ocean uncertain.

The regional sea level in the southwest Indian Ocean is expected to rise by between +0.4 to +0.6 m in 2070-2100 as compared with the period 1960-1990 (Chang-Seng (2007)). (Source: Chang-Seng, S. D., 2007. *Seychelles Climate Change Scenarios for Vulnerability and Adaptation Assessments*, Report for Ministry of Environment and Natural Resources, Republic of Seychelles).

Sea level monitoring data for the Seychelles are limited and the data observed at Pointe Larue, Mahe, are only available for 18 years (1993-2010). Nevertheless, the JICA Study Team tried to analyse the data and obtained a recent mean sea level rise rate of 6.6mm/year (Progress Report 1 (2011)). If this rate remains constant this century, the sea level will rise by +0.264m by 2050 and by +0.594m by 2100 as compared with the year 2010.

(2) Wave Climate

In the Seychelles, offshore winds/waves are mainly dominated by two-directional ones (north-western monsoon and south-eastern trade wind) which give rise to reversal of the wind/wave direction during different seasons. Therefore, the wave will not be altered to a significant extent unless the patterns of the monsoons change. Concerning the projection of future wave conditions in the Seychelles taking into account climate change, the information is very limited. Only the possibility of increased wave height is touched on in conjunction with the possible intensification of tropical depressions/cyclones.

The Indian Ocean is the most prolific of all oceans in generating tropical cyclones. Nevertheless, tropical cyclone trajectories rarely come close to those islands of the Seychelles located close to the equator. However, it is important to note that extreme wave swells resulting from Indian Ocean tropical cyclones do affect the Seychelles (Seychelles National Climate Change Strategy (2009)). (Source: The Seychelles National Climate Change Committee, 2009. *Seychelles National Climate Change Strategy*, p.96)

While there is wide variation in the results of global climate model studies, there is a tendency towards reduced frequency of tropical cyclones, but increased intensity compared with the situation at the end of the 20th and 21st centuries. A technique for downscaling tropical cyclone climatology for the Indian Ocean from global analyses concludes similar results, namely an overall tendency toward reduced frequency of tropical cyclones and a general increase in storm intensity (INGC Climate Change Report (2009)). (Source: *Sea Level Rise and Cyclone Analysis*, INGC Climate Change Report, p.33-66, 2009)

Other than the above discussions, even if offshore wave conditions do not change, greater wave energy will reach the coastal zones of the Seychelles on a significantly higher sea level that loses less energy due to the deeper sea bottom. This will cause more severe coastal erosion and higher wave run-up than at present.

(3) Storm Surges

Based on the study of tropical cyclone storm tracks from 1972 to 2001, the Seychelles is generally outside the major storm tracks. According to the records, cyclones on the same latitude as the major three islands of Mahe, Praslin and La Digue targeted in this Study are extremely rare. The last such event occurred in 1956 (Seychelles National Climate Change Strategy (2009)). Tropical cyclone trajectories do not come close to those islands of the Seychelles located close to the equator, although there have been a few incursions. (Source: The Seychelles National Climate Change Committee, 2009. *Seychelles National Climate Change Strategy*, p.96)

At present, it may be beyond technical capabilities to predict how climate change will influence tropical cyclone/depression intensity or storm tracks. So the JICA Study Team analysed 18 years (1993-2010) of tide observation data at Pointe Larue, Mahe, and obtained the following probability curve for an extreme annual high tide. In this extreme high tide, both astronomical tide and storm surge are included.

Probable extreme high tide level (m: above M.S.L) = 11.921 x ln (yrs.: return period) + 105.73

2-6-3 Hydrological Changes

(1) Rainfall

Table 2-6-2 provides projections of local rainfall changes by the end of this century obtained from several GCMs (Chang-Seng (2007)). Although projection variability is relatively great, the projections by the composite model show smaller annual rainfall changes, 3-5% and 5-6% for 2050 and 2100, respectively.

Table 2-6-2: Projected Rainfall Changes by End of 21st Century (relative to 1972-1990 average) (from Chang-Seng (2007))

SRES Scenario	Year	Season	Rainfall Change (mm)		Percentage Change (%)	
			Composite Model	**Projection Range**	**Composite Model**	**Projection Range**
B2	2050	Annual	**+58**	-105 ~ +184	**+2.7**	-4.8 ~ +8.5
		Rainy season (DJF)	**+17**	-11 ~ +25	**+5.3**	-0.3 ~ +9.3
		Dry season (JJA)	**+6**	-6 ~ +18	**+7.3**	-7.7 ~ +22.7
	2100	Annual	**+119**	-188 ~ +355	**+5.4**	-8.6 ~ +16.3
		Rainy season (DJF)	**+15**	-18 ~ +39	**+4.9**	-5.6 ~ +12.4
		Dry season (JJA)	**-9**	-31 ~ +13	**-10.8**	-36.3 ~ +14.9
A1	2050	Annual	**+99**	+50 ~ +212	**+4.6**	+2.3 ~ +9.7
		Rainy season (DJF)	**+11**	-11 ~ +25	**+3.4**	-3.4 ~ +8.2
		Dry season (JJA)	**+0**	-20 ~ +6	**-8.7**	-25.0 ~ +7.8
	2100	Annual	**+125**	-199 ~ +375	**+5.8**	-9.1 ~ +17.2
		Rainy season (DJF)	**+16**	-19 ~ +41	**+5.2**	-6.0 ~ +13.1
		Dry season (JJA)	**-9**	-31 ~ +13	**-11.4**	-38.3 ~ +15.8

Note: DJF (December, January and February), JJA (June, July and August)
(Source: Chang-Seng, S. D., 2007. *Seychelles Climate Change Scenarios for Vulnerability and Adaptation Assessments*, Report for Ministry of Environment and Natural Resources, Republic of Seychelles))

Air temperature is not directly related to rainfall. However, it is an important factor when hydrology is considered. According to the IPCC 4th Report, the global air temperature is projected to rise by the end of this century as shown in Table 2-6-3.

Table 2-6-3: Projected Increase in Global Mean Air Temperature by End of 21st Century (2090-2099) (relative to 1980-1999 average)

SRES Marker Scenario		**B2**	**A1F1**
Air Temperature(ºC)	Annual Mean	2.4	4
	Range	1.4 ~ 3.8	2.4 ~ 6.4

(Source: IPCC 4th Report)

The B2 mid-range emission with a mild-range climate sensitivity scenario shows that the local mean air temperature in the Mahe area is likely to warm by +3.0 ºC by the end of this century. The relative rate of warming will occur mainly during the cooler southeastern trade wind. The warming rate is projected to be +2.1 ºC(+1.8 to +2.5 ºC) for 2100 (B2 Scenario) (Chang-Seng (2007)).

Table 2-6-4: Projected Increase in Local (Mahe) Annual Mean Air Temperature by End of 21st Century (2100) (relative to 1972-1990 average) (from Chang-Seng (2007))

SRES Marker Scenario		**B2**	**A1**
Annual Mean Air Temperature (ºC)	Average	2.1	2.2
	Range	1.8 ~ 2.5	?

(Source: Chang-Seng, S. D., 2007. *Seychelles Climate Change Scenarios for Vulnerability and Adaptation Assessments*, Report for Ministry of Environment and Natural Resources, Republic of Seychelles))

2-6-4 Coral Reefs

(1) Coral Reefs

The coral reefs of the Seychelles inner islands are the most extensively used and are in areas where the coral reef ecosystems face the greatest threat. Reefs are very common in the inner islands and are made up of corals growing over granitic boulders. The coral reefs of the Seychelles suffered extensively from the mass coral bleaching event resulting from thermal stress to corals brought about by the 1998 El Nino phenomenon. The bleaching event reduced coral cover to less than 5% on most reefs in the inner islands. Although these granitic reefs have been shown to have better ability to recover their coral communities after coral bleaching events and have better survival of coral recruits, recent surveys across the entire inner islands suggest that recovery is highly patchy. The mean coral cover across the inner islands is presently estimated at 11% (Bijoux et al. (2007)). (Source: Jude Bijoux et.al, 2007. *Status of Coral Reefs of the Seychelles Islands*)

A morphological study (Kennedy et al. (2002)) proposes that Holocene fringing reef growth is described by six models of evolution as shown in Figure 2-6-1. Fringing reefs around Mahe are classified into Model "D" or "E". As for Model "D", reefs prograde by episodically attaching linear shore-parallel reefs to the existing reef with sediment infill between them, usually unconsolidated reef-derived sediment. As for Model "E", reef accretion is initially focused offshore, creating a shallow landward lagoon. Fringing reefs preferentially accrete vertically. If there is no vertical accommodation space available, they will prograde laterally. For reefs with ample vertical accommodation space, accretion will be relatively faster in the crest and fore reef zones. Therefore, reef establishment during a period of sea level rise will be able to accrete vertically as vertical space is created above it. (Source: Kennedy. D.M., Woodroffe. C.D., 2002. *Fringing reef growth and morphology: a review*, Earth Science Review 57, 255-277)

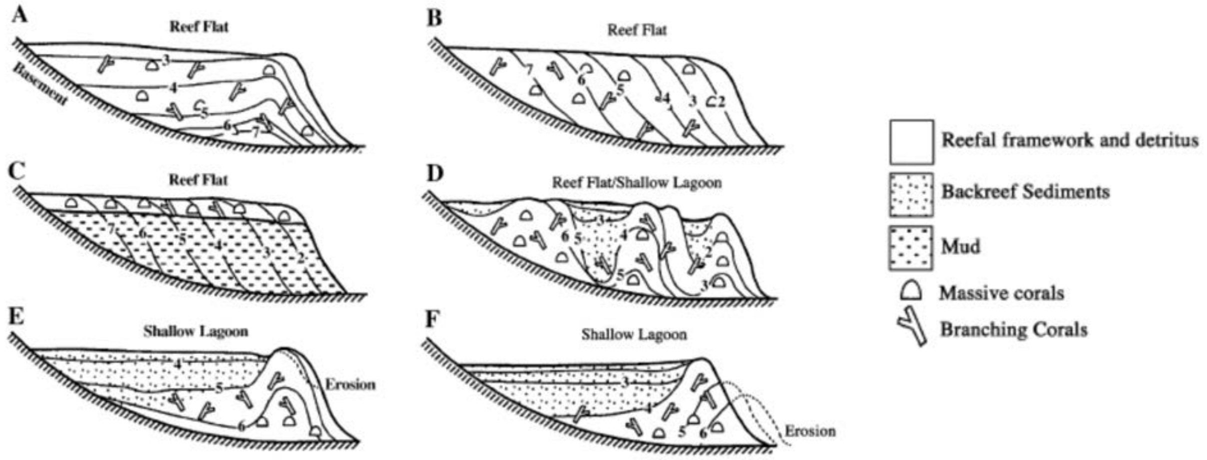


Figure 2-6-1: Fringing Reef Development Models (Kennedy et al. (2002))

While ecology reflects year-by-year sea conditions, the lithology and structure of the reefs are affected by exceptional storms, with the effects of the changing sea level superimposed. Analysing boreholes through the outlet edge of a fringing reef at Anse Aux Pins on Mahe Island, Braithwaite (2000) reveals a record of Holocene sediment accumulation first established approximately 8 ka (8,000 yrs.) ago. The growth of this body began in relatively deep water but the water became shallower within 1 ka. Subsequent accumulation was of the “keep-up” style, but as the rate of sea-level rise slowed, shoaling became frequent and aggradation was limited due to reduced accommodation space. Volumetrically dominant detrital facies requires new reef accretion models which suggest that a contiguous framework forms in areas of moderate fair weather energy without extreme storm events and that severe storms destroy the continuity of reef structures and generate increasing volumes of coarse detritus. (Source: Braithwaite. C.J.R., 2000. *Origins and development of Holocene coral reefs: a revisited model based on reef boreholes in the Seychelles, Indian Ocean*, Int J Earth Sci 89, 431-445)

Montaggioni (2005) provides a general development scheme for coral reefs since the last deglaciation mainly based on re-examination of the borehole studies, and suggests an approximate vertical reef accretion rate of 3.5 (2.3 – 8.8) mm/year for Mahe Island. Montaggioni (2005) also suggests that nutrient levels, hydrodynamic energy, substrate availability and coral recruitment are the most significant factors controlling coral and reef growth. (Source: Montaggioni, L.F., 2005. *History of Indo-Pacific coral reef systems since the last glaciation: Development patterns and controlling factors*)

(2) Surface Seawater Temperature (SST)

Observational records show that SST has been increasing by 0.1ºC per decade in the oceans where most SIDS are located. Coral reefs are threatened by SST rises which lead to coral bleaching. In the past 20 years, an approximate 1ºC SST rise above the normal maximum summer temperature has led to bleaching events. Some studies predict that in the next 30 to 50 years bleaching events could occur every year in most tropical oceans (UNFCCC background paper for the expert meeting on adaptation for SIDS (2007)). (Source: *VULNERABILITY AND ADAPTATION TO CLIMATE CHANGE IN SMALL ISLAND DEVELOPING STATES,* UNFCCC background paper for the expert meeting on adaptation for small island developing States, 2007)

In the Seychelles, the extreme maximum and minimum SSTs impact on fisheries and coral reefs. The data analysed by CRU (Climate Research Unit, UK) indicates an upward trend in SST, whereas a spatial regional scale SST variability analysis by NOAA shows a cooling in the Western Indian Ocean (Seychelles National Climate Change Strategy (2009)). Lack of data makes these observations inconclusive so far. (Source: The Seychelles National Climate Change Committee, 2009. *Seychelles National Climate Change Strategy*, p.96)

The SST changes within the IS92a emission scenario in the Seychelles predict that SST growth will range from 0.38ºC to 2.58ºC around 2100 (Payet et al. (2006)). The impact of climate change on coral reefs will nevertheless be catastrophic. Assuming the situation worsens as a result of increased background levels of mean SST, the likelihood of survival of remaining coral reefs is in doubt (Payet et al. (2006)). (Source: Rolph Payet and Wills Agricole. 2006. *Climate Change in the Seychelles: Implications for Water and Coral Reefs*, Ambio Vol. 35, No. 4, 182-189)

(3) Others

Another threat to coral reefs is rising CO_2 concentrations in the oceans related to rising atmospheric CO_2. Based on projected CO_2 levels, it is suggested that the calcification rate of corals could decrease by about

14 to 30 per cent by 2050. The resulting acidification of sea waters through increased dissolved CO_2 will impede biogenic calcification. This will be a serious problem for corals. The present 8-8.2 pH levels in the surface ocean are anticipated to fall to much lower pH levels by 2100 as atmospheric CO_2 levels increase (INGC Climate Change Report (2009)). (Source: *Sea Level Rise and Cyclone Analysis*, INGC Climate Change Report, p.33-66, 2009)

2-6-5 Impacts of Climate Change on Coastal Erosion and Flooding

Sea level rise may have the most significant impact on the Seychelles. It will have a great impact on coastal erosion and flooding by altering the oceanographic, meteorological and hydrological conditions. In addition, most living and economic activities are so concentrated in the coastal areas of the three major islands that the sea level rise will have a very serious impact on the Seychelles especially when it is combined with other adverse effects. A possible worst-case scenario can be assumed if a tropical cyclone/depression passes close by these islands and causes an extreme high tide and flooding simultaneously. In 2100, if a 1.4m high tide (return period: 25 yrs) run-up occurs with a sea level that has already risen by 0.6m and the rivers overflow with a flood depth of 0.5m, buildings or roads below 2.5m (above the present mean sea level) are expected to be inundated.

Using the existing GIS data set, the number of buildings/facilities that would be inundated and the length of roads that would be inundated are estimated as shown in Table 2-6-5 and Table 2-6-6. The results in Table 2-6-5 show that 2,017 buildings (14%) in Mahe, 1,601buildings (63%) in Praslin and 321 buildings (48%) in La Digue are expected to be inundated, including a total of 11 hospitals, 15 schools, 21 restaurants and 69 hotels/guesthouses on the three islands.

The results in Table 2-6-6 show that 67km of roads in Mahe, 43km of roads in Praslin and 7km of roads in La Digue are expected to be inundated, including 33km of coastal main roads in Mahe, 20km in Praslin and 3km in La Digue. In other words, 42% of the coastal main roads in Mahe, 72% in Praslin and 27% in La Digue are expected to be inundated. The impacts would be serious.

The data set used for this risk assessment was provided by the GIS Centre, Ministry of Land Use and Housing (MLUH). Though the building data and road data were updated in 2005 and in 2008 respectively, the GIS Centre is now conducting a detailed aerial survey and will revise the GIS data set by the end of 2012. It should be noted that the above-mentioned risk assessment should be revised when the newest GIS data set becomes available.

Table 2-6-5: Projected Number of Inundated Buildings in a Possible Worst-case Scenario (2100)

Island	**District**	**Risk of Inundation**				
		No. of buildings	**(No. of facilities included)**			
			Hospital	**School**	**Restaurant**	**Hotel**
MAHE (14,529)	*Glacis*	48	1	0	0	1
	Anse Etoile	113	0	1	1	1
	English River	109	1	1	0	1
	St. Louis	82	1	0	1	0
	Bel Air	82	1	0	1	0
	Mount Fleuri	191	2	0	0	1
	Plaisance	7	0	0	0	0
	Les Mamelles	29	0	0	0	0
	Roche Caiman	198	0	1	0	0
	Cascade	73	0	0	0	0
	Pointe Larue	150	0	2	0	0
	Anse Aux Pins	168	1	1	1	2
	Au Cap	192	0	0	3	6
	Anse Royale	66	1	2	0	0
	Takamaka	41	0	0	0	3
	Baie Lazare	89	0	0	3	1
	Anse Boileau	122	1	1	0	0
	Grand Anse Mahe	98	0	0	0	1
	Port Glaud	77	0	1	0	0
	Bel Ombre	27	0	0	0	1
	Beau Vallon	55	0	0	4	6
	Sub-total	**2,017**	**9**	**10**	**14**	**24**
PRASLIN (2,528)	*Baie Ste Anne*	656	0	1	4	15
	Grand Anse Praslin	945	1	2	3	18
	Sub-total	**1,601**	**1**	**3**	**7**	**33**
LA DIGUE (674)	*La Digue*	**321**	**1**	**2**	**0**	**12**
Total		**3,939**	**11**	**15**	**21**	**69**

Note: The numbers in parentheses show the total number of buildings for each island.

Table 2-6-6: Projected Lengths of Inundated Roads in a Possible Worst-case Scenario (2100)

Island	District	Risk of Inundation				Inundated Coastal Main Roads	
		Total length of inundated roads (m)	Inundated length by road type (m)			Total length of coastal main roads (m)	Length (m) & rate (%) of inundation
			Coastal main	Other main	Secondary /Feeder		
MAHE	*Glacis*	1,541	1,295	0	245	*North Coast Road*	*3,843*
	Anse Etoile	1,665	1,486	0	180	*16,611*	*23.1%*
	English River	976	772	205	0	*5th June Avenue*	*1,391*
	St. Louis	1,627	303	1,231	94	*1,391*	*100.0%*
	Bel Air	4,375	804	3,333	238	*Mont Fleuri Road*	*617*
	Mount Fleuri	4,819	1,179	3,299	341	*2,012*	*30.7%*
	Plaisance	49	49	0	0	*Bois De Rose Avenue*	*1,429*
	Les Mamelles	1,236	1,188	0	48	*1,703*	*83.9%*
	Roche Caiman	5,925	2,875	259	2,791	*East Coast Road*	*9,578*
	Cascade	4,170	2,447	1,665	58	*17,069*	*56.1%*
	Pointe Larue	4,075	1,910	0	2,165	*Palmistes Avenue*	*3,164*
	Anse Aux Pins	2,611	1,238	106	1,266	*3,550*	*89.1%*
	Au Cap	8,175	3,645	349	4,180	*Providence Hwy. Road*	*686*
	Anse Royale	2,541	1,490	508	542	*3,211*	*21.4%*
	Takamaka	1,151	920	0	231	*South Coast Road*	*1,756*
	Baie Lazare	4,617	1,676	243	2,699	*8,418*	*20.9%*
	Anse Boileau	5,827	3,490	308	2,029	*West Coast Road*	*10,697*
	Grand Anse Mahe	5,189	3,302	0	1,887	*25,509*	*41.9%*
	Port Glaud	3,765	2,230	49	1,486	-	-
	Bel Ombre	1,060	0	704	356	-	-
	Beau Vallon	1,642	863	0	779	***sub-total***	***33,162***
	Sub-total	**67,037**	**33,162**	**12,260**	**21,615**	***79,475***	***41.7%***
PRASLIN	*Baie Ste Anne*	19,066	10,521	416	8,129	-	-
	Grand Anse Praslin	23,942	9,922	66	13,953	-	-
	Sub-total	**43,007**	**20,443**	**482**	**22,082**	***28,267***	***72.3%***
LA DIGUE	*La Digue*	**7,472**	**3,270**	**1,199**	**3,003**	***12,108***	***27.0%***
Total		**117,516**	**56,875**	**13,941**	**46,700**	***119,850***	***47.5%***

Chapter 3 Component 2: Formulation of Management Plan

Chapter 3 Component 2: Formulation of Management Plan

3-1 General

From the basic study, the main issues are as follows:

- Coastal erosion and flood damage in lowland areas are caused by human activities together with natural conditions. The damage is caused by the construction of roads, breakwaters, houses and schools without consideration for the natural characteristics.
- The damage can be minimised by coastal zone management or environmental impact assessments. However, the EIA system and organisation do not function effectively. In particular, manpower and experience are lacking. In addition, legal regulations are not effective either.
- There have been few past disasters and public interest in disasters is low. Also, basic information about natural conditions and damage is lacking and has not been archived.
- The Seychelles Strategy 2017, Strategy for Climate Change in Seychelles, Environment Management Plan of Seychelles 2011-2020, and Seychelles Sustainable Development Strategy 2021-2030 are current development documents. The contents are general and do not fully address the characteristics and limitations of the Seychelles.
- New types of disaster are expected in the coastal zone due to further national economic development and climate change in the future.

Under these conditions, the coastal conservation plan and flood management plan should be included in the long-term proactive management plans for climate change and economic development in coastal areas, together with preventive measures for the present coastal erosion and drainage problems.

As for the impact of climate change on coastal areas, it is clear that the sea level rise and precipitation increase will bring the threat of flooding to coastal lowlands, though detailed examination has not been concluded yet. Because the coastal lowlands which are surrounded by reefs are used heavily, they will be influenced by wave overtopping, coastal erosion, flooding and drainage difficulties.

3-2 Procedures for Formulation of Plan

There are a number of ways to produce a coastal conservation plan or flood management plan. Because the future is uncertain regarding climate change and economic development, we have selected the planning cycle shown in Figure 1 from the general steps for formulation of a management plan. The steps can also be used for improvement of the plan in the future. It means that simply implementing an adaptation plan is not an end point; instead the adaptation plan is a continuous process.

The steps in the planning cycle are:

1) Issue identification and baseline assessment,
2) Management plan preparation and adoption,
3) Action plan and project implementation,
4) Monitoring and evaluation.

Hence, the performance of any adaptation measures should be carefully monitored and assessed and the lessons fed back through the cycle to improve maintenance and future interventions. For the process, information management and education are required as basic components.

In utilising this framework, it should be possible to provide well-planned and effective adaptation measures which in turn promote sustainable development of the coastal zone. It is important to note, however, that although adaptation measures can reduce vulnerability to coastal hazards, total protection from coastal erosion and flooding is not achievable.

The plan will start from issue identification and baseline assessment. Then the management plan for coastal erosion and flooding will be prepared and adopted. It is only after that that an action plan will be formulated and selected projects will be implemented. The results of the management plan and the action plan will be monitored and evaluated. For the planning cycle, related information is managed and public education will be provided to obtain support for the plan.

The procedure can be applied to future improvements. Two plans for coastal conservation and flood management are unified because in the plans there are no major differences especially for non-structural measures.

For the management plan, the objectives, target year and area, and the responsible organisation are also discussed and decided. In the Study the coastal conservation plan to prevent disasters and the flood management plan for the priority coasts or areas are considered as the action plan and formulated. The implementation of pilot projects is shown as an example of project implementation.

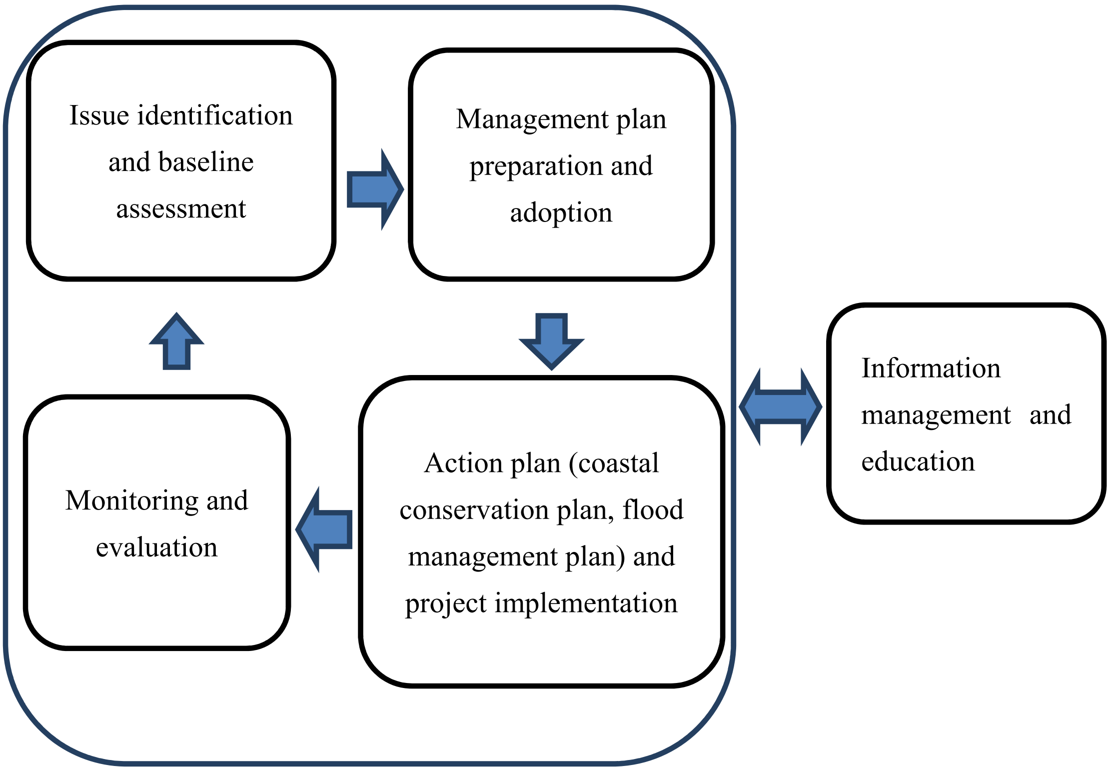


Figure 3-2-1: Planning Cycle

3-3 Objectives

The objectives of the management plan are established under the policies and strategies to reduce the potential adverse consequences of erosion on human life, the environment and economic activities as follows:

- To mitigate damage to human lives and property from coastal erosion, flooding, tides, waves and tsunamis.
- To harmonise the mitigation measures with nature conservation and the use of coastal areas, wetlands and rivers.
- To contribute to coastal zone development and climate change adaptation for sustainable development in the future.
- To promote awareness and understanding of the value of the coasts and rivers and bring together stakeholders.

The objectives are derived from the strategy and policy documents, namely the Seychelles Strategy 2017, Strategy for Climate Change in Seychelles, Seychelles Sustainable Development Strategy, SSDS, 2011-2020 and Seychelles National Disaster Management Policy as explained in Chapter 2.

3-4 Basic Conditions of the Plan

As the basic conditions for the plan, the target area, target year, design return period, natural conditions and responsible organisation were discussed and proposed.

3-4-1 Target Area and Design Period

The target areas are the three main islands of Mahe, Praslin and La Digue. Three target years were set, namely 2020 for the short term, 2050 for the medium term and 2100 for the long term. The target years were set in view of the usual 10-year evaluation period in the Seychelles and the availability of future climate change estimates in 2050 and 2100. For the planning and design of structural measures, the return period was decided at 1/10 for small structures, 1/25 for ordinary structures and 1/100 for important structures. In general, the probability is decided by the importance and life of the structures. Usually, for small structures such as drainage improvement, the return period is from 5 to 10 years, considered as short term. For ordinary structures such as coastal revetments or river improvement, it is from 30 to 50 years, considered as medium term. For important structures, it is over 100 years, considered as long term. In the Seychelles such structures do not exist at present. In the storm water drainage design guidelines in the Seychelles, the recommended return period for drainage facilities is 1/10 for Victoria and 1/5 for other areas, and for the main facilities which are culverts on main streams it is 1/25. Based on the guidelines, the figures were decided as shown in Table 3-4-1.

Table 3-4-1: Target Year and Design Period

	Short Term	**Medium Term**	**Long Term**
Target Year	2020	2050	2100
Design Return Period			
Area	**Small Scale**	**Medium Scale**	**Large Scale**
Victoria Town	10 years	25 years	100 years
Others	5 years	25 years	100 years

3-4-2 Natural Conditions

(1) Tide

The tidal conditions for planning and designing were decided by analysis based on the observed data as shown in Table 3-4-5.

Table 3-4-1: Tidal Conditions (unit: m above MSL)

Return Period	**Target Year**		
	2010	2050	2100
1/10	1.33	1.59	1.92
1/25	1.44	1.70	2.03
1/100	1.61	1.87	2.20

(2) Waves

The wave conditions of each coast are estimated from wave observations in the 30 years from 1971 to 2000. The maximum significant wave height in the data is applied as 1/25 year probability as in Table 3-4-2 (http://www.knmi.nl/home/onderzk/oceano/waves/era40/climatology.html).

Table 3-4-2: Design Wave Conditions

Name of Coast	**Wave Height (m)**	**Wave Period (s)**	**Wave Direction**
North East Point (Mahe)	4.0	8.0	ESE
Anse aux Pins (Mahe)	5.0	8.0	SSE
Au Cap (Mahe)	5.0	8.0	SSE
Anse Royale (Mahe)	5.0	8.0	ESE
Baie Lazare (Mahe)	4.0	7.0	SSW
Anse a La Mouche (Mahe)	4.0	7.0	WSW
Anse Boileau (Mahe)	4.0	7.0	SSW
Anse Kerlan (Praslin)	4.0	7.0	SSW
Grand Anse (Praslin)	5.0	8.0	SSE
La Passe (La Digue)	4.0	6.0	WSW

(3) Rainfall

The rainfall for planning and designing is based on the storm water drainage design guidelines in the Seychelles, with some modifications according to the regional analysis in Chapter 2-5. The modified intensity is 1.1 times the rainfall intensity in the guidelines in the north area and 0.9 times in the south area. In the central area there is no change.

(4) Planning and Design Guidelines

Because there are no established guidelines in the Seychelles except the storm water drainage design guidelines, the guidelines of Japan, the United States and U.K. are used but with consideration given to their applicability to the Seychelles.

(5) Construction Materials and Methods

Basically, local materials are used as construction materials except iron bars and filter cloths which are imported. The construction methods also allow for the use of local methods.

3-4-3 Responsible Organisation

The responsible organisation is the Department of Environment (DOE) of the Ministry of Environment and Energy. DOE is the only organisation engaged in conservation of coastal areas and mitigation of coastal erosion and flood disasters.

3-5 Risk Estimation

3-5-1 Classification of Coasts

(1) Summary of Coastal Erosion Areas

For the classification of eroded coasts, the characteristics of each coastal erosion area can be summarised as shown in Table 3-5-1. The coasts were selected from past reports of coastal erosion, analysis of coastal changes and field observations. The length indicates the length of the sediment cell which shows one index of erosion severity. If the coast is long, the erosion affects a wide area and mitigation measures become difficult.

As the plain forms the coast, if it is convex, the coast receives waves from a wide range of directions. This means that the beach changes according to the seasonal wave direction due to alongshore sediment transport. If it is concave, the changes are limited and erosion problems are rare, such as for pocket beaches. The direction of the coast is also a factor. In the Seychelles, waves from the southeast are high and from the north they are moderate. Therefore, the coasts facing southeast receive high waves.

If there is a reef, it works as a wave dissipater, especially if it is a reef flat. Beach rock also prevents erosion. Another factor is the existence of coastal structures which may have caused past erosion or be the cause of present erosion. Coastal use is also a factor. If the coast is heavily used, the erosion becomes severe and the solution is difficult and expensive.

There are several types of erosion problems. They include loss of land and property, wave overtopping onto roads or private property, tsunami inundation and so on. Loss of land and property was caused at Anse Kerlan on Praslin. Traffic problems on the coast were caused at North East Point, Au Cap, Anse Royale, Baie Lazare, Anse a La Mouche and Anse Boileau.

Table 3-5-1: Characteristics of Each Coastal Erosion Area

Island	Name of Coast	Length	Beach Condition	Coastal Use	Erosion Problem
Mahe	North East Point	1.7 km	Convex coast facing northeast with reef and beach rock. Small revetment	Coastal road, housing, hospital and rehabilitation centre	20 m of erosion and 20 m seasonal change with wave overtopping at high tide
	Anse Aux Pins	0.5 km	Straight coast facing east fronted by reef flat and reclaimed land	Coastal road, housing and market	Beach scarp and accretion in front
	Au Cap	2.3 km	Slightly concave coast facing east with reef flat. Concrete revetment	Coastal road, housing, hotels and bathing	Past erosion by sand mining and wave overtopping at high tide
	Anse Royale	2.5 km	Concave coast facing east with reef flat and channel. Concrete and armoured revetments	Coastal road, housing, church and bathing	Past erosion by sand mining and wave overtopping
	Baie Lazare	1.7 km	Concave coast facing southwest with reef and channel. Damaged concrete revetment	Coastal road, housing and shops	20 m erosion, seasonal change at outlet and wave overtopping
	Anse a La Mouche	0.35 km	Concave coast facing west with reef. Wood pile revetment	Coastal road, housing and bathing	Accretion, with partly eroded portion in front of the road, and wave overtopping
	Anse Boileau	2.0 km	Concave coast facing southwest with reef. Armoured and wood pile revetments	Coastal road, housing and bathing	Wave overtopping
Praslin	Anse Kerlan	2.0 km	Convex coast facing east with reef. Groynes and armoured revetment	Coastal road, hotels, restaurant, bathing and fishing	30 m erosion and seasonal changes. Loss of private land, relocation of road
	Grand Anse	3.0 km	Next to Anse Kerlan, concave coast facing southeast	Hotels, restaurant, bathing and fishing	20 m accretion, water quality problem in northwest monsoon
La Digue	La Passe	2.3 km	Convex coast facing west and Praslin in front. Breakwaters, armoured revetment and man-made island	Hospital, restaurant, guest houses and bathing	Erosion and accretion caused by structures, large seasonal variation and no clear erosion overall

(2) Classification

The purpose of classification of the eroded coasts is to use the results for coastal management and coastal erosion mitigation. In the Seychelles, the coasts are classified mainly into three components: sandy coast, rocky coast and reclaimed coast. For the coastal erosion study, only the sandy coasts are of main concern. Erosion of the rocky coasts is very small because the rock is granite and resists erosion.

For analysing coastal erosion and sediment budgets on sandy coasts, it is useful to introduce the notion of littoral cells. They are defined as the compartments of a coast separated by two rocky barriers or headlands which mark the end of the beach. Within the cell, the difference in input and output of sediments is analysed to show the amount of erosion or accretion.

The types of erosion are classified into several categories as shown in Table 3-5-2.

Table 3-5-2: Types of Coastal Erosion

Type of Coast	Explanation	Example
(a) Coast with long-term changes	Erosion caused by offshore sediment transport	North East Point
(b) Coast with erosion by changes in waves	The changes in wave height and direction bring coastal changes by onshore-offshore and longshore transport.	Beau Vallon Beach
(c) Coast with erosion influenced by structures	Coastal structures bring coastal erosion and accretion. Breakwaters, groynes and revetments cause coastal erosion of adjacent beach.	Anse Kerlan in Praslin La Passe in La Digue
(d) Pocket beach	A pocket beach is protected by the headlands, hence it is stable.	

(a) Coasts with Long-Term Changes

Two types of changes are evident on the three islands. One is long-term erosion caused by offshore sediment transport and the other is erosion and accretion by longshore transport. Originally the coral islands, especially coral beaches, were formed by the accumulation of coral debris transported from the reef edges by wave action. Possible loss of sediment is due to offshore transport by waves, offshore transport at river outlets and sand mining. At present, offshore transport at river outlets seems to be the main cause of sediment loss. Reef channels are formed in the reefs by fresh, muddy water from the rivers. During floods, sediment is transported offshore through the channels and it is difficult to return it to the beach.

In a relatively narrow bay such as Anse a La Mouche, sediment is transported along the coast from the mouth of the river to the end of the bay and is accumulated gradually. In this type of bay, the beach may be eroded by land reclamation or the construction of jetties. The beach can recover in the long term.

Sand mining is one of the causes of coastal erosion. In 1991, the Removal of Sand and Gravel Act was issued. This means that sand mining had caused some kind of damage to the coast. A report in 1994 said that 35,000 tonnes of sand were extracted every year. The surface of the old concrete blocks provides a clue as to where the building material originated. The USGS report in 1995 explains that mineral production in the Seychelles consisted mostly of unspecified quantities of construction materials, clay, coral, stone and sand. At that time, granite was used on a trial basis.

(b) Coasts with Erosion by Changes in Waves

The change in wave direction brings coastal changes by longshore transport. In particular, small islands receive waves from every direction. The example of Cousin Island near Praslin is shown in Figure 3-5-1. The changes in the beach are great and sediment moves around the island.

Figure 3-5-1: Beach Changes on Cousin Island
in August 2008 (right) and March 2009 (left) from Google

The changes in wave height also cause coastal erosion and accretion. The coast is eroded by high waves and accreted by low waves. An example is shown in Figure 3-5-2 with photographs taken in March and July 2011 at Beau Vallon Beach on Mahe. The eroded beach in March recovered in July and again returned to eroded beach in November as it had been in March.

Figure 3-5-2: Erosion in March and Accretion in July at Beau Vallon Beach in 2011

Several examples of scarp which show the characteristics of erosion are seen on the Seychelles beaches. In the second national communication, severe erosion is specified on the coast where a 2 m-high scarp exists. However, seasonal fluctuations of the beach profile are a normal process as the coastline is always adjusting to its equilibrium. In the report, it is explained that North East Point and Intendance Beaches are good examples of beaches that have made significant recovery. The two beaches experienced severe erosion during both Cyclone Bondo and the spring tides from 15th to 16th May 2007.

(c) Coasts with Erosion Influenced by Structures

Sometimes coastal structures cause coastal erosion and accretion. In the Seychelles, breakwaters, groynes and revetments cause coastal erosion of the adjacent beach. The breakwaters at La Passe on La Digue cause accretion and erosion. The erosion at Anse Kerlan is related to groyne construction.

If there is a coastal dike on a beach, scouring of the beach occurs in front of the dike. An example of the scour depth on sandy beaches is shown in Figure 3-5-3. The depth increases as the wave steepness decreases and has a maximum value around the h_t/H_s ratio of 2. Also, the figure shows that scouring occurs if the dike is located below the water level. On the reefs, the wave steepness is reduced and the wave height becomes the same as the h_t/H_s ratio because of breaking. This means that scouring always exists if the dike is under the water. The beach scarp also acts as a coastal dike and creates scouring in front (Sutherland J., A. Brampton, G. Motyka, B. Blanco, and R. Whitehouse (2003): Beach Lowering in front of Coastal Structures, Appendices 1-3, R&D Project Record FD1916/PR, Defra.).

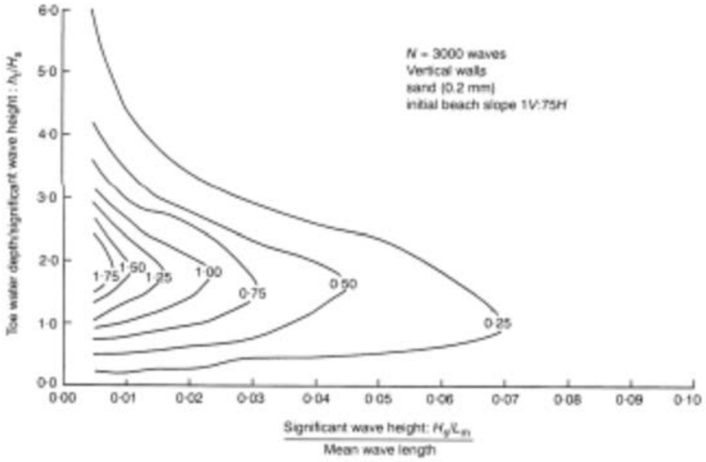


Figure 3-5-3: Iso-parametric Scour Plot for Sand Beaches

(h_t/H_s: maximum relative water depth where h_t is the water depth at the wall and H_s is the extreme unbroken deep water wave height, H_s/L_m: wave steepness where L_m is the mean wave length of the unbroken wave (using $T^2g/2$), S: scour depth after 3,000 waves. Powell K, Whitehouse R.J.S. (1998), The occurrence and prediction of scour at coastal and estuarine structures. 33rd MAFF Conference of River and Coastal Engineers, 1-3 July 1998).

(d) Pocket Beaches

A pocket beach is protected by headlands, hence it is stable. As a natural phenomenon, sediment movement is classified into onshore-offshore transport and alongshore transport. On pocket beaches, alongshore transport is limited because the waves come only in limited directions.

3-5-2 Risk Estimation for Eroded Coasts

The type and magnitude of risk are estimated for the eroded coasts in the examples on the basis of the characteristics and scale of damage. The risk is classified into two types: the risk under the present conditions and the risk related to economic development and climate change in the future. In estimating the risk, the sample coasts were used instead of the classified coasts in order to be more specific and definite.

The risk under the present conditions of the sample coasts can be estimated from the past and the experience of other small island countries. The eroded coasts caused by long-term erosion and the construction of structures face the risk of land loss and beach use and of coastal flooding by wave overtopping. If there is a coastal road, sometimes wave overtopping affects the traffic. The sandy beaches are used by tourists and for nature conservation such as turtle nests. The coasts eroded by changes in the waves also face the same risks except for land loss. The beach changes caused by structures in certain cases reach an equilibrium. Then the risk also decreases.

The risk related to economic development is almost the same as that caused by the construction of structures. Other types of development are land reclamation which modifies the coastline. The rate of development is estimated from the increase in GNP of 5% from 2004 to 2010 and 2% from 2007 to 2010. By applying the rate, the increase in damage in 2050 will be 6 times or twice that of the present respectively. This means that good estimates are very difficult to make because of the uncertainty.

The risk related to climate change is caused by the sea level rise, intensified storms and sea temperature warming. Sea-level rise is considered to be a contributory factor to the retreat of the shoreline because the incoming waves depend on the sea level on the reef. High sea level means high waves. On reef islands, carbonate beaches are maintained by sand produced from the reefs. Degradation of the coral reefs caused by sea warming will accelerate beach erosion. Intensified storms will bring high waves and storm surges which also cause beach erosion. On the three islands, which are periodically susceptible to flooding and scouring by storm surges, an increase in storminess would further stress the natural and human systems located on the coast.

At present, the sea level rise will have the greatest impact. It is estimated as shown in Table 3-4-2 that a sea level rise of 0.6 m will bring about 10 m of erosion of sandy beaches.

The risk is defined as the probability of occurrence of hazardous events, and the hazard is defined as an event or process with the potential for harm to people, property and the environment. Therefore, hazard is ranked by significance and hazard occurrence is also ranked. Detailed classification is difficult because basic data are lacking and future estimates are uncertain. In the management process these will be improved. Each hazard is ranked by significance using the description of effects as shown in Table 3-5-3 and Table 3-5-4.

Table 3-5-3: Hazard Ranking

Rank	Descriptor	Description of Effects
1	Insignificant	No damage to houses and property, no economic loss; no media or public interest
2	Minor	Minimal damage to houses and property, limited or no economic loss; limited media reporting
3	Moderate	Limited damage to houses and property, some economic loss; limited media reporting
4	Major	Damage to houses and property, economic loss; critical media reports
5	Catastrophic	Severe economic loss: international media reports

Table 3-5-4: Assessment of the Likelihood of Hazard Occurrence

Level	Descriptor	Description
A	Almost certain	Is expected to occur in most circumstances
B	Likely	Will probably occur in most circumstances
C	Possible	Might occur at some time
D	Unlikely	Could occur at some time
E	Rare	May occur in exceptional circumstances

Consequences: qualitative guide, E = Extreme risk, immediate action required, H = High risk; senior management attention needed, M = Moderate risk; management responsibility must be specified, L = Low risk; manage by routine procedures.

For the coastal erosion on the sample coasts, the risk analysis matrix is shown in Table 3-5-5 for present risk and in Table 3-5-6 for future risk.

Table 3-5-5: Risk Analysis Matrix at Present

Hazard Area	Likelihood of Occurrence	Severity of Consequences	Overall Level of Risk
Coastal Erosion			
North East Point	Almost certain	Minor	Moderate
Au Cap	Possible	Minor	Low
Anse Royale	Possible	Minor	Low
Baie Lazare	Likely	Minor	Moderate
Anse a La Mouche	Rare	Insignificant	Low
Anse Kerlan	Almost certain	Major	Moderate
La Passe	Likely	Minor	Moderate

Table 3-5-6: Risk Analysis Matrix in Future

Hazard Area	Likelihood of Occurrence	Severity of Consequences	Overall Level of Risk
Coastal Erosion			
North East Point	Almost certain	Moderate	Moderate
Au Cap	Likely	Minor	Low
Anse Royale	Likely	Minor	Low
Baie Lazare	Almost certain	Minor	Moderate
Anse a La Mouche	Possibly	Insignificant	Low
Anse Kerlan	Almost certain	Major	High
La Passe	Likely	Moderate	Moderate

The likelihood of hazard occurrence is estimated for each eroded coast. At North East Point and Anse Kerlan erosion has been experienced in the past and will possibly happen in the future if no action is taken. Therefore, they are classified as almost certain. At Baie Lazare and La Passe the road or hospital will probably experience wave overtopping at high tide. Therefore, they are classified as likely. At Au Cap and Anse Royale the coastal road might experience wave overtopping at high tide and high waves during the southeast trade winds. Therefore, they are classified as possibly. Anse a La Mouche is classified as rare because the coast is generally accreting and the chances of wave overtopping are rare.

In future, because of the sea level rise, it is estimated that the probability of occurrence will increase from likely to almost certain, and from possibly to likely. At Anse a La Mouche the coast is accreting but the sea level will cause some kind of erosion even if the coast is accreting. Therefore, the probability of occurrence will increase from rare to possibly.

The severity of the consequences is judged as follows. At Anse Kerlan the coast is continuously eroding and the hotels and houses are in danger and there is media reporting. Therefore, the severity is judged as major. At North East Point, Au Cap, Anse Royale, Baie Lazare and La Passe the damage to houses and property and economic losses are minimal and there is limited media reporting. Therefore, the severity is judged as minor. At Anse a La Mouche there is no damage to houses and economic losses are limited. Therefore, the severity is judged as insignificant.

In future, at North East Point and La Passe limited damage to houses and property is expected because of the sea level rise. Therefore, the severity will change from minor to moderate. At the other coasts it is estimated that the severity will be the same as at present because no significant increase in damage to houses and property is expected.

The overall level of risk is estimated from the likelihood of hazard occurrence and the severity. At Anse Kerlan the likelihood and severity are the same at present and in the future. However, in future attention to management will be necessary because of its importance as tourism resources. Therefore, the risk will be high. At the other coasts the risk is below moderate level which means management responsibility must be specified.

3-5-3 Classification of Flood Risk Areas

(1) Summary of Flood Risk Areas

For the classification of flood risk areas, the characteristics of each flood risk area can be summarised as shown in Table 3-5-7. The areas were selected from past reports by the drainage task force, analysis of past floods and field observations.

Table 3-5-7: Characteristics of Each Flood Risk Area

Island	Name of District & River or Area	Natural Conditions	Land Use	Flooding Problem
Mahe	North East Point	Lowland area along the coast with wetland	Houses, hospital, rehabilitation centre, coastal road	Outlet problem due to sand bar and flooding in lowland
	Anse Etoile	Reclamation fronting outlet	School, district office, shops and road	Flooding at school due to reclamation in front
	Victoria Town	Steep river with reclamation fronting old coastline	Commercial and housing area	Inadequate and blocked drainage, increased discharge due to urban development
	Pointe Larue	Reclamation fronting old coastline with lowland and wetland	Airport, petrol station, school, houses and road	Drainage blocked by continuous airport reclamation, lowland reclamation, inadequate drainage
	Anse Aux Pins	Coastal lowland with wetland and outlet	School, shops and housing development	Inadequate drainage, outlet clogged by sand
	Au Cap	Coastal lowland with wetland and outlet	Housing, school and hotel	Lowland reclamation, inadequate drainage
	Anse Royale	Coastal lowland with wetland and outlet	University development, housing and agricultural land	Inadequate drainage, outlet clogged by sand
	Anse a La Mouche	Coastal lowland with wetland and outlet	Housing development, road	Inadequate drainage, outlet clogged by sand
	Anse Boileau	Coastal lowland with wetland and outlet	Housing development, road	Inadequate drainage, outlet clogged by sand
Praslin	Anse Kerlan	Coastal lowland with wetland and outlet	Hotels, guest houses, housing and road	Inadequate drainage, outlet clogged by sand
	Grand Anse	Coastal lowland with wetland and outlet	Hotels, guest houses, housing and road	Inadequate drainage, outlet clogging by sand
La Digue	La Passe	Wide coastal lowland with limited outlets	Housing, guest houses, road and agricultural land	Inadequate drainage, outlet clogged by sand

(2) Classification

Based on the collected data and inventory survey of the flood risk areas, the floods were classified according to flood pattern based on local characteristics and the severity of damage as shown in Figure 3-5-8.

Table 3-5-8: Classification of Floods

Type of Flood	Explanation	Example
River flood		
Urban flood	Urban development increases the discharge of floodwater and causes flooding.	Victoria Town
Improper drainage	The design of the drainage channel lacks the necessary capacity.	Pointe Larue
Lowland development	Reclamation in front of outlet reduces flood capacity. Housing development on low land causes drainage difficulties.	Anse Aux Pins, Au Cap, Anse Royale
River with wetland	Coastal lowland with wetland has some outlet problems because of outlet clogging by sand accumulation.	Au Cap, Anse Royale

Floods are usually caused by river flooding. However, in the Seychelles there are no large rivers and such cases are limited.

The drainage problem in Victoria Town is characterised as a kind of urban flood. In Victoria the natural rivers flow into urban areas which have been extended to the sea as a result of land reclamation. The rivers gather flood water through the drain system such as road drains and side drains. With increased development and associated run-off over the years, together with increased flood discharge, the flow capacity of the drains is no longer adequate.

Usually flooding is caused somehow by inadequate drainage. Here inadequate drainage means that flooding is caused by ignoring proper planning or design of the drainage system. For example, at Pointe Larue, reclamation for the international airport obstructed the existing drainage from the coastal road to the sea, without considering landward flooding. Because the available land area in the Seychelles is limited, the lowlands where flooding sometimes occurs are developed for housing projects or are used for public facilities. Therefore, lowland development is one of the causes of flooding. Rivers flow from the mountains to the sea through lowlands where lagoons or wetlands are formed behind the coastal sand dunes. Reclamation of the lagoon sometimes aggravates the situation because the lagoon has the function of keeping the river outlet open to the sea.

In the Seychelles, as a natural phenomenon, most of the storm water is discharged into the nearby wetland before reaching the sea because the sand dunes along the coast prevent smooth water flow. The stored wetland water maintains the outlet in the dry season. Therefore, the river and the wetland system form a natural system which brings flooding around the wetland.

3-5-4 Risk Estimate of Flood Risk Areas

The basic concept of risk estimation for flooding is the same as in Section 3-5-3. Now, a great deal of land development can be observed in the coastal areas and in the wetland and lowland areas. This brings increased risk now and in the future.

Table 3-5-9: Risk Analysis Matrix at Present

Hazard Area	Likelihood of Occurrence	Severity of Consequences	Overall Level of Risk
Flooding and Drainage Problem			
Victoria	Possible	Insignificant	Low
Pointe Larue	Possible	Minor	Low
Anse Aux Pins	Likely	Insignificant	Low
Au Cap	Likely	Minor	Moderate
Anse Royale	Likely	Minor	Moderate

Table 3-5-10: Risk Analysis Matrix for the Future

Hazard Area	Likelihood of Occurrence	Severity of Consequences	Overall Level of Risk
Flooding and Drainage Problem			
Victoria	Likely	Moderate	Moderate
Pointe Larue	Likely	Minor	Low
Anse Aux Pins	Likely	Minor	Low
Au Cap	Likely	Moderate	Moderate
Anse Royale	Likely	Moderate	Moderate

The risk analysis for the flood risk areas is shown in Table 3-5-9 for the present and in Table 3-5-10 for the future. The likelihood of hazard occurrence is estimated for each flood risk area. At Anse Aux Pins, Au Cap and Anse Royale flooding or drainage problems in the lowlands will occur in the rainy season in most circumstances. The southeast trade winds bring high waves which cause accumulation of sediment on the beach and outlet clogging in the dry season makes drainage from the lowlands difficult. In Victoria and Pointe Larue drainage problems are caused only during intensive rainfall. Therefore, the likelihood is estimated as likely at Anse Aux Pins, Au Cap and Anse Royale and possible at Victoria and Pointe Larue. The severity is estimated as minor at Pointe Larue, Au Cap and Anse Royale because there is little damage to houses and property and limited media reporting. The severity at Victoria and Anse Aux Pins is estimated as insignificant because on 30th October 2011 heavy rain with a probability of more than 1/10 did not cause any damage.

In future the sea level rise will cause drainage problems. It is estimated that at Anse Aux Pins, Au Cap and Anse Royale the frequency will not increase remarkably, but the severity will increase. Therefore, the severity changes from minor to moderate and from insignificant to minor. At Victoria and Pointe Larue the occurrence of drainage problems will increase from possible to likely. The severity will change at Victoria from insignificant to moderate because the impact of the sea level rise will be great. However, at Point Larue the impact of the sea level rise will be limited because the drainage problems have been caused by improper drainage and the impact of the sea level rise is limited.

The overall level of risk was estimated from the likelihood of hazard occurrence and the severity. The overall risk is moderate or low. At Pointe Larue and Anse Au Pins the overall risk is estimated to be low because the scale of damage will be smaller than that of the other areas in future.

3-6 Alternative Measures

There are several measures to mitigate coastal erosion and flooding and they are classified into three categories: protection, accommodation and retreat together with do-nothing. The applicability of the measures to the Seychelles was discussed together with the natural and socio-economic conditions.

3-6-1 Do-Nothing: baseline

If no measures are taken, the properties in the coastal area will be affected by coastal erosion and flooding, especially by the sea level rise. The affected area is estimated in Chapter 2. The coastal road is also difficult to use during high tides and heavy rain in some parts. Public facilities in the lowlands such as schools and hospitals have some problems due to flooding. Development, especially for tourism, in the lowland may be limited. The impacts on coastal ecosystems and the landscape are not clear.

3-6-2 Protect

As protective measures against coastal erosion, coastal revetments, sand nourishment and groynes are applicable.

(1) Coastal Revetments

Revetments and seawalls are traditional types of armoured shorelines. The cost of armouring is justified when wave damage in low areas threatens substantial human investment. Historically, for eroding coasts, it must be expected that erosion will continue to diminish the width of the buffer strip between the armoured shoreline and the sea. Scouring in front of the armouring and impacts on the adjacent beach will be a problem. The impacts on coastal ecosystems and the landscape will also bring changes in the present conditions.

(2) Nourishment

As beach nourishment, loose sediment material such as coral sand or gravel can be placed on the beach. This soft alternative solution for shore protection is now a common alternative selected for a variety of reasons. In particular, it is flexible for adaptation to future sea level rises and beach use as tourism develops.

(3) Groynes

Groynes moderate the coastal sediment transport process to reduce the local erosion rate. Their construction should be considered where chronic erosion is a problem due to the diminished sediment supply. They are often combined with beach nourishment to reduce down drift impacts. The purpose is to slow the loss of placed sand, not to trap sand from the littoral system and create more problems elsewhere.

(4) Detached Breakwaters

Detached breakwaters are one measure to stabilise beaches and reduce wave energy for beach protection. However, reef flats also have the same function in the Seychelles. Sometimes accumulated sediment behind the breakwater means erosion of the adjacent beach. Therefore, detached breakwaters are not applicable because of their effect and cost. Detached breakwaters provide limited benefits and need detailed study before application.

As protective measures against flooding, river improvement, outlet improvement and other measures may be applicable as follows:

(5) River Improvement

River improvement works include widening of the river channel width, construction of river dikes and implementation of control structures against river mouth clogging. River improvement works ensure the discharge of floodwater to the sea. Construction works are the types commonly adopted in the Seychelles and the materials are those available in the market. Therefore, maintenance of the completed structures will be minimised. Usually, river channels need a constant width from the middle reaches to the outlet (ocean) to ensure the smooth discharge of rainwater. However, in the Seychelles the river channels near the outlets are narrower than the upstream channels because of the ground elevation or topography. Therefore, the construction of river improvement works requires land acquisition and compensation. In addition, to implement river improvement works in the future, it is necessary to conserve both sides of the river channel in a prompt manner by considering land use regulations or zoning ordinances. As for flexibility to climate change, structural facilities cannot easily and rapidly make up for the changes.

(6) Drainage Improvement

Drainage works include extension of the drainage channels and construction of proper sized drainage. Drainage improvement works are commonly implemented by DOE and DOT. The construction cost is less expensive than river improvement works.

(7) Ring Levees

Ring levees are one of the methods for the protection of lowland areas from floodwater, but they make it difficult for the water inside to flow out of the levee. Ring levees can protect priority areas completely and the top of the levee can be paved as a main road because of its high and safe elevation. The top elevation can be embanked based on the climate change situation. Construction of ring levees requires a large volume of embankment materials due to structural requirements. The construction cost is also expected to be higher than other methods. In addition, during and after flood events, a pump system is required to quickly discharge the rainwater inside the levee. This pump system requires regular maintenance and operating expenses.

(8) Retaining Ponds

Retaining ponds store water for a short period of time during flood events and release the water slowly after the water level subsides in the river channel. Retaining ponds are effective for short-term flooding. The location of the retaining pond is basically in a lowland area to allow the water to flow into the pond naturally. In some cases, the retaining pond can be constructed under houses or facilities to minimise the construction cost. In the Seychelles, lowlands and wetlands are available in most river outlet areas. However, these areas are mostly utilised for agriculture, schools or houses.

It is necessary to have an agreement with agricultural landowners for this purpose, and the government might need to consider compensation for damages. To increase the effectiveness, a series of retaining ponds is also needed. In this case, it is very important to consider conservation of the wetlands, and modification of the building standards is also required.

(9) Pump Systems

The pump system will help discharge water quickly from the lowlands to the river channel or the ocean. However, the system needs regular maintenance and a fuel supply. Generally, the operation cost depends on the size of the pump, but it is costlier than other measures. It is therefore not suitable for the Seychelles.

(10) Water Gates

Water gates are provided along the river channels to prevent floodwater and/or tidal water from flowing into lowland residential areas. A single gate is not expensive, but for a certain number of gates the total cost will be high. In addition, operation of the gates requires manpower, including the observance of operation rules, and this duty may cause additional responsibilities for the agencies concerned.

3-6-3 Accommodation

To accommodate coastal erosion and flooding, improvement of buildings, regulations, EIA, increased awareness of hazards, hazard risk maps and warnings are applicable. These measures have been already applied or planned in the Seychelles as explained in the following. The next step is to improve their applicability and to concentrate on specific measures because of limited resources and capacities.

(1) Improvement of Houses

House improvements include raising the house's foundations, adopting waterproofing materials and elevating the ground level by filling. All improvement works are effective against flood events and sometimes against coastal erosion, but they require expenses for rebuilding the house and landfilling. To promote these countermeasures, the Government of the Seychelles will examine the possibility of a subsidy system to support people living in risk areas.

(2) Regulations

Improvement of land use regulations is very important. The new Land Use Act is almost completed, pending approval by the Cabinet, and seven related implementation rules and regulations are under preparation by the Ministry of Land Use and other concerned agencies. The new regulations are expected to be finalised in May or June 2012.

(3) EIA

The EIA requirement is at present under revision by the Department of Environment (DOE). The first draft is expected to come out in June 2012 and be approved by the Cabinet in September 2012. The revision of the EIA is being outsourced to a local consultant. EIA is a useful tool for mitigation measures against coastal erosion or flooding of new development areas.

(4) Awareness

DRDM is the facilitator for conducting awareness programmes with international donors and NGOs. The plan for education strategies was prepared in 2011 and the action plans will depend on the proposals from each donor and NGO.

The DOE has an education section and the JICA study team may coordinate with this section in further activities. The awareness programme includes evacuation drills, map preparation exercises and awareness activities targeted at communities and schools. Awareness activities require sustainable operation and they should be conducted regularly with a proper budget based on the action plans.

(5) Risk Maps

The Flood and Tsunami Hazard Maps were prepared in 2008 based on the old base maps (issued in

1998-1999 with the reclaimed area added in 2004). The basic topographic data are being updated by the Ministry of Land Use and the data may be available by the end of 2012.

The Seychelles has been developing international business and tourism in the last few years and there are many developments around the country. With the new topographic data, DRDM may be able to prepare better disaster risk maps for floods and tsunamis.

(6) Warnings

Broadcasting of weather conditions is conducted by the media every day. Due to the limited radar functions, forecasting lacks adequate accuracy. Since floodwaters flow down the rivers in a short time, the warning system will be effective once the communication system between the NWS and users is available. However, a warning system requires expenses and maintenance of the equipment and experts need to be on standby before, during and after a flood event.

(7) Emergency Operation

Emergency operation of damaged structures and facilities is common practice in the Seychelles. Emergency repair of drainage, river, wetland and coastal facilities is being implemented by the DOE-EEWS.

3-6-4 Retreat

Retreat is one measure against coastal erosion and flooding, particularly with regard to the future sea level rise. Setback and relocation belong to the category of retreat practices and are applicable to the Seychelles, though it is difficult to get local peoples' agreement.

(1) Setback/Zoning

The setback idea will be adopted in the new EIA and it will help to clarify the limits of development in the lowlands, wetlands and coastal zones. Zoning is the concept of identifying topographic characteristics and setting the minimum ground level for new developments in each zone, to conserve both sides of the river channel boundary for future channel improvement. Furthermore, this concept will lead to the conservation of coastal areas and river basins in the future.

Setback only applies to new developments, not to existing facilities. In future, the government must consider how to encourage people to move to higher land with subsidies or some other system.

(2) Relocation

It is difficult to protect people living along the coast and in lowland areas from coastal erosion and flooding due to the topographic conditions. On the other hand, raising the ground level of a few facilities is especially costly and may not be the proper way to solve flooding problems. To solve coastal erosion and flooding problems and adapt to the projected future sea level rise, relocation can be an alternative solution.

3-7 Prioritisation and Management Plan

3-7-1 Prioritisation

Several measures are proposed to mitigate coastal erosion and flooding. The applicability of each measure to the conditions in the Seychelles is analysed for prioritisation. In order to select the adaptive measures, priority items and standards for determining effectiveness are necessary. Seven items are selected. The first three items are based on the management objectives and are: mitigation of coastal erosion and flooding, enhancement of use of the coast and lowland areas, and conservation of the natural conditions. The fourth item is flexibility to future climate change. The fifth is cost and the sixth is the need for maintenance. The seventh is applicability to the Seychelles' natural, social and economic conditions. Total evaluation was carried out based on these items.

The degree of effectiveness is decided using the numbers +1, 0, and -1. Effective is indicated as +1, not effective as -1 and difficult to decide as 0. At present, it is difficult to decide more detailed degrees because of insufficient information. Therefore, in this case the minimum classification is employed. If sufficient data and methods are accumulated, different criteria can be used. The difficulty lies in estimating the costs and benefits of non-structural measures.

The factors for evaluating each measure are as follows:

- Function: Effective for the Seychelles (yes: +1, not clear: 0, no: -1)
- Use: Contributes to sustainable development (yes: +1, neither: 0, no: -1)
- Environmental Impact: Environmentally friendly (yes: +1, neither: 0, no: -1)
- Future Change: Flexible to climate change (yes: +1, not clear/neither: 0, no: -1)
- Cost: Requires a budget (little or no cost: +1, not clear/neither: 0, high cost: -1)
- Maintenance: Frequent operation and maintenance (little or none: +1, not clear/neither: 0, regular: -1)
- Applicability: A must for the Seychelles (yes: +1, not clear/neither: 0, no: -1)

The results for coastal protection are shown in Table 3-7-1, for flood protection in Table 3-7-2 and for accommodation and retreat with regard to coastal erosion and flooding in Table 3-7-3.

Table 3-7-1: Priority List for Coastal Protection

Item No.	Measures	Function	Use	Environ-ment	Future Change	Cost	Mainte-nance	Appli-cability	Total
1	Revetment	+1	0	-1	-1	-1	+1	+1	0
2	Groyne	+1	0	0	0	-1	+1	0	+1
3	Nourishment	+1	+1	+1	+1	-1	-1	+1	+1
4	Detached Breakwater	+1	+1	-1	-1	-1	+1	0	0

Table 3-7-2: Priority List for Flood Protection

Item No.	Measures	Function	Use	Environ-ment	Future Change	Cost	Mainte-nance	Appli-cability	Total
1	River Improvement	+1	-1	0	-1	-1	+1	+1	0
2	Drainage Improvement	+1	-1	0	-1	+1	+1	+1	+2
3	Ring Levee	+1	0	-1	+1	-1	-1	0	-1
4	Retaining Pond	+1	0	+1	0	-1	0	0	+1
5	Pump System	+1	-1	0	-1	-1	-1	-1	-4
6	Water Gate	+1	-1	0	0	+1	-1	-1	-1

Table 3-7-3: Priority List for Accommodation and Retreat

Item No.	Measures	Function	Use	Environ-ment	Future Change	Cost	Mainte-nance	Appli-cability	Total
1	Improvement of Houses	+1	0	0	-1	-1	+1	+1	+1
2	Regulations	+1	0	+1	+1	0	0	+1	+4
3	EIA	0	0	+1	+1	0	0	+1	+3
4	Awareness	+1	0	0	+1	0	-1	0	+1
5	Risk Map	+1	0	0	+1	0	0	0	+2
6	Warning	+1	0	0	+1	-1	-1	0	0
7	Emergency Operation	+1	0	0	0	-1	0	+1	+1
8	Setback/Zoning	+1	-1	+1	+1	-1	0	+1	+2
9	Relocation	+1	-1	0	+1	-1	0	0	0

3-7-2 Management Plan

Based on the results of the priority lists in Table 3-7-1 to Table 3-7-3, a positive total score is recommended for implementing coastal erosion and flood management plans in the Seychelles. A negative total is not recommended in the Seychelles. Zero score is implemented based on the availability of a budget.

The management plan for the classified coasts or areas was formulated from the prioritisation of alternative measures for coastal erosion and flooding. The main measures are shown in Table 3-7-4 and Table 3-7-5.

The selected structural measures are nourishment and groynes for coastal protection, and drainage improvement and retaining ponds for flood protection. As non-structural measures, regulations, EIA, risk maps and setback/zoning are proposed.

Table 3-7-4: Classification of Coastal Erosion and Mitigation Measures

Classification	Problem	Mitigation Measures
Coast with long-term changes	Erosion caused by offshore sediment transport	Nourishment of sediment loss, setback/zoning, relocation
Coast with erosion by changes in waves	The changes in wave height and direction bring coastal changes by onshore-offshore and longshore transport.	Setback/zoning of changing area, groynes or sand bypass for longshore transport, nourishment for offshore transport, regulations
Coast with erosion influenced by structures	Coastal structures bring coastal erosion and accretion. Breakwaters, groynes and revetments cause coastal erosion of the adjacent beach.	EIA, regulations, structural measures according to the type of impact
Pocket beach	A pocket beach is protected by the headlands, hence it is stable. Future erosion by economic development and climate change	Do-nothing, monitoring, land use regulations, EIA

Table 3-7-5: Classification of Flood and Mitigation Measures

Classification	Problem	Mitigation Measures
River flood	Rare in Seychelles	River improvement
Urban flood	Urban development increases the discharge of floodwater and causes flooding.	Drainage improvement, regulations, EIA
Improper drainage	The design of drainage channels lacks the necessary capacity.	Drainage improvement, regulations, EIA
Lowland development	Reclamation in front of outlet reduces flood capacity. Housing development on low land causes drainage difficulties.	Drainage improvement, EIA, retaining ponds, risk maps, setback/zoning, improvement of houses
River with wetland	Coastal lowland with wetland has some outlet problems because of outlet clogging by sand accumulation.	River improvement, outlet improvement, retaining ponds, regulations, setback/zoning, EIA

By considering the analysis results of climate change in 2100, ground elevation lower than 2.5 m will no longer be safe. Even without heavy rain, ground elevation below 2.0 m will suffer the combined adverse effects of sea level rise and high tide. In view of this, the Government of the Seychelles needs to consider long-term measures using the results of the short-term and medium-term measures.

3-7-3 Priority Areas

After the formulation of the coastal management plan, the coastal conservation plan is formulated for the priority coasts as a medium-term plan. The priority coasts are selected based on necessity, urgency, engineering characteristics, future local development and requests from the Seychelles' side. The candidate coasts are North East Point, Anse Aux Pins, Au Cap, Anse Royale, Anse Takamaka, Baie Lazare, Anse a La Mouche, Anse Boileau and Beau Vallon on Mahe, Anse Kerlan and Anse Lazio on Praslin and La Passe on La Digue. Four coasts were requested by the Seychelles' side for detailed study: North East Point, Baie Lazare, Anse Kerlan and La Passe. At Anse Aux Pins the beach is protected by the reclamation of Ile Soleil and is accreted offshore. The only erosion was caused by the diffraction of waves from a channel for fishing boats and it is not serious. At Au Cap and Anse Royale the problem is erosion and wave overtopping on the coastal road. The measures are similar to the measures at North East Point. Anse Takamaka was reported as an eroded coast in the preliminary study by JICA. The erosion does not seem to be serious because the coast is protected by a reef and is not very long. At Anse a La Mouche and Anse Boileau, RECOMAP projects were already started and wooden pile protections were already constructed. Beau Vallon and Anse Lazio on Praslin are important beaches for tourists because of their white sand, clear water and green trees. These areas are necessary not only for the coastal conservation plan with regard to disasters but to formulate a sustainable plan which includes tourism development and nature conservation. For the reasons stated above, four coasts proposed by the Seychelles' side were selected as priority coasts. In Chapter 4 the coastal conservation plan is formulated for the selected coasts. For coastal erosion, in the preparatory study twelve coasts were selected as the candidate sites and four priority coasts were selected. The selected coasts are North East Point, Baie Lazare, Anse Kerlan and La Passe as shown in Table 3-7-6.

Table 3-7-6: List of Priority Coasts

No.	Name of Coast	Erosion Problem	Priority Coast
1	North East Point	Long-term erosion and wave overtopping on coastal road Selected as representative of this type of coast	◎
2	Anse Aux Pins	Small beach scarp and protected by reclaimed land	
3	Au Cap	Long-term erosion and wave overtopping on coastal road with revetment	
4	Anse Royale	Long-term erosion and wave overtopping on coastal road with revetment	
5	Anse Takamaka	Small erosion and protected by coral reef	
6	Baie Lazare	Long-term erosion and wave overtopping on low coastal road with no structures	◎
7	Anse a La Mouche	Accreted coast with pile revetment in RECOMAP project	
8	Anse Boileau	Small erosion with pile revetment in RECOMAP project	
9	Beau Vallon	Stable beach but large variation requires future improvement	
10	Anse Kerlan	Severe erosion caused by longshore transport due to groynes	◎
11	Anse Lazio	Beach scarp without reef requires future improvement	
12	La Passe	Erosion and accretion by breakwaters	◎

The ◎ symbol shows the priority coasts. RECOMAP: Regional Programme for the Sustainable Management of Coastal Zones of the Indian Ocean Countries

For the flood management plan, Victoria Town, Pointe Larue, Anse Aux Pins, Au Cap and Anse Royale were proposed by the Seychelles' side. From analysis of the drainage task force report, the problems are mainly caused by improper drainage including outlet clogging on the coast. The clogging mainly occurs on the east coast of Mahe which receives relatively high waves. Anse Aux Pins, Au Cap and Anse Royale are located in these areas. Pointe Larue is selected because at times of heavy rain it becomes difficult to access the international airport which is important for tourism due to flooding. The priority areas were selected at the request of the Seychelles' side. A detailed flood management plan is formulated for the five areas in Chapter 5.

As for flooding, ten areas were proposed in the preparatory study and four priority areas were selected. The selected areas are Victoria Town, Pointe Larue, Anse Aux Pins, Au Cap and Anse Royale.

Table 3-7-7: List of Priority Areas

No.	Name of Area	Flooding Problem	Priority Area
1	Victoria Town	Flooding of the boundary area where shops and roads are located between original and reclaimed land because of small flow capacity of drainage.	◎
2	North of Mahe	Lack of proper drainage at foot of mountainous area	
3	Pointe Larue	Flooding during heavy rain on the road and surroundings from Victoria Town to the international airport.	◎
4	Anse Aux Pins	Flooding of lowland around housing development because of improper drainage.	◎
5	Au Cap	Flooding of lowland around schools and housing development because of improper drainage and outlet clogging by sand bar.	◎
6	Anse Royale	Flooding of lowland around schools and housing development because of improper drainage and outlet clogging by sand bar.	◎
7	Baie Lazare	Flooding in lowland area by outlet clogging	
8	Anse Boileau	Flooding in lowland area by improper drainage	
9	Southwest of Praslin	Drainage problem in lowland housing development sites.	
10	West of La Digue	Drainage difficulty in lowland area because of sand bar along the beach.	

3-7-4 Implementation Schedule

Based on the above results, the implementation schedule was prepared and proposed as in Table 3-7-8. In the schedule the target periods are classified as short-term, medium-term and long-term with target years of 2020, 2050 and 2100 respectively. The activities are prioritised in Table 3-7-1 as structural measures and non-structural measures. For coastal conservation, the main activity is nourishment with groynes as the main measure for mitigation of coastal erosion on the priority coasts in the medium term. In the long term the development of coastal areas for tourism and conservation of the natural environment will be important issues. They will be solved by SSDS and integrated coastal zone management in which coastal erosion problems will also be included. This is shown as coastal zone management in the table.

For flood management, the main issue is drainage improvement which has already started and is included in the action plan for the priority areas. These are short-term projects and the main activities are improvement and maintenance. The drainage problem in the lowland requires improvement of the river channels and river mouth as short-term projects. In the medium term, river improvement works will be necessary in the priority areas. In the long term, river basin management including water resources will be the main issue for sustainable development.

As for non-structural measures, some have already been formulated and implemented. Therefore, these activities have been added to the implementation schedule.

Table 3-7-8 Implementation Schedule

		Target Period	Short Term (2020)		Middle Term (2050)		Long Term (2100)		Remark
	Activities Items								
1	Structural Measures								
	For Coastal Erosion								
	a	Groynes and Nourishments	▒	▒	▒	▒			Mitigation of erosion
	b	Coastal Zone				□	□	□	Management of coastal zone
	For Flooding								
	a	Drainage System	□	□					Improve and enhance drainage system
	b	River System		□	□	□			Improve river system
		i) partial work for river channel and river mouth		▒					
		ii) river improvement work			▒	▒			
	c	River Basin System				□	□	□	Management of river basin
2	Non-Structural Measures								
	a	Regulation for Land Use/Zoning Ordinance	□	□					Control regulation of land use and zoning ordinance
		i) enhance land use regulation	▒						
		ii) adapt zoning ordinance with minimum elevation	▒						
		iii) enforcement of improvement EIA & regulation	▒	▒					
	b	Early Warning and Forecasting System	□	□	□	□			Enhance a communication system
		i) improve forecasting system in nation wide	▒						
		ii) enhance a communication system between NMD and DA office	▒	▒					
		iii) install warning system in the risk area			▒	▒			
	c	Improvement/Enhancement of Evacuation Center	□	□	□				Improve the evacuation route and relief plan
		i) countercheck facilities, location and evacuation route (road and bridge) to the evacuation center	▒						
		ii) enhance facilities and elevated evacuation center and route (road and bridge) for safety	▒	▒					
	d	Awareness Program for Concerned People	□	□	□	□			Publicities of flooding risk information. (activities shall be sustainable)
		i) enhancement of disaster education	▒	▨	▨	▨	▨	▨	
		ii) establish the system of emergency evacuation	▒	▒▨	▨	▨	▨	▨	
		iii) enhancement of disaster prevention scheme	▒	▨	▨	▨	▨	▨	
		iv) share information of river basin status		▒	▒	▒	▨	▨	

□ operating periods ▒ implementing ▨ as needed and continuously

3-8 Monitoring and Evaluation

Hence, the performance of any adaptation measures should be carefully monitored and assessed and the lessons fed back through the cycle to improve maintenance and future interventions, as shown in Figure 3-2-1. For this process, information management and education are required as basic components.

Utilising this framework, it should be possible to provide well-planned and effective adaptation which in turn will promote sustainable development of the coastal zone. It is important to note, however, that although adaptation measures can reduce vulnerability to coastal hazards, total protection from coastal erosion and flooding is not achievable.

3-8-1 Monitoring

To evaluate the effectiveness of the plan, it is necessary to monitor to what extent the plan is working. The monitoring programme depends on the plan's objectives, resources and available methods. Because of limited budget or funding and manpower, simple and effective monitoring was proposed.

For coastal erosion, beach monitoring is an essential activity. The frequency is twice a year between the northwest monsoon and the southeast trade winds. The target coasts are the priority coasts and, if possible, Beau Vallon, Anse a La Mouche and Anse Boileau on Mahe and Anse Lazio on Praslin. Monitoring will last about one week. The records of coastal erosion can be obtained from the DAs and newspapers. The changes in the coastlines can be obtained from Google Earth.

For flooding and drainage problems, information from the DAs or local people is useful. It should be recorded by the DOE. Newspaper articles also provide useful information.

Basic data such as tidal level, wind speed and direction, and rainfall can be obtained from NMS.

3-8-2 Evaluation

It is said that evaluating the effectiveness of coastal conservation or flood management plans is a recent development. Since disasters occur very rarely in the Seychelles, it is difficult to evaluate the effectiveness of the plan in the short-term. Therefore, evaluation has to be conducted every 10 years.

The evaluation of the plans is performed in relation to the stated objectives. The first objective is to mitigate damage to human lives and property. The records of disasters and claims from local people can be analysed to evaluate the effectiveness of the objective, together with data from meteorological observations. The second objective is to harmonise the disaster mitigation measures with nature conservation, use of the coastal areas and so on. This is evaluated from the activities of DOE, newspaper articles and the opinions of nature conservation NGOs. The third is to contribute to sustainable development and the fourth is to promote awareness. These objectives can be evaluated within the evaluation of SSDS in which the objectives are included in the strategy. The performance of non-structural measures and development of the coastal zone will be analysed using the GIS database.

3-9 Information Management and Education

3-9-1 Information Management

In order to manage coastal erosion and flooding, maintenance of databases related to the natural conditions, socio-economic conditions, past disaster records, existing coastal structures and drainage facilities is very important. At present, the only database for management is the GIS database of MLUH, but it is not fully used for planning or daily management. The records were collected by DRDM. However, they are difficult to use on a daily basis and will be revised. The basic data for the drainage reports were lost and it was difficult to discover the basic conditions which were used to analyse the drainage problems.

3-9-2 Databases

The necessary data for the management of coastal erosion and flooding are topography, tides, waves and rainfall as natural data, land use, existing property, public infrastructures and public utilities as social and economic data, and past records of disasters related to coastal erosion and flooding. Because of the limited resources and capacity of the related organisations, the minimum necessary data should be collected and maintained. At present, data on the meteorological conditions, disaster records, beach monitoring data and GIS data are available.

(1) Meteorological Data

Rainfall, tide and wind data are important basic data. Rainfall data of short duration are important because the river basins in the Seychelles are small. Only last year three rainfall gauges were installed in Victoria for short-term observation. It takes more than ten years to obtain probable rainfall intensity curves. Wind data can be used for forecasting wave conditions because the wave data are limited around the Seychelles. Tidal data are important for estimation of future tidal conditions which affect flooding in lowland areas. These basic data should be published every year on the website and analysed every 5 years to study the impacts of climate change.

(2) Disaster Records

In this study the lack of disaster information together with the short duration of the rainfall data makes it difficult to analyse the flood conditions. Some of the plans were formed using estimations from the available data and improvement is necessary based on new data. The scale of flooding is limited and more detailed data is necessary.

(3) Beach Monitoring

Beach monitoring started in 2003 and lasted until 2009.Beach monitoring data are very important for analysis of coastal changes. The results will be used to study long-term coastal changes in erosion and accretion, seasonal variations and the response of beaches to tidal and wave changes. These can be used for deciding setback lines or for analysing beach changes caused by the sea level rise. Therefore, continuation of beach monitoring is recommended.

In the study important coasts were selected and the basic conditions including survey lines, benchmarks and frequency of measurement were studied. The proposed coasts are North East Point, Anse Royale, Baie Lazare, Anse a La Mouche and Beau Vallon on Mahe, Anse Kerlan and Grand Anse on Praslin and La Passe on La Digue. It will take one week to collect one set of data and this will be done twice a year to measure seasonal changes.

(4) GIS Data

The Geographical Information System (GIS) is a useful system for the management of coastal areas. Moreover, in the Seychelles a very good GIS was established by MLUH in the past. However, it is not fully utilised for ordinary coastal or drainage management activities. One reason is that the operational software, ArcGIS, is complex and expensive. Therefore, it is better to use simpler inexpensive GIS software such as Post GIS, QGIS or simpler Mapwindow GIS.

GIS data can be maintained as a governmental project. Revision of the 1998 GIS data started last year. The required task is only to add the GIS data on coastal and flood management to the existing data. The GIS data to be added are disaster records, beach monitoring data and data on coastal structures. Fortunately, the CESD has GIS and a database management unit. The unit is the key organisation for preparing basic data, supplying software and providing training in the use of the GIS database. The results of this Study will be one of the components of the database.

3-9-3 Public Awareness

In general, DRDM is responsible for public awareness matters related to coastal erosion and other coastal disasters such as tsunamis. A report was compiled by Sustainability for Seychelles for the DRDM in 2009. In the report, a diagnosis of the status of public awareness of disaster and risk management issues is presented based on an analysis of information from a community survey, stakeholder interviews, focus group interviews and a stakeholder workshop. Recommendations are presented on key components of a public awareness strategy. They include a list of attitudes, knowledge and behaviour objectives to guide the strategy, as well as an action plan (Sustainability for Seychelles, DRDM (2009): Risk and Disaster Management, Public Awareness Strategy for Seychelles).

DRDM has already started to conduct these activities nationwide recently. The activities include producing newsletters, launching a blog highlighting its activities (http://drdm-drdm.blogspot.com/) and issuing text message alerts via mobile phone. Therefore, DRDM should be carefully monitored by DOE and the achievements evaluated in order to contribute and modify future activities.

The time scale for coastal disaster problems is very long. Therefore, local people who once experienced coastal erosion or tsunamis will be aware of such incidents. Hence, the publishing of past records of coastal erosion or reproducing of people's experiences in a textbook for school children is one of the measures. Selected essays from people who experienced such events in the past are also important records.

3-9-4 Stakeholder Involvement

Coastal erosion and the flood management plan are addressed in the Seychelles Sustainable Development Strategy (SSDS). The *stakeholder involvement strategy* is one of the strategies in the SSDS and it is expressed as the continuation of the inter-sectorial steering committee, a platform which brings together stakeholders involved in the implementation and coordination of the SSDS. The strategic focus is on (i) ensuring effective governance of the SSDS, (ii) adequate coordination of initiatives, and (iii) access to information. The implementation mechanism is explained in the strategy.

The plan for stakeholder involvement in coastal erosion will be included in the strategy and the action plan of the SSDS. For coastal erosion, the stakeholders are listed as follows:

- DOE: Climate and Environment Services Division, Wildlife Enforcement and Permits, and Divisions of Risk and Disaster Management
- Department of Transport and Energy
- Ministry of Community Development, Youth and Sports
- Ministry of Land Use and Housing
- District Administrators
- NGO: Nature Seychelles, Sustainability for Seychelles,

The inter-sectional steering committee will be the focal organisation.

3-10 Environmental and Social Considerations

The Environmental Protection Act requires environmental impact assessment (EIA) of activities in protected or ecologically sensitive areas. In the regulations, projects for sea defences, sea walls and drainage networks are one of the activities that require EIA. The structural measures proposed in the management plan such as sand nourishment, groynes and drainage improvement will be included in the activities. The ecologically sensitive areas include coastal strips, streams and surroundings. Therefore, the structural measures in the management plan require EIA according to the regulations.

In the Detailed Planning Study which was carried out in 2010 by JICA, scoping was already performed as shown in Table 3-10-1. To conduct EIA for the project, it is necessary to specify the project in more detail. Then EIA will be carried out for the projects for the priority coasts and areas in Chapters 4 and 5 based on this scoping.

Table 3-10-1: Scoping Checklist for the Projects (Detailed Planning Study)

	Item	Rating	Reasons
Social Environment:	Involuntary Resettlement	B	In the urban flood management plan for Victoria Town, involuntary resettlement is necessary for improvement of the drainage channel in some cases.
	Local Economy such as Employment, Livelihood, etc.	B	The contents of the plan may affect the local economy.
	Land Use and Utilisation of Local Resources	B	The new land use plan related to coastal erosion prevention and flood damage affects present land use.
	Existing Social Infrastructures and Services	B	Community-based projects have some kind of effect on local communities.
	Local Conflicts of Interest	B	The prevention of coastal erosion in one area causes erosion in another in some cases.
	Water Usage or Water Rights and Communal Rights	B	The flood management plan brings changes in water use and drainage patterns.
	Sanitation	B	The flood management plan brings a change in water quality in the related area.
	Hazards (risk) Infectious Diseases such as HIV/AIDS	B	The plan improves coastal erosion and flood damage. However, in some places there are adverse effects if the plan is not well considered.
	Social Institutions such as Social Infrastructure and Local Decision-making Institutions	C	The contents of the plan may affect the social institutions.
	Poor, Indigenous and Ethnic People	C	At present, the existence of poor, indigenous and ethnic people in the planned area is unclear, and therefore the effects are unknown.
	Misdistribution of Benefits and Damage	C	In the plan, there is some possibility of misdistribution of benefits and damage.
	Cultural Heritage	C	At present, the cultural heritage in the planned area is unclear, and therefore the effect is unknown.
Natural Environment	Topography and Geographical Features	B	There are some topographical changes when structural measures are taken for the prevention of coastal erosion and flood damage.
	Groundwater	B	The changes in drainage patterns for flood management cause modification of the ground water level.
	Hydrological Situation	B	The changes in drainage patterns for flood management cause modification of the hydrological conditions.
	Coastal Zone	B	The coastal management plan modifies the coastal zone characteristics.
	Flora, Fauna and Biodiversity	B	The flora, fauna and biodiversity may be affected by the coastal management plan and flood management plan especially on the coast and in the wetland.
	Landscape	B	The construction of preventive measures changes the landscape.
	Global Warming	C	The contents of the plan may affect global warming.
	Soil Erosion	-	No activities related to soil erosion during construction.
	Meteorology	-	The scale of the activities is not large enough to affect the climate.
Pollution	Water Pollution	B	The flood management plan brings a change in water quality in the related area.
	Bottom Sediment	B	The change in drainage pattern for flood management causes modification of the bottom sediment.
	Accidents	B	During the construction of structures, in some cases accidents can be expected.
	Air Pollution	C	During the construction of structures, in some cases air pollution can be expected.

	Item	Rating	Reasons
	Waste	C	In some cases waste can be expected during construction.
	Noise and Vibration	C	During the construction of structures, in some cases noise can be expected.
	Ground Subsidence	C	If the ground water level changes, ground subsidence will occur.
	Soil Contamination	-	No sources of contaminated material during construction.
	Offensive Odour	-	No sources of offensive odour in the plan.

Rating; A: Serious impact is expected
B: Some impact is expected
C: Extent of impact is unknown
No Mark: No impact is expected. IEE/EIA is not necessary

3-11 Evaluation of the Management Plan

The management plan was analysed from six perspectives: whether it is technologically, economically, financially, socially, administratively and environmentally sound. In the management plan, observation, planning and designing measures are simple measures which are applicable to the Seychelles. The cost of structures is reasonable and financial support from the government or donors can be obtained. The DOE can manage the plan with its own staff and capacity. The plan also considers environmental issues. The objects and methods will be acceptable to local people.

Chapter 4 Coastal Conservation Plan for Priority Coasts

Chapter 4 Coastal Conservation Plan for Priority Coasts

4-1 General

In the management plan, measures for coastal erosion were already proposed and the priority coasts were selected in Chapter 3. As the detailed action plan, a coastal conservation plan with regard to disasters was investigated for the priority coasts. , The coastal conservation measures were planned for each priority coast according to the planning steps. In the plan structures are usually designed for a certain probability of occurrence. In the plan, the return period is set at 25 years and it can be called a medium-term plan.

The planning steps cover from problem identification, forecasting if no action is taken and evaluating alternatives to deciding the plan. The plans were formulated for the priority coasts, which are North East Point, Baie Lazare, Anse Kerlan and La Passe.

A summary of each plan for the priority coasts is shown in Table 4-1-1 to Table 4-1-4.

Table 4-1-1: North East Point Conservation Plan

Item	Explanation
Coastal conditions	The 2km-long coast is located in the northeast part of Mahe and is protected by a narrow coral reef and beach rock. Waves come from the northwest in winter and from the southeast in summer. A coastal road and houses are located along the coast and the beach is used by local residents for recreation.
Problems	Erosion and wave run-up at high tide on the coastal road affect traffic. The beach was eroded for 20m in width from 1960 to 2011 and the seasonal variation was about 20 m. A possible cause of the long-term erosion is offshore transport.
Evaluation of alternatives	Sand or gravel nourishment is selected to compensate for the loss of sand and to make beach use even the needs of maintenance nourishment because revetments cause loss of sand in front of the revetment.
Contents of the plan	Sand nourishment for 20m in width for a 2 km stretch of the beach is proposed with maintenance nourishment.

Table 4-1-2: Baie Lazare Conservation Plan

Item	Explanation
Coastal conditions	The coast is located on the southwest coast of Mahe and is partly protected by a coral reef. Wetland has formed behind the sand bar where a coastal road and houses are located. The Baie Lazare River flows into the wetland and flushes out the sand bar in times of flooding. This possibly causes the loss of sand from the beach.
Problems	Coastal erosion and wave run-up affect the coastal road, shops and houses along the beach. Coastal erosion started two or three years before 2008. Wave run-up and coral debris were reported during high tide in May 2007. Stone and wooden pile revetments were constructed in the past and today broken revetments remain.
Evaluation of alternatives	Maintenance of the beach by sand nourishment is better than direct protection by revetments because revetments cause loss of sand from the beach. The prevention of sand loss during flooding by a submerged reef fronting the channel is not feasible because of cost. Traffic control at high tide is not reliable and other measures are necessary for future sea level rise.
Contents of the action plan	Sand nourishment for 20m in width for a 400 m stretch of the beach is proposed with maintenance nourishment. It is necessary to monitor the beach profile to estimate the causes of erosion and necessary sand volume for maintenance.

Table 4-1-3: Anse Kerlan Conservation Plan

Item	Explanation
Coastal conditions	The coast is located in the west part of Praslin and is protected by a coral reef. It receives waves from the northwest in winter and the south in summer, causing seasonal changes in longshore sediment transport. Along the coast hotels and restaurants have been developed for tourism activities. The coast has one of the best beaches in Praslin.
Problems	The erosion causes the loss of property and use of the sandy beach for bathing. This causes deterioration of tourism activities. Originally at Anse Kerlan the beach sand was transported from the north to the south and was deposited at Grand Anse. After the erosion became severe, five groynes were constructed in 1990 and they prevent the return of sediment from the south. The coastal road was shifted inland due to the erosion.
Evaluation of alternatives	In view of the importance of the beach for tourism, sand nourishment and groyne construction are appropriate measures for recovering the beach and reducing longshore transport. Revetments may cause loss of beach sand.
Contents of the plan	Three groynes and sand nourishment for 20m in width for a 1,000 m stretch of the beach are proposed with maintenance nourishment to stabilise the beach.

Table 4-1-4: La Passe Conservation Plan

Item	Explanation
Coastal conditions	The coast is located in the west part of La Digue and is protected by a wide coral reef and Praslin Island to the west. Therefore, waves come from the north and south and not from the west. A jetty is provided for the ferry to Praslin. The anchorage is protected by three breakwaters.
Problems	The breakwaters at the jetty cause accretion in the anchorage and erosion of the south beach. Erosion causes loss of land and wave overtopping onto the hospital property. The anchorage is difficult to use and needs dredging.
Evaluation of alternatives	To reduce the accumulation of sediment in the sheltered area, a groyne with sand bypass from the anchorage to the eroded beach was proposed. Rearrangement of the breakwaters and jetty is one alternative. However it would be necessary to conduct a detailed study and this is not within the action plan. The arrangement of the groynes was considered for future development based on the existing proposed plan.
Contents of the plan	One groyne and sand bypass of 1,000 m3 of sand from the anchorage to the south beach are proposed.

4-2 Conservation Plan for Priority Coasts

4-2-1 Planning Steps

The planning involves the following five steps: specification of problems, estimation of conditions if no action is taken, formulation of alternative plans, evaluation of effects and comparison of alternatives, and selection of a plan. The flow chart is shown in Figure 4-2-1.

As the basic conditions, the natural tidal, wave, topographical and ecological conditions and the socio-economic conditions such as land use and infrastructure form the base of the plan. The project starts from the need to mitigate erosion problems. The second step is to specify the problems and opportunities. After that, what happens if no action is taken is estimated. To solve and improve the conditions, several alternatives are formulated and evaluated from various perspectives. Then the alternative plans are compared. One of the plans is selected as the final plan.

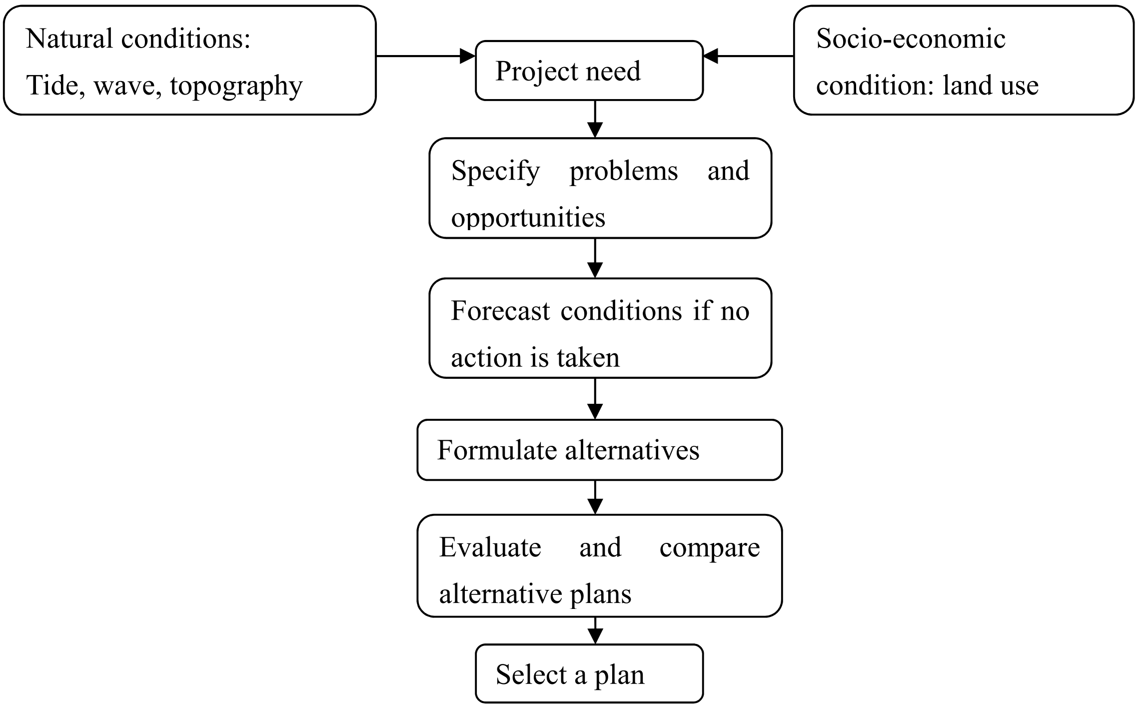


Figure 4-2-1: Planning Flowchart

In the steps, *do nothing* is treated as one of the alternatives because in some cases this option will be adopted. In the management plan in Chapter 3, several alternative measures are selected and prioritised in view of the natural and socio-economic conditions in the Seychelles. In this chapter the alternatives are proposed for each priority coast because the issues and conditions are different. The alternatives are a combination of several measures to solve site-specific issues. In some cases not all the measures in the alternatives are prioritised in Chapter 3. For a comparison of the effectiveness, other alternatives to the prioritised measures were also proposed.

4-2-2 Plan for Priority Coasts

(1) North East Point

(a) Problems

In summary, long-term erosion occurred for about 30 m from the 1960s to 2011 or 0.5 m/year on average and the seasonal variation in the coastline is about 20 m. Wave and sand run-up at high tide on the coastal road is also one of the problems. A possible cause of the long-term erosion is offshore transport. The seasonal variation is caused by the north-west monsoon and the south-east trade winds.

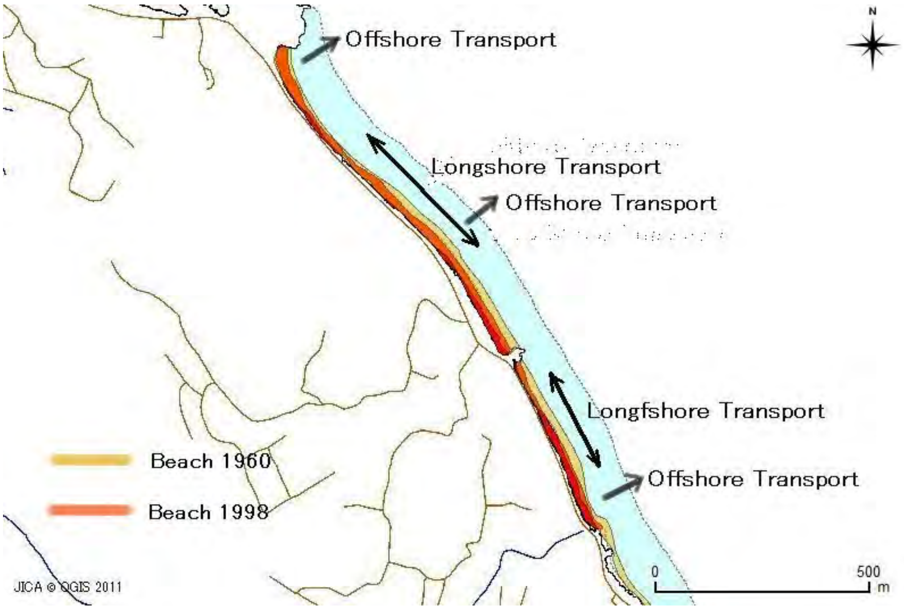


Figure 4-2-2: Estimated Sediment Movement at North East Point

(b) Basic Conditions

For the plan, the beach profile, design wave height and period, and design tidal level are determined. The profile of the beach is shown in Figure 4-2-3 from the survey results. The beach is about 2.5 m high on average and the slope is about 1/7. The ground height of the road along the beach ranges from 2.5 m to 3.0 m and the beach ranges from 2.5 m to 4 m high. In some sections the beach has retreated because of seasonal changes and the profile above a height of 1.5 m is steeper than in other parts.

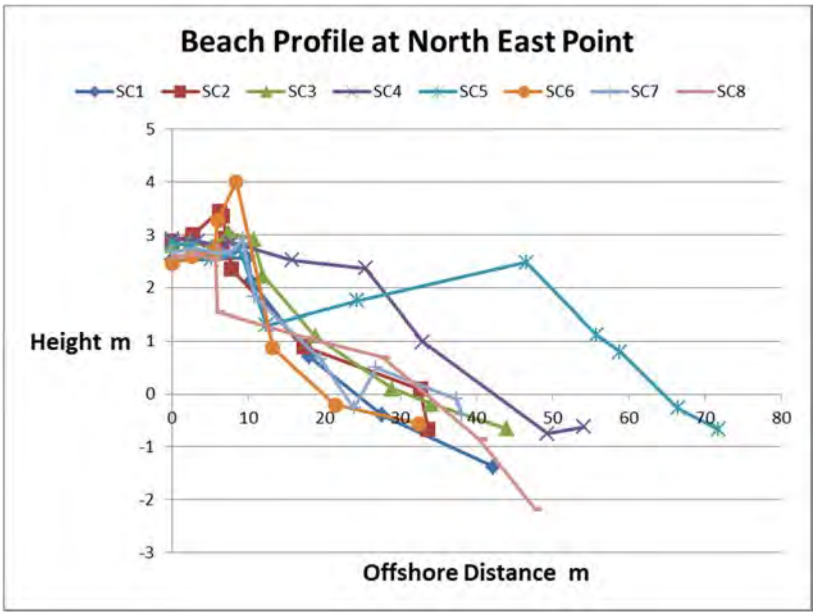


Figure 4-2-3: Beach Profile at North East Point

The design wave height, period and tidal level are determined as a probability of 1/25 years from the results of observation as follows:

- Design wave height: 4m, wave period: 8.0s
- Tidal level: 1.44 m in 2010 and 1.70 m in 2050 above MSL

The change in the wave height on the reef was estimated by the proposed equation and the wave run-up height was estimated at 3.6 m in 2010 and 4.0 m in 2050 because of the sea level rise. The figure comes from the design wave of 4m and 1/7 beach slope. The run-up height was 4.3 m in the retarded section where the beach slope is 1/7 and less than 1.5m in ground height and the slope above is nearly vertical. Therefore, incoming waves run up onto the road at high tide under the present conditions. The estimation method is explained later in the guidelines for coastal structures, with examples.

(c) Alternative Plans

The following measures are selected as several alternative plans:

- Alternative 1: Do nothing
- Alternative 2: Protection: Construction of revetment along the road or elevated coastal road for the prevention of wave run-up and overtopping
- Alternative 3: Gravel Nourishment: Gravel nourishment to counter long-term erosion, seasonal variation and wave overtopping
- Alternative 4: Sand Nourishment: Sand nourishment to counter long-term erosion, seasonal variation and wave overtopping
- Alternative 5: Accommodation: Traffic control at high tide and during north-west winds and monitoring and investigation of sediment loss through channels and its causes

Alternative 1: Do Nothing

Alternative 1 involves taking no action to recover the beach and to prevent wave overtopping. The do-nothing alternative has several negative impacts over the short and long term. In the short term, there are several places along the road which are being undermined by beach erosion, requiring road repair or rock armouring in the near future. In the long term, beach erosion and wave overtopping may increase, requiring more traffic control and road maintenance and repairs.

Alternative 2: Revetments

Alternative 2 involves the construction of revetments along the existing coastal road. At North East Point, smooth traffic flow from Victoria to Beau Vallon through Glacis is important. The coast will be eroded to some degree and will sometimes be stable because beach rock and a coral reef in front of the beach act as a kind of protection. Revetments will reduce further erosion of the beach and should be high enough to prevent increased wave overtopping caused by the erosion. They should be higher than 4.5 m. However, they do not address the causes of erosion and seasonal variations. The revetments will be about 2 km long from the north to the south of the beach. The coastal road, rehabilitation centre and private houses will be protected.

There are two outlets from wetland on both sides of the rocks in the centre of the beach. The advantage is that if the beach is eroded, the installation of water gates on the sea side of the revetment may help smooth the outflow of flood water into the wetland.

Alternative 3: Gravel Nourishment

Beach nourishment is one of the alternatives used as a soft engineering approach. Gravel or sand can be placed on the beach. The nourishment material is preferably compatible with the existing beach material. A wider nourished beach will reduce wave run-up onto the road. Nourishment does not halt erosion in some instances, and the volume is determined from the eroded volume and the variation in beach changes, together with the beach width to reduce wave run-up. The advantages of gravel nourishment are that the loss of sediment will decline because of the resistance of the gravel against wave action, and the cost is low. The disadvantage is the difference in beach material from the original material for beach use, hence from the point of view of authenticity.

Alternative 4: Sand Nourishment

Alternative 4 is identical to Alternative 3, except that sand is used instead of gravel as the beach material. The function is almost the same as Alternative 3. The disadvantage is that it needs a larger volume of sand and maintenance nourishment than gravel. The advantage is that since the same material used is as the original material, then the beach use is enhanced for bathing and it is more pleasing aesthetically.

Alternative 5: Accommodation

As accommodation, traffic control at times of high tide and north-west winds will be required. The north-west wind blows from December to March and high tide occurs twice a month and lasts about 3 days. Therefore, the forecasting of weather and tide conditions can be used for warnings. The advantage is the cost. The disadvantage is that it is necessary to manage the traffic according to the warnings.

For long-term measures, the coastal setback line is defined and development within the line is one of the retreat solutions. The existing coastal road and the rehabilitation centre need to be relocated or raised.

(d) Alternative Comparison

From the five alternative plans, the action plan is selected according to a comparison of the selection criteria as shown in Table 4-2-1.

(e) Conservation Plan

At North East Point beach nourishment is selected because it corresponds easily with future climate change. For the future sea level rise, setback and relocation are preferable if the rate of sea level rise increases. The decision should be made after long-term monitoring of the tidal level. The arrangement of nourishment and setback is shown in Figure 4-2-4.

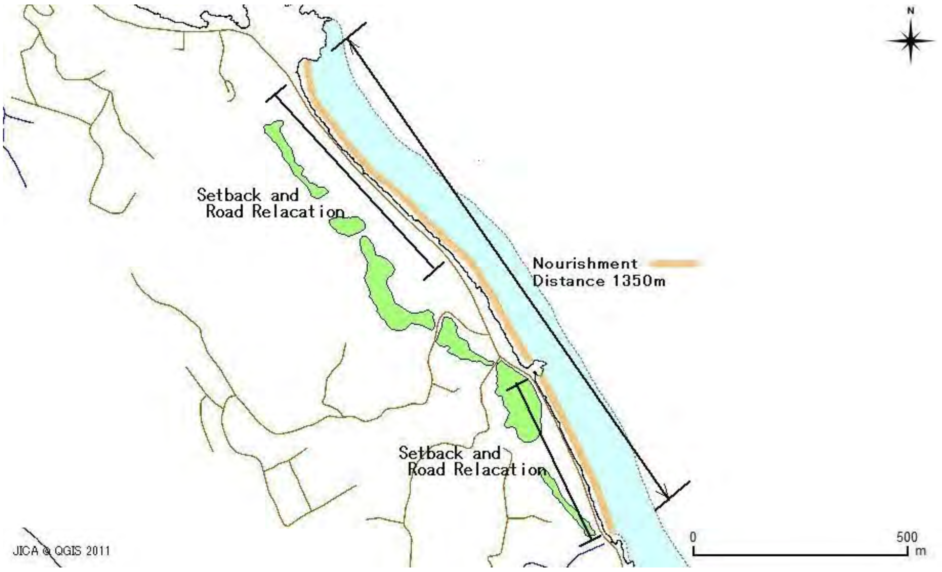


Figure 4-2-4: Arrangement of Measures at North East Point

Table 4-2-1: Prioritisation of Alternatives at North East Point

Evaluation Items/Measures	Alternative 1 Do Nothing	Alternative 2 Revetments	Alternative 3 Gravel Nourishment	Alternative 4 Sand Nourishment	Alternative 5 Accommodation
Function	-1	+1	+1	+1	0
Use	-1	-1	0	+1	-1
Environment	-1	-1	+1	+1	+1
Future Change	-1	-1	+1	+1	+1
Cost	+1	0	-1	-1	+1
Maintenance	-1	0	0	-1	-1
Applicability	0	+1	+1	+1	0
Total	-4	-1	+3	+3	+1
Function: Effective for mitigation of coastal erosion (yes: +1, not clear: 0, no: -1)					
Use: Contributes to sustainable development (yes: +1, neither: 0, no: -1)					
Environmental Impact: Environmentally friendly (yes: +1, neither: 0, no: -1)					
Future Change: Flexible to climate change (yes: +1, not clear/neither: 0, no -1)					
Cost: Requires a budget (little or no cost: +1, not clear/neither: 0, high cost: -1)					
Maintenance: Frequent operation and maintenance (little or none: +1, not clear/neither: 0, regular: -1)					
Applicability: A must for the Seychelles (yes: +1, not clear/neither: 0, no: -1)					

(2) Baie Lazare

(a) Problems

Coastal erosion was reported to have started two or three years before 2008, and wave run-up and coral blocks were reported during the high tide in May 2007 on the road running along the beach (UNFCC (2008)). Stone and wooden pile revetments were constructed in the past and today only half-broken remains are left. Wave run-up also affects the shops and houses along the road.

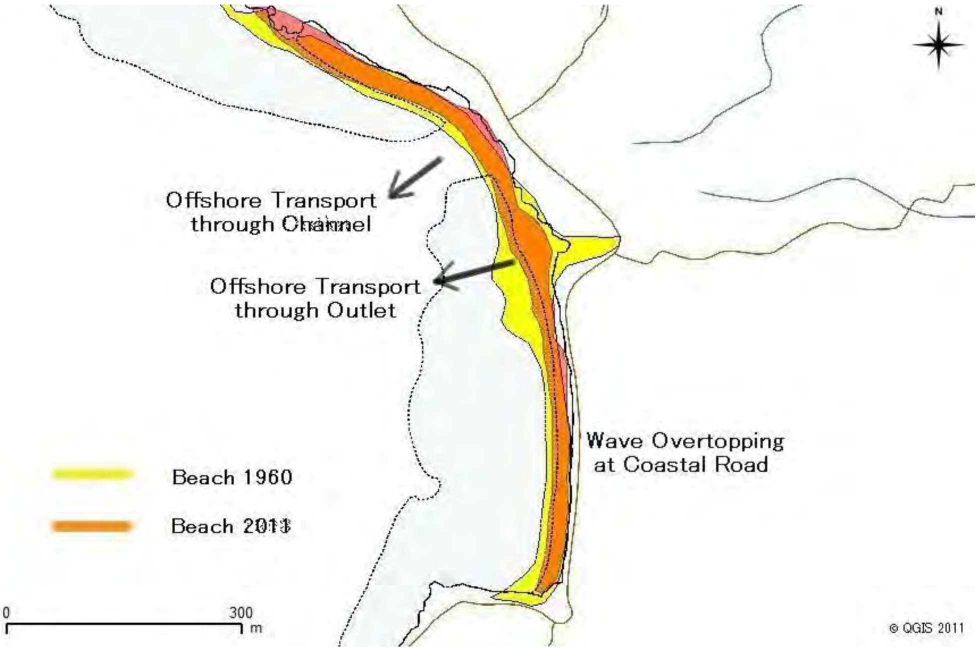


Figure 4-2-5: Estimated Sediment Movements at Baie Lazare

(b) Basic Conditions

For the plan, the standard beach profile, design wave height and period, and design tidal level are determined. The profile is shown from the survey in Figure 4-2-6.

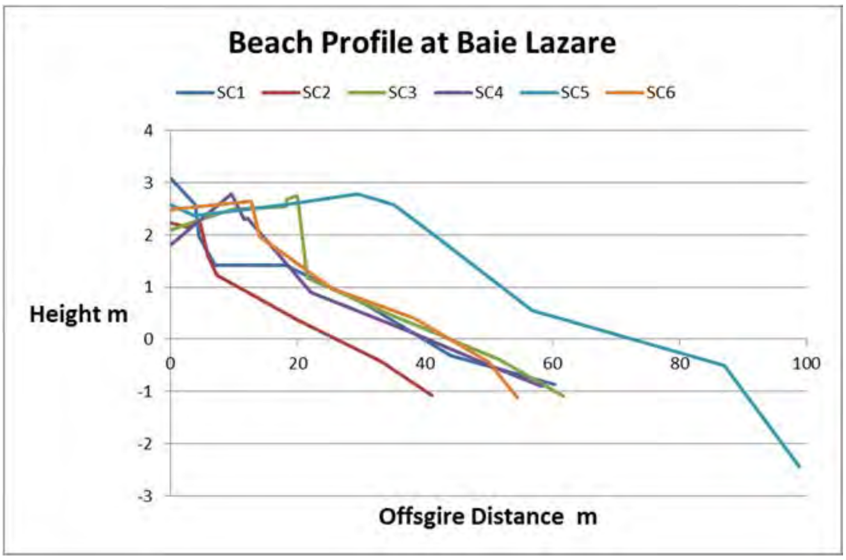


Figure 4-2-6: Beach Profile at Baie Lazare

The beach is about 2.5 m high and the slope is about 1/16. The ground height of the road along the beach ranges from 2.0 m to 2.5 m and the beach is less than 3 m in height. In some sections the beach has retreated because of seasonal changes and the profile above a height of about 1 m is steeper than in other parts.

The design wave height, period and tidal level are determined as a probability of 1/25 years from the results of observations as follows:

- Design wave height: 4.0 m, wave period: 7.0s
- Tidal level: 1.44 m above MSL

The change in the wave height on the reef was estimated by the proposed equation and the wave run-up height above MSL was estimated at 2.5 m in 2010 and 2.8 m in 2050 which corresponds to the design wave and 1/6 beach slope. The run-up height was 3.1 m in the retarded section where, below 1 m, the beach was 1/6 and, above 1 m, the slope was nearly vertical. Therefore, under the present conditions, incoming wave run-up occurs on the road at high tide.

(3) Alternative Plans

The following measures are selected from several alternative plans:

- Alternative 1: Do nothing
- Alternative 2: Protection: Construction of revetment along the road
- Alternative 3: Sand nourishment to counter long term erosion, seasonal variations and wave overtopping
- Alternative 4: Accommodation: Traffic control at high tide and during south-west winds and monitoring and investigation of the sediment loss through channels and its causes

Alternative 1: Do Nothing

Alternative 1 involves taking no action to recover the beach and prevent wave overtopping. The do-nothing alternative has several negative impacts over the short and long term. In the short term, there are several places along the road which are overtopped by waves, requiring road maintenance. In the long term, beach erosion and wave overtopping may increase, requiring more traffic control, road maintenance and repairs.

Alternative 2: Revetments

Alternative 2 involves the construction of revetments along the existing coastal road. The revetments will further reduce erosion of the beach and should be high enough to prevent increased wave overtopping caused by the erosion. However, they do not deal with the causes of erosion. Rock armouring produced in the Seychelles is used and is popular. The coastal road, shops and houses will be protected.

Alternative 3: Sand Nourishment

Beach nourishment is one of the alternative soft engineering approaches. Sand can be placed on the beach. The nourishment material will preferably be compatible with the existing beach material. A wider nourished beach will reduce the wave run-up on the road. Nourishment does not halt erosion in some instances, and the volume is determined from the eroded volume and the variation in beach changes, together with the beach width to reduce wave run-up. The disadvantage is that it needs a larger volume of sand and maintenance nourishment. The advantage is that use of the beach is enhanced for bathing and it is more pleasing aesthetically.

Alternative 4: Accommodation

As accommodation, traffic control at times of high tide and during the south-east winds will be applicable. The south-west wind blows from April to October and high tide occurs twice a month and lasts about 3 days. Therefore, the forecasting of weather and tide conditions is applicable.

Table 4-2-2: Prioritisation of Alternatives at Baie Lazare

Evaluation Items/Measures	**Alternative 1 Do Nothing**	**Alternative 2 Revetment**	**Alternative 4 Sand Nourishment**	**Alternative 5 Accommodation**
Function	-1	+1	+1	0
Use	-1	-1	+1	-1
Environment	-1	-1	+1	+1
Future Change	-1	-1	+1	+1
Cost	+1	0	-1	+1
Maintenance	-1	0	-1	-1
Applicability	0	+1	+1	0
Total	-4	-1	+4	+1

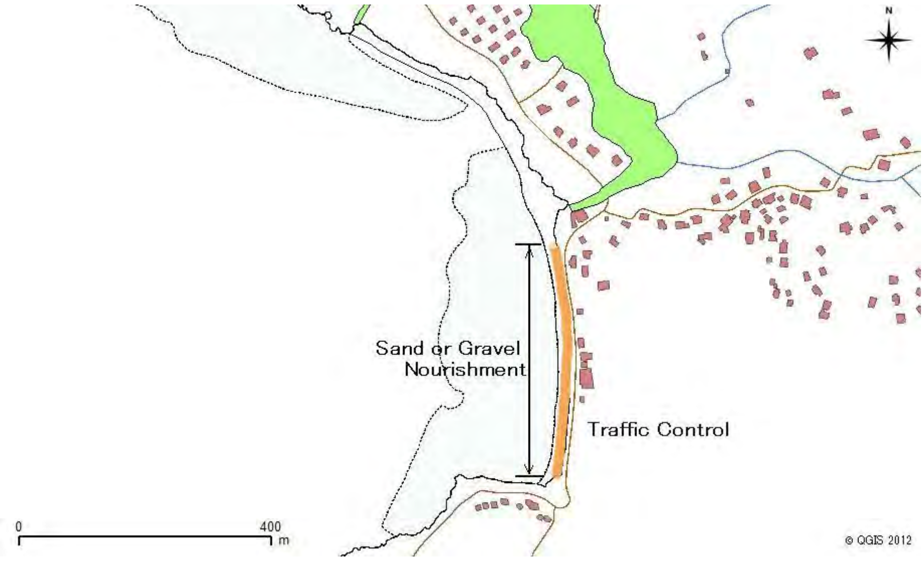


Figure 4-2-7: Arrangement of Measures at Baie Lazare

(4) Anse Kerlan

(a) Problems

Essentially, the beach material is transported from the north to the south and is deposited at Grand Anse. Also, there are seasonal variations due to changes in wind conditions, namely the north-west monsoon and south-east trade winds. After the erosion became severe, five groynes were constructed in 1990. They prevented the return of sediment from the south. Because the bottom slope of the sea bed is about 1/50 to a depth of 12 m, the seasonal longshore movement of sediment plays a large part and offshore loss is estimated to be small. The loss of land and property is most serious. The beach is also one of the attractions for tourists. The construction of hard structures is not good for beach users.

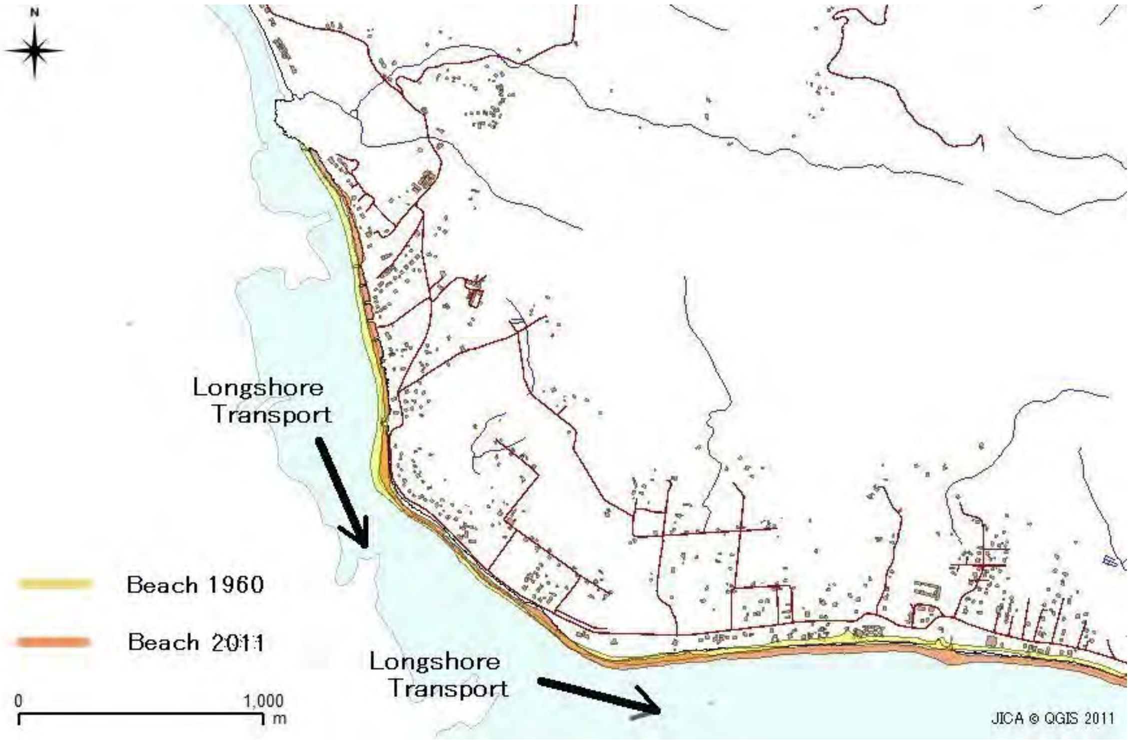


Figure 4-2-8: Estimated Sediment Movements at Anse Kerlan and Grand Anse

(b) Basic Conditions

For the plan, the standard beach profile, design wave height and period, and design tidal level are determined. The profile of the beach is shown in Figure 9 from the survey results. The beach is about 3 m high and the slope is about 1/10. The ground height of the beach changed from 3 m to 4 m. In some sections, the beach has retreated because of seasonal changes and the profile above a height of 1.5 m is steeper than in other parts.

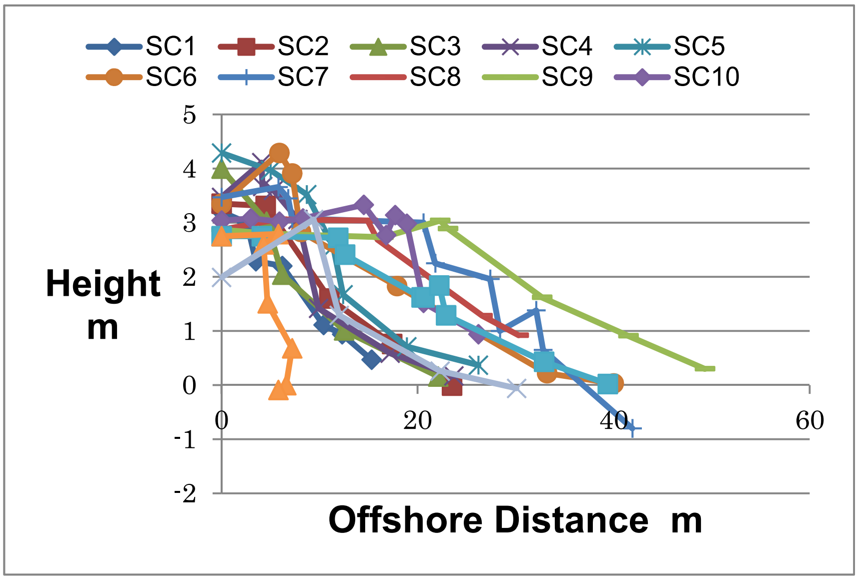


Figure 4-2-9: Beach Profile at Anse Kerlan

The design wave height, period and tidal level are determined as a probability of 1/25 years from the results of observations as follows:

- Design wave height: 4.0 m, wave period: 7.0s
- Tidal level: 1.44 m above MSL at maximum tide

The change in the wave height on the reef was estimated by the proposed equation and the wave run-up height above MSL was estimated at 2.9 m in 2010 and 3.2 m in 2050, corresponding to the design wave and 1/10 beach slope. The run-up height was 3.7 m in the retarded section where, below 1.5 m, the beach slope is 1/10 and, above 1.5 m, the slope is nearly vertical.

(c) Alternative Plans

The following measures are selected as several alternative plans:

- Alternative 1: Do nothing
- Alternative 2: Protection: Construction of revetments along the coast
- Alternative 3: Construction of Groynes and Sand Nourishment: Reduction of longshore sediment transport and recovery of the beach
- Alternative 4: Construction of Groynes and Artificial Reef: Reduction of longshore and offshore sediment transport, and protection of the existing beach
- Alternative 5: Accommodation: Setback and relocation of houses and hotels

Alternative 1: Do Nothing

Alternative 1 involves taking no action to recover the beach and prevent beach erosion. The do-nothing alternative has several negative impacts over the short and long term. In the short term, there are several places along the beach which are being eroded, requiring rock armouring and relocation of properties in the near future. The existing rock armouring and groynes sometimes cause increased sediment transport by waves and contribute further to beach erosion. In the long term, loss of beach and construction of rock armouring will impact negatively on the tourist industry at Anse Kerlan.

Alternative 2: Construction of Revetments

Alternative 2 involves the construction of revetments along the beach. The revetments will further reduce erosion of the beach and should be high enough to prevent increased wave overtopping caused by the erosion. The land and properties will be protected. However, revetments do not address the causes of erosion and seasonal variations. The beach material will be lost, resulting in the decline of beach tourism activities.

Alternative 3: Construction of Groynes and Sand Nourishment

The construction of two groynes will divide the long sediment cell into a manageable length of three parts which will reduce the loss of the beach and seasonal variations as shown in Figure 4-2-10. The first part is located to the north, facing west. The second part is located in the middle, facing south-west. The third part covers Grand Anse. The groynes and revetments can use the existing rocks as construction materials. The sand is replenished between each groyne, allowing for recovery of the beach which was once used for bathing.

Alternative 4: Construction of Groynes and Artificial Reefs

Alternative 4 is identical to Alternative 3, except that an offshore artificial reef is used to retain the beach material instead of nourishment. The existing rock armouring and groynes can be used as construction materials for the groynes and reef. The disadvantage lies in the difficulty of proper design of artificial reefs. Essentially, the artificial reef generates an onshore current which brings sediment to the shore. The onshore current returns offshore by the law of continuity. If the reef is not designed properly, the offshore current transports beach material offshore, causing erosion.

One of the advantages of the reef is that it does not disturb the scenery, especially from the beach. The disadvantage is the possibility of beach erosion in some cases near the artificial reef.

Alternative 5: Accommodation: Setback and relocation of houses and hotels

For long-term measures, one of the solutions is to set a coastal setback line and regulate development within the line. It is necessary to relocate the houses and hotels.

Setback provides a highly effective method of minimising property damage due to coastal erosion, by removing structures from the hazard zone. Unlike hard structures, setback helps to maintain the natural appearance of the coastline and preserve the natural shoreline dynamics.

Over time, the sea level rise will reduce the size of the buffer zone between the structures and the sea. As a result, setbacks will need to be periodically reviewed, for example, every 10 years to ensure that the buffer zones continue to provide sufficient protection.

Problems may arise as a result of review and revision of the setback. If existing structures are within the buffer zone, compensation may be required for landowners who have lost development potential. Another problem is that good quality or historic data are required to establish setbacks according to the threat of coastal flood or erosion. One of the most significant barriers to the implementation of setbacks is public opposition.

Table 4-2-3: Prioritisation of Alternatives at Anse Kerlan

Evaluation Items/Measures	**Alternative 1 Do Nothing**	**Alternative 2 Revetment**	**Alternative 3 Groyne & Nourishment**	**Alternative 4 Reef & Nourishment**	**Alternative 5 Accommodation**
Function	-1	+1	+1	+1	0
Use	-1	-1	+1	+1	-1
Environment	-1	-1	+1	+1	+1
Future Change	-1	-1	+1	+1	+1
Cost	+1	-1	-1	-1	+1
Maintenance	-1	0	-1	-1	-1
Applicability	0	+1	+1	+1	0
Total	-4	-2	+3	+3	+1

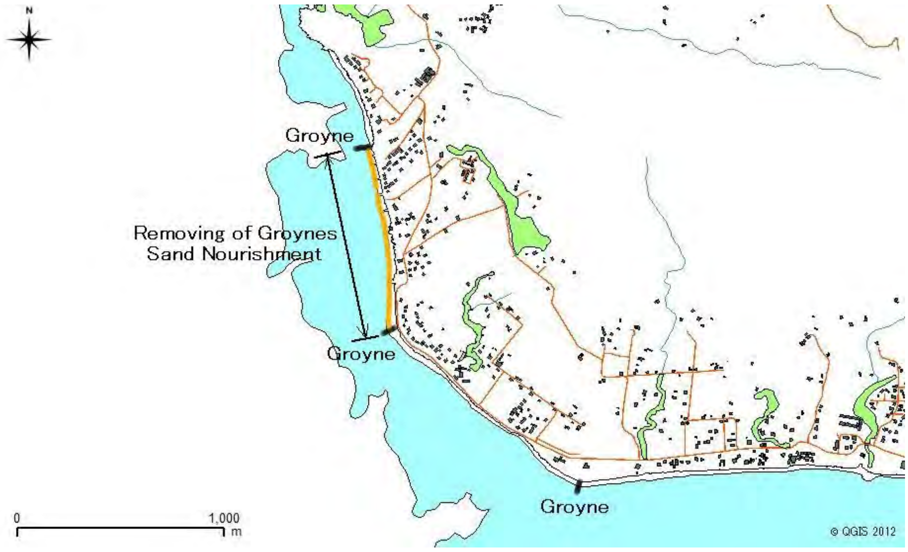


Figure 4-2-10: Arrangement of Measures at North East Point

(5) La Passe

(a) Problems

At La Passe on La Digue, the construction of breakwaters changed the wave pattern and the coastline changed to a new pattern. The newly built breakwater prevents waves from the north, and the beach is accreting in the sheltered area. The sediment comes from the south where the beach is eroding. A hospital was in danger and rock armouring was installed. The accretion continues to occur because there is no mechanism to move the sediment to the south. The other problem is accretion at the anchorage south of the pier.

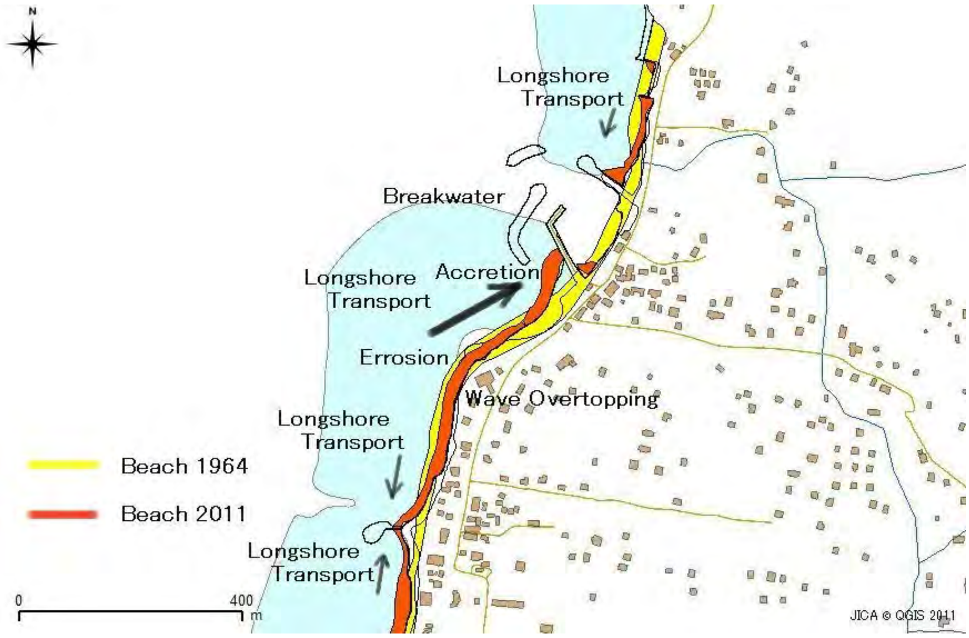


Figure 4-2-11: Estimated Sediment Movements at La Passe

(b) Basic Conditions

For the plan, the standard beach profile, design wave height and period, and design tidal level are determined. The profile of the beach is shown in Figure 1 from the survey results. The beach is about 2.5 m high and the slope is about 1/7. The ground height of the road along the beach ranges from 2.5 m to 3.0 m and the beach ranges from 2.5 m to 4 m high. In some sections the beach has retreated because of seasonal changes and the profile above a height of 1.5 m is steeper than in other parts.

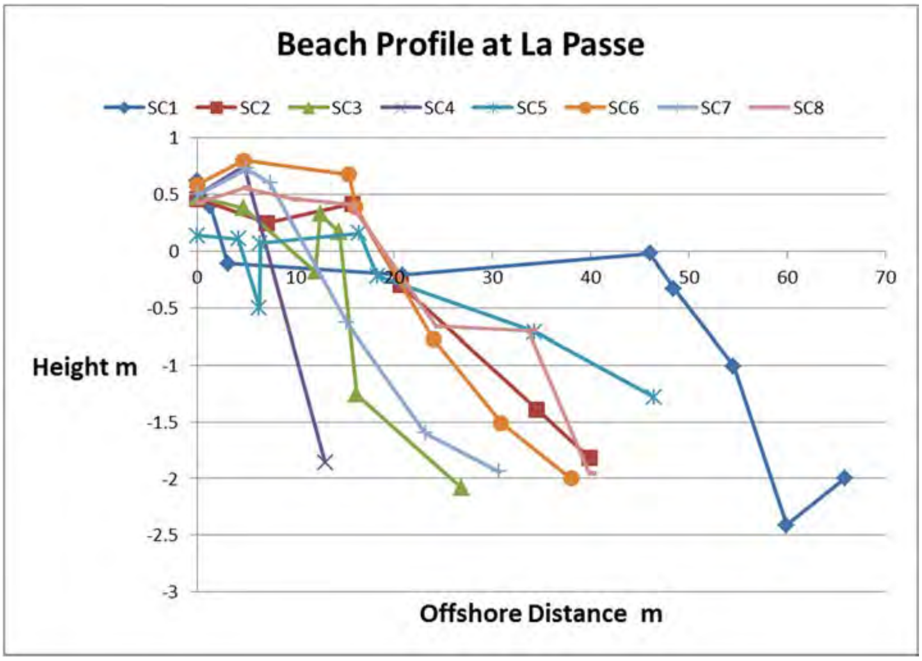


Figure 4-2-12: Beach Profile at La Passe

The design wave height, period and tidal level are determined as a probability of 1/25 years from the results of observation as follows:

- Design wave height: 4.0 m, wave period: 6.0s
- Tidal level: 1.44 m above MSL

Wave comes from the north or the south because Praslin is located opposite and prevents waves from the west. Therefore, variation in longshore sediment transport is the main cause of beach changes. The breakwaters also modify the wave conditions on the beach.

The change in the wave height on the reef was estimated by the proposed equation and the wave run-up height was estimated at 2.7 m in 2010 and 3.0m in 2050 because of the sea level rise. The figure corresponds with the design wave conditions and 1/10 beach slope.

(c) Alternative Plans

The following measures are selected as several alternative plans:

- Alternative 1: Do nothing
- Alternative 2: Construction of groyne and sand nourishment
- Alternative 3: Modification of breakwater arrangement to increase southward sediment transport from anchorage area

Alternative 1: Do Nothing

Alternative 1 involves taking no action to recover the beach and prevent erosion. The do-nothing alternative has several negative and positive impacts over the short and long term. In the short term, the south beach is continuously eroded and accreted land increases. The hospital will be in danger due to wave overtopping and scouring. In the long term, beach erosion and wave overtopping may exist, though the degree will decline, requiring more protection and repairs.

Alternative 2: Groyne and sand nourishment

For the prevention of northward sediment transport, construction of a groyne is one of the alternatives, together with sand transport from the accreted area to the eroded area as a recovery activity. This helps to keep the anchorage free from sedimentation.

Alternative 3: Modification of breakwater arrangement

One of the measures to solve the erosion on the south beach and the sedimentation at the anchorage is modification of the arrangement of the breakwaters. By extending the breakwaters to a point near the hospital, accumulation will start in front of the hospital. The disadvantage is the cost.

Alternative 4: Accommodation

The relocation of the hospital building is one of the accommodation measures. The accumulation south of the pier will decrease and tend to reach equilibrium.

Table 4-2-4: Prioritisation of Alternatives at La Passe

Evaluation Items/Measures	Alternative 1 Do Nothing	Alternative 3 Gravel Nourishment	Alternative 3 Modification of Breakwaters	Alternative 4 Accommodation
Function	-1	+1	+1	0
Use	-1	0	+1	-1
Environment	-1	+1	+1	+1
Future Change	-1	+1	+1	+1
Cost	+1	-1	-1	+1
Maintenance	-1	0	0	-1
Applicability	0	+1	+1	0
Total	-4	+3	+3	+1

Figure 4-2-13: Arrangement of Measures at La Passe

4-3 Basic Design

The proposed structures are gravel nourishment, sand nourishment and groynes. They are designed to fulfil the function of stabilising external forces.

4-3-1 Nourishment

For nourishment, gravel or coarse sand is preferable to fine sand. The beach is not frequently used for bathing. For the prevention of offshore movement of sediment, it is better to use coarse material. The volume is decided by considering the wave run-up height in the long term together with seasonal changes of the beach.

The slope of the nourished beach will become steeper if the beach material is coarser than that of the original beach.

4-3-2 Groynes

The function of the groynes is to control the longshore sediment transport. The function is then extended to the active zone of sediment movement. The sediment moves along the beach and the active zone can be detected from aerial photographs or Google Earth by the whiteness of the sea bed. The length is determined by the extent of the active zone. At Anse Kerlan, it is 50 m and at La Passe it is also 50 m. The direction is perpendicular to the beach because it is most effective in that direction. The height should be 0.5 m higher than the beach profile for the control of sediment movement.

Groynes using rock armouring can be constructed in the Seychelles. The size of the rocks to resist wave action is determined by the Hudson Formula. The width is determined in consideration of the construction method. The minimum number of rocks at the crown is three for the stability of the groyne.

(1) Groyne at La Passe

The length of the groyne shall be 50 m and the top width shall be 4.0 m. The weight of the rocks used will be around 30 kg (Hudson Formula). The thickness of the armour will be twice the size of the rocks. The longitudinal section and cross section are shown in Figure 4-3-1.

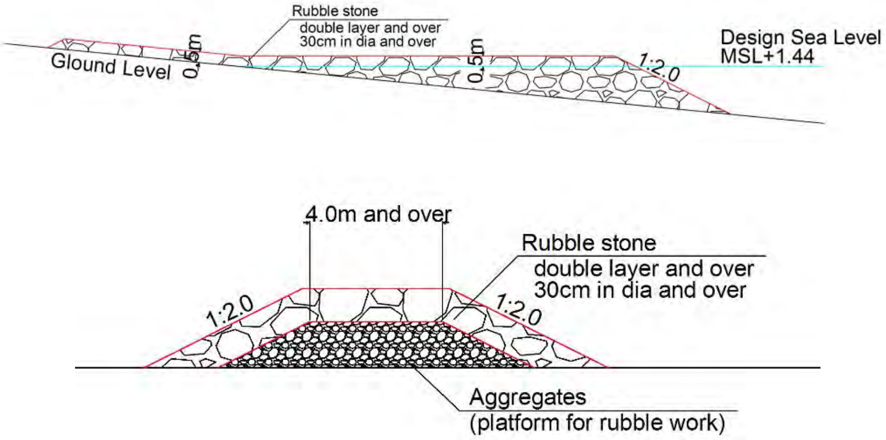


Figure 4-3-1: Longitudinal Section and Cross Section of the Groyne at La Passe

4-4 Operation and Maintenance

The structural measures are sand nourishment and construction of groynes and revetments. Sand nourishment needs maintenance if sediment loss occurs. Before re-nourishment, the beach changes should be monitored as explained in Chapter 3-8. The types of sediment movement are classified as loss of sediment or seasonal changes caused by onshore-offshore movement or alongshore movement or both.

The long-term loss of sediment is rare under the natural conditions in the Seychelles because the lowland area was formed by coral deposits over many years. One of the possible causes of loss is offshore movement through channels in the reef as at Baie Lazare. Originally, reef channels are formed by the flow of fresh or muddy water from rivers. Then during a flood, the deposited sediment at the outlet moves offshore and the beach is eroded. This is evident from the sediment accumulation in the deeper parts at the bottom of the channel. The coastal current generated by wave action also brings offshore current through the channel. When waves break at the reef edge, onshore current is generated. This onshore current gathers at the channel and changes its direction to offshore.

If the volume of loss is not predominant, it is better to re-nourish. If the sand is lost continuously, structural measures or retreat is one solution. In this case, further investigation will be necessary.

The maintenance of structures depends on the damage and deterioration of their functions. When damage occurs under severe wave conditions, the stability has to be checked. If the changes are gradual, repair of the structures is necessary. Sometimes scouring occurs in front of a revetment or around groynes. In this case, foot protection is necessary.

On the coastal road, high tides and high waves bring wave overtopping which causes traffic problems. In this case, as a preventive measure, traffic control can be implemented. High tides and strong winds are predictable. Therefore, traffic control warnings can be issued.

For maintenance, a database of coastal structures is a useful tool. The database will contain the location, type and dimensions of the structures, photos and past records of claims. In the Study, a GIS database was proposed and can be partly constructed.

4-5 Cost and Benefits

In general, the unit cost of several structures was investigated from past contracts. The costs of concrete revetments, dynamic revetments, groynes and sand nourishment are shown in Table 4-5-1.

Table 4-5-1: Unit Cost of Countermeasures

Name	Height m	Width m	Material	Unit Cost SR/m
Concrete Revetment	3.0	1.0	Concrete	16,000
Dynamic Revetment	2.0	5.0	Gravel	7,000
Groyne	3.0	5.0	Rock Armouring	11,000
Sand Nourishment Mahe Praslin La Digue	 3.0 3.0 3.0	 10.0 20.0 20.0	Coral Sand	 12,000 33,000 33,000

The total cost is estimated from the unit cost as shown in Table 4-5-2.

Table 4-5-2: Cost of the Structural Measures

Name of Coast	Structure	Length m	Unit Cost SR/m	Cost 1,000*SR
North East Point	Nourishment	1,350	12,000	16,200
Baie Lazare	Nourishment	400	12,000	4,800
Anse Kerlan	Groyne	3*100=300	11,000	3,300
La Passe	Groyne	50	11,000	550
	Nourishment	100	33,000	3,300
			Total	28,150

The Coastal Zone Management Unit has no continuous budget. Coastal works are implemented with aid from donors, such as the RECOMAP project. It is difficult to provide a budget for coastal works. The total cost is about SR30 million until 2050.

4-6 Environmental and Social Considerations

4-6-1 Summary of Environment and Activities

Table 4-6-1: Summary of Environment and Activities

	Items	Explanation
North East Point	Coastal Conditions	The sandy coast is 1.7 km long and about 30m wide and protected by a narrow coral reef and beach rock in front. A coastal road and houses are located along the coast and the beach is used by local residents for recreation. There are three outlets for the drainage of wetland behind the coastal road.
	Conservation Plan	Sand nourishment for 20m in width for about a 2 km stretch of the beach is proposed with maintenance nourishment to counter long-term erosion, seasonal variations and wave overtopping.
Baie Lazare	Coastal Conditions	The sandy coast is 2km long and 30m wide and partly protected by a coral reef. Wetland has formed behind the sand bar where a coastal road and houses are located. The Baie Lazare River flows into the wetland and flushes out the sand bar at times of flooding.
	Conservation Plan	Sand nourishment for 20m in width for a 400 m stretch of the beach is proposed with maintenance nourishment. It is necessary to monitor the beach profile to estimate the causes of erosion and necessary sand volume for maintenance.
Anse Kerlan	Coastal Conditions	The coast is 2 km long and has a narrow sandy beach protected by a coral reef in front. It receives waves from the northwest in winter and the south in summer, causing seasonal changes in longshore sediment transport. Along the coast hotels and restaurants are being developed for tourism activities. The coast has one of the best beaches in Praslin.
	Conservation Plan	Three groynes and sand nourishment for 20m in width for a 1,000 m stretch of the beach are proposed with maintenance nourishment to stabilise the beach.
La Passe	Coastal Conditions	The coast is located in the west part of La Digue and is protected by a wide coral reef and Praslin Island to the west. Then waves come from the north and south and not from the west. A jetty is provided for the ferry to Praslin. The anchorage is protected by three breakwaters.
	Conservation Plan	One groyne and sand bypass of about 1,000 m3 of sand from the anchorage to the south beach are proposed.

It was reported that coastal vegetation (up to 100 m asl) has been altered by human settlement activities, especially through mining of sand and construction. The majority of species growing along the coast are common to the shores of most tropical islands (Carlstroem 1996).

Riverine forests are mainly composed of palms (Arecaceae/Palmae) and pandans (or screwpines; *Pandanus* spp.), but they have suffered greatly from human activities and can now only be found in the upper reaches of river systems (Carlstroem 1996).

(**Carlstroem, A.** 1996. *Endemic and threatened plant species on the granitic Seychelles.* Mahé, Seychelles, Conservation and National Parks Section, Division of Environment, Ministry of Foreign Affairs, Planning and Environment)

4-6-2 Environmental Impact Assessment

Based on the collected information and preliminary observations in the study of the sites, IEE (Initial Environmental Examination) analysis of all of the sites in the master plan was conducted for environmental impact assessment. The analysis summarised below will be correlated to the following environmental impact assessment for the pilot projects. The evaluation in the table below only indicates the impact as far as "C-" which signifies that the extent of negative impact is unknown, whereas the impact evaluated as "D" which signifies that no impact is expected has been omitted.

Table 4-6-2: Summary of Environmental Impact Assessment

Category	Item	Remarks	Coast			
			North East Point	Baie Lazare	Anse Kelan	La Passe
Social Environment	Existing Social Infrastructures and Services	The discharge outlet from the wetland to the beach will be improved to avoid clogging by sand accretion. Therefore, restoration of the sandy beach might clog the outlet, but the effect will be insignificant.	X			
	Misdistribution of Benefits and Damage	The shape of the beach that will be affected by the plan may fluctuate depending on the position of the elements. Therefore, monitoring of the shape of the beach shall be put into operation.	X	X	X	X
	Local Economy such as Employment, Livelihood, etc.	Inshore fishery is carried out on a small scale off the beach, therefore, reconciliation may be desirable.		X		X
Natural Environment	Hydrological Situation	Monitoring of transfer of the sand that is supplied for beach nourishment is necessary to see whether the sand will clog the outlet of water course or not.	X			
	Landscape	The landscape may change because the width of the beach will extend, but this modification will not affect the benefits of nature with the sand on the beach staying coral white.	X	X	X	X
Pollution	Air Pollution	Dump trucks, tractor shovels and other equipment will discharge exhaust fumes. Debris generated during removal of the existing revetment for temporary entry and particles included in the nourishment material may be scattered about and drift around the adjacent beach.	X	X	X	X
	Water Pollution	Clayey particles of nourishment sand may be scattered about and make the water muddy, affecting benthos and fishes.	X	X	X	X
	Noise and Vibration	Construction machines will emit noise, but the effect will be slight because the works will be done far from the housing estates. Vibration will also be emitted by the construction vehicles transporting the beach sand and removing the revetment, but the effect will be slight because the housing estates are distant from the road and work site. It is desired that restrictions on work at night and on holidays are contained in the contract.	X	X	X	X

Source: Study Team